Research Institute Leiden Observatory

(Onderzoekinstituut Sterrewacht Leiden)

Annual Report

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Cover:

During the past 10 years, characterization of exoplanet atmospheres has been confined to transiting planets. Now, thanks to a particular observational technique and to a novel data analysis designed by astronomers of Leiden Observatory, it is possible to study the atmospheres of planets that do not transit, which represent the majority of known exoplanets. The first of its kind now to be characterized is τ Boötis b (artist impression on the cover). Due to the very high resolution of the CRIRES spectrograph at the VLT, it was possible to detect molecular absorption from CO at 2.3 micron in the dayside spectrum of this planet, and to measure the Doppler shift due to its motion along the orbit. This yielded the planet mass and the orbital inclination, which were unknown before. Recently, using this technique also CO from 51 Pegasi b (the first planet discovered around a main-sequence star), and HD 189733 b were successfully detected. Ultimately, using ground-based high-resolution spectroscopy on the next-generation of telescopes (such as E-ELT) biomarkers may be detected in terrestrial planets orbiting M-dwarfs.

An electronic version of this annual report is available on the web at
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STERREWACHT LEIDEN

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Sterrewacht Leiden

Review of major events

Chapter 1

It is my pleasure to report that 2012 was another excellent year for the observatory. The best proof of this is the many exciting scientific results produced by our staff, postdocs, PhD and master students. We are particularly proud of the excellent PhD theses that represent a significant fraction of the scientific work which is being carried out at the observatory. This year, 9 graduate students can be congratulated on the successful defence of their Ph.D. theses. The scientific studies at the observatory encompass the entire history of the Universe, from local exo-planets up to the most distant galaxies. In Chapter 2 of this annual report the year's highlights are presented in full. Although any limited and personal selection will be biased, it is nevertheless gratifying to mention here a few very noteworthy results.

Matteo Brogi, Ignas Snellen, Jayne Birkby and colleagues have shown that the giant planet orbiting the star τ Boötis has an atmosphere. Using extremely high spectral resolution spectroscopy they detected carbon monoxide - the greenhouse gas that in our atmosphere has such a profound influence on the temperature at the Earth's surface. Analysis of the observed signal led to the unexpected and surprising conclusion that the temperature in the atmosphere of this exo-planet decreases towards higher altitudes.

The new Atacama Large Millimeter/submillimeter Array (ALMA) is now in operation, and the Allegro team, headed by Remo Tilanus and Michiel Hogerheijde, is playing an important role in helping Dutch observers make efficient use of this powerful facility. A highlight from the 'van Dishoeck team' was the ALMA observations of gas surrounding IRAS 16293-2422, a young Sun-like star. In the spectra they discovered the imprint of sugar molecules, showing that essential building blocks of life can be formed around young stars.

Much progress has also been made in studying the distant Universe. Rychard Bouwens, Ivo Labbé and Marijn Franx have led several projects to study the most distant galaxies. The pinnacle was the discovery of the most distant object known, with the - as astronomers sometimes jokingly say - telephone number MACS0647-JD. This baby galaxy was observed when the Universe was only 3 per cent of its present age of 13.7 billion years.

Concerning awards and prizes, 2012 was a truly exceptional year. In the Nieuwe Kerk in The Hague, on Friday 7 September, Xander Tielens was awarded a Spinoza prize, the highest scientific award in the Netherlands, in recognition of his pioneering research into polycyclic aromatic hydrocarbons (PAHs) in space. These PAHs are conglomerates of hundreds of organic molecules, are found in many locations in the near and far Universe, and are of paramount importance in shaping the formation of planets, stars and galaxies. The Royal Netherlands Academy of Sciences (KNAW) awarded an Academy Professorship to Ewine van Dishoeck. The KNAW Academy Professorship is intended as a lifetime achievement award for researchers who have demonstrated that they are amongst the absolute top of their scientific field. As a recognition of her scientific impact, Ewine was made Leiden University's first Faculty Professor. In this position she will be a visible spokesperson for science in general in Leiden. On March 26, George Miley was honoured with a knighthood in the Order of the Netherlands Lion (Ridder in de Orde van de Nederlandse Leeuw). The honour was awarded by the Mayor of Leiden, Henri Lenferink, on behalf of Queen Beatrix, in recognition of George's outstanding academic career and his efforts to use astronomy for global capacity building.

Ignas Snellen has been very active in the emerging field of exo-planet research. His NWO-VICI project "Atmospheres of extra-solar planets: bridging the gap towards Earth-like planets" was granted. This will enable him to carry out a large research project to detect many more transiting exo-planets and to characterise their atmospheres. Two NWO-M grants were also awarded. Koen Kuijken's grant will make the KIDS survey possible - a survey of about 8 % of southern sky. Making use of the weak lensing technique, the exceptional image quality of the survey will enable accurate mapping of the distribution of the enigmatic dark matter in the Universe. Paul van der Werf, in collaboration with Akira Endo of the Technical University of Delft, received his grant to develop DESHIMA, a revolutionary new sub-millimetre spectrograph. The heart of the instrument is based on developments in nanotechnology that allow ultra-sensitive detectors to be created. In addition, the 'technologiestichting' STW approved funding for the transfer of astronomical technology to other sciences. Based on ideas first realised with the Dutch Open Telescope (DOT), Christoph Keller and his team will develop and build lightweight towers with a stable platform for astronomical, meteorological and civil-engineering measurements. Finally, David Sobral was awarded a VENI grant to study large samples of star forming galaxies to further understand how these objects form and evolve.

An important and very pleasant endeavour all of us are involved in is bringing the results of astronomy research to the attention of the general public. Many lectures have been delivered at schools and at a range of public events. A good example of our outreach activities was the extensive press coverage of the spectacular work by the Hubble Space Telescope to obtain the deepest images of the extragalactic sky. Vincent Icke presented these results on 'De Wereld Draait Door' daily show, while Ivo Labbé appeared on the 'Pauw en Witteman' the daily news show. While the originality and enthusiasm of Vincent's presentation style are well known, Ivo's crystal clear performance on national television was a revelation. To quote a NOVA press officer: "A new star is born". Another highlight was the special on VPRO television on ALMA, with Leiden astronomers Ewine van Dishoeck and Tim van Kempen. Rumour has it that as a special tribute to Leiden it was broadcast on October 3. A fascinating project that combines outreach, techniques developed for astronomy and citizen science is ISPEX. ISPEX is a small device that is clicked onto an iPhone and enables you to make measurements of the small particles in the atmosphere. For this very innovative idea Frans Snik, Christoph Keller and their team won the Academic Year prize, a nationwide contest to bring science to the general public.

This year's Oort lecture was given by Sandra Faber, professor at the University of California. Her lively account of our present understanding of the evolution of galaxies captivated the large audience. We were also very honoured by the visit of Brian Schmidt, the 2011 Nobel Laureate for Physics. His well attended Sackler lecture told the story of his surprising discovery that the expansion of the Universe is accelerating. The old observatory continues to play an important role in our outreach program. A particular highlight was its beautiful, and popular, exhibition celebrating 50 years of ESO, which displayed many magnificent pictures of the Universe taken with ESO telescopes.

In 2012 Jan Lub, Vincent Icke, Frank Israel and Walter Jaffe officially retired. These sterrewachters have, over many years, played an important role in making the observatory such a success story. Jan, Vincent, Frank and Walter will remain active members of the observatory. We thank them all for their past, present and future contributions.

Both Ignas Snellen and Paul van der Werf were promoted to full professor. As they have made many scientific contributions and been very active in helping to run the observatory, these promotions are well deserved. We were happy to welcome Niek Doelman (TNO) as a new affiliate professor. Niek's expertise in control loops and adaptive optics will be extremely useful for many projects, including those related to the E-ELT. In 2012 the move of Christoph Keller's group from Utrecht to the observatory was completed. Their knowledge of how to build complex and innovative instrumentation will be a permanent boost to our ambition to play an important role in this area.

Finally, for me personally 2012 was special. In August I had the privilege of taking over the directorship from Koen Kuijken. There are three reasons why this transition was relatively smooth. First, thanks to Koen's excellent organisational skills, combined with his personal touch, the institute was (and I hope still is...) in good shape. During the transition period Koen gave me all the help I needed. And even now - every time I enter Koen's office he is staring at his fantastic KIDS images with a big smile - he is always available for good advice. Second, we have an excellent supporting staff. With enormous energy, Evelijn Gerstel does a fantastic job in managing the institute and Erik Deul's group does a great job running all our computing infrastructure. I also greatly appreciate the help I get from Jeanne in running my daily life in my new position. Third, the award of an A-ERC grant will greatly help me to continue my scientific adventures. And it is these adventures that are the ultimate raison d'être for our beautiful institute.

Huub Röttgering

Scientific Director.

Chapter 2

Research

Research

Chapter 2

2.1 Proto-planetary disks and exo-planets

2.1.1 A disintegrating, rocky planet

The star KIC 12557548 observed by the exoplanet-hunting Kepler satellite exhibits a very strange behaviour: At very regular intervals of 15.7 hours, the light from this star decreases by up to $\sim 1\%$. In contrast to normal exoplanet transits, the transit depth is highly irregular. Early in 2012 a US-based group led by Saul Rappaport qualitatively explained the observations in terms of a disintegrating, rocky planet that has a trailing dust tail created and constantly replenished by thermal surface erosion. The variability of the transit depth is then a consequence of changes in the tail's size.

Based on a discussion of the Rappaport et al. paper in the exoplanet journal club, Sterrewacht members Brogi, Keller, de Juan Ovelar, Kenworthy and Snellen together with colleagues de Kok at SRON and Min at UvA quantitatively modelled the observed, average transit light curve and were able to reproduce the observations down to minute details (Fig. 2.1). The brightening in flux just before the beginning of the transit is explained by forward scattering, and an asymmetry in the transit light curve shape is easily reproduced by an exponentially decaying distribution of optically thin dust, with a typical grain size of 0.1 μm. This quantitative analysis supports the hypothesis that the transit signal is due to a variable dust tail, most likely originating from a disintegrating object. KIC 12557548b. This work opens the exciting possibility to directly study solid (and/or molten)

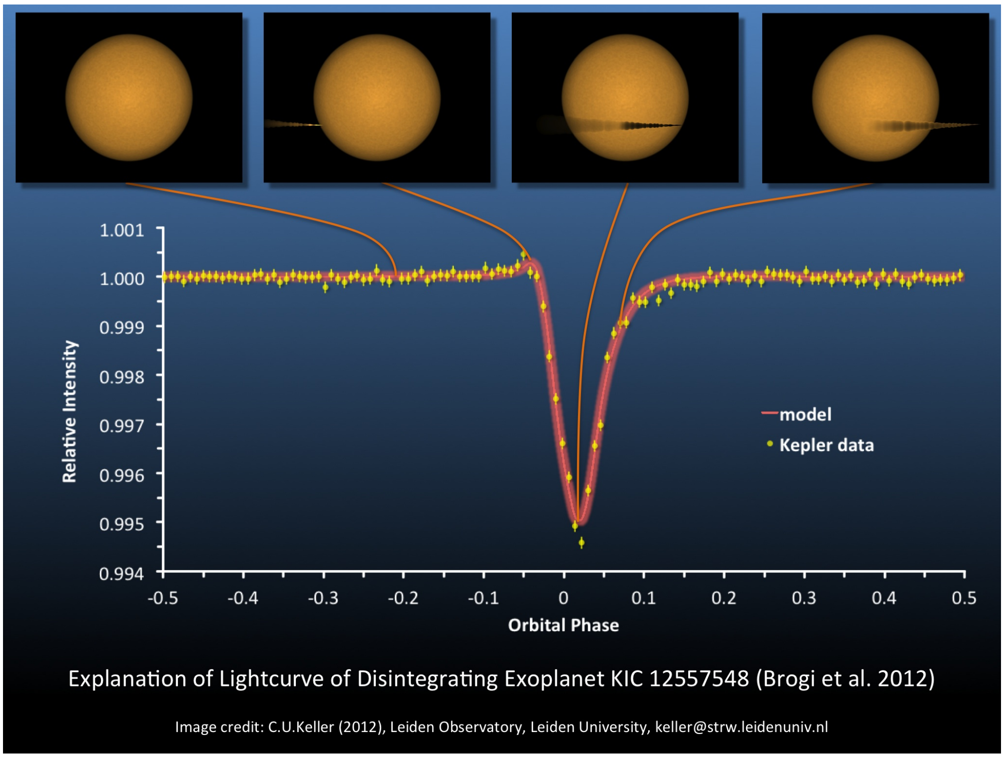

FIGURE 2.1: A disintegrating, rocky planet.

material from the surface and/or inside of a rocky exoplanet. If this exoplanet has been losing mass for a substantial amount of time, we may indeed see the very core of an originally much larger planet.

2.1.2 The atmosphere of a non-transiting hot Jupiter

Brogi, Snellen, Birkby and colleagues were the first in the world to detected the atmosphere of a non-transiting hot Jupiter. The giant planet orbiting τ Bootis was among the first extrasolar planets to be discovered through the reflex motion of its host star. It is one of the brightest known and most nearby planets with an orbital period of just a few days. Over the course of more than a decade, measurements of its orbital inclination have been announced and refuted, and have subsequently remained elusive until now. The team detected carbon monoxide absorption in the thermal day-side spectrum of τ Bootis b. At a spectral resolution of $R \sim 100,000$, the change in the radial velocity of the planet was traced over a large range in phase, revealing an orbital inclination of $i = 44.5 \pm 1.5$ degrees and a true planet mass of $5.95 \pm 0.28\mathrm{M}_{\mathrm{Jupiter}}$. This result extends atmospheric characterisation to non-transiting planets. The strong absorption signal points to an atmosphere with a temperature that is decreasing towards higher altitudes. This is in stark contrast to the temperature inversion invoked for other highly irradiated planets, and supports models in which the absorbing compounds believed to cause such atmospheric inversions are destroyed by the ultraviolet emission from the active host star.

2.1.3 The warm gas atmosphere of disks revealed by Herschel

The surface layers of disks are heated by the UV radiation from the young star resulting in high gas temperatures > 1000 K. However, this gas temperature structure has never been tested before. Herschel-PACS has detected high-J CO lines in the atmospheres of protoplanetary disks for the first time, together with the [C II] and [O I] lines. Bruderer (MPE), in collaboration with van Dishoeck, Doty (Denison) and Herczeg (KIAA), developed a new series of thermo-chemical models coupled with radiative transfer to analyse these data. Given a density structure of the disk, the model computes the temperature, excitation, and chemical abundance of species. The sensitivity to various disk parameters has been studied. A model of the disk around the Herbig Be star HD 100546 is able to reproduce the CO ladder only for a warm atmosphere with $T_{\rm gas} \gg T_{\rm dust}$. The low-J lines of CO, observable from the ground, are dominated by the outer disk with a radius of several 100 AU, while the high-J CO observable with Herschel-PACS are dominated from regions within some tens of AU. When combined with ground-based APEX-CHAMP+ data on [C textsci], all principal forms of carbon can be studied. The data indicate a low abundance of volatile carbon in the disk, perhaps due to transformation of solid CO into more complex species in the embedded phase.

2.1.4 A 30 AU radius CO gas hole in the transitional disk around Oph IRS 48

The physical processes leading to the disappearance of disks around young stars are not well understood. A subclass of transitional disks with large inner dust holes provides a crucial laboratory for studying disk dissipation processes. Brown (Harvard/MPE), Pontoppidan (StScI), van Dishoeck and co-workers studied the

A0 star Oph-IRS 48, which has a 30 AU radius hole previously measured from dust continuum imaging at 18.7μm. VLT-CRIRES high-resolution ($R \sim 100,000$) spectra of the CO rovibrational bands at 4.7μm peak off-source at 30 AU. The gas is thermally excited to a rotational temperature of 260 K and is also strongly UV pumped, showing a vibrational excitation temperature of $\sim$ 5000K. The kinematics and excitation of the gas indicate that the CO emission arises from the dust hole wall. Surprisingly, PAH molecules appear to be located inside this hole.

2.1.5 First detection of near-infrared line emission from organics in disks

Bast, in collaboration with Mandell (Goddard), van Dishoeck and others, obtained high-resolution VLT-CRIRES spectroscopy of bright T Tauri stars to reveal the first detections of simple organic molecules, HCN and C_2H_2, at near-infrared wavelengths. Advanced data reduction techniques developed by Mandell were needed to achieve a dynamic range of $\sim$ 500 at 3μm. Stringent upper limits were also obtained for two other molecules thought to be abundant in the inner disk, CH_4 and NH_3. The line profiles suggest that the emission has both a Keplerian and non-Keplerian component arising from < 1AU, as observed previously for CO emission. LTE slab models and disk radiative transfer models are used to determine abundance ratios and compared with disk chemical models.

2.1.6 Deuterium enhancement in the disk around TW Hya

Hogerheijde's research focuses on protoplanetary disks aroud Solar-type stars as well as disks that surround their higher mass counterparts. Together with scientists from the Harvard-Smithsonian Center for Astrophysics and the University of Virginia, Hogerheijde presented evidence for multiple pathways for deuterium enhancement inside the disk around TW Hya. Understanding how the disk material can become enriched in deuterium is important accurately reading the cometary record of the Solar System's formation. This publication is the second paper ever that appeared in the refereed literature using data from the newly commissioned Atacama Large Millimeter / submillimeter Array (ALMA).

2.1.7 The kinematics of material around a massive young star

PhD student Wang, together with Hogerheijde and van der Tak (Groningen) published a detailed analysis of the kinematics of the material around the massive young star AFGL 2591. Unlike the disks around low-mass stars which show well-behaved Keplerian rotation, the motions in this disk fall well below what is needed to orbit the star, suggesting that magnetic fields may play an important role in the dynamics. At the same time, some tracers show outward motions, suggesting that the upper layers of the disk are eroded by the stellar radiation and wind. Extending this research to another region of massive star formation, W3 IRS5, Wang et al. find a very different mode of star formation, one where a small cluster of objects is forming and where just two massive stars are in the process of dispersing the entire cloud core. Other objects embedded in this core are destined to have their growth stunted and remain low-mass stars. Together, these two studies illustrate the complex ways in which massive star formation proceeds, and the many physical processes that affect the distribution of stellar masses that result.

2.2 Protostars

2.2.1 Water in star-forming regions with Herschel (WISH)

WISH is a Herschel-HIFI guaranteed time program designed to probe the physical and chemical structures of young stellar objects using water and related molecules and to follow the water abundance from collapsing clouds to planet-forming disks (PI: van Dishoeck). It involves a collaboration between 70 scientists in Europe, USA and Canada and includes Kristensen, Mottram, Yildiz, San Jose Garcia and Harsono in Leiden and Karska and Bruderer at MPE. In 2012 a total of 12 WISH papers were published.

A 2012 highlight was the first detection of water vapor in a core just prior to collapse, led by Caselli (Leeds). Pre-stellar cores provide the original reservoir of material from which future planetary systems are built, but few observational constraints exist on the formation of water and its partitioning between gas and ice in the densest cores. Thanks to the high sensitivity of HIFI, the first detection of water vapour has been obtained toward a dense cloud on the verge of star formation, L1544. The high-resolution line shows an inverse P-Cygni profile, characteristic of gravitational contraction. To reproduce the observations, water vapour has to be present in the cold and dense central few thousand AU of L1544, where most species are expected to freeze-out onto dust grains. The observed amount of water vapour within the core can be maintained by far-UV photons locally produced by the impact of galactic cosmic rays with H_2 molecules. Such FUV photons irradiate the icy mantles, liberating water vapour in the core centre in a process that has been quantified through experiments in the Sackler laboratory and through molecular dynamics models by Arasa, with Kroes (LIC) and van Dishoeck.

Karska (MPE/Leiden), in collaboration with van Dishoeck, Kristensen, Herczeg (KIAA) and others finished her far-infrared Herschel-PACS spectral survey of 18 low-mass protostars. Water is detected in all objects, including the high-excitation 63.3μm line in 7 sources, and has a typical excitation temperature of $\sim$ 150K. CO transitions from J=14–13 up to 49–48 show two distinct temperature components on Boltzmann diagrams with rotational temperatures of $\sim$ 350K and $\sim$ 700K. Emission from both Class 0 and I sources is usually spatially extended along the outflow direction but with a pattern depending on the species and the transition. The H_2O line fluxes correlate strongly with those of the high-J CO lines, as well as with the bolometric luminosity and envelope mass. They correlate less strongly with OH and not with [O I] fluxes, suggesting two different physical components. The H_2O and CO emission likely arises in non-dissociative (irradiated) shocks along the outflow walls with a range of pre-shock densities, whereas [O I] and some of the OH emission probe dissociative shocks in the inner envelope. The total far-infrared cooling is dominated by H_2O and CO, with [O I] increasing with protostellar evolution.

2.2.2 Imaging warm water in deeply embedded protostars

Water is present during all stages of star formation: as ice in the cold outer parts of protostellar envelopes and dense inner regions of circumstellar disks, and as gas in the envelopes close to the protostars, in the upper layers of circumstellar disks and in regions of powerful outflows and shocks. As a complement to WISH, Persson and Jørgensen (Copenhagen), in collaboration with van Dishoeck, have used the

IRAM PdB interferometer to image the warm gas-phase water abundance in the innermost hundred AU of three deeply embedded low-mass protostars The para-$H_2{}^{18}O$ line at 203 GHz ($E_u = 203.7$K) is one of the few water lines that can be observed from the ground. Compact $H_2{}^{18}O$ emission is detected toward all three sources. A scenario is presented in which the origin of the emission from warm water is in a flattened disk-like structure dominated by inward motions rather than rotation. The gas-phase water abundance varies between the sources, but is generally much lower than a canonical abundance of 10^{-4}, suggesting that most water ($> 96\%$) is frozen out on dust grains at these scales.

2.2.3 The CO ladder in low-mass protostars

Young stars interact vigorously with their surroundings, as is evident from the highly rotationally excited CO (up to $E_u = 6000$K) seen by Herschel in even low-luminosity embedded protostars. The detection of CO lines up to J=49–48 opens up an entirely new window on using this molecule as a probe of the physical structure. A spectacular example is provided by the PACS 55–200μm spectral scan of NGC 1333 IRAS4B, analysed by Herczeg (MPE/KIAA), in collaboration with Karska, van Dishoeck, Bruderer (MPE) and others from the WISH team (see Fig. 2.2). Another highlight is the first complete PACS + SPIRE spectrum from 55–670μm of a low-mass protostar, Serpens SMM1, obtained by Goicoechea, Cernicharo (both Madrid) and WISH co-workers. Multi-component radiative transfer models allow to quantify the contribution of the different temperature components suggested by the CO rotational ladder ($T_{\rm hot} \sim 800$K, $T_{\rm warm} \sim 300$K and $T_{\rm cool} \sim 150$K). High gas densities ($> 5 \times 10^6$cm^{-3}) are found for the warm and hot components. H_2O/CO is close to unity in the warm/hot gas, but much lower in the colder gas. Fast dissociative J-shocks (> 60 km/s) as well as lower velocity non-dissociative shocks (< 20 km/s) are needed to explain both the atomic fine structure lines and the hot CO and H_2O lines. Observations also show the signature of UV radiation and thus, most observed species likely arise in UV-irradiated shocks. The lower energy CO lines are associated with the cool entrained outflow gas, also probed by HIFI by Yildiz and collaborators.

Visser (Michigan), in collaboration with Kristensen, Harsono, Bruderer, van Dishoeck and others constructed a model that reproduces these observations quantitatively. The model consists of a spherical envelope with a power-law density structure

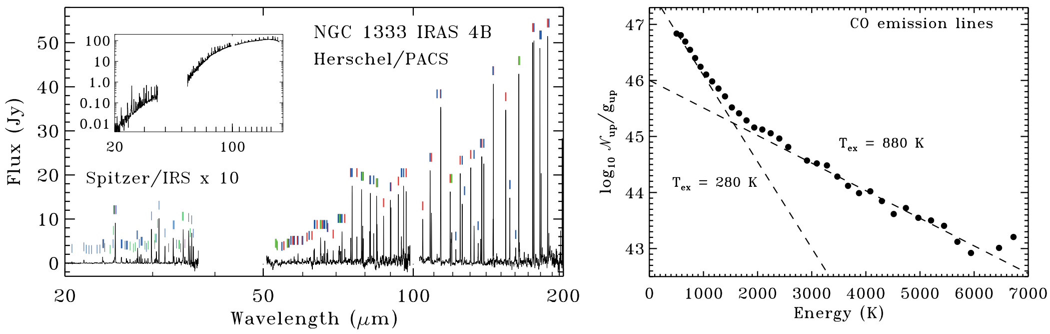

FIGURE 2.2: Left: The Herschel/PACS and Spitzer-IRS continuum-subtracted spectra of the low-mass protostar NGC 1333 IRAS 4B, with bright emission in many H_2O, CO, OH and atomic or ionised lines indicated. The inset shows the combined spectrum including the continuum. Right: CO rotational ladder showing the warm and hot CO components (Herczeg et al. 2012).

and a bipolar outflow cavity. Three heating mechanisms are considered: passive heating by the protostellar luminosity, ultraviolet irradiation of the outflow cavity walls, and small-scale C-type shocks along the cavity walls. Most of the model parameters are constrained from independent observations; the two remaining free parameters are the protostellar UV luminosity and the shock velocity. Line fluxes are calculated for CO and H_2O and compared to Herschel data and complementary ground-based data. The bulk of the gas in the envelope, heated by the protostellar luminosity, accounts for 3–10% of the CO luminosity summed over all rotational lines, and is best probed by the low-J lines. The UV-heated gas and the C-type shocks, probed by CO 10–9 and higher-J lines, contribute 20–80% each. The model fits show a tentative evolutionary trend: the CO emission is dominated by shocks in the youngest source and by UV-heated gas in the oldest one. The total H_2O line luminosity in all cases is dominated by shocks ($> 99\%$).

2.2.4 Detection of the simplest sugar in a solar-type protostar with ALMA

Glycolaldehyde ($HOCH_2COH$) is the simplest sugar and an important intermediate in the path toward forming more complex biologically relevant molecules. Using ALMA science verification data, Jørgensen (Copenhagen) and collaborators including van Dishoeck, obtained the first detection of this molecule around a solar-type young star, the protostellar binary IRAS 16293-2422 (Fig. 2.3). The

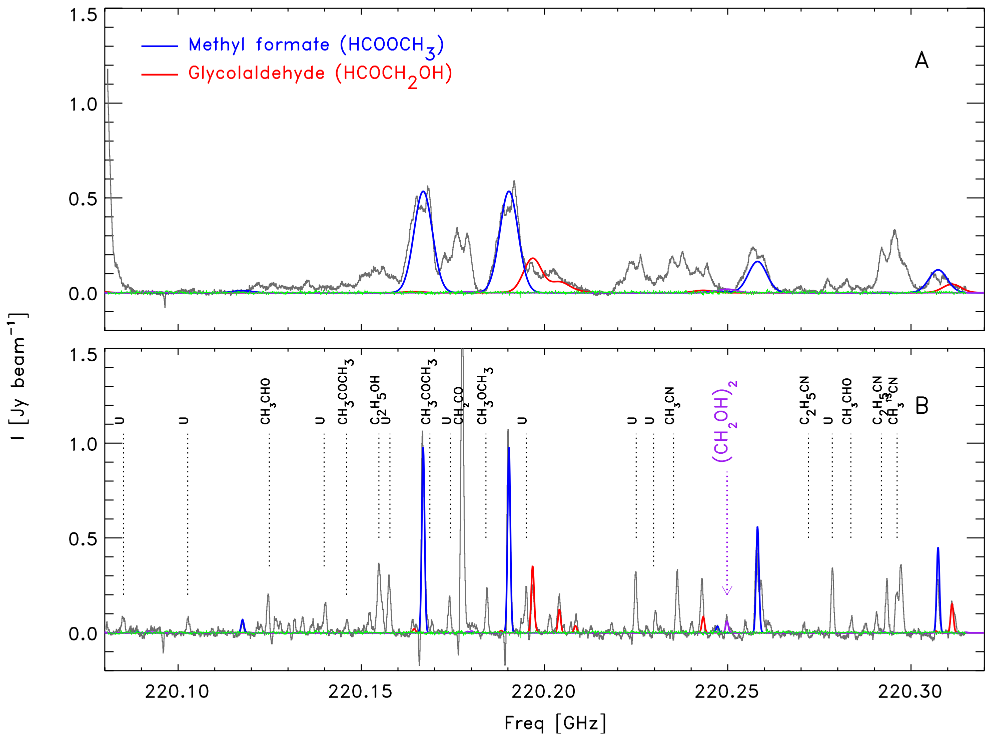

FIGURE 2.3: ALMA spectra toward both components of the IRAS 16293-2422 protostellar binary showing the detection of glycolaldehyde. Fits from LTE models of the methyl formate and glycolaldehyde emission are overplotted. Note the much narrower lines toward source B and the inverse P-Cygni profiles showing red-shifted absorption indicating infall (Jørgensen et al. 2012).

glycolaldehyde lines have their origin in warm (200–300K) gas close to the individual components of the binary. Glycolaldehyde co-exists with its isomer, methyl formate ($HCOOCH_3$), which is a factor 10–15 more abundant toward the two sources. In the 690 GHz data obtained with the Dutch-built Band 9, all transitions show redshifted absorption profiles toward one component in the binary indicative of infall. The abundance ratios are consistent with laboratory experiments of the photochemistry of methanol-containing ices carried out in the Sackler laboratory. The order of magnitude increase in line density in these early ALMA data illustrates its huge potential to reveal the full chemical complexity associated with the formation of solar system analogs.

2.2.5 Methanol masers as probes of high-mass star-formation

Van Langevelde worked on measuring the outflows in methanol maser sources in collaboration with Bartkiewicz (Torun, Pl). Water masers observed with the European VLBI Network (EVN) seem to trace outflow structures perpendicular to the methanol structures. Similar findings obtained on thermal methanol were used to prepare for ALMA observations. Additionally, together with Vlemmings (Onsala) and Surcis (JIVE), progress has been made in observing a statistically significant sample of sources with outflows and detected magnetic fields through the Zeeman splitting of methanol masers. Possibilities were explored to make laboratory measurements of the methanol Lande factors, necessary for interpreting the Zeeman splitting measurements quantitatively.

Following up on parallax measurements of star-forming regions in Cygnus, Van Langevelde joined the Bessel programme that aims to measure the kinematics of the Galactic spiral structure, by methanol maser parallax observations. Preparations were made to start a large-scale programme on the Very Long Baseline Array (VLBA). In addition some effort was made to explore measuring the inner Galaxy masers with Very Long Baseline Interferometry (VLBI) telescopes under construction in Africa.

2.2.6 Small scale outflows in high mass star forming regions

High mass star formation is not nearly as well understood as the formation processes involved in forming stars like the sun. A lot of progress has been made recently through direct comparisons between observations and simulations. Recently Peters (ITA Heidelberg), Klaassen and collaborators created simulated ALMA observations from 3D models of high mass star forming regions which included ionization feedback from the forming high mass stars. These models made specific predictions about small scale outflows which should be seen in these regions. These ionisation driven outflows occur on very small scales, and have a different powering source to the large scale outflows generally seen in star forming regions of all masses. This type of outflow, as predicted by models, was also seen in the high mass star forming region K3-50A.

K3-50A is a very large high mass star forming region with no evidence for a large scale molecular outflow. However, high resolution CARMA observations reveal a small scale velocity gradient in the molecular gas. This velocity gradient is along the same direction as that of the ionised gas which appears to be in a large scale ionised outflow. These new observations suggest that the ionised outflow is entraining a small scale molecular one, as predicted by models.

2.2.7 Fragmentation of protostellar clumps in Orion

In 2012, a group led by van Kempen investigated the fragmentation of protostellar clumps NGC 2071 and L1641 in Orion, using submillimeter interferometry and Spitzer photometry. They found that fragmentation is strongly constrained. The comparison of two seemingly very similar sources on large scales and in the infrared, showed wildly different results at the small scales. The first clump, L1641, was forming a single, heavier protostar while the other, NGC 2071 with the same circumstellar mass as L1641, was forming a cluster of low-mass protostars. Such diversity has large implications for the evolution of very young stars, in particular the energetics.

2.3 Stars and compact objects

2.3.1 GAIA

The Gaia group in Leiden, led by Brown, is involved in the preparations for the data processing for ESA's Gaia mission. Scheduled for launch in 2013, Gaia aims at providing a stereoscopic census of the Milky Way by measuring highly accurate astrometry (positions, parallaxes and proper motions), photometry and radial velocities for 1 billion stars and other objects to 20th magnitude. The main activities in 2012 were:

1) Brown and Busso continued their work on the development of the data processing software for the photometric instrument of Gaia in collaboration with groups in Rome, Teramo, Cambridge, and Barcelona. The photometric data for Gaia will be collected through low dispersion spectrophotometry with prisms and the group

in Leiden is responsible for developing the algorithms that extract the spectra from the raw data.

2) Busso and Brown participated in an operations rehearsal for the Gaia mission. In this rehearsal the Gaia commissioning phase was simulated and Busso and Brown took part as so-called ‘payload experts’, examining the processed telemetry and passing judgement on the Gaia photometric instrument health.

3) In order for Gaia to reach its astrometric accuracy goals the highest quality for the attitude knowledge of the spacecraft is needed. It is thus important to incorporate a complete physical understanding of the dynamics of a continuously rotating space platform into the attitude modelling for Gaia. In this context Risquez developed detailed simulations of Gaia’s attitude, incorporating all of the relevant physical effects. This model was developed in collaboration with van Leeuwen (Cambridge) and Keil (Bremen). Risquez closed off his work on the Gaia attitude model with a paper describing an analysis of the capabilities and limitations of the Gaia attitude reconstruction, focusing on the effects on the astrometry of bright ($V \lesssim 11$) stars and the implications of employing cubic B-splines in the modelling of the attitude measurements. From this work the final noise in the attitude reconstruction for Gaia is estimated to be ≈ 20 μas, and the main source of noise will be the Micro-Propulsion System. However its effect on the astrometric performance will be limited, adding up to 7 μas RMS to the parallax uncertainties. This is larger than the 4 μas from previous estimations and would affect the performance for the brightest ($V \lesssim 11$) stars.

2.3.2 The variability of a nearby brown dwarf binary

Matthew Kenworthy concluded a study on the infra-red variability of one of the nearest brown dwarf binaries, Gliese 569B. Understanding this system is challenging, and even the number of stars in the system is still being debated. Periodic variations in the brightness of the binary system imply rapid rotation rates for these stars, and further observations will confirm the inclinations of the stars with respect to each other.

2.3.3 Stellar compact objects

Stellar compact objects — such as white dwarfs and neutron stars — can generate the strongest gravitational field we know of. For this reason conditions are extreme in the vicinity of these objects, leading to a variety of highly energetic phenomena, such as X-ray and gamma-ray radiation, high frequency oscillation, fast winds and relativistic jets. These objects, however, are extremely interesting in their own right: matter can be degenerate and relativistic, densities can be higher than nuclear, and magnetic fields can be far greater than we can generate on Earth. Since we cannot reproduce such conditions in laboratories, our knowledge of the behaviour of matter in these extreme situations is still approximate, calling for further combined observational and theoretical efforts.

Dr. E. M. Rossi with collaborator Dr. S. Dall'Osso (HUJI, Jerusalem) has been investigating the reaction of the compact stellar interior to the extreme gravitational tidal interaction, arising when compact objects are in binaries. The first paper in a series on the topic focused on double neutron stars. These systems will be the main target of near future gravitational wave detectors.

As we observe in the moon-earth system, tidal interactions in binaries can lead to angular momentum exchange. The presence of viscosity is generally regarded as the condition for such transfer to happen, however, neutron stars are considered almost inviscid bodies. Dr. Rossi and collaborator show that there is a dynamical mechanism that can cause a persistent torque between the binary components, even for inviscid bodies. This preferentially occurs at the final stage of the coalescence, when the orbit shrinks by gravitational waves on a timescale shorter than the viscous timescale. They find that the total orbital energy transferred to the secondary is quite remarkable: a few 0.001 of its binding energy. Furthermore they show that this persistent torque induces a differential rotation within the star, which is a highly excited energy state. The free energy associated with this non-equilibrium state can be around 10^{47} erg just prior to coalescence.

The next step is to investigate the fate of this substantial accumulated energy. One possibility is that fluid instabilities would lead to a burst of gravitational waves. Alternatively, a preexisting magnetic field could be substantially amplified, recycling and old neutron star into a highly magnetic one, known as magnetar. A magnetar-like luminous flare prior to coalescence would be the expected signature.

2.3.4 Galactic Wolf-Rayet stars

Wolf-Rayet stars are very hot massive stars with a large mass loss, close to the end of their lifetime. They are enshrouded in dense and extended envelopes, and show an emission spectrum, with sub-class WC stars showing amongst others very prominent emission lines of carbon. Van Genderen, Veijgen and van der Hucht (SRON, Utrecht) analyzed archival multi-colour photometric (Walraven VBLUW, Strömgren uvby, and Bessel UBV) data of the variable WC9-type Wolf-Rayet star WR 103 = HD 164270, observed over a time interval of eleven years.

WR 103 turned out to be stochastically variable (continuum light and emission lines). Its continuum variability is exceptional, as the continuum radiation of other WC9 stars is almost photometrically stable. In this respect WR 103 resembles WN8-type stars. The time scale of the light and colour variations hovers between a few hours to a few days, with light amplitudes of ~ 0.1 magnitude in the visual, to 0.2 magnitude in the ultraviolet. Stellar (multi-mode) pulsations are likely the cause. Models of hot massive stars, like Wolf-Rayet stars, offer a possible source of instability: a sub-photospheric convection zone. Their pulsations propagate through many layers of wind with decreasing density. Hence, possible periodic variations are altered rapidly by the wind, and before they reach the region where the continuum light is emitted, they become stochastic. And, of course this stochastic nature remains up to larger radii in the wind, where the emission lines are formed.

It is shown that, to a certain extent, the accurate photometry, is able to differentiate between continuum and emission line variations and to quantify them. As a result, we discovered a flux-enhancement lasting for three days of the C III emission lines by at least 10%. Such strong spectroscopic flare-like events are very seldom observed in Wolf-Rayet stars. So far the one of WR 103 has the longest duration ever observed.

2.3.5 The stars responsible for nebular He II emission

PhD student Shirazi and Brinchmann searched the Sloan Digital Sky Survey (SDSS) database of galaxy spectra to assemble the largest sample of galaxies with nebular He IIλ4686 emission. This recombination line can only form when there is a source of radiation with significant output at energies in excess of 54.4 eV.

Current models for massive star evolution predict that only Wolf-Rayet stars are sufficiently hot to emit this radiation so the characteristic signatures of these stars ought to be detected at the same time as nebular He II is seen.

What Shiraz & Brinchmann found in galaxies with metal content about half that of the sun was indeed that Wolf-Rayet signatures always were seen when nebular He II was seen. However at lower metallicities, fewer and fewer galaxies showed Wolf-Rayet signatures together with the He II emission lines. They also showed that in low metallicity galaxies the He II emission line was much weaker than predicted in models of single star evolution.

The latter problem can likely be solved by including the effect of binarity and/or rotation in the calculation of stellar evolution. These two processes allow more abundant lower mass stars to evolve to the Wolf-Rayet state and thus more energetic ionising would be produced.

But the former problem — the lack of Wolf-Rayet stars in low metallicity galaxies with nebular He II emission — is harder to resolve. It is also in conflict with the proposed solution of the first problem. At the moment no satisfactory solution can be given and work continues on understanding this discrepancy.

2.4 Nearby galaxies

2.4.1 Diagnostics for mechanical heating in star-burst environments

Observations of the CO molecule in various transitions in the central regions of other galaxies have revealed that much of the dense gas surrounding the nuclei of these galaxies has a high kinetic temperature, of the order of 100 K or more. Such high temperatures over large volumes are hard to explain invoking only excitation by UV photons. Instead they may be caused by the dissipation of turbulent energy fuels by shocks in the central volume.

Kazandjian, Meijerink, Pelupessy, Israel, and Spaans (Groningen, NL) are involved in a program to study this process quantitatively and numerically. As a first step, they determined whether, and to what extent, mechanical heating should be taken into account in the frequently-used photon-dominated region (PDR) models, and explored the effect of dissipated turbulence on the thermal and chemical properties of PDRs. To this end, they modelled clouds as one-dimensional semi-infinite slabs, and solved the thermal and chemical equilibrium using the Leiden PDR-XDR code. They found that in a steady-state treatment, mechanical heating plays a major role in determining the kinetic temperature of the gas in molecular clouds. In particular in high-energy environments such as found in star-burst galaxies and galaxy centres, model gas temperatures are underestimated by at least a factor of two if mechanical heating is ignored. The models constructed by Kazandjian and colleagues show that the implied column densities of CO, HCN and H_2O increase as a function of mechanical heating. In high-density regions (typically 10^5 cm^{-3}) the integrated HNC/HCN column density ratio decreases by a factor of at least two, and the similar HCN/HCO^+ ratio has a strong dependence on mechanical heating with boosts of up to three orders of magnitude.

Kazandjian et al. concluded that the effects of mechanical heating cannot be ignored in studies of the molecular gas excitation above a threshold that is easily reached in galaxy centers, and even in star-forming disks. If in such environments mechanical heating effects are ignored, derived gas column densities may be underestimated by as much as a few orders of magnitude. They established that mechanical heating already has non-negligible effects when it is as low as one per cent of the UV heating in a PDR. In a follow-up study, these results are pursued to yield quantitative diagnostic line ratios.

2.4.2 CO maps and the CO/FIR correlation in the SINGS galaxy sample

As part of the JCMT Nearby Galaxies Legacy Survey (NGLS), Wilson, Warren (both McMaster Univ., Canada), Israel, and a large numbers of international collaborators mapped an HI-selected sample of 155 galaxies in the J=3–2 line of CO with the HARP instrument on the James Clerk Clerk Maxwell Telescope in Hawaii. The galaxies spanned all morphological types, and were limited to distances less than 25 mega-parsec. They presented an atlas and analysis of the CO J=3–2 maps for the 47 galaxies in the NGLS that are also part of the Spitzer Infrared Nearby Galaxies Survey (SINGS). The team found a wide range of molecular gas mass fractions in the galaxies in this sub-sample. They explored the correlation of the far-infrared luminosity, which traces star formation, with the CO luminosity, which traces the molecular gas mass. In a comparison of the NGLS sample with merging galaxies at low and high red-shift which had also been observed in the CO J=3–2 line, they showed that the correlation of far-infrared and CO luminosity exhibits a significant trend with luminosity. This trend is consistent with a molecular gas depletion time which is more than an order of magnitude shorter in the merger galaxies than in nearby normal galaxies. They also noted a strong correlation of the far-infrared to CO(3–2) luminosity ratio with the atomic to molecular gas mass ratio. This correlation suggests that some of the far-infrared emission originates from dust associated with atomic gas and that its contribution is particularly important in galaxies where most of the gas is in the atomic phase.

2.4.3 Dense Gas in M33 (HerM33es)

In an attempt to better understand the emission of molecular tracers of the diffuse and dense gas in giant molecular clouds, and the influence that environmental factors (metallicity, optical extinction, spatial density, far-UV field intensity, and star-formation rate) have on these tracers, Buchbender, Kramer, Gonzalez-Garcia (all IRAM-Granada, Spain), Israel, and several other members of the HerM33es team, observed the Local Group galaxy M33 with the IRAM 30m telescope. They detected molecular line emission from HCN, HCO^+, ^{12}CO, and ^{13}CO in six giant molecular clouds (GMCs) along the major axis of M33 at a linear resolution of about 115 pc, and out to a radial distance of 3.5 kpc. Optical, far-infrared, and sub-millimeter data from Herschel and other observatories complement these observations. To interpret the observed molecular line emission, Buchbender and co-workers created two grids of models of photon-dominated regions (PDRs), at solar sub-solar metallicities. The observed HCO^+/HCN line ratios were found to be quite high, ranging from 1.1 to 2.5. Similarly high ratios have been observed in the Large Magellanic Cloud. The HCN/CO ratio varies between 0.4% and 2.9% in the disk of M33. The $^{12}CO/^{13}CO$ line ratio varies between 9 and 15 similar to variations found in the diffuse gas and the centres of GMCs of the Milky Way. By stacking all spectra, the team also detected very weak HNC and C_2H emission. The resulting HCO^+/HNC and HCN/HNC ratios of 8 and 6, respectively, lie at the high end of ratios observed in a large set of (ultra-)luminous infrared galaxies. HCN abundances are lower in the sub-solar metallicity PDR models, while HCO^+ abundances are enhanced. For HCN this effect is more pronounced at low optical

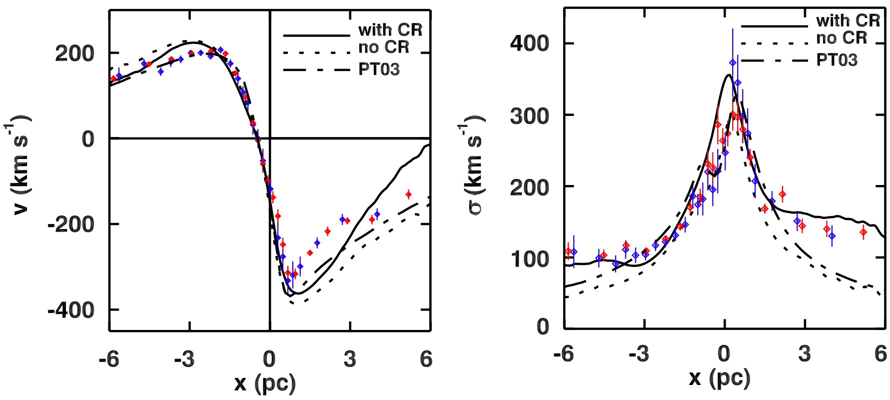

FIGURE 2.4: Kinematics of of the nucleus of Andromeda's nucleus is demonstrated: The left panel shows the rotation curve and the right panel the line of sight velocity dispersion. The solid (dotted) curves are the kinematics with (without) counter-rotation. The super-massive black-hole is at the origin. The main impact of counter-rotation is the improved asymmetry of the line of sight velocity dispersion curve. All other models, dashed dotted being the best of those, fail to reproduce the asymmetry in the line of sight velocity dispersion.

extinctions. The observed HCO^+/HCN and HCN/CO line ratios are naturally explained by sub-solar PDR models having relatively low optical extinctions between 4 and 10 mag, and moderately high densities between 3000 and 30 000 cm^{-3}. The FUV field strength only has a small effect on the modeled line ratios. However, it was also found that the line ratios are almost equally well reproduced by the solar-metallicity models, which indicates that variations in metallicity only play a minor role in influencing these particular line ratios.

2.4.4 The kinematics of the nuclear regions of Andromeda

Kazandjian with Touma (American University of Beirut) have studied the motions of stars around the super-massive black hole in the nucleus of the Andromeda galaxy. Super-massive black holes lurk in the centres of galaxies. They dominate and structure dynamics in their sphere of influence — a sphere in which asymmetric stellar dynamical features can at once be excited and safely sheltered. Such, in particular, is the case of the double-peaked lopsided nucleus of the Andromeda galaxy, with a fainter peak lying close to Andromeda's central black hole, and a brighter peak off-centre from it. It is strongly believed that Andromeda's lopsided nucleus signals a disk of stars revolving on eccentric Keplerian orbits with nearly aligned apsides. A self-consistent stellar dynamical origin for this apparently long-lived alignment has so far been lacking, with indications that cluster self-gravity is capable of sustaining such lopsided configurations if and when stimulated by external perturbations.

Kazandjian and Touma showed that unstable counter-rotating nuclear stellar clusters saturate into uniformly precessing, thick, eccentric disks of apo-apse aligned stars. These disks are the first self-organised examples of three dimensional lopsided, slowly precessing, stellar disks around super-massive black holes. They are in close qualitative agreement with Keplerian disk models of Andromeda's double nucleus, and can readily reproduce salient observed features of Andromeda's lopsided, double nucleus (see Fig. 2.4). Given on one hand the strong likelihood of counter-rotating (CR hereafter) excitations in galactic centres, and on the other the robustness and efficiency of the proposed mechanism, we suggest that lopsided stellar disks are natural features of stellar clusters dominated by super-massive black holes. More generally, the proposed mechanism can be deployed to customise triaxial equilibrium configurations with which to model observed kinematics of stellar black hole nuclei (the Milky Way's included), to improve estimates of the mass of the black hole within, and to address fundamental questions regarding the statistical mechanics of self-gravitating systems around super-massive black holes.

2.4.5 Nearby starburst galaxies

Van der Werf worked with Rosenberg and Israel to derive a quantitative relation between the [FeII] 1.26 micron emission and the supernova rate in nearby starburst galaxies. This was done using a pixel-pixel analysis of SINFONI data cubes. Using Brγ equivalent width and luminosity as the only observational inputs into a Starburst99 model, supernova rate at each pixel and thus maps of supernova rates were derived. These were then compared morphologically and quantitatively to the [FeII] 1.26 luminosity, revealing a strong linear and morphological correlation exists between supernova rate and [FeII] 1.26 on a pixel-to-pixel basis. This relation is valid for normal star-forming galaxies but breaks down for extreme ultraluminous galaxies. The supernova rates derived are in good agreement with the radio derived supernova rates, which underlines the strength of using [FeII] emission as a tracer of supernova rate.

2.4.6 Molecular gas in (Ultra)luminous infrared galaxies

Van der Werf completed with Papadopoulos (MPIfR, Bonn) his extensive analysis of multi-line observations of the molecular gas in local (ultra)luminous infrared galaxies. Simple comparisons of their available CO spectral line ladders show a surprisingly wide range of average interstellar medium (ISM) conditions, with most of the surprises found in the high-excitation regime. These take the form of global CO ladders dominated by a very warm (Tkin > 100 K) and dense (n > 10^4 cm^{-3}) gas phase, involving galaxy-sized (few 10^9 $M_\odot$) gas mass reservoirs under conditions that are typically found only for ∼1-3% of mass per typical SF molecular cloud in the Galaxy. Strong supersonic turbulence and high cosmic ray energy densities rather than far-ultraviolet/optical photons or supernova remnant induced shocks from individual star formation sites can globally warm the large amounts of dense gas found in these merger-driven starbursts and easily power their extraordinary CO line excitation. This exciting possibility can now be systematically investigated with Herschel and the Atacama Large Milimeter Array (ALMA). As expected for an IR-selected (and thus SF rate selected) galaxy sample, only few cold CO ladders are found, and for fewer still a cold low/moderate-density and gravitationally bound state (i.e. Galactic type) emerges as the most likely one. The rest remain compatible with a warm and gravitationally unbound low-density phase often found in ULIRGs.

The total molecular gas masses were estimated via the explicitly calculated X(CO) = M(H2)/L(CO) factors. One-phase radiative transfer models of the global CO spectral line ladders yield an X(CO) distribution with X(CO)∼(0.6 ± 0.2) $M_\odot$ (K km s^{-1} $pc^2)^{-1}$ over a significant range of average gas densities, temperatures, and dynamic states. The latter emerges as the most important parameter in determining X(CO), with unbound states yielding low values and self-gravitating states yielding the highest ones. Nevertheless, in many (U)LIRGs where available higher-J CO lines (J = 3-2, 4-3, and/or J = 6-5) or HCN line data from the literature allow a separate assessment of the gas mass at high densities ($\geq 10^4$ cm−3) rather than a simple one-phase analysis, we find that near-Galactic X(CO) values become possible. In the highly turbulent molecular gas in ULIRGs, a high-density component will be common and can be massive enough for its high X(CO) to dominate the average value for the entire galaxy. Using solely low-J CO lines to constrain X(CO) in such environments (as has been the practice up until now) may have thus resulted in systematic underestimates of molecular gas mass in

ULIRGs, as such lines are dominated by a warm, diffuse, and unbound gas phase with low X(CO) but very little mass. Only well-sampled high-J CO SLEDs (J = 3-2 and higher) and/or multi-J observations of heavy rotor molecules (e.g., HCN) can circumvent such a bias, and the latter type of observations may have actually provided early evidence of it in local ULIRGs. The only way that the global X(CO) of such systems could be significantly lower than Galactic is if the average dynamic state of the dense gas is strongly gravitationally unbound. This is an unlikely possibility that must nevertheless be examined, with lines of rare isotopologues of high gas density tracers being very valuable in yielding (along with the lines of the main isotopes) such constraints. For less IR-luminous, disk-dominated systems, the galaxy-averaged X(CO) deduced by one-phase models of global SLEDs can also underestimate the total molecular gas mass when much of it lies in an star-formation-quiescent phase extending beyond a central star-forming region. This is because such a phase (and its large X(CO)) remains inconspicuous in global CO SLEDs. Finally, detailed studies of a subsample of galaxies find ULIRGs with large amounts ($\sim 10^9$ $M_\odot$) of very warm ($\geq$100 K) and dense gas ($>10^5$ cm^{-3}), which could represent a serious challenge to photon-dominated regions as the main energy portals in the molecular ISM of such systems.

2.5 Distant galaxies and clusters

2.5.1 Colliding massive clusters: probing particle acceleration in Mpc-sized shocks

Galaxy clusters grow by mergers with other clusters and galaxy groups. These mergers create shock waves within the intracluster medium (ICM) that can accelerate particles to extreme energies. In the presence of a weak magnetic field, this leads to large ($\sim$ Mpc) regions of diffuse radio emission. Such regions have been classified into two main groups: relics and halos. Cluster relics are large elongated diffuse structures at the periphery of clusters. Often they are highly polarised. Cluster radio halos are located at the centres of clusters, their diffuse morphologies following that of the X-ray emission.

van Weeren, Röttgering and others reported the discovery of large-scale diffuse radio emission in the galaxy cluster MACS J1752.0+4440 (z= 0.366). Using Westerbork Synthesis Radio Telescope (WSRT) observations they found that the cluster hosts a double radio relic system as well as a 1.65 Mpc radio halo covering the region between the two relics. The relics are diametrically located on opposite sides of the cluster centre. The NE and SW relics have sizes of 1.3 and 0.9 Mpc, respectively. The relative sizes of the relics suggest a mass ratio of the merging clusters of about 2:1.The relatively flat spectral indices suggest that the relics trace shock waves with relatively high Mach numbers of around 3.5-4.5.

Van Weeren, Röttgering and others studied the cluster 1RXS J0603.3+4214 ($z = 0.225$) and found that it hosts a large bright 1.9 Mpc radio relic, an elongated 2 Mpc radio halo, and two fainter smaller radio relics . The large radio relic has a spectacular linear morphology and a clear spectral index gradient from the front of the relic towards the back, in the direction towards the cluster center. Parts of this relic are highly polarized with a polarization fraction of up to 60%. The XMM-Newton observations clearly show a violent cluster-cluster merging event. As double mergers naturally give rise to curved traveling shock fronts, the linear morphology is puzzling. A way to explain this morphology is to invoke a triple merger event. Brüggen (Hamburg), van Weeren and Röttgering carried out hydrodynamical N-body AMR simulations of a number of triple merger events. A scenario that resulted in a 2 Mpc linear shock started with two equal mass clusters with an an initial relative velocity of 1500 km s^{-1} whose cores collide 1.3 Gyr after the start of the simulation. Before core passage a less massive third cluster grazes the southern cluster and loses some of its gas and dark matter. As it then heads north, this third cluster drives a second major shock into the ICM that merges with the previous shock to form a fairly flat shock front. In projection this shock front has a morphology similar to the Toothbrush relic.

2.5.2 First LOFAR observations at very low frequencies of cluster-scale non-thermal emission: the case of Abell 2256

Abell 2256 is one of the best known examples of a galaxy cluster hosting large-scale diffuse radio emission that is unrelated to individual galaxies. It contains both a giant radio halo and a relic, and a number of head-tail sources and smaller

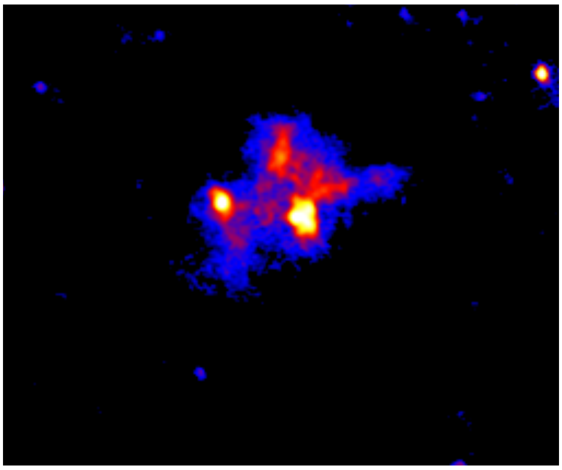

FIGURE 2.5: LOFAR image of the cluster Abell 2256 at 60-65 MHz. The resolution is 25 arcsec and the noise level is 10 mJy/beam.

diffuse steep-spectrum radio sources. The origin of radio halos and relics is still being debated, but over the last years it has become clear that the presence of these radio sources is closely related to galaxy cluster merger events. On behalf of the LOFAR collaboration, van Weeren and Röttgering presented the results from the first LOFAR observations of Abell 2256 between 18 and 67 MHz. The images are the deepest ever obtained at frequencies below 100 MHz (See Figure 2.5)

Both the radio halo and the giant relic are detected in the image at 63 MHz, and the diffuse radio emission remains visible at frequencies as low as 20 MHz. The observations confirm the presence of a previously claimed ultra-steep spectrum source to the west of the cluster center, suggesting that this source is an old part of a head-tail radio source in the cluster. For the radio relic they find a relatively flat radio spectrum which could indicate that the efficiency of particle acceleration at the shock substantially changed in the last ~ 0.1 Gyr due to an increase of the shock Mach number. In an alternative scenario, particles are re-accelerated by some mechanism in the downstream region of the shock, resulting in the relatively flat integrated radio spectrum. In the radio halo region they find indications of low-frequency spectral steepening which may suggest that relativistic particles are accelerated in a rather inhomogeneous turbulent region.

2.5.3 Characterising the hosts of nearby radio galaxies

Low luminosity radio-loud active galactic nuclei (AGN) are generally found in massive red elliptical galaxies, where they are thought to be powered through gas accretion from their surrounding hot halos in a radiatively inefficient manner. These AGN are often referred to as "low-excitation" radio galaxies (LERGs). When radio-loud AGN are found in galaxies with a young stellar population and active star formation, they are usually high-power radiatively-efficient radio AGN ("high-excitation", HERG). Using a sample of low-redshift radio galaxies identified within the Sloan Digital Sky Survey (SDSS), Janssen, Röttgering, Brinchman and Best (Edinburgh) determined the fraction of galaxies that host a radio-loud AGN, f_{RL}, as a function of host galaxy stellar mass, M_*, star formation rate, color, radio luminosity and excitation state (HERG/LERG). The results are interpreted that the presence of cold gas in a LERG enhances its probability to become a luminous radio-loud AGN compared to LERGs in a red elliptical galaxy. They speculate that feedback of the enhanced AGN activity in blue galaxies is responsible for the reduced probability of green galaxies to host a LERG.

2.5.4 The first large Hα+[O ii] double-blind study at $z \sim 1.5$

By combining narrow-band filter observations from both the Subaru Telescope and the UKIRT telescope, Sobral and collaborators have been able to obtain clean panoramic maps of parts of the distant universe about 9 billion years ago. This dual mode of surveying faint galaxies provides a powerful technique for selecting and studying star-forming galaxies during their formation and evolution. The dual-line technique takes advantage of a unique combination of the capabilities of the 8.2 m Subaru Telescope and the 3.8 m UKIRT to view very distant galaxies over wide areas. The combined Subaru-UKIRT survey uses two filters: a narrow-band filter on the Subaru Telescope to look for oxygen emission lines and another narrow-band filter on UKIRT to look for hydrogen emission lines, and yields a panoramic view of the distant universe about 9 billion years ago that one survey alone could not provide.

They have found 190 distant galaxies seen simultaneously through their hydrogen and oxygen lines and were able to derive how much star formation was occurring in the universe 9 billion years ago. The results reveal that the overall population of star-forming galaxies has been continuously decreasing their star formation activity for the last 11 billion years. The findings from this research also contribute greater details to our general understanding of how galaxies form and evolve. For the first time, they allow a comparison of dust extinction (i.e., the amount of light absorbed by dust) affecting typical star-forming galaxies today and those that existed 9 billion years ago. Contrary to past assumptions, dust extinction has similar effects on both distant young galaxies, which are much more active, and local ones. This result is very important for accurate measurement of star formation rates at early epochs in the Universe.

2.5.5 The 11 Gyr evolution of star-forming galaxies from HiZELS

Sobral and colleagues used deep data from UKIRT, Subaru and the VLT to select large, robust samples of Hα emitters at$z = 0.40, 0.84, 1.47$ and 2.23 (corresponding to look-back times of 4.2, 7.0, 9.2 and 10.6 Gyrs) in a uniform manner over $\sim$ 2deg^2 in the COSMOS and UDS fields. The deep multi-epoch Hα surveys reach $\sim 3M_\odot$/yr out to $z = 2.2$ for the first time, while the wide area and the coverage over two independent fields allow to greatly overcome cosmic variance.

These data were used to determine the Hα luminosity function and its evolution across these redshifts. This is the first time Hα has been used to trace SF activity with a single homogeneous survey at $z = 0.4$–2.23. Overall, the evolution seen in Hα is in good agreement with the evolution seen using inhomogeneous compilations of other tracers of star formation, such as FIR and UV, jointly pointing towards the bulk of the evolution in the last 11 Gyrs being driven by a strong luminosity increase from $z \sim 0$ to $z \sim 2.2$. The faint-end slope is found to be -1.60 ± 0.08 over $z = 0$–2.23, showing no evolution. The characteristic luminosity of SF galaxies, L^*, evolves significantly as $\log[L^*(z)] = 0.45z + \log[L^*(z = 0)]$.

The uniformity of this analysis allowed Sobral and co-workers to derive the Hα star formation history of the Universe, for which the simple parametrisation $\log(\mathrm{SFRD}) = -2.1/(1 + z)$ is a good approximation for $z < 2.23$. Both the shape and normalisation of the Hα star formation history are consistent with the measurements of the stellar mass density growth, confirming that our Hα analysis traces the bulk of the formation of stars in the Universe up to $z \sim 2.2$. The star formation activity over the last $\sim$ 11Gyrs is responsible for producing $\sim$ 95% of the total stellar mass density observed locally today.

2.5.6 The Properties of the Star-Forming Interstellar Medium at z=0.8-2.2 from HiZELS

In two papers, Sobral and co-workers presented adaptive-optics-assisted, spatially resolved spectroscopy of a sample of nine H-alpha-selected galaxies at $z = 0.84$–2.23 drawn from the HiZELS narrow-band survey. These galaxies have star-formation rates of 1–27$M_\odot$/yr and are therefore representative of the typical high-redshift star-forming population. The $\sim$kpc-scale resolution observations show that approximately half of the sample have dynamics suggesting that the ionised gas is in large, rotating disks. The velocity fields of the galaxies were modelled to infer the inclination-corrected, asymptotic rotational velocities. We use the absolute B-band magnitudes and stellar masses to investigate the evolution of the B-band and stellar mass Tully-Fisher relationships. By combining this sample with a number of similar measurements from the literature, we show that, at fixed circular velocity, the stellar mass of star-forming galaxies has increased by a factor 2.5 between $z = 2$ and $z = 0$, whilst the rest-frame B-band luminosity has decreased by a factor $\sim$ 6 over the same period. Together, these demonstrate a change in mass-to-light ratio in the B-band of $\Delta(M/L_B)/(M/L_B)_{z=0} \sim 3.5$ between $z = 1.5$ and $z = 0$, with most of the evolution occurring below $z = 1$.

They also use the spatial variation of [N II]/Hα to show that the metallicity of the ionised gas in these galaxies declines monotonically with galactocentric radius, with an average $\Delta(\log \mathrm{O/H})/\Delta R = -0.027 \pm 0.005$ dex/kpc. This gradient is consistent with predictions for high-redshift disk galaxies from cosmologically based hydrodynamic simulations.

The data were further used to demonstrate that within the interstellar medium of these galaxies, the velocity dispersion of the star-forming gas (σ) follows a scaling relation $\sigma \propto \Sigma_{\mathrm{SFR}}^{1/n}$ + constant (where Σ_{SFR} is the star formation surface density and the constant includes the stellar surface density). By assuming the disks are marginally stable (Toomre $Q = 1$) they show that this follows from the Kennicutt–Schmidt relation ($\Sigma_{\mathrm{SFR}} = A\Sigma_{\mathrm{gas}}^n$), and derive best fit parameters of $n = 1.34 \pm 0.15$ and $A = 3.4^{+2.5}_{-1.6} \times 10^{-4} M_\odot/\mathrm{yr/kpc}^2$, consistent with the local relation and implying cold molecular gas masses of $M_{\mathrm{gas}} = 10^{9-10} M_\odot$ and molecular gas fractions $M_{\rm gas}/(M_{\rm gas} + M_*) = 0.3 \pm 0.1$, with a range of 10-75%. These values confirm the high gas fractions for high-redshift star-forming galaxies, independent of the CO to H_2 conversion factor.

They also identify eleven ∼kpc-scale star-forming regions (clumps) within their sample and show that their sizes are comparable to the wavelength of the fastest growing unstable mode. The luminosities and velocity dispersions of these clumps follow the same scaling relations as local H II regions, although their star formation densities are a factor 15 ± 5 times higher than typically found locally. We discuss how the clump properties are related to the disk, and show that their high masses and luminosities are a consequence of the high disk surface density.

2.5.7 The clustering of Hα emitters at $z = 2.23$

Sobral and co-workers presented a clustering analysis of 370 high-confidence Hα emitters (HAEs) at $z = 2.23$. The HAEs are detected in the Hi-Z Emission Line Survey (HiZELS), a large-area blank field 2.121μm narrowband survey using the United Kingdom Infrared Telescope (UKIRT) Wide Field Camera (WFCAM). Averaging the two-point correlation function of HAEs in two ~ 1 degree scale fields (United Kingdom Infrared Deep Sky Survey/Ultra Deep Survey [UDS] and Cosmological Evolution Survey [COSMOS] fields) they found a clustering amplitude equivalent to a correlation length of $r_0 = 3.7 \pm 0.3$ Mpc/h for galaxies with star formation rates of $> 7{\rm M}_\odot$/yr. The data are well-fitted by the expected correlation function of Cold Dark Matter, scaled by a bias factor: $\Omega_{\rm HAE} = b^2\Omega_{\rm DM}$ where $b = 2.4^{+0.1}_{-0.2}$. The corresponding 'characteristic' mass for the halos hosting HAEs is $\log(M_h/[{\rm M}_\odot/h]) = 11.7 \pm 0.1$.

The results were compared to the latest predictions from the semi-analytic GALFORM model and the authors found broad agreement with the observations, with GALFORM predicting a HAE correlation length of ~ 4Mpc/h. Motivated by this agreement, they exploited the simulations to construct a parametric model of the halo occupation distribution of HAEs, and used this to fit the observed clustering. The best-fitting halo occupation distribution can adequately reproduce the observed angular clustering of HAEs, yielding an effective halo mass and bias in agreement with that derived from the scaled $\Omega_{\rm DM}$ fit, but with the relatively small sample size the current data provide a poor constraint on the halo occupation distribution. These results support the broad picture that "typical" ($\sim L^*$) star-forming galaxies have been hosted by dark matter haloes with $M_h < 10^{12}\mathrm{M}_\odot/\mathrm{h}$ since $z \sim 2$, but with a broad occupation distribution and clustering that is likely to be a strong function of luminosity.

2.5.8 Clustering around high-redshift radio galaxies

Rigby, Röttgering, Miley and collaborators used the SPIRE instrument on the Herschel Space Observatory to search for $z > 2$ protoclusters by observing 26 powerful high-redshift radio galaxy (HzRG) fields at far-infrared wavelengths. Targeting HzRGs is an efficient tool for selecting these overdense regions which will eventually grow into today's massive clusters. Indeed, the statistics of radio galaxy environment luminosity functions are consistent with every brightest cluster galaxy having gone through an evolutionary phase, with radio-selected protoclusters being typical ancestors of local galaxy clusters. Studying them is therefore a powerful tool for tracing the emergence of large scale structure and studying the evolution of galaxies in dense environments.

Examination of the environment within 3.5 arcmin of the central HzRG in each field, revealed that on average they contain a higher density of galaxies than the background at the longest wavelength. This analysis was repeated for galaxies identified by their SPIRE colours as lying close to the redshift of the HzRG (and therefore within the protocluster). 32% of the fields showed a far-infrared excess in source numbers, and there is a tentative trend for the most powerful HzRGs to host the strongest galaxy overdensities. Extending the search out to higher radii shows that these potential protoclusters are generally contained within 4 arcmin (~ 6 co-moving Mpc at $z = 2$), which is in agreement with simulations and previous work.

2.5.9 High redshift submillimetre galaxies

Van der Werf collaborated with Smail and Swinbank (Durham), Weiss (MPIfR) and Walter (MPIA) on further analysis of the LESS (LABOCA Extended Chandra Deep Field-South Survey) data, and follow-up of these with ALMA. The ALMA data identify the counterparts to these previously unidentified submillimetre sources and serendipitously detect bright emission lines in their spectra which were shown most likely to be [CII] 157.74 micron emission yielding redshifts of z=4.42 and 4.44. The ratio of L[CII]/LFIR in these SMGs is much higher than seen for similarly far-infrared-luminous galaxies at z=0, which is attributed to the more extended gas reservoirs in these high-redshift ultraluminous infrared galaxies. Using the volume probed by the ALMA survey, it was shown that the bright end of the [CII] luminosity function evolves strongly between z=0 and 4.4, reflecting the increased interstellar medium cooling in galaxies as a result of their higher star formation rates. These observations demonstrate that even with short integrations, ALMA is able to detect the dominant fine-structure cooling lines from high-redshift ULIRGs, measure their energetics and spatially resolved properties and trace their evolution with redshift.

Van der Werf also worked with Gonzalez-Nuevo (Trieste) and the Herschel-ATLAS team to develop a method for selecting strongly gravitationally lensed submillimeter galaxies: the Herschel-ATLAS Lensed Objects Selection (HALOS). HALOS will allow the selection of up to 1000 candidate strongly lensed galaxies over the full H-ATLAS survey area. Applying HALOS to the H-ATLAS Science Demonstration Phase field (~ 14.4 deg^2) yielded 31 candidate objects, whose candidate lenses were identified in the VIKING near-infrared catalog. Using the available information on candidate sources and candidate lenses they tentatively estimated a $\simeq 72\%$ purity of the sample. The redshift distribution of the candidate lensed sources is close to that reported for most previous surveys for lensed galaxies, while that of candidate lenses extends to redshifts substantially higher than found in the other surveys.

Van der Werf also worked with Harris (University of Maryland) and the H-ATLAS team to obtain the first blind redshifts of candidate lensed high-z galaxies based on measurements of the carbon monoxide ground state rotational transition (CO J = 1-0) with the Zpectrometer ultrawideband spectrometer on the 100 m diameter Green Bank Telescope. The sample comprises 11 galaxies with redshifts between z=2.1 and 3.5 from a total sample of 24 targets identified by Herschel-ATLAS photometric colors from the SPIRE instrument. Nine of the CO measurements are new redshift determinations, substantially adding to the number of detections of galaxies with rest-frame peak submillimeter emission near 100 micron. The CO detections confirm the existence of massive gas reservoirs within these luminous dusty star-forming galaxies. Corrected for magnification, most galaxy luminosities are consistent with an ultraluminous infrared galaxy classification, but three are candidate hyper-LIRGs with luminosities greater than 10^{13} $L_\odot$.

2.5.10 Surveys for High-z Galaxies

Patel, Fumagalli and Franx studied high redshift galaxies using the 3D-HST grism survey. In his survey spectra are taken with the Hubble Space Telescope of more than 10.000 galaxies. In their first paper, Fumagalli studied the increase in the Hα equivalent width with look back time. They found a clear increase towards higher redshift, proportional to $(1+z)^{1.8}$. A simple model could fit the observed results, and predicts very high equivalent widths at z=8 (of 400 Å). Nelson et al used this survey to study the Halpha sizes of galaxies, and found that the Halpha sizes are systematically larger than the continuum light sizes.

Wake, van Dokkum and Franx studied the colors of galaxies in the Sloan Digital Sky Survey and found that velocity dispersion is the best "predictor" of color, better than stellar mass, surface mass density, or morphology.

Muzzin, Franx and collaborators worked on the UltraVista survey, a deep survey co-lead by Franx to take deep Near-IR imaging of the cosmos field. Muzzin et al. constructed a deep catalogue, and found a multiply lensed red galaxy. This lensed galaxy has no star formation, and is at a redshift of about 2.4 This provides a very high resolution image of the very compact galaxy.

Weinmann and collaborators studied the evolution of the mass function for galaxies with masses around 3 10^9. She found that almost all models predict the wrong evolution with redshift: the data show gradual evolution from high redshift to 0, whereas the models show a nearly flat mass function at a redshift of 1. The models have a basic problem, which is likely insufficient feedback to stop star formation at higher redshift.

2.5.11 The star formation rate functions of the Universe in the first 1–2 billion years

Taking advantage of published determinations on the prevalence of galaxies 1 to 2 billion years after the Big Bang and estimates of the dust extinction in these galaxies based on galaxy colors in the ultraviolet, PhD student Renske Smit and staff member Rychard Bouwens presented the first ever determinations of the star formation rate functions for galaxies in the first one to two billion years of the universe (Fig. 2.6). These star formation rate functions indicate a much more

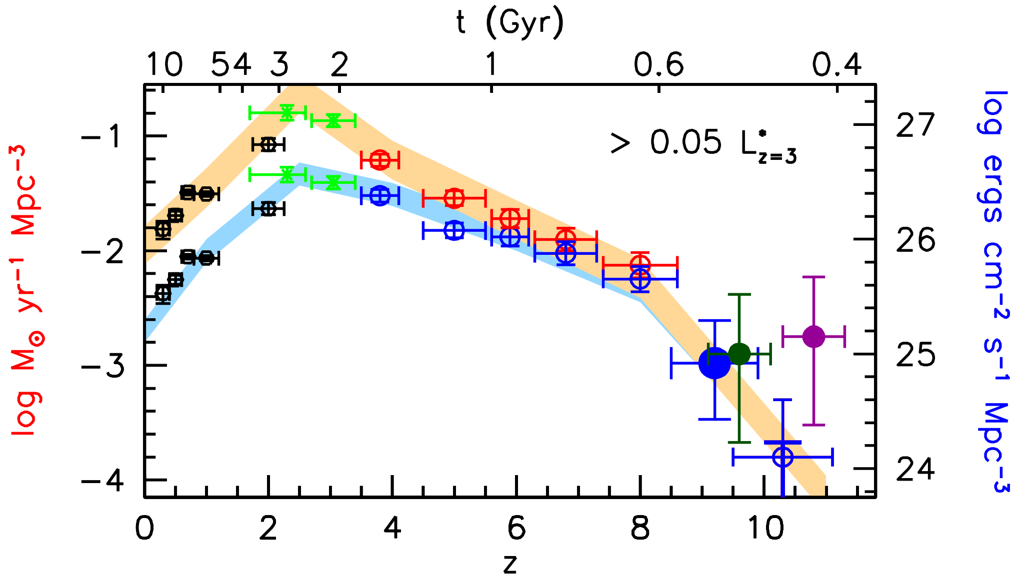

FIGURE 2.6: The star formation rate density of the universe as a function of cosmic time (upper horizontal axis) and cosmological redshift (lower horizontal axis). A recent search for gravitationally lensed galaxies behind lower redshift galaxy clusters allowed staff member Rychard Bouwens to derive the first meaningful measurement of the star formation rate density 550 million years after the Big Bang. This measurement is indicated with the large blue circle at redshift ("z") of 9 (corresponding to a time 0.55 Gyr after the Big Bang).

rapid build-up of galaxies in the early universe than is indicated by studies of the prevalence of galaxies in the ultraviolet. These star formation rate functions are especially useful to astrophysicists who run very sophisticated simulations of the universe, since they provide them with physical observables against which they can compare their simulation results. The paper that Renske Smit and Rychard Bouwens published on this topic is already attracting significant attention.

Bouwens and Smit have also been taking advantage of the huge quantity of Hubble Space Telescope observations taken in and around $\sim$ 20 massive galaxy clusters to explore the properties of galaxies present at the earliest epochs of the universe. Deep Hubble Space Telescope observations have been obtained as part a very large, 2-month Hubble program called CLASH. Rychard Bouwens used observations from this program to conduct a systematic search for galaxies just 550 million years after the universe in $\sim$ 20 massive galaxy clusters and discovered just 3 candidates (Fig. 2.7). The 3 candidates compared with some $\sim$ 18 candidates at a slightly later epoch of the birth of the universe, indiocating a substantial drop in the rate at which the universe is forming stars just 550 million years after the Big Bang.

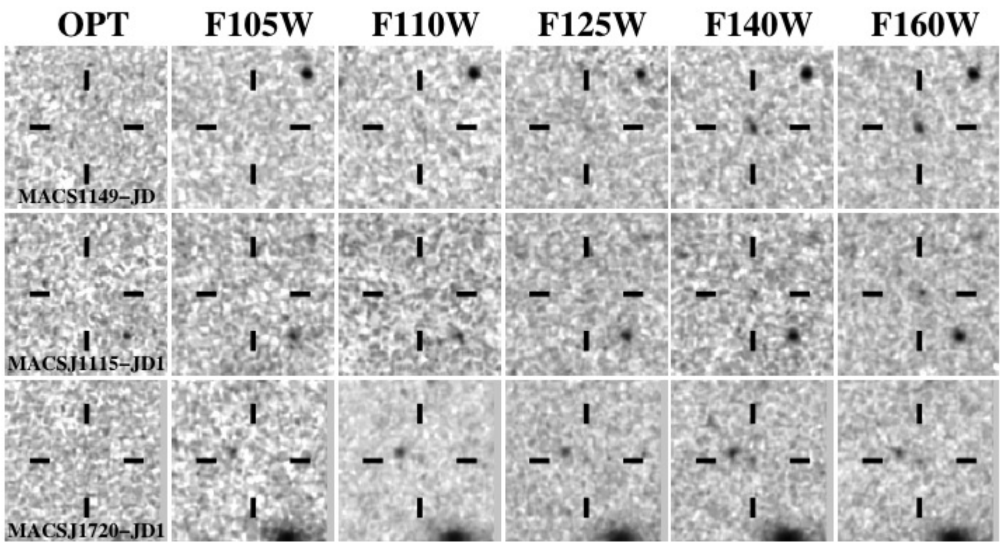

FIGURE 2.7: Images of three galaxies (one per row) that likely emitted their light just 550 million years after the Big Bang. The images are 6.6 arcsec on a side. The different columns correspond to the images we have of these galaxies in different wavelength channels, from bluest wavelength images on the left to the reddest wavelength images on the right. Galaxies that emitted their light near the beginning of the universe are only detected at the reddest wavelengths.

What was noteworthy about this drop in the star formation rate was that it was even larger than one would have expected from an extrapolation of results later in the universe.

PhD student Renske Smit has also been involved in a comprehensive effort to study light from older stars in galaxies at very early times based on lensing from the same set of ~ 20 clusters as Bouwens had used for his analysis. To obtain information on the older stars, Smit is using images from the Spitzer Space Telescope which can view distant galaxies at much redder wavelengths than is possible with the Hubble Space Telescope. She uses the combined flux information from the Hubble and Spitzer Space Telescope to determine what the average galaxy in the universe looks like 600 to 900 million years after the Big Bang and also to infer what the likely properties of these galaxies are. She has already succeeded in demonstrating on the basis of her study that galaxies in this era are building up stellar mass for their star formation rate much faster than galaxies at later epochs of the universe. Her study has also shown quite unequivocally that nebular emission lines are very prominent in the spectra of galaxies in the early universe.

2.5.12 Gravitational weak lensing

Hoekstra, Semboloni, Kuijken in collaboration with the rest of the CFHTLenS team completed the weak lensing analysis of data obtained as part of the CFHT Legacy Survey. This resulted in a number of papers constraining cosmological parameters with more sophisticated analyses, while providing also more challenging tests of the measurements. Highlights include the first large-scale tomographic measurements and tests of the laws of gravity using lensing together with measurements of redshift space distortions. This work is also a nice benchmark for the Kilo Degree Survey which is now in full operation, and covers the main science goals of Euclid, which was selected for adoption by ESA in June.

Hoekstra is one of the coordinators for the weak lensing science of Euclid, and work continued on refining requirements and flowing these down to algorithm developments. With his collaborators, Hoekstra also finished the analysis of the Canadian Cluster Comparison Project and published results on the weak lensing and X-ray masses. Hoekstra also completed the weak lensing analysis for a sample of clusters discovered by the South Pole Telescope, and these measurements form the basis of the mass calibration needed for the cosmological interpretation of these data.

2.6 Theoretical studies of galaxies and large scale structures

2.6.1 Simulating the formation of disc galaxies

McCarthy (Birmingham), Schaye, Crain and collaborators examined the rotation rates, sizes and star formation (SF) efficiencies of a representative population of simulated disc galaxies. Over the wide galaxy stellar mass range, $9.0 < \log 10[M_*(\mathrm{M}_\odot)] < 10.5$, the simulations reproduce the observed Tully-Fisher relation, the rotation curves of disc galaxies in bins of stellar mass, the mass-size relation of disc galaxies, the optical rotation to virial circular velocity ratio and the SF efficiencies of disc galaxies as inferred from stacked weak lensing and stacked satellite kinematics observations. They also reproduce the specific star formation rates of L^* galaxies but predict too low levels of SF for low-mass galaxies, which is plausibly due to the finite resolution of the simulations. At higher stellar masses the simulated galaxies are too concentrated and have too high SF efficiencies, which may reflect the neglect of feedback from accreting supermassive black holes in these simulations. They concluded that it is possible to generate a representative population of disc galaxies that reproduces many of the observed trends of local disc galaxies using standard numerical hydrodynamic techniques and a plausible implementation of the "subgrid" astrophysical processes thought to be relevant to galaxy formation.

2.6.2 Simulating galactic outflows with thermal supernova feedback

Cosmological simulations make use of sub-grid recipes for the implementation of galactic winds driven by massive stars because direct injection of supernova energy in thermal form leads to strong radiative losses, rendering the feedback inefficient. Dalla Vecchia (MPE) and Schaye argued that the main cause of the catastrophic cooling is a mismatch between the mass of the gas in which the energy is injected and the mass of the parent stellar population. Because too much mass is heated, the temperatures are too low and the cooling times too short. They used analytic arguments to estimate, as a function of the gas density and the numerical resolution, the minimum heating temperature that is required for the injected thermal energy to be efficiently converted into kinetic energy. They proposed and tested a stochastic implementation of thermal feedback that uses this minimum temperature increase as an input parameter and that can be employed in both particle-based and grid-based codes. They used hydrodynamic simulations to test the method on models of isolated disc galaxies and found that the thermal feedback strongly suppresses the star formation rate and can drive massive, large-scale outflows (Fig. 2.8).

2.6.3 Properties of gas in and around galaxy haloes

Van de Voort and Schaye used cosmological simulations to study the properties of gas inside and around galaxy haloes as a function of radius and halo mass. They found that the properties of cold- and hot-mode gas, which they separated

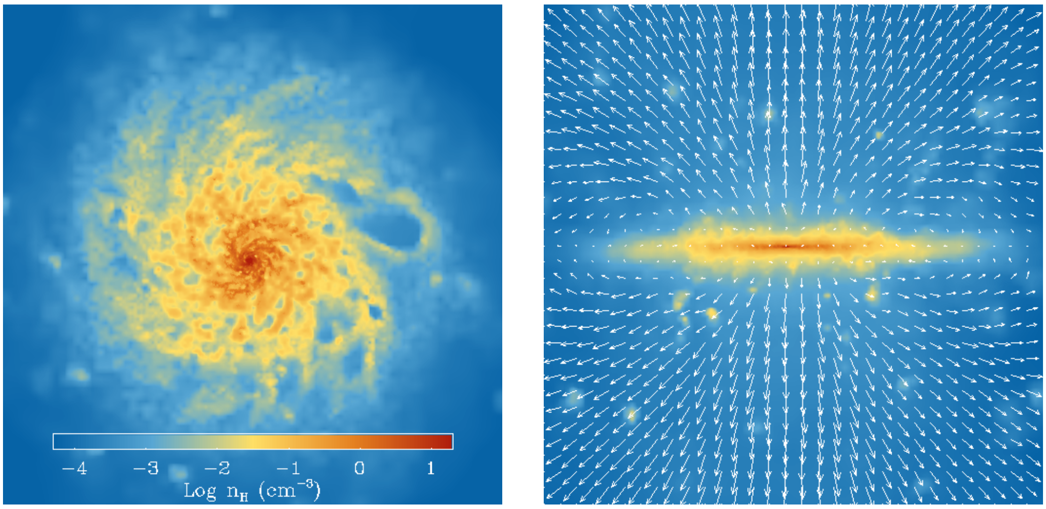

FIGURE 2.8: Face- (left) and edge-on (right) projections of the disc gas distribution in two simulations employing thermal supernova feedback. Images are 45 kpc/h on a side and the colour coding is logarithmic in density. A velocity field vector length of 1/32 the side of the images corresponds to 400 km/s. Feedback from star formation drives a strong bi-conical outflow and blows bubbles in the disc.

depending on whether the temperature has been higher than $10^{5.5}$ K while it was extragalactic, are clearly distinguishable in the outer parts of massive haloes. The differences between cold- and hot-mode gas resemble those between inflowing and outflowing gas. The cold-mode gas is mostly confined to clumpy filaments that are approximately in pressure equilibrium with the diffuse, hot-mode gas. Besides being colder and denser, cold-mode gas typically has a much lower metallicity and is much more likely to be infalling. However, the spread in the properties of the gas is large, even for a given mode and a fixed radius and halo mass, which makes it impossible to make strong statements about individual gas clouds. Metal-line cooling causes a strong cooling flow near the central galaxy, which makes it hard to distinguish gas accreted through the cold and hot modes in the inner halo. Stronger feedback results in larger outflow velocities and pushes hot-mode gas to larger radii. The gas properties evolve as expected from virial arguments, which can also account for the dependence of many gas properties on halo mass. They argued that cold streams penetrating hot haloes are observable as high column density H I Lyman-α absorption systems in sightlines near massive foreground galaxies.

2.6.4 Neutral Hydrogen Optical Depth near Star-forming Galaxies

Rakic, Schaye, Steidel (Caltech) and Rudie (Caltech) studied the interface between galaxies and the intergalactic medium by measuring the absorption by neutral hydrogen in the vicinity of star-forming galaxies at $z = 2.4$. Their sample consisted of 679 rest-frame UV-selected galaxies with spectroscopic redshifts that have impact parameters < 2 (proper) Mpc to the line of sight of one of the 15 bright, background QSOs. They presented the first two-dimensional maps of the absorption around galaxies (Fig. 2.9), plotting the median Ly-α pixel optical depth as a function of transverse and line-of-sight separation from galaxies. The median optical depth, and hence the median density of atomic hydrogen, drops by more than an order of magnitude around 100 kpc, which is similar to the virial radius of the halos thought to host the galaxies. The median remains enhanced, at the $> 3\sigma$ level, out to at least 2.8 Mpc (i.e. > 9 comoving Mpc). The mean galaxy overdensity around absorbers increases with the optical depth and also as the length scale over which the galaxy overdensity is evaluated is decreased. They clearly detected two types of redshift space anisotropies. On scales < 200 km/s, or < 1 Mpc, the absorption is stronger along the line of sight than in the transverse direction. This "finger of God" effect may be due to redshift errors, but is probably dominated by gas motions within or very close to the halos. On the other hand, on scales of 1.4–2.0 Mpc the absorption is compressed along the line of sight (with $> 3\sigma$ significance), an effect that they attributed to large-scale infall (i.e., the Kaiser effect).

2.6.5 Cold accretion flows and the nature of high column density H I absorption

Simulations predict that galaxies grow primarily through the accretion of gas that has not gone through an accretion shock near the virial radius and that this cold gas flows towards the central galaxy along dense filaments and streams. There is, however, little observational evidence for the existence of these cold flows. Van de Voort, Schaye, Altay (Durham) and Theuns (Durham) used a simulation to study the contribution of cold flows to the observed $z = 3$ column density distribution of neutral hydrogen, which their simulation reproduces. They found that nearly all

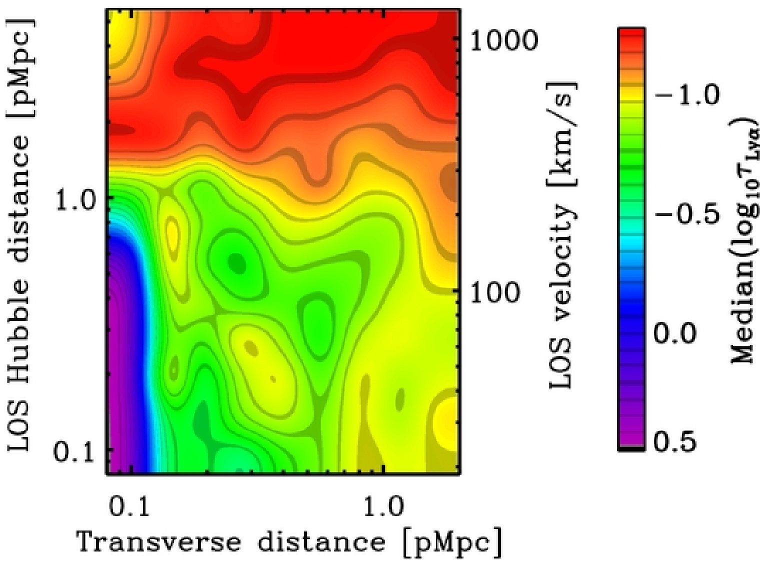

FIGURE 2.9: Median H I Ly-α absorption as a function of transverse and line-of-sight distance from $\langle z \rangle = 2.4$ star-forming galaxies. Absorption is clearly enhanced close to galaxies, out to at least 2 proper Mpc (pMpc) in the transverse direction, but only out to ≈ 1.5 pMpc along the line of sight. This anisotropy suggests large-scale infall of gas. On the other hand, on small scales the absorption declines more rapidly in the transverse direction than in the line-of-sight direction.

of the H I absorption arises in gas that has remained colder than $10^{5.5}$ K, at least while it was extragalactic. In addition, the majority of the H I is falling rapidly towards a nearby galaxy. Although very little of the H I in Lyman limit systems resides inside galaxies, these absorbers are closely related to star formation: most of their H I either will become part of the interstellar medium before $z = 2$ or has been ejected from a galaxy at $z > 3$. Cold accretion flows are critical for the success of our simulation in reproducing the observed rate of incidence of damped Lyman-α and particularly that of Lyman limit systems. They therefore concluded that cold accretion flows exist and have already been detected in the form of high column density H I absorbers.

2.6.6 The filling factor of intergalactic metals

Observations of quasar absorption-line systems reveal that the $z = 3$ intergalactic medium (IGM) is polluted by heavy elements down to H I optical depths $\ll 10$. What is not yet clear, however, is what fraction of the volume needs to be enriched by metals and whether it suffices to enrich only regions close to galaxies in order to reproduce the observations. Booth, Schaye, Delgado, and Dalla Vecchia (MPE) used gas density fields derived from large cosmological simulations, together with synthetic quasar spectra and imposed model metal distributions, to investigate what enrichment patterns can reproduce the observed median optical depth of C IV as a function of H I. Their models can only satisfy the observational constraints if the $z = 3$ IGM was primarily enriched by galaxies that reside in low-mass (total halo mass $< 10^{10} M_{\odot}$) haloes that can eject metals out to distances $> 10^{2}$ kpc. Galaxies in more massive haloes cannot possibly account for the observations as they are too rare for their outflows to cover a sufficiently large fraction of the volume. Galaxies need to enrich gas out to distances that are much greater than the virial radii of their host haloes. Assuming the metals to be well mixed on small scales, their modelling requires that the fractions of the simulated volume and baryonic mass that are polluted with metals are, respectively, > 10 per cent and > 50 per cent in order to match observations.

2.6.7 Disentangling galaxy environment and host halo mass

The properties of observed galaxies and dark matter haloes in simulations depend on their environment. The term 'environment' has, however, been used to describe a wide variety of measures that may or may not correlate with each other. Popular measures of environment include, for example, the distance to the N^{th} nearest neighbour, the number density of objects within some distance or, for the case of galaxies only, the mass of the host dark matter halo. Haas, Schaye, and Jeeson-Daniel (MPA) used results from the Millennium Simulation and a semi-analytic model for galaxy formation to quantify the relations between different measures of environment and halo mass. They showed that the environmental parameters used in the observational literature are in effect measures of halo mass, even if they are measured for a fixed stellar mass. They demonstrated that the distance to the Nth nearest neighbour becomes insensitive to halo mass if it is constructed from dimensionless quantities. This can be achieved by scaling the minimum luminosity/mass of neighbours to that of the object that the environment is determined for and by reducing the distance to a length-scale associated with either the neighbour or the galaxy under consideration. Their results will help future studies to disentangle the effects of halo mass and external environment on the properties of galaxies and dark matter haloes.

2.6.8 Rest-frame ultraviolet line emission from the intergalactic medium

Rest-frame ultraviolet (UV) emission lines offer the exciting possibility to directly image the gas around high-redshift galaxies with upcoming optical instruments. Bertone (UCSC) and Schaye used a suite of simulations to predict the nature and detectability of emission lines from the intergalactic medium (IGM) at $2 \leq z \leq 5$. The brightest H I Ly-α emission arises exclusively in highly overdense gas, but the highest surface brightness emission from high-ionisation metal lines traces a much wider range of overdensities. Bright metal-line emission traces gas with temperatures close to the peak of the corresponding emissivity curve. While H I Ly-α, He II Hα, C III, Si III and Si IV are excellent probes of cold accretion flows and the colder parts of outflows, C IV, N V , O VI and Ne VIII are powerful tracers of the diffuse warm-hot IGM and galactic winds. Several rest-frame UV emission lines from the high-redshift IGM will become detectable in the near future, possibly starting with the Cosmic Web Imager, which is already operating on Palomar. The Multi Unit Spectroscopic Explorer, which will be commissioned in 2014 on the Very Large Telescope, and the proposed Keck Cosmic Web Imager have the potential to revolutionise studies of the interactions between high-redshift galaxies and their environment.

2.6.9 The evolution of low-mass galaxies, an unsolved problem

Models of galaxy formation and evolution predict that low-mass galaxies should form early, and have relatively low star formation rates today. Weinmann, Oppenheimer, Crain and international collaborators showed that these basic predictions are at odds with new observational results. They used a variety of different models of galaxy formation, hydrodynamical and semi-analytical, to demonstrate that all these models show a consistent mis-match with observational results. This indicates that there is a fundamental unsolved problem in the field of galaxy formation, regarding the evolutionary history of low-mass galaxies, indicating that our understanding of the evolution of those galaxies is still incomplete. They also

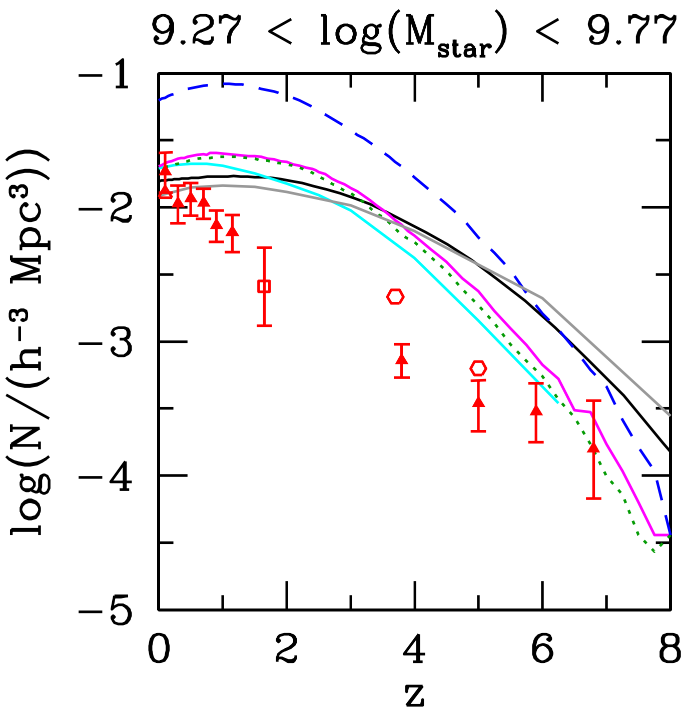

FIGURE 2.10: The evolution in the number density of low-mass galaxies with masses around $\log(M/M_{\odot}) = 9.5$ as a function of redshift in several semi-analytical and hydrodynamical models (lines) and according to observations (data points).

showed that the observations of star formation rates and the evolution of the stellar mass function are internally consistent, indicating that the problem does not lie in an incorrect interpretation of observations.

2.7 Computational astrophysics

The research group for Computational Astrophysics Leiden (CAstLe) aims at studying the universe by means of simulation. The specific areas of research in astrophysics include the evolution of binary (and higher order multiple) stars, the dynamical evolution of dense stellar systems and of galactic nuclei. From a computational point of view the research group aims at simulation environments for solving the equations for gravitational dynamics, stellar structure and evolution, hydrodynamics and radiative transfer. Calculations are performed on computers built by the research group, graphical processing units, supercomputers and grid environments.

In collaboration with Evghenni Gaburov (SARA) we made a new implementation and improved performance of a super efficient gravitational N-body tree-code that is specifically designed for the graphics processing unit (GPU).The code is publicly available at: `http://castle.strw.leidenuniv.nl/software.html`. All parts of the tree-code algorithm are executed on the GPU. the algorithms are presented for parallel construction and traversing of sparse octrees. The gravitational tree-code outperforms tuned CPU code during the tree-construction and shows a performance improvement of more than a factor 20 overall, resulting in a processing rate of more than 2.8 million particles per second. In their recent presentation of the Kepler GPU Architecture NVIDIA CEO Jen-Hsun Huang adopted this code to demonstrate[1]. the enormous speed of the GPU.

Pelupessy and Jänes presented new methods for the integration of gravitational N-body systems. The new methods take advantage of the hierarchies present in astrophysical N-body systems to accelerate the time stepping in the simulation while conserving energy to high precision.

Pelupessy and Portegies Zwart investigated the formation of planets around binary stars. They found that the binary driven density enhancement at the inner edge of the circumbinary disk explains the orbital configuration of planetary systems around binary stars such as discovered by the Kepler mission (Fig. 2.11).

2.7.1 AMUSE

On December 6th, version 7.1 of the AMUSE software package (van Elteren, Pelupessy, de Vries and Portegies Zwart) was released. This release included 35 astrophysical codes, amongst which codes for gravitational dynamics, stellar evolution, hydrodynamics and radiative transfer, in a comprehensive framework for computational astrophysics. This release included new options for couplings amongst the aforementioned domains.

The first major AMUSE result was published in MNRAS in 2012. In this paper Pelupessy & Portegies Zwart studied the evolution of embedded clusters. The equations of motion of the stars in the cluster are solved by direct N-body integration while taking the effects of stellar evolution and the hydrodynamics of the

[1] The presentation can be seen on YouTube: `http://www.youtube.com/watch?v=aByz-mxOXJM`

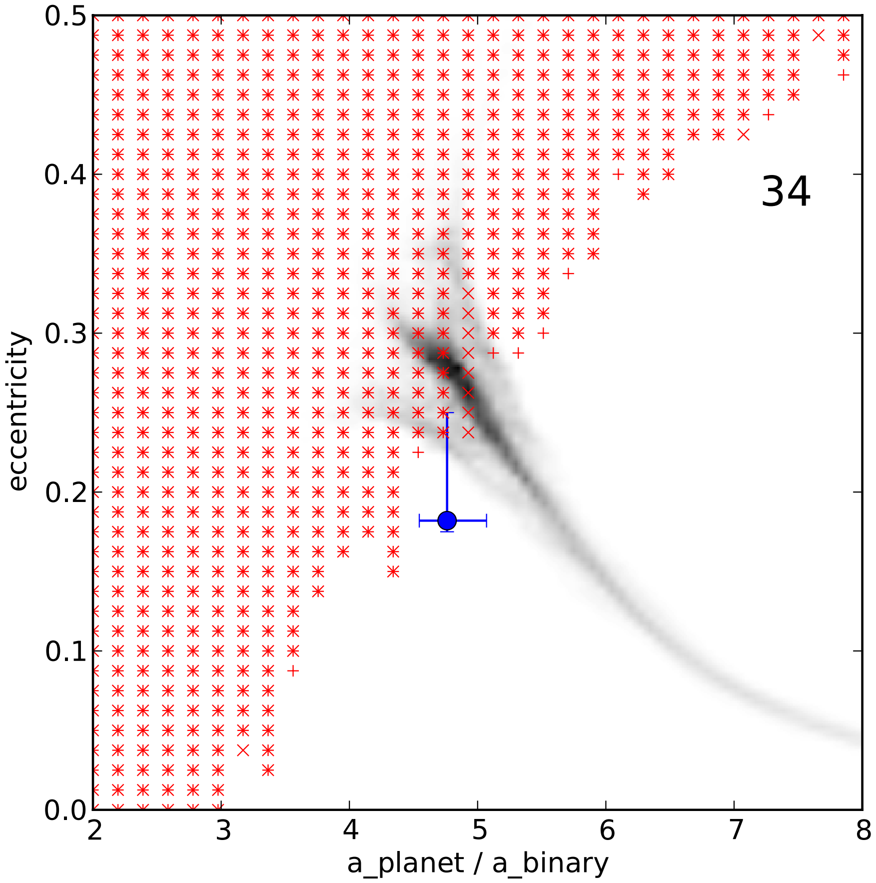

FIGURE 2.11: The formation of the circumbinary planet Kepler 34: Circumbinary disk and stability analysis. This figure shows the correspondence of the distribution protoplanetary disk material in the semi-major axis-eccentricity plane (grey shading) and the planet (symbol with error bars) as well as the region of dynamical instability (red stars).

natal gas content into account. The gravity of the stars and the surrounding gas are coupled self-consistently to allow the realistic dynamical evolution of the cluster. While the equations of motion are solved, a stellar evolution code keeps track of the changes in stellar mass, luminosity and radius. The gas liberated by the stellar winds and supernovae deposits mass and energy into the gas reservoir in which the cluster is embedded. They examined cluster models with 1000 stars, but varied the star formation efficiency (between 0.05 and 0.5), cluster radius (0.1–1.0 pc), the degree of virial support of the initial population of stars (0–100 per cent) and the strength of the feedback. They found that the degree of mass segregation in open clusters such as the Pleiades is not the result of secular evolution but a remnant of its embedded stage.

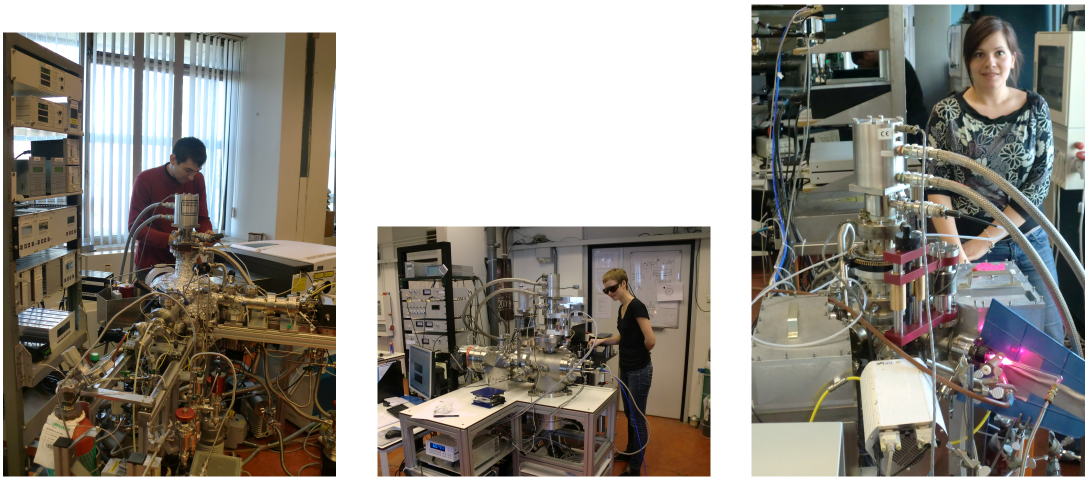

FIGURE 2.12: The Sackler laboratory for Astrophysics

2.8 The Raymond and Beverly Sackler Laboratory Astrophysics

In 2012 a number of technological breakthroughs have been realized in the Sackler Laboratory for Astrophysics. Two new ultra-sensitive detection techniques were developed that will change the way optical spectroscopic studies of molecules of astrophysical interest can be performed; os-BBCEAS (optomechanical shutter-broad band cavity enhanced absorption spectroscopy) allows to search for diffuse interstellar band carriers covering large spectral ranges in very short times – on the order of a few seconds — and CESAS (cavity enhanced self absorption spectroscopy) makes it possible to study light-emitting matter even without the need for an external light source. The latter technique will also have applications in pure applied sciences, e.g., combustion, flame and plasma research. The conceptual simplicity of both techniques combined with high detection sensitivity (better than one part per billion) over extended spectral ranges makes them ideal for spectral laboratory surveys.

Another ultra-precise cavity enhanced technique (cw-CRDS) has been extended to the infrared and has been used to record fully rovibrationally resolved transitions of astrophysically relevant molecular transients. The first results show that molecular data are accurate enough to be used for an (in)direct interpretation of ALMA data.

Also, in 2012, a new atom beam line was added to an experiment capable of studying atom addition reactions in interstellar ice analogues, making the new setup one of the most complete setups for this type of studies worldwide. Chemical reactions upon bombardment with different atoms can be studied in one run. Research topics covered the formation of water in space, the production of hydroxylamine, known to be a precursor molecule in the generation of amino-acids as well as the H/D ratio in ice formation (H_2O vs. HDO). The latter helps to interpret the cosmochemical origin of e.g., water on Earth.

Furthermore a new mobile setup — iPOP (Instrument for Photodynamics of PAHs) became operational. This setup (constructed within a collaborative project with Prof. Tielens) combines ion-trapping and time-of-flight mass spectrometry to study the long term photobehaviour of PAHs upon light excitation. The setup is mobile and will be used at large beam line facilities, such as SOLEIL and FELIX. Finally a new experimental concept was developed to study the porosity decrease upon thermal annealing of interstellar ices, combining frequency stabilised interferometry and Fourier transform infrared spectroscopy. The results show that interstellar ice — known to be amorphous, and assumed to be compact — keep a substantial degree of porosity upon heating. This is important particularly for surface induced chemical reactions, as with the increase of available surface area also the efficiency of solid state reactions in the inter- and circumstellar matter increases.

The many results of the laboratory group have not remained unnoticed. As a consequence the Sackler Laboratory has been asked to act as scientific host for IAU297 "The diffuse interstellar bands" (2013) and the Faraday Discussions 168 "Solid State Astrochemistry" (2014).

2.9 Instrumentation

2.9.1 Improved APP coronographs

Matthew Kenworthy's research is concerned with the direct detection and characterization of planets around nearby stars. Coronagraphs help cut down the glare of a bright star next to a fainter planet, and in research led by graduate student Tiffany Meshkat, the Apodizing Phase Plate (APP) coronagraph on the VLT is carrying out surveys around stars that may harbour gas giant planets, including famous stars such as Fomalhaut. In parallel with this observational work, laboratory development of a new type of APP coronagraph that can work over very broad ranges of wavelengths demonstrated the feasibility of this technology. Kenworthy's graduate student, Gilles Otten, worked with Frans Snik on the testing of the Vector APP that shows promise of increasing the collected flux from faint companions. Additional sensitivity can be achieved with point spread function reconstruction, and work with Johanan Codona (U. Arizona) is showing results both in the laboratory and on the sky, with a paper published in 2013.

2.9.2 ASSIST

ASSIST, the Adaptive Secondary Setup and Instrument Stimulator, is the testbed for ESOs Very Large Telescope Adaptive Optics Facility. ASSIST was developed by NOVA and designed, build and tested by Stuik and team over the last 10 years at Leiden Observatory. ASSIST allows for the testing and calibration of Adaptive Optics instruments and the Deformable Secondary Mirror for Unit Telescope 4 under conditions (seeing, natural guide stars and laser guide stars) that are present at the VLT at Paranal Chile, without having to use valuable on-sky telescope time. In 2011 and early 2012 ASSIST was built up at ESO and in October 2012 ASSIST passed preliminary Acceptance at ESO. This milestone effectively means that ASSIST had been fully delivered to ESO.

2.9.3 Allegro

The year 2012 was a turning point for the ALMA Regional Center node in the Netherlands, Allegro, hosted by Leiden Observatory and coordinated by Hogerheijde. In this year, science observing with the ALMA array started in earnest, and data for a first set of projects was processed, calibrated, and analysed by Allegro staff. They worked closely with the Principal Investigators of the projects to verify the data quality and enhance the scientific analysis of the products. This resulted in several papers using ALMA data with Leiden staff as (co) author, describing, e.g., warm gas in the outflow of the embedded young stars IRAS 16293-2422, the detection of a simple sugar molecule in the same object, and infalling motions in the surrounding gas. The staff of Allegro was strengthened by the return of van

Kempen from a two-year tour of duty with ALMA commissioning in Chile and the appointment of Tilanus as program manager.

2.10 History of science

D. van Delft holds a part-time appointment as professor in the history of science at Leiden Observatory. His research in 2012 focussed on the Leiden cryogenic laboratory, W.J. de Haas and Paul Ehrenfest. Van Delft is supervising three PhD-projects: "Op weg naar Urenco: Jacob Kistemaker en zijn laboratorium voor massaspectrografie 1945–1960" (together with Van Lunteren), "Ruska and the early history of the electron microscope" and "ASML and high tech innovation in the Netherlands" (together with Van Lente, Utrecht University).

Chapter 3

Education popularization and social events

Chapter 3 Eduction, popularization and social events

3.1 Education

Teaching and training of students is a major priority of Leiden Observatory. In 2012, 51 freshmen started their studies in astronomy. Of this number, 13 (25,5%) were women, and 18 (35%) pursued a combined astronomy/physics or astronomy/mathematics/computer science degree. The Observatory registered a total number of 91 BSc students at the end of the year, of which 39 (42%) aimed at a combined astronomy/physics degree or astronomy/mathematics degree; 23% of all BSc students is female. There were 30 MSc students, including 12 (40%) women. Out of 30, 10 (33%) were from abroad. Several students from the applied physics department of Delft Technical University took courses from the Leiden astronomy curriculum as part of the requirements for a minor in astronomy. Seventeen students passed their propedeutical exam, of which twelve completed the requirements within the nominal one year. There were 17 BSc exams, and 11 MSc exams.

Pen continued as the education coordinator taking care of the daily tasks. Hoekstra continued as BSc study adviser. In September Portegies Zwart stepped down as the MSc study adviser and Schaye took over. In addition to counseling by the student adviser, incoming students were assigned to small groups meeting at regular intervals with a staff mentor (Linnartz, Hogerheijde, Kuijken, Portegies Zwart) and a senior student mentor. In the tutor programme, physics and astronomy freshman students were provided on a voluntary but regular basis with coaching by senior students.

As part of the introductory astronomy course, students were taken to the Artis Planetarium in Amsterdam for a lesson in coordinate systems, time and constellations in the sky (Snellen). As part of the second-year training in practical astronomy, 9 honors students were offered the opportunity to take part in a specially arranged observing trip to the Isaac Newton Telescope on La Palma, Canary Islands (Hoekstra, Israel and Otten).

The astronomy curriculum is monitored by the Education committee (Opleidingscommissie), which advises the Director of Studies on all relevant matters, and which was chaired by Röttgering. Under the authority of the Education Committee, the lecture course monitoring system was continued. In this system, students provide feedback to lecturers during and after the course. The quality of curriculum and exams is the responsibility of the board of Examiners (Examencommissie) chaired by Lub. Admission to the master-curriculum for students without a BSc in astronomy from a Netherlands university requires a recommendation by the Admissions committee (Toelatingscommissie) chaired by Schaye and having Portegies Zwart and Brandl as members.

3.2 Degrees awarded in 2012

3.2.1 Ph.D. degrees

A total of 9 graduate students successfully defended their Ph.D. theses in 2012 and were awarded their Ph.D. degree. They are:

Name:	M. Velander
Graduation Date:	20-06-2012
Supervisor:	Kuijken
Thesis title:	Studying Dark Matter: Haloes with Weak Lensing
Current position:	Postdoctoral Fellow,Oxford,United Kingdom

Name:	R. Martinez Galarza
Graduation Date:	19-06-2012
Supervisor:	Brandl
Thesis title:	Mid-Infrared Spectroscopy of Starbursts: from Spitzer-IRS to JWST-MIRI
Current position:	Postdoc Harvard-Smithsonian Center for Astrophysics, USA

Name:	E. van Uitert
Graduation Date:	29-05-2012
Supervisor:	Kuijken
Thesis title:	Weak Gravitational Lensing in the RCS2
Current position:	Postdoc Argelander Institut fur Astronomie, Bonn, Germany

Name:	F. van de Voort
Graduation Date:	28-03-2012
Supervisor:	Schaye
Thesis title:	The Growth of Galaxies and their Gaseous Haloes
Current position:	University of California at Berkeley, USA

Name:	A-M. Madigan
Graduation Date:	16-02-2012
Supervisor:	Kuijken/co: Levin/Hopman
Thesis title:	Secular Stellar Dynamics near Massive Black Holes
Current position:	Postdoc Leiden Observatory, Leiden, The Netherlands

Name:	M. van Hoven
Graduation Date:	15-02-2012
Supervisor:	Kuijken/co: Levin/Hopman
Thesis title:	Seismology of Magnetars
Current position:	

Name:	O. Rakic
Graduation Date:	07-02-2012
Supervisor:	Schaye/Steidel/De Zeeuw
Thesis title:	The Intergalactic medium near High-Redshift Galaxies
Current position:	Postdoc Max Planck Institut fur Astronomie, Heidelberg, Germany

Name:	E. Kuiper
Graduation Date:	24-01-2012
Supervisor:	Röttgering/Miley
Thesis title:	Growing up in the City: a Study of Galaxy Cluster Progenitors z > 2
Current position:	

Name:	L. Vermaas
Graduation Date:	11-01-2012
Supervisor:	Israel/Van der Werf
Thesis title:	Spectroscopy and Nuclear Dynamics of Starburst Galaxies
Current position:	Topdesk Software, Delft, The Netherlands

3.2.2 Master degrees

The following 11 students were awarded Masters degrees in 2012:

Name	**Date**	**Present Position**
Margriet van der Laan	13-1-2012	travelling
Arthur Bakker	26-6-2012	software developer bij de NCIM-groep
Tjibaria Pijloo	28-8-2012	PhD Nijmegen
David Huijser	28-8-2012	Phd Auckland
Maria Drovdoskaya	28-8-2012	PhD Leiden
Jeroen Franse	28-8-2012	PhD Leiden
Axel Buddendiek	28-8-2012	PhD Duitsland
Siebe Weersma	28-8-2012	Finance
Ricardo Herbonnet	30-8-2012	PhD Leiden
Sascha Zeegers	27-11-2012	PhD Leiden (applying)

3.2.3 Bachelor degrees

The following 16 students were awarded BSc degrees in 2012:

Name	**Date**	**Present Position**
Rinse Heinsbroek	25-01-12	MSc Programme, Astronomy
Atze de Vries	10-05-12	?
Joris Voorn	13-07-12	MSc Programme, Astronomy
Bernie Lau	26-07-12	MSc Programme, Astronomy
Geert Talens	26-07-12	MSc Programme, Astronomy
Roman Tatch	26-07-12	MSc Programme, Astronomy
Robert Feld	26-07-12	?
Joris Hanse	26-07-12	MSc Programme, Astronomy
Yorick Bonnema	26-07-12	?
Arthur Jakobs	26-07-12	travelling, afterwards MSc Programme, Astronomy
Martin de Valois	13-08-12	MSc Programme, Astronomy
Leandra Swiers	15-08-12	MSc Programme, Astronomy
Thomas Warmerdam	23-08-12	MSc Programme, Astronomy
Steven Duivenvoorden	24-08-12	MSc Programme, Astronomy
Chris Lemmens	29-08-12	MSc Programme, Astronomy
Merel van t Hoff	30-08-12	MSc Programme, Astronomy

3.3 Academic courses and pre-university programmes

3.3.1 Courses taught by Observatory staff

Bachelor course title	**Semester**	**Teacher**
Introduction to astrophysics	1	H. Linnartz
Astronomy lab 1	2	I. Snellen
Planetary systems	2	M. Hogerheijde
Modern astronomical research	3	M. Kenworthy
Stars	4	X. Tielens
Astronomy lab 2	4	H. Hoekstra
Observational techniques 1	5	B. Brandl
Radiative processes	5	E. Rossi
Python cursus	5	E. Deul
Bachelor research project	5-6	P. van der Werf & C. Keller

Master course title	**Semester**	**Teacher**
IAC 2012: Galaxies, Structure, dynamics and evolution of galaxies	7, 8, 9, 10	M. Franx
Stellar structure and evolution	7, 8, 9, 10	J. Schaye
Origin and evolution of the universe	7, 8, 9, 10	K. Kuijken
Interstellar matter	7, 8, 9, 10	P. van der Werf
Large Scale Structure & Galaxy Formation	7, 8, 9, 10	J. Brinchmann
Stellar dynamics	7, 8, 9, 10	V. Icke
Computational astrophysics	7, 8, 9, 10	S. Portegies Zwart
Detection of Light	7, 8, 9, 10	M. Kenworthy
Radio Astronomy	7, 8, 9, 10	M. Garrett

3.3.2 Pre-university programme

LAPP-Top, the Leiden Advanced Pre-University Programme for Top Students, is aimed at enthusiastic and ambitious high-school students from the 5th and 6th grade. Candidates are selected on the basis of their high-school grades and their enthusiasm to participate, as shown by a letter of motivation. Students that are selected then take part in 6 to 8 meetings from January till May, following the programme of their own choice. The Sterrewacht has been participating in the LAPP-TOP programme since its start in 2001. In that pilot year 5 students participated, growing to 6 (2002/3), 11 (2003/4), 33 (2004/5), 17 (2005/6), 27 (2006/7), 16 (2007/8), 20 (2008/9), 10 (2009/10) , 25 (2010/11) and 26 (2011/12). The astronomy LAPP-TOP programme was developed by Van der Werf from 2002 onward. From 2005-2008 the project was coordinated by Snellen. From 2008-2009 it was coordinated by Franx. Since 2010 the project has been coordinated by Lub. In eight sessions the following subjects were covered:

Course title	**Teacher**
Extrasolar planets	I. Snellen
The Milky Way and other galaxies	J. Schaye
Practicum I	A. Brown
Building moleculs and planets in the universe	E. van Dishoeck
Black Holes	P. van der Werf
Practicum II	V. Icke
Cosmology	H. Hoekstra
Excursion to the radio telescopes in Westerbork and Dwingeloo	

After successfully completing the programme participants have been awarded a certificate from the University of Leiden. High-school students are allowed to use this project to achieve credits for their final exams.

3.3.3 Contact.VWO

Contact.VWO has been in existence since May 2007. Buisman and Van der Hoorn (physics teachers in secondary schools) both work one day a week for the Physics and Astronomy Departments in order to intensify the contacts between secondary schools and the university. Van der Hoorn organizes twice yearly a production and mailing of posters and organizes three times an informative meeting for physics teachers, starting at 5 p.m. and featuring a lecture on modern developments in physics or astrophysics, an informal dinner with extensive networking between teachers and university workers, and after-dinner subjects dealing with the change from secondary school to university study. Buisman is concerned with school classes (programmes for whole-day visits as well as individual help(assisting ¿50 pupils with practical work). He also has organized a training session for the module Measuring in Star Systems (Meten aan Melkwegstelsels) which is part of the school curriculum track Nature, Life and Technology (Natuur, Leven en Technologie). Contact.VWO answers requests for assistance by school pupils or teachers. Buisman also has an appointment for half a day a week as local coordinator of the HiSPARC project, but although related, this is not a part of the activities of Contact.VWO. Contact.Vwo works in cloth cooperation with the Regionaal Steunpunt Leiden, directed by Ludo Juurlink. Further information: http://www.physics.leidenuniv.nl/edu/contactpuntvwo/index.asp

Date	**Activities at Leiden University in 2012 for teachers**
19 jan	Meeting with teachers: visit of the renovated Oude Leidse Sterrewacht
03 feb	Instituutsdag for pupils visiting CERN afterwards (preparation)
15 feb	Visit Hogeschool Zeeland with a delegation of faculteit W&N. Theme: Materials
02 Mar	VLC: Exoplanets
14 mar	Meeting with pupils & teachers: Einsteins Birthday
09 May	Leo Kanner: Exoplanets
15 may	Meeting with teachers: theme: Relation between experimental and theoretical physics
29 Jun	RGS Slingerbos-levant: Exoplanets
13 nov	Meeting with teachers: theme: Astrophysics: the molecular universe by Alexander Tielens
10 oct	Educational Seminar Astronomy
13 Oct	Stedelijk Gym: Exoplanets
08 Nov	Visser t Hooft: Exoplanets
30 Nov	Bonaventura: Exoplanets

3.4 Popularization and media contacts

van der Burg

Venus en Jupiter bijna op een lijn, diverse kranten (ANP), Maart 12 idem, Radio 5, Maart 13
idem, TV NED2 Tijd voor Max, Maart 13
Een gigantisch heelal gedomineerd door donkere materie, Publiekslezing, Leiden, Juni 29
Knappe kop leidt vaak eenzaam bestaan, krant Spits, Juli 5
UFO's boven Zuid-Holland?, TV Omroep West, Augustus 16
De radio telescoop SKA pathfinder, BNR nieuwsradio, Oktober 5
Een gigantisch heelal gedomineerd door donkere materie, Publiekslezing, Leiden, November 8
Het belang van de maan bij het ontstaan van (complex) leven op aarde, Radio 5, November 15
Voyager 1 in een nieuwe zone van het zonnestelsel, BNR nieuwsradio, December 5

van Kempen

Twice-weekly column on ALMA on www.astronomie.nl
Assistance and appearance on an episode on ALMA of Labyrinth (NTR/VPRO)

Kuijken

Gravitational Lensing: Studying the Dark Universe with Light Rays, public lecture, Leiden Natuurkundig Genootschap, January 19
Sterrenkunde, les voor basisschoolleerlingen, Montessorischool Oegstgeest, September 6
Astronomy (in the Netherlands), lecture for Brazilian government delegation, Oude Sterrewacht, September 10
The Euclid Mission, Dutch Space company, Leiden; October 23

van Lunteren

Frederik Kaiser en Nederlandse sterrenkunde van de negentiende eeuw, Rotary Club Delft, February 15

De tragikomische geschiedenis van de meter, Ouderdag Leidsche Fles, Leiden, April 21

Wetenschap als spiegel van de maatschappij, Woensdagavondgezelschap, Utrecht, October 3

De Fundamental Physics Group en de quantum revival, NNGC-Congres, Leiden, October 27

Paul Ehrenfest en de moderne fysica, Natuurkundig Gezelschap, Utrecht, November 6

Maaskant

Sterrenkundige 'live' voorstellingen in het planetarium van Artis, Amsterdam (hele jaar door o.a. museumnacht, ZOOmeravonden, kinderfeestjes).

van der Marel

Schijven met gaten: de geboortewieg van planeten, Sterrenkijkdagen, Leiden, March 4

Chemie in de ruimte, KNVWS Arnhem, Arnhem, November 21

Portegies-Zwart

Leidse weer en sterrenkunde vereniging, Leiden, 24 Jan

VARA Radio 18 May

VPRO Radio 16 September

Presentation new Book of Ed van den Heuvel, Amsterdam 16 Mei 2013

Lecture at basisschool ter Cleeff, group 1, 5 and 7

Röttgering

Press releases on LOFAR

3.5 Universe Awareness programme

A child's early years are widely regarded to be the most important for their development and the formation of their value systems (see article: Too Young to Learn? http://www.unawe.org/about/audience/). Universe Awareness is an IAU-endorsed programme that exploits the inspirational aspects of astronomy to awaken the imagination of young children between 4 and 10 years, and excite in them an early curiosity about science and technology. The goals are twofold: to encourage children to develop an interest in science and technology and utilise the unique perspective of astronomy to help broaden their minds, thereby stimulating a sense of global citizenship and tolerance while they are still forming their value systems.

An important goal of the UNAWE programme is to create an international network that will provide a platform for sharing ideas, best practices and resources between educators around the world. Since 2012, UNAWE is now active in 54 countries around the world, with a total of 16 new national programmes beginning last year alone. The global UNAWE network now consists of well over 600 astronomers, teachers and other educators.

The National Project Managers (NPMs) for each of these countries are tasked with running workshops that will give primary school teachers the training and confidence to bring astronomy and space science topics to the classroom, and organizing activities to inspire their local communities. Last year a total of 2869 teachers were trained by the programme and 124 491 children reached through UNAWE activities.

Furthermore the NPMs are tasked with developing innovative new educational resources for engaging young children in astronomy and space science. Several of these resources are already being used in classrooms across the world, including Universe in a Box (http://unawe.org/resources/universebox/) a new educational toolkit for educators and Space Scoop (http://unawe.org/kids/) a regular astronomy news service for kids which is available in 19 different languages. In 12, 67 new Space Scoops were published making Space Scoop the world's biggest and best resource for astronomy news for children.

3.6 Astronomy for Development

As Vice President of the International Astronomical Union, Miley continued to lead the implementation of the IAU Strategic Plan 2010 - 2020 Astronomy for the Developing World. This Plan foresees a substantial expansion of programmes and funding, together with a large increase in the number of volunteers. Building on the IYA model, the focus will be on a demand-driven coherent mix of sustainable activities. As stated in the Plan, the large expansion and strategic approach requires a more suitable organisational structure and the creation of a small IAU Office of Astronomy for Development (OAD) to coordinate and manage the implementation of the Plan. This office, a joint venture between the IAU and the South African National Research Foundation hosted by the South African Astronomical Observatory in Cape Town began work in 2011, with Kevin Govender as Director and Miley as Chair of its Steering Committee and of the IAU Extended Development Oversight Committee.

During 2012, the OAD made considerable progress in establishing the structures foreseen in the Plan. Three Task Forces were formed, namely Universities + Research, Schools + Children and Public Outreach. Following a Call for Proposals, IAU Regional Nodes of the OAD were created in East Asia and South East Asia and as envisaged in the Plan, additional nodes are expected to come into operation during the next few years. The Task Forces, regional nodes together with 400 OAD volunteers will guarantee a demand-driven portfolio of activities. It is expected that fund-raising activities for an expansion of the activities will begin in 2013.

Miley gave several talks to committees in the European Parliament about the importance of astronomy for capacity building and development, particularly in Africa and together with Govender (OAD; Cape Town) organised a Special Session at the IAU General Assembly in Beijing in August 2012.

3.7 The Leidsch Astronomisch Dispuut F. Kaiser

L.A.D. 'F. Kaiser' has organized several activities in 2012 to encourage the contacts between Astronomy students from different years. Examples are movienights and dinners. Furthermore, over 50 people (bachelor, master and PhD students and a few staff members) participated in our annual soccer tournament on June 22nd.

At the end of August, Joris Hanse and Bart Bijvoets left the board. The new board (as of September 1st) consists of Chris Lemmens and Jeroen van Gorsel. The new board continues the organization of activities for all Astronomy students in 2013. In addition, it will resume its popular avondje sterrewacht in the Old Observatory, just like L.A.D. 'F. Kaiser' did in the past.

3.8 Vereniging van Oud-Sterrewachters

The 'Vereniging van Oud-Sterrewachters' (VO-S; http://www.vo-s.nl) is the official association of Sterrewacht/Observatory (ex-)affiliates. It has been in existence for over 15 years now and has seen another active year. As usual, the 150 members were offered a variety of activities. The activities included a social drink prior to the Oort Lecture and an annual meeting. This year, the annual meeting was held at the Kapteyn Institute in Groningen. The attending members where given a tour of the laboratories where the detectors for the ALMA observatory are prepared. The day was ended with a visit to the University Museum in the city Groningen. VO-S members also received a newsletters with Sterrewacht news and were offered an electronic member dictionary.

Further information: http://www.vo-s.nl/

Appendix I

Observatory staff

Observatory staff

Appendix I

(As on December 31, 2012)

Names, e-mail addresses, room numbers, and telephone numbers of all current personnel can be found on the Sterrewacht website:
http://www.strw.leidenuniv.nl/people

Telephone extensions should always be preceded by (071) 527 ... (from inside The Netherlands) or by +3171527 ... (from abroad)

Full Professors	
E.F. van Dishoeck	
M. Franx	
C.U. Keller	
K.H. Kuijken	
H.V.J. Linnartz	
F.H. van Lunteren	(UL (o.5) / VU (0.3), Teijler's hoogleraar)
S.F. Portegies Zwart	
H.J.A. Röttgering	
J. Schaye	
I.A.G. Snellen	
A.G.G.M. Tielens	
P.P. v.d. Werf	
P.T. de Zeeuw	(0.0, DG ESO)

Affiliate Professors

D. van Delft*	(0.0, Stichting tot beheer Museum Boerhaave, Museum Boerhaave)
N.J. Doelman	(0.0, J.H. Oortfonds)
C.W.M. Fridlund**	(0.0, J.H. Oortfonds)
M.A. Garrett***	(0.0)
W.J. Jaffe	(0.0, Universiteit van Amsterdam)

* Director Museum Boerhaave
** Staff scientist ESTEC / ESA
*** Director ASTRON

Associate Professors, Assistant Professors, senior researchers

R.J. Bouwens	
B.R. Brandl	
J. Brinchmann	
A.G.A. Brown	
M. Haverkorn*	(0.0)
H. Hoekstra	
M.R. Hogerheijde	
W.J. Jaffe	(0.0)
M.A. Kenworthy	
H.J. van Langevelde**	(0.0)
I.F.L. Labbé	
Y. Levin***	(0.0)
J. Lub	(0.0)
R.S. Le Poole	(0.0)
E.M. Rossi	
R. Stuik	
R.P.J. Tilanus	(0.0)

* Staff Radboud University Nijmegen
** Director JIVE, Dwingeloo
*** Monash University Melbourne, Australia

Emeriti

A.M. van Genderen	
H.J. Habing	
I. van Houten-Groeneveld	
V. Icke	(0.0)
F.P. Israel	(0.0)
K. Kwee	
G.K. Miley	(0.0)

Postdocs and Project Personnel and longterm visiting scientists

F.C.M. Bettonvil	(0.0 ASTRON)
J.L. Birkby	NWO-VC
J.B. Bossa	EU- IEF
G. Busso	NOVA
M. Cacciato	NWO-VI
A. Candian	NWO
L.R. Carlson	EU-ERC
R.A. Crain	NWO-VC
B.A. Devecchi	EU-ERC
N. Drost	(0.0, E-science Center, NWO)
S. Giodini	NWO-VI
A.K. van Elteren	NWO-M
I.R. Guerra Aleman	NWO-SPINOZA
J.S. Guss	NWO-VI
B. Holwerda	guest (ESTEC)
R.H. Hammerschlag	guest
A.N. Heays	UL
J. Holt	NWO SPINOZA
S. Ioppolo	UL
M. Iwasawa	NWO-M
E.M. Helmich	NWO-M
N. Irisarri Mendez	NWO-M
J.T.A. de Jong	NWO-M
A. Juhasz	NWO-ALLEGRO
J.K. Katgert-Merkelijn	guest
T.A. van Kempen	NOVA
P.D. Klaassen	NWO-ALLEGRO

V.A. Korkiakoski	STW
L.E. Kristensen	UL
A.F. Loenen	NOVA
A. Madigan	NWO-VI
T.P.K. Martinsson	NOVA
G.S. Mathews	EU-ERC
S.L. McGee	NWO-VC
J.A. Meisner	NOVA
R. Meijerink	(0.0, RUG)
J.C. Mottram	NWO-VC
A.V. Muzzin	NWO-SPINOZA
B.D. Oppenheimer	NWO-VI
S.G. Patel	EU-ERC
F.I. Pelupessy	NWO-M
A. Petrignani	EU_ERC
D.A. Rafferty	NOVA
F.L. Rafferty	NOVA
M. Raicevic	NWO VC
E.E. Rigby	NWO-TOP
D. Risquez Oneca	NOVA
M. Rodenhuis	STW
P.M. Rodrigues Dos Santos Russo	EU-EUNAWE
K.J. Rosdahl	EU-ERC
E. Schmalzl	NOVA
M. Schmalzl	NOVA
W.C. Schrier	EU-EUNAWE
E. Semboloni	EU-ERC
D.R. Serrano Goncalves Sobral	NWO-VI
M. Shiraki Fuji	guest (JSPS grant)
F. Snik	NWO-ESFRI-ELT
S. Taylor Muzzin	NWO-SPINOZA
S. v.d. Tol	NOVA
L. Venema	guest (ASTRON)
M. Viola	NWO-VC, EU-ERC
N. de Vries	NWO-M
A.J. Walsh	NWO-VI
C. Walsh	EU-ERC

R.J. van Weeren	NOVA
S.M. Weinmann	EU-ERC
D. Zhao	NWO-VI
J. Zhen	ERC
J.E. van Zwieten	guest (Science&Technology, ASTRON)

Promovendi

A.S. Abdullah	EU-ERC
H.E. Andrews Mancilla	EU-ERC
J. Bedorf	NWO
T.C.N. Boekholt	NWO-VI
J. de Boer	NWO-VI
M. Brogi	NOVA
R.F.J. v.d. Burg	NWO-VI
D.P. Caputo	NWO-VI
D.J. Carton	NWO-VC
Y. Cavecchi	NOVA/UL (Amsterdam)
N. Clementel	NWO-VC
S.H. Cuylle	EU-ITN-LASSIE
M.P. van Daalen	UL
M. De Juan Ovelar	NWO-ESFRI-ELT
E. Di Gloria	NWO-VI
M.N. Drozdovskaya	UL
A. Elbers	ASTRON
E.C. Fayolle	NOVA
G. Fedoseev	NWO-VI
J. Franse	NWO (LION)
M. Fumagalli	EU-ERC
G. Goncalves Ferrari	guest
K.M. Guss	NOVA, UL
A.S. Hamers	NWO-VI
D.S. Harsono	NOVA-SRON-UL
G. van Harten	UU
S. Heikamp	NWO-ESFRI-ELT
E. v.d. Helm	NOVA
R.T.L. Herbonnet	EU-ERC
M. Iacobelli	NWO/UL

M.P.H. Israel	ASTRON, UL
T. Karalidi	(0.0) SRON
M. Kazandjian	UL
F. Koehlinger	NWO
F. Krause	EU-ERC
S. Krijt	UL
M.A. Kulkarni	NWO ESFRI-ELT
A.L.M. Lamberts	NWO-Astrochemie
X. Li	NWO-Astrochemie
N. Lopez Gonzaga	NWO-VC
K.M. Maaskant	NOVA
N. v.d. Marel	NOVA
C.A. Martinez Barbosa	EU-ITN-GREAT
J.R. Martinez Galarza	NOVA
T.R. Meshkat	UL / EU-IG
L.K. Morabito	NWO-TOP
M. Mosleh	UL
S.V. Nefs	NWO-VC
B.B. Ochsendorf	EU-ERC
G.P.P.L. Otten	NWO-ESFRI-ELT
D.M. Paardekooper	NWO-VI
B. Pila Diez	NOVA
W.M. de Pous	NWO-SPINOZA
A. Rahmati	NOVA
A.J. Richings	EU-ITN-COSMOCOMP
S. Rieder	NWO
A.J. Rimoldi	NWO-VI
M.J. Rosenberg	NOVA
M. Sadatshirazi	UL
F.J. Salgado Cambiazo	EU-ERC
I. San Jose Garcia	EU-ITN-LASSIE
J. v.d. Sande	NOVA
H. Schwarz	EU-ITN-LASSIE
C. Shneider	NWO-VI
C.J. Sifon Andalaft	EU-ERC
R. Smit	NWO-VC
C.M.S. Straatman	NWO-SPINOZA

A.H. Streefland	FOM/UL
A. Stroe	NWO-TOP
D. Szomoru	EU-ERC
M.L. Turner	NWO-ITN-COSMOCOMP
M.B.M. Velander	NWO-M
M. Velliscig	EU-ITN-COSMOCOMP
S. Verdolini	UL
F. v.d. Voort	NWO-VI
K. Wang	NOVA
M.P.M. Weiss	UL/Teylers stichting
T.I.M. van Werkhoven	STW
W.L. Williams	UL-ASTRON
U. Yildiz	UL

Support Staff

J.C. Drost	Management assistant
E. Gerstel	Institute Manager
A.N.G. Pen-Oosthoek	Programme Coordinator BSc and MSc
N. Strookman	Assistant Programme Coordinator
G.A. v.d. Tang	Secretary
L. v.d. Veld	Secetary

Computer Staff

E.R. Deul	Manager Computer group
D.J. Jansen	Scientific Programmer
N. Verbeek	Programmer
A. Vos	Programmer

NOVA office

W.H.W.M. Boland	Managing Director
E.F. van Dishoeck	Scientific Director
C.W.M. Groen	Financial Controller
J.T. Quist	Management Assistant

Appendix II

Committee membership

Committee membership

Appendix II

II.1 Observatory Committees

Directorate

(Directie onderzoekinstituut)
H.J.A. Röttgering (director of research)
P.P. van der Werf (director of studies)
E. Gerstel (institute manager)

Observatory management team

(Management Team Sterrewacht)
H.J.A. Röttgering (chair)
E.R. Deul
J. Drost (minutes)
I. Snellen (outreach)
E. Gerstel (chair)
F.P. Israel
P.P. van der Werf (advisor)

Supervisory council

(Raad van Advies)
J.A.M. Bleeker (chair)
B. Baud
J.F. van Duyne
K. Gaemers
C. Waelkens

Research committee

(Onderzoek-commissie OZ)
M. Franx (chair)
A.G.A. Brown
M. Hogerheijde
W. Jaffe
P.P. van der Werf

Research institute scientific council

(Wetenschappelijke raad onderzoekinstituut)

B. Brandl
A.G.A. Brown
E.R. Deul
E.F. van Dishoeck
M. Franx (chair)
H. Hoekstra
M. Hogerheijde
C.U. Keller
K.H. Kuijken
R. Bouwens
M. Kenworthy
F.P. Israel
R.S. Le Poole
W. Jaffe
D. van Delft
M. Garret
H.J. van Langevelde
H.V.J. Linnartz
F. van Lunteren
S. Portegies Zwart
H.J.A. Röttgering
J. Schaye
I. Snellen
R. Stuik
A.G.G.M. Tielens
P.T. de Zeeuw
J. Brinchmann
E. Rossi
V. Icke
G.K. Miley
J. Lub
N. Doelman
M. Haverkorn

Institute council

(Instituutsraad)

E. Deul (chair)
J. Drost
W.J. Jaffe
H. Hoekstra
M. Hogerheijde
T. Pijloo
E. van Uitert

Astronomy education committee

(Opleidingscommissie OC)

H.V.J. Linnartz (chair)
E. van Dishoeck
M. Franx
C.U. Keller
J. van de Sande
G. de Wit
J. Hoeijmakers
S. Khalafinejad
A. Pietrow
M.C. Segers
M. Sunder

Astronomy board of examiners

(Examencommissie)

J. Lub (chair)
J. Aarts (Physics)
J. Brinchmann
F.P.Israel
I. Snellen

Oort Scholarship Committee

B. Brandl
S. Portegies Zwart
J. Schaye

Mayo Greenberg Prize committee

G. Miley (chair)
E.F. van Dishoeck
E. Gerstel
H.V.J. Linnartz
J. Lub

PhD admission advisory committee

E. Rossi (chair)
R. Bouwens

MSc admission advisory committee

J. Schaye (chair)
B. Brandl
S. Portegies Zwart

Graduate student review committee

(Promotie begeleidingscommissie)

A.G.G.M. Tielens (chair)
B. Brandl
J. Brinchmann
H. Linnartz
M. Franx

Colloquium committee

J. Brinchmann
M. Kenworthy

Computer committee

R. Bouwens (chair)
R. Crain
M. Schmalzel
R. Stuik
S. Portegies Zwart

Library committee

W.J. Jaffe (chair)
F.P. Israel
J. Lub

Public outreach committee

I. Snellen (chair)
M. van Daalen
R. Smit
J. van de Sande
R. van der Burg

Social committee

E. Fayolle
T. Meshkat
M. Rosenberg
A. van der Tang
N. van der Marel
R. Meijerink
I. Snellen
F. Snik

II.2 University Committees (non-Observatory)

Brown
Member, Faculteitsraad

van Dishoeck
Member, Raad van Toezicht, Leiden Institute of Physics (LION)

Franx
Director, Leids Kerkhoven Bossche Fonds
Director, Leids Sterrewacht Fonds
Director, Oort Fonds
Organizer, Oort professor workshop
Member, School of Science Science Committee (WECO)

Kuijken
Chairman, Board of Directors Leids Sterrewacht Fonds
Chairman, Board of Directors Oort Fonds
Member, Board of Directors Leids Kerkhoven Bosscha Fonds
Member, curatorium Teylers Professorship on History of Science
Member, Lorentz Chair appointment committee (Physics)

van Langevelde
Chairman, Board of directors Leids Kerkhoven Bosscha Fonds
Member, Board of directors Leids Sterrewacht Fonds
Member, Board of directors Jan Hendrik Oort Fonds

Linnartz
Member, FMD/ELD user committee

van Lunteren
Scientific Board Scaliger Institute
Historical Committee of Leiden University
Studium Generale Committee Leiden University
Writer-in-residence Committee Leiden University

Röttgering
Chair, Education Committee Astronomy
Member, Joint Education Committee Physics and Astronomy
Member, Curatorium of the professorship at Leiden University “Experimental Astroparticle physics”

Schaye
Member, astronomy program board, Lorentz Center

Snellen
Member, LUF International Study Fund (LISF) committee
Member, PR committee, Faculty of Science

van der Werf
Organist of the Academy Auditorium

Appendix III

Science policy functions

Science policy functions

Appendix III

Brandl
PI, METIS (mid-IR instrument for the E-ELT)
Deputy co-PI MIRI (mid-IR instrument for the JWST)
co-I KINGFISH Herschel Open Time Nearby Galaxies Key Project
Member, NOVA Instrument Steering Committee (ISC)
Member, DAG (Turkish 4m telescope) advisory board
Member, ESFRI board
Member, METIS Chopper CDR review board
Member, METIS cooler review board
Member, METIS immersed grating review

Brown
Chair, Gaia Data Processing and Analysis Consortium
Member, Gaia Science Team
Vice President, IAU Commission 8
Member, IAU Commission 37
Member, EU Marie-Curie ITN Gaia Research for European Astronomy Training (GREAT)
Member, Steering Committee ESF-RNP Gaia Research for European Astronomy Training (GREAT)

van Dishoeck
Scientific Director, Netherlands Research School for Astronomy (NOVA)
Co-Editor, Annual Reviews of Astronomy & Astrophysics
Member, SRON Board

Member, Gebiedsbestuur Exacte Wetenschappen (GB-E)
Member, National Committee on Astronomy (NCA)
Member, MPIA-Heidelberg Fachbeirat
Member, Kavli Institute for Astrophysics review committee
Member, Herschel-HIFI Science team
Co-PI, European JWST-MIRI consortium
President, IAU Division H
Vice-President, IAU Commission 14
President, IAU Working Group on Astrochemistry
Coordinator, Herschel-HIFI WISH Key Program

Franx
Coordinator, Nova network 1 science team
Organizer and lecturer, National Astronomy course
Member, Young Academy selection committee
Member, KNAW sectie physics and astronomy
Member, James Webb Space Telescope Science Working Group
Member, NIRSPEC Science Team
Member, MUSE Science Team
Member, IAU commission 28 Organizing committee

Hoekstra
Member, Science Advisory Committee, Isaac Newton Group
Euclid Consortium Coordinator
Lead Weak Lensing Group
Member Euclid Consortium Coordination Group
Member Euclid Consortium Calibration Working group
Member Euclid Consortium Membership committee
Member Euclid Consortium Editorial Board

Hogerheijde
Member, ALMA Science Advisory Committee
Member, ALMA European Science Advisory Committee
Member, ALMA European Regional Center Coordinating Committee
Project Scientist for CHAMP+/Netherlands

Co-coordinator, JCMT Gould Belt legacy Survey
Secretary/treasurer, Board of Directors Leids Kerkhoven-Bosscha Fonds
Secretary/treasurer, Board of Directors Leids Sterrewacht Fonds
Secretary/treasurer, Board of Directors Jan Hendrik Oort Fonds

Keller
Chair of the Board, Isaac Newton Group of Telescopes
Chair, Science Advisory Committee, Kiepenheuer Institute for Solar Physics, Freiburg, Germany
Chair of the Board, Olga Koningfonds, The Netherlands
Member, E-ELT Project Science Team, ESO
Member, Foundation of the Kiepenheuer Institute for Solar Physics, Freiburg, Germany
Member, Scientific Committee of the Istituto Ricerche Solari Locarno (IRSOL) Locarno, Switzerland

Kenworthy
Member, NRF/NWO workshop on defining "Astronomy and Enabling Technologies for Astronomy"

Kuijken
Scientific Delegate from the Netherlands, ESO Council
Member, Scientific Strategy Working Group, ESO Council
Chair, ESO contact committee
Member and Chair (until November 2012), NOVA Board
Member and Vice-chair, Netherlands Committee for Astronomy
Co-editor, Strategic Plan for Astronomy in the Netherlands 2011-2020
PI, ESO KiDS Survey
PI, OmegaCAM project
Co-I, ESO VIKING Public Survey
Co-I, Planetary Nebulae Spectrograph project
Board Member, Physics Society Diligentia (the Hague)
Board Member, Kapteyn Fonds (Groningen)
Member, European Research Council Starting Grants Panel

Linnartz
Chair, 'SPIN' chair for Molecular Laboratory Astrophysics, LCVU
Editor, CAMOP (Comments on Atomic, Molecular and Optical Physics / Physica Scripta)
Chair, LOC and co-chair SOC IAU297 The diffuse interstellar bands
Chair, LOC and co-chair SOC FD168 Solid state astrochemistry
External advisor, RSC/RAS Astrophysical Chemistry Group
Member, European Task Force for Laboratory Astrophysics
Research coordinator, FP7 ITN 'LASSIE' (Laboratory Astrochemical Surface Science In Europe)
Theme coordinator NWO-EW/CW 'DAN' (Dutch Astrochemistry Network)
Workgroup leader, FOM group FOM-L-027
Member, NWO-CW 'Spectroscopy and Theory'
Member, NWO-FOM 'COMOP" (Condensed Matter and Optical Physics)
Member, HRSMC research school

Lub
Member Board Astronomy and Astrophysics
Penningmeester Nederlandse Astronomenclub

van Langevelde
Member, Consortium board of directors European VLBI Network
Member, RadioNet Board and Executive Board
Coordinator, NEXPReS (Novel EXploration Pushing Robust e-VLBI Systems), board and management team
Member, European SKA Consortium
Member, NOVA Instrumentation Steering Committee
Member, Dutch URSI committee
Member, SKA klankbordgroep NL
Member, Allegro steering committee

van Lunteren
Education and Research Board Huizinga Institute, Research School for Cultural History

Miley

Vice President, International Astronomical Union (Education and Development)
Chair, IAU Extended Development Oversight Committee
Chair, Steering Committee, IAU Office of Astronomy for Development (OAD)
International Coordinator, EU Universe Awareness FP7 Project
Chair, LOFAR Research Management Committee
Chair, LOFAR Survey Science Group, Highest Redshift Objects
Trustee, Associated Universities, Inc. (AUI- managing body of US National Radio Astronomy Observatory)
Member, Executive Committee International Astronomical Union
Member, Advisory Panel on Astronomy to the South African Minister for Science and Technology
Member, European Research Council, Selection of Advanced Grant Awardees
Member, UK South Eastern Universities Physics Network (SEPNET) Scientific Advisory Committee
Member, Board of Governors of the LOFAR Foundation
Member, Core Team, LOFAR Surveys Key Project

Portegies-Zwart

Member of the Scientific Steering Committee, PRACE
International review commision board, ESF
Member of the science advisory board, GAIA
AMUSE progress representative, NOVA ISC
External advisor, Quatar NSF, Quatar national science foundation
Member, IAU Division VII Galactic System
Member, IAU Division VII Commission 37 Star Clusters & Associations

Röttgering

Key researcher NOVA research school
Member, ASTRON Science Advisory Committee
Member, Science team MID-infrared Interferometric instrument for VLTI (MIDI)
Member, XMM Large Scale Structure Survey Consortium
PI, DCLA (Development and Commissioning of LOFAR for Astronomy) project for the scientific preparation of science with LOFAR at 4 partaking Netherlands universities
PI, LOFAR surveys: Opening up a new window on the Universe

Member, LOFAR's NL-LAC, national LOFAR steering committee
Member, Spitzer warm legacy survey project SERVS
Member, Euclid consortium board
Member, Herschel H-ATLAS survey
Member, SCUBA-2 legacy surveys review panel
Member, Board LOFAR International Telescope
Member, Extra-galactic science team SPICA/SAFARIMember, NOVA Board

Schaye
Member of the steering committee, Virgo Consortium for cosmological supercomputer simulations
Co-Investigator, MUSE (Multi Unit Spectroscopic Explorer)
Key researcher, NOVA (the Dutch research school for astronomy)
Member, MUSE science team
Member, LOFAR Epoch of Reionization science team
Member, EUCLID cosmological simulations working group
Member, Editorial Board, Scientific Reports
Member, Scientific Organizing Committee, "The picture of galaxy evolution painted with Lyman alpha", Rome, Italy
Member, Scientific Organizing Committee, "COSMOCOMP Workshop", Trieste, Italy
PI, OWLS collaboration (OverWhelmingly Large Simulations)
PI, EAGLE collaboration (Evolution and Assembly of GaLaxies and their Environments)

Snellen
Member, PLATO consortium
Member, ESA ECHO science study team
Member, METIS consortium
Board member, Nederlandse Astronomen Club
Member, Telescope Allocation Committee, NASA Hubble Space Telescope - cycle19
Member, NWO Rubicon Committee

Tielens

Member KNAW, sectie Physics and Astronomy

van der Werf

Member, James Clerk Maxwell Telescope Board
Principal Investigator, SCUBA-2 Cosmology Legacy Survey
Principal Investigator, Herschel Comprehensive ULIRG Emission Survey
Co-investigator, HIFI
Co-investigator, MIRI
Member, METIS Science Team
Member, STFC Herschel Oversight Committee
Member, TAMASIS Network
Project Scientist, AMKID submillimeter camera

Appendix IV

Workshops, colloquia and lectures

Workshops, colloquia and lectures

Appendix IV

IV.1 Workshops

Most of the workshops were held in the Lorentz Center, an international center which coordinates and hosts workshops in the sciences. In 2012 the Leiden astronomers contributed to the following workshops there:

Feb 27 - Mar 2
Exciting CO in the Local and High-Redshift Universe
Organizers: Bergin, van Dishoeck, Kristensen, Loenen, Meijerink, Ossenkopf, Röllig, Visser

Mar 26 - 30
Astronomy to Inspire and Educate Young Children: EU Universe Awareness Workshop
Organizers: Bailey, Govender, Madsen, Manxoyi, Miley, Odman, Pacini, Quirrenbach, Ros, Russo, Scorza

June 4 - 15
Studies of Star and Planet Forming Regions with Herschel
Organizers: van Dishoeck, Evans

July 23 - 27
Gas, Stars, and Black Holes in the Galaxy Ecosystem
Organizers: Miley, Overzier, Wild

Aug 6 - 10
The Dynamic Nature of Baryons in Halos
Organizers: Bregman, Bullock, Crain, Oppenheimer, Putman, Tumlinson

Sep 10 - 14
Compact Binaries in Globular Clusters
Organizers: Benacquista, Heinke, Knigge, Pooley, Portegies Zwart, Voss

Oct 22 - 26
How to Find Our Nearest Neighbors
Organizers: Fridlund, Kenworthy, Malbet, Oppenheimer, Quirrenbach, Stapelfeldt, Traub

IV.2 Endowed Lectures

May 10 (University Auditorium)
Oort Lecture Cosmology: it really makes you wonder
Organizers: Sandra Faber (LICK observatory, University of California, santa Cruz, USA)

Dec 18 (De Sitter Lecture Hall)
Sackler Lecture Type Ia Supernovae, The Accelerating Cosmos and Dark Energy
Organizers: Brian Schmidt (Australian National University, School of Astronomy and Astrophysics, Canberra, Australia)

Dec 19 (University Auditorium)
Public Lecture The Accelerating Universe
Organizers: Brian Schmidt (Australian National University, School of Astronomy and Astrophysics, Canberra, Australia)

IV.3 Scientific Colloquia

Date	Speaker (affiliation)	Title
01/05/13	Liesbeth Vermaas (Leiden Observatory)	Spectroscopy and nuclear dynamics of starburst galaxies [PhD colloquium]
01/19/13	Vanessa Hill (Observatoire de la Cte d'Azur)	Stellar chemistries in the Milky-Way and its satellites as probe of galaxy assembly
01/25/13	George Sonneborn (Goddard Space Flight Center NASA)	SN 1987A: The Supernova of the Century
01/26/13	Coryn Bailer-Jones (Max Planck Institute for Astronomy, Heidelberg)	Patterns in astronomical impacts on the Earth: Testing the claims
01/31/13	Maarten van Hoven (Leiden Observatory)	Seismology of Magnetars (PhD colloquium)
02/02/13	Luis A. Aguilar (Instituto de Astronomia, UNAM, Mexico)	Detecting substructure in the galactic stellar halo with Gaia
02/06/13	Chuck Steidel (Caltech)	Lyman Alpha and Lyman Continuum Emission from High-z Galaxies
02/09/13	Sandy Faber (Lick Observatory)	Emerging Principles of Galaxy Formation
02/16/13	Roman Teyssier (CEA Saclay)	Galaxy formation: the role of feedback from small to large scales
02/23/13	Steve Eales (School of Physics and Astronomy, Cardiff University)	Twelve billion years of star formation in galaxies ? the Herschel perspective so far

03/01/13	Freeke van de Voort (Leiden Observatory)	Feeding galaxies and their gaseous haloes (PhD Colloquium)
03/08/13	Leen Decin (KU Leuven)	Chemical enrichment of the ISM through the mass loss of evolved stars
03/22/13	Juan Rafael Martinez Galarza (Leiden Observatory)	Infrared Spectroscopy of Starbursts: From Spitzer-ORS to JWST-MIRI (PhD colloquium)
03/29/13	Eugene Chiang (UC Berkeley)	Close-in Planets: From Hot Jupiters to Super Mercuries
04/19/13	Sylvain Veilleux (University of Maryland)	Galactic Winds and Their Cosmological Implications
04/26/13	Imke de Pater (University of California, Berkeley)	What Wonderful Worlds: Exploring our Solar System
05/03/13	Adam Deller (ASTRON)	Mapping the Galactic neighbourhood with microarcsecond astrometry
05/10/13	Suzanne Aigrain (Oxford University)	From exoplanet atmospheres to starspots: using Gaussian processes to model astrophysical time-series data
05/24/13	Nicole Nesvadba (Institut dAstrophysique Spatiale, Centre Universitaire d'Orsay)	Winds and turbulence: The two faces of AGN feedback
05/30/13	Jeanette Bast (Leiden Observatory)	Hot Chemistry and Physics in Planet Forming Zones of Disks (PhD colloquium)
05/31/13	David Hogg (New York University)	Finding the dark matter
06/07/13	Max Pettini (University of Cambridge)	In Search of Near-Pristine Gas at Intermediate Redshifts
06/14/13	Giovanni Strazzulla (INAF ? Osservatorio Astrofisico di Catania)	Ion Irradiation Induced Effects on Airless Bodies in the Solar System

06/21/13	Joe Hennawi (MPIA, Heidelberg)	Quasars Probing Quasars: Circumgalactic Gas in Absorption and Emission
06/28/13	Karl Gordon (STScl)	Extragalactic Dust Mass Determinations in the Optical and Infrared: Dust Emissivity Variations
09/27/13	Brad Gibson (University of Central Lancashire)	Spirals with Supercomputers: Have We Finally Got it Right?
10/04/13	Mark Wyatt (Institute of Astronomy, University of Cambridge)	Signatures of planets and of planet formation in debris disks
10/11/13	Meghan Gray (University of Nottingham)	STAGES: Galaxy Evolution and Environment
10/18/13	Glenn van de Ven (Max Planck Institute for Astronomy, Heidelberg)	A mixed origin of the Milky Way?s thick disk
11/01/13	Nick Cox (Leuven)	New developments towards identifying the diffuse interstellar band carriers
11/08/13	Michele Cappellari (University of Oxford)	Galaxy scaling relations, dark matter and the variation of the stellar IMF
11/15/13	Lucio Mayer (ETH Zurich)	Realistic spiral galaxies and no missing satellites in simulations of the CDM Universe: the combined role of star formation modeling and resolution
11/22/13	Barbara Catinella (MPA Garching)	HI and star formation properties of massive galaxies
11/29/13	Karoliina Isokoski (Leiden Observatory)	The physics and chemistry of interstellar ice (PhD colloquium)
12/06/13	Phil Uttley (Astronomical Institute Anton Pannekoek)	Signals from the noise: how to decode black hole variability
12/13/13	Melvyn Davies (Lund Observatory)	The Dynamical Evolution of Exoplanet Systems

IV.4 Student Colloquia

Date	Speaker	Title
02/20/13	Siebe Weersma	Cooling in nearby active galaxies
06/04/13	Tjibaria Pijloo	Statistically probing the influence of AGN on their host galaxies with COSMOS
06/18/13	Jeroen Franse	Looking for a Dark Matter Decay Signal
06/22/13	Maria Drozdovskaya	Spitzer and Herschel Study of RCW49
06/29/13	Axel Buddendiek	Shear Nulling after PSF Gaussianization (SNAPG): A New Shape Measurement Algorithm for Weak Lensing
09/03/13	Ricardo Herbonnet	Finding Protoclusters With SPIRE
09/17/13	Sascha Zeegers	Feasibility of transit spectroscopy of nearby debris disks
09/25/13	Carla Natario	Activity Level of Solar-Type Stars in CoRoT and Kepler Field and Its Impact on Planetary Detection
09/26/13	Jaya Ramchandani	Molecules to Diagnose Young Stellar Objects: The LOMASS Database
09/27/13	Lars Einarsen	A new Polarimetric Investigation of the Atmosphere of Venus
10/01/13	Vincent Oomen	Modeling the CO-ladder of NGC 4418: AGN or starburst galaxy?

IV.5 Colloquia given outside Leiden

Brandl

To See or not to See: Zooming in on Starbursts, Department of Astronomy, University of Vienna; January 23
Idem, NRAO, Charlottesville; March 29
Idem, STScI, Baltimore; April, 2
METIS - the Mid-infrared E-ELT Imager and Spectrograph, NAC Meeting, Ameland; May 24
Idem, SPIE Meeting, Amsterdam; July 6
Idem, MOS workshop, Amsterdam; October 25
Idem, SRON Colloquium Series, Utrecht; November 2
Idem, RAS Special Meeting, London; November 8

Bossa

Mass-analytical tool for reactions in interstellar ices (MATRIICES), Colloque SFE 2012, France; November 12

Bouwens

Galaxy Build-up and Evolution at z$\geq$7: Results from ultra-deep WFC3/IR observations over the HUDF, GOODS, and CANDELS fields, Garching, Germany; January 30
The Build-up and Evolution of Galaxies in the First 2 Gyr of the Universe, Strasbourg, France; April 23
Idem, Kyoto, Japan; May 24
New Results on Galaxy Build-up, Faint-end Slopes, and the Role of Galaxies in Reionizing the Universe from the CANDELS+HUDF09+IUDF programs, Rome, Italy; July 2
Early Results from the Cluster Lensing and Supernovae Survey with Hubble, Rome, Italy; July 5
Build-up of Galaxies in the First 3 Gyr of the Universe, Santa Cruz, USA; August 13
Using HST+Spitzer to characterize the Build-up of Galaxies in the Early Universe, Beijing, China; August 27

Characterizing the Build-up of stellar mass using MUSE and Spitzer/IRAC Observations, Satillieu, France; October 3
Systematic Searches for z 9 Galaxies within CLASH, Bilbao, Spain; October 17

Brown
Gaia status and data release scenario, Galaxy Modelling with a Gaia mock catalogue, Barcelona, Spain; February 29
Gaia Early data releases and thoughts on data access facilities, Dynamics Meets Kinematic Tracers,Ringberg Castle, Germany; April 13
Gaia archive preparation, EWASS, Rome, Italy; July 4
Gaia mission overview and early data releases, Science with 4MOST, Potsdam,Germany; November 13

van der Marel
Mind the gap: Cold gas in transitional disks, ETH, Zurich, Switzerland; January 24
Idem, University of Michigan, Ann Arbor, USA; June 19
Idem, PUC, Santiago, Chile; August 31
Idem, ALMA SCO, Santiago, Chile; September 7
Idem, KIAA, Beijing, China; September 24
Planet formation in action: Resolved gas and dust images of a transitional disk and its cavity, NOVA Network 2 meeting, Groningen, the Netherlands; December 7
Triggered planet formation in action: Resolved gas and dust images of a transitional disk and its cavity, First Science with ALMA conference, Puerto Varas, Chile; December 14

van Dishoeck
VLT-CRIRES survey of protostars and disks around T Tauri stars: from physics to chemistry,ETH, Zurich, Switzerland; January 23
Water in space: from interstellar clouds to planet-forming disks, University of Heidelberg, Heidelberg, Germany; January 27
Idem, Cornell University, Ithaca, USA; March 26
Idem, California Institute of Technology, USA; April 25 (Greenstein lecture)
Idem, University of California, Santa Cruz, USA; April 28

Idem, University of Copenhagen, Denmark; May 23
Idem, University of Lund, Lund, Sweden; May 24
Idem, Kavli Institute for Astrophysics, Beijing, China; August 16
Idem, Institut fur Astrophysik, Gottingen, Germany; November 6
A WISH come true: water in star-forming regions with Herschel, Universitat Sternwarte, Munich, Germany; January 25
Idem,Institute for molecules and materials, Nijmegen; April 13
Idem,Universiteit van Amsterdam, Netherlands; October 31
Molecular processes between the stars,Dalian Institute for Chemical Physics, Dalian, China; August 23
Building stars, planets and the ingredients for life between the stars, Cornell University, USA; March 27 (University lecturer)
Idem, Institute for Complex Molecular Systems, Eindhoven; October 4
Idem, Physikalisches Institut, Cologne, Germany; October 19
Sweet results from ALMA,Joint ALMA Office, Santiago, Chile; December 19
Idem, Paranal Observatory, Paranal, Chile; December 27

Hoekstra

The dark side of the Universe, TU Eindhoven, February 16
Weak lensing by large-scale structure, Joint Astronomy Colloquium, Garching, Germany, June 21
Cosmology & More with Euclid, NIKHEF, Amsterdam, September 28

Iacobelli

RM-Synthesis at 2m wavelength of the Fan region: Unveiling screen and bubbles, Chalmers University of Technology Gothenburg , Sweden; May 29
Turbulence in the diffuse Galactic synchrotron emission. Imaging the Galactic foreground with LOFAR, Radboud University Nijmegen, The Netherlands; 4 December

Keller

Sterrekundig Instituut Utrecht: The Last Years, 370 years of Astronomy in Utrecht, Noordwijkerhout,The Netherlands; April 2
The Show Must Go On: The recent past and future of the Utrecht Instrumentation Group, 370 years of Astronomy in Utrecht, Noordwijkerhout,The Netherlands;

April 5
Extremely Fast Focal-Plane Wavefront Sensing for Extreme Adaptive Optics, SPIE, Amsterdam, The Netherlands; July 5
Integrated High-Resolution Observations through Turbulence, Smart Optical Systems Annual Conference, Leiden, The Netherlands; October 31

Kenworthy
Looking for Close Companions in the Fomalhaut System, ESO Santiago, Chile; March 8
Finding the NCP Aberrations with Focal Plane Wavefront Sensing, ESO Santiago, Chile; March 09
An Extrasolar Protoplanetary Ring System Caught in Transit?, Groningen, Netherlands; March 19
Thermal Imaging of Extrasolar Planets, Lund Observatory, Sweden; April 12
Exoplanet Imaging Challenges with the APP Coronagraph, ASTRON, Netherlands; September 27
VLT Coronagraphy, Lorentz Center Workshop, Netherlands; October 22
AO Instrumentation, ACAO Summer School, South Africa; December 06
Real Life Experience with AO, ACAO Summer School, Sutherland, South Africa; December 07

van Kempen
ALMA Calibration using quasars: Why we need a Calibrator Database, Joint ALMA Offices, Santiago, Chile; June 1

Klaassen
Gas Dynamics in High-Mass Star Forming Regions, ESA, Noordwijk; October 26
Ionized and Molecular Gas in a few High-Mass Star Forming Regions, ALMA observatory, Santiago; August 30
Gas Dynamics in the Ionized and Molecular gas in and around HII regions, Dwingeloo observatory; May 3

Kristensen
Feedback from low-mass protostars - some like it hot, From atoms to pebbles:

Herschel's view of star and planet formation, Grenoble, France; March 21
Water vapor around young low-mass protostars, European week of astronomy and space science, Rome, Italy; July 2
WISH: Water in star-forming regions with Herschel, Studies star and planet forming regions with Herschel, Leiden Lorentz Center, the Netherlands; June 11

Kuijken

KiDS: the Kilo-Degree Survey, SNOWPAC conference, University of Utah, USA; March 22
VST Surveys, at Southern Cross Conference: Surveys: a Vintage Decade, Hunter Valley, Australia; June 6
Dwarf Spheroidal Kinematics: a MICADO science case, at MICADO Science day, Groningen, Netherlands; June 19
Local Dark Matter, at: Dark Attack 2012 conference, Ascona physics center, Switzerland; July 16
KiDS: the Kilo-Degree Survey, Benasque physics Center, Spain; August 14
Idem, GAMA conference, Durham, UK; September 20
Idem, ESO Surveys Science workshop, Garching, Germany; October 17

van Langevelde

Masers in star formation, IAU Symposium 287: Cosmic masers - from OH to H0, Stellenbosch, South Africa; January 31
The Future of VLBI, Resolving the SKY 2012, Manchester, UK; April 20
VLBI in Europe, mm-VLBI with ALMA workshop, Garching, Germany; June 26
Zooming in on star formation with radio telescopes, Frontiers of star formation, Noordwijk; August 17
JIVE: what's next?, 11th EVN symposium, Bordeaux, France; October 11
Astronomy with e-VLBI, VLBI technology workshop, Haystack Obs., USA; October 22

Linnartz

Wavelength dependent formation of molecules in space, University of Nottingham; January
The formation of complex molecules in space the laboratory perspective, University of Nijmegen; March

Chem-ice-try, pathways towards molecular complexity in space, MOLECXII, University of Oxford; September
Idem, 2nd national conference on laboratory and molecular astrophysics, Sevilla; November
CRYOPAD and OASIS; Shining light on interstellar ices, Meudon Workshop on laboratory based solid state research, Meudon; November
Shining light on interstellar ices; pathways towards molecular complexity in space, Bonn; November

van Lunteren
Isaac Newton and the Scientific Revolution, Utrecht Summerschool : Revolutions in Science, Utrecht August 27
History of the Quantum Revolution, Utrecht Summerschool : Revolutions in Science?,Utrecht August 30
Lavoisier en de Chemische Revolutie, Woudschoten Chemie Conferentie, Zeist, November 2 Paul Ehrenfest and the dilemmas of modernity, Annual Meeting of the History of Science Society, San Diego, November 17

Miley
Wonderful radio galaxies: Dinosaurs of the early Universe, Woltjer Lecture, EAS, Rome, Italy; July 4
KAstronomy for capacity building, Workshop on Science for poverty alleviation, Sheraton Hotel, Brussels, Belgium; September 18
A Gonzaga boy's adventure in the wonderful Universe, Gonzaga College, Dublin, Ireland; November 29
Wonderful radio galaxies: Dinosaurs of the early Universe, Trinity College, Dublin, Ireland; November 30
Astronomy for Development: Implementation of the IAU Strategic Plan (IAU GA Special Session 11, Beijing, China; August 27
Astronomy for capacity building, AERAP Workshop, EU Parliament, Brussels, Belgium; November 15

Mottram
The Lifetimes of Massive Young Stellar Objects and Compact HII regions, UK and German National Astronomical Meeting, Manchester, UK; March 29th

Herschel water observations: revealing envelope dynamics in low-mass protostars, Origins of Stars and their Planetary Systems, Hamilton, Canada; June 14th
Splashing around in the dark: Water in motion in star forming regions with Herschel, Leiden Observatory Science Day; September 13

Pelupessy
The formation and early evolution of stellar clusters, Sexten centre for Astrophysics, Sexten, Italy; July 26

Rigby
Observing protoclusters with Herschel (and LOFAR), Nice, France; May 15

Rosdahl
Simulating extended Lyman-alpha emission from cold accretion streams, COSMO-COMP workshop, Trieste, Italy; September 6

Röttgering
LOFAR meeting Imaging the Low Frequency Radio Sky with LOFAR, Snellius centre Leiden, Jan 14-18
LOFAR data reduction workshop, Meudon, France, Jan 30-Feb 2
Herschel observations of protoclusters of galaxies, and the path to SPICA, at SPICA/SAFARI science meeting, Groningen, the Netherlands, March 13-15.
LOFAR and the origin and evolution of galaxies and clusters, colloquium at Mount Stromlo, Canberra, March 28
LOFAR and the origin and evolution of galaxies and clusters, colloquium at CSIRO, Sydney, March 29
LOFAR and the origin and evolution of galaxies and clusters, colloquium at Osservatorio Astronomico di Roma, Monteporzio, Italy, April 22
LOFAR surveys of the radio sky: probing shocks and magnetic fields in galaxy cluster, at Galaxy Clusters as Giant Cosmic Laboratories, ESAC, Madrid, Spain, May 21-23
LOFAR Cluster meeting, Nice, France, May 14-16
How the SKA Pathfinders Complement Each Other, at Exploring the Radio Continuum Universe with SKA Pathfinders, CSIRO, Sydney, May 30 - June 1

LOFAR and the origin and evolution of galaxies and clusters, Nottingham, UK, June 20
XXL cluster meeting, Meudon, France, July 9-12
LOFAR and the Ionosphere - the longer story, LOFAR busy week, Munich, July 28
LOFAR and the origin and evolution of galaxies and clusters, MPIA, Munich, July 26
Herschel and LOFAR observations and the study of proto-clusters, Growing-up at high redshift: from proto-clusters to galaxy clusters, European Space Astronomy Centre (ESAC) ESA, Villanueva de la Canada, Madrid, Spain, Sept 10-13
Testing the cold versus hot accretion paradigm, at SPICA/SAFARI science meeting, Leuven, Belgium, September 27
Observations of relativistic electrons in galaxy clusters, Nature's particle accelerators, Annapolis, Maryland, USA, Oct 22-25
LOFAR - Opening up a New Window on the Universe, Goddard Space Flight center, Greenbelt, Maryland USA, 23 October

Schaye
Gas around Galaxies Heidelberg Joint Astronomical Colloquium, Heidelberg, Germany; January 10
Outflows in Numerical Simulations, at Gas Flows in Galaxies, STScI, Baltimore, USA; May 8
Implementation and consequences of outflows in cosmological simulations, invited review at Disc Galaxy Formation in a cosmological context, Heidelberg, Germany; May 18
'Natural' disks: What is the secret?, at Theory Goes out on a Limb: Predictions for z 1 Galaxies, Leiden; May 14
Feedback: Metal-Fueling the IGM, at Whereabouts, Physical State and Metallicity of the Missing Baryons in the Local Universe, Cervia-Milano Marittima, Italy; May 28
Theoretical Studies of the IGM/CGM connection, at UV Astronomy, HST and Beyond, Kauai, USA; June 20
The effects of baryon physics on the distribution of matter, at The quest for dark energy, when theory meets simulations, Ringberg, Germany; June 27
Self-regulated growth of galaxies and supermassive black holes, at Gas, Stars, and Black Holes in the Galaxy Ecosystem, Leiden; July 24

The physics determining CGM dynamics, at The Dynamic Nature of Baryons in Halos, Leiden; August 6
Gas around galaxies, Astron colloquium, Dwingeloo; October 25

Schmalzl
ALMA: Gearing up for Cycle 1, ASTRON Dwingeloo, The Netherlands; 27 June
Idem, SRON/RU Groningen, The Netherlands; 28 June
Water Chemistry in Protostellar Envelopes: From Herschel to ALMA, SRON/RU Groningen, The Netherlands; December 7

Schneider
Constraining the thermal electron and cosmic ray densities in M51 via the degree of polarization, Erbacher Hof, Mainz, Germany; July 9-13

Sobral
Invited Seminar, University of Concepcion, Chile
Caltech Astronomy Colloquium, Caltech, Pasadena, US
Seminar, University of California - Riverside, US
Colloquium, Institute for Astronomy, University of Hawaii, US
Subaru Seminar, Subaru Telescope, Hilo, Hawaii, US
Colloquium, CAAUL, Lisbon, PT
Seminar, IAC Tenerife, Spain
Contributed Talk, Stellar Populations across Cosmic Times, Subaru-IAP, Paris, France
Invited Talk, UKIDSS 2012 Workshop, IfA, University of Edinburgh, UK

Snellen
Exoplanet Atmospheres, Astron Dwingeloo
idem, University of Amsterdam, February 2
MASCARA, SPIE Amsterdam, July 1
idem, MPE Munich, November 13
Ground-based High-resolution spectroscopy of exoplanets, MPE Munich, November 15
idem, Cambridge, September 14

van der Werf

Fingerprinting (Ultra)luminous infrared galaxies; National Astronomy Meeting, Manchester, United Kingdom; March 27
Star formation and molecular gas in (Ultra)Luminous InfraRed Galaxies; Cosmic-ray induced phenomenology in star-forming environments Sant Cugat del Valles, Spain; April 17
Fingerprinting (Ultra)luminous infrared galaxies; University of British Columbia, Vancouver, Canada; June 28
The Veil of Orion; The Orion Nebula: a laboratory for the study of star formation and gaseous nebulae, 2nd NCAC Symposium, Warsaw, Poland; July 16
DESHIMA; NOVA Instrumentation Day, Utrecht; September 25

Weinmann

A fundamental problem in low-mass galaxy evolution?, MPIA, Heidelberg, Germany; July 12
The evolution of galaxies below $M*$: theory vs. observations, ETH, Zurich, Switzerland; March 21
A fundamental problem in low-mass galaxy evolution, Quantum Universe Workshop II, Groningen; April

Yildiz

High-J CO and O2 in Low-Mass Star Forming Regions with Herschel, NASA/JPL, Pasadena, USA; November 20
High-J CO and O2 in Low-Mass Star Forming Regions with Herschel and Turkish mm-Telescope Project, Caltech Cahill Center for Astronomy & Astrophysics, Pasadena, USA; November 19
Star Formation with sub-/mm astronomy and National Radiotelescope, 18th Turkish National Astronomy Congress, Malatya, Turkey; August 28
Journey of Turkish Membership to ESO, 18th Turkish National Astronomy Congress, Malatya, Turkey; August 29
Survey of APEX-CHAMP+ High-J CO Observations of LowMass Young Stellar Objects, Science with the APEX Telescope Conference, Ringberg Castle, Germany; February 12-15

Appendix V

Grants

Grants

Appendix V

Only major grants above €20.000,-

Bossa / Linnartz
FP7-PEOPLE-2011-IEF, NATURALISM (novel analysis toward understanding the molecular complexity in the interstellar medium)
€192,000

Bouwens
Vrij-competitie, NWO, Characterizing the build-up of stars in galaxies in the early universe using gravitational lensing and the Hubble+Spitzer Space Telescopes
€218,682

van Dishoeck
Advanced ERC, EU, 'Astrochemistry and the origin of planetary systems'
€2,500,000
Academy professorship, KNAW
€1,000,000

Keller
STW. Open Technologieprogramma, Light-weight towers with stable platform for astronomical, meteorological and civil-engineering measurements
€1,091,300
PEP, NSO, SPEX2Earth, a multi-angle spectropolarimeter for aerosol and cloud characterization
€334,000

Kuijken
NWO-M, NWO: Producing the KiDS Survey
€792,000
Vrije Competitie, NWO: KiDS: Studying the Dark Universe with Light Ray
€221,000
Netwerk 1 AiO, NOVA: Group Galaxy Lensing from GAMA, VIKING and KiDS
€200,000

Sobral
NWO Veni grant
€250,000

Röttgering
Advanced ERC grant: A new window on the Universe: The formation and evolution of galaxy clusters and proto-clusters NewClusters
€2,500,00

Snellen
NWO VICI Grant, 'Atmospheres of Extrasolar Planets: bridging the gap towards Earth-like planets'
€1,500,000

Snik
Academische Jaarprijs, 2012, Team iSPEX
€100,000

Tielens
NWO Spinoza
€2,500,000

Appendix VI

Observing time

Observing time

Appendix VI

Bouwens
Spitzer/IRAC, Quantifying the Stellar Mass Density of the Universe out to z$\sim 9-10$: Ultra-Deep Spitzer Observations of Two Highly Magnified $z \sim 9-10$ Galaxies, 55 hrs

van der Marel
JCMT, Completing the SEDs: constraining disk properties of cold disks, 21 hrs
APEX, Completing the SEDs: constraining disk properties of transitional disks, 28 hrs
WHT, Properties of stars with planet-forming disks: evaluating disk dissipation mechanisms, 5 nights
VLT, Determining the hole size of transitional disk candidates, 3 hrs

van Dishoeck
ALMA Cycle 1, Quantifying gas inside dust cavities in transitional disks, 4.0 hr

Kenworthy
VLT, Transmission Spectroscopy of Fomalhaut's Debris Disk, 8 hrs
VLT, Constraining the nature of a ringed extrasolar disk system with SAM and NaCo, 8 hrs

Klaassen
VLA, Accretion Dynamics and HII regions, 40 hrs

Kristensen
JCMT, Chemical inventory of low-mass protostars: H2CO and CH3OH in Class I sources in Ophiuchus, 17hrs
JCMT, HDO/H2O toward low-mass protostars in Serpens (resubmission), 26hrs
SMA, Probing small-scale UV heating in Ser SMM1 with HCN/CN emission, 1 track
VLT, Using VLT-CRIRES to constrain protostellar wind conditions and chemistry, 5 hrs

Kuijken
VLT Survey Telescope, the KiDS survey, 500 hrs

Linnartz
VLT-UVES, A search for C3 and C4 in the diffuse interstellar medium; 8 hrs

McGee
VLT, "The timescale of environmental change: Halpha imaging of galaxy groups at z=0.4", 26.7 hrs WHT, "Unveiling Herschel/SPIRE - selected protoclusters in the optical", 3 nights

Mottram
ALMA, The infall rate of massive young stellar objects, 2.6 hrs
JCMT, Investigating the properties of the dense gas around WILL survey embedded YSOs, 31 hrs
JCMT, A survey of molecular clouds and star formation in the new Outer Scutum-Centaurus Arm, 34 hrs
JCMT, Mapping molecular clouds and star formation in the new Outer Scutum-Centaurus Arm, 46 hrs

Ochsendorf
VLT/X-shooter, Tracing the ejecta of RCrB stars with molecules, 4 hrs

Portegies-Zwart

ORCL TITAN, Virtual Galaxy, 220,000 hrs
ESCC Hector, Virtual Galaxy, 200,000 hrs

Rigby

GMRT, Understanding the formation and evolution of protoclusters, 20 hrs

Röttgering

INT, La Palma, Oct 13-22
WSRT, 50*12hours
GMR, 16 hours
Herschel, 22 hours

Schaye

VLT, Gas around galaxies in absorption, 31 hrs

Sobral

VLT, The role of the environment at z∼1 with a super-cluster, 35 hrs
WHT/ING, The nature and evolution of luminous Ha emitters at z∼0.8-2.2, 4 nights
CFHT, The widest, contiguous narrow band survey at z 1-9, 7 nights
INT/ING, The widest survey for Lyman-alpha emitters and blobs at z∼3, 6 nights
ESO/NTT, The nature and evolution of luminous Ha emitters at z∼0.8-2.2, 4 nights
TNG, The nature of bright Ha emitters at z∼1.5, 5 nights
WSRT, Shock and Awe: Do cluster collisions change the history of cluster galaxies?, 520 hrs
INT/ING, Shock and Awe: Do cluster collisions change the history of cluster galaxies?, 10 nights
ESO/VISTA,Re-ionisation beacons: a wide NB survey for Lya emitters, 36 hrs
Subaru, The mass-metallicity relation and sSFR for galaxies at $z > 1$, 2 nights

Van der Werf

ALMA: H2O in high redshift galaxies, 7 hours highest priority

Jansky Very Large Array: 13CO and C18O in a lensed high redshift galaxy, 28 hours

James Clerk Maxwell Telescope: The SCUBA-2 Lensing survey (S2LS), 24 hours

James Clerk Maxwell Telescope: Imaging the reddest Herschel-selected SMGs and the environments they signpost at $z > 5$, 24 hours

Yildiz

JCMT, Separating the truly embedded sources, 4 hrs

Appendix VII

Scientific publications

Scientific publications

Appendix VII

VII.1 Ph.D. Theses

A total of 9 graduate students successfully defended their Ph.D. thesis in 2012 and were awarded their Ph.D. degree. They are in order of date:

M. Velander	Studying Dark Matter: Haloes with Weak Lensing
R. Martinez Galarza	Mid-Infrared Spectroscopy of Starbursts: from Spitzer-IRS to JWST-MIRI
E. van Uitert	Weak Gravitational Lensing in the RCS2
F. van de Voort	The Growth of Galaxies and their Gaseous Haloes
A-M. Madigan	Secular Stellar Dynamics near Massive Black Holes
M. van Hoven	Seismology of Magnetars
O. Rakic	The Intergalactic medium near High-Redshift Galaxies
E. Kuiper	Growing up in the City: a Study of Galaxy Cluster Progenitors z > 2
L. Vermaas	Spectroscopy and Nuclear Dynamics of Starburst Galaxies

VII.2 Publications in refereed journals

Aalto, S., and 7 co-authors, including **van der Werf, P.**; Detection of HCN, HCO^+, and HNC in the Mrk 231 molecular outflow. Dense molecular gas in the AGN wind; *A&A*; 2012; **537**; A44

Acke, B., and 35 co-authors, including **Fridlund, M.**, **Hogerheijde, M. R.**; Herschel images of Fomalhaut. An extrasolar Kuiper belt at the height of its dynamical activity; *A&A*; 2012; **540**; A125

Adams, S. M., and 6 co-authors, including **Hoekstra, H.**; The Environmental Dependence of the Incidence of Galactic Tidal Features; *AJ*; 2012; **144**; 128

Amiri, N., and 3 co-authors, including **van Langevelde, H. J.**; VLBA SiO maser observations of the OH/IR star OH 44.8-2.3: magnetic field and morphology; *A&A*; 2012; **538**; A136

Anders, P., and 3 co-authors, including **Portegies Zwart, S.**; How well do STARLAB and NBODY compare? II. Hardware and accuracy; *MNRAS*; 2012; **421**; 3557

Aresu, G., and 5 co-authors, including **Meijerink, R.**; Far-ultraviolet and X-ray irradiated protoplanetary disks: a grid of models. II. Gas diagnostic line emission; *A&A*; 2012; **547**; A69

Bahé, Y. M., and 3 co-authors, including **Crain, R. A.**; The competition between confinement and ram pressure and its implications for galaxies in groups and clusters; *MNRAS*; 2012; **424**; 1179

Bartelmann, M., and 3 co-authors, including **Viola, M.**; Calibration biases in measurements of weak lensing; *A&A*; 2012; **547**; A98

Bartkiewicz, A., and 2 co-authors, including **van Langevelde, H. J.**; Milliarcsecond structure of water maser emission in two young high-mass stellar objects associated with methanol masers; *A&A*; 2012; **541**; A72

Bédorf, J., and 2 co-authors, including **Portegies Zwart, S.**; A sparse octree gravitational N-body code that runs entirely on the GPU processor; *Journal of Computational Physics*; 2012; **231**; 2825

Beirão, P., and 40 co-authors, including **Brandl, B. R.**; A Study of Heating and Cooling of the ISM in NGC 1097 with Herschel-PACS and Spitzer-IRS; *ApJ*; 2012; **751**; 144

Berné, O., and **Tielens, A. G. G. M.**; Formation of buckminsterfullerene (C60) in interstellar space; *Proceedings of the National Academy of Science*; 2012; **109**; 401

Bertin, M., and 9 co-authors, including **Fayolle, E. C.**, **Linnartz, H.**; UV photodesorption of interstellar CO ice analogues: from subsurface excitation to surface desorption; *PCCP*; 2012; **9929**; 14

Bertone, S., and **Schaye, J.**; Rest-frame ultraviolet line emission from the intergalactic medium at $2 \leq z \leq 5$; *MNRAS*; 2012; **419**; 780

Bezanson, R., and 2 co-authors, including **Franx, M.**; Evolution of Quiescent and Star-forming Galaxies since $z \sim 1.5$ as a Function of their Velocity Dispersions; *ApJ*; 2012; **760**; 62

Bildfell, C., and 11 co-authors, including **Hoekstra, H.**; Evolution of the red sequence giant to dwarf ratio in galaxy clusters out to $z \sim 0.5$; *MNRAS*; 2012; **425**; 204

Birkby, J., and 19 co-authors, including **Snellen, I.**; Discovery and characterization of detached M dwarf eclipsing binaries in the WFCAM Transit Survey; *MNRAS*; 2012; **426**; 1507

Bîrzan, L., and 6 co-authors, including **Rafferty, D. A.**, **Röttgering, H. J. A.**; The duty cycle of radio-mode feedback in complete samples of clusters; *MNRAS*; 2012; **427**; 3468

Bjerkeli, P., and 14 co-authors, including **van Dishoeck, E. F.**; H_2O line mapping at high spatial and spectral resolution. Herschel observations of the VLA 1623 outflow; *A&A*; 2012; **546**; A29

Boccaletti, A., and 29 co-authors, including **Snik, F.**, **Rodenhuis, M.**; SPICES: spectro-polarimetric imaging and characterization of exoplanetary systems. From planetary disks to nearby Super Earths; *Experimental Astronomy*; 2012; **34**; 355

Bonafede, A., and 8 co-authors, including **van Weeren, R.**; Discovery of radio haloes and double relics in distant MACS galaxy clusters: clues to the efficiency of particle acceleration; *MNRAS*; 2012; **426**; 40

Bond, N. A., and 36 co-authors, including **van der Werf, P.**; The Infrared Properties of Sources Matched in the WISE All-sky and Herschel ATLAS Surveys; *ApJ*; 2012; **750**; L18

Booth, C. M., and 3 co-authors, including **Schaye, J.**; The filling factor of intergalactic metals at redshift z= 3; *MNRAS*; 2012; **420**; 1053

Bossa, J.-B., and 3 co-authors, including **Isokoski, K.**, **Linnartz, H.**; Thermal collapse of porous interstellar ice; *A&A*; 2012; **545**; A82

Bourne, N., and 44 co-authors, including **Rigby, E. E.**, **Werf, P. v. d.**; Herschel-ATLAS/GAMA: a census of dust in optically selected galaxies from stacking at submillimetre wavelengths; *MNRAS*; 2012; **421**; 3027

Bouwens, R. J., and 10 co-authors, including **Franx, M.**, **Labbé, I.**, **Smit, R.**; UV-continuum Slopes at z $\sim$ 4-7 from the HUDF09+ERS+CANDELS Observations: Discovery of a Well-defined UV Color-Magnitude Relationship for z >= 4 Star-forming Galaxies; *ApJ*; 2012; **754**; 83

Bouwens, R. J., and 9 co-authors, including **Labbé, I.**, **Franx, M.**; Lower-luminosity Galaxies Could Reionize the Universe: Very Steep Faint-end Slopes to the UV Luminosity Functions at z >= 5-8 from the HUDF09 WFC3/IR Observations; *ApJ*; 2012; **752**; L5

Bowler, R. A. A., and 12 co-authors, including **Holt, J.**; Discovery of bright z $\sim$ 7 galaxies in the UltraVISTA survey; *MNRAS*; 2012; **426**; 2772

Bradley, L. D., and 9 co-authors, including **Bouwens, R. J.**, **Smit, R.**; Through the Looking Glass: Bright, Highly Magnified Galaxy Candidates at z $\sim$ 7 behind A1703; *ApJ*; 2012; **747**; 3

Bradley, L. D., and 8 co-authors, including **Bouwens, R. J.**; The Brightest of Reionizing Galaxies Survey: Constraints on the Bright End of the z $\sim$ 8 Luminosity Function; *ApJ*; 2012; **760**; 108

Braine, J., and 9 co-authors, including **Israel, F. P.**, **van der Werf, P.**; Spectrally resolved C II emission in M 33 (HerM33es). Physical conditions and kinematics around BCLMP 691; *A&A*; 2012; **544**; A55

Braithwaite, J., and **Cavecchi, Y.**; A numerical magnetohydrodynamic scheme using the hydrostatic approximation; *MNRAS*; 2012; **427**; 3265

Brammer, G. B., and 29 co-authors, including **Franx, M.**, **Fumagalli, M.**, **Patel, S.**, **Labbé, I.**, **Muzzin, A.**; 3D-HST: A Wide-field Grism Spectroscopic Survey with the Hubble Space Telescope; *ApJS*; 2012; **200**; 13

Brammer, G. B., and 19 co-authors, including **Labbé, I.**, **Franx, M.**, **Fumagalli, M.**, **Patel, S.**; 3D-HST Grism Spectroscopy of a Gravitationally Lensed, Low-metallicity Starburst Galaxy at z = 1.847; *ApJ*; 2012; **758**; L17

Brandl, B. R., and 4 co-authors, including **Rosenberg, M.**, **van der Werf, P. P.**; High resolution IR observations of the starburst ring in NGC 7552. One ring to rule them all?; *A&A*; 2012; **543**; A61

Brogi, M., and 6 co-authors, including **Keller, C. U.**, **de Juan Ovelar, M.**, **Kenworthy, M. A.**, **Snellen, I. A. G.**; Evidence for the disintegration of KIC 12557548 b; *A&A*; 2012; **545**; L5

Brogi, M., and 5 co-authors, including **Snellen, I. A. G.**, **Birkby, J.**; The signature of orbital motion from the dayside of the planet τ Boøtis b; *Nature*; 2012; **486**; 502

Brown, J. M., and 4 co-authors, including **van Dishoeck, E. F.**; Matryoshka Holes: Nested Emission Rings in the Transitional Disk Oph IRS 48; *ApJ*; 2012; **758**; L30

Brown, J. M., and 3 co-authors, including **van Dishoeck, E. F.**; A 30 AU Radius CO Gas Hole in the Disk around the Herbig Ae Star Oph IRS 48; *ApJ*; 2012; **744**; 116

Bruderer, S., and 3 co-authors, including **van Dishoeck, E. F.**; The warm gas atmosphere of the HD 100546 disk seen by Herschel. Evidence of a gas-rich, carbon-poor atmosphere?; *A&A*; 2012; **541**; A91

Brüggen, M., and 2 co-authors, including **van Weeren, R. J.**, **Röttgering, H. J. A.**; Simulating the toothbrush: evidence for a triple merger of galaxy clusters; *MNRAS*; 2012; **425**; L76

Brüggen, M., and 3 co-authors, including **Röttgering, H.**; Magnetic Fields, Relativistic Particles, and Shock Waves in Cluster Outskirts; *Space Sci. Rev.*; 2012; **166**; 187

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