FIR Fine Structure Line Workshop

Workshop Program

June 8-11, 2015 | Haus der Astronomy, Heidelberg, Germany

Monday	*Topic*	*Speaker*	*Affiliation*
8:30	***Bus Leaves HD***		
8:45	***Coffee & Registration Fee in House of Astronomy***		
9:15	**Welcome and opening remarks**	***Roberto Decarli & Carl Ferkinhoff***	
9:30	**40 Years of FIR Fine-Structure-Line Spectroscopy**	***Martin Harwit***	Cornell University

2015 is the 40th anniversary of the discovery of the first of the far-infrared astronomical fine-structure transitions. Early in 1975, two Cornell PhD students, Dennis Brien Ward and Brian Dennison, and George Gull on our team, and I, discovered the 88 micron [O III] line in a series of flights with NASA's taxi-sized Lear jet and its onboard 12-inch telescope. Later that year, we published our finding in the ApJ Letters, and Dennis Ward's PhD thesis amplified the results. In the eight years to follow, Cornell PhD students, Gary Melnick, and Gordon Stacey, and postdoc Ray W. Russell and I, also discovered the 52 micron [O III], the 63 micron [O I], the 158 micron [C II], and the 145 micron [O I] fine structure lines. In1980 Moorwood et al. in Europe first detected the [N III] 57 micron emission on a balloon flight, and many years later the two [N II] lines also were located. The main problem in detecting some of these lines, all of which had been theoretically predicted, was that they could not be observed in the laboratory and their calculated wavelengths often were uncertain. As we went along, we were surprised that [C II] emission extended far beyond the H II regions, where it originally had been thought to arise. This led to David Hollenbach's 1981 concept of photo-dissociation regions. Astrophysical calculations based on fine-structure lines also began to provide useful temperature and pressure probes for previously inaccessible interstellar domains. Such interpretations usually depended on efforts by theorists whose names are seldom recalled today, but whose work continues to be critical if future explorations are to benefit from similar theoretical advances. Over the past 40 years, FIR fine-structure-line work has greatly evolved. Along the way, new technical approaches were tried, not all of which succeeded; other attempts, some of which originally had been considered more difficult, often turned out to be easier to implement. Uncertain choices still face us today, and we may need to consider new compromises to further advance the field.

Session 1: Modeling of FIR Fine-Structure Line Emission *(Chair: Ilse De Looze)*

10:00	**Keynote: Modelling FIR fine-structure line emission**	***Rowin Meijerink***	Leiden Univ.

I will review the efforts that have been done on the modeling of fine-structure lines emitted by galactic and extra-galactic objects. I will discuss their diagnostic power and limitations to probe the physical conditions in the atomic and molecular phases of the insterstellar medium. In particular, I will highlight the current status of the theoretical interpretation of the fine-structure line deficits in ultra-luminous infared galaxies (ULIRGs). I will conclude with a discussion of our efforts to model the ISM of the ULIRGs observed within the Herschel HerCULES program.

10:30	***Coffee Break***		
11:00	**Disentangling the multiphase contribution to CII**	***Brent Groves***	Australian National University

As one of the strongest cooling lines of the ISM, [CII]158um can provide key insights into a galaxies physical properties. However, as C^+ exists in ionized, neutral and molecular gas, using this line as a diagnostic is complex. In this talk I will compare the strength of this emission line from ionized vs atomic gas using both photoionization/photodissociation models and compare these with resolved observations to discuss what is the best way forward to disentangle the various multiphase contributions to the [CII] line.

11:20	**Understanding ULIRG Energetics via Comparisons of Observed and Simulated Merger SEDs**	***Howard Smith***	Harvard-Smithsonian Center for Astrophysics

We compare ULIRG SEDs derived from our GADGET-2 hydrodynamic simulations combined with SUNRISE radiative transfer modeling to our set of observed UV-to-FIR ULIRG SEDs. We quantify the evolving character of the SED with merger stage; its shape is determined by the changing star formation activity as well as a variable AGN contribution. The agreement between models and simulations seems quite good. The SF and AGN activity set the environment for line excitation. In the IR the SED itself, which reflects the dust emission from multiple temperature components, plays a key role in the excitation of molecular species. We pay particular attention to mid-IR spectral features.

11:40	**[CII] Synthetic Emission Maps of Simulated Galactic Discs**	***Annika Franeck***	I. Physikalisches Institut der Universitaet zu Koeln

The C+ fine structure emission [CII] has recently been studied with Herschel and Sofia. The results promote C+ as a tracer for star formation in galactic discs and for CO-dark molecular gas. Furthermore, the scale height of the [CII] emission in the Milky Way and in distant galaxies is not well understood. Does it trace the disc dynamics? Using RADMC-3D, we post-process three-dimensional, magneto-hydrodynamical simulations of pieces of stratified, galactic discs with a solar-neighborhood gas surface density of 10 Msun/pc^2 to compute synthetic [CII] emission maps. Excluding the emission from photon-dominated regions, we find that most of the [CII] emission in our model originates from the surfaces of cold molecular clouds. These contribute a narrow but prominent component to the [CII] maps. Moreover, we see a broad component distributed around the midplane, which stems from warmer gas. We compare simulations including different physics (with/without gas self-gravity, or with/without magnetic fields) and different supernova rates, and study the influence on the [CII] scale height. We find that the [CII] scale height is highly variable, as the emission traces the onset of galactic outflows.

12:00	**Using CII and OI to trace CO-dark molecular gas**	***Simon Glover***	Institute for Astronomy, University of Heidelberg

In the classical picture of the multiphase ISM, there is a clear observational distinction between cold atomic clouds, traced by HI 21cm emission, and cold molecular clouds, traced by CO emission. However, there is growing observational evidence that there is also a significant amount of mass in between these two regimes. This material has a high H2 fraction but is largely devoid of CO, and so it cannot easily be observed using molecular line emission. It is in this CO-dark molecular phase that we expect to see the clearest signature of the gas flows responsible for molecular cloud formation, and so it is important to understand how we can best observe this phase of the dense ISM. In this contribution, I will present results from a series of numerical simulations of cloud formation in the ISM in which we explore how well we can use the fine structure lines of CII and OI to study this CO-dark molecular phase.

12:25 ***Lunch***

Session 2: Galactic studies of FIR FSL Lines *(Chair: Eric Bertram)*

13:30	**Keynote: Galactic studies of FIR fine structure lines**	***Sarah Ragan***	University of Leeds

Stars are born in the densest regions of molecular clouds, but the nature of cloud formation remains an open question. Traditional tracers like CO do not capture the full picture of cloud formation, but the fine structure lines of ionised carbon ([CII]) and atomic oxygen ([OI]) reliably trace the full extent of molecular clouds and their environments. With new observations from Herschel and SOFIA, we now have the resolution to isolate cloud substructures which is essential to connecting the large scale to individual star formation regions. I will discuss recent results of our high-resolution studies of Galactic dark clouds in the early phase of star formation, comparing and contrasting the stories told by molecular, atomic and ionised species of carbon. I will show the first results of our study of [OI] and [CII] in dark clouds using the recently-commissioned FIFI-LS aboard SOFIA and discuss what we can learn about the cooling and star formation timescales in Galactic molecular clouds.

14:00	**Ionized, atomic and molecular carbon at the onset of high-mass star formation**	***Henrik Beuther***	MPIA

How do molecular clouds form out of the atomic gas and what are the relative fractions of carbon in the ionised, atomic and molecular phases? To address these question we mapped four very young infrared dark clouds (IRDCs) with Herschel, Sofia, Apex and the IRAM 30m telescope in the ionised [CII], the atomic [CI] and the molecular CO emission at a spatial resolution between 12'' and 25''. With these data, we dissect the spatial and kinematic structure of the four IRDCs and determine the abundances of gas phase carbon in its ionised, atomic, and most abundant molecular form. I will present the results from this study, among them are: In at least two out of the four regions, we find kinematic signatures strongly indicating that the dense gas filaments have formed out of a dynamically active and turbulent atomic and molecular cloud, potentially from converging gas flows. The atomic carbon-to-CO gas mass ratios are low between 7% and 12% with the lowest values found toward the most quiescent region.

14:20	**The Galactic distribution of [CII] and its relationship with Star Formation.**	***Jorge L. Pineda***	Jet Propulsion Laboratory, California Institute of Technology

The [CII] 158um line is an important tracer of several critical stages of the evolution of the interstellar medium (ISM) and star formation. It has been increasingly observed in a large number of distant galaxies with Herschel and ALMA. But detailed observations of the [CII] line and other tracers in the local universe are a requirement for the interpretation of these observations of distant galaxies. We present a study of the distribution of the [CII] line in the plane of the Milky Way. This study has been made possible with spectrally resolved observations of [CII] with the HIFI instrument on Herschel, as part of the GOT C+ Open Time Key Program. We use the [CII] emission to derive, together with observations of HI, CO, and 13CO, the Galactic distribution of the different phases of the ISM. We also relate the Galactic [CII] luminosity to the star formation rate (SFR) and derive the relationship of each ISM phase to the SFR. We study the relationship between the SFR and the surface density of the different Phases of the ISM. We compare these relationships between the [CII] luminosity and gas surface densities derived in the Milky Way with those observed in external galaxies.

14:40	**[NII] Fine Structure Emission Survey of the Galactic Plane**	***Paul Goldsmith***	Jet Propulsion Laboratory, California Institute of Technology

We report the preliminary results from a Herschel survey of the Galactic Plane. We have observed both [NII] FIR fine structure transitions with the PACS instrument in about 150 directions in the plane of the Milky Way. We determine the electron densities and N+ column densities for each pointing direction using the intensity averaged over all 25 PACS pixels, and assess the variation among them. We find the electron densities to be much greater than expected for the Warm Ionized Medium (WIM) and more consistent with those expected for HII regions. The [NII] emission observed in each pointing is clearly extended rather than pointlike. We also have 10 HIFI spectra of the 205 micron [NII] line at selected positions and compare these with [CII] spectra at the same positions from the GOT C+ Survey to asses the contribution of ionized gas to the C+ emission.

15:00	**Detection of a large fraction of atomic gas not associated with star-forming material in M17 SW**	***Juan-Pablo Perez-Beaupuits***	Max-Planck fur Radioastronomie

The [C II] 158 micron line is one of the dominant coolants of the ISM, and it is considered an important probe with which to study the star formation process. However, recent Herschel/HIFI and SOFIA/GREAT observations showed that assuming the total velocity-integrated intensity of this line is directly associated with the star-forming (molecular) material, as done in many galactic and extragalactic studies, is Inadequate. I will present spectrally resolved maps (4.1pc x 4.7pc) of [C II], [C I], and low-J CO lines observed with SOFIA/GREAT, APEX and IRAM 30m toward the massive star-forming region M17SW. I will show that only ~20% of the velocity range (~40 km/s) that the [C II] line spans is associated with the star-forming material traced by [C I] and CO. The spatial distribution of the [C I] and all CO isotopologues emission was found to be associated with that of [C II] in about 20%-80% of the mapped region, with the high correlation found in the central (15-23 km/s) velocity channels. The total gas mass estimated from the [C II] emission gives a lower limit of ~4.4x10^3 Msun. At least 64% of this mass is not associated with the star-forming material in M17SW. I will also show that about 36%, 17%, and 47% of the [C II] emission is associated with the HII, HI, and H_2 regimes, respectively. Comparisons with the H41\\alpha line shows an ionization region mixed with the neutral and part of the molecular gas, in agreement with the clumped structure and dynamical processes at play in M17SW. I will also show similar results in another massive star-forming region, NGC3603.

15:20 ***Coffee Break***

15:50 **Fine structure line emission from the young planetary nebula NGC7027 - a case study with GREAT** ***Helmut Wiesemeyer*** Max-Planck-Institut fur Radioastronomie, Bonn

Young planetary nebulae (PNe) are intriguing objects: They still carry signatures of the AGB winds that formed them, manifesting themselves as an expanding molecular envelope, often in form of an equatorial torus. The large variety of phenomena confined to a small volume with length scales of less than 0.1~pc leads to complex situations where multiple, misaligned outflows occur together with PDRs forming in response to the strong UV radiation from the white dwarf. As a consequence, the abundance patterns revealed by UV and optical spectroscopy cannot be exPlained with simple nebula models. Further difficulties in their interpretation arise from the UV extinction curve in PNe which is steeper than that in the ISM, but also from uncertain assumptions regarding the ionization structure and electron temperature of the nebula. Fine structure lines of [OI] and [CII] provide a useful tool to probe the density and temperature of the gas, owing to their collisional excitation. While previous observations with ISO-SWS and the KAO suffered from a limited spatial and spectral resolution, especially in young PNe, GREAT aboard SOFIA has considerably improved the situation. - This contribution will present recent observations of the strongest fine structure lines of [OI] and [CII] in the young (~600 yr) and therefore dense and hot PN NGC7027, as a case study that will soon be extended to more evolved PNe.

16:10 **Thermal balance in S140: Mysterious fine structure lines as mapped with GREAT/SOFIA.** ***Evgenia Koumpia*** SRON/Kapteyn Astronomical Institute

Trying to understand the gas cooling balance in the S~140 star forming region we map the main fine structure lines of [OI] and [CII] GREAT/SOFIA and combine them with previous ground-based observations of molecular lines. While previous studies and observations make the IRS1 a well known main heating source of dust and large scale gas visible in continuum, PAH emission, and many molecular lines, the new GREAT/SOFIA data reveal that the main cooling lines peak at a position north of IRS1 and closer to the less massive and five times less luminous cluster IRS2. We attempt to identify the origin of that peak by studying the spatial and velocity distribution of the different species. We try to distinguish between a possible ionized outflow origin or local column density effect. For the outflow scenario we need to consider the already known outflow from IRS1 (Maud et al. 2013), which points west of IRS2 and it cannot fully explain the observations. We use the higher resolution [OI] observations to estimate the emitting source size to within 5.5 arcseconds (0.02pc). A density of 10^4 cm^-3 can explain the observed [OI]/[CII] ratio while it fails when it comes to the the total luminosity for both lines that require a much higher density.

16:30 **The role of [OI] self-absorption in S140** ***Volker Ossenkopf*** I. Physikalisches Institut der Universitaet zu Koeln

Koumpia et al. (this workshop) present new data from [OI] and [CII] observations in S140 showing bright emission from an otherwise completely inconspicuous source. Here, we try to model that source using the constraints from the fine structures lines in the frame of a photon-dominated region (PDR). Normal PDR models completely fail to explain the combination of source size, line ratios, and absolute line intensities. A match is, however, possible if we include the effect of [OI] self-absorption. Although the line only shows a weak self-absorption dip, the total effect of self-absorption must be a large factor. As a draw-back, our computations show that [OI] is almost useless as a tracer of PDR properties as it may frequently trace completely other conditions if any foreground material is involved.

16:50 **[CII] and CO SOFIA observations in M17SW** ***Cristian Guevara*** University of Cologne

Omega Nebula M17 is a Giant Molecular Cloud and an appropriate place for exploring the physical conditions and the different phases of theISM, due to its edge-on orientation. M17SW in particular, the region located in the southeastern part of the GMC, is an excellent area for studying the structure of a clumpy PDR and the effects of the ionization source on the molecular cloud. [CII] 158 um is one of the main coolant of the ISM and a powerful tool for tracing the different stages of the ISM. It can be found in the warm diffuse medium, the warm and cold neutral medium and in the warm and dense molecular gas. GREAT receiver on SOFIA airborne telescope was used to obtain [CII] and different CO lines maps of 5.7' x 3.7'. The aim is to study the physical properties of the PDR derived from the [CII] observations and the correlation between [CII] and different CO lines in a clumpy medium.

17:10	**Observations of the circumnuclear disc with FIFI-LS**	***Aaron Bryant***	Universitaet Stuttgart

The Field Imaging Far-Infrared Line Spectrometer (FIFI-LS) is a German-built science instrument that has been commissioned for use on the Stratospheric Observatory for Infrared Astronomy (SOFIA). As part of its initial commissioning campaign, FIFI-LS observed the Sagittarius A* region of the galactic centre. Here, early results of these observations are presented. The circumnuclear disc, a clumpy, uneven ring of molecular structures, exists between 1.5 and roughly 5 pc from the central point of Sgr A*. It is of uncertain mass, is fed by infalling gas from dense molecular clouds in outer regions, and seems to be actively feeding material into the central cavity via streamers. FIFI-LS observed the circumnuclear disc at 6 far-infrared lines: OIII 52 and 88, OI 63 and 145, CII 157 and CO 186. The line and continuum fluxes of these wavelengths are analysed, and the possibilities of constraining certain characteristic values of the disc, such as dust and gas mass, are discussed. The potential implications for the theory of the disc's formation and evolution into the future, and the relationship this has with the general morphology of the galaxy, are investigated. Also shown are some of the data reduction and observing methods used to achieve these results.

17:40	***End of Day***
18:00	***Bus Departs***

Tuesday	Topic	Speaker	Affiliation
8:30	***Bus Leaves HD***		
8:45	***Coffee***		
9:15	**The Quantum Mechanics of fine structure lines: [CI, CII, OI, and OIII]**	***Hans Zinnecker***	SOFIA Science Center

Session 3: Resolved studies of FSL in Nearby Galaxies *(Chair: Maria Kapala)*

9:35	**Key Note: Resolving the cooling line deficit in the local and distant universe**	***JD Smith***	U of Toledo

The flow of radiation energy through the interstellar medium in galaxies sets the physical characteristics of clouds and governs the process of star formation itself. It is controlled through the delicate balance between indirect radiative heating of gas via dust grain ionization events, and collisional cooling by a small suite of powerful emission lines in the mid- and far-infrared. Both the heating and cooling sides of this energy flow equation can be studied directly, with an expectation that they should remain in approximate balance. And yet, mysteriously, across a wide range of environments, the line luminosity and total infrared power, which track the two sides of this heating/cooling balance, vary in relative proportion by more than two orders of magnitude. There is as yet no consistent explanation for this incredible variation.

I will review both foundational and exciting new results on this so-called "cooling line deficit", concentrating on global and spatially resolved studies of normal galaxies in the nearby universe, and placing these results in the context of resolved gas disks at the extreme limits of star formation in the early universe. And I will highlight what future studies can do to uncover the mechanisms responsible for this radical change in the flow of radiation through the ISM.

10:05	**ISM properties in the Local Group dwarf irregular galaxy IC10**	***Fiorella Lucia Polles***	CEA Saclay, SAp

How galaxies evolve from primordial environment to present-day galaxies is still widely discussed. The clues to this issue can lie in the interstellar medium (ISM). The ISM plays a key role in the evolution of galaxies, being the site of stellar birth and the repository of stellar ejecta, thus hosting the signatures of metal enrichment. The local universe dwarf galaxies are convenient laboratories to study the effect of star formation (SF) on a wide range of low metallicity ISM properties. We are studying the nearby irregular dwarf galaxy IC10, a low metallicity (Z ~ 1/5) Local Group galaxy, that we have fully mapped in Herschel PACS and SPIRE photometry, as well as Spitzer MIR to FIR photometry. Additionally we are exploiting our complementary Herschel/PACS spectroscopic maps of several large-scale SF regions of IC10 observed in 5 far infrared fine-structure lines: [CII] 157 micron, [OIII] 88 micron, [OI] 63 micron, [OI] 145 micron, [NII] 122 micron. We will present the results of our self-consistent photoionisation and photodissociation region modeling of the dust and gas properties throughout IC10.

10:25	***Coffee***		
10:55	**Revealing a complex velocity structure and variation of the column densities by velocity resolved [CII], [CI], and CO observations of the N159 star-forming region in the LMC**	***Yoko Okada***	I. Physikalisches Institut der Universitaet zu Koeln

The [CII] 158 micron line is one of the dominant cooling lines in star forming active regions. According to the modeling, its integrated intensity compared to the CO emission is expected to be stronger in lower metallicity environments due to the lower dust shielding of the UV radiation, and this trend is also shown by spectral-unresolved observations. In the commonly assumed clumpy, UV-penetrated cloud scenario, the models would predict a [CII] line profile similar to that of CO. However, recent spectral-resolved observations show that the line profile of the [CII] emission is very different from that of CO lines, indicating a more complex origin of the line emission including the dynamics of the source region. In this workshop we present the results of 4'x(3'-4') mapping observations in the N159 star-forming region in the LMC with [CII] 158 micron and [NII] 205 micron by the GREAT onboard SOFIA, as well as CO(3-2), (4-3), (6-5), 13CO(3-2), [CI] 3P1-3P0 and 3P2-3P1 with APEX. All transitions observed show a large variation in the line profiles across the map, and the [CII] emission line profile is substantially wider than that of CO and [CI] at most positions. We estimated the fraction of the [CII] integrated line emission that cannot be fitted by the CO line profile: 20% around the CO cores and up to 50% at the area between cores, indicating a gas component that has a much larger velocity dispersion that the ones probed by the CO and [CI] emission. We estimated the contribution of the ionized gas to the [CII] emission using the ratio to the [NII] emission, and found that the ionized gas contributes only 8% to the [CII] emission at its peak position. We derived the relative contribution from C+, C, and CO to the column density in each velocity bin. It clearly shows that the contribution from C+ dominants the velocity range far from the velocities traced by the dense molecular gas. Spatially, the region located between CO cores of N159W and E has a higher fraction of C+ even at the line center.

11:15	**Witnessing the Effects of Massive Star Formation in 30Doradus of the LMC**	***Melanie Chevance***	CEA/SAp/AIM

We will present a far infrared view of the spectacular nearby star forming region, 30 Doradus in the Large Magellanic Cloud (LMC), commonly considered to contain our nearest super star cluster, R136. This region offers the best laboratory to zoom into the interplay between stellar activity and metal-poor ISM due to its proximity (50 kpc) and half-solar metallicity. The new Herschel/PACS and SPIRE/FTS observation of far infrared (FIR) fine structure lines, combined with Spitzer IRS spectroscopic maps, provide constraints for modeling the gas in the photo-dissociation regions (PDR) with the Meudon PDR code, as well as the ionized gas, thus allowing us to construct a comprehensive, self-consistent picture of the density, radiation field, and ISM structure in this well-studied region and to quantify the effect of intense star formation on the low metallicity ISM. Effects of the intense star formation activity and lowering the metal abundance, hence decreasing the shielding necessary for the formation of molecular gas, can be witnessed throughout. The extreme luminosity of the 30Dor region makes it the only region of the Magellanic Clouds that can be extensively studied on large scales. Observations of the FIR fine structure lines in 30Dor ([CII] 157 micron, [OI] 63 micron, [OI] 145 micron and [OIII] 88 micron) over the entire 6'— 5' region (90 pc — 75 pc), covering the full range of contiguous PDR and ionized conditions influenced by the massive cluster will provide the most complete 3D picture of a well-resolved (4 pc scales) star-forming region divulging the structure and physical conditions of the diverse gas phases throughout the low metallicity ISM in a powerful starburst

<u>Session 4: Unresolved FSL studies in nearby galaxies</u> *(Chair: Melanie Chevance)*

11:35	**Keynote: Over the Peak: Probing the Radiation, Particle, and Column Densities in IR-Bright Galaxies using Far-IR Fine-Structure Lines**	***Jacqueline Fischer***	Naval Research Lab

Far-infrared spectroscopic observations of local IR-bright galaxies have shown an anti-correlation between far-infrared fine-structure line strengths and absorption strengths of radiatively-pumped far-infrared transitions of OH, H2O, and other molecules. I will review early and more recent studies of these correlations and as well as comparisons with spectral simulations and what they tell us about some characteristic parameters of these dusty and gas-rich systems. I will compare the OH and H2O column densities, the FIR colors, and the fine-structure line deficits in small samples of these galaxies to Cloudy and other spectral simulations using both starburst and active galactic nuclei (AGN) as central power sources and will discuss results for some local templates.

12:05	**Observations of OI and CII in M33 with SOFIA/GREAT**	***Christof Buchbender***	I. Physik. Institut, Universitaet zu Koeln

Nearby galaxies like M33 in which individual molecular cloud complexes can be resolved, while the large scale structure of the disk is observable, provide important stepping stones to relate observations of the ISM in the Milky Way with observations of galaxies farther away. The FIR lines [CII] 158 um and [OI] 63 um are the strongest cooling lines of the ISM. In part they originate from the transition regions between the atomic and molecular and allow to study the physics, thermal balance, dynamics and the link with star formation of the ISM. Very recently we made a pilot study to observe OI and CII in M33 with the GREAT receiver on SOFIA. The target of choice has been the giant HII-region NGC604 in M33. NGC604 is the second most massive in the local group after 30 Doradus and the most luminous source in M33 in OI and CII among the sources observed with ISO/LWS at a much lower spatial resolution than offered by SOFIA. The new observations extend an already large dataset of M33 (so far excluding NGC604) which was obtained and compiled by the Herschel open-science key project HerM33es, including observations of individual regions along the major axis of M33 in CII and OI. In general the GREAT observations add information on the velocity structure of the OI line at high spatial and spectral resolution and thus allow an insight into the dynamics of the warmer and denser neutral medium, which is in this form not available from the Herschel data on M33. Here, I will present our first results of the analysis of the SOFIA/GREAT CII and OI observations and set these into a larger perspective with the on-going analysis conducted by the HERM33ES consortium of the OI and CII observations with PACS and HIFI in the nucleus as well as the southern and northern spiral arms of M33.

12:25	***Lunch***

13:30	**A study of fine structure lines in a nearby blue compact galaxy**	**Drew Brisbin**	**National Radio Astronomy Observatory**

We present observations of seven fine structure lines in a nearby blue compact galaxy. This data represents one of the most extensive sets of whole-galaxy-integrated FIR line measurements from a single system. These lines, which probe both the ionized and neutral gas in the system, provide excellent insight to the star formation history, UV field intensity, source of [CII] emission, and potentially nitrogen to carbon abundance. As a well studied unresolved galaxy with extensive multi-wavelength data, this source will be an important proof-of-concept for techniques to investigate systems in the early universe.

13:50	**The reliability of FIR lines as star formation rate indicator**	**Ilse De Looze**	**1. Institute of Astronomy, University of Cambridge 2. Ghent University**

We analyze the reliability of three bright far-infrared fine-structure lines ([CII], [OI], [OIII]) to probe the star formation activity in a sample of 500 galaxies, ranging from metal-poor dwarf galaxies over starburst and AGN to high-redshift sources. Our study shows that the gas cooling is not linked to the star formation rate (SFR) in a similar way across different galaxy populations. Knowing the important parameters (i.e., metal abundance, radiation field, ionization and gas phase filling factors) dictating the efficiency of the ISM cooling through far-infrared line emission, we calibrate the fine-structure lines as star formation rate indicators over a wide range of metallicity and galaxy classification. Based on theoretical models, we examine the uncertainties on the SFR relations due to variations in the star formation history, elemental abundances, and the importance of gas heating mechanisms other than the photo-electric effect in galaxies.

14:10	**Non-SF heating related [CII] emission in the bulge of M31**	**Maria Kapala**	**MPIA**

M31 is a unique target because of its prominent bulge that can serve as a laboratory to study resolved ISM in the early type galaxy (ETG)-like environment. We revisit archival ISO [CII] observations {Mochizuki et al. 2000) across the bulge (no active star-formation). We find a surprisingly high [CII] and [CII]/TIR in comparison with the star-forming regions in the disk (SLIM survey; Kapala et al. 2015). The photoelectric heating mechanism seems as the largest contributor to gas heating (where FUV flux is generated by evolved stellar populations), however photoionization and cosmic rays heating mechanisms are likely to be responsible for the observed [CII] "excess" in the bulge. We show that we can predict [CII] emission in the SLIM fields in the disk based on the estimated from integrated SED fitting fraction of the stellar energy that contributes to gas heating (PEeffxUVatt) with a constant photoelectric heating efficiency (PEeff). We also found that the attenuated UV energy relative to the total attenuated energy (UVatt/TOTatt) correlates well with the [CII]/TIR ratio, suggesting that it is the soft photon heating of dust that is driving the variation in the [CII]/TIR ratio across this disk. This is in agreement with a previous result suggesting that TIR is varying much more strongly across the disk than [CII]. We propose that a better method to approximate the PE heating efficiency (than [CII]/TIR) is to use a SED fitting technique: [CII]/UVatt.

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14:30	**Overview of Discussion/Unconference Sessions**
14:40	**Discussion/Unconference Session #1**
16:00	***Coffee***
16:20	**Discussion/Unconference Session #2**
17:40	***End of the Day***
18:00	***Bus Departs***

Wednesday	Topic	Speaker	Affiliation
8:30	*Bus Leaves HD*		
8:45	*Coffee*		

Session 5: FSL Studies in Nearby Extreme Systems *(Chair: Bitten Gullberg)*

9:15	**Keynote: ISM Properties of Local LIRGs: From Main-Sequence Galaxies to Starbursts**	***Tanio Diaz Santos***	Univ. Diego Portales

Luminous and Ultra-luminous Infrared Galaxies ((U)LIRGs) represent the most important galaxy population at z > 1 as they account for > 50% of all star formation taking place in the Universe at those epochs; and encompass what it is called the main-sequence (MS) of star-forming galaxies. Investigating their local counterparts –cold, low luminosity LIRGs– is therefore critical to understand the physical properties and phases of their inter-stellar medium (ISM) – a task rather challenging in the distant Universe. On the other hand, high-z star-bursting (out of the MS) systems are more similar to local ULIRGs, and although small in number, they account for a modest yet still significant fraction of the total energy production. Thus, LIRGs represent the key transition population that links normal MS star-forming galaxies with starbursts systems with higher IR luminosities. In this talk I will present results from Herschel far-IR emission line studies ([CII]158μm, [OI]63μm, [OI]145μm, [OIII]88μm, [NII]122μm, [NII]205μm) for different samples of local LIRGs, including the Great Observatories All-sky LIRG Survey (GOALS), a sample of more than 240 relatively cold systems, and other samples of local ULIRGs with warm mid- to far-IR colors, indicative of ongoing extreme nuclear starbursts and/or an AGNs. Using emission line diagnostics and photo-dissociation region (PDR) models it is possible to derive the basic characteristics of the ISM for these samples and study differences among systems as a function of AGN activity, merger stage, dust temperature, and compactness of the starburst – parameters that are thought to control the life cycle of galaxies moving in and out of the MS, locally and at high-z.

9:45	**The ISM properties of low-metallicity star-forming galaxies unveiled by Herschel.**	***Diane Cormier***	ITA/ZAH, University of Heidelberg

I will talk about our ongoing efforts to study the FIR line emission in nearby star-forming dwarf galaxies. In those low-metallicity environments, molecular tracers are rare and the FIR lines may be our best handle on their star formation properties. Observations of the [CII] 157mu, [OI] 63 and 145mu, [NII] 122mu, and [OIII] 88mu FIR cooling lines, obtained with PACS as part of the Herschel Dwarf Galaxy Survey, are analyzed together with detailed radiative transfer models to characterize the physical conditions in the ISM of those galaxies. We find that the low-metallicity ISM differs dramatically from that of more metal-rich objects. It is characterized by harder radiation fields and a porous structure, with larger filling factors of ionized gas, [OIII] being often the brightest FIR line, dense PDRs of low covering factors, and strong effects of photodissociation, resulting in high [CII]/CO ratios. The C+ line is mostly PDR-associated in those dwarf galaxies, as also suggested by ongoing work on SOFIA/GREAT data, and can thus be calibrated as a tracer of the CO-dark gas.

10:05	**FIR line emission from low-z gas-rich massive galaxies: line deficits and implications for high-z galaxies**	***Benjamin Weiner***	Steward Observatory

Far-infrared lines are probes of the physical conditions in star forming regions. However, the causes of the "[C II] deficit" are still debated at low redshift, and predicting and interpreting observations of FIR lines from star forming galaxies at high redshift depends on what systems we choose as low-z analogs, e.g. for predicting ratios of [C II] to star formation rate or far-IR luminosity. For example, local high-SFR mergers with small size and high density are probably not good analogs for z=1-2 high-SFR disk galaxies. We have identified a sample of low-redshift massive galaxies that are both IR-luminous and disky rather than mergers. Herschel observations of these galaxies showed most had strong [C II] emission, suggesting the line deficit is less present in disky galaxies where SFR is less concentrated. I will present ALMA CO maps of a subset of these galaxies, showing they tend to be rich in molecular gas, and discuss correlations between gas mass, SFR, and FIR line luminosities and ratios. The implications for FIR lines from both z=1-2 and very-high-z galaxies depend on how we reason from imperfect local analogs.

10:25	**Fine Structure Lines in the Nearby Universe and Connections to High-z Sources**	***Alberto Bolatto***	University of Maryland

I will present results from the Herschel mapping of FIR transitions in the Small Magellanic Cloud (HS3MC), and compare our measurements to normal local galaxies (KINGFISH). I will discuss the relation between [CII] and CO at low metallicity and the use of [CII] measurements to trace translucent molecular gas. If time allows, I will present [NII] 205 um results from the Beyond the Peak (BTP) sample with determination of the distribution of ionized gas densities in local galaxies, as well as our early efforts at determining the pressure in the neutral gas.

10:45 ***Coffee***

<u>Session 6: FSL studies in the High-z Universe</u> *(Chair: Drew Brisbin)*

11:15	**Keynote: Fine-structure lines for studying the chemical evolution of galaxies**	***Tohru Nagao***	Ehime University

Metallicity is a key parameter to diagnose the evolution of galaxies, and the gas-phase metallicity in galaxies has been extensively measured for high-redshift galaxies up to z~3 through systematic optical and near-infrared spectroscopy. However, rest-frame optical spectra are hard to be investigated for galaxies at z>4 and also for galaxies with a heavy dust extinction. In this talk I would like to review how fine-structure emission lines are powerful for assessing chemical properties in such high-z galaxies.

11:45	**On the [CII]-SFR relation in high redshift galaxies**	***Livia Vallini***	Universita di Bologna - Dipartimento di Fisica e Astronomia

After two ALMA observing cycles, no searches for [C II] 158 micron emission line in z ~ 7 normal star forming galaxies have reported a positive detection, questioning the applicability of the local [CII]-SFR relation to high-z systems. To investigate this issue we perform a high-resolution, radiative transfer cosmological simulation that allows us to predict the [C II] 158 micron emission arising from the interstellar medium of a z ~ 7 galaxy. The [C II] luminosity is achieved: (i) by coupling the simulation with the Vallini et al. (2013) sub-grid ISM model that accounts for the emission from the diffuse neutral gas, (ii) by considering the contribution of Photo-Dissociation Regions, and (iii) by taking into account of the effects of the Cosmic Microwave Background on [C II] line luminosity. We then study the relative contribution of the diffuse neutral gas to the total [CII] luminosity and its correlation with the star formation rate and the metallicity profile within the galaxy. I will discuss the results of our model showing that the [C II] deficit suggested by actual data, if confirmed by deeper ALMA observations, can be ascribed to negative stellar feedback disrupting molecular clouds around star formation sites and/or low gas metallicity.

12:05	**The nature of the [CII] emission in dusty star-forming galaxies from the SPT survey**	***Bitten Gullberg***	ESO

ALMA spectroscopy (cycle 0 and 1) of point sources from the South Pole Telescope survey has uncovered a population of high-redshift (z = 2 - 5.7), strongly lensed dusty star-forming galaxies (DSFGs). This has resulted in an unbiased redshift distribution for DSFGs peaking for z = 3.5, i.e. higher than previously believed of z = 2.5, and doubled the number of sources at z > 4. In this talk I will present the latest result from our fine-structure line survey of 20 DSFGs. Comparing [CII] velocity profiles (APEX and Herschel) with CO velocity profiles from ALMA reveals consistent velocity profiles, suggesting little differential lensing between these species. Combining the [CII] detections with low-J CO detections (ATCA), we find [CII]/CO(1-0) luminosity ratios of 5200+/-1800, and argue that this line ratio is best described by [CII] and CO emitting gas with higher [CII] than CO excitation temperature, high CO optical depth (>>1), and low to moderate [CII] optical depth (<~1). The geometric structure of photodissociation regions (PDRs) allows for such conditions.

12:25 ***Lunch***

13:30	**First detection of the CO(17-16) line in a z>6 quasar**	***Simona Gallerani***	Scuola Normale Superiore
	I will present the serendipitous detection of the CO(17â€“16) line toward the quasar SDSSJ114816.64+525150.3 (J1148) at z ~ 6.4, obtained with the Plateau de Bure Interferometer. This is the highest CO transition in the millimeter range ever detected in such distant sources. I will show that the CO(17-16) line is possibly contaminated by OH+ emission, that may account for 35 - 60% of the total flux observed. Photo- Dissociation and X-ray Dominated Regions (PDRs and XDRs) models show that PDRs alone cannot reproduce the high luminosity of the CO(17-16) line relative to low- J CO transitions and that XDRs are required. By adopting a composite PDR+XDR model these observations allow us to derive the molecular cloud and radiation field properties in the nuclear region of J1148. I will discuss the possibility of using highly excited CO lines to infer the presence of X-ray faint or obscured supermassive black hole progenitors in high-z galaxies.		
13:50	**The brightest strongly lensed dusty star forming galaxies through the Herschel SPIRE FTS**	***Richard George***	University of Edinburgh
	Large area far-infrared surveys with Herschel have allowed us to assemble a large sample of strongly-lensed high redshift dusty star-forming galaxies. I will present the results of a large programme of observations of the brightest of these using the Herschel SPIRE FTS, searching for fine structure lines in order to characterise the physical state of the interstellar medium.		
14:10	**The ISM at z=7**	***Bram Venemans***	MPIA
	Luminous quasars at high redshift are powered by supermassive black holes. These massive black holes are thought to be located in the progenitors of the massive early type galaxies we see in the local Universe. Therefore, studying the host galaxies of the most distant quasars enables us to study the formation of massive galaxies in the early Universe. Recently, using wide field infrared surveys, we successfully discovered several quasars at z>6.5 with a central black hole of >10^9 solar mass. In this talk I will present ALMA Cycle 1 and Plateau de Bure Interferometer observations of the [CII] and CO lines in the host galaxies of the z>6.5 quasars. All the observed host galaxies have been detected, and show a range of properties. I will discuss our results and the implications for massive galaxy formation at high redshift.		
14:30			
15:00	***Coffee Break***		
15:30	**Discussion/Unconference Session #3**		
17:30	***End of Day***		
17:45	***Bus departs for HD***		
18:30 - 20:45	***Conference Dinner at Semann's***		
20:45 - 21:30	Conference Summary		

Thursday	Topic	Speaker	Affiliation
9:00	***Bus Leaves HD***		
9:15	***Coffee***		

Session 7: Instruments and Facilities for FSL studies *(Chair: Hans Zinnecker)*

9:45	**Fine Structure Line Observations with SOFIA**	***Juergen Stutzki***	I. Physik. Institut, Universitaet zu Koeln

This talk will cover the observational opportunities for FIR fine-structure line observations with SOFIA's present instruments, in particular GREAT/upGREAT. It will present recently obtained results and will discuss what these observations have provided in new insight. The talk will also discuss the future perspectives for SOFIA observations and new instrumentation.

10:05	**Science with the Far-Infrared Spectroscopic Explorer (FIRSPEX)**	***Dimitra Rigopoulou***	University of Oxford

Far-infrared (FIR) dust continuum emission has routinely been used as a tracer of the integrated contribution of components forming the interstellar medium (ISM). However, it is virtually impossible to use this observation method to isolate and separately study the ISM constituents. Fortunately, the FIR regime is also rich in atomic, ionized and molecular lines which can be detected and characterised via high-resolution spectroscopy. This powerful observation technique allows exploration of key astrophysical processes including: cloud-collapse and formation of proto-stellar cores; chemical networks in the ISM; cooling mechanisms in galaxies; and the role of feedback in active galactic nuclei (AGN). The attenuating effect of the Earth's atmosphere however, prevents observations of key species such as [OI]63.18micron (4.75THz), [OH]119 micron (2.52THz), [CII]157.74micron (1.90THz), [NII]205.17micron (1.46THz) from the ground, and observation from high-altitude aircraft and balloon platforms does not provide sufficient atmospheric clarity and spatial coverage. The Far-Infrared Spectroscopic Explorer (FIRSPEX) is a concept aiming to fulfil this requirement. FIRSPEX is a small satellite (1m telescope) operating from Low Earth Orbit (LEO). It consists of a number of heterodyne detection bands targeting key molecular and atomic transitions in the terahertz (THz) and Supra-Terahertz (>1 THz)frequency range. The primary goal of FIRSPEX is to perform an `unbiased' all sky spectroscopic survey in a number of important far-infrared lines. FIRSPEX will perform the first wide area high spectral resolution survey in the far-infrared delivering the first 3D-maps of the galaxy. The spectroscopic surveys will build on the heritage of Herschel and complement the broad-band all-sky surveys carried out by the IRAS and AKARI observatories. In addition FIRSPEX will enable targeted observations of nearby and distant galaxies allowing for an in-depth study of the ISM components. In this talk, I will review the science goals, capabilities and timeline of the FIRSPEX mission.

10:25	**IR spectroscopy of fine-structure lines ad diagnostics of galaxy evolution**	***Luigi Spinoglio***	IAPS-INAF

Mid- to far-IR spectroscopy gives us one of the best tools to study the physical processes in dust enshrouded galaxies along evolution. The peak of both star formation and black hole accretion at z=1-3 can be studied in detail through fine structure lines. Starting from the results of Herschel (and also Spitzer) the potential of an IR space telescope such as SPICA to perform the first \"physical\" study of galaxy evolution in the IR will be outlined.

10:45	***Coffee***		
11:15	**Conference Summary Writing**		
12:25	***Lunch***		
13:00	**Closing remarks during lunch**		
13:35	***Workshop Ends***		
13:50	***Bus Leaves***		