Stormy Cosmos: The Evolving ISM from Spitzer to Herschel and Beyond

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Talk Abstracts

Mark G. Wolfire (University of Maryland)
The Stormy Cosmos: Theoretical Overview
Spitzer and Herschel observations have provided new insights into interstellar medium processes - many of which can best be described by non-equilibrium physics. The interstellar medium is known to be a dynamic environment in which shocks and turbulence modify the density and chemistry of the ISM and inject energy into the gas. In addition, far-ultraviolet radiation heats the gas and grains while the far-ultraviolet, X-rays, and cosmic rays can ionize the gas and dissociate molecules. The chemical and heating/cooling rates span a wide range of time scales and can be temperature and density dependent. When can we expect chemical equilibrium and thermal equilibrium models to apply in light of the changing physical conditions? I will review the basic physics of time dependent chemistry, thermodynamics, and radiative processes and discuss a few of the Herschel and Spitzer observations that constrain the physics. There are certainly some regions for which an equilibrium approximation is appropriate, our understanding, however, is indeed rapidly changing with time. I will also discuss some of these phenomena which have been brought to light by Spitzer and Herschel observations.

Astrochemistry of Shocks and Other Dynamic Interstellar Processes

Edith G. Falgarone (Observatoire de Paris & Ecole Normale Superieure)
CH+ in the Diffuse Interstellar Medium : A Tracer of Turbulent Dissipation?
Absorption spectroscopy performed with Herschel/HIFI against the dust continuum emission of bright galactic star-forming regions confirms the anticipated high opacity of the ground-state line of CH+ in the diffuse gas sampled by these sight-lines (1,2,3,4). Alike other light hydrides, CH+ that need H2 to form but is also destroyed by H2, appears as a sensitive tracer of a poorly known component of the interstellar medium (ISM) : molecular gas weakly shielded from UV radiation. Because its formation route is so highly endoenergic, the CH+ cation has been shown to be a specific tracer of turbulent dissipation occurring in diffuse gas with low molecular fraction (5,6). Its elusive origin in the diffuse ISM is therefore much more than a chemical riddle : it is rooted in the physics of the diffuse ISM, its turbulent dissipation rate and connects with the far broader issue of galaxy evolution and formation. The power of CH+ absorption spectroscopy as a probe of mild dissipative processes in diffuse media will be illustrated on existing Herschel/HIFI and CSO data in light of the so-called Turbulent Dissipation Regions model.
References: 1 Falgarone, Ossenkopf, Gerin et al. 2010 A&A 518, L118 2 Falgarone, Godard, Cernicharo et al. 2010 A&A Herschel/HIFI Special issue, in press 3 Gerin, de Luca, Black et al. 2010 A&A 518, L110 4 Neufeld, Goicoechea, Sonnentrucker et al. 2010 A&A Herschel/HIFI Special issue, in press 5 Godard, Falgarone, Pineau des Forets 2009 A&A 495 847 6 Godard, Falgarone, Gerin, Hily-Blant, de Luca 2010 A&A in press, arXiv1006.0582G

Maryvonne Gerin (LERMA)
Molecules in the Diffuse ISM
Thanks to its excellent sensitivity and broad frequency coverage, the Herschel satellite is bringing new information on the formation of molecules in the diffuse interstellar medium. I will present the first results of the PRISMAS (PRobing InterStellar Molecules with Absorption line Studies) key program, together with similar observations obtained in the framework of other Herschel key programs. A main outcome of the spectroscopic investigation of the far infrared and submillimeter wavelength range is the confirmation of the key roles of interstellar hydrides as building blocks of molecules and as tracers of the properties of the diffuse interstellar medium. I will particularly discuss the examples of the oxygen hydrides (OH+,H2O+,H2O and OH), carbon hydrides (CH, CH+), nitrogen hydrides (NH,NH2 and NH3) as well as hydrogen fludoride (HF).

Paul Goldsmith (Caltech/JPL)
Results from the Herschel Oxygen Project
Oxygen is the third most abundant element in the cosmos, yet its form in dense regions of the interstellar medium remains a mystery. Gas phase oxygen can be ionized, atomic, or molecular, and it is also incorporated into grains. ISO observations suggested that, contrary to chemical models, atomic oxygen is significantly more abundant than carbon monoxide (CO) in well-shielded regions. Gas-phase chemistry models predict molecular

oxygen (O2) to be almost as abundant as carbon monoxide. Searches for molecular oxygen carried out with the SWAS and Odin spacecraft have yielded upper limits on the abundance of molecular oxygen typically 2 orders of magnitude below those predicted by gas-phase models. One fairly clear detection of O2 again indicates a low abundance. A variety of explanations have been proposed to explain this. Some of these are based on depletion of atomic oxygen onto dust grains, resulting in incorporation of this species into water that remains on the grain surface. Available gas-phase oxygen is largely in CO, leaving little for gas-phase O2. Other models involve circulation of material between UV-irradiated and well-shielded regions. The Herschel Oxygen Project addresses this important problem in astrochemistry, exploiting the high angular resolution and sensitivity of the Herschel HIFI instrument to observe 3 rotational transitions of O2 in a broad sample of molecular clouds. The sensitivity and angular resolution of HIFI is a dramatic improvement over anything previously available at these frequencies. These data should, whether yielding detections or significantly improved upper limits, provide critical information about interstellar chemistry and the structure of these molecular regions. We will discuss the HOP observations to date including exceptionally low upper limits to the abundance of O2 as well as some provocative, tentative positive results.

Vincent Guillet (IAS)
Modeling Dust Processing in Shocks in Dense Clouds
Interstellar shocks are commonly observed around YSOs where they are triggered by jets and outflows from the new-born stars. Such energetic events affect the population of dust grains in the shocked gas, through high velocity gas-grain collisions (sputtering of grain mantles and cores) and grain-grain collisions (vaporization and shattering of grains). The sputtering and vaporization of grains release chemical species in the gas phase which are then observed through their emission lines, while the shattering of grains break them into small fragments. Various shock models have been proposed to explain the line intensities and profiles of chemical species like H_2, SiO or CH_3OH : steady-state shocks, mono-fluid (J-type) or multi-fluid (C-type), as well as time dependent shocks. Modeling the evolution of dust in shocks involves the complete determination of the size-dependent charge and dynamics of grains through the shock (Guillet et al. 2007), of the outcome of gas-grain and grain-grain collisions and their feedback on the shock ionization and dynamics (Guillet et al. 2009, 2010). We will present new results on the modeling of dust evolution in low velocity C and J-type shocks (Vs < 50 km/s) propagating in dense clouds (n_H ~ 10^4-10^5 cm-3). It turns out that the shattering of grains in C-type (multi-fluid) shocks may deeply affect the dust size distribution and the shock dynamics in reverse. We will also show how vaporization, unlike sputtering, can destroy grains and produce SiO or Fe II in J-type shocks, and how it can affect the line intensities and profiles of SiO in C-type shocks.

Eric Herbst (Ohio State University)
Gas and Grain-Surface Chemistry Throughout the ISM
Although interstellar chemistry was developed to explain two types of regions - nearby diffuse clouds and dark cold clouds - it is now well known that the ISM is heterogeneous and that different types of sources are sites for diverse chemical processes. The chemistry

of cold dark clouds is essentially a gas-phase one in which radicals, molecular ions, and simple carbon-chain species are dominant, whereas the chemistry of hot cores produces all sorts of hydrogen-rich terrestrial-like species such as alcohols and esters. The mechanism by which these species are produced in hot cores is still in some doubt. Some of the chemistry occurs during the actual warming up of the hot core due to star formation; during this period smaller molecules on grain surfaces are converted into reactive species by photons and particle bombardment. These reactive species subsequently combine to form larger organic species, which eventually sublime into the gas as the temperature of the hot core exceeds 100 - 200 K. In heterogeneous regions such as protoplanetary disks, significant portions of the object lie at high temperatures, and their chemistry must be treated by expanded networks that include reactions with barriers. In regions undergoing dynamic motions, the chemistry must be coupled to the dynamics, whether one uses hydrodynamics or some simpler model of motion. An example is the chemistry that occurs as diffuse matter partially collapses to form cold dense cores, or as hot cores convert into protoplanetary disks. Thus, even the standard astrochemistry of the ISM consists of a complex assortment of different types of processes. The new generation of telescopes will test our ideas and models of astrochemistry quite closely, and reveal much that has not yet been conceived.

David J. Hollenbach (SETI Institute)
Oxygen Chemistry in Molecular Clouds
Oxygen chemistry varies considerably as one goes from the ultraviolet illuminated surface to the deep opaque interiors of molecular clouds. At the surface photodissociation, photoionizaton, and photodesorption of ices plays a dominant role. In the interior, the freezeout of water ice and various desorption processes play a key role, along with time dependent effects since the chemical timescales become longer than the cloud lifetime. This talk focuses on models relevant especially to Herschel and Spitzer observations: the abundances and column densities of gas phase H2O, O2, OH+, H2O+, and H3O+, the water ice abundance, and CO depletion in the cloud interior.

Jim Ingalls (SSC)
Stirring the Galactic Pot: Warm H2 in Cold Clouds
Using the Spitzer IRS, we have detected emission in the S(0), S(1), and S(2) pure-rotational transitions of molecular hydrogen (H2) towards 6 positions in two translucent high Galactic latitude clouds. The detection of these lines raises important questions regarding the physical conditions inside low-extinction clouds that are far from ultraviolet radiation sources. The ratio between the S(2) flux and the flux from PAHs at 7.9 microns averages 0.016 for these 6 positions. This is a factor of about 9 higher than the same ratio measured towards the central regions of normal Galaxies in the SINGS survey. Thus the environment of these translucent clouds is more efficient at exciting H2 per PAH-exciting photon than the disks of entire galaxies. The H2 excitation diagram indicates that the emitting gas probably has a rotational temperature of around 170K (compared with a median HI temperature of 70K), and has an extremely low ortho/para ratio, implying an out-of-equilibrium scenario. We find that UV pumping cannot be the sole source of excitation in these regions and suggest collisional heating via shocks or vortices as a major cause of the H2 emission. The location of the clouds on the edge of

the Local Hot Bubble lends plausibility to the idea that the medium is at least partially shocked and that the cold and warm neutral media are not isolated from each other. We suggest that pockets of warm gas in diffuse or translucent clouds, integrated over the disks of galaxies, may represent a major source of all normal galaxy H2 emission.

Michael Kaufman (San Jose State University)
Diagnostics of Molecular Shocks: From YSOs to SNe
Shock waves are unique laboratories for the study of physical and chemical processes in molecular gas. Relatively sophisticated thermal/chemical models of molecular shocks have been available for some time, but only with the advent of space-based infrared and submillimeter spectroscopy and mapping has it become possible to take full advantage of these modeling tools. I will discuss a variety of molecular shock observations, in outflows and supernovae, made with Spitzer, Herschel, SWAS, etc. which demonstrate the diagnostic value of shock observations.

Lars E. Kristensen (Leiden Observatory)
Water Tracing the Stormy Stages of Star Formation
During the earliest embedded stages of star formation the young star interacts with its surroundings through high velocity shocks and UV radiation, providing feedback on the medium from which the star is forming. At the same time, in-falling gas is heated to several 100 K by the accretion luminosity. The Key Program "Water in Star-forming regions with Herschel" (WISH; PI: van Dishoeck) uses high spectral and spatial resolution observations of water and related molecules to provide observational constraints on this energetic input and feedback. An overview of the low-mass protostellar survey of WISH will be presented here. The HIFI and PACS observations cover about 20 low-mass protostellar objects at various evolutionary stages. They comprise more than 10 H2O and H2-18O lines per object with energies up to 500 K above the ground state, together with lines of the other major coolants CO, OH, O I and C II. Data are compared to Spitzer observations of the same objects of rotationally excited H2 and atomic lines. Such a comparison puts stringent constraints on the excitation conditions along the protostellar outflow as well as the cooling budget. Furthermore, in at least one object, even higher excited water emission has been observed with Spitzer resulting in a unique dataset covering water transitions up to 3000 K above the ground state. Explaining these data requires a combination of state-of-the-art shock and PDR models along the outflow cavity. New advances in the 2D modeling, interpretation and understanding of the densest parts of the interstellar medium surrounding protostars will be highlighted.

William Langer (JPL/Caltech)
CII Detections of Warm H2 Gas in Galactic Atomic and Molecular Clouds with Herschel's GOT C+ Survey
We need information about the transition from diffuse atomic to molecular gas clouds and their PDR layers to understand the lifecycle of the interstellar gas and star formation. Until now our knowledge of interstellar gas has been limited primarily to the diffuse atomic phase traced by HI and the dense molecular H2 phase traced by CO. However, we are missing an important phase of the ISM that is mostly H2 with little HI and CO. Here,

I discuss the new opportunity and the first results, to explore this phase of the diffuse ISM with the Galactic Observations of Terahertz C+ (GOT C+) program, a Herschel Space Observatory Open Time Key Program to study the ISM by sampling [CII] 1.9 THz (158-micron) line emission throughout the Galactic disk using HIFI. I will review the first GOT C+ observations in which we detected 146 interstellar clouds along sixteen lines-of-sight towards the inner Galaxy in [CII] emission. This [CII] emission is stronger than expected for diffuse and transitional clouds, given their HI and 12CO column densities. The excess [CII] emission is best explained by the presence of a significant warm H2, "dark gas" component. This first [CII] 158-micron detection of warm "dark gas" shows the value of this tracer for mapping it throughout the Milky Way and other galaxies. In our sample of 51 transition clouds about 25%, on average, of the total H2 is traced only by CII and resides in the layer surrounding the CO core. We detected 58 dense clouds containing 13CO in which the FUV radiation field can be estimate from CII and 12CO by comparison to PDR models. This research was conducted at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.

Patrick Morris (Caltech/NHSC)
Mapping [CII] and CH+ Towards Orion KL with Herschel/HIFI
We have taken spectral maps of the inner region of the Orion KL nebula (typically 2' x 2' in Nyquist steps of ~5".5) around the deeply embedded young massive star IRc2 at the [CII] 1900 GHz (158 um) and CH+ J=1-0 835 GHz (359 um) transitions at high velocity resolution with Herschel/HIFI. These maps are of very high quality and provide excellent views on the velocity and isotopic structure of the cooling regions which have accommodated molecular cloud contraction and subsequent star formation. We present the distribution of the intense [CII] and CH+ lines from the turbulent hot and dense core and the surrounding relatively cool material, exhibiting a wide range of velocity profiles and 12C/13C isotopologue ratios. The results allow us to trace the turbulence around the central source in which both PDR and shock mechanisms are probably at work, the nature of controversial CH+ formation mechanisms (from shock chemistry vs UV pumping), the spatial and relationship to photodissociation surface illuminated by theta1 Ori C to the south, and a test of previously deduced agreement of the isotope ratio with PDR models which imply that chemical fractionation in this highly illuminated region is unimportant.

Volker Ossenkopf (I. Physikalisches Institut der Universitaet zu Koeln)
New Results on the Physics and Chemistry of PDRs from HIFI Observations
Within the Herschel key project "The Warm and Dense Interstellar Medium (WADI)", we started to systematically observe a number of prominent photon-dominated regions (PDRs) and supernova shocks. We scan a large range of physical parameters to measure the impact of varying UV fields and shock velocities on the energy balance and the chemical and dynamical structure of heated molecular clouds. The measured HIFI spectra trace a large variety of chemical species. We obtained in particular an inventory of reactive ionic species that are only formed in translucent clouds or at the heated surfaces of dense molecular clouds. They are powerful diagnostics of the active chemistry in these regions. By observing light hydrides in their ground state, we derived abundance ratios

for essential nodes in the chemical network of reactions so that we can calibrate the chemistry in the PDR models. By mapping the main cooling lines and tracers for different gas temperatures, we obtained a self-consistent picture of the energy-balance in the sources involving a deep penetration of UV radiation into a clumpy interstellar medium. Within the Herschel beam, we see emission from material with a broad temperature distribution. Radiative transfer models allow to disentangle the different components from the details of the line profiles. The analysis of the variation of the line profiles across the interface regions allows to trace the dynamics of the gas in the PDRs. We find no clear signatures of evoporation or advection flows, but indications of pressure driven streams leading to pillar formation. Further analysis is needed to obtain a full three-dimensional picture of the interface regions including the chemical structure and their velocity fields.

Thermodynamics and Mechanics of the Interstellar Medium

Marc-Andre Besel (Max-Planck-Institut fur Astronomie)
Three-Dimensional Mapping of the Interstellar Medium
Little is known about the true three-dimensional structure of the interstellar medium, as observations usually only yield an average of physical parameters along the line-of sight. The discovery of infrared light echoes around the Cassiopeia A supernova remnant with Spitzer provides the unique opportunity to study the true three-dimensional structure of the interstellar medium in high resolution. Infrared echoes occur when the UV and visible light pulse from the supernova explosion encounters the surrounding ISM and is being scattered and absorbed by dust grains. By observing multiple epochs of light echoes, a series of tomographic image slices of the 3-D ISM is recorded. These maps cover a volume of about 200 x 200 x 0.9 pc. Combining the large scale Spitzer-MIPS-24 μm maps with ground-based NIR data, ISM structures ranging from 0.01 to about 10 pc can be resolved. In addition to IR mapping we use Spitzer-IRS spectroscopy of the echoing clouds to constrain the physics of the supernova outburst and the composition of the cloud itself. For the first time we can directly study the self-similar fractal structure of the ISM and its underlying turbulent movements covering a considerable span of spatial sizes. Modelling of the densest echoing clouds suggests that they belong to the cold neutral medium.

Bruce Elmegreen (IBM Research Center)
Thermodynamics and Mechanics of the ISM
Energy sources from stars, galactic stellar gravity and ISM gravity stir the gas in a variety of ways, producing shells, spirals, filaments, cores, and other well-defined structures, in addition to hierarchical compression patterns where turbulence decays. Cosmic rays and magnetic fields also derive energy from stars and galactic gravity, and they stir the gas as well. The result is a chaotic ISM layer with a velocity dispersion of 10 km/s and large-scale variations from long-range forces. At the same time, there is another cycle of energy flow through the thermal motions of the gas, which are fed mostly by starlight, cosmic rays, and shock fronts. The thermal energy density is only 1/10th of the mechanical energy density on average. Because all of these energy sources act simultaneously on the gas, it has been difficult to sort out the primary drivers of cloud structure and motion. Power-law power spectra of whole galaxies indicate there is a coherence to the structure that is reminiscent of the coherence in turbulence, even on multi-kpc scales. Recent simulations reproducing this power law suggest that most of the ISM random motions and density structures are driven by gravity, with stellar feedback at the same energy density serving primarily to limit the build-up of dense clouds. This implies that power density is not enough to indicate primary drivers: different types of energy sources affect different aspects of ISM behavior. This talk will review these and other recent developments in thermal and mechanical processes in the ISM. The emerging picture suggests that the ISM is mostly in a state of detailed balance without mechanical equilibrium.

John W. Hewitt (NASA Goddard)
The Violent Evolution of Supernova in Molecular Clouds
Supernovae have a formidable impact on the dynamics, chemistry and evolution of their local environments. Shocks carve into dense molecular clouds, radiatively cooling the remnant through strong molecular hydrogen and ionic fine-structure lines. We report on a dozen such supernova remnants (SNRs) with prominent infrared lines detected by Spitzer and ground-based Palomar and Anglo-Australian telescopes, probing the multi-phase medium and the evolution of shocks. In these remnants, the excitation of molecular hydrogen requires two shock components: both a slow shock through dense clumps, and a fast shock through a medium density. The ortho-to-para ratio for molecular hydrogen is typically much less than the LTE value, indicating shocks are propagating into cold quiescent cloud cores. Near-infrared lines of molecular hydrogen and ionized species provide further constraints on fast C- and J-shocks in the lower density inter-clump medium. Evidence of dust grain heating and shattering by the shock is derived from black-body fits to the dust continuum. The luminosity of bright IR lines (H2, [OI]) and dust provides a direct measure of radiative cooling in these remnants, which we compare to other astrophysical shocks in galaxies and HH objects. Furthermore, these interacting remnants have a high density of non-thermal particles, apparent from prominent GeV-energy gamma-rays detected with the Fermi Gamma-ray Space Telescope. Infrared and Radio observations provide strong constraints on models of non-thermal emission, indicating that supernova are formidable accelerators of cosmic rays. Finally, We will discuss future observations with Herschel and SOFIA which probe the shock evolution and chemistry in these complex environments, providing further insights into the effect of supernova evolution on the evolution of molecular clouds.

Pierre Hily-Blant (IPAG)
The Filamentary Diffuse ISM
The Herschel satellite unveils the filamentary nature of the diffuse Interstellar Medium in all its glory. It is to be expected that these filaments play a key role at the origin of dense cores and their mass distribution. It is therefore crucial to understand how these filaments form, how they survive in a tenuous diffuse ISM, and what determines their physical characteristics. The kinematics of these filaments, and their relationships with turbulence and magnetic fields are thus indispensable clues to make progress in our understanding of the ISM. We present here a multi-scale view of the diffuse ISM towards the Polaris molecular cloud, in which filaments are seen in the CO line, all the way from 10 to 0.001 pc (Falgarone et al 2009, Hily-Blant et al 2009). The statistical analysis of the velocity field reveals a new type of filamentary structures which remain coherent up to the parsec scale. Though they are not obviously related to density enhancements, the comparison with Herschel/SPIRE data (Andre et al 2010) suggests that these pure velocity structures pinpoint extremely tenuous regions. Quite unexpectedly, the turbulence at the parsec scale bears predicted signatures of intermittent, incompressible, and unmagnetized turbulence. This kinematic view is complemented with the large scale topology of the magnetic field lines. Estimates of their intensity suggest that the cloud is currently in a trans-Alvfenic regime. This talk thus presents the most comprehensive dataset available towards a non star- forming diffuse molecular cloud, and opens avenues to the unprecedented spatial resolution and sensitivity of ALMA.

Tracy L. Huard (University of Maryland)
Quiescent Musca: What's Wrong with Peace and Tranquility?
The Cores-to-Disks and Gould's Belt Spitzer Legacy teams observed most of the known nearby (< 400 pc) large molecular clouds. One of these clouds, Musca, appears to stand apart. Spitzer observations of Musca span more than 1.1 square degrees, covering most of its dense regions, revealing that relatively little star formation has occurred in this cloud. Thus, "stormy" star formation processes, such as outflows and jets present in most other large molecular clouds surveyed, are not significantly affecting the quiescent environment in Musca. Deep near-infrared observations are combined with mid- and far-infrared observations from Spitzer and IRAS to probe the structure of Musca and investigate whether dust in this environment may be discernibly different from dust in other large molecular clouds. Such comparisons provide insight into ISM evolution as a result of star formation.

Nick Indriolo (University of Illinois at Urbana-Champaign)
Cosmic Rays in the Interstellar Medium
As cosmic rays traverse the interstellar medium, they interact with the ambient material in a variety of ways. Some of these interactions include the ionization and excitation of atoms and molecules, spallation of nuclei, excitation of nuclear states, and the production of neutral pions via inelastic collisions. In all of these interactions observables are produced which may be used to constrain the flux of cosmic rays. While the latter two processes only produce signatures in the gamma-ray regime, certain products of spallation and ionization are observable in the infrared and terahertz regimes. Specifically, the spallation of C, N, and O nuclei can produce ^{6}Li and ^{7}Li (observable in the form of LiH), and the rich ion-molecule chemistry initiated by cosmic-ray ionization can lead to species such as OH^+, H_2O^+, and H_3O^+. With HIFI now operational aboard Herschel, various observations of these species have been executed and the initial results published. I will discuss what has been learned about the cosmic-ray ionization rate from detections of OH^+ and H_2O^+, and how these results complement constraints put on the cosmic-ray spectrum by H_3^+ and gamma ray observations.

Crystal L. Martin (UC Santa Barbara)
A Panchromatic View of Galactic Winds
I will review empirical constraints on the circulation of gas and metals between galaxies and the circumgalactic medium. I will discuss how observations over a broad range of frequencies trace gas over a wide temperature range in the winds. This panchromatic picture obtained from nearby starburst galaxies shapes our understanding of how outflows are powered. Beyond the local universe, observations are largely restricted to the low-ionization absorption lines measured in galaxy spectra. To address the impact of these outflows on galaxies and the intergalactic medium, we have measured the properties of low-ionization outflows in $0.6 < z < 1.4$ galaxies covering a significant range in star formation rates. I will show how the properties of these low-ionization outflows correlate with galaxy properties and discuss whether they may be powered by the same mechanisms at work in closer starburst galaxies.

Patrick M. Ogle (Caltech/SSC)

Jets, Galactic Winds, and their Interaction with the ISM

Spectroscopic observations with Spitzer and Herschel have highlighted the impact of radio jets and galactic winds on the thermal and dynamical state of the ISM in active galaxies. First I will discuss the discovery of a new class of radio galaxies (radio MOHEGs) with extremely luminous emission from warm molecular hydrogen. A large fraction of the molecular ISM in these galaxies (up to 10 billion solar masses) has been heated to temperatures of 100-1500 K. We have ruled out UV heating by star formation and X-ray heating by the AGN, and conclude the the molecular gas is heated by magnetic shocks driven by the radio jet. In several cases, the radio jet appears to be driving a 1000 km/s wind, viewed in H I absorption. I will also review Herschel and ground-based high-J CO and OH absorption observations indicating warm molecular gas outflows in quasar host galaxies. Finally, I will assess the impact of radio jet and quasar driven outflows on the ISM composition and star formation rates in massive galaxies.

Coupling of Radiation, Gas and Dust

Arnold O. Benz (ETH Zurich)
Simon Bruderer, and Susanne F. Wampfler Institute of Astronomy, ETH Zurich
Radiation Diagnostics in High-mass Star-forming Regions using Hydrides
Hydrides and their ions are a class of molecules that have become newly observable in their major lines with the Herschel Space Observatory. They are key species in the chemical evolution. If high-energy photons - FUV or X-rays - interact with the molecular gas, hydrides and particularly their ions are greatly enhanced in abundance, thus, tracing gas irradiated by UV or X-rays. As the critical densities for line emission are of the order of >107cm-3, irradiated dense regions are expected to light up or cold regions to absorb in the ground state of the molecule. First observations by Herschel/HIFI have explored the abundances of major hydrides in high-mass objects. The target lines of CH, NH, H3O+, and the new molecules SH+, H2O+, and OH+ are detected (Benz et al. 2010; Bruderer et al. 2010a). The lines are observed in emission, absorption or both (P-Cyg-like). For the first time, tentatively OH+ and possibly H2O+ are observed in emission. Emissions need high density and thus originate likely near the protostar. This is corroborated by the absence of line shifts relative to the young stellar object. Nevertheless, H2O+ and OH+ also show strong absorption components shifted relative to the star forming region. Such line components are attributed to foreground clouds. The molecular column densities derived from observations correlate well with predictions of a model by Bruderer et al. 2010b, assuming the main emission region in outflow walls, heated and irradiated by protostellar UV radiation.
References: Benz A.O. et al. 2010, A&A, in press, arXiv:1007.3370 Bruderer S. et al. 2010a, A&A, in press, arXiv:1007.3408 Bruderer S., Benz A.O., St‚àö¬ßuber P., & Doty S.D., 2010b, Ap.J., in press, arXiv:1007.3261

Caroline Bot (Observatoire Astronomique de Strasbourg)
Dust Emission in the Small Magellanic Cloud: Reviewing Excesses
The Small Magellanic Cloud (SMC) is one of the nearest galaxies to ours and has a low metallicity (1/5 solar). This gives us a unique opportunity to study dust properties at low metallicity, both from a resolved point of view (diffuse medium, HII regions, molecular clouds) or from an integrated point of view (the whole galaxy). I will review new results on dust emission in the SMC from the infrared to the millimeter. The SAGE-SMC survey observed the whole SMC region with Spitzer. The SEDs show a "flat" far-infrared peak (60microns excess) that put constraints on different dust models. Modeling the SEDs in each point from 3.6 to 160 microns, maps of the PAH mass fraction and the dust density are obtained. As was observed previously, dust emission traces more cold gas than what is seen with usual tracers (HI, CO). This mass excess is also observed with millimeter dust emission (SEST/LABOCA) in individual giant molecular clouds of the SMC. The mass of cold gas as traced by the virial theorem, could be underestimated by a factor 4. Alternatively, dust properties in the SMC could be different than in our Galaxy. The integrated SED of the SMC from the far-infrared to the micro-wave (using DIRBE, TopHat and WMAP data) shows a significant flattening of the SED in the millimeter range above expected dust, free-free and synchrotron emission. This millimeter excess

can not be attributed to CMB fluctuations, very cold dust, nor a change of the dust emissivity due to the amorphous structure of grains (TLS/DCD effects). Spinning dust emission is a viable solution but remains to be tested on smaller scales with Herschel and Planck data. All these results on dust emission in the SMC give new keys for understanding the dust emission in more distant galaxies.

Darren Dowell (Jet Propulsion Laboratory)
Interstellar Magnetic Fields and Polarimetry of Dust Emission
Magnetic fields are an important agent shaping the stormy cosmos. Comprehensive measurements of magnetic fields in the interstellar medium present a significant observational challenge, but within recent years we have learned about diffuse clouds and perhaps a few molecular clouds dominated by magnetic pressure, the magnetic structure of the Galactic Center, and "hourglass" magnetic fields in cloud cores and protostellar envelopes. At the same time, theoretical problems in interstellar magnetic fields have been addressed with increasing fidelity using computer modeling. I discuss progress and prospects for one of the few approaches for measuring magnetic fields in the neutral phase of the ISM -- polarimetry of thermal dust emission. While most of the work in the past decade has been done from the ground, we are on the verge of having new results from space (Planck) and from balloon-borne telescopes. SOFIA and future space far-IR/millimeter-wave telescopes provide a natural sequence for broader application of interstellar polarimetry and the inference of magnetic field strengths.

Jacqueline Fischer (Naval Research Laboratory)
Herschel Observations of Ultraluminous Infrared Galaxies: What they Reveal About the Strong Coupling Between Radiation, Gas, and Dust
Coupling between radiation, gas, and dust is strong in the compact central regions of gas-rich mergers in their ultraluminous infrared galaxy (ULIRG) stage. I discuss the telltale signs of the effects of high ionization parameters, high far- infrared optical depths, and outflows that may be driven by this coupling, as well as the implications of new Herschel far-infrared observations for the evolutionary stage traced by these systems. The massive outflows detected via P-Cygni profile signatures of excited transitions of molecules such as OH and H2O are seen in early PACS observations of both warm and cold ULIRGs and provide evidence of feedback that may be capable of halting the star-formation process.

Min-Young Lee (University of Wisconsin-Madison)
Perseus Molecular Cloud: A Laboratory for Studying Molecule Formation
The formation of molecular gas from the atomic interstellar medium is a critical step toward star formation. Yet, what controls the ratio of atomic to molecular gas in molecular clouds has been largely unexplored. Recently, Krumholz et al. (2009) provided analytical predictions for the molecular content in atomic-molecular complexes as a function of galactic properties (total gas column density and metallicity). We investigate the atomic-to-molecular transition across the Perseus molecular cloud at sub-parsec scales. We estimate the dust column density using the IRIS 60 and 100 micron images and derive the H2 column density from the excess of infrared emission relative to the HI column density. With the HI data from the GALFA-HI Survey, we derive the map of R_H2 (H2 surface density / HI surface density) for Perseus. Our results show that R_H2

smoothly varies across the cloud and H2 is more extended than CO, supporting the idea that CO is photodissociated while H2 self-shields in the outskirts of the cloud. Our comparison of observations with the Krumholz's prediction shows that the model reasonably well describes R_H2 as a function of total gas column density even at sub-parsec scales. We compare R_H2 for several star-forming and dark clouds in Perseus to investigate the role of interstellar radiation field in molecule formation.

Suzanne C. Madden (CEA/ SAP)
Dwarf Galaxies as Keystones to Galaxy Evolution: Effects of Metallicity on the ISM Properties
Local universe dwarf galaxies provide a rich variety of conditions to study star formation and feedback on the ISM in conditions that may be representative of early universe environments. The Herschel Dwarf Galaxy Survey investigates the physical properties of dwarf galaxies of widely varying metallicity values, over wide ranges of size scales and from the multi-wavelength point of view with the goal of understanding how metallicity impacts the evolution of the gas and dust properties. Their low mass, prominent star formation activity, and metal-poor ISM have a striking impact on the physical processes that take place to shape the structure of the ISM and the nature of the molecular clouds and PDRs. While molecular gas is considered to be an essential ingredient for star formation, detecting CO, the standard probe of molecular hydrogen reservoir in galaxies, has always been a challenge In low metallicity dwarfs. The 158 mu [CII] line in dwarf galaxies show a remarkably high [CII]/CO ratio compared to dustier starbursts, suggesting a very clumpy environment and the presence of substantial reservoirs of molecular gas which are not traced by CO, but instead reside in the PDR envelopes. Thus, CO is an unreliable tracer of molecular gas in dwarf galaxies and [CII] can help trace the molecular gas. Additionally, the dust reservoirs of dwarf galaxies are not negligible, as originally perceived, given their relatively low metal abundance. Modeling of the MIR to submm SEDs of low metallicity galaxies also shows notable differences compared to more metal-rich counterparts and a potentially large dust mass if the submm excess often seen in dwarf galaxies, is due to cold dust. I will summarise the gas and dust properties of low metallicity dwarf galaxies as unveiled by Spitzer and Herschel.

Elisabetta R. Micelotta (USRA/NASA Goddard Space Flight Center)
Fighting to Survive: PAHs in the Stormy Cosmos
Polycyclic Aromatic Hydrocarbons (PAHs) are an ubiquitous component of the Interstellar Medium (ISM) of galaxies. Interstellar PAHs are apparently able to withstand the rigors of the harsh environment of the ISM for some 100 million years and thus are resilient against processing by UV and X-ray photons and supernova shock waves. PAHs in space are mainly studied through their characteristic emission bands, due to infrared fluorescence following photo-excitation. Therefore, the photophysics of PAHs in space has been extensively investigated. Besides, PAHs are strongly affected by collisional processes, i.e. bombardment by high-velocity ions and electrons, arising from shocks, hot gas and cosmic rays. However, a detailed study of the physics of this collisional processing was still missing, especially in terms of PAH damage and destruction. This lack of information has made the interpretation of PAH observations difficult in regions subjected to such processes. What happens to the PAHs? Will they survive, be damaged

or destroyed? What are the astrophysical implications? Our research aims to answer these questions. We first describe the models that we have developed, that take into account the molecular nature of the target PAH and allow for the first time a quantitative description of the collisional processing of PAHs by ions and electrons in the energy range 10 eV - 10 keV (shocks and hot gas) and 5 MeV - 10 GeV (cosmic rays). We then apply our models to observations, estimating the lifetime of PAHs against collisional processing in selected objects observed by Spitzer. Our sample includes very different objects such as the starburst galaxy M82 and the supernova remnant N132D, and we discuss the astrophysical implications of our findings. Finally, we illustrate the possibilities offered by the observations in the far-infrared window opened by Herschel.

Vincent Minier (CEA Saclay)
Pillar Creation: Physical Origin and Connection to Star Formation
We present Herschel observations and simulation of molecular cloud pillars that form around the HII region in the Rosette Nebula. Early optical and IR studies revealed that ionizing radiation from OB-stars can form elongated structures in the neutral gas at the interface between HII regions and molecular clouds. They were called pillars such as in the Eagle Nebula. How do pillars form and what role do they play in the process of star formation ? Our recent observations with Herschel and Spitzer revealed many more pillars but only in regions where OB stars have already formed such as the Rosette Nebula, Cygnus X and M16, suggesting that the UV radiation from massive stars plays an important role in their formation. The characteristics of these features pointing toward illuminating sources include a bright rim at the edge of the cloud and a concentration of mass at the tip which is often forming stars as revealed by Spitzer. The importance of turbulence and gravitation for molecular clouds and star formation in general is becoming more and more recognized, and (magneto)-hydrodynamic simulations begin to successfully model pillar formation. In combination with the Herschel observations, a dedicated project to fully simulate the formation of pillars has been undertaken at CEA Saclay, using the HERACLES code that comprises hydrodynamics with various equation of state, radiative transfer, gravity, non-equilibrium thermo-chemistry, cooling and heating, and thermal conduction. Our aim here is to fully model a number of pillars in different physical environments, and address key questions: Is strong UV radiation mandatory for their formation? Under what temperature and density conditions do pillars form ? Is star formation enhanced or hindered in pillars/globules? Which stars form under which initial conditions in the pillars ? co-authors: Schneider, N.; Tremblin, P.; Audit, E; Hill, T; Bontemps, S; Motte, F.

Deborah Paradis-Cami (Caltech/SSC)
Evidence for Dust Emission in the Ionized Medium of the Large Magellanic Cloud
The Large Magellanic Cloud (LMC) is the nearest galaxy external to the Milky-Way, and its favorable viewing angle offers a direct view of the processes taking place in the diffuse ISM. Dust emission associated with ionized gas has so far been detected in our Galaxy and for wavelengths longer than 60 mic. Newly available Spitzer data now offer the opportunity to carry out a similar analysis in the LMC. We performed a correlation study using the Spitzer data from the SAGE (Surveying the Agents of a Galaxy's Evolution) Legacy program, combined with the ATCA/Parkes HI data tracing the atomic

phase, the NANTEN 12CO data tracing the molecular phase, and both the SHASSA Halpha and the Parkes 4.75 GHz data tracing the ionized phase. We evidence for the first time dust emission associated with the ionized phase of the gas, from 3.6 to 160 mic. Using a dust emission model, and testing our results with several radiation fields spectra, we show that dust in the ionized gas is warmer than dust associated with the other gas phases (atomic and molecular). In addition, we report in the ionized phase a decrease of the PAH relative abundance with respect to BGs, probably due to PAH destruction, and an increase of the near-infrared continuum, which does not seem to correlate with PAH emission. These results are found consistently for the diffuse gas, the typical and bright HII regions. However, the molecular phase indicates good environmental conditions for the subsistence of the PAH component. Furthermore, as opposed to the PAHs, the VSGs relative abundance tends to increase in the ionized phase, especially in bright HII regions. We also evidence a low emissivity value in the ionized phase of the LMC, with respect to our Galaxy.

Ramin A. Skibba (Steward Observatory)
Dust and Stellar Emission of Nearby Galaxies
We exploit data from the ultraviolet to submillimeter wavelengths of 61 galaxies in KINGFISH (Key Insights in Nearby Galaxies: a Far-Infrared Survey with Herschel). We use the spectral energy distributions computed by Dale et al., using data from GALEX, SDSS (or other optical), 2MASS, Spitzer, and SCUBA, and to these we add SPIRE data from Herschel. Herschel observations allow us to trace cold dust components invisible to Spitzer, with reduced systematic uncertainties relative to ground-based submillimeter measurements. By using these data together, we can now measure precisely how much stellar radiation is intercepted and reradiated by dust, and how this quantity varies with galaxy properties such as morphological type, star formation rate, mass, and metallicity. We can also determine what kind of local galaxies are most similar to those dominating the extragalactic background light. We estimate the dust and stellar emission of these galaxies, in a way that is as empirical and model-independent as possible. The dust/stellar flux ratio varies with morphology, metallicity, and infrared luminosity in a way that suggests a common evolutionary sequence for some galaxies. We also find significant scatter between dust/stellar mass and dust/stellar flux, especially for early-type galaxies. In particular, some S0 galaxies have relatively high specific star formation rates, in addition to bright FIR emission and warm FIR colors compared to other S0s with similar masses. For these galaxies, we interpret this as evidence for ongoing star formation, which is significantly heating some of the dust populations. Finally, we discuss implications of our results for galaxy formation models and high redshift studies.

Juergen Steinacker (MPIA Heidelberg)
Large Grains in Molecular Cloud Cores: The New Coreshine Window
Investigating Spitzer data of the molecular cloud L183 we find emission in the 3.6 and 4.5 micron IRAC bands from the inner parts of the cloud which have $A_v > 50$. We interpret this emission to be MIR scattered light from dust grains larger than the average ISM grain. Our 3D radiative transfer scattered light modeling can reproduce the main features of the 3.6, 4.5, and 8.0 micron Spitzer images. Our further studies indicate that this "coreshine" effect is wide-spread among cores with important implications on

measuring the column density, constraining 3D core models, on surface chemistry, on the seed population for grains occurring in later phases of the star formation process, and on measuring the pre-stellar core "age". We will discuss the potential of the new effect to be applied as a routine investigation method to cores observed with the JWST.

Susan Terebey (Cal State LA)
Cold Cores and Star Formation in the Spitzer Taurus and Gould Belt Surveys
The Spitzer MIPS 160 micron data are sensitive to dense cold cores in star forming regions. Using IRAS data we are able to disentangle the cold cores (T~10K) from the extended cold cloud (T~ 14-17K) in nearby star forming regions. Taurus contains about 180 cold cores with approximately Av > 4 extinction. This compares with 124 class II sources within the same region. If all the cold cores eventually form one or two stars then the estimated lifetime of the cold cores is about 2.5 Myr, modestly longer than the class II lifetime in Taurus. The presence of class I YSOs and the large mass reservoir in cold cores imply that star formation in Taurus is active and able to continue for several million years. By contrast, other star-forming regions in the Gould Belt vary widely in their cold core reservoirs. We compare the YSO and cold core content to place star forming regions in an evolutionary sequence, from regions that appear poised to begin star formation to regions where star formation has ended.

Alexander Tielens (Leiden Observatory)
The Dusty Universe: From ISO and Spitzer to Herschel, SOFIA, and JWST
Astronomical observations and analysis of stardust isolated from meteorites have revealed a highly diverse interstellar and circumstellar grain inventory, including a wide range of amorphous materials and crystalline compounds (silicates and carbon). This diversity reflects the wide range of stellar sources injecting solids into the interstellar medium each with its own physical characteristics such as density, temperature and elemental composition. Once injected into the interstellar medium, dust is highly processed during its sojourn from its birthsite (stellar outflows and explosions) to its incorporation into protoplanetary systems. Of particular interest is the processing that occurs in the planet-forming disk around Young Stellar Objects either through high temperature chemistry in the inner nebula or by temporal events such as shock waves or lightning throughout the nebula. I will review what we have learned from ISO and Spitzer on the inventory of interstellar dust, its characteristics, and the processes relevant for the origin and evolution of interstellar dust and preview where Herschel, SOFIA, and JWST may contribute.

Properties over Galactic and Cosmic Timescales

Philip N. Appleton (Caltech/NHSC)
Observations of Shocked Molecular Hydrogen in High-Speed Galaxy Collisions
I will review recent developments in our understanding of the excitation of molecular hydrogen emission from gas shock-heated in high-speed galaxy collisions. Starting with the discovery of extremely powerful H2 emission from the compact group Stephan's Quintet, I will discuss new observations of other collisional systems (The Taffy, Arp 143, Arp 118) in which the powerful molecular hydrogen emission lines observed by Spitzer are likely driven by mechanical heating derived from the collisions. The results have implications for future observations of nearby galaxies with Herschel, as well as future observations of the high-z universe with JWST, ALMA and the proposed SPICA telescope.

David Elbaz (CEA Saclay - Service d'Astrophysique)
The Fundamental Tryptic of Star Forming Galaxies
Determining how and when did galaxies form their stars has been a challenge for modern astrophysics since their discovery. Great progress had been made in this field during the last fifteen years after the first version of the history of star formation at cosmic scales was proposed. Since then, it has appeared that the twofold representation of the star formation rate (SFR) as a function of cosmic time lacks other dimensions such as the impact of the environment, e.g. star formation timescales are accelerated in denser regions, or active nuclei (AGN). In particular, timescales of star formation for individual galaxies are not reflected by the average cosmic SFR history and the separation of spiral and ellipticals progenitors which formed their stars with long and short timescales respectively remains uncertain. Until now studies of galaxy evolution have been severely limited by the uncertainties affecting the interpolations used to derive the bolometric output of galaxies, hence their SFR. The deepest extragalactic surveys with Herschel in the GOODS fields have been designed to overcome these limitations by sampling the 100 to 500 microns range where the most active galaxies radiate the bulk of their light down to the confusion limit, hence providing information on typical and not only extreme galaxies. In combination with multiwavelengths data from HST, Spitzer, Chandra and ground-based facilities such as IRAM, VLT and Keck, the first results of these surveys reveal a puzzling uniformity of star formation processes in galaxies over cosmic timescales. Two regimes of star formation are emerging, a continuous and a stochastic mode, in three independent diagrams providing a similar signature, for star forming galaxies, than the fundamental plane, for non star forming early-type galaxies, i.e. a sort of "fundamental tryptic" of star forming galaxies.

Nicolas Flagey (SSC/Caltech)
Dust-free and Dust-rich Evolved Stars within the Galactic Plane
We have discovered over 400 compact sources in the Spitzer-MIPSGAL 24 microns survey of the inner Galactic plane. These small (< 1 arcminute) MIPSGAL "bubbles" (MBs) are pervasive through the entire Galactic plane in the mid-infrared. The analysis of the IRAC 3.6 to 8.0 microns and MIPS 24 and 70 microns images indicates that the MBs

are mostly detected only at 24 microns: 10% have counterparts in IRAC bands, and 30% in the MIPS70 band. It remains uncertain whether the broadband observations indicate dust emission. About 15% and 25% of the MBs have a central point source at 24 microns and in the near-IR (IRAC and 2MASS data) respectively. We identify 15% of the MBs by extensive cross matching with available catalogs (planetary nebulae (PNe), supernova remnants (SNR), luminous blue variables (LBV), Wolf-Rayet (WR), emission line stars). The remaining 85% of the MBs are yet unknown objects but the likely candidates are mainly stars in the late stages of their evolution. Evolved stars are the main sources of dust in the Galaxy and beyond. Massive evolved stars are particularly interesting since one detects, at visual and near infrared wavelengths, a smaller number of objects than expected. Therefore, the discovery of several hundreds of candidates is of major importance to obtain an accurate census of the dust production in the Milky Way as well as in other galactic systems. In order to identify the nature of the MBs, we have obtained follow-up spectroscopic observations of several unknown MBs with Spitzer/IRS in the mid-IR (10-35 microns) and of several central sources with Palomar/TripleSpec in the near-IR (1-2.5 microns). Near-IR spectra reveal several newly discovered WRs. Mid-IR spectra reveal that the extended emission of half the of the targeted MBs is accounted for by highly ionized gas in dust-free shell while the other half comprises iron-rich dust-rich objects. Modeling and comparison with templates of evolved stars lead to the conclusion that the dust-free objects are PNe with a very hot central white dwarf. Several iron-rich dust-rich shells are suggested as new LBV candidates. Accepted broadband observations and proposed spectroscopic follow-up with Herschel/PACS will lead to additional constrains on the fraction of dust-free and dust-rich MBs.

David T. Frayer (NRAO)
Molecules at High Redshift

I will discuss the recent CO results for the Spitzer and Herschel-selected high-redshift sources and will compare the infrared and molecular gas properties at high-redshift with those found for the local population of ULIRGs.

Javier Gracia Carpio (Max Planck Institute for Extraterrestrial Physics)
Far-infrared Emission Lines in Galaxies: The SHINING Contribution to the Understanding of General Trends

Far-infrared fine structure lines are one of the main coolants of the interstellar medium in galaxies. They may account up to ~2% of the total IR emission, and can be used to study with almost no extinction effects the nuclear regions of the most obscured galaxies. I'll present the first results from the SHINING GTKP survey in a sample of local starbursts, AGN and IR bright galaxies (LIRGs and ULIRGs). We find that galaxies with high Lfir to molecular gas mass (MH2) ratios tend to have much lower line to FIR continuum ratios than galaxies with more moderate Lfir/MH2 values. A similar result was observed for the [CII] line with ISO (the so-called [CII] deficit), but now with Herschel we are able to integrate much deeper and find a similar result for the other PDR ([OI] 63 and 145 micron) and HII ([OIII]52 and 88, [NII]122 and [NIII]57) fine structure lines observed with PACS. We interpret these line deficits as an effect produced by the much higher values of the ionization parameter in galaxies with high Lfir/MH2. I will compare our results with previous observations at high redshift, and show that high redshift objects follow the same trends found in the local Universe if they are compared in terms of their Lfir/MH2 ratios, instead of their total IR luminosities.

Guillermo Quintana-Lacaci (IRAM)
Herschel M33 Extended Survey. First Results
In the local universe, most of the observable matter is contained in stellar objects shaping the morphology and dynamics of their "parent" galaxy. In view of the dominance of stellar mass, a better understanding of star formation and its consequences is mandatory and forms a central topic of contemporary astrophysical research. There exist a large number of high linear resolution studies related to individual star forming regions of the Galaxy as well as of low linear resolution studies of external galaxies. For a complete view onto the physical and chemical processes driving star formation and galactic evolution it is, however, essential to combine local conditions affecting individual star formation with properties only becoming apparent on global scales. The optimal target providing such a complete view is M33. A galaxy that is actively forming stars, that is not seen edge-on (like our Galaxy), that has been studied at radio, optical and X-ray wavelengths, and that is sufficiently nearby to also permit studies on small scales. For our carefully chosen template galaxy, we are using HIFI to obtain fully-sampled large-scale [CII] (and H2O) maps. PACS is adding add important interstellar cooling lines, [OI], [NII], [NIII]. And SPIRE & PACS have mapped the dust spectral energy distribution over the entire galaxy. Observing a deep, extended strip along the major axis of M33, is allowing us to study the ionized, atomic, and molecular phases of the interstellar medium, its life cycle and thermal balance, tracing the formation of molecular clouds and of stars. Aside of insights related to the local processes in the galaxy itself, the mapped source will set a standard, providing a basis for the interpretation of phenomena encountered in other targets of the Local Group and in more distant galaxies.

Yong Shi (Caltech/SSC)
Old Stars Control How Efficient New Stars Form
We show the existence of a tight correlation between the star formation efficiency (SFE=SFR/Mgas) and stellar mass surface density. The correlation has a power index of 0.5 and holds over 5 orders of magnitude in the stellar mass density for various types of galaxies especially the low-surface-brightness ones that deviate significantly from the Kennicutt-Schmidt (KS) law. We further show that this correlation can also be applied to spatially resolved regions within galaxies down to the low gas density where the KS law shows a break. We argue that this relation presents another star-formation law that is independent from the KS one and emphasizes the critical role of old stellar populations in the current star formation activity. By applying this new star formation law into the model of cosmic gas accretion in lambda CDM, we show that it can produce well the observed main sequence from z=0 up to z=2 without imposing unknown mechanisms to delay star formation in low mass systems.

Kevin Xu (Caltech/NHSC)
Specific SFR (sSFR) Enhancement in Close Major-Merger Pairs
I will present results from our studies on sSFR enhancement in spiral galaxies within both local and z~1 major-merger pairs. Our Spitzer observations of a sample of z=0 K-band

selected close major-merger pairs show very diversified IR emission properties. Only some massive galaxies (~30% of paired spirals) in S+S pairs show significant sSFR enhancement compared to single spirals in a control sample. On the other hand, spiral galaxies in S+E pairs and less massive spirals in S+S pairs have about the same level of sSFR as their counterparts in the control sample. Another interesting result is, among massive spirals in S+S pairs, the sSFR of the two galaxies in individual pairs is significantly correlated with each other ("Holmberg effect"). Some results from our current study on sSFR of z~1 pairs using Herschel data in COSMOS field will also be presented.