Reionization to Exoplanets: Spitzer's Growing Legacy (Talk Abstracts)

1. Exoplanets and Exoplanetary Systems

1.1 Properties of Exoplanetary Systems: A Spitzer Portrait Gallery

Heather Knutson (University of California, Berkeley)

The Spitzer Space Telescope has been a remarkably successful platform for characterizing the properties of extrasolar planets, with notable results including the first detection of the light emitted by an extrasolar planet, the first spectrum of an extrasolar planet, and the first map of the flux distribution across the surface of an extrasolar planet. Observations of transiting planet systems, where the planet periodically passes in front of and behind its star as seen from the earth, have been at the heart of these advances, as they allow us to move beyond a simple estimate of minimum mass to learn something about their structure, composition, and atmospheric dynamics. In my talk I will review the current ensemble of Spitzer observations of extrasolar planets and discuss corresponding advances in our understanding of these unusual systems. I will then conclude with a look ahead at observations planned for the warm mission.

1.2 Models for Exoplanets

Adam Burrows (Princeton University)

Approximately 400 exoplanets, mostly giant planets in the Jovian mass range, but also more than 50 "Neptune-mass" planets, have been detected orbiting stars in the solar neighborhood. More than 15% of these are transiting their primaries and these have collectively yielded a wealth of structural and physical information. A number of these exoplanets have recently been detected directly by the Spitzer infrared space telescope in secondary eclipse and primary transit. Arguably, these constitute the first remote-sensing data of extrasolar worlds. I will present the embryonic theory of such irradiated giant planets and discuss what we have learned (and, in anticipation of the warm Spitzer era, can still learn) about their atmospheres, radii, and compositions. I will also address what we may soon learn from ground-based high-contrast near-IR imaging of exoplanets in wide orbits and from optical measurements at high photomtric precision by CoRoT and Kepler of close-in exoplanets in the optical.

1.3 Thermal and Dynamical Properties of Exoplanet Atmospheres

Gregory P. Laughlin (University of California, Santa Cruz)

It was a case of great serendipity that the launch of the Spitzer Cold Mission corresponded quite closely with the discovery of transiting "hot Jupiter" exoplanets orbiting a handful of relatively bright nearby stars. In this talk, I will give an overview of the many and varied scientific insights that have emerged from Spitzer's exoplanetary forays. Highlights include direct measurements of the temperature distributions on planetary surfaces, real-time weather reports of brewing exoplanetary storms, and solid inferences regarding the atmospheric composition and radiative properties of diverse worlds. I will also argue that we can expect a great deal of additional and fundamentally new discoveries to emerge during the warm mission. As a particular example, I will show that the newly discovered HAT-P-13 system will allow Spitzer to make direct and startlingly accurate measurements of both the interior structure and the tidal Q of HAT-P-13's innermost planet.

1.4 Atmospheric Composition and Structure of Hot-Jupiters

Giovanna Tinetti (University College London)

In the past decade, more than 370 planets orbiting other stars (extrasolar planets) have been discovered. For a growing sample of giant extrasolar planets orbiting very close to their parent star (hot-Jupiters), we can already probe their atmospheric constituents using transit techniques. With the primary transit method, we can indirectly observe the thin atmospheric ring surrounding the optically thick disk of the planet -the limb- while the planet is transiting in front of its parent star. With the secondary transit method, we can collect photons emitted or reflected by the planet. In our talk, we will focus in the most recent detections of water vapour and other carbon-bearing molecules in the atmospheres of the Hot-Jupiters HD 189733b and HD 209458b using photometry and spectroscopy measurements with Spitzer and Hubble. These results provide an accurate and deep understanding of the molecular composition and thermal structure of these very exotic planetary atmospheres.

1.5 Comparative Mid-Infrared Mineralogy : Clues to the Origins and Evolution of Solar Systems

Carey M. Lisse (Johns Hopkins University Applied Physics Laboratory)

With observations made by the Spitzer Space Telescope, we are beginning to understand the details of how the composition and formation of our own Solar System compares to those of other stars in our Galaxy. This is a major question in astronomy, and recent, detailed observations by Spitzer of comets (remnants of the solar systems proto-planetary disk), proto-planetary disks around Young Stellar Objects, debris disks around moderate-age stars, and dust rich DZ white dwarfs have given us a collection of detailed spectra containing clues about our Galactic context. In this talk I will discuss Spitzer and related ISO mid-infrared (5 to 40 μm) spectroscopy of 6 comets and the dusty systems SST-LUP3-1, HD100546, HD163296, HD113766, HD172555, HD69830, G29-38 and GD362. Using the results from the recent Deep Impact and STARDUST space missions as ground truth, we can now constrain the relative abundances of silicates, carbonates, water ice/gas, amorphous carbon, sulfides, and polycyclic aromatic hydrocarbons (PAHs) in dusty disks, and directly relate the temperature of the circumstellar dust to its location with respect to the system primary. I will discuss the similarities and differences in the spectra, the amount, kind, and location of the dust and gas species detected, the primitive or advanced state of processing of the dust, compositional solar system analogues for the inferred source parent bodies, and their implications for our Solar System's origin and evolution.

2. Star Formation

2.1 The First Stage of Star Formation: Cores to Disks

Neal J. Evans (University of Texas)

Spitzer has revolutionized our understanding of the early stages of star formation. The combination of sensitivity, wavelength coverage, and fast imaging has provided unprecedented databases for the Galactic Plane, massive clusters, nearby clouds, and small molecular cores. The sensitive spectroscopic capability has revealed complex flows between dust, ice, and gas. The Spitzer data are helping us to answer questions like these. What is the star formation rate and efficiency in nearby clouds? What star formation "law" would we infer? How long does each phase of star formation take? Do existing models of low mass star formation explain what we see? What are the chemical processes that determine the state of material brought to forming planetary systems?

2.2 New Views on Gas in the Planet Formation Region of Disks

Joan Najita (NOAO)

I will review the impact of Spitzer on our understanding of gaseous protoplanetary disks. New probes of the planet formation region of gaseous disks include transitions of water and organic molecules as well as atomic transitions such as Ne II. These and other previously known diagnostics can be used to probe the chemistry of disks and to search for evidence of planet formation in various evolutionary stages. Work to date suggests a bright future for studies of gaseous inner disks.

2.3 Disk Structure and Evolution

Lee Hartmann (University of Michigan)

Spitzer has made major contributions to our understanding of the structure of protoplanetary disk structure and evolution. We now have SEDs and spectra for reasonably complete samples of star-forming regions reaching out to nearly a kpc. The results show that disks have a wide range of evolutionary timescales, and that dust growth and settling occurs but not in quite the way envisioned by simple models. Finally, we are finding hints that evolution of inner disks is proceeding quite rapidly even at ages of ~ 1 Myr.

2.4 Planet Formation from PMS disks

Sean N. Raymond (University of Colorado)

It is well known that planets form from disks of gas and dust around young stars. Gas giant planets must form within a few million years, while gas remains in the disk. Rocky planets, on the other hand, can form more slowly, on 10-100 Myr timescales. I will review the state of knowledge in planet formation, and highlight the contributions made by Spitzer.

2.5 Debris Disks - From Spitzer to Herschel and Beyond

George H. Rieke (Steward Observatory) & Kate Su (University of Arizona)

Planetary debris disks are perhaps our best tool to study planetary system evolution after the dissipation of the protoplanetary disk. Prior to Spitzer, our view of debris disks was simplistic, with rudimentary ideas of how their incidence depended on stellar age and perhaps spectral type. We now have an incredible wealth of information that shows them to have complex and varied structures. We trace their evolution from the stages of terrestrial planet formation to 10 Gyr. We witness their fading with age as a function of stellar type and disk zone, and find that it is due to a combination of steady decay and violent stochastic processes. The general behavior we find is reminiscent of our ideas for the evolution of our Solar System, but also indicates processes that happened in the Solar System that seem to be rare in other systems. I will review these insights in light also of the capabilities of Herschel and JWST to advance our understanding of these systems much!

3. The Dusty Universe

3.1 Infrared Spectra of Dusty Galaxies to $z > 2$

Daniel W. Weedman (Cornell University)

Results from many different observing programs using the Spitzer Infrared Spectrograph in low resolution are summarized to show the evolution of the most luminous starbursts and AGN as determined with the same spectral parameter seen for $0 < z < 3$. The crucial question of whether luminosity evolution peaks at $z \sim 2.5$ is examined. Starbursts discovered with Spitzer are systematically more luminous in PAH features than submillimeter-discovered starbursts, but analysis of bolometric luminosities is just beginning. The most luminous AGN discovered by Spitzer are the most luminous galaxies in the universe and range from unobscured (type 1?) AGN showing only dust emission to heavily obscured (type 2?) AGN with strong dust absorption. Bolometric luminosities seem similar and consistent with the "unification" hypothesis based on viewing angle, but thick dust clouds close to the AGN are required. The use of IRS high resolution spectral diagnostics for analysis of dusty starbursts and AGN is also reviewed.

3.2 LIRGs to Submm Galaxies: Evolution with Redshift

Reinhard Genzel (Max Planck Institute)

3.3 Growing Supermassive Black Holes and Bulges Behind a Veil of Dust

Lars E. Hernquist (Harvard University)

3.4 Nearby Galaxies

Daniela Calzetti (University of Massachusetts)

I will review recent progress enabled by the Spitzer Space Telescope in the field of Nearby Galaxies, with special attention to star formation rates as traced by the infrared, including inferences on the stellar Initial Mass Function, and the characteristics of dust emission. With its unprecedented angular resolution and sensitivity, Spitzer has paved the road for a quantum leap in understanding the link between stellar populations and the dust they heat across the vast range of properties covered by galaxies.

3.5 Dusty Galaxies at the Highest Redshifts-how to find them and what they mean

Peter L Capak (SSC/Caltech)

For $z > 4$ galaxies Spitzer data has provided the first probe of the rest frame optical and near infrared wavelengths, providing information about stellar mass, obscured star formation and AGN activity in a period only 1.5 Gyr after the big bang. Combined with ancillary data from HST, Chandra, and the ground we are beginning to assemble a picture of how the first galaxies assembled and the importance of starbursts in this process. Using data from the COSMOS and GOODS surveys I have assembled a statistically significant number of $z > 4$ extreme starbursts. With this sample I show that heavily obscured star formation missed by UV surveys accounts for $\sim 50\%$ of the total star formation rate density at $4 < z < 5$, similar to the fraction found at $z \sim 2$. Furthermore, using > 300 spectroscopically confirmed galaxies at $z > 4$ I show the majority of $M > 10^{11.5} M_{\odot}$ galaxies appear to be assembled in the 600 Myr between $z \sim 6$ and $z \sim 4$, strongly suggesting bursty star formation is important in the early universe.

4. The Early Universe

4.1 The History of Star Formation

Mark Dickinson (NOAO)

I will review recent efforts to measure the global history of star formation in galaxies over a broad swath of cosmic time. Spitzer has played a key role in this work: MIPS and IRS have offered a view of dust emission from star formation at cosmological distances, while IRAC observes rest-frame near-infrared and optical light at high redshift, providing constraints on the stellar populations and masses of distant galaxies. I will emphasize the impressive progress in this field, as well as the uncertainties and limitations of the data currently in hand and of efforts to interpret those data.

4.2 Young Galaxies as Seen by Spitzer, Cold and Warm

Giovanni G. Fazio (Harvard Smithsonian Center for Astrophysics)

One of the most important observations made by the Spitzer Space Telescope has been the detection of luminous galaxies back to the era of reionization ($z \sim 7$), when the Universe was less than a billion years old. The key advance made by Spitzer imaging is the ability, for the first time, to sample the redshifted rest-frame visible light of these galaxies. When combined with broadband multi-wavelength data, Spitzer observations can be fit to stellar population synthesis models to determine the spectral energy distribution of these galaxies and to constrain their stellar masses and ages and their star formation histories. As a result, there is evidence that most of the stellar mass of these galaxies formed at even higher redshifts ($z > 7$ to 10), and that a significant number of galaxies should exist in this region. Spitzer observations of massive lensing clusters have also played a pivotal role in this study. The first IRAC detection of a $z > 6$ galaxy came from such observations. Since most of these results were obtained with IRAC 3.6/4.5 μm bands, the Spitzer Warm Mission will provide a unique opportunity to obtain the first complete census of the assembly of stellar mass as a function of cosmic time back to the era of reionization, yielding unique information on galaxy formation in the early Universe.

4.3 Theories of Structure Growth: Confrontation with Observation

Rachel S. Somerville (STScI/JHU)

Spitzer has allowed us to probe the physical properties of galaxies at low and high redshift: together with observations at other wavelengths, near-IR observations with IRAC constrain the mass in long-lived stars, and longer wavelength observations with MIPS constrain the birthrate of new stars. Together, these measurements tell us how the star formation rate in galaxies evolved over time and how galaxies assembled their mass, posing stringent challenges for theoretical models. I will review the current state-of-the-art in theoretical models of galaxy formation and evolution, with a particular focus on how well these models can account for observations from Spitzer and what we have learned from these comparisons.

4.4 Stellar Populations and Masses of Galaxies at High Redshifts

Claudia Maraston (University of Portsmouth)

The baryonic mass of galaxies and its evolution with redshift are important physical quantities for the understanding of galaxy formation and evolution, Hence it is crucial to determine galaxy masses as accurately as possible from observations. Galaxy masses are obtained by fitting stellar population models to observed spectro-photometry. Up-to-date models have only recently been completed with the emission by cold and red Asymptotic Giant Branch stars that dominate the light emission in the rest-frame near-IR. For young galaxies in the early Universe this radiation is shifted to the mid-IR and was detected for the first time by the Spitzer Space Telescope. The Spitzer data are of paramount importance for a precise determination of galaxy masses.

4.5 The Early Universe in 2010 and Beyond

Richard S. Ellis (Caltech)

5. The Galaxy

5.1 The Milky Way and Its Neighbors: What's New?

Robert Benjamin (University of Wisconsin, Whitewater)

The unparalleled sensitivity of the Spitzer Space Telescope made it possible to perform large scale surveys of the Milky Way and companion galaxies such as the LMC and the SMC. I will summarize how these surveys have changed our view of the Milky Way and its neighbors, and speculate about what additional hidden gems may lie in the Spitzer Space Telescope archives, just waiting to be found.

5.2 New Views of the ISM from Spitzer Space Telescope
Bruce T. Draine (Princeton University)

Observations with Spitzer Space Telescope (SST) have advanced our knowledge – and our understanding – of the nature of the interstellar medium in the Milky Way and other galaxies. This talk, which will not pretend to be complete, will be limited to a few areas: (1) the properties, abundance, and destruction of PAHs; (2) the density structure of the ISM; and (3) the wavelength-dependence of interstellar extinction.

6. Summary Talks

6.1 Exoplanets: From Hot Jupiter to Habitable Earths
D. Charbonneau (Harvard University)

Over the past 5 years, the observational study of exoplanet atmospheres has flourished due to the discovery of transiting systems, and the availability of powerful space-based observatories with which to study them. Observations spanning times of secondary eclipse, when the light from the planet passes out of view behind the star, have permitted the direct investigation of the structure, chemistry, and dynamics of the atmospheres of these exotic worlds. Cold or warm, the Spitzer Space Telescope is the preeminent facility for such work. In the coming few years, astronomers will extend their earlier studies of gas giant exoplanets to worlds composed primarily of rock and ice, and ultimately to rocky planets orbiting with their stellar habitable zones. The techniques and wisdom garnered from Spitzer will prove invaluable as we plan our studies of the atmospheres of these habitable worlds with the James Webb Space Telescope.

6.2 Galactic Astronomy
Anneila I. Sargent (Caltech)

6.3 Spitzer's Contributions to Extragalactic Astronomy
Patrick J. McCarthy (Carnegie Observatories)

I will give an overview of Spitzer's contributions to the study of galaxy formation and evolution. Contrasting pre-launch expectations with on-sky results illuminates both the evolution of the field during the development of the spacecraft and the power of Spitzer in opening new discovery space. Three areas deserve particular attention: the evolution of the most massive galaxies, the importance of MIPS and IRS observations in understanding the global star formation history and the power of IRAC as a probe of galaxies at the end of the reionization epoch, and perhaps before. Lastly I will speculate on the impact of the warm mission and the continuing legacy value of Spitzer data.