INFRARED SCIENCE INTEREST GROUP

Special Spitzer Telescope Edition

No. 4 | August 2020

Contents

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From the IR SIG Leadership Council

In the time since our last newsletter in January, the world has changed. Travel restrictions and quarantine have necessitated online-conferences, web-based meetings, and working from home. Upturned semesters, constantly shifting deadlines and schedules, and the evolving challenge of keeping our families and communities safe have all taken their toll. We hope this newsletter offers a moment of respite and a reminder that our community continues its work even in the face of great uncertainty and upheaval.

In January we said goodbye to the Spitzer Space Telescope, which completed its mission after sixteen years in space. In celebration of Spitzer, and in recognition of the work of so many members of our community, this newsletter edition specifically highlights cutting edge science based on and inspired by Spitzer. In the words of Dr. Paul Hertz, Director of Astrophysics at NASA:

> *"Spitzer taught us how important infrared light is to our understanding of our universe, both in our own cosmic neighborhood and as far away as the most distant galaxies. The advances we make across many areas in astrophysics in the future will be because of Spitzer's extraordinary legacy."*

Though Spitzer is gone, our community remains optimistic and looks forward to the advances that the next generation of IR telescopes will bring.

The SIG's primary mission is to collect community input, foster consensus, and help shape the long-term goals of IR astrophysics. Our main priority is to reach out to the community spanning the entire IR wavelength range, including users of current facilities like SOFIA, ALMA, and the range of suborbital platforms, as well as upcoming observatories like JWST and NGRST (WFIRST). This semi-annual newsletter is a part of this effort highlighting results, technological developments, and events from the IR community. We encourage contributions describing interesting, unique, and important science and technology breakthroughs from all our readers. Throughout the year, we will also continue to host a monthly webinar series (https://cor.gsfc.nasa.gov/sigs/irsig.php) and an annual splinter session at the winter AAS meeting. We encourage members of the community to get involved with the IR SIG, and remain dedicated to ensuring our activities reflect the needs of our community, stakeholders, and early-career scientists of diverse backgrounds.

Sincerely,
IR SIG Leadership Council

Unlocking the Mysteries of Exoplanet Atmospheres with Consistent Systematic Modelling

Written by: Erin May (Johns Hopkins University Applied Physics Laboratory)

Paper: Introducing a New Spitzer Master BLISS Map to Remove the Instrument-Systematic – Phase-Curve-Parameter Degeneracy, as Demonstrated by a Reanalysis of the 4.5 µm WASP-43b Phase Curve,[1] *May and Stevenson, arXiv:2007.06618v1*

With Spitzer, we are able to observe entire orbital phase curves, letting us probe direct emission from the planet's atmosphere as a function of longitude as we watch the planet orbit its host star. Combining observations at 3.6 and 4.5 µm allows us to reconstruct the heat transport in these tidally locked atmospheres – showing us how heat from the highly irradiated day side of the planet is moved towards the perpetual darkness of the night side. The strong winds required to drive this transport result in the hottest spot on the planet actually being shifted from the substellar point, typically by about approximately ten degrees in longitude – a signal large enough to be measured with Spitzer.

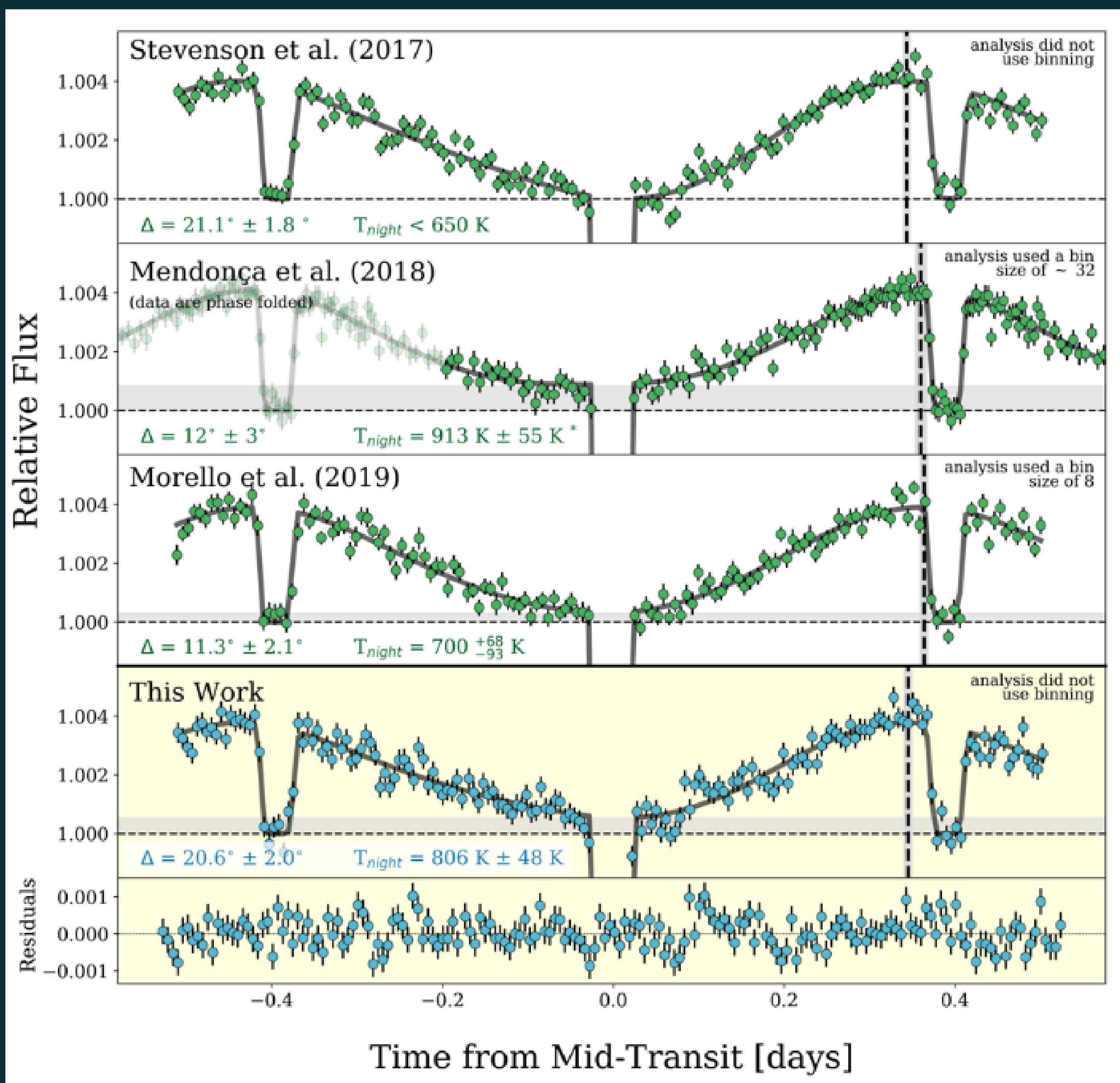
As we now know, Spitzer was largely affected by intrapixel sensitivity variations that would affect the amount of flux measured on the detector by a few percent as the centroid of the star shifted around on within a single pixel. This effect may be unimportant for some uses of Spitzer, but when staring at an exoplanet system for around one day straight, every little percent matters – especially when our observed signals can be smaller than the size of the intrapixel systematic.

Over the approximate decade of Spitzer's warm mission, 60 exoplanet phase curves were observed, each one teaching us something new about how to detrend against the troublesome systematics. Naturally, when systematics are so large, our measurements depend heavily on the method used. As a result, population-wide trends in measured atmospheric parameters (i.e. the degree of hotspot shift and the amplitude of the phase curve) do not match 3D circulation model predictions. In some cases, different detrending methods result in very different modeled phase curves, begging the question of how to "correctly" remove the intrapixel effect. If we hope to derive any understanding from trends in observed exoplanet properties from Spitzer, we must be confident that trends we see are astrophysical in nature, and not due to different levels of remaining correlated noise in observations.

To those ends, in our recent paper we explored issues with some current detrending methods – namely degeneracies between methods when used together, as well as shifting results if the data is temporally binned prior to detrending. With an eye towards developing an even stronger legacy for the Spitzer mission's contribution to exoplanet science, we present a new fixed intrapixel sensitivity map based on over 4 million exposures of calibrator stars with Gaussian centroiding to be treated as a constant detrending method and applied to all phase curve observations equally. In this initial paper we apply our new fixed map method to the WASP-43b data set as a proof-of-concept, demonstrating the effects that different analysis methods can have on exoplanet phase curve results. Importantly, we find our new results to be in agreement with 3D circulation model predictions.

SCIENCE HIGHLIGHTS

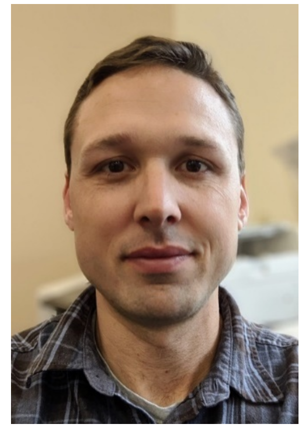
Infrared observations are key to the interpretation of exoplanet atmospheres, but with little chance of repeating any significant number of Spitzer observations with JWST, it is paramount that we make the best use of the current data. We are excited to see how our new fixed sensitivity map changes measured atmospheric trends, and how models may be able to explain them!



Best fit data and models from Stevenson et al. (2017), Morello et al. (2019), Mendon¸ca et al. (2018), and this work [1]. The dashed vertical lines in each panel correspond to the location of peak flux with a shaded region for the 1σ uncertainties. The dashed horizontal lines correspond to the stellar flux level with the shaded region corresponding to the level of night side emission for each analysis. The results of the night side emission presented in this work [1] are in agreement with Mendon¸ca et al. (2018) within 1.5σ and Morello et al. (2019) within 1.3σ. The hotspot offset agrees with Stevenson et al. (2017) to within 0.19σ.

Relevance of Spitzer in the Era of Roman, Euclid, Rubin & SPHEREx

Written by: Daniel Masters
Caltech/IPAC



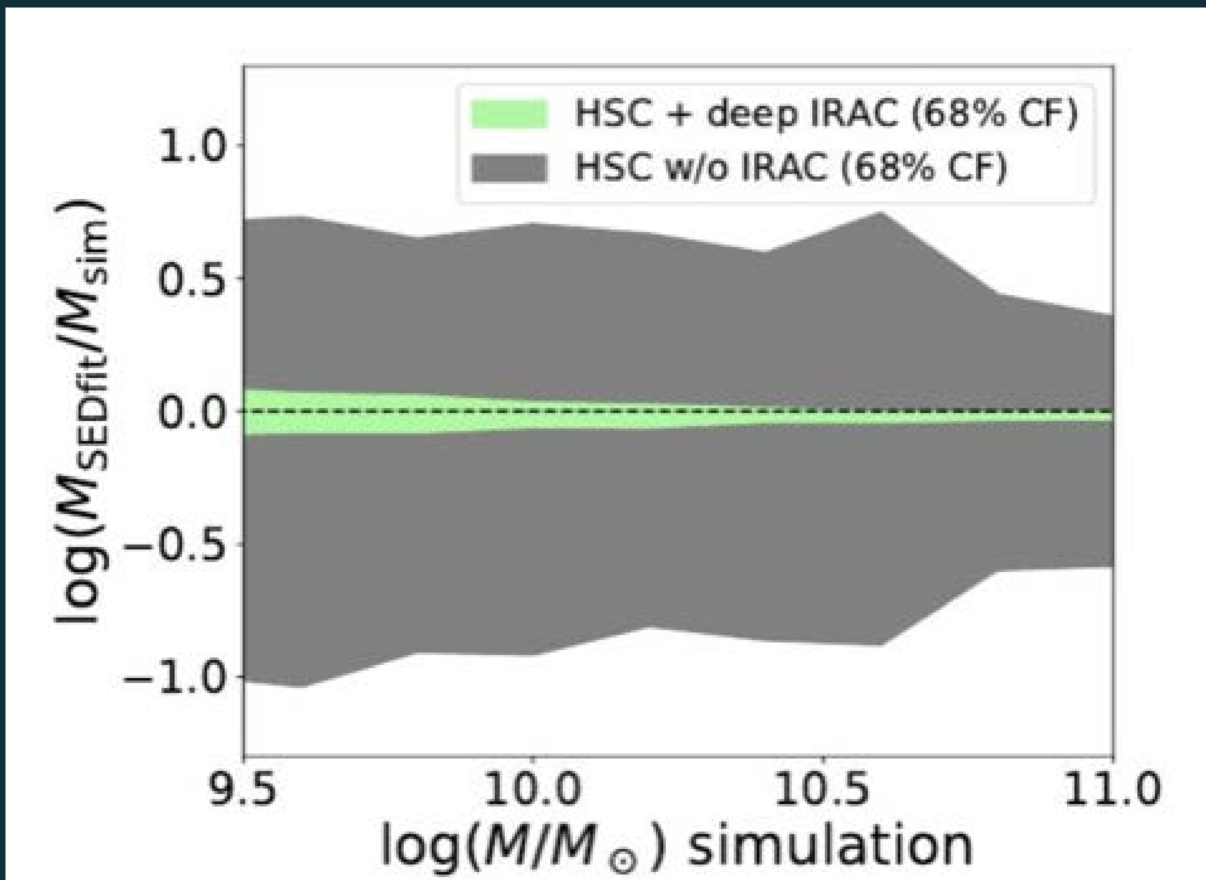
Spitzer has revealed a tremendous amount about galaxy growth and evolution. Its infrared sensitivity was the key to measuring the evolution of stellar masses to high redshift and identifying the earliest galaxies, among other discoveries. In this decade, the ESA/NASA Euclid mission, the NASA Nancy Grace Roman Space Telescope, and the Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) will obtain exquisitely detailed views of the universe in the optical and near-IR. However, these surveys will be spectrally limited, with only ~7-8 broadband filters – the minimum necessary to measure galaxy redshifts at the required precision for weak lensing cosmology.

Spitzer data remains highly relevant in the era of these wide surveys. The largest allocation of Spitzer time ever awarded (~5300h, PI Capak), taken near the end of the mission, obtained deep IRAC 3.6 and 4.5 μm imaging covering 20 deg^2, split between the North Ecliptic Pole (NEP) and Chandra Deep Field South (CDFS). These regions are the deep drilling fields for the Euclid mission and will play a similar role for Roman and (in the case of CDFS) LSST as well. Euclid will obtain ultradeep 1-2 μm imaging in these fields, which will make them the premier regions for high-redshift galaxy and reionization studies for at least a decade. The impact of large-scale structure on reionization and early galaxy formation can only be measured over large, contiguous regions such as these. The Hawaii 2-0 (H20, PI Sanders) survey is currently obtaining deep HSC optical imaging and Keck spectroscopy on these fields to complement the Spitzer data and measure the evolution of the galaxy stellar mass function to high precision. This science would not be possible without the Spitzer data. JWST, while powerful, will not be able to cover large areas and thus is not suited to statistical studies like these.

The Spitzer IRAC data obtained in NEP/CDFS, combined with legacy Spitzer data in deep fields such as COSMOS, will play another important role for upcoming cosmology missions: it will be used to help calibrate photo-z estimates for galaxies across the entire sky. Weak lensing cosmology depends critically on unbiased and low-scatter redshift estimates. It is in the deep and calibration fields, with extensive ancillary data from Spitzer and other telescopes, that the relation between galaxy colors and redshift can be robustly determined.

Spitzer data will also be crucial to measuring galaxy physical properties beyond redshift using the limited data from the upcoming wide-area surveys. The broadband data obtained by Euclid/Roman/Rubin will likely contain a huge amount of information about galaxy evolution, especially given its raw statistical power. We have done analysis that shows that galaxy physical properties beyond redshift (SFR, metallicity, etc.) are in fact encoded in just the ~7-8 observed broadband colors that these missions will obtain. By applying the galaxy color manifold mapping technique developed in Masters et al. 2015, we can stack archival Spitzer MIPS data (together with Herschel) across that color manifold to build a complete picture of the galaxy color-SFR relation. Spitzer will therefore play a critical role in understanding the "big picture" of galaxy evolution in the era of upcoming wide surveys.

SCIENCE HIGHLIGHTS



Difference between the intrinsic stellar mass of 3<z<6 galaxies and those recovered with SED fitting. When IRAC data are not available estimates have over 1.5 dex of scatter, making impossible to constrain stellar mass assembly as a function of cosmic time. The HSC-SSP survey lacks sufficiently deep IRAC data (> 0.5 dex scatter below M-star) except in the two 1.8 deg ultra-deep fields which are too small for the proposed science and suffer from large cosmic variance. Image credit: H20 Survey

Spitzer: The Star-Formation Legacy Lives On

Written by: Rob Gutermuth
University of Massachusetts at Amherst

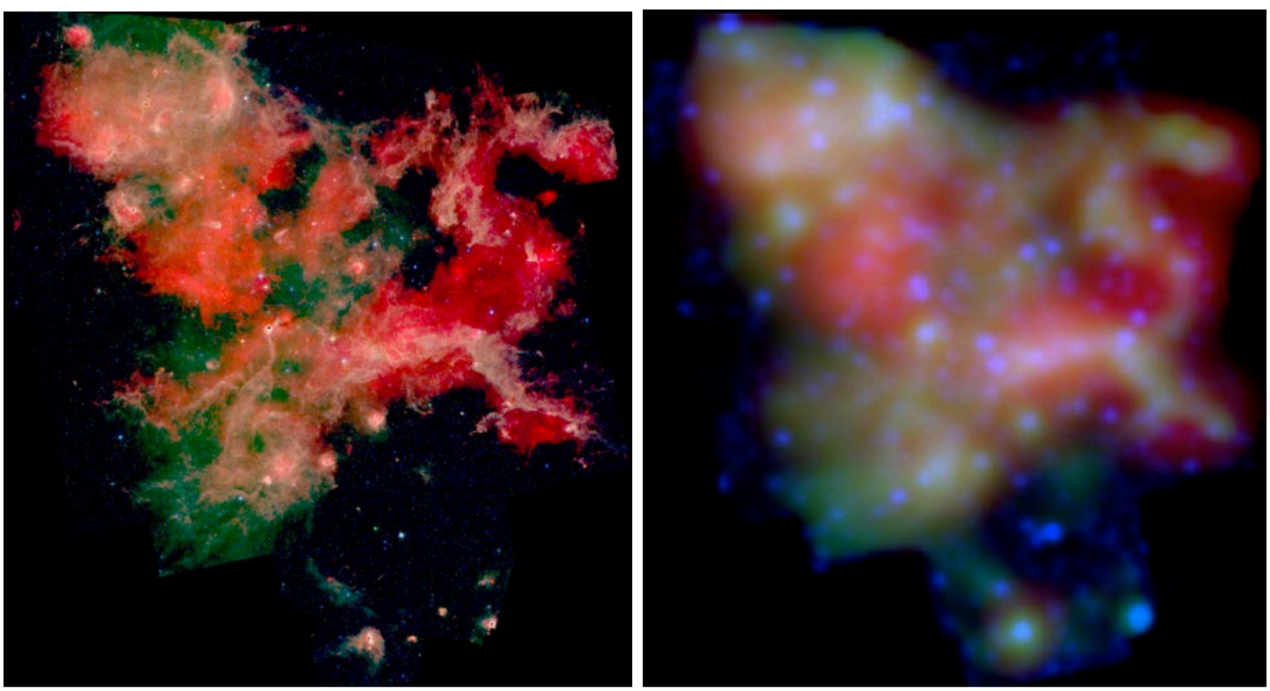
Spitzer's legacy, and its impact on the coming decade of research in star and planet formation, is hard to capture in brief. Despite being downscoped (twice!) in its meandering path to the spacecraft so many of us knew and loved, Spitzer's simultaneous improvement in mid-IR sensitivity and angular resolution over the Infrared Space Observatory (ISO), Midcourse Space Experiment (MSX), and IRAS before it was truly transformative for so many fields, and star formation was no exception. Spitzer was officially switched off earlier this year, capping off an amazing 16 years of fun and science. But is the fun over now that we have said our goodbyes?

Of course not! Indeed, in the coming decade, our mid-IR view of the universe will be that of SOFIA and JWST. But Spitzer's future remains secure in that it could do something that its successors cannot: survey large areas of mid-IR sky to moderate depth. Spitzer's wide reach was utilized with aplomb by many research teams, and it left in its wake a tremendous archive of survey data awaiting further scientific exploitation in the wonderful InfraRed Science Archive (IRSA). It is doubtless that JWST's pending launch heralds yet another transformative epoch in star and planet formation research. Yet Spitzer's archive is how we will decide where to look with those new eyes. Just as vital, Spitzer's expansive view of star formation sets the interpretive framework for the myriad of more distant and more exotic star-forming environments that JWST's advanced capabilities will allow us to reach.

Spitzer imaging surveys have achieved incredible censuses of young, forming stars. They are identified through their excess IR emission over a simple stellar photosphere, signifying the presence of warm dust from the inner parts of protoplanetary disks or reprocessed emission through cold, dusty protostellar envelopes. Because of its impressive sensitivity, Spitzer surveyed over 90% of all known star-forming clouds in the nearest kiloparsec down to masses near the hydrogen-burning limit. Spitzer revealed low-mass, dusty young stellar objects (YSOs) in sufficient numbers (a couple thousand closer than Orion, twelve thousand in the 0.4-1 kiloparsec range) to provide strict constraints on a wide variety of fundamental measurements of the star-formation process. From Spitzer, we have some of the best constraints to date of the protoplanetary disk lifetime, the protostellar phase lifetime, the protostellar luminosity function, the range of stellar density environs that stars form within, the efficiency that stars form in different densities of molecular gas, and even the frequency and amplitude range of mid-IR variability in YSOs over timescales ranging from hours to years. These results not only constrain the growing capabilities and complexity of modern simulations, they also bring a purely empirical framework for the interpretation of future surveys that reach well beyond the nearest kiloparsec enabled by JWST.

The breadth of nearby regions surveyed by Spitzer include high-mass star-forming events with associated plethora of low-mass stars like in Orion, as well as diffuse, low-mass star-forming clouds like in Lupus. They include deeply embedded protoclusters like Serpens South and largely exposed young clusters like IC 348 and Cep OB3b. The sum and total of these surveys is a wide-spanning portrait of the entire star-forming process across every evolutionary stage in regions large and small. As we look ahead to JWST, it is fun to imagine what we will be able to see as Spitzer did: infrared dark clouds in the molecular ring imaged as Spitzer saw Orion, or star-forming regions in the extreme outer galaxy and the Central Molecular Zone imaged as Spitzer saw Cygnus-X! The fact that we will be able to make direct comparisons between star formation measures in regions that span much of the Milky Way in the next few years is truly exciting! Even as we look beyond the confines of the Milky Way to nearby galaxies, Spitzer surveys will play critical roles in demonstrations of what we can and cannot infer as we zoom in on distant star-forming regions without fully resolving their stellar content. Much recent effort has gone into reducing and resampling Spitzer's view of distinguished young stellar distributions and resolved nebulosity in nearby regions to ascertain limits on the ability of resolved emission estimates of star formation rate in nearby galaxies to replicate actual YSO tallies.

The legacy of Spitzer is its archive. It will permeate most efforts to expand our view of the star formation process going forward, and great things are coming! Whether for planning next generation observations or interpreting them to determine where and how stars form in an ever-growing range of environments within the Milky Way and beyond, Spitzer's influence now goes far beyond the spacecraft itself.



The Spitzer Cygnus-X Legacy Survey in its original appearance, 1400pc away (left), and how JWST would see it if it were located in the galaxy M83, 4.5 Mpc (right). In both, RGB = 24, 8.0, and 3.6 µm. The field of view is 100 pc x 120 pc, containing over 22,000 YSOs. Only the brightest stars and most compact star-forming regions would be detected at 3.6 µm, and nebular emission will mislead star-formation rate surface density estimation at scales smaller than 20 pc for more evolved star-forming regions.

Revealing *All the PAHs* in Galaxies with an AKARI-Spitzer Survey

Written by: Thomas Lai and JD Smith
Ritter Astrophysical Research Center, University of Toledo

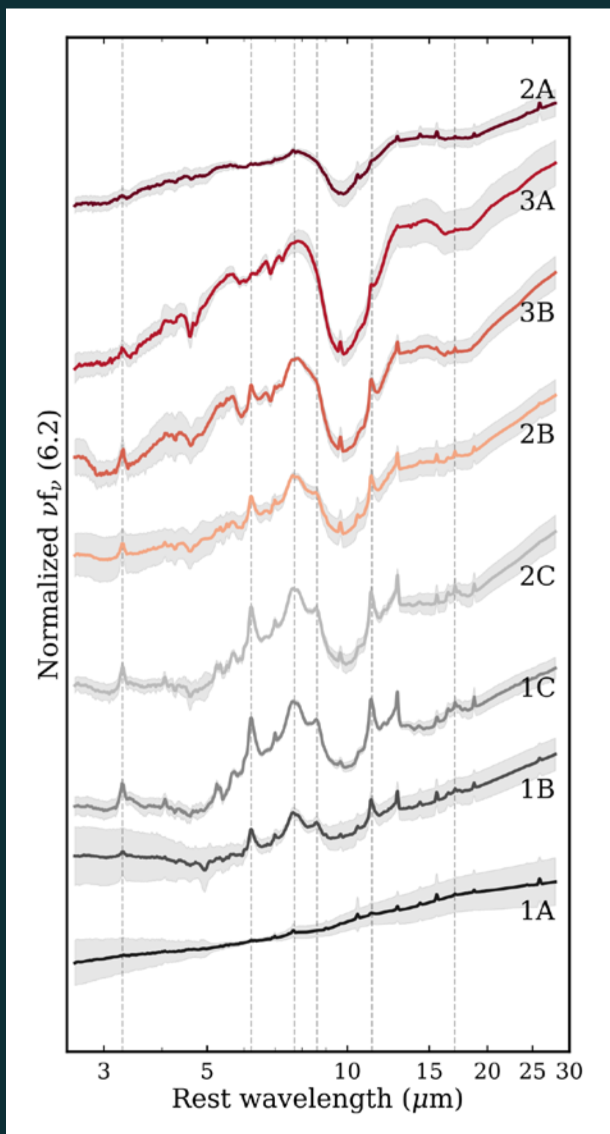
Paper: All the PAHs: an AKARI-Spitzer Cross Archival Spectroscopic Survey of Aromatic Emission in Galaxies, Thomas S.-Y. Lai, J.D.T. Smith, Shunsuke Baba, Henrik W.W. Spoon, Masatoshi Imanishi, and Takao Nakagawa, submitted to ApJ.
Poster.

On January 30, 2020, the decommissioning of Spitzer marked the end of the Spitzer era, but Spitzer's legacy will be carried on by the upcoming successor James Webb Space Telescope (JWST), and Spitzer's archives still contain untold riches. One of the most significant findings of Spitzer is the pervasive aromatic nature of the Universe. The emission of polycyclic aromatic hydrocarbon (PAH) molecules, mainly observed at 3.3, 6.2, 7.7, 8.6, 11.3, and 17 µm, is found in an incredible variety of sources and can comprise up to 20% of the total infrared luminosity from a galaxy. The band ratios among these features provide powerful diagnostics to probe the physical conditions in the ISM, including size distribution and ionization states.

Among all the features, the 3.3 µm band is the shortest wavelength PAH, and originates from the smallest members of the emitting PAH population, making it the best-known tracer of small dust grains. The smallest of dust grains have long been assumed to be fragile, subject to destruction by harsh radiation fields and sensitive to the surrounding environment due to their large surface-to-volume ratios. As a result, small grains can provide crucial insight into the physical properties of the ISM. While the 3.3 µm band can be observed by the Infrared Space Observatory (ISO) and ground-based facilities with L-band spectroscopy, there has been no systematic investigation of the behavior of the 3.3 µm feature with respect to other prominent counterparts on galaxy-wide scales.

The reason why studies of the 3.3 µm PAH have been rare compared to redder features is that Spitzer's Infrared Spectrograph (IRS), while covering almost a factor of four in wavelength, extended down only to 5 µm, leaving the shortest wavelength and most sensitive of the PAH bands relatively unexplored. But thanks to complementary observations by the Infrared Camera (2.5-5 µm) aboard the Japanese AKARI Space Telescope, and the extensive legacy of Spitzer/IRS spectra of galaxies, we are able to access the 3.3 µm PAH feature with a comparable spectral resolution to Spitzer across a large, diverse sample of galaxies.

In our recently submitted paper, we presented a large sample of 2.5-38 µm galaxy spectra drawn from a complete cross-archival comparison in the AKARI-Spitzer Extragalactic Spectral Survey (ASESS). This survey covers a broad diversity of galaxies, ranging from star-forming systems to deeply obscured AGNs. In particular, we focus on 113 star-forming galaxies with prominent PAH emission, and model for the first time *all the PAH bands* simultaneously using a modified version of the spectral decomposition model PAHFIT that takes into account dust attenuation and two limiting cases of obscuration geometry.



Galaxy templates ranging from 2.5-30 µm that are drawn from our AKARI-Spitzer survey (ASESS).

Our study leads to a rather non-intuitive result that the fractional 3.3 µm PAH power— the ratio of 3.3 µm PAH luminosity to total PAH luminosity — shows no sign of decrease with increasing integrated infrared luminosity. This indicates galaxies with a strong radiation field can still exhibit relatively strong PAH emission at shorter wavelengths, even though small grains are thought to be easily destroyed in such environments. II Zw 40, a blue compact low metallicity dwarf with Z ~ 1/4 Z⊙, serves as a perfect example to illustrate this idea. II Zw 40 shows both strong 3.3 µm PAH emission and an absence of PAH emission at 17 µm, which is attributed to the largest PAH populations, suggesting a size distribution shifting towards the smaller end. This finding contradicts some early studies claiming only larger PAH molecules are able to survive under prevailing UV radiation fields. We suggest the likely mechanisms leading to a relatively strong 3.3 µm PAH emission are (i) enhanced stability of small PAH molecules from efficient relaxation processes and (ii) the migration of PAH power to shorter wavelengths under environments with intense radiation fields.

With the impending launch of the JWST, the underlying physics of the smallest PAH molecules can be scrutinized anew. JWST/NIRSpec operates with wavelength coverage from 0.6-5 µm. Together with JWST/NIRCam and the calibration between the 3.3 µm PAH power and the photometric observation offered by ASESS, we can probe this shortest but in some ways most important PAH band into the more distant Universe. This is just one example of how Spitzer's legacy has retained tremendous relevance some 17 years after its launch, and 11 years after its cryogenic mission ended.

The Science Impact of the SOFIA-HIRMES Termination

Written by: Klaus Pontoppidan
Space Telescope Science Institute

On April 1, 2020, NASA announced the termination of the High-resolution Mid-infrared Spectrometer (HIRMES), which was under development as a 3rd generation instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA). The reasons for the termination were related to technical challenges, and associated cost and schedule overruns associated with detector technology readiness.

The loss to the scientific community is substantial and fundamental, and the highly unique science that HIRMES was built to accomplish remains as exciting as ever. HIRMES would have measured the total gas -- and ice -- masses of protoplanetary disks around solar-mass stars, determined the location of warm water vapor out to the snowline, searched for the origins of volatiles in debris disks, measured the deuterium abundance of the giant planets, and greatly increased the spectral mapping speed for fine structure lines in nearby galaxies.

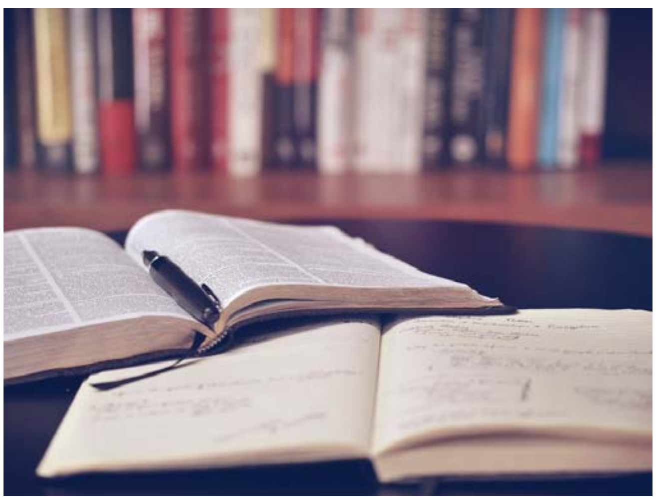
HIRMES was meant to accomplish these science goals by offering a highly versatile far-infrared spectroscopic platform on SOFIA with optimized instrument throughput (using Fabry-Perot Interferometers) and detector sensitivity (using new low-noise Transition Edge Sensors). *In a nutshell, HIRMES would have offered Herschel/PACS-like spectroscopic sensitivity, but at resolving powers 100 times higher* (R~100,000). Further, by also offering low-resolution spectroscopy of the 35-55 μm gap between the historical coverages of Spitzer and Herschel, HIRMES would have enabled the sensitive detection of water ice in emission, in particular in planet-forming and debris disks.

These are all science cases that cannot be accomplished by any other currently approved facility, yet have profound consequences for our interpretation of complementary observations from e.g., ALMA and JWST. Without HIRMES, or a similar sub-orbital instrument, we may well have to wait for ESA/JAXA to build and launch SPICA, and we may have to wait for the Origins Space Telescope to recover the ability to measure far-infrared line profiles. These missions will come far too late to directly influence JWST observations. As a poignant example, JWST will detect many unresolved water vapor lines in planet-forming disks, and HIRMES would have been able to measure their location in the disks by spectrally resolving them. Without a HIRMES-like facility, it will likely be difficult to develop unambiguous models of water in disks, as observed with JWST.

HIRMES was designed from the very beginning as an infrared community facility instrument, and the entire community was invited to participate in early HIRMES science. Flexibility was a priority, with continuous spectral coverage from 25-122 μm, and multiple choices of spectral resolving power and spectral mapping speeds. The leap in spectral sensitivity would have brought in communities that had not previously been able to use SOFIA. With a planned Legacy Science Program for 100s of hours of SOFIA time, HIRMES would have produced a significant database for all its core science cases available to all with no exclusive access period. In particular the worldwide planet formation communities saw new opportunities in HIRMES for observations of protoplanetary and debris disks, and others interested in the energy balance of nearby galaxies, giant planets and comets in the Solar System, were also taking a strong interest.

There is no question that HIRMES was technically challenging. In particular its low-noise detectors were difficult to make. However, HIRMES was also intended be a trailblazer for the future, including the Origins Space Telescope. Origins similarly requires low-noise detectors, and has defined core science cases that aim to produce large spectral surveys of volatiles in planet-forming disks, debris disks, comets, and to create large maps of fine-structure lines in the Universe. HIRMES would have made significant contributions to these science cases and shown the way for Origins science.

In summary, the termination of HIRMES represents a great loss for the general far-infrared science community. The science of HIRMES is a significant step on along the roadmap articulated in the Origins report to the 2020 decadal survey, as well as the science case written for SPICA. That science will not go away, but we may have to wait a little longer for it.



Further Reading

If you want to know more about the Spitzer Space Telescope's origins, operations, and legacy, the following books and reviews might help scratch the itch!

Nature Astronomy's 2020 Spitzer Retrospective Collection
https://www.nature.com/collections/cabbfadjgg

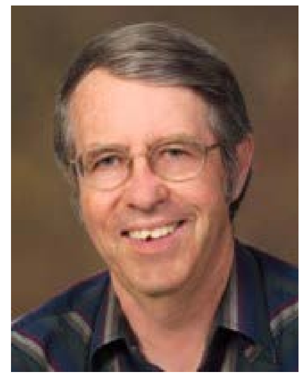
"More Things in the Heavens" Michael Werner & Perter Eisenhardt, Princeton University Press, 2019

"Making the Invisible Visible: A History of the Spitzer Infrared Telescope Facility (1971-2003)" Renee M. Rottner, National Aeronautics & Space Administration, 2017

"The Last of the Great Observatories: Spitzer and the Era of Faster, Better, Cheaper at NASA" George H. Rieke, University of Arizona Press, 2006

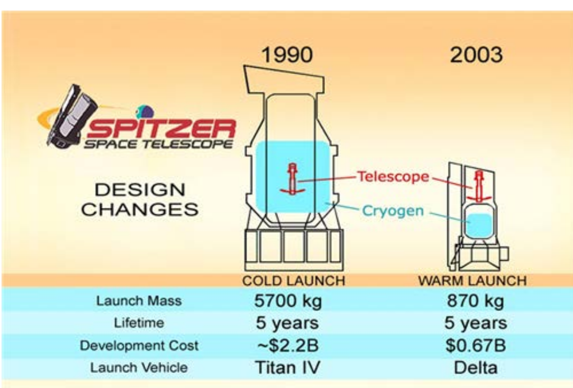
On the Shoulders of the Small but Mighty: Spitzer's Legacy for JWST

Written by: Stacey Alberts and George Rieke
(Steward Observatory, University of Arizona)



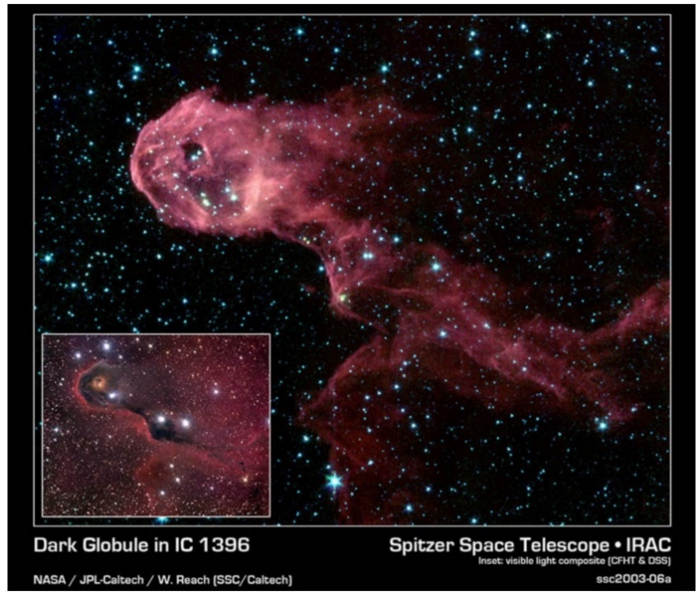
The long awaited and highly anticipated James Webb Space Telescope (JWST) promises to revolutionize our understanding of the Universe. Our most ambitious telescope yet, JWST is an engineering marvel that has also survived blizzards, hurricanes, and now a pandemic, which may leave us on the edge of our seats a little longer. But even before all that, there was a time not that long ago (the 60's and 70's!) when infrared astronomy was just ramping up, many technologies unimagined or untested, the science unclear. A great many accomplishments paved the way for a dream like JWST, culminating in its technological and scientific predecessor: the Spitzer Space Telescope.

Spitzer (2003-2020) was one of NASA's Great Observatories, covering 3.6-160 μm during its 5 year cryogenic mission with a cooled 85 cm mirror, and then continuing its warm mission at 3.6 and 4.5 μm for an additional 11 years. Its long career was an exquisite demonstration of the power of space-based infrared astronomy, taking full advantage of the ultra-low temperatures and lack of atmospheric absorption. Like JWST, however, getting Spitzer off the ground was no straightforward task. Recurring budgetary and political crises made the "cold" launch design of its predecessors Infrared Astronomical Satellite (IRAS) and Infrared Space Observatory (ISO), which were fully encased in a cryostat, unfeasible. An innovation "warm" launch redesign saved the day: operating temperatures of ~5 K were reached by placing the telescope in an earth trailing orbit with an architecture designed for passive radiative cooling (to ~40 K) with only a small helium cryostat needed to make up the difference [1] (and image, left). Without this, cooled mirrors of >1 m in space may never have been realized, much less the 6.5 m aperture of JWST!



Along with its new architecture, Spitzer's instrumentation represented a great leap forward. High performance, large format mid- and far-infrared detector arrays and a cold telescope allowed the long wavelengths to enter (and expand!) the science realms previously dominated by optical astronomy. The per-pixel performance of Spitzer's infrared arrays demonstrated the sensitivity and stability we had grown accustomed to with CCDs. So much so that the Spitzer arrays served as prototypes for JWST, particularly for its Mid-Infrared Instrument (MIRI).

With over 8,700 publications, Spitzer's science legacy directly informs countless aspects of the four pillars of JWST science, in many cases having taken the first steps into new parameter space. As examples, Spitzer's high performance star tracking provided both the accuracy and stability to broaden the scope of exoplanet transits to thermal atmospheric characterization. This revealed the first "weather" outside our solar system via the gas-giant HD 189733b in 2007 [2] (JWST science theme: *Planets and Origins of Life*). Spitzer's photometric coverage and spectroscopic modes threw our view of the dusty and molecule-rich Universe wide open: from peering past the veil into the hearts of stellar nurseries with its first light image of the Elephant Trunk Nebula [3] *(image right: Birth of Stars and Protoplanetary Systems)* to the dust-enshrouded star formation dominating at cosmic noon to the most hidden and most distant supermassive black holes (*Assembly of Galaxies*). And finally, Spitzer proved to be quite the time machine, using its unique sensitivity at its shortest wavelengths to peer into the Era of Reionization, well past the (then optimistic) z~3 goal; during planning, it was never dreamed that Spitzer could match HST in redshift! Nevertheless, Spitzer's deep photometry at 3.6 and 4.5 μm provided a rest-optical anchor for objects like GN-z11 at z=11.1 [4], characterizing their stellar populations in a stunning preview of what JWST will observe at cosmic dawn (*First Light and Reionization*).



Though now retired, Spitzer's vast data archive will keep us busy for years to come, providing us with a rich list of targets and science programs as we enter the era of JWST science. A big legacy for the small, but mighty [5].

[1] https://academic.oup.com/astrogeo/article/47/6/6.11/232786
[2] https://www.nasa.gov/mission_pages/spitzer/news/spitzer-20070509.html
[3] http://www.spitzer.caltech.edu/news/149-ssc2003-06-NASA-Releases-Dazzling-Images-from-New-Space-Telescope
[4] https://ui.adsabs.harvard.edu/abs/2016ApJ...819..129O/abstract
[5] https://uanews.arizona.edu/story/astronomers-bid-farewell-spitzer-nasas-coldest-space-telescope

Spitzer's Final Voyage – Highlights from JPL's Tribute to Spitzer

Written by: Lisa Locke
Jet Propulsion Laboratory

The Spitzer Space Telescope was the last of NASA's Great Observatory program that included the Hubble Space Telescope, Chandra X-ray Observatory, and the Compton Gamma Ray Observatory. Launched aboard a Delta-2 rocket on August 25, 2003, the satellite took up a heliocentric, Earth-trailing orbit which was different than previous telescopes. The advantage being the ability for the telescope to radiatively cool itself by orienting itself away towards the dark cold space. Initially planned for a 3-5 year lifetime the mission lasted over 16 years.

Optics	Primary: 85 cm, f/1.2, Secondary: 15 cm, Ritchey–Chrétien design, overall f/12
Orbit	Heliocentric, Earth-trailing
Cryogenic lifetime	~5 years
Wavelength coverage	3.6 – 160 µm (imaging) 5.2 – 38 µm (spectroscopy) 51 – 106 µm (SED)
Spectroscopic Resolving Power	64-128,600 (IRS) 15 – 25 (MIPS SED)
Diffraction Limit	5.5 µm
Image size	1.5" at 6.5 µm
Field of View	~0.5' x 5' at 160 µm ~1' x 1' at 13-26 µm ~5' x 5' in other bands
Telescope minimum temperature	5.6 K
Maximum tracking rate	1.0"/ sec

Another unique feature was its "warm launch" mission design, the telescope was launched warm and then cooled down radiatively by the exposure, unlike previous telescopes launched cold requiring heavy cryogenic systems and larger reservoirs of cryogen, this new design allowed for a much smaller and lighter telescope.

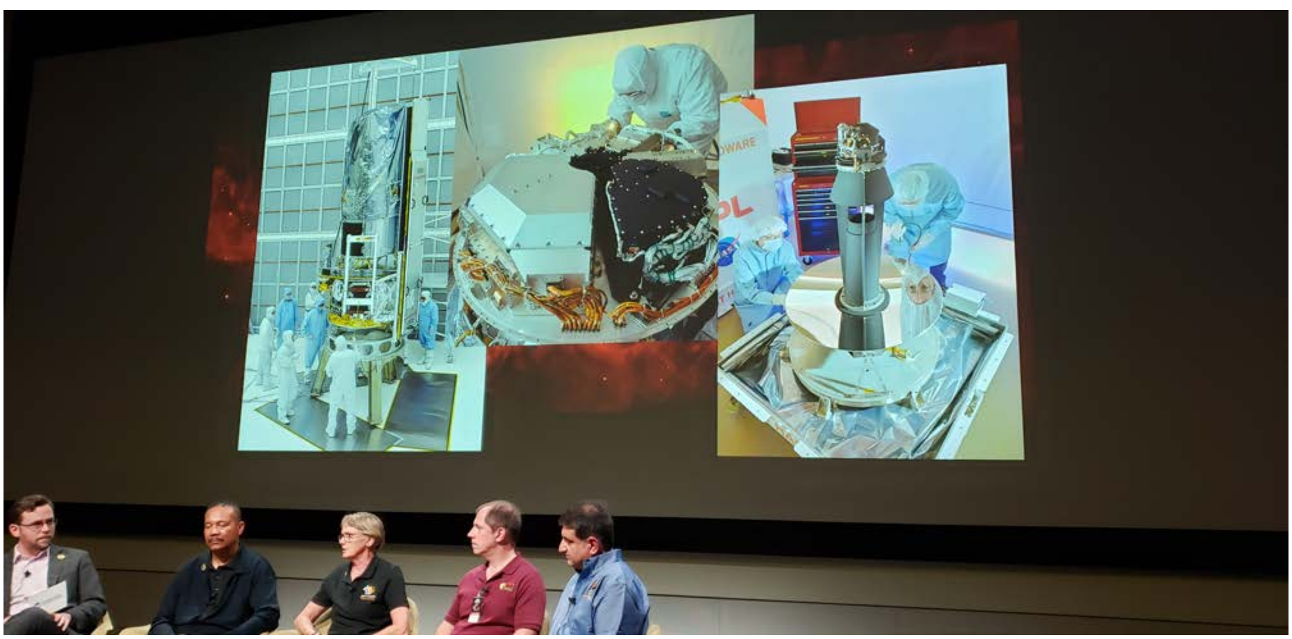
The observatory was ~4m tall and ~2m in diameter, mass of 900 kg. Three onboard instruments were:

- Infrared Array Camera (IRAC), simultaneous observations at 3.6, 4,5, 5.8, 8 µm
- Infrared Spectrograph (IRS) for low and high resolution observation in bands between 5.3 and 40 µm
- Multiband Imaging Photometer for Spitzer (MIPS) with arrays at 24, 70, 160 µm.

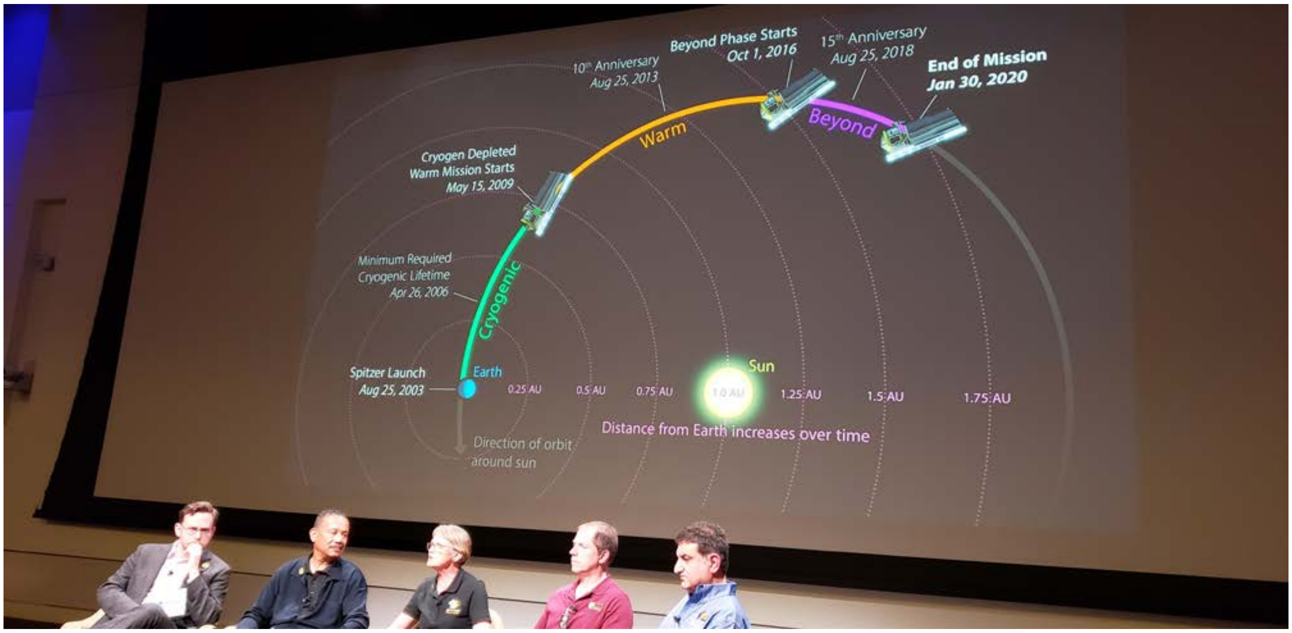
To commemorate the Final Voyage, a two-day event was planned at JPL in Pasadena, CA. Brian White hosted a panel and covered the history, legacy and some memorable moments from the Spitzer mission. The panel consisted of:

- Joseph Hunt, Project Manager (2017-2020), JPL
- Suzanne Dodd, Project Manger (2010-2016), JPL
- Robert Hurt, Spitzer Visualization Scientist, Caltech/IPAC
- Varoujan Gorijan, Spitzer Research Scientist, JPL

Spitzer: The Final Voyage panel at JPL, January 2020 (all photographs: L. Locke)



Spitzer: The Final Voyage panel at JPL describing the telescope and instrumentation, January 2020



Spitzer: The Final Voyage panel at JPL, January 2020

After the presentation, everyone was invited to have kettle corn in the JPL courtyard.

UPCOMING EVENTS

3-7 Aug, 2020 51st Annual Meeting of the AAS Dynamical Astronomy Division – **ONLINE**
https://dda.aas.org/meetings/2020

4 Sept, 2020 Proposal Call – SOFIA Cycle 9, Regular and Legacy Programs
https://www.sofia.usra.edu/science/proposing-and-observing/proposal-calls/

8-10 Sept, 2020 TESS Science Meeting – **ONLINE**
https://online.tess.science/

6-8 Oct, 2020 AAS Event - Galaxy Formation and Evolution in the Era of WFIRST - **ONLINE**
https://aas.org/events/2020-04/online-galaxy-formation-and-evolution-era-wfirst

12-16 Oct, 2020 ESO Ground-based thermal infrared astronomy – past, present and future – **ONLINE**
https://www.eso.org/sci/publications/announcements/sciann17256.html

9-12 Nov, 2020 Exoplanet Demographics, Pasadena, CA
https://aas.org/events/2020-01/exoplanet-demographics

11-15 Jan, 2021 237th AAS Meeting - **ONLINE**
https://aas.org/meetings/aas237

IRSIG Has a New Web Presence!

We are proud to announce 2 new ways to keep in touch with the IR Science Interest Group.

NEW WEBSITE

https://cor.gsfc.nasa.gov/sigs/irsig.php

Our new website will be hosted on the Cosmic Origins website. It is a continual work in process; please contact us with any questions, comments, or suggestions for content.

@ir_sig

NEW EMAIL LIST

https://cor.gsfc.nasa.gov/sigs/irsig/maillist/irsig_maillist.php

Please sign up for announcements, information, and community discussion on our new email listserv! If you have been receiving email from us, no action is necessary, but if you have fallen out of touch or want to subscribe for the first time, please sign up.

IR SIG LEADERSHIP COUNCIL

The current members of the IR Science Interest Group (SIG) Leadership Council are:

Meredith MacGregor (Co-Chair)	University of Colorado Boulder
Mike Zemcov (Co-Chair)	Rochester Institute of Technology
Stacey Alberts	University of Arizona
Pete Barry	Argonne National Laboratory
Duncan Farrah	University of Hawaii
Jeyhan Kartaltepe	Rochester Institute of Technology
Jens Kauffmann	Massachusetts Institute of Technology
Lisa Locke	NASA Jet Propulsion Laboratory
Eric Murphy	National Radio Astronomy Observatory
Omid Noroozian	NASA Goddard Space Flight Center
Naseem Rangwala	SOFIA Science Center
JD Smith	University of Toledo
Johannes Staguhn	Johns Hopkins University, NASA GSFC
Kevin Stevenson	Applied Physics Laboratory

Additional information about the IR SIG:

To contact the IR SIG LC directly, email: **irsiglc@gmail.com**.