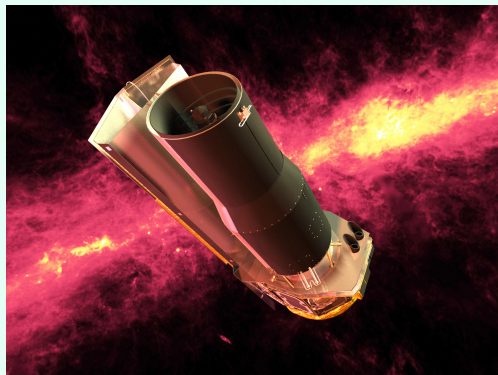


COPAG/SAG 9: Science Enabled by Spitzer Observations Prior to JWST Launch – 2 Science Cases

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AAS-225, Seattle (WA), January 4th, 2015

Picture credits (for entire presentation): ESA and NASA

Current (Warm) Spitzer Capabilities

[courtesy of Sean Carey (SSC-IPAC)]

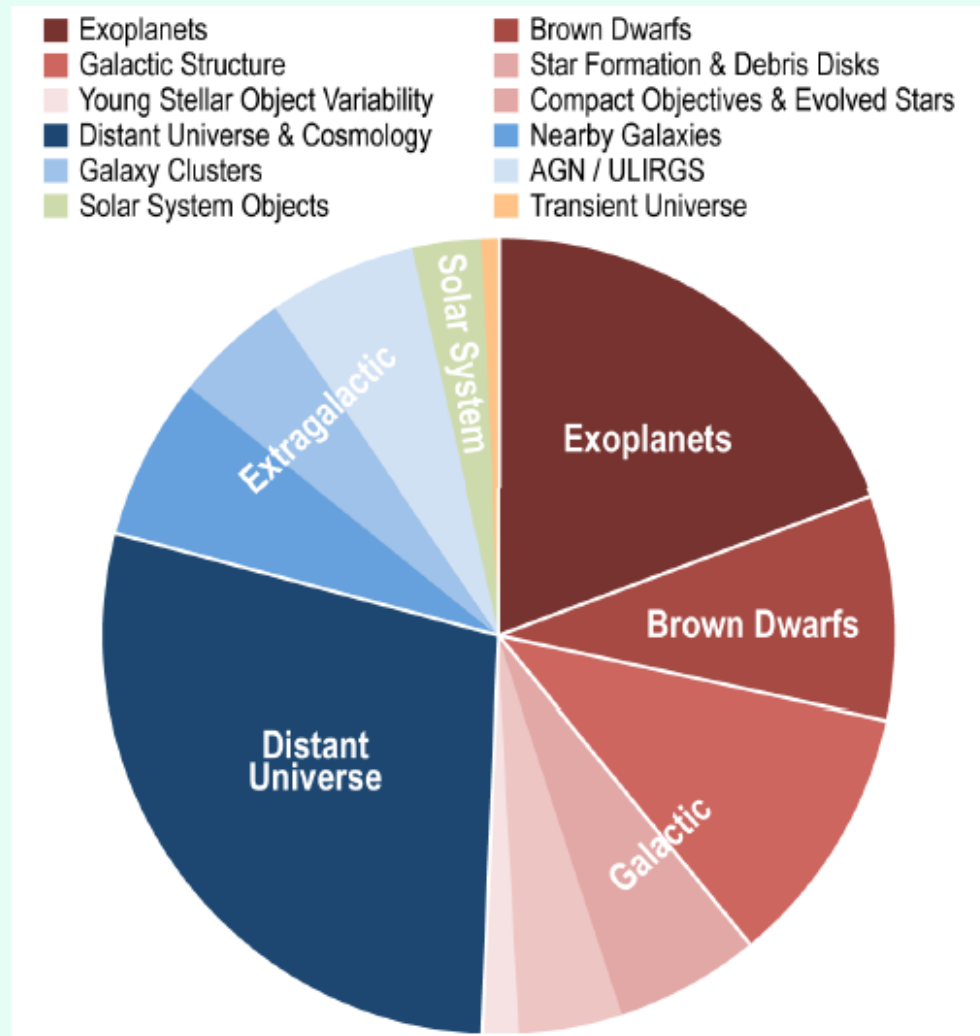
- ▶ **Two IRAC Cameras** at 3.6 and 4.5 μm , with $\sim 1.7''$ resolution; 2% absolute calibration accuracy.

Channel	λ_0	$\lambda/\Delta\lambda$	FOV	1σ in 1hr integration	Mapping speed ^A
	μm		arcminutes	μJy	hours
3.6	3.550	4.7	5.2 x 5.2	0.14	3.3
4.5	4.493	4.4	5.2 x 5.2	0.21	3.3

^ATo confusion limit ([3.6], [4.5] ~ 17 Vega magnitudes, 49 & 28 μJy , respectively) in Galactic plane at $l = 60^\circ$, $b = 0^\circ$ for 1 square degree in hours.

- ▶ **Deep Imaging:** Demonstrated depth of 81 nJy (3σ) in 34 hours for unconfused sources. SB limit ~ 0.5 kJy/sr. SNR increases as $t^{0.4}$ for total integration times above 10 hours.
- ▶ **Exoplanets:** near Poisson limited precisions for relative photometry at both 3.6 and 4.5 μm . The best precision obtained with IRAC for an eclipse is 28 ppm from four epochs of observations of 55 Cnc e.
- ▶ **Solar System:** Track moving targets at 0.1 milliarcsec/sec to 1 arcsec/sec rates. Demanding result: detection of 2011 MD with a flux density of 0.6 mJy and rate of 0.14 arcsec/sec detected in a 19.3 hour observation with IRAC.
- ▶ **Zodi Light:** absolute measurements possible for a range of solar elongations 82.5° and 120° with an accuracy of $<2\%$ if the IRAC shutter is used to remove the instrumental bias pattern.
- ▶ **Orbital Stability+Uninterrupted Viewing:** Monitoring 20+ days of M dwarfs for Earth-size companions; monitoring 20+ hrs of Sgr A for variability (in sync with Chandra)

Warm Spitzer Observing Time Distribution



Excerpted from Senior Review Report 2014

Science Areas of SAG 9

▶ Galaxy Evolution and Cosmology

- ▶ Ranga-Ram Chary (Lead), Lee Armus, Pierre Ferruit, Adam Stanford, Massimo Stiavelli, Rogier Windhorst

▶ Nearby Galaxies

- ▶ Daniel Dale (Lead), Kathleen Kraemer, Massimo Stiavelli, Mike Werner

▶ Milky Way (incl. Evolved Stars, etc.)

- ▶ Kathleen Kraemer (Lead), Rachel Osten, John Stauffer, Mike Werner

▶ Extra-solar Planets

- ▶ Avi Mandell (Lead), Sean Carey, Drake Deming, Pierre Ferruit, Rachel Osten, John Stauffer

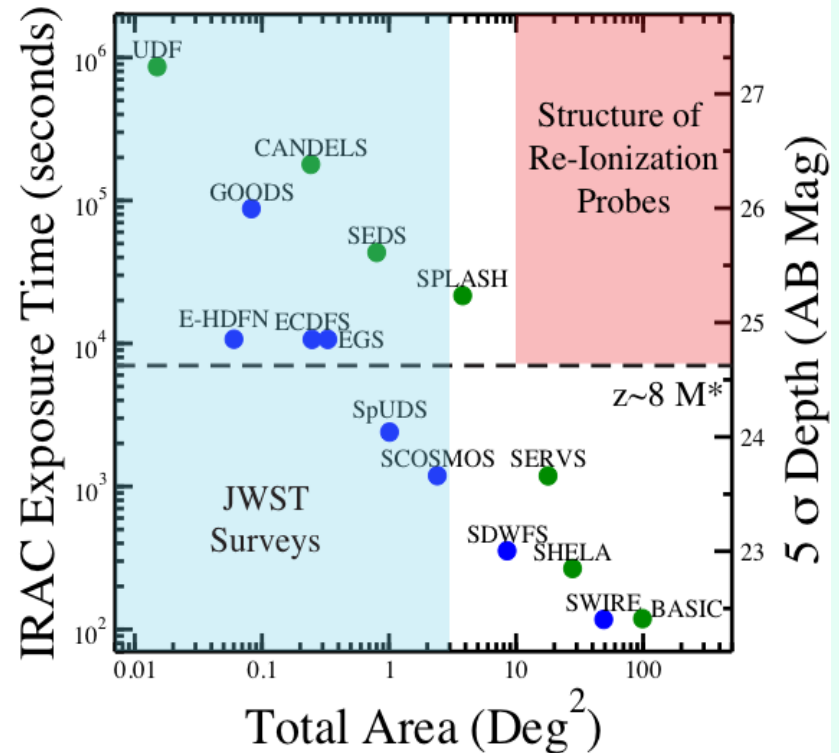
▶ Solar System

- ▶ Stefanie Milam (Lead), Sean Carey, Josh Emery

Galaxy Evolution and Cosmology

A number of surveys already in existence. See Figure: blue points for cryogenic and green points for warm Spitzer. 1σ depth of 26.2 – 27.4 AB in 50 hours. Light-blue area is practical region for JWST. (Figure courtesy of Peter Capak)

Recently approved observations push into confusion noise (~ 200 hrs per pixel), and require use of priors, e.g., from HST.



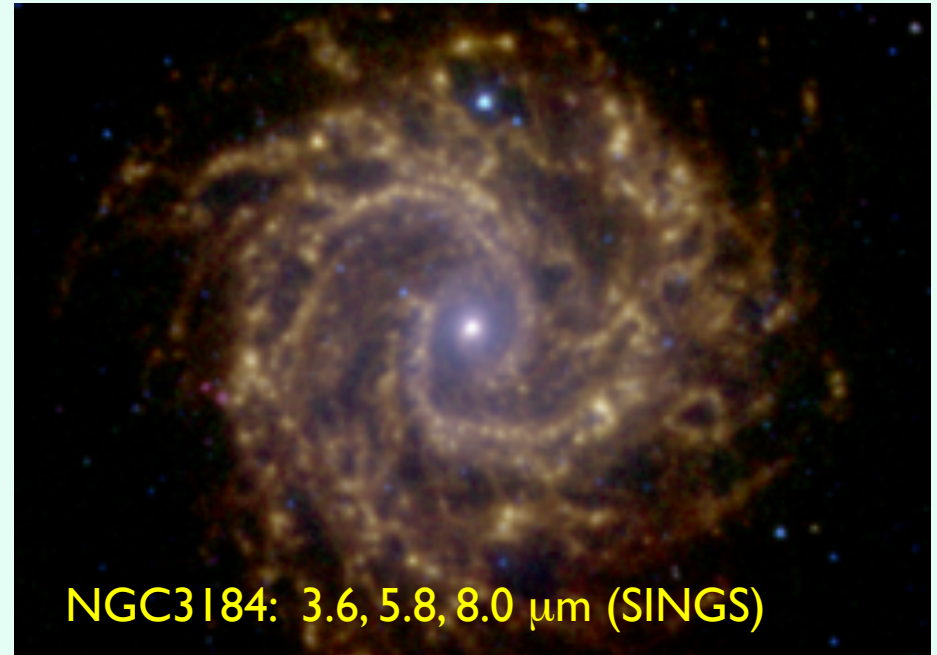
▶ Key questions/observations:

- ▶ Reach similar levels of confusion noise for all deep fields (incl. WFIRST ones, once defined) – define best JWST spectrosc. candidates with HST
- ▶ Observe best lensing groups/clusters for $z \sim 13$ candidates
- ▶ Characterize Zodi/Background Light

Nearby Galaxies

Many surveys of the local Universe in the archive, both with cryogenic (e.g., SINGS, LVL, SAGE, ..., see Figure) and warm Spitzer (e.g., S4G, EDGES, etc.)

Programs have focused on both inner and outer disk regions, including subregions (e.g., HII regions, nuclear and circumnuclear regions, etc.).



NGC3184: 3.6, 5.8, 8.0 μm (SINGS)

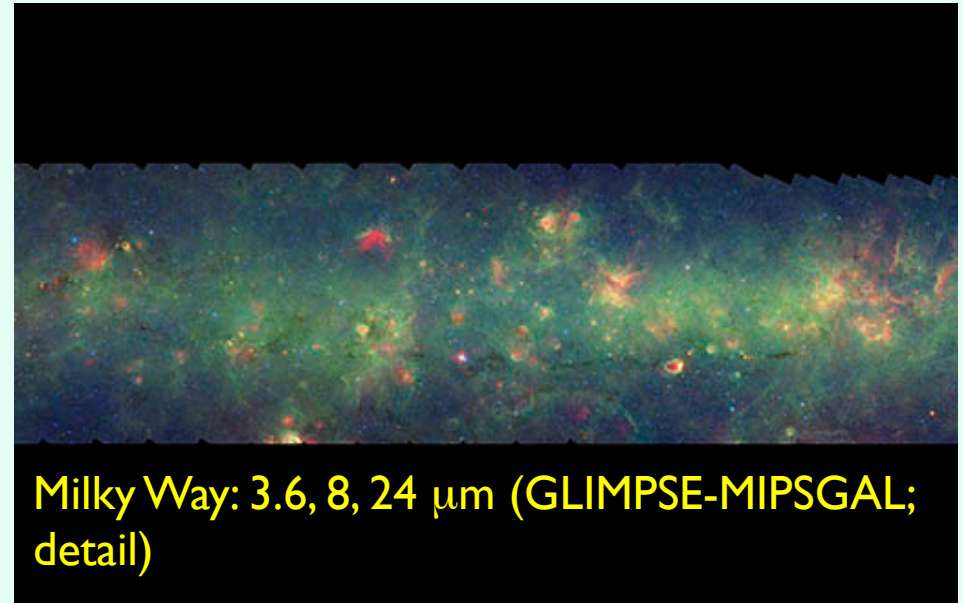
➤ Key questions/observations:

- Observe and characterize Cepheids and RR Lyra stars (Hubble Flow)
- Deep images of the recently discovered ultra faint dwarf galaxies
- A 3rd (or Nth) epoch map of the LMC, SMC, other local group galaxies
- A YSOVAR-like program on the LMC or SMC YSOs
- Variability/evolution for particular classes of evolved stars, SNRs, ...
- The missing dwarf galaxy companions

The Milky Way

The Milky Way has been extensively mapped with both the cryogenic and the warm Spitzer missions. Extended areas as well as regions of interest have been targeted (GLIMPSE+extensions, MIPS GAL, c2d, SMOG, ...).

Both the plane and the outer regions, as well as the far side of the Galaxy have been imaged.



➤ Key questions/observations:

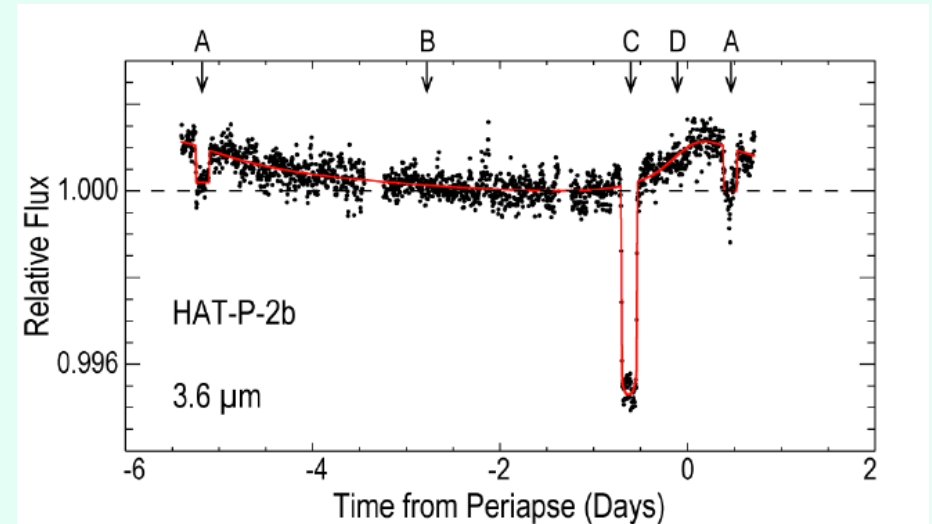
- Polluted White Dwarf Observations (Exoplanet tie-in, leveraging WISE)
- IRAC Photometry for GAIA RR Lyr & Cepheid Variables (Cosmology tie-in – further in the Hubble Flow for JWST, better distance ladder)
- IRAC Photometry for K2 Field 9 Bulge Microlensing Fields
- Tracing the Disk Warp in the Outer Galaxy
- IRAC Characterization of K2 Exoplanet Candidates and their Host Stars
- Outer Galaxy star forming regions

Exoplanets

Key capability: photometric precision to better than 30 ppm over several hours.

Existing and on-going work:

- Secondary eclipse measurements of newly discovered hot Jupiters
- Thermal phase curves for new and remaining key targets
- Microlensing parallax measurements
- Transits for Neptunes/Super-Earths to lock down presence of clouds
- Imaging outer planets with precise PSF subtraction – long time baseline for JWST
- Deep search for planet(s) around Alpha Cen B
- Repeating eclipse and transit measurements to search for variability

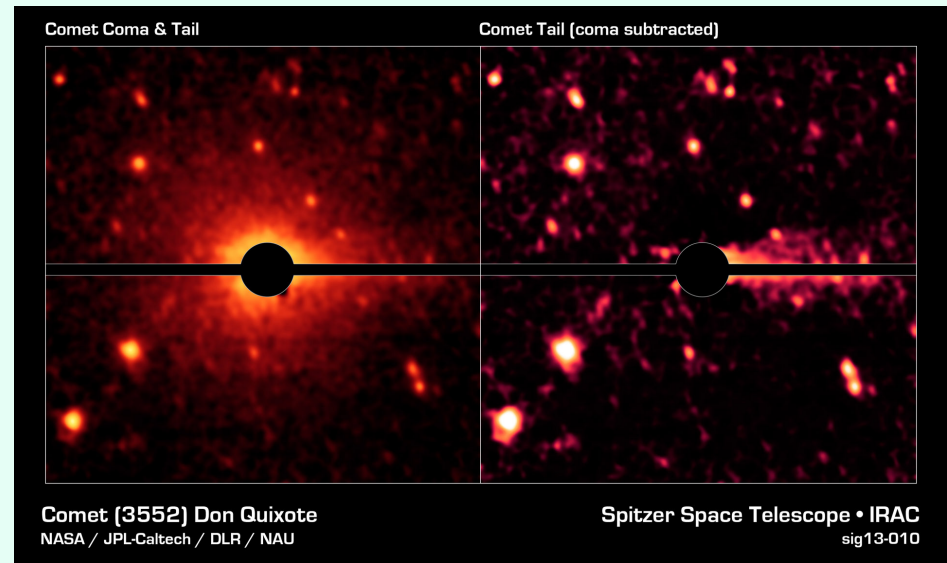


Spitzer's measurement of the phase curve of the transiting planet HAT-P-2b. A: Eclipse—the planet moves behind the star; B: Apoapse; C: Transit—the planet moves in front of the star; D: Periapse. Data from Lewis et al. (2013).

- **Key questions/observations (optimize targets for JWST):**
- Multi-epoch phase-mapping of the brightest hot Jupiters
 - Transiting/Earth-like planet search around nearby late M to T (ultracool) stars
 - Colors and astrometry of WISE Cold Brown Dwarfs/Free Floating Planets

Solar System

The archive contains a robust inventory of observations of solar system objects, including satellites, comets, asteroids, NEOs, etc., in some cases including monitoring (e.g., weather). Spitzer has the mid-infrared sensitivity and required orbital geometry for many observations.



- **Key questions/observations:**
 - Continue to identify the best targets for future direct contact missions
 - Determine sizes and albedos for faint NEOs