The Spitzer Infrared Nearby Galaxies Survey: A Review

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Science Goals

Kennicutt et al. (2003) stated that the science goals were the following:

- Provide new insights into the physical processes connecting star formation to the interstellar medium properties of galaxies.
- Characterize the infrared emission of galaxies.
- Provide a foundation for understanding infrared observations of the distant universe and ultraluminous and active galaxies.
- Produce data with a high archival value for the Spitzer user community at large.


Data

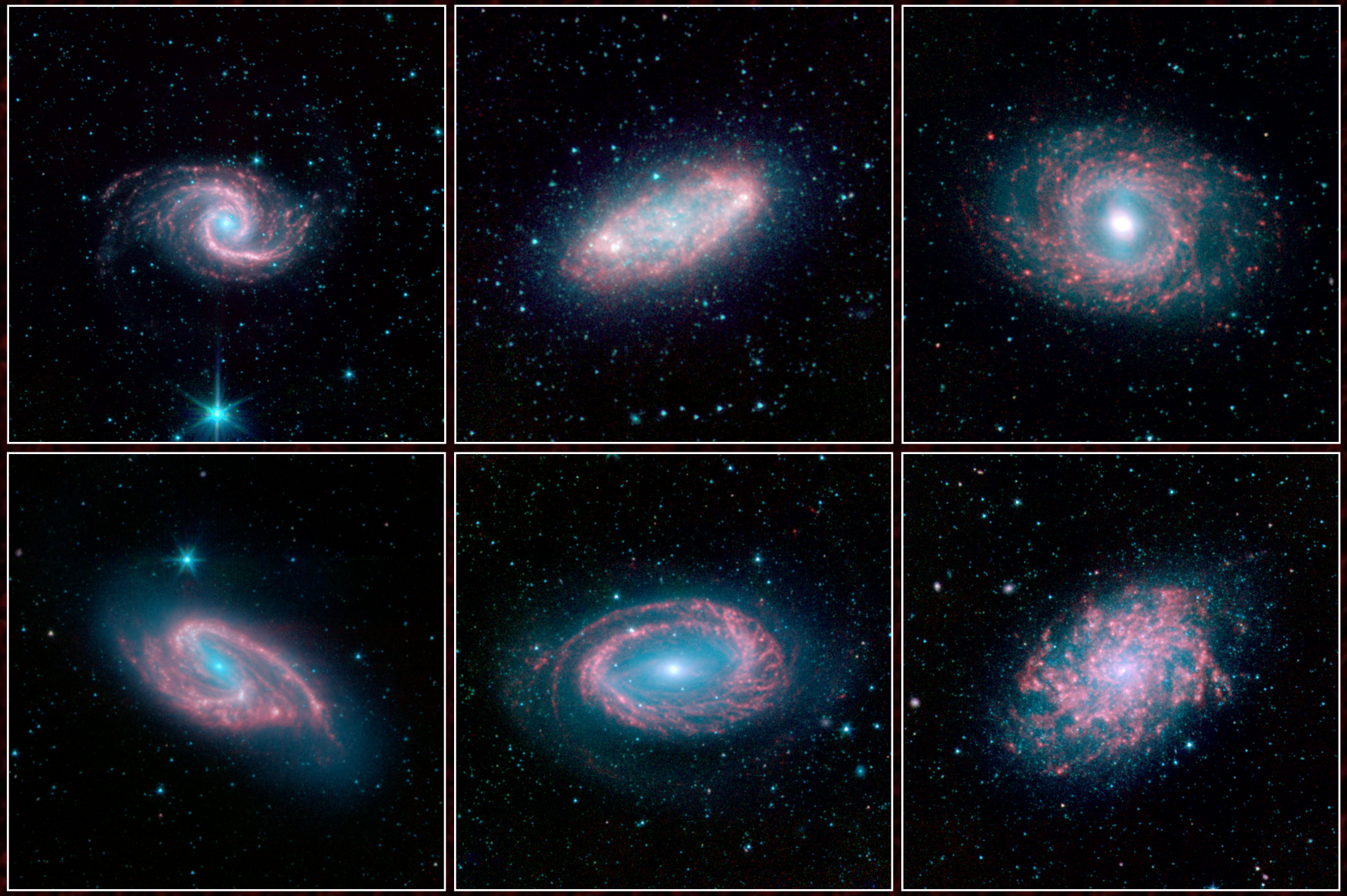
Sample

The SINGS sample contains 75 galaxies that span the following parameters:

- Morphology
- Optical luminosty
- Optical/IR ratios

Attempts were also made to include galaxies with a broad range of other properties, including environment, AGN type, bar structure, inclination, surface brightness, CO/HI ratio, and spiral structure.

Additionally, all galaxies in the M81 Group were included (in either SINGS or guaranteed time programs) so as to have a small volume-limited sample.



SINGS Data

The Spitzer data from SINGS includes:

- 3.6, 4.5, 5.7, 8.0 μm images from IRAC
- 5-40 μm spectral cubes from IRS (for nuclei and some HII regions)
- 24, 70, and 160 μm images from MIPS
- 50-90 μm MIPS spectral cubes

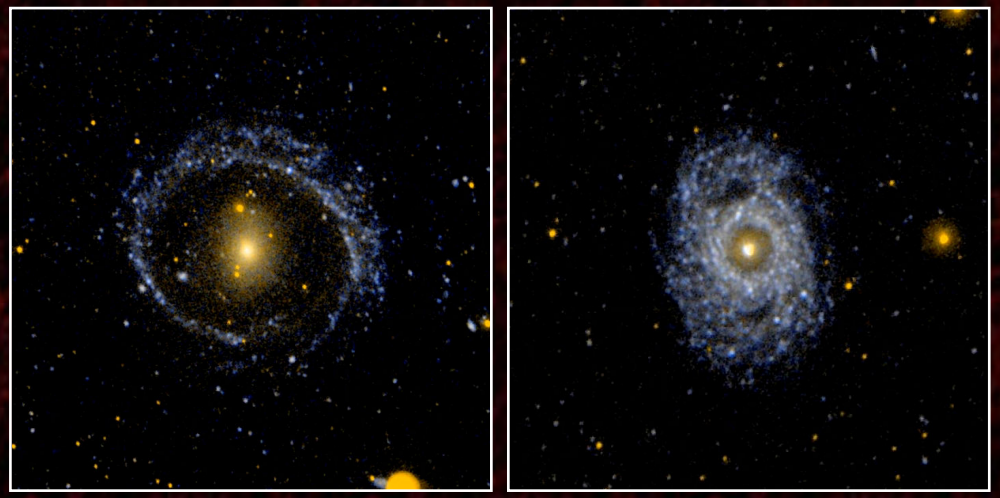
Ancillary data from SINGS includes:

- BVRI and Hα images
- Nuclear optical spectra
- Drift scan optical spectra

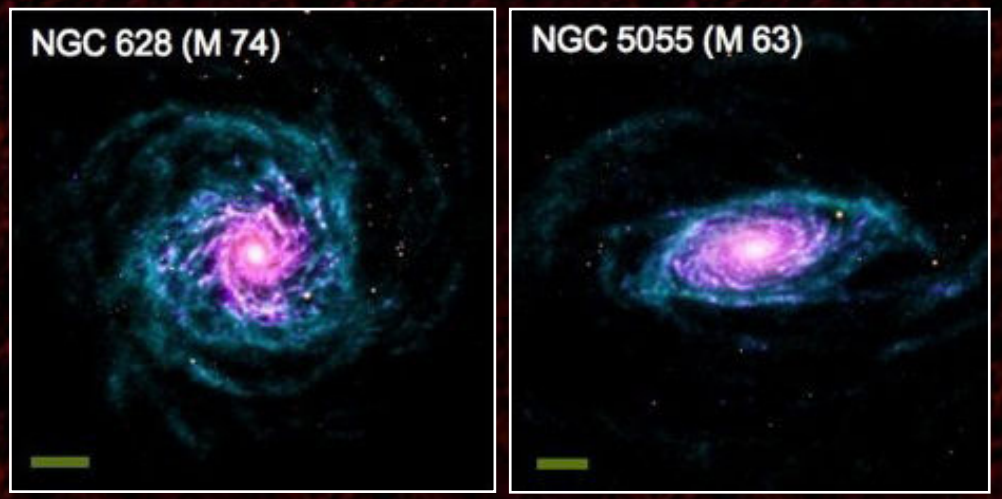
All data are now available from multiple sources, including the NED and SSC websites.

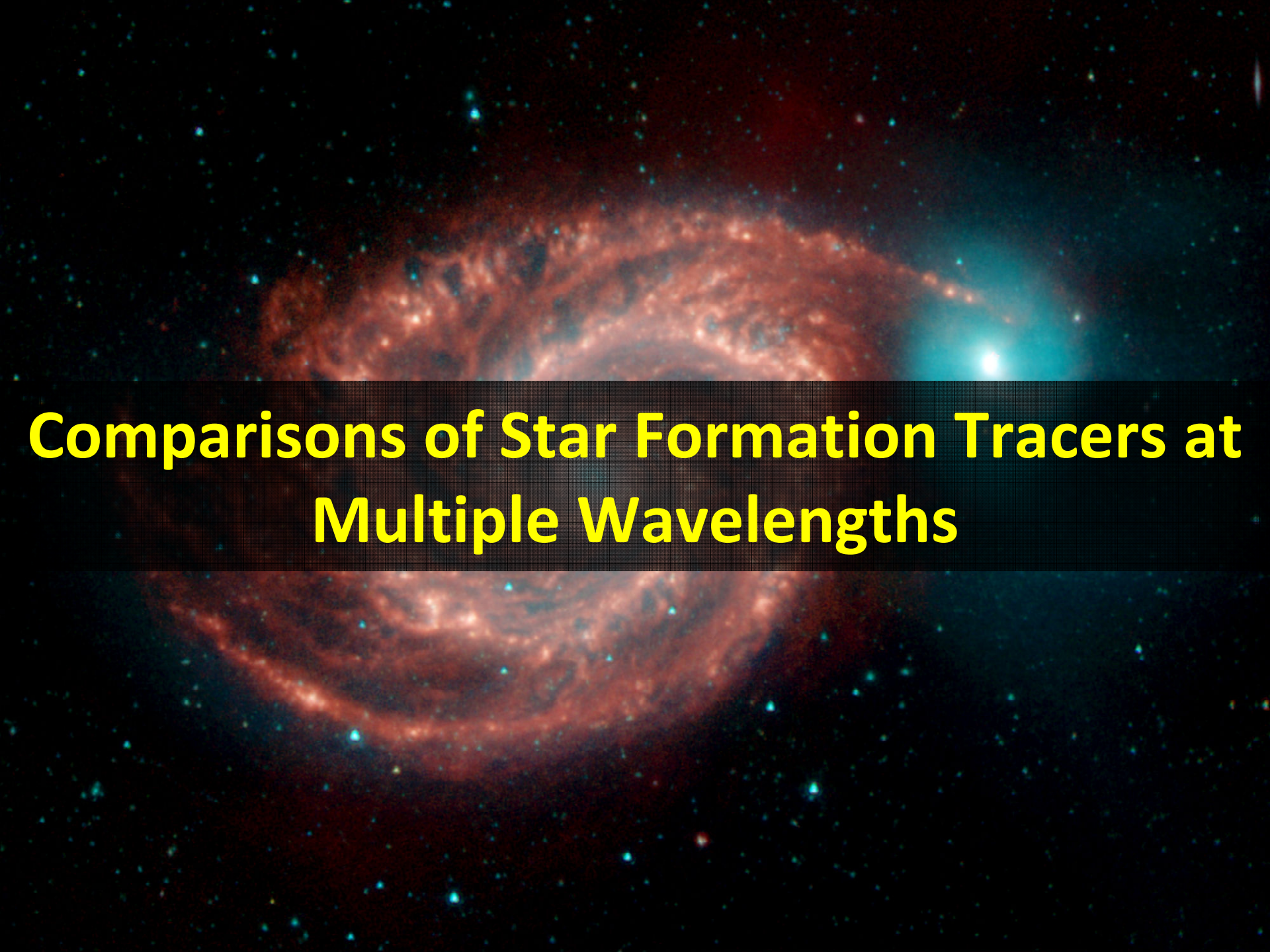
Related Surveys

GALEX has observed all SINGS galaxies in the ultraviolet (see Gil de Paz et al. (2007)).



THINGS has acquired HI data from the VLA for many of the SINGS galaxies (Walter et al. 2007), and another radio survey was carried out at Westerbork (Braun et al. 2007).



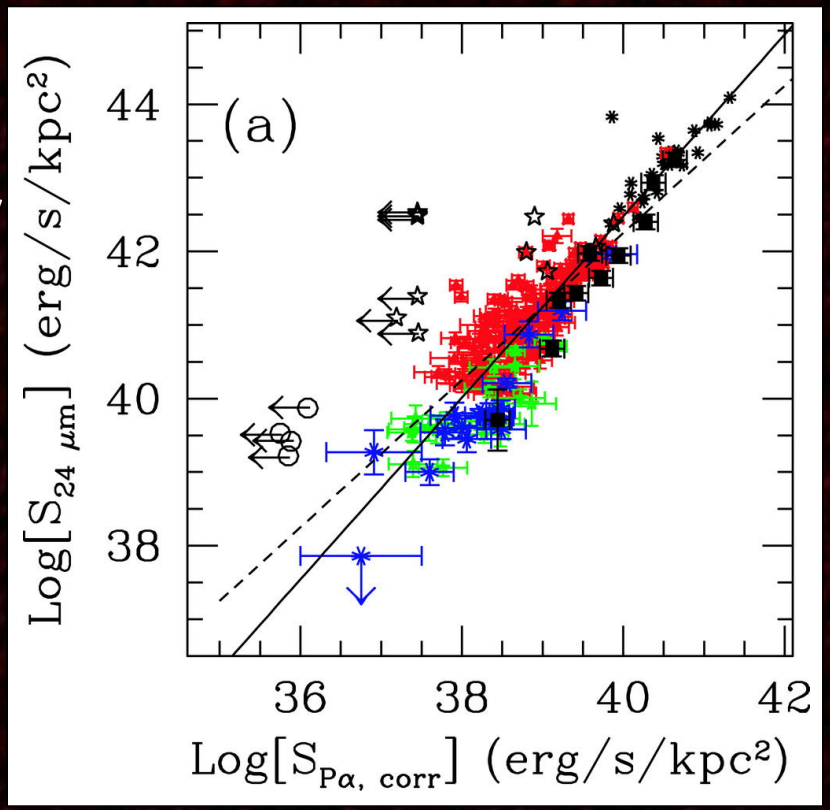

Comparisons of Star Formation Tracers at Multiple Wavelengths

Cross-Calibration of UV/Optical/NIR and 24 µm Data

Studies with flux densities measured for unresolved sources have demonstrated that the 24 µm band can be used as effectively as recombination lines and UV emission as a star formation tracer in spiral galaxies.

However, these relations break down in irregular galaxies.

SFR equations using both 24 µm and UV/optical/NIR data are now available.



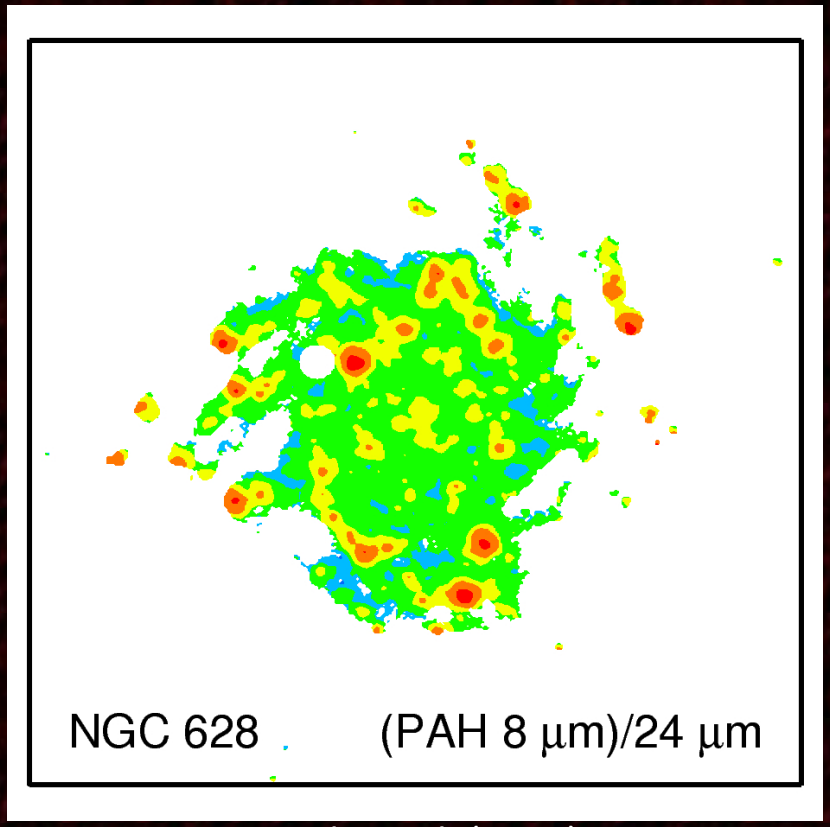
Calzetti et al. (2007)

Further reading: Gordon et al. (2004); Calzetti et al. (2005, 2007); Cannon et al. (2005, 2006, 2006); Perez-Gonzalez et al. (2006); Prescott et al. (2007); Kennicutt et al. (2007); Thilker et al. (2007)

The Relation between PAHs and Star Formation

PAHs generally do not trace star formation well.

- PAHs are relatively underluminous in SFR.
- PAHs are relatively overluminous in the diffuse ISM.
- PAH emission levels vary with the hardness of the illuminating radiation field (which varies with metallicity).



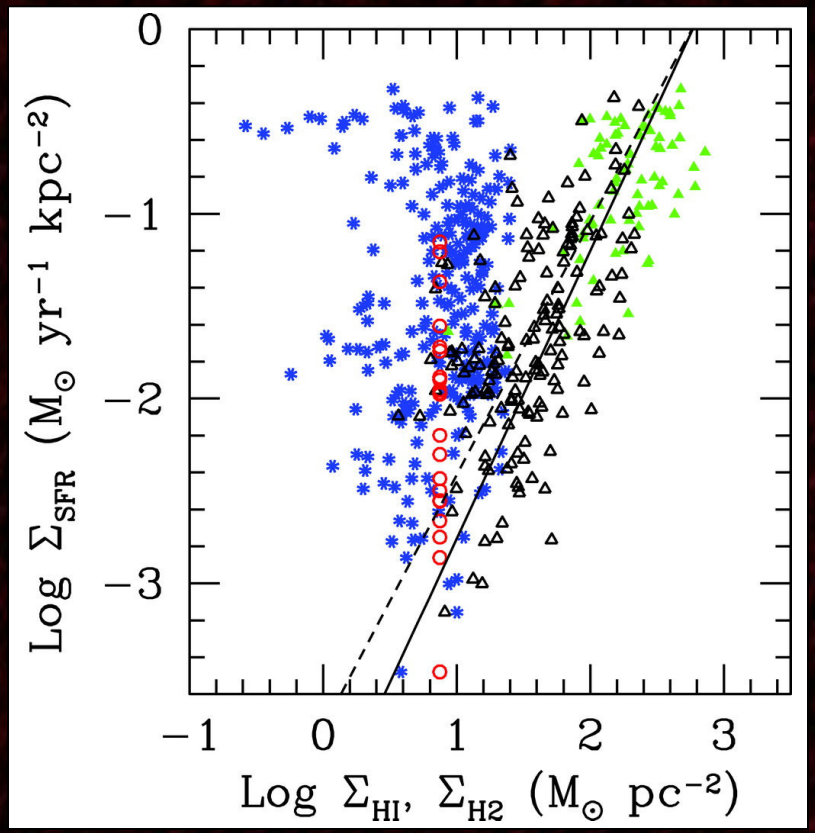
Bendo et al. (2008)

Further reading: Dale et al. (2005); Calzetti et al. (2005, 2007); Perez-Gonzalez et al. (2006); Bendo et al. (2006, 2008); Thilker et al. (2007)

The Schmidt Law

Combined IR/optical or IR/UV data have been used to calculate SFR rates in an examination of the Schmidt law in M51 and NGC 7331.

A strong correlation is found between SFR and either total or molecular gas surface density but not between SFR and atomic gas surface density.



Kennicutt et al. (2007)

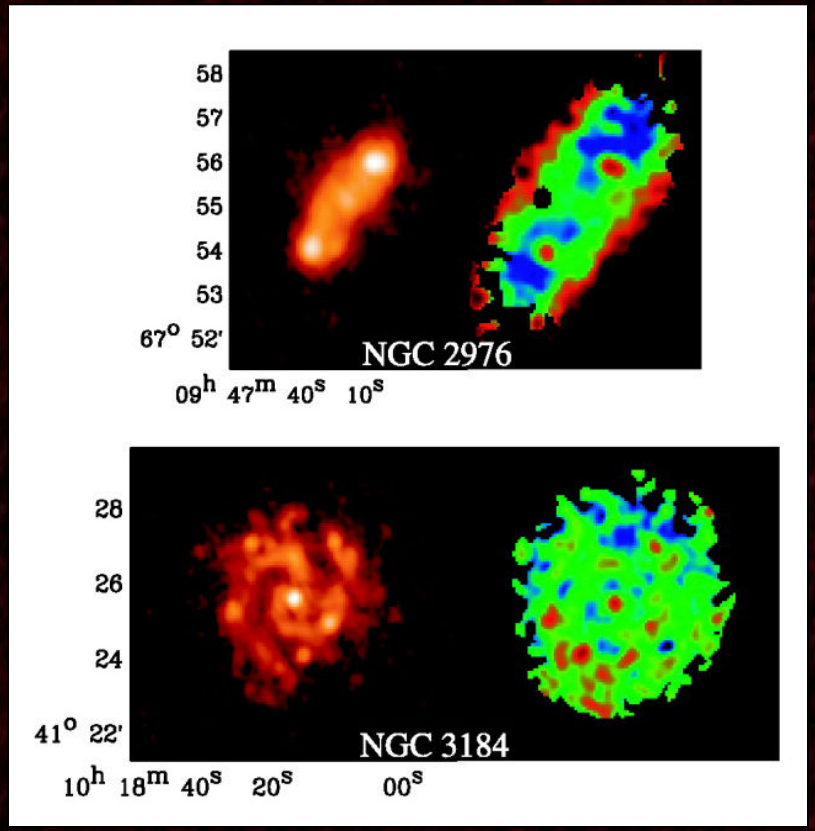
Further reading: Kennicutt et al. (2007); Thilker et al. (2007)

The FIR/Radio Relation

On small spatial scales, FIR and radio emission look correlated, but Murphy et al. (2006, 2006, 2008) have found that spatially resolved radio emission is more extended than FIR emission.

Some notable exceptions to the FIR/radio relation have been found:

- NGC 1377 (nascent starburst)
- NGC 1705 (galaxy with SSC)



Murphy et al. (2006)

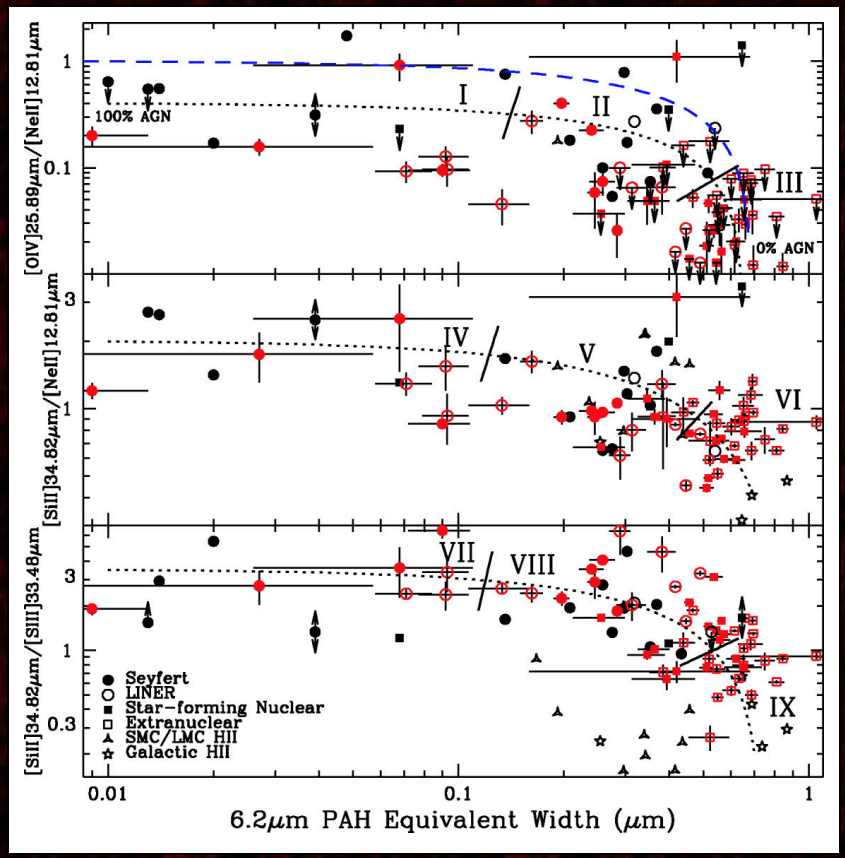
Further reading: Murphy et al. (2006, 2006, 2008); Cannon et al. (2006); Roussel et al. (2006)

Other Aspects of Star Formation

AGN/Starburst Diagnostics

Dale et al. (2006) have refined and expanded the use of mid-infrared spectral diagnostics for separating AGN and starburst nuclei.

These diagnostics have been used to identify AGN in SINGS galaxies and other nearby galaxies.



Dale et al. (2006)

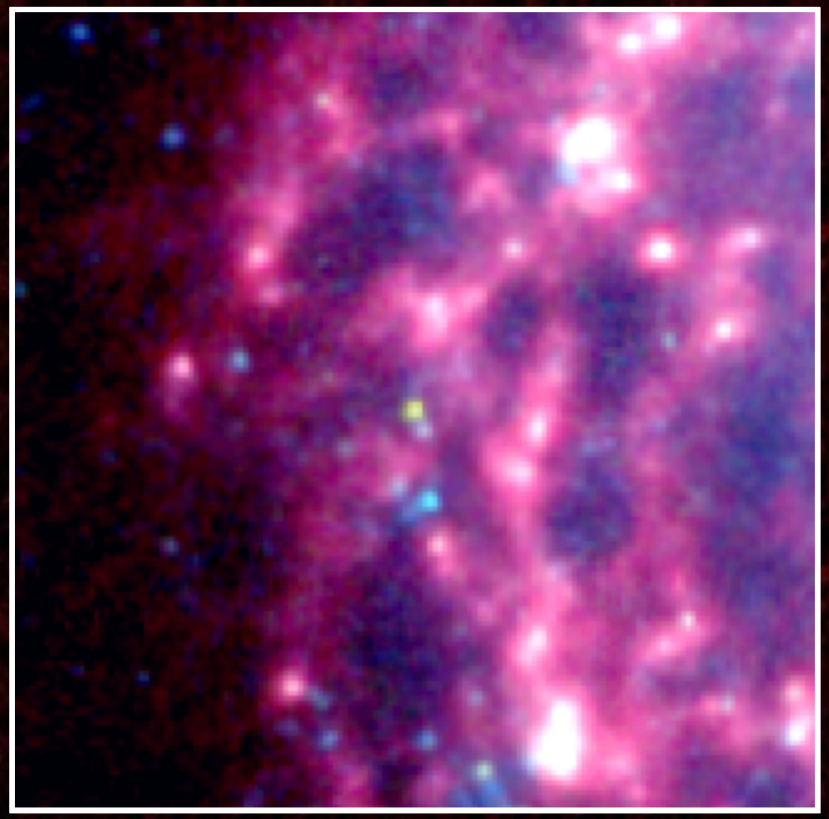
Further reading: Dale et al. (2006); Bendo et al. (2006); Satyapal (2007, 2008)

Supernovae

At least three supernovae have been serendipitously observed in SINGS:

- SN 2002hh (NGC 6946)
- SN 2003gd (NGC 628)
- SN 2004dj (NGC 2403)

While the SINGS data have been only supplementary, they have been useful in constraining the masses of dust produced in supernovae.



SN 2003gd (Sugerman et al. 2005; Meikle et al. 2007)

Further reading: Barlow et al. (2005); Kotak et al. (2005); Meikle et al. (2006; 2007)

Superwinds

An examination of the Spitzer data for M82 show that the superwind contains large amounts of PAHs. The PAHs extend up to 6 kpc from the midplane of the galaxy.

M82 (Engelbracht et al. 2005)

Further reading: Engelbracht et al. (2006)

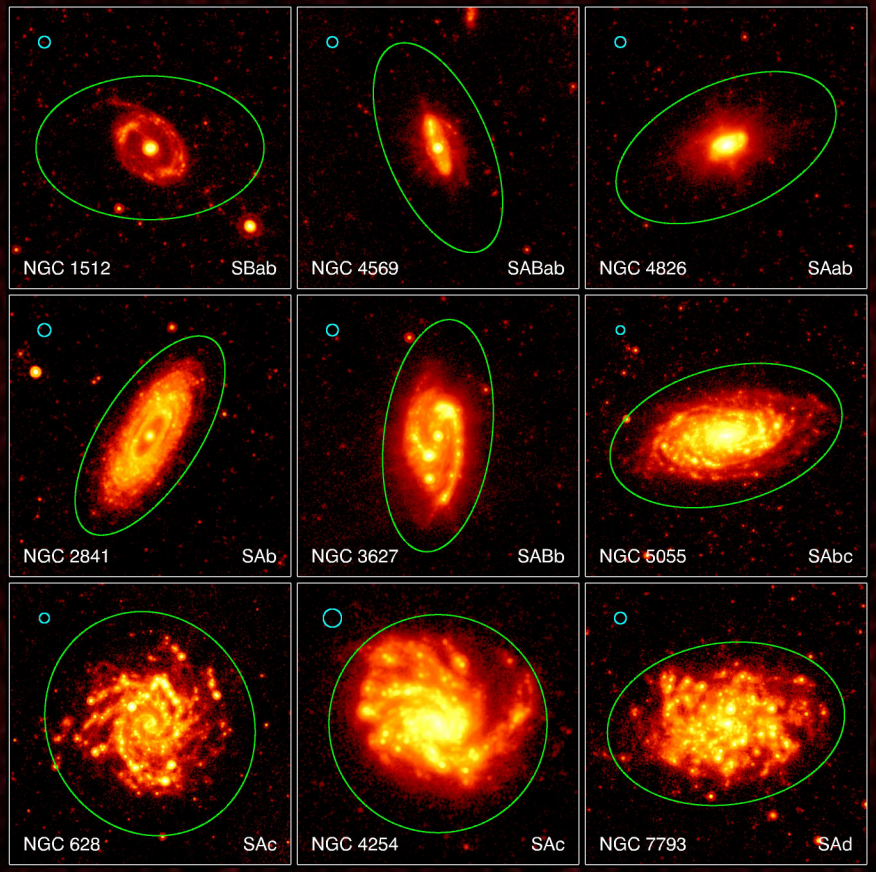
Distribution of Dust/Star Formation

Bendo et al. (2007) found variations in the distribution of star formation between early- and late-type galaxies.

Several groups found that bars also lead to centrally concentrated dust and strong nuclear star formation within spiral galaxies.

Two groups found instances where tidal stripping truncated star formation and gas disks in Virgo Cluster galaxies.

Thornley et al. (2006) found highly extended dust emission in M51 that implied that low-efficiency star formation was present.



Bendo et al. (2007)

Further reading: Regan et al. (2006); Allard et al. (2006); Boselli et al. (2006); Thornley et al. (2006); Bendo et al. (2007)

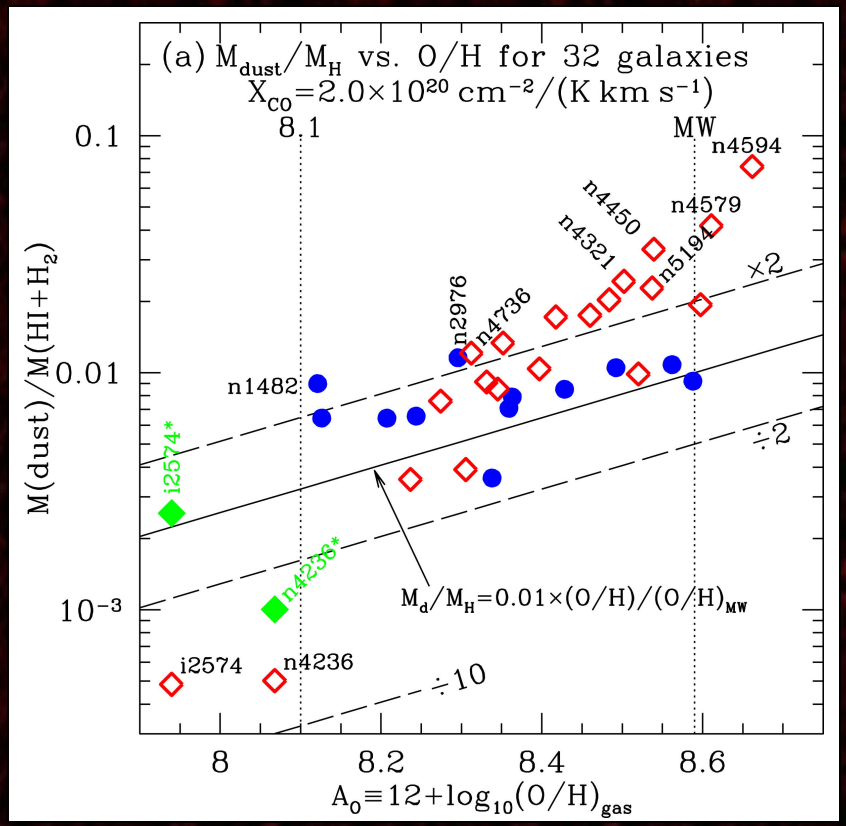

Properties of Dust

Dust/Gas Ratios

SINGS has repeatedly shown that the bulk of dust in nearby galaxies is ~15-25 K and that the gas/dust ratio is ~100 for spiral galaxies.

However, dwarf galaxies with lower metallicities are found to have higher gas/dust ratios.

Although "excess" 850 μm emission was found in NGC 4594 and NGC 4631, the conclusions were that this did not imply large masses of <10 K dust.



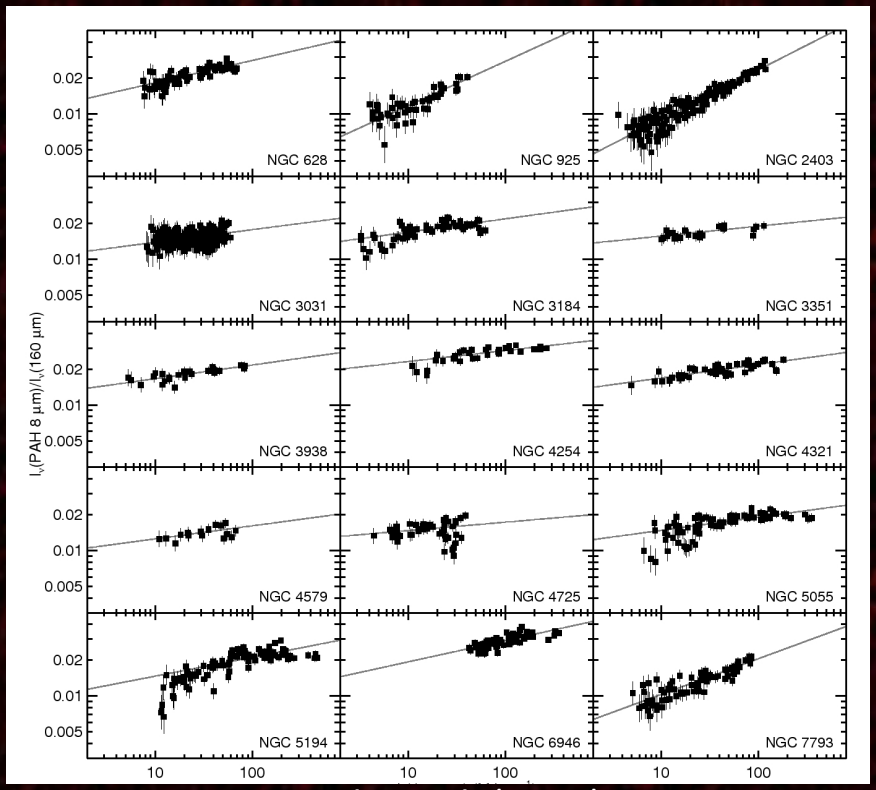
Draine et al. (2007)

Further reading: Regan et al. (2004); Cannon et al. (2006); Bendo et al. (2006, 2006); Perez-Gonzalez et al. (2006); Walter et al. (2007); Draine et al. (2007)

PAH/Dust Ratios

The PAH/24 μm ratio has been shown by SINGS and other surveys to be highly sensitive to ionization, which also leads to a drop in PAH emission in low metallicity regions.

However, PAHs have been shown to be associated with cold dust emission and CO.



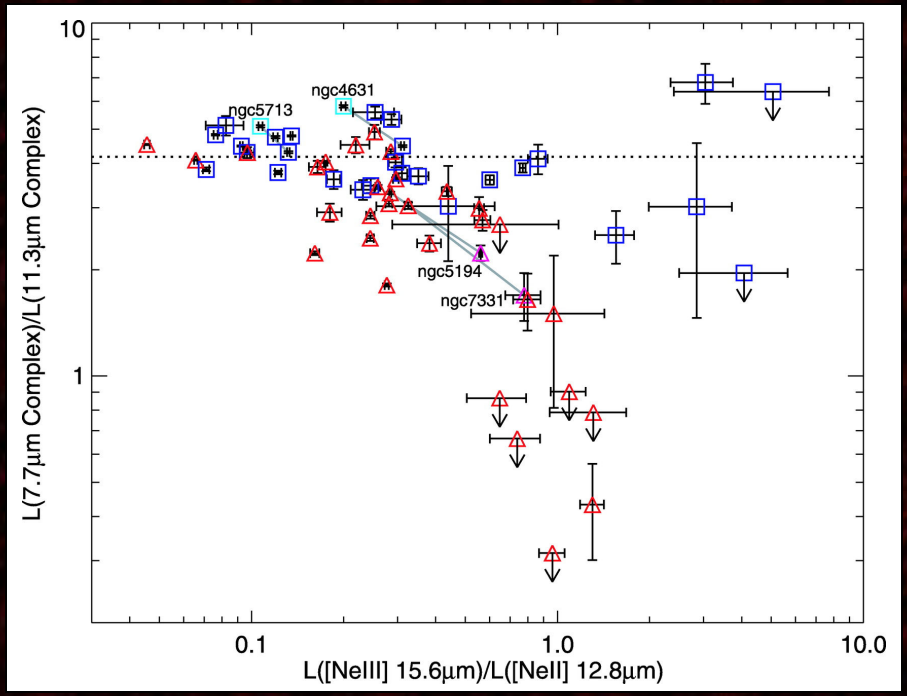
Bendo et al. (2008)

Further reading: Dale et al. (2005); Regan et al. (2006); Bendo et al. (2006, 2008); Smith et al. (2007); Draine et al. (2007); Calzetti et al. (2007); Munoz-Mateos et al. (2008)

PAH Spectral Feature Ratios

Smith et al. (2007) and Hunter & Kaufman (2007) found that PAH spectral features vary relative to each other.

Smith et al. (2007) found that the relative strength of the 11.3 μm complex increased relative to 5-8 μm PAH features as the hardness of the illuminating spectrum increased.



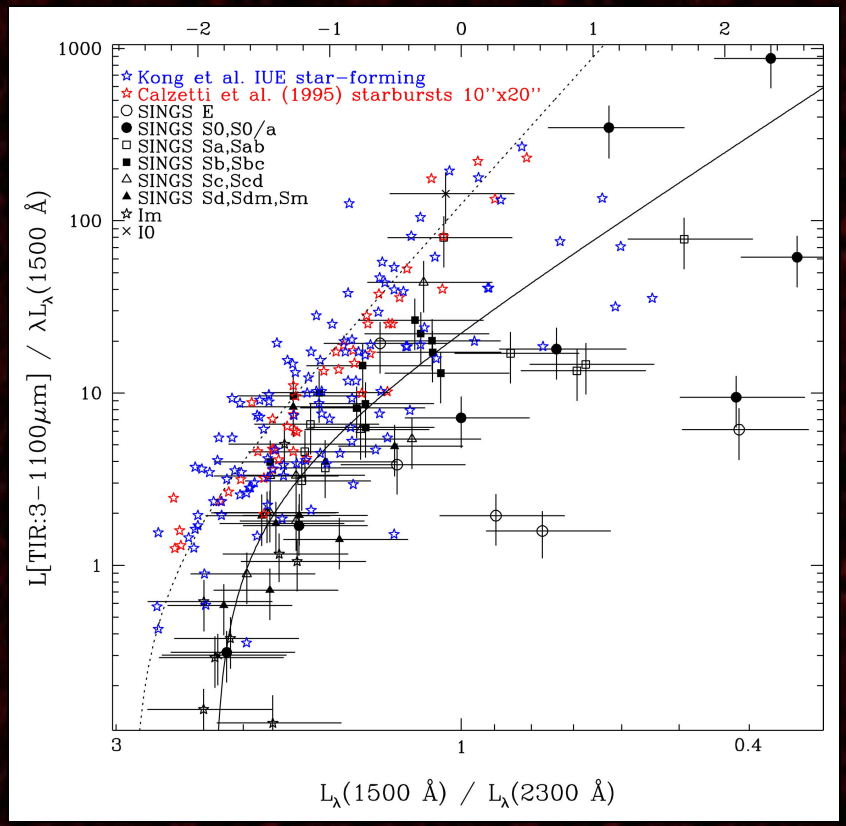
Smith et al. (2007)

Further reading: Smith et al. (2007); Hunter & Kaufman (2007)

Extinction

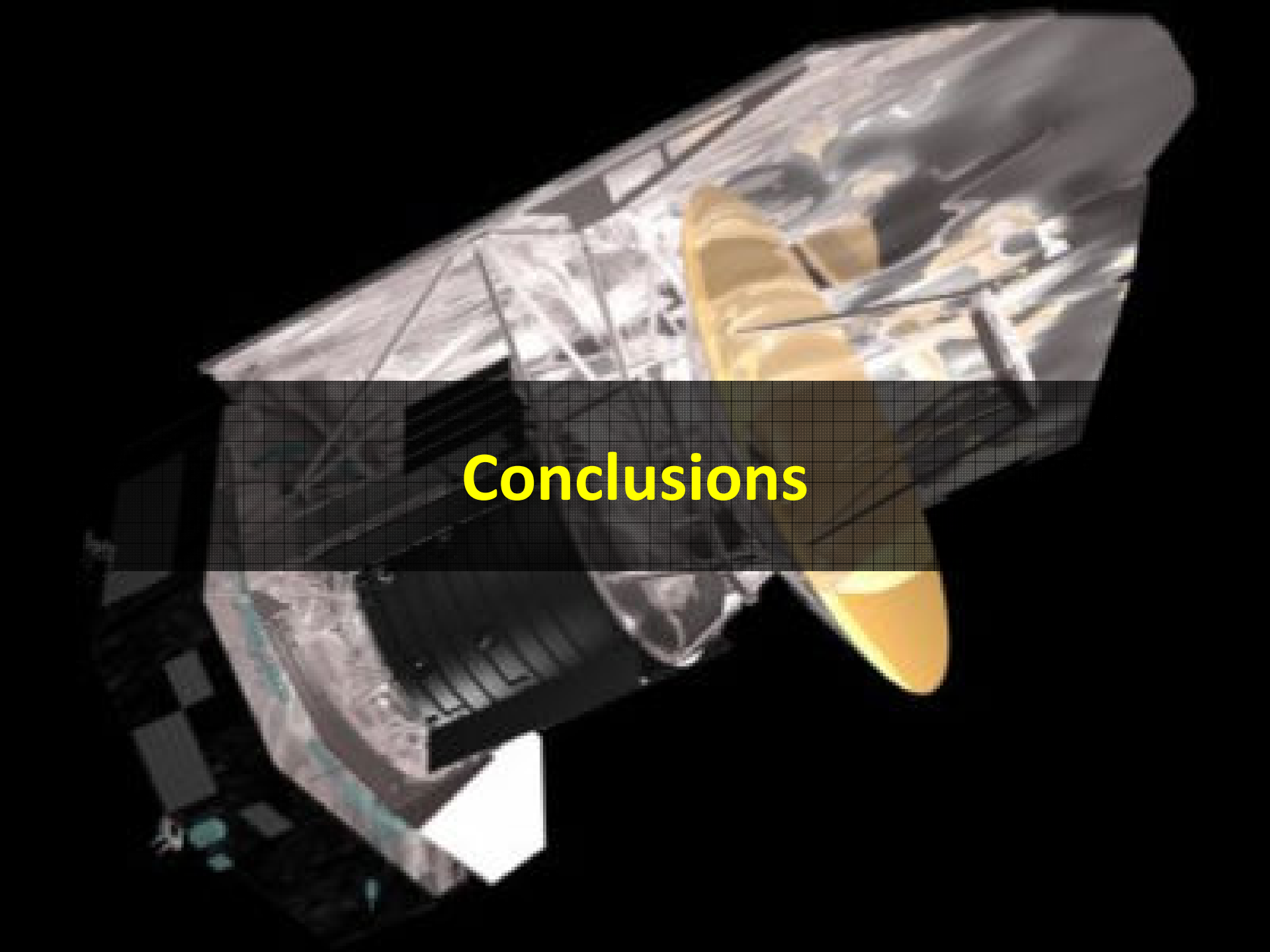
FIR data have been combined with UV and optical data to examine extinction.

The most significant result is a strong correlation between the FIR/UV ratio and UV spectral slope. Most galaxies fall on the relation for normal star-forming galaxies, but some are more starburst-like in terms of extinction.



Dale et al. (2007)

Further reading: Dale et al. (2007); Holwerda et al. (2007); Thilker et al. (2007); Munoz-Mateos et al. (2008)


Conclusions

Goals Achieved by SINGS

- Various infrared wave bands were tested as star formation tracers. In particular, the 24 μm band was shown to be a very good tracer of spatially resolved star formation, and calibration terms have been derived to convert 24 μm flux density into star formation rates.
- SEDs and basic properties of dust in nearby galaxies have been characterized using SINGS data.
- Results from SINGS (including SFR equations, AGN diagnostics, and SEDs) have been applied to the study of more distant galaxies and infrared-bright galaxies.
- Data from SINGS have been used for archival studies, for bolstering other Spitzer studies, and for preparation for future surveys.

Future Surveys on SINGS Galaxies

SPIRE SAG2

Three guaranteed time Herschel surveys (Very Nearby Galaxies, Dwarf Galaxies, and Herschel Reference Sample) will cover 16 of the SINGS galaxies.

KINGFISH

Kennicutt is leading an open time key program on Herschel to observe many of the SINGS galaxies with Herschel.

JCMT Nearby Galaxies Survey

This survey will observe approximately half of the SINGS galaxies with the JCMT, obtaining 450 μm, 850 μm, and CO (3-2) data.