Infrared properties of Infrared Galaxies: from Spirals to ULIRGs

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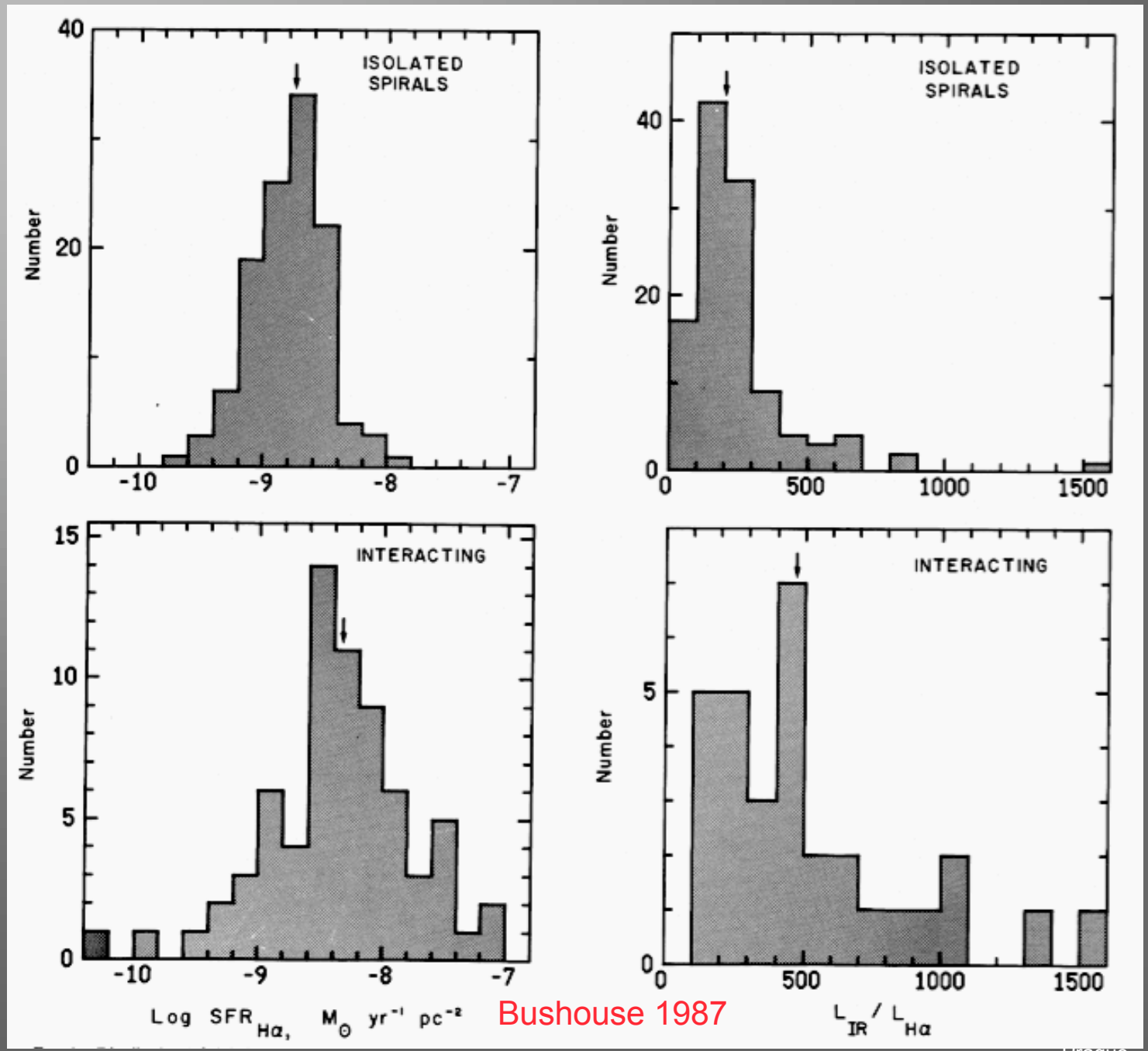
Relevant Presentations
Talks IAU 235: Cesarsky, Sanders
Talks IAU 237: Kennicutt, Struck, Duc
Posters: Appleton, Boquien, Relano, Zezas

Why study Interacting Galaxies

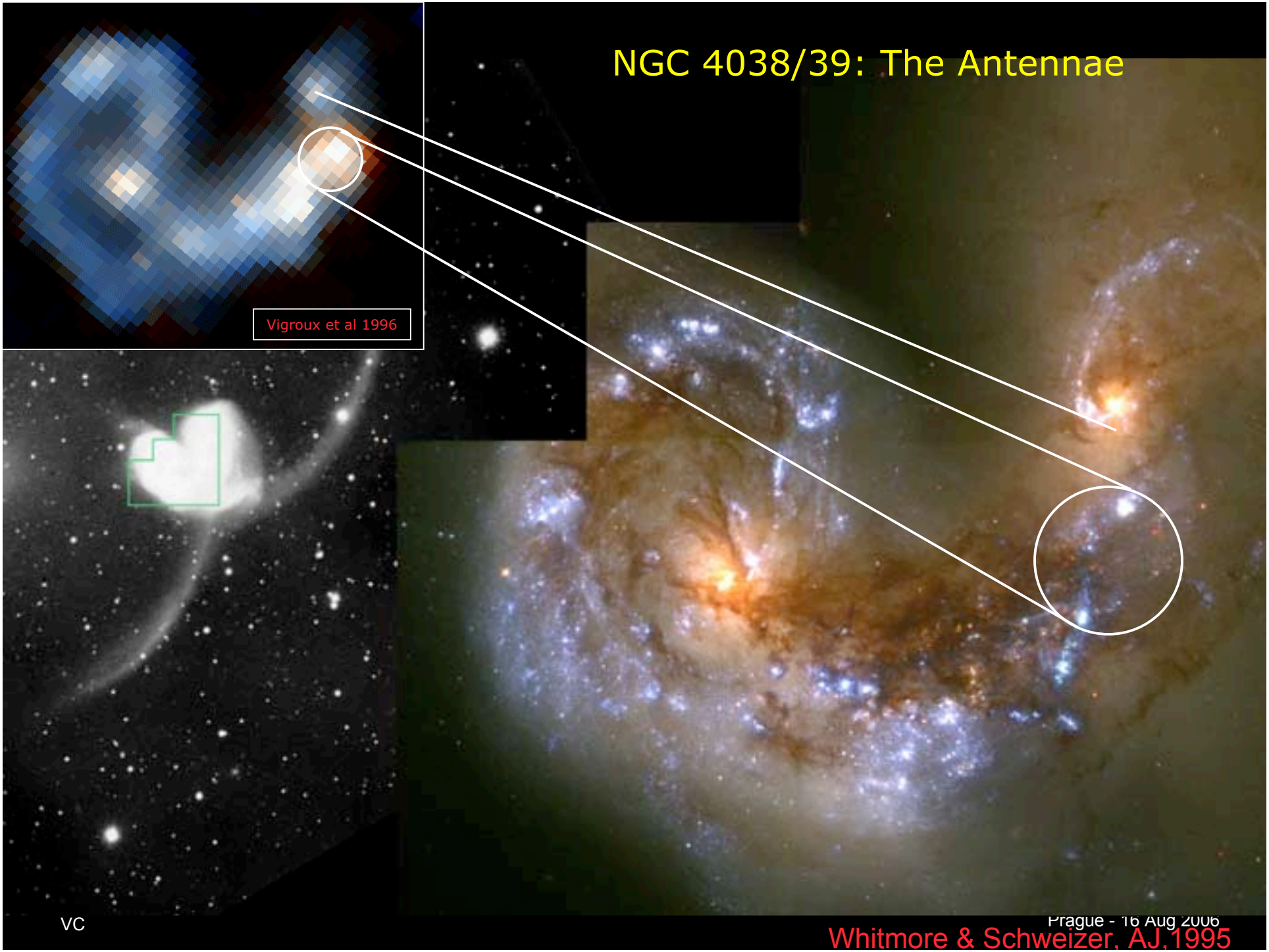
- Most galaxies are not isolated (Baade 1920)
- Interactions determine the morphology and evolution of galaxies.
- Our own Galaxy is interacting with the LMC and SMC
- The galaxy merging rate increases with redshift ~$(1+z)^m$, m>2 (Carlberg et al. 1990, Lavery et al '96)

  => Cosmological implications (a must in order to attract attention and funding!)

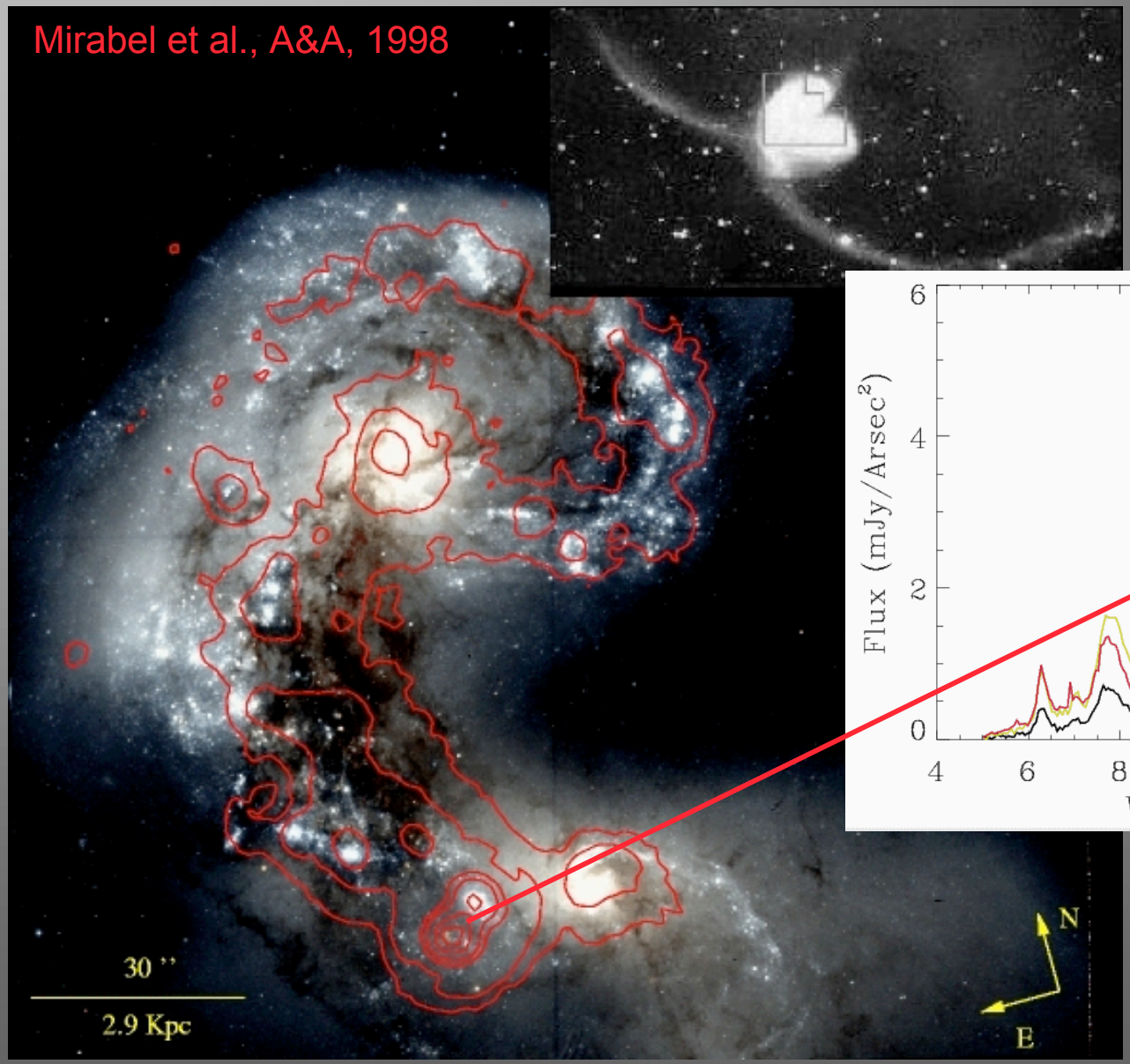
- Massive starbursts are found in regions with high dust content
  - ⇨ *they are often hidden in the optical -> IRAS (Soifer et al. 1984, Houck et al. 1984, Bushouse 87)*
  - ⇨ *most of the energy is emitted in the infrared wavelengths*
- Nearly all Luminous IR galaxies (LIGs) are mergers (ie. Sanders 1988)
- The optical/near-IR morphology is misleading (Bushouse & Werner 1990, Mirabel et al. 1998)

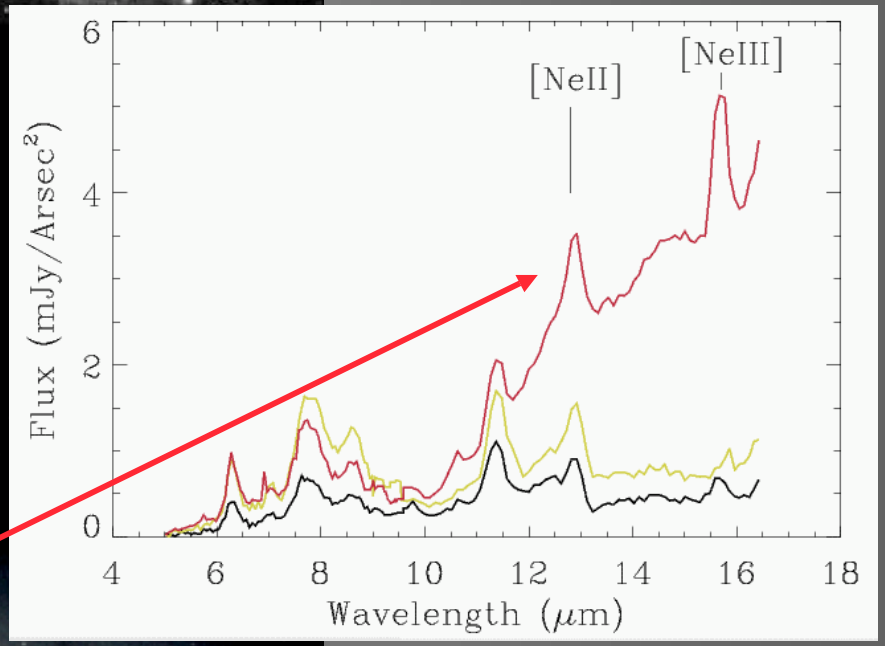


Bushouse 1987


NGC 4038/39: The Antennae
Vigroux et al 1996
VC
Prague - 16 Aug 2006
Whitmore & Schweizer, AJ,1995

NGC4038/39 – Mid-IR spectroscopy



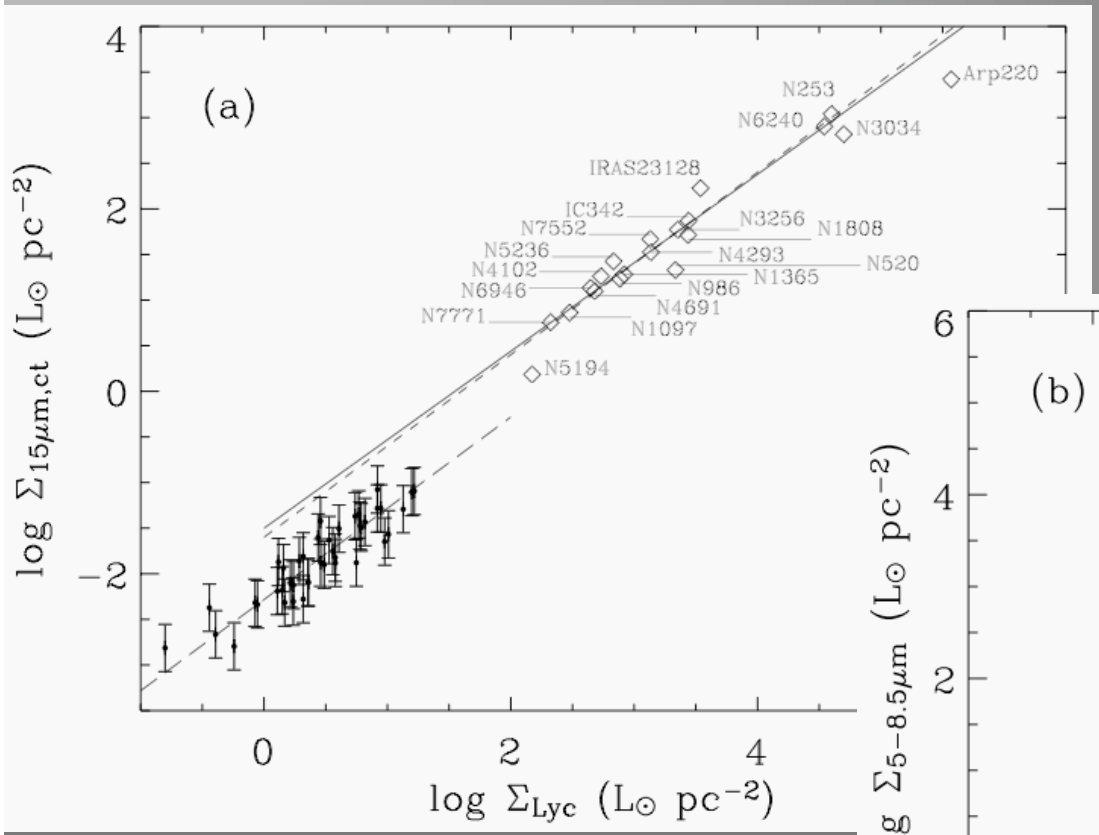


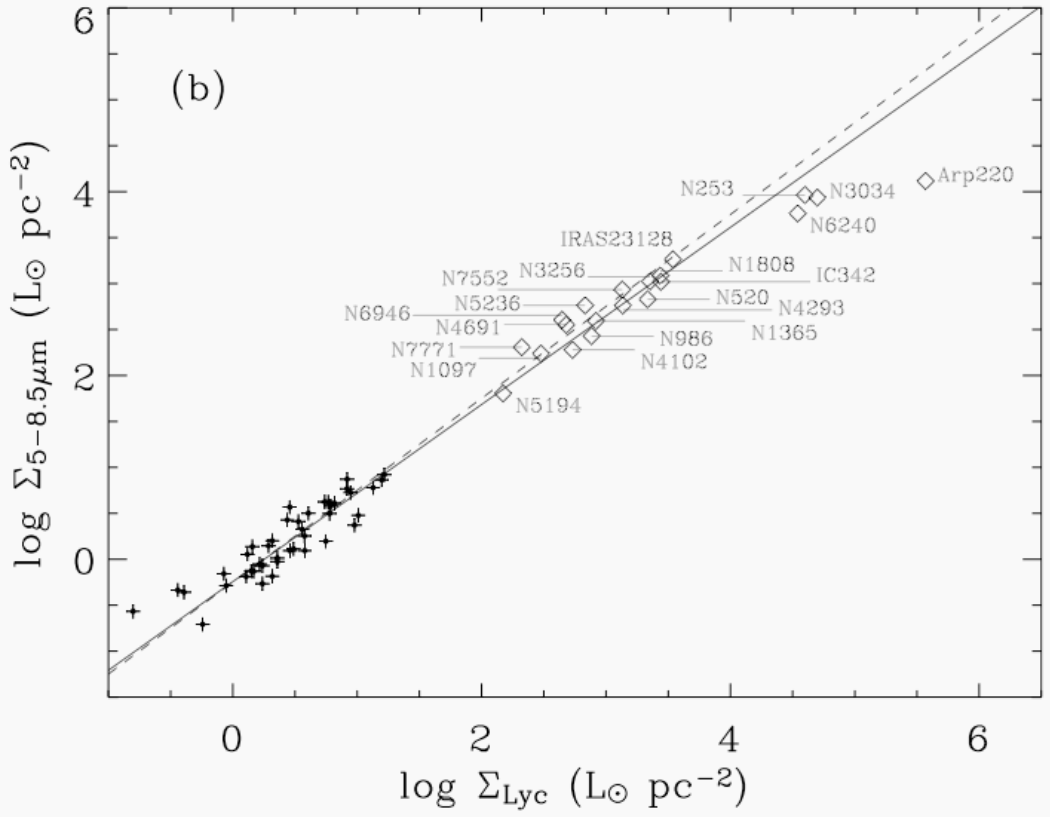
L(IR)~5x10^{10} Lsun

Dust and Star Formation

- Dust grains act as catalyst for the formation of molecular gas
- Dust grains are responsible for the heating of the gas
  - *A far-UV photon hits a dust grain and ejects an electron*
  - *The ejected photoelectron heats the gas (very inefficiently ~0.1 - 1 %)*
    - 50% of gas heating is due to grains of sizes < 15 Å
  - *Subsequently the gas cools via far-IR emission lines ([OI] 63 um , [CII] 158 um)*
- Emission from Polycyclic Aromatic Hydrocarbons (PAHs), dominate the mid-IR (5-20 um) flux in normal galaxies and quiescent star forming regions
- One can use mid- / far-IR prescriptions to estimate star formation rates (Far-IR: Kennicutt 1998, Mid-IR/ISO: Rousell et al. 2002, Forster-Schreiber et al 2004, Mid-IR/Spitzer: Calzetti et al. 2005, Wu et al. 2005, Relano et al. 2006)

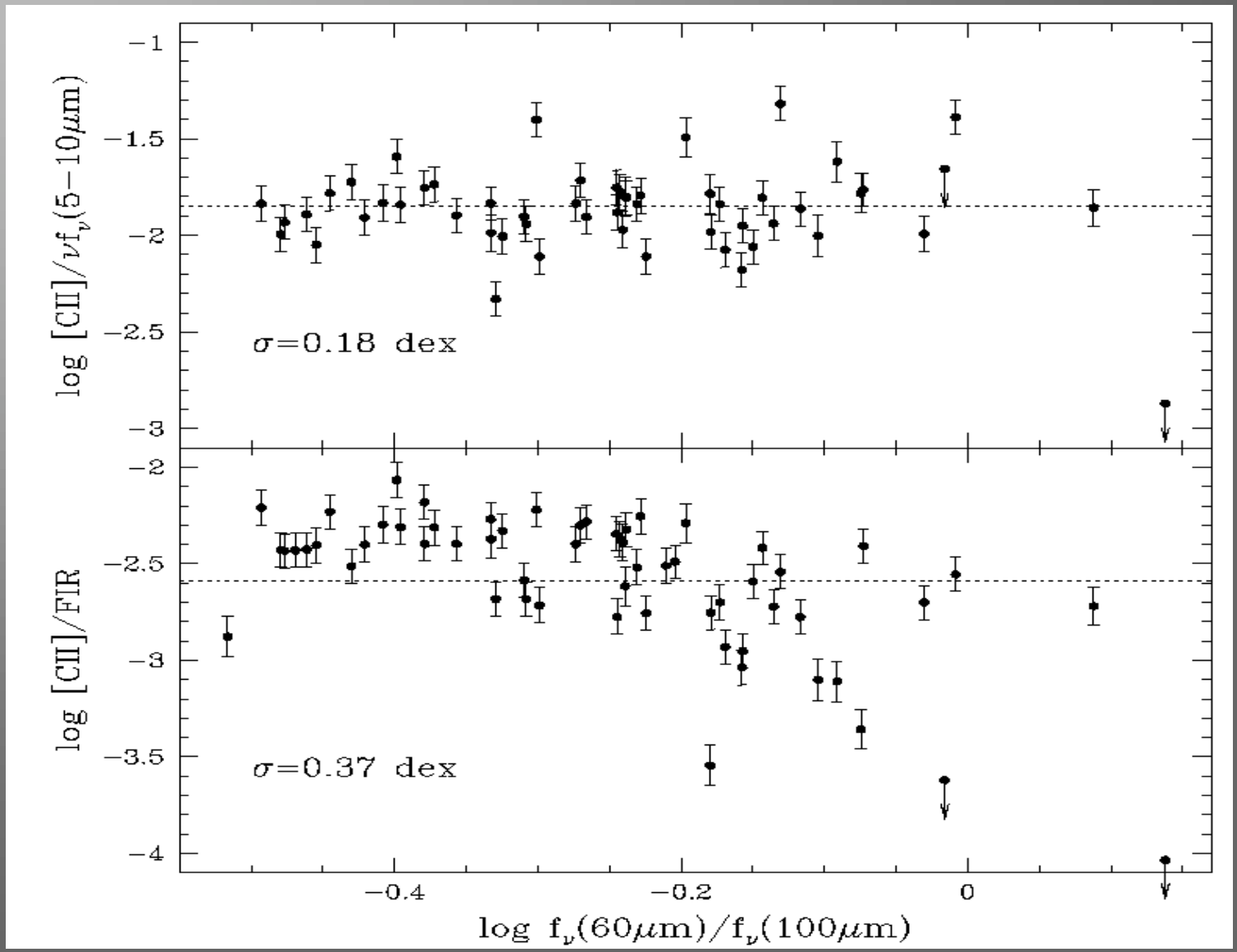
Mid-IR Emission as star formation tracer





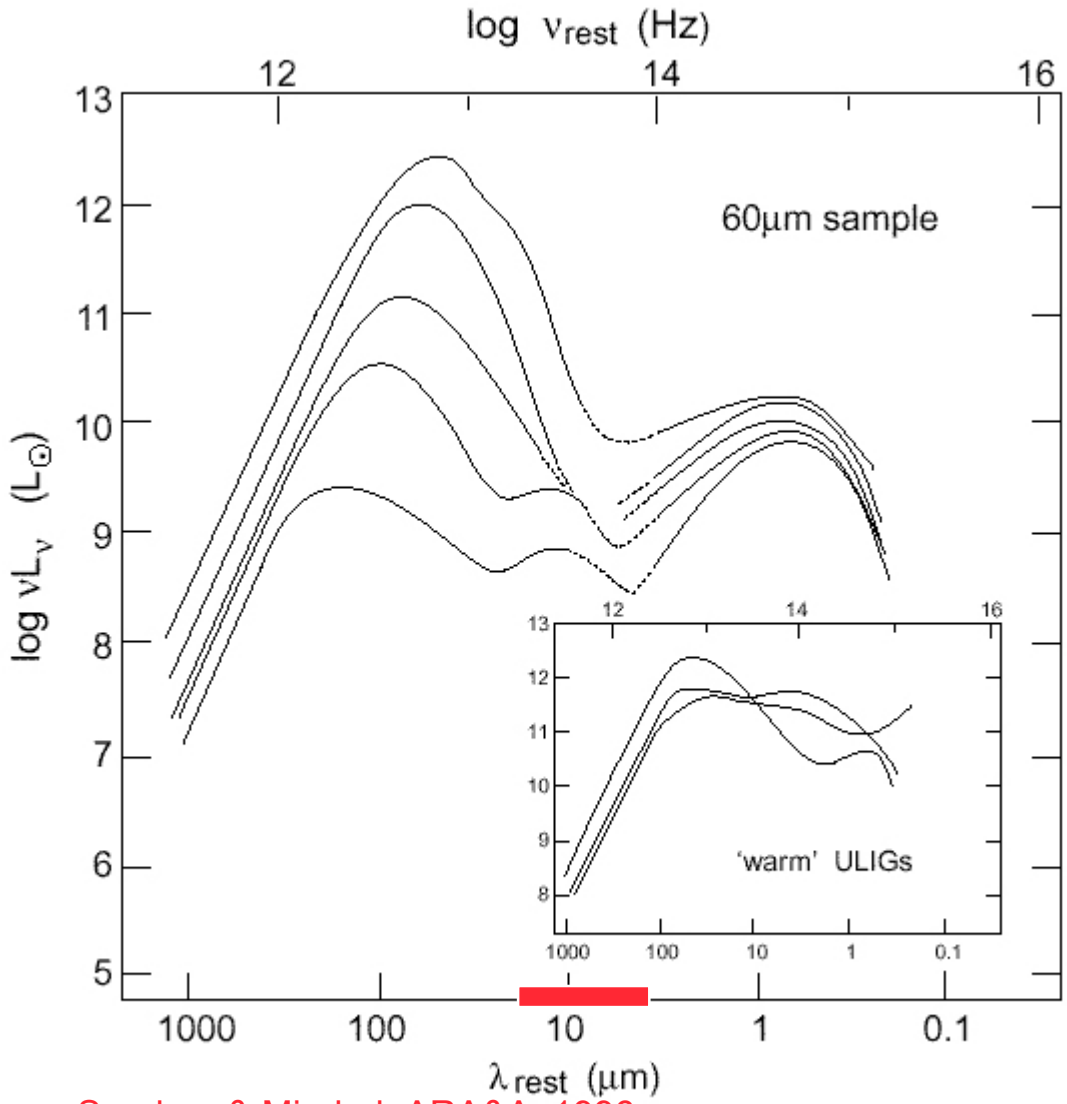
Forster-Schreiber et al., A&A, 2004

Energy Balance



Helou et al., ApJ, 2001

The SED of LIGs



Sanders & Mirabel, ARA&A, 1996

In the Mid-IR:

- we are less affected by absorption than in optical Av = 70*A (15um)
- better spatial resolution than Far-IR

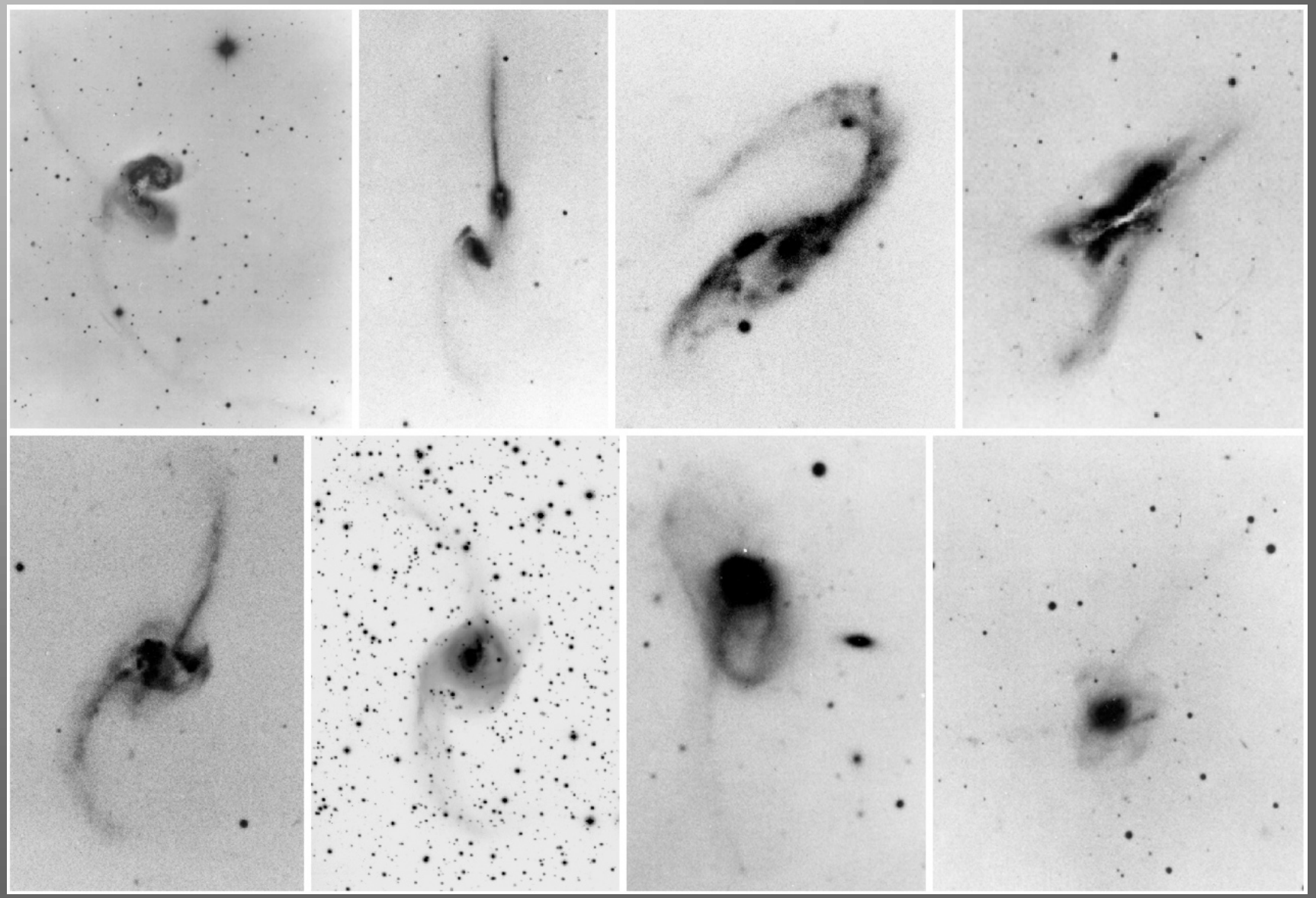
BUT…

•Only a fraction of the bolometric luminosity is emitted in the mid-IR.

Can we still say something about the global energy production using the mid-IR?

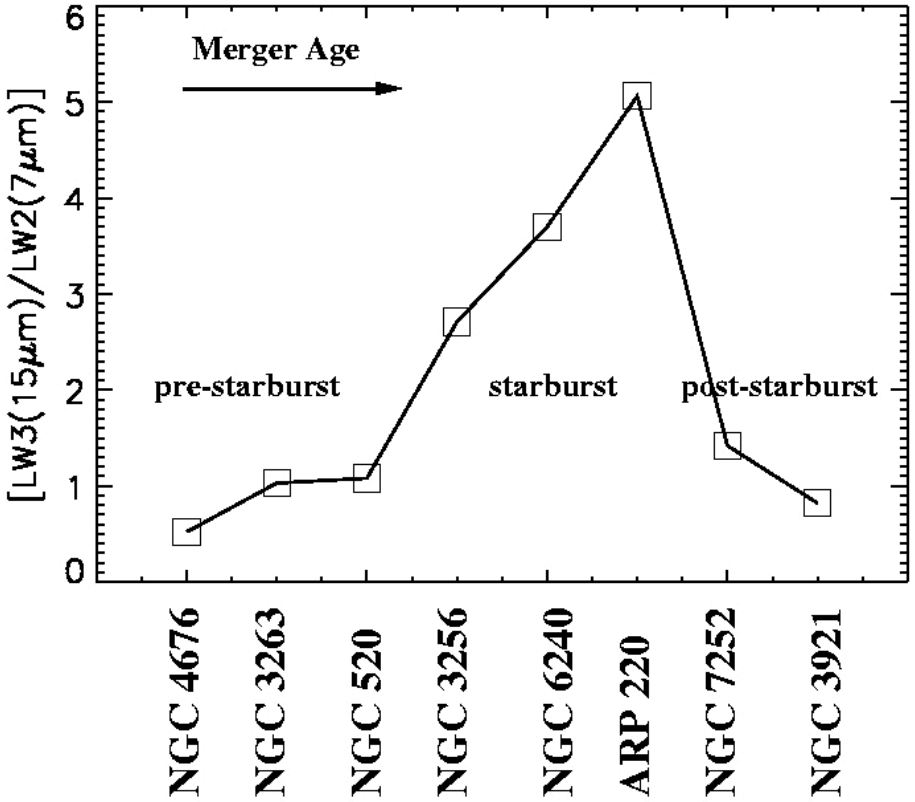
Yes! or maybe...

Toomre's Sequence

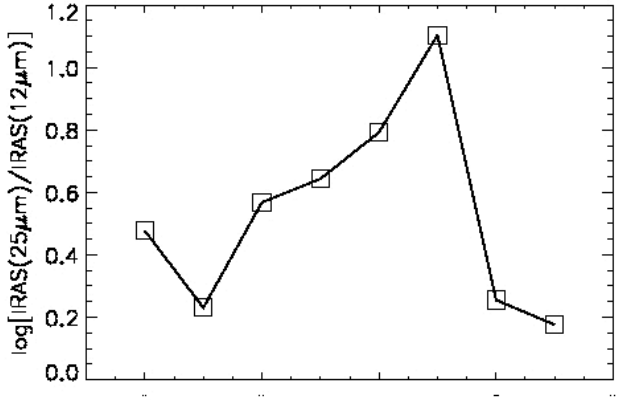


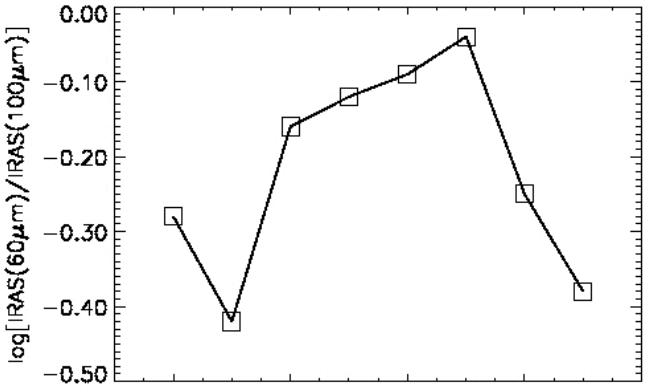
Mid-IR Far-IR Correlation in Toomre's Sequence

ISO: 15um / 7um



IRAS 25um / IRAS 12um



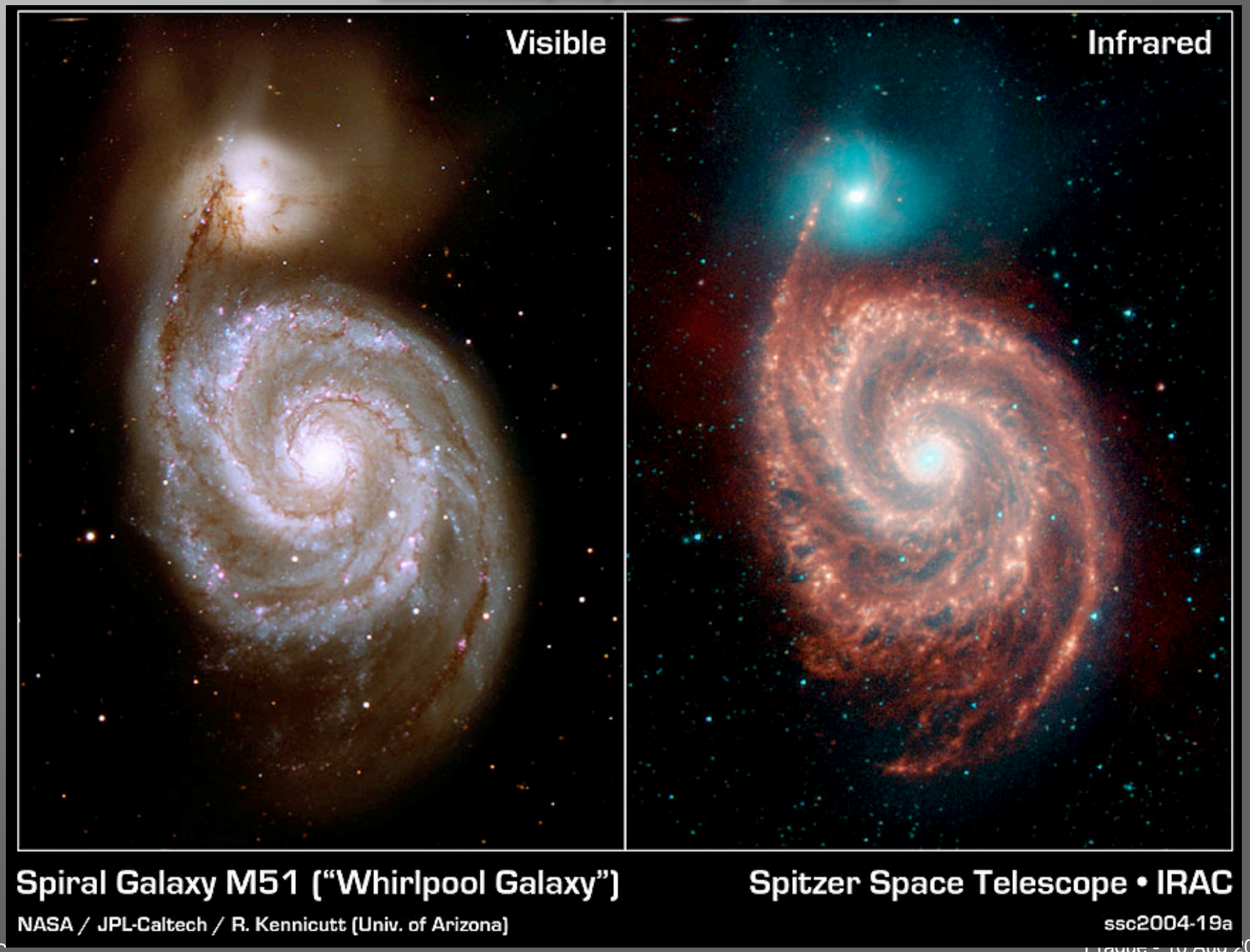


Charmandaris et al., 2001

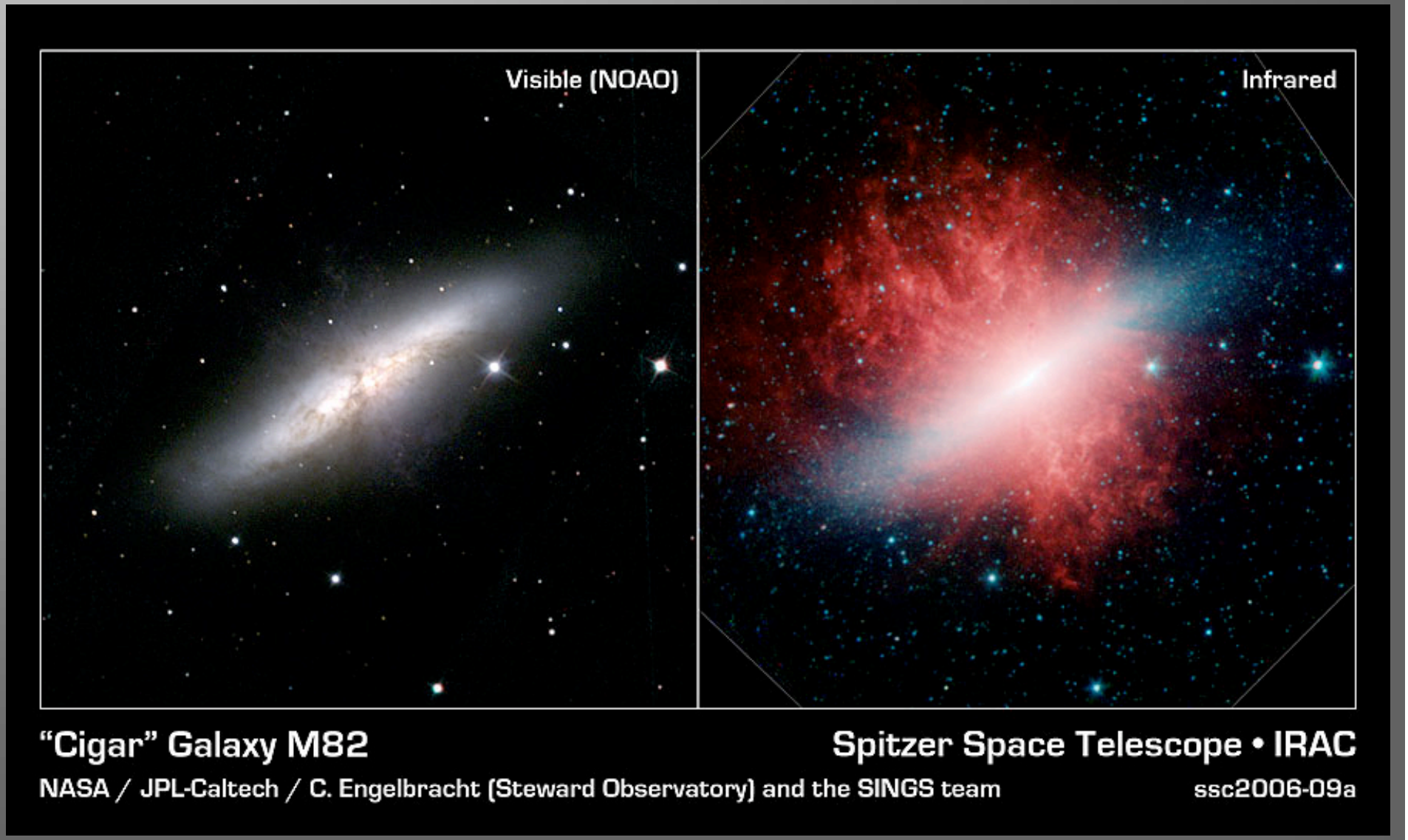
IRAS 60um / IRAS 100um

Mid-IR imaging does reveal the intensity/age of a starburst

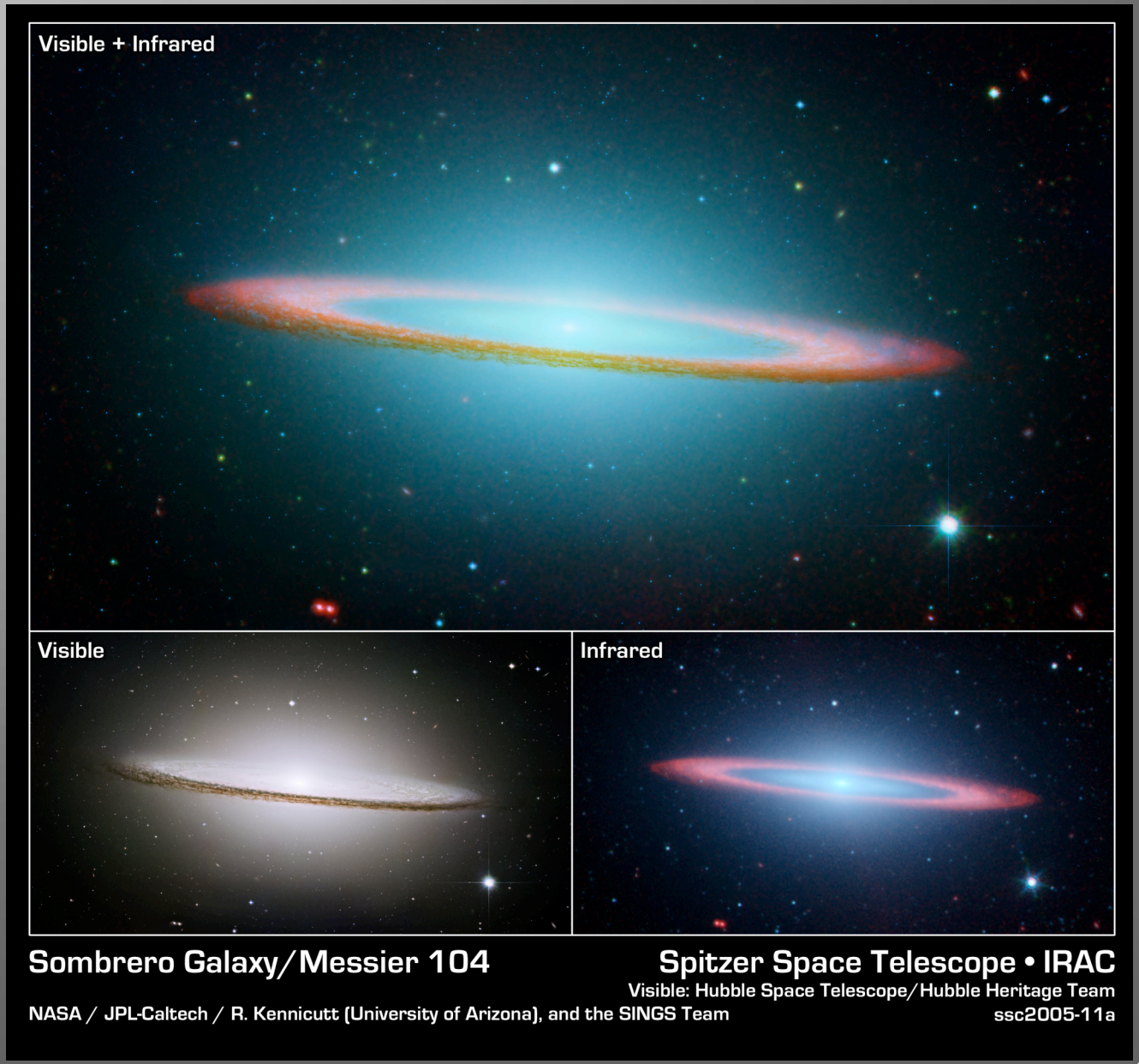
M51 - L(IR)~5x10^{10} Lsun



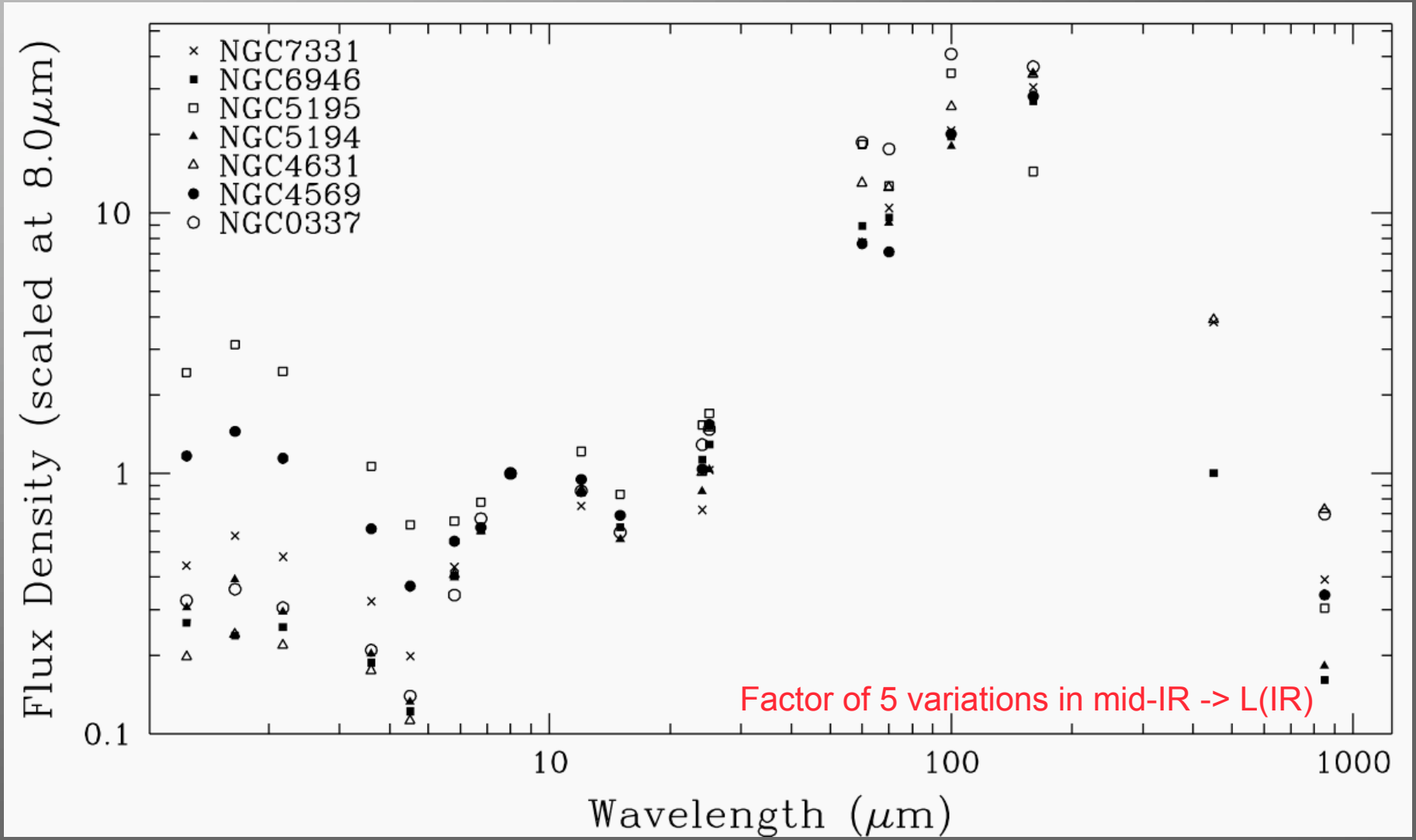
M82 - L(IR)~3x10^{10} Lsun



M104 - L(IR)~1.5x10^9 Lsun

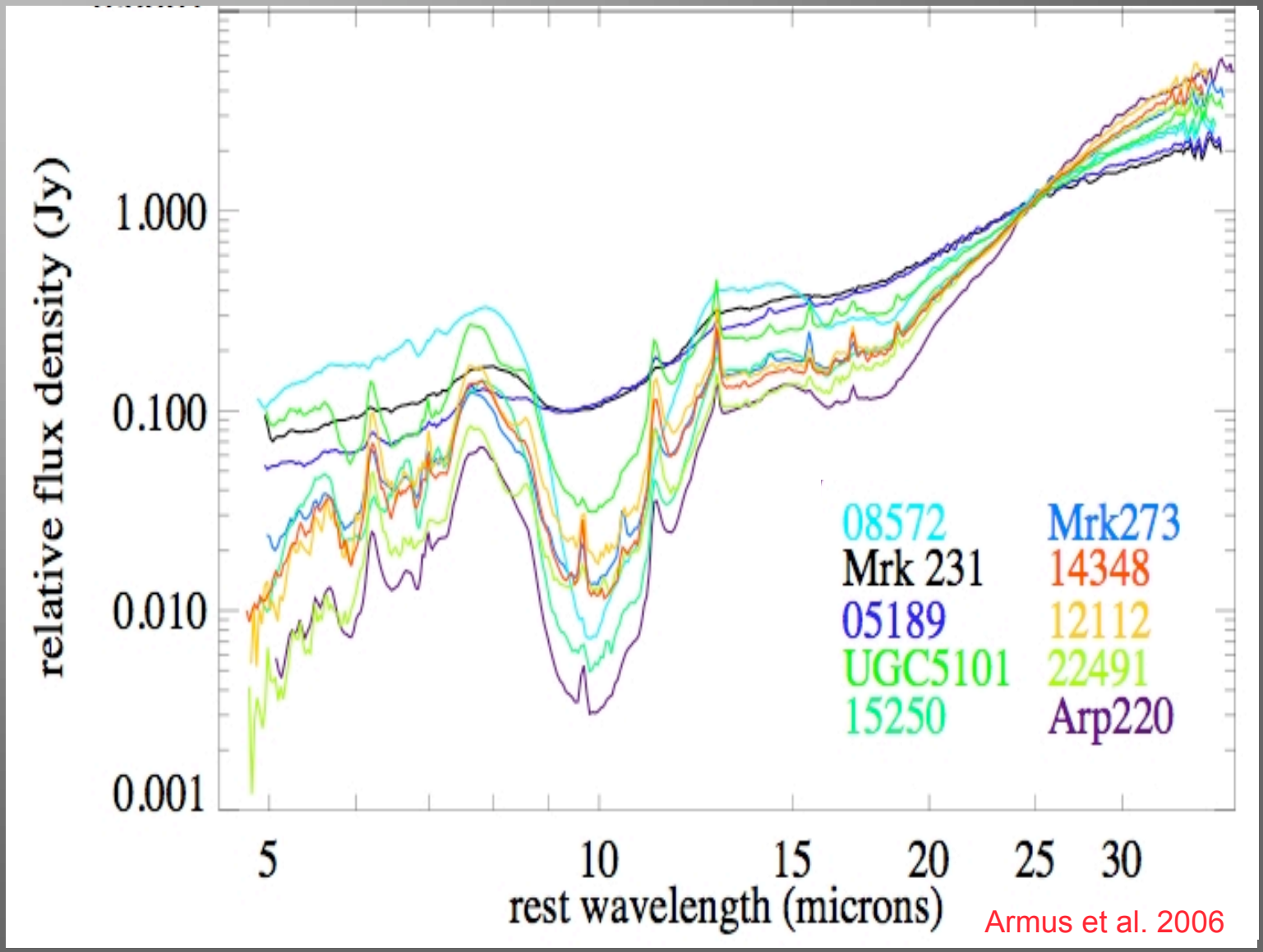


SED variation in Spiral Galaxies



Dale et al., ApJ, 2005

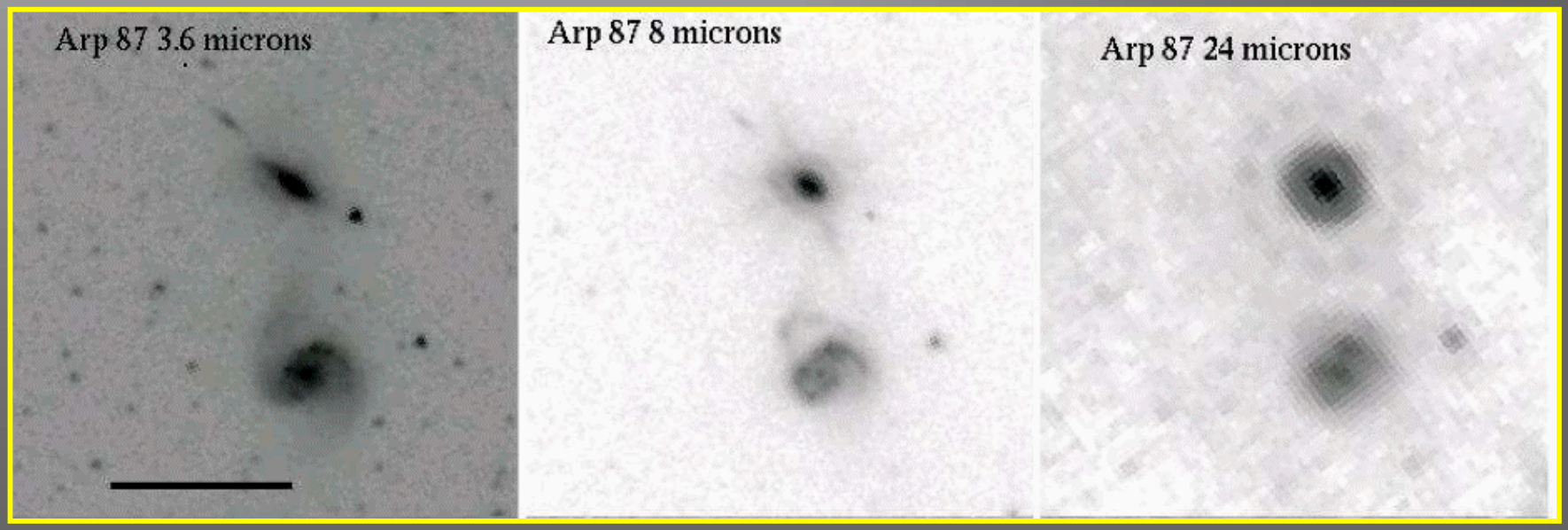
SED variations in ULIRGs



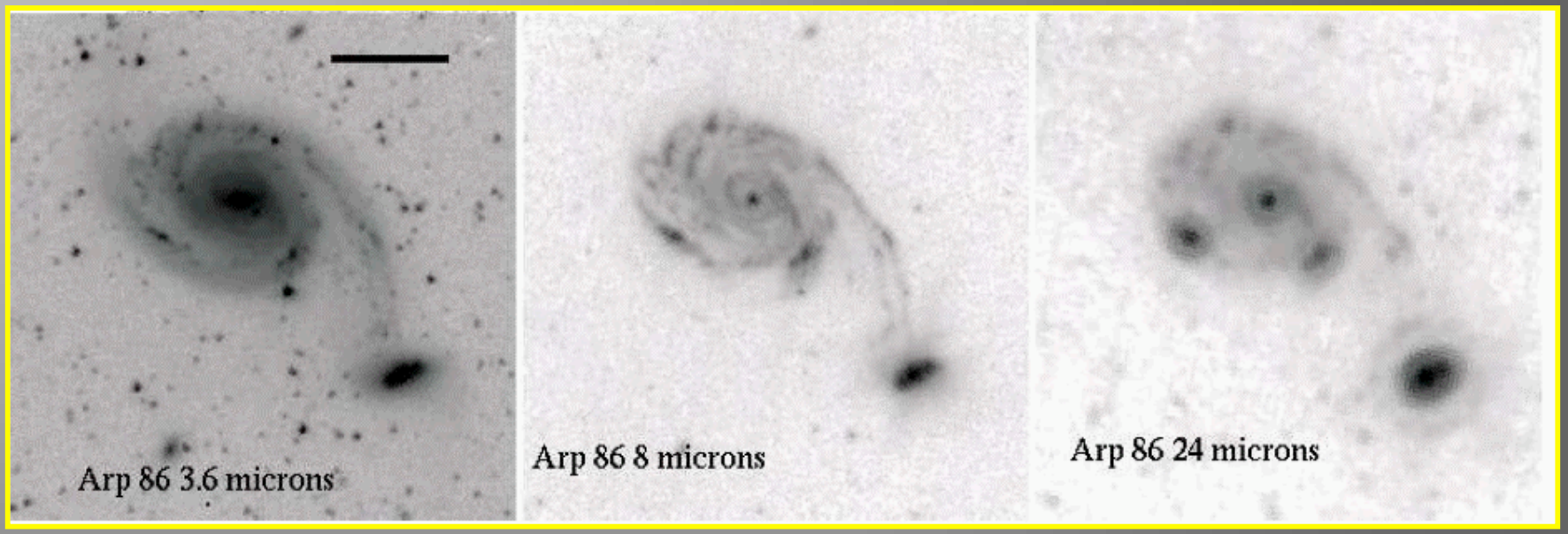
Armus et al. 2006

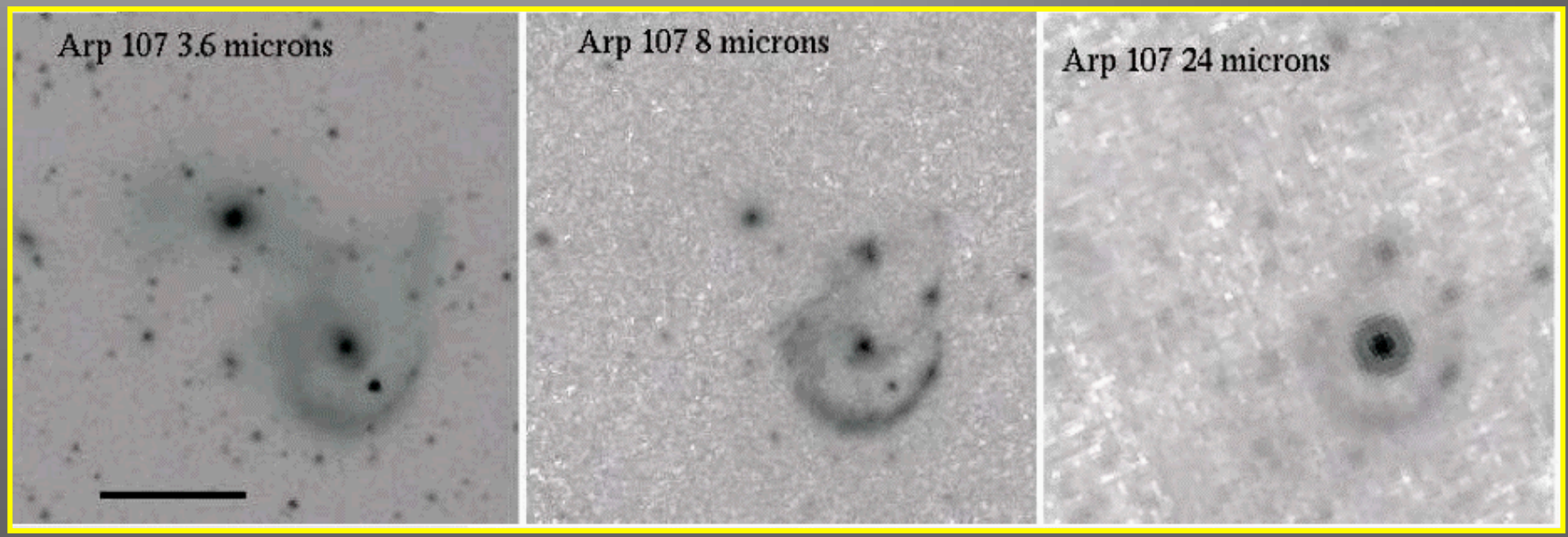
Interacting Galaxies with Spitzer

- A Sample of 35 binary interacting systems has been imaged with Spitzer (IRAC/MIPS : GO-1 Struck et al.)
- Systems are nearby (<150Mpc), disturbed in the optical, with extended tidal features (>3arcmin), well separated, with $8.9<\log[L(IR)]<11.2$
- Their mid-IR properties were analyzed and compared to a control sample of normal galaxies (Spirals, Es, Irr) (Smith et al. 2006, AJ submitted)



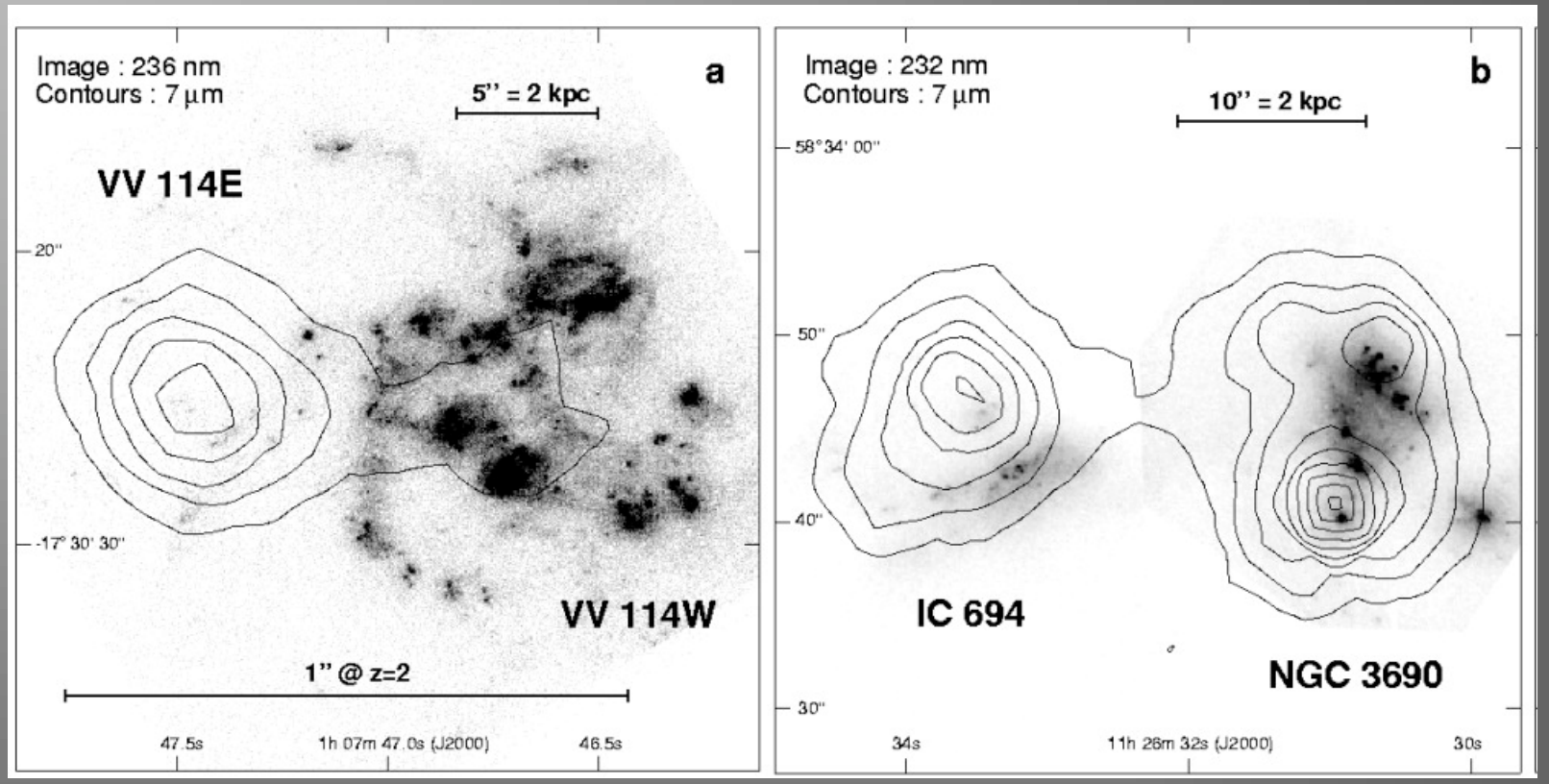
Interacting Galaxies with Spitzer (2)





UV/mid-IR comparison of two LIRGs

Images: HST/STIS UV - Contours: ISO/CAM 7um

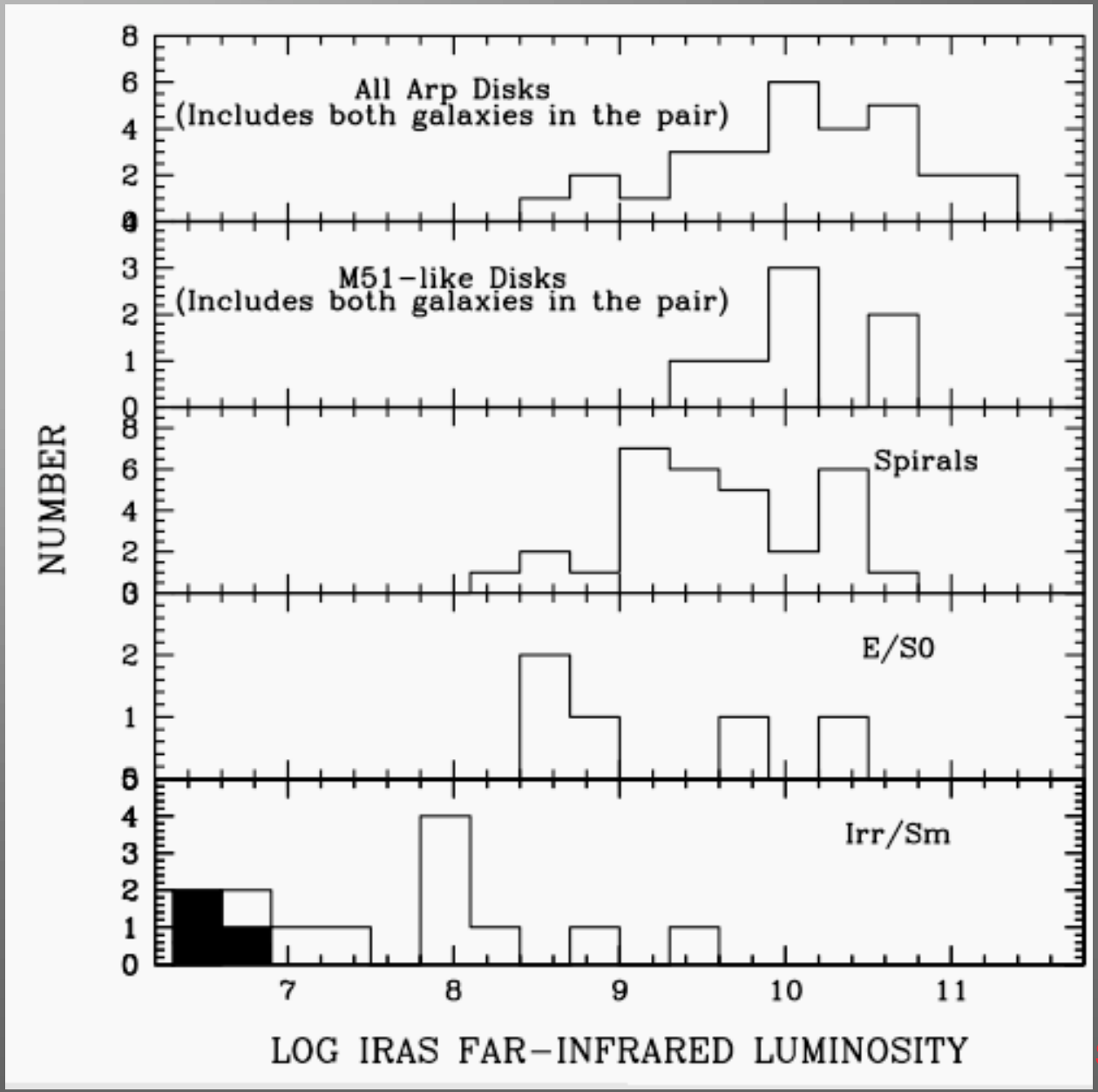


7um/UV ~ 800:10:35 **7um/UV ~ 330:160:190**

The spatial resolution of ground & Spitzer/MIPS24 surveys of LIRGs at z~2 will result in blending of the emission from the unresolved interacting components leading to a systematic underestimation of their dust content.

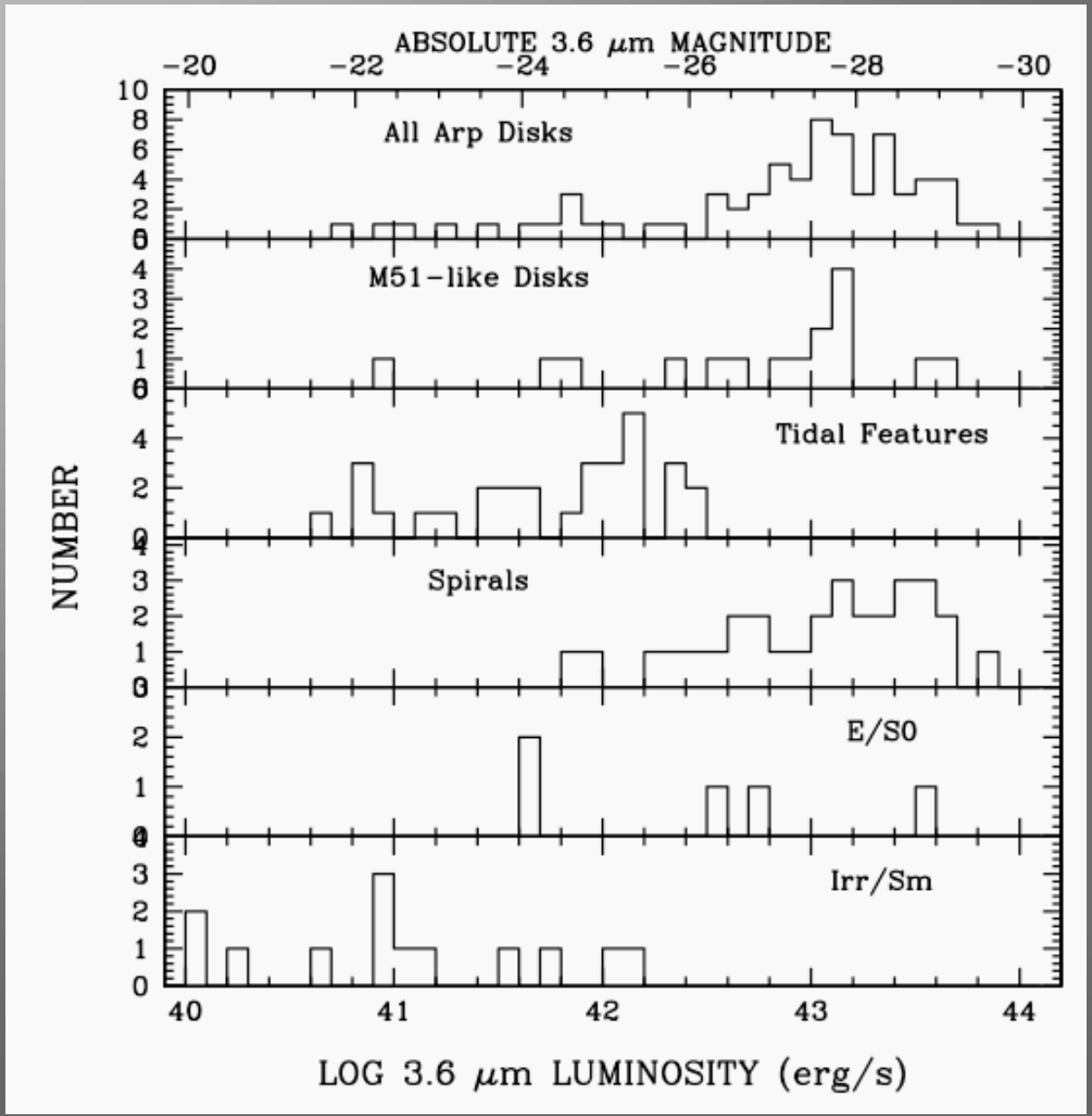
UV data: Goldader et al. 2002
Charmandaris, et, al 2004

Interacting Galaxies: mid-IR Luminosities



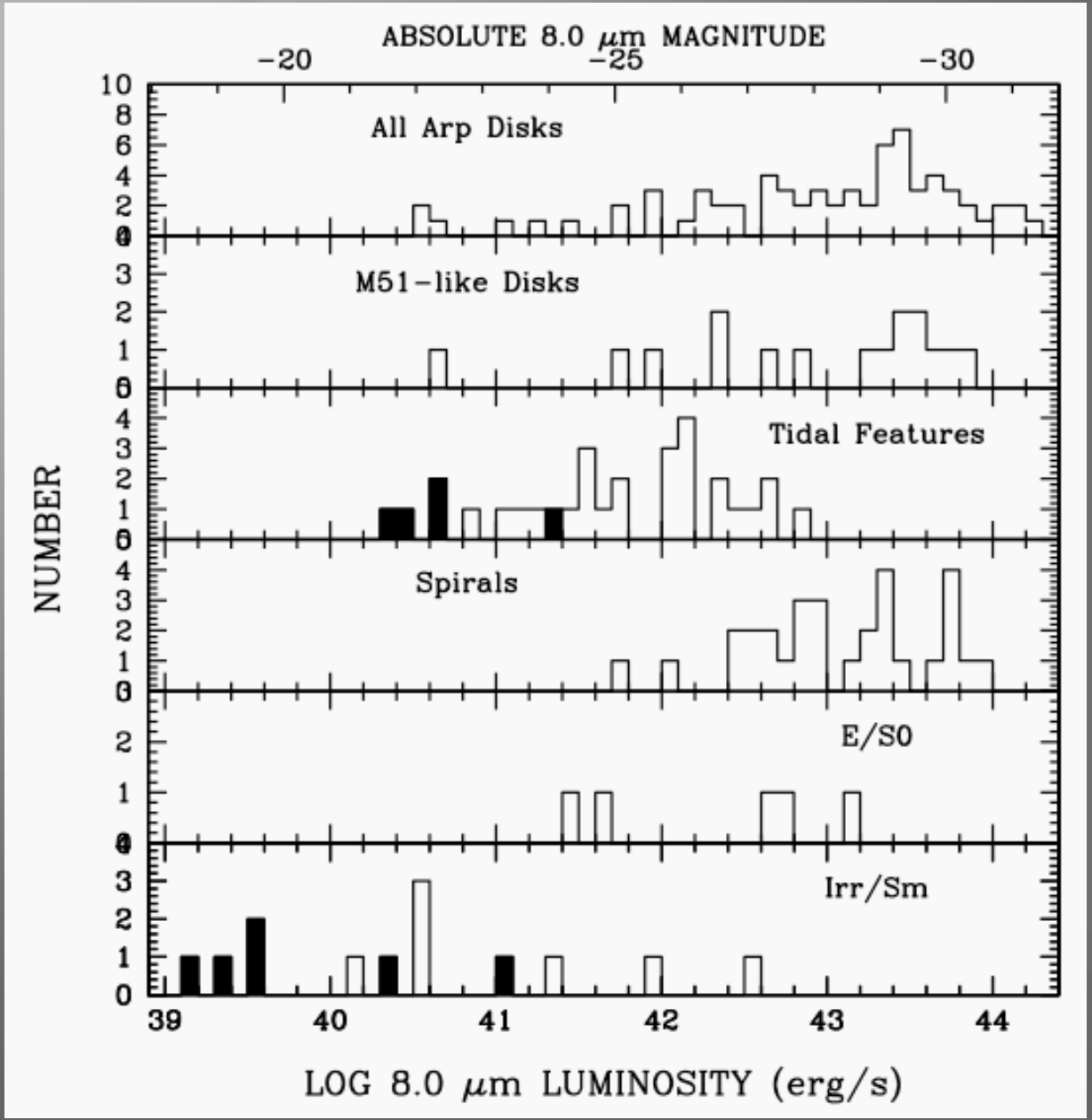
Smith, et, al 2006

Interacting Galaxies: mid-IR Luminosities



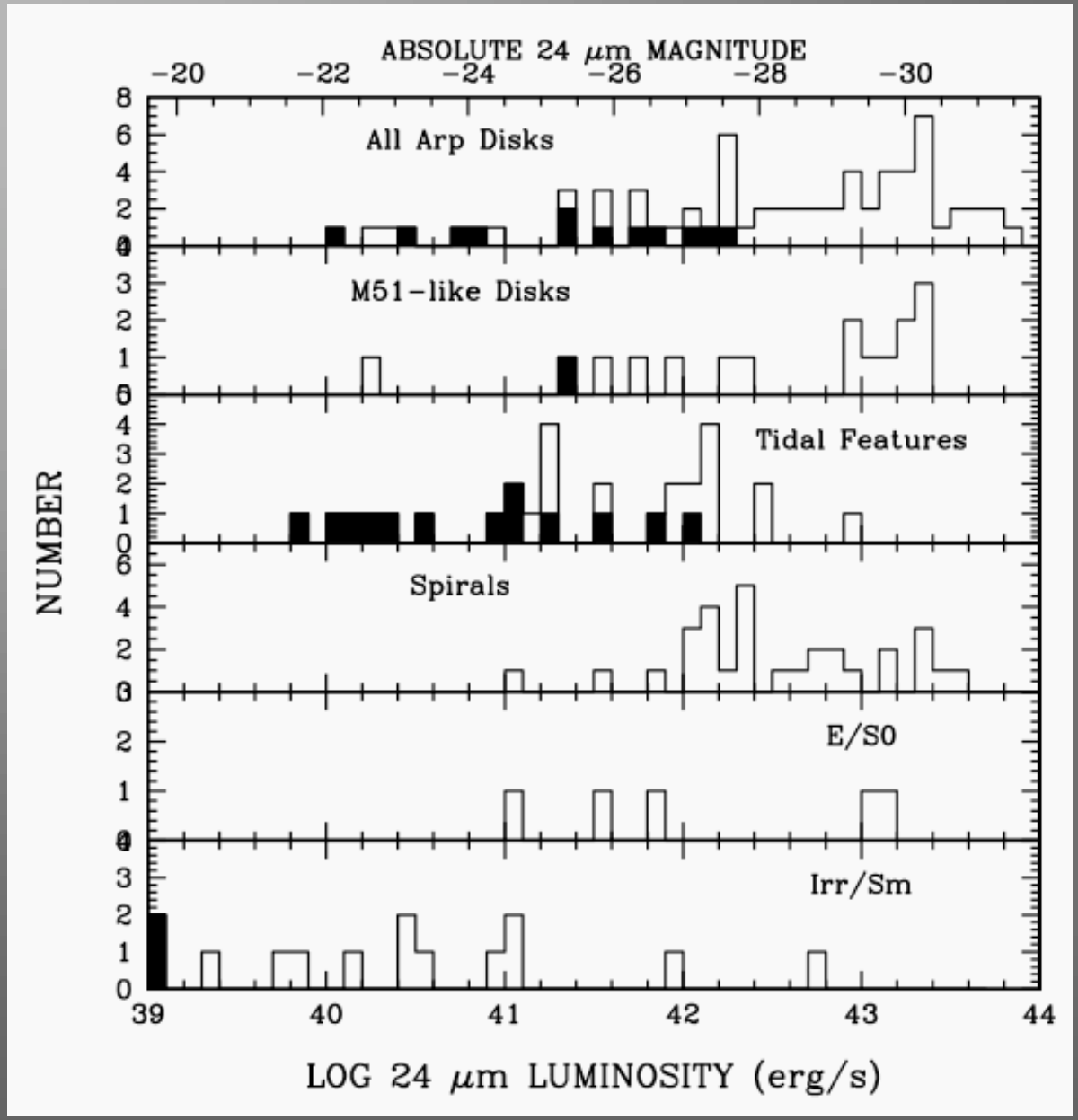
7% of Arp disks

Interacting Galaxies: mid-IR Luminosities



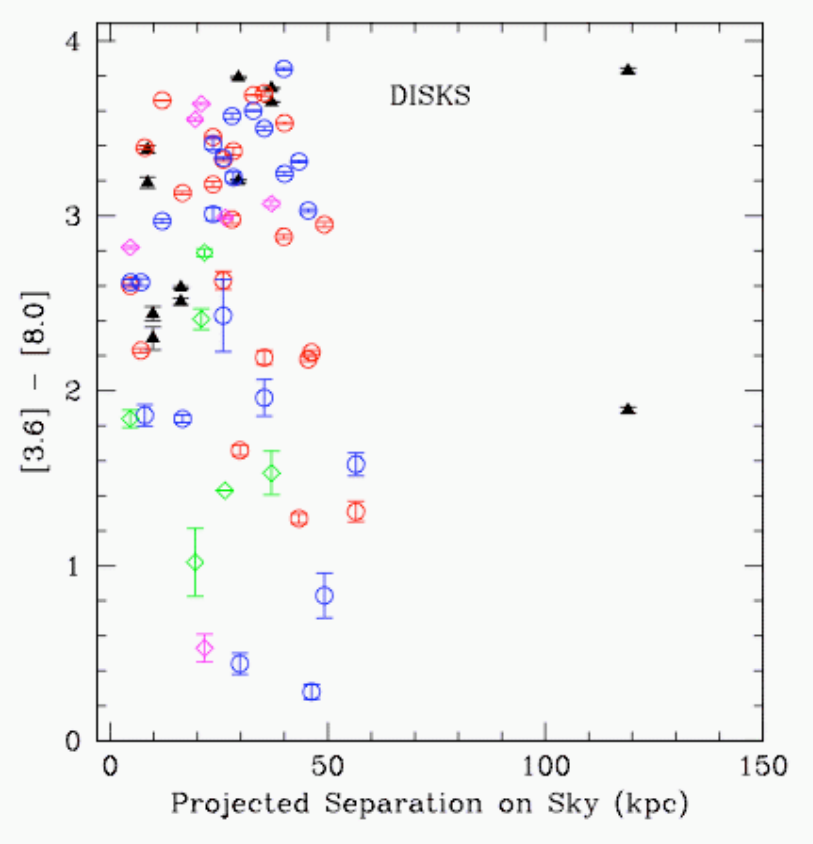
<10% of Arp disks

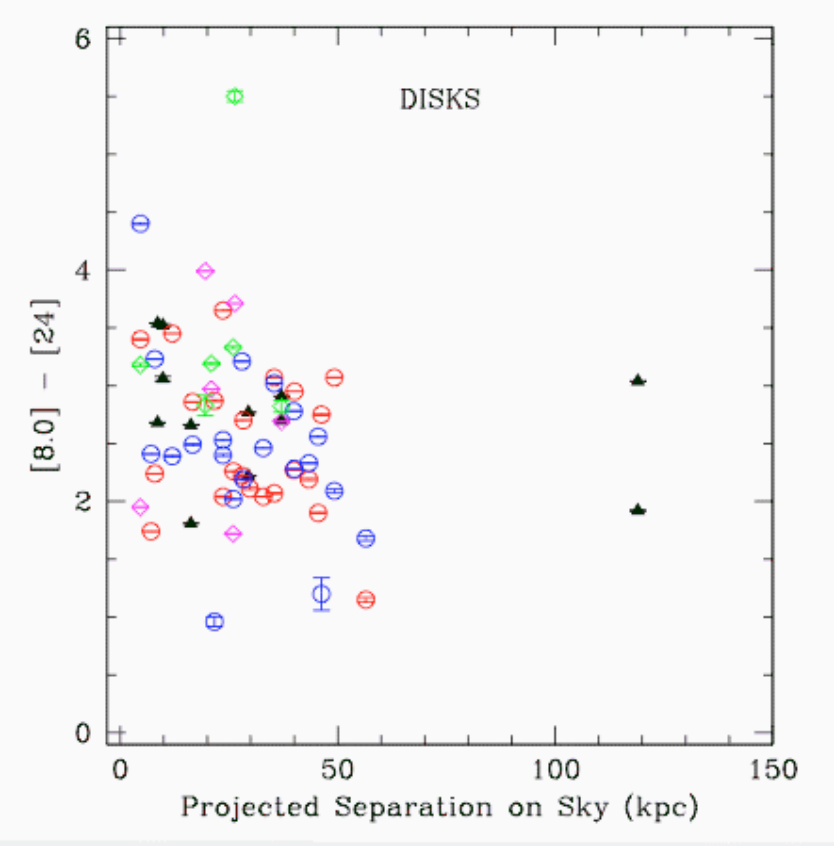
Interacting Galaxies: mid-IR Luminosities



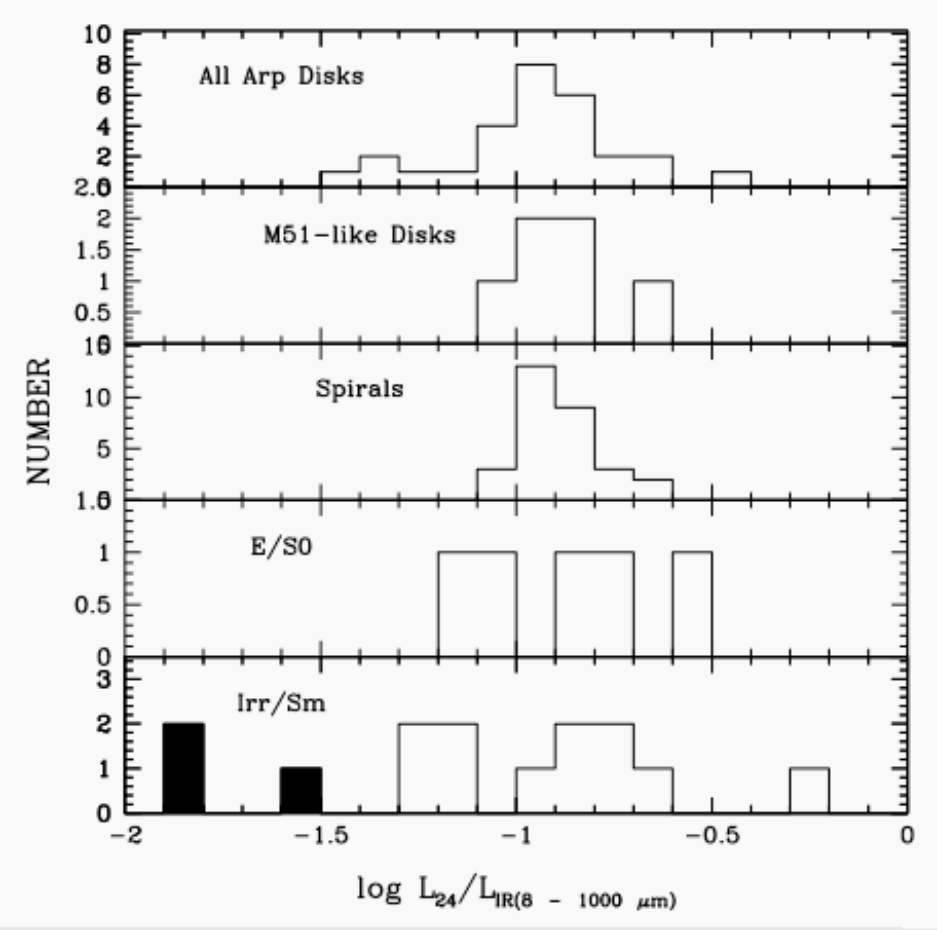
<10% of Arp disks

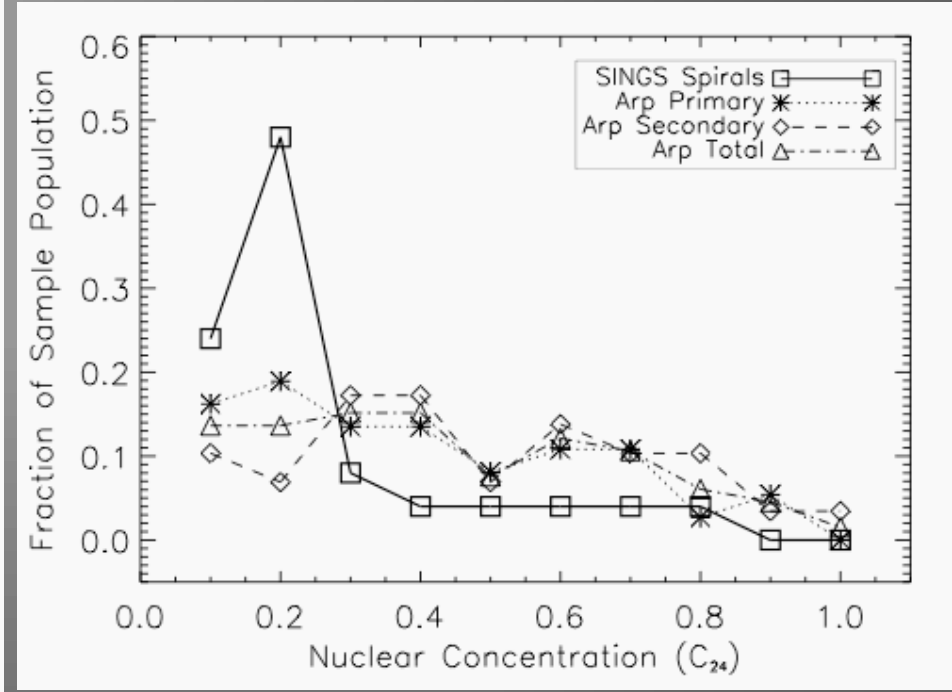
Mid-IR colors vs Separation





Star Formation Rate & mid-IR nuclear concrentation





Smith, et, al 2006

The SFR for isloated spirals (SINGS) and well well separated interacting Arp systems is similar ~ few Msun/yr. However, in the Arp systems the mid-IR flux is 2-4 times more centrally concentrated.

Conclusions/Perspectives

- Spatially resolved mid-IR imaging of interacting systems in now easily possible with Spitzer.
- Directly probes deeply and moderately enshrouded star formation with minimal need (if at all) correction for extinction.
- Wealth of data available in Spitzer (samples of Struck, Mazzarela, Zezas)
- Comparison and cross calibration with other star formation stacers UV (Galex) and Halpha (where available) will provide unique tools in probing the properties and distribution of the population.