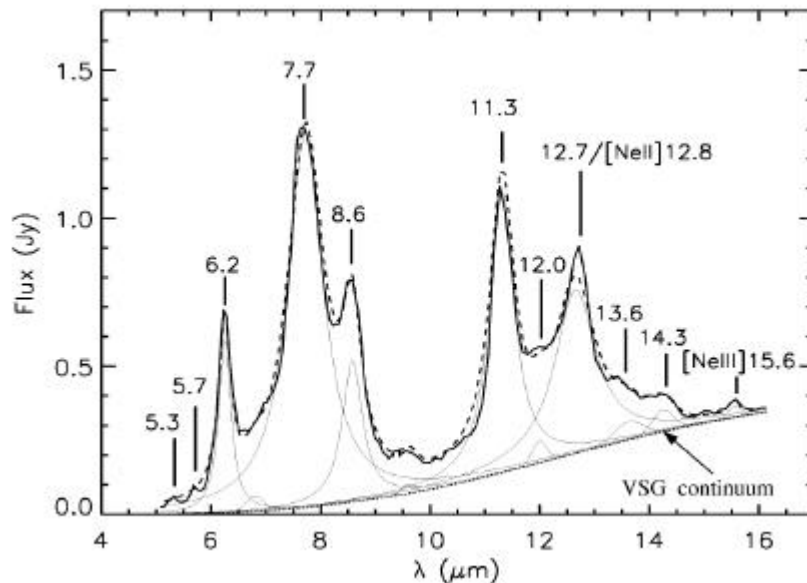
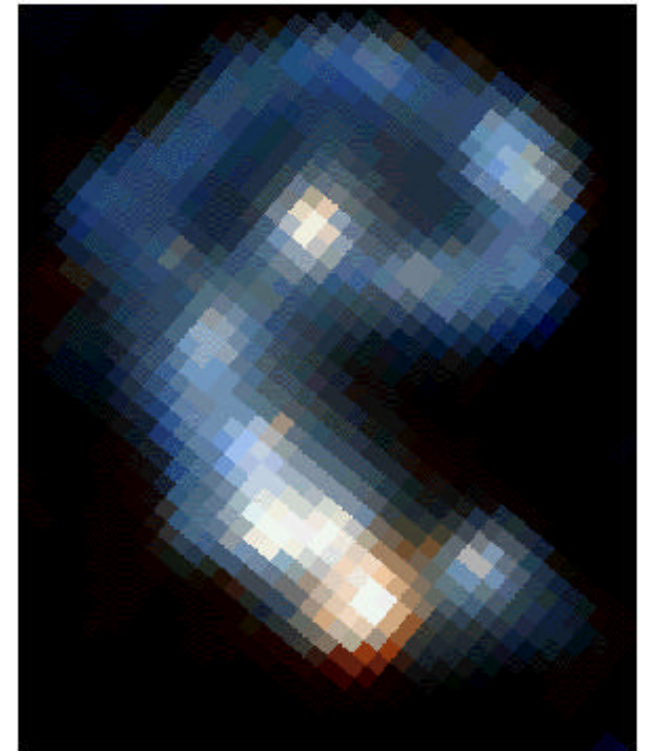


Dust and **mid-IR** properties of Interacting Galaxies

Vassilis Charmandaris

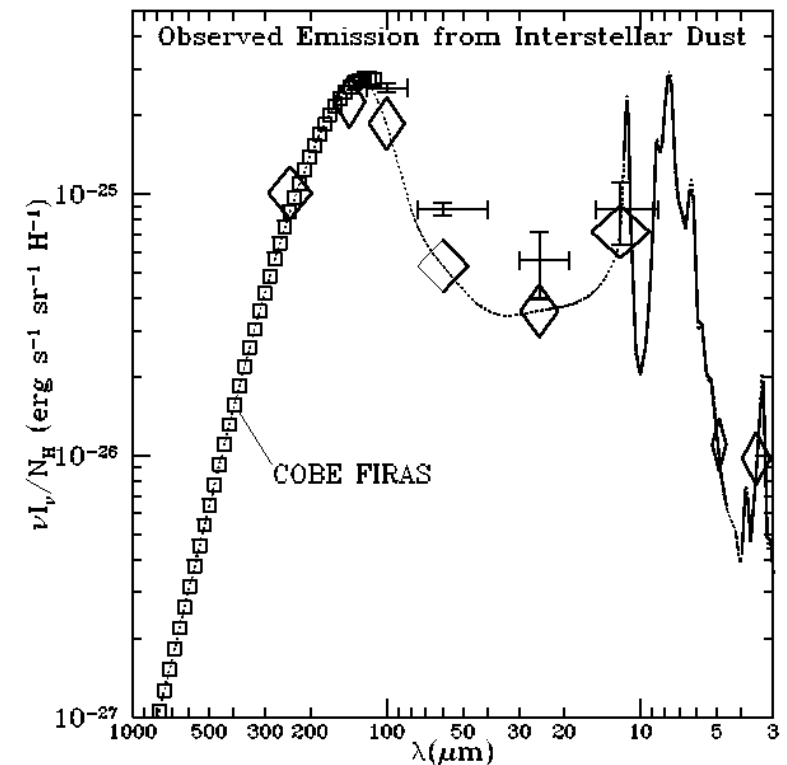
IRS Science Center, Cornell University

198th AAS Meeting, Pasadena, CA - June 5th 2001



◆ Dust is everywhere!

- *Directly coupled to Star Formation*
Forms at late stages of stellar evolution
Acts as catalyst for the formation of molecules
- *Wavelength dependent extinction*
Galactic center: $A_V \sim 30 \text{ mag}$ $\rightarrow$ 1 photon in 10^{12} penetrates
 $A_{2.2 \mu\text{m}} \sim 2.5 \text{ mag}$ $\rightarrow$ 1 photon in 10 penetrates
- *Continuum bump at $\sim 100 \mu\text{m}$*
- *Presence of ice absorption features (3.1 mm)*
- *IR features at 9.7 & 18 μm*
(amorphous silicates $\sim$ olivine $\text{Mg}_x\text{Fe}_{2-x}\text{SiO}_4$)
- *Infrared emission from dust grains*
+ aromatic hydrocarbons



(Draine 1999)

June 5th 2001

Dust grains range in size from a few hundred Å to a few μm. They are composed mainly of elements such as carbon and silicate compounds, and various kinds of ices.

- “classical” dust grains → 0.1 μm in size, containing ≥ 10000 atoms
responsible for the FIR, sub-mm emission
- very small grains → containing ≤ 100 atoms (less than 10nm in size)
responsible for a rising continuum $\sim 10\mu\text{m}$
- PAHs (Polycyclic Aromatic Hydrocarbons) → benzene rings contain $N \sim 50$ atoms
trace photodissociation regions.

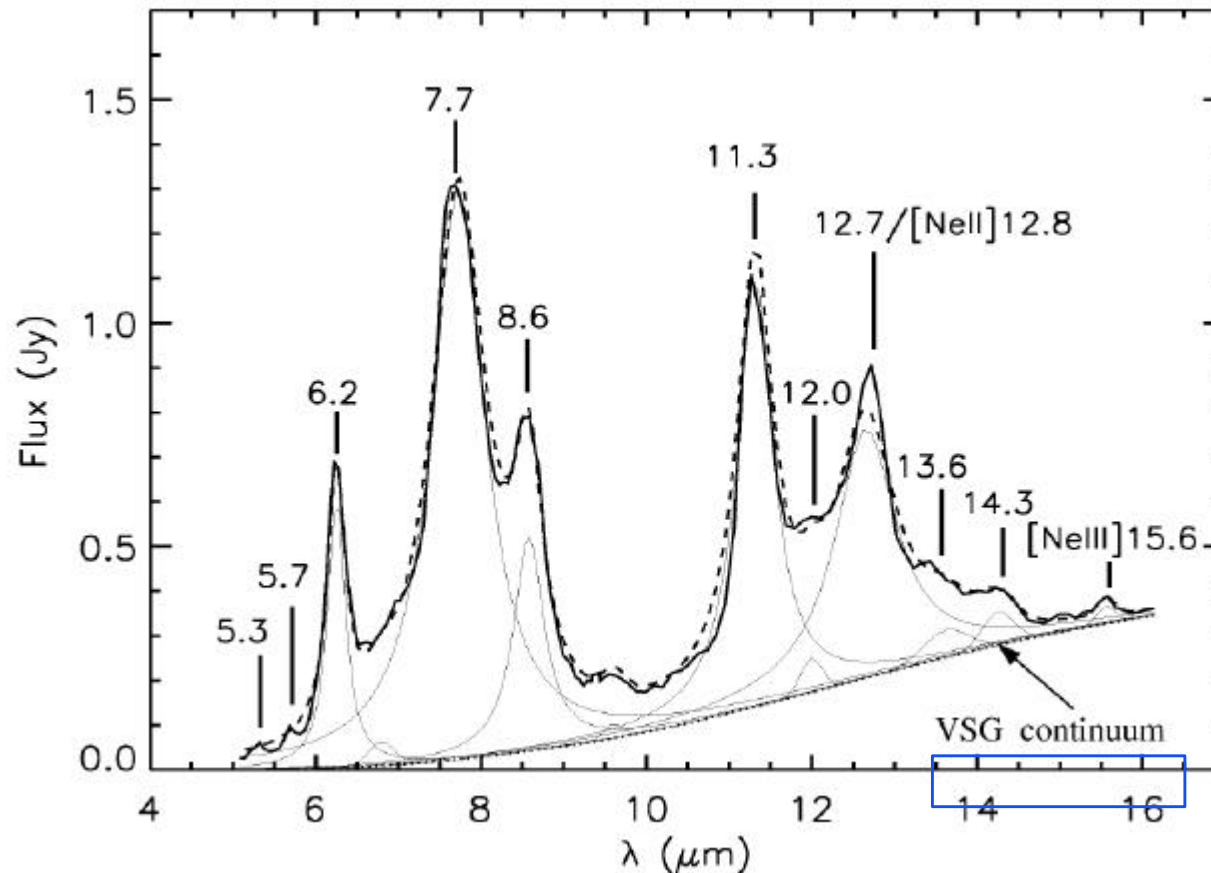
Due to the size distribution of grains & variations in the underlying radiation field the dust temperature varies (cold, warm, hot dust)

Spectra of different dust components are fitted by modified Planck curves

$$I_\nu \propto \epsilon_\nu B_\nu(T)$$

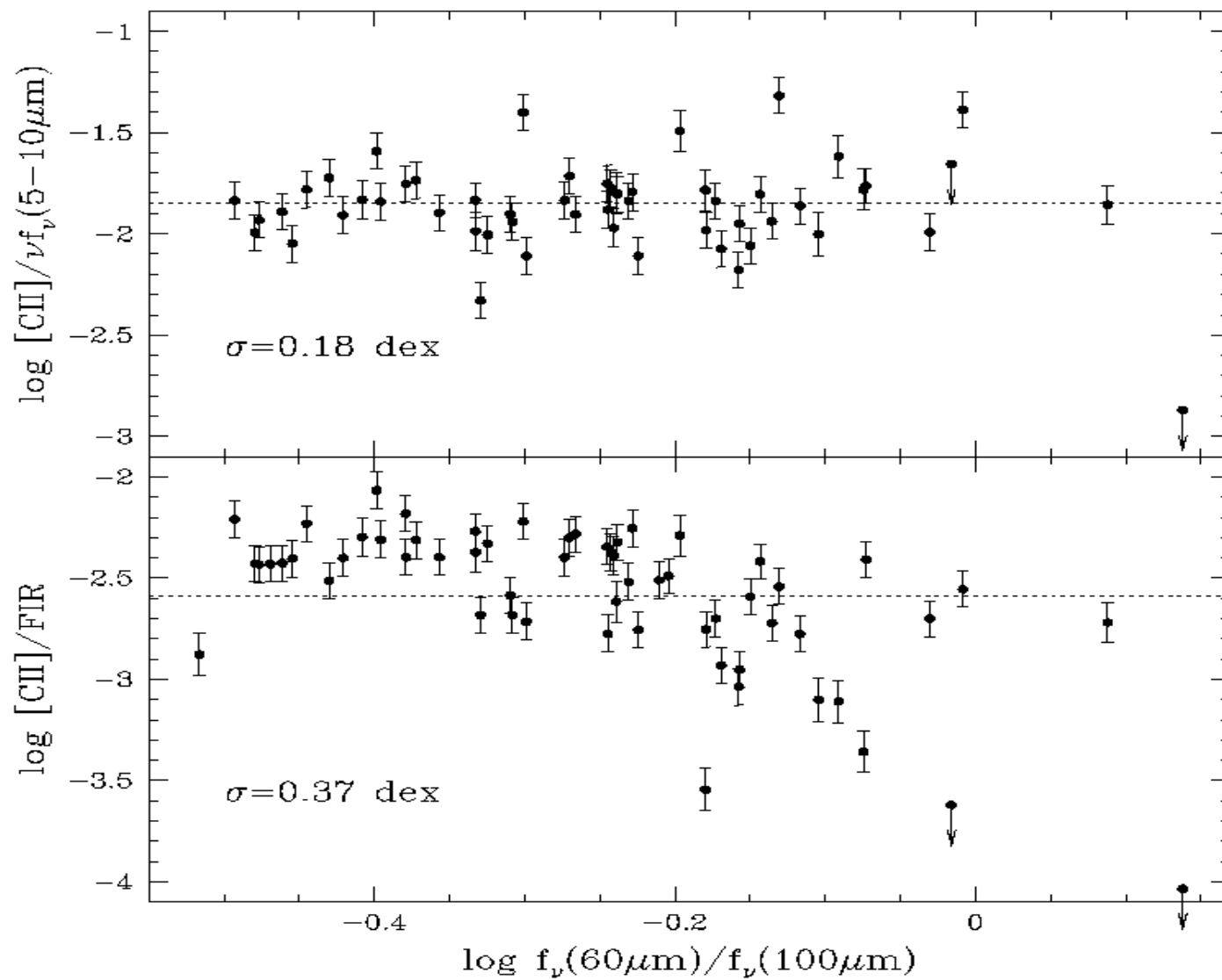
Power-law emissivity: $\epsilon_\nu \propto \nu^n$ (i.e. Dale et al, ApJ, 2001)

Really hot dust ($\sim 200\text{-}1500\text{K}$) in a equilibrium is observed via a near/mid-IR “bump” close to tori of AGNs.



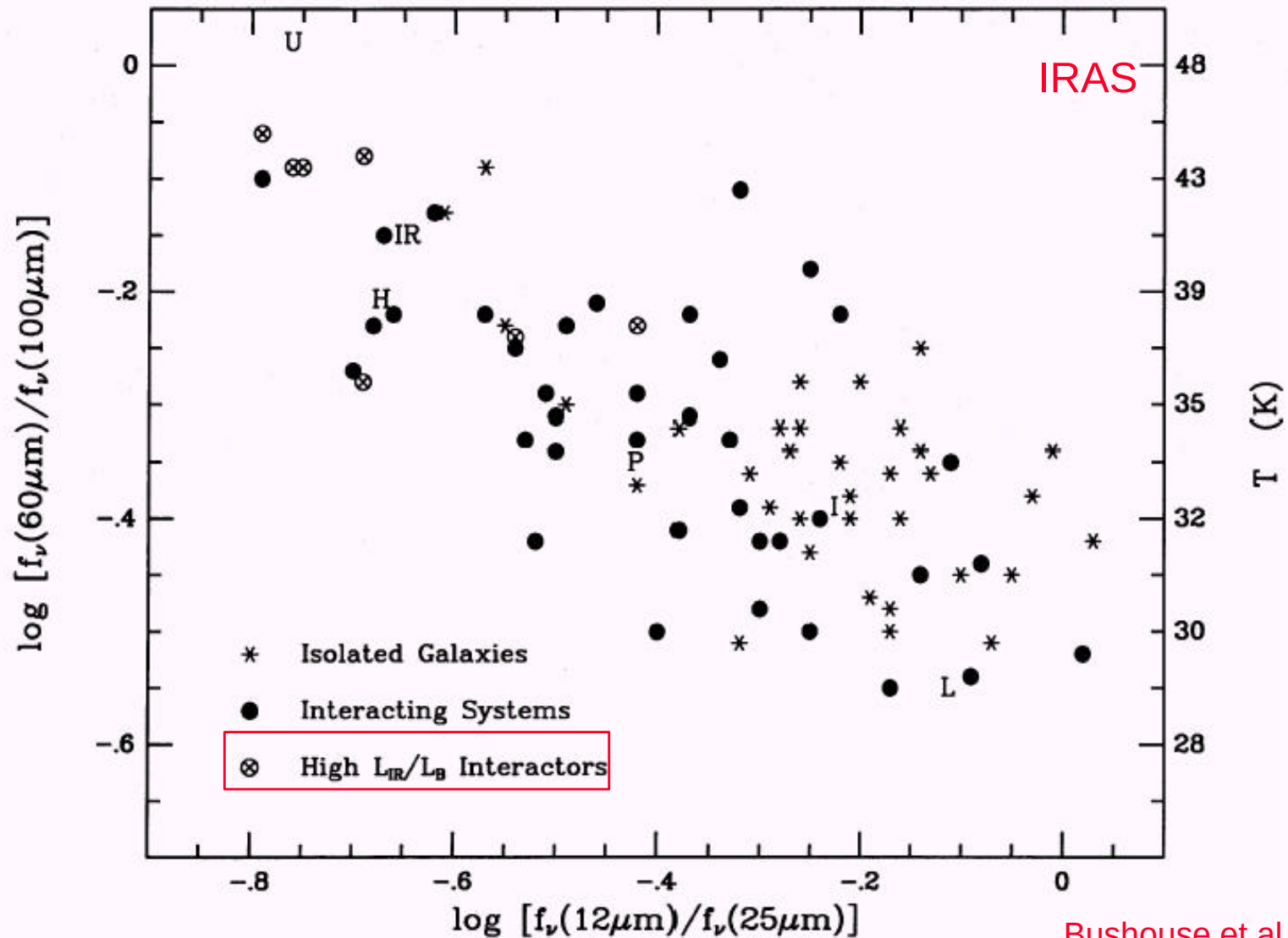
- Band emission from Polycyclic Aromatic Hydrocarbons (PAHs or UIB)
- Continuum emission attributed to Very Small Grains
- Ionic/high excitation line emission

- ◆ A far-UV photon hits a dust grain and ejects an electron
- ◆ The ejected photoelectron heats the gas (very inefficiently $\sim 0.1 - 1 \%$)
 - 50% of gas heating is due to grains of sizes $< 15 \text{ \AA}$
- ◆ Subsequently the gas cools via far-IR emission lines ([OI] $63 \text{ \mu m}$, [CII] $158 \text{ \mu m}$)
- ◆ Process of randomly heating dust grains to high T ($\sim 1000\text{K}$) for short periods ($\sim 1\text{s}$)
 - *Not in equilibrium.*
- ◆ PAHs, dominate the mid-IR ($5\text{-}20 \text{ \mu m}$) flux in normal galaxies and quiescent star forming regions via the so-called Unidentified IR Bands (UIBs) or IR Emission Features (IEFs).
 - Normal Galaxies: $L(\text{mid_ir}) \sim 20\% L(\text{IR})$ (Dale et al. 2001, Roussel et al 2001)
 - Active/Interacting galaxies: $L(\text{mid_ir}) < \sim 5\% L(\text{IR})$
- ◆ In normal late type galaxies most of their energy is released in the FIR.

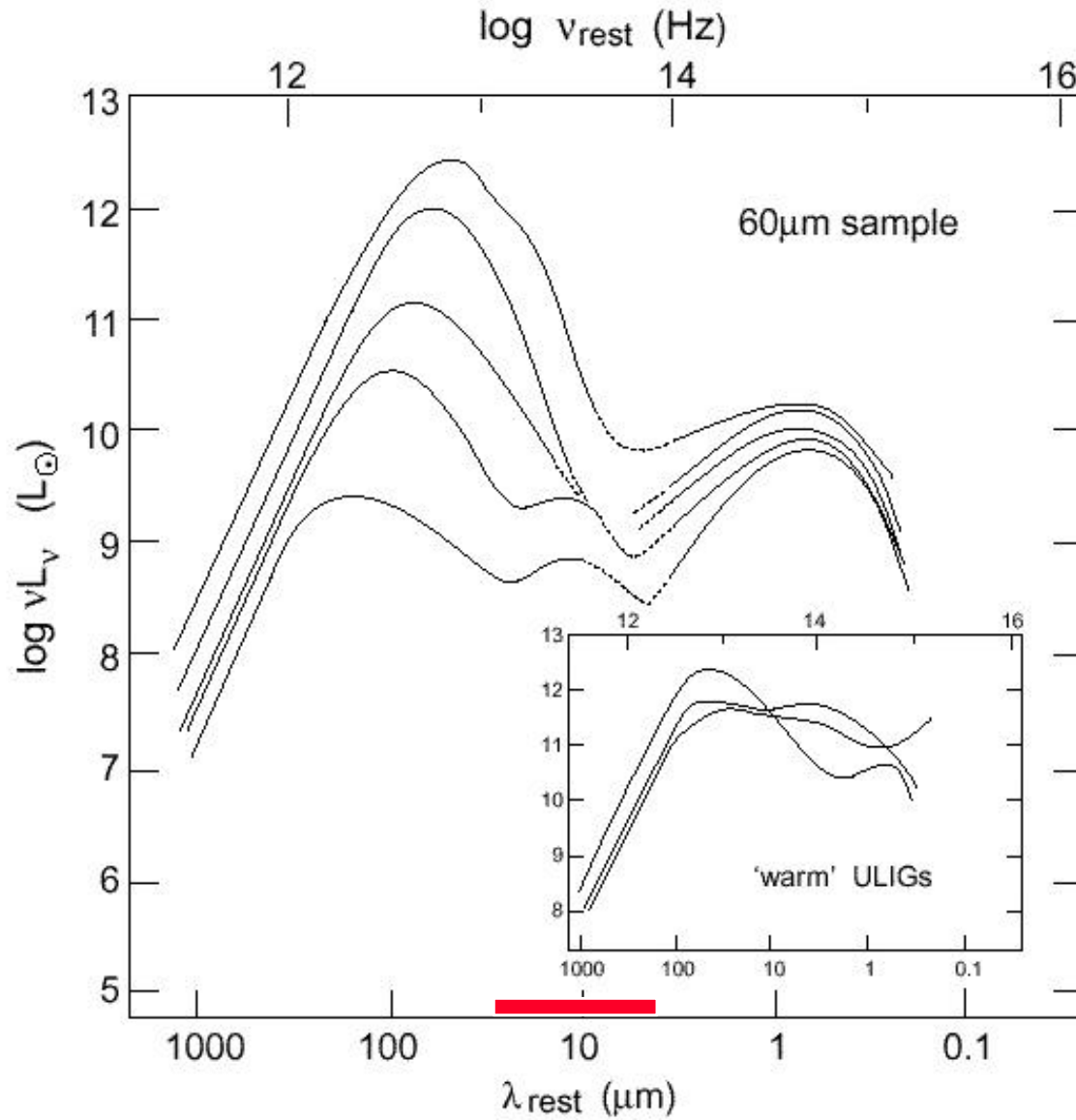


Helou et al., ApJ, 2001

A Hotter Dust Component



Bushouse et al., ApJ, 1988



In the Mid-IR:

- we are less affected by absorption than in optical $A_v = 70 \cdot A(15\mu\text{m})$
- 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?

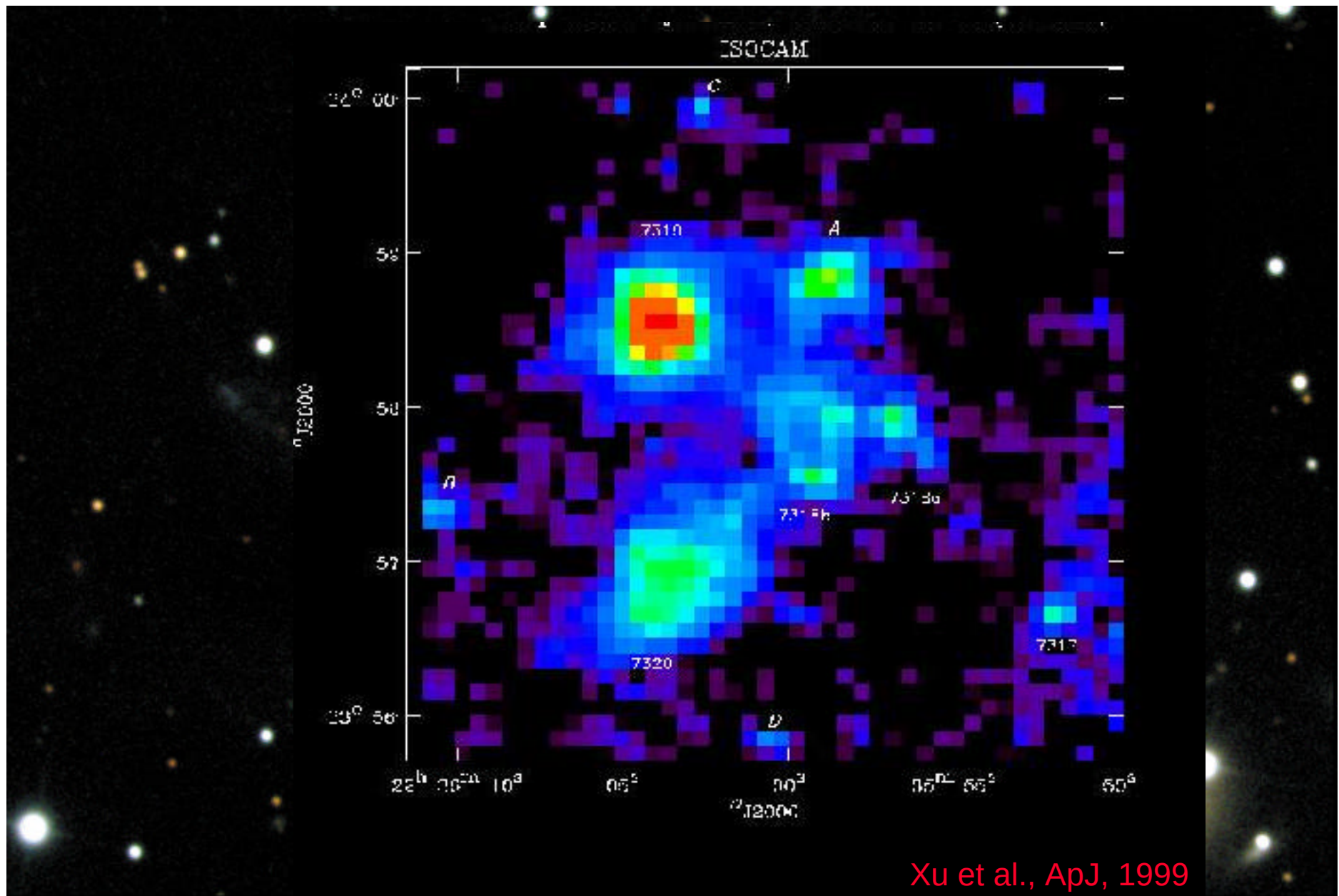
YES!

Sanders & Mirabel, ARA&A, 1996

Stephan's Quintet



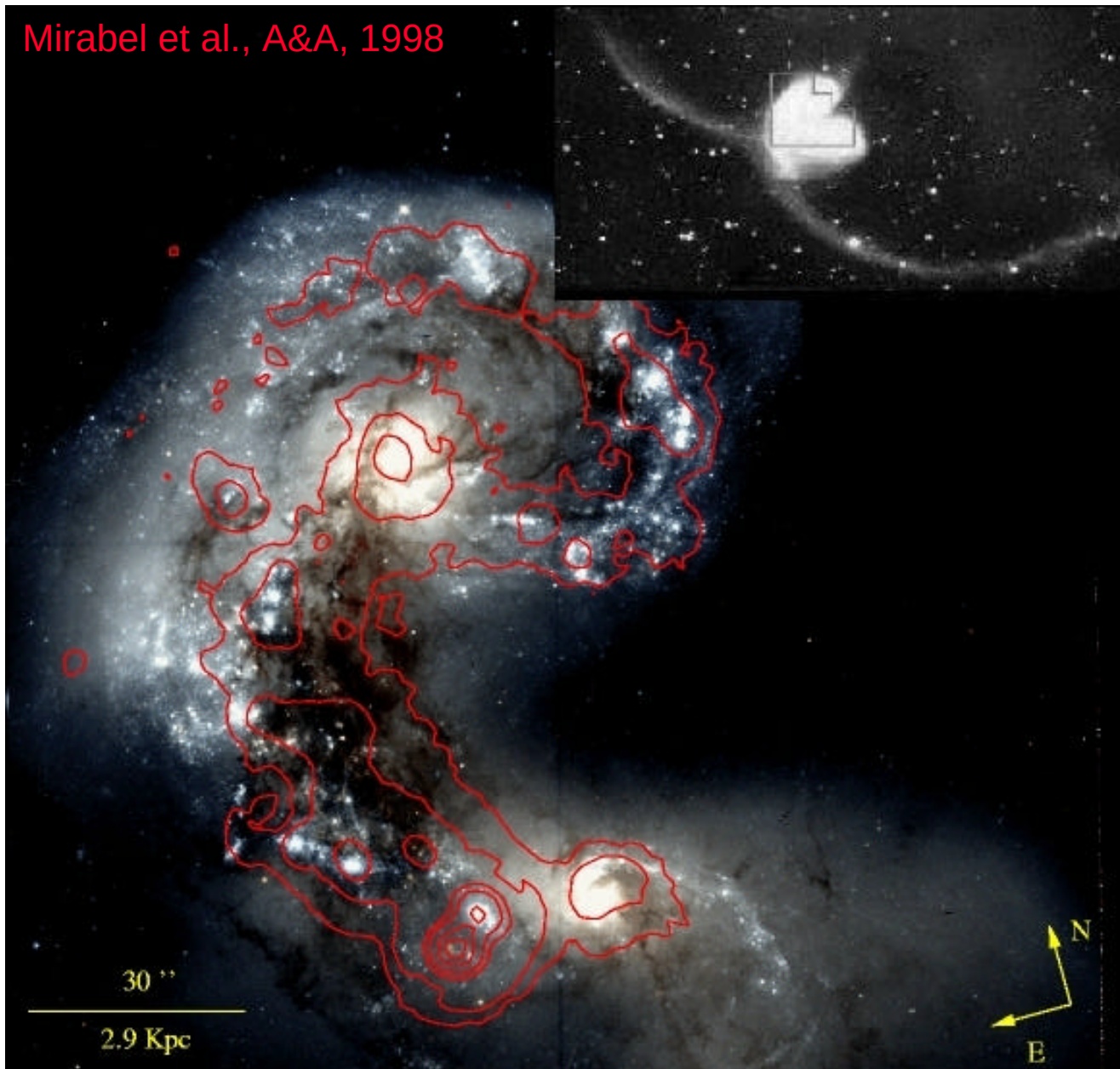
Stephan's Quintet



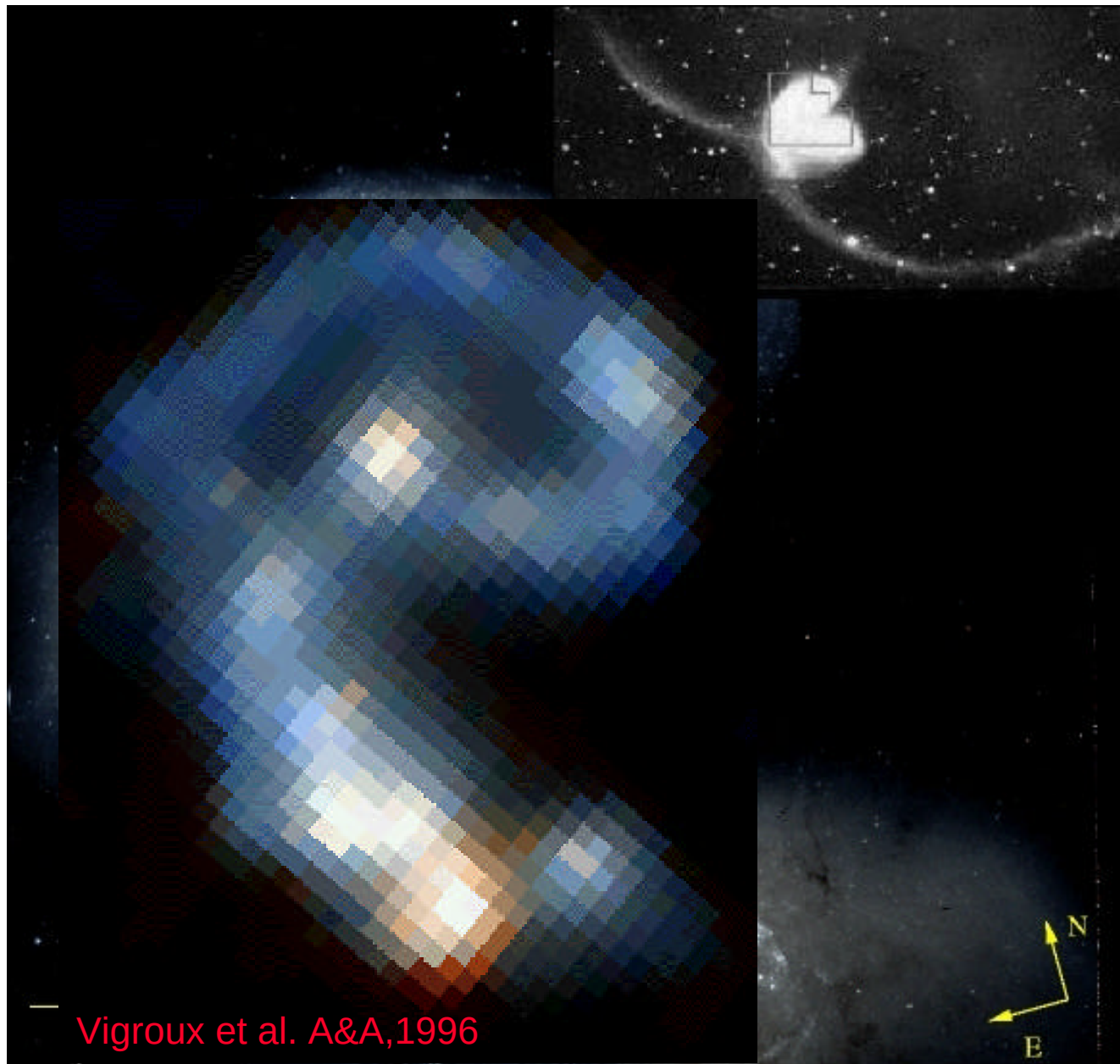
NGC4038/39 in Mid-IR



Mirabel et al., A&A, 1998

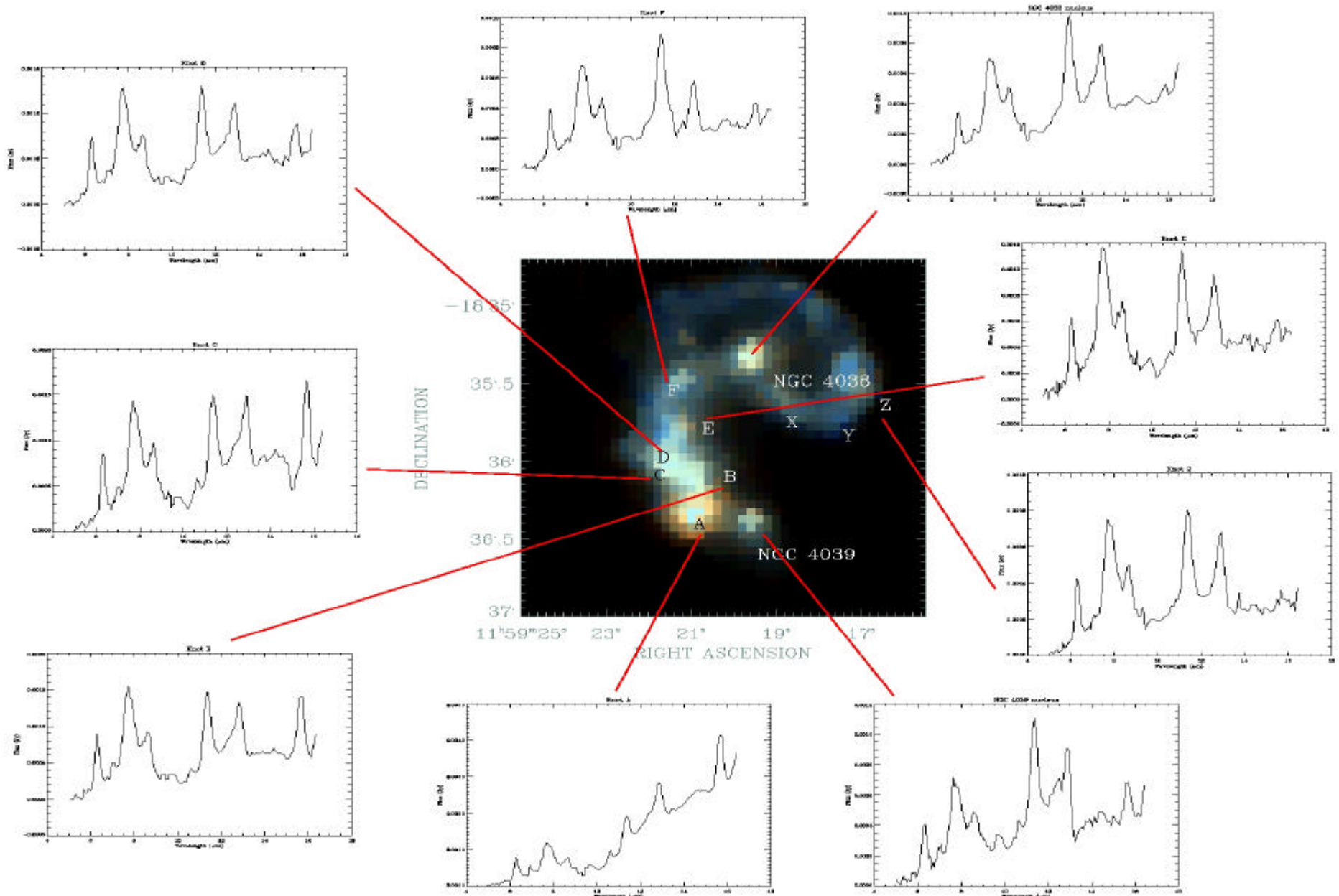


NGC4038/39 in Mid-IR



Vigroux et al. A&A,1996

The MIR spectrum varies



A sample of galaxies where we know **a priori** their stage of interaction

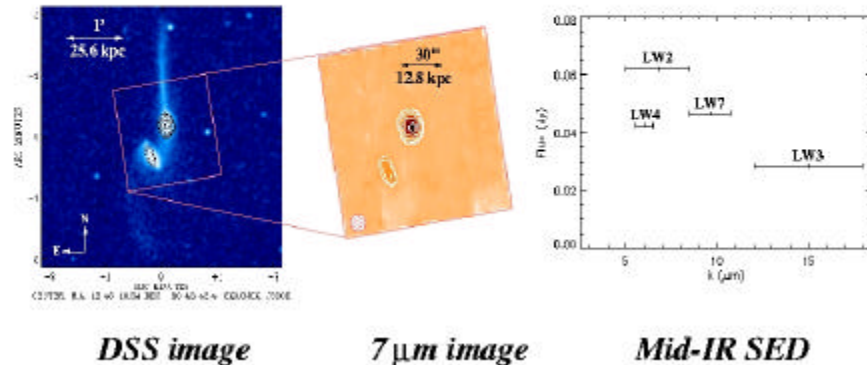
Source	LW2(5-8.5 μm) (mJy)	LW4(5.5-6.5 μm) (mJy)	LW3(12-18 μm) (mJy)	<u>LW2</u> LW4	<u>LW3</u> LW2	$\log(\frac{IRAS(60\mu m)}{IRAS(100\mu m)})$
NGC 4676(B) [†]	4	2	2	<2	<2	–
NGC 4676(A) [†]	58	40	30	1.45	0.52	-0.28
NGC 3263(Nuc : 4.5 ")	59	31	61	1.90	1.03	-0.42
NGC 520	485	231	522	2.10	1.08	-0.16
NGC 3256(Nuc : 4.5 ")	441	211	1195	2.09	2.71	-0.12
NGC 3256(Disk)	201	84	426	2.10	2.12	–
NGC 6240	212	100	785	2.12	3.70	-0.09
Arp 220	141	60	714	2.35	5.06	-0.04
NGC 7252	70	28	100	2.50	1.42	-0.25
NGC 3921	35	–	42	–	0.82	-0.38
NGC 4038/39(KnotA : 6 ")	82	41	399	2.00	4.87	
NGC 4038/39(Nuc : 6 ")	55	23	115	2.39	2.10	

Early stage interactions – pre-starburst phase



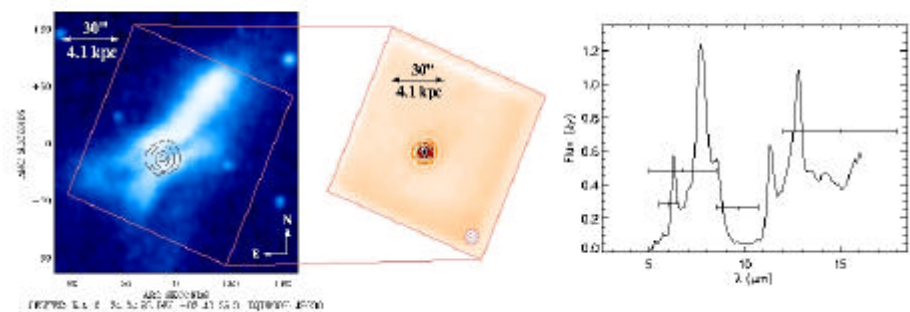
1

NGC 4676



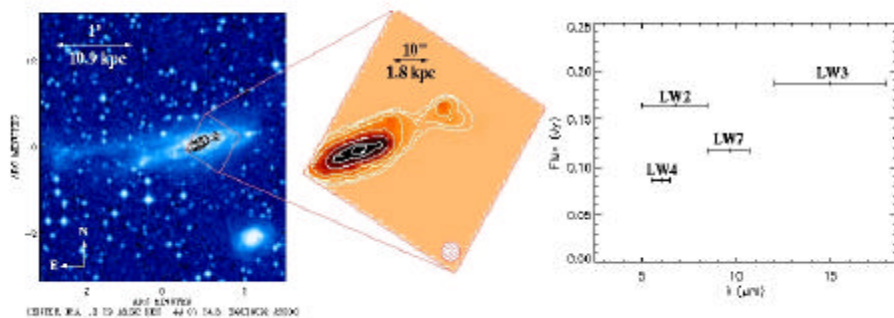
3

NGC 520



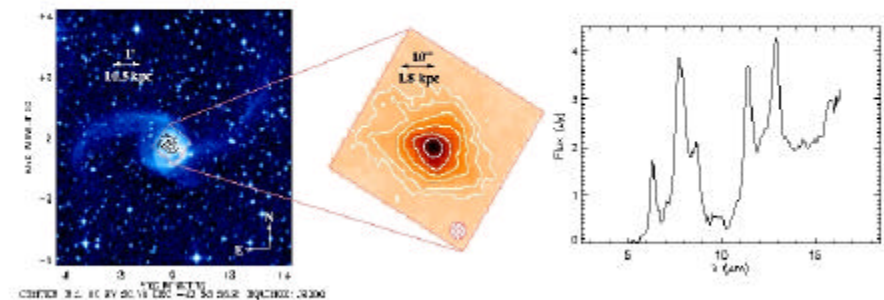
2

NGC 3263



4

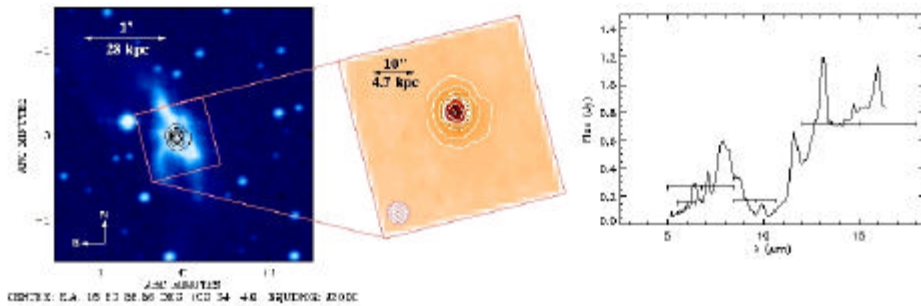
NGC 3256



Charmandaris et al., 2001

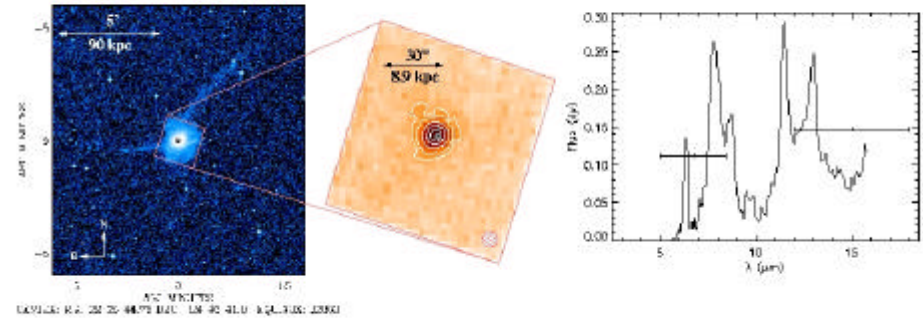
5

NGC 6240



7

NGC 7252



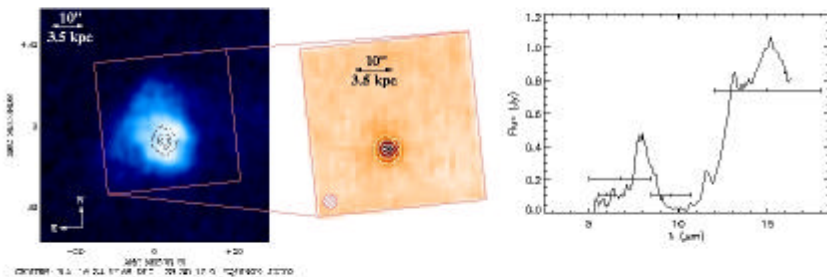
DSS image

7 μm image

Mid-IR SED

6

Arp 220



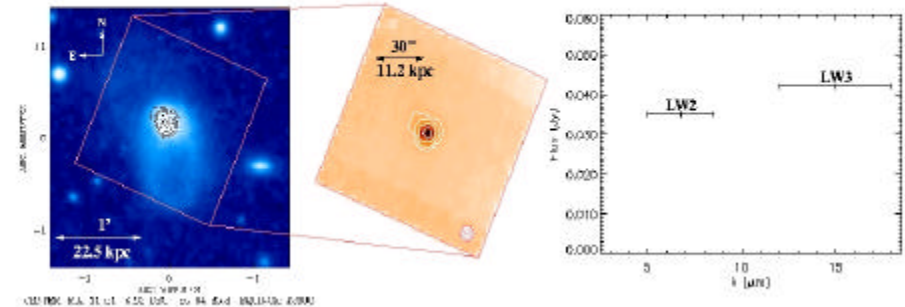
DSS image

7 μm image

Mid-IR SED

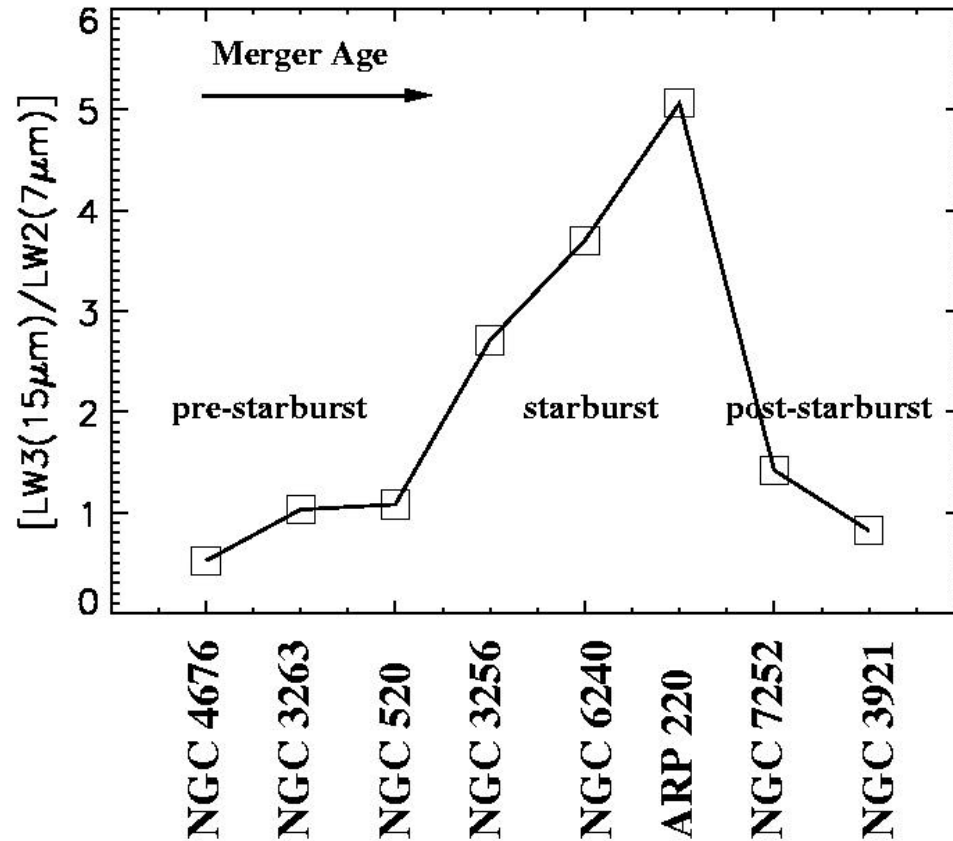
8

NGC 3921

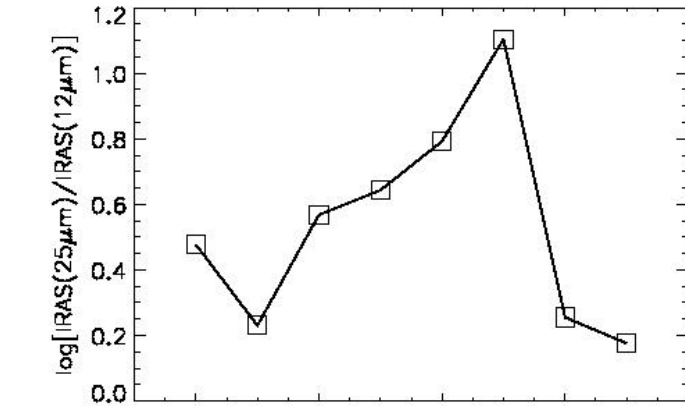
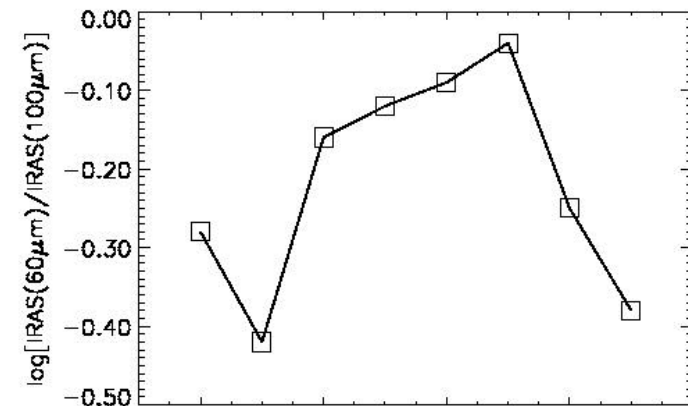


Mid-IR Far-IR Correlation

ISO: 15 μ m / 7 μ m



IRAS 25 μ m / IRAS 12 μ m



IRAS 60 μ m / IRAS 100 μ m

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



- ◆ The LW3(15 μ m) / LW2(7 μ m) mid-IR flux indicator is a powerful diagnostic of the star formation intensity.
- ◆ The 15 μ m / 7 μ m ratio is correlated with the IRAS colors suggesting that **the mid-IR spectrum may be used as a tracer of the far-IR SED.**
- ◆ None of the galaxies presented shows AGN characteristics
However...
- ◆ **...the absorption in merger remnants such as Arp220 is high** (ie Soifer et al 1999, Fischer et al. 1997, this work) so a based **only** on mid-IR data a weak enshrouded AGN can not be excluded in these systems

◆ Current Caveats:

- *Measuring the extinction using only the 5-17 μm range is “tricky”.*
- *If one uses a mixed instead of a screen model for dust the estimated A_V increases (factor 4-5).*
- *If all galaxies host a black hole its contribution in mid-IR needs to be quantified*
- *ISO integrated spectra over large areas. Smaller slit sizes are necessary.*

◆ Perspectives: **SIRTF** (my sponsor!)

- *IRS: Higher sensitivity and wider spectral wavelength coverage (5-40 μm)*
- *IRAC/MIPS: larger fields, mid-IR / far-IR imaging provide total energy content*
- *IRS: Identify, measure their distance using the redshifted UIB features.*