From IRAS to IRS: Evolution of the Most Luminous Galaxies in the Universe

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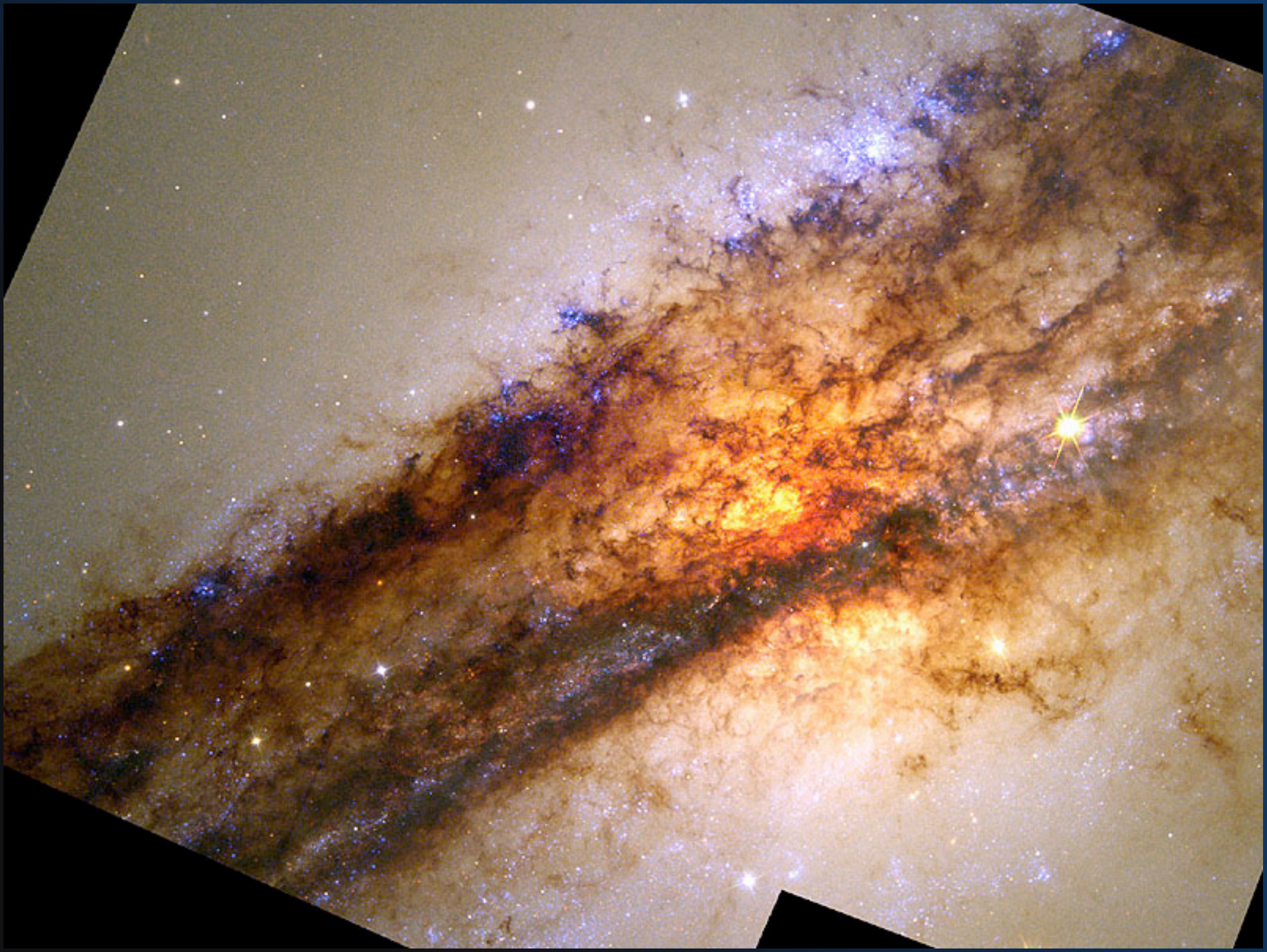
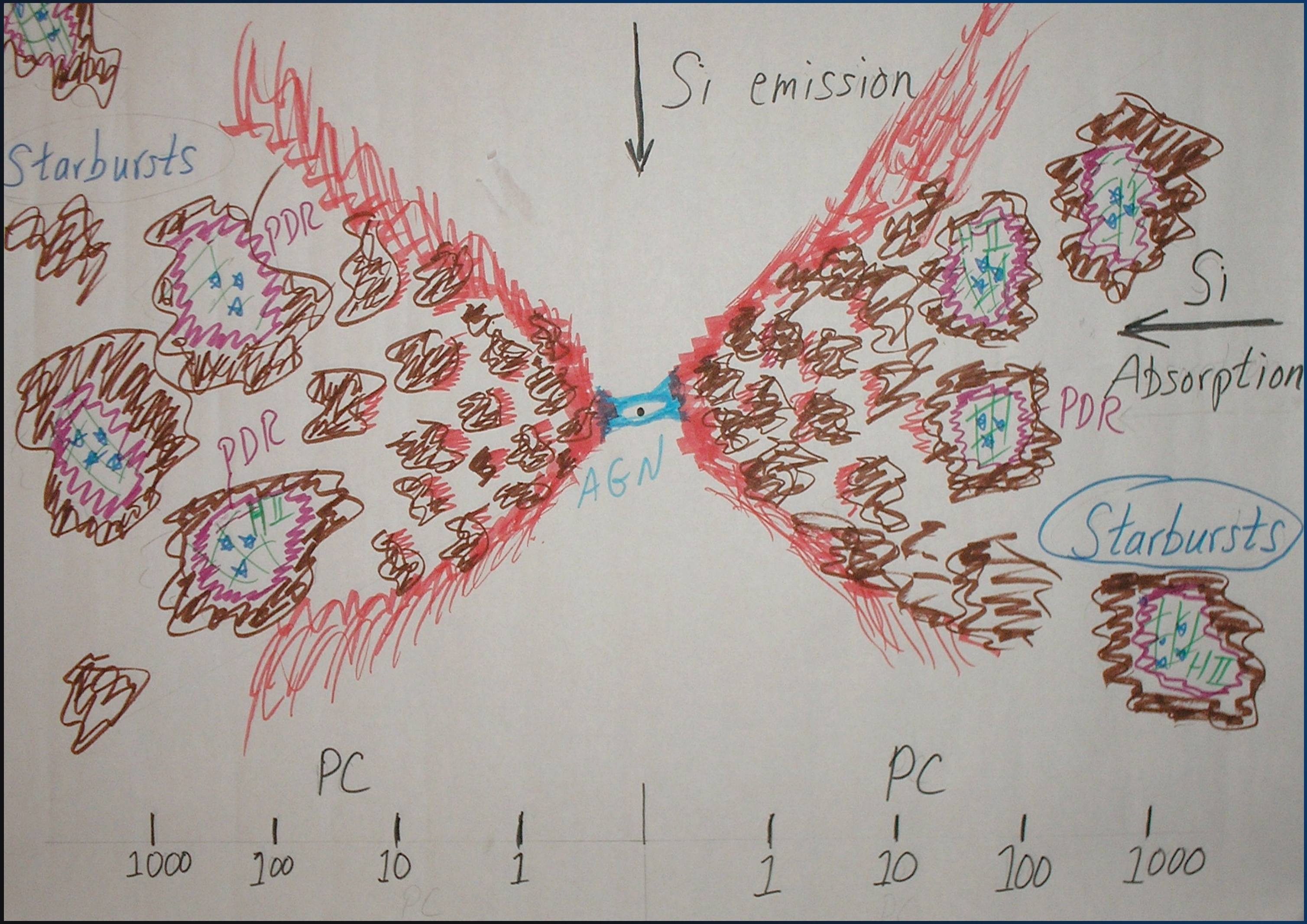
(Presented by Dan Weedman)

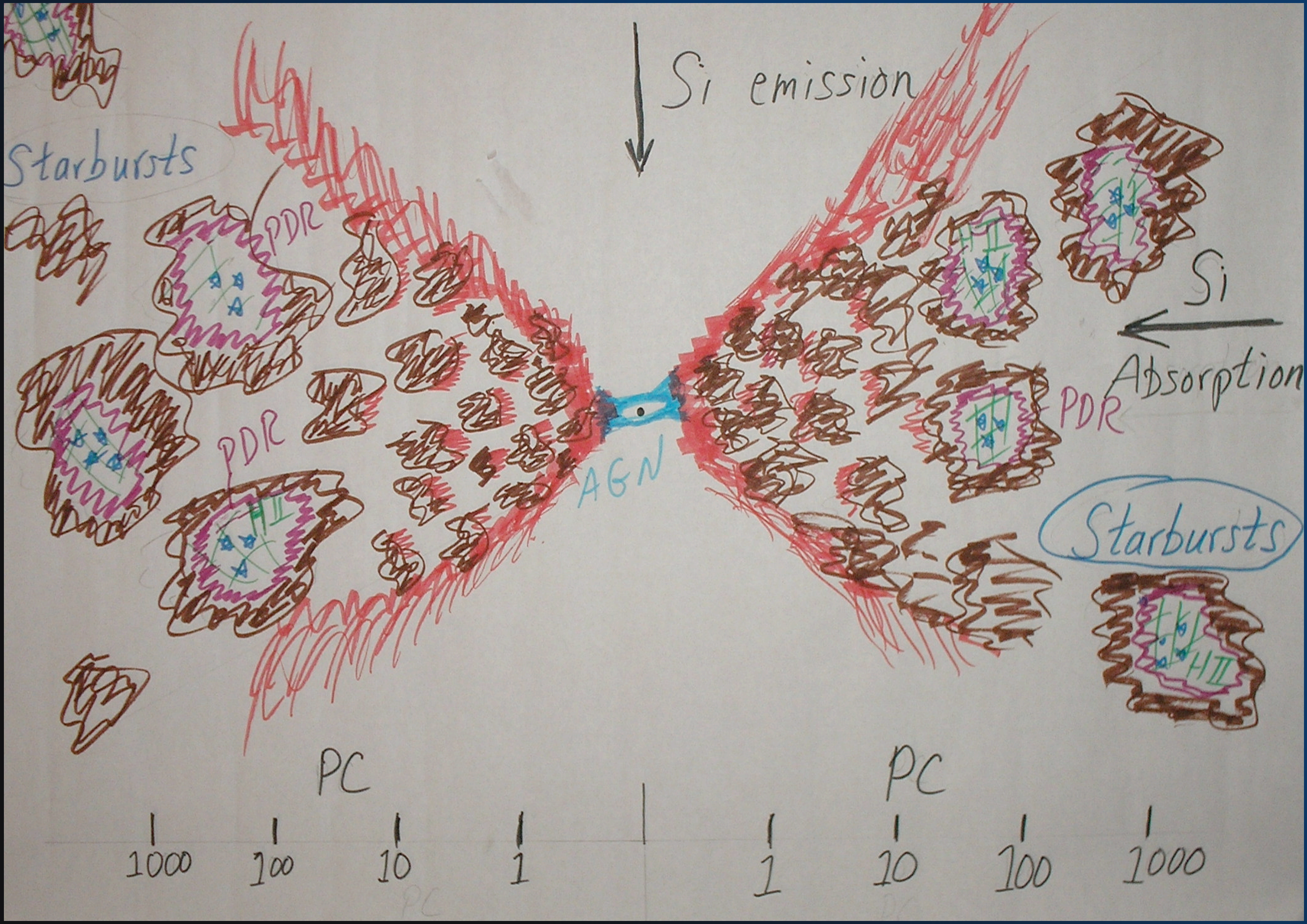
Dusty Center of Centaurus A

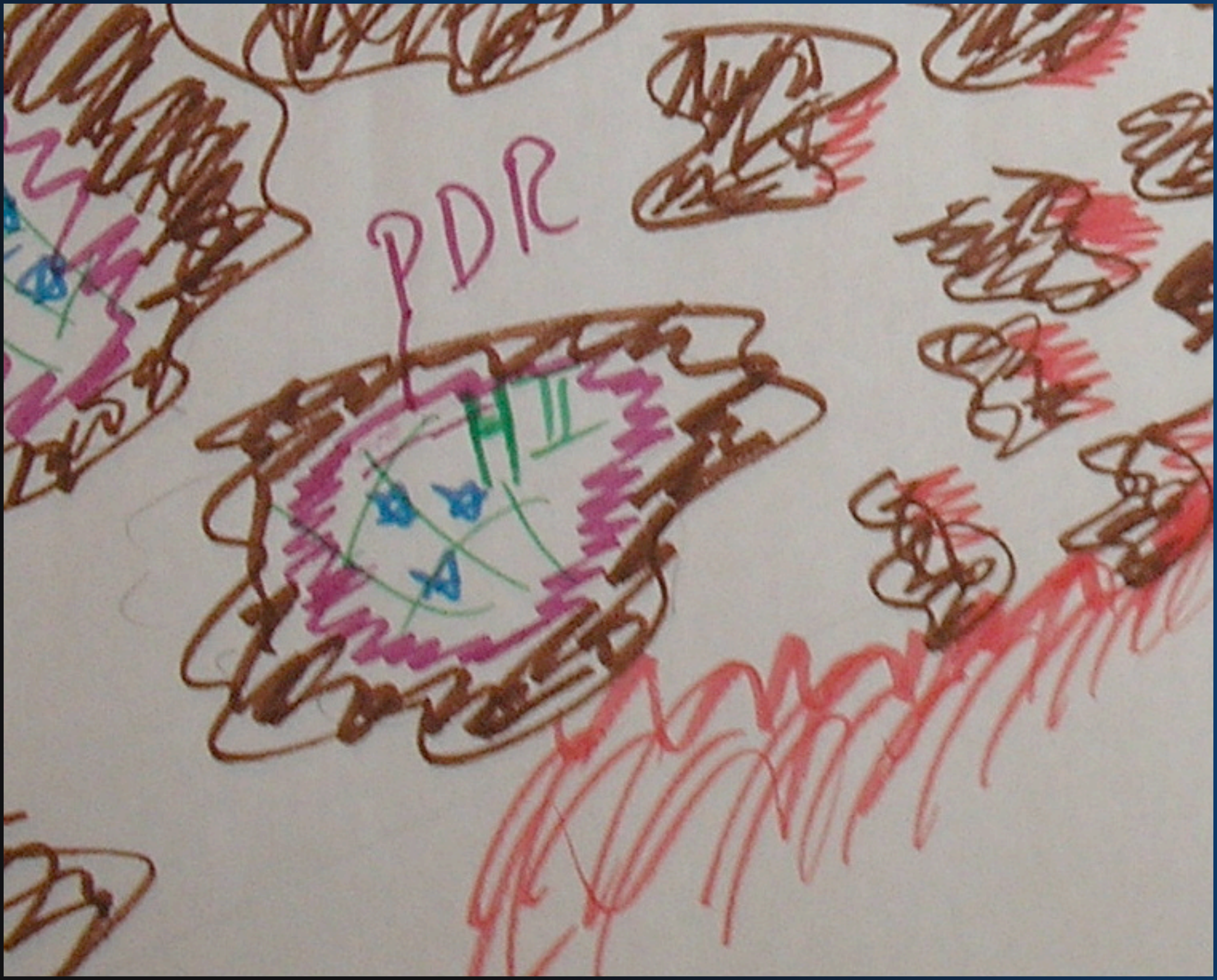


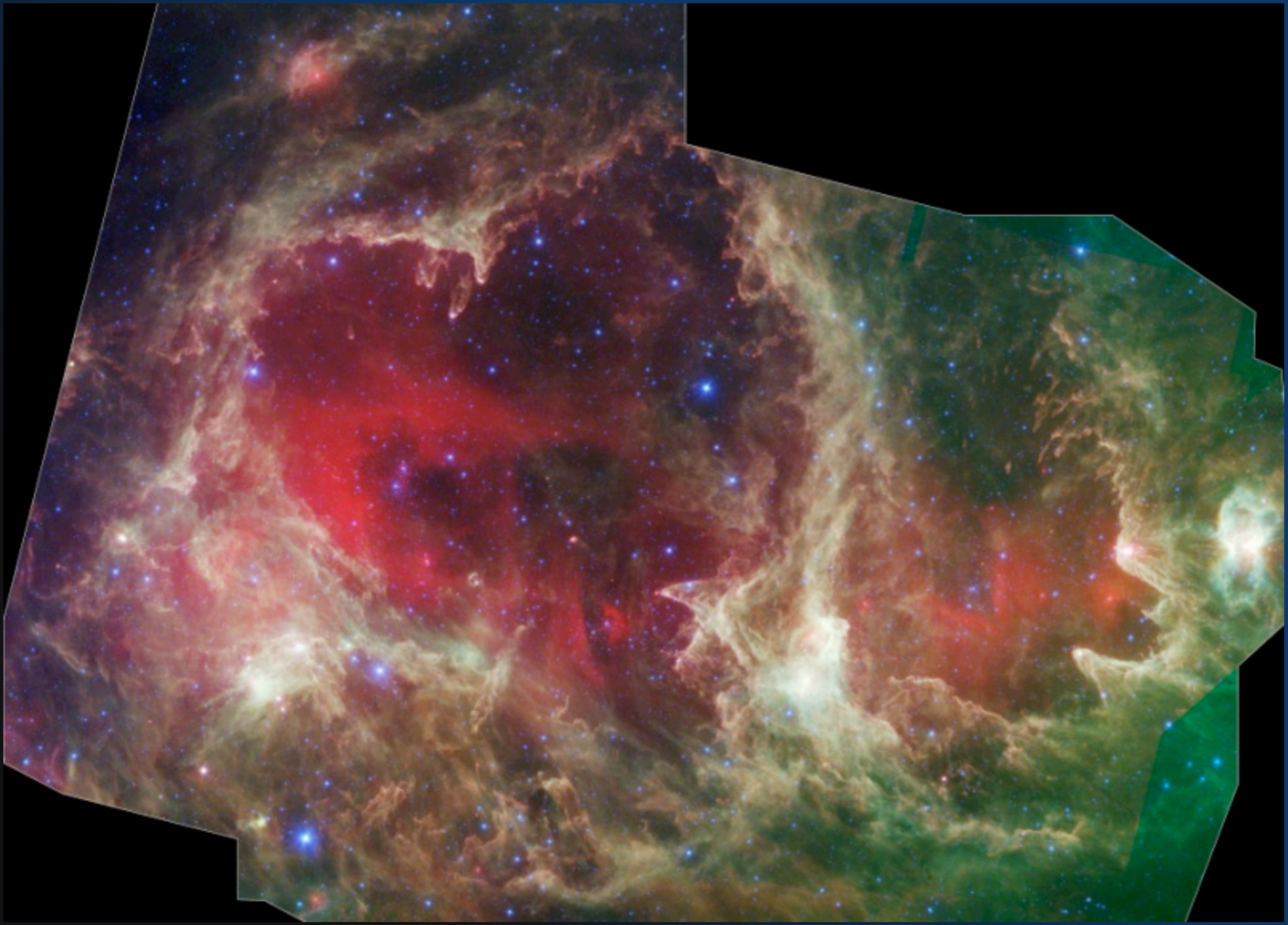
Observed spectrum of AGN depends on viewing direction



Dust clouds in torus also contain obscured starbursts




PDR
H II



Brandl et al. 2006

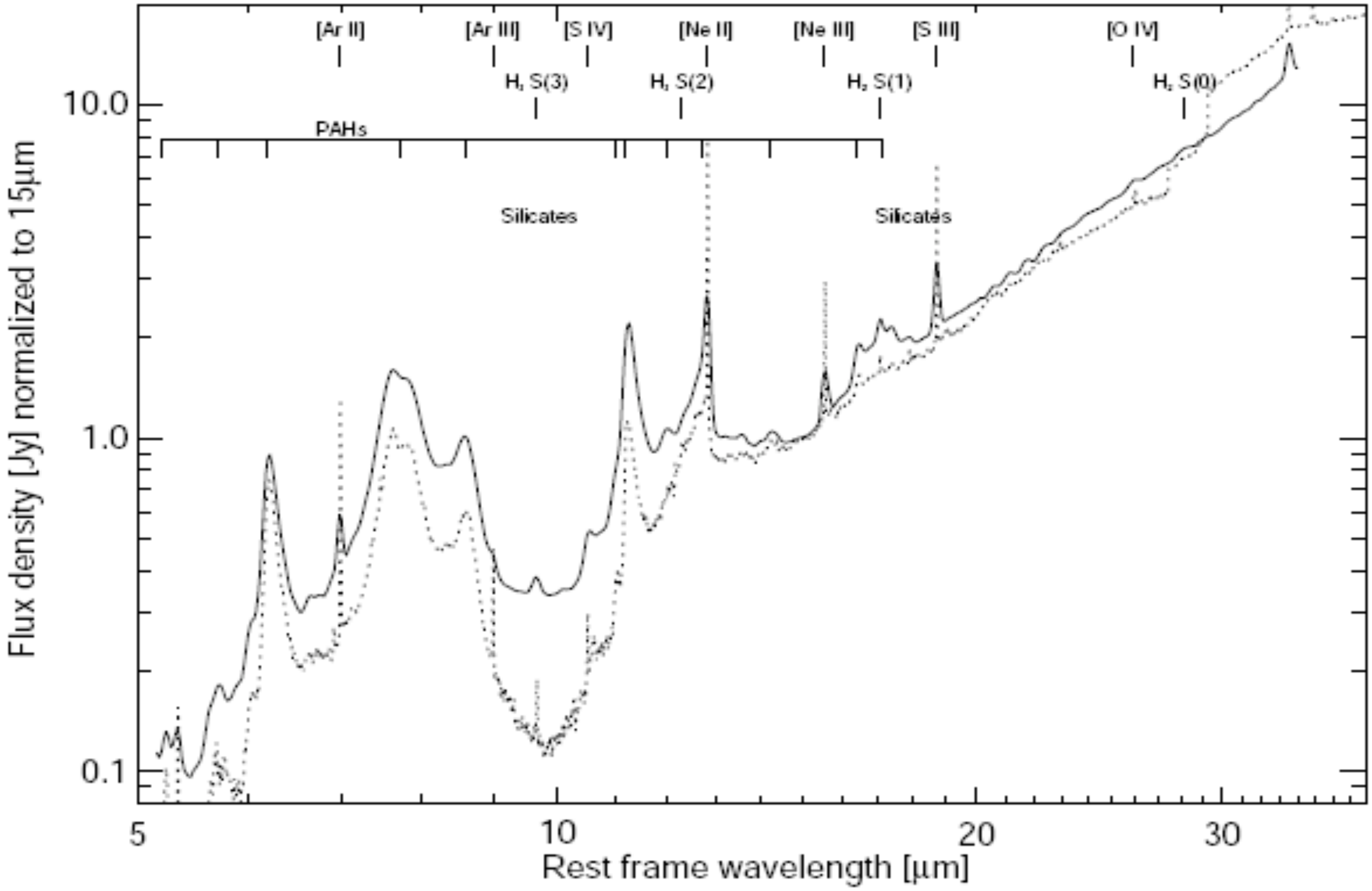


FIG. 6.— Average *IRS* spectrum of 13 starburst galaxies (IC

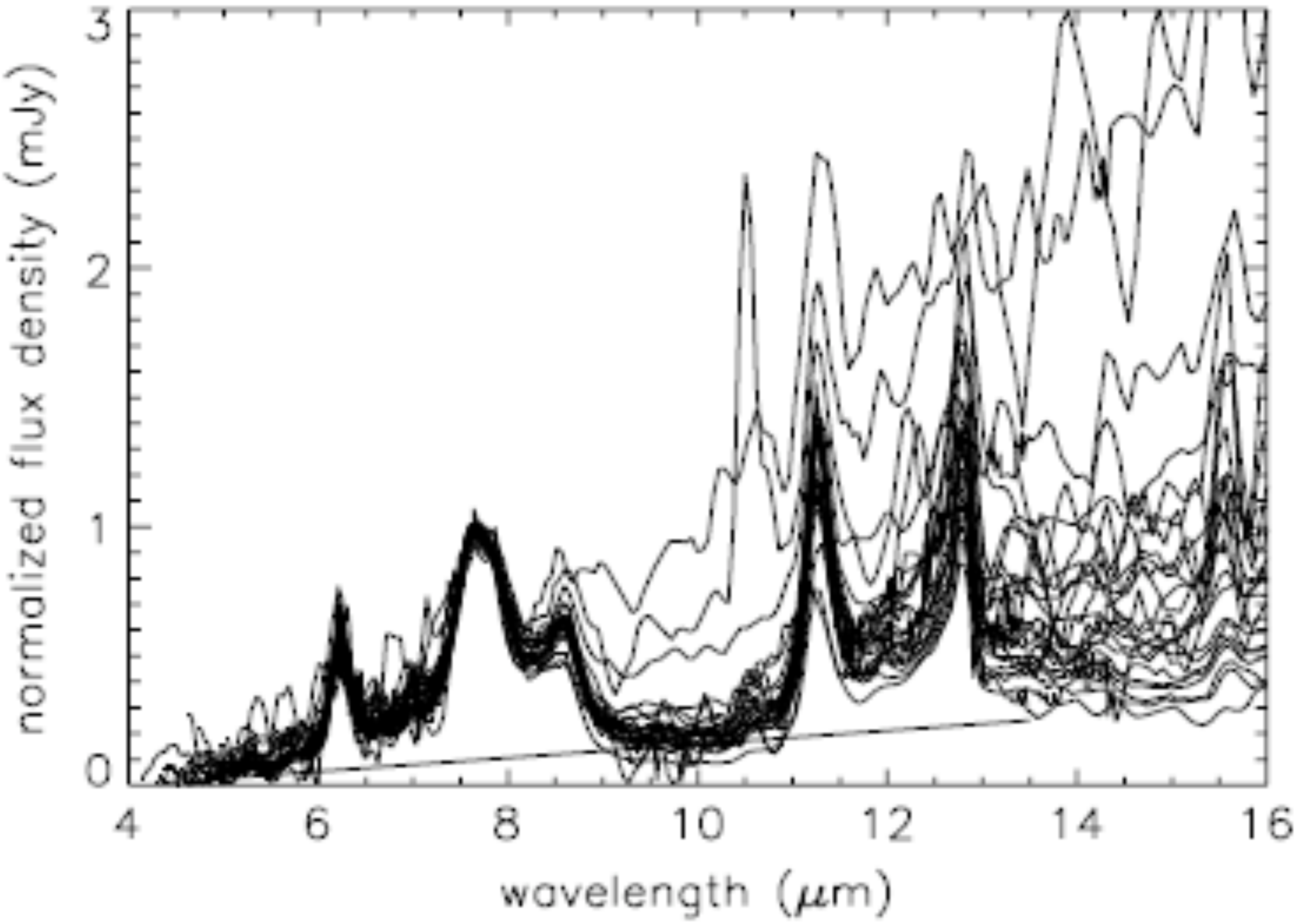


Figure 2. Overplots of *Spitzer* IRS spectra for all 25 sources in the *Spitzer* 10 mJy sample of Weedman & Houck (2008) which have SDSS classifications as starburst (H II for SDSS classification, instead of any AGN classification).

3 Most Luminous ULIRGs

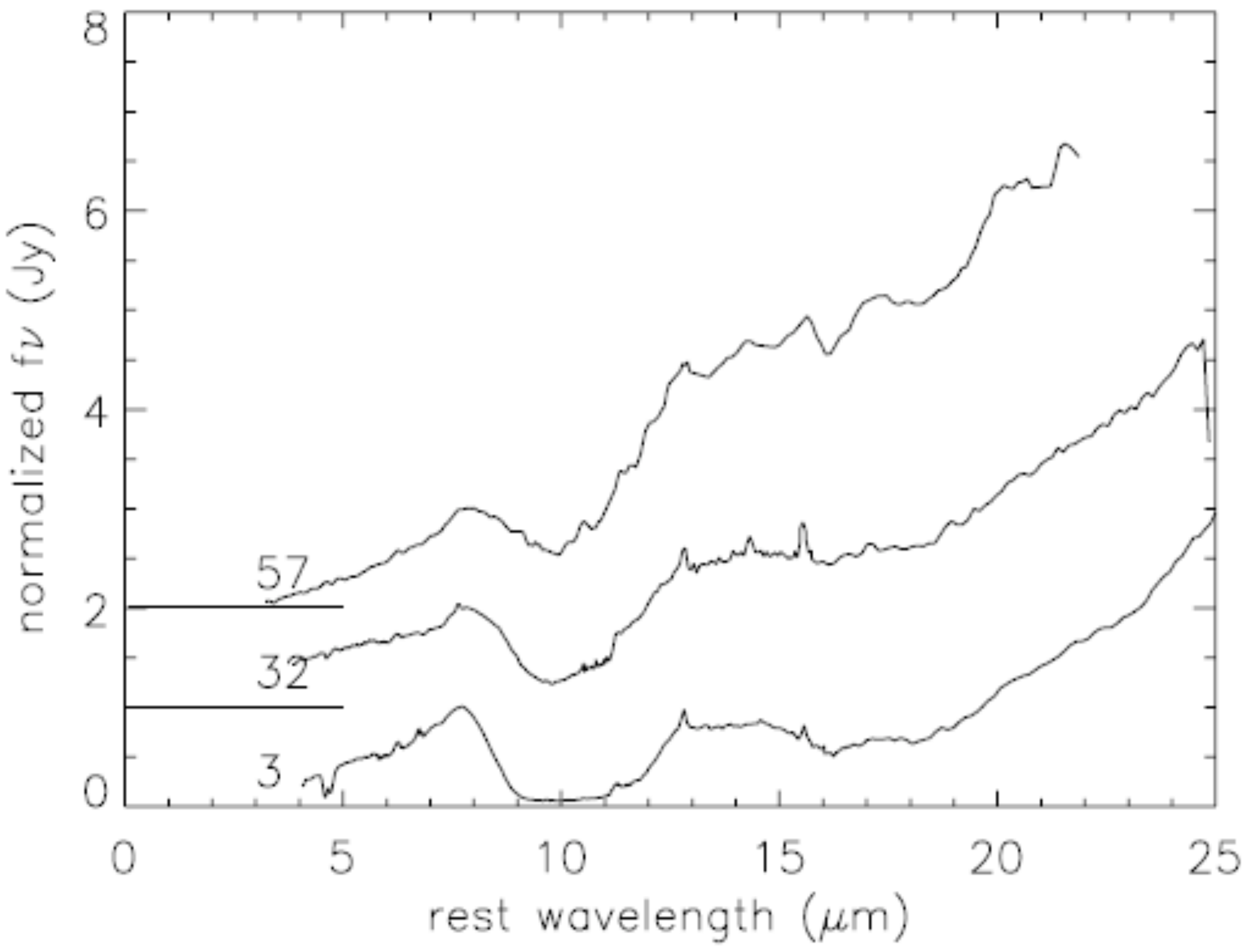


Figure 5. Rest-frame spectra of the three most luminous ULIRGs in Table 1

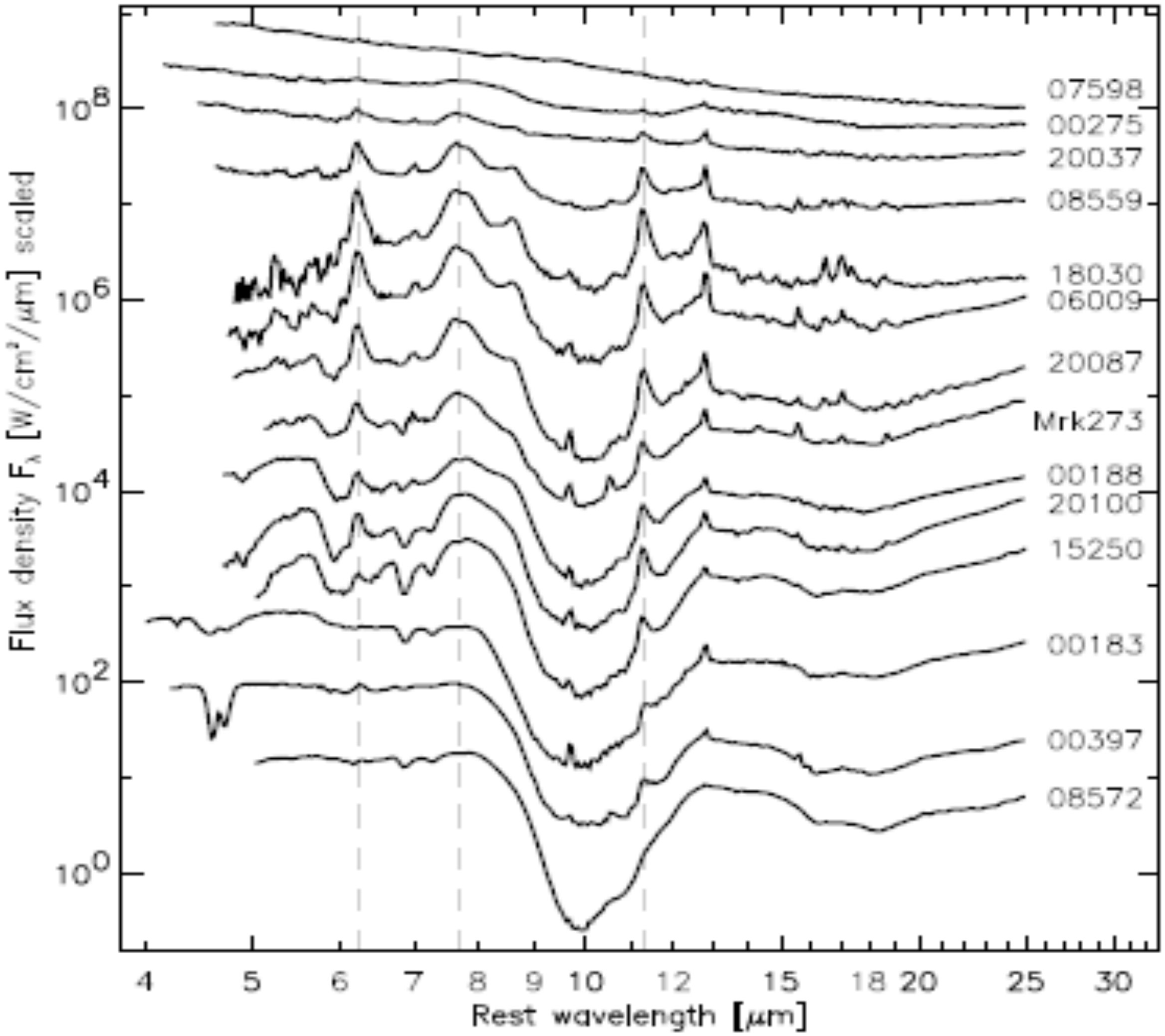
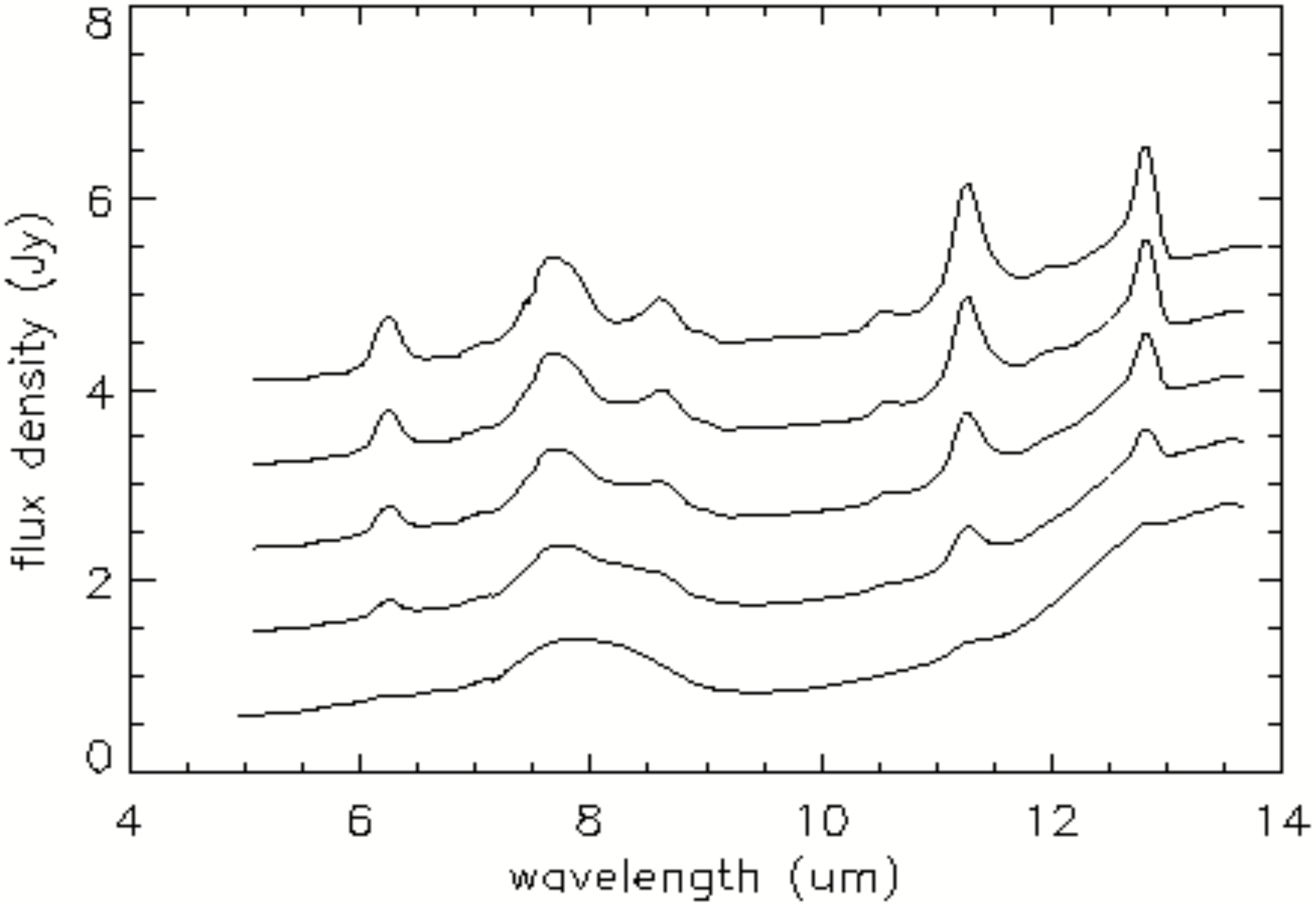


Figure 1. Spitzer IRS low-resolution spectra of ULIRGs sorted by spectral shape. The three spectra at the top are continuum-dominated (AGN-like), the next four are PAH-dominated (starburst-like) and the rest are absorption-dominated (burried nuclei). Vertical lines indicate the positions of the 6.2, 7.7 and 11.2 μm PAH emission bands

Starburst and AGN Fraction measured by 6.2um PAH



Spitzer MIPS surveys found many dusty sources which are optically very faint (R > 26) but bright enough for IRS spectroscopy [f(24um) > 0.5 mJy].

Hundreds of IRS spectra from many different observing programs allow systematic study of these sources to z ~ 3 and determination of whether AGN or starbursts, depending on PAH presence.

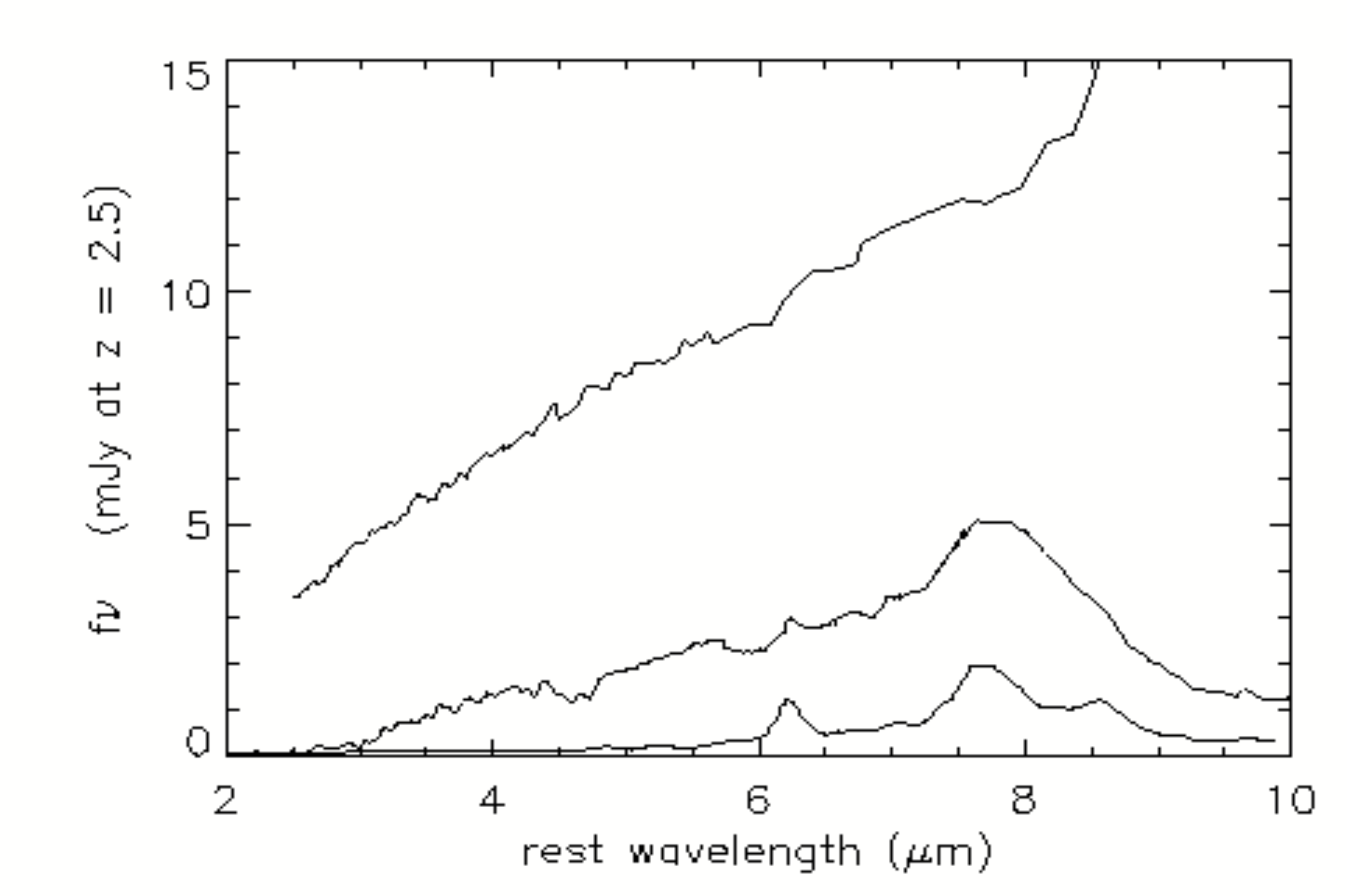
Luminous Starbursts from:

Brand et al.(2008); Bootes 70um
Brandl et al. (2006); optical starbursts
Dasyra et al. (2009); FLS 24um
Desai et al. (2009); Bootes faint 24um
Farrah et al. (2007); IRAS ULIRGs
Farrah et al. (2008); SWIRE 24um
Farrah et al. (2009); SWIRE 70um
Houck et al. (2005); Bootes 24um
Houck et al. (2007); Bootes 10 mJy
Imanishi et al. (2007); IRAS ULIRGs
Dole; Lagache; Helou; Schiminovich archive; various 24um
Menendez-Delmestre et al. (2009); submillimeter
Pope et al. (2008); submillimeter
Sargsyan et al. (2008); IRAS ULIRGs
Sargsyan and Weedman (2009); 24um + GALEX
Weedman and Houck(2009); FLS 10 mJy
Weedman et al. (2006a); SWIRE 24um
Weedman et al (2006b); FLS radio, 24um
Weedman et al.(2010); SWIRE 24um
Yan et al. (2007); FLS 24um

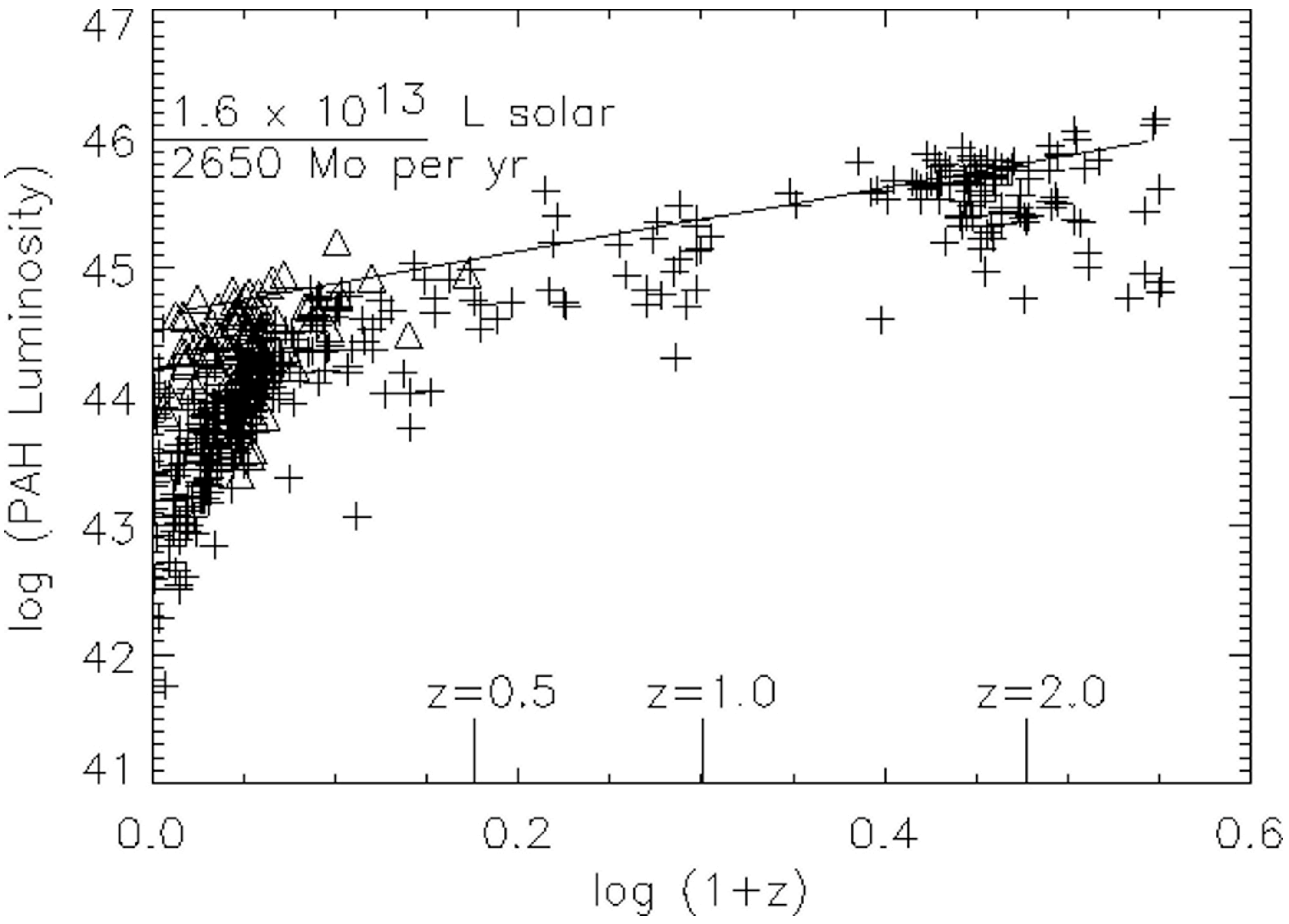
Luminous AGN from:

Brand et al. (2008b); Bootes 70um
Dasyra et al. (2009); FLS 24um
Farrah et al. (2007); IRAS ULIRGs
Farrah et al. (2009); SWIRE 70um
Hao et al. (2005); type 1 AGN
Helou, archive Legacy; 5 mJy 24um
Houck et al. (2005); Bootes 24um
Imanishi et al. (2007); IRAS ULIRGs
Markwick-Kemper et al. (2007); type 1 AGN
Martinez-Sansigre et al. (2008); obscured quasars
Polletta et al. (2008); 24um and dusty torus models
Sajina et al. (2007); FLS 24um
Sargsyan et al.(2008); IRAS ULIRGs
Schweitzer et al. (2008); type 1 AGN
Shi et al.(2006); local AGN
Weedman and Houck (2009a); 10 mJy 24um,Bootes, FLS
Weedman and Houck (2009b);SWIRE,FLS 24um 5 mJy
Weedman et al. (2006a); FLS radio 24um
Weedman et al. (2006b); SWIRE 24um
Yan et al. (2007) ; FLS 24um

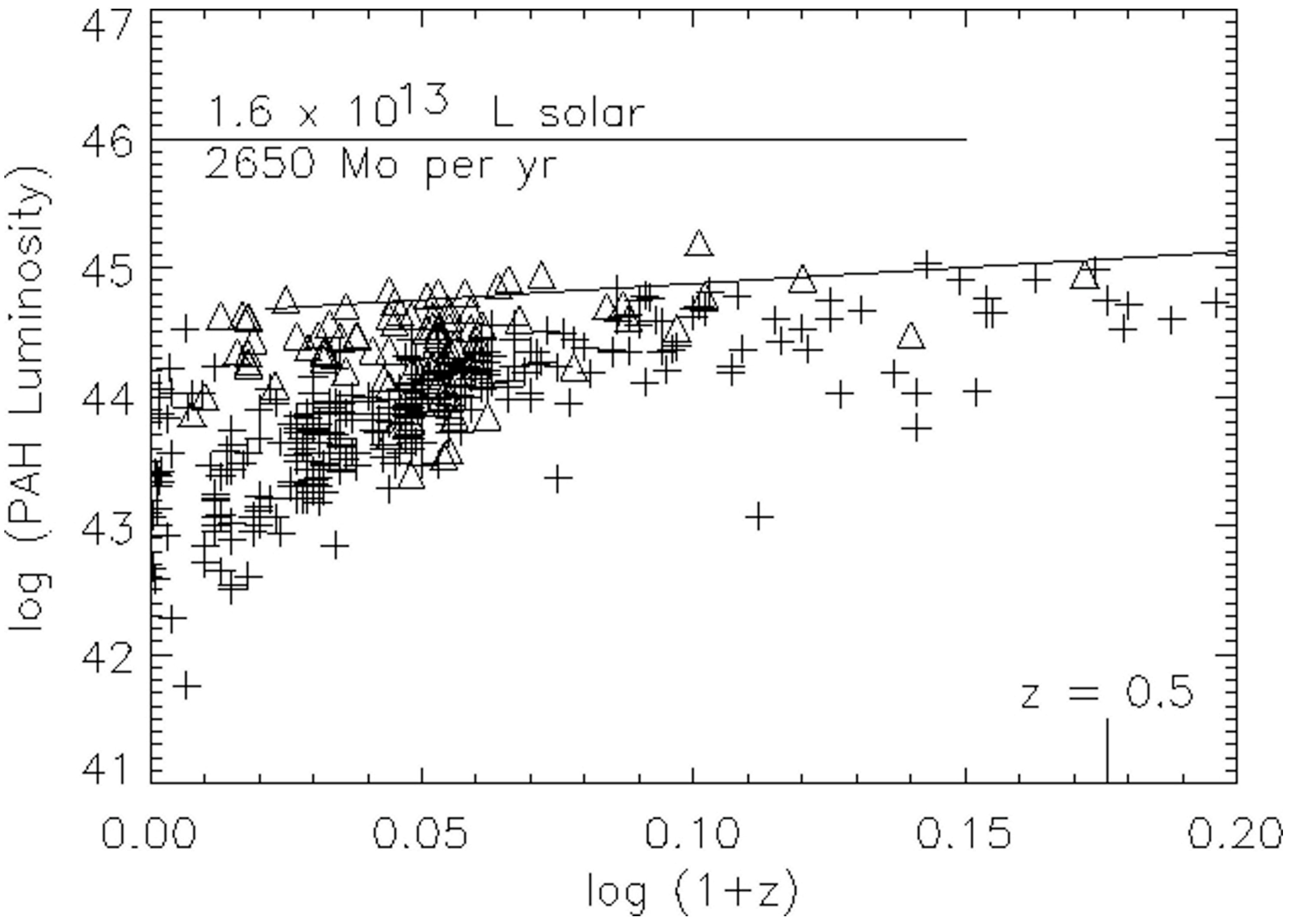
Most Luminous Unobscured AGN, Obscured AGN, and Starburst as would be observed at z = 2.5



Evolution of Most Luminous Starbursts (Weedman and Houck 2008)



Evolution of Most Luminous Starbursts z < 0.5



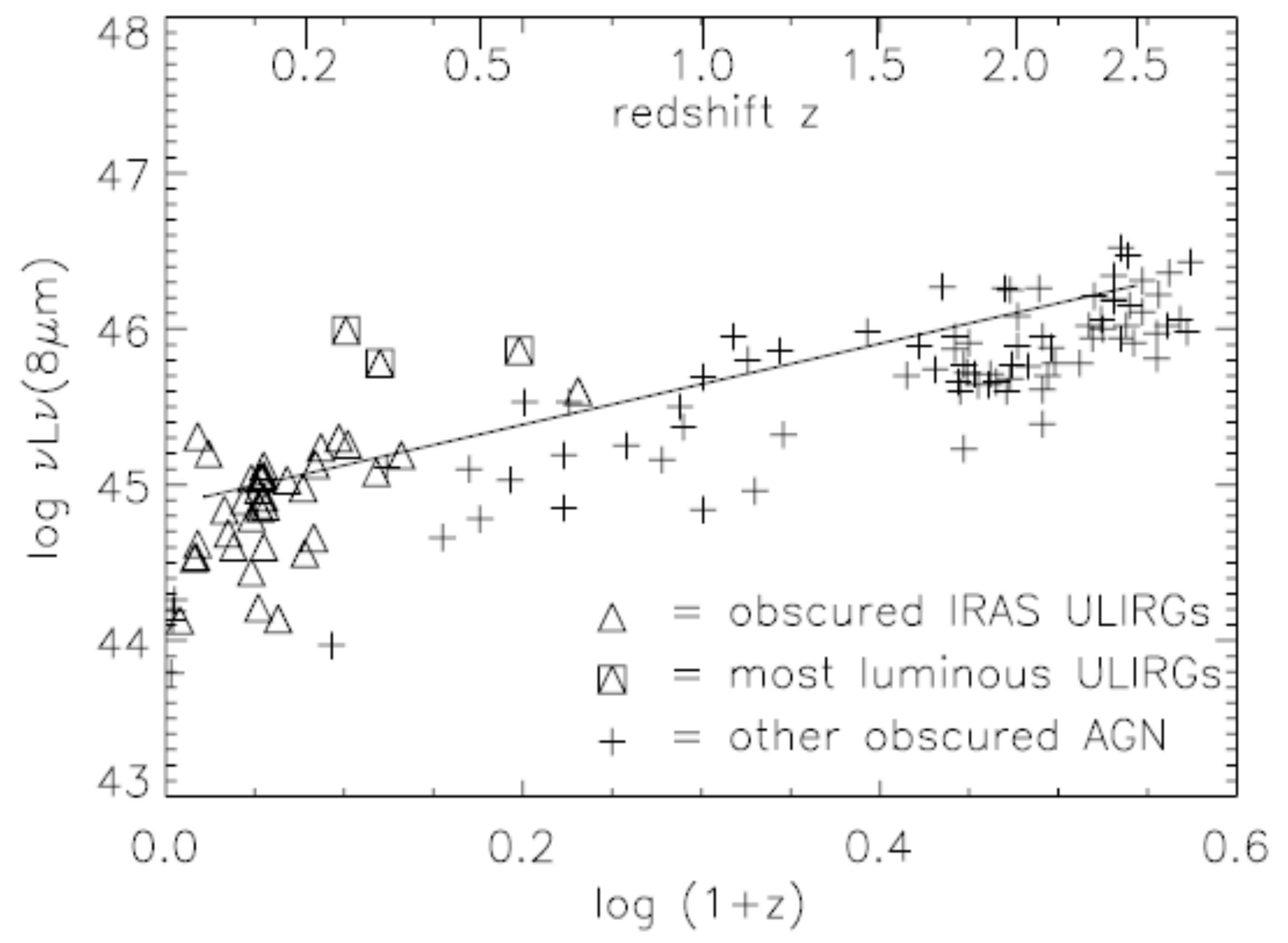
Evolution of Most Luminous Starbursts

- Luminosity scales as $(1+z)^{2.5}$
- Scale PAH Luminosity to Lir (solar) using starbursts observed with IRAS; Lir measures SFR
- To $z = 2.5$, $\log \mathrm{Lir} = 11.8 + 2.5\log(1+z)$
- The most luminous starbursts produce >3000 solar masses per year

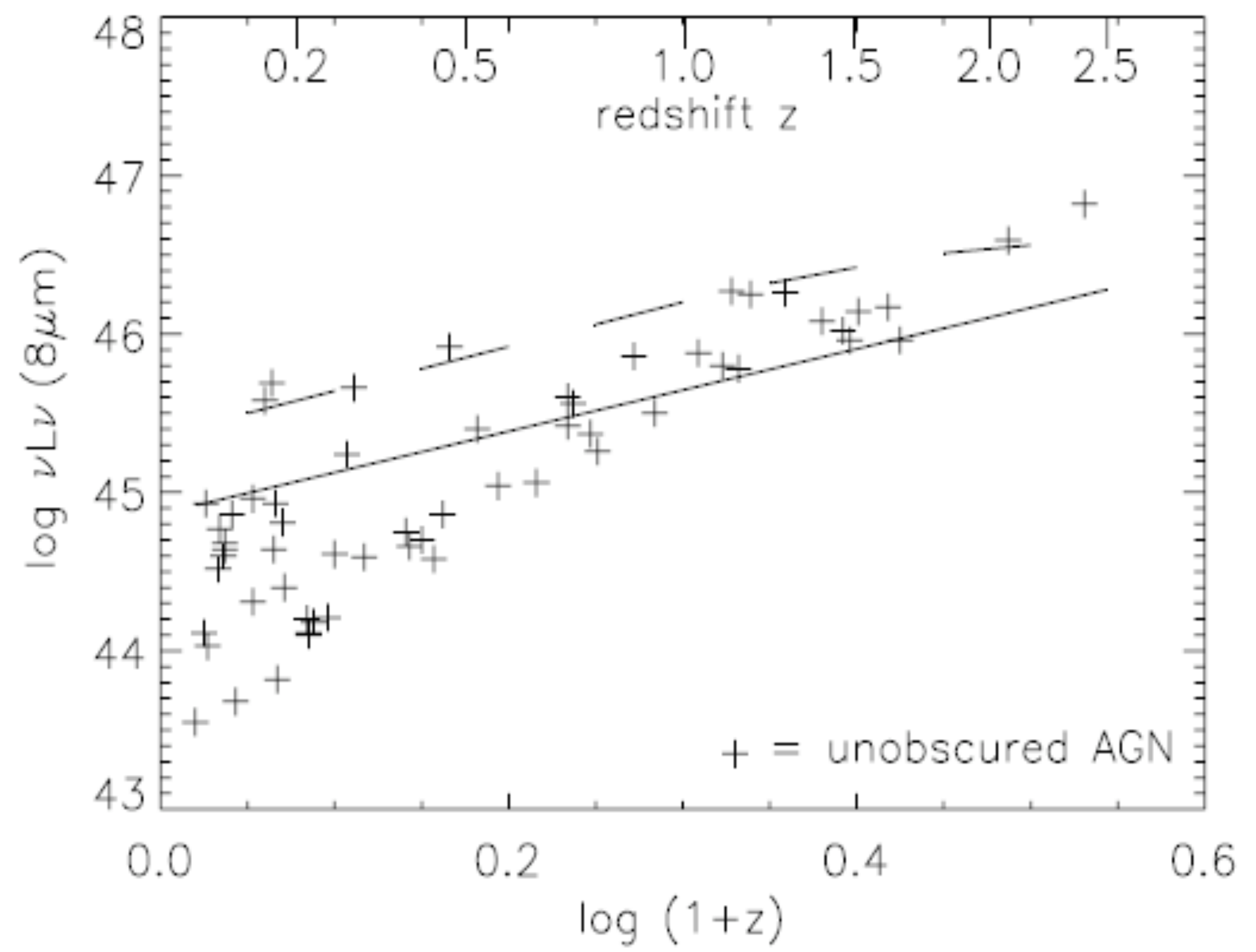
“Obscured” AGN are those with deep silicate absorption at ~10um.

“Unobscured” AGN are those with silicate emission.

Evolution of Most Luminous Obscured AGN (Weedman and Houck 2009)



Evolution of Most Luminous Unobscured AGN



Evolution of Most Luminous AGN

Luminosity also scales as $(1+z)^{2.5}$; identical scaling as starbursts implies both are triggered by same events (interactions?)

Scale 8um luminosity to total infrared luminosity Lir (solar) using AGN observed with IRAS.

Obscured and unobscured AGN have same Lir so observed differences at 8um arise from extinction of about half the 8um luminosity in obscured AGN, as expected from orientation

Most luminous AGN at z = 2.5 is 8×10^{13} solar luminosities, 3 times more luminous than most luminous starburst.

Why is this happening to us??

Shouldn’t processes depending on dust and molecules get brighter, not fainter, as the universe ages??

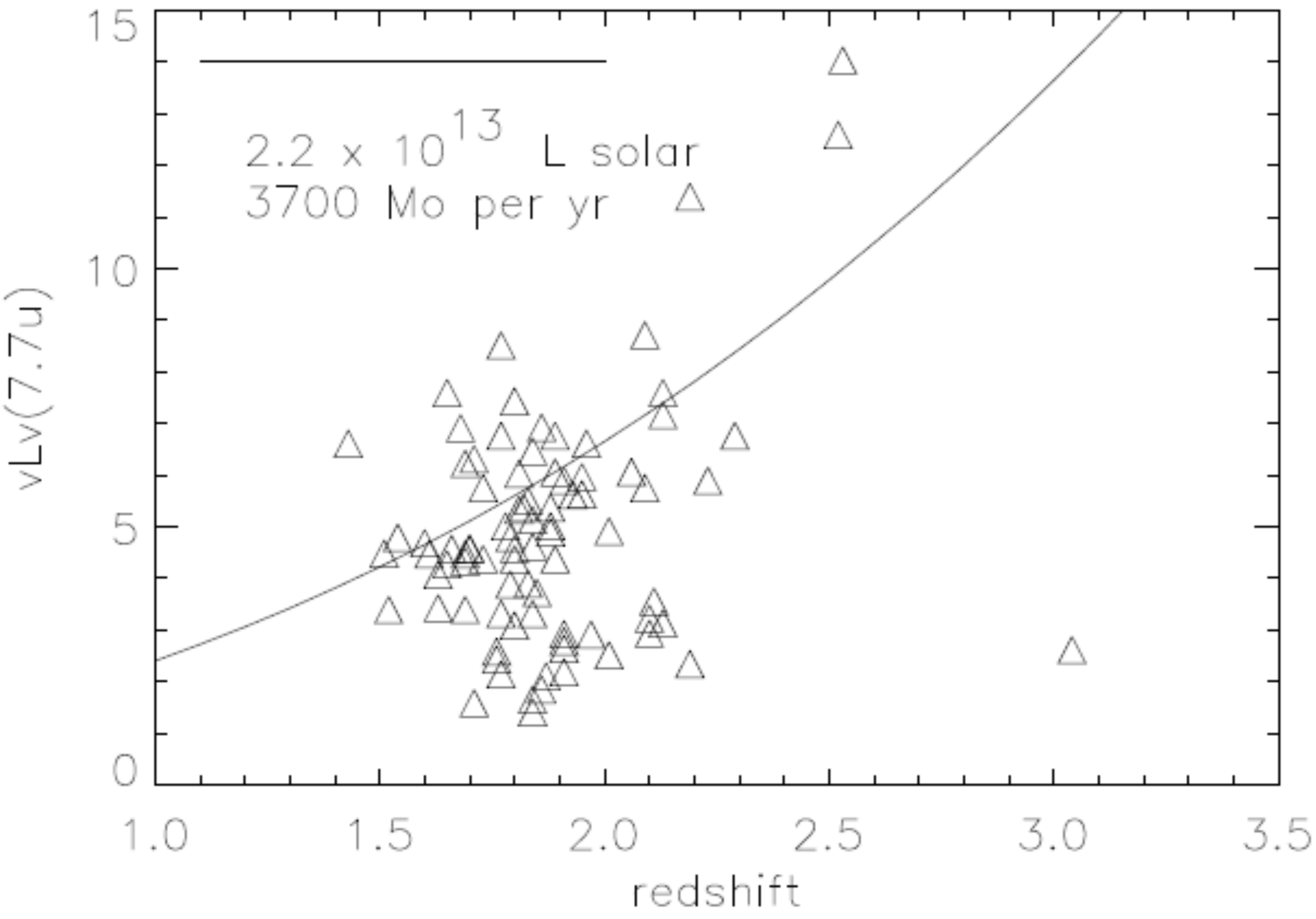
What does the 2.5 exponent tell us??

Where does evolution stop?? When was the peak luminosity??

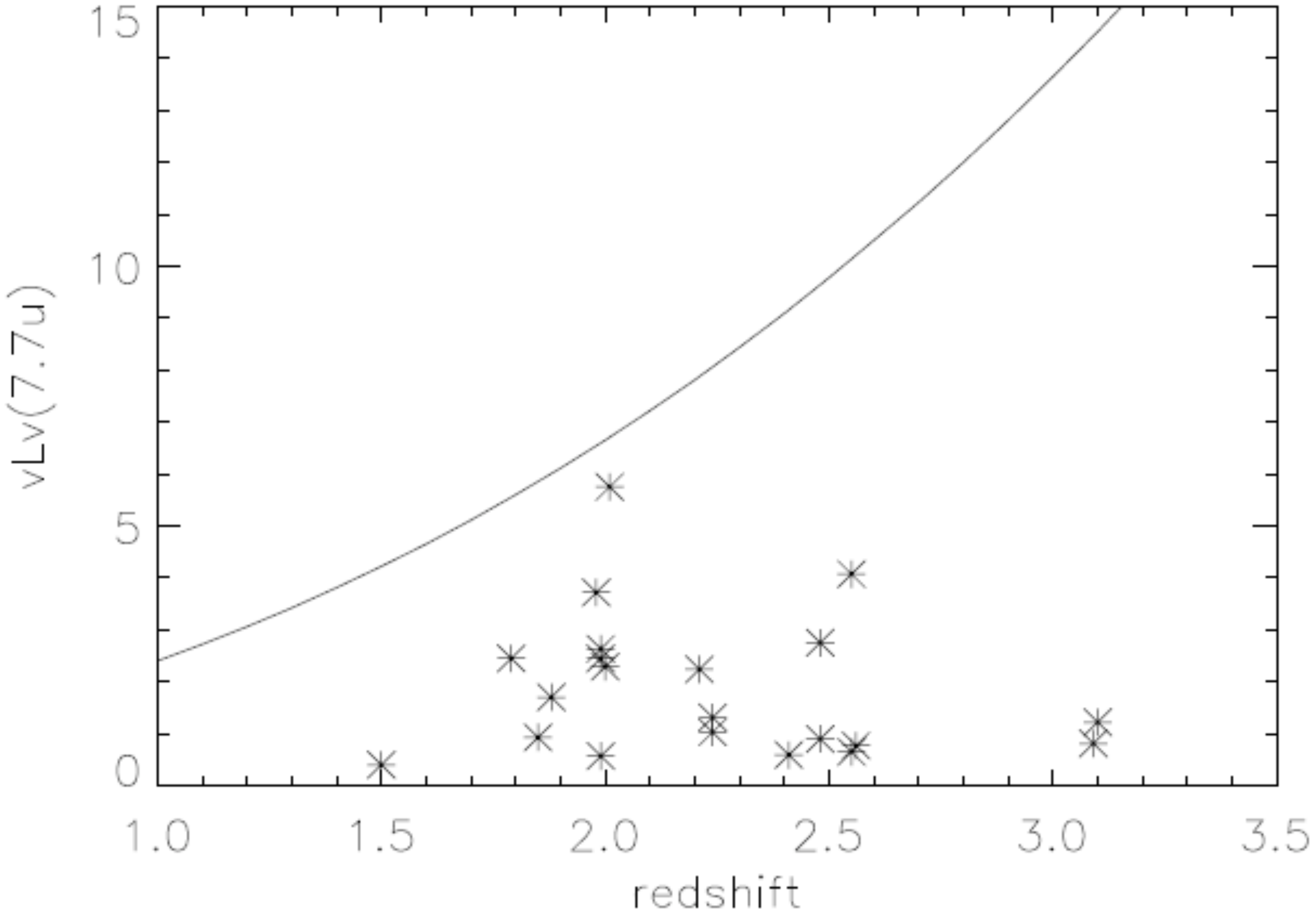
Are AGN and starburst peaks different?

Which caused the other??

7.7um PAH luminosities (10^{45} ergs/s) for starbursts selected at 24um



7.7um PAH luminosities (10^{45} ergs/s) for starbursts selected by submm



Comparing Spitzer Selected PAH Starbursts with Submm Starbursts.

- Submm-selected starbursts less luminous in PAH by 2x to 3x than 24um-selected
- 24um-selected starbursts less luminous in submm than submm-selected
- Probably extremes of cold dust distribution in pure starbursts; no evidence of hot, AGN dust in 24um selected.

High Redshift Starbursts show negligible hot dust continuum (Farrah et al. 2008)

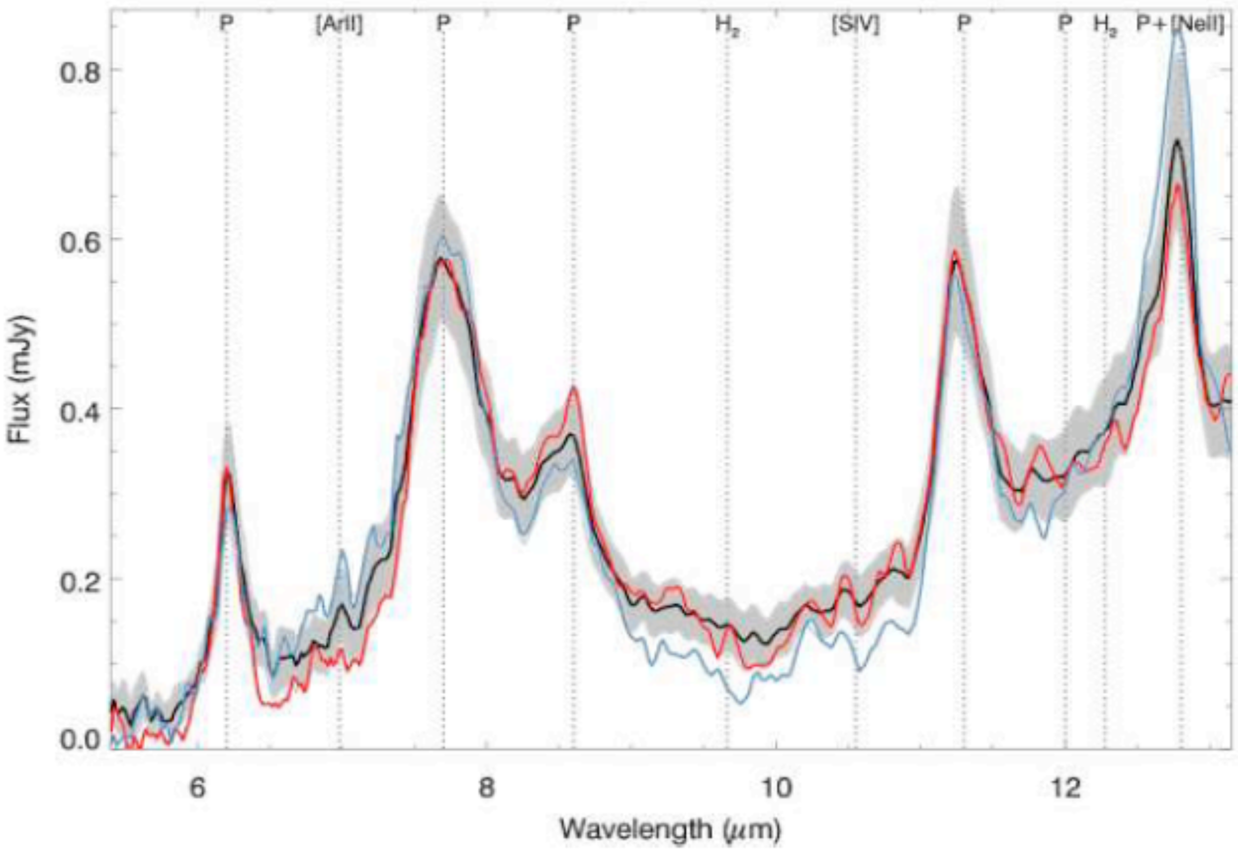
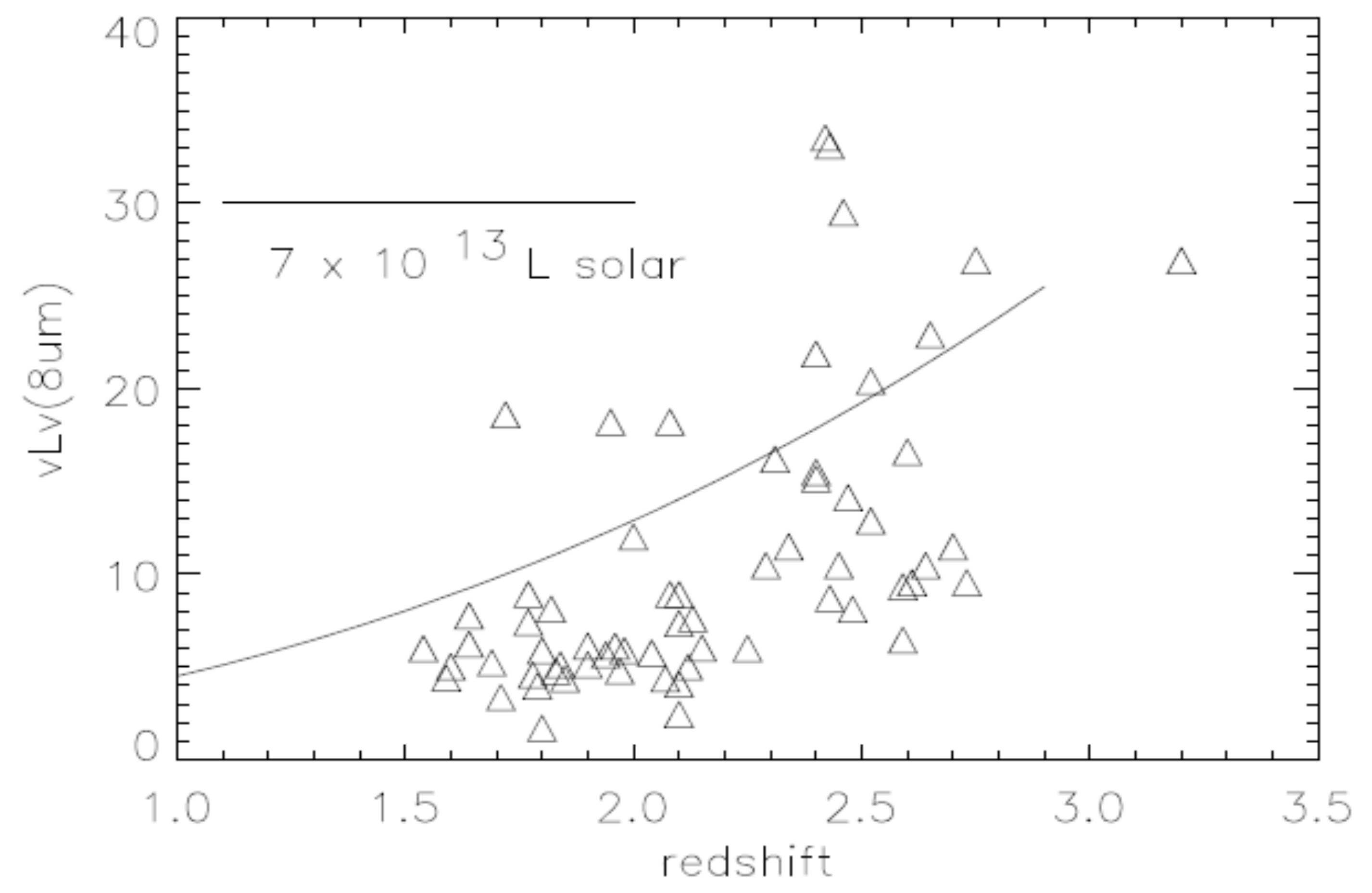


Fig. 4.— Averaged spectra. The average of all 32 objects is plotted in black, with the grey shaded region indicating the 1σ dispersion. The average of the ten objects with the largest PAH 6.2μm EWs is plotted in red, and the average of the ten objects with the largest silicate strengths is plotted in blue. A 'P' denotes the wavelength of a PAH feature.

8um continuum luminosities for absorbed AGN selected at 24um



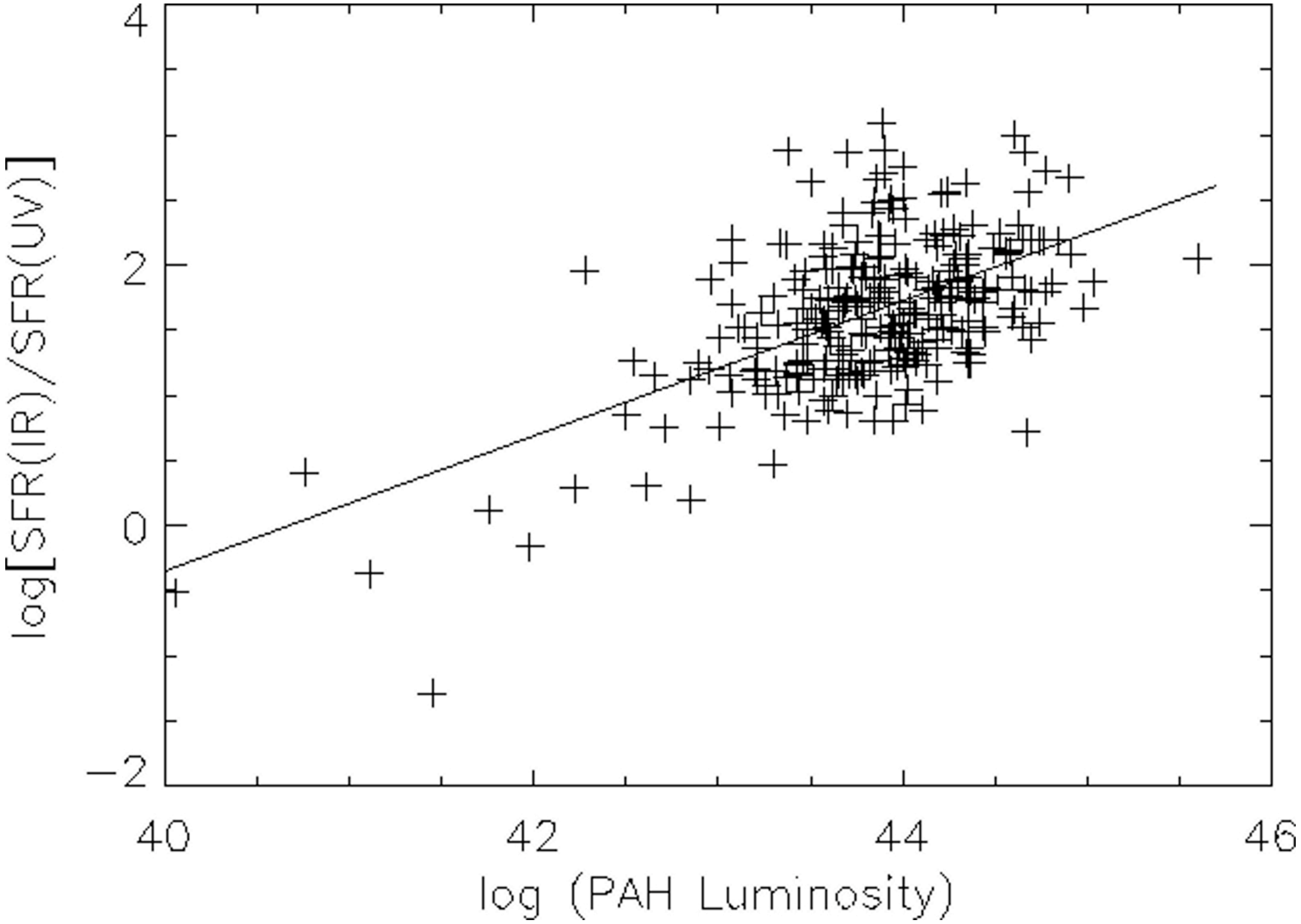
HELP

How do we keep seeking the peak luminosity for dusty sources?

Obscured starbursts and obscured AGN for z > 3 very faint in optical and infrared

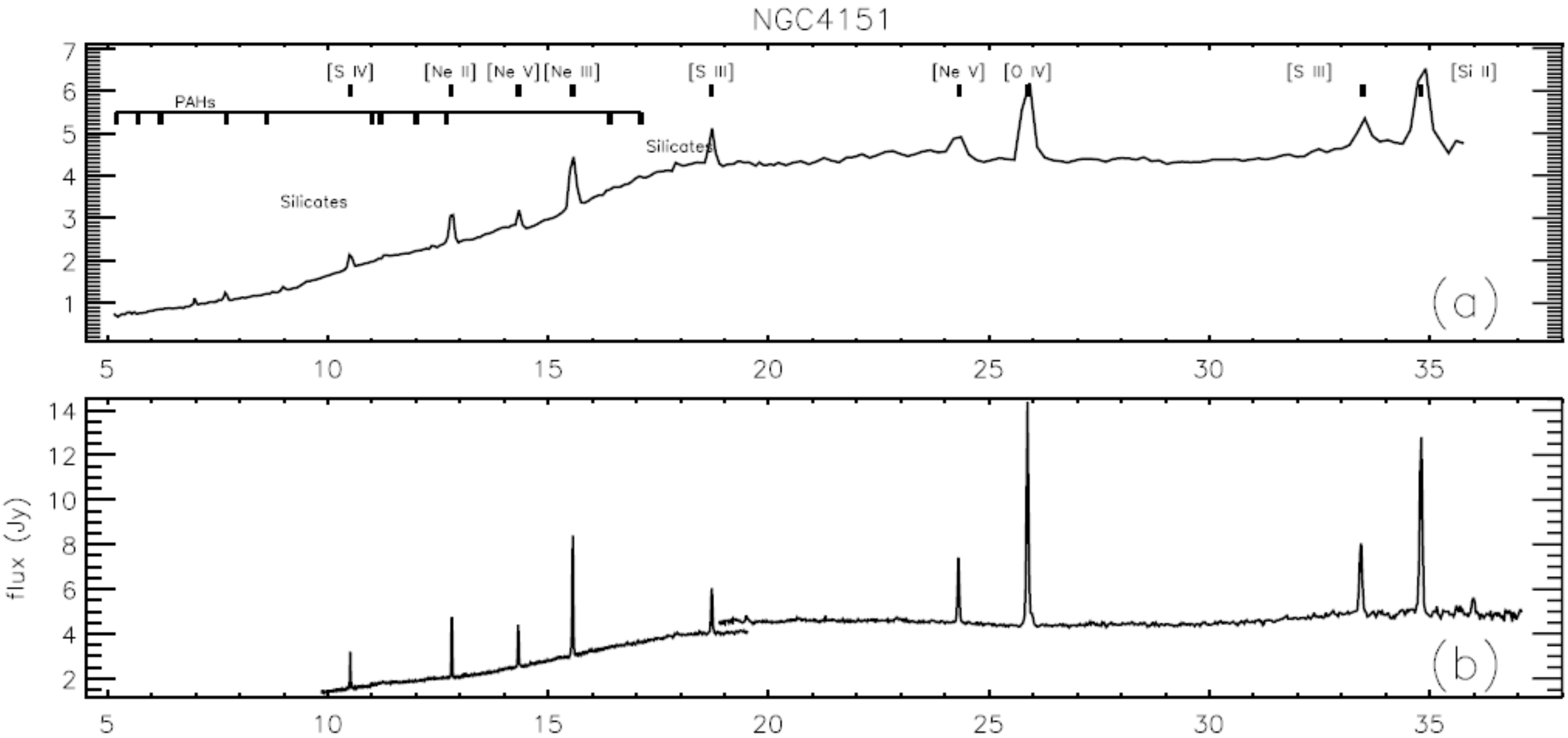
Unobscured AGN (type 1 quasars) only help if we can measure dust emission

PAH/GALEX UV ratio of star formation rates shows only 1% of UV escapes luminous starbursts (Sargsyan and Weedman 2009)

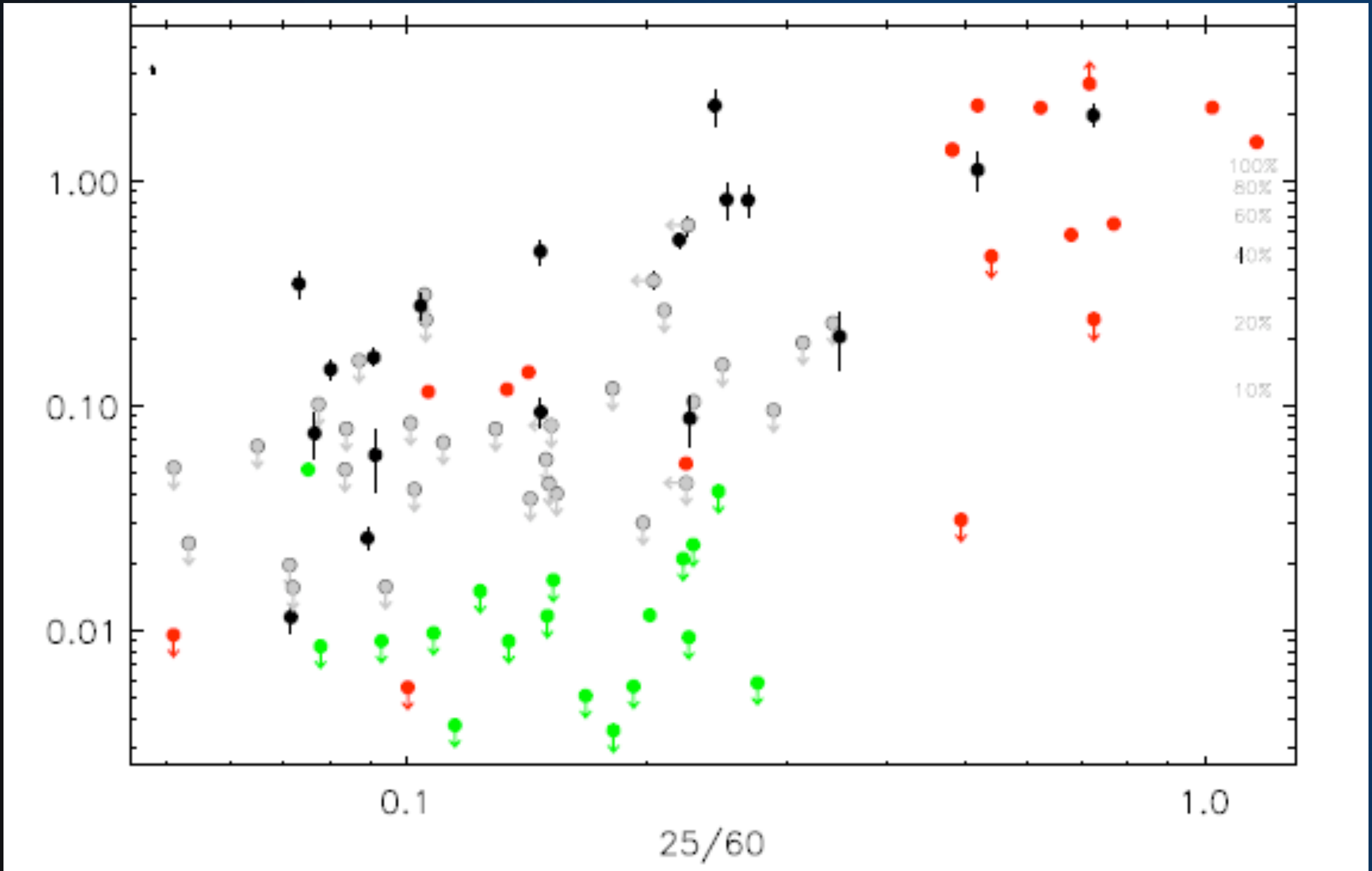


Examples of Diagnostics with High Resolution IRS Spectroscopy

Low Resolution and High Resolution for type 1 AGN



[NeV] / [NeII] vs dust temperature (25um/ 60um) for ULIRGs (black), AGN (red), starbursts (green) (Farrah et al. 2007)



Always-blueward line asymmetries show absorbing dust in forbidden line region (Spoon and Holt 2009)

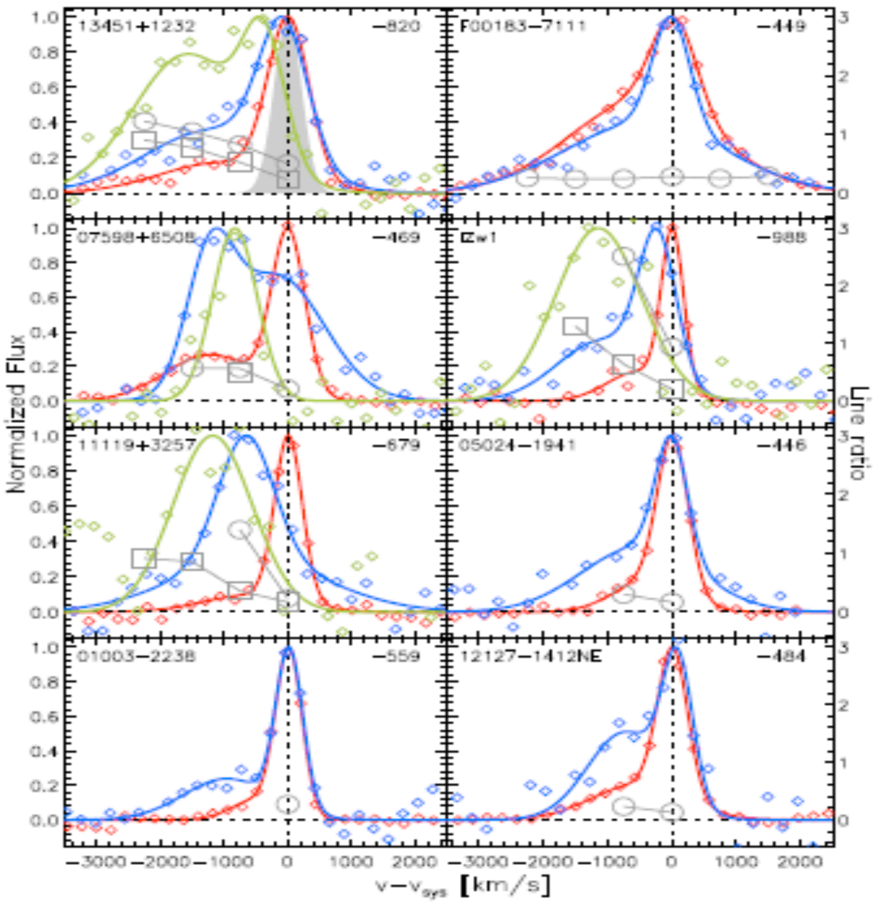
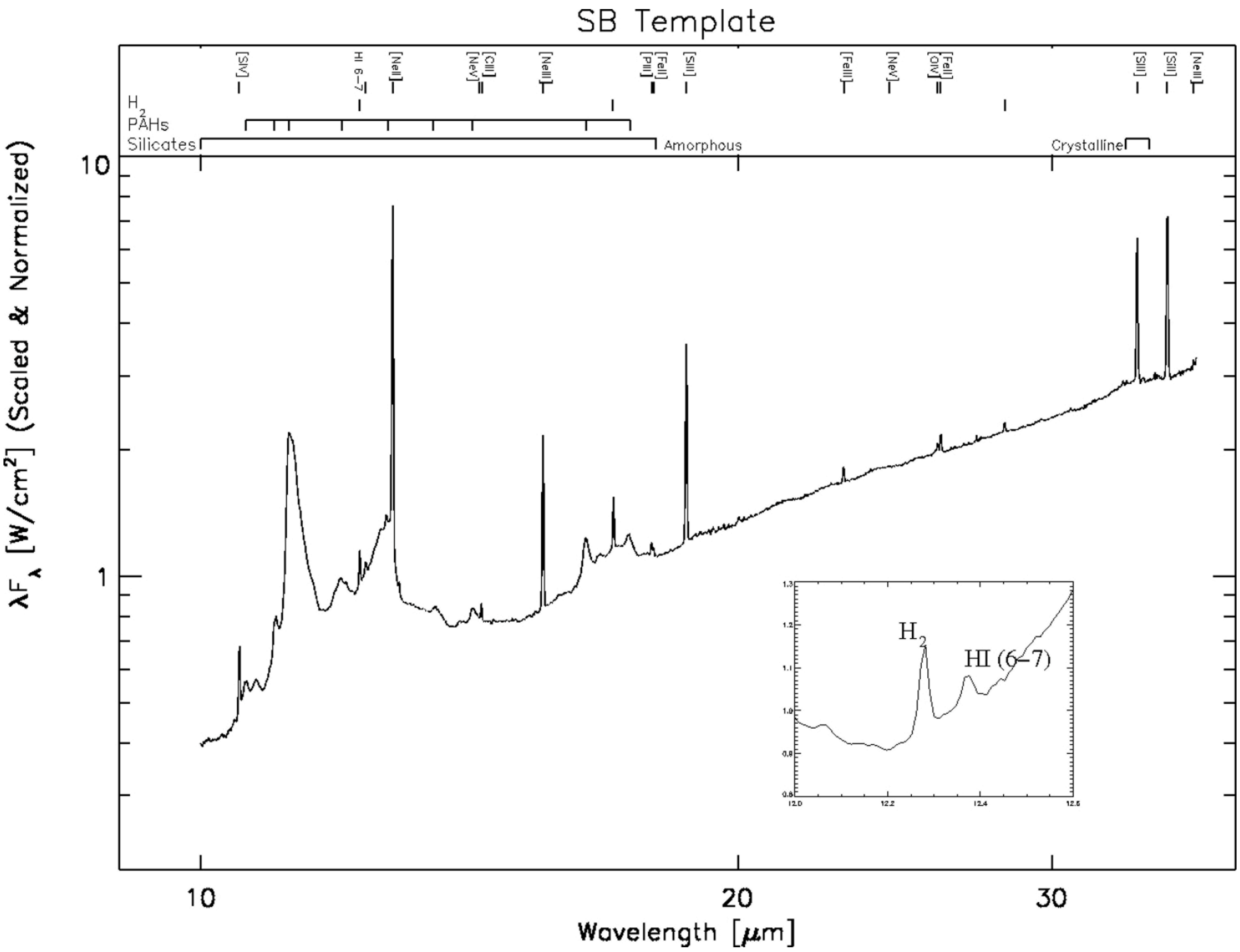


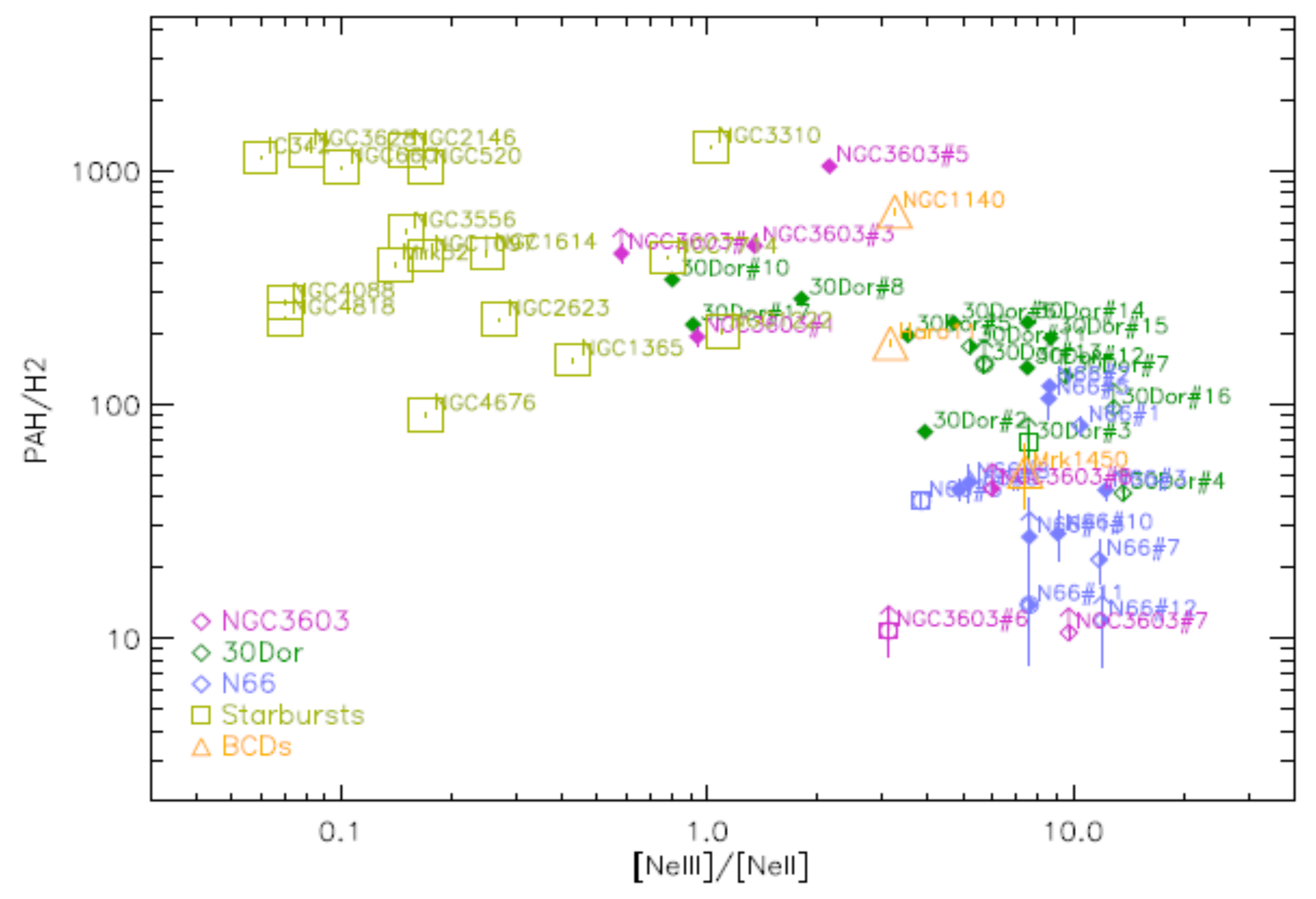
Fig. 2.— Comparison of the line profiles of 12.81 μm [Ne II] (*red*), 15.56 μm [Ne III] (*blue*) and 14.32 μm [Ne V] (*green*), as observed with the Spitzer-IRS high-resolution spectrographs

High Resolution Average Starburst

(Bernard-Salas et al. 2009)



PAH/H2 decreases with radiation hardness (Lebouteiller et al., in preparation)



Future of Mid-Infrared Spectroscopy

- IRS archive will be essential for continued research on dusty starbursts and AGN
- Over 6000 low resolution galaxy spectra await more detailed analysis and comparison to multiwavelength properties (GALEX UV, optical spectra, IRAS fluxes, submm and radio fluxes,….)
- New Optimal SMART Extraction (arXIv 0910.1846; http://isc.astro.cornell.edu/IRS/SmartRelease)
- Determination of bolometric luminosities as function of spectral classification is crucial (submm, Herschel)
- Over 2000 high resolution galaxy spectra await careful emission line analysis and comparison to multiwavelength properties

Thanks, NASA, for 25 great years of discovery!

(but we are not done yet)