Emission properties of (interstellar) dust

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Layout

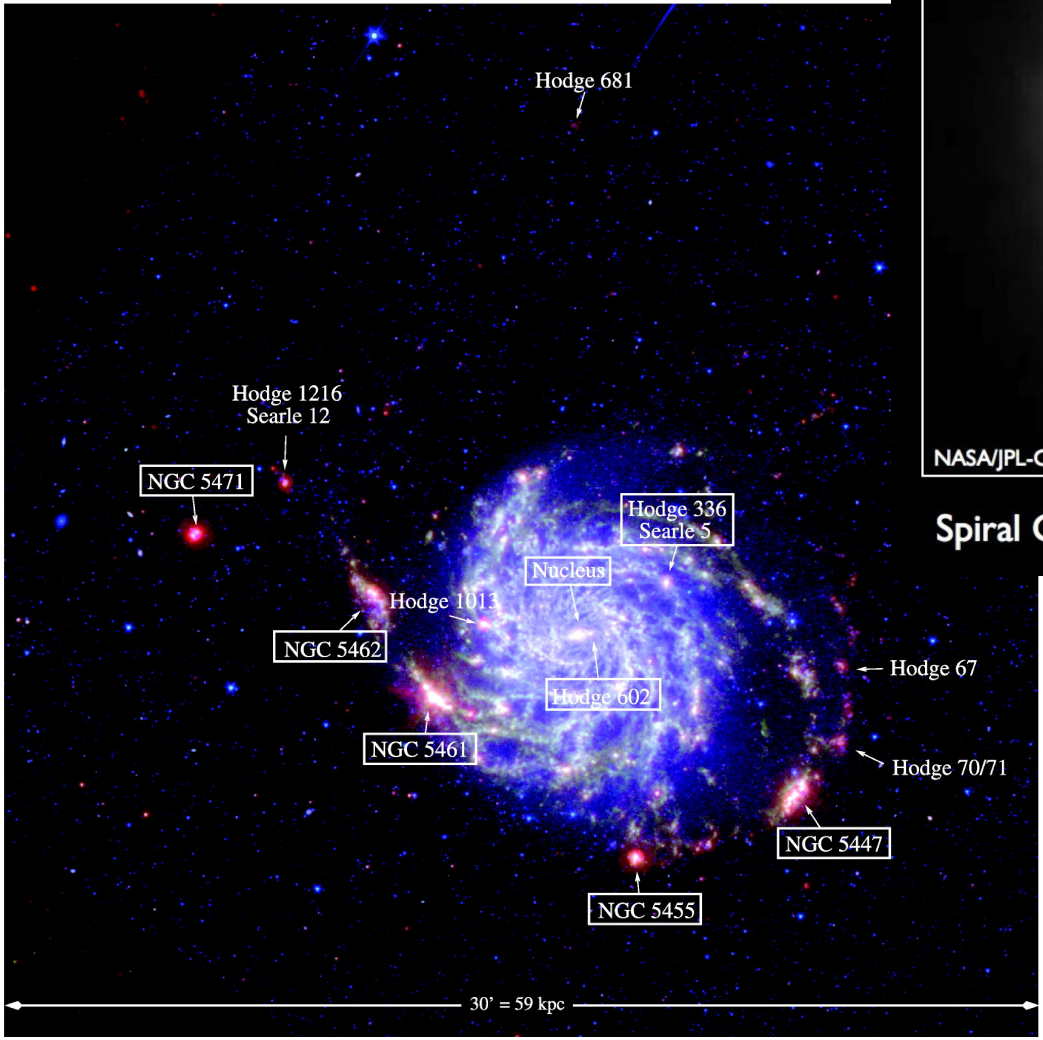
- A few caveats
- (Towards) A standard model for interstellar dust: a key for the interpretation of observables
- Line emission at mid-infrared (IR) wavelengths in the low- and high-redshift (z) Universe
- IR continuum emission, nearby and far away
- Puzzling dust for the evolving dark Universe
- Conclusions

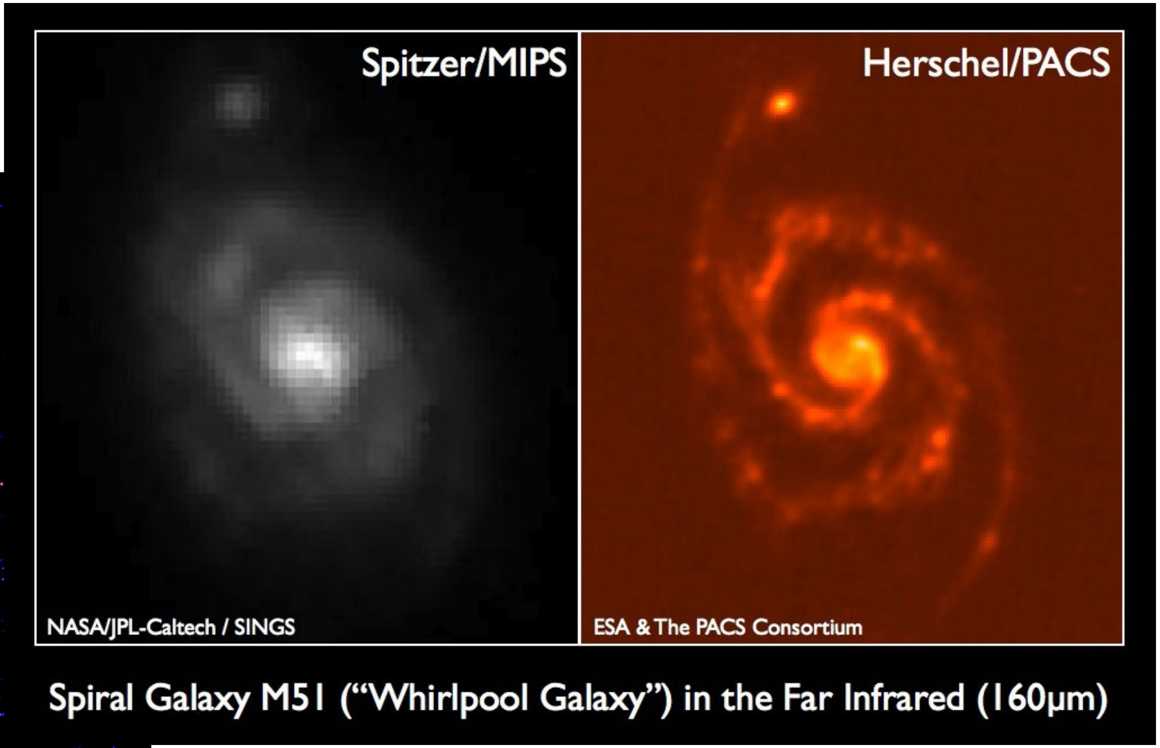
This presentation does not address:

- Zodiacal light
- Interplanetary dust
- Circumstellar dust
- Extended Red Emission

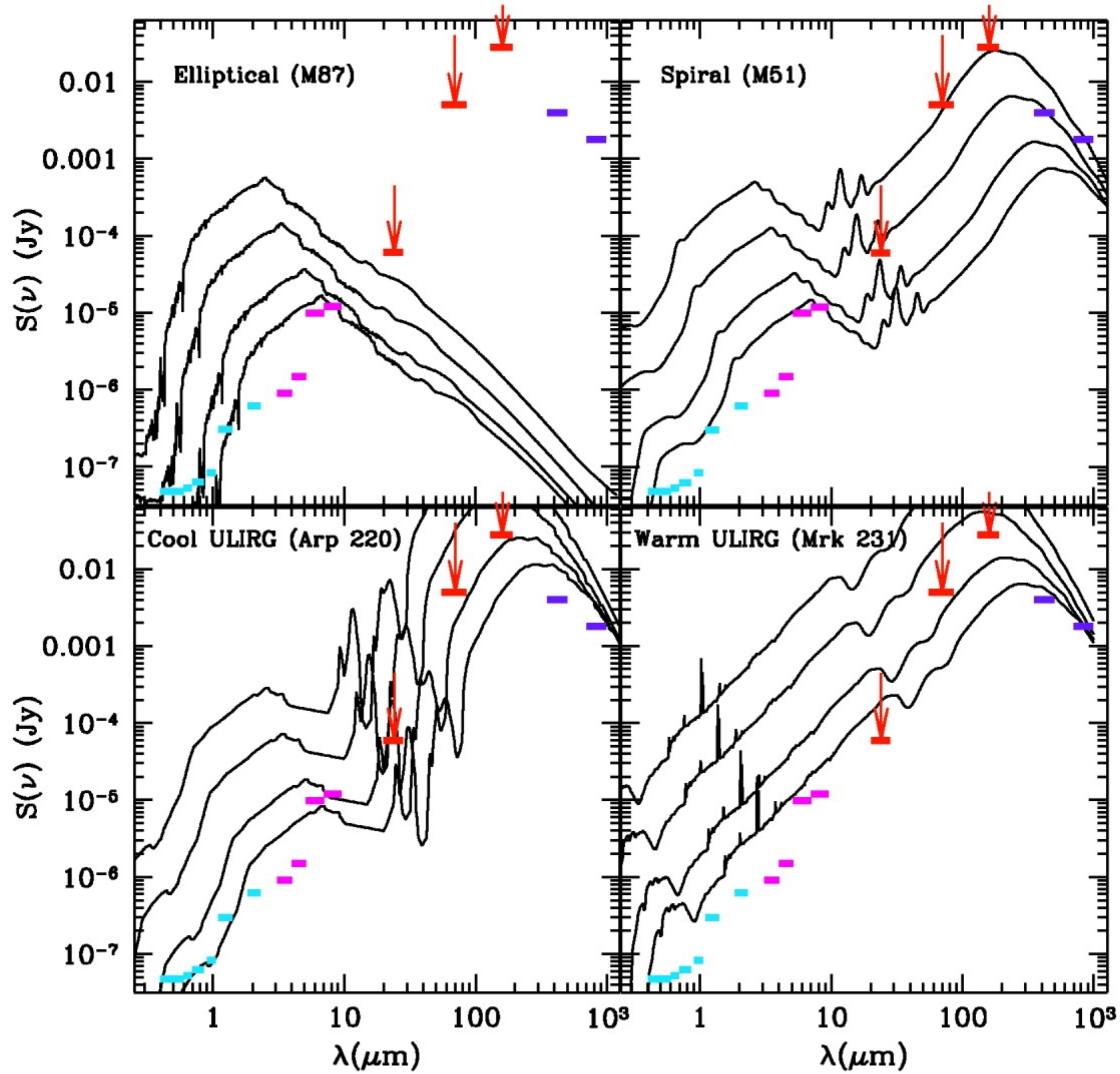
An improving angular resolution

(Gordon et al. 2008)





Sensitivity narrows the COSMOS



(Sanders et al. 2007)

IR emission from interstellar dust

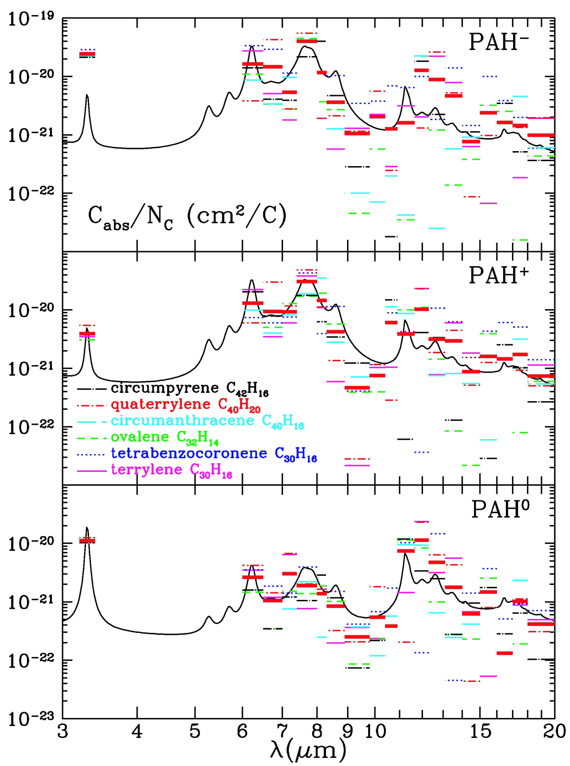
- Silicate-graphite (Mathis et al. 1977; Draine & Lee 1984; Kim et al. 1994) -PAH model (Siebenmorgen & Krügel 1992; Li & Draine 2001; Weingartner & Draine 2001; Draine & Li 2007)
- Silicate core carbonaceous mantle model (Désert et al. 1990; Jones et al. 1990; Li & Greenberg 1997)
- Composite model or dust as low-density aggregates of small silicate and carbonaceous particles (Mathis & Whiffen 1989; Mathis 1996; Zubko et al. 2004)

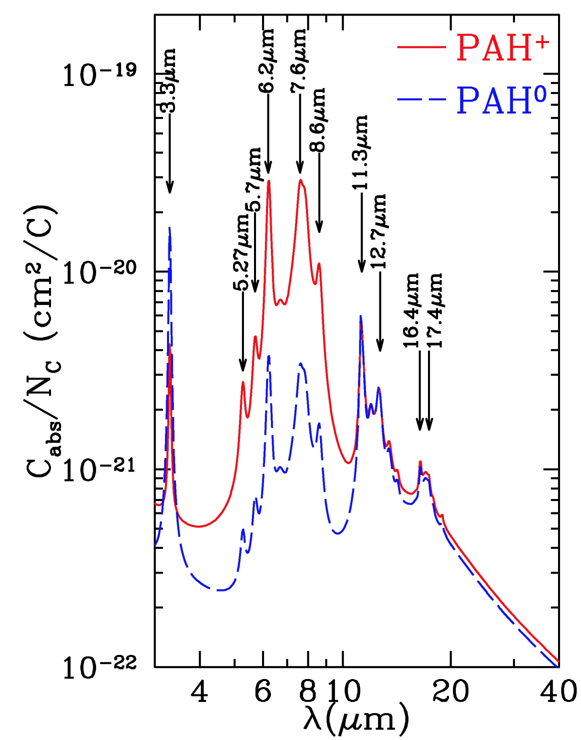
Single-grain emission spectra I.

- Importance of chemistry, structure, charge and size (Bakes et al. 2001; Mattioda et al. 2005)

$$p_\lambda = \int 4\pi C_{\rm abs}(\lambda) B_\lambda(T) \frac{dP}{dT}\, dT,$$

$$B_\lambda(T) \equiv 2hc^2\lambda^{-5}[\,\exp(hc/\lambda kT) - 1]^{-1}.$$

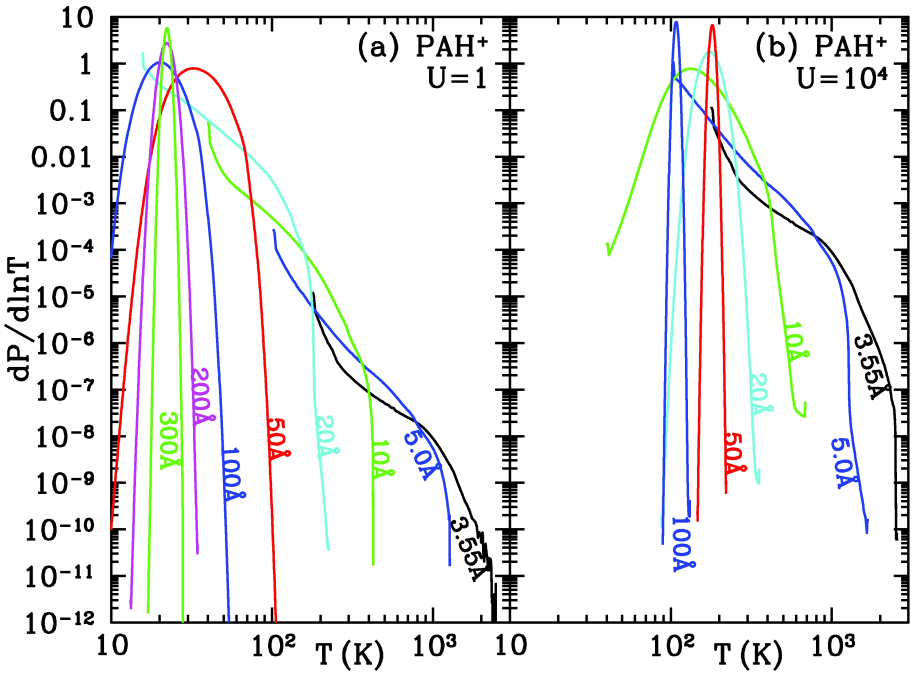




(Draine & Li 2007)

Single-grain emission spectra II.

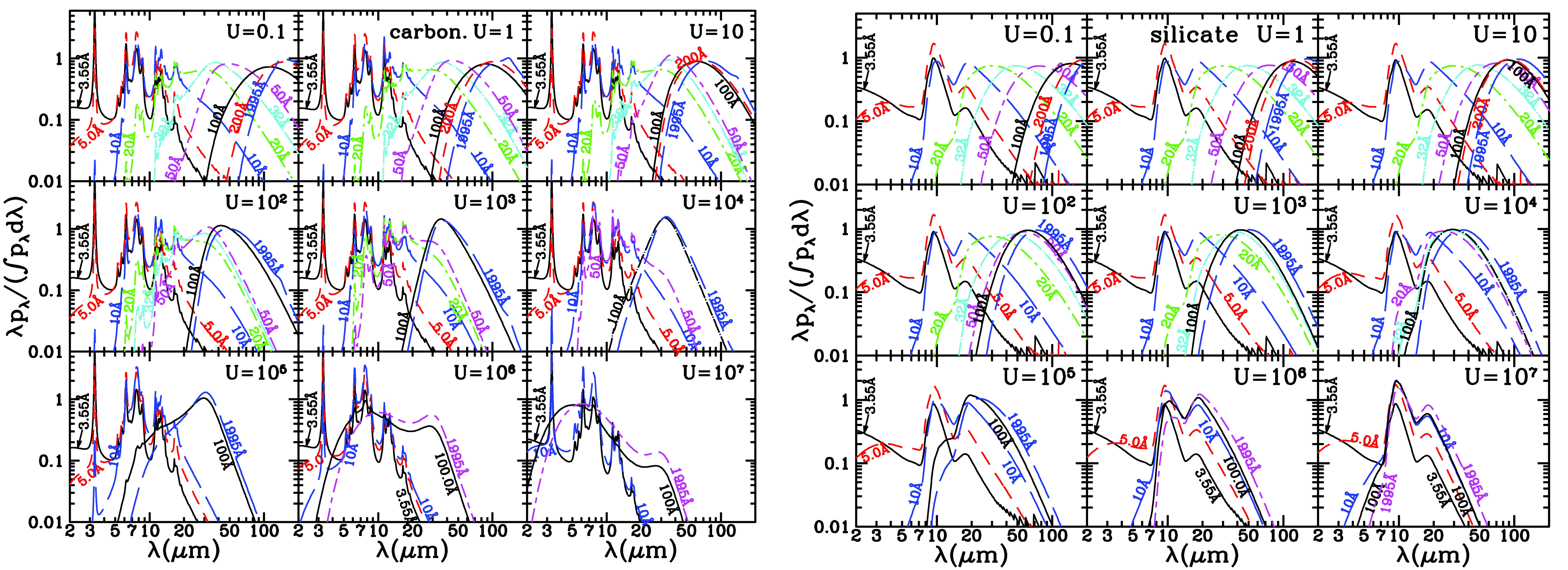
- Small grains (e.g., PAHs) undergo extreme excursions in T (single-photon heating).
- For large grains, T exhibits small excursions around a steady-state value.
- With increasing rate of starlight heating (i.e., U), the steady-state T approximation holds for smaller grains.



(Draine & Li 2007)

Single-grain emission spectra III.

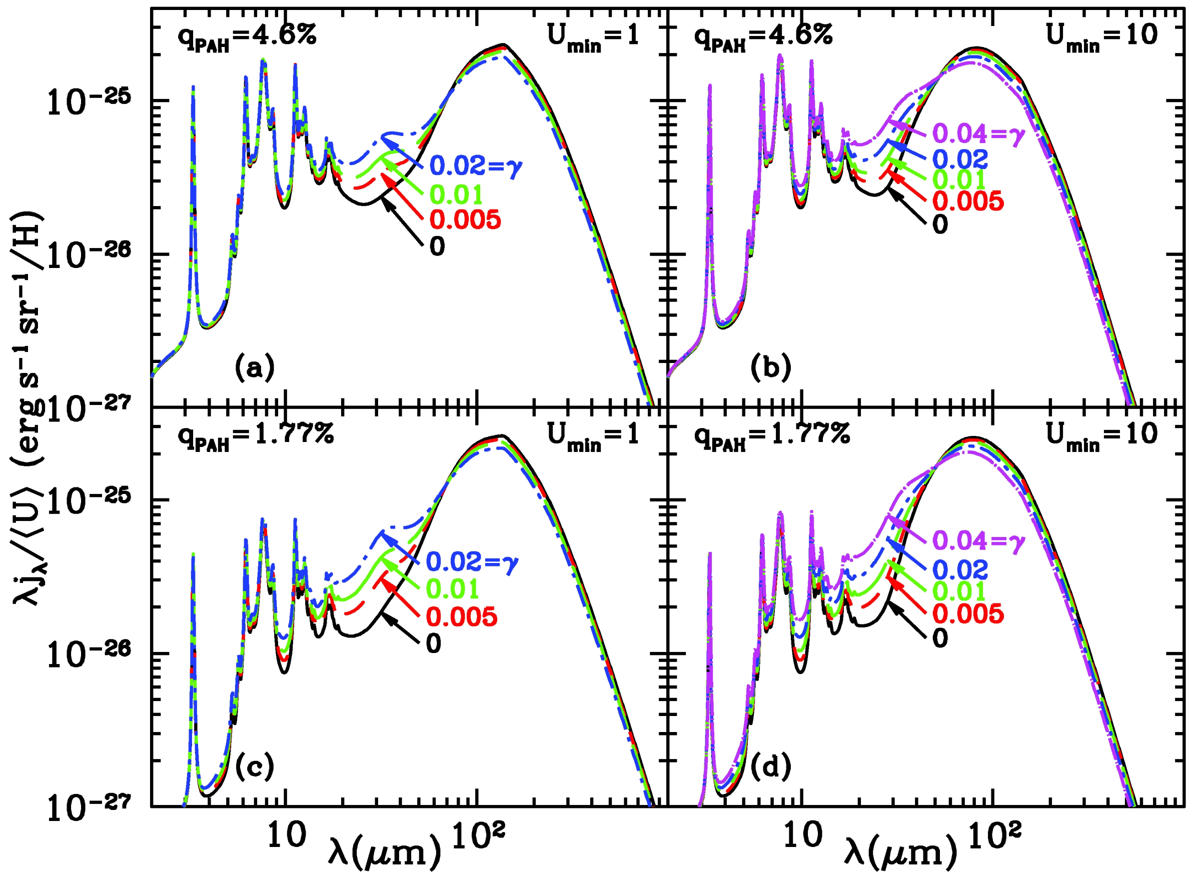
- The relative contribution of grains of different compositions and sizes to the mid-IR – sub-mm emission spectrum depends on U.



(Draine & Li 2007)

Emission spectra for MW dust

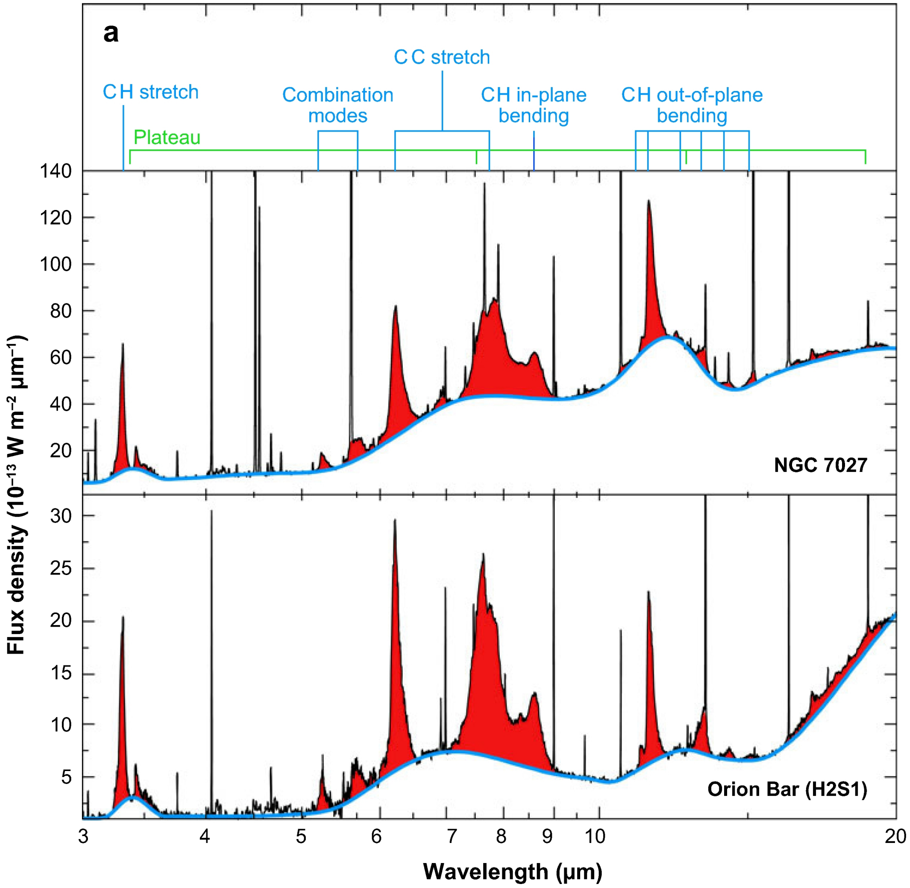
- Strong dependence of the mid-IR emission on the dust mass exposed to radiation fields with U_{min}<U< U_{max}.



(Draine & Li 2007)

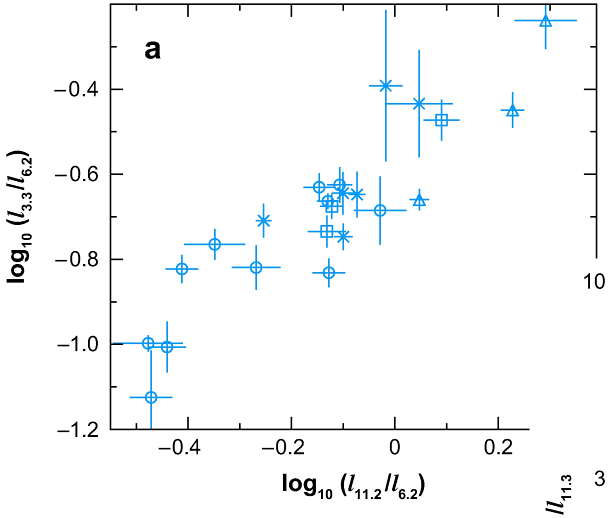
Line emission in the mid-IR I.

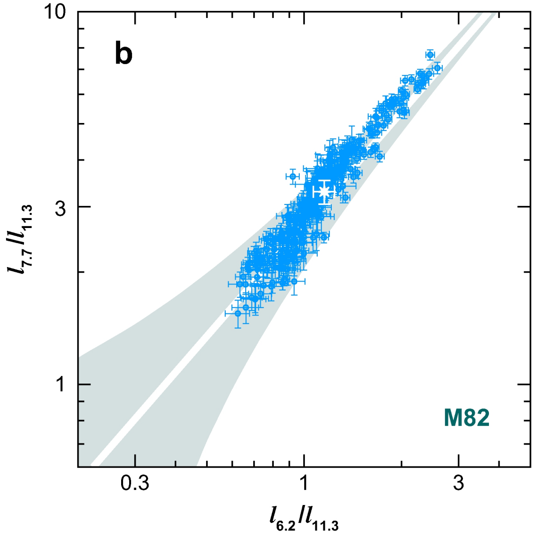
- Ubiquitous emission features at 3.3, 6.2, 7.7, 8.6, 11.3, 12.7 μm (Gillett et al. 1973; Peeters et al. 2004; Smith et al. 2007)



(Tielens 2008, figure adapted from Peeters et al. 2002)

(Tielens 2008, figure taken from Hony et al. 2001)





(Tielens 2008, figure taken from Galliano et al. 2008)

Line emission in the mid-IR II.

- Excitation to very high “temperature” even in cold environments upon absorption of a single (far-UV) photon (Sellgren 1984) -> small sizes (~10 Å, or 50–100 C atoms)
- Non-zero absorption efficiency at optical/near-IR wavelengths for PAHs (Mattioda et al. 2005)
- Many proposed carriers of the UIR features, all sharing an aromatic hydrocarbon structure at the smallest scales, but PAHs perform better than all others (e.g., Tielens 2008)

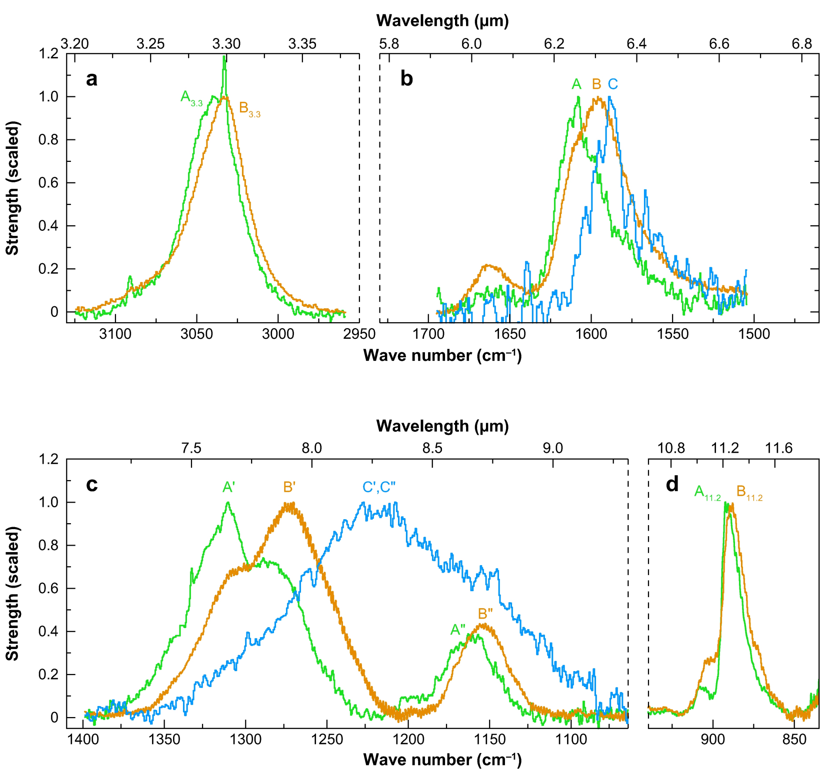
UIR features: why do we care?

- 20–30% of the MW IR radiation is emitted in the UIR features, and 10–15% of the cosmic C is locked up in the UIR carriers (Snow & Witt 1995)
- The UIR carriers dominate heating and cooling of the ambient ISM via photoelectric ejection (Verstraete et al. 1990; Bakes & Tielens 1994), IR emission and gas-grain collisional cooling (Aannestad & Kenyon 1979; Dwek 1986).
- They influence the ISM gas-phase abundances and chemistry (Lepp & Dalgarno 1988; Bakes & Tielens 1998; Tielens & Allamandola 1987).

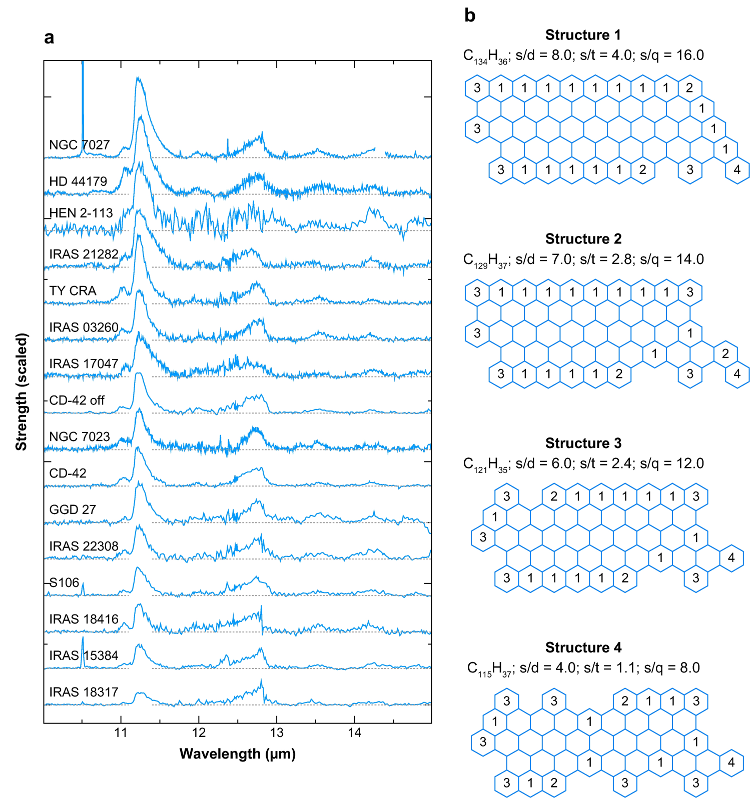
UIR features: galactic environments

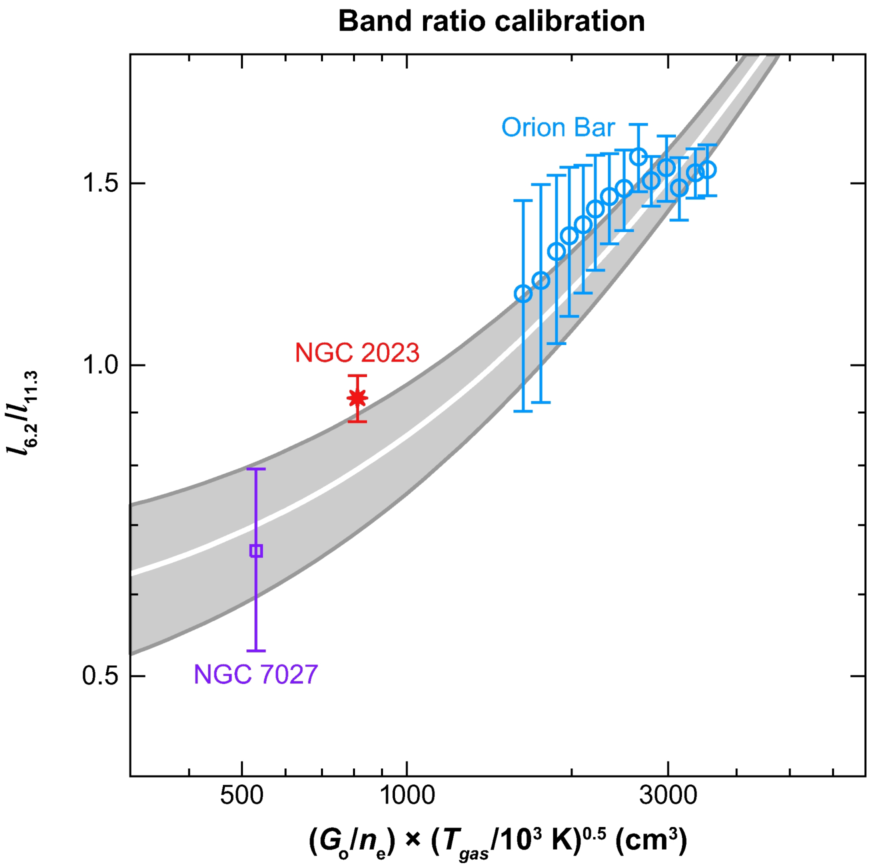
- Variations as a function of ionization balance, dehydrogenation, size, structure, PAH/dust abundance (e.g., Schutte et al. 1993; Hony et al. 2001; Peeters et al. 2001; Vermeij et al. 2002)

(Tielens 2008, figure taken from van Diedenhoven et al. 2004)



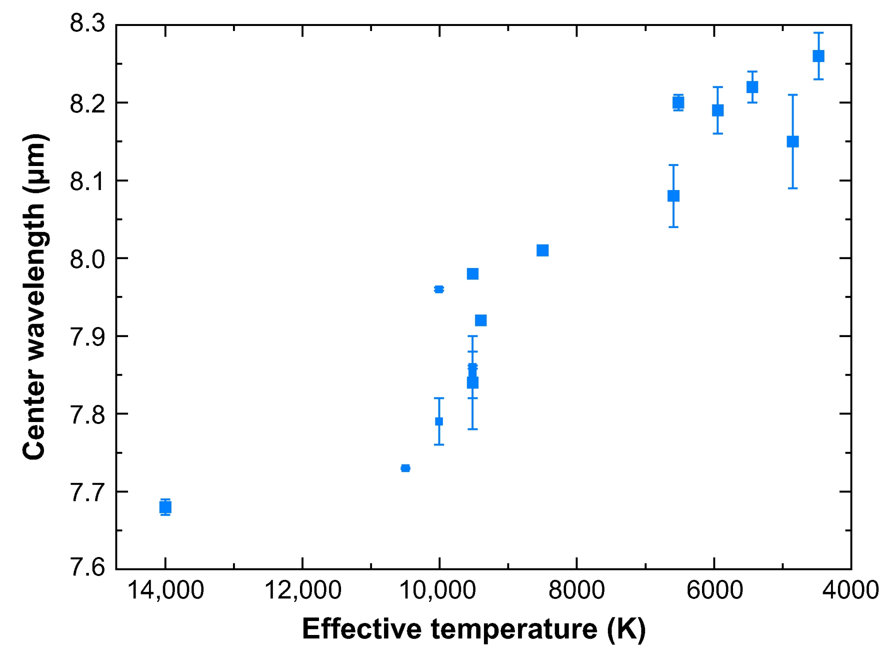
(Tielens 2008, figure taken from Hony et al. 2001)





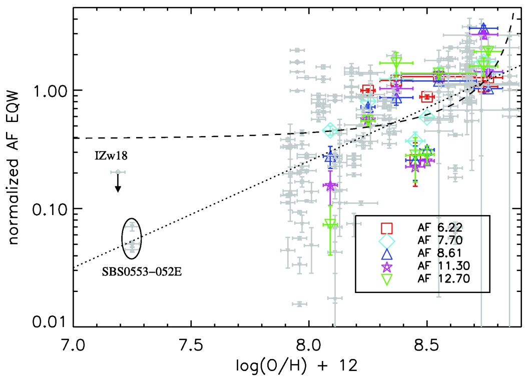
(Tielens 2008, figure taken from Galliano et al. 2008)

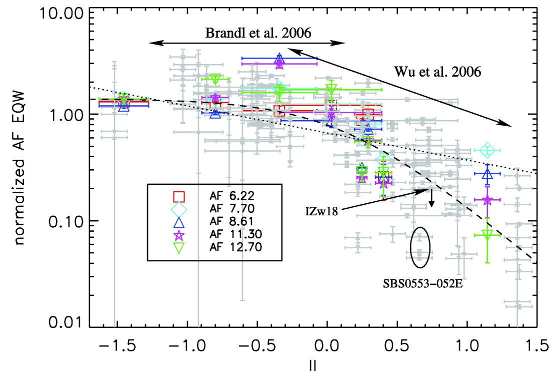
(Tielens 2008, figure taken from Boersma et al. in preparation)

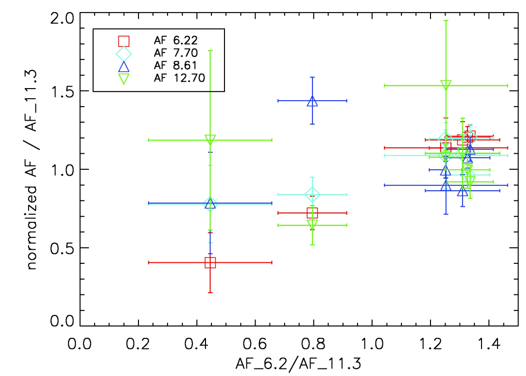


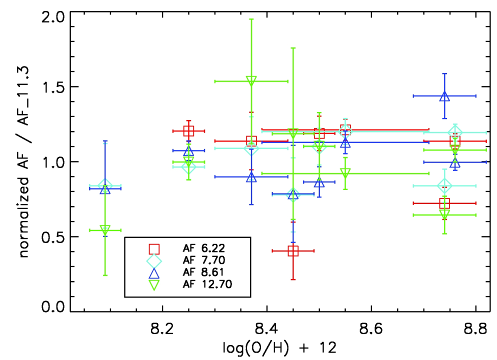
Dust processing in M101 HII regions

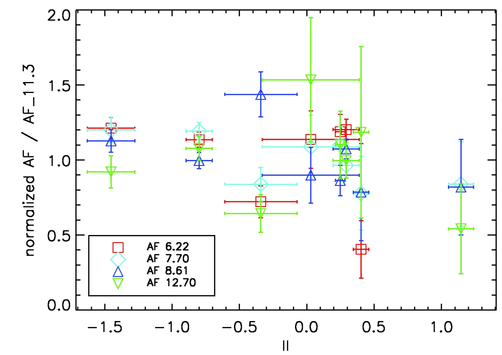
- UIR features are more sensitive to ionization index than metallicity in HII regions and local SBs (Gordon et al. 2008).
- The behavior of their relative strengths is consistent with the PAH model (e.g., Galliano 2006) but not the lack of correlation between variations and ionization index (Gordon et al. 2008).











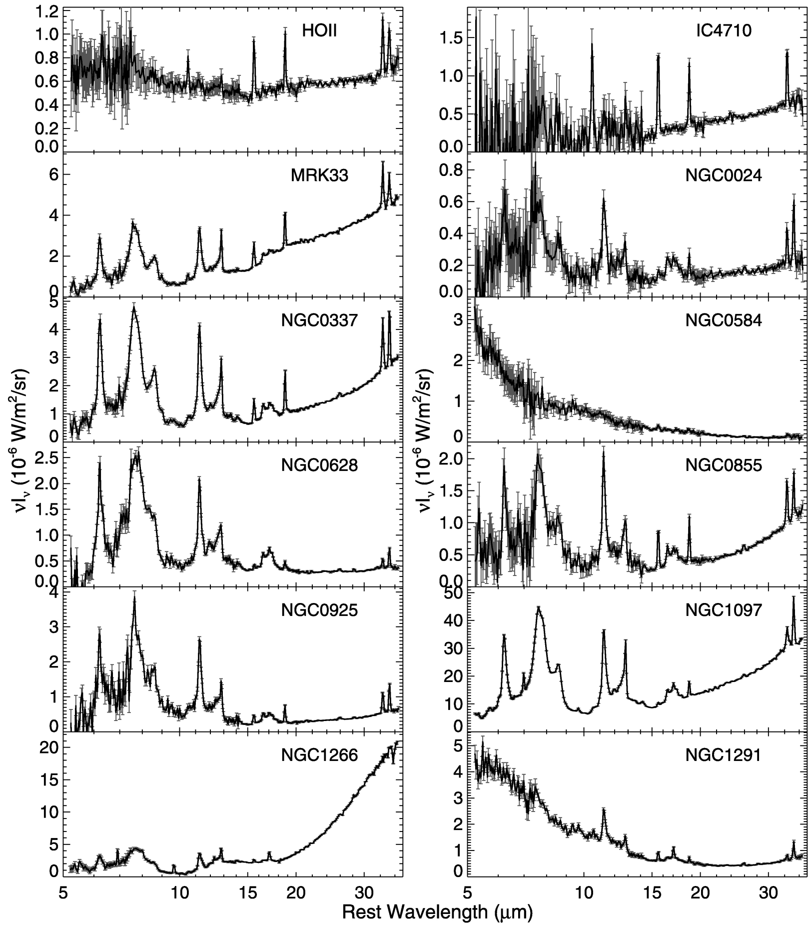
(Gordon et al. 2008)

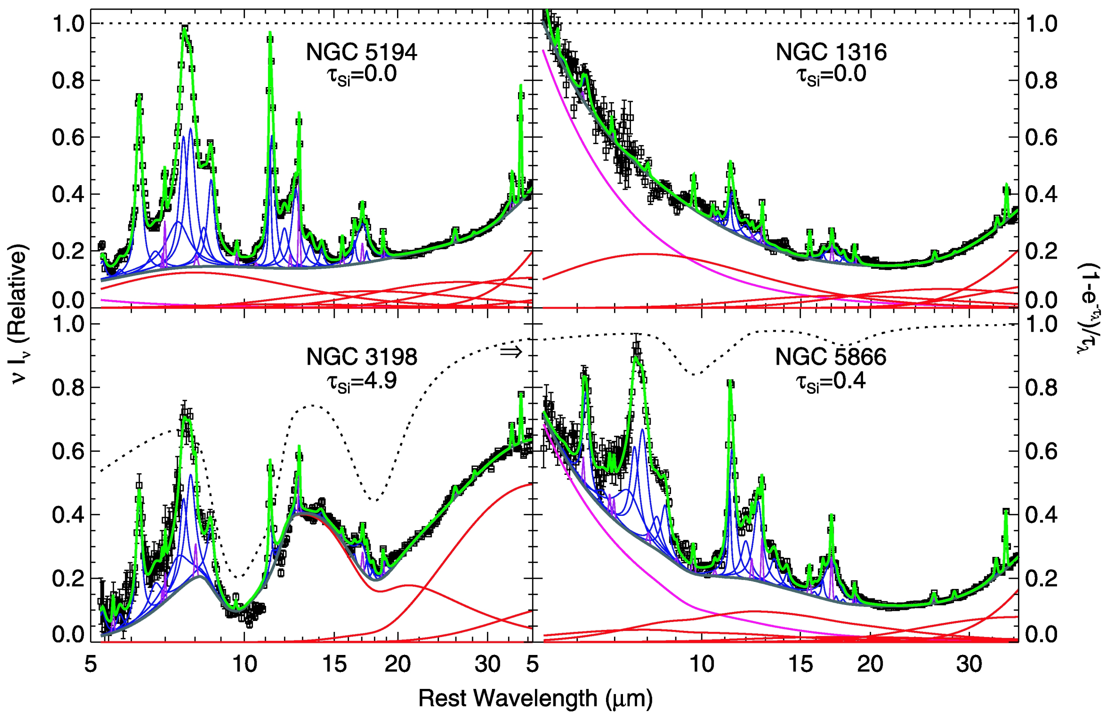
UIR features: open questions

- What's the origin of the changes in the feature positions and profiles from source to source and within a source? A reaction of the PAH family to the very local physical conditions rather than a difference in chemical history?
- Does the hardness of the radiation field control the small end of the PAH size distribution?
- What's the origin of PAHs: mass loss from C-rich red giant, AGB or WR stars (Frenklach & Feigelson 1989; Tielens 1990; Latter 1991; Cherchneff et al. 2000), fragmentation of large carbon grains in diffuse cloud regions (Omont 1986; Jones et al. 1996; Greenberg et al. 2000), in-situ formation in dense clouds (Herbst 1991)?
- Does the PAH model hold (Gordon et al. 2008)?

UIR features on galaxy scales

- A rapidly increasing high-quality data set provides more robust conclusions and better defined questions

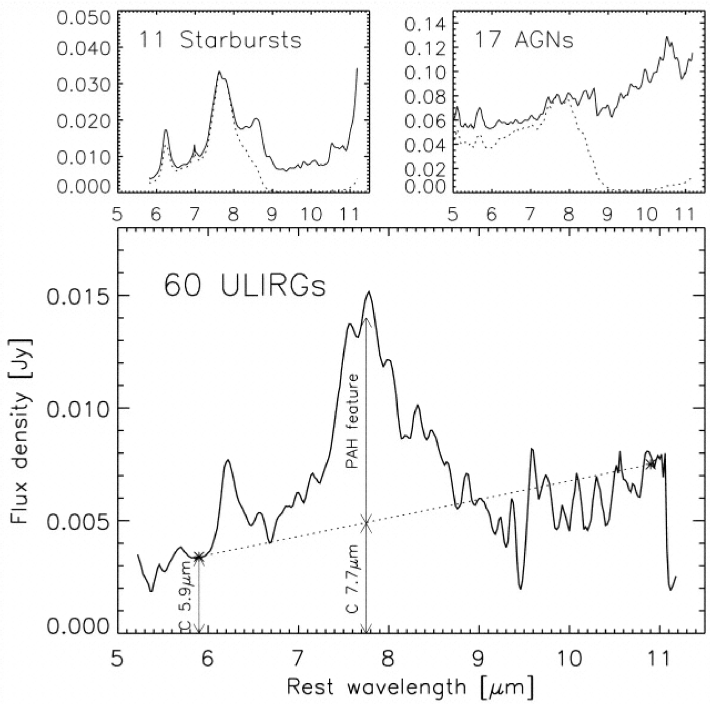




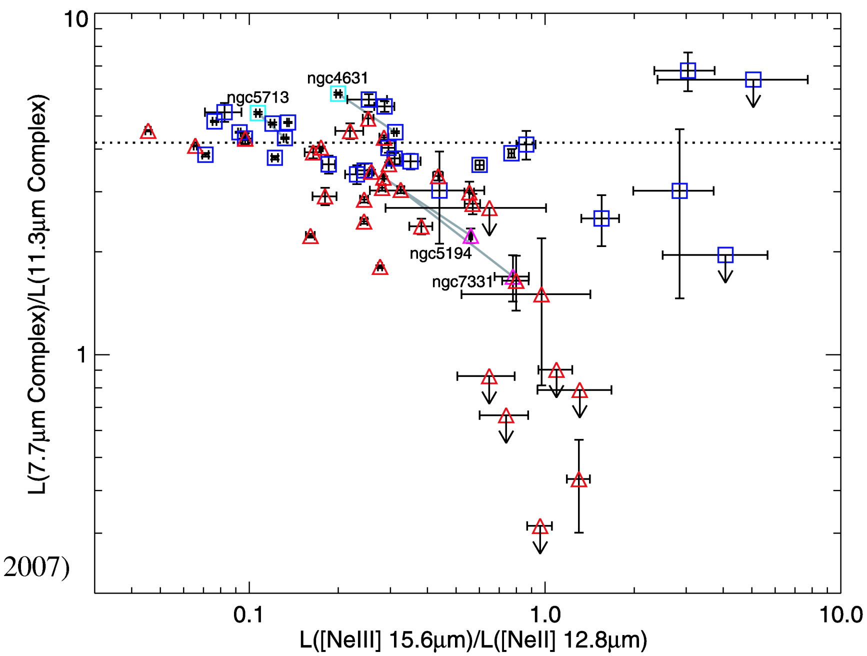
(Smith et al. 2007)

Peculiar mid-IR spectra & AGN

- Size-selective destruction of PAHs (Voit 1992; Lutz et al. 1998)?
- Dilution of PAH bands against a very high mid-IR continuum (Siebenmorgen et al. 2005; Hao et al. 2005; Sturm et al. 2005)?
- Weak star formation intensity (i.e., weak UV field and large neutral fraction) instead of a direct excitation by an AGN?



(Lutz et al. 1998)

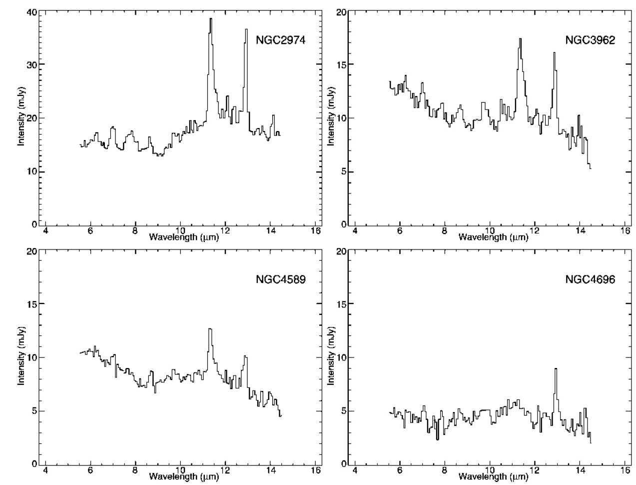


(Smith et al. 2007)

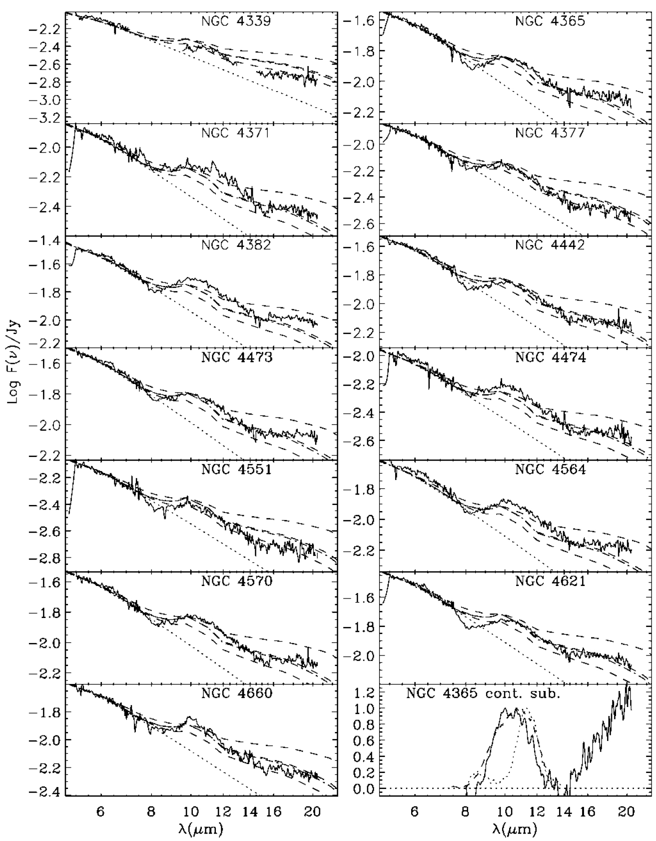
Dusty early-type galaxies

- Do passively evolving, early-type galaxies have a dusty ISM in addition to circumstellar dust (Temi et al. 2004; Bressan et al. 2006; Kaneda et al. 2007a,b)?

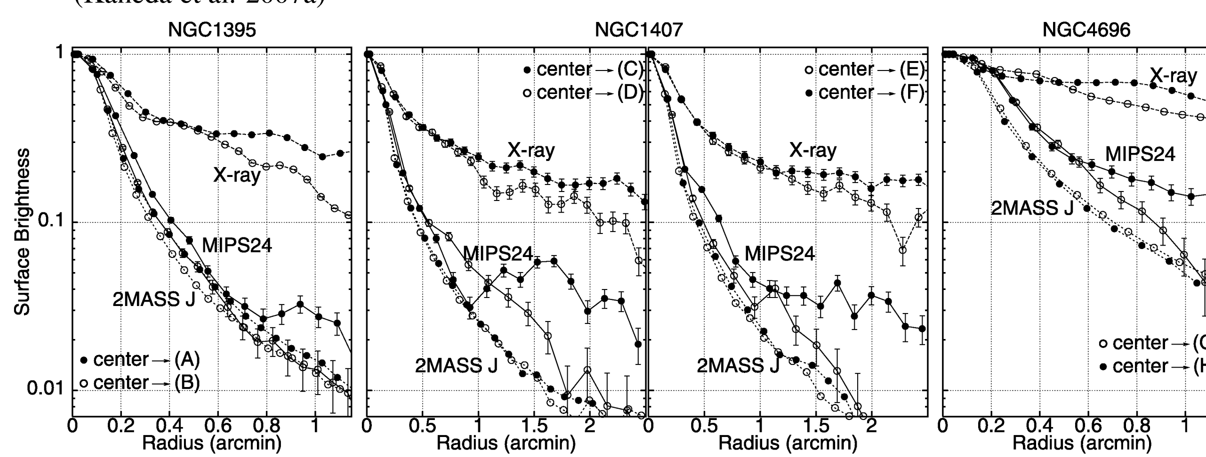
(Kaneda et al. 2007b)



(Bressan et al. 2006)

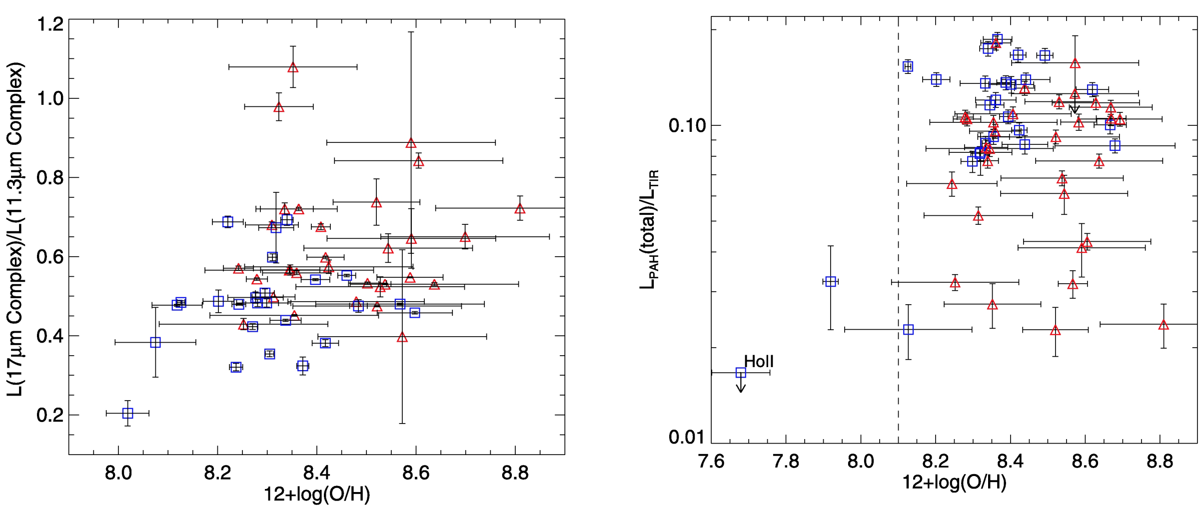


(Kaneda et al. 2007a)



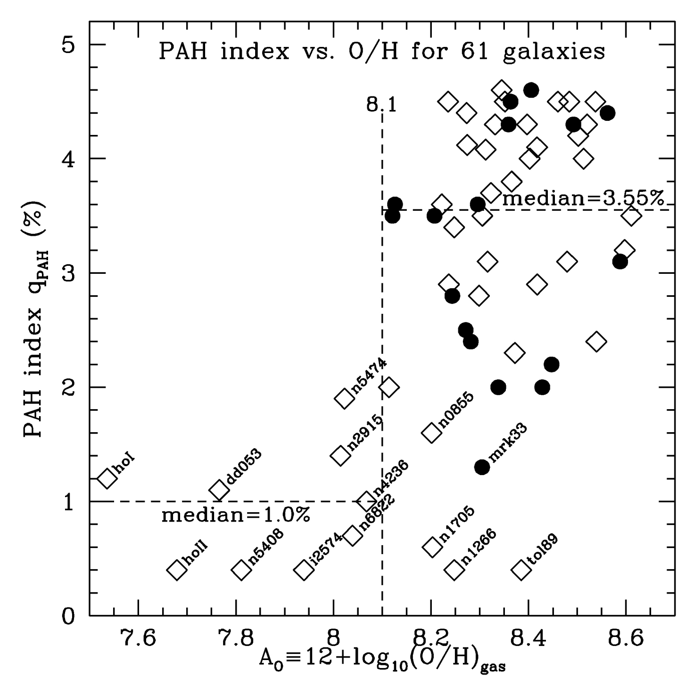
UIR features & low metallicity

- Enhanced formation of larger grains in environments with higher metal abundance instead of selective destruction of smaller grains by harder radiation fields in low-metallicity environments (Engelbracht et al. 2005; Smith et al. 2007; Draine et al. 2007)



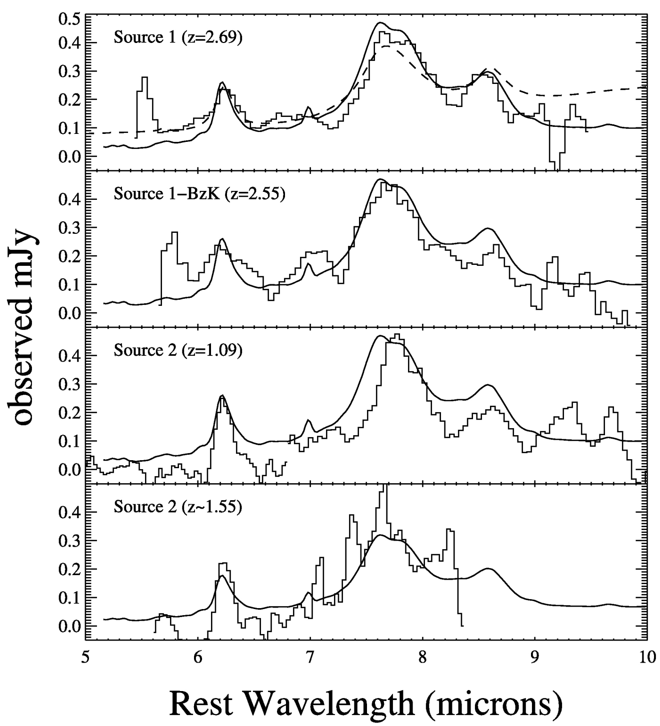
(Smith et al. 2007)

(Draine et al. 2007)



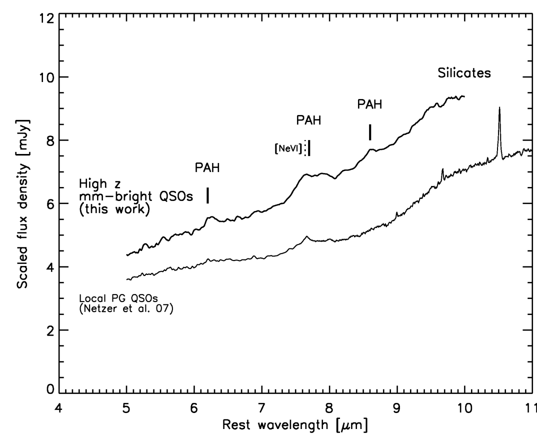
Ubiquitous UIR bands at high-z?

- Mostly powered by star formation (as in nearby LIRGs, ULIRGs) in IR-luminous galaxies at 1<z<3, mm-luminous QSOs at z~2, sub-mm galaxies at z~2.7, magnified LBGs at z~3.

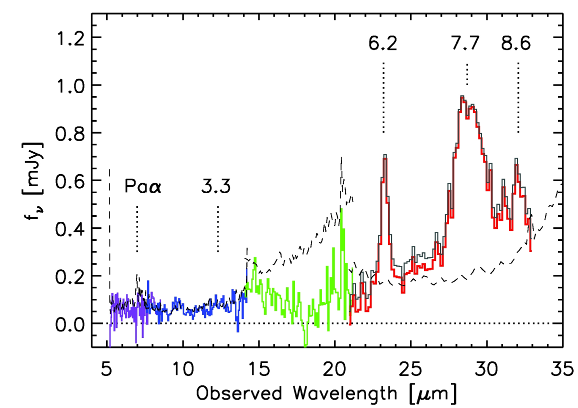


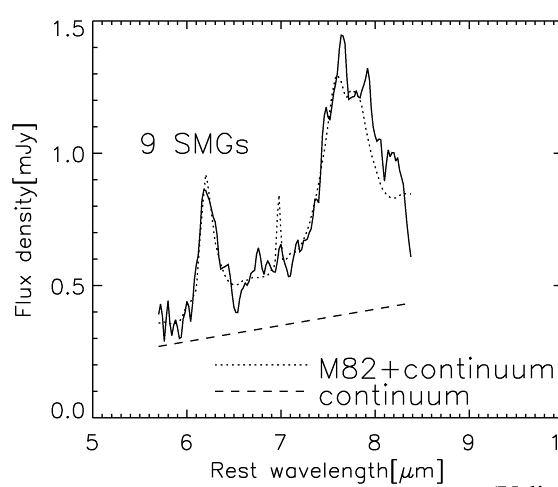
(Teplitz et al. 2007)

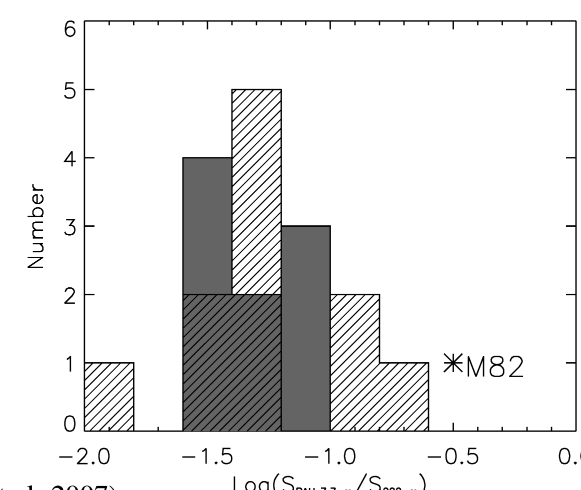
(Lutz et al. 2008)



(Siana et al. 2008)

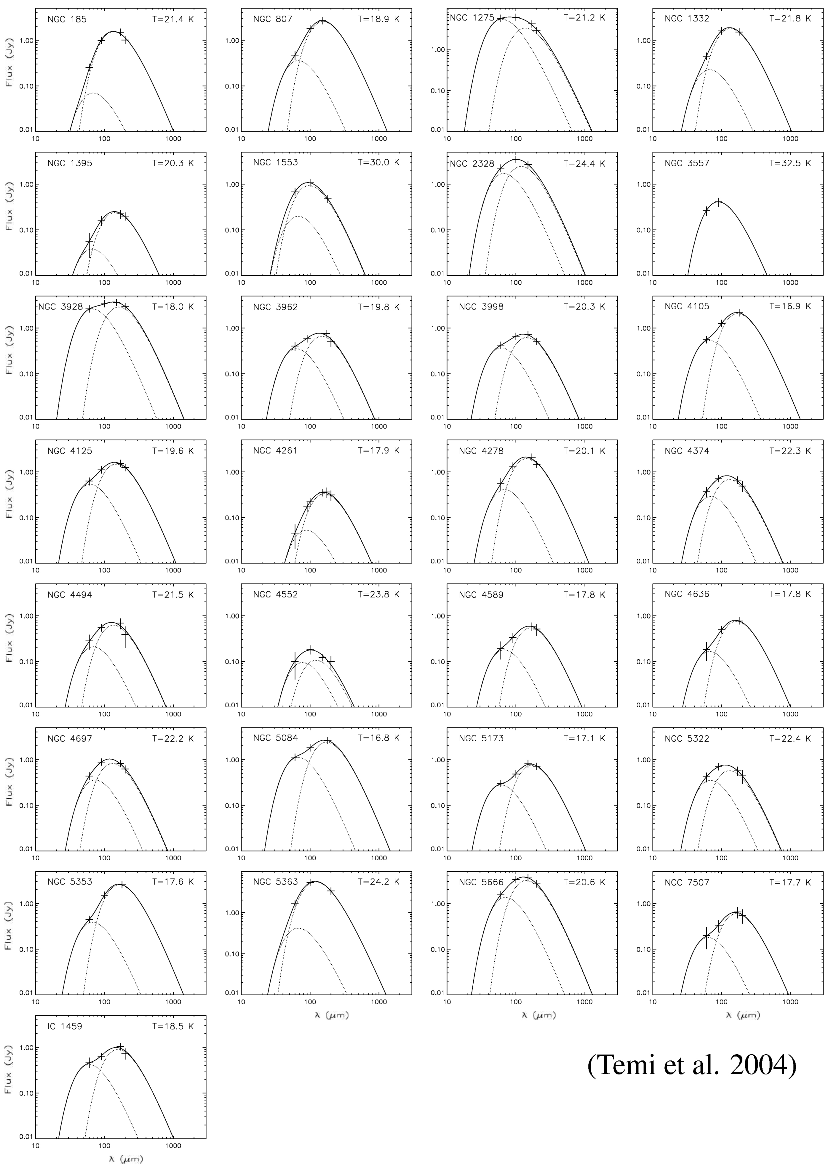




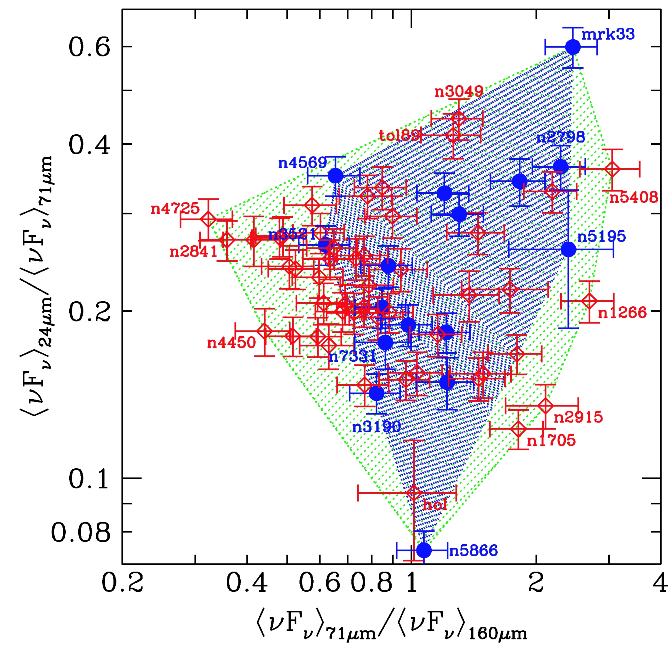


(Valiante et al. 2007)

Normal galaxies: a lot of cold dust!

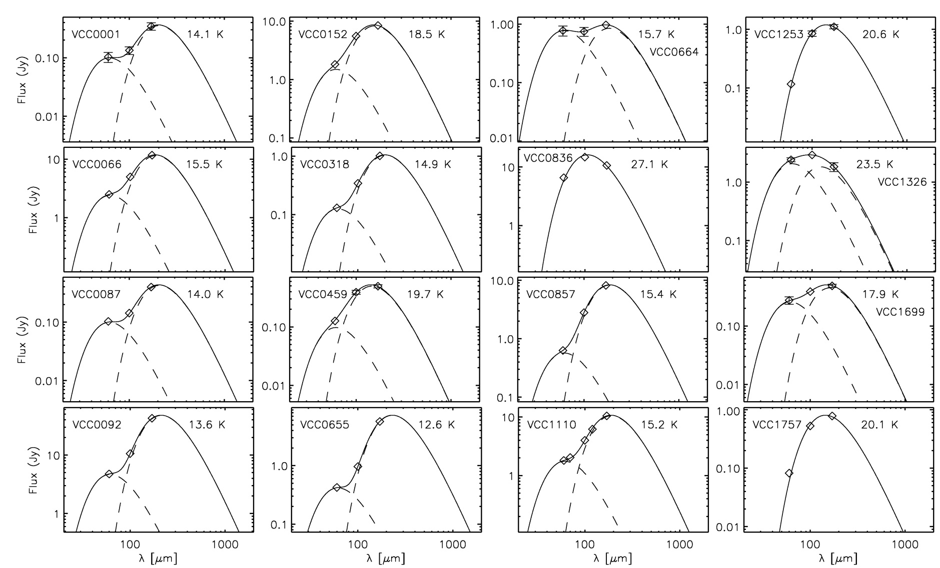


(Temi et al. 2004)



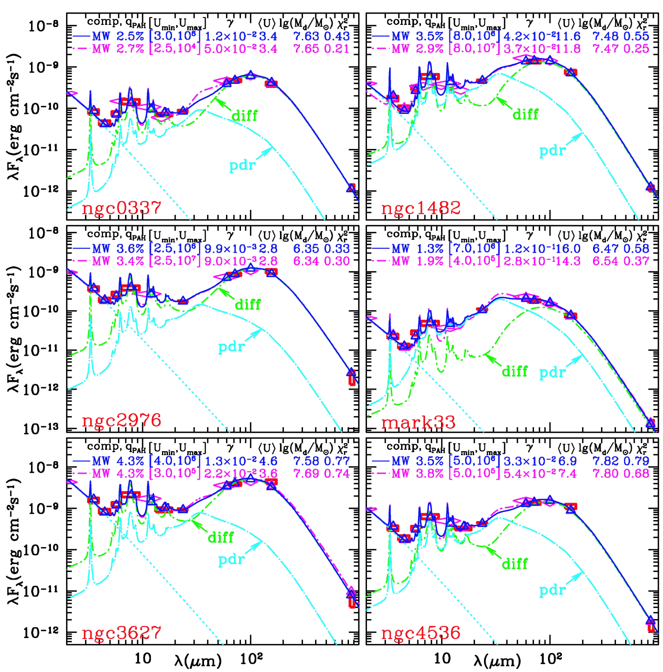
(Draine et al. 2007)

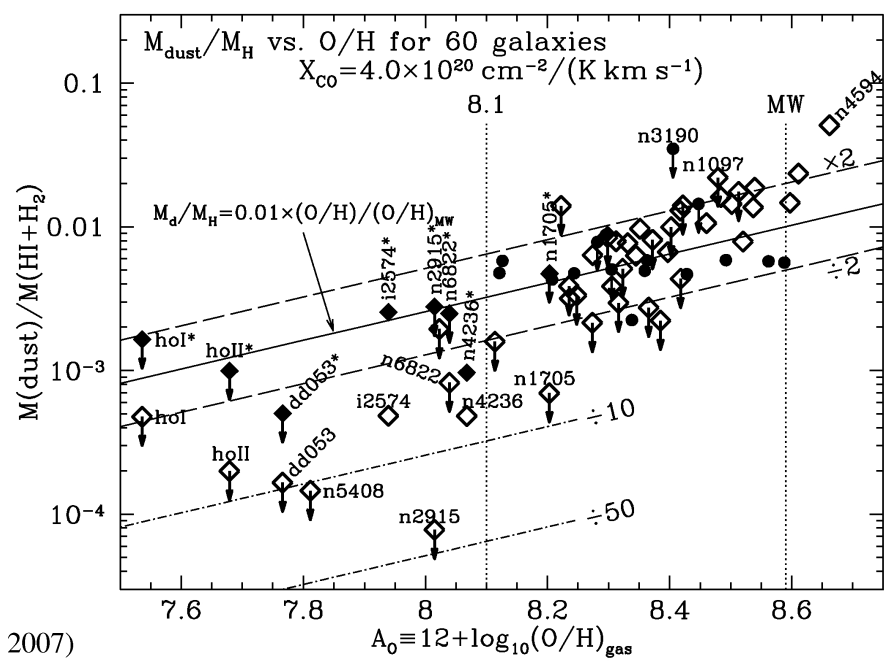
(Popescu et al. 2000)



Normal galaxies “a la SINGS”

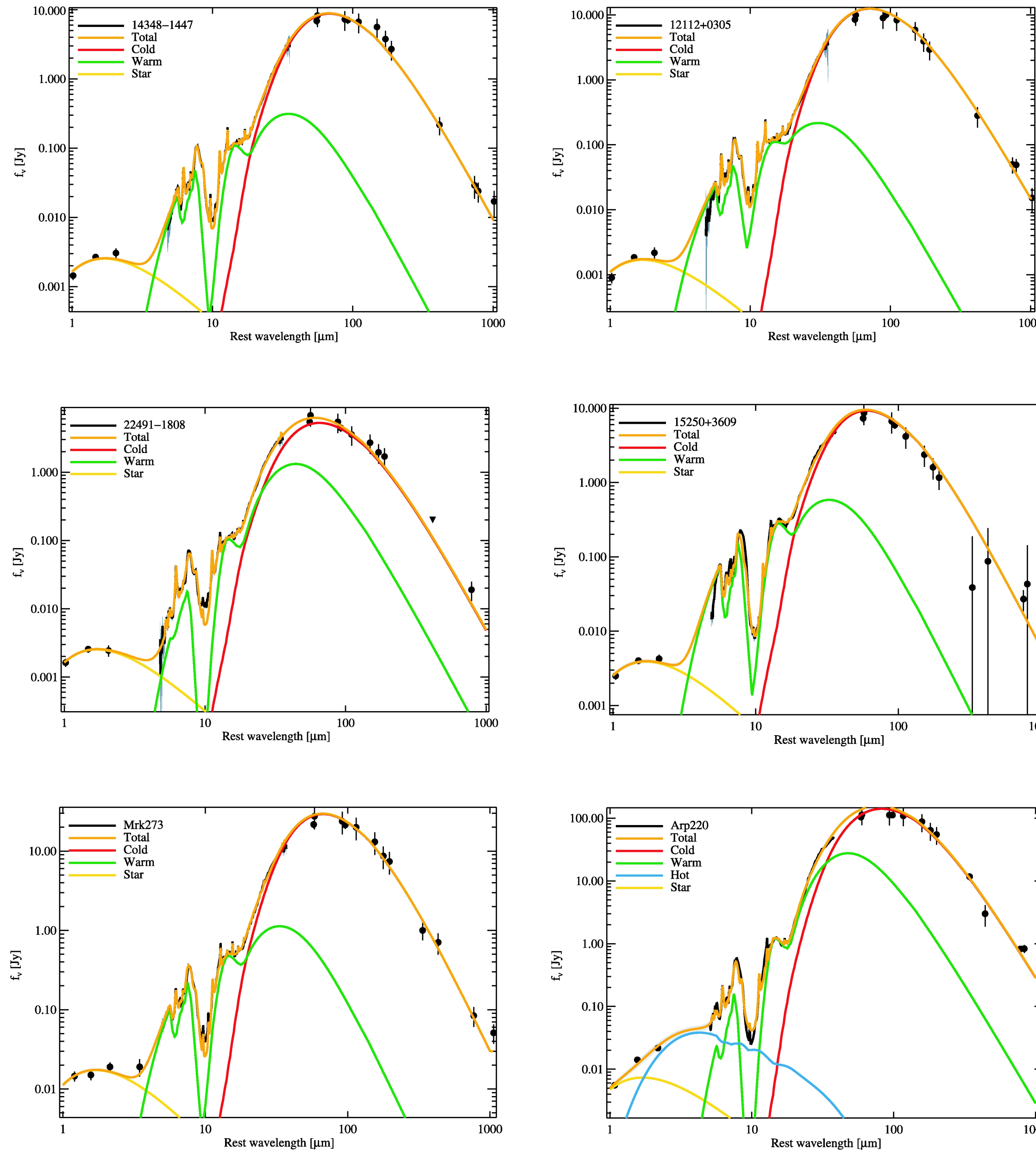
- In spirals, dust resembles that in the local MW ISM, with similar dust-to-gas ratio and PAH abundance (Draine et al. 2007).
- There is no need for very cold dust (i.e., with T ≤ 10 K).
- The dust-to-gas ratio depends on metallicity.
- In general, dust in the diffuse ISM dominates the IR power.





(Draine et al. 2007)

SBs & ULIRGs: dust enshrouding



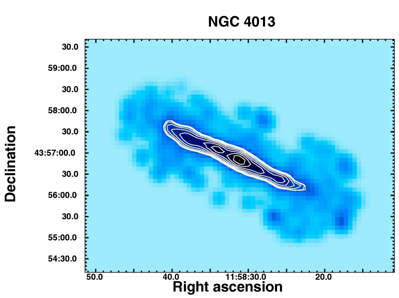
(Armus et al. 2007)

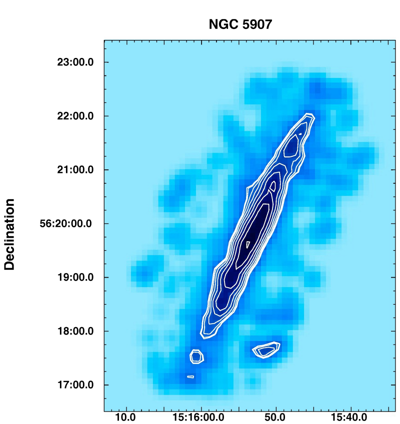
On dust mass estimates

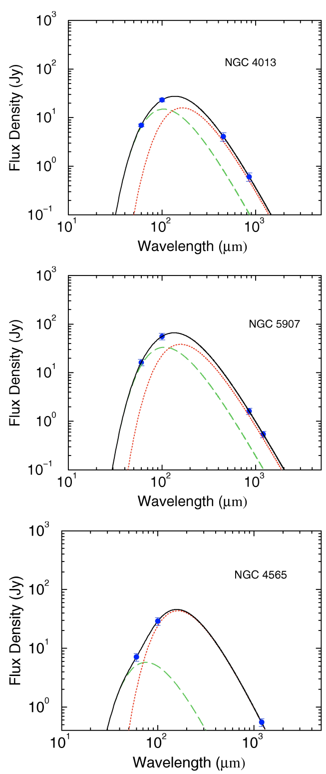
- How much dust is there in a galaxy halo? What are its size distribution and temperature there? Is it detectable?
- Do we sample all (cold) dust in dwarf/low-metallicity galaxies?
- What is the level of contamination from molecular emission at sub-mm wavelengths in galaxies with different SFRs?
- Does the dust emissivity parameter depend on environment, e.g. because of adsorption/coagulation (del Burgo et al. 2003; Cambresy et al. 2004; Dasyra et al. 2005; Bot et al. 2009)?
- What method is best and when (cf. Alton et al. 2004; Draine et al. 2007)? Do different methods produce consistent results?

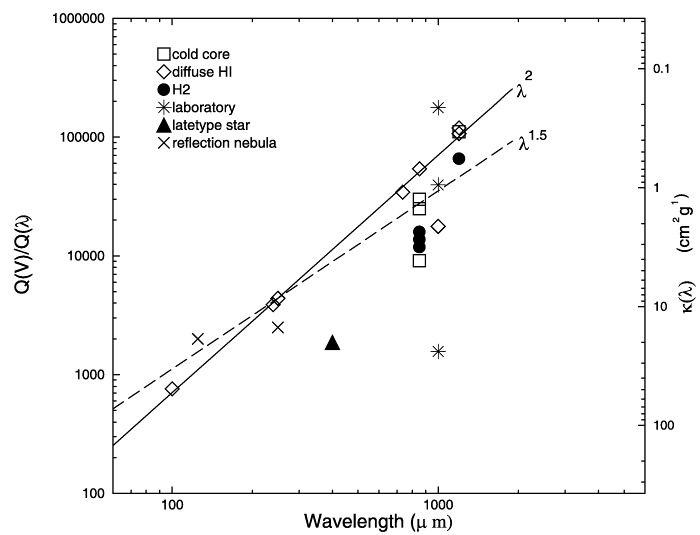
Dust emissivity in spiral galaxies

- Dust emission at sub-mm/mm wavelengths may chiefly originate from molecular gas clouds, where amorphous fluffy grains are formed thanks to the high density. Such grains have emissivities ~3 times larger than refractory cores in the diffuse ISM (Ossenkopf & Henning 2004; Alton et al. 2004).

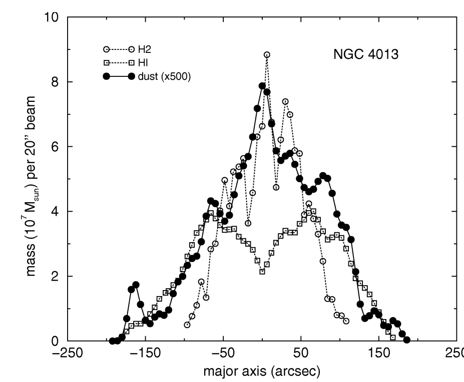


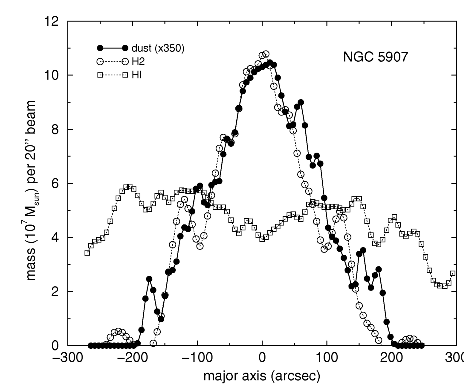






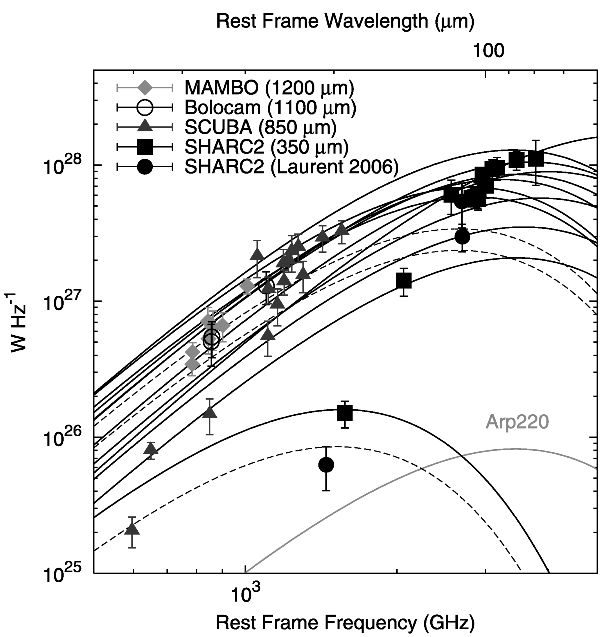
(Alton et al. 2004)





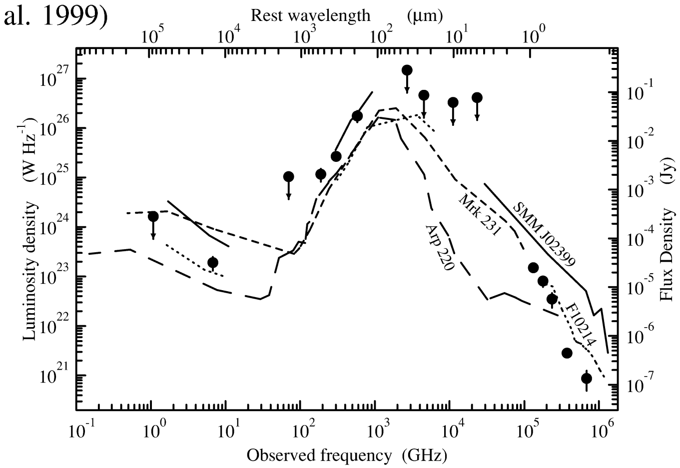
The high-z Universe is (quite) dusty

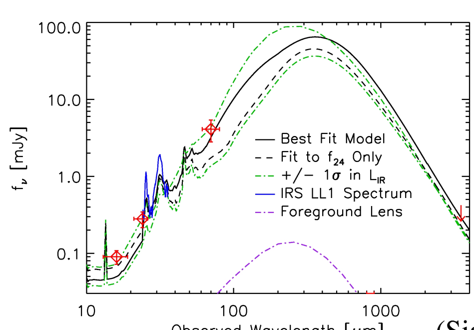
- High-z sub-mm/mm galaxies, dusty IR selected galaxies, LBGs, QSOs exhibit similar IR SEDs to their lower-z analogs.
- Large amounts of molecular gas (~10^9–10^{11} M_o) and (warm) dust can be present at scales of a few Kpc.



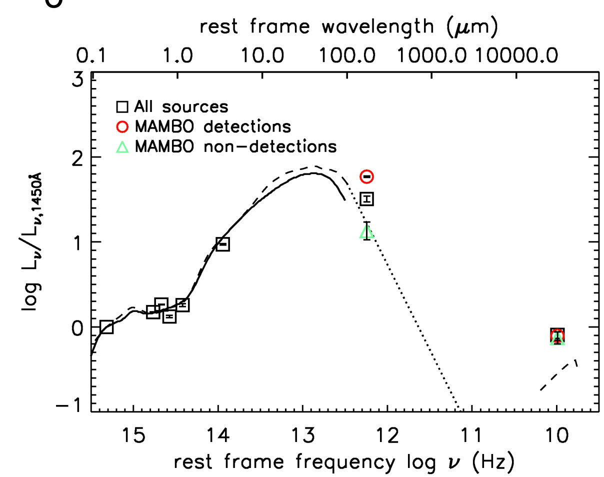
(Kovács et al. 2006)

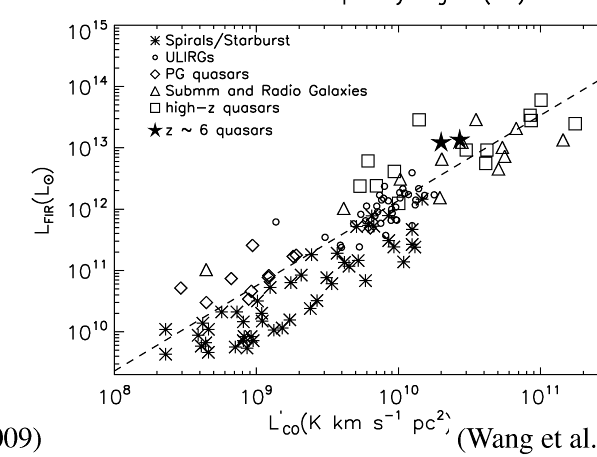
(Day et al. 1999)





(Siana et al. 2009)





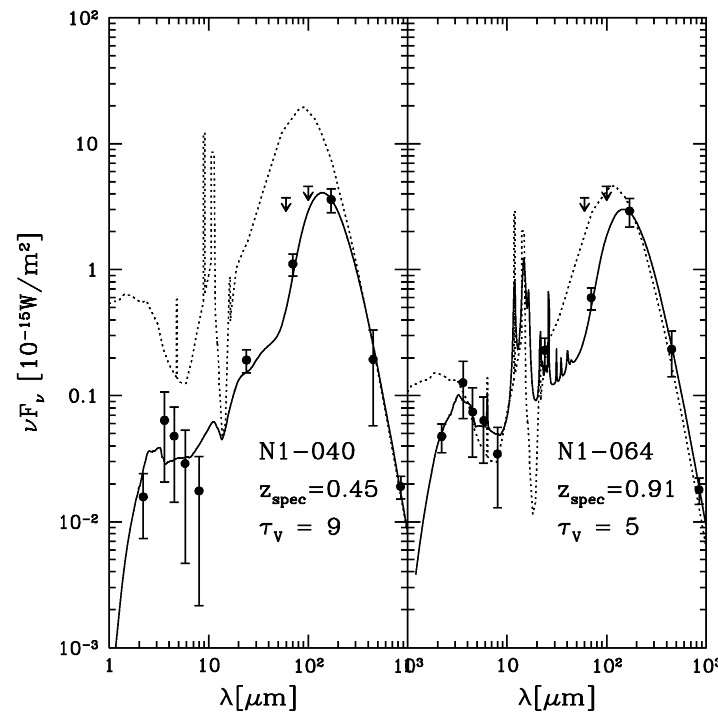
(Wang et al. 2008)

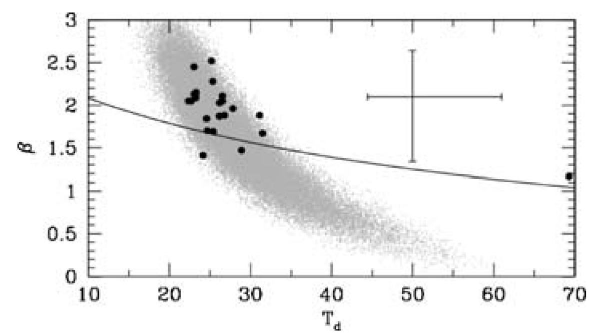
High-z dusty Universe: unknowns

- Cold dust and emissivity at far-IR–mm wavelengths
- Dust-to-gas and dust-to-metal ratios
- Relative importance of AGN and star formation to dust heating
- How to go from a sparsely sampled (IR) SED to a SFR estimate
- Configuration of dust/gas/stars (e.g., sub-mm galaxies vs. local ULIRGs, Menéndes-Delmestre et al. 2009)
- Validity of local templates
- Local dust analogs

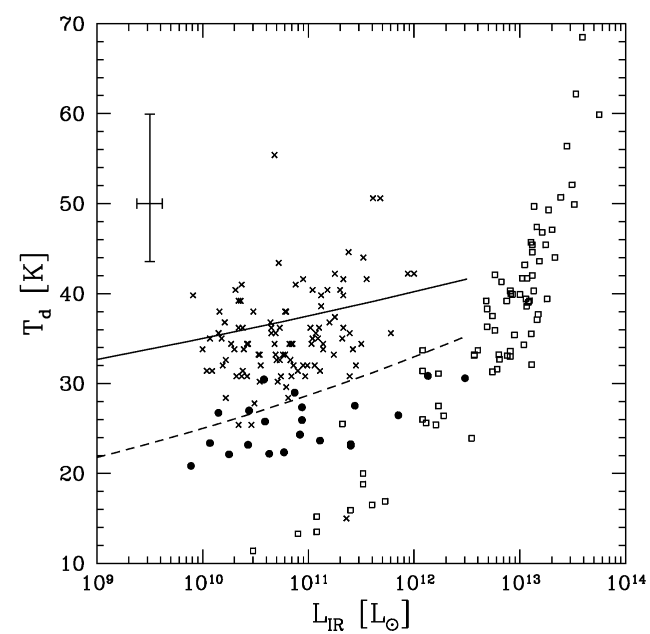
Star-forming disc galaxies at z~1?

- ISO 170 µm selected galaxies represent the brightest 10% of the cosmic IR background (Lagache et al. 2005).
- They mostly appear as standard disc galaxies with enhanced but extended star formation activity (Sajina et al. 2006).



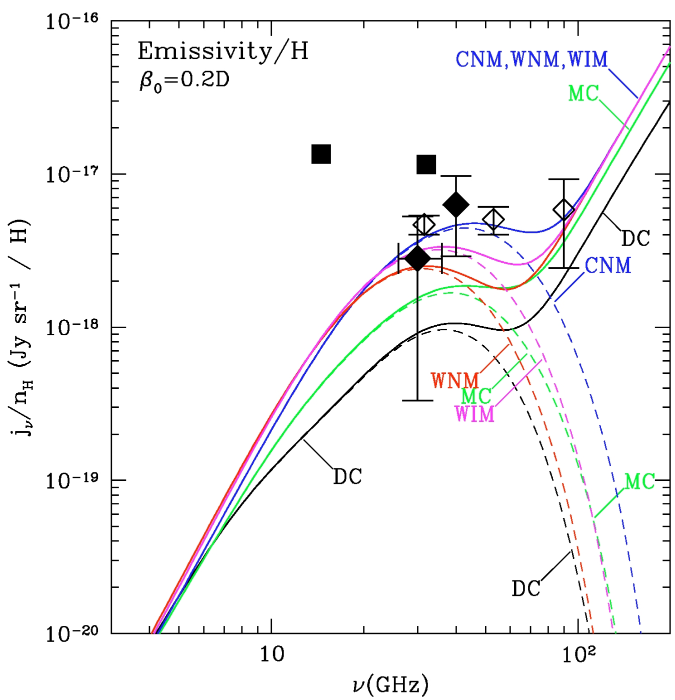


(Sajina et al. 2006)



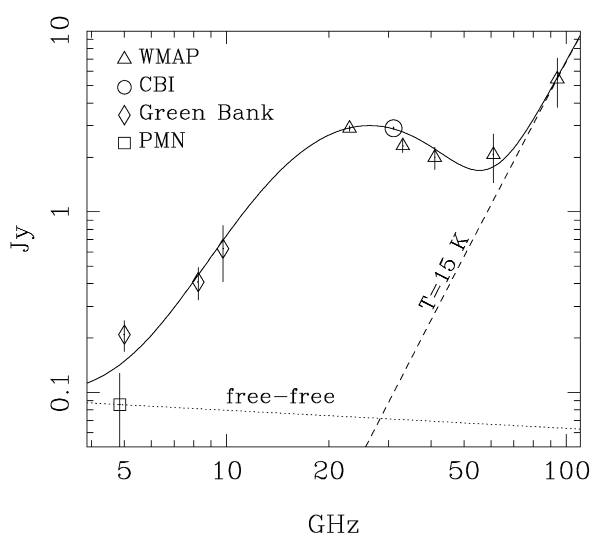
Spinning dust as a CMB foreground

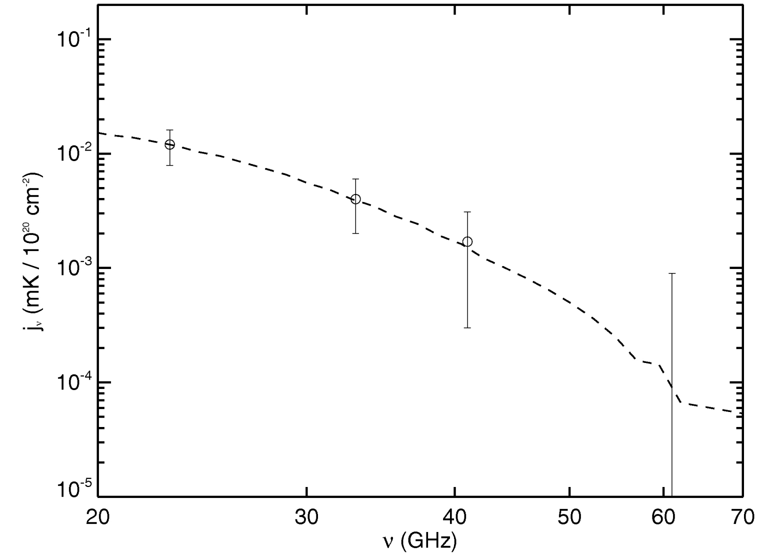
- Electric dipole radiation from spinning dust grains can explain much, if not all, of the anomalous emission at 14–50 GHz in observations of the Cosmic Microwave Background (Kogut et al. 1996; Draine & Lazarian 1998; Casassus et al. 2006; Miville-Deschênes et al. 2008).



(Draine & Lazarian 1998)

(Casassus et al. 2006)

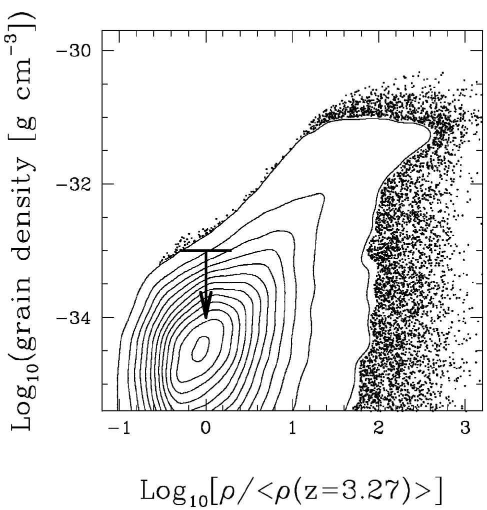


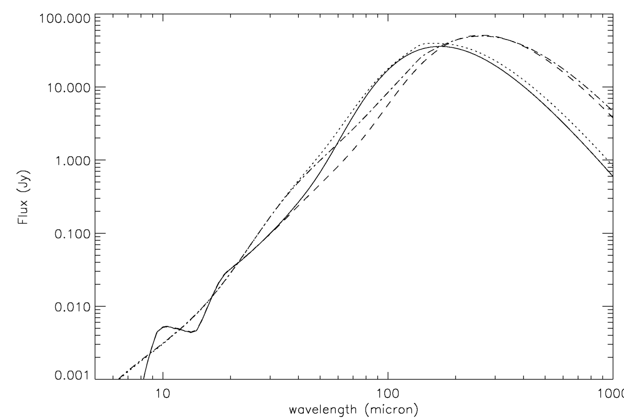


(Miville-Deschênes et al. 2008)

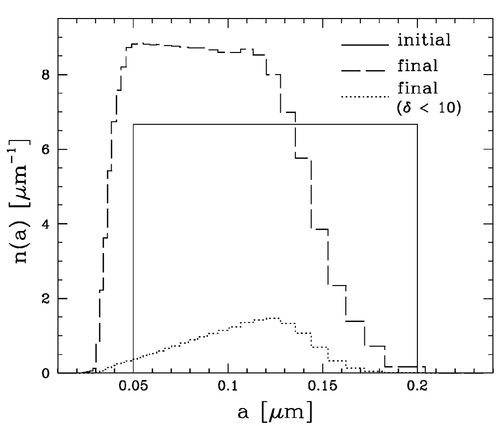
Intergalactic dust

- SN feedback (at least) can pollute the ICM with metals through dust sputtering (Aguirre et al. 2001; Bianchi & Ferrara 2005).
- Have we observed a dusty IGM? Can we in the far-IR/sub-mm?

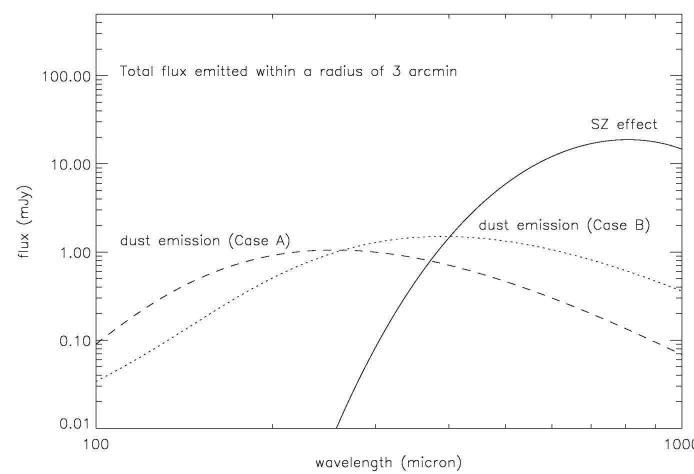




(Popescu et. al. 2002)



(Bianchi & Ferrara 2005)



Conclusions and outlook

- Confirmations, progress and new puzzling results
- Higher spatial resolution and better sensitivity at hand
- Study of dust formation/processing in space and time
- Metal enrichment/depletion vs. astration
- Understanding foregrounds and observational bias
- Importance of laboratory physics and modeling
- Implementation of dynamical dusty media in simulations