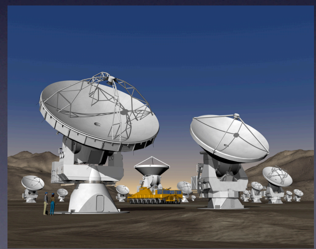
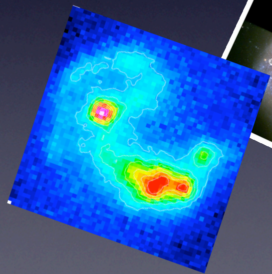
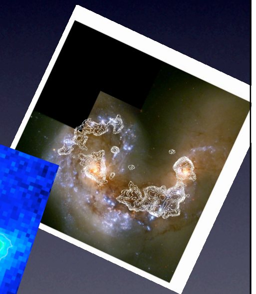
# Uncertainties in the submm SEDs of high- and low-z galaxies

Thomas R. Greve (MPIA)

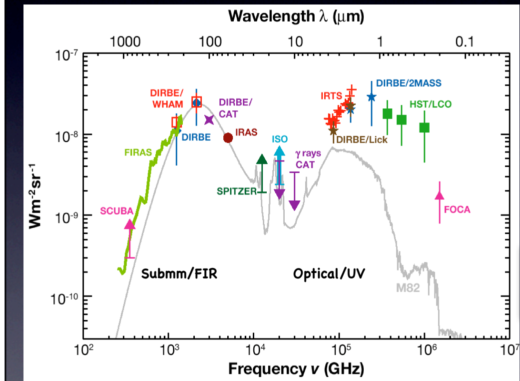


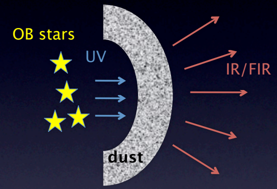




# The importance of dust

Small interstellar dust grains (0.01-0.1um) - that sparsely populate the ISM and make up a tiny fraction of the mass budget - play a huge role in galaxy formation and evolution due to their 'downconversion' of UV-light to IR/submm wavelengths

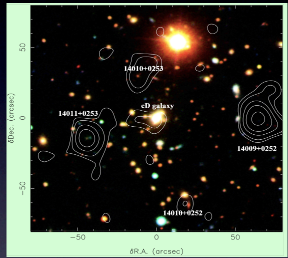


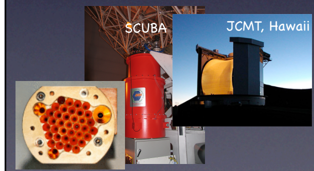




$$\int_{\mathrm{UV/optical}} \pi a^2 Q_\nu c u_\nu \, d\nu = 4\pi \int_{\mathrm{FIR/submm}} B_\nu(T_d) \pi a^2 Q_\nu \, d\nu.$$

# Dust in distant galaxies

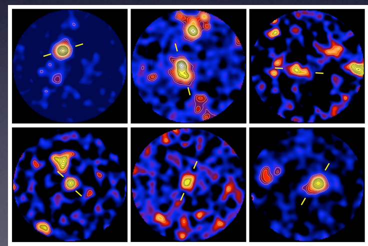
Submillimeter-selected galaxies: in the past decade submm/mm surveys have found a population of distant, highly dust-enshrouded IR-luminous starburst galaxies




- Forced the community to consider dust as an important component in the puzzle of galaxy formation and evolution

QSOs and HzRGs: in some cases targeted submm/mm observations have demonstrated the presence of vast amounts of extended, cold dust in these AGN-dominated systems



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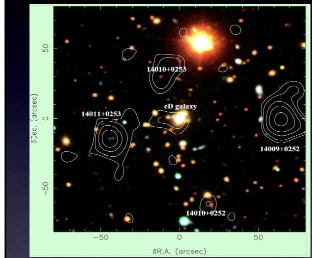


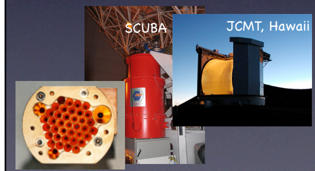


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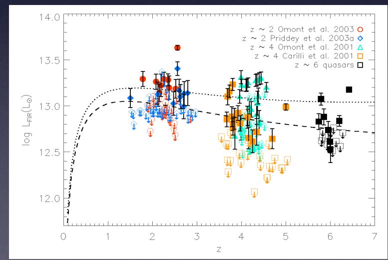
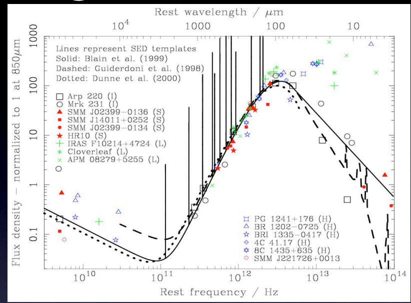


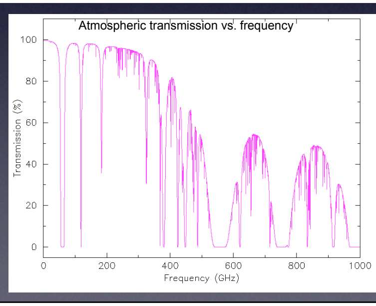
# Challenges

1) Detailed modeling of the FIR/mm SEDs of galaxies is highly non-trivial!

- radiative transfer
- large-scale geometry
- dust grain sizes, multiple components, compositions and shapes




2) Poor frequency sampling of the FIR/mm SED. Typically less than a handful of photometry points - complicating even a simple modeling of the dust properties



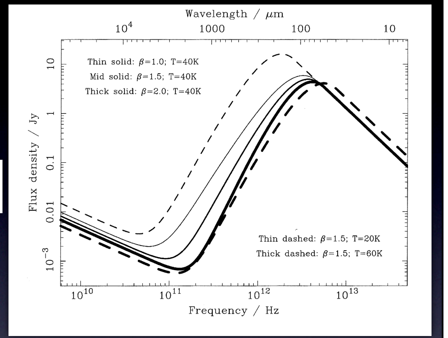

3) Lack of spatially resolved dust emission on <1kpc, only exist for nearby sources

# The modified black body law

Typical approach: assume a uniform grain population, the emission is well-approximated by a (modified) black body law:

$$S_d(\nu) = N(\sigma_d/D_L^2)Q(\nu)B(\nu, T_d)$$

$$Q(\nu) = 1 - exp\ [-(\frac{\nu}{\nu_c})^\beta]$$




Some physical motivation for adding a dust opacity and not simply consider optically thin model

This means 4 parameters to fit

These are effective, brightness-weighted average values from complex mixtures of dust grains with different properties (temperature, opacities etc)

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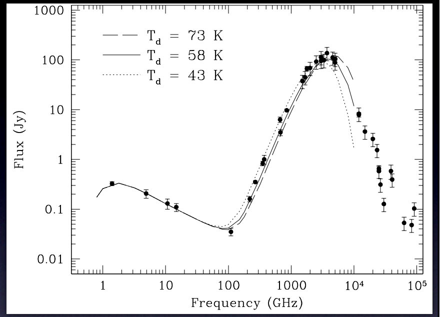


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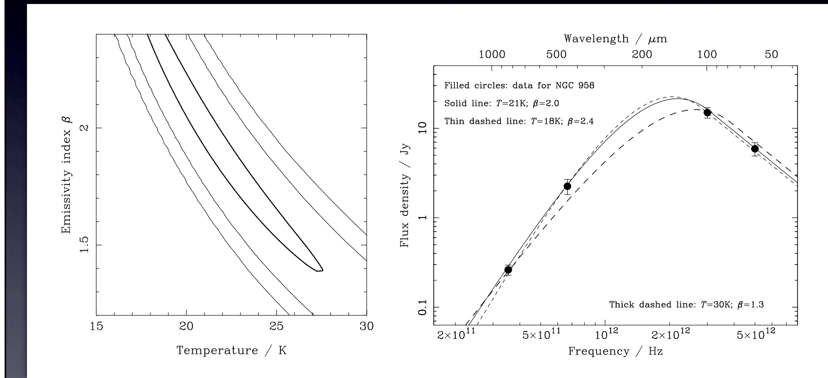
# $T_d$ - β degeneracy in SED fits

Further challenges: When fitting to only a few data-points there is significant correlation between $T_d$ and β



# $T_d$ dependence on β

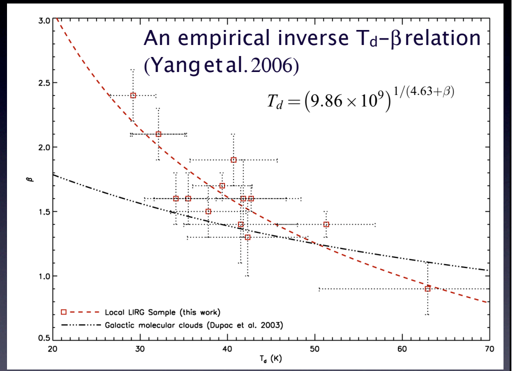
Despite the degeneracy between $T_d$ and β in SED fits there is empirical evidence for a real physical inverse relation between the two parameters. This may be used as a guide in parameter space when fitting SEDs.

- Simple theoretical arguments favor a Td-β dependence

$$T_d \propto \left(\frac{F}{Q_0}\right)^{1/(4+\beta)}$$

- Laboratory experiments supports this

- Dependence could be due to a mix of dust populations. Fx. β~3 have been found for grains covered in ice mantles (formed in cold dust), whereas β~1 is more typical for small grains (which are more easily heated)



# IR-luminosities and dust masses

- Inferring the IR-luminosities and dust masses of galaxies is key to obtaining their starformation rates and evolutionary stage

- Yet doing so means uncertainties in $T_d$ and $\beta$ translate into similar or bigger uncertainties on $L_{IR}$ and $M_d$

$$\mathrm{L_{FIR}} = 4\pi\,\mathrm{D_L^2} \int_{40\,\mu\mathrm{m}}^{1000\,\mu\mathrm{m}} \mathrm{S}_\nu\,\mathrm{d}\nu$$

$$\mathrm{M_d} = \frac{\mathrm{S}_\nu\,\mathrm{D_L^2}}{\kappa\,\mathrm{B}_\nu(\mathrm{T_d})},$$

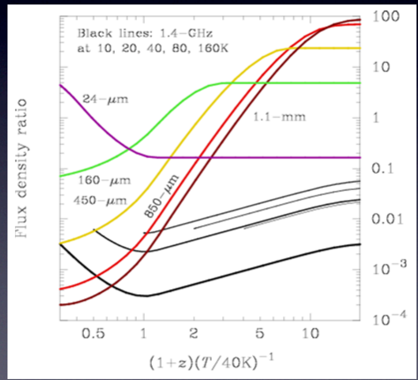
$$\kappa_\nu = 3Q_\nu/4a\rho$$

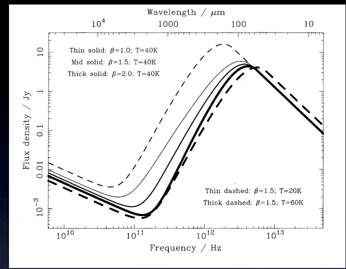
Assumes spherical dust grains (a big if!)

- In general one should therefore be somewhat cautious about quoting dust masses of (high-z) galaxies with the utmost confidence, other than as a comparative measure to distinguish galaxies

# $T_d$-z degeneracy and phot-z's

- Increasing the redshift of a galaxy has the same effect on its measured submm colours as decreasing its dust temperature



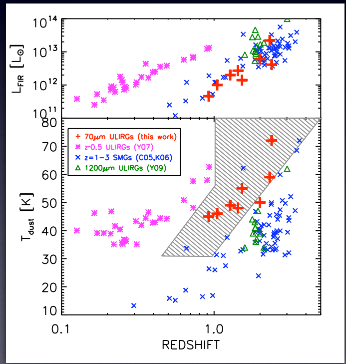



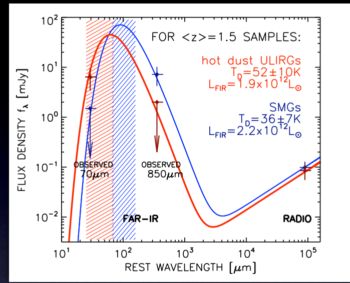

- Combine several submm-bands to derive z and Td together
- Strongest lever from 200-1000um
- Large-format, multi-colour submm cameras (SCUBA-2, KIDS)
- Generous SED sampling combined with sophisticated phot-z techniques may ultimately provide unbiased redshift distribution

# Selection effects: cool vs. hot

- 850um-selected SMGs vs. optically faint, radio-selected galaxies (OFRGs - Chapman et al. 2006), not detected at 850um

- OFRGs a new population of hot ULIRGs at z > 1?




- Submm observations of z~1-3 galaxies have a strong bias towards cool systems

- Our knowledge about the z > 1 ULIRG population is still incomplete

- Herschel, SCUBA-2 combined with deep radio observations will help remedy the situation

# Summary

- Obtaining robust FIR/submm SEDs is still extremely hard work - especially at high-z

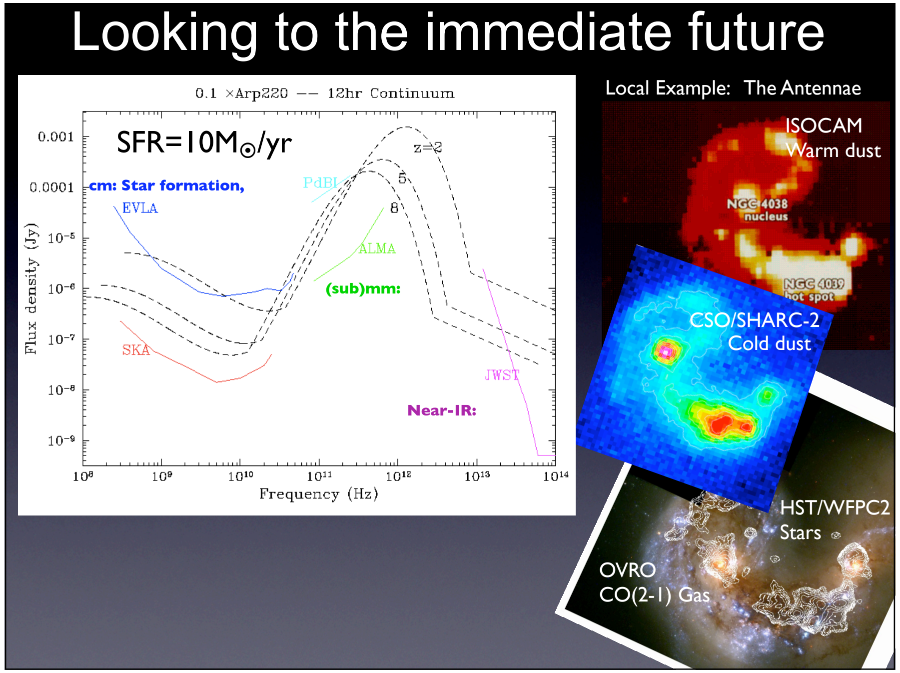
- Better frequency sampling is needed on both sides of the dust peak

- As is spatially resolved observations in order to disentangle hot dust from cold dust

- This will result in much more accurate dust masses, IR luminosities, star formation rate etc, but is unlikely to shield much light on the microscopic properties of the dust (composition, shape etc)

- Photometric redshifts based on submm colours as well as our ability to select high-z dust-enshrouded galaxies an a Td-independent way is hampered by the the $T_d$-z degeneracy and the sensitivity limits on current submm cameras

- ALMA, Herschel, SCUBA-2 combined with up-coming radio facilities will drastically improve the situation


Looking to the immediate future
0.1 ×Arp220 -- 12hr Continuum
SFR=10M⊙/yr
cm: Star formation,
EVLA
SKA
PdBI
ALMA
(sub)mm:
z=2
5
8
JWST
Near-IR:
Flux density (Jy)
Frequency (Hz)
0.001
0.0001
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁸
10⁹
10¹⁰
10¹¹
10¹²
10¹³
10¹⁴
Local Example: The Antennae
ISOCAM
Warm dust
NGC 4038
nucleus
NGC 4039
hot spot
CSO/SHARC-2
Cold dust
HST/WFPC2
Stars
OVRO
CO(2-1) Gas