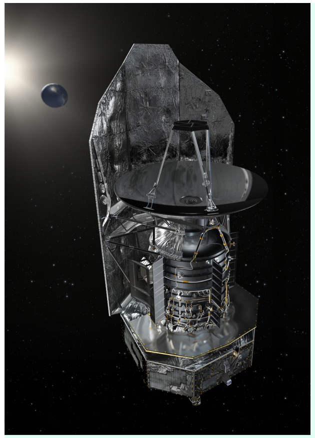


The Herschel View of Nearby Galaxies (<~30 Mpc)

Daniela Calzetti (University of Massachusetts)
+ KINGFISH and HerM33ES

Personal bias

The Universe Explored by Herschel,
ESA/ESTEC, Noordwijk, The Netherlands, October 15-19, 2013

Herschel Key Programs on Nearby Galaxies

Guaranteed Time:

DGS:	Sue Madden
HEXGAL:	Rolf Gusten
HRS:	Steve Eales
SHINING:	Eckard Sturm
VNGS:	Chris Wilson

Open Time:

HerM33ES:	Carsten Kramer
HERITAGE:	Margaret Meixner
HerCULES:	Paul van der Werf
HeVICS:	Jonathan Davies
KINGFISH:	Rob Kennicutt

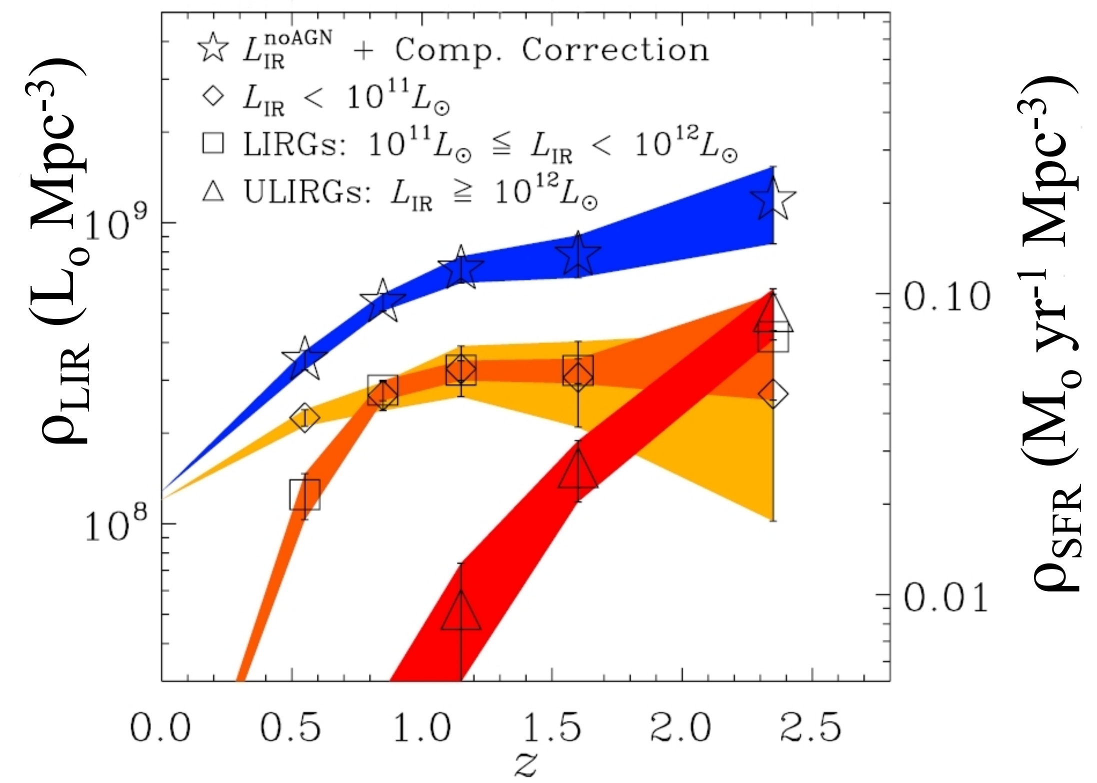
The grand sum of these Key programs is about 2,340 hrs. Plus a sizeable number of Round 1+2 programs (e.g., BtP, HELGAI+II, …).

A review is a daunting task!

So, this will end up being a very biased review….

(see also talks by: Smith, Ford, Croxall, …)

The Importance of the Dark Side



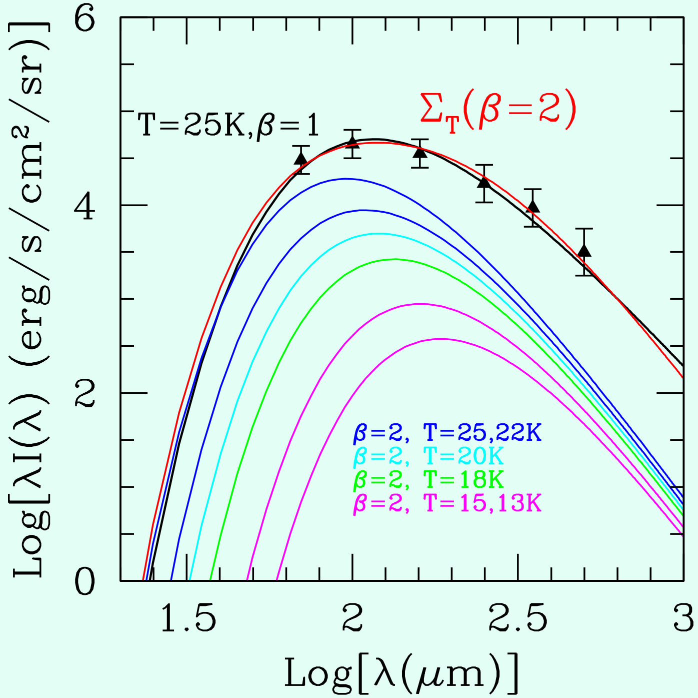
1. Although dust is not the dominant component (~0.01%-0.1% by mass) of a galaxy, it re-processes ~½ of the bolometric radiation across all redshifts from stars/AGNs into the IR/sub-mm
(Hauser & Dwek 2001; Dole et al. 2006)

2. As redshift increases, IR-bright galaxies start dominating the SFR density
(Murphy et al. 2011; Le'Floc et al. 2005; Caputi et al. 2007; Magnelli et al. 2009, Elbaz et al. 2011)

3. The SEDs of high-z IR-bright galaxies are similar to those of local normal SF galaxies, but at least 10 times more IR luminous (U/LIRGs)
(Pope et al. 2006, Elbaz et al. 2011)

Understanding the connection between a galaxy's properties and its IR SED is paramount for understanding galaxy evolution.

The Challenge



Often, IR SEDs are fitted with 1 or 2 MBBs $\sim B(\nu, T)\,\nu^{\beta(\mathrm{fit})}$, but:

$\beta(\mathrm{fit}) \neq \beta_{\mathrm{dust}}$ (in unresolved systems)

where β_{dust} is the physical quantity:

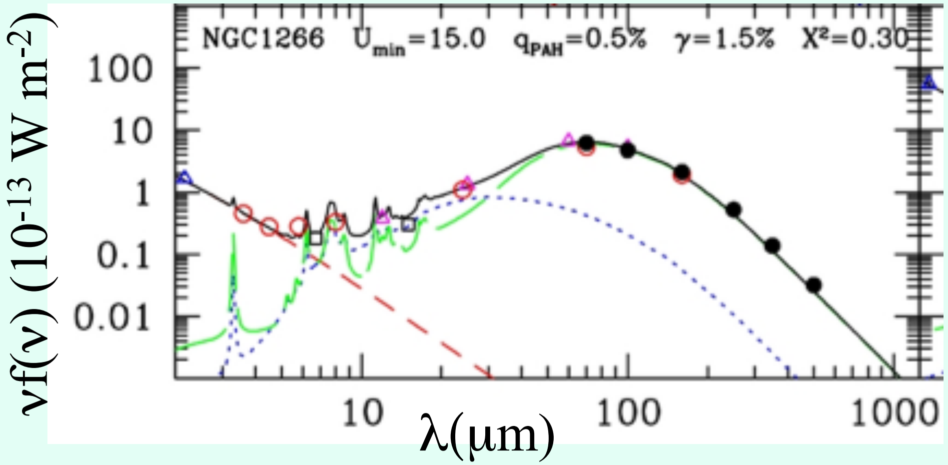
$\Sigma_T\, \alpha(T)\, B(\nu, T)\, \nu^{\beta\mathrm{dust}}$

Ideally, one would use physics-grounded models (e.g., Draine & Li 2007):

Extensive degeneracy, that has generated community-wide discussions on the value(s) of β_{dust} ($1 \leq \beta_{\mathrm{dust}} \leq 2$):

$\beta_{\mathrm{dust}} \sim 2$ for classical graphite/silicate dust (e.g., Draine 2009).

$\beta_{\mathrm{dust}} \sim 1.5$ for hydrogenated amorphous carbons (Ysard et al. 2012).



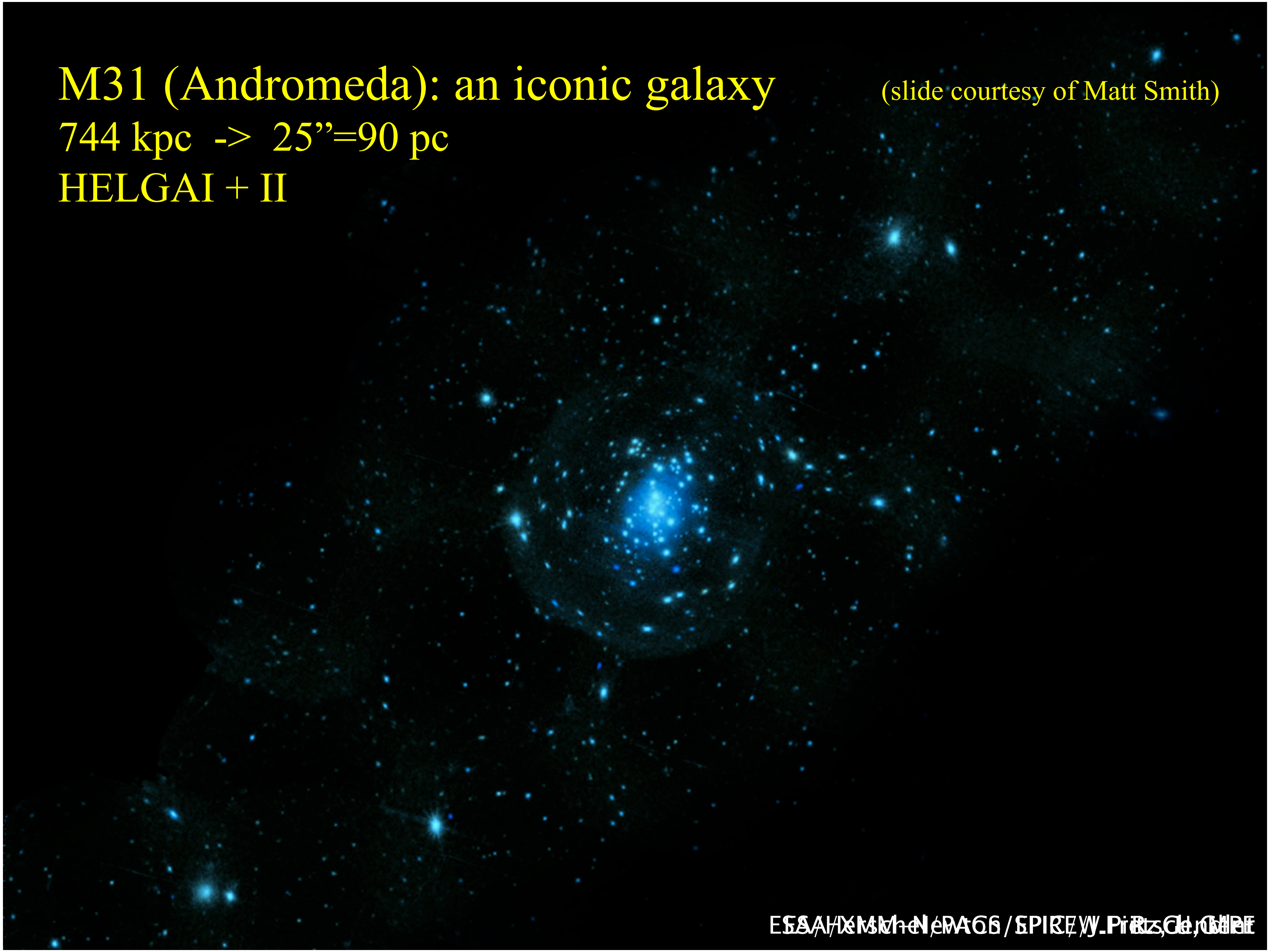
Dale et al. 2012

M31 (Andromeda): an iconic galaxy

(slide courtesy of Matt Smith)

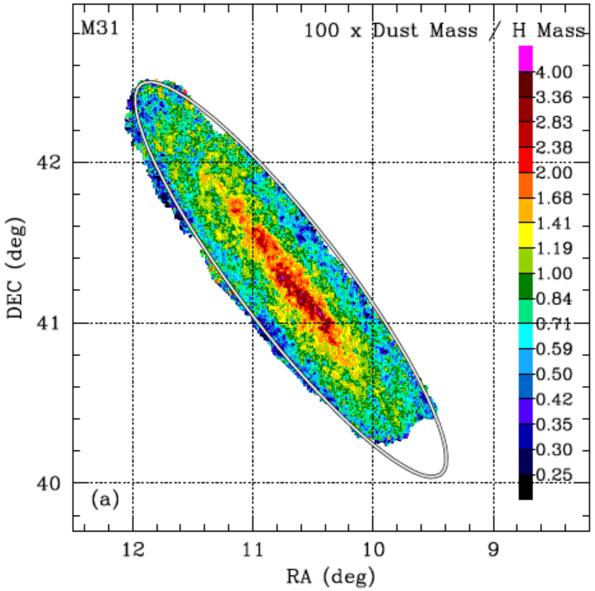
744 kpc -> 25”=90 pc

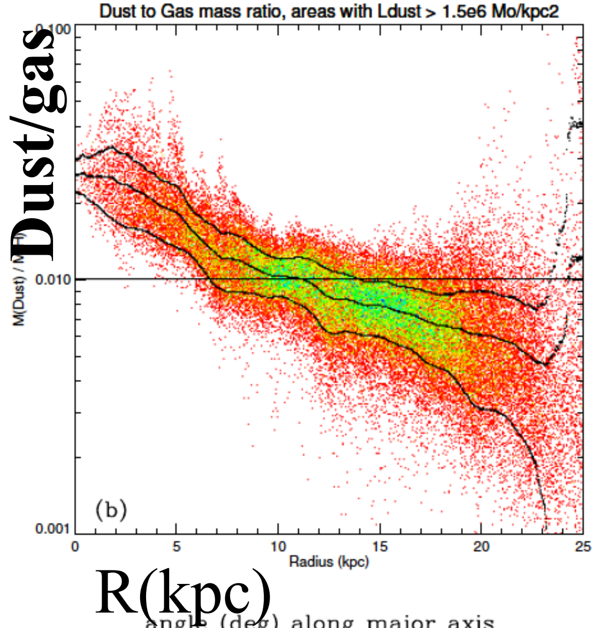
HELGAI + II



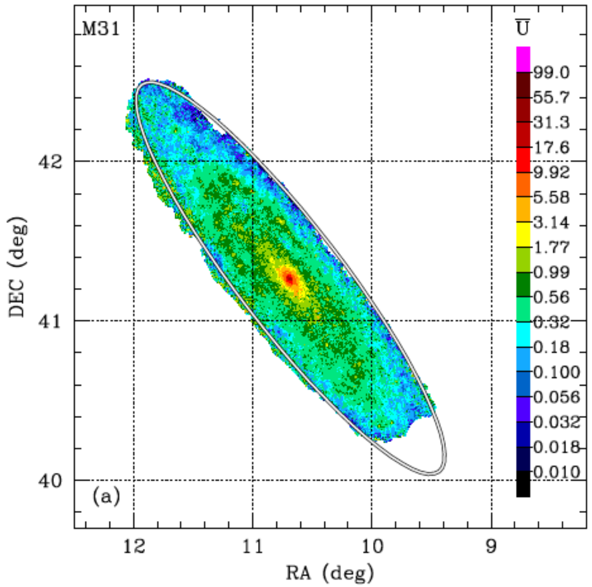
Andromeda’s Dust

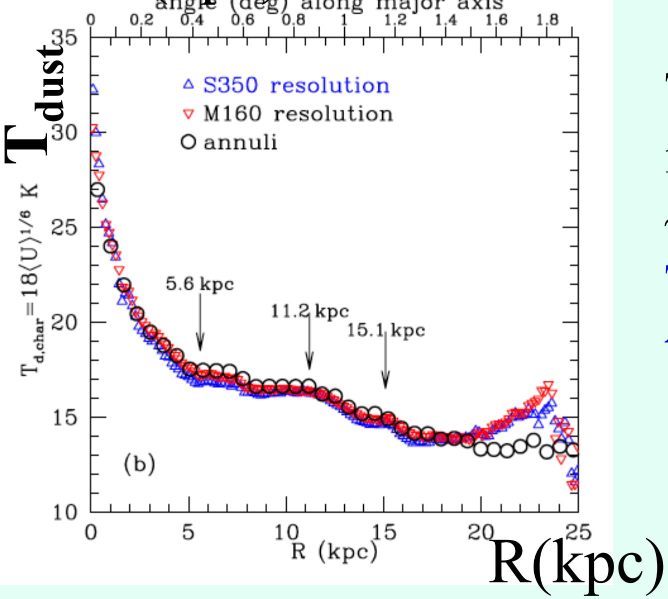
Draine et al. 2013





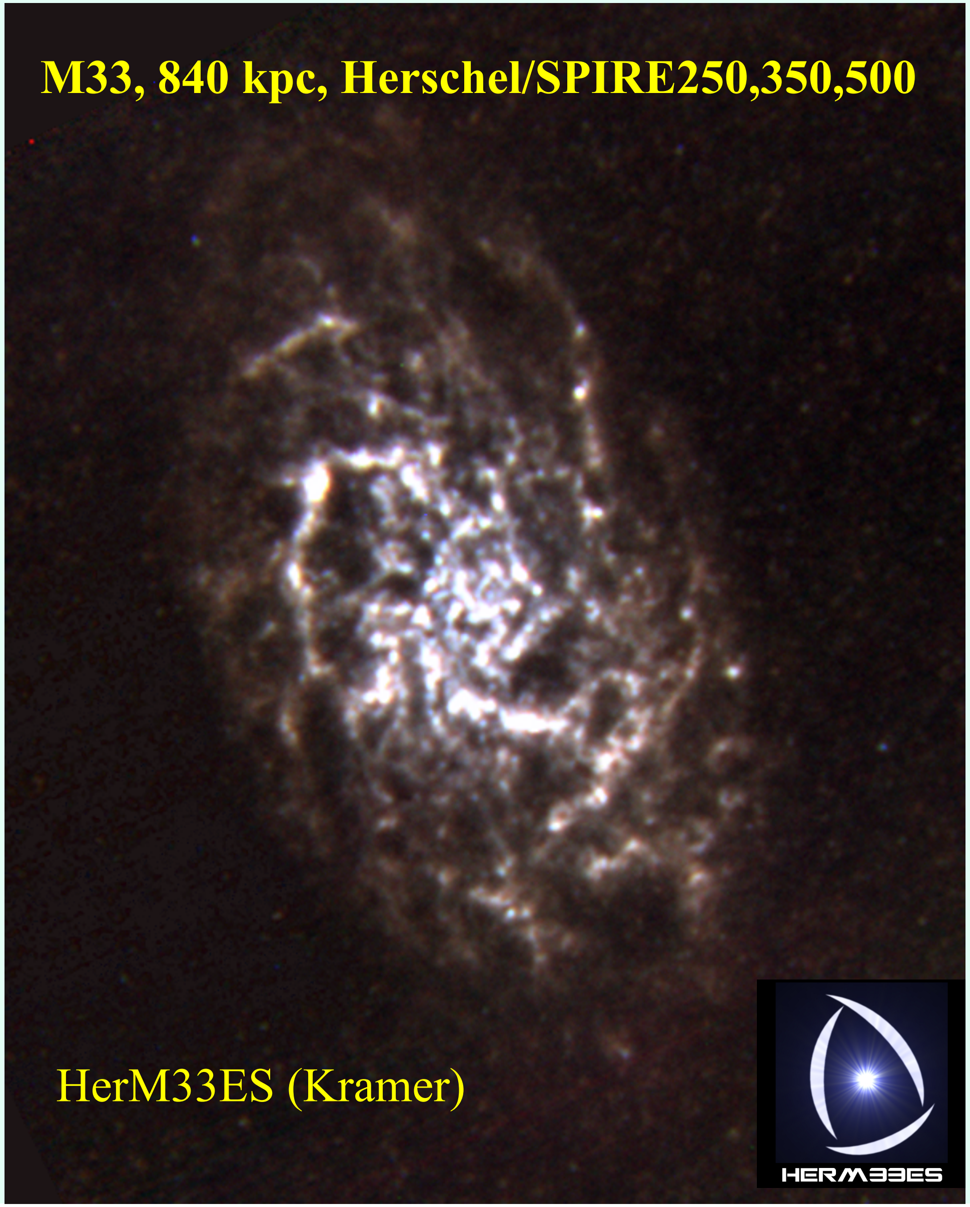
The dust/gas ratio decreases by 10x from the center to the outskirts, implying metal abundance decrease from ~3 solar to 0.3 solar



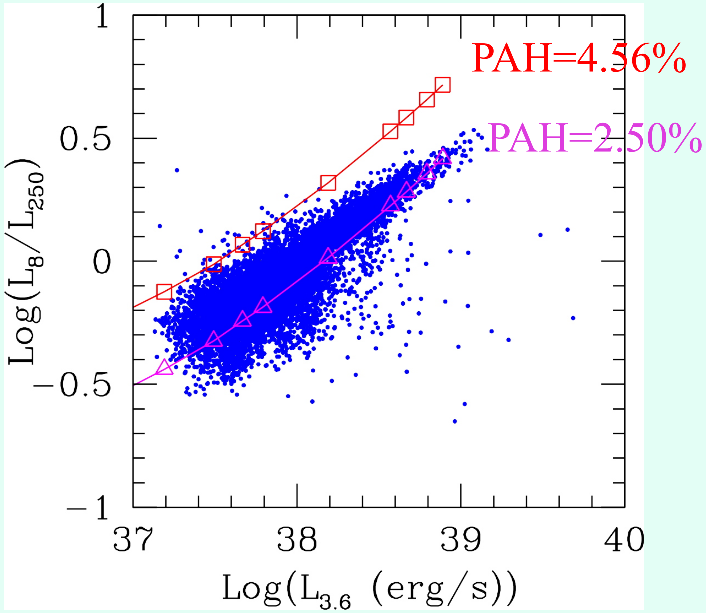


The starlight heating intensity also decreases, by ~140x, implying T_{dust} decreases from ~30 K to ~15 K

M33: the high-resolution star-forming lab

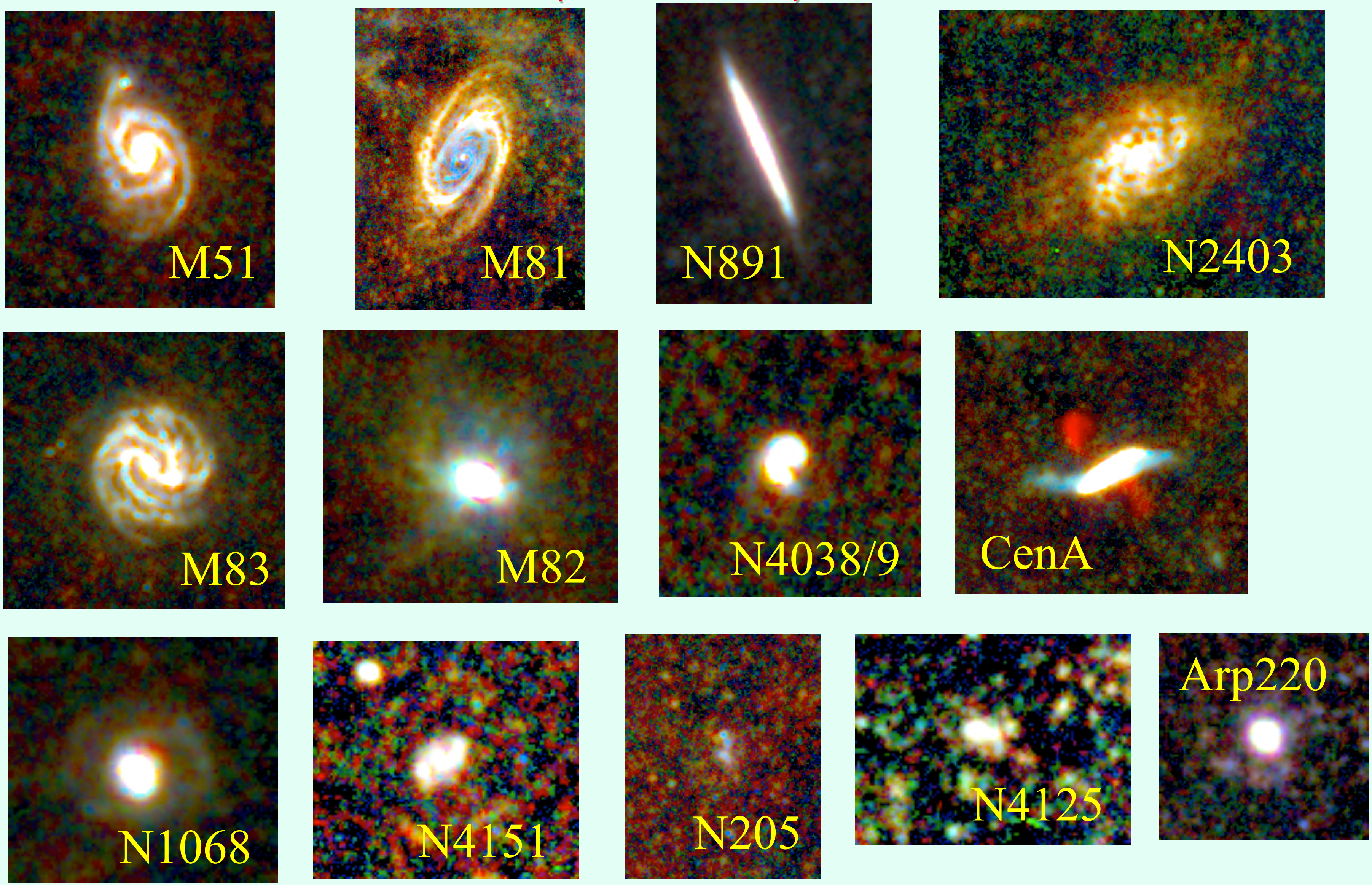


The cold dust T is driven by the heating from evolved stellar pops.
The warm dust T is due to a combination of young and evolved stellar pops (Boquien et al. 2011). Galaxy dependent (Bendo et al. 2012).
The 8 μm emission is tightly correlated with the cold dust and the evolved stellar pops (Calapa et al., in prep.)



The Herschel Very Nearby Galaxies Survey

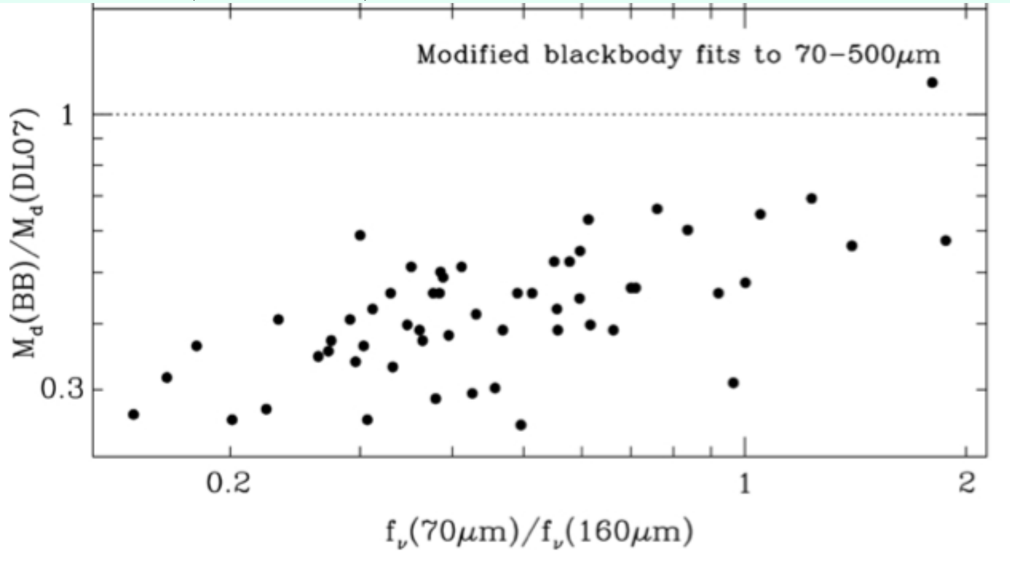
(VNGS: Wilson)



250/350/500 μm images by L. Cortese

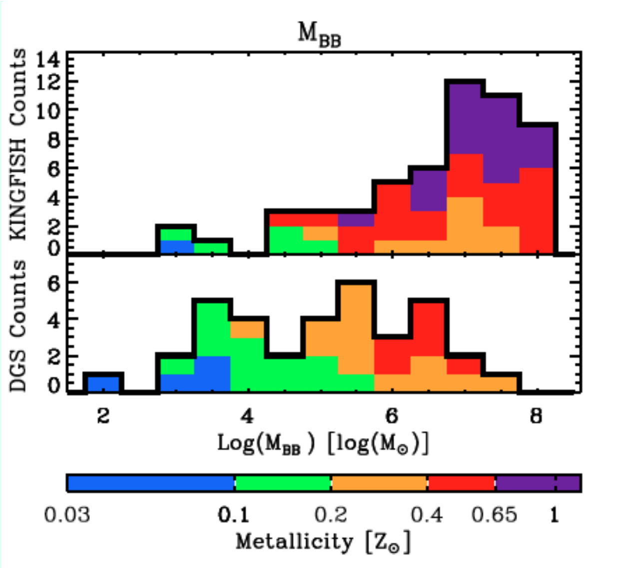
General Results on Dust Masses

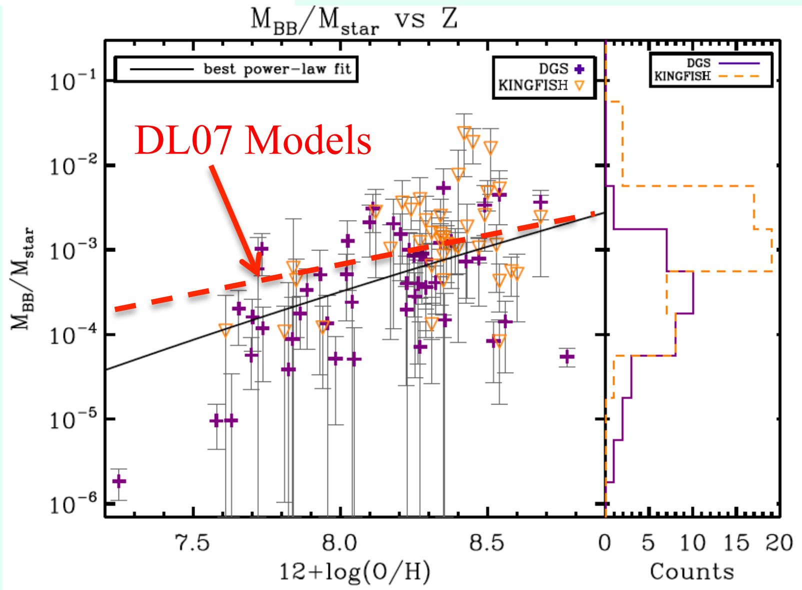
KINGFISH (Kennicutt): Dale et al. 2012



2-3X higher dust masses when using Spitzer+Herschel, and tighter, esp at low metallicity.

Physical models (e.g., DL07) produce higher dust masses, again esp. at low metallicities, by ~2-3x.



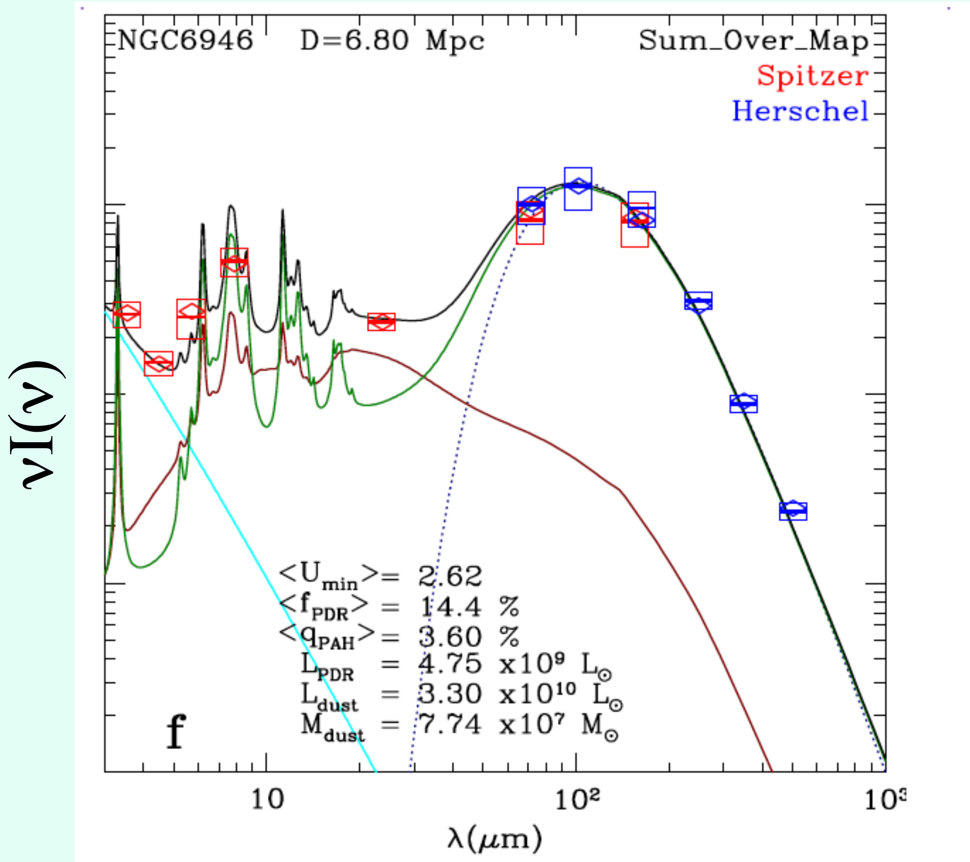


DGS (Madden): Remy-Ruyer et al. 2013, M(BB) with free β(fit)

Summarizing the Dust Masses…

… no surprises:

1. no unusual dust masses (beyond what expected from metal abundances);
2. no unusually cold components ($T \leq 12$ K)



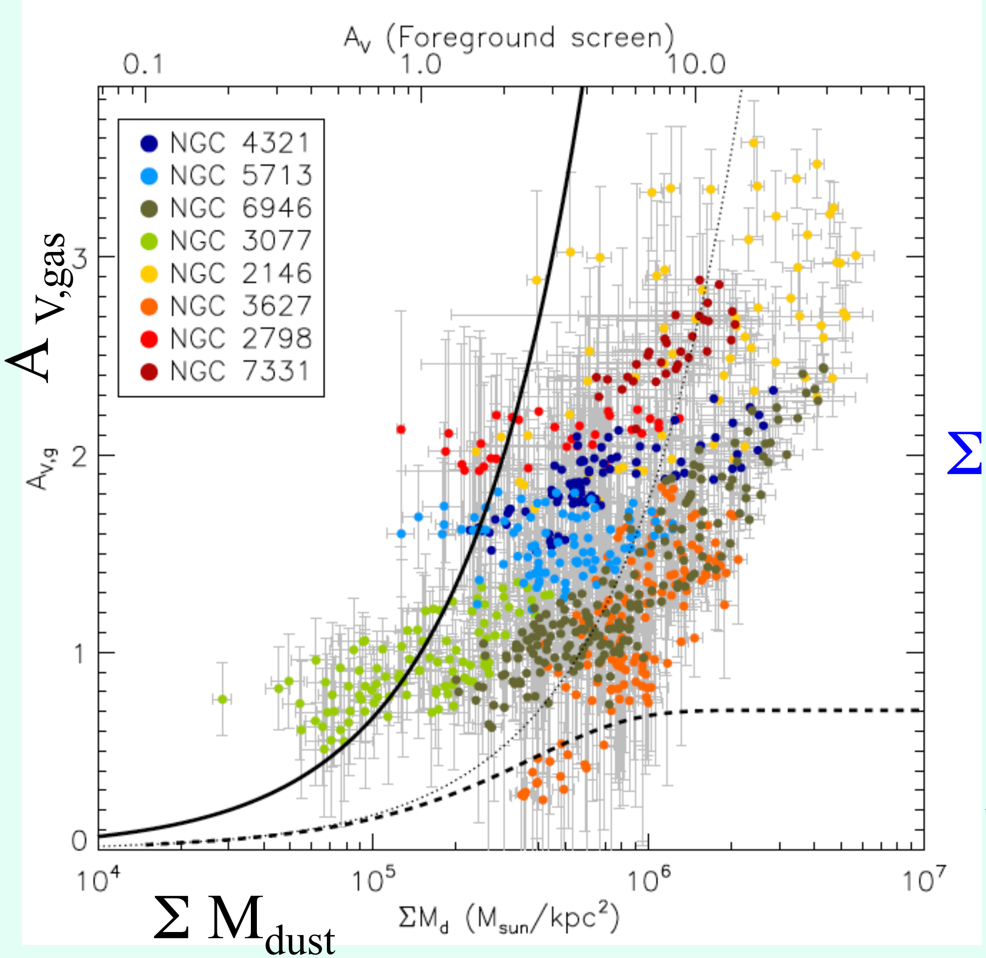
In addition (Galametz et al. 2012, Kirkpatrick et al. 2013 in prep):

a. Global fits usually yield slightly lower total masses (~10%-60%) than spatially-resolved fits
b. Cold temperatures or β values decrease smoothly from center to outskirts of galaxies

Aniano et al. 2012 (KINGFISH)

Dust and Extinction

Kreckel et al. 2013



Dust maps can thus be used to derive proxies for extinction/ attenuation maps.

ΣM_{dust} (M_o kpc^{-2})= 5.7×10^5 $A_{V,gas}$

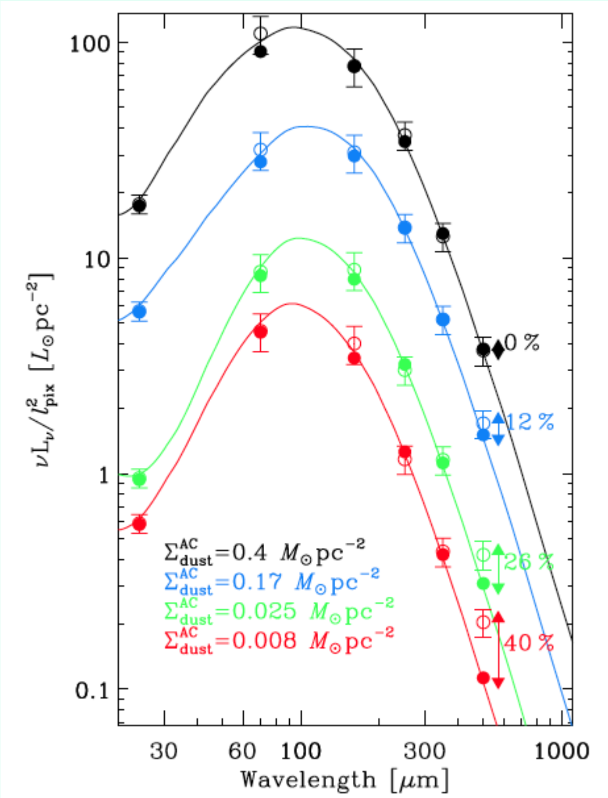
(for regions 0.35-2 kpc)

$A_{V,stars}$ = (0.47+/-0.006) $A_{V,gas}$

(for regions with Σ_{SFR}>0.1 $M_o yr^{-1} kpc^{-2}$)

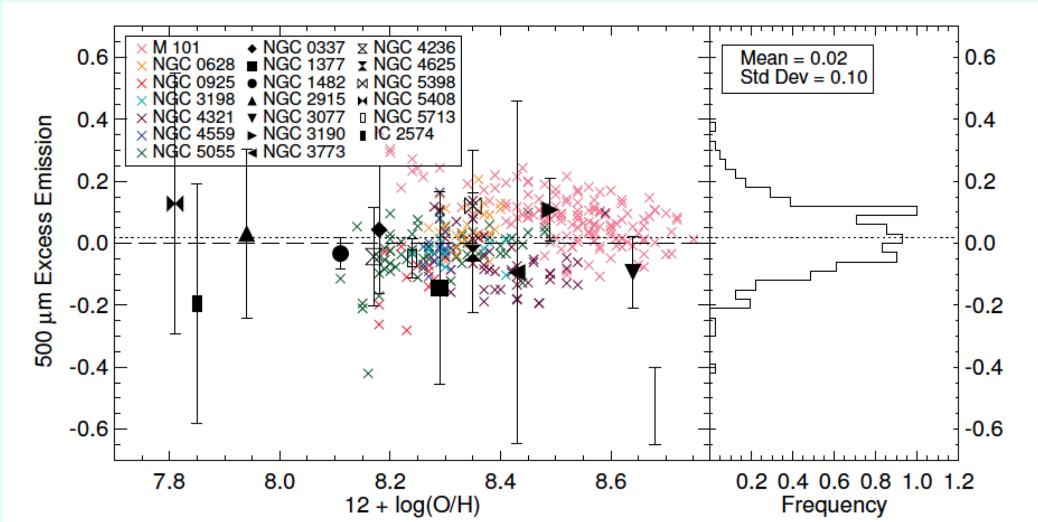
To be compared with $A_{V,stars}$ = (0.44+/-0.03) $A_{V,gas}$ in starbursts (C. et al. 2000)

The `Submm Excess'



LMC: Galliano et al. 2011

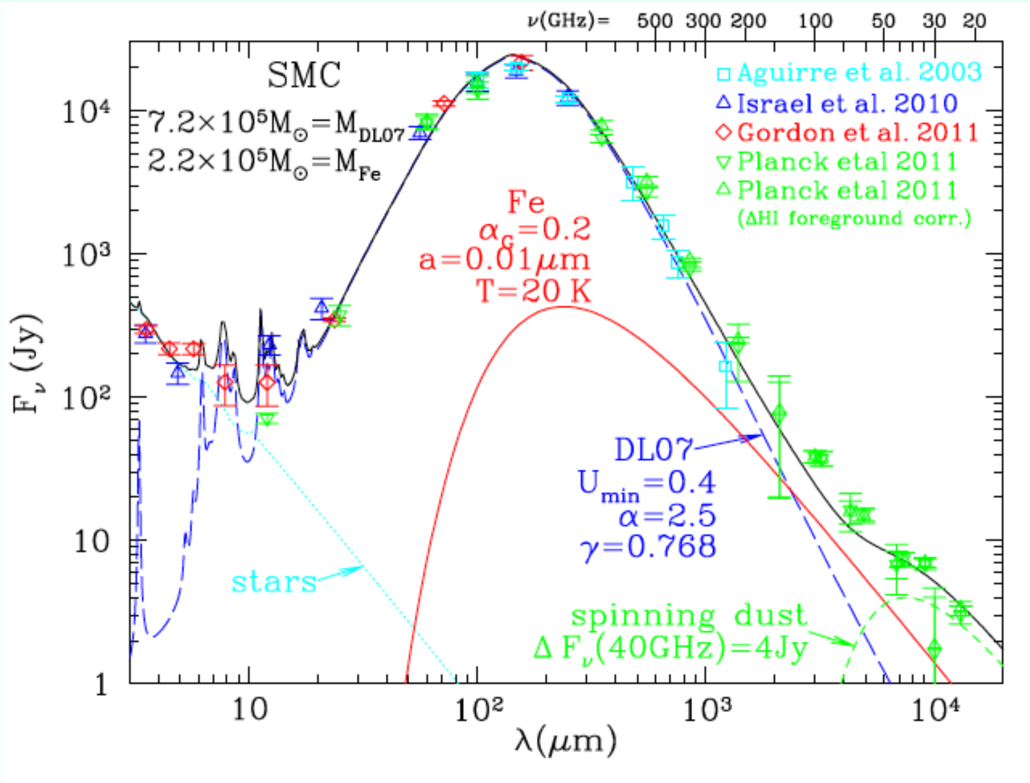
- Highly dependent on definition!
  - Higher levels of `excess' are generally found when fixing β(fit) (e.g., Remy-Ruyer et al. 2013). Lower levels when allowing it to vary (e.g.,Kirkpatrick et al. 2013, subm.) or when using physical models (e.g., Galliano et al. 2011).



β(fit) free=no 500 μm excess: Kirkpatrick et al. 2013

Excess tends to be observed in some low metallicity environments, which tend to have shallow RJ tails (Remy-Ruyers et al. 2013), and in diffuse emission (Galliano et al. 2011).

Submm Excess Beyond SPIRE



Draine & Hensley 2012

However, there is mounting evidence for excess beyond 500 μm.

[COBE/FIRAS (Reach et al. 1995), WMAP (Bot et al. 2011), SCUBA, MAMBO (Galliano et al. 2003), LABOCA (Galametz et al. 2013) Planck (Planck Collaboration 2011)].

Most `classical’ models of dust composition cannot explain these `extra component’.

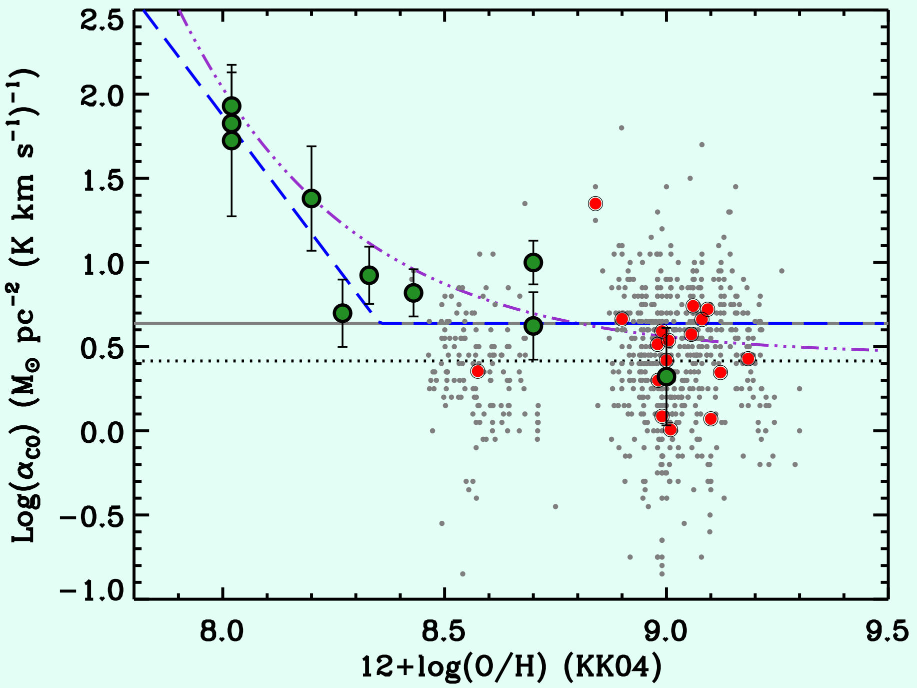
Advocating: very small magnetic grains or spinning particles, CMB fluctuations, amorphous dust grains, etc.

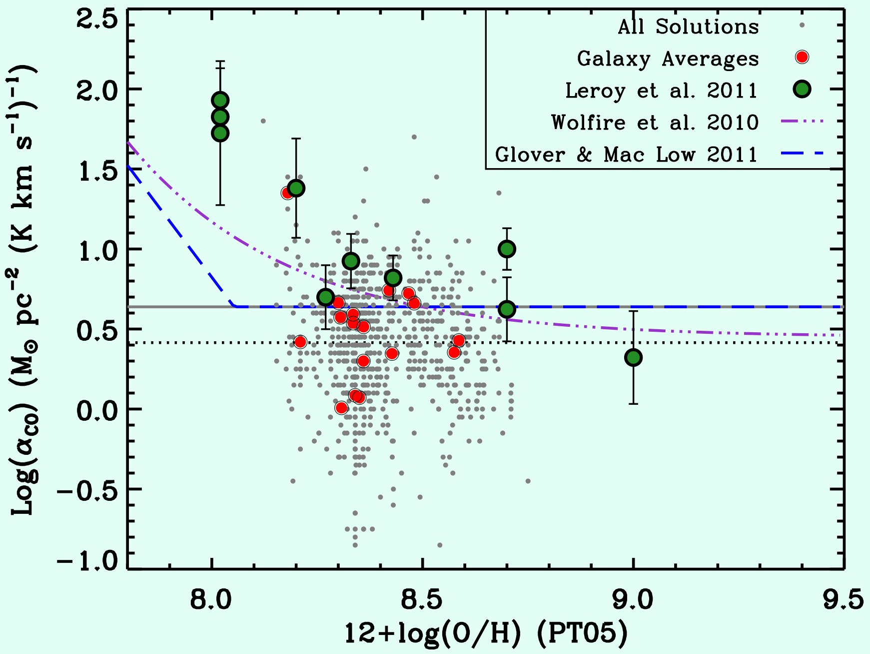
The excess emission can affect dust mass determinations, both local and global, when using λ>500 μm measurements.

Trends for α_{CO} (CO/H_2 conversion)

It is becoming increasingly common to use dust maps as proxies for H_2, provided HI maps are also available.

Herschel can help solve the equation:
$\Sigma_{dust}/DGR = \Sigma_{HI} + \alpha_{CO} I_{CO}$
simultaneously for DGR and α_{CO}, in maps of galaxies.



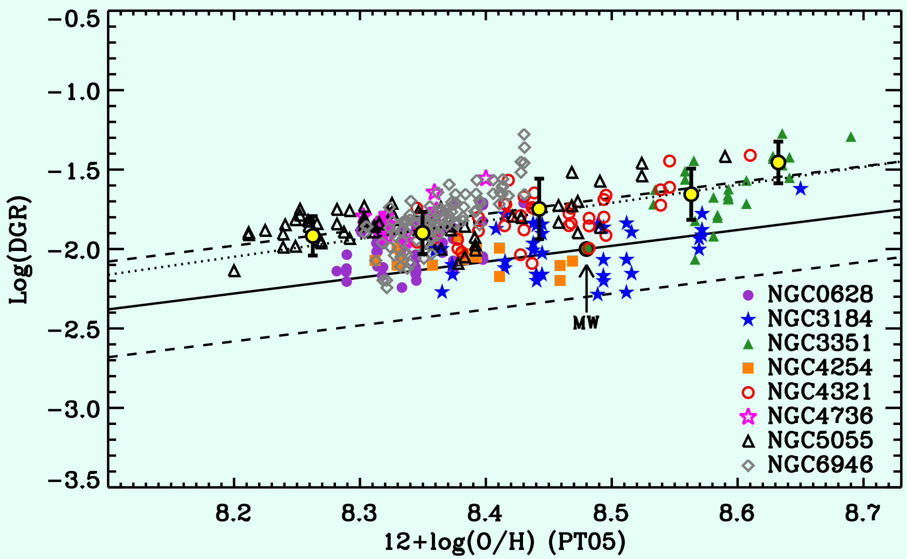


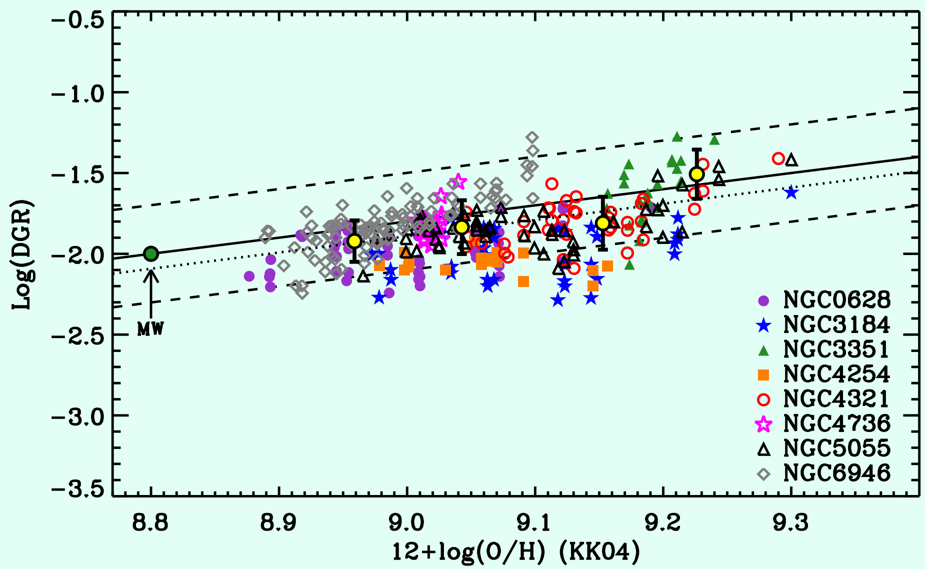
Both local and global α_{CO} show evidence for an increase in value for decreasing metal abundance

Sandstrom et al. 2013 (KINGFISH)

Spatially-Resolved DGR

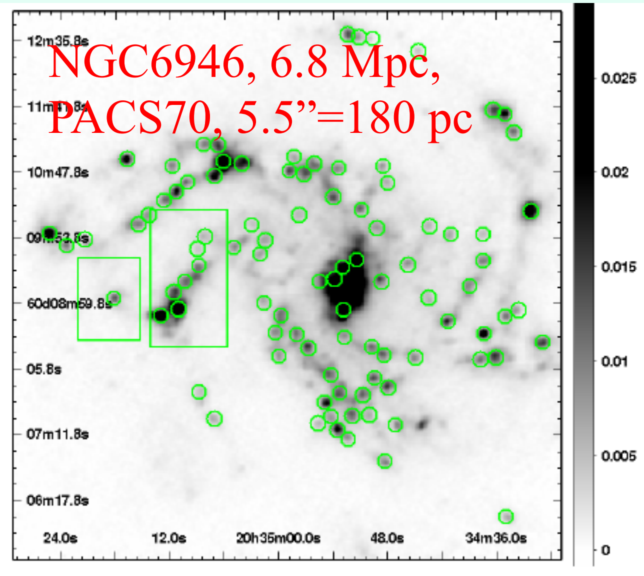
Sandstrom et al. 2013 (KINGFISH)

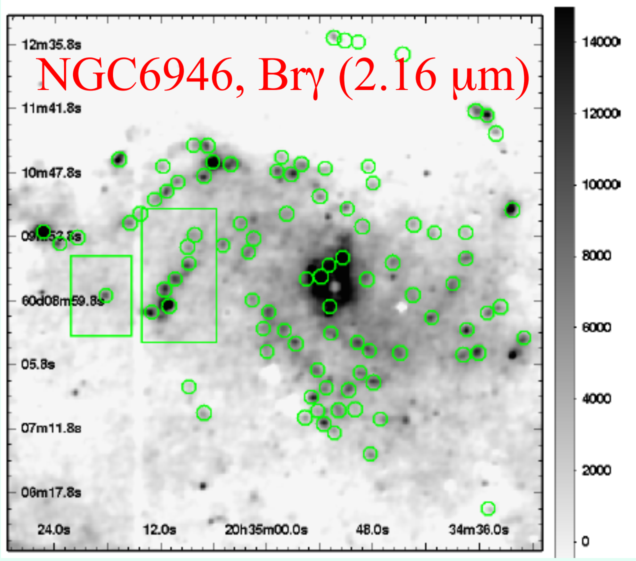




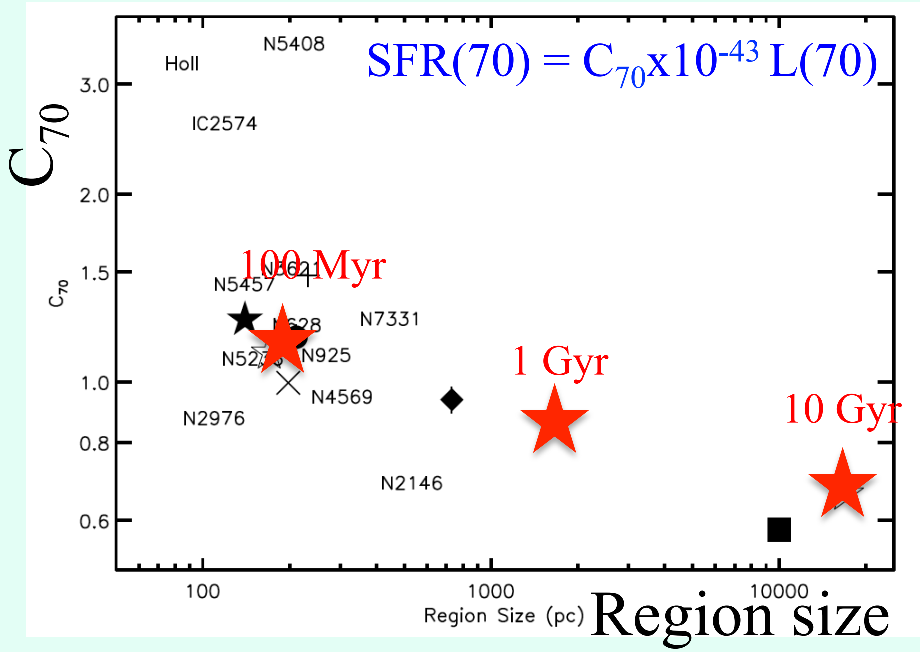
The DGR follows the linear trend as a function of metallicity expected by rescaling the MW values, suggesting that a constant fraction of metals is converted into dust over the factor ~3 metallicity probed by the sample.

Herschel as a SFR `Machine'





High-resolution 70 μm emission traces recent star formation at a range of scales.



Use Brγ as SFR `truth'.

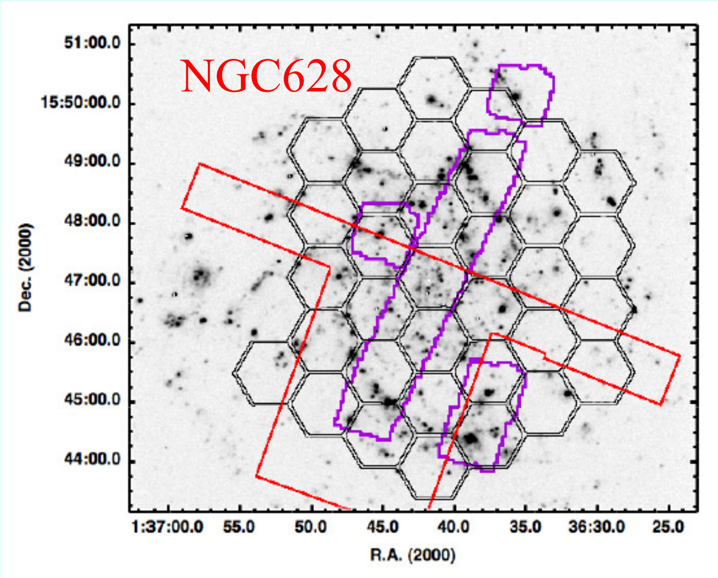
Only ~50% of the global 70 μm emission from galaxies is associated with current SF (current= younger than 100 Myr).

Li et al. 2013a,b

Solving for the Abundance Scale Discrepancy

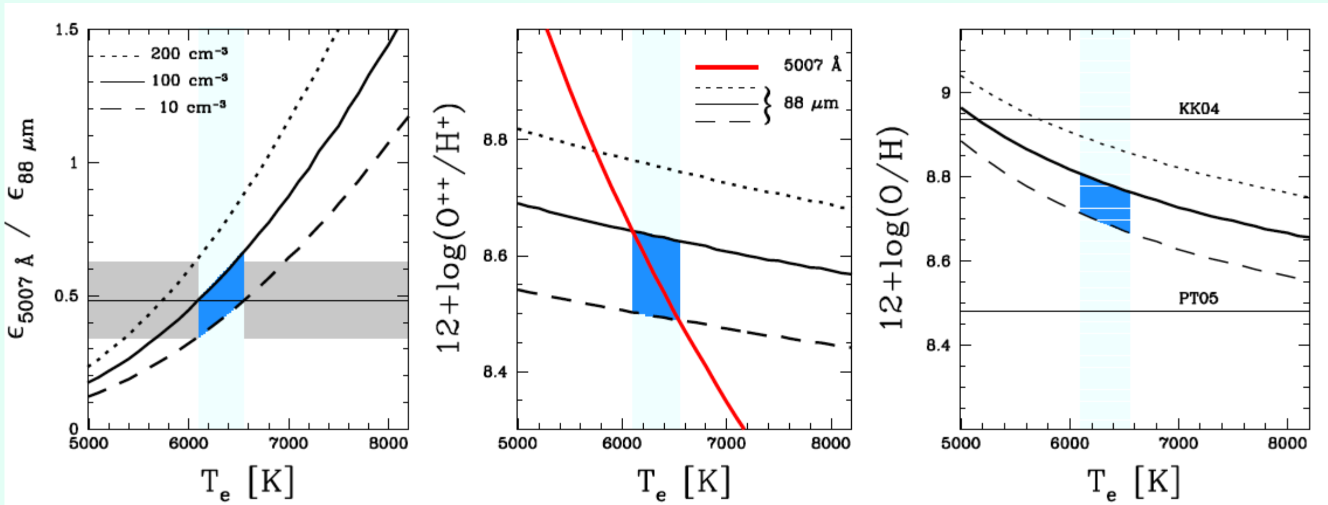
(the only spectroscopy presented)

KINGFISH:Croxall et al. 2013



Empirical (PT05) and model-based (KK04) calibrations from oxygen abundance differ by ~0.6 dex. Irreconcilable, unless use of `temperature-independent' O lines (e.g., Herschel [OIII] 88μm).

Combine ground-based, Spitzer IRS, and PACS spectroscopy.



Resulting (O/H) is in-between the PT05 and KK04 scales.

Conclusions

1. Herschel Space Observatory's imaging and spectroscopy are enabling much progress in our understanding of both the characteristics of the dust emission from galaxies and the conditions of the ISM.
2. Dust masses tend to be higher than inferred with earlier data, mainly in low metallicity galaxies, which tend to have shallower RJ tails than more metal rich galaxies. Higher resolution also yields higher (~10%) masses.
3. The excess at 500 μm is mostly not present, except perhaps in very specific environments (low metallicity and diffuse), when SED fits are performed with physical models. However, excess at longer wavelengths has been confirmed, questioning dust mass determinations from monochromatic mm measurements.
4. Dust masses have been used to relate to visual extinction, and derive the CO/H_2 conversion factor (consistent with MW values) and the DGR (showing constant metals-to-dust depletion).
5. SFRs at IR wavelengths have calibration factors that are dependent on the physical scale (the mean age of the stellar population) being considered.
6. PACS spectroscopy is along the way to solve the abundance scale discrepancy.