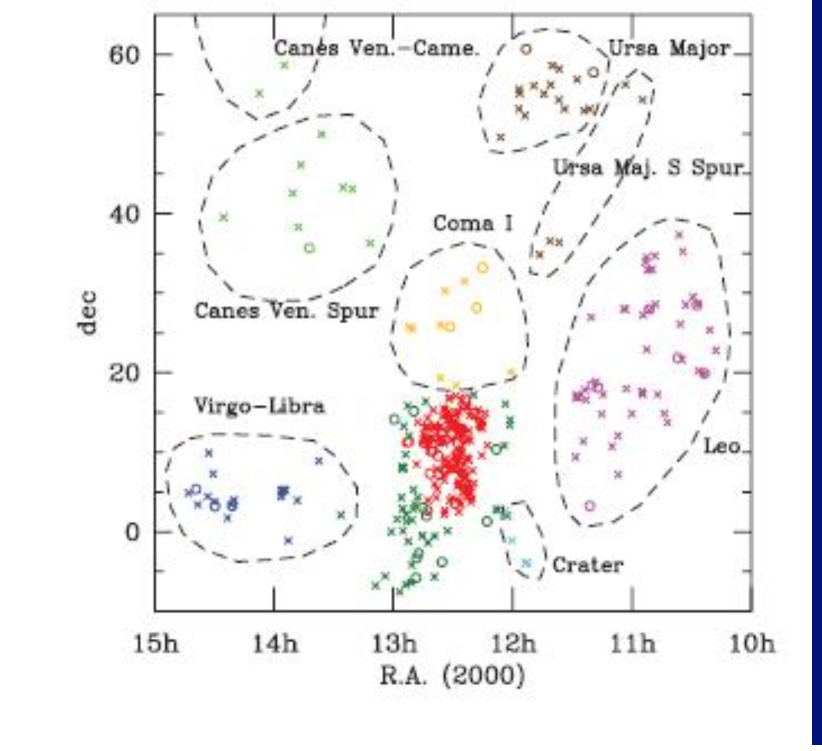
# THE HERSCHEL REFERENCE SURVEY

S. Eales and SPIRE GT SAG – 2 (Auld, Baas, Barlow, Bendo, Bock, Boselli, Bradford, Buat, Castro-Rodriguez, Chanial, Charlot, Cortese, Ciesla, Clements, Cooray, Cormier, Davies, Dwek, Elbaz, Galametz, Galliano, Gear, Glenn, Griffin, Hony, Isaak, Levenson, Lu, Madden, O'Halloran, Okumura, Oliver, Page, Panuzzo, Papageorgiou, Parkin, Perez-Fournon, Pohlen, Rangwala, Rigby, Roussel, Rykala, Sacchi, Sauvage, Schulz, Schirm, Smith, Spinoglio, Srinivasan, Stevens, Symeonidis, Trichas, Vaccari, Vigroux, Wozniak, Wilson, Wright and Zeilinger

- 15 < D < 25 Mpc
- b>55°, $A_B$ < 0.2
- K < 8.7 for E, S0, Sa and < 12 for everything else
- 323 galaxies
- 250, 350 and 500 micron observations
- data sharing agreement with HeVICS in Virgo

*Boselli et al. 2010, PASP, 122, 261*



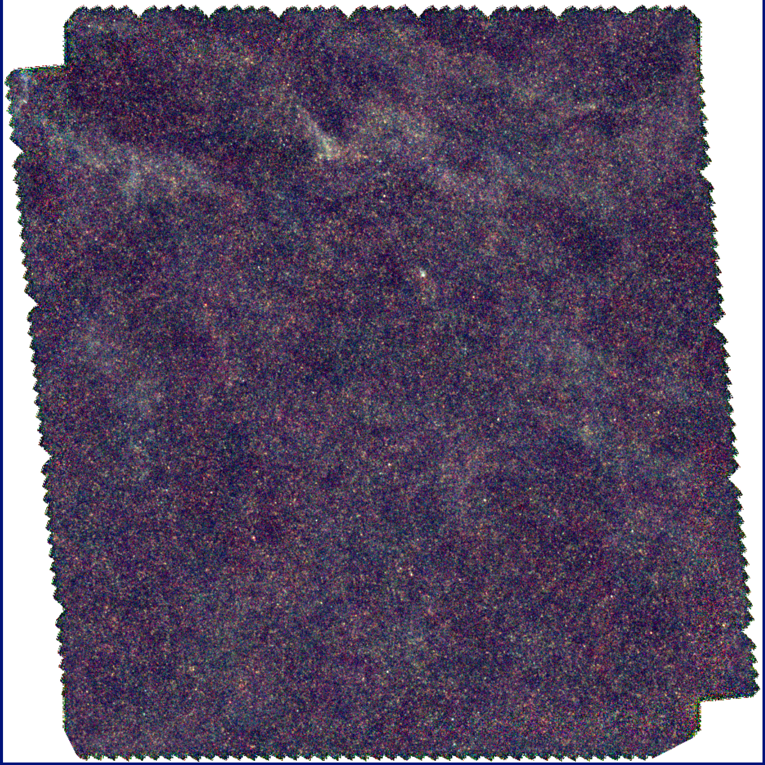
# Science Demonstration

*Nine targets: M86, M99, M100, Arp 205, NGC 3683, NGC 3982, NGC 4339, NGC 4532, NGC 4438/35. These have generated the following papers for the special issue:*

- Boselli et al. – FIR colours and SEDs of nearby galaxies observed with Herschel
- Cortese et al. – Herschel/SPIRE observations of the disturbed galaxy NGC 4438
- Eales et al. – Mapping the interstellar medium in galaxies with Herschel/SPIRE
- Gomez et al. – The dust morphology of the elliptical galaxy M86 with SPIRE
- Pohlen et al. – The radial distribution of gas and dust in spiral galaxies: the case of M99 (NGC 4254) and M100 (NGC 4321)
- Sauvage et al. – The central regions of spiral galaxies as seen by Herschel

# How do we measure the gas reservoirs in the thousands of galaxies detected by Herschel?

*Herschel can measure the hidden star formation rate in galaxies, but to understand galaxy evolution we also need to measure the gas reservoirs.*



Both HI and CO observations are limited to low redshift and with CO there is the notorious X-factor

CARDIFF UNIVERSITY
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# Measuring the Gas Reservoir with Dust Emission

$$M_{\mathrm{hydrogen}} = \frac{S_\nu D^2}{\kappa_\nu B_\nu(T_d) Z \epsilon f}$$

James et al. 2002, MN 335, 753

Fraction of mass of gas of solar metallicity in metals = 0.019

Fraction of metals in dust (from measurements of depletion in local ISM) = 0.46

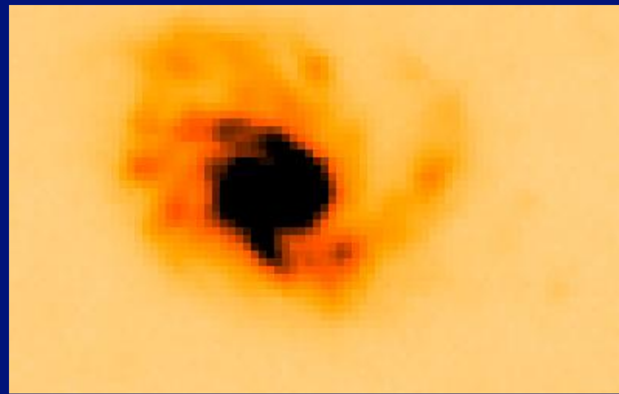
Mass-opacity coefficient

metallicity

# M99 and M100

*Two big spiral galaxies in the Virgo Cluster*

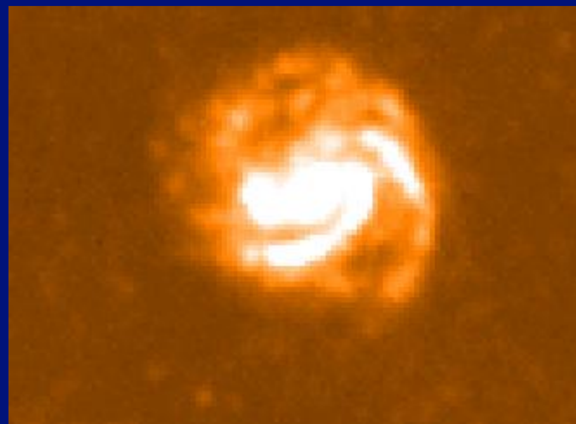
***M99***



*optical*

*SPIRE at 250 microns*

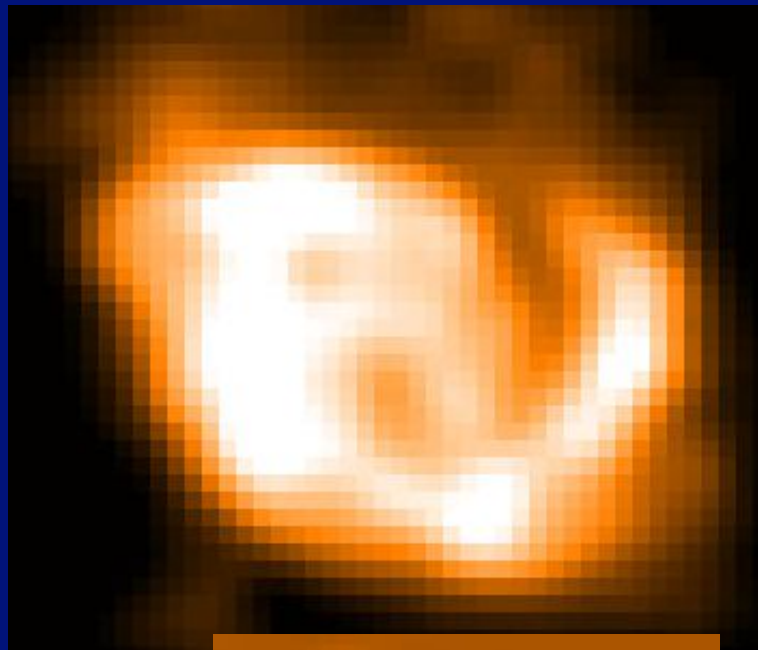
***M100***



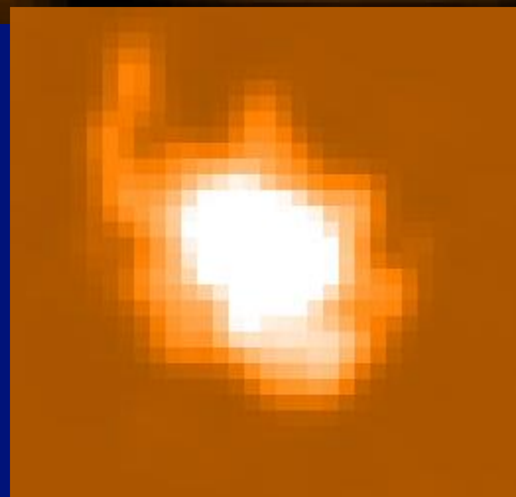
# Method 1

- Atomic gas from VIVA HI map
- Molecular gas from CO 1-0 map of Kuno et al. (2007) using an X factor of $2 \times 10^{20}$ $cm^{-2}$ (K km $s^{-1}$)$^{-1}$

HI



CO



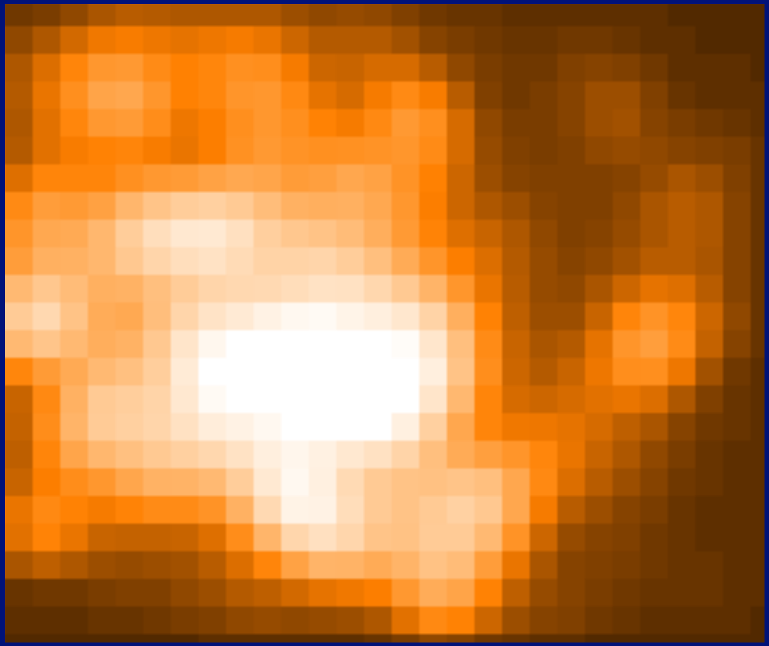
# Method 2

- ***Estimate metallicity from metallicity radial profiles measured from optical spectroscopy (Skillman et al. 1996)***
- ***Estimate dust temperatures at each pixel from fitting single-temperature dust model to 70, 250 and 350-micron flux densities  (17 < T < 25 K)***
- ***Estimate mass-opacity coefficient from value at 850 microns estimated by James et al. = $(850/350)^2$ x 0.07 $m^2\ kg^{-1}$***

* See poster by Matthew Smith on estimating the distribution of the dust temperature in HRS and HeVICS galaxies.

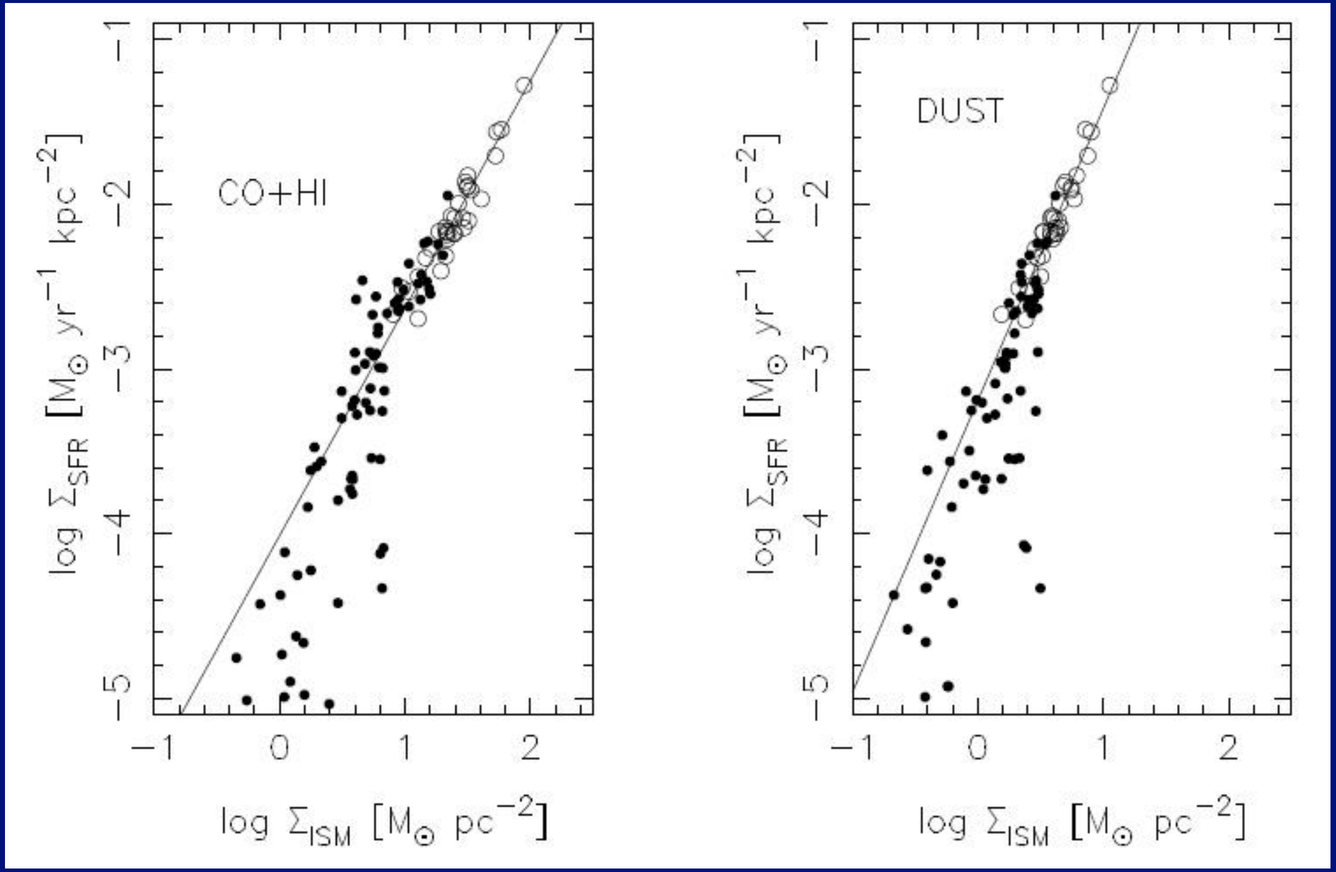
# Comparison of the Methods

- **Assume that there is an intrinsic relationship between the star-formation rate per unit area of the disk and the surface density of the ism.**
- **Measure the dispersion around the relationship**



***Estimate of the total star-formation rate in M99 from 24-µm and Hα images (Wilson et al. 2009)***

# M100

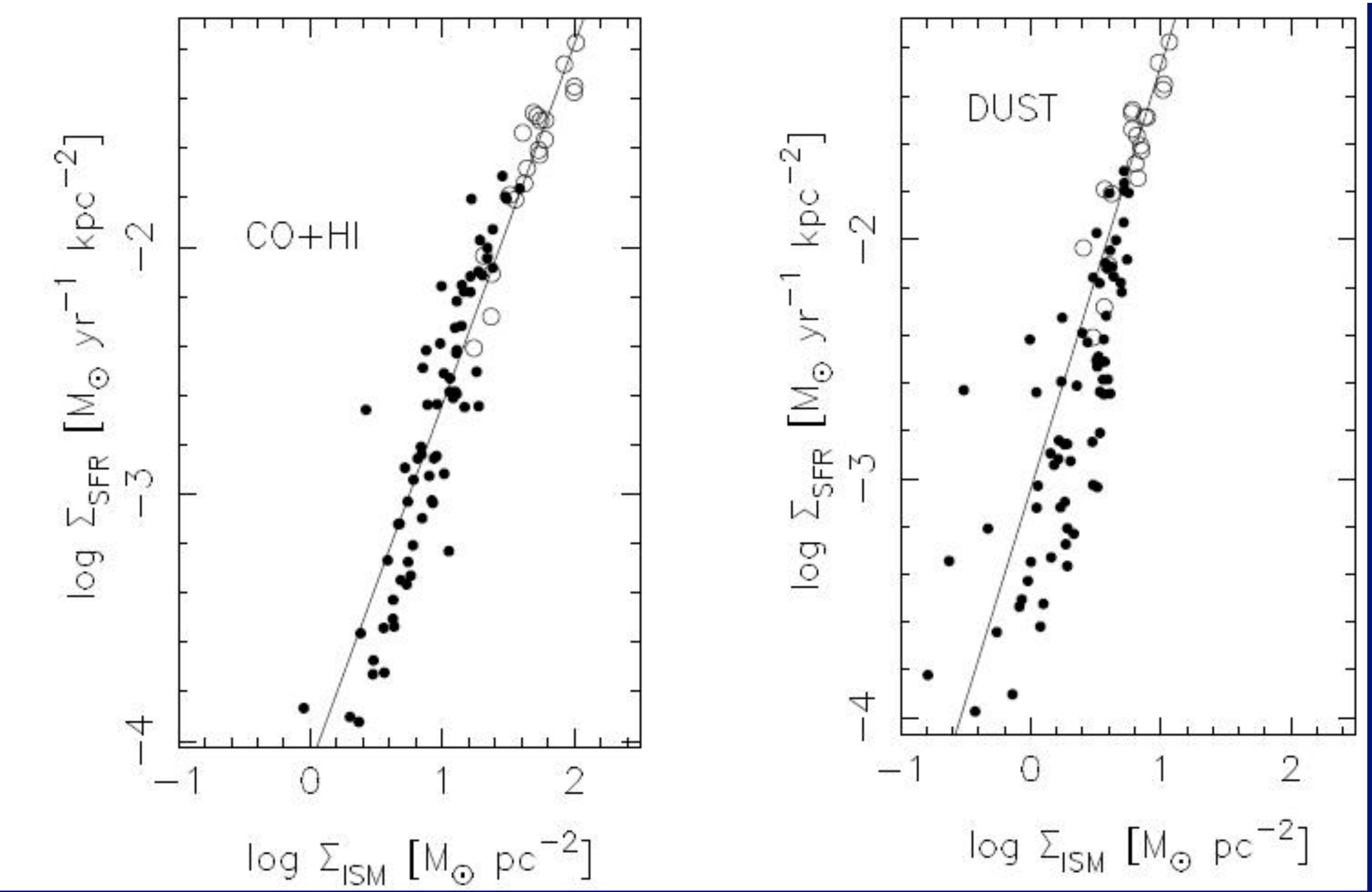



$$\text{Log}_{10}(\Sigma_{SFR}) = N \log_{10}(\Sigma_{ISM}) + c$$

CO/HI: N=1.38±0.08 $x_{res}$ = 0.070 $y_{res}$ = 0.096

Dust: N=1.77±0.10 $x_{res}$ = 0.050 $y_{res}$ = 0.088

M99




$$Log_{10}(\Sigma_{SFR}) = N \log_{10}(\Sigma_{ISM}) + c$$

CO/HI: N=1.46±0.13 $x_{res}$ = 0.077 $y_{res}$ = 0.111

Dust: N=1.77±0.22 $x_{res}$ = 0.086 $y_{res}$ = 0.152

# Estimates of the Mass-Opacity Coeffcient

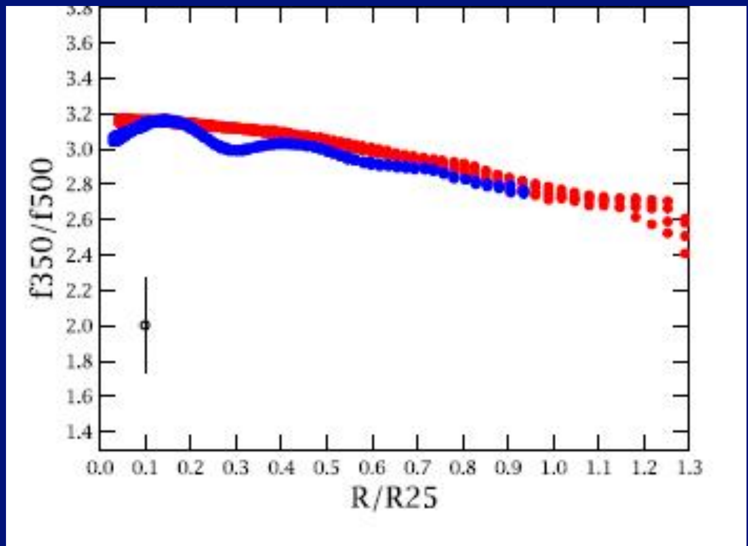
By comparing the relationships for the two methods, we can estimate a value for the mass-opacity coefficient at 350 μm:

- M99 – 0.056 $m^2 kg^{-1}$
- M100 – 0.063 $m^2 kg^{-1}$

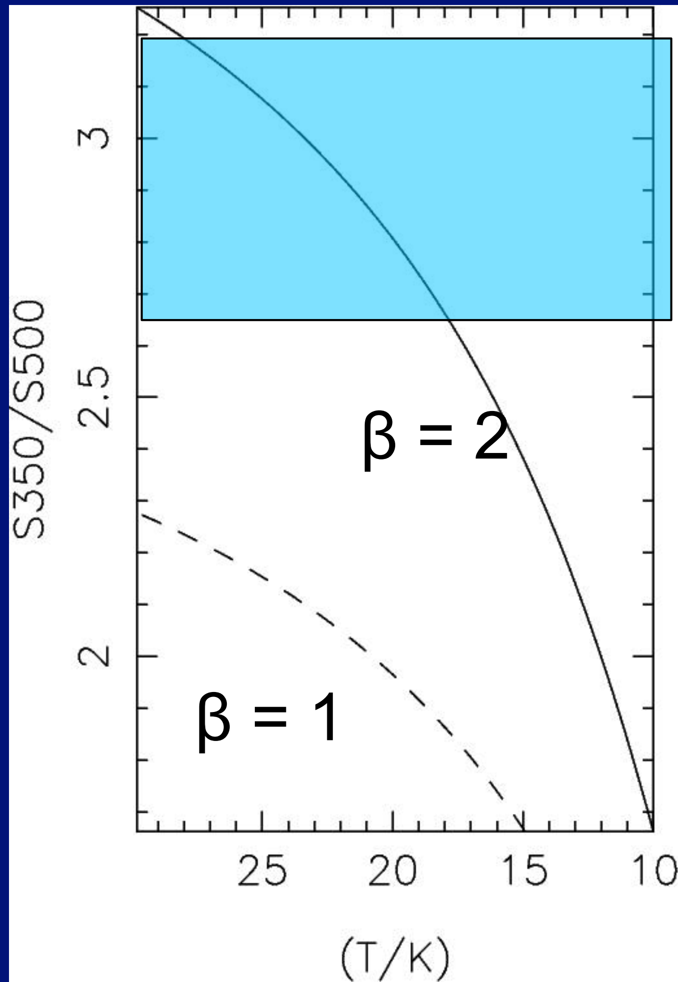
- 0.19 $m^2 kg^{-1}$ (theoretical models – Draine and Li)
- 0.35$m^2 kg^{-1}$ (COBE observations of high-latitude galactic dust with the assumption of a standard galactic dust-to-gas ratio – Boulanger et al. 1996)
- 0.41 $m^2 kg^{-1}$ (extrapolation from the 850-μm estimate from using β=2 – James et al. 2002)

# Are we missing cold dust?

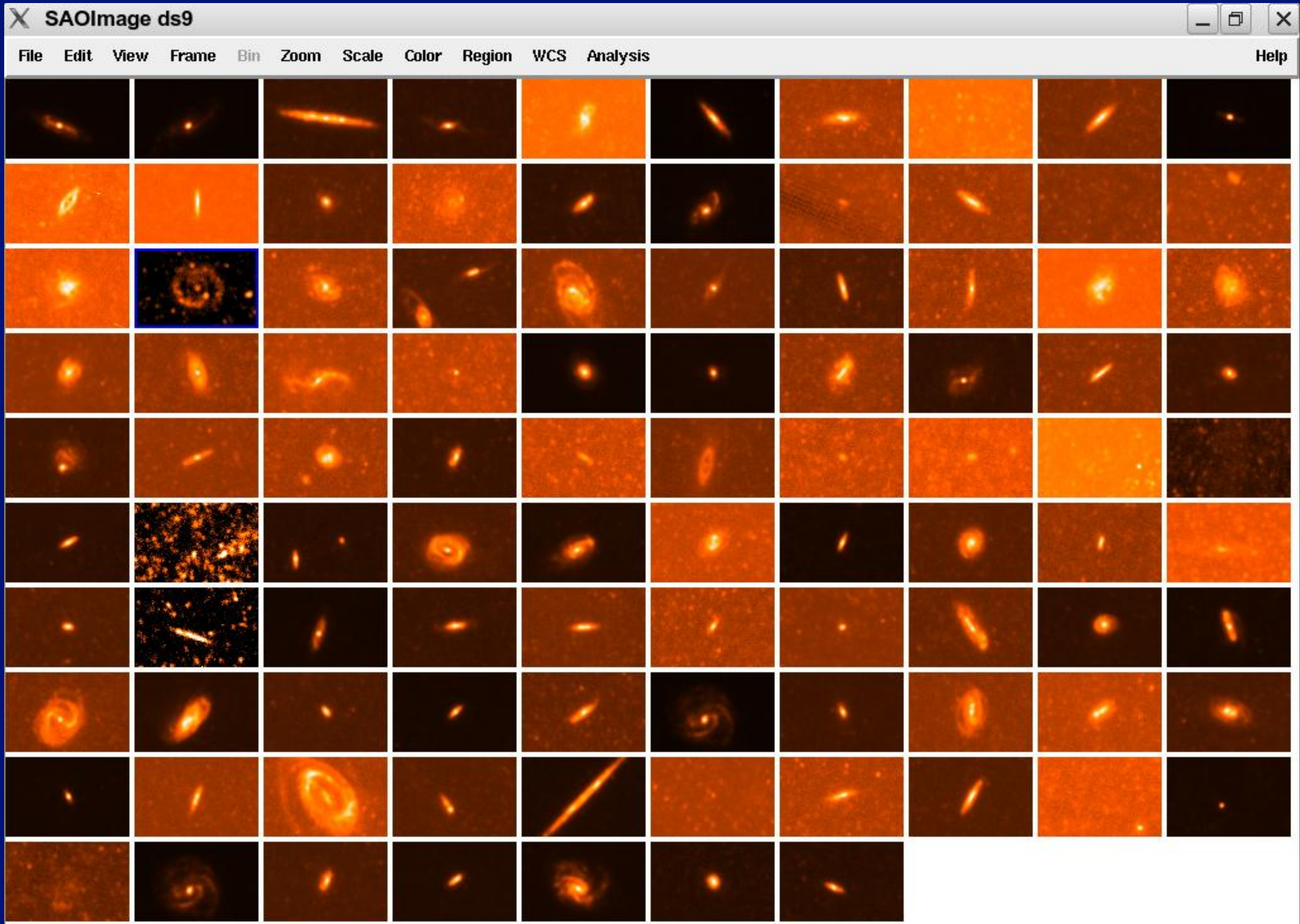
- If the dust in these galaxies was at 10 K rather than 20 K, our estimate of the mass-opacity coefficient would be similar to previous estimates
- The ratios of 350/500 μm flux density suggest this isn't so.




Radial profiles of the 350/500 μm flux ratio for M99 and M100 from Pohlen et al. 2010



# After SDP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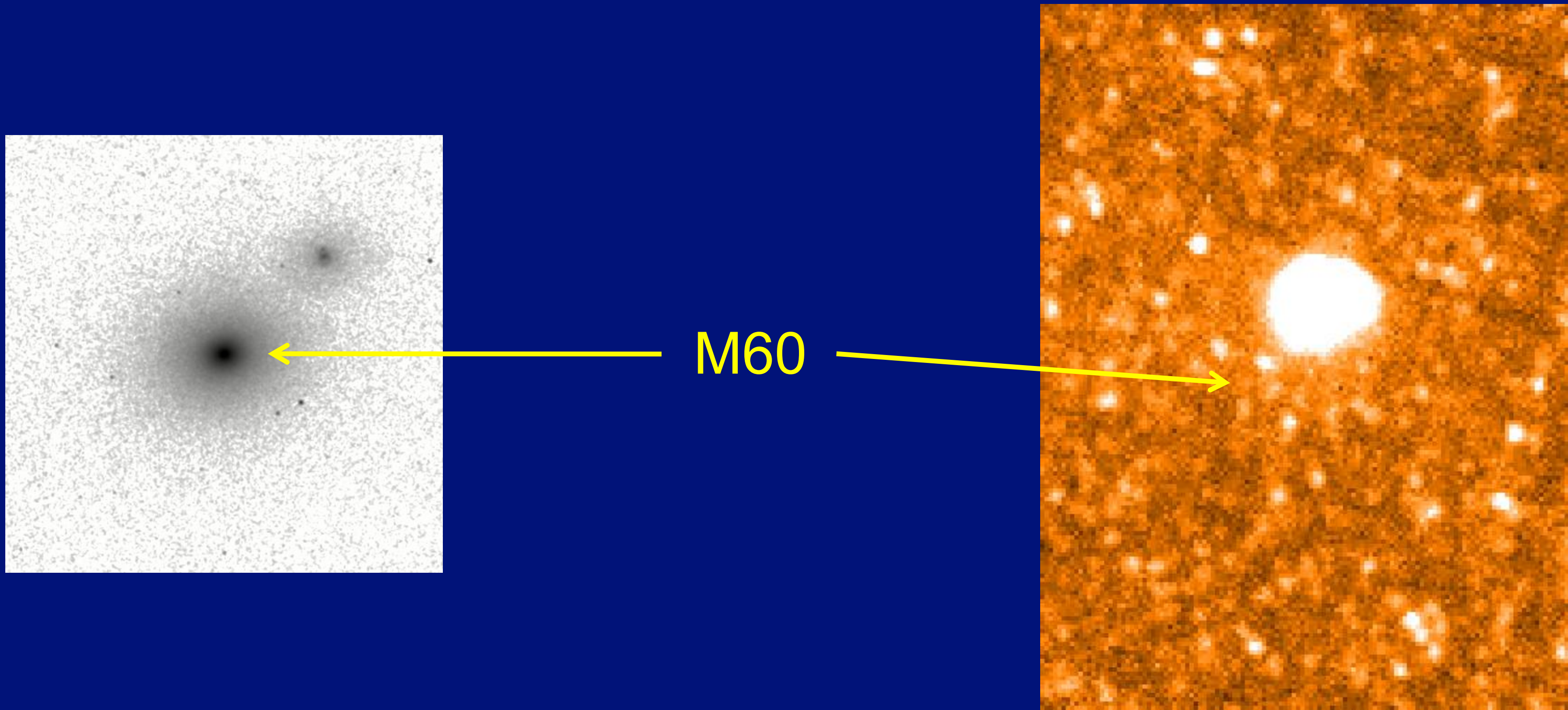
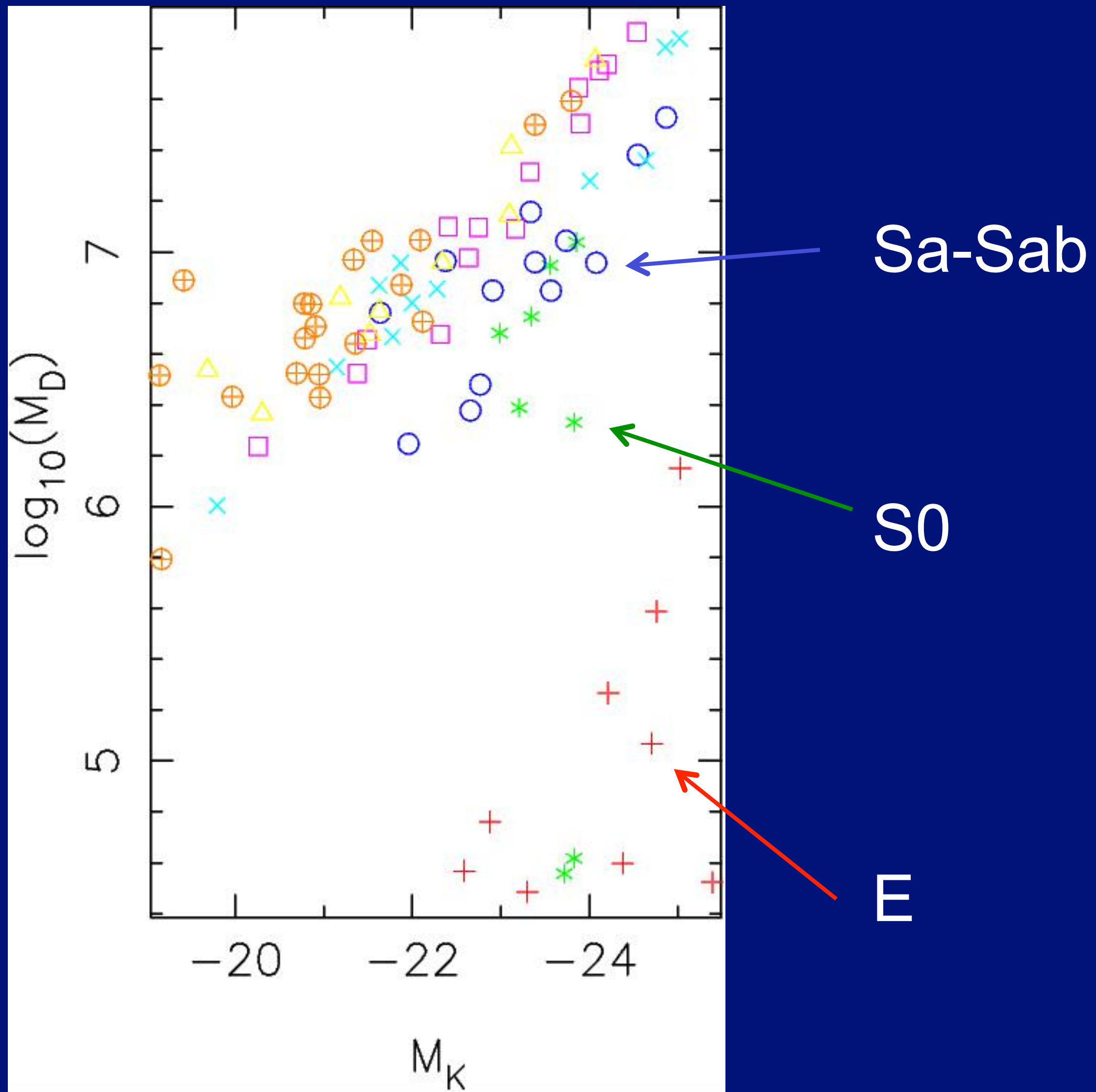
# Some galaxies really don’t have much dust




**See poster by Haley Gomez on the elliptical M86**

# A crude investigation of the dependence of dust mass on morphology

- Dust masses estimated from 250-μm flux densities and the assumption that T=20 K
- K-band absolute magnitude is roughly proportional to stellar mass



# Conclusions

- Using the dust emission is a promising method for estimating the mass of the interstellar medium in high-redshift galaxies but much work needs to be done in calibrating this method
- The Herschel Reference Survey will be important for understanding the relationship between the stars and the ISM in galaxies and as a zero-redshift benchmark for the deep Herschel surveys