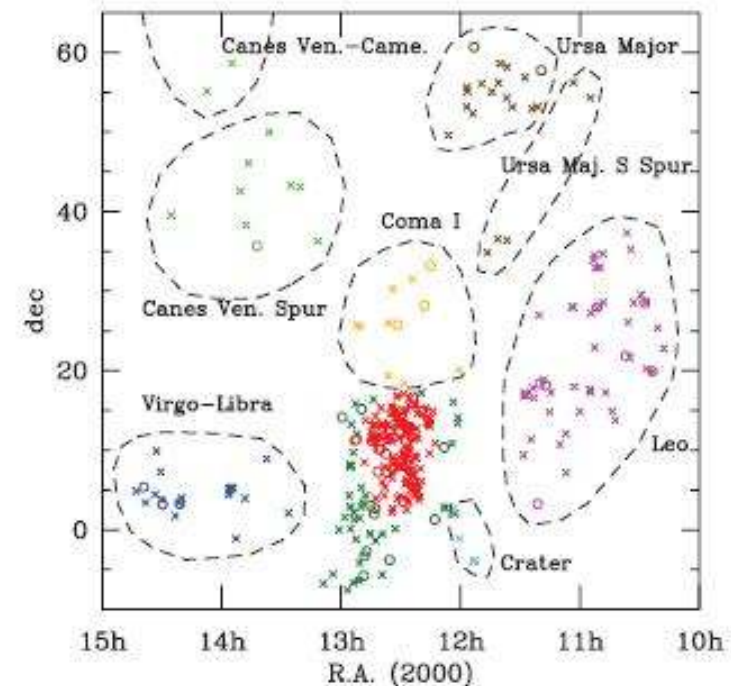


THE HERSCHEL REFERENCE SURVEY

S. Eales and SPIRE GT SAG – 2 (Auld, Baas, Barlow, Bendo, Bock, Boselli, Bradford, Buat, Castro-Rodriguez, Chaniel, 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
- $b > 55^\circ$, $A_B < 0.2$
- $K < 8.7$ 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



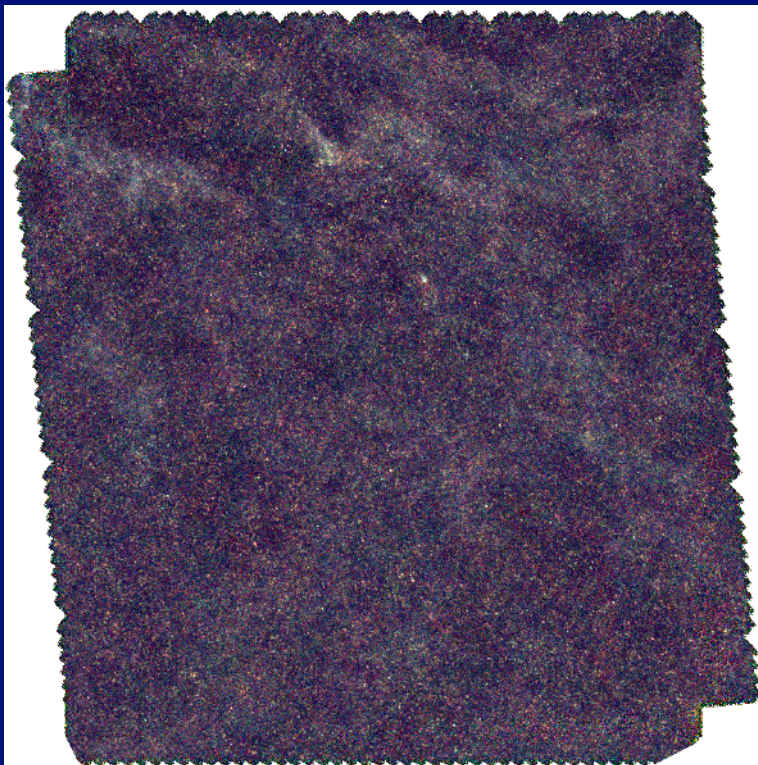
Science Demonstration

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

Measuring the Gas Reservoir with Dust Emission

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

Mass-opacity coefficient

metallicity

James et al. 2002,
MN 335, 753

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

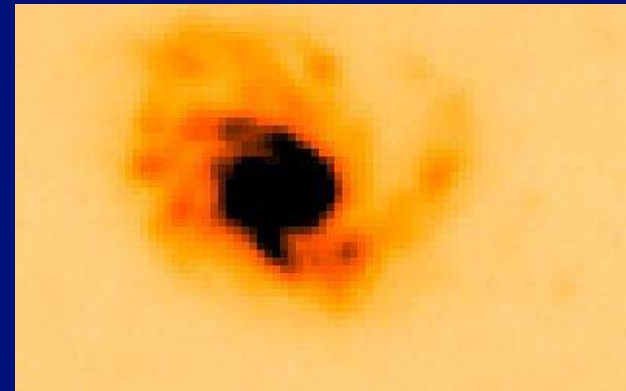
Fraction of metals in
dust (from
measurements of
depletion in local
ISM) = 0.46

M99 and M100

Two big spiral galaxies in the Virgo Cluster



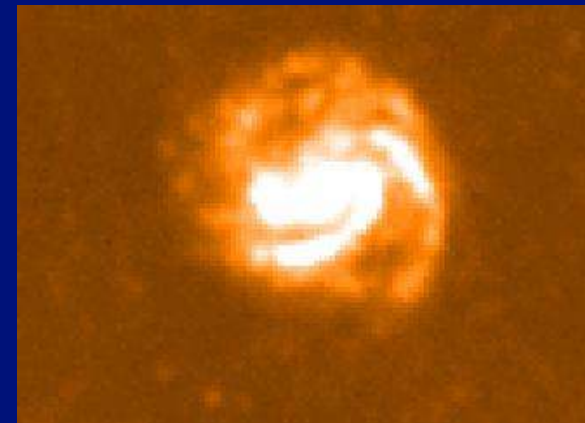
M99



SPIRE at 250 microns



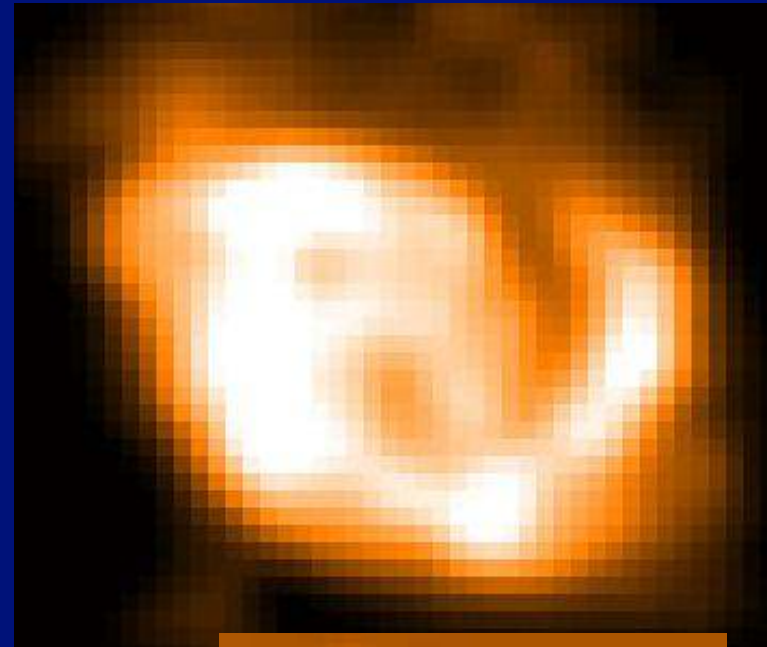
M100



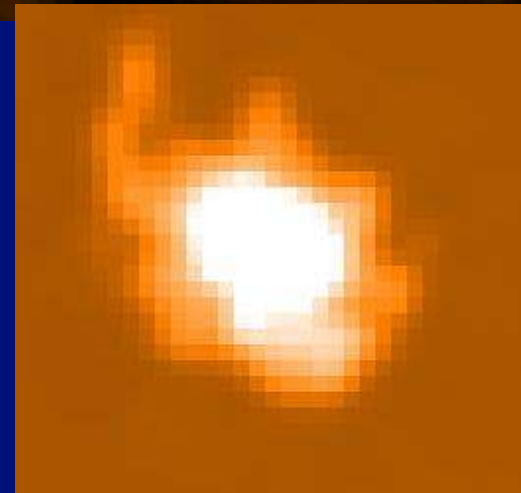
Method 1

HI

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



CO

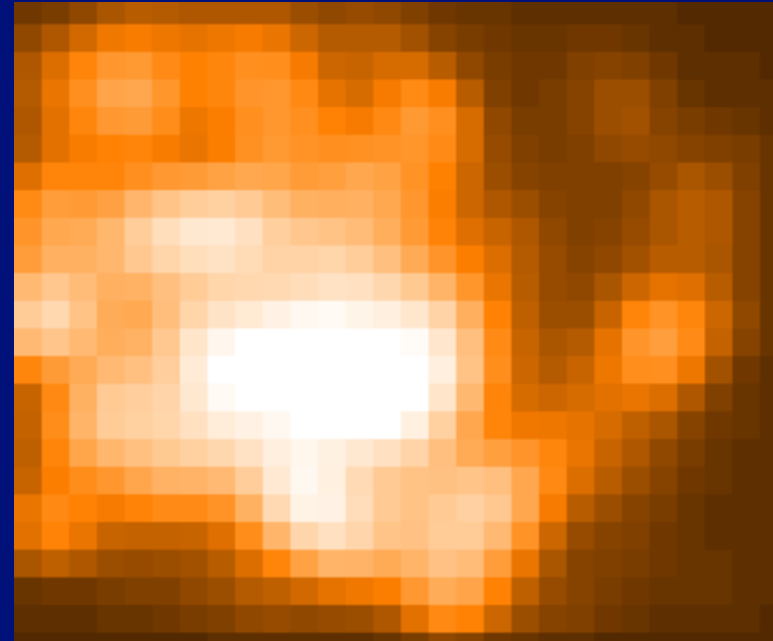


Method 2

- *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. = $(850/350)^2 \times 0.07 \text{ m}^2 \text{ kg}^{-1}$*
- * See poster by Matthew Smith on estimating the distribution of the dust temperature in HRS and HeVICS galaxies.

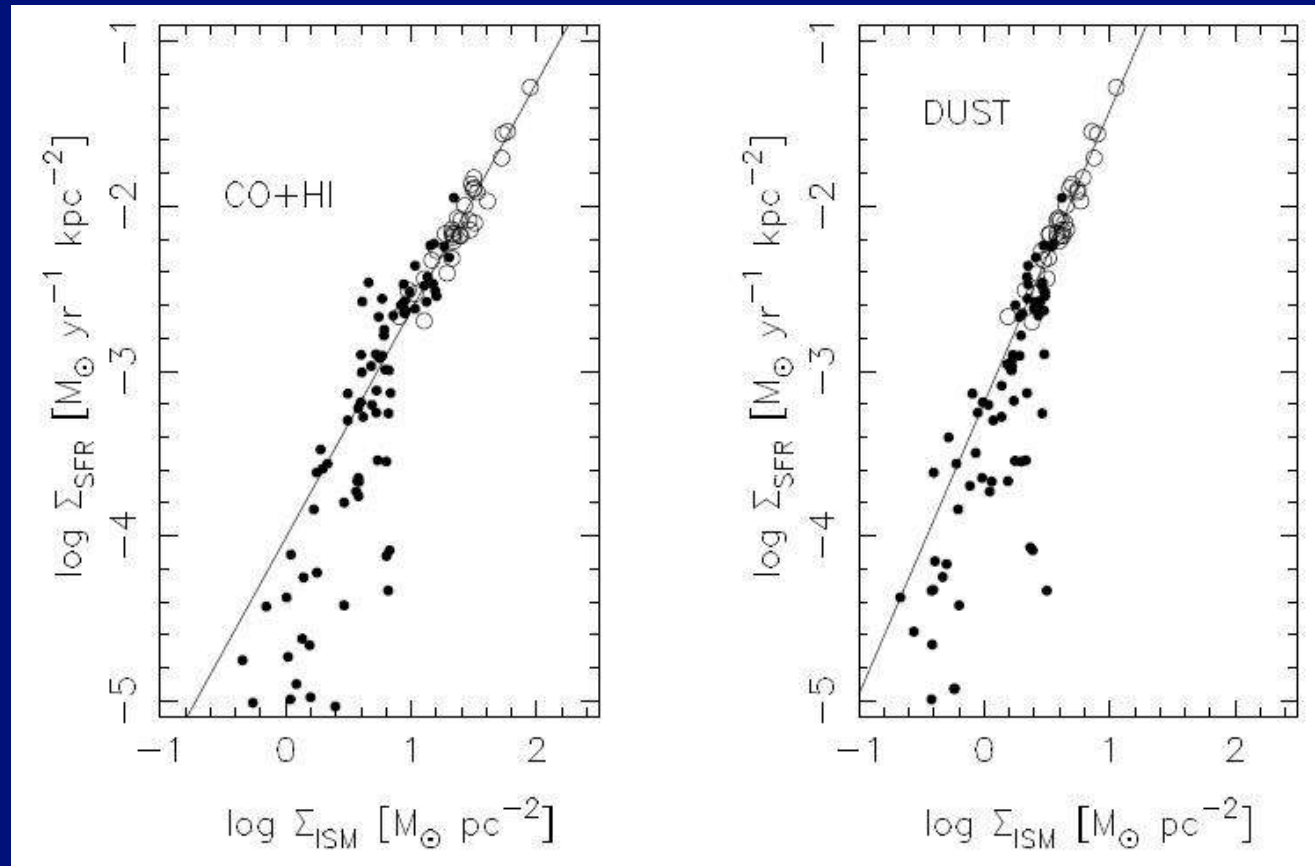
Comparison of the Methods

- 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- μ m and H α images (Wilson et al. 2009)

M100

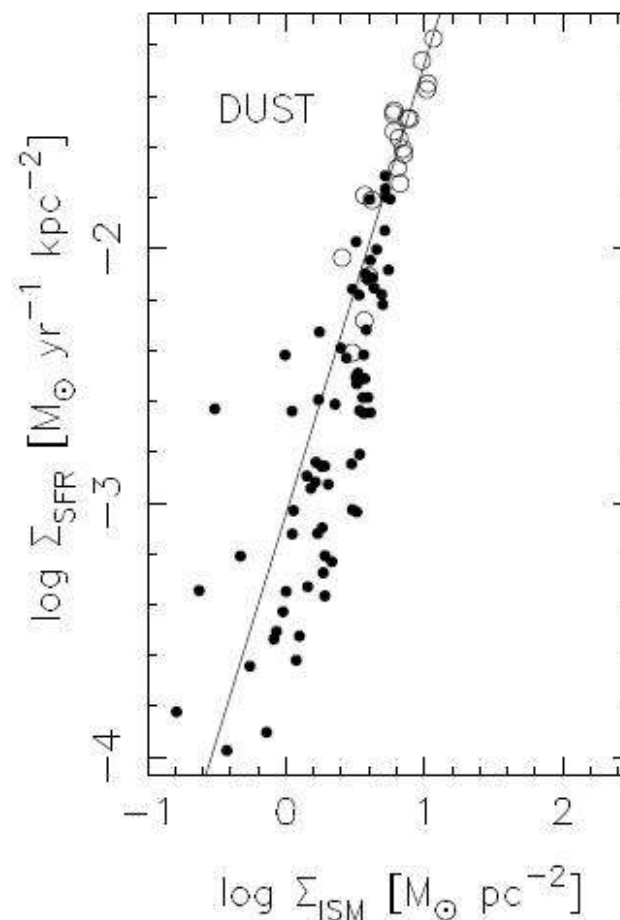
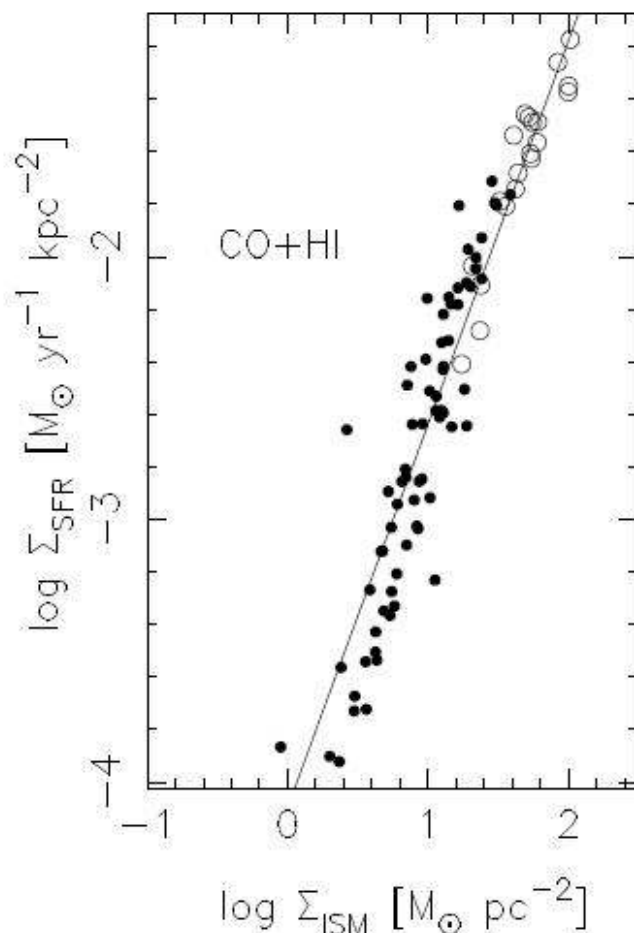


$$\text{Log}_{10}(\Sigma_{\text{SFR}}) = N \log_{10}(\Sigma_{\text{ISM}}) + c$$

$$\text{CO/HI: } N=1.38 \pm 0.08 \quad x_{\text{res}} = 0.070 \quad y_{\text{res}} = 0.096$$

$$\text{Dust: } N=1.77 \pm 0.10 \quad x_{\text{res}} = 0.050 \quad y_{\text{res}} = 0.088$$

M99



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

$$\text{CO/HI: } N=1.46 \pm 0.13 \quad x_{\text{res}} = 0.077 \quad y_{\text{res}} = 0.111$$

$$\text{Dust: } N=1.77 \pm 0.22 \quad x_{\text{res}} = 0.086 \quad y_{\text{res}} = 0.152$$

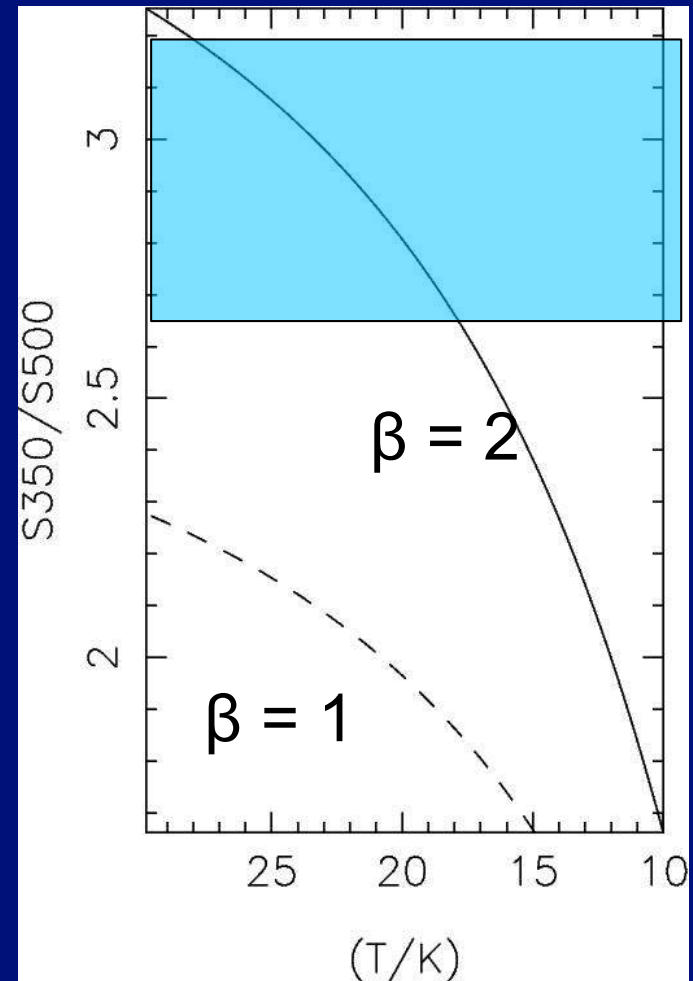
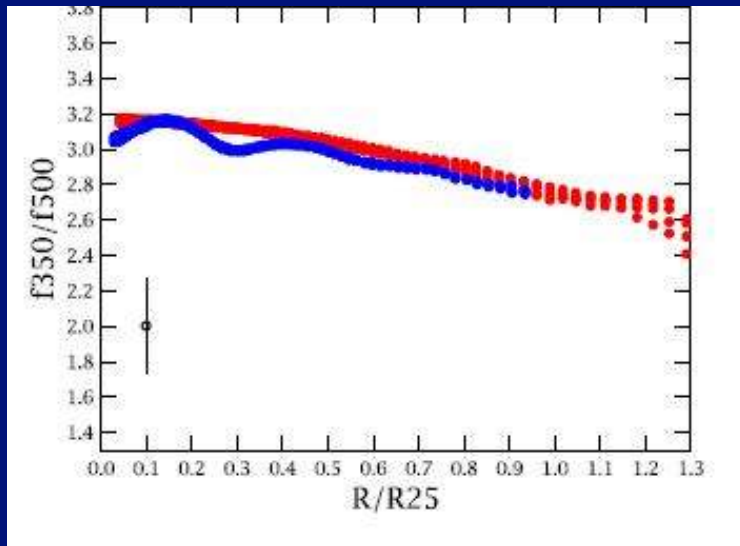
Estimates of the Mass-Opacity Coefficient

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

- M99 – $0.056 \text{ m}^2 \text{ kg}^{-1}$
- M100 – $0.063 \text{ m}^2 \text{ kg}^{-1}$
- $0.19 \text{ m}^2 \text{ kg}^{-1}$ (theoretical models – Draine and Li)
- $0.35 \text{ m}^2 \text{ kg}^{-1}$ (COBE observations of high-latitude galactic dust with the assumption of a standard galactic dust-to-gas ratio – Boulanger et al. 1996)
- $0.41 \text{ m}^2 \text{ kg}^{-1}$ (extrapolation from the 850- μm estimate from using $\beta=2$ – James et al. 2002)

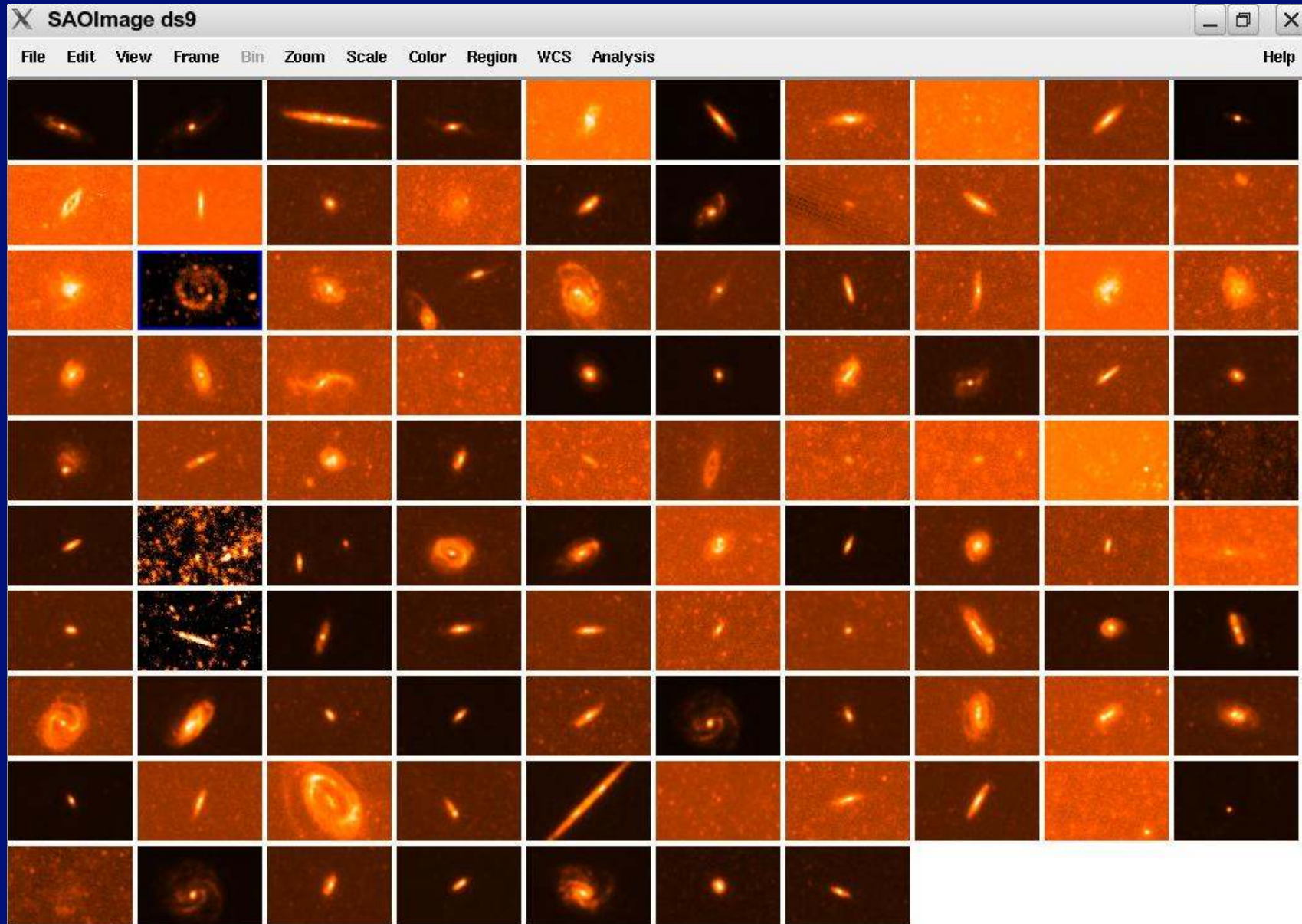
Are we missing cold dust?

- 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.

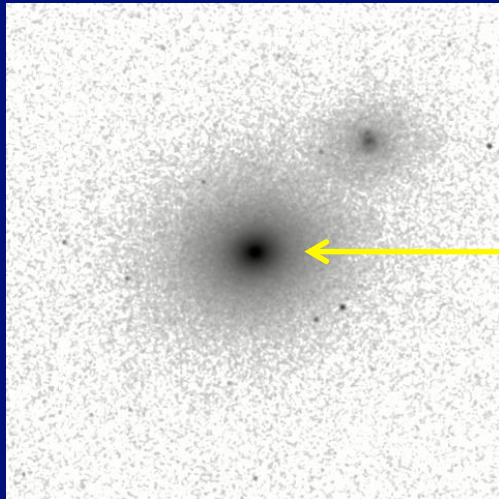


Radial profiles of the 350/500 μm flux ratio for M99 and M100 from Pohlen et al. 2010

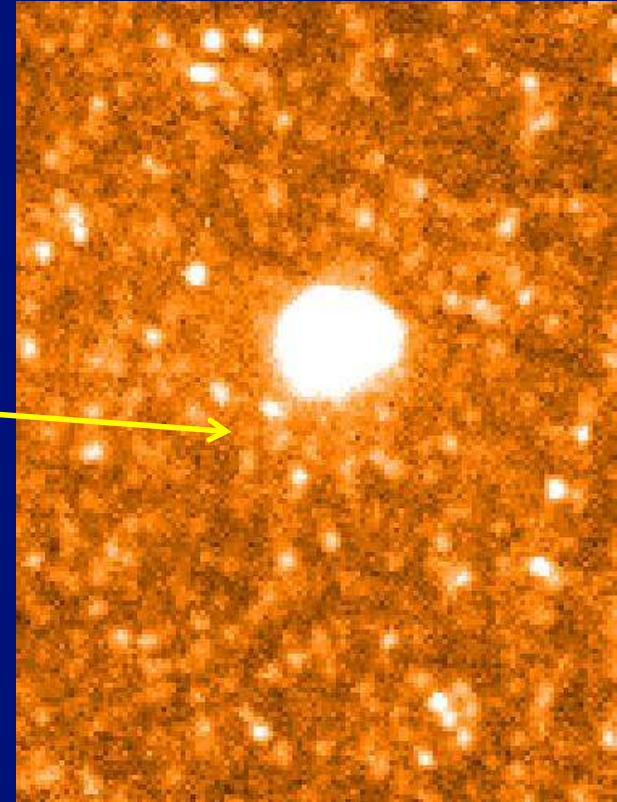
After SDP



Some galaxies really don't have much dust



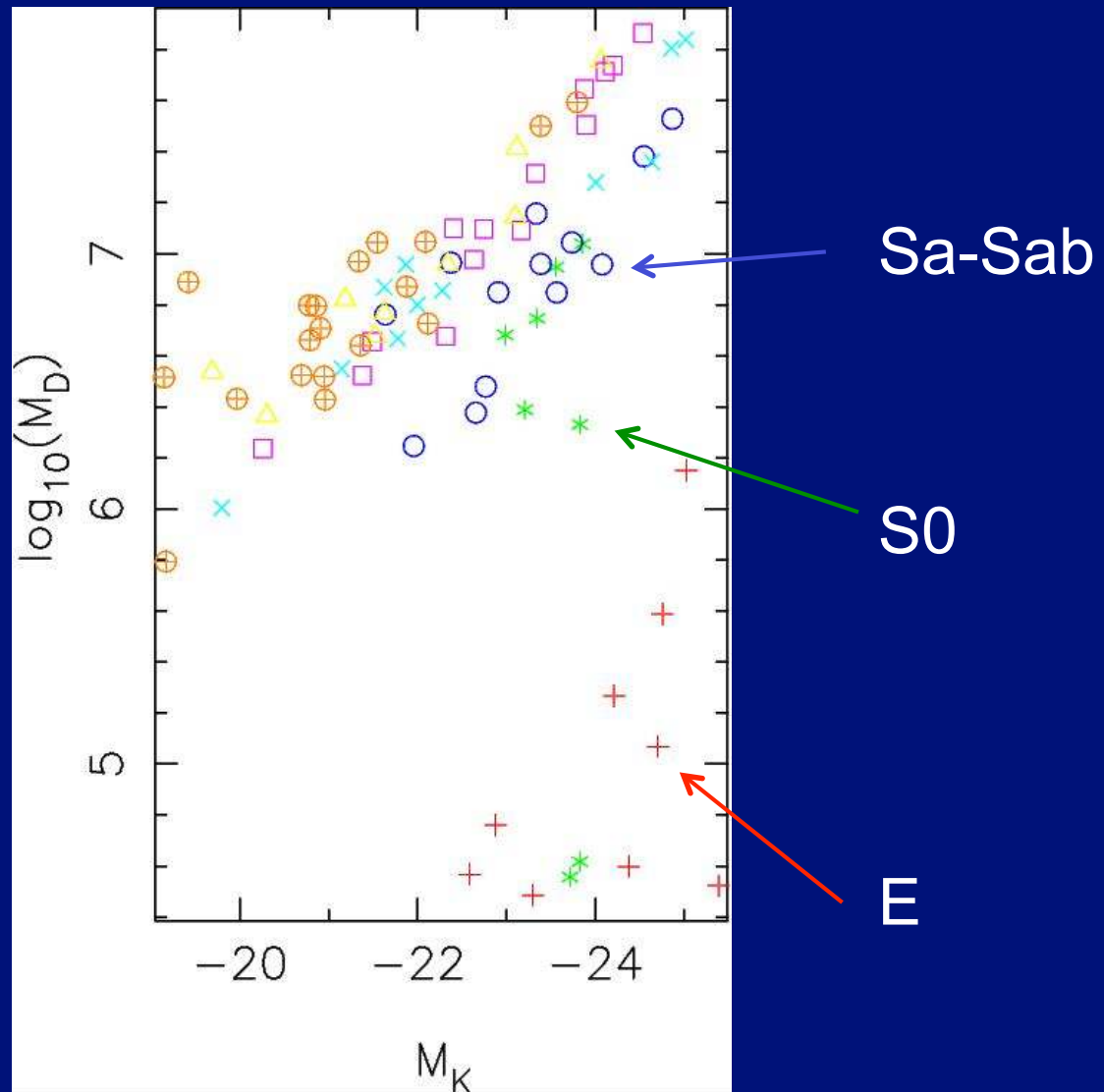
M60



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 $T=20\text{ K}$
- 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