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Radio to infrared spectra of late-type galaxies with Planck and WMAP data

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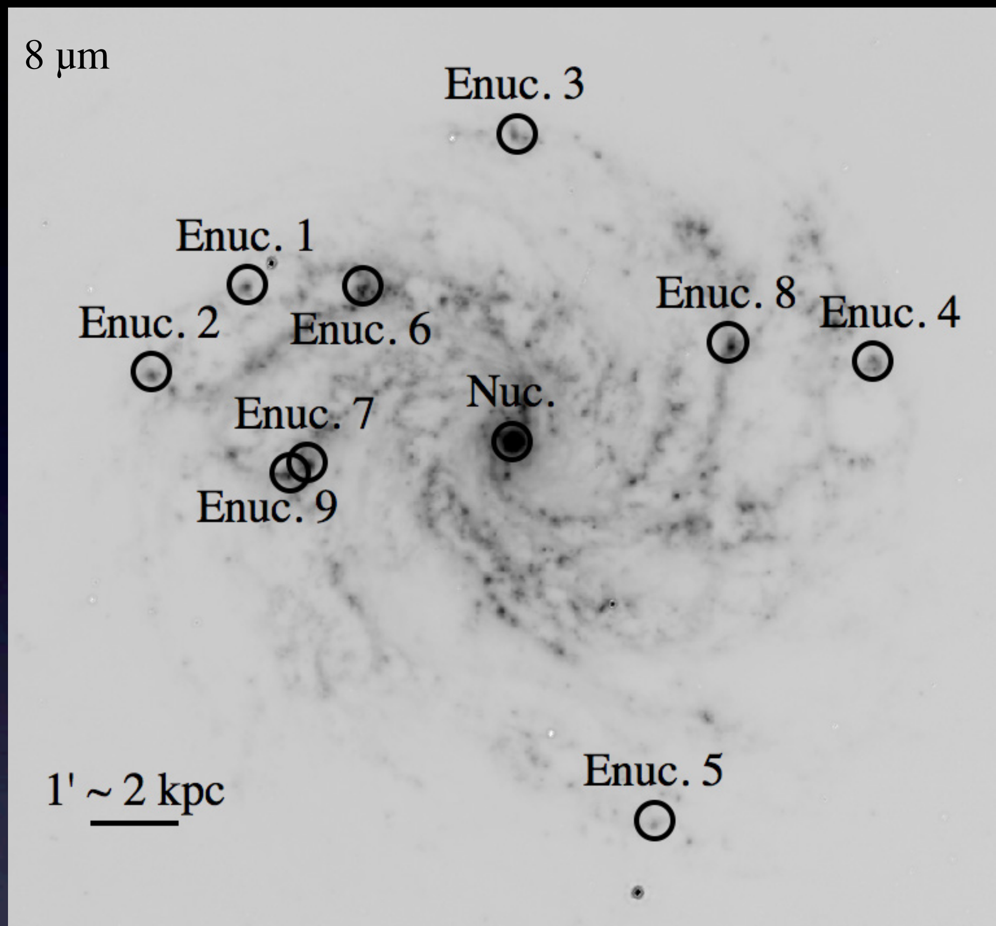
Overview

- Motivation
- Emission components and data
- Individual galaxies
  - M82
  - NGC253
  - NGC4945
- Conclusion

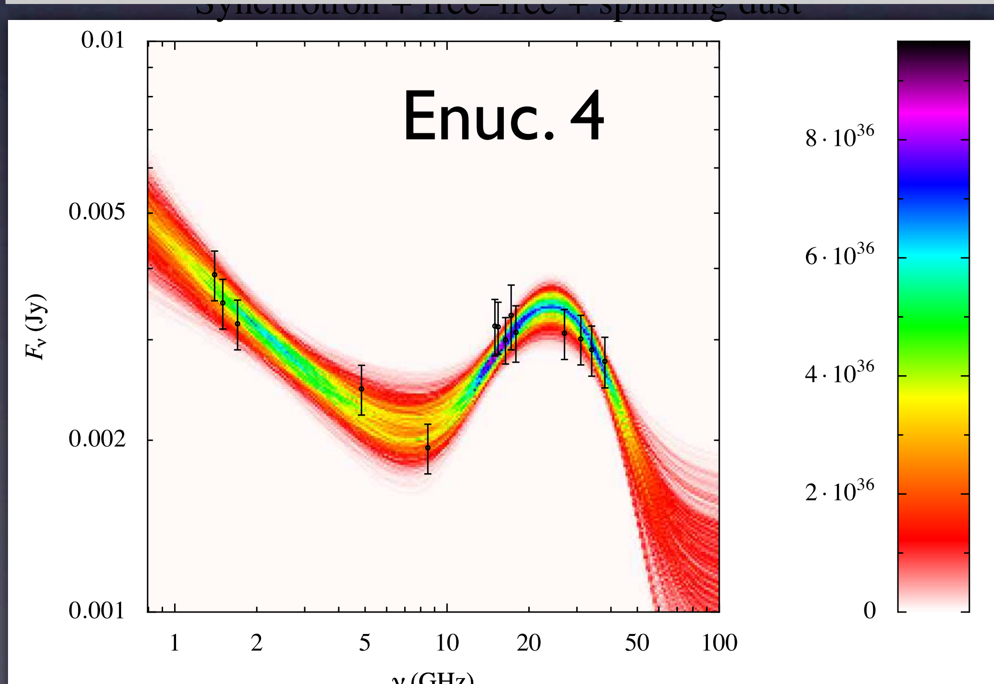
Motivation

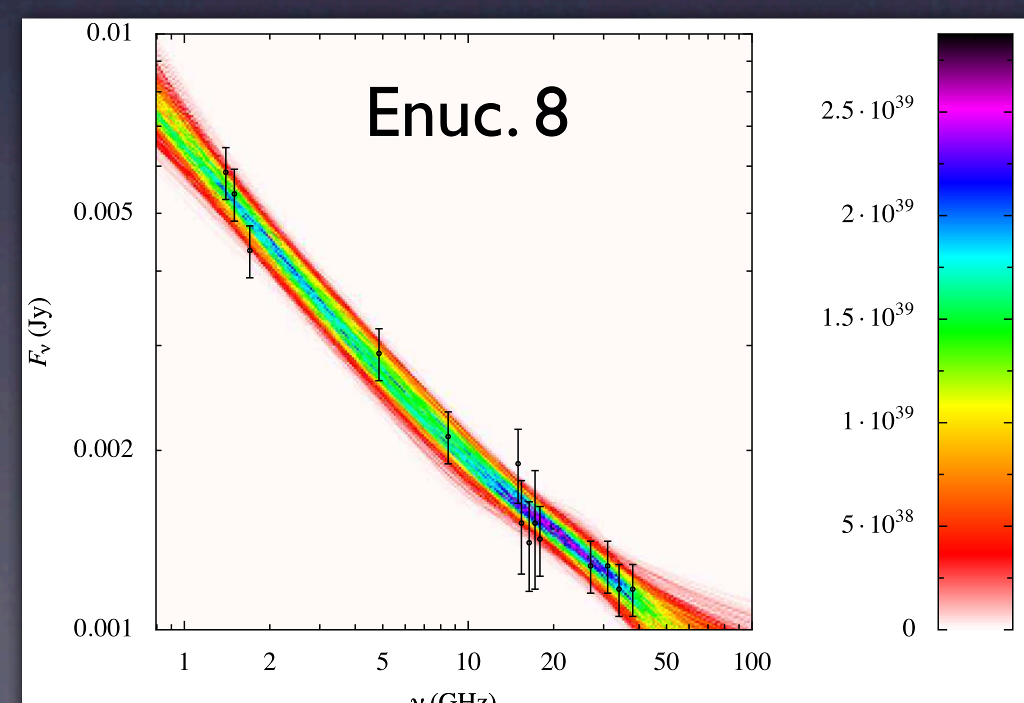
- Measure total emission of late type galaxies to compare with the Milky Way
- First time we can accurately measure the complete spectra from radio to infrared
- Quantify free-free emission, match with star formation rate
- Constrain AME on a global basis - is it everywhere, or patchy?

NGC6946

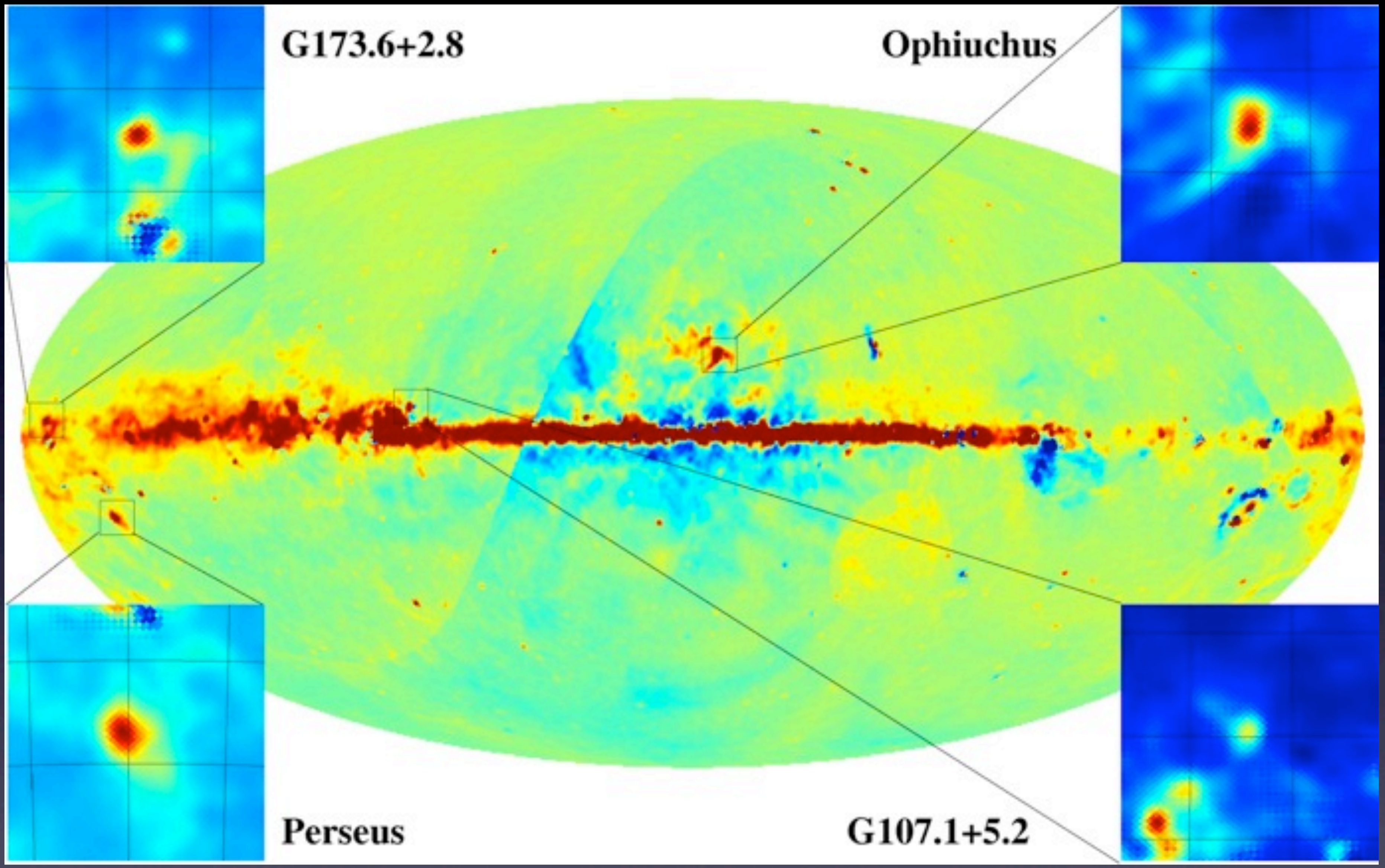


- GBT (Murphy et al. 2010)
- 10 star-forming regions - only 1 anomalous
- Confirmed by AMI (Scaife et al. 2010)





Our Galaxy



- Expect 30GHz AME emission to be around 1/3000th of the 100μm emission

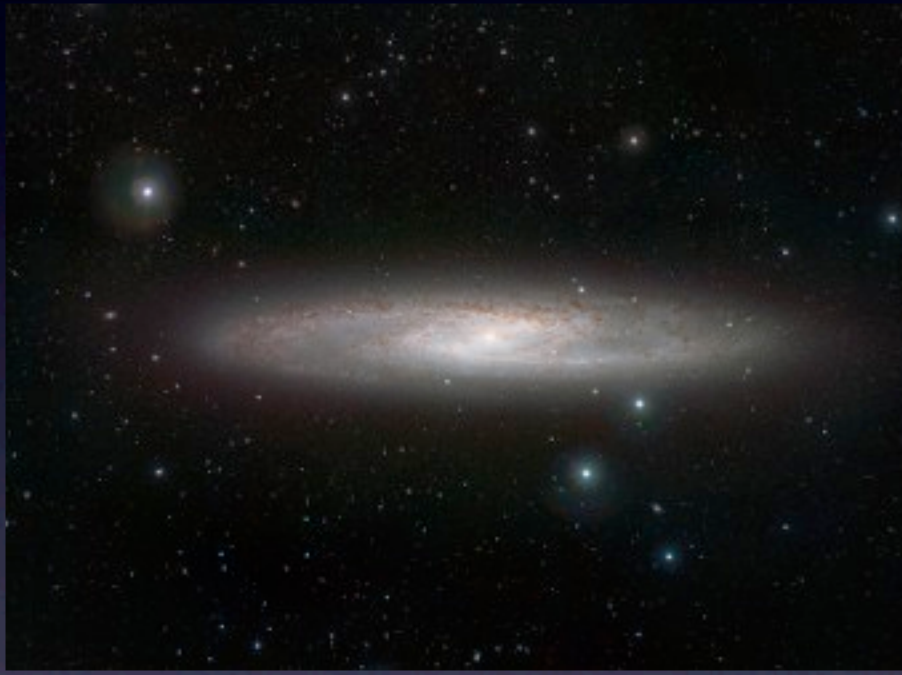
The sample

M82

HST optical (green)
Spitzer infrared (red)
Chandra X-ray (blue)
(Public Domain)

NGC4945

Optical, MPG/ESO 2.2m at La Silla
(CC-BY-3.0 ESO)



NGC253

Optical with VISTA
(CC-BY-3.0 ESO)

Emission components

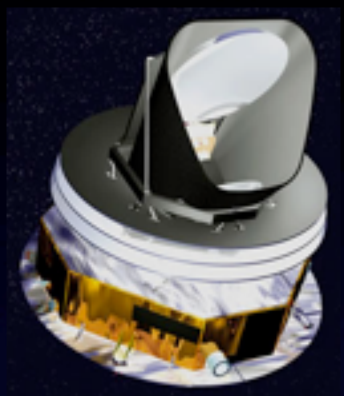
- Galactic emission between 1 and 1000 GHz is a mix of (steepening) synchrotron, free-free, anomalous dust and thermal dust

$$S(\nu) = A_{\rm sync}\nu^{\alpha} + S_{\rm ff} + \frac{A_{\rm dust}h}{k}\frac{\nu^{\beta+3}}{\exp(h\nu/kT_{\rm dust})-1}$$

$$S_{\rm ff} = 2\times10^{26}\,k\,T_{\rm e}(1-e^{-\tau_{\rm ff}})\,\Omega\,\nu^2c^{-2}$$

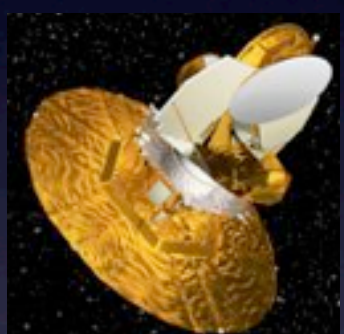
$$\tau_{\rm ff} = 3.014\times10^{-2}\,T_{\rm e}^{-1.5}\,\nu^{-2}\,{\rm EM}_{\rm ff}\,g_{\rm ff}$$

Data



Planck ERCSC at 28.5-857 GHz

Planck Collaboration (2011). 3-7% cal uncertainty; colour corrections applied. Exclude 100 and 217 GHz due to CO.



WMAP 7-yr catalogue at 22.3-93.5 GHz

Gold et al. (2011). 3% cal uncertainty, colour corrections applied (Jarosik et al. 2003).

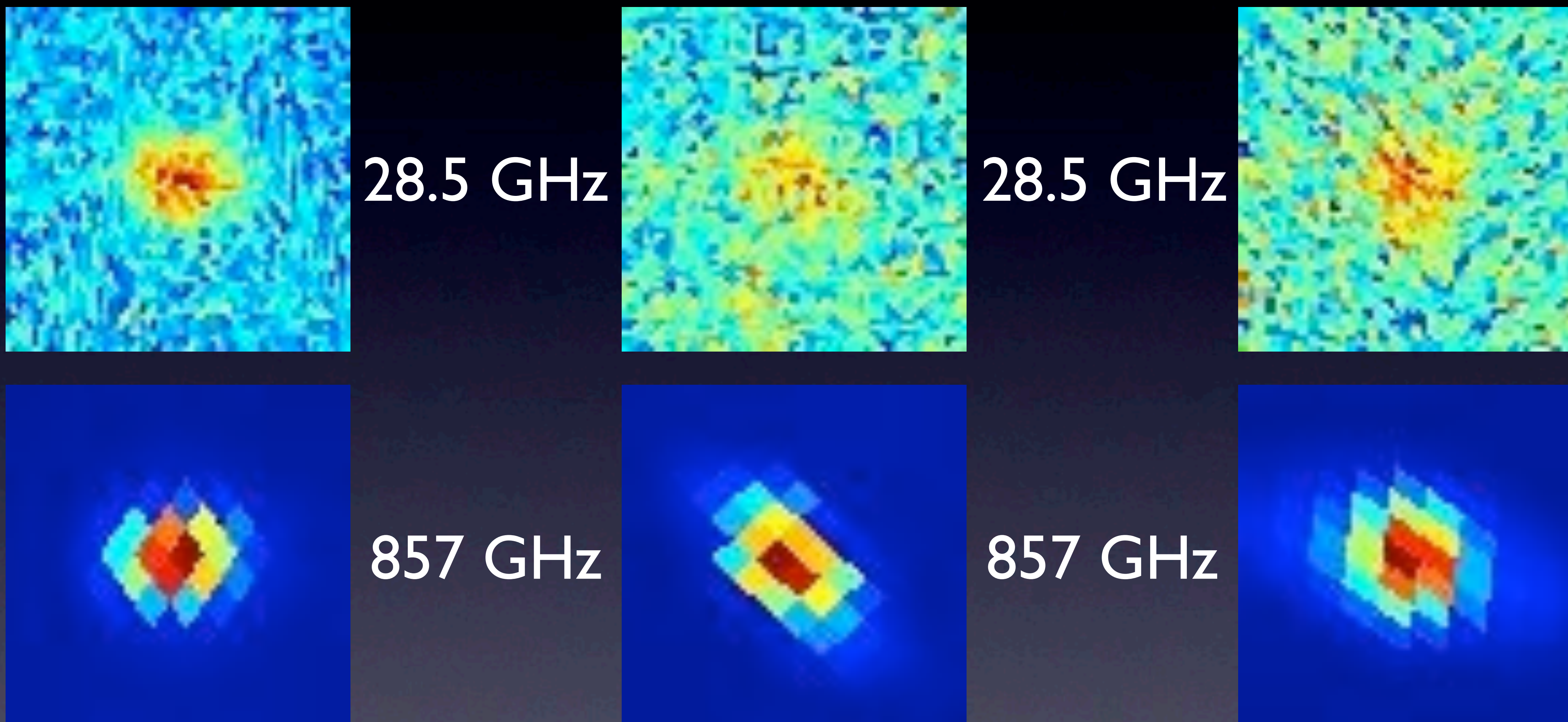
IRAS 100um

Wang & Rowan-Robinson (2009). 13% uncertainty. Don't use higher frequency data due to small dust grains.

Ancillary radio data

Many references; most found via NED. 5% uncertainty; only fit to data above 1.5GHz due to sync. ageing & free-free absorption.

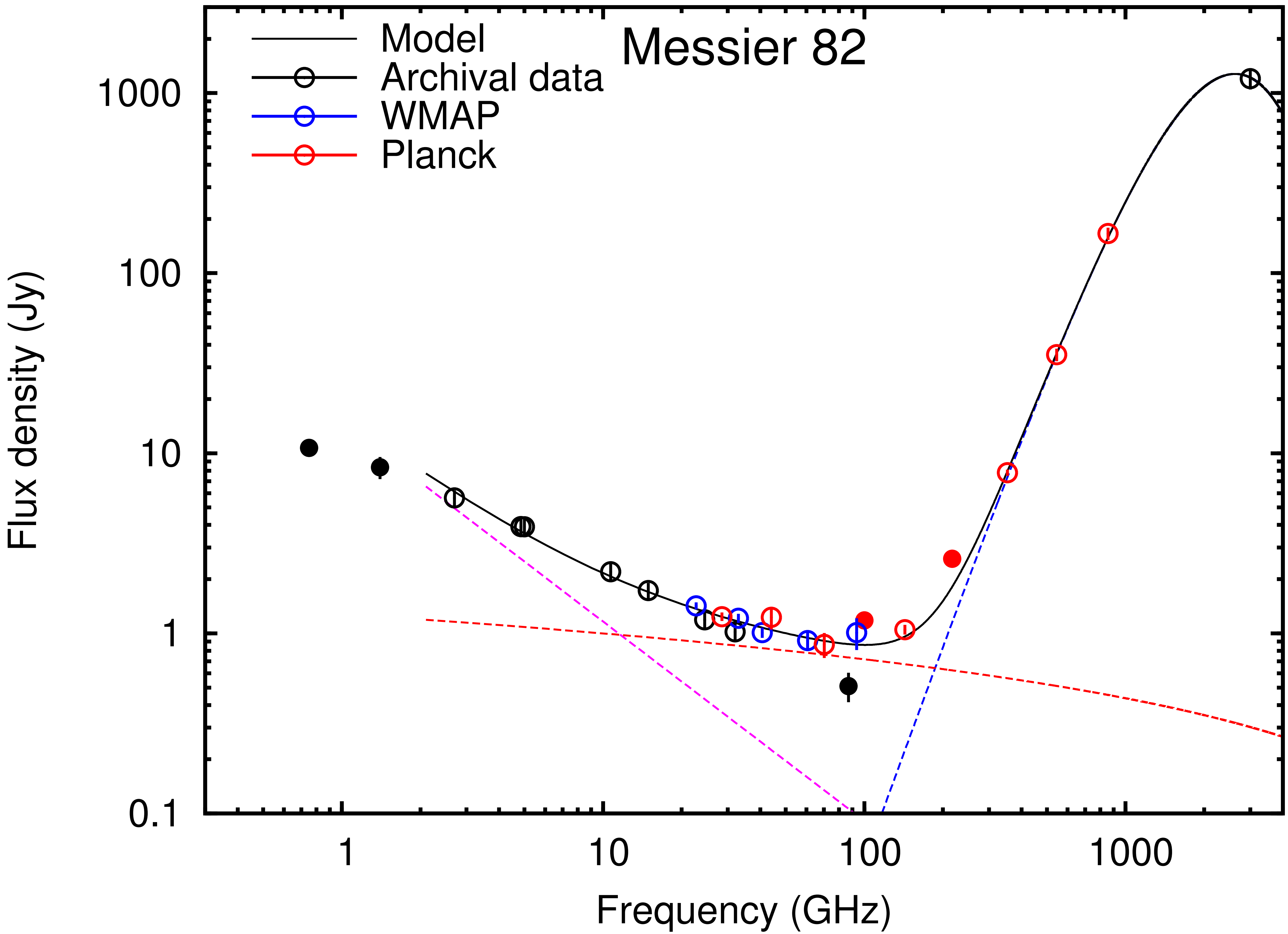
The sample



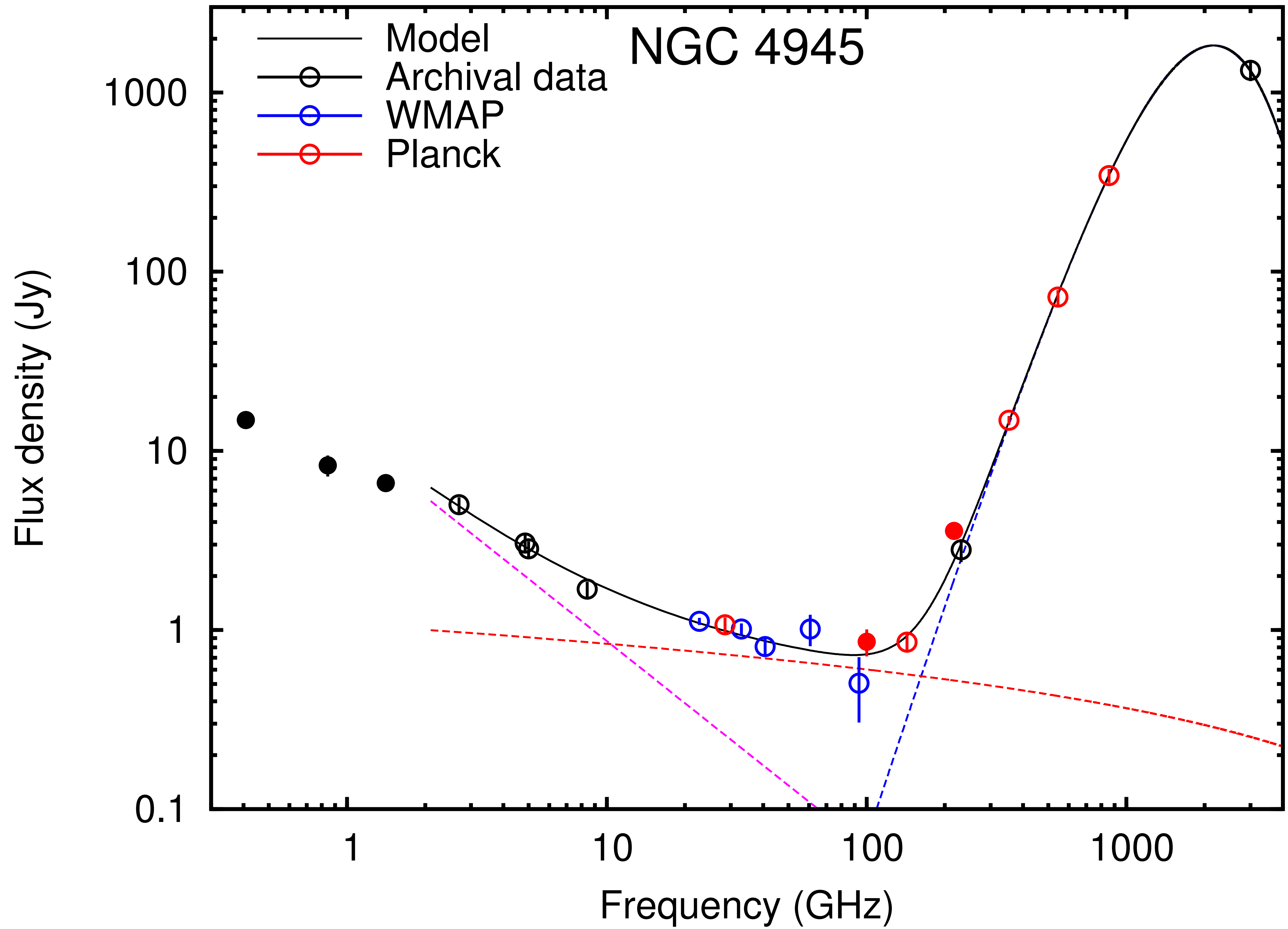
M82 | NGC4945 | NGC253

G141.40+40.56 | G305.27+13.34 | G097.18-87.96

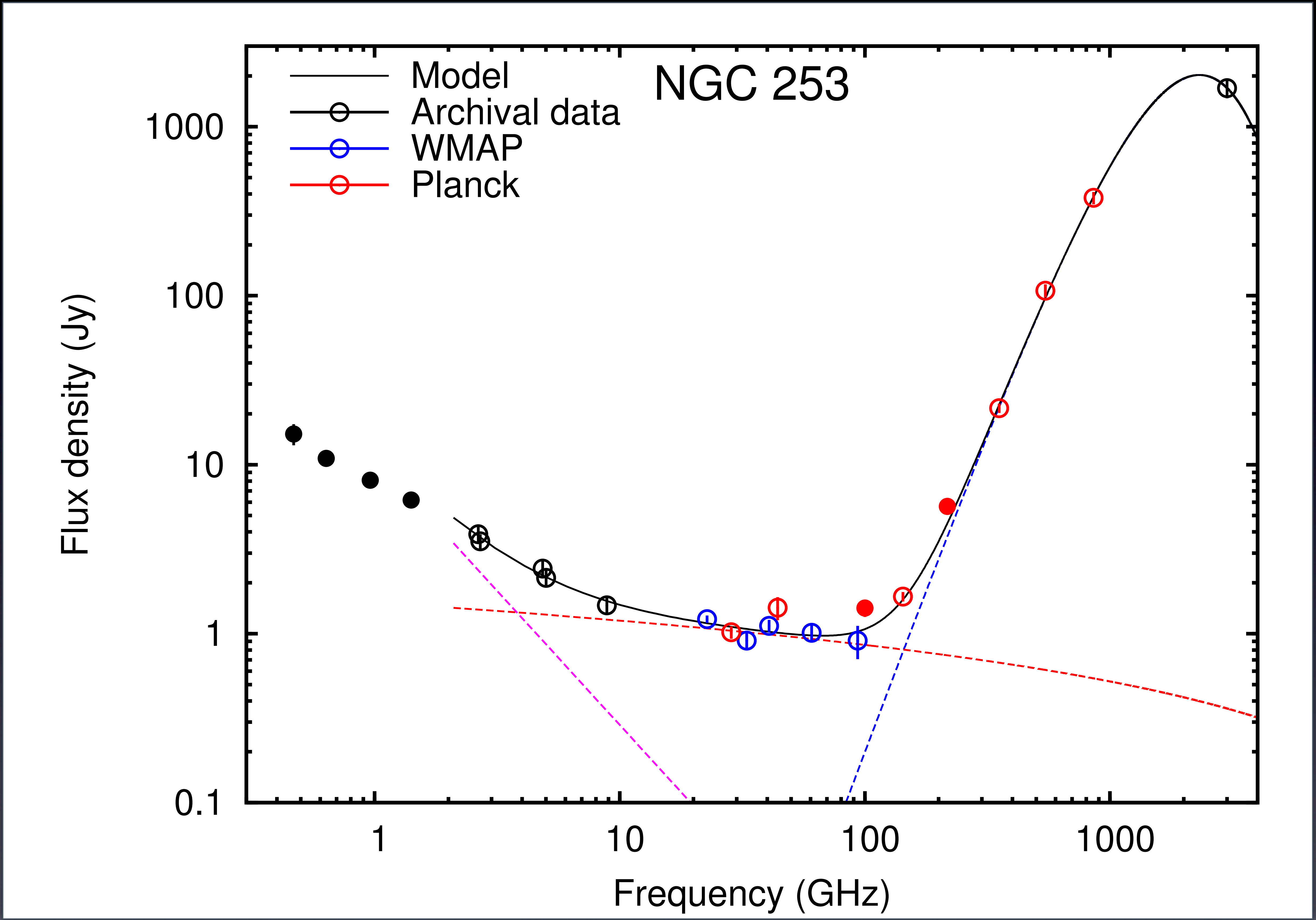
(Planck ERCSC postage stamps)



Messier 82
Model
Archival data
WMAP
Planck
Flux density (Jy)
0.1
1
10
100
1000
1
10
100
1000
Frequency (GHz)



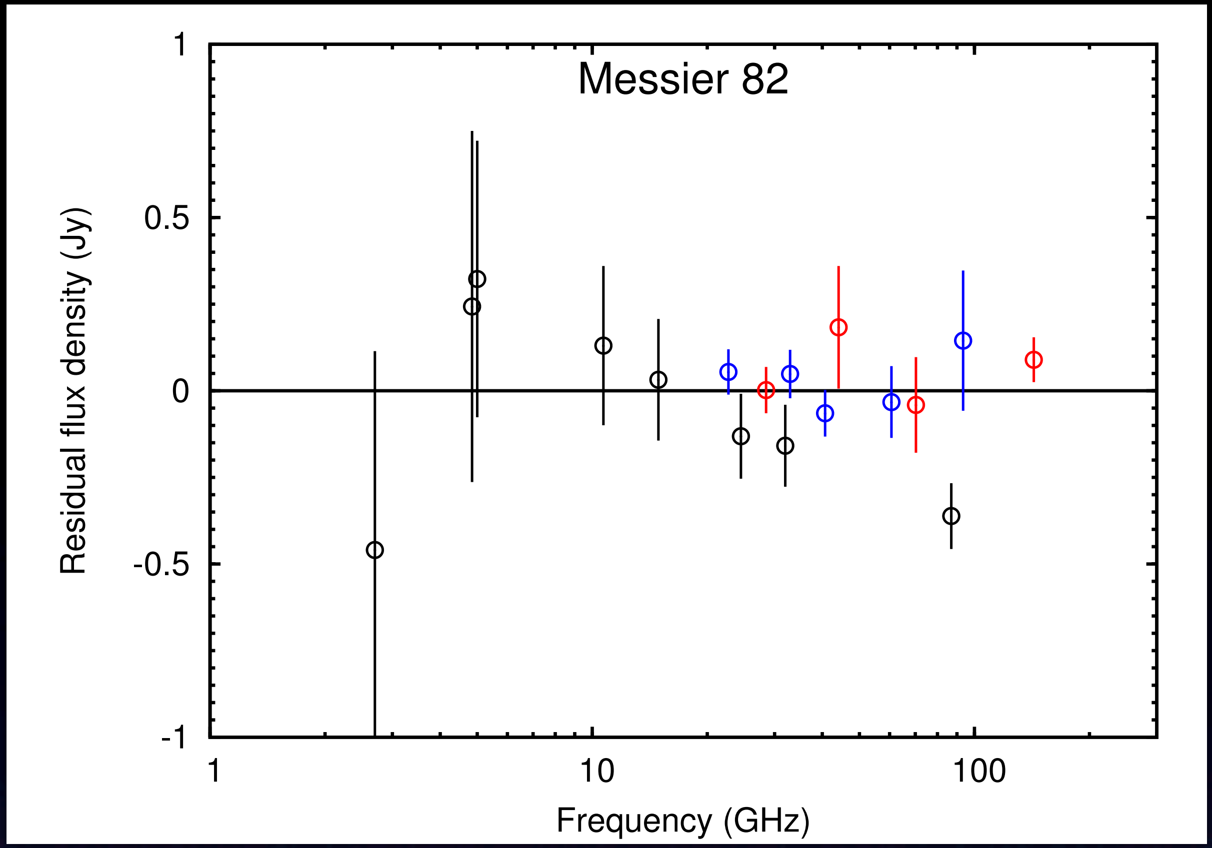
Model
Archival data
WMAP
Planck
NGC 4945
1000
100
10
1
0.1
Flux density (Jy)
1
10
100
1000
Frequency (GHz)

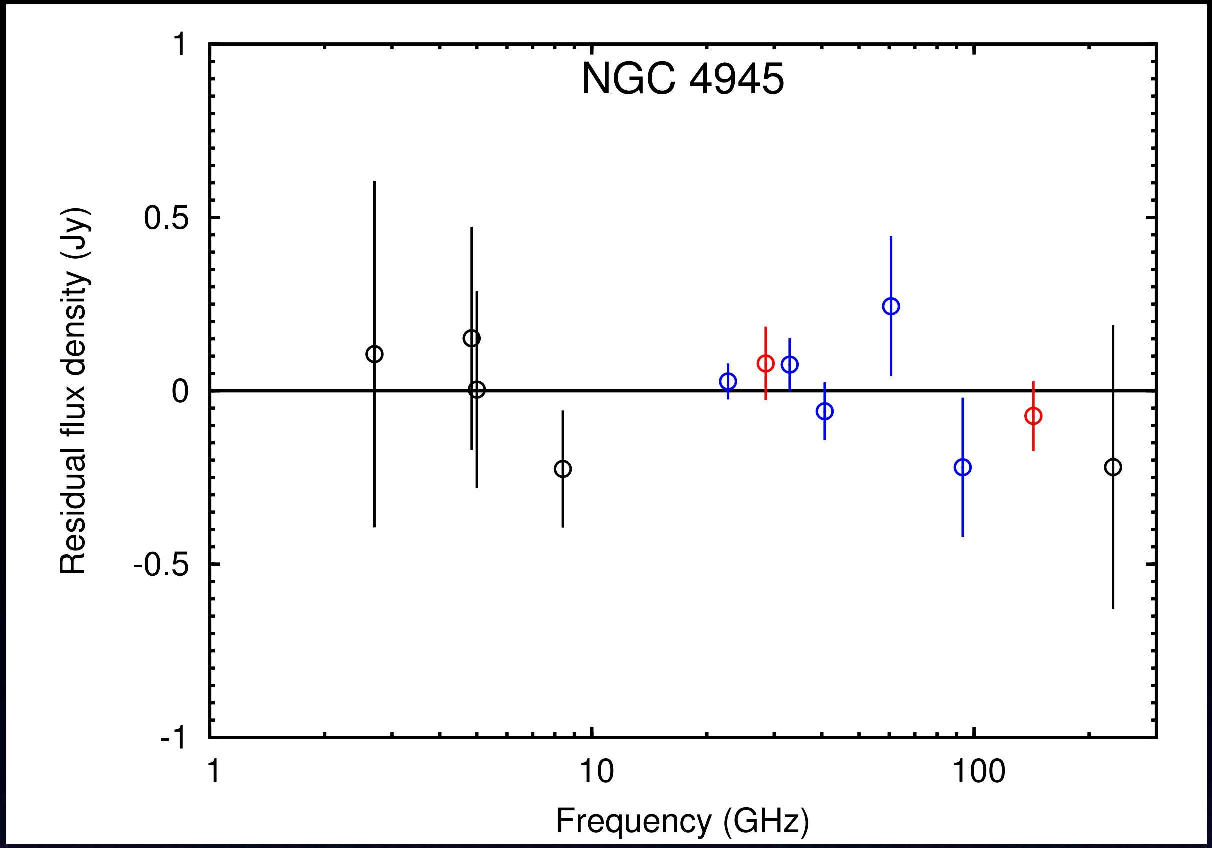

NGC 253
Model
Archival data
WMAP
Planck
1000
100
10
1
0.1
1
10
100
1000
Flux density (Jy)
Frequency (GHz)

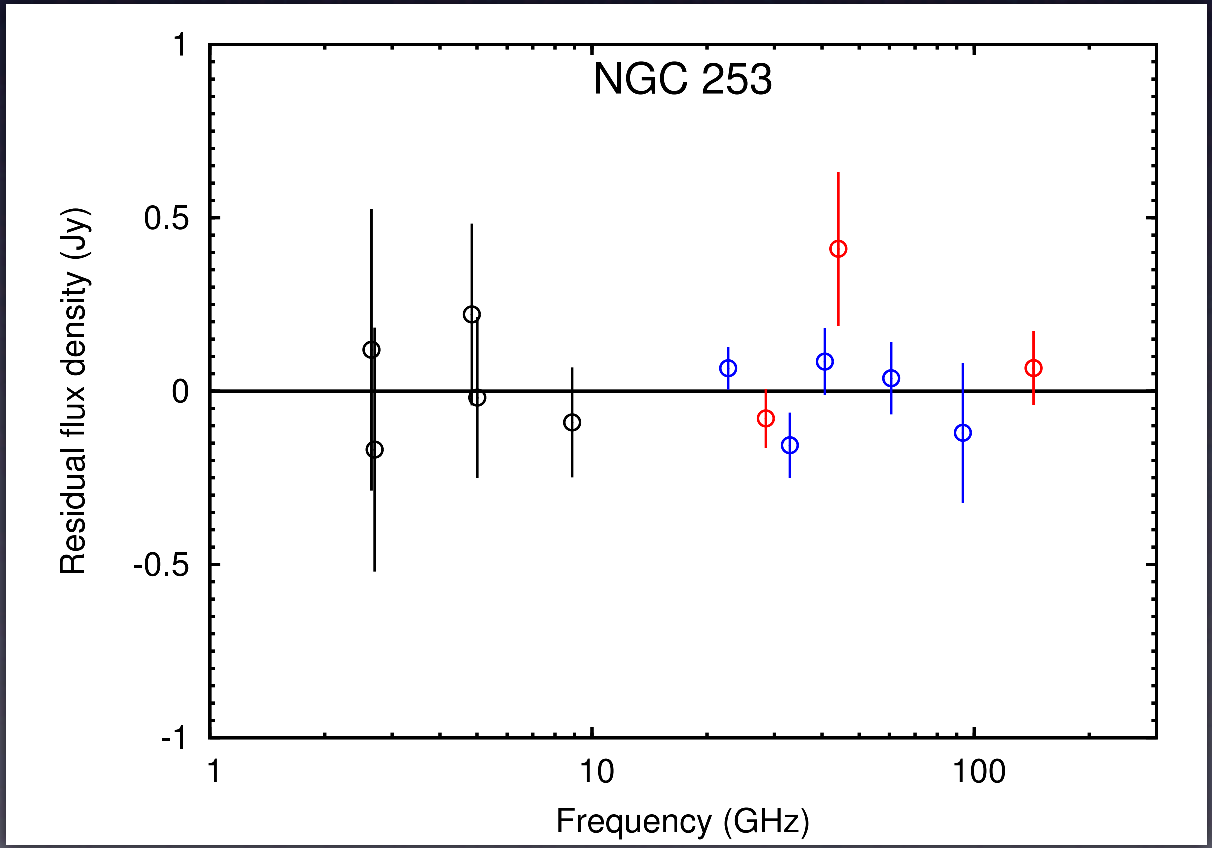
Fit values

Parameter	M82	NGC253	NGC4945
A_{sync} [Jy]	14.9±2.9	11.1±4.3	12.3±3.1
α_{sync}	-1.11±0.13	-1.59±0.35	-1.15±0.20
EM_{ff}	920±110	284±17	492±81
β_{dust}	2.10±0.13	1.96±0.11	2.5±0.2
T_{dust} (K)	24.8±1.9	22.6±1.3	18.9±1.1
Residual (3σ)	<0.15 Jy	<0.14 Jy	<0.13 Jy
100μm/3000	0.36 Jy	0.5 Jy	0.4 Jy

NB: high-frequency synchrotron index, hence steeper than low frequency end.







Residuals all consistent with zero.

Hint of AME in NGC 4945?

Star Formation Rates

SFR ($M_\odot$/yr)	M82	NGC253	NGC4945
Sync	2.6	1.3	2.7
Free-free	3.0	2.2	2.9
Radio SN	1.8-2.0	N/A	N/A
RRL	N/A	N/A	2-8
Niklas (1997)	<0.2	1.0	N/A

Using formulae from Condon (1992)

Conclusions

- Find substantially more free-free emission
- Higher FF brings SFR into better agreement
- AME constraints lower than expected c.f. our Galaxy - supports ‘patchy’ AME
- Cold dust with high β (but degeneracies)
- Need more sources - next Planck catalogue? Also more data from ground-based telescopes (RRLs particularly useful).

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Template fitting of WMAP 7-year data: anomalous dust or flattening synchrotron emission?

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1. Jodrell Bank Centre for Astrophysics, University of Manchester, 2. Université Paul Sabatier, Toulouse, CNRS, IRAP, 3. Rhodes University, Department of Physics and Electronics, * email: email@mikepeel.net

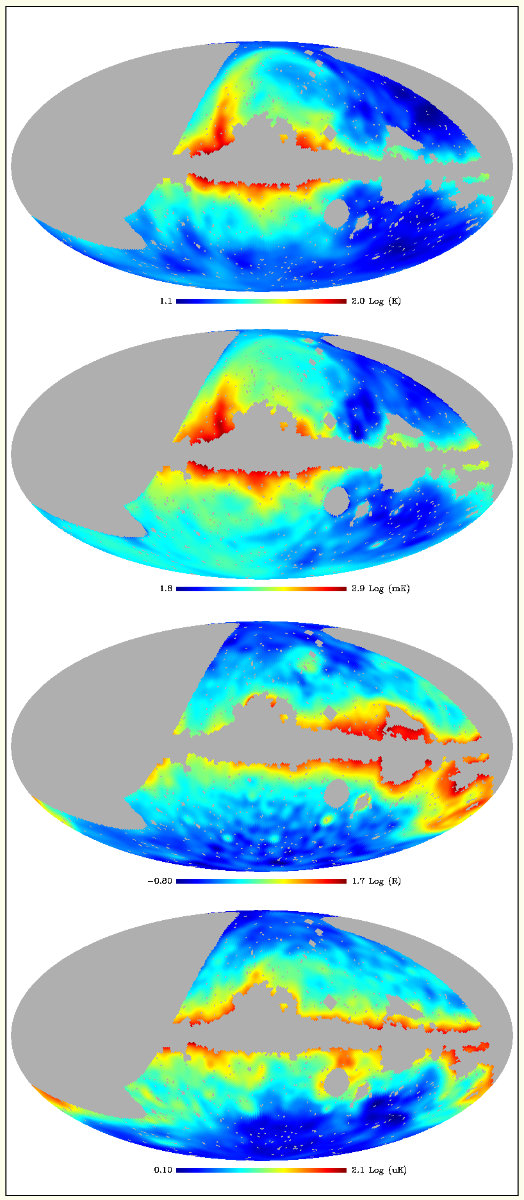

Figure 1: The input templates.
Top to bottom: Haslam 408 MHz, Jonas 2.3 GHz, Hα, FDS 94 GHz

Anomalous microwave emission at 20-40 GHz has been detected across our Galactic sky. It is highly correlated with thermal dust emission and hence it is thought to be due to spinning dust grains. Alternatively, this emission could be due to synchrotron radiation with a flattening (hard) spectral index.

Following the method set out in Davies et al. [1], we **cross-correlate** synchrotron, free-free [2] and thermal dust [3] templates with the WMAP 7-year maps **using synchrotron templates either at 408 MHz** [5] **or 2.3 GHz** [6]. Comparison of these results lets us assess the amount of flat synchrotron emission that is present, and the impact that this has on the correlations with the other components, since the higher frequency map will be a better tracer of flat-spectrum emission. The templates shown in Figure 1 display the clear differences in morphology between the different emission mechanisms that they trace.

Figure 2a shows the template coefficients for the three components as a function of frequency, using either 408 MHz (solid lines) or 2.3 GHz (dashed lines) smoothed to 3°. We find that there is only a small amount of flattening visible in the synchrotron spectral indices by 2.3 GHz, of around $\Delta\beta \approx 0.05$, and that **the significant level of dust-correlated emission in the lowest WMAP bands is largely unaffected by the choice of synchrotron template**, particularly at high latitudes (it decreases by only ~7 per cent when using 2.3 GHz rather than 408 MHz).

The robustness of this result has been tested by looking at the effects of different resolutions, Hα templates and areas of the sky (hemispheres, masks and regions). Figure 2b shows a strong dependence of the 22.8 GHz template coefficients on the map resolution, likely due to a number of artifacts in the templates, which converge by 3°, in agreement with the findings of Ghosh et al. [4]. Figure 2c shows the dependence of the 22.8 GHz coefficients with foreground mask; there is a difference when masking less of the Galactic plane implying that flat-spectrum emission becomes more important nearer the plane. The results are otherwise shown to be robust.

These results agree with expectation if the bulk of the anomalous emission is generated by spinning dust grains. In the future, C-BASS data at 5 GHz will further constraint the relative levels of flat-spectrum synchrotron emission and anomalous microwave emission.

[1] Davies et al. (2006), MNRAS, 370, 1125
[2] Dickinson et al. (2003), MNRAS, 341, 369
[3] Finkbeiner et al. (1999), ApJS, 146, 407
[4] Ghosh et al. (2011), arXiv:1112.0509
[5] Haslam et al. (1982), A&AS, 47, 1
[6] Jonas et al. (1998), MNRAS, 297, 977

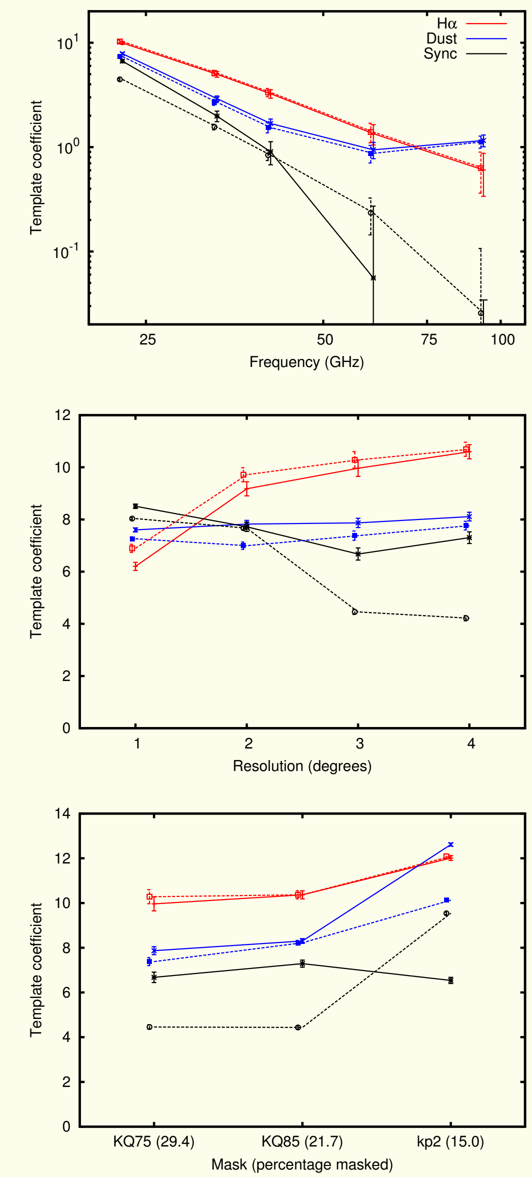

Figure 2: Template coefficients. Top: As a function of frequency. Middle: varying resolution. Bottom: different masks.

Thanks for listening!

Questions?

For more info, see:
MNRAS Letters, 416, 99
arXiv:1105.6336