Planck on Extragalactic Radio Sources: Data and Findings

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IAU 2015

Limitations

Will discuss only **extragalactic** sources (Galactic science covered yesterday)

Will focus on **radio** sources (SFG and the Cosmic Infrared Background [CIB] covered later in this session)

Will emphasize **results rather than the data** (properties of the *Planck* catalogues covered in next talk)

Outline of Talk

Properties of the *Planck* surveys and catalogues (see also following talk by López-Caniego)

Any entirely new category of sources?

Counts of sources

SEDs of sources

Variability studies

Using *Planck* to calibrate ground-based instruments

Resolved sources (M31)

A Radio Astronomer's Dream...

… a Survey that

- Covered the **entire sky**
- Was conducted **at many frequencies**
  - (some impossible to reach from the ground)
- Provided **full Stokes** for the brighter sources
- Was **repeated** periodically, with a cadence of minutes to years
- Was **absolutely calibrated** to 1-2% precision

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This is precisely Planck's gift to the radio astronomy community

Relevant Properties and Products of *Planck*

Focal plane "footprint"

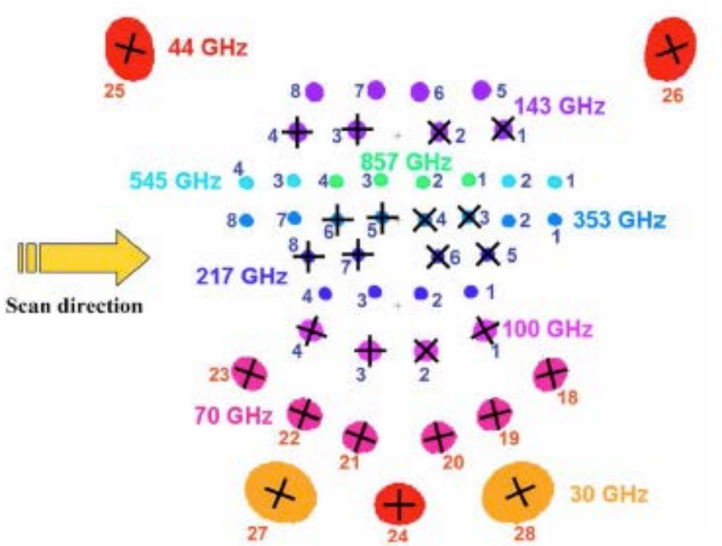
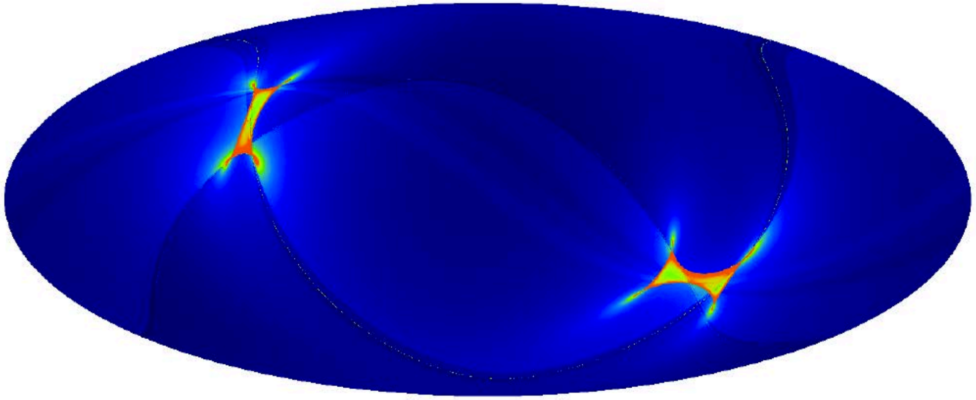


Fig. 1. Focal plane, showing spacing of the *Planck* receivers.

Scan pattern covers whole sky every six months

With denser coverage at ecliptic poles



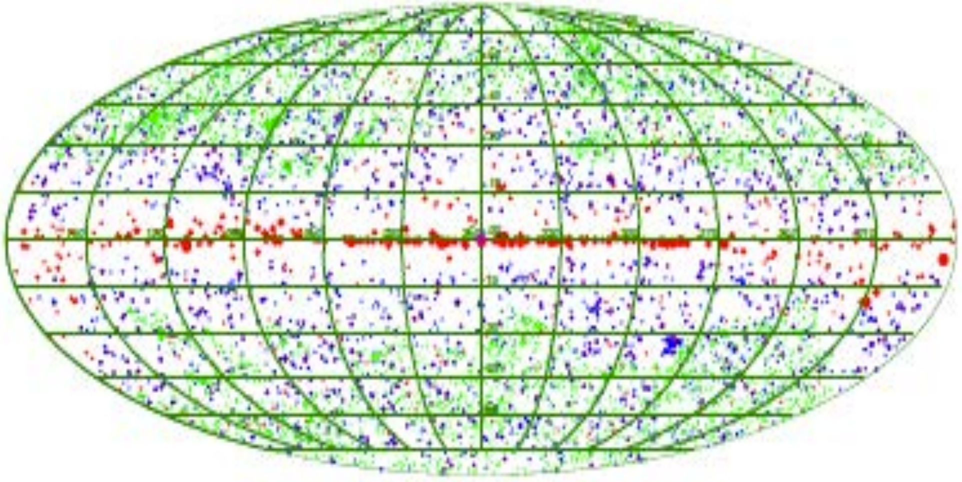
Relevant Properties and Products of *Planck:* the PCCS2

Frequency GHz	Beam HWFM arcmin	~Catalogue Sensitivity	Approx. Number of Sources Detected	Typical Type (Extragalactic)
28	32	0.43 Jy	1500	AGN
44	27	0.69	900	AGN
70	13	0.50	1300	AGN
100	9.7	0.27	1700	AGN
143	7	0.18	2200	AGN, some SFG
217	5	0.15	2100	½ AGN, ½ SFG
353	5	0.30	1300	SFG, few AGN, CIB
545	5	0.55	1700	SFG and CIB
857	4.5	0.80	4900	SFG and CIB

For details on PCCS2, see following talk by Marcos López-Caniego

All Sky Surveys (at High Frequencies)

Perfect to detect rare (but bright) sources



red, blue green = 30, 143 & 857 GHz

Some results:

1. *Planck*: No entirely new category of sources emerged
   -- e.g. at |b| > 20^{o}, ~95% of 30, 44, 70 and 100 GHz *Planck* sources are already catalogued
   (Planck Collab. XXVI, 2015, and Caniego's talk here)

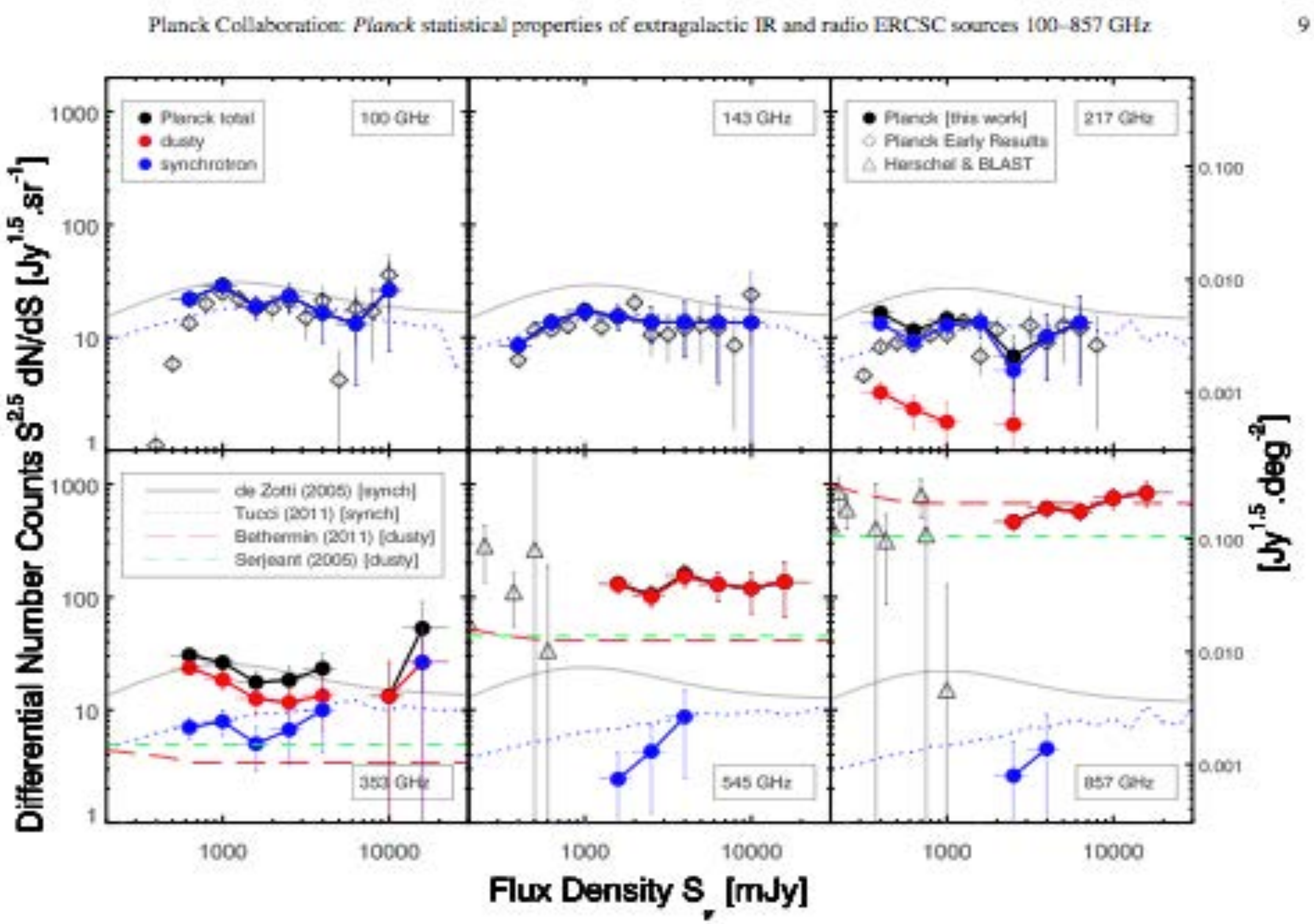
2. *Planck*: Counts ν < 217 GHz dominated by radio sources

2a. *Planck*: High-frequency spectra are quite flat

3. SPT discovery (Vieira et al 2013) of lensed sub-mm galaxies

4. *Planck* detection of clumps of high-redshift sources (see Lagache's talk later)

First Results: Source Counts



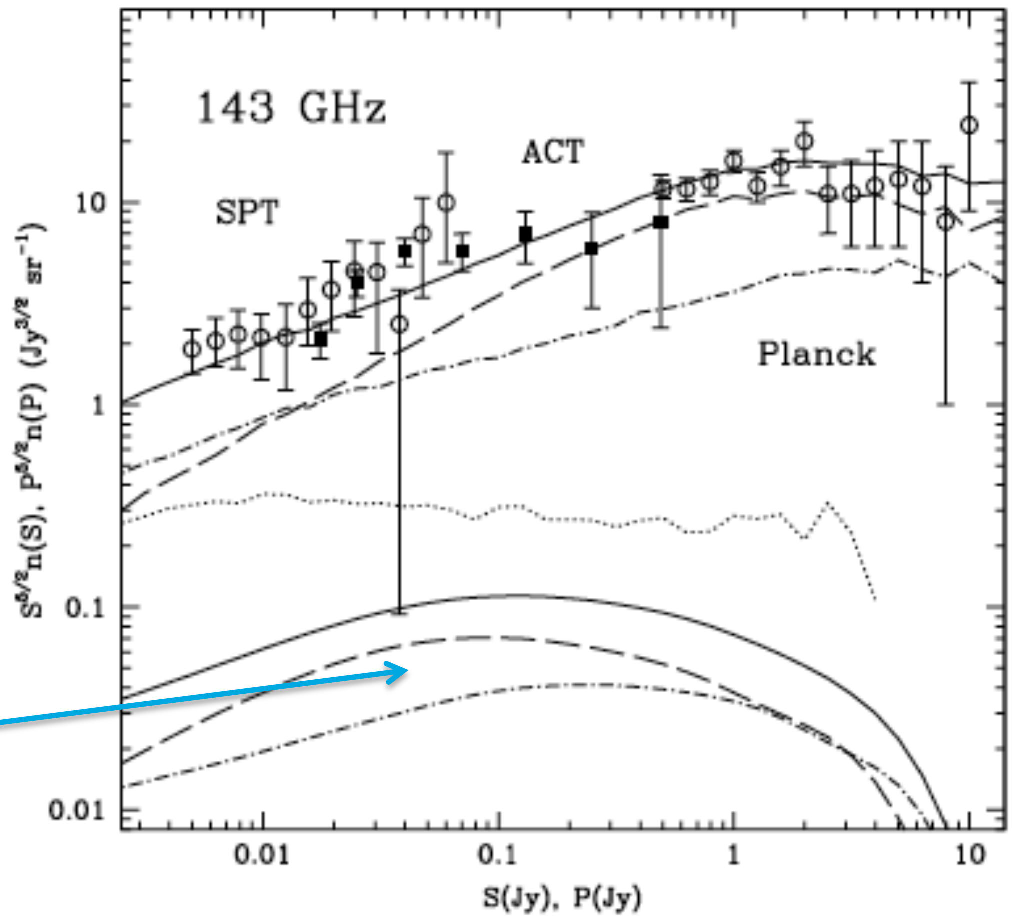
From Planck Intermediate Results VII, 2013

Counts of Sources at 143 GHz

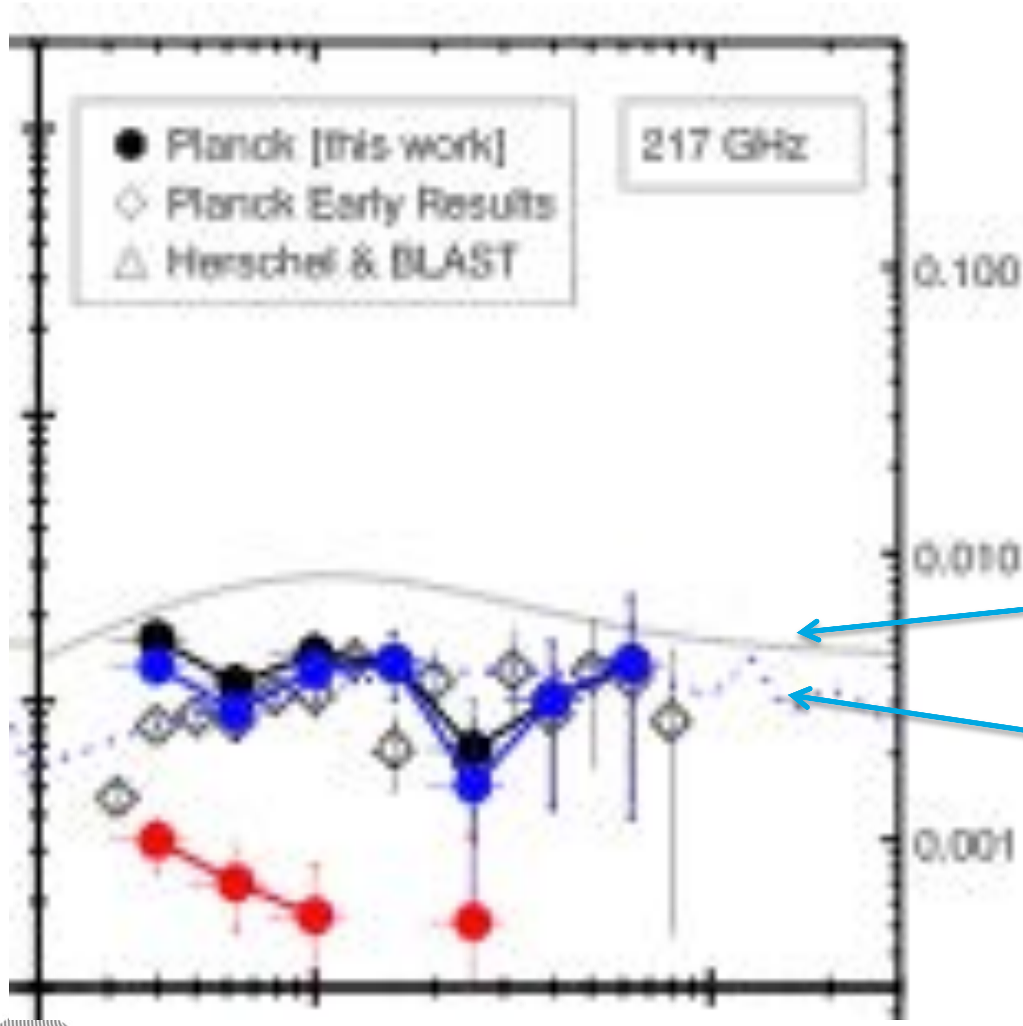
ACT and SPT extend *Planck* counts to lower flux densities

Tucci et al. (2011) model:
Dashes – radio quasars
Dot-dash – BL Lacs
Dots – radio galaxies (sub-dominant)

Predictions for polarization



Counts of Sources at 217 GHz



Blue: AGN

Red: Dusty galaxies

Compared to pre-Planck models:

DeZotti et al. 2005

Tucci et al. 2011

Which Sources Dominate Counts?

planck

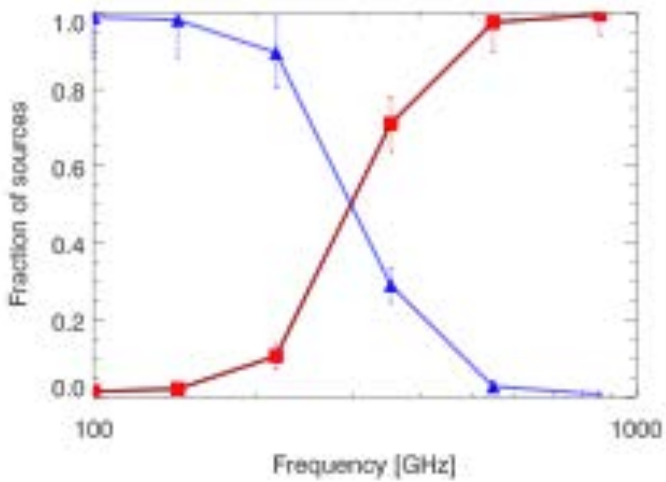


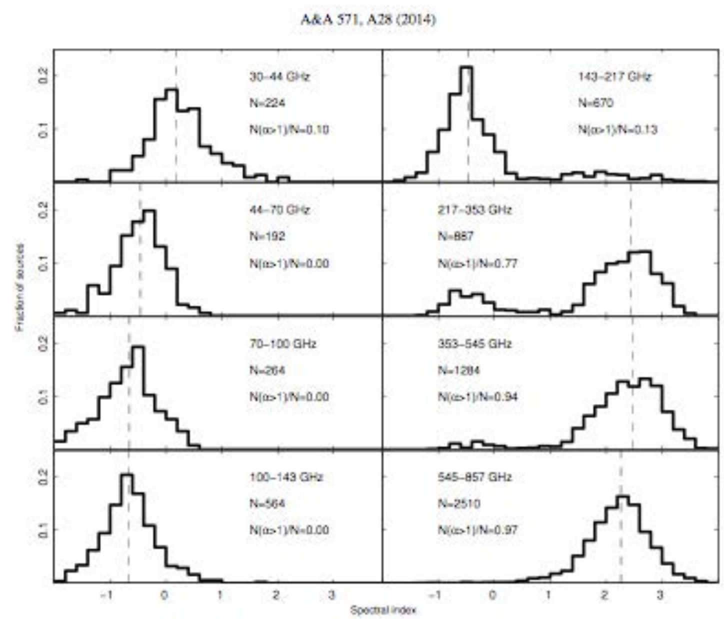
Figure 8. Fraction of galaxy types as a function of frequency.

Blue: AGN

Red: Dusty galaxies

(Planck Intermediate Results VII, 2013)

Spectral indices: Another way of showing the same result

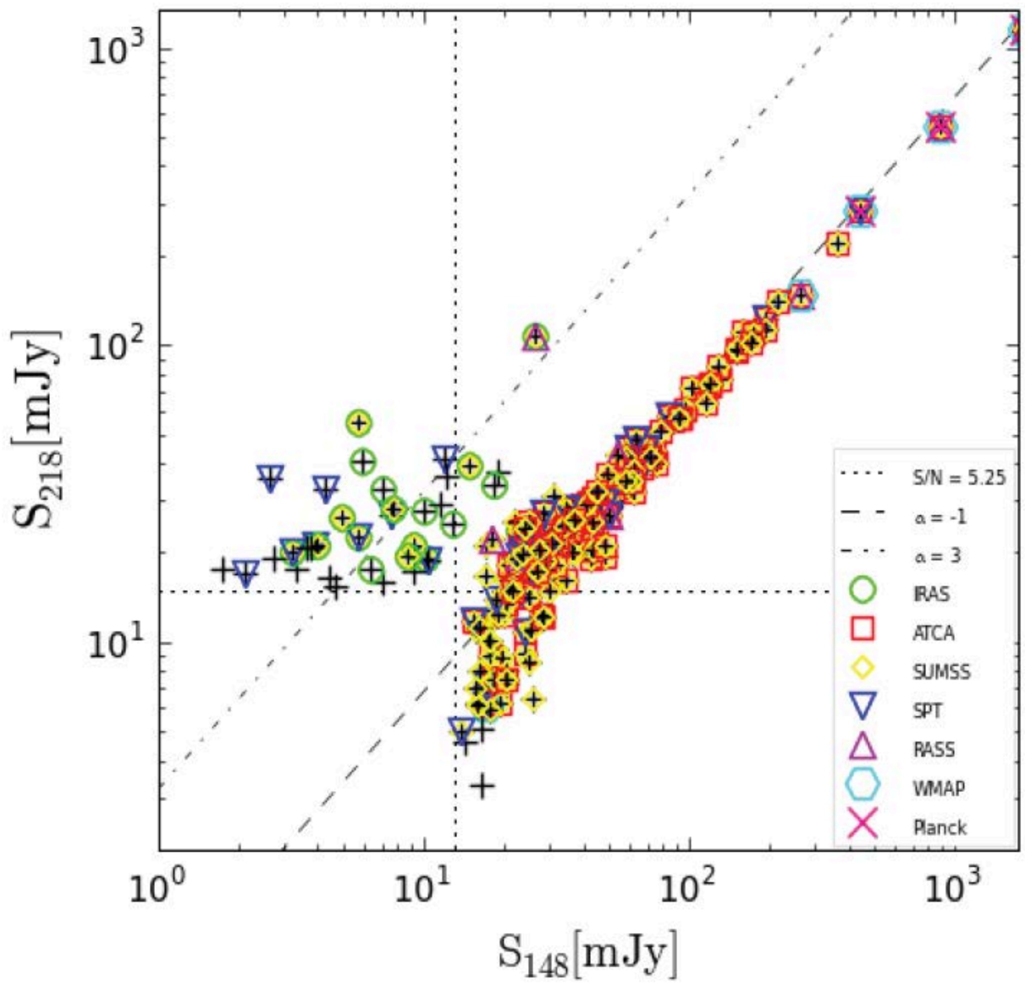


esa

Which Sources Dominate Counts?

Based on ACT Observations
(Marsden et al. MN, 2014)

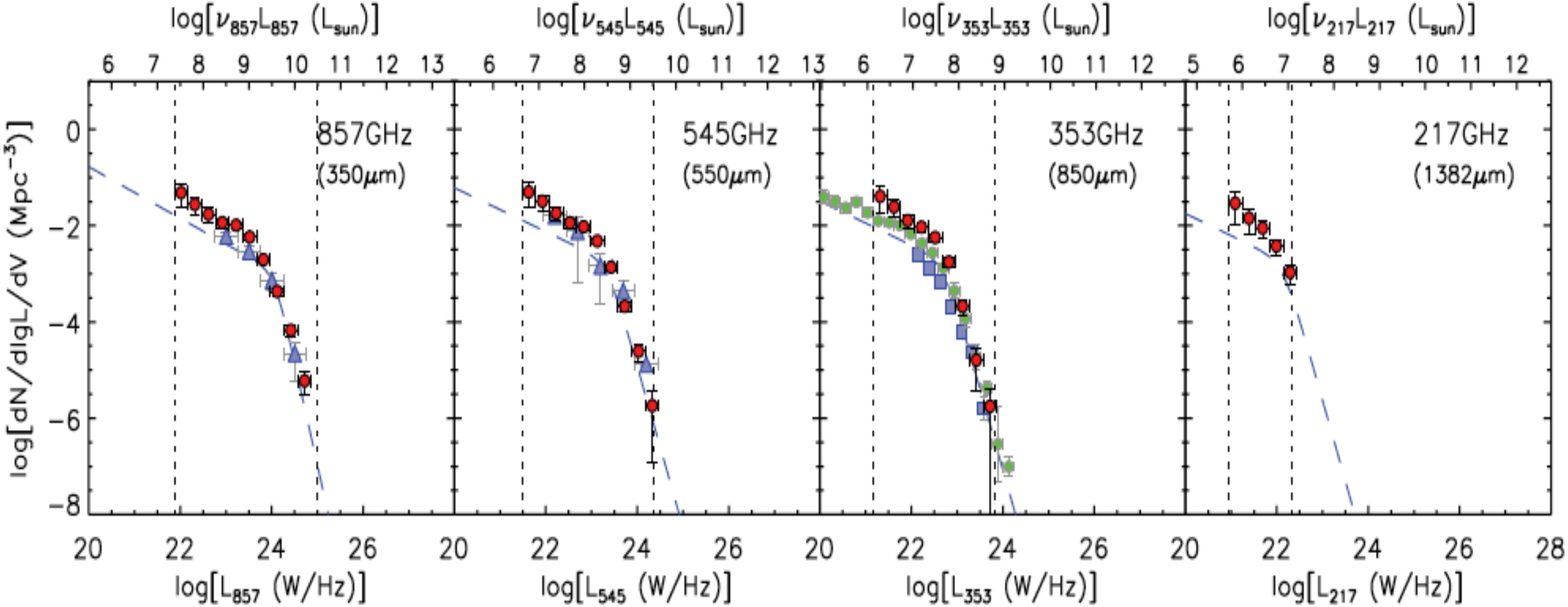
Even at ~ 10 mJy, radio sources dominate the counts at 150 GHz



Partridge, IAU 2105

Luminosity Functions at Several Frequencies

Wide frequency coverage of *Planck* has allowed determination of luminosity functions (Negrello et al. MNRAS, 2013) at frequencies not available from ground



Source SEDs: A Sample

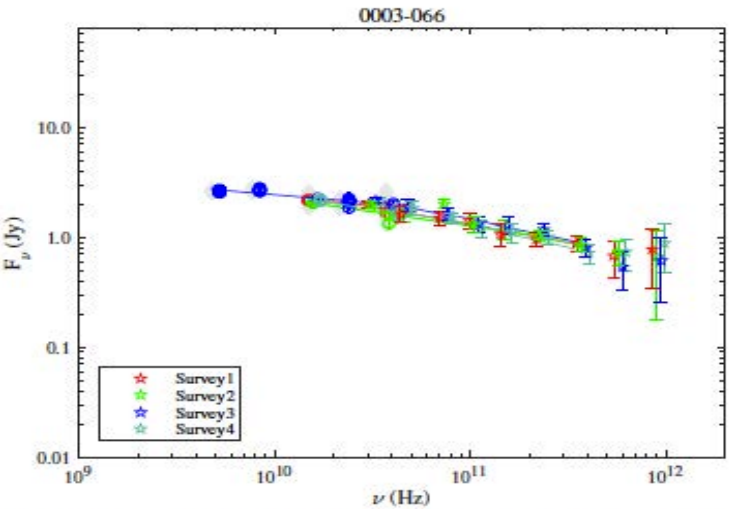
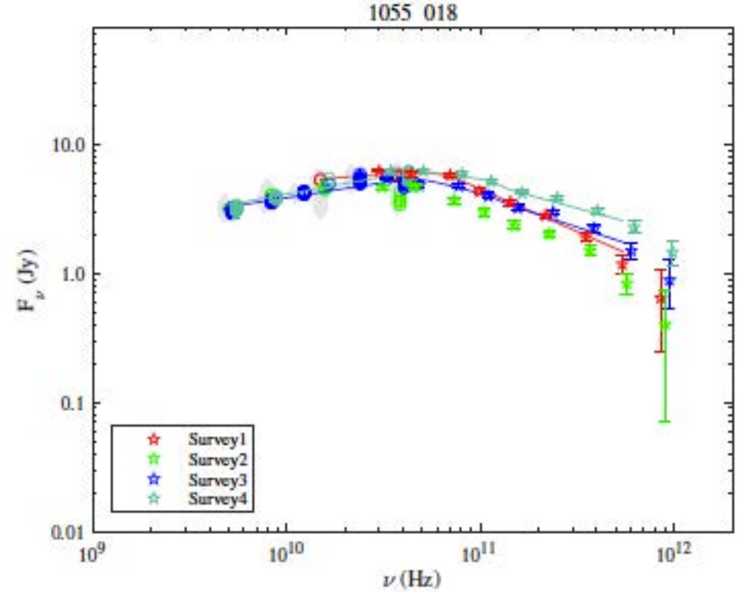
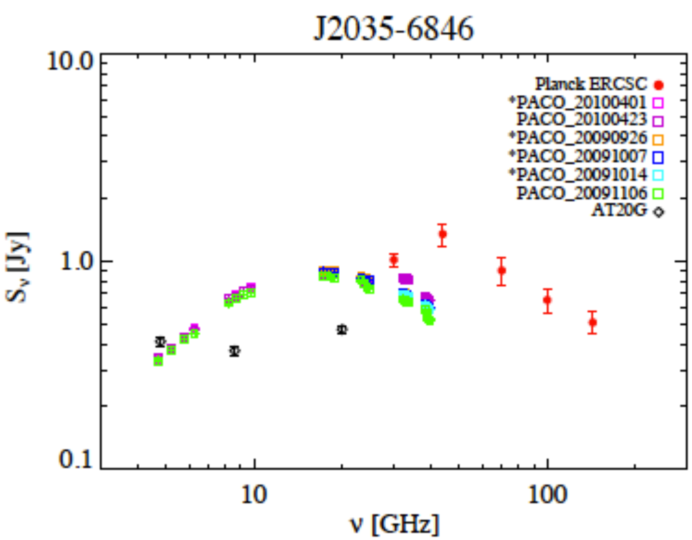
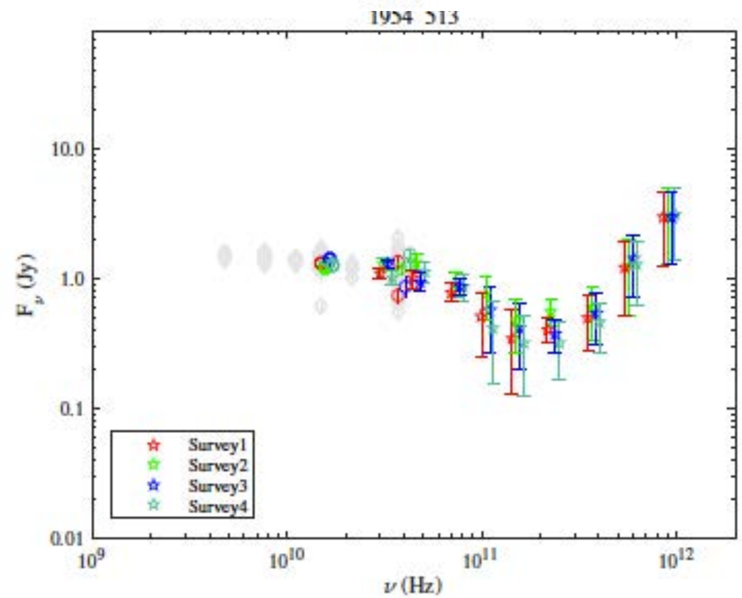


Fig. 11. The radio spectrum of 0003-066. Coloured stars, *Planck* data from four surveys; coloured circles, data simultaneous to the *Planck* observations; grey circles, historical data; solid lines, broken power law fits.

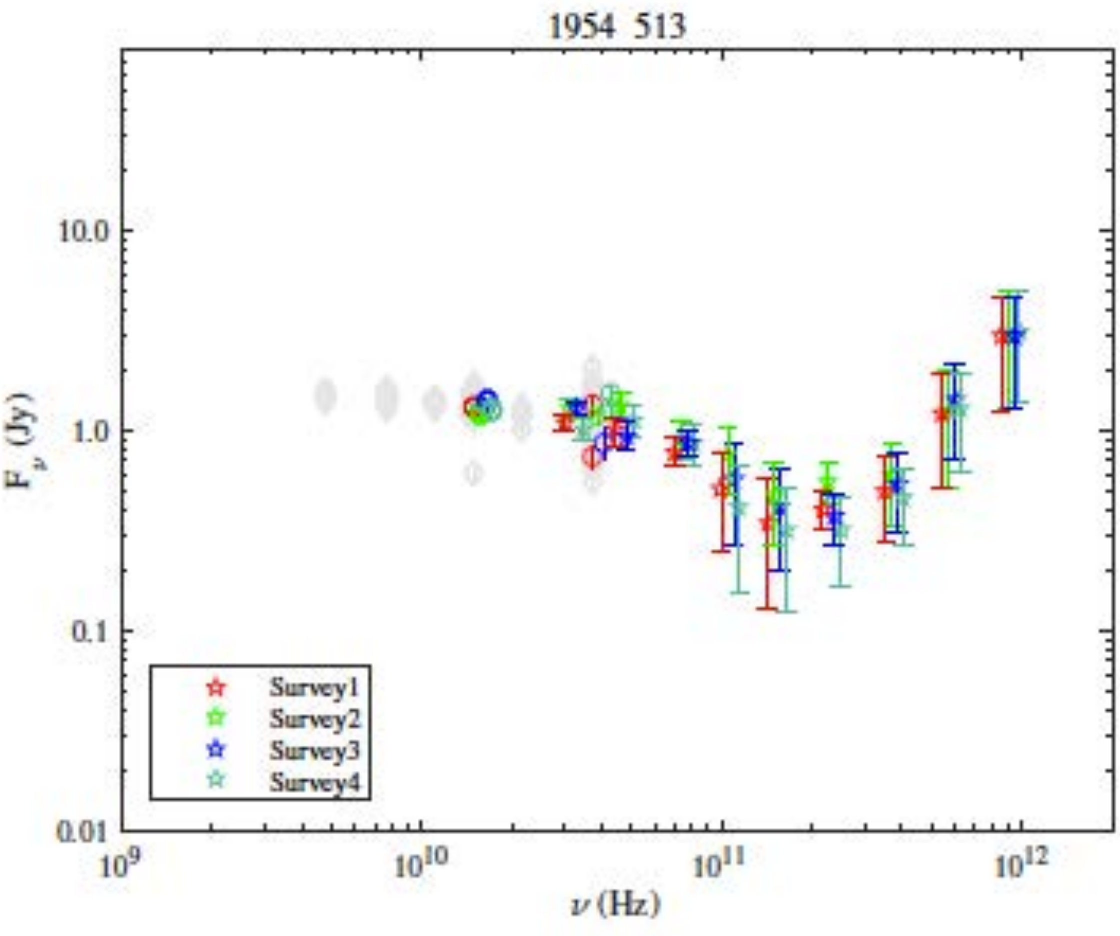






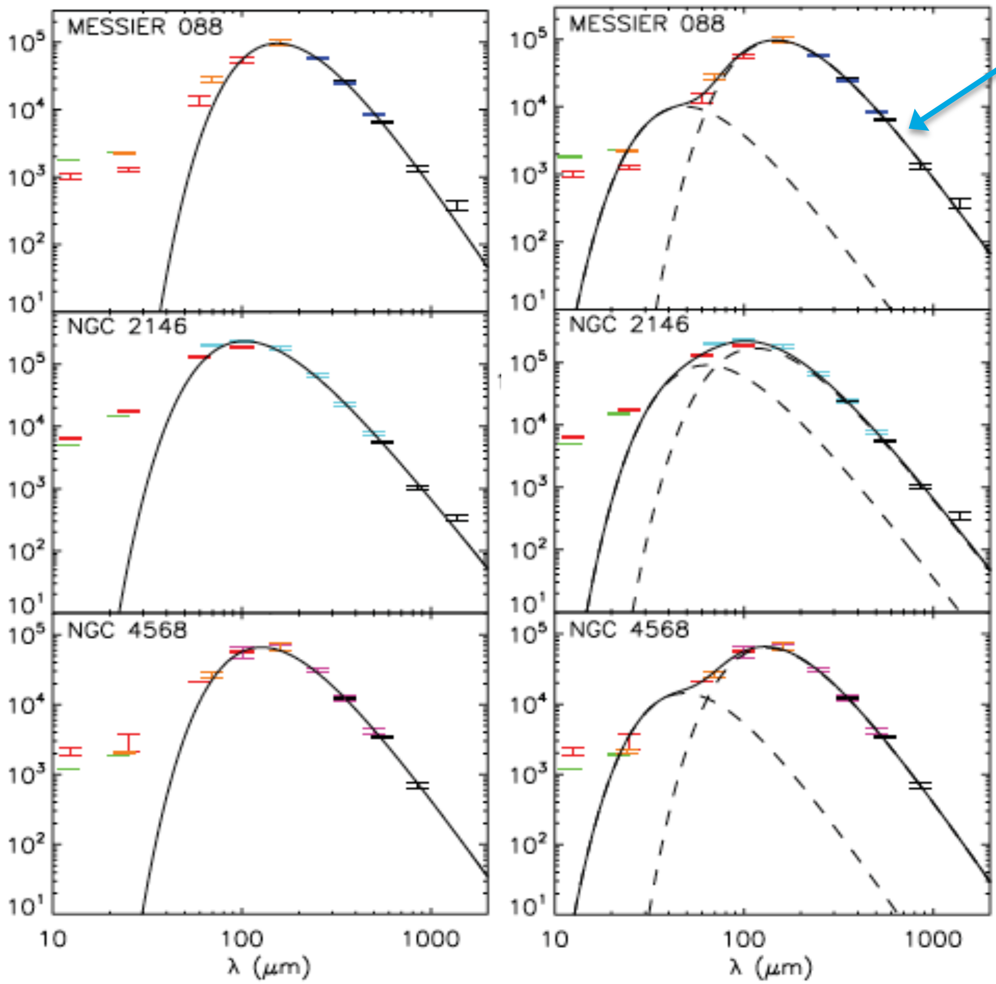
Source SEDs

An sample
hybrid spectrum:
Synchrotron,
then dust emission
at v > 200 GHz



Source SEDs: Star Forming Galaxies (SFGs)

One and two temp. fits

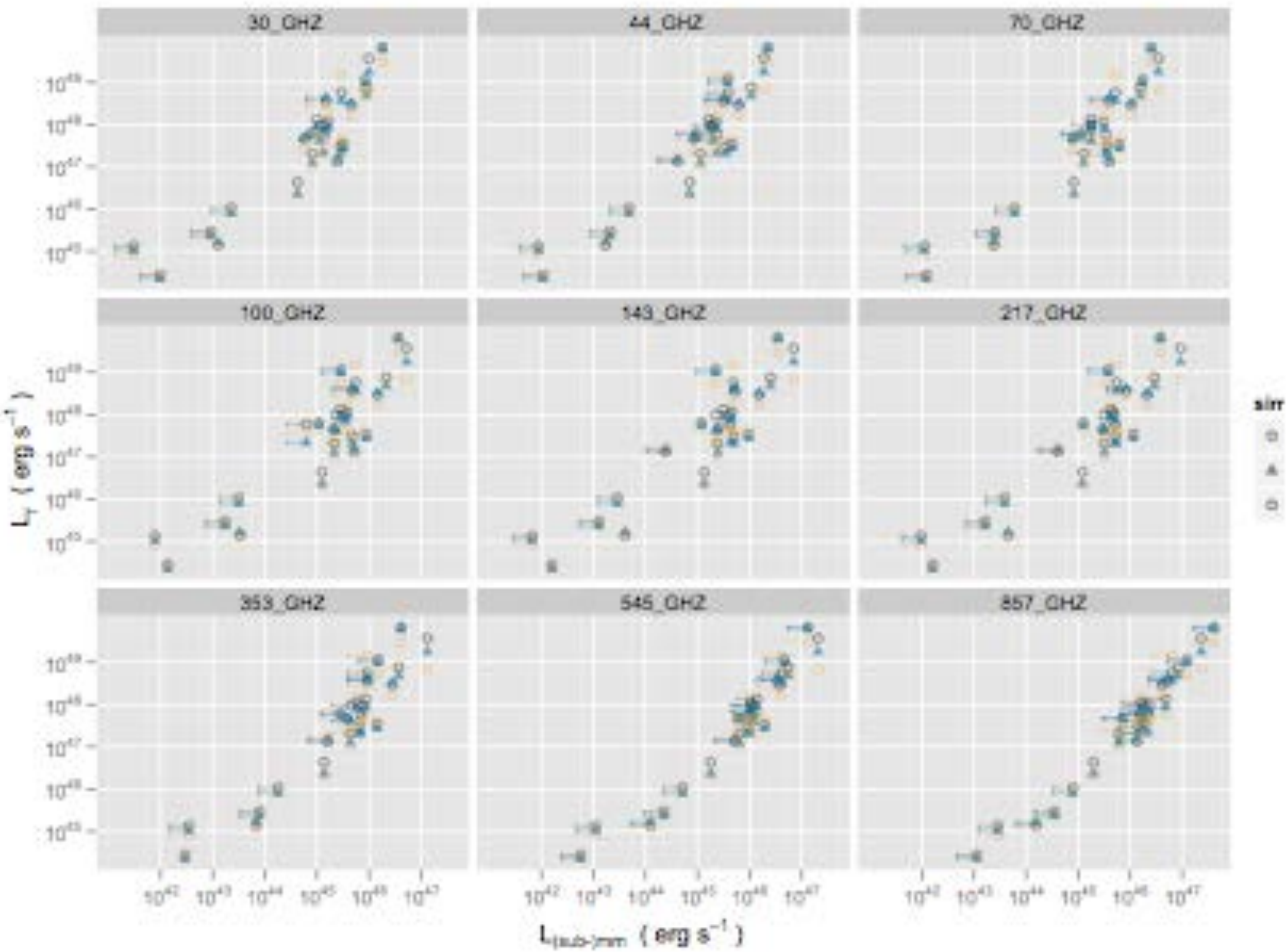


Planck gets low-temp dust

Conclusions from Clemens et al. MNRAS 2013

- T = 10-25 K fits *Planck* data
- No super-cool (6-10 K) dust
- Warm dust, though negligible in mass, contributes ~1/3 of sub-mm luminosity
- Dust mass = 0.022 HI mass
- Density of dust in local Universe = 7 ± 1.4 x 10^5 M_o/Mpc^3

Correlation between Planck and Fermi Luminosities



Strong Correlation between sub-mm and γ-ray flux, when latter is averaged over time

(Leon Tavares et al. ApJ 2012)

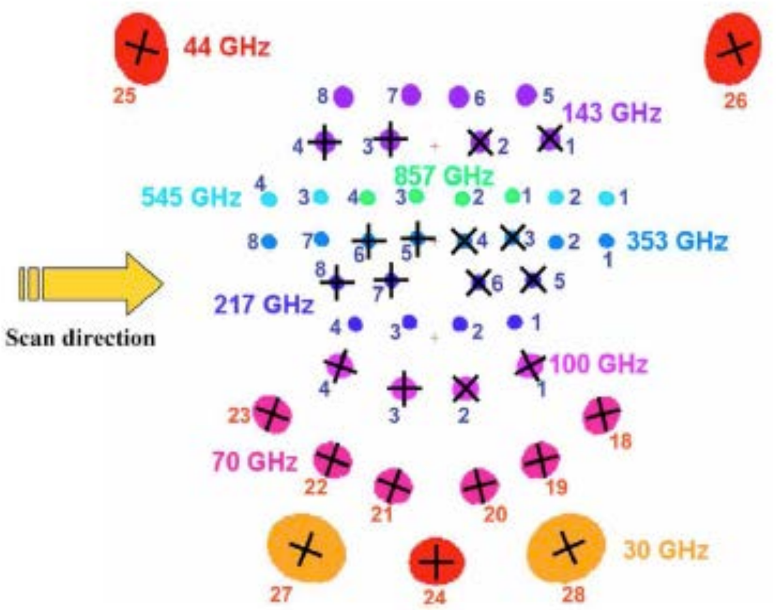
Variability Studies

To increase sensitivity, CMB experiments scan sky repeatedly with varying cadence

Valuable data for studies of source variability

Planck as an example:

Sources sweep through beams every minute, integrating for hours; beams return to same spot in sky every 6 months



Variability Studies

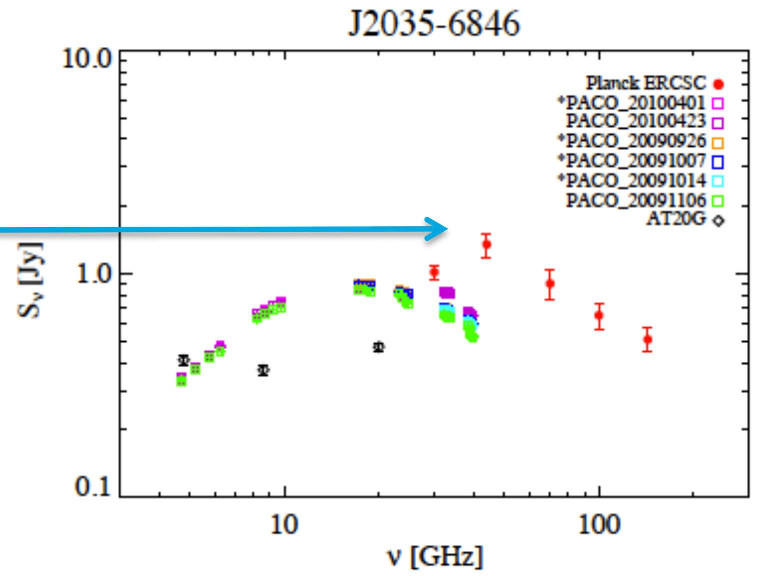
Phenomena

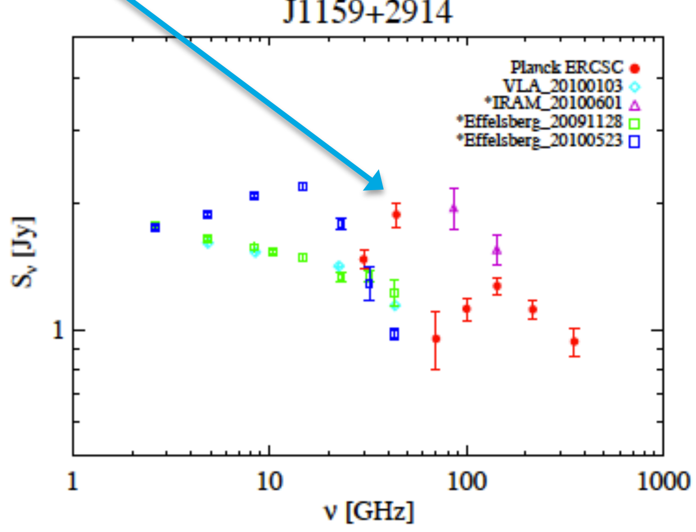
Flares

Spectral changes (on <10 day time scale in this case)

Planck data in red

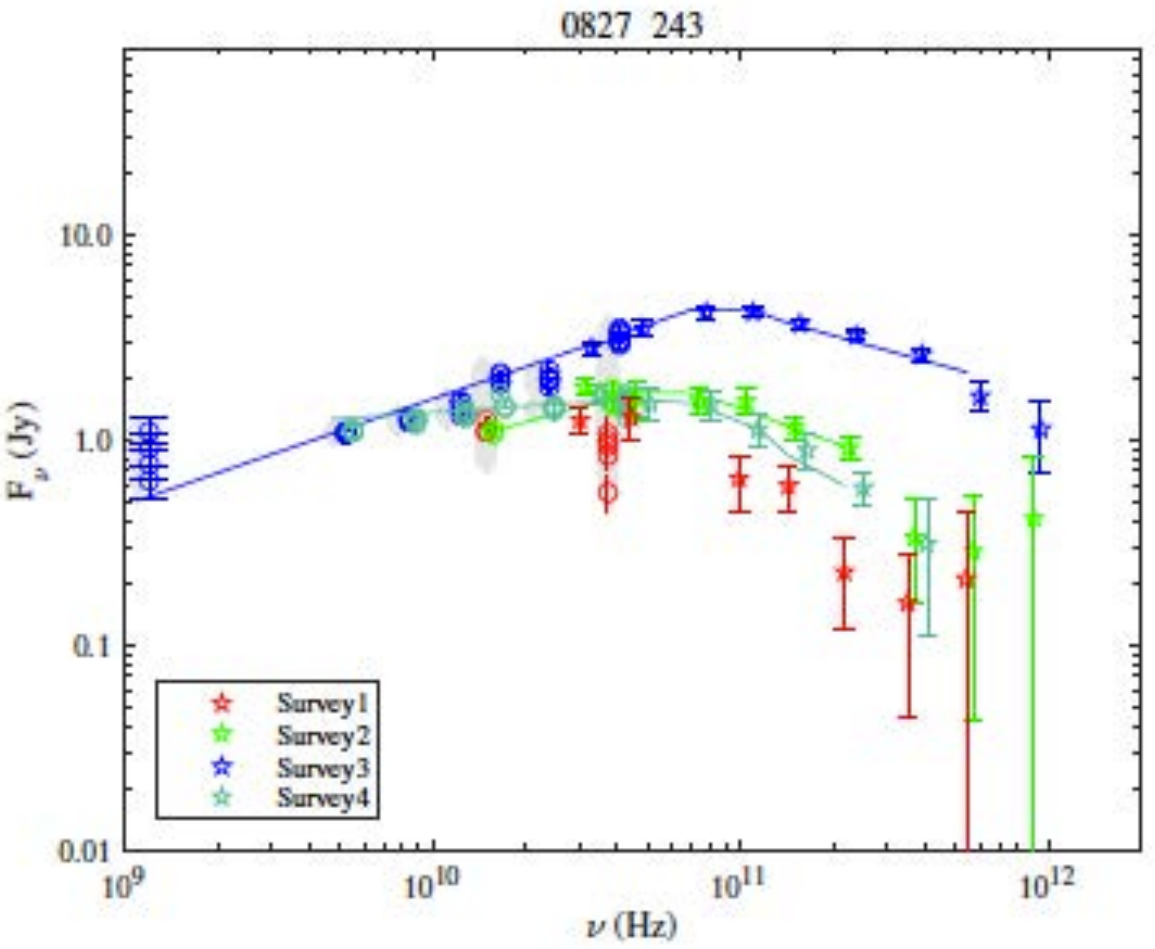
(from Planck Early Results XVII, 2011)





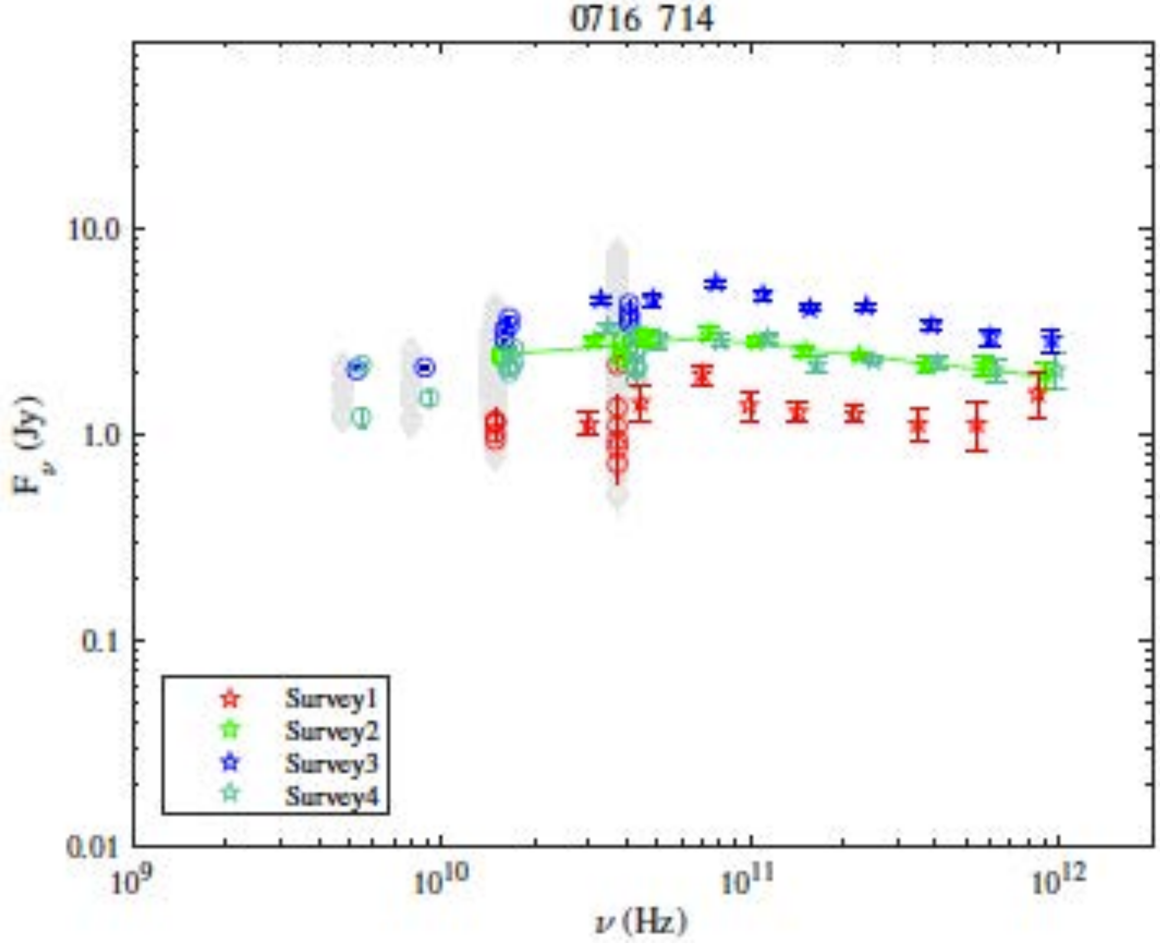
Flaring Source

These and other spectra from Planck Intermediate Paper 48, 2015 (Lahteenmaki et al.)



Achromatic Variability

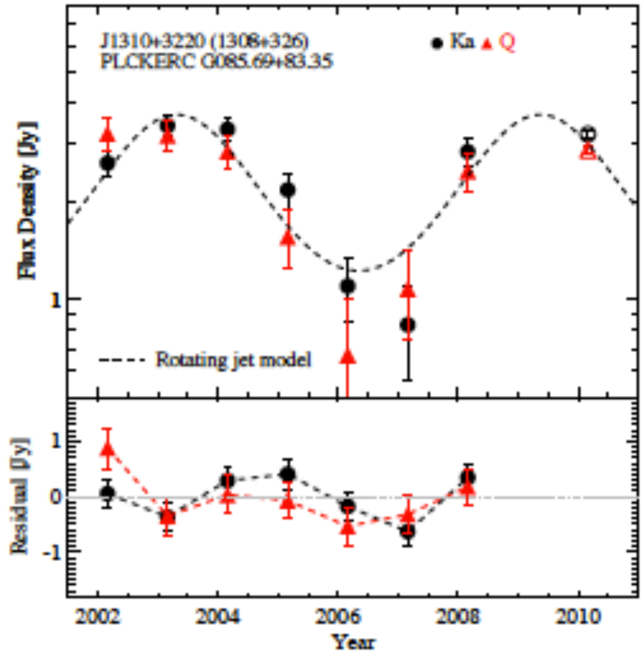
Achromatic flux changes frequently observed



Variability Studies

Long term achromatic variability using WMAP and *Planck* year and 6 month average measurements (Chen et al. 2013; see also poster by Rachen et al. here)

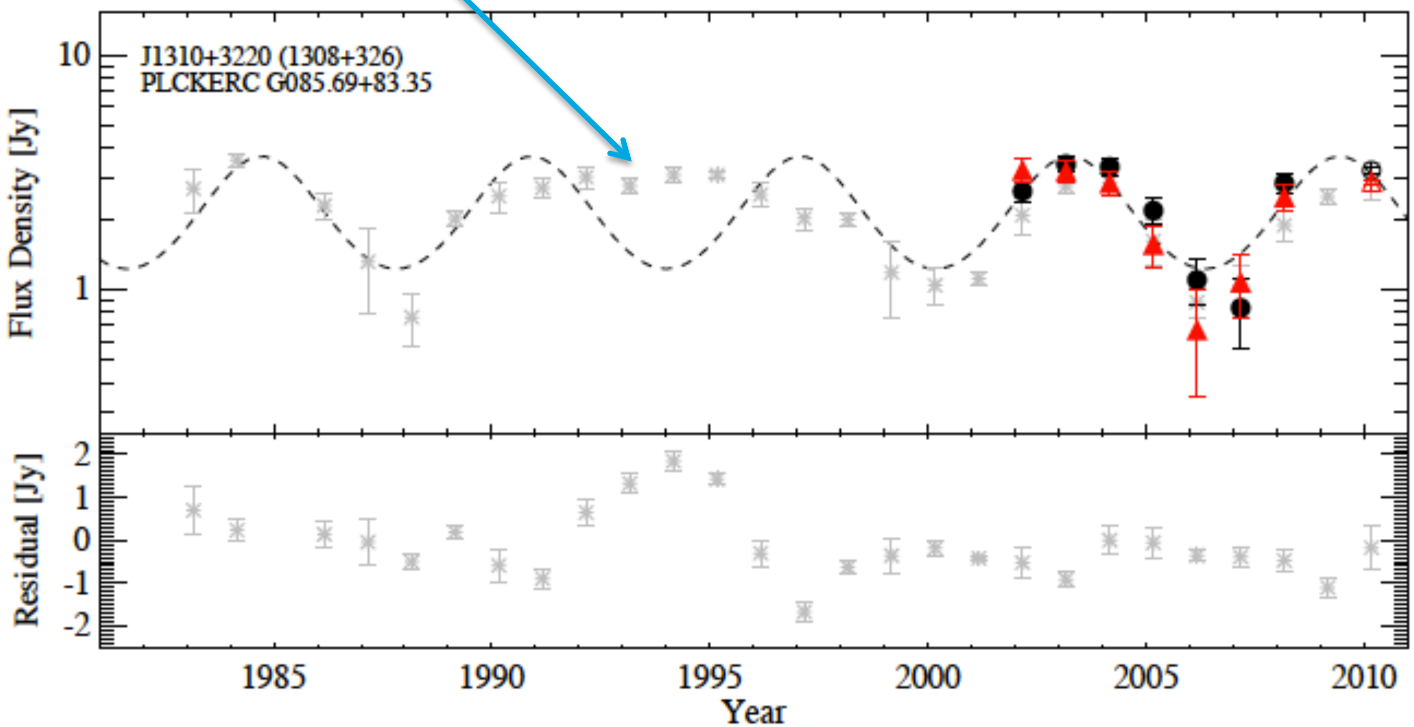
Intriguing possibility – sinusoidal light curves produced by a precessing jet



Variability Studies

But be careful…

…same source over longer timespan



Absolute Calibration

Planck and WMAP calibrated using CMB dipole induced by yearly motion of satellites– an ***absolute calibration***

Transfer calibration to ground-based radio telescopes:

First step – indirect – VLA observations of Mars, with Mars emission model adjusted to WMAP observations (Perley and Butler 2013). Estimated precision ~5%

Direct – compare flux density measurements at VLA and Australia Telescope (AT) with nearly simultaneous *Planck* measurements (Partridge, Perley et al. 2015)

Extend to ALMA, etc.

And use to confirm calibration of other CMB experiments (e.g. ACT; Louis et al. 2014)

Absolute Calibration

planck

Results at 28 and 43 GHz (from Partridge, Perley et al., ApJ 2015)

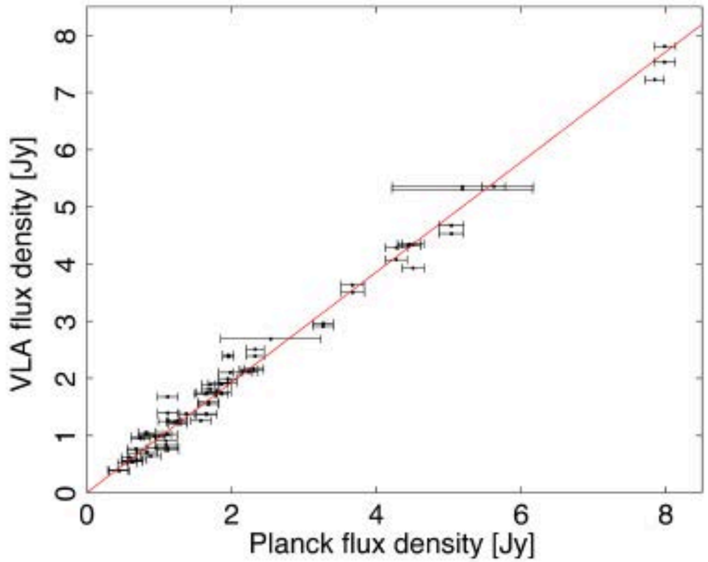


Fig. 2.— Comparison between color-corrected *Planck* and VLA measurements at 28.45 GHz; the observed scatter is due mainly to variability of the sources. The slope and 1σ uncertainty of the fit (solid line) are 0.964 ± 0.008.

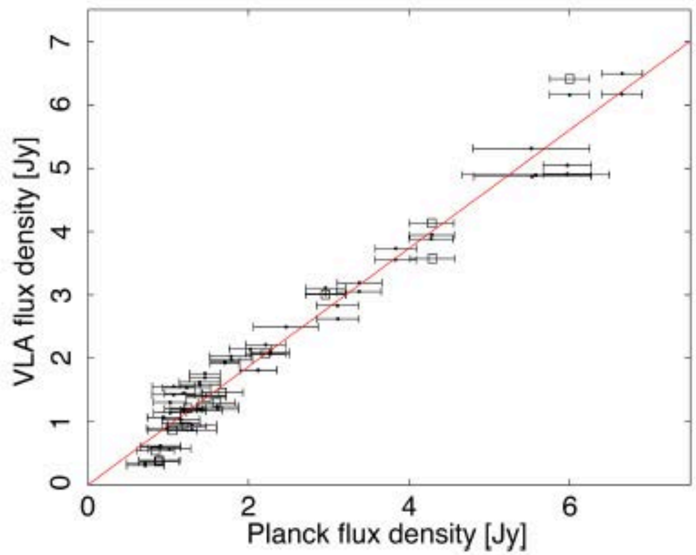


Fig. 3.— Color-corrected (and extrapolated) *Planck* flux densities compared to VLA measurements (*dots*) and ATCA measurements (*open squares*) of the same sources at 43.34 GHz. The slope and 1σ uncertainty of the constrained fit (solid line) are 0.9384 ± 0.013.

Absolute Calibration

Results

At 22 GHz, ground-based (ATCA) flux density scale = 0.98 of *Planck's*

At 28 GHz, ground-based (VLA) flux density scale = 0.98-0.97 of *Planck's (+/- 0.01)*

At 44 GHz, ground-based (VLA) scale = 0.94 of *Planck's (+/- 0.014)*

At 148 GHz, ground-based (ACT) scale = 1.015 of *Planck's (+/- 0.03)*

At 217 GHz, ground-based (ACT) scale = 0.99 of *Planck's*

Good (few percent) agreement at all but 44 GHz

Absolute Calibration

Similar study comparing *Planck* to Herschel (Negrello et al. MN 2013); see also Louis, et al. 2014 for a *Planck*-ACT comparison

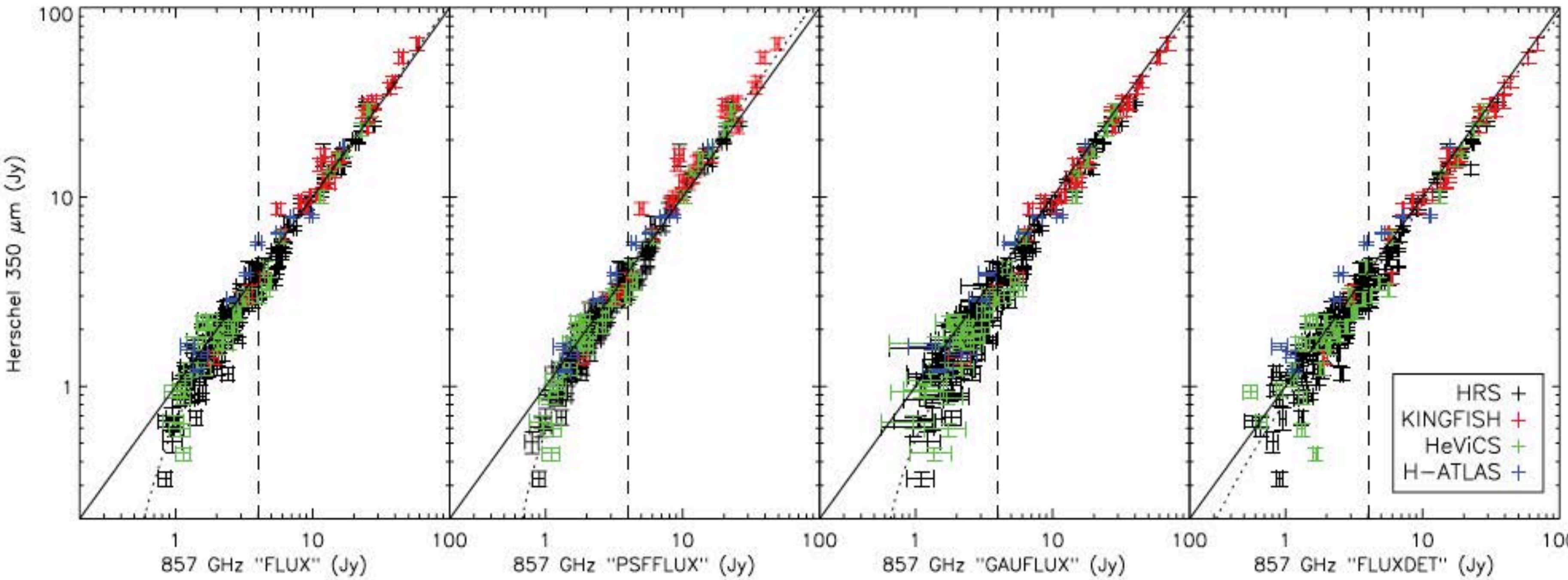
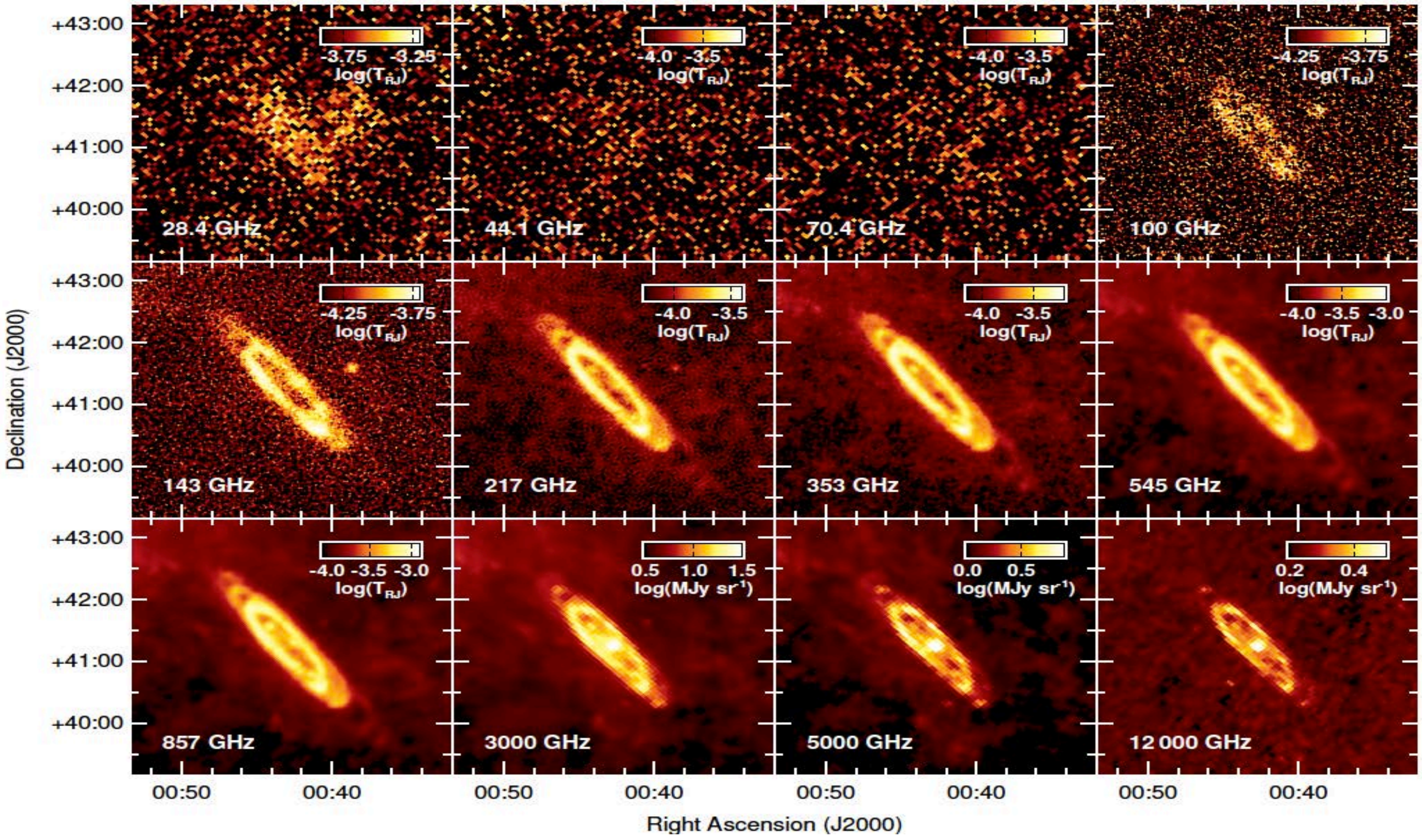


Figure 2. Comparison of the four *Planck* flux density estimations at 857 GHz (350 μm) with *Herschel* measurements at the same frequency. The symbols and the lines have the same meaning as in Fig. 1.

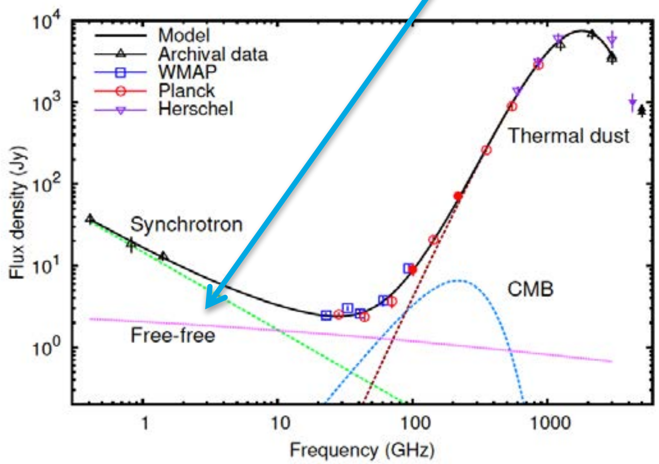
Resolved Nearby Galaxies (e.g., M31)

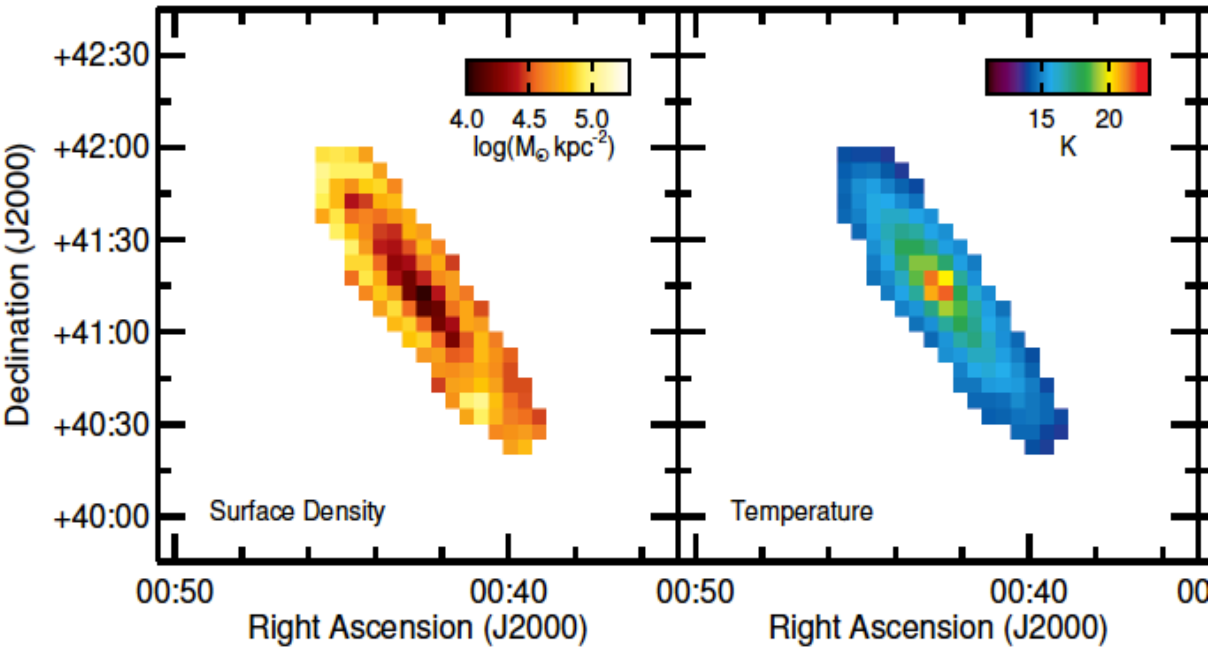


Planck images of M31 (Planck 2013 Results XXV, 2014)

Resolved Nearby Galaxies (M31)

Integrated spectrum of M31 (*Planck* highlights *free-free*)





Planck maps of dust column density and temperature in M31 (Planck 2013 Results XXV, 2014)

The scientific results that we present today are a product of the Planck Collaboration, which includes individuals from more than 100 scientific institutes in Europe, the USA and Canada

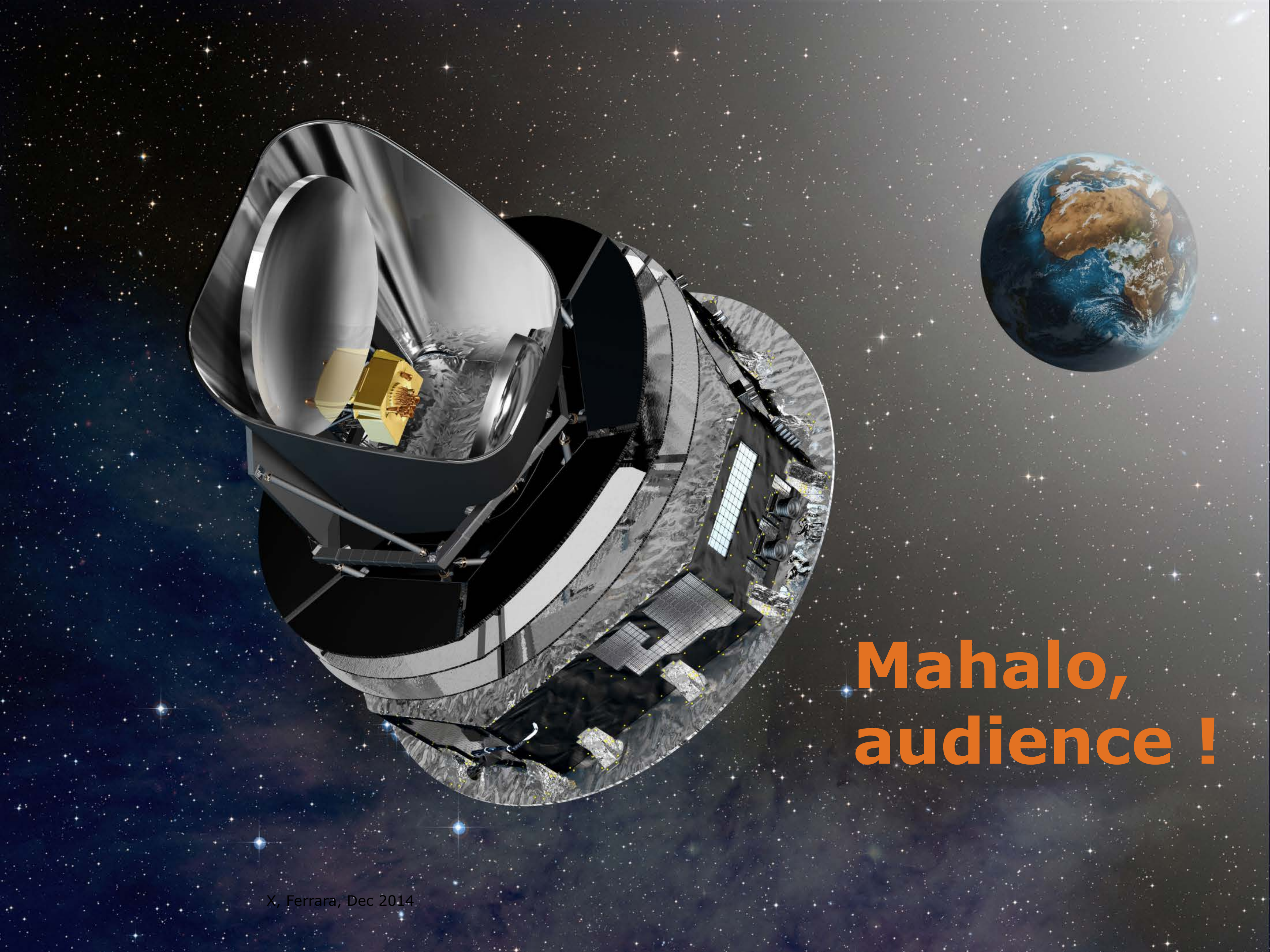
Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

Please Use These Resources !

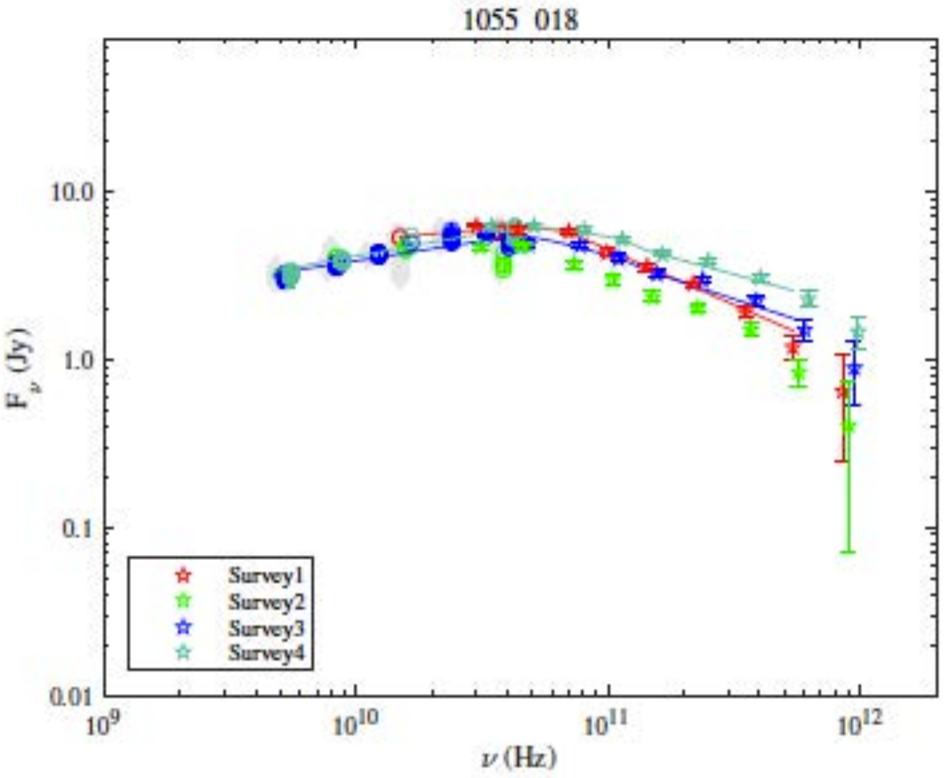
These few results just a sample of what *Planck* can contribute to extragalactic (and Galactic) science.

The rest is up to you!

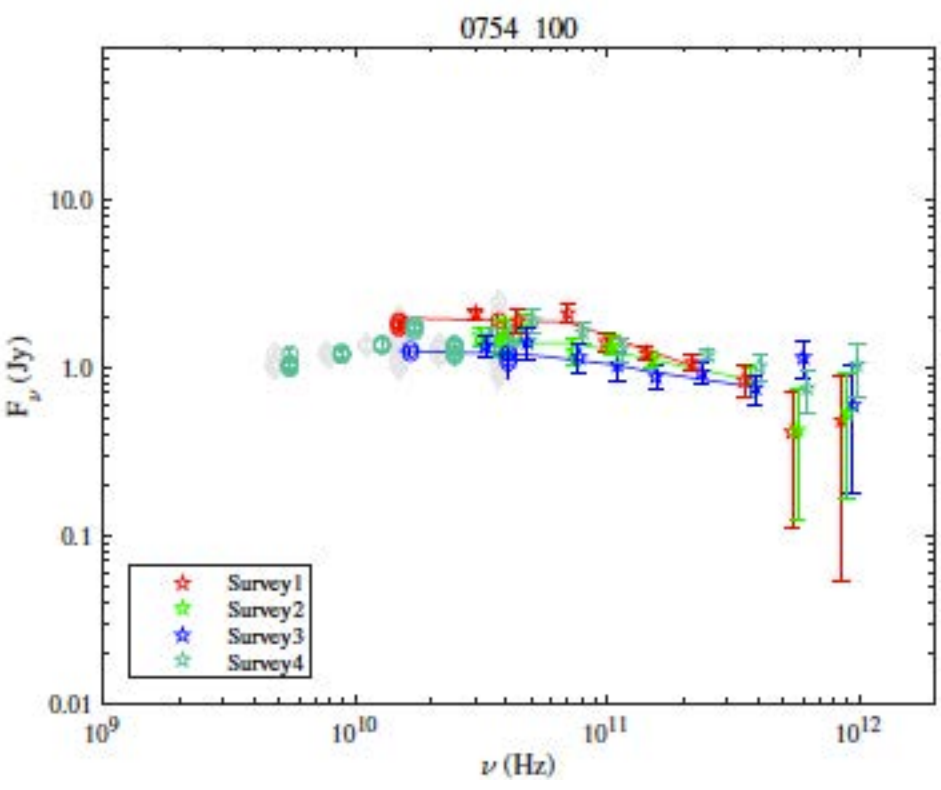
Please use *Planck* maps and catalogs


Mahalo,
audience !
X. Ferrara, Dec 2014


and thank you,
Planck!



Partridge, IAU 2015


0754 100
10.0
1.0
0.1
0.01
F_ν (Jy)
10^9
10^{10}
10^{11}
10^{12}
ν (Hz)
Survey1
Survey2
Survey3
Survey4

Some General Properties of CMB Experiments

Frequencies in CMB “sweet spot” 70-150 GHz AND ~217 GHz (SZ null)

-- with extension to lower and higher frequencies to control foreground Galactic emission

Rapidly increasing sky coverage

-- driven in part by B mode searches

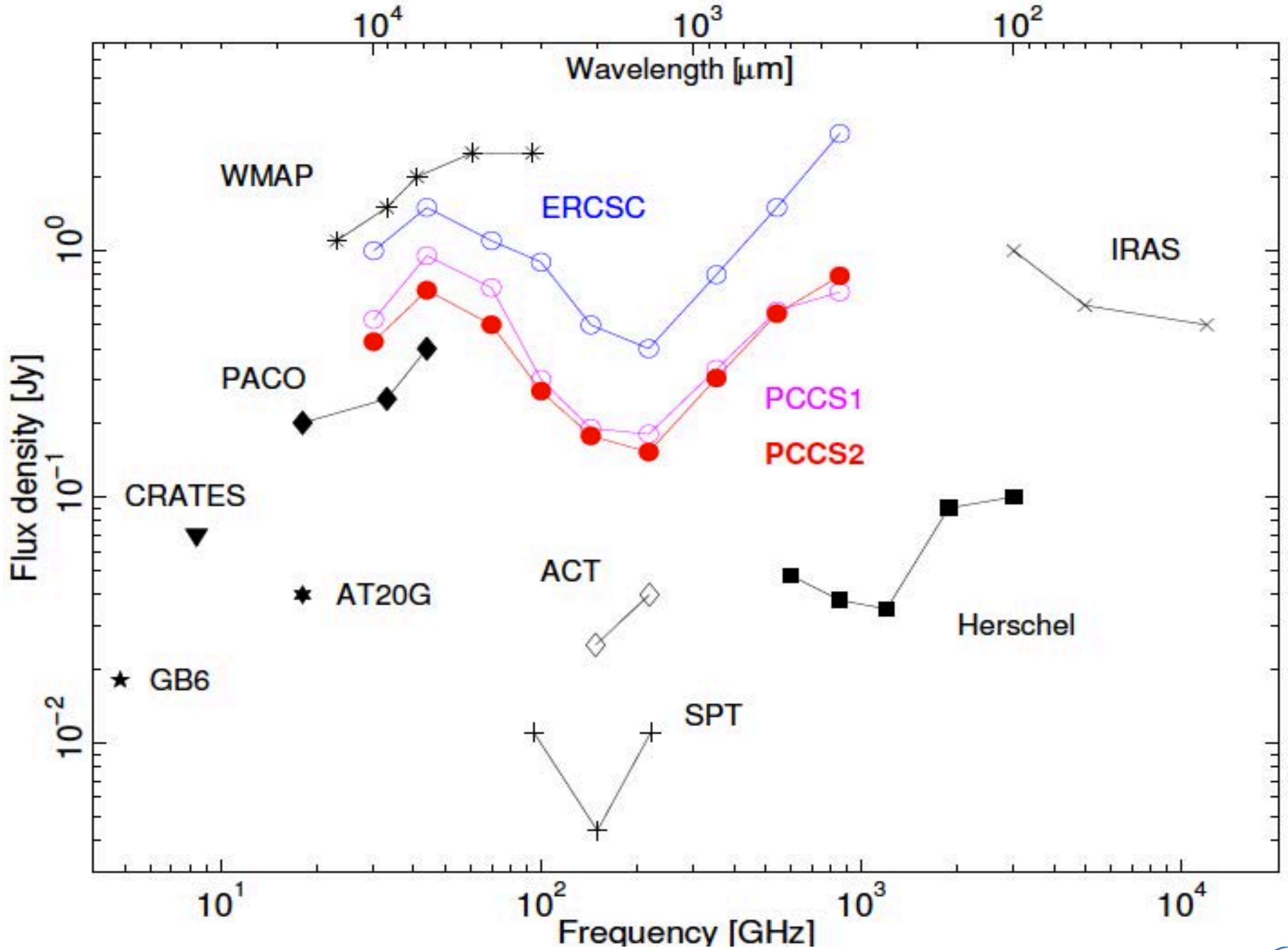
Repeated observations

Relatively insensitive to compact sources (limited aperture)

Polarization measured

-- B modes again

Products of *Planck*: the Catalogue of Compact Sources



Partridge, Ferrara, Dec 2014

Wide Frequency Coverage

Planck data could add confirmation

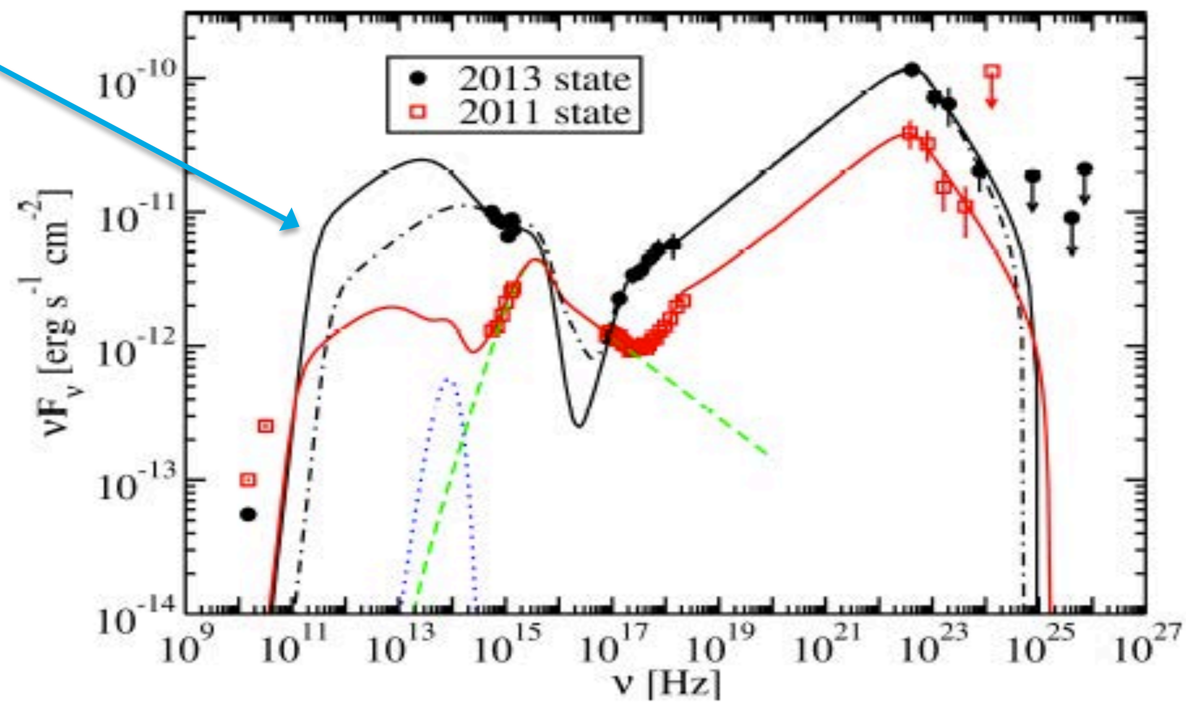


Figure 4. SEDs and models for the 2013 and 2011 activity states from PMN J0948+0022. The filled circles are the data from the 2013 flaring state, and the open squares are the data from the 2011 intermediate state taken from D'Ammando et al. (2014).

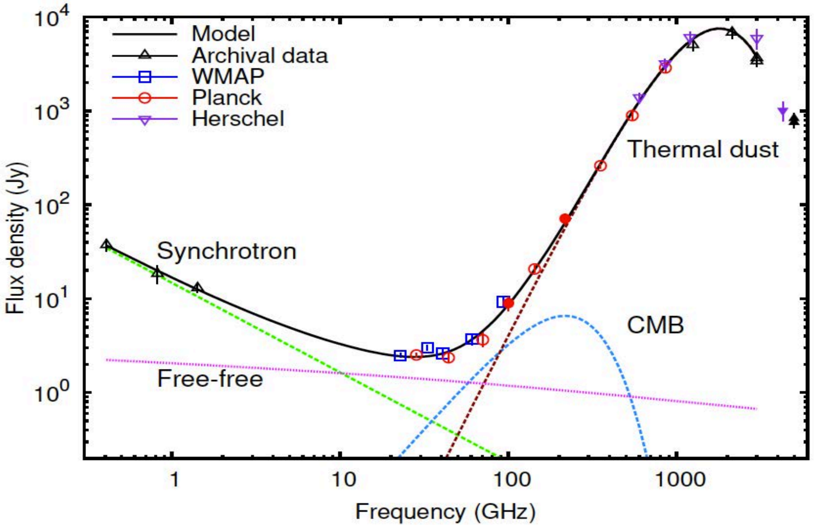
Wide Frequency Coverage

Why do CMB observers bother?

To measure and control foregrounds, mainly Galactic:

-- study CMB fluctuations in minimum of foregrounds (50-150 GHz)

-- lower (higher) frequencies added to control synchrotron (dust) emission (e.g. Advanced ACTPol will add 28, 41 and 90 GHz channels)



M31 (Planck Collab. XXV, 2013)

Wide frequency coverage was a key element of *Planck* design

Allows **simultaneous** measurements of source SEDs from **30 – 857 GHz**

Polarization

Great interest for Galactic studies

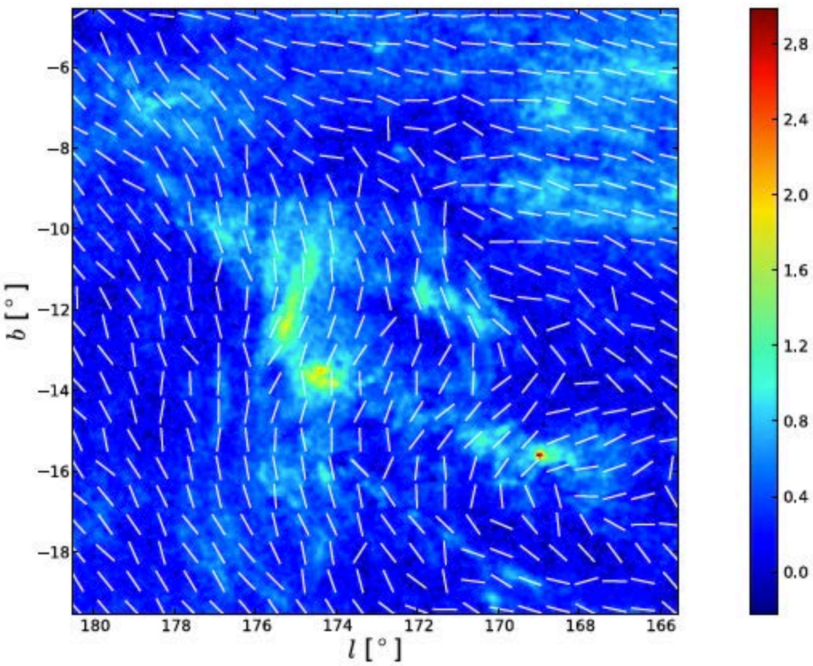


Fig. 26. Polarized intensity at 353 GHz (in mK_{CMB}) and polarization orientation indicated as segments of uniform length, in the Taurus region.

Polarization of compact sources covered earlier by Caniego here