Synergy: Radio Astronomy and CMB Observations (Especially *Planck's*)

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Haverford College, on behalf of the Planck Collaboration

A Radio Astronomer's Dream…

A Dream 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

One instance of the impact of CMB experiments on conventional radio astronomy

Some General Properties of Today's 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

Relevant Properties and Products of *Planck*

Frequency GHz	Beam HWFM arcmin	~Catalogue Sensitivity	Approx. Number of Sources Detected	Typical Type (Extragalactic)
28	32	0.46 Jy	1500	AGN
44	27	0.83	900	AGN
70	13	0.57	1300	AGN
100	9.7	0.23	1700	AGN
143	7	0.15	2200	AGN, some SFG
217	5	0.13	2100	½ AGN, ½ SFG
353	5	0.24	1400	SFG, few AGN
545	5	0.54	1700	SFG
857	4.5	0.72	4900	SFG

PRELIMINARY

See earlier talk by Lopez-Caniego on PCCS2

Relevant Properties and Products of *Planck*

Focal plane “footprint”

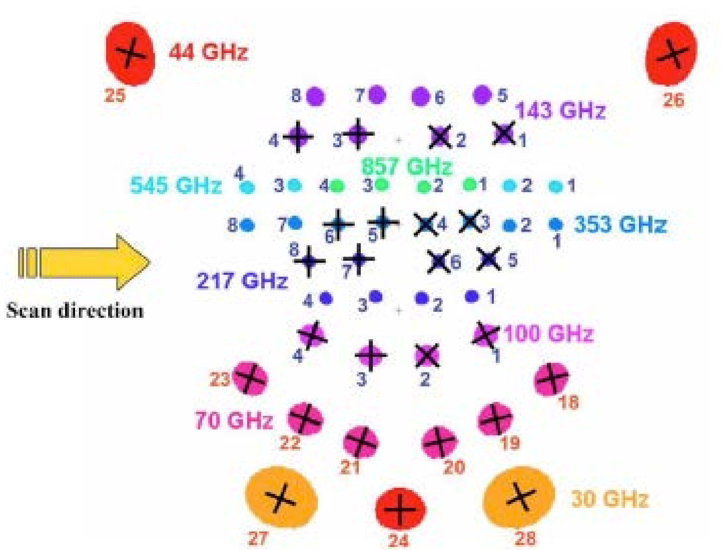
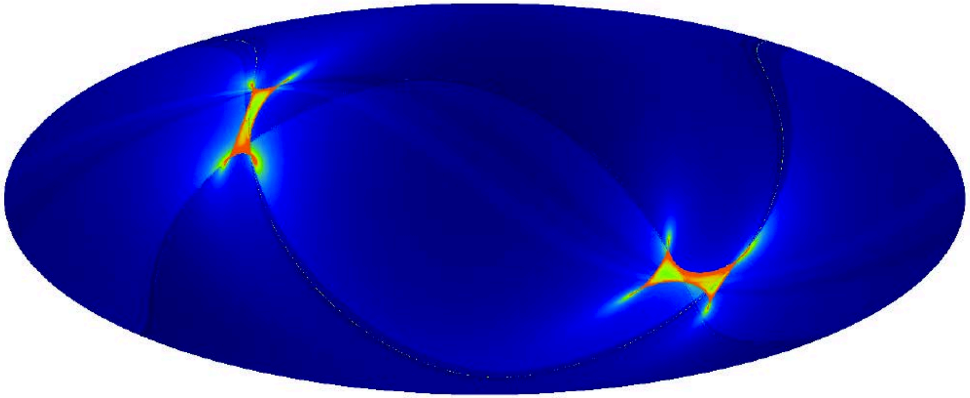


Fig. 1. Focal plane, showing spacing of the *Planck* receivers.

Scan pattern covers whole sky every six months

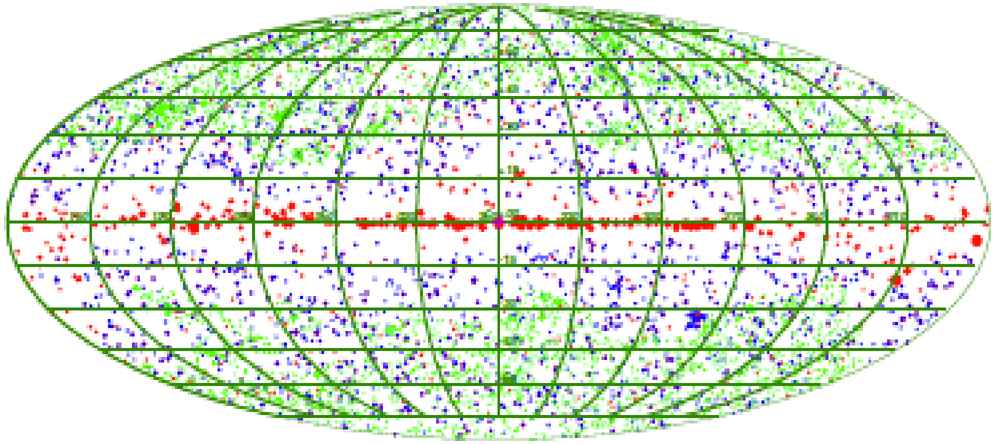
Denser coverage at ecliptic poles



1. All (or Large) Sky Surveys (at High Frequency)

Perfect to detect rare (but bright) sources

Sample results:



red, blue green = 30, 143 and 857 GHz

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. XXXV, 2015)

2. SPT discovery (Vieira et al., *Nature* 2013) of lensed sub-mm galaxies

3. *Planck* detection of clumps of high-redshift sources (Montier's talk here)

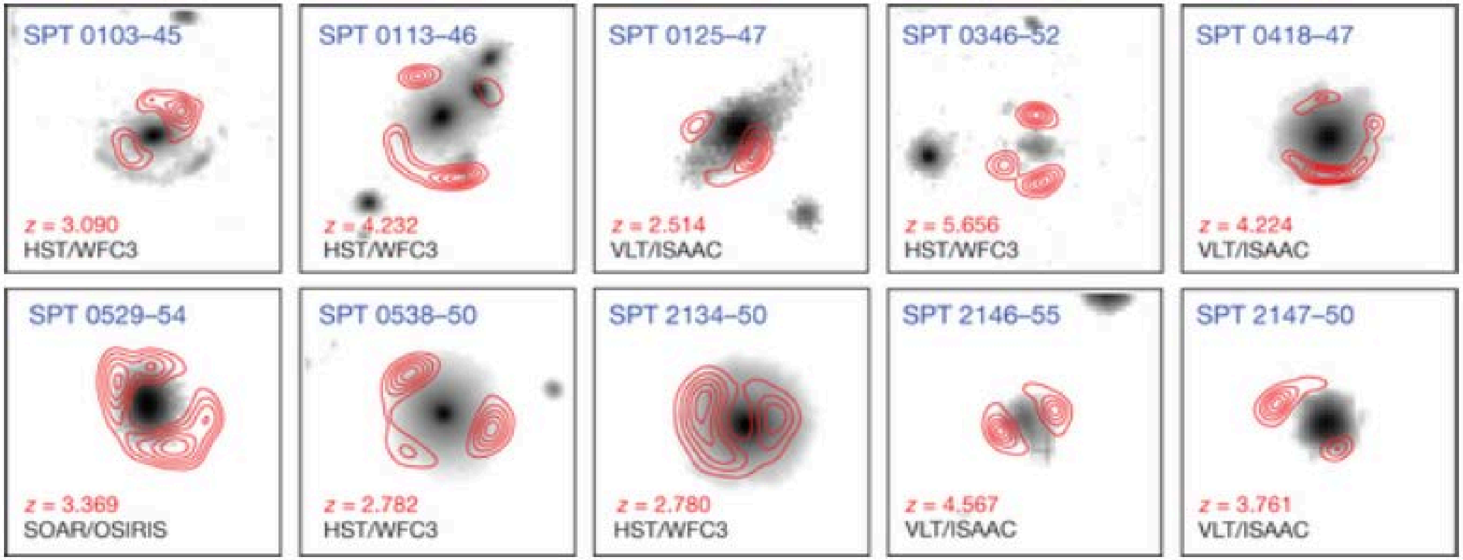
Lensed Sub-mm Galaxies

Strongly lensed sub-mm galaxies:

rare (at most ~0.01-0.1 deg^{-2}) above *Planck* thresholds

Hence more sensitive instruments found them first (SPT: Vieira et al., *Nature*, 2013)

Lensing also magnifies, allowing follow-up study of fine details, < 1 kpc (e.g. Canameras, Nesvadba et al., 2015 PRELIMINARY)



2. Wide Frequency Coverage

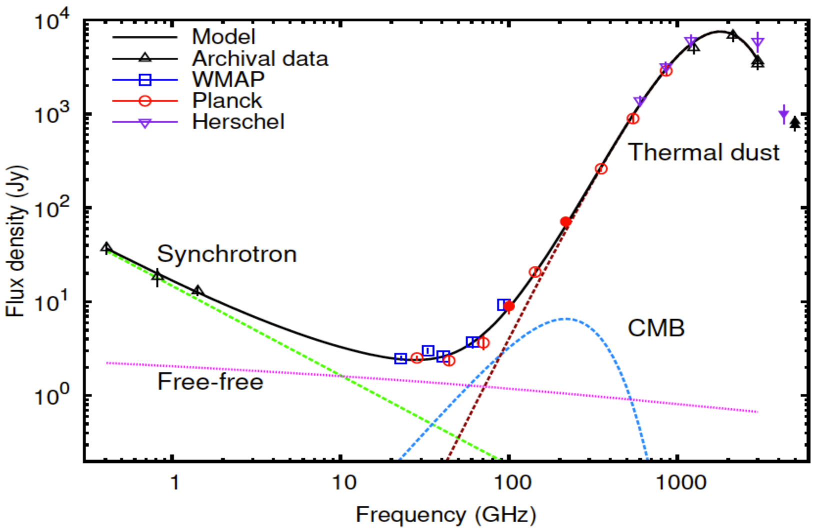
Why do CMB observers bother?

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)

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

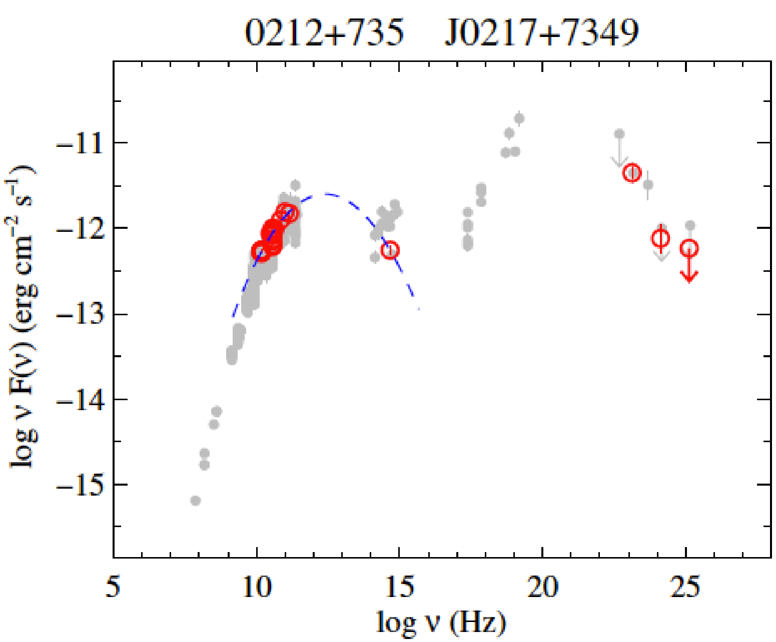


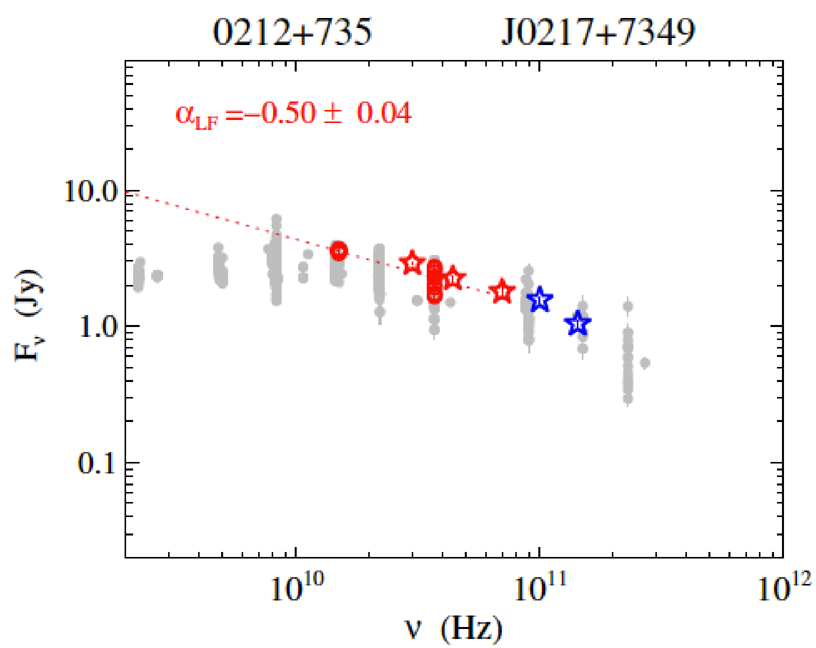
M31 (Planck Collab. XXV, 2013)

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

Source SEDs: Blazars

Sample spectra from Planck Early Release XV, 2011





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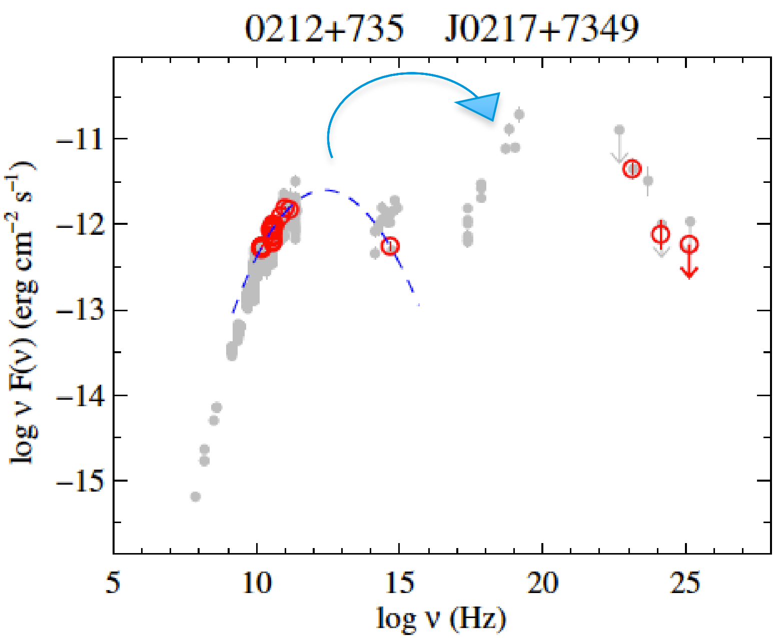
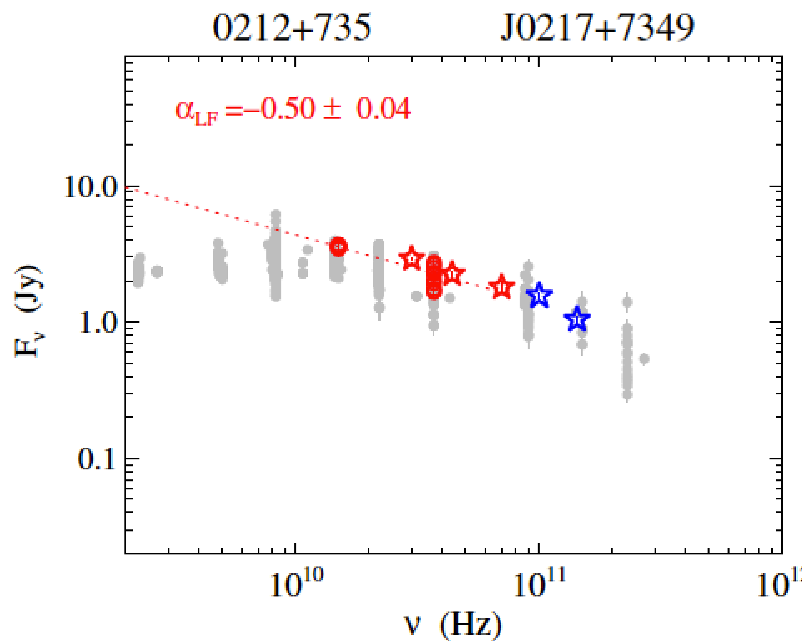




Planck comes close to covering frequency range of sub-mm/FIR photons that inverse Compton boosts (by ~10^9) to X/gamma energies

Wide Frequency Coverage

Planck data could add confirmation

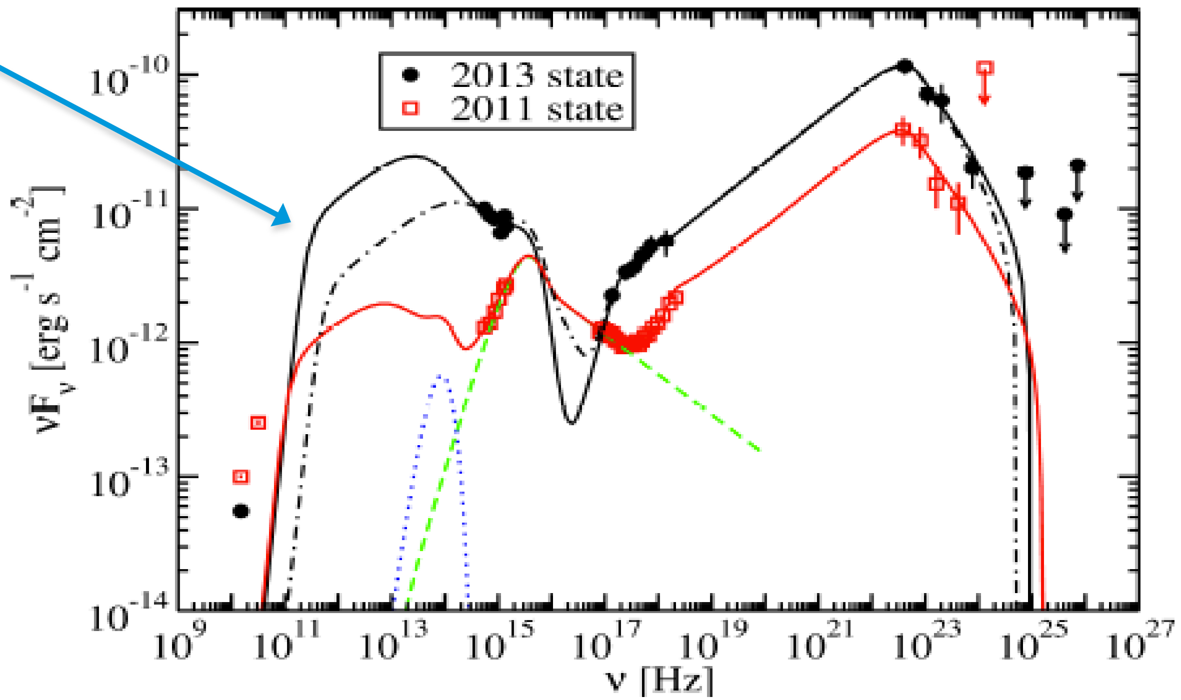
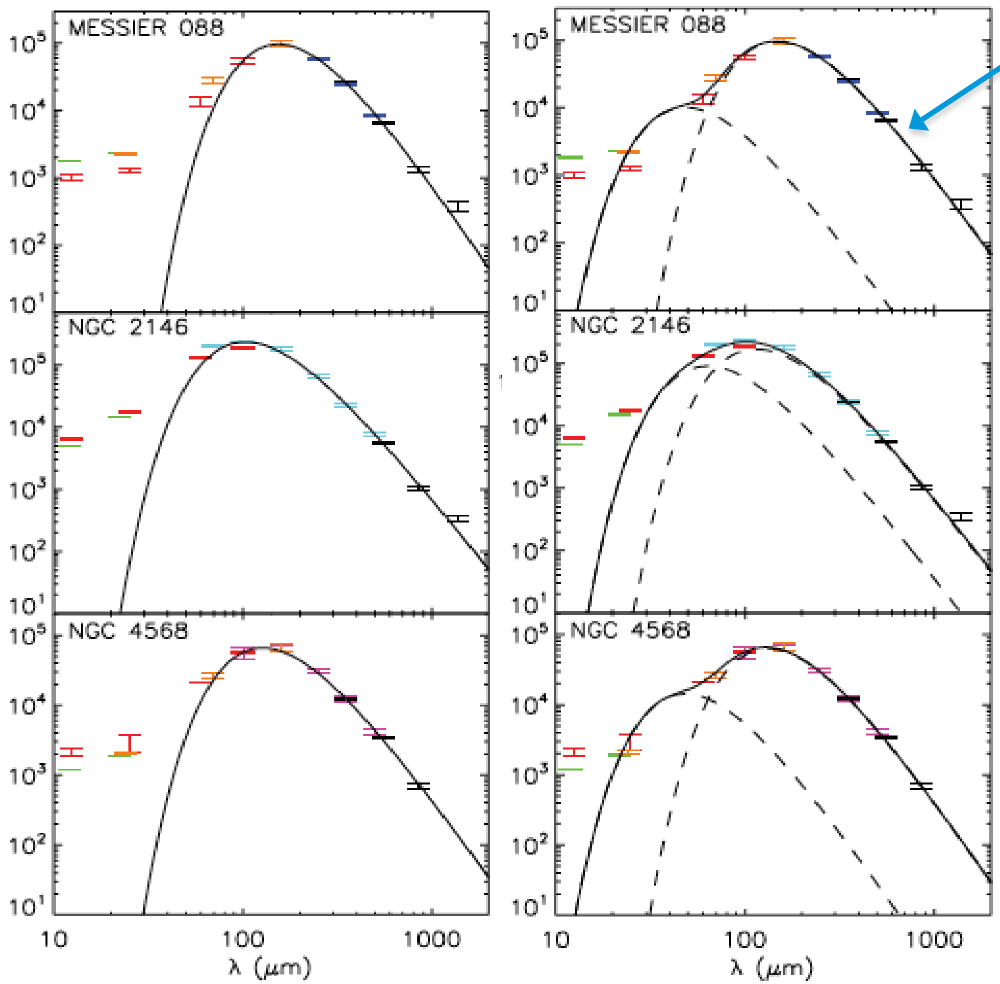


Figure 4. SEDs and models for the 2013 and 2011 activity states from PMN J0948+0022. The filled circles are the data from the 2013 flaring state, and the open squares are the data from the 2011 intermediate state taken from D'Ammando et al. (2014).

Source SEDs: Star Forming Galaxies (SFGs)

One and two temp. fits



Planck gets low-temp dust

Conclusions on local galaxies from Clemens et al. MN 2013

No super-cool (6-10 K) dust

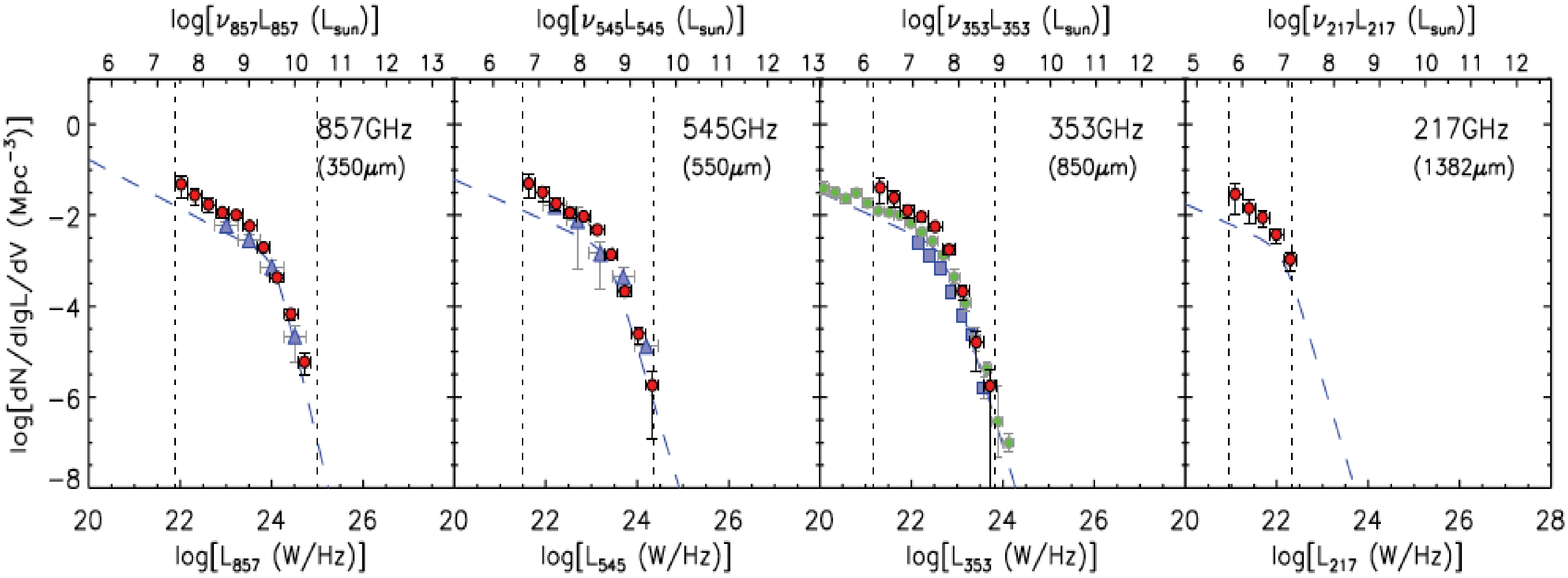
Warm dust, though negligible in mass, contributes ~1/3 of sub-mm luminosity

Dust mass = 0.022 HI mass

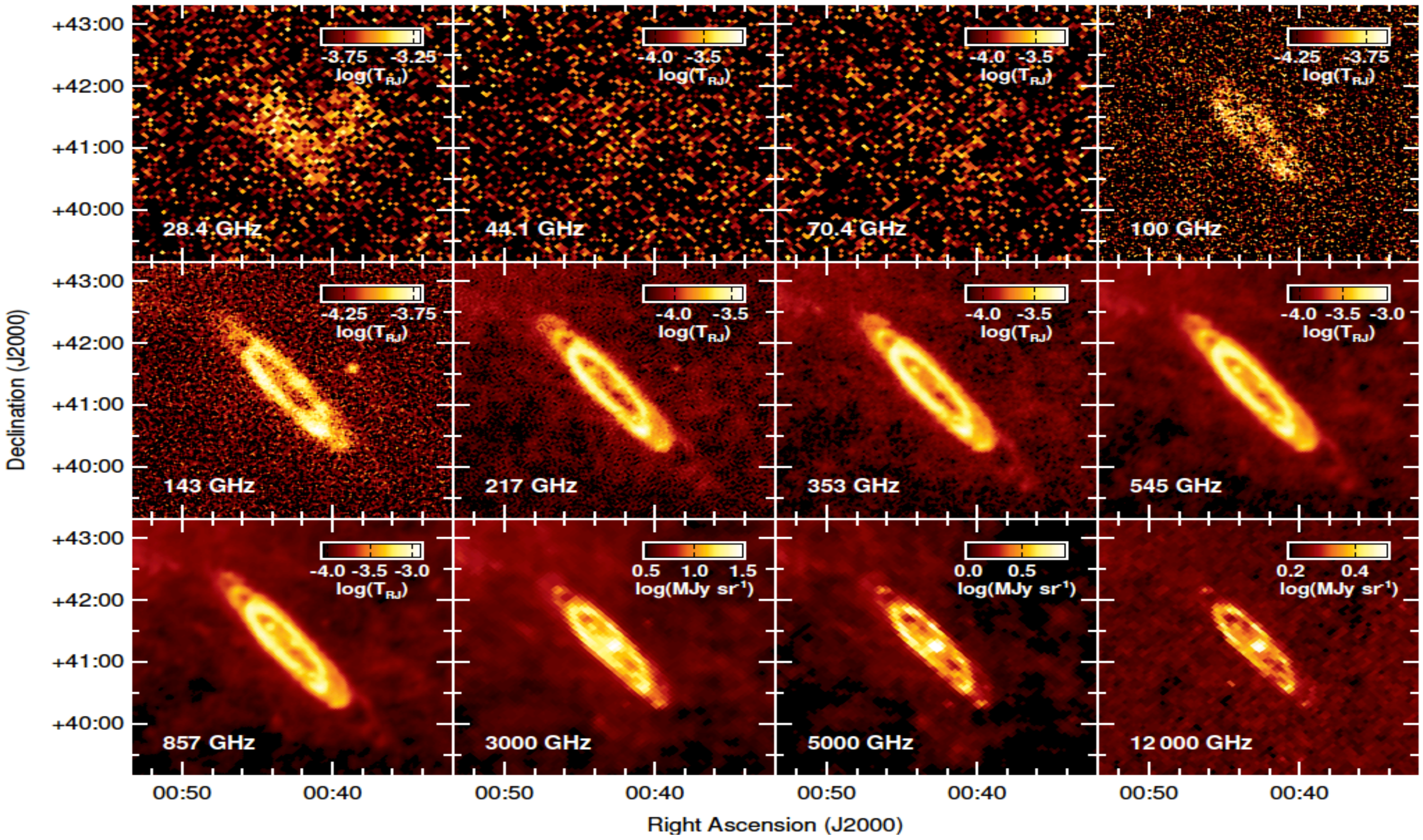
Density of dust in local Universe = 7 ± 1.4 x 10^5 M_o/Mpc^3

Frequency Coverage (Including those Hard to Reach from the Ground)

Has allowed determination of luminosity functions (Negrello et al. MN, 2014)



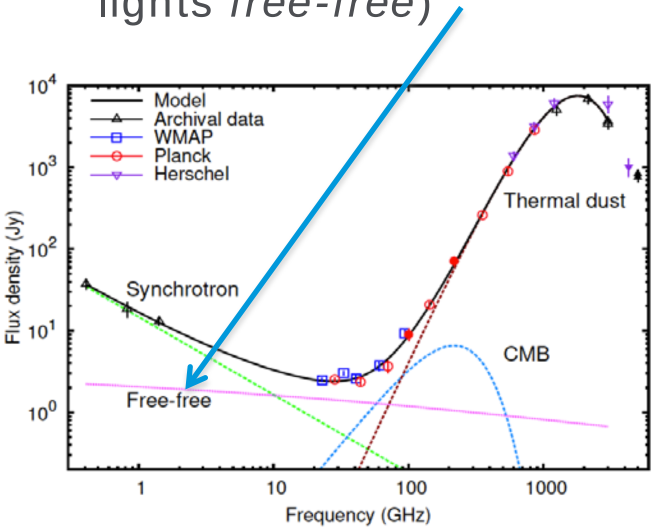
Resolved Nearby Galaxies (M31)

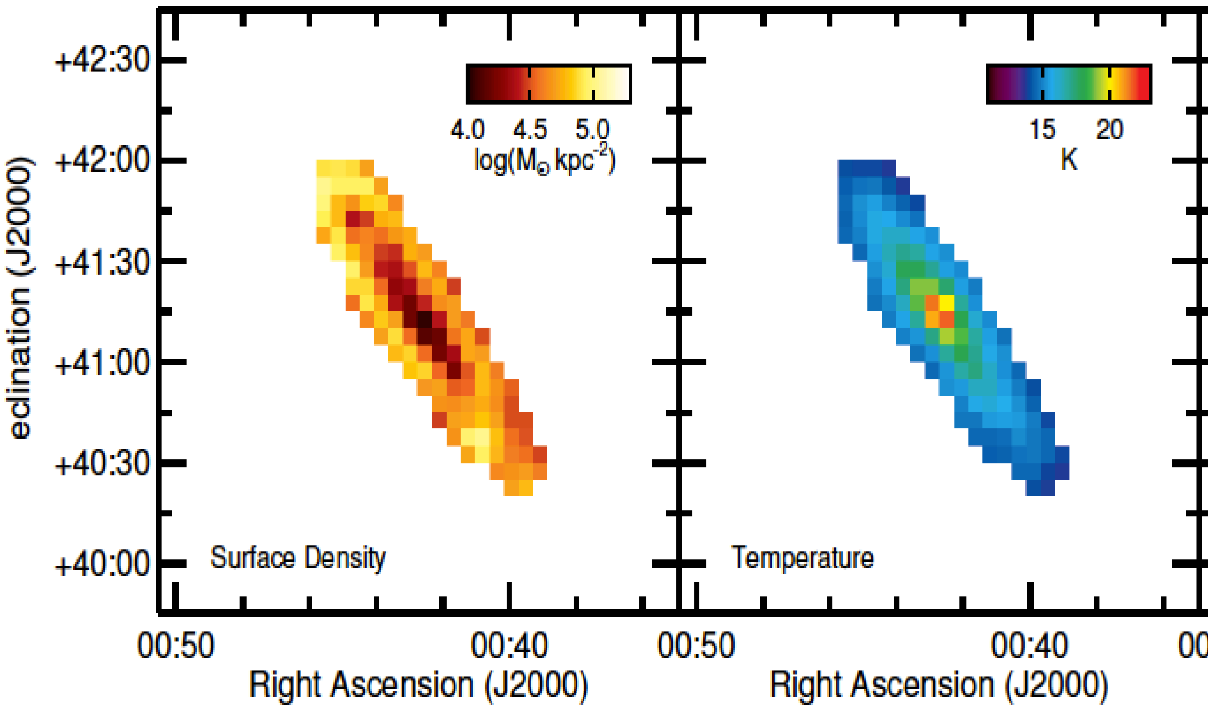


Planck images of M31 (Planck Intermediate Results XXV, 2014)

Resolved Nearby Galaxies (M31)

Integrated spectrum of M31 (*Planck* high-lights *free-free*)





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

3. Polarization

Great interest for Galactic studies

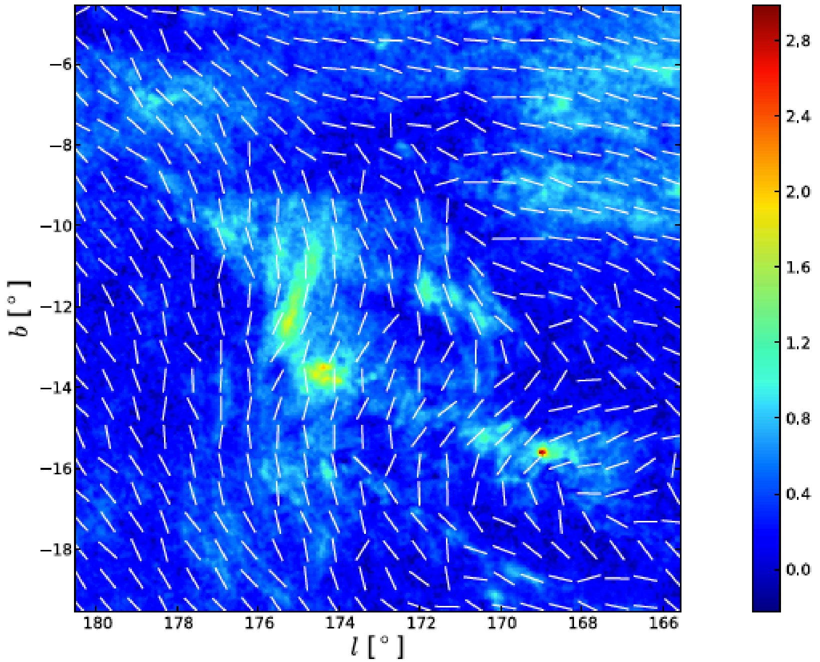


Fig. 26. Polarized intensity at 353 GHz (in mK_{CMB}) and polarization orientation indicated as segments of uniform length, in the Taurus region.

Polarization

But I will skip over

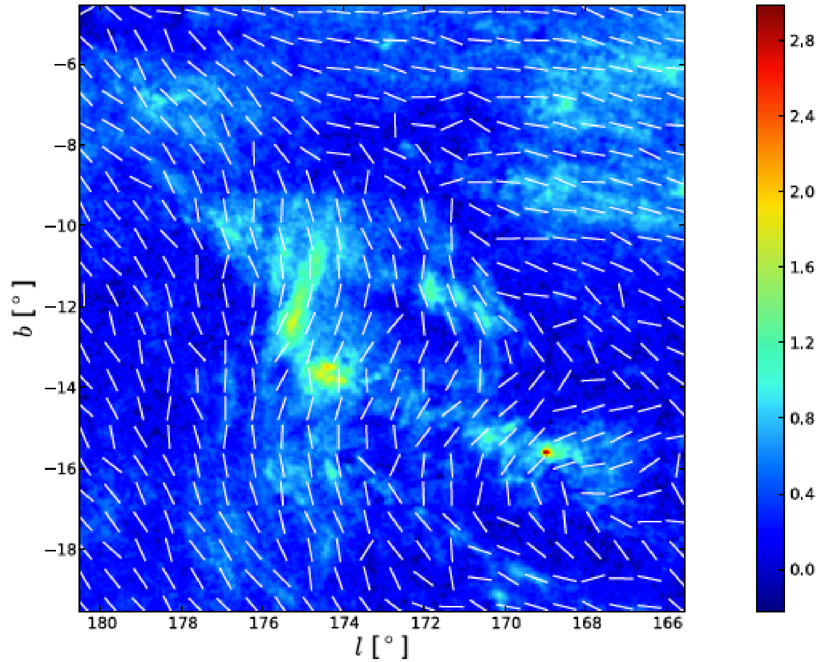


Fig. 26. Polarized intensity at 353 GHz (in mK_{CMB}) and polarization orientation indicated as segments of uniform length, in the Taurus region.

Polarization of compact sources covered earlier by Lopez-Caniego here

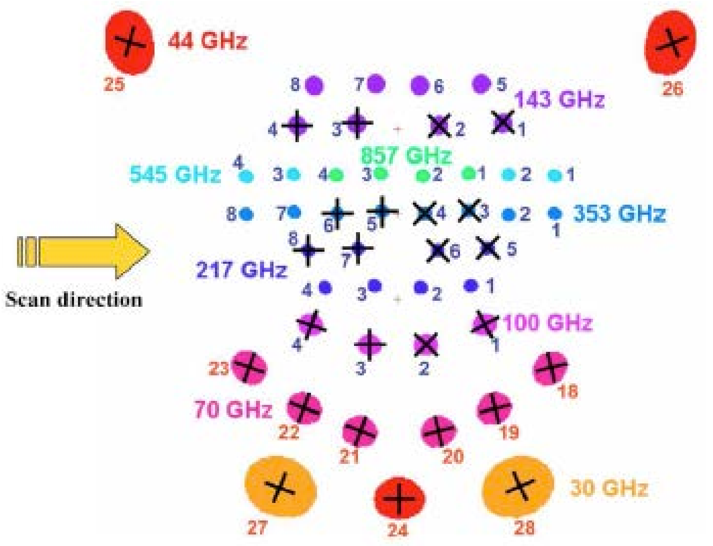
4. Cadence Allows Variability Studies

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

So data available 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

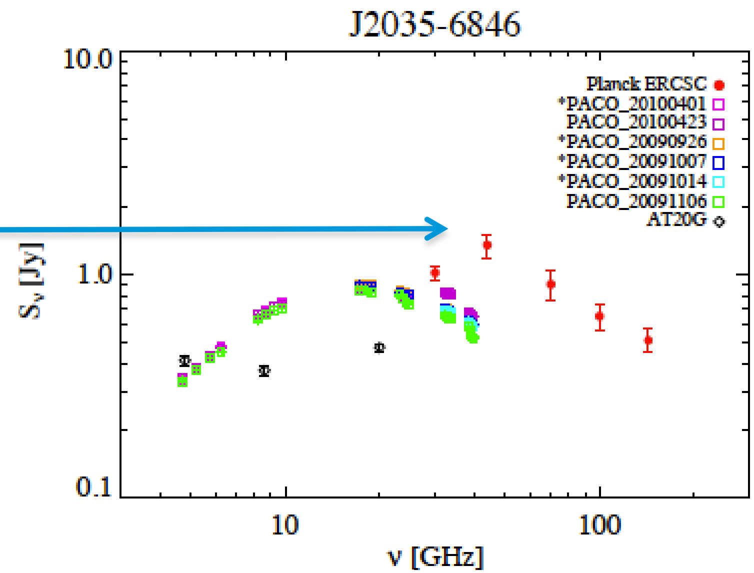


Variability Studies

Phenomena:

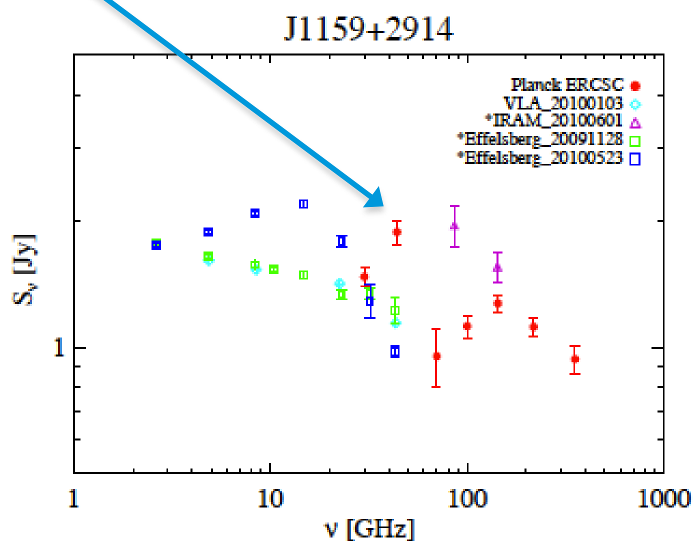
Flares

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



Planck data in red

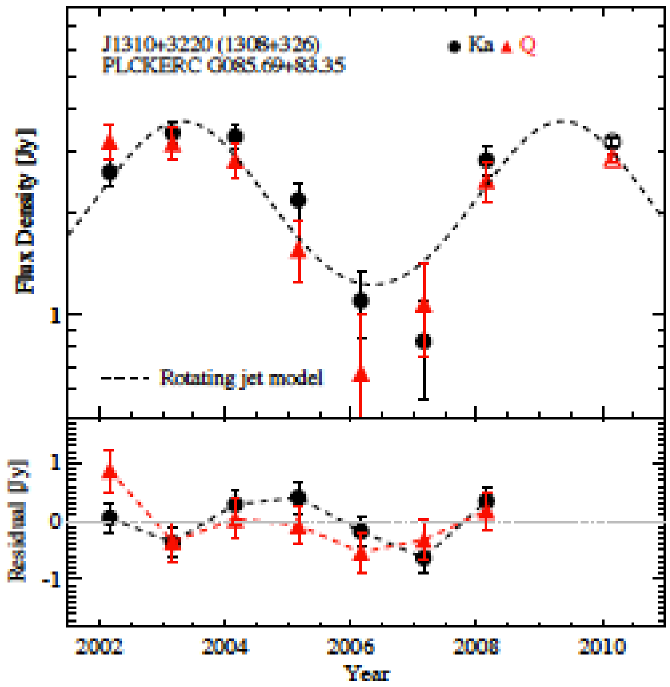
(from Planck Early Results XIV, 2011)



Variability Studies

Long term variability using WMAP and *Planck* year and 6 month average measurements (see Chen et al., *A&A*, 2013)

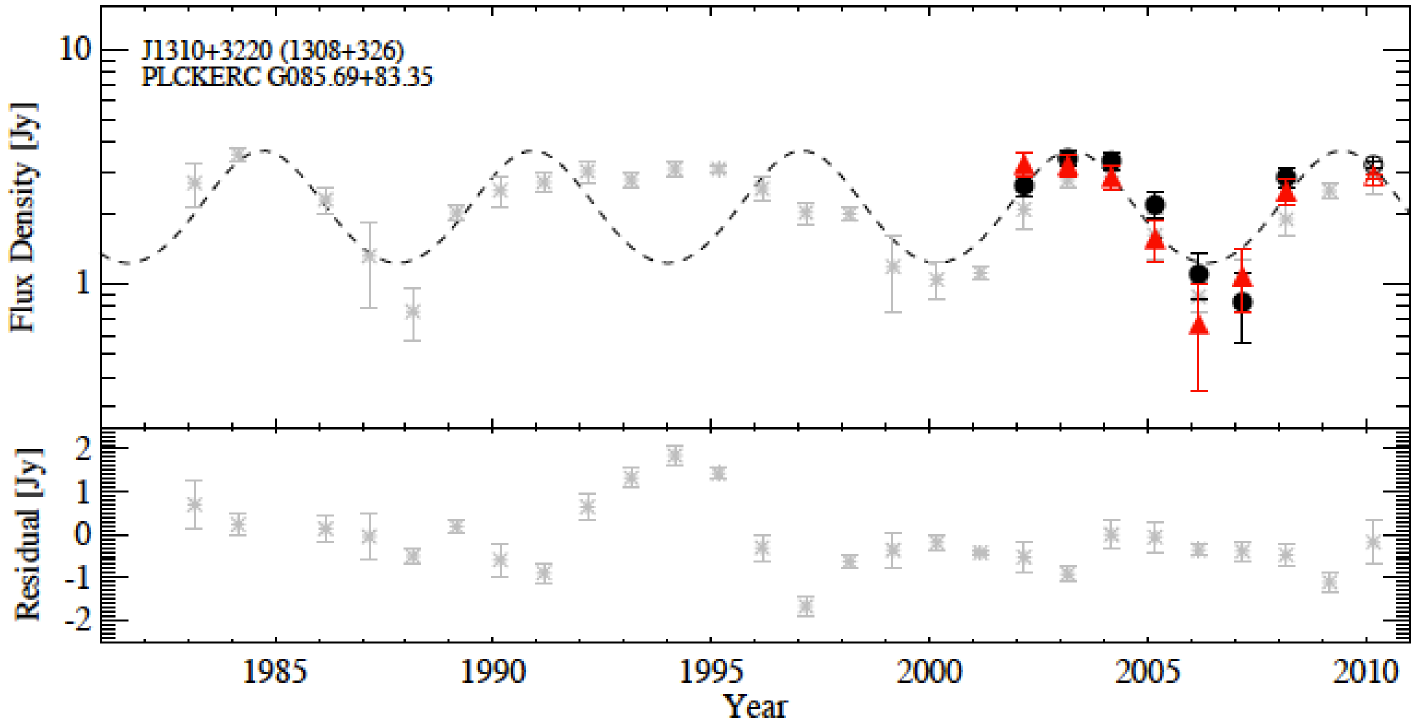
One intriguing possibility – sinusoidal light curves produced by a rotating jet



Variability Studies

But be careful...

...same source over longer timespan



5. Absolute Calibration

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

Ground based CMB experiments calibrate against Planck and WMAP – hence also ***absolute***

Transfer to ground-based radio telescopes:

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

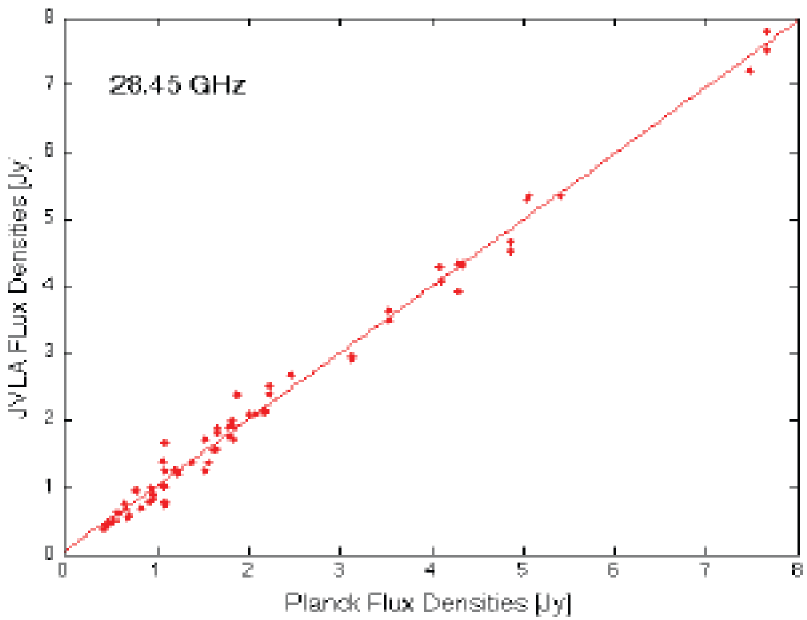
Direct – compare flux density measurements at VLA and Australia Telescope (AT) with nearly simultaneous *Planck* measurements (Perley, Partridge et al. 2015)

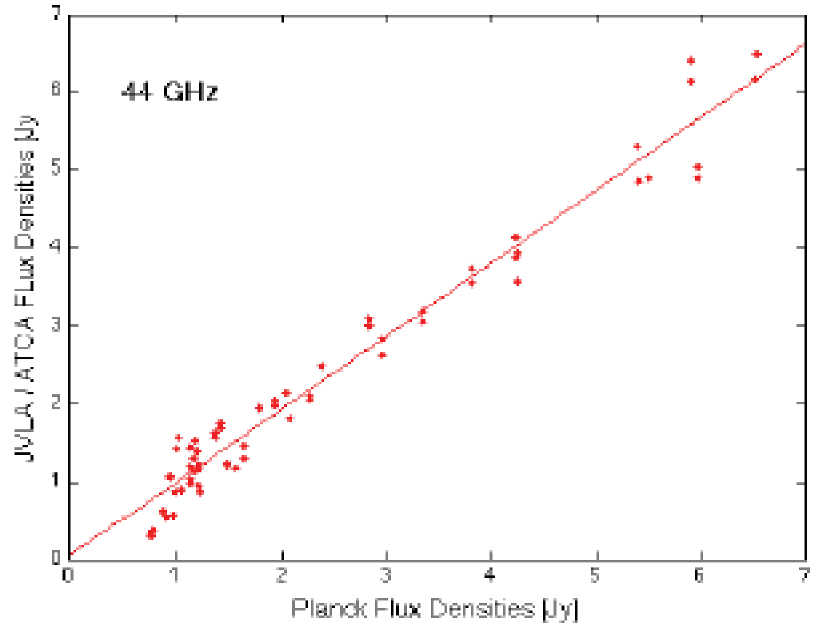
Extend to ALMA, etc.

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

Absolute Calibration

Results at 28.45 and 43.34 GHz PRELIMINARY





VLA = 0.97 ± 0.012 *Planck*

ATCA & VLA = 0.94 ± 0.017 *Planck*

See Louis et al. *JCAP*, 2014. Updated: at 143 GHz, ACT = 0.96 ± 0.02 *Planck*

Absolute Calibration

Similar study comparing *Planck* to Herschel (Negrello et al. MN 2013)

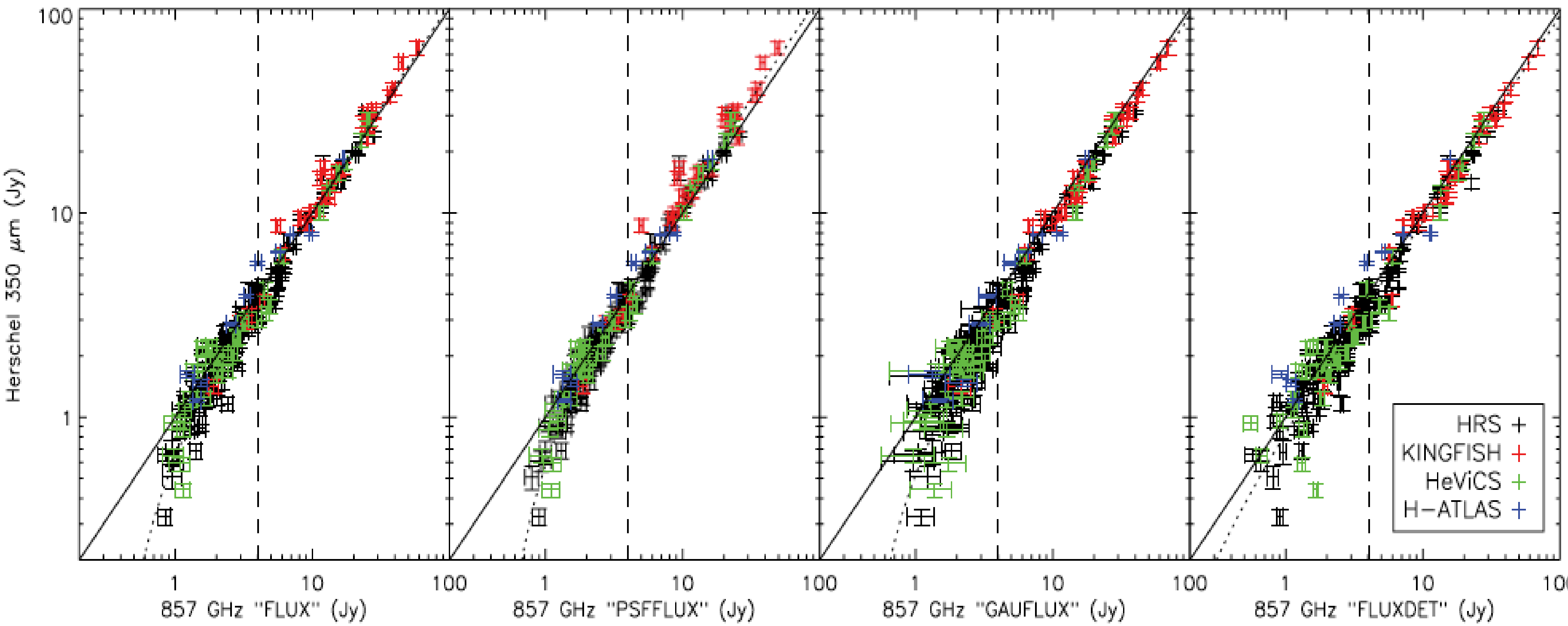


Figure 2. Comparison of the four *Planck* flux density estimations at 857 GHz (350 μm) with *Herschel* measurements at the same frequency. The symbols and the lines have the same meaning as in Fig. 1.

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.


Thank you, audience
X. Ferrara, Dec 2014


and thank you,
Planck!