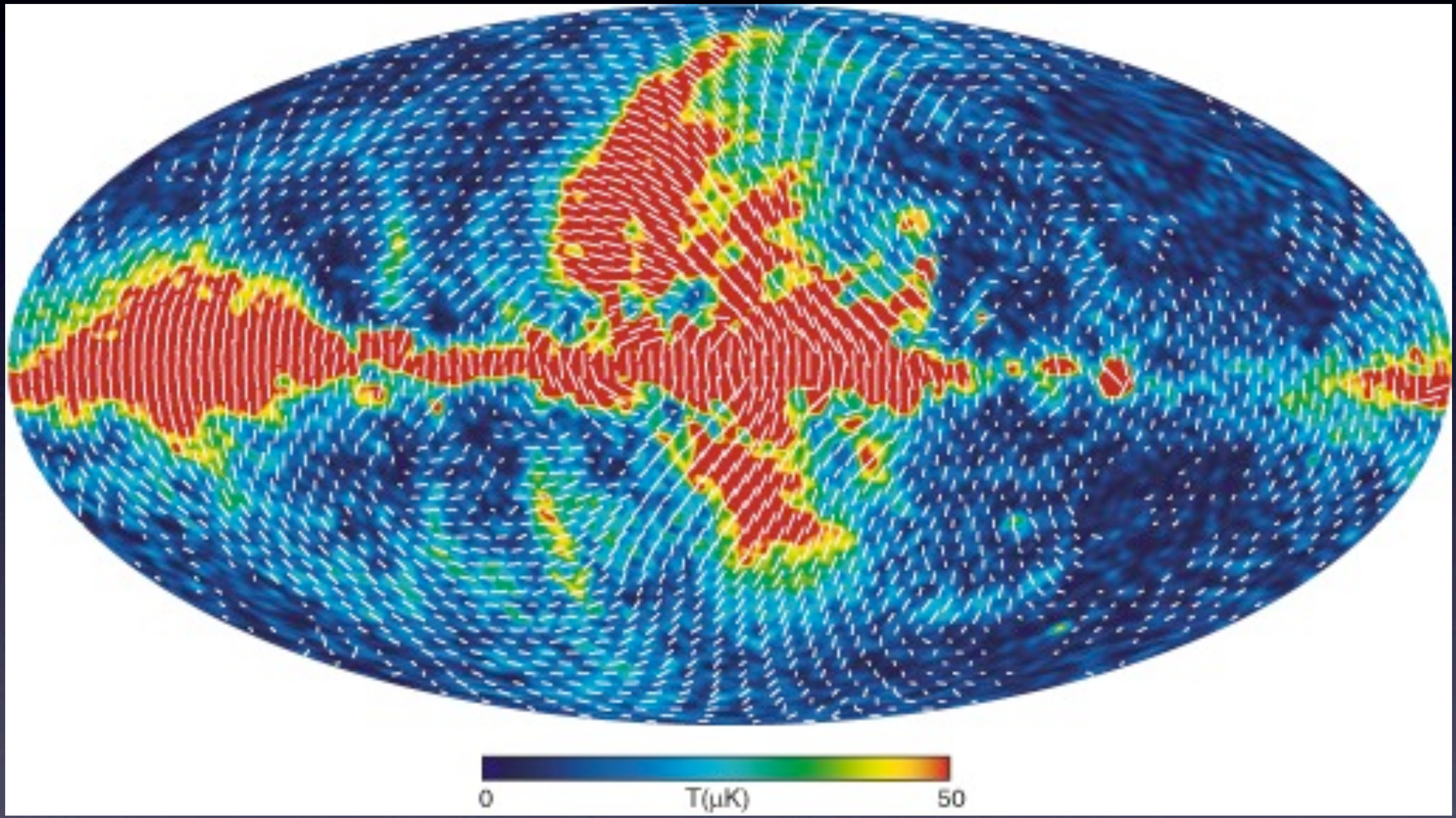
Polarized foregrounds: Free-free and Anomalous Microwave Emission



Clive Dickinson
Jodrell Bank Centre for Astrophysics, University of Manchester

Polarized foregrounds workshop, MPA, Munich, 26-28 November 2012

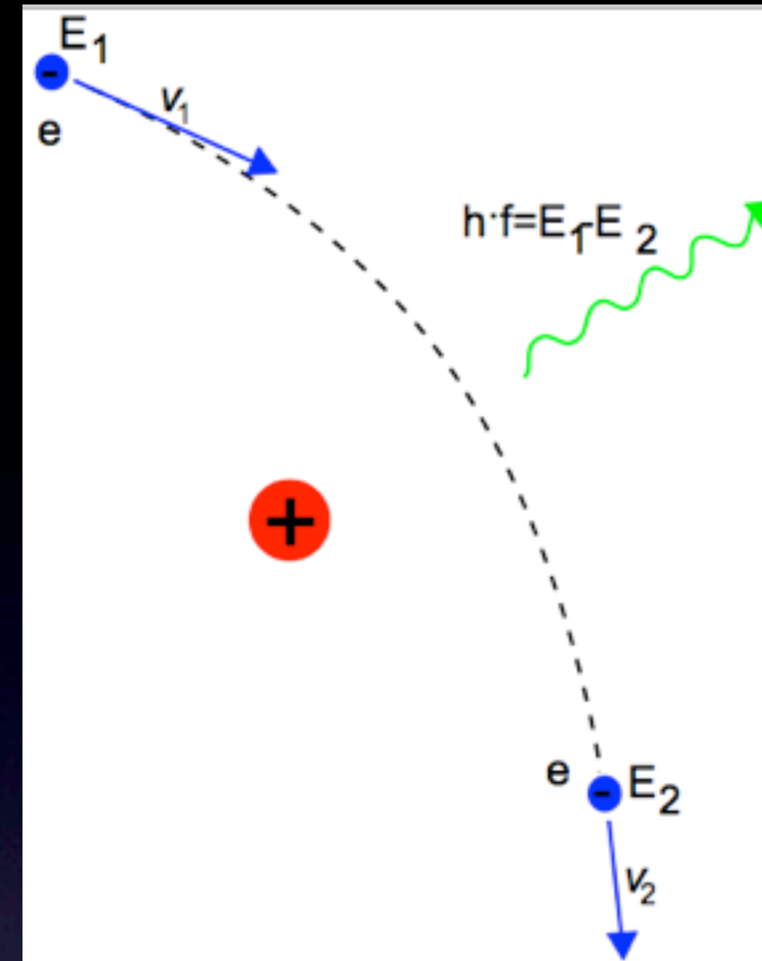
I begin with the conclusions

- Both free-free and AME (if due to spinning dust grains) probably have a very low level of polarization
  - Free-free <1% (on average)
  - AME ~1% or less (on average)
- Synchrotron & thermal dust polarization will dominate

A cosmologist

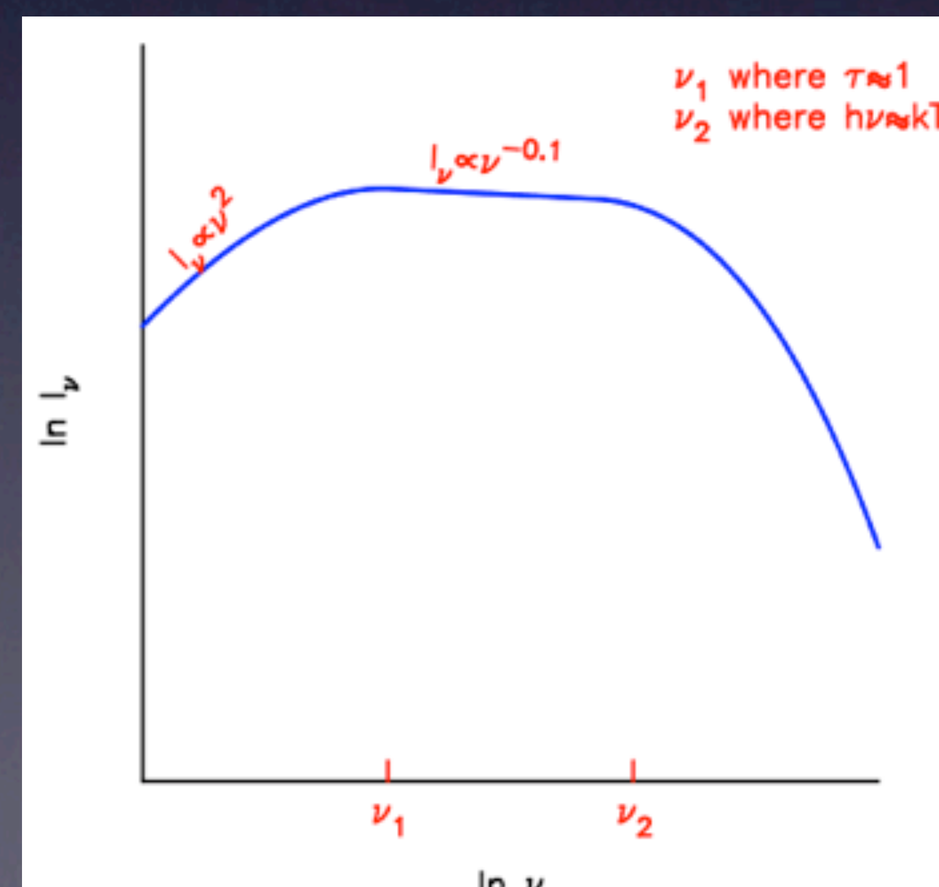
Free-free emission

- Thermal bremsstrahlung
- Coulombic interaction of electrons with ions
- Well-defined spectrum
  - β=-2.1
  - Slight steepening at higher frequencies (Gaunt factor)



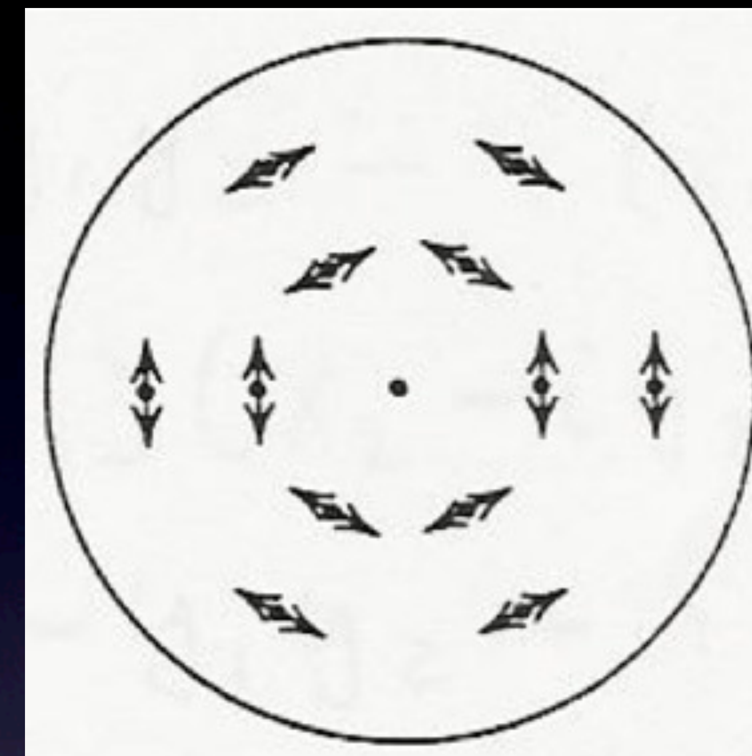
$$\tau_\nu \approx 3.28 \times 10^{-7} \left(\frac{T_e}{10^4\ \mathrm{K}}\right)^{-1.35} \left(\frac{\nu}{\mathrm{GHz}}\right)^{-2.1} \left(\frac{EM}{\mathrm{pc\ cm^{-6}}}\right)$$

$$T_b = T_e(1 - e^{-\tau})$$



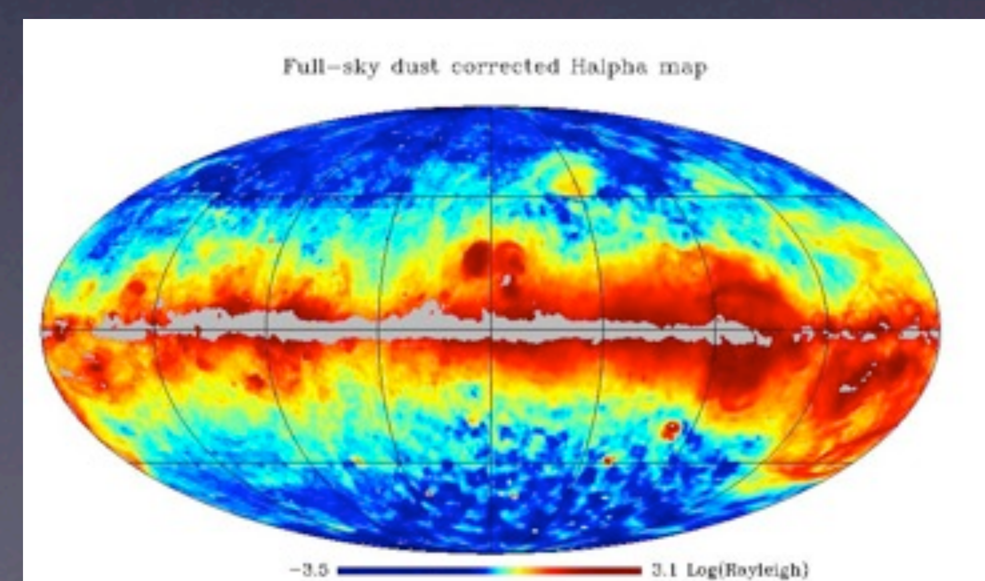
Free-free polarization (theory)

- Process is intrinsically direction independent
  - No polarization
- Thomson scattering by electrons in the HII region itself
  - Frequency independent
  - Polarized tangentially to the edge of the cloud
  - Potentially up to 100% polarized! (when $\theta=\pi/2$)
  - Max ~10% for optically thick cloud (Keating et al. 1998)
- At high latitudes, away from bright structures, will be <u>much</u> smaller!
  - No strong edges -> negligible polarization



$$\Pi = \frac{1-\cos^2\theta}{1+\cos^2\theta}$$

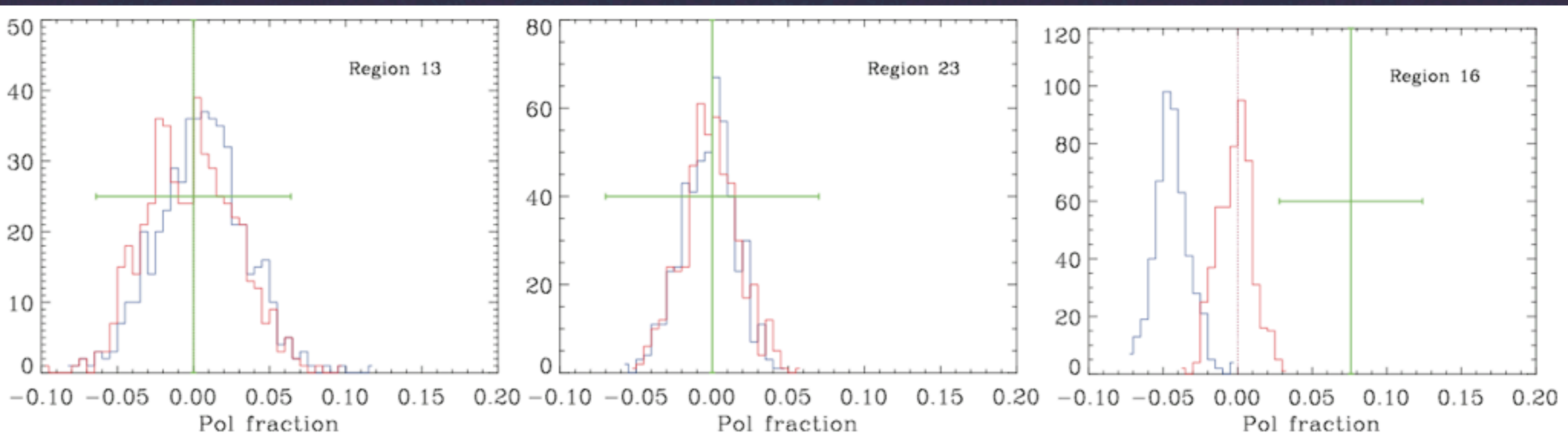
Rybicki & Lightman (1979)



Free-free polarization - data

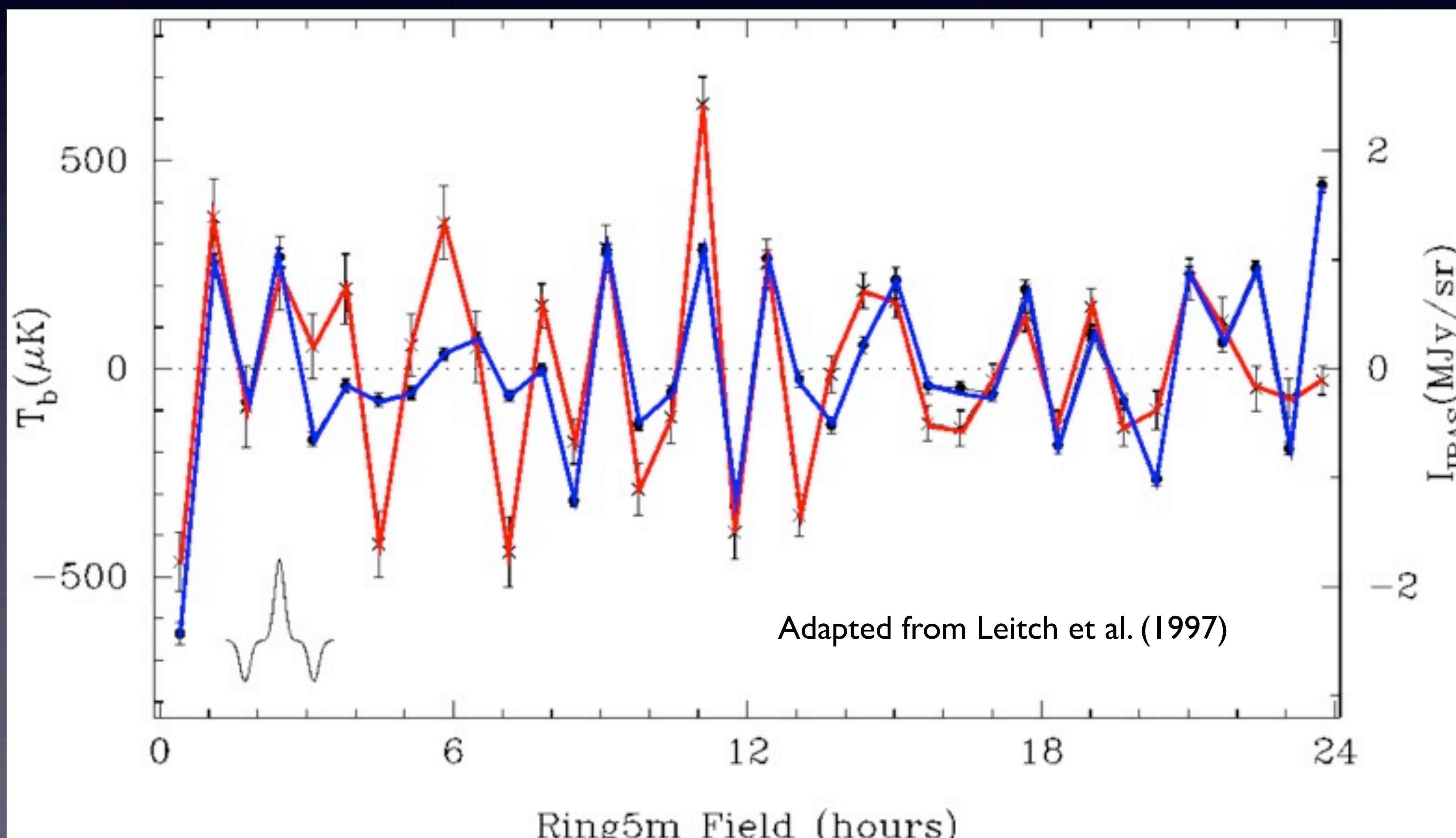
- Not much out there!!!
- Macellari et al. (2011) used template fitting to estimate average properties including free-free (Hα) correlated foregrounds
  - <3.4 % (95% CL) average of regions
  - <1% all-sky analysis

Macellari et al. (2011)



Anomalous Microwave Emission

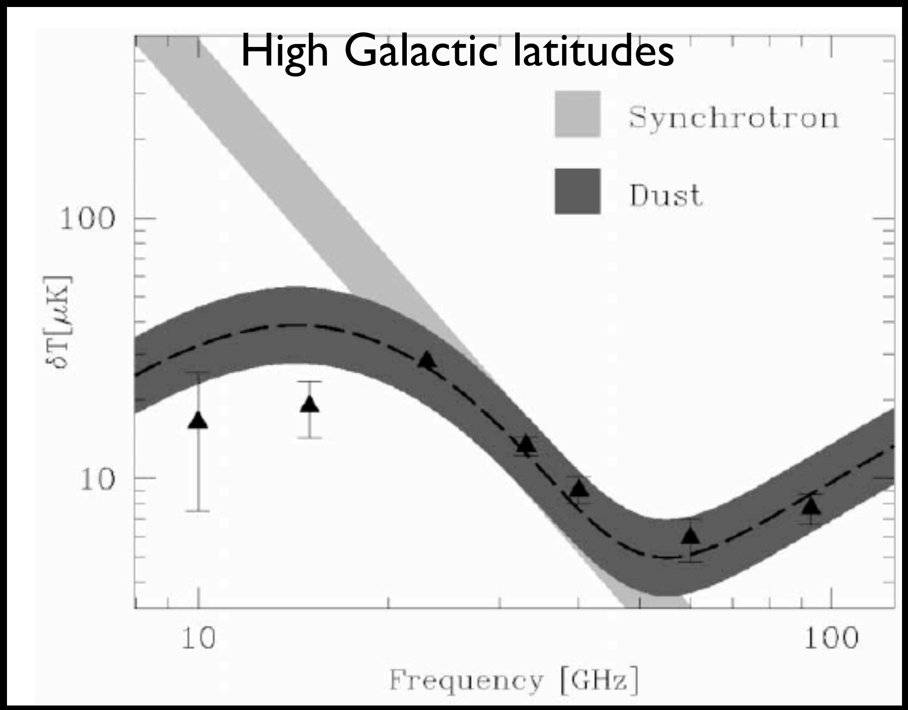
- AME is strong at ~10-100 GHz
- Correlated with FIR dust emission



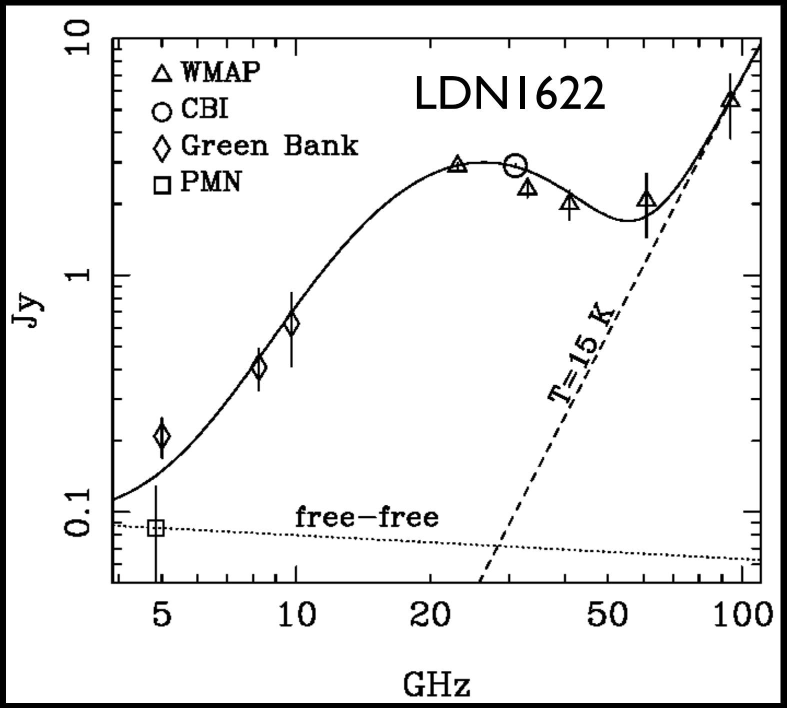
Quite a bit of evidence over the years...(!)

- A lot of evidence over the last 15 years - very active area of research, but still little is known about it! (lack of data!)
- Many papers, instruments, techniques, frequency ranges. E.g.:-
  - OVRO: Leitch et al. (1997)
  - COBE-DMR: Kogut et al. (1996), Banday et al. (2003)
  - Saskatoon: de Oliveira-Costa (1997)
  - Tenerife: Mukherjee et al. (2001), de Oliveira-Costa et al. (2002, 2004)
  - Python V: Mukherjee et al. (2003)
  - Green Bank: Finkbeiner (2002), Finkbeiner et al. (2004)
  - Cosmosomas: Watson et al. (2005), Battistelli et al. (2006), Hildebrandt et al. (2007)
  - VSA: Scaife et al. (2007), Tibbs et al. (2010), Todorovic et al. (2010), Tibbs et al. (2011)
  - CBI: Casassus et al. (2004,2006,2007,2008), Dickinson et al. (2006,2007,2009a,2010), Castellanos et al. (2011), Vidal et al. (2011)
  - AMI: Scaife et al. (2008), Scaife et al. (2009a,b), Scaife et al. (2010), Tibbs et al. (2012)
  - WMAP: Bennett et al. (2003), Lagache et al. (2003), Davies et al. (2006), Bonaldi et al. (2007), Miville-Deschenes et al. (2008), Gold et al. (2009), Dobler & Finkbeiner (2009), Ysard et al. (2009), Dickinson et al. (2009a, 2011), Lopez-Caraballo (2011), Peel et al. (2011), Macellari et al. 2011, Ghosh et al. (2011), Genova-Santos et al. (2011)
  - Planck: Planck collaboration (Early paper A20, A21; 2012 in prep.)
  - & now extragalactic as well! (Murphy et al. 2010; Scaife et al. 2010)

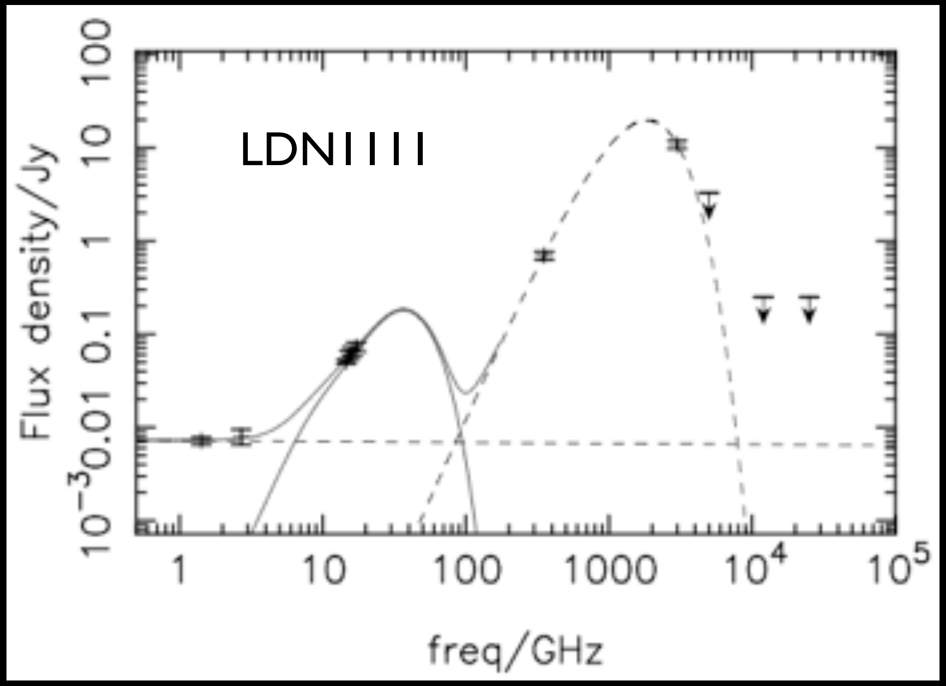
Example detections (need more data!)



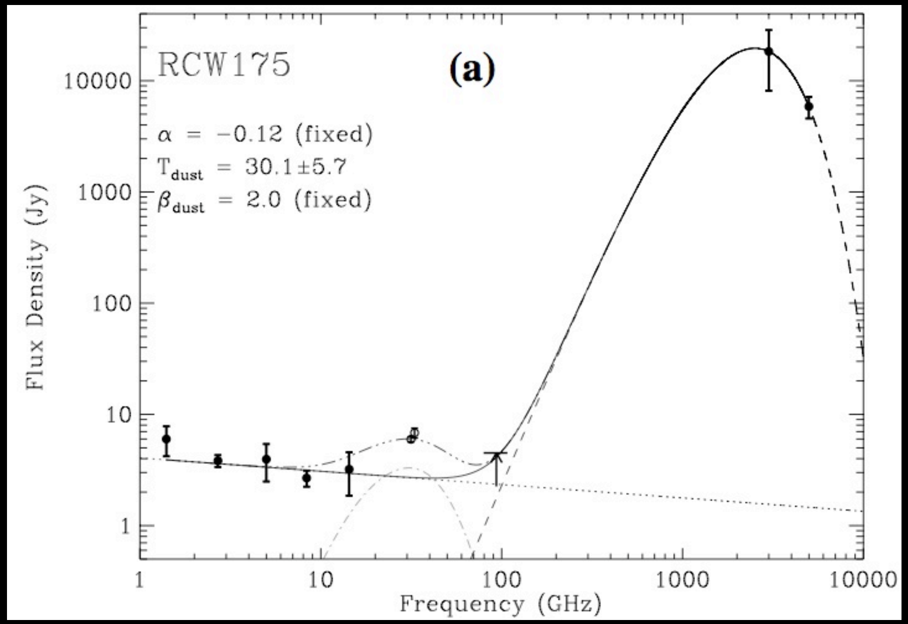
de Oliveira-Costa (2004)



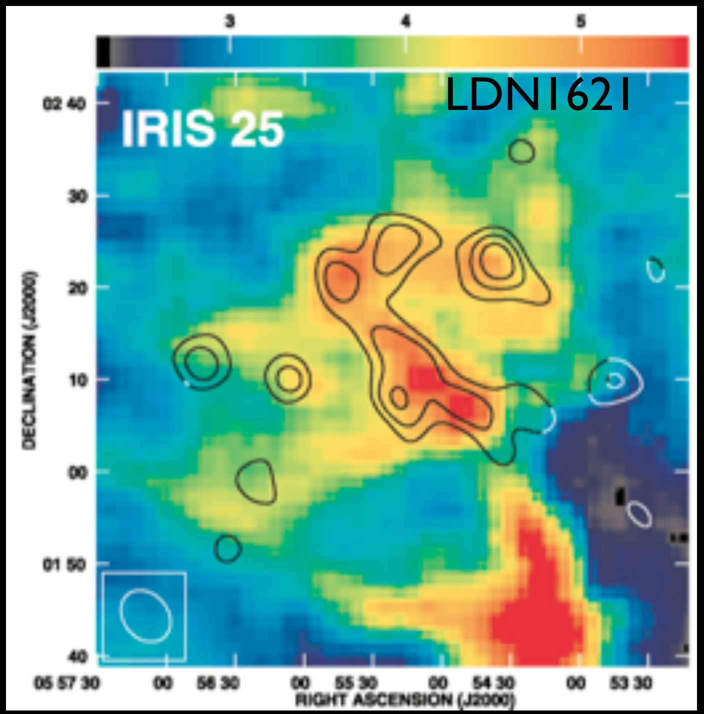
Casassus et al. (2006)



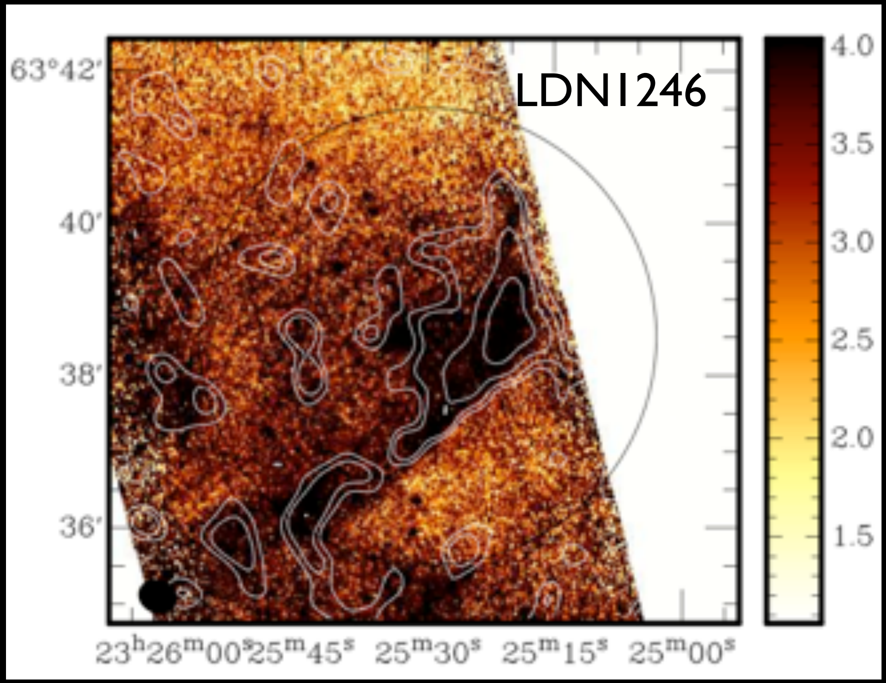
Scaife et al. (2009a)



Dickinson et al. (2009)



Dickinson et al. (2010)



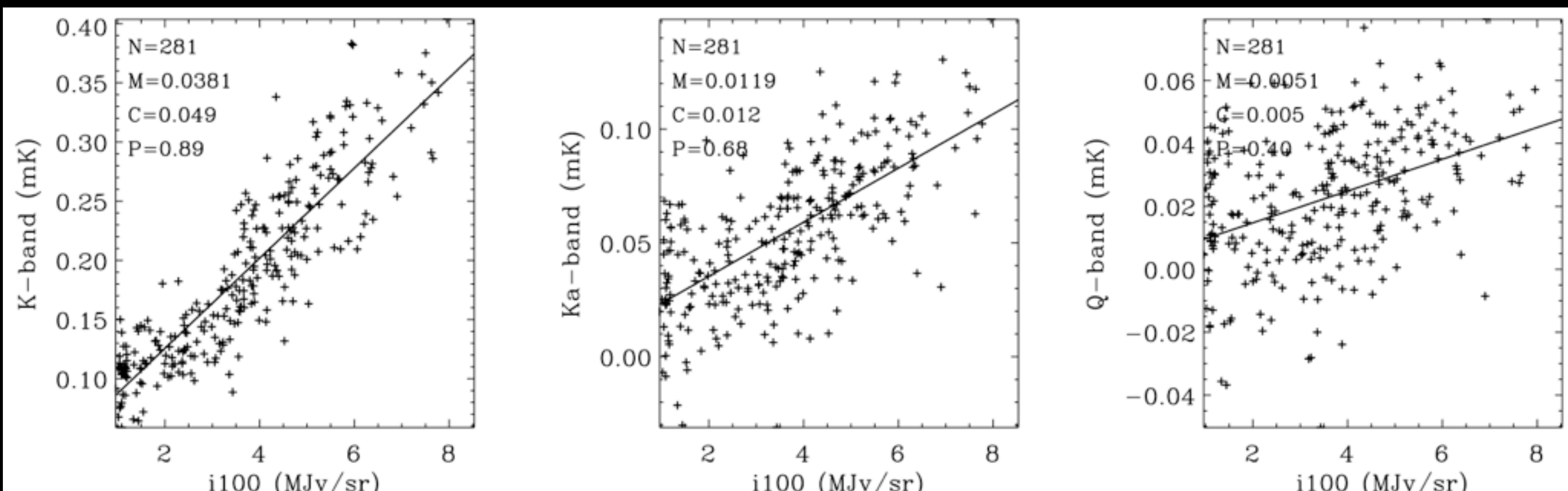
Scaife et al. (2009b)

AME is almost everywhere!

(at least as seen from our position)

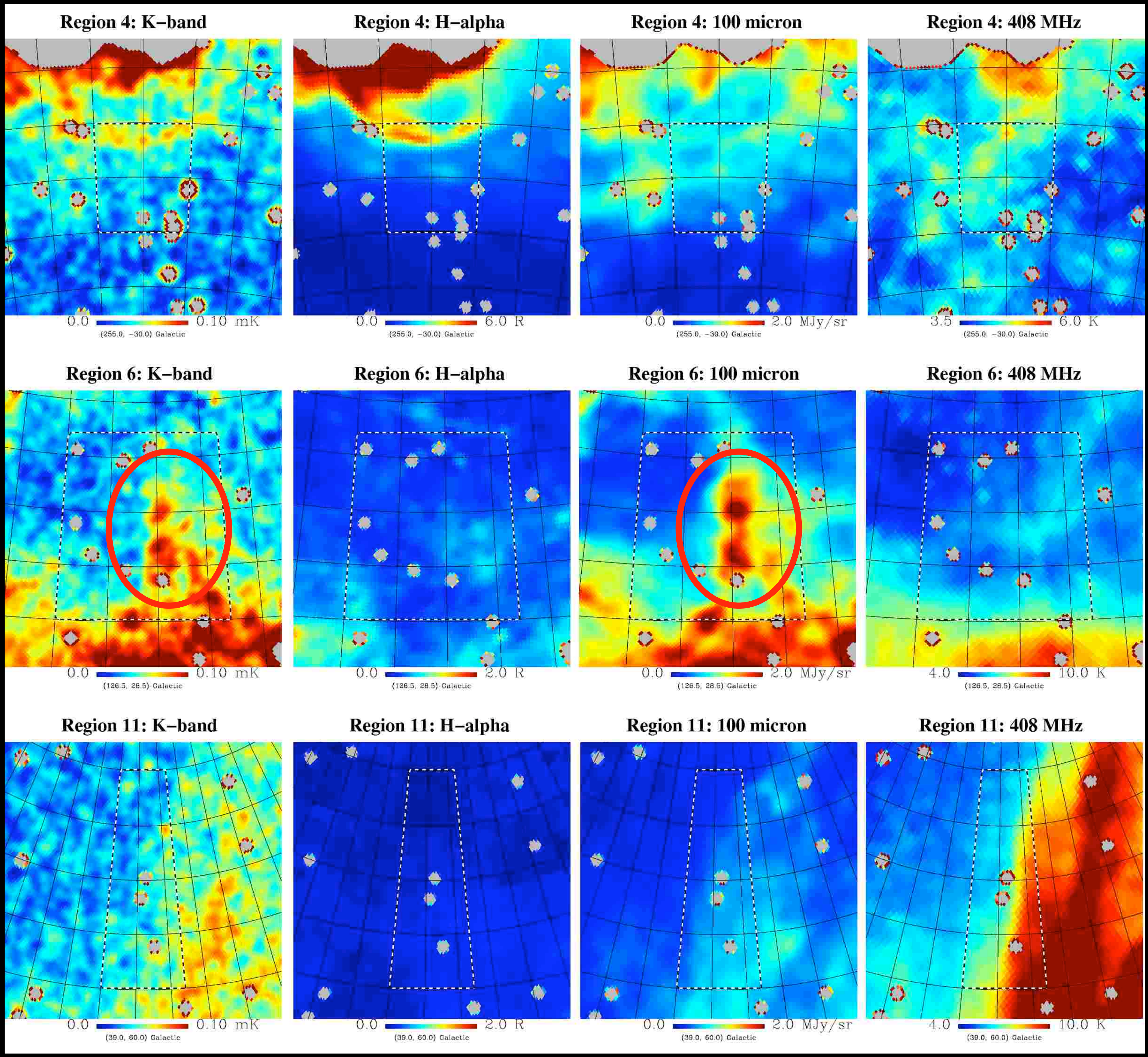
WMAP vs IRAS 100 microns:
AME is dust-correlated emission at ~20-60 GHz

23 GHz 33 GHz 41 GHz



Davies et al. (2006)
Peel et al. (2011a) show that addition of 2.3 GHz does not change this picture

Visual comparison of AME with WMAP data

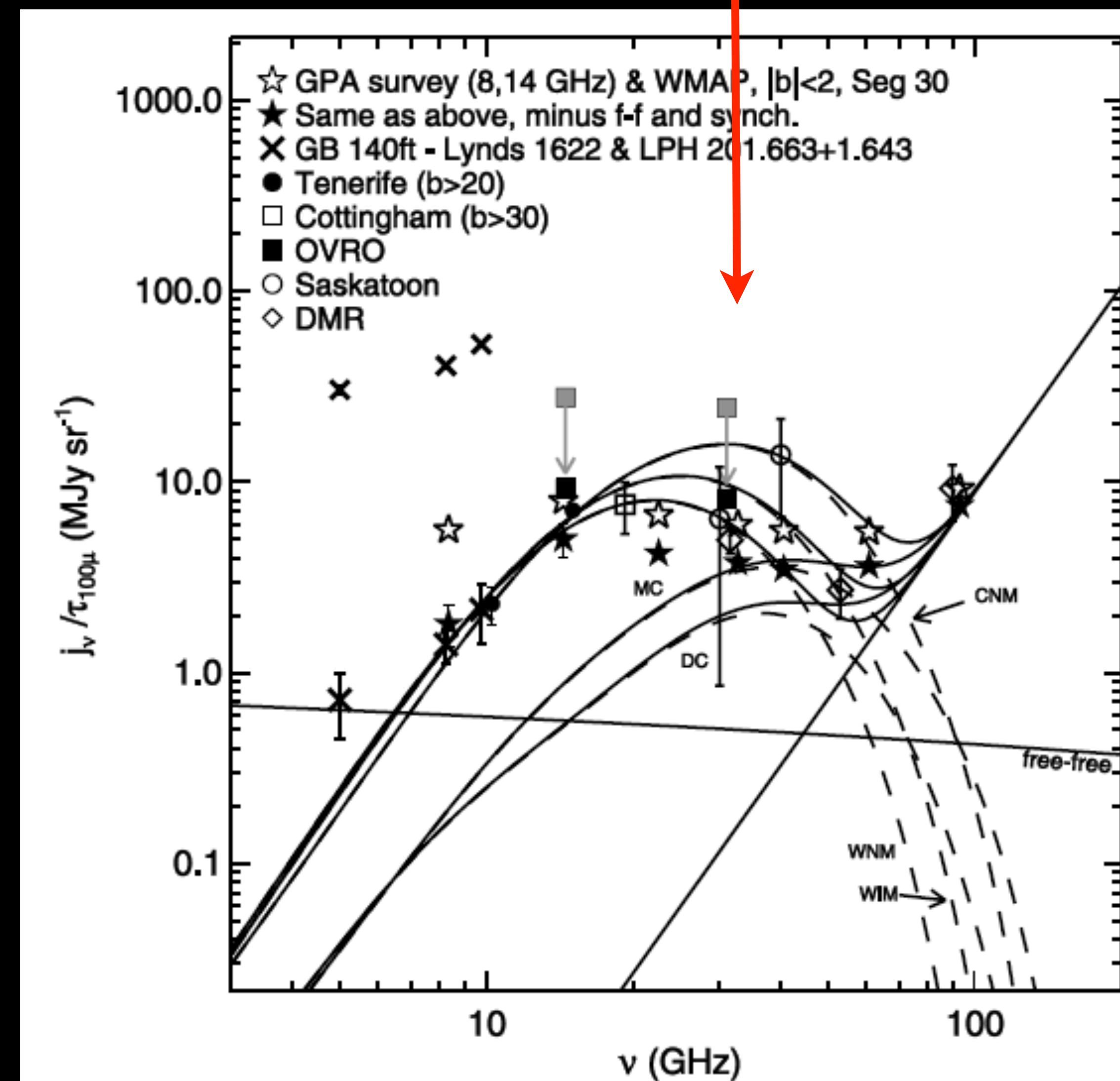


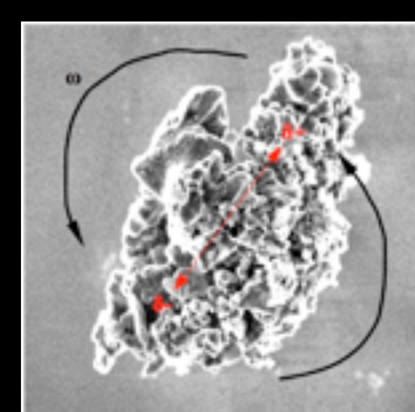
Davies et al. (2006)

What is the anomalous microwave emission?

- Lots of possibilities have been considered
  - Warm (T~10000 K) free-free
  - Hot (T~10^6 K) free-free
  - Absorbed free-free from UCHII regions
  - Flat spectrum (β~-2.5) synchrotron emission
  - Magneto-dipole radiation
  - Cold dust / emissivity variations
  - & others!
- Best explanation is electro-dipole radiation from small spinning dust grains ("spinning dust")
  - Basic theory understood (Draine & Lazarian 1998a,b and more recent enhancements)

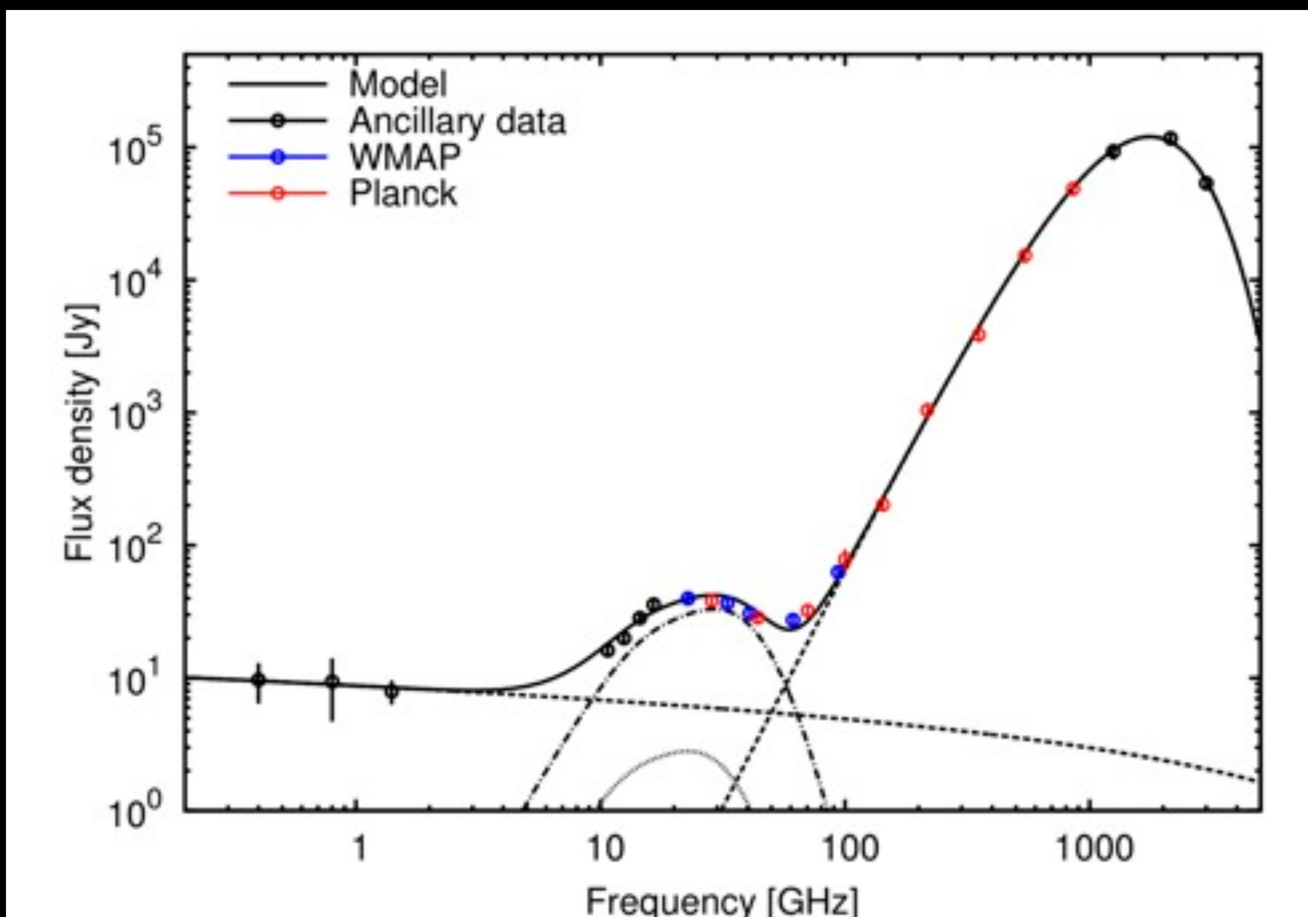
Peaked spectrum over ~10-100 GHz

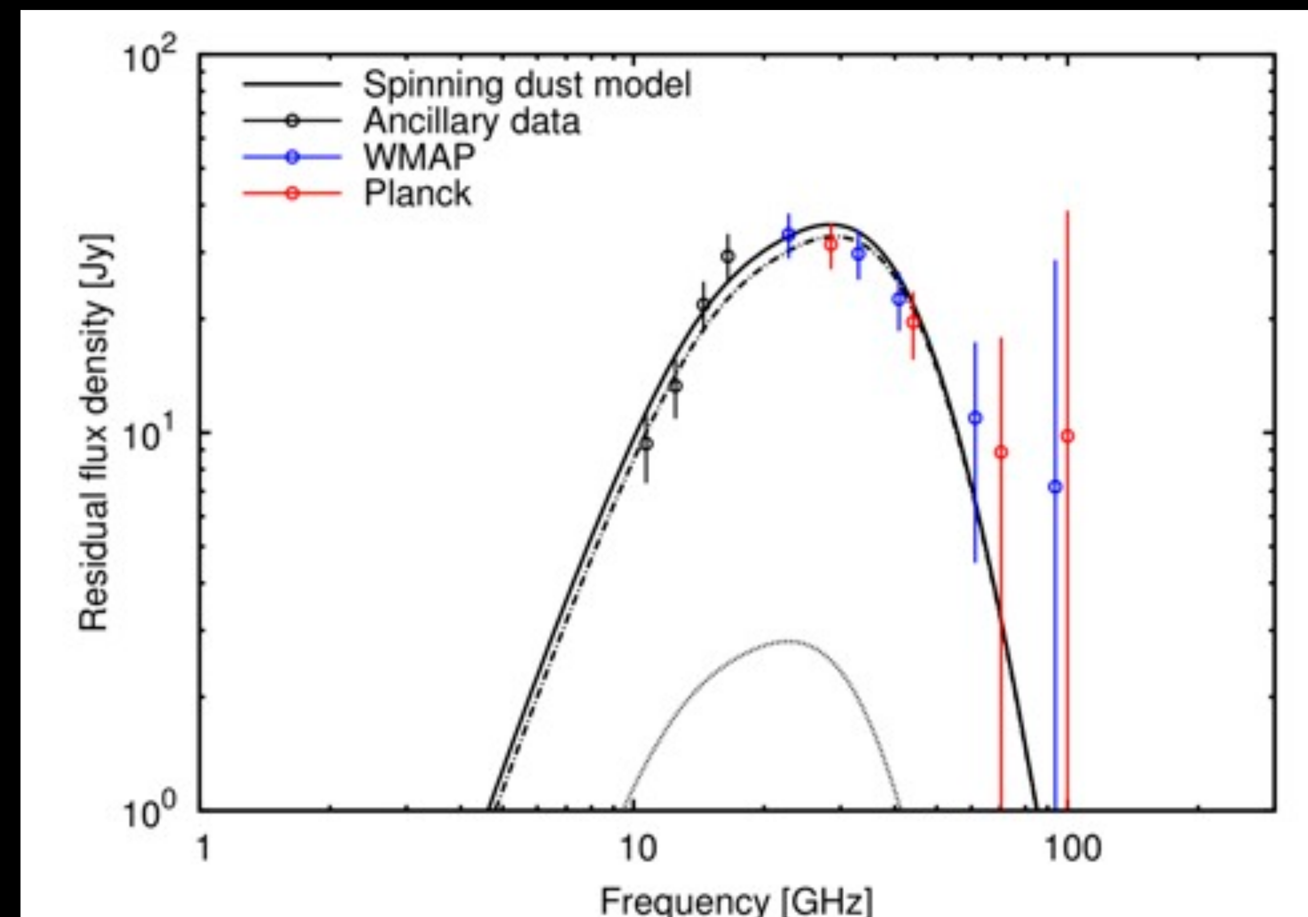




Draine & Lazarian (1998)
Finkbeiner (2004)

Planck SEDs of AME clouds

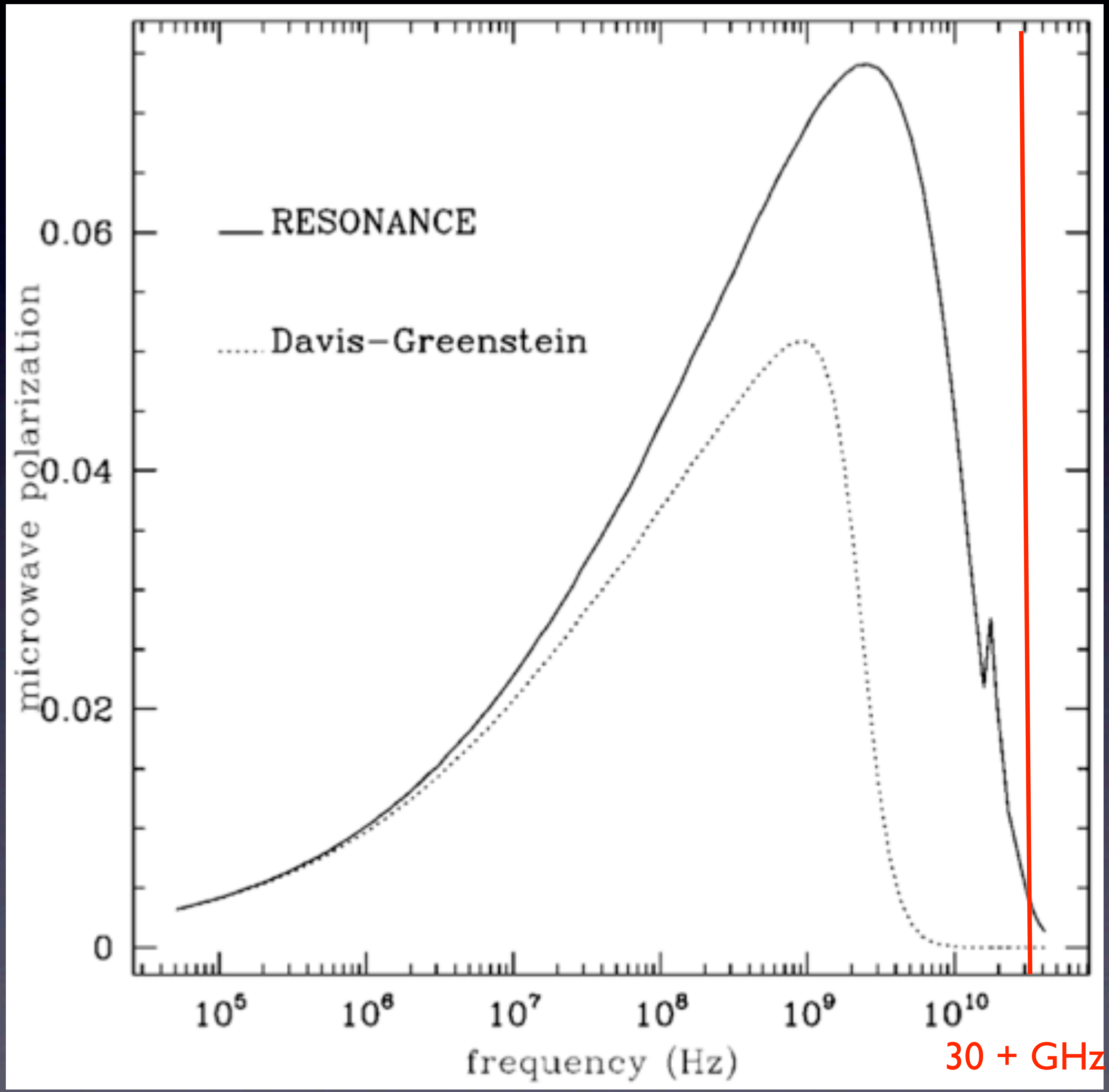




Reasonably definitive evidence for spinning dust in Perseus/ρ Ophiuchi clouds
(Planck collaboration et al., 2011, A&A, 536, A20)

Spinning dust polarization theory

- Small grains generally thought not to align very well with magnetic field
  - Davis-Greenstein paramagnetic relaxation (1951)
- But, splitting of energy levels due to rotation leads to energy dissipation and grain alignment
  - "Resonance relaxation" (Lazarian & Draine 2000)
  - ~few % at 10-30 of GHz
  - <1% at higher frequencies



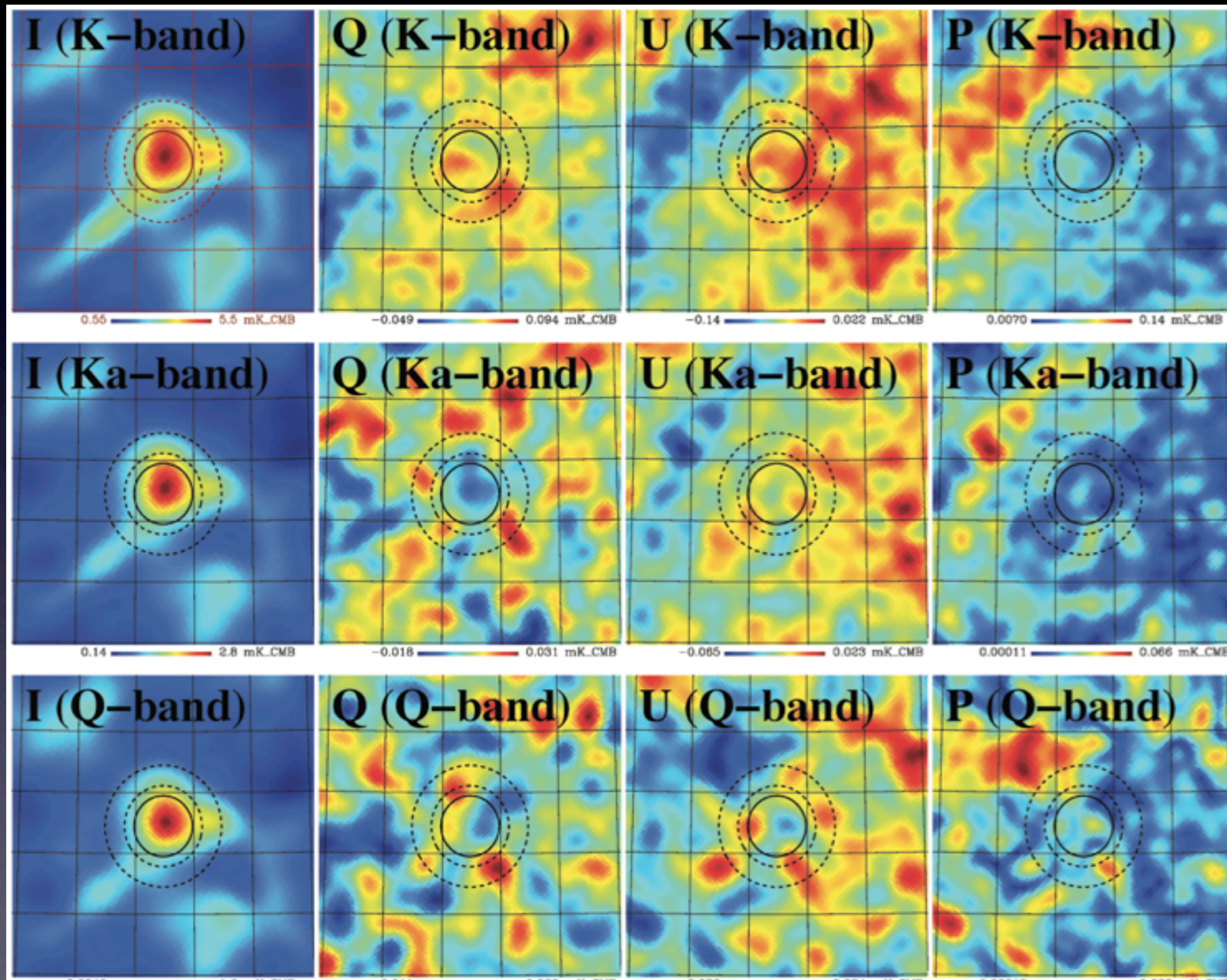
Lazarian & Draine (2000)

AME polarization constraints

See review by Rubino-Martin et al. (2012), AME special issue

Reference	Region	Data / frequency	Polarization constraint (%)
Battistelli et al. (2006)	G159.6-18.5	COSMOSOMAS (11 GHz)	3.4 +/- 1.7
Dickinson et al. (2006)	LPH96 HII region	CBI (31 GHz)	<10
Dickinson et al. (2007)	HII regions	CBI (31 GHz)	<1
Casassus et al. (2007)	Helix	CBI (31 GHz)	<8
Casassus et al. (2008)	Ophiuchi	CBI (31 GHz)	<3.2
Mason et al. (2009)	LDN1622	GBT (9 GHz)	<2.7
Kogut et al. (2007)	All-sky	WMAP (23-94 GHz)	<1
Macellari et al. (2007)	All-sky	WMAP (23-94 GHz)	<5
Lopez-Caraballo et al. (2011)	Perseus	WMAP (23-94 GHz)	<1
Dickinson et al. (2011)	Perseus, Ophiuchi	WMAP (23-94 GHz)	<1.4, <1.7
Rubino-Martin et al. (2012)	Pleiades	WMAP (23-94 GHz)	<2.6

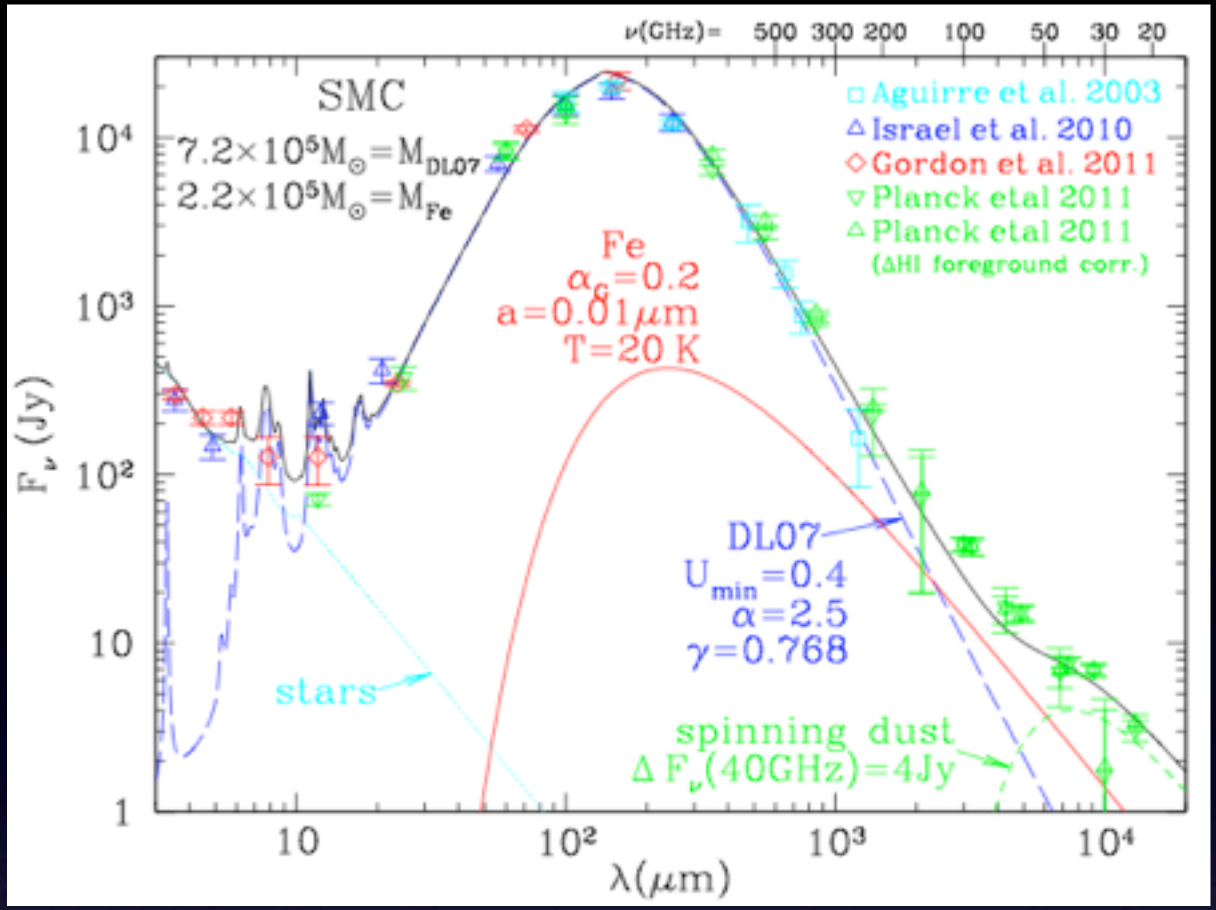
AME polarization in ρ Ophiuchi

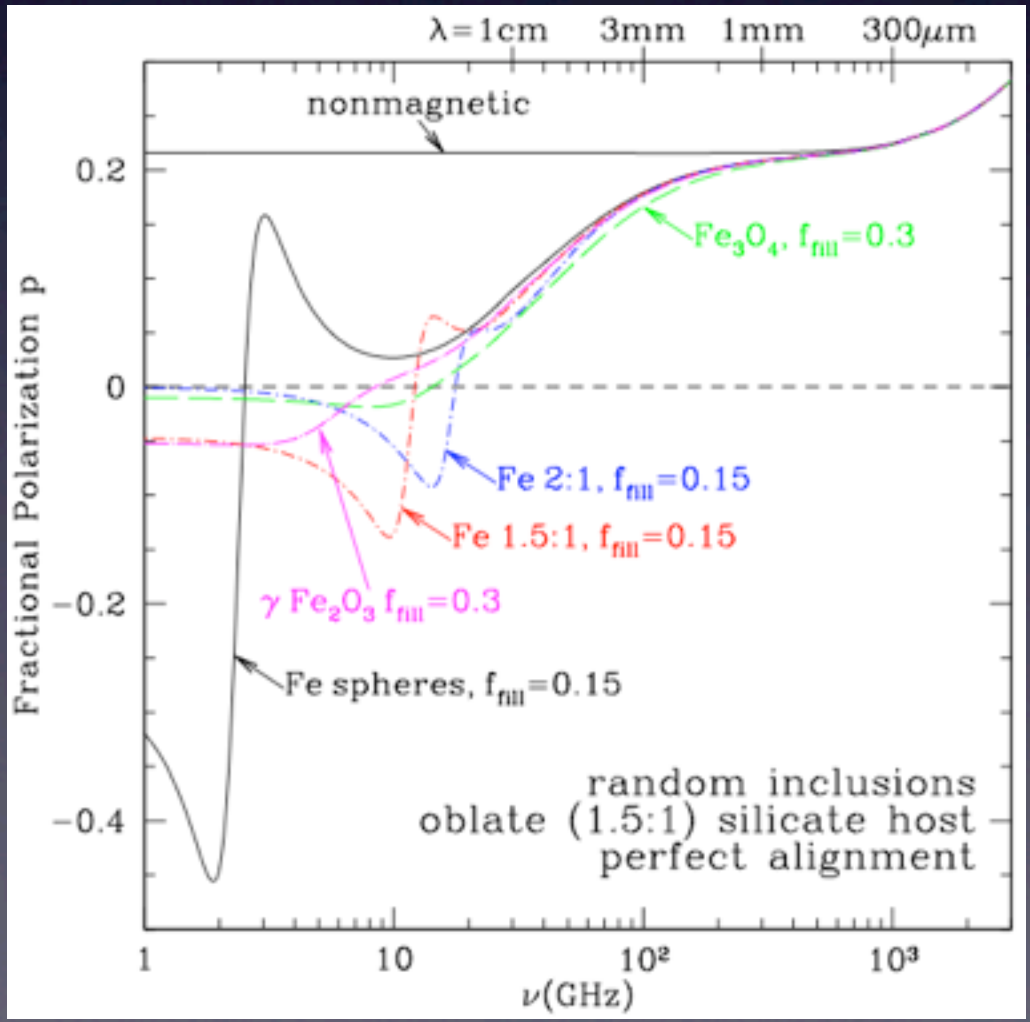


Dickinson, Peel, Vidal (2011)

Magnetic dust

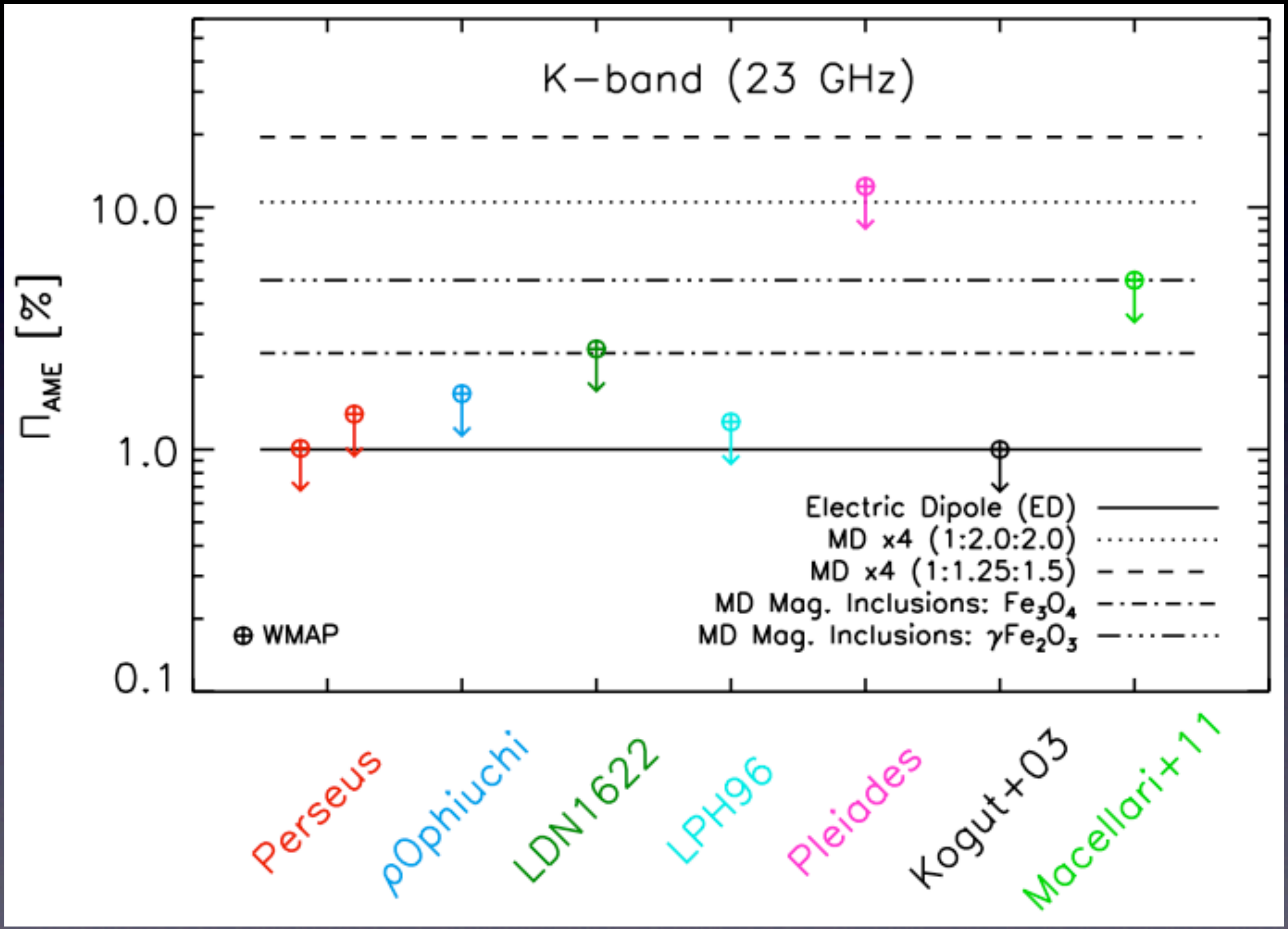
- Grains expected to have magnetic inclusions (e.g. Fe)
- Thermal fluctuations in the magnetization of grains gives rise to magnetic dipole radiation (Draine & Lazarian 1999)
- Recent updates from Draine & Hensley (2012)
  - May explain sub-mm SEDs of some galaxies
- Strongly polarized with variations with frequency
  - ~20-30% at frequencies >100 GHz





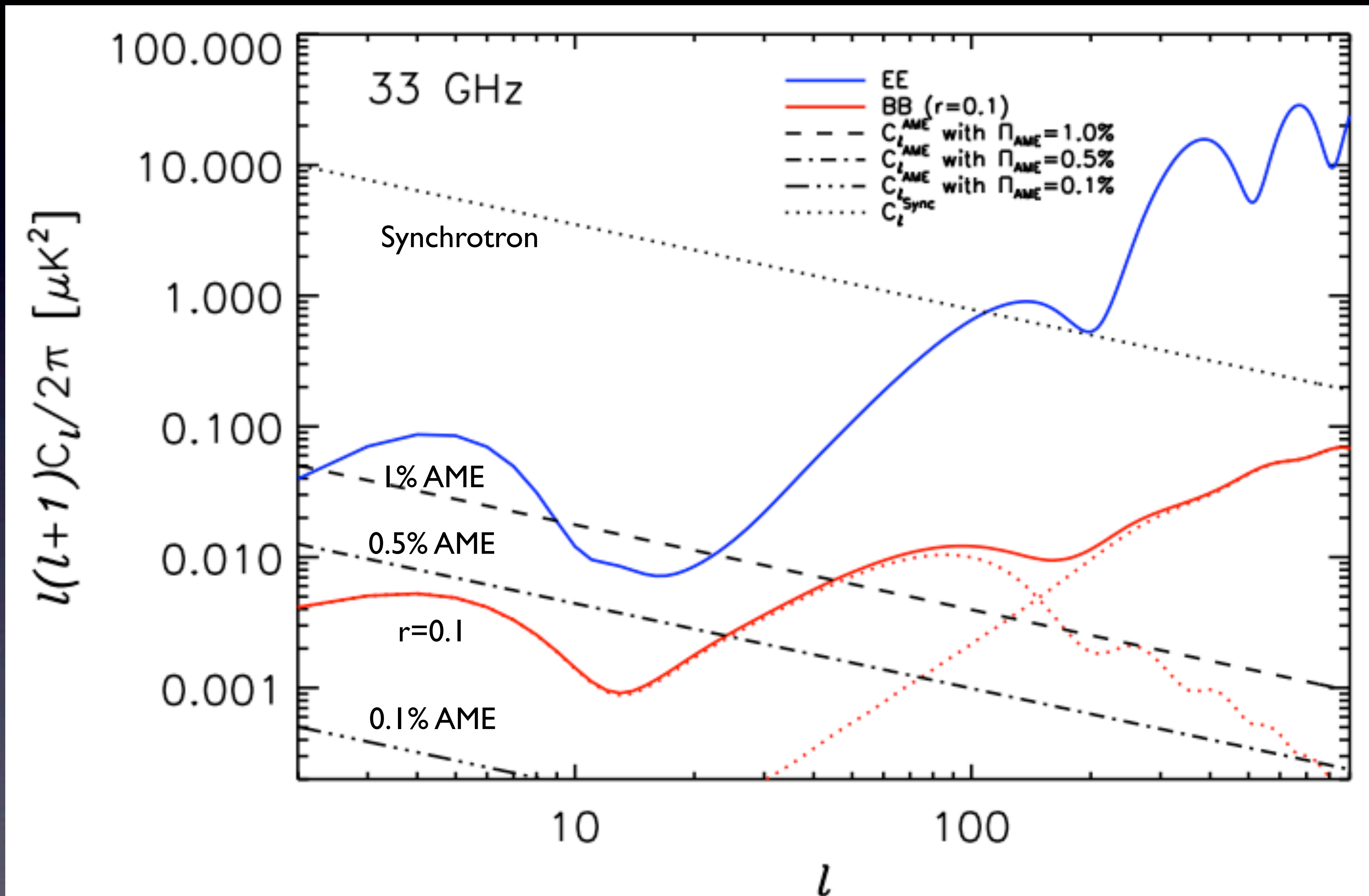
Draine & Hensley (2012)

Constraining AME models



Rubino-Martin et al. (2012), AME special issue

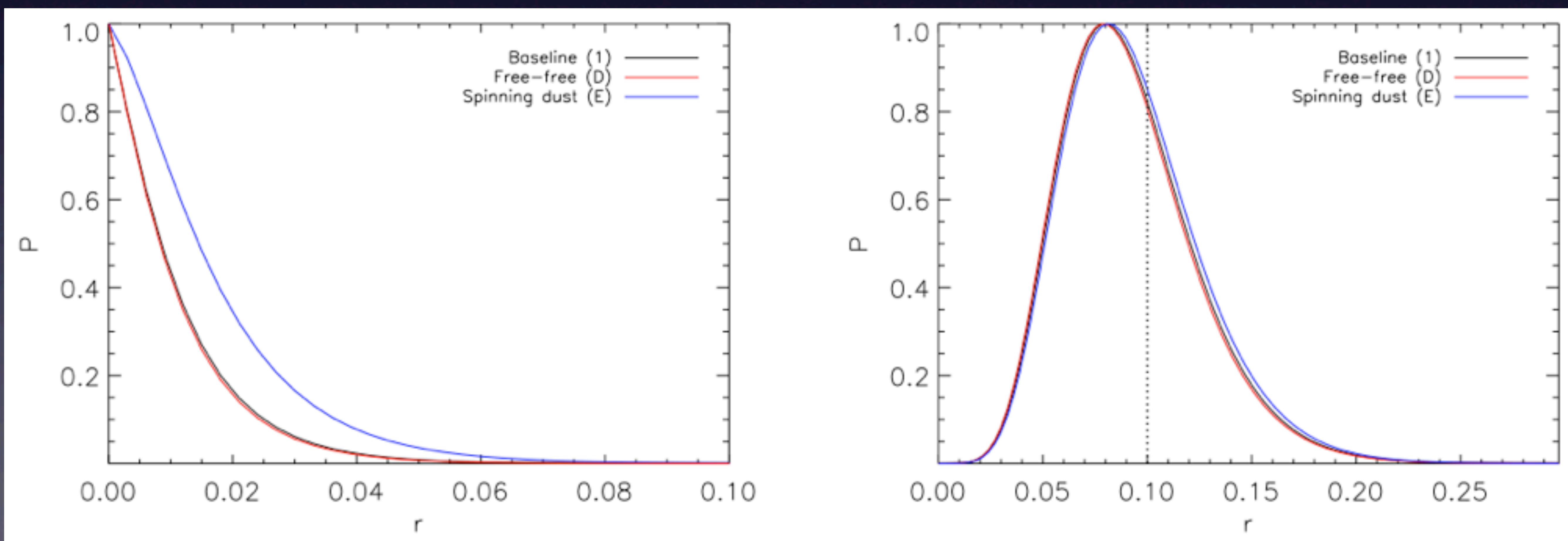
AME polarized power spectra



Rubino-Martin et al. (2012), AME special issue

Effect on cosmological B-modes

- For r~0.1 (Planck sensitivity) ~1% free-free/AME has small/negligible effect
- For $r \sim 10^{-3}$ (CMBpol) it will likely be significant



Armitage-Caplan et al. (2012)

Conclusions

- Synchrotron and thermal dust emission are the main polarization foregrounds
- Both free-free and AME (if due to spinning dust grains) will have a very low level of polarization
  - <~1% (on average)
  - Need more precise measurements because AME is so strong in temperature
- Magnetic dust potentially significant at ~100 GHz and above

Still a happy cosmologist

Job advertisement

- 3 ERC-funded PDRA positions available at Manchester
  - 1 CMB polarization foregrounds
  - 2 in HI intensity mapping
- **Deadline 4th January 2013**
- email: Clive.Dickinson@manchester.ac.uk