



Microwave Emission from Spinning Dust Grains

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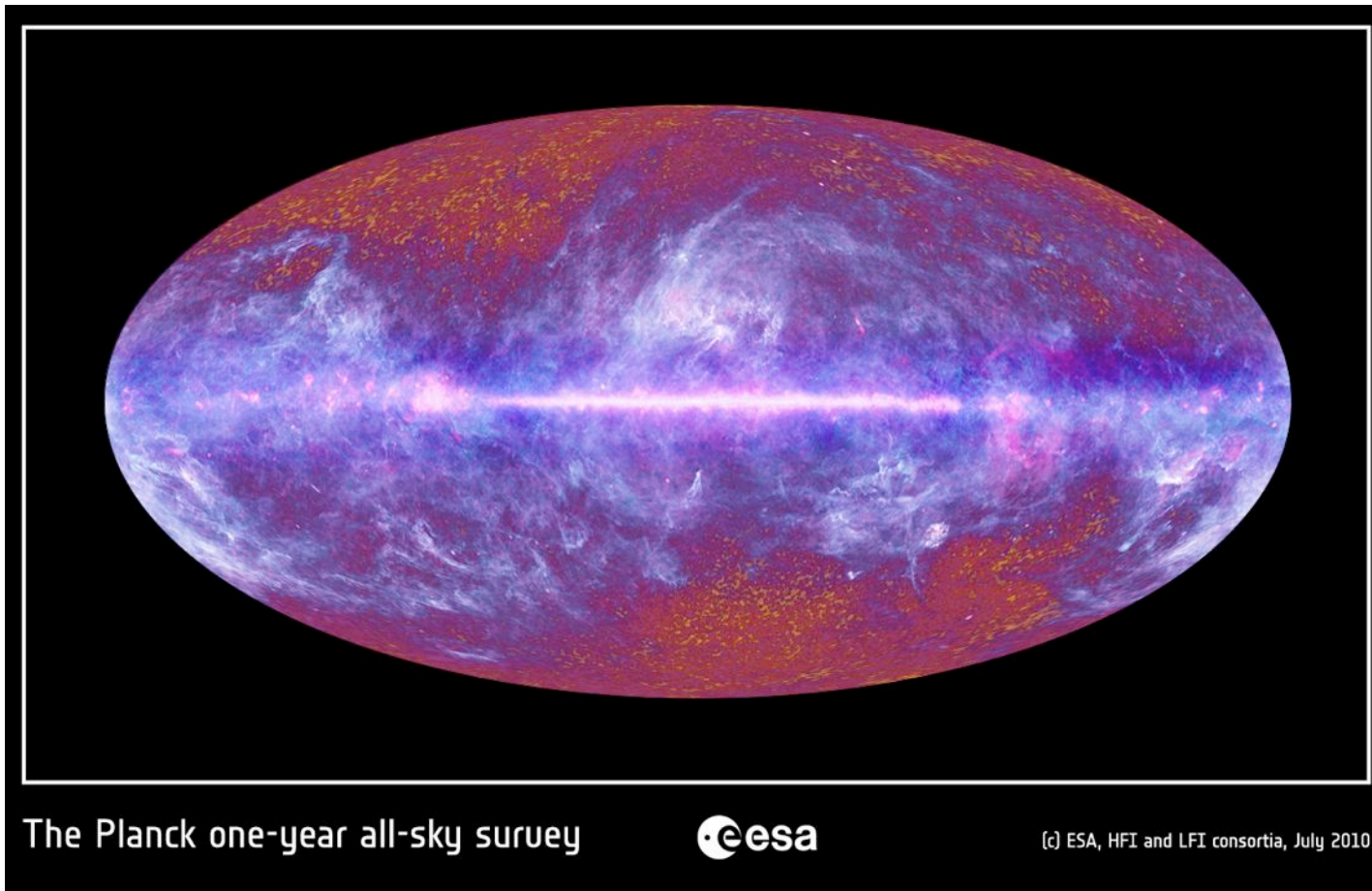
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SOFIA Teletalk - Sept, 11 2013

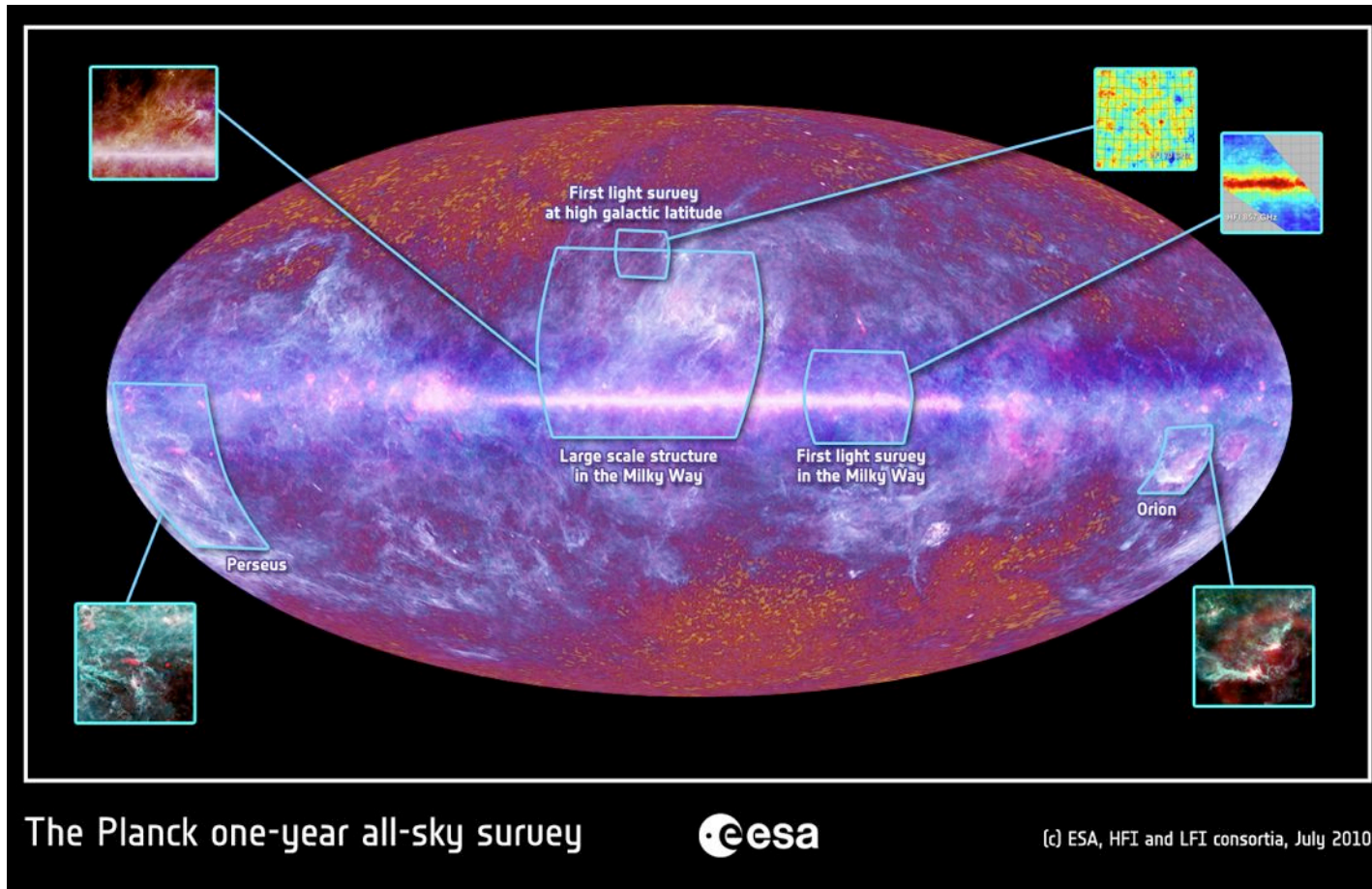
Outline

- Introduction to Anomalous Microwave Emission (AME)
- Proposed explanations for the AME
- Why is AME important?
- Recent AME Results
- What we still need to understand about AME
- The need for SOFIA observations
- Conclusions

Planck All-Sky Map

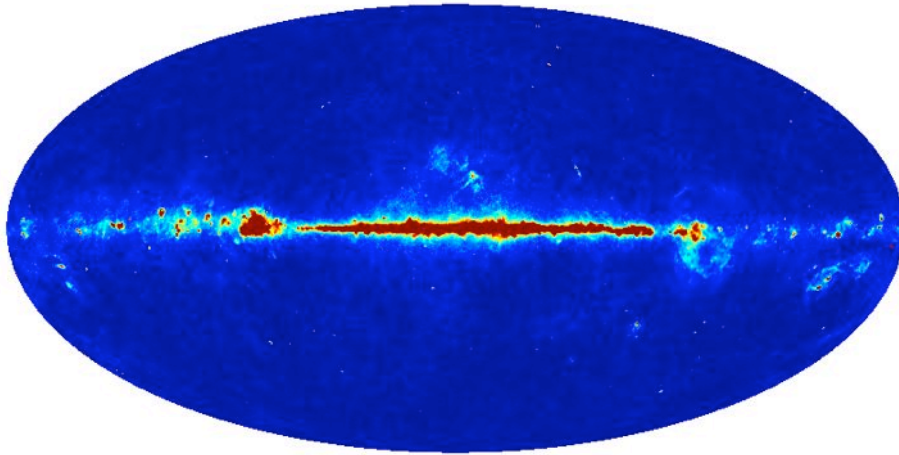


Planck All-Sky Map

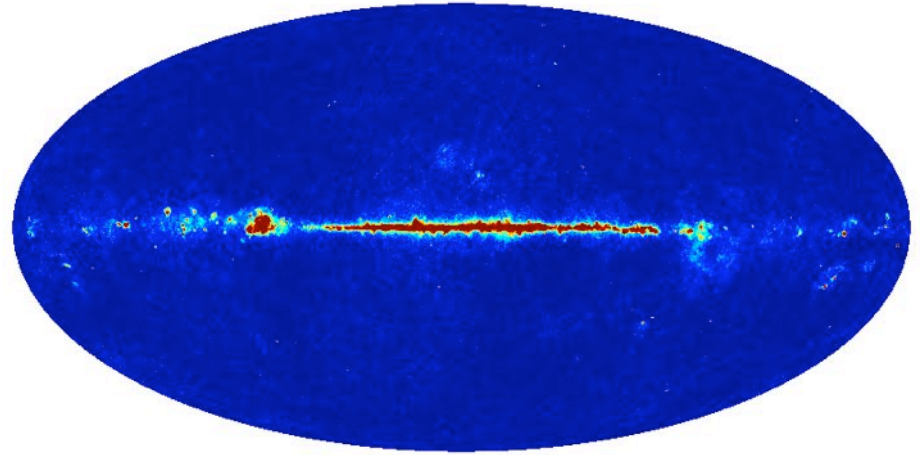


The Microwave Sky

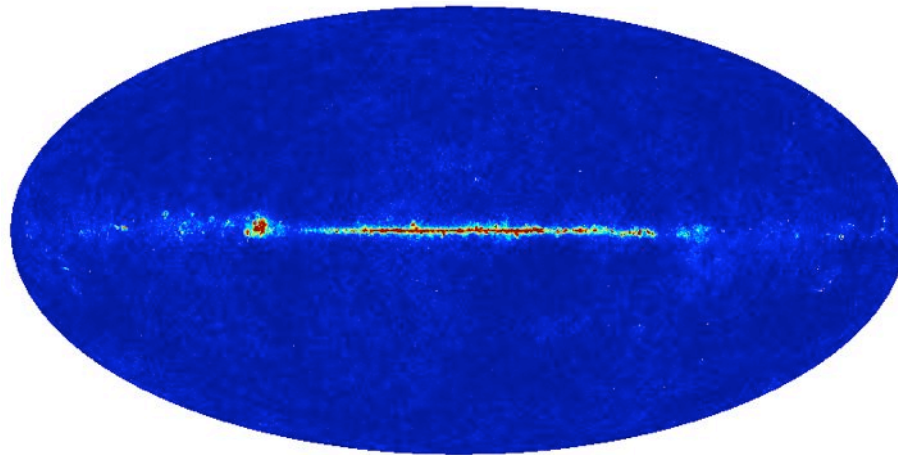
Planck 30GHz Map



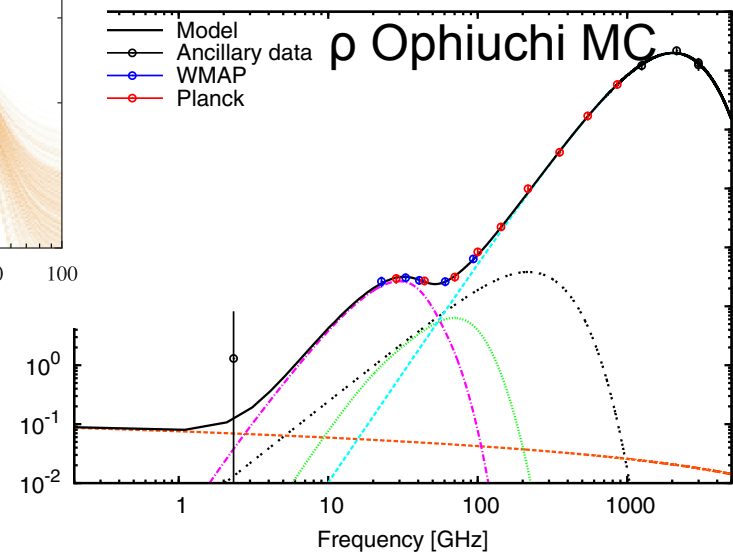
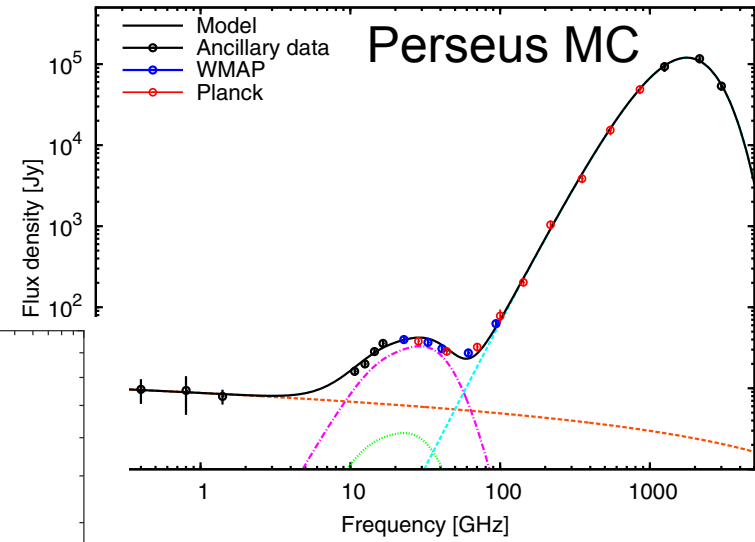
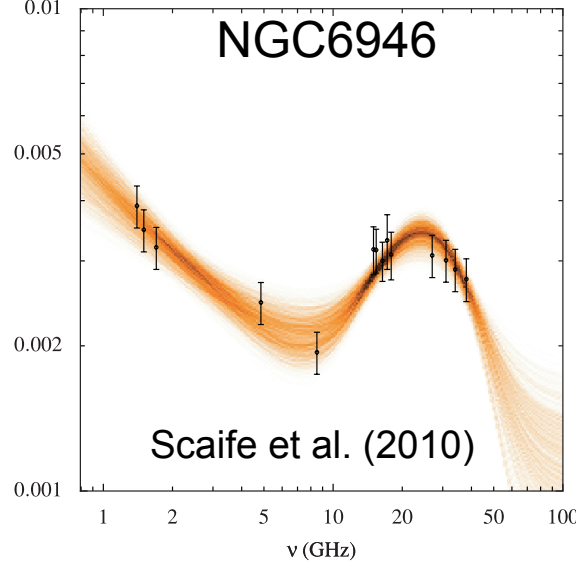
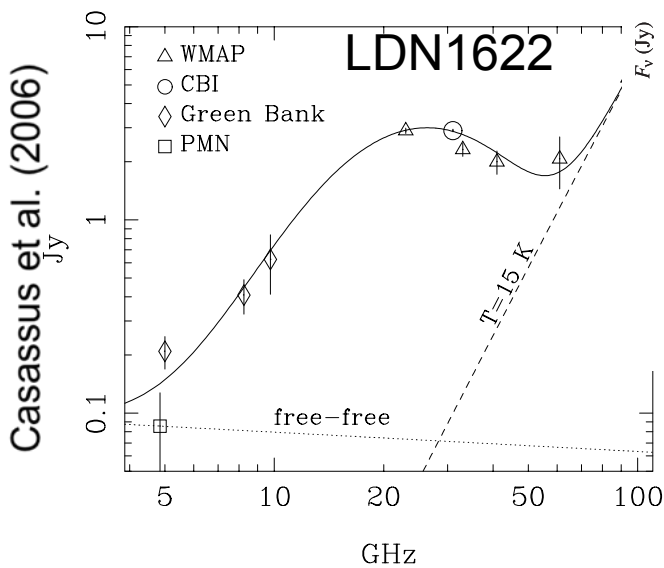
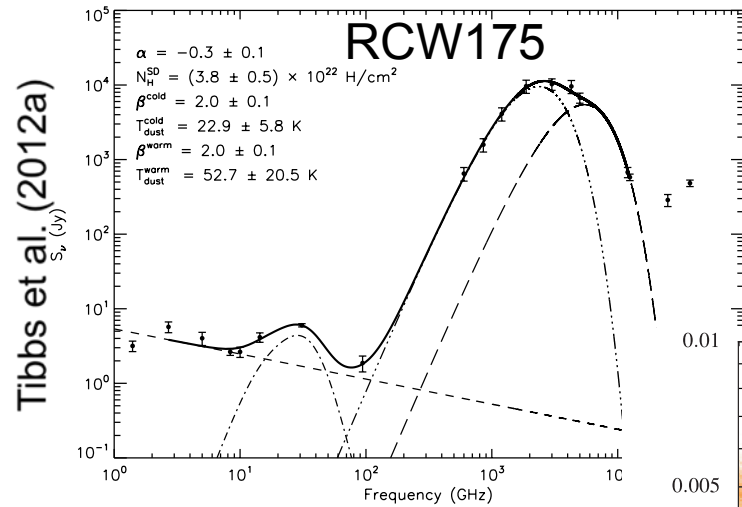
Planck 44GHz Map



Planck 70GHz Map

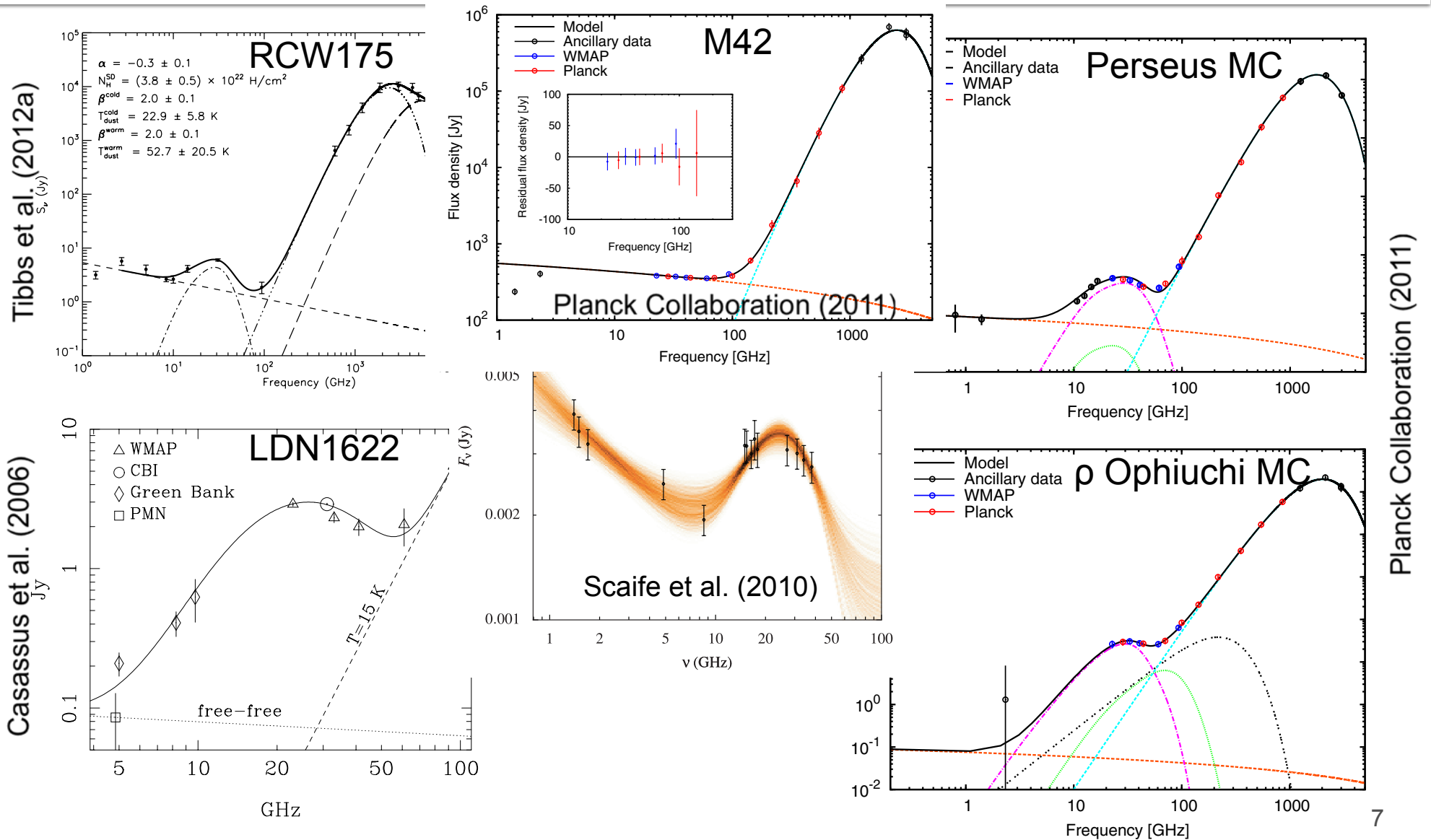


Examples of AME Detections



Planck Collaboration (2011)

Examples of AME Detections



What is AME?

- Many theories on the emission mechanism producing the AME
 - Free-free emission from shock heated gas (Leitch et al. 1997)
 - Flat spectrum synchrotron emission (Bennett et al. 2003)
 - Self-absorbed free-free emission (McCullough & Chen 2002)
 - Magnetic dipole radiation (Draine & Lazarian 1999)
 - Cold dust/ emissivity variations
- Preferred explanation is electric dipole emission from rapidly rotating very small dust grains “spinning dust” (Draine & Lazarian 1998)

Spinning Dust Grains

A MECHANISM OF NON-THERMAL RADIO-NOISE ORIGIN*

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Received September 19, 1956; revised May 10, 1957

ABSTRACT

A mechanism of non-thermal radio-noise origin is proposed. The action of this mechanism may be summarized in the following manner. Suppose that clouds of interstellar grains exist in the radio-source regions. If a high-velocity gas cloud collides with a cloud of grains, the grains will be bombarded by moderately fast atoms and/or ions. These collisions will transfer angular momentum to the grains, and, in fact, the angular velocity of each grain will execute a dynamical "walk." It is shown that rotational frequencies comparable with radio frequencies may be attained. If some of the grains possess electric or magnetic dipole moments due to polar or ferromagnetic substances or statistical fluctuations in the distribution of charge on the grains, they will radiate classically at radio frequencies. Rather improbably high grain densities are required in order to account for the total radio-frequency radiation of high-emissivity sources. However, the high-frequency portion of this radiation could be generated with moderate grain densities.

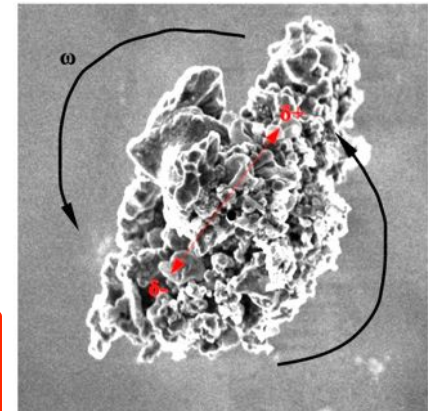


Image courtesy of A. Scaife

A spinning grain with electric dipole moment μ radiates power:

$$P = \frac{2}{3} \frac{\omega^4 \mu^2 \sin^2 \theta}{c^3}$$

Spinning Dust Grains

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Various excitation and damping processes involved.

Excitation:

- collisional excitation
- plasma excitation
- IR emission
- photoelectric emission
- H₂ formation

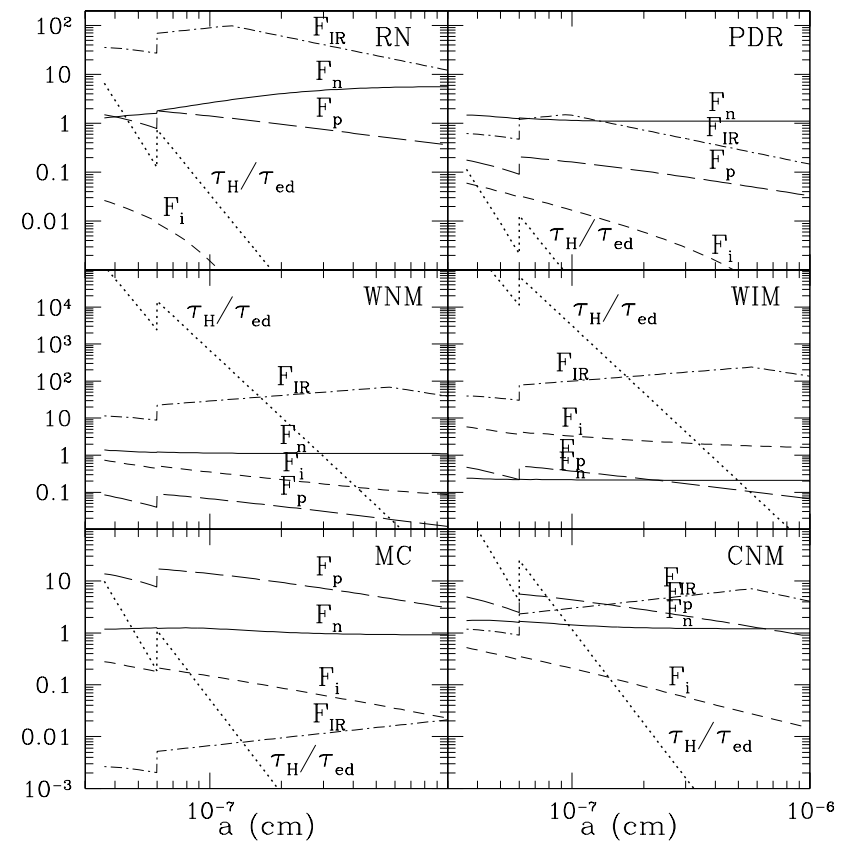
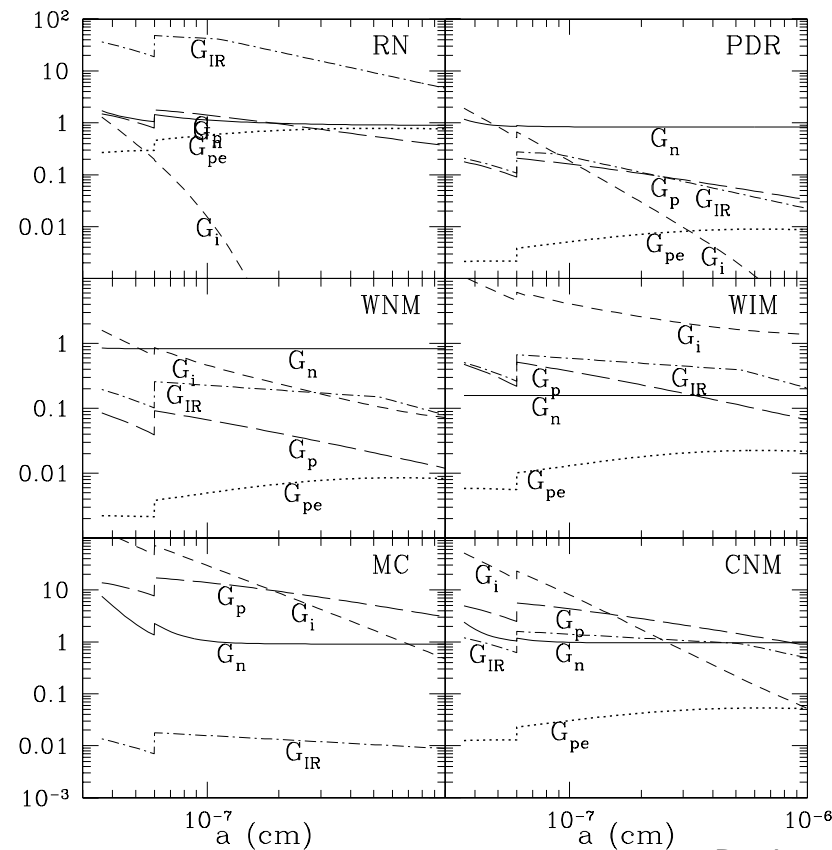
Damping:

- collisional drag
- plasma drag
- IR emission
- electric dipole emission

Spinning Dust Grains

A spinning grain with electric dipole moment μ radiates power:
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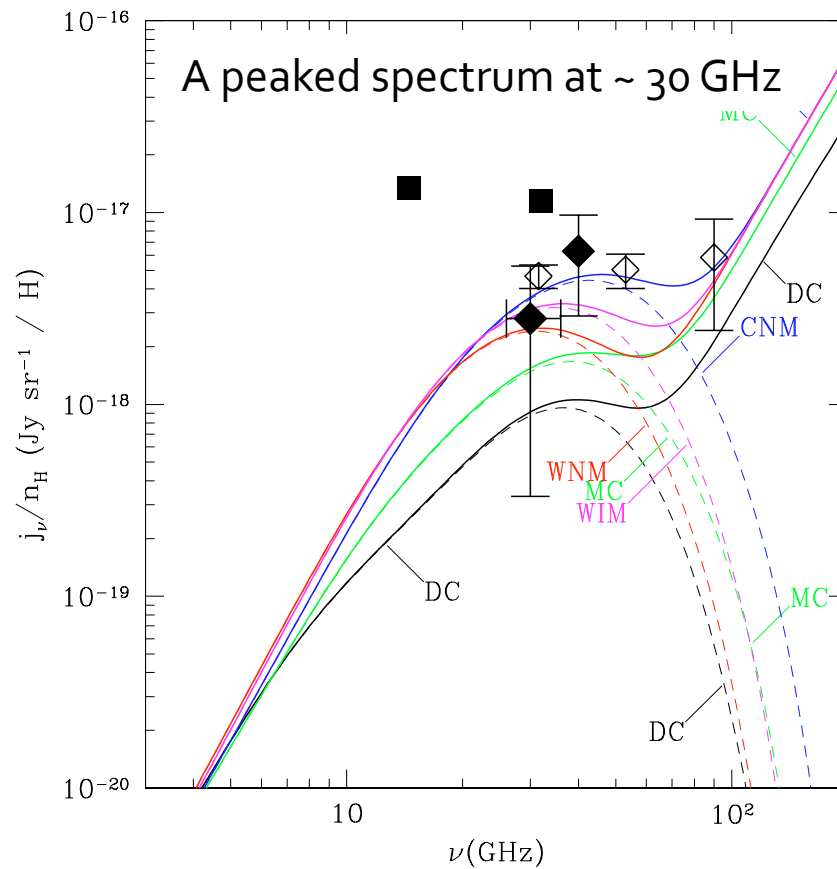
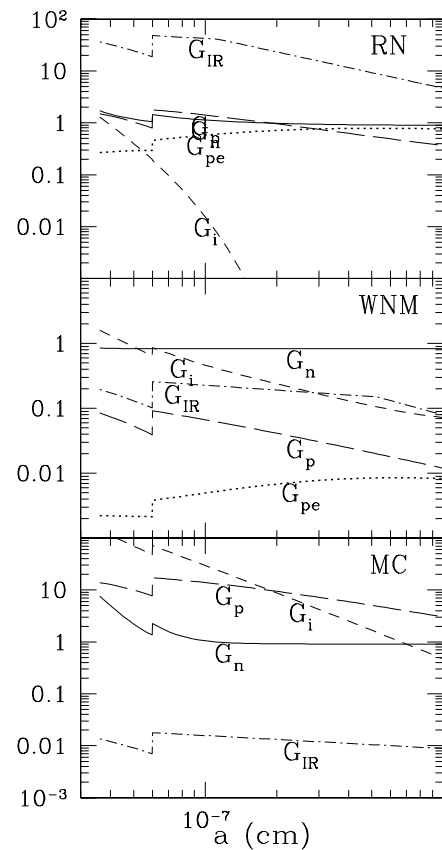
Draine & Lazarian (1998)

Spinning Dust Grains

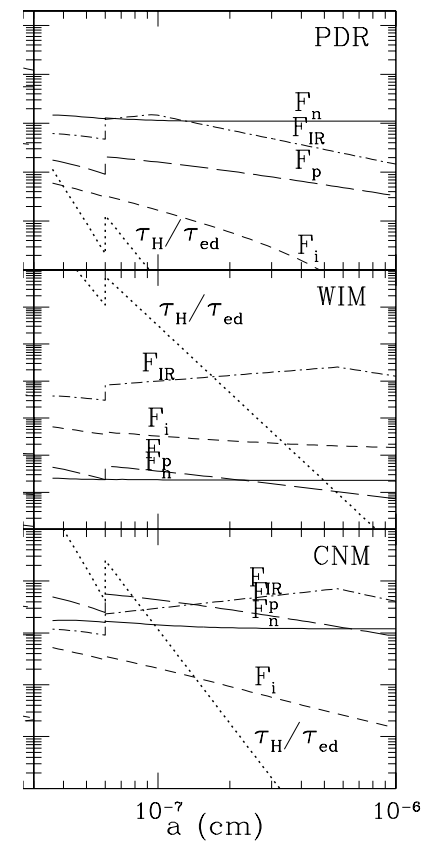
A spinning grain with electric dipole moment μ radiates power:

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Various excitation and d



Draine & Lazarian (1998)

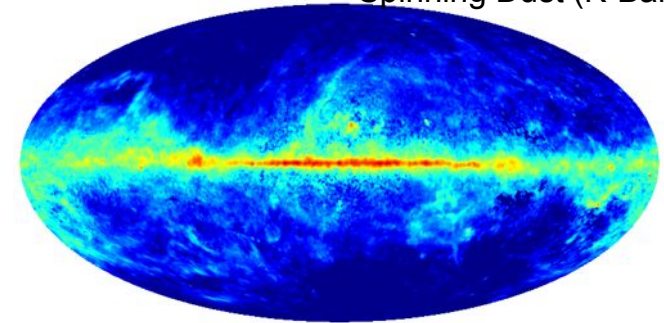


Why is Spinning Dust Important?

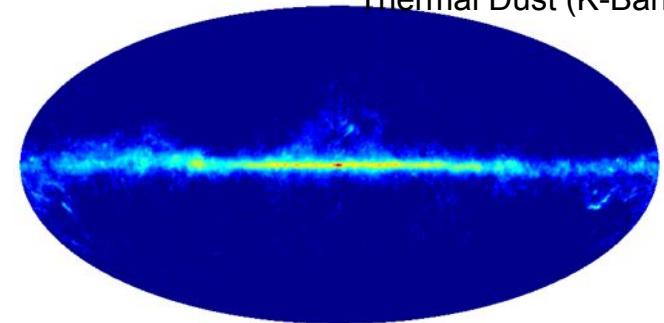
- Important foreground for CMB studies
 - Dominant component in total-intensity
~20-60GHz
 - Possible polarization contribution

- New diagnostic for dust grains and the interstellar medium
 - Spinning dust traces the small dust grains in the ISM
 - Dust plays an important role in star formation, the gas physics of molecular clouds etc
 - The spinning dust spectrum depends on many parameters e.g. grain size distribution, interstellar radiation field, column density etc
 - Complementary to IR data

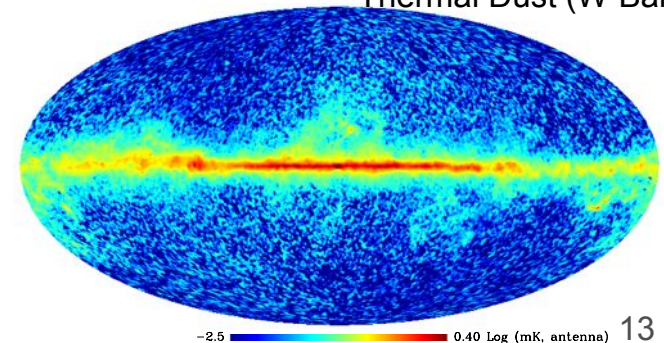
WMAP 9yr Spinning Dust Map (K-Band - MEM)
Spinning Dust (K-Band)



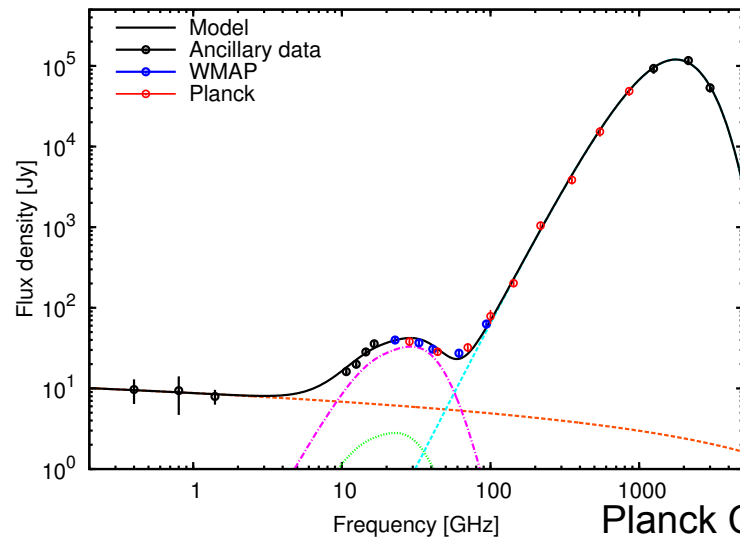
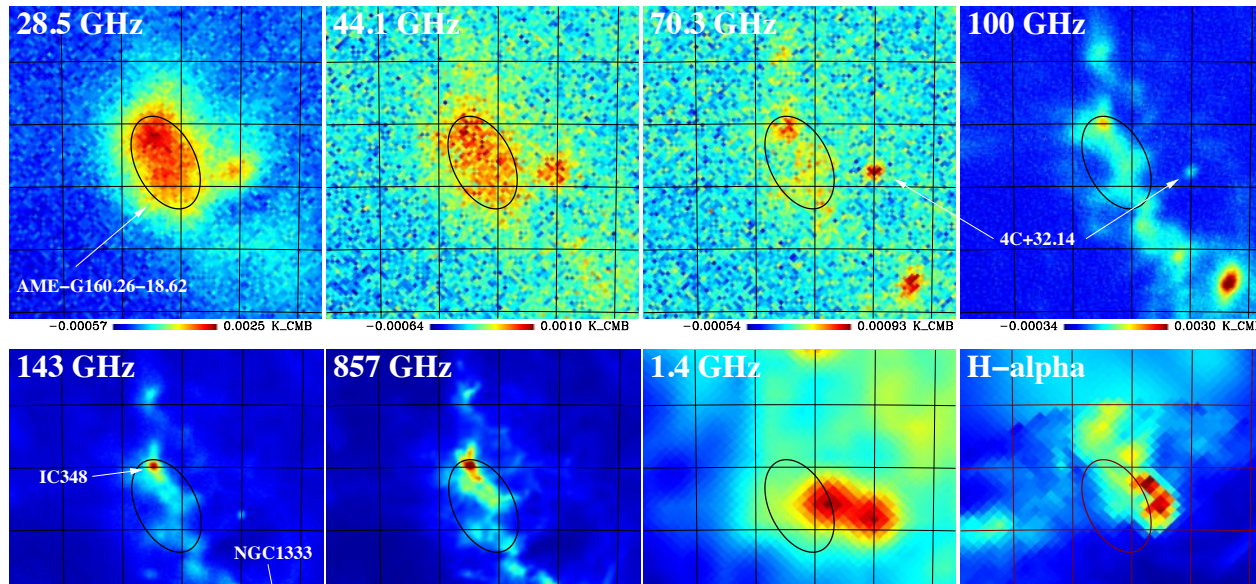
WMAP 9yr Thermal Dust Map (K-Band - MEM)
Thermal Dust (K-Band)



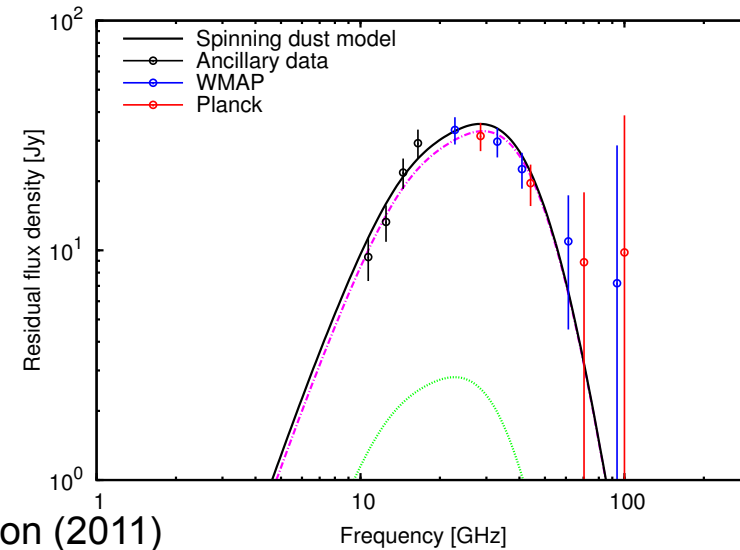
WMAP 9yr Thermal Dust Map (W-Band - MEM)
Thermal Dust (W-Band)



Case Study: Perseus



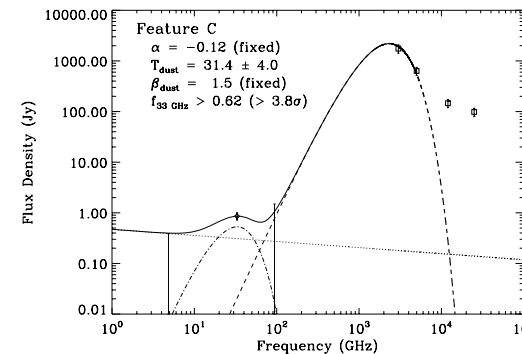
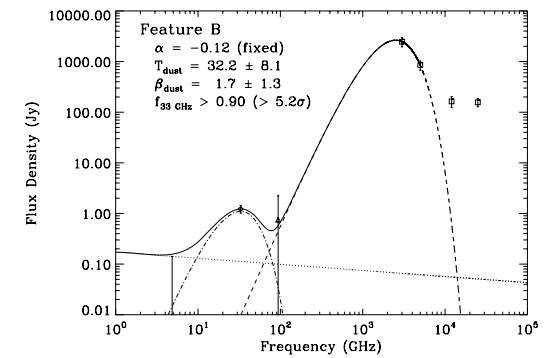
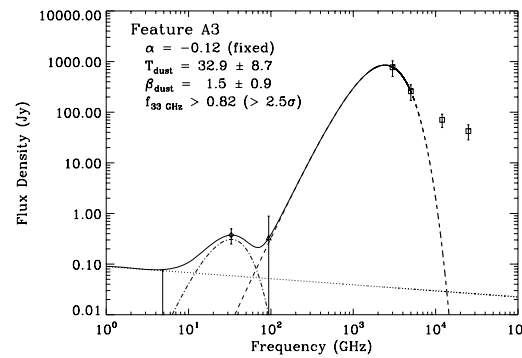
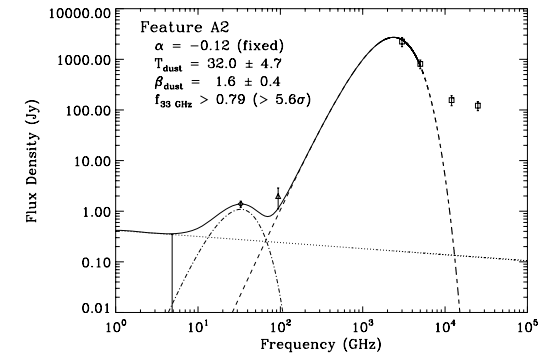
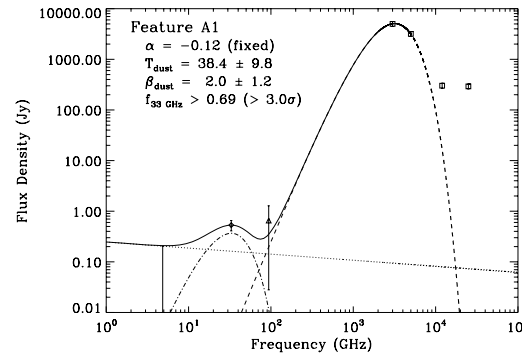
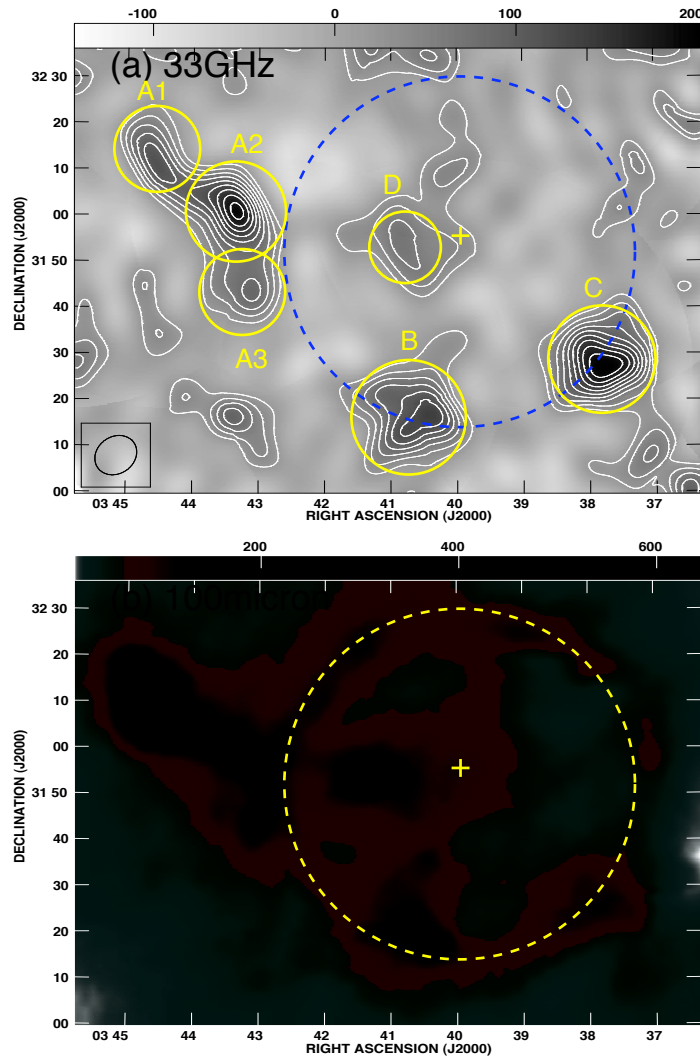
Planck Collaboration (2011)



Results: Perseus

Tibbs et al. (2010)

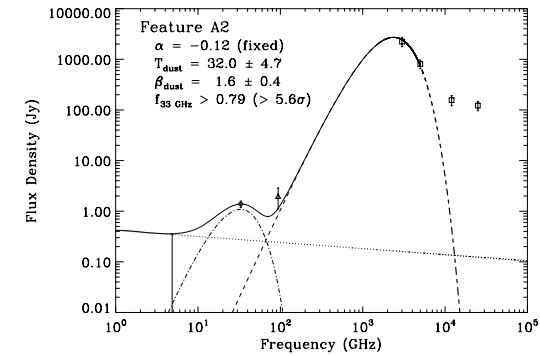
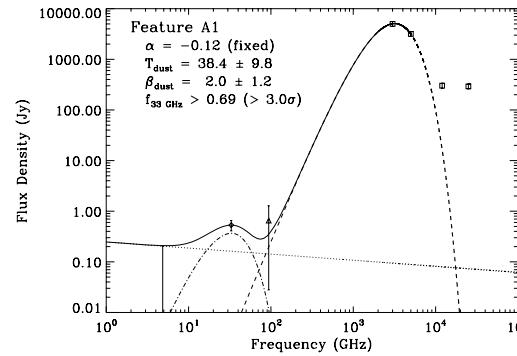
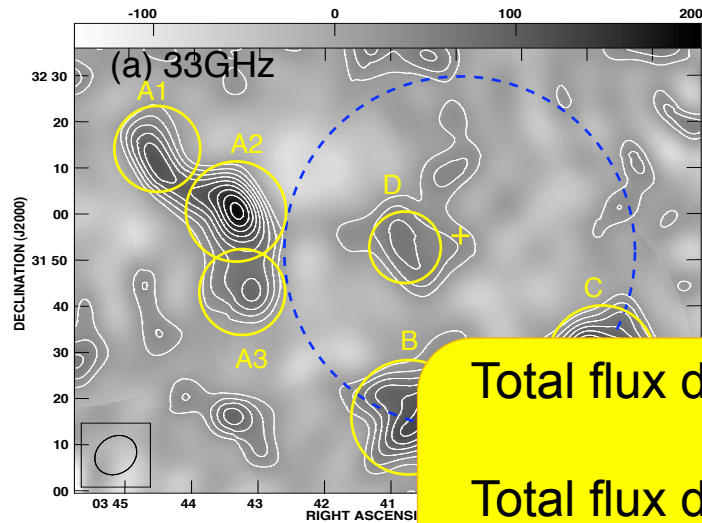
VSA Observations



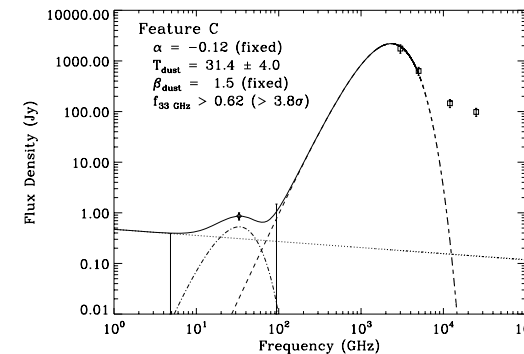
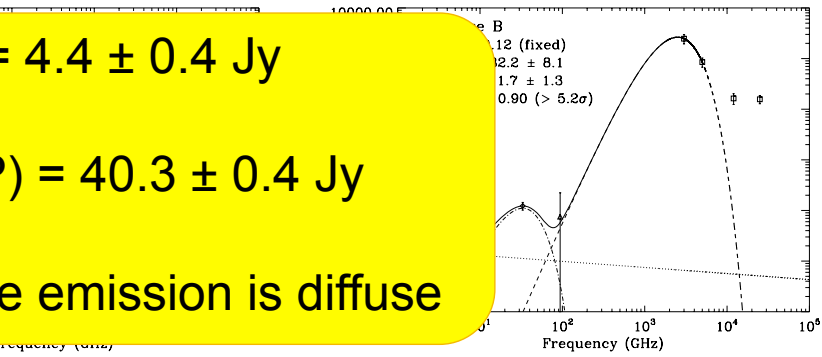
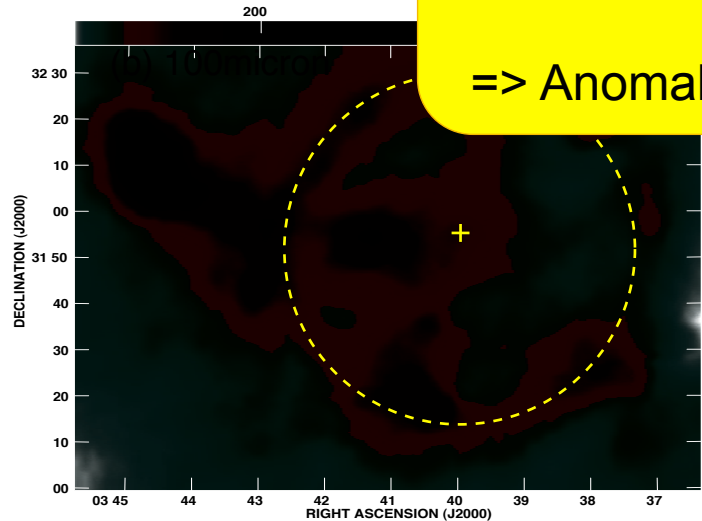
Results: Perseus

Tibbs et al. (2010)

VSA Observations



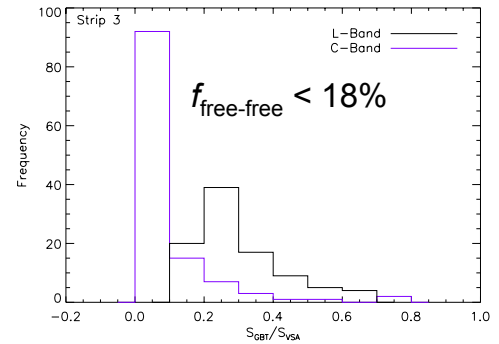
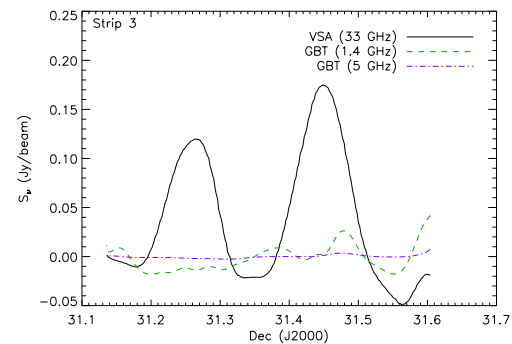
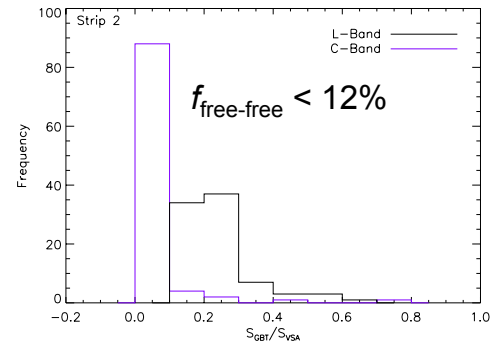
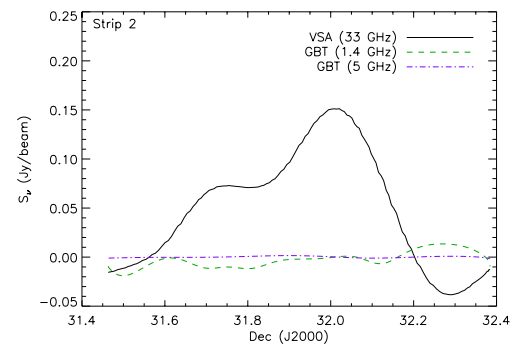
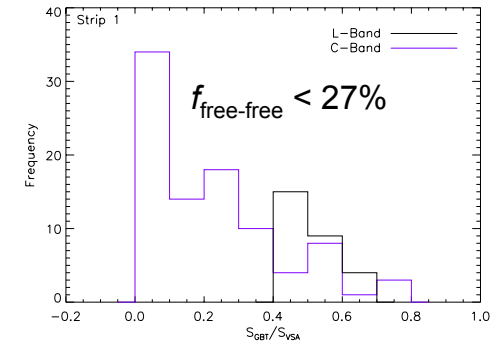
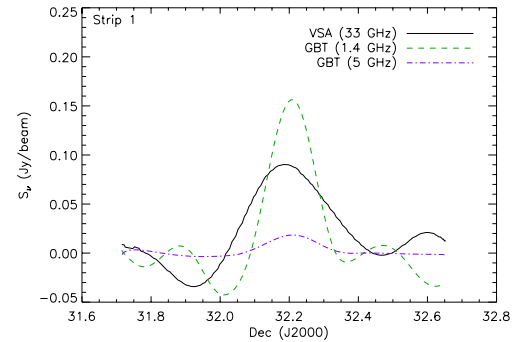
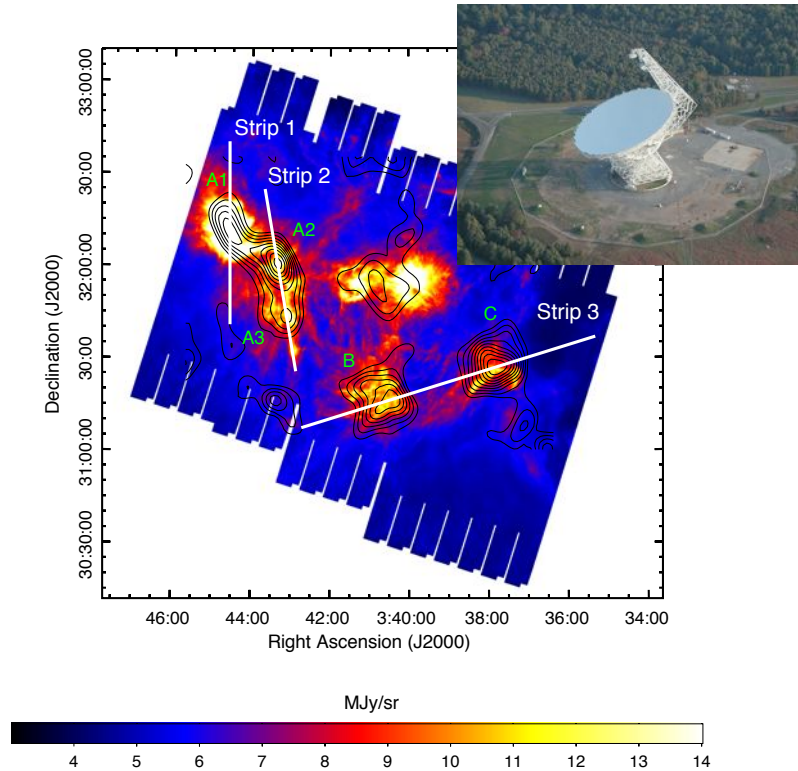
Total flux density (VSA) = 4.4 ± 0.4 Jy
 Total flux density (WMAP) = 40.3 ± 0.4 Jy
 => Anomalous microwave emission is diffuse



Results: Perseus

Tibbs et al. (2013b)

GBT Observations

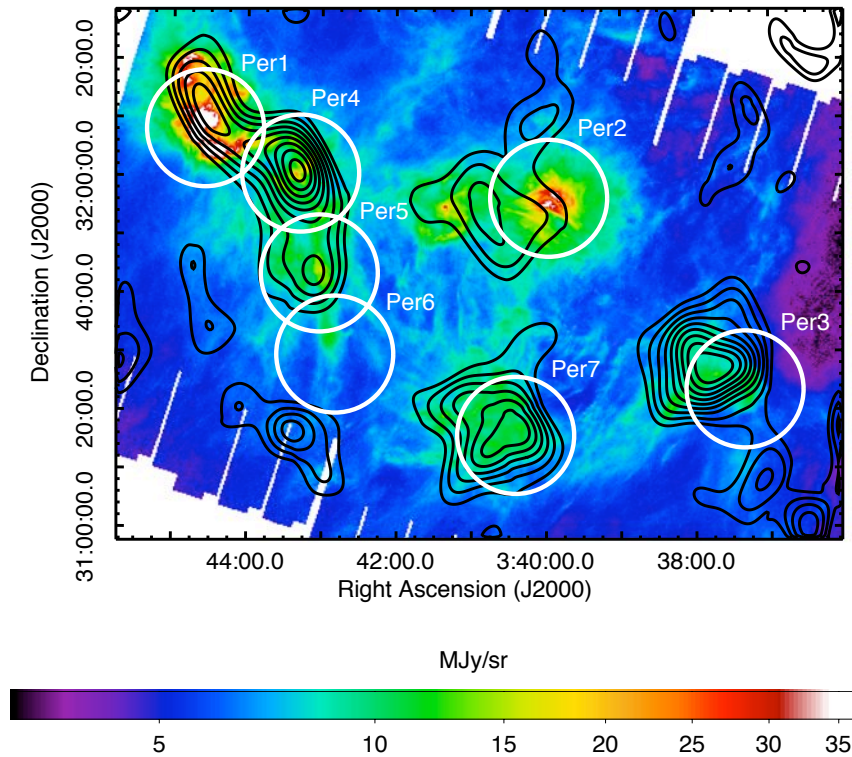


GBT observations

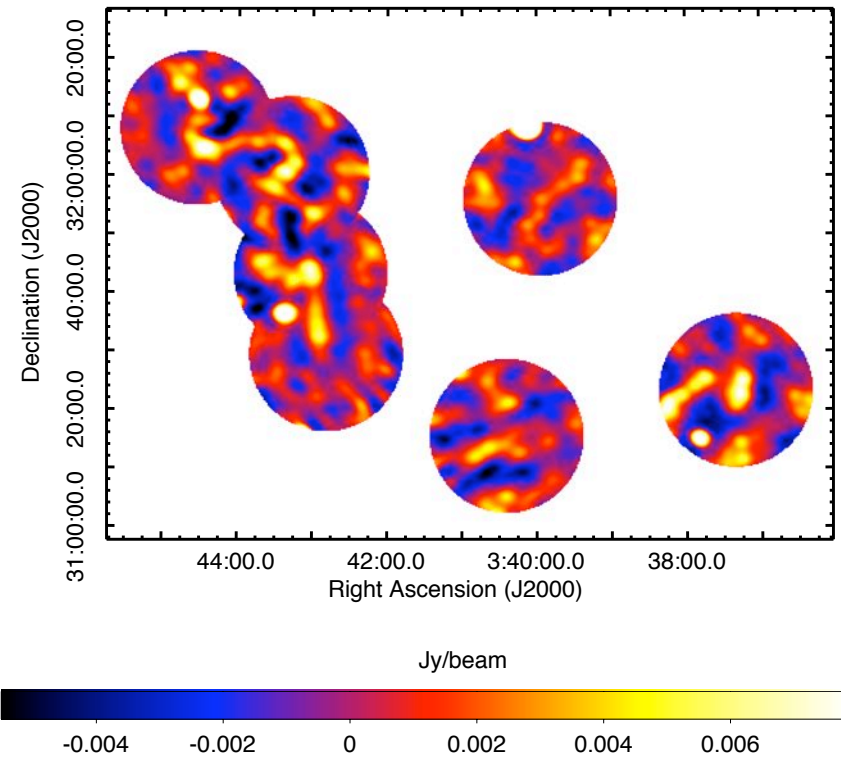
- 3 strips at 1.4 GHz and 5 GHz
- Covering the AME features identified with the VSA

Results: Perseus

Tibbs et al. (2013a)

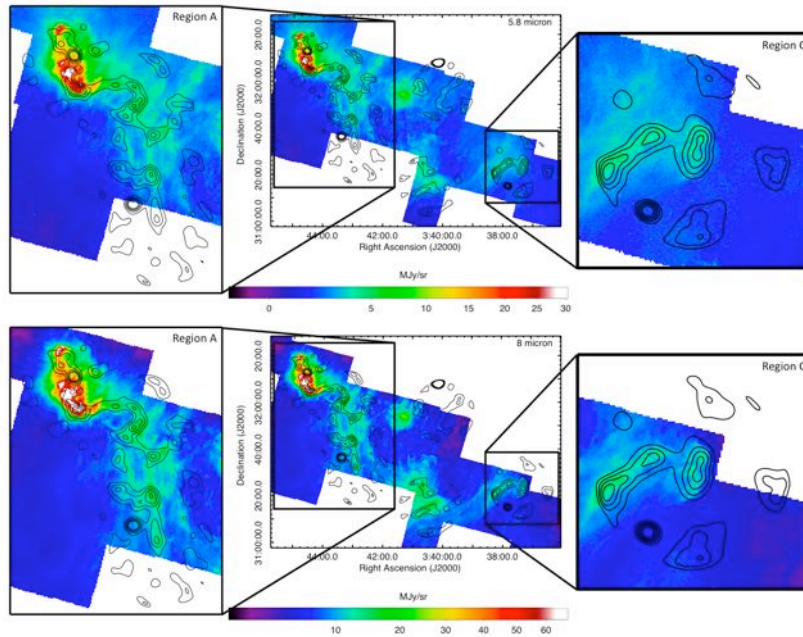
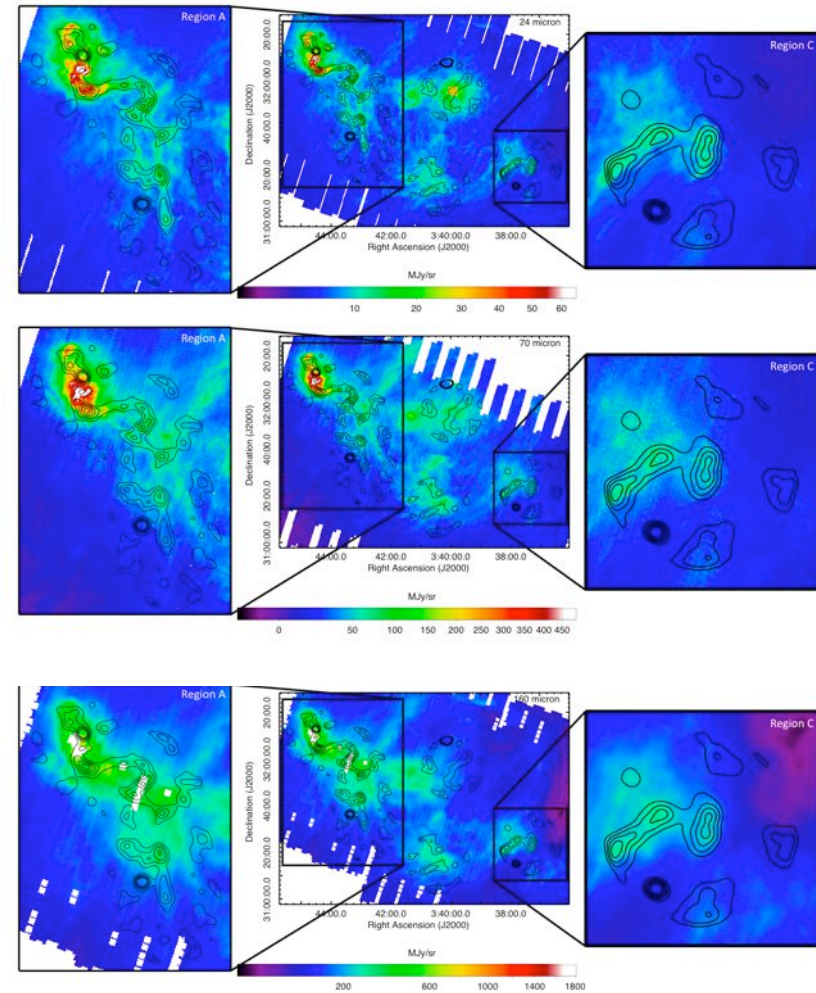
MIPS 24 μ m/VSA 33GHz

AMI 16GHz



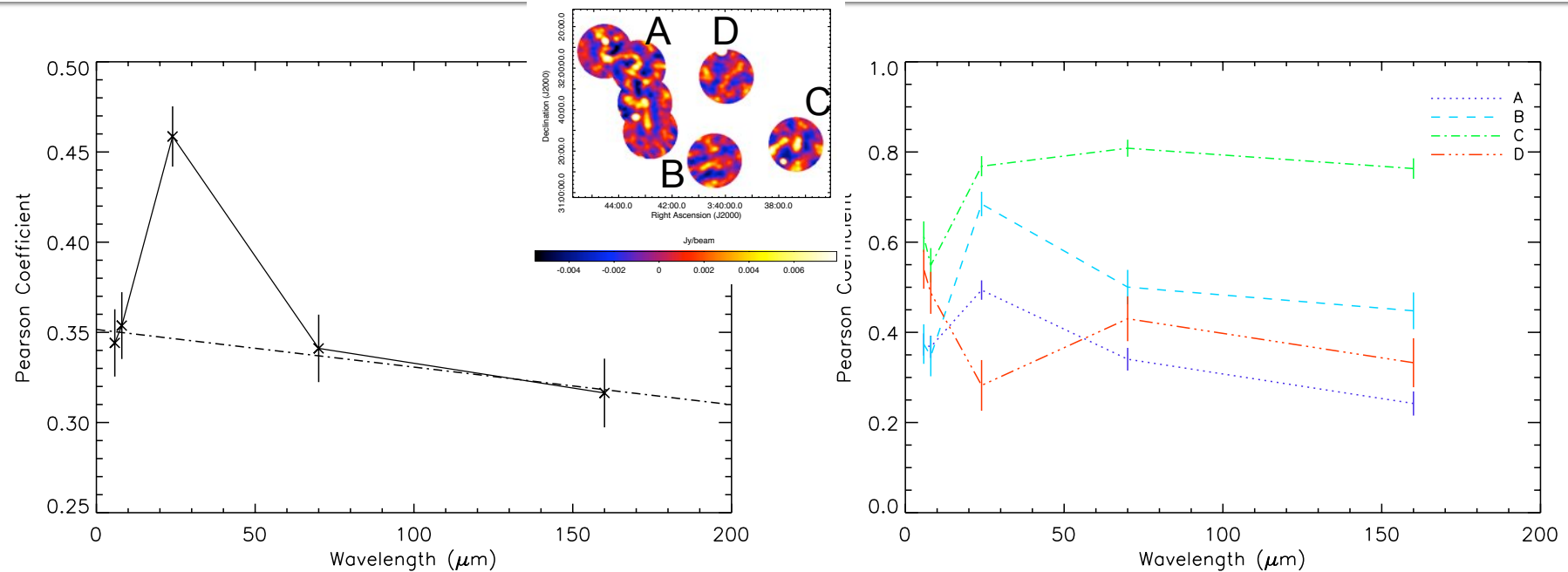
Results: Perseus

Tibbs et al. (2013a)

IRAC 5.8 and 8 μ m/AMI 16GHzMIPS 24, 70 and 160 μ m/AMI 16GHz

Results: Perseus

Tibbs et al. (2013a)



- Clear peak in the correlation at 24 μm (6.7σ).
- Region A and B peak at 24 μm with region C also strongly correlated with 24 μm .
- Region D is not strongly correlated with 24 μm , but this is the location of the OB star and is surrounded by very hot gas => 24 μm emission possibly due to thermal emission => lack of correlation.

Results: Perseus

Tibbs et al. (2013a)

- AMI observations confirm that the microwave-IR correlation observed at larger angular scales of $\approx 10\text{-}40$ arcmin is still present at angular scales of ≈ 2 arcmin.
- We find a preference for the microwave emission to correlate with the $24\mu\text{m}$ emission rather than the shorter wavelengths.

Is the AME due to spinning VSGs?

- or -

Is the AME more dependent on the excitation than the abundance of the carriers?

- or -

Is the AME due to spinning molecules that are not traced by the 5.8 or $8\mu\text{m}$ Spitzer bands?

What we still need to understand?

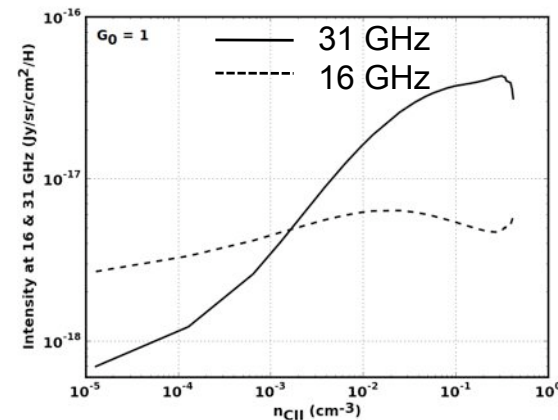
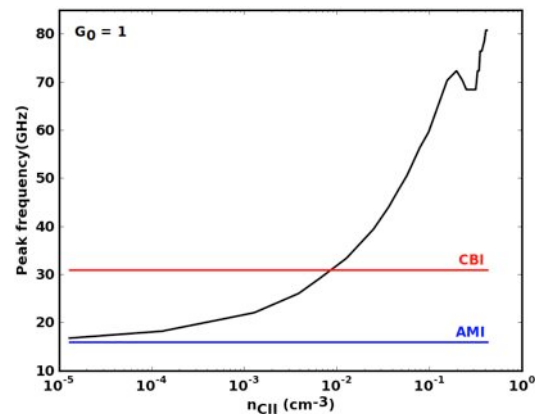
- Determine the population/size of the dust grains that are emitting
 - Theory states small grains: PAHs or VSGs? (e.g. Tibbs et al. 2013a)
- Determine the dominant excitation mechanism
 - There are many excitation mechanisms in the spinning dust models
 - Very dependent on environment (e.g. Tibbs et al. 2012a)
 - Determine the role played by gas ions in the spinning dust models (e.g. SOFIA cycle 1 observations to observed [CII] (P.I. Tibbs))
- Determine the role of star formation
 - Is AME connected to star formation?

What we still need to understand?

- Increase the number of AME detections
 - Currently only ~20 sources with AME detections
 - Need to increase this number to do a statistical analysis (e.g. Planck Collaboration, submitted to A&A.)
- Gain a better understanding of the morphology of the AME
 - Follow-up Planck targets with increased angular resolution (e.g. Programs to use CARMA and AMI interferometers)

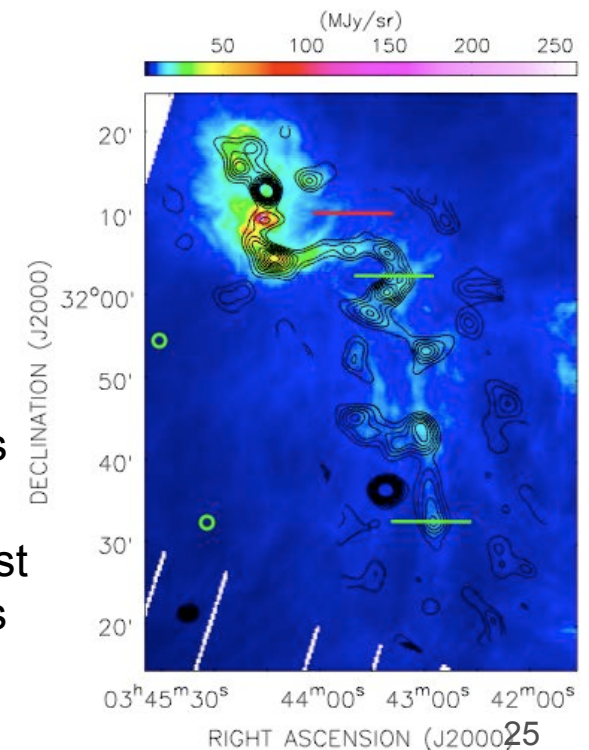
SOFIA Observations

- “Exploring the role of CII in current Spinning Dust Models”
 - SOFIA cycle 1 proposal to use GREAT to observe CII in 3 strips in Perseus
 - Team of experts in both theory and observation: C. Tibbs (PI), R. Paladini, A. Boogert, A. Scaife, N. Ysard, S. Casassus, A. Noriega-Crespo, S. Carey, C. Dickinson and N. Flagey.
- Scientific Justification
 - Although the spinning dust model attributes AME to the dust, the smallest dust grains, producing the spinning dust emission, are sensitive to the ionisation state of the gas, i.e. the abundance of the major charged species.
 - Therefore, one would expect that the spinning dust emission is also sensitive to the ionisation state of the gas (Ysard et al. 2011).



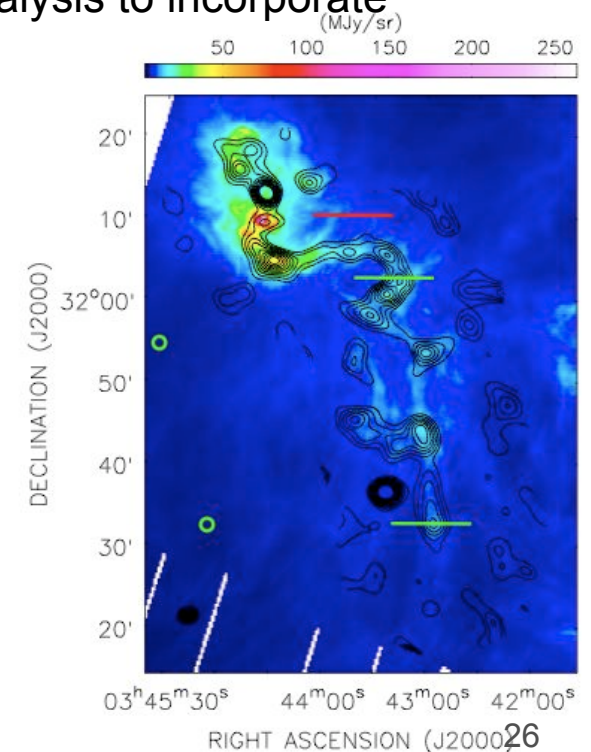
SOFIA Observations

- Target Selection
 - Perseus was chosen as it represents the best detection of AME to date
 - AME detected at angular resolutions of 2 arcmin (Tibbs et al. 2013a)
 - Wide selection of ancillary data available (particularly ^{12}CO , ^{13}CO data cubes will help distinguish between multiple CII components along the line of sight).
- Observing Strategy
 - Observe the CII 158 μm line with band L #2 (1.815 – 1.91 THz) of the GREAT instrument using the Acousto-Optical Spectrometers (AOS) backend.
 - Additionally, since GREAT is a dual channel receiver, we will simultaneously observe the NII line with band L #1b (1.417 – 1.52 THz).
 - Use on-the-fly mapping to observe three 11arcmin stripes (see Figure).
 - 2 of the stripes are positioned to intersect filaments of dust where AME has been detected (green) while one stripe is located away from any AME (red).



SOFIA Observations

- Goals
 - To investigate how the CII emission correlates with the AME
 - To better constrain the ionized carbon fractional abundance parameter in the spinning dust models
 - To combine the CII observations with a dust modelling analysis of the IR continuum emission resulting in the first spinning dust analysis to incorporate both the dust and gas properties.



Conclusions

- AME is a new emission mechanism that has been observed in numerous Galactic environments
- The currently favoured explanation is electric dipole emission from rapidly spinning dust grains.
- The Perseus molecular cloud represents one of the best examples of AME detection. In fact the AME in Perseus has been observed on a range of angular scales from degrees to a few arcmin.
- The microwave – IR correlation present on 10arcmin angular scales is still present at 2arcmin angular scales.
- The 24 μ m emission is most highly spatially correlated with the microwave emission suggesting that it is VSGs rather than PAHs that are spinning.
- There are still open questions that need to be answered, one of which involves determining the dominant excitation mechanism. For this we proposed SOFIA GREAT observations to observe CII in Perseus.