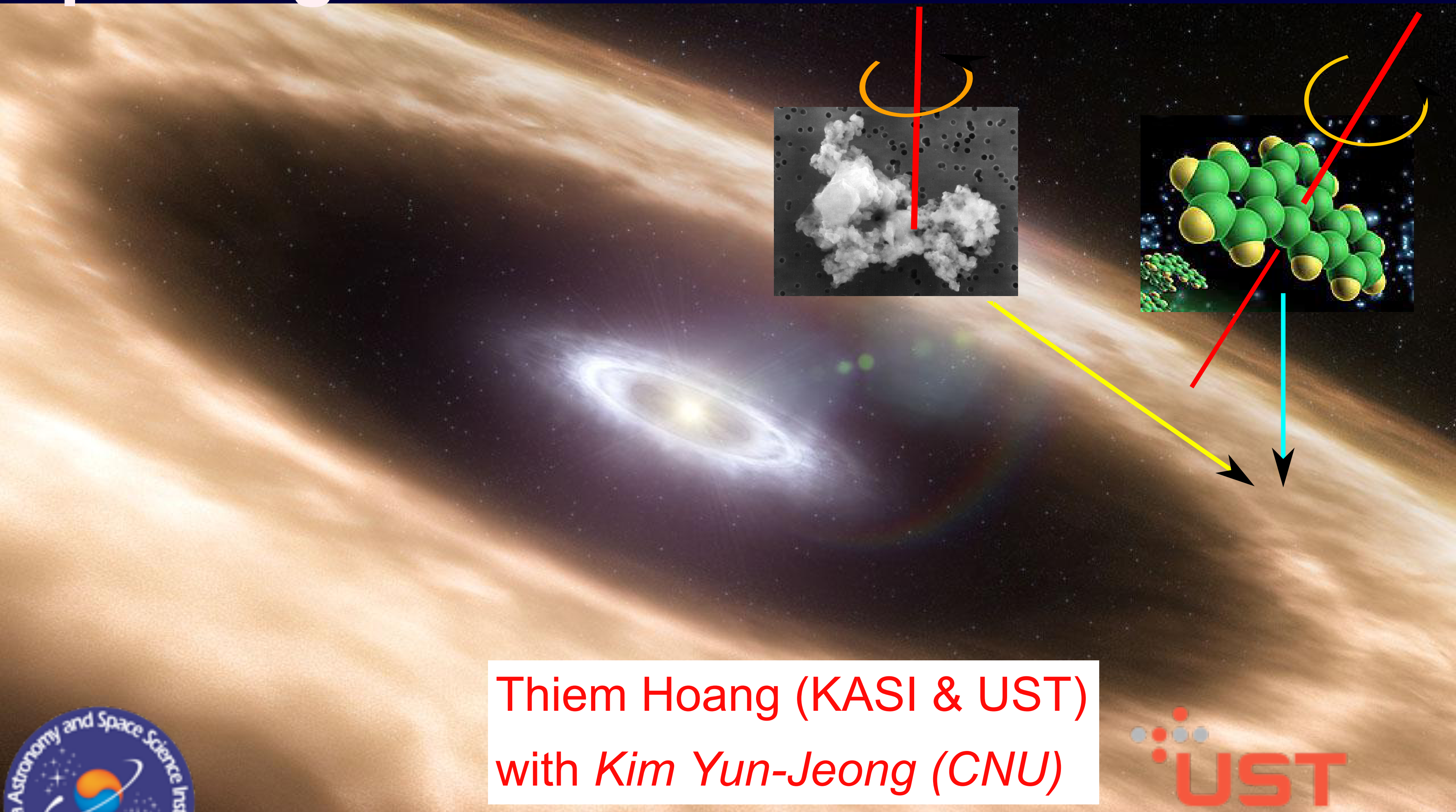
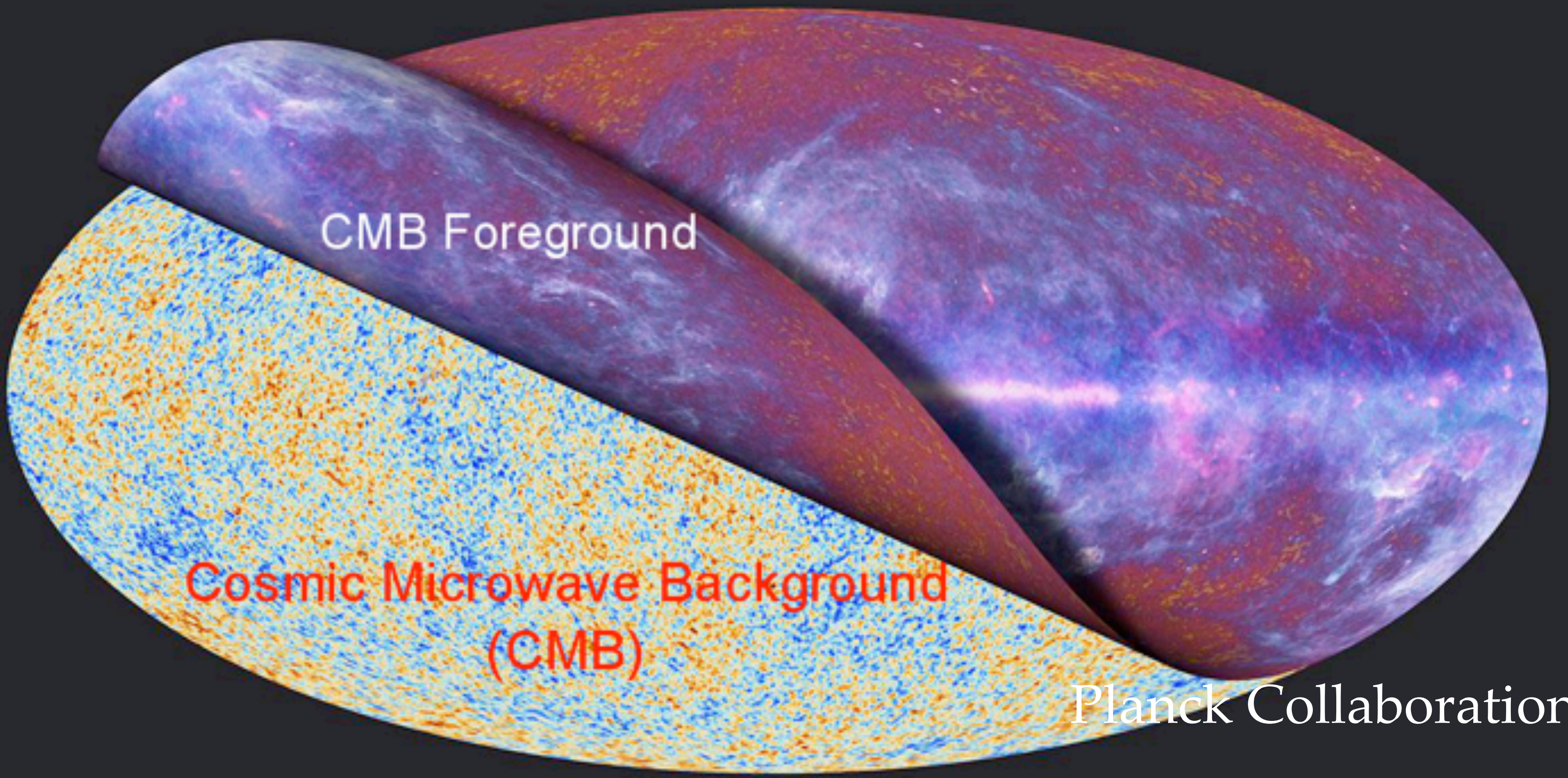
Circumstellar Disks: a Testbed of Spinning Dust **with ALMA Band 1?**



Thiem Hoang (KASI & UST)
with *Kim Yun-Jeong (CNU)*

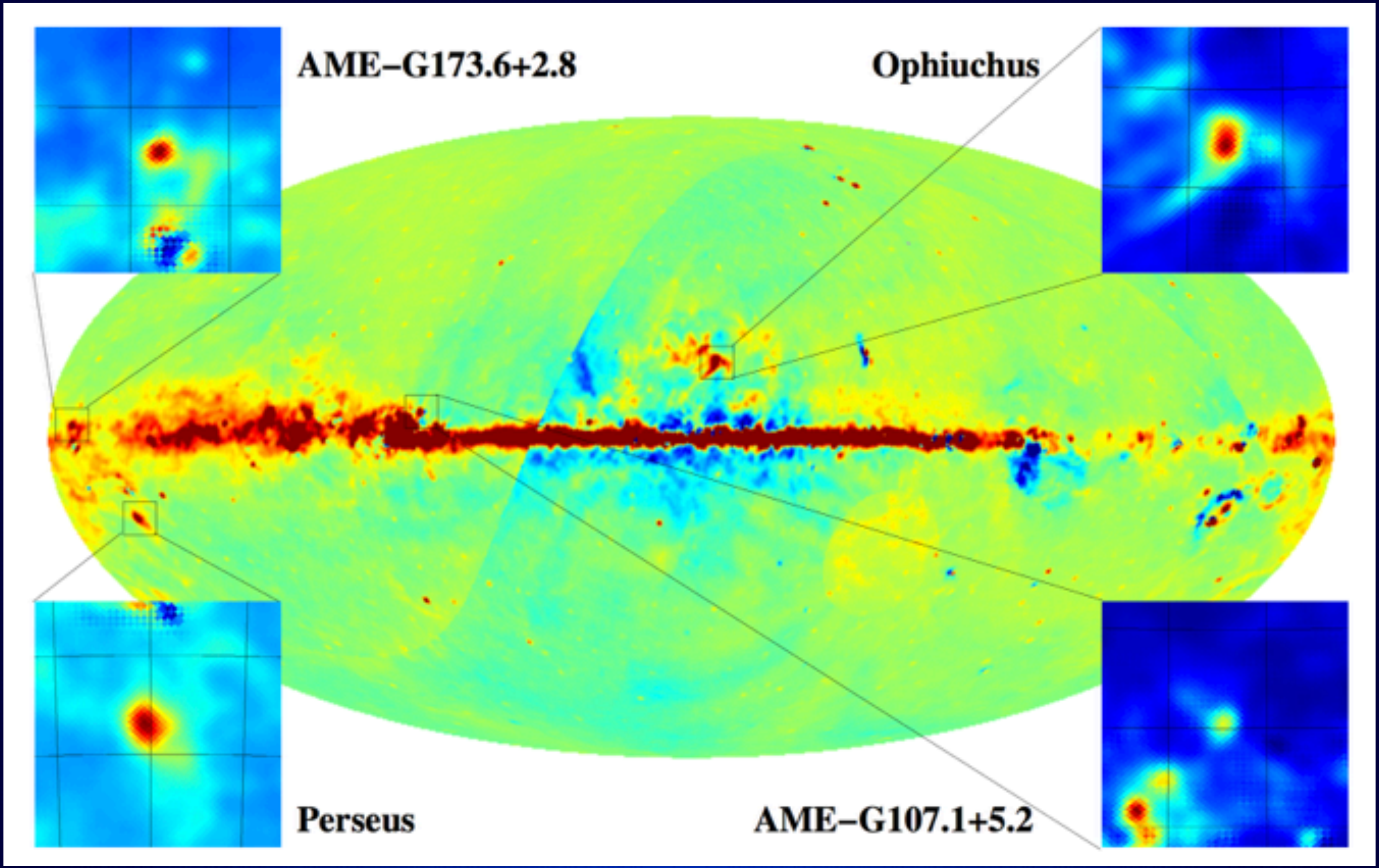
East-Asia ALMA Science Workshop, Daejeon, Nov 28-30, 2017

History of Anomalous Microwave Emission (AME) & Spinning Dust



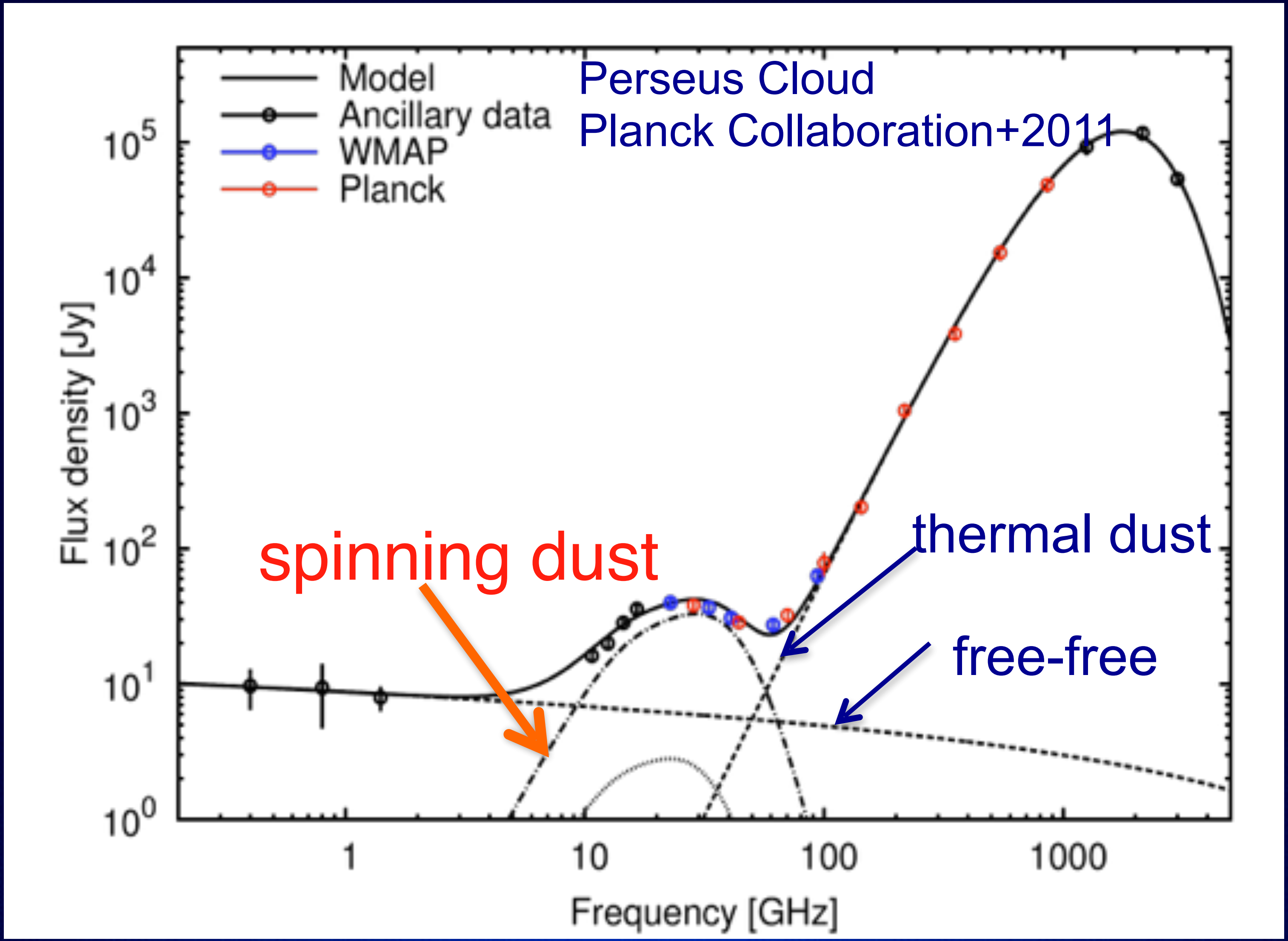
- 1996 Kogut et al. found emission excess at 31 GHz
- 1997 Leitch et al. found emission excess at 14.5 & 31GHz (AME intro)
- 1998 Draine & Lazarian proposed spinning dust by very small grain (PAH)

Selected AME regions discovered by Planck 2011

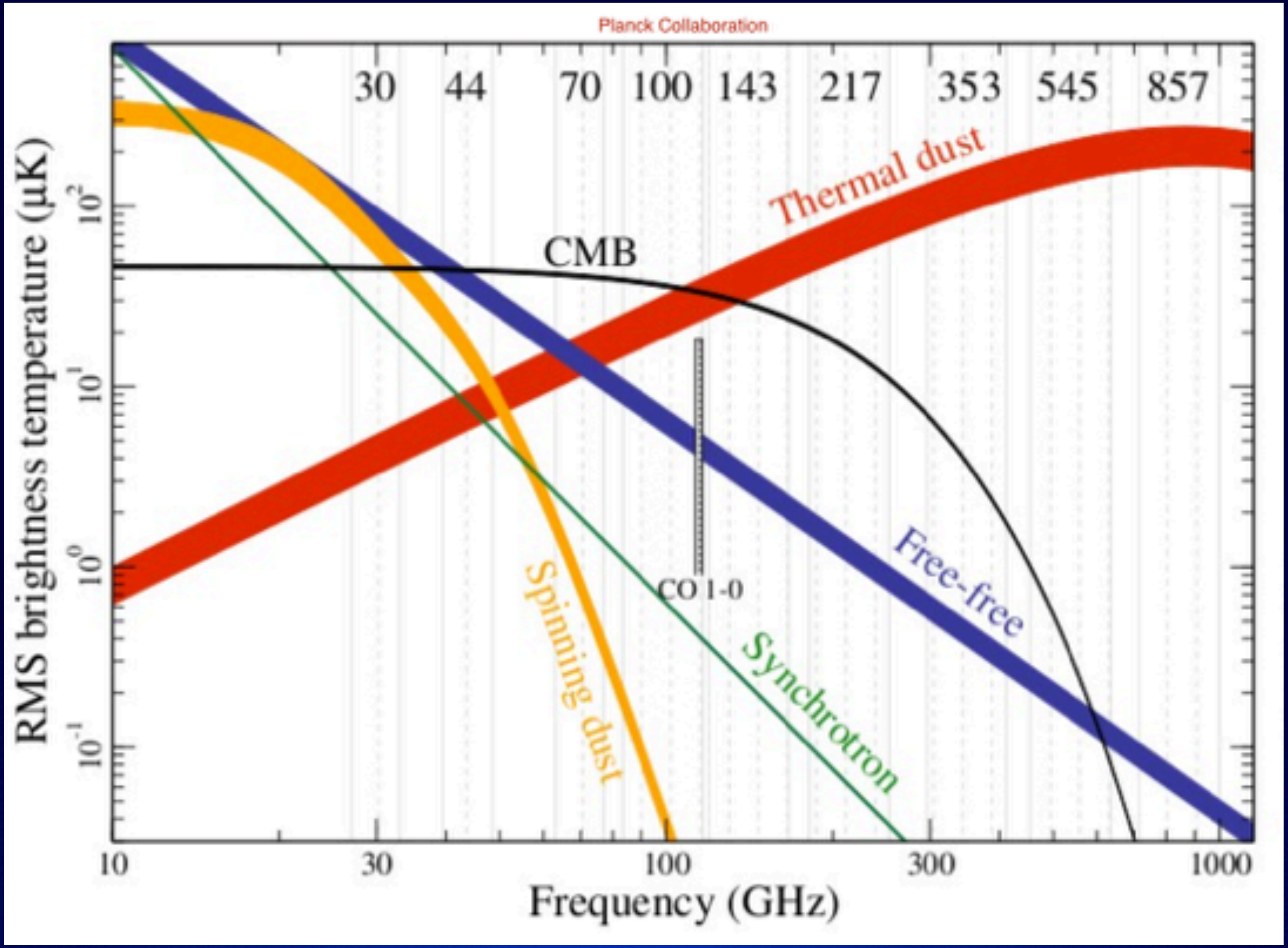


Planck Collaboration 2011, A20

Spinning dust provides a great fit to AME from *Planck*



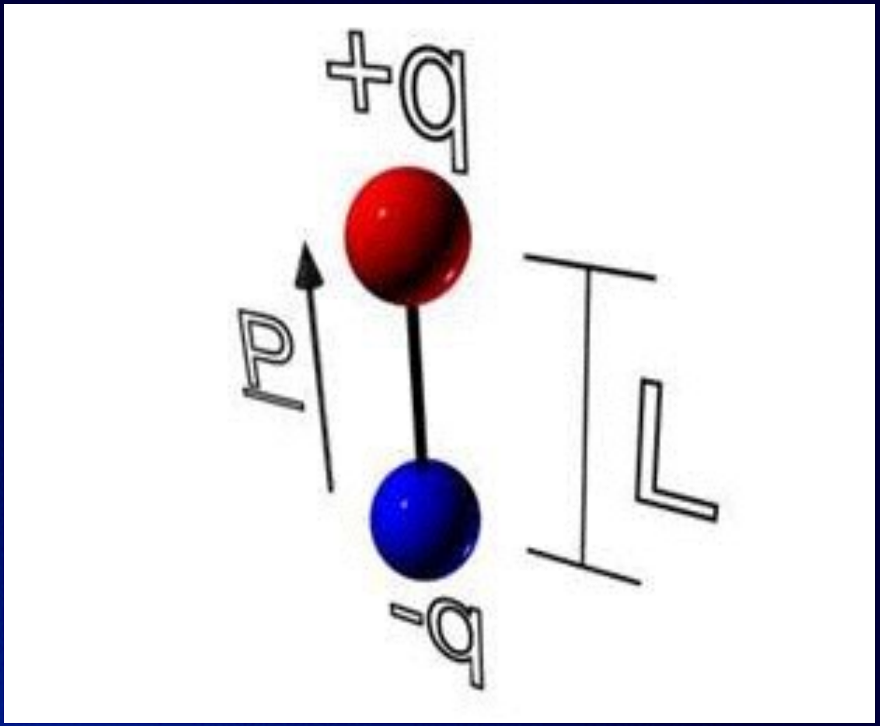
Spinning dust becomes an accepted CMB foreground



Physics of Spinning Dust Emission

Rapidly spinning

dipole moment



Key Developments of Spinning Dust Theory

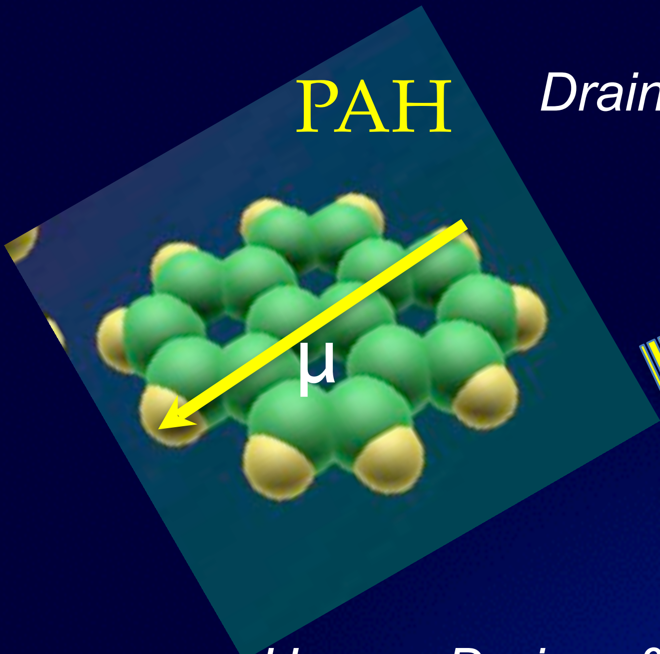
Development	Reference
First proposal for electric dipole radiation fr	Erickson (1957)
First full treatment of spinning dust grain th	Draine and Lazarian (1998b)
Quantum suppression of dissipation and ali	Lazarian and Draine (2000)
Factor of two correction in IR damping coe	Ali-Haïmoud et al. (2009)
Fokker-Planck treatment of high-ω tail	Ali-Haïmoud et al. (2009)
Quantum mechanical treatment of long-wav	Ysard and Verstraete (2010)
Rotation around non-principal axis	Hoang et al. (2010); Silsbee
Transient spin-up events	Hoang et al. (2010)
Effect of tri-axiality on rotational spectrum	Hoang et al. (2011)
Effects of transient heating on emission fro	Hoang et al. (2011)
Magnetic dipole radiation from ferromagne	Hoang and Lazarian (2016b)
Improved treatment of quantum suppressio	Draine and Hensley (2016)

Dickinson, et al., incl Thiem Hoang (2018, A&A Review)

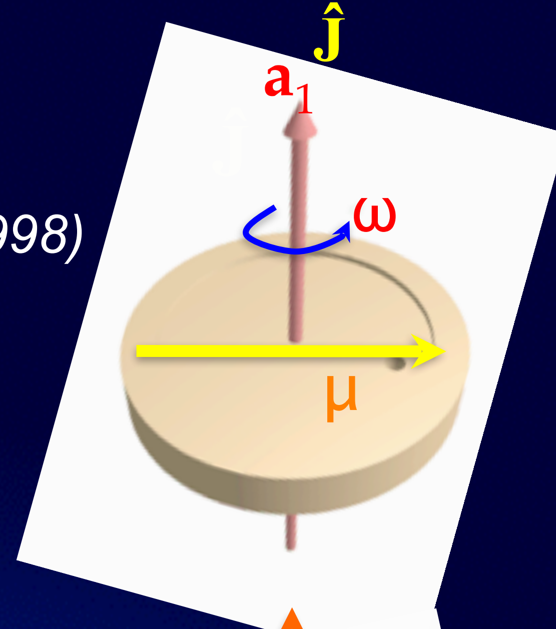
AME from nanosilicates: Hoang + (2016), Hensley & Draine (2017)

AME polarization: Hoang + (2013), Hoang & Lazarian (2016a, 2017)

Spinning Dust Emission Model



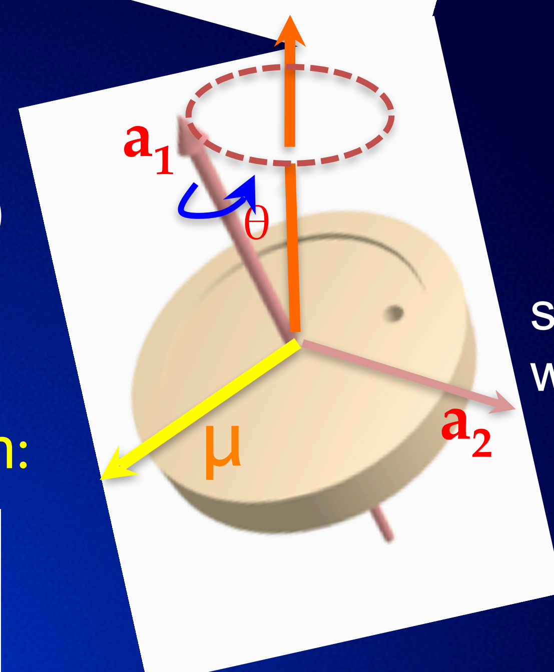
Draine & Lazarian (1998)



spinning only

Hoang, Draine, & Lazarian (2010)

Hoang, Lazarian, & Draine (2011)



spinning & wobbling

Emissivity integrated over size distribution:

$$\frac{j_\nu}{n_H} = \frac{1}{4\pi} \int_{a_{\min}}^{a_{\max}} da \frac{1}{n_{\rm H}} \frac{dn}{da} 4\pi\omega^2 f_\omega 2\pi P_{\rm ed}(\omega)$$

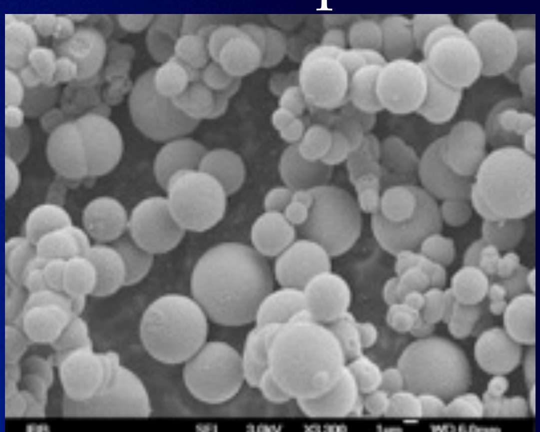
What is the exact carrier of AME?

1. **Spinning dust emission**:
    1. spinning PAH molecules (Draine & Lazarian 1998)
    2. spinning silicate nanoparticles (Hoang et al. 2016)
    3. spinning iron nanoparticles (Hoang & Lazarian 2016)
2. **Magnetic Dipole Emission**

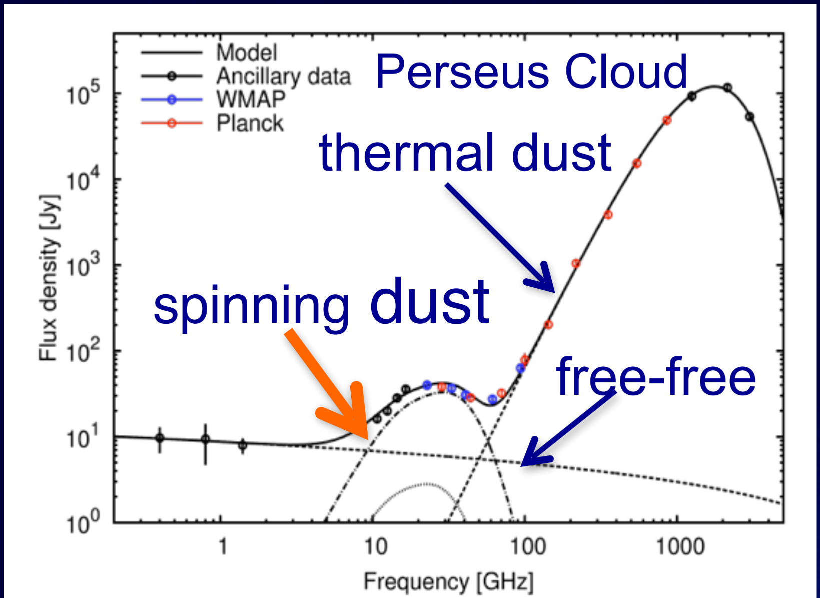
PAH molecule

Nanosilicate

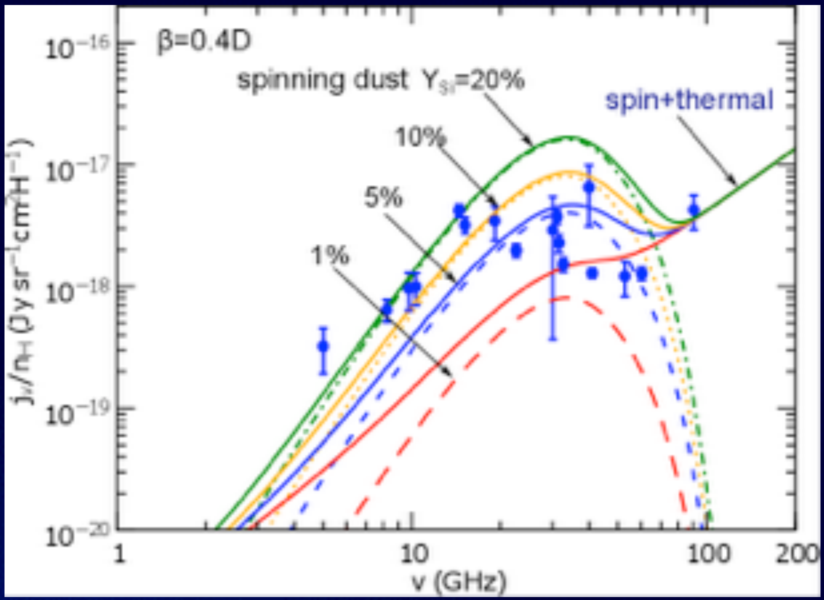
Iron Nanoparticle



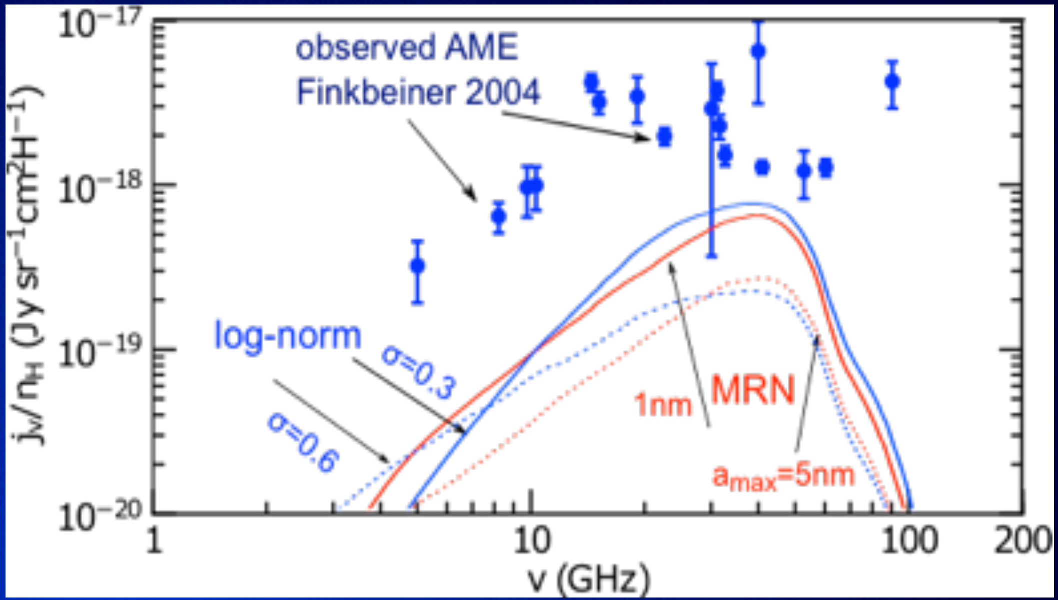
spinning PAH (Planck collaboration 2011)



spinning nanosilicates (Hoang et al. 2016)



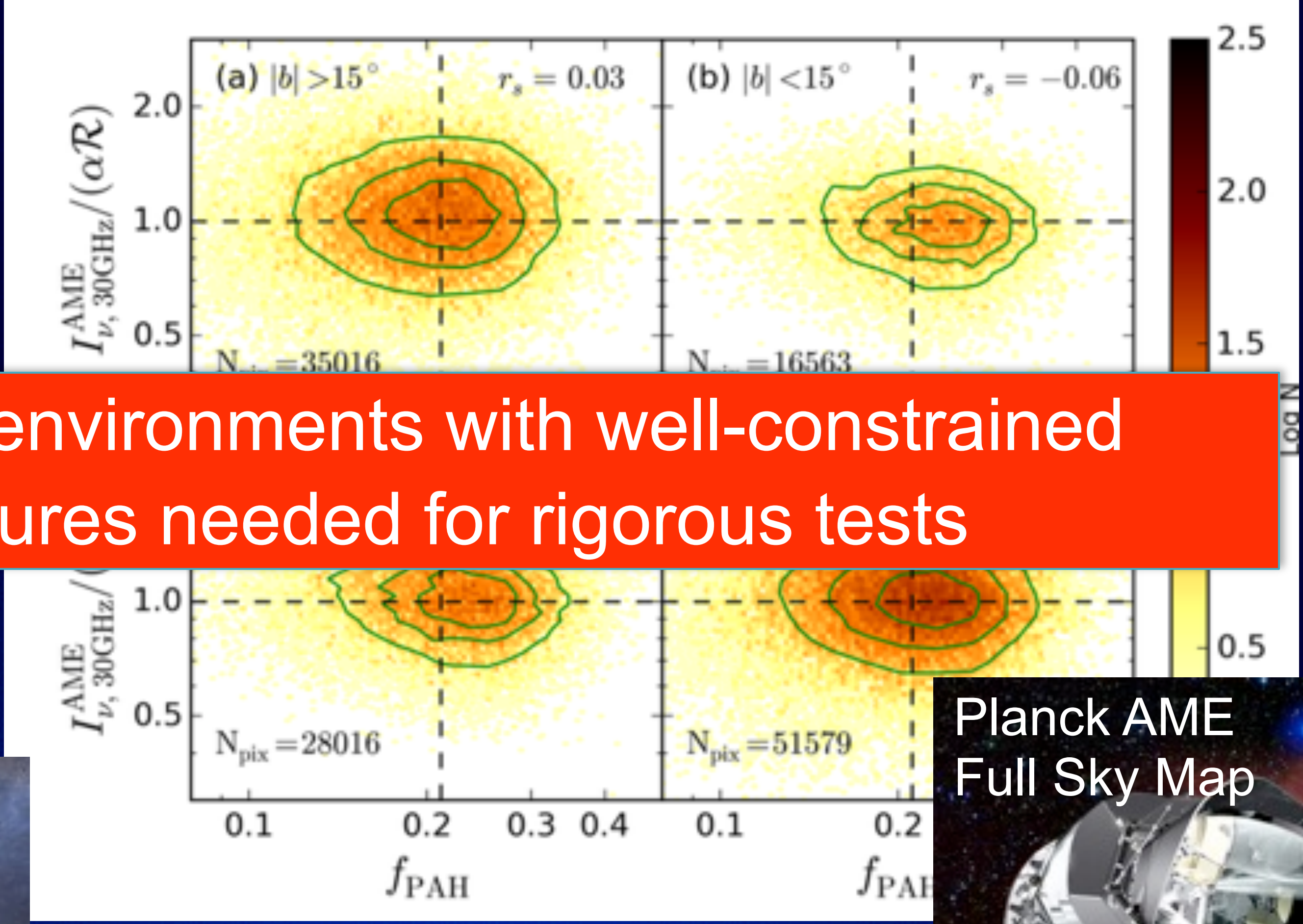
spinning iron nanoparticle (Hoang & Lazarian 2016)



Full-sky analysis found no correlation of AME with PAH abundance

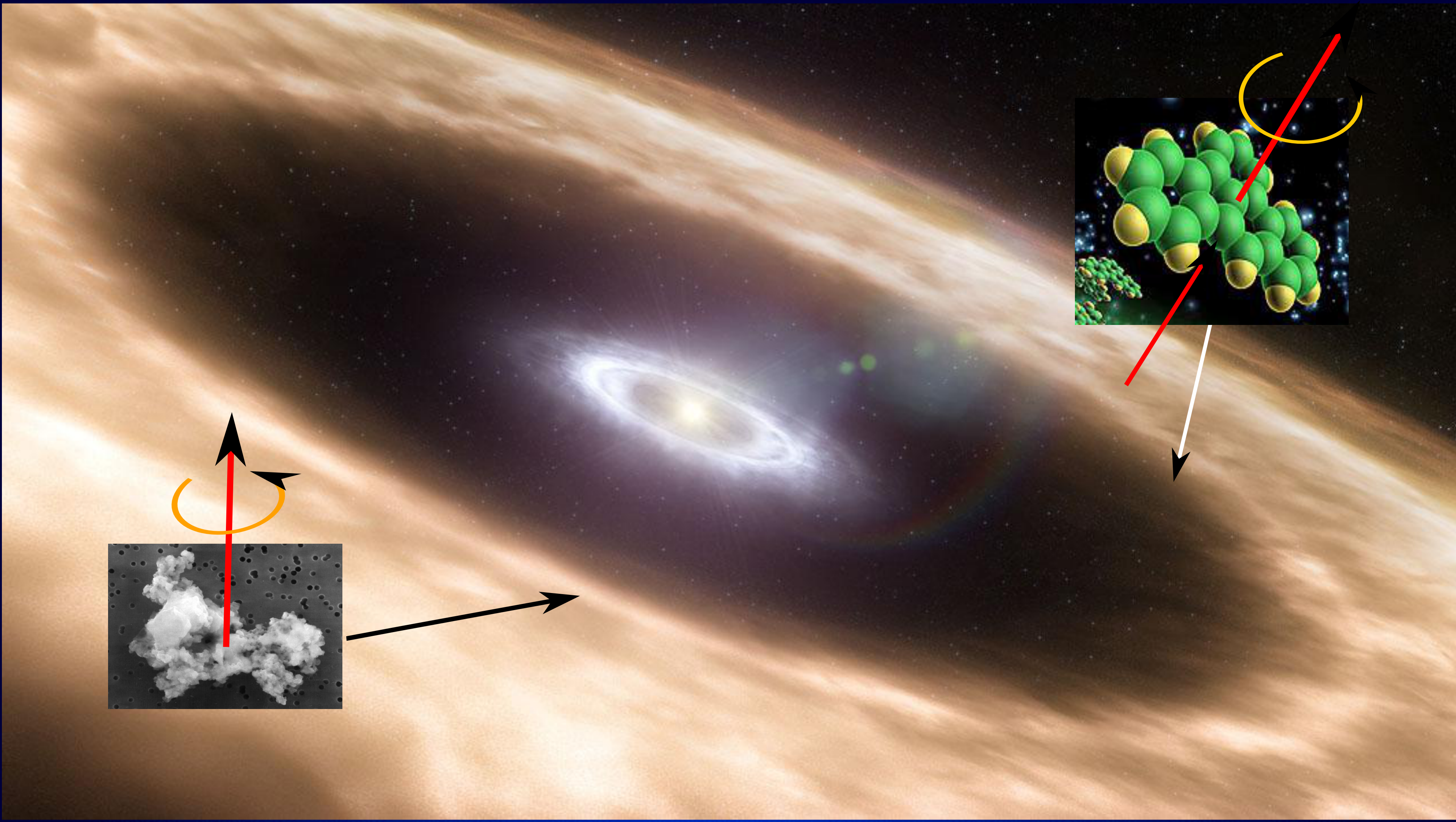
Hensley, Draine, & Meisner (2015)

- AME from *Planck*
- f_{PAH} from *WISE*
- R: Radiance



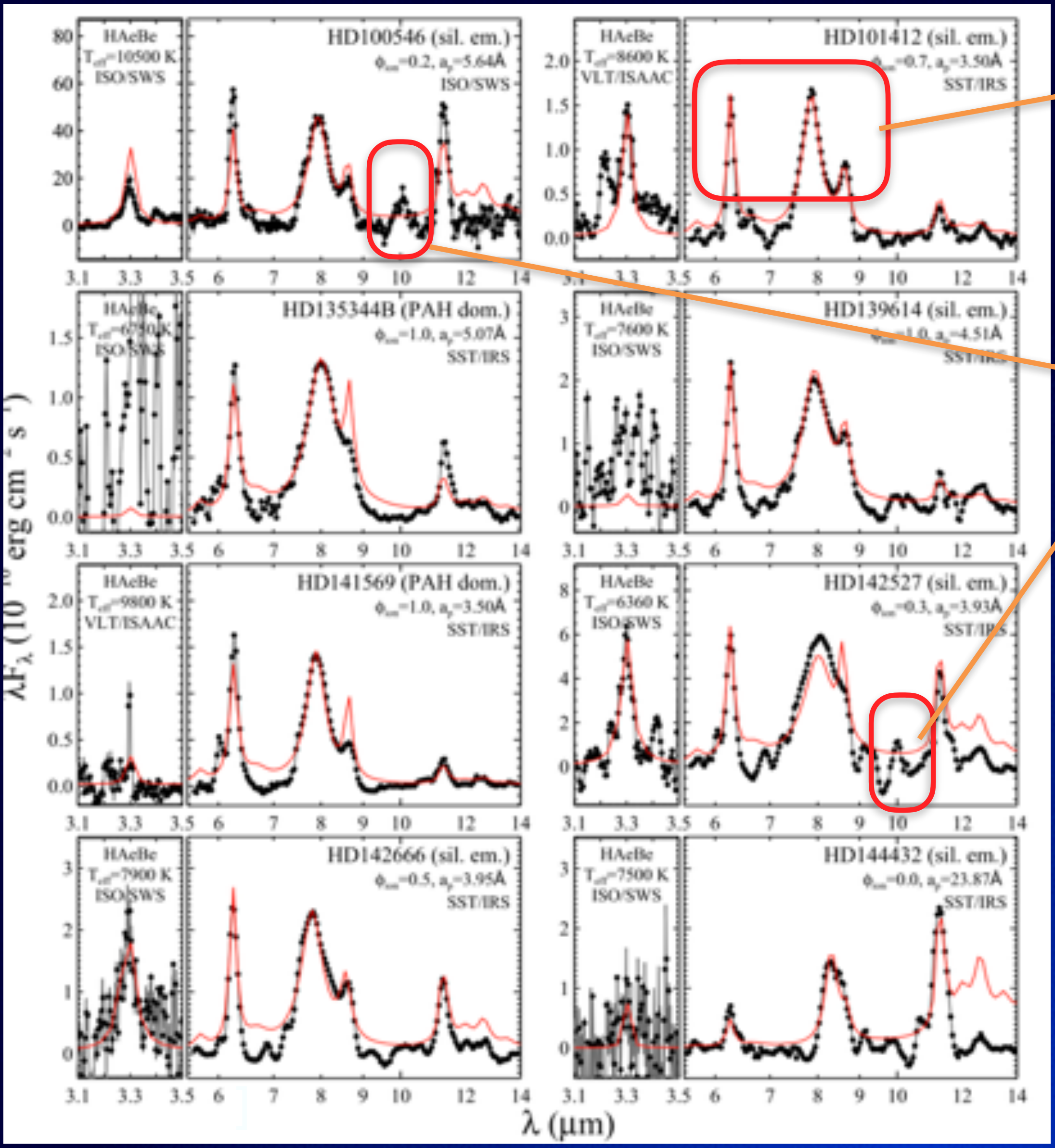
Specific environments with well-constrained PAH features needed for rigorous tests

Circumstellar Disk: a Testbed for Spinning Dust Theory



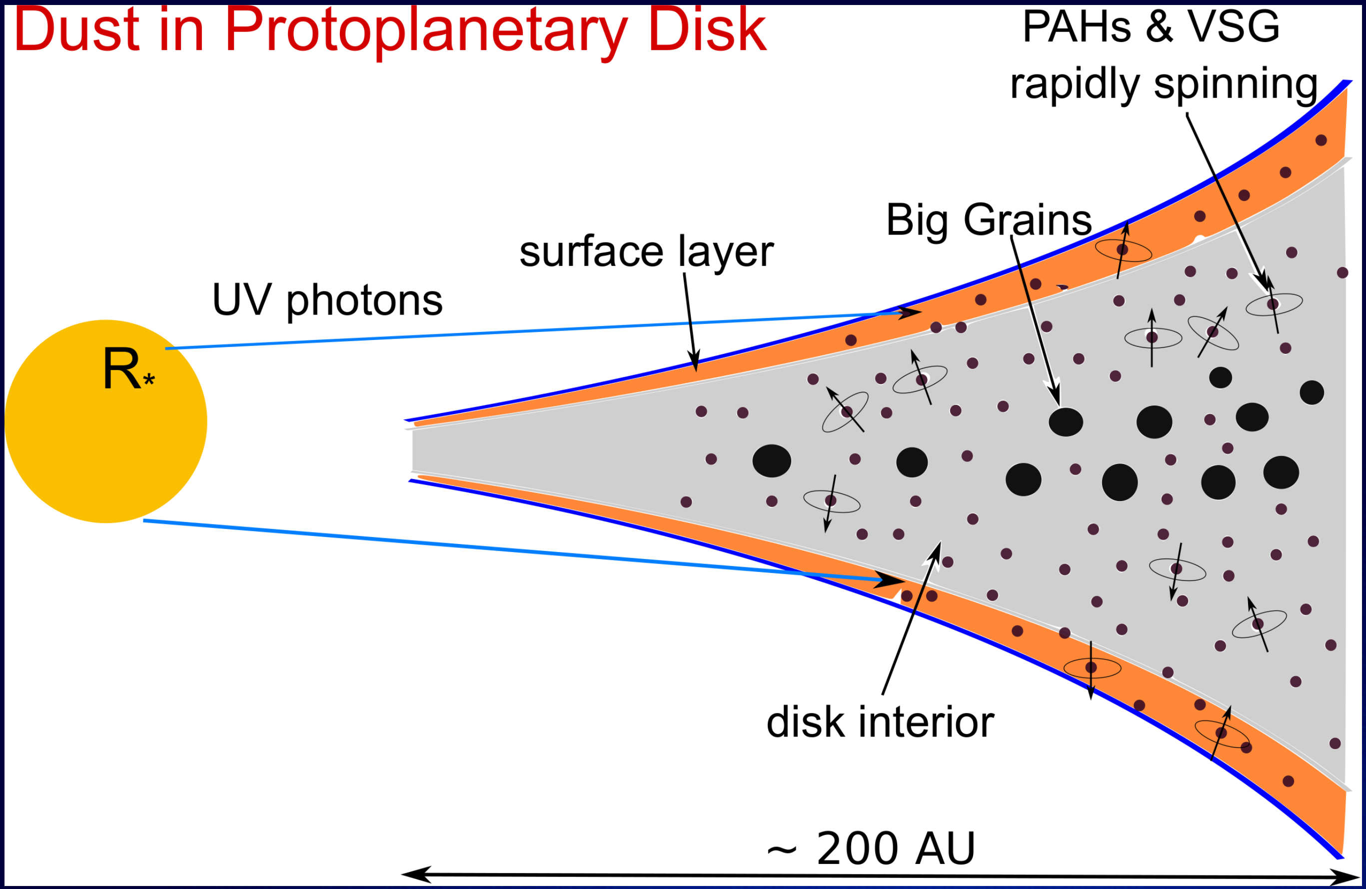
PAHs and Nanodust in circumstellar disks

IR Emission Spectrum (Seok & Li 2017)



- Strong PAH features detected (Acke + 2004, Habart + 2004)
- 9.7 micron Silicate emission features detected in some disks

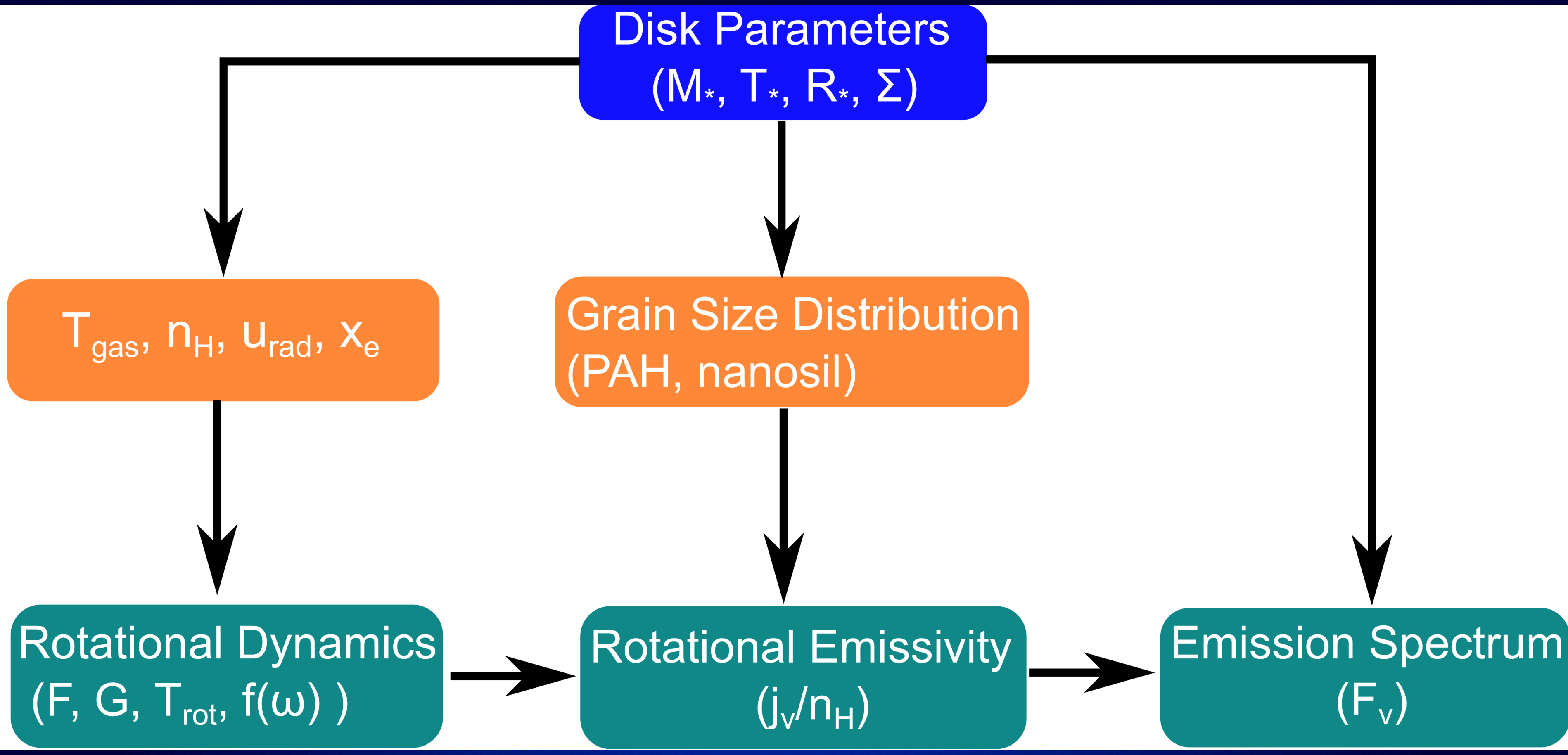
Spinning Dust from Disk and Its Importance



- PAHs/VSG well mixed to the gas due to turbulence (Dullemond + 2005)
- Fragmentation produces PAHs/VSG
- Grain coagulation and dust settling

- Observations provide smoking-gun evidence for spinning PAHs and spinning nano silicates
- Spindust trace Nanodust in the entire disk (cf. Mid-IR)

Modeling of Spinning Dust Emission in Disk

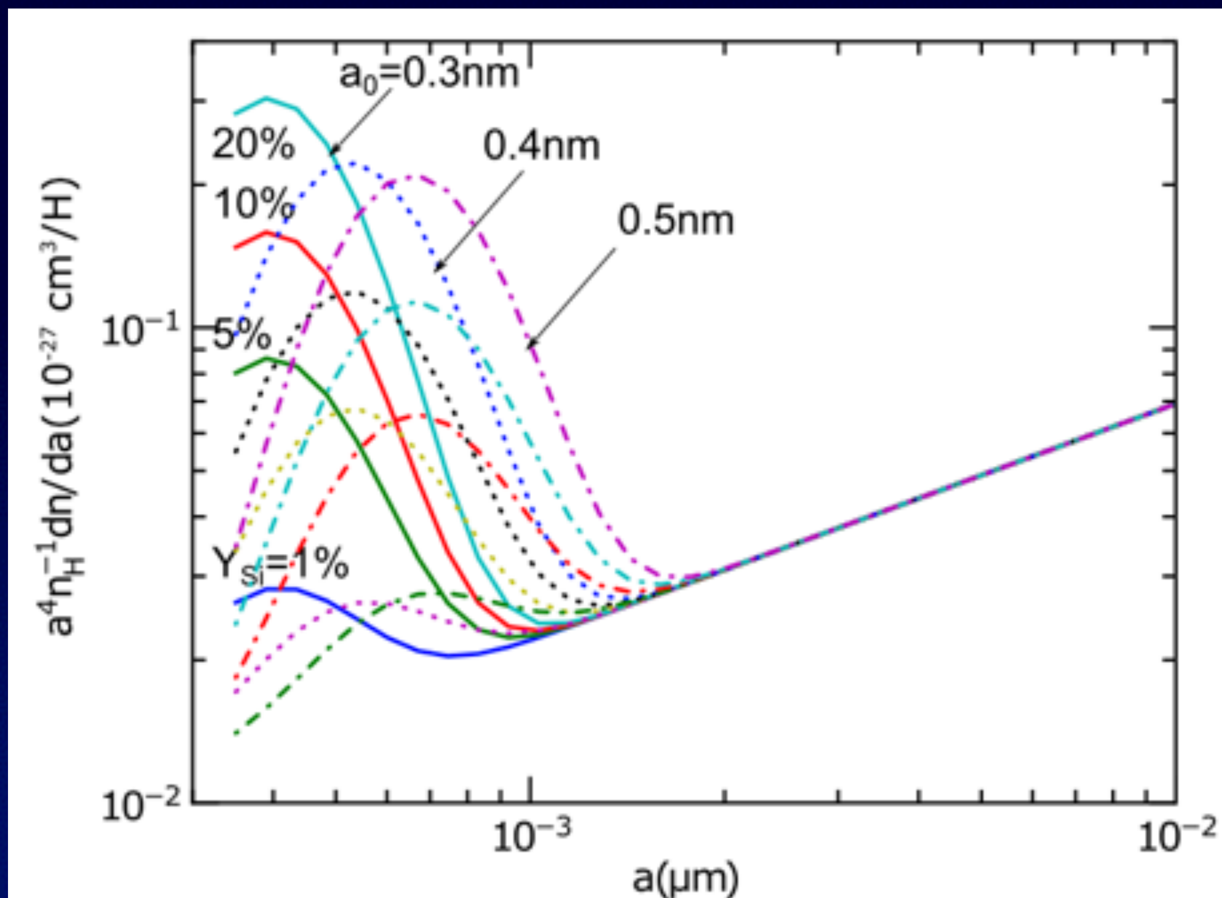


Size Distribution of PAH/VSG

Log-normal grain size distribution

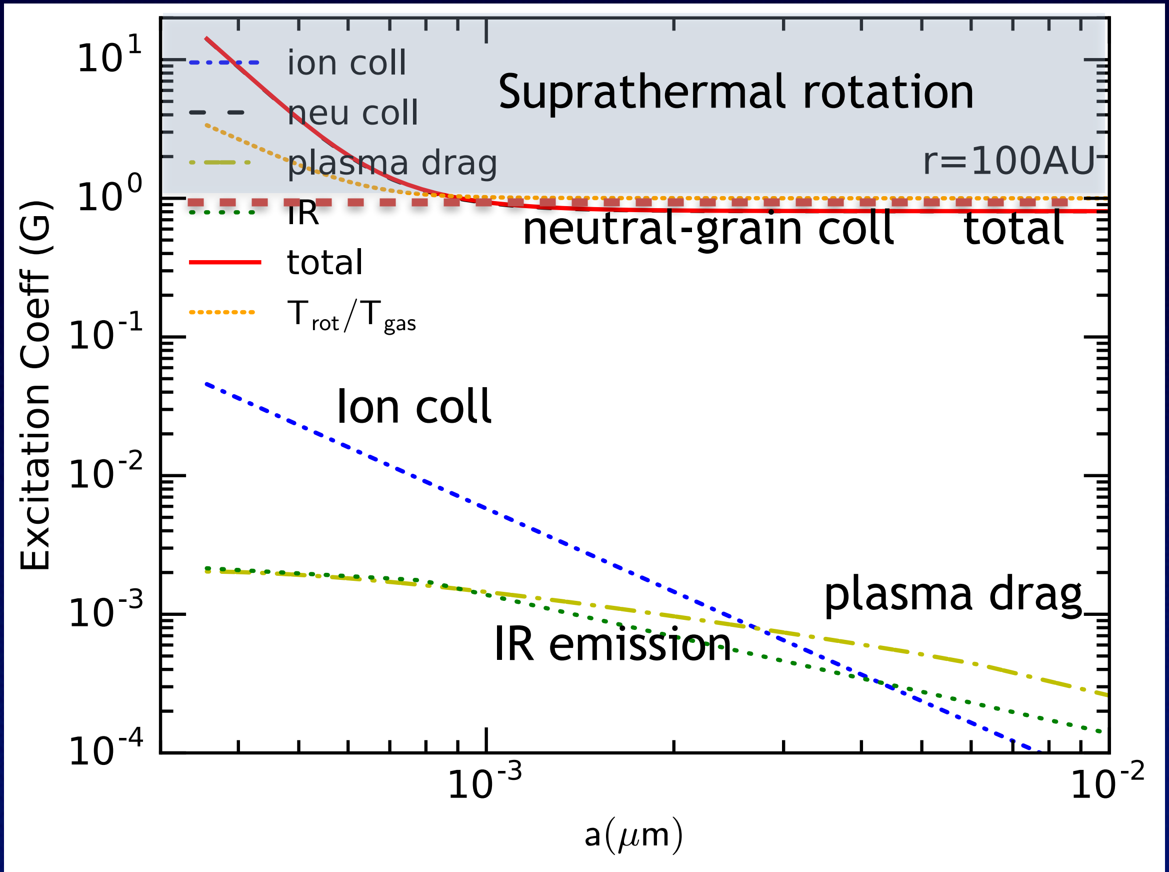
$$\frac{1}{n_H}\frac{dn}{da} = \frac{B}{a}\exp\left(-0.5\left[\frac{\log(a/a_0)}{\sigma}\right]^2\right)$$

where B is determined by abundance of C/Si in nanoparticles, a_0, sigma controls the peak

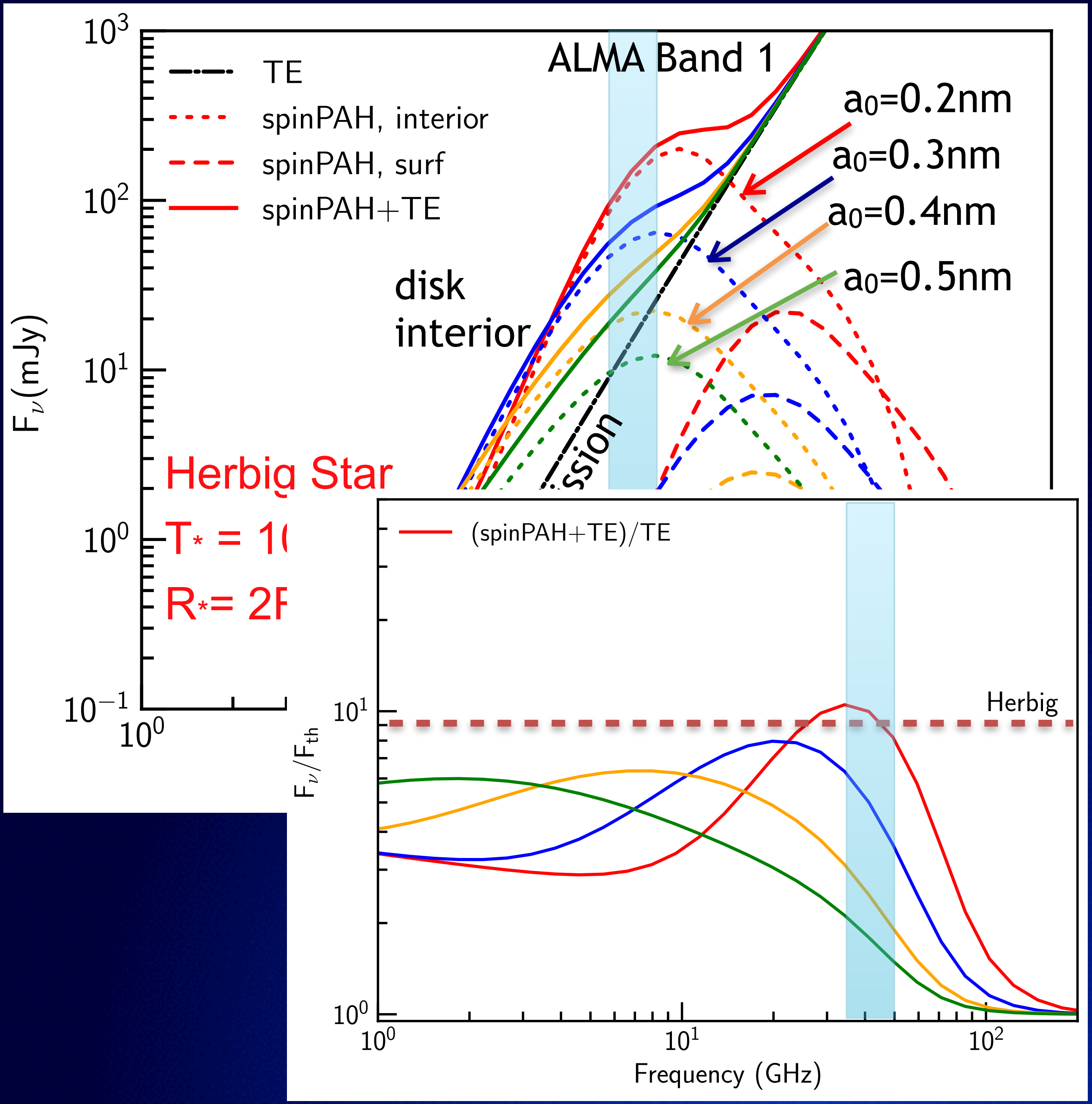


Rotational Dynamics of PAH/VSG

- PAH/VSGs acquire/loose momentum by neutral and ion collisions, plasma drag, and IR emission
- In the disk interior, PAH/VSGs are negatively charged
- Small PAH/VSGs have suprathermal rotation

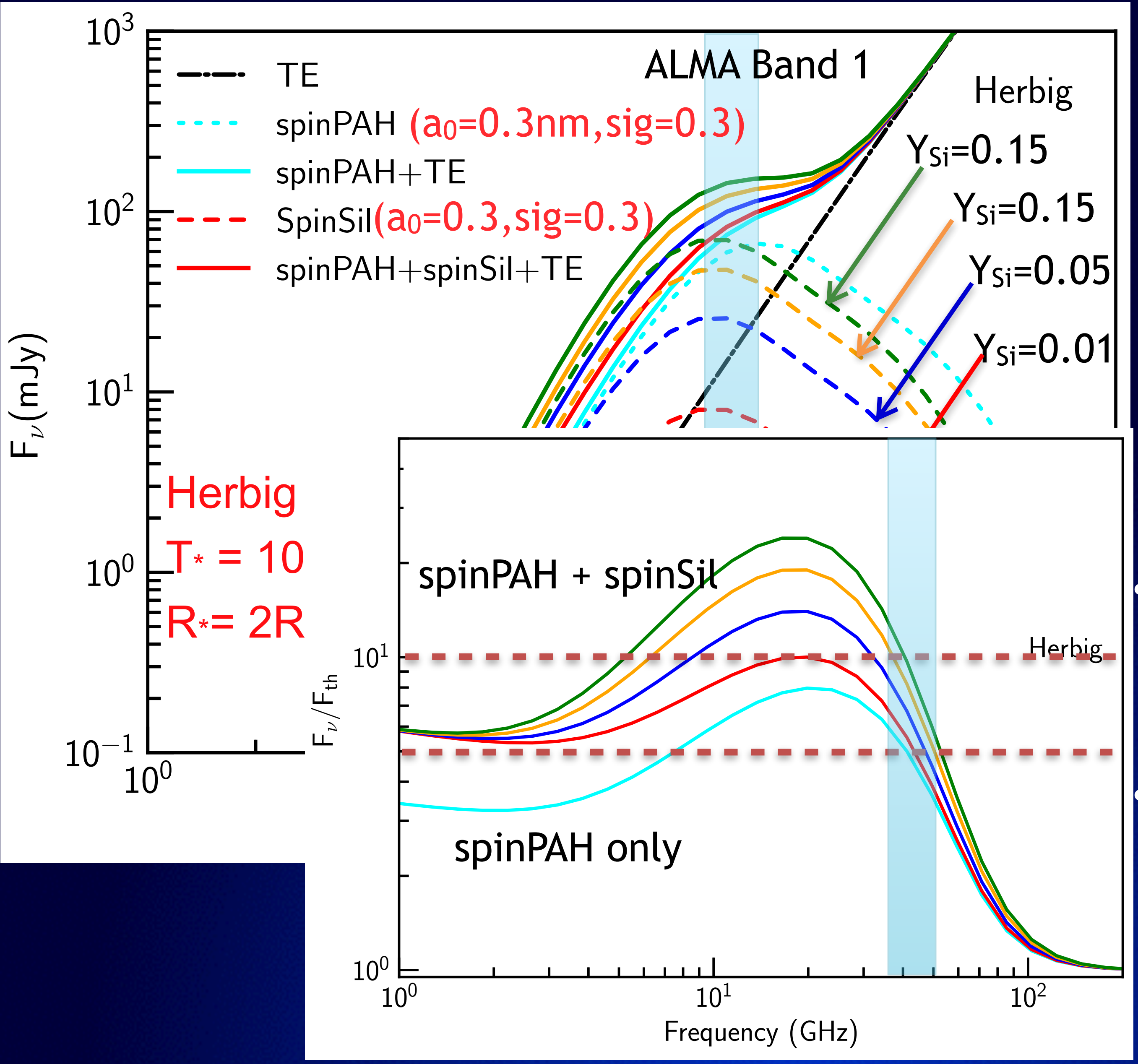


Microwave Emission Spectrum: Spinning PAHs



- Smaller PAHs emit stronger spindust emission
- Surface layer little contribution
- Spindust emission larger than thermal emission up to 10 times

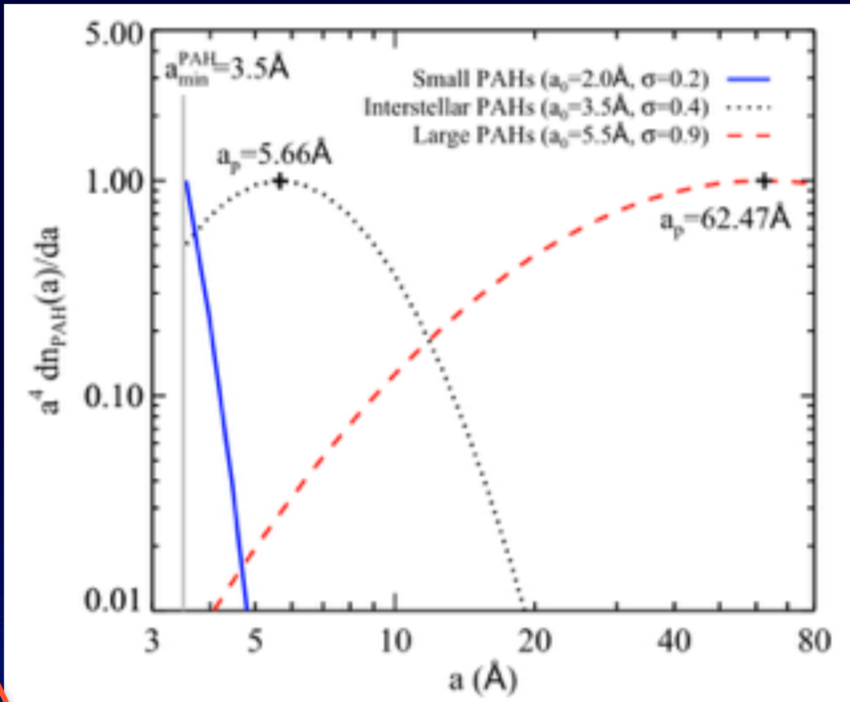
Emission Spectrum: Spinning PAH & Nanosilicate



- Spinning nanosil increases emission flux by 3 times
- Spindust emission up to 25 times of thermal emission

Best targets for Observations

Object	a_0 (Å)	σ	a_p (Å)	ϕ_{ion}	$M_{PAH}^{10\,au\,c}$ ($10^{-6}\,M_{\oplus}$)
	Best-fit				
AB Aur	5.0	0.2	5.64	0.7	1.96
AK Sco	2.5	0.3	3.50	0.0	0.56
BD+40°4124	5.5	0.4	8.89	0.3	1.01
BF Ori	2.5	0.6	7.36	0.1	0.44
DoAr21	5.5	0.2	6.20	0.1	12.4
EC82	2.0	0.2	3.50	0.0	540
HD 31648	4.5	0.2	5.07	0.4	1.56
HD 34282	4.0	0.2	4.51	0.8	3.86
HD 34700	2.0	0.2	3.50	0.5	17.7
HD 35187	2.5	0.5	5.29	1.0	1.12
HD 36112	5.0	0.2	5.64	0.3	0.96
HD 36917	5.5	0.3	7.20	0.3	0.62
HD 37357	2.0	0.2	3.50	0.1	0.69
HD 37411	3.5	0.3	4.58	1.0	2.27
HD 37806	5.0	0.5	10.59	0.6	0.41
HD 38120	2.0	0.2	3.50	0.3	0.96
HD 58647	5.5	0.2	6.20	1.0	0.052
HD 72106	2.0	0.2	3.50	0.5	2.87
HD 85567	5.0	0.3	6.55	0.9	0.054
HD 95881	4.0	0.2	4.51	0.7	4.32
HD 97048	5.0	0.2	5.64	0.4	6.42
HD 97300	5.5	0.2	6.20	0.9	1.60
HD 98922	2.5	0.2	3.50	0.6	0.99
HD 100453	2.0	0.2	3.50	0.7	4.72
HD 100546	5.0	0.2	5.64	0.2	5.37
HD 101412	2.0	0.2	3.50	0.7	3.13
HD 135344B	4.5	0.2	5.07	1.0	1.55
HD 139614	4.0	0.2	4.51	1.0	1.83
HD 141569	2.0	0.2	3.50	1.0	0.19
HD 142527	3.0	0.3	3.93	0.3	7.51
HD 142666	3.5	0.2	3.95	0.5	2.08
HD 144432	3.5	0.8	23.87	0.0	6.50
HD 145718	2.0	0.2	3.50	0.2	5.17

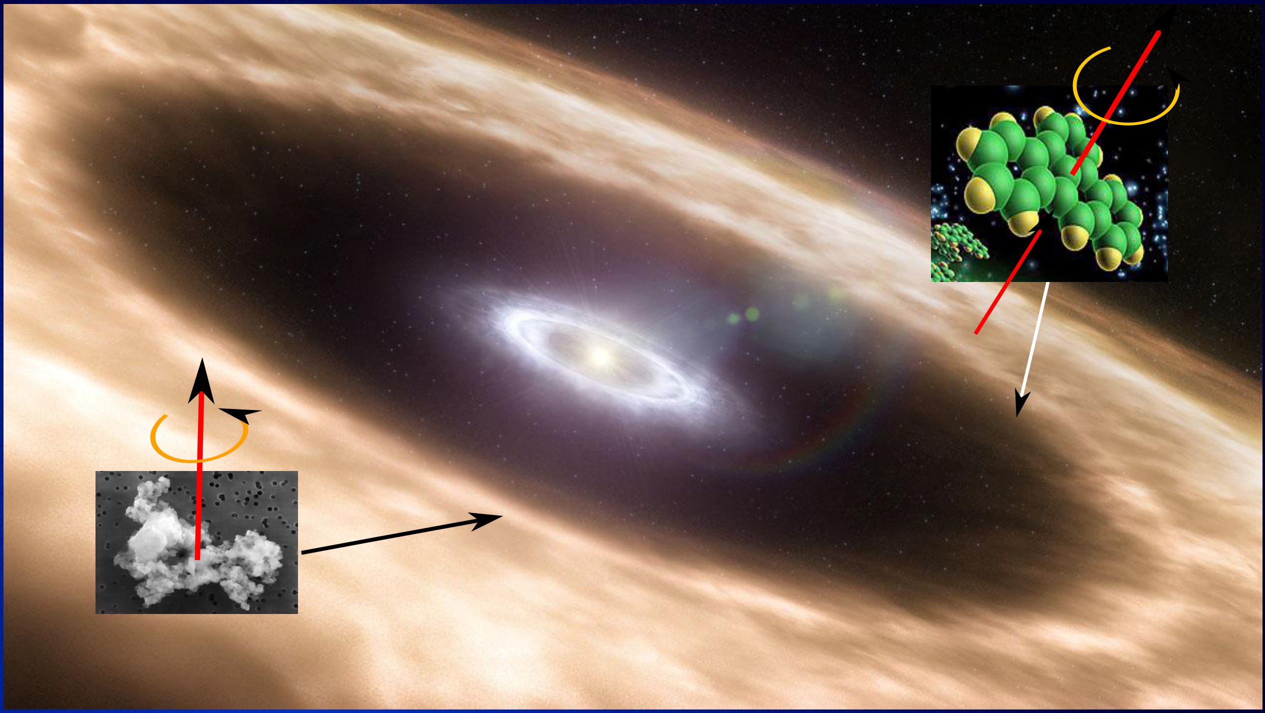


Seok & Li (2017)

- Disks with small PAHs exhibit strong Spinning dustAME, most favored targets for observations

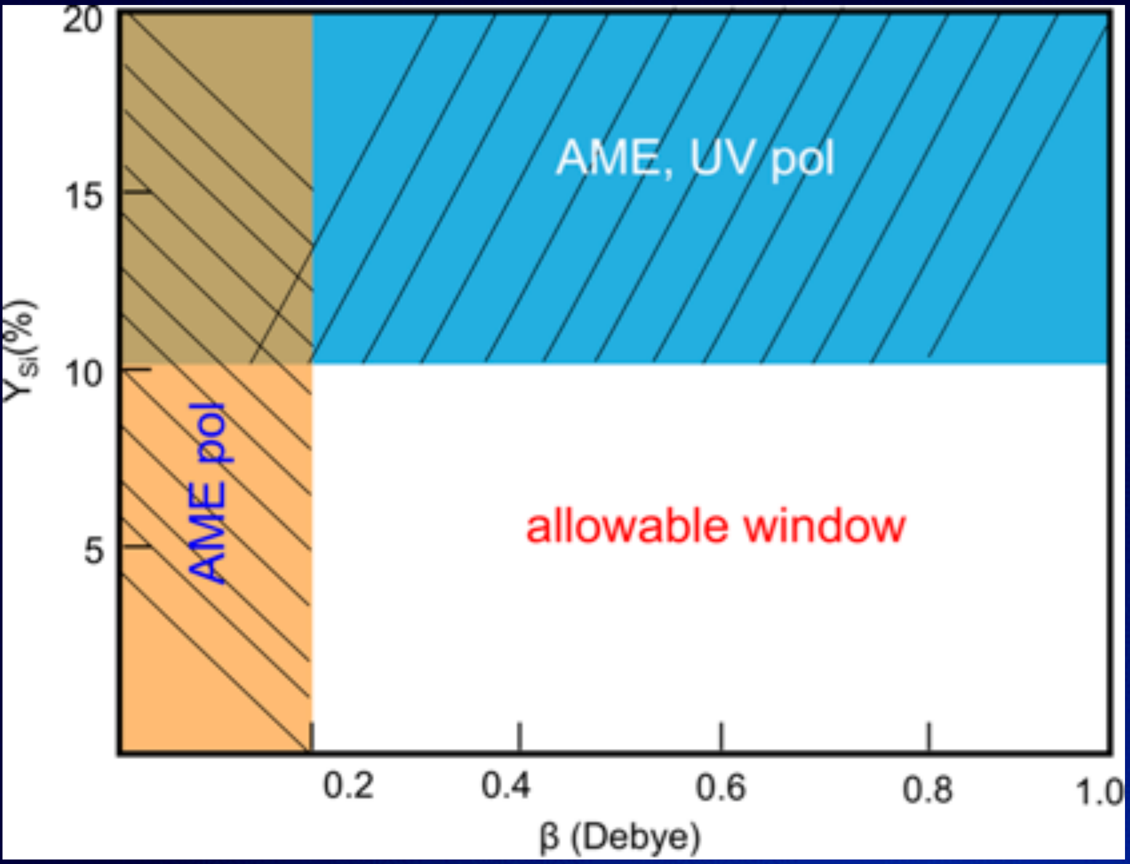
Summary and Discussion

- The AME is real, lots of observational evidence for spinning dust
- The exact carrier is still unclear, polarization can distinguish
- PAHs and Nanosilicate from PPDs produce strong emission excess, up to 25 times thermal dust emission
- Future ALMA Band 1 and SKA perfect tools for testing Spindust
- A powerful new probe of nano dust in the entire disk (cf. mid-IR only traces surface layer)

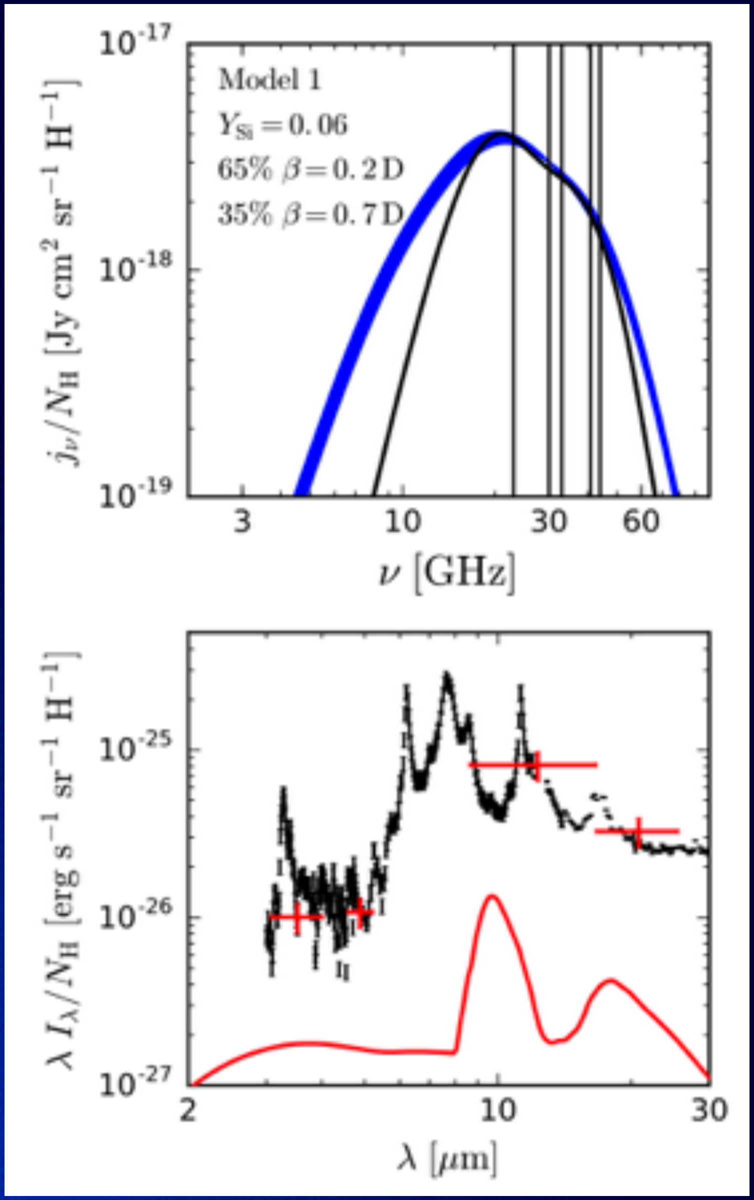


Thank You Very Much!
감사합니다!

Constraining abundance of nanosilicate



Hoang, Vinh, & Lan 2016, ApJ, 824, 18



Hensley & Draine (2017)