Conflicting Measurements of the Dust Emissivity Index in OMC 2/3

Sarah Sadavoy (Hubble Fellow: CfA-SAO)

Cosmic Cycle of Dust and Gas in the Galaxy
Quy Nhon, Vietnam, July 13 2018

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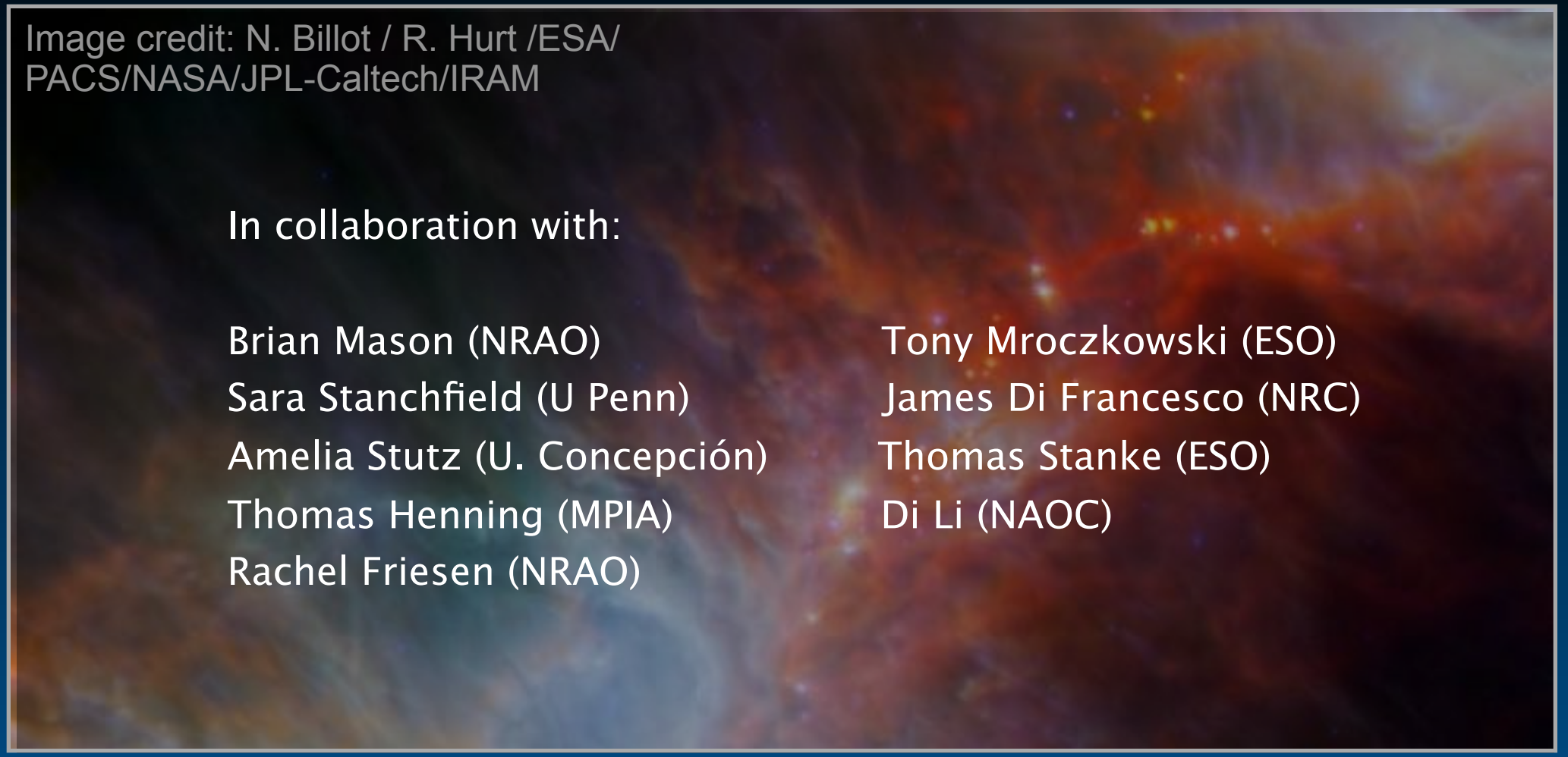

In collaboration with:

Brian Mason (NRAO)
Sara Stanchfield (U Penn)
Amelia Stutz (U. Concepción)
Thomas Henning (MPIA)
Rachel Friesen (NRAO)
Tony Mroczkowski (ESO)
James Di Francesco (NRC)
Thomas Stanke (ESO)
Di Li (NAOC)

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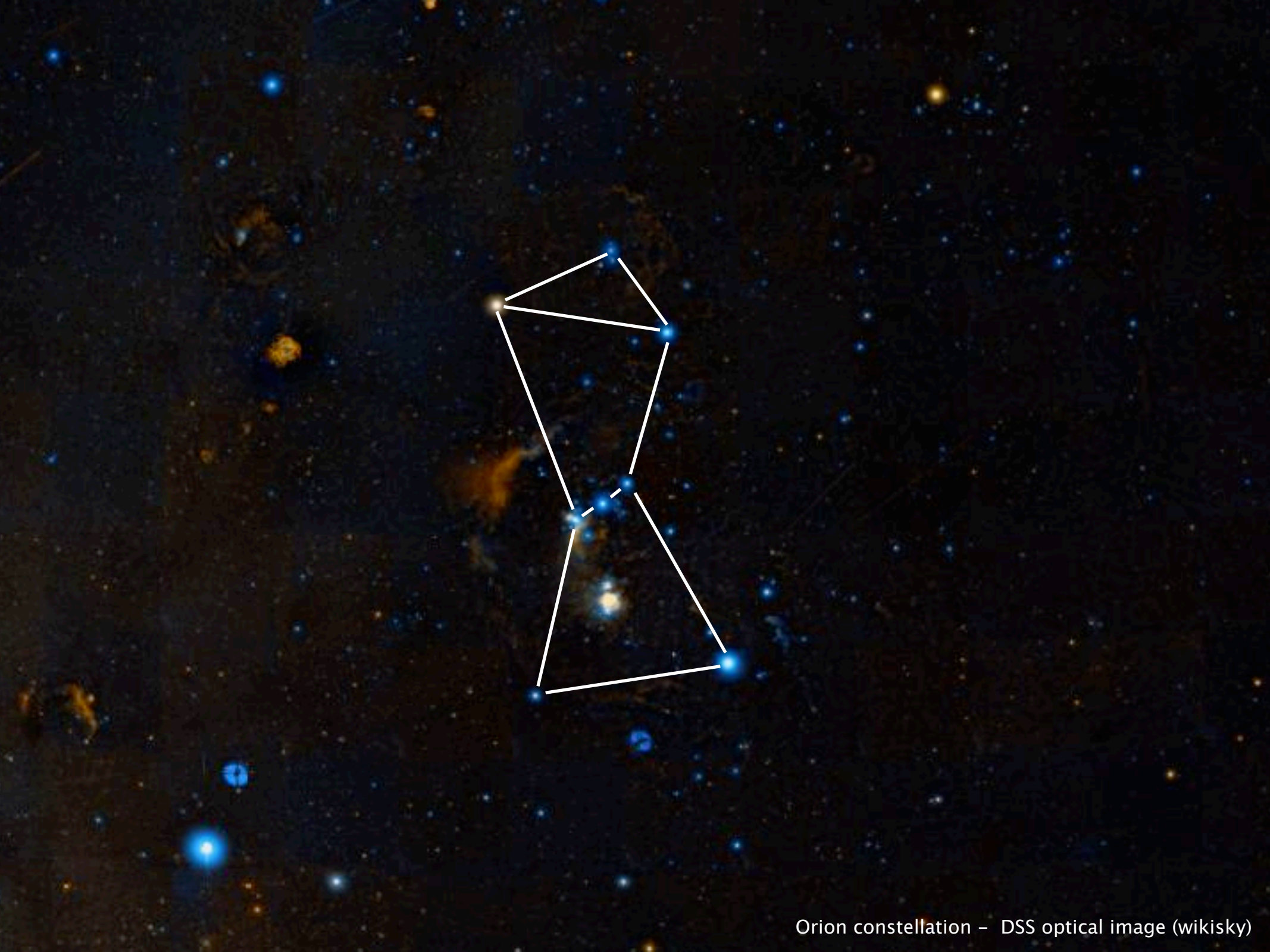
Orion constellation - DSS optical image (wikisky)



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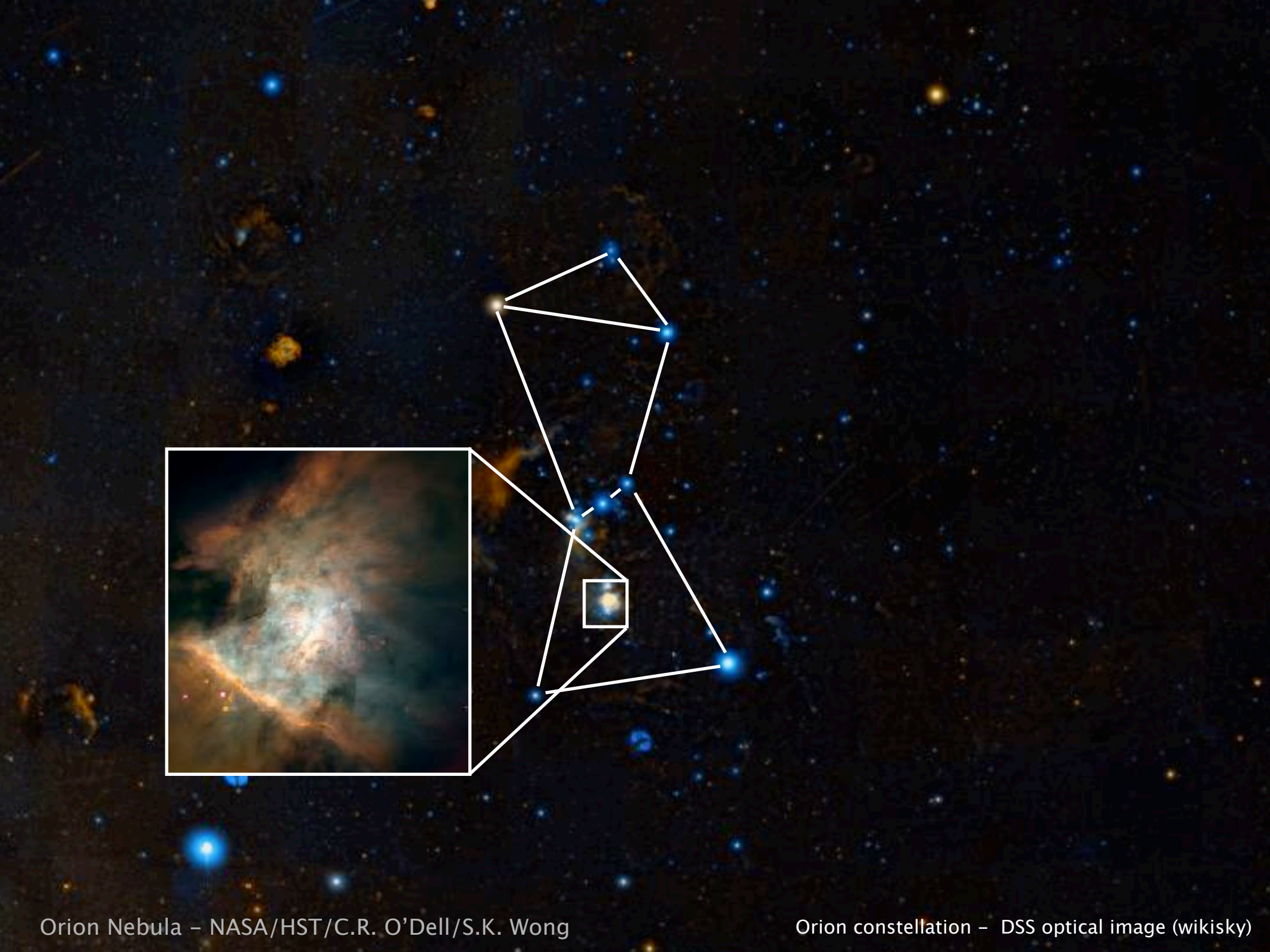
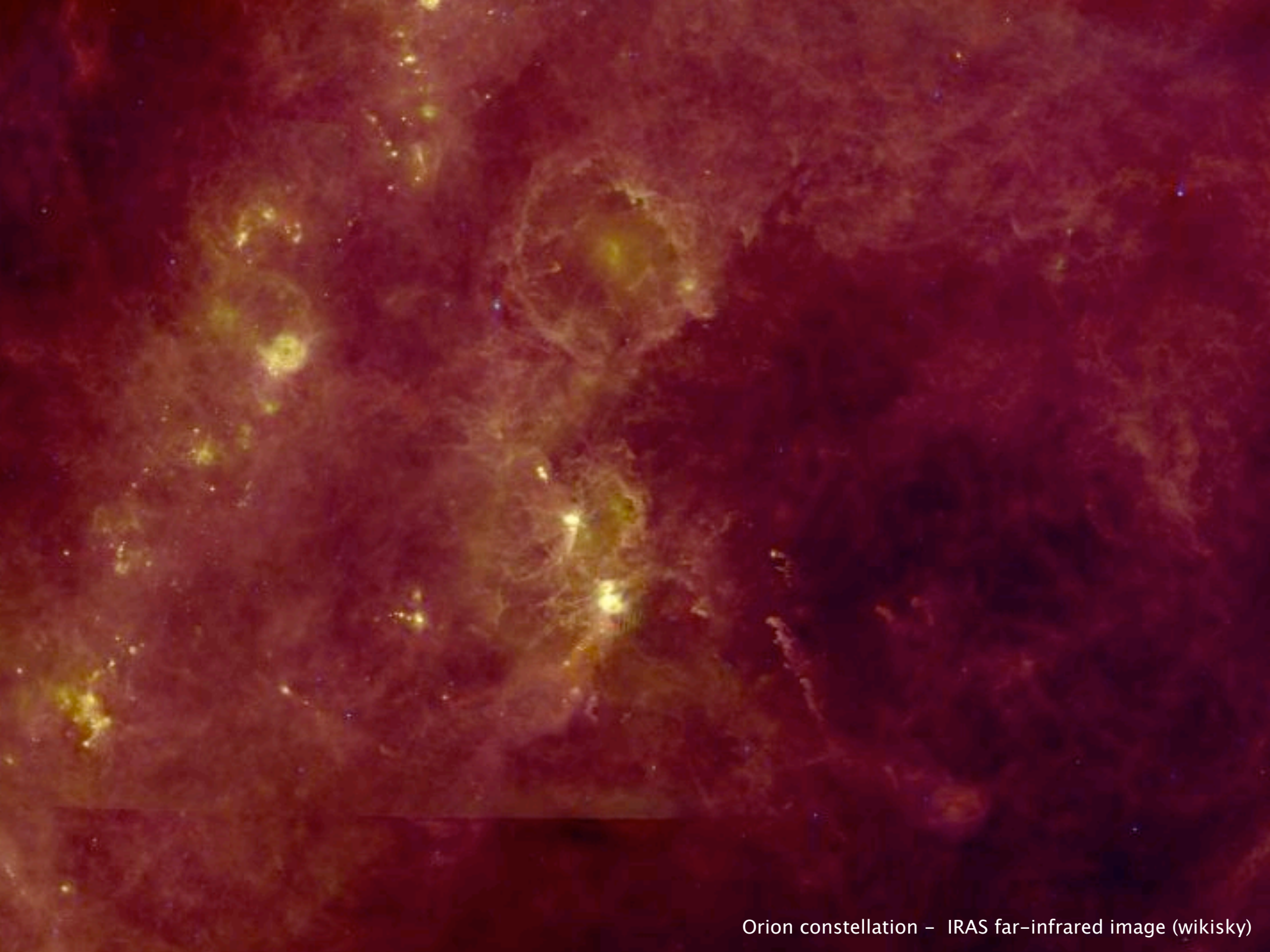


Orion Nebula - NASA/HST/C.R. O'Dell/S.K. Wong

Orion constellation - DSS optical image (wikisky)



Orion constellation - IRAS far-infrared image (wikisky)

Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE

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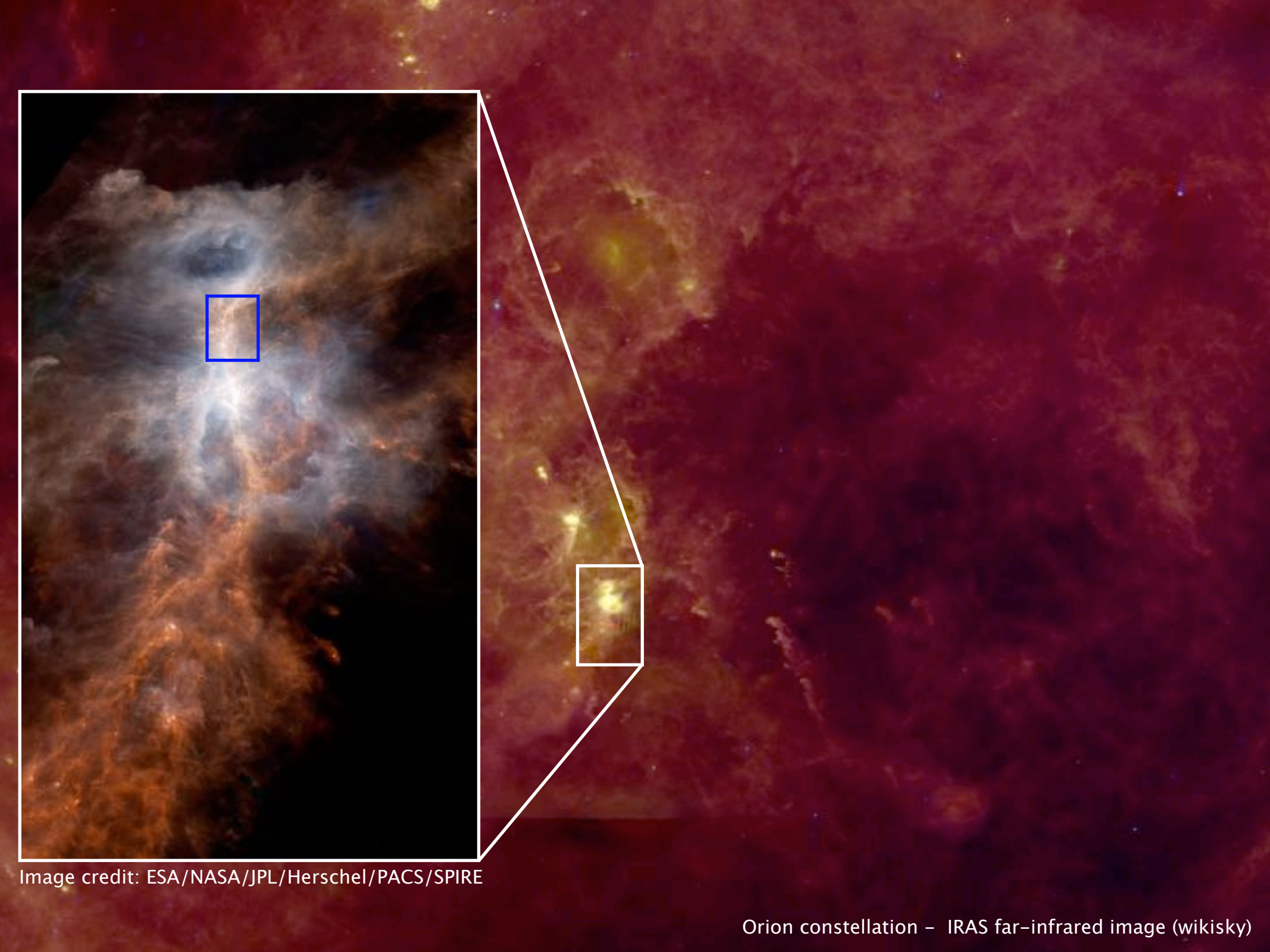
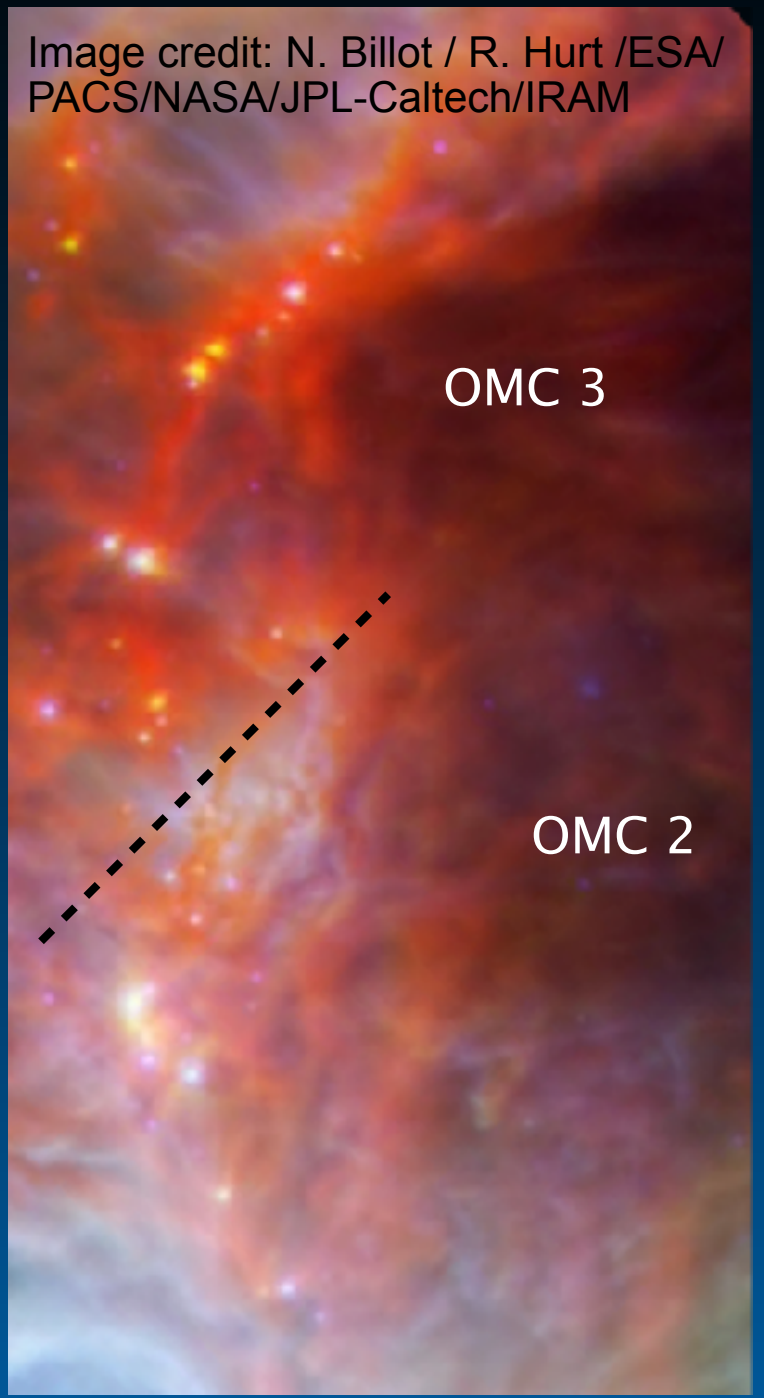


Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE

Orion constellation - IRAS far-infrared image (wikisky)

Orion Molecular Cloud (OMC) 2/3



One of the closest filaments forming high-mass stars

Active filament (~ 2 pc) with lots of protostars and starless cores

Well-studied with much ancillary data

e.g., Peterson & Megeath 2008; Sadavoy+ 2010; Schnee+ 2014; Stutz & Kainulainen 2015; Meingast+ 2016; Kainulainen+ 2017

Typical Values for the Dust Emissivity Index

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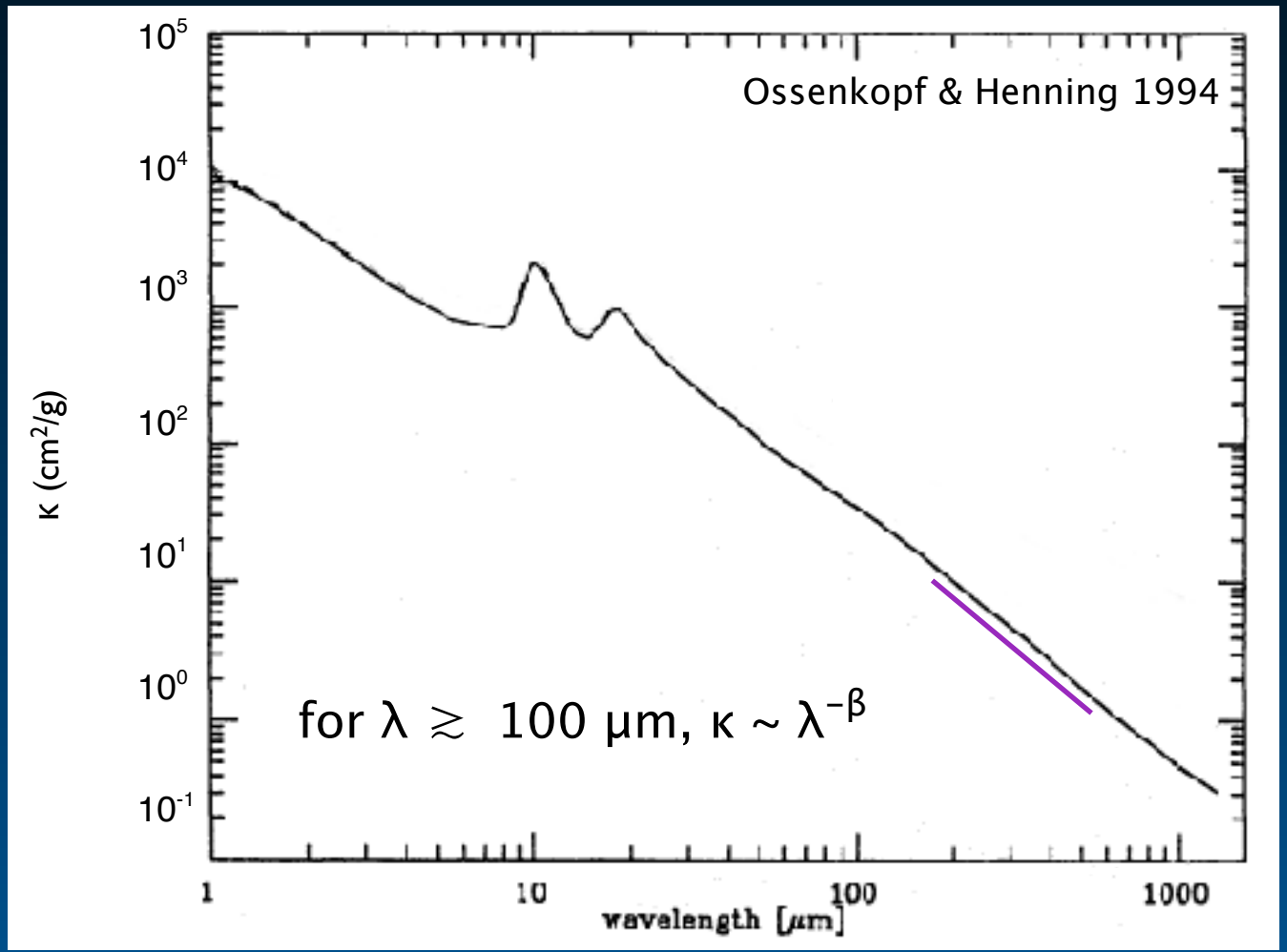
The dust emissivity index, β, represents the slope of the dust opacity curve



see also, e.g., Hildebrand 1983; Draine & Li 1984; Henning+ 1995; Ormel+ 2011; Testi+ 2014

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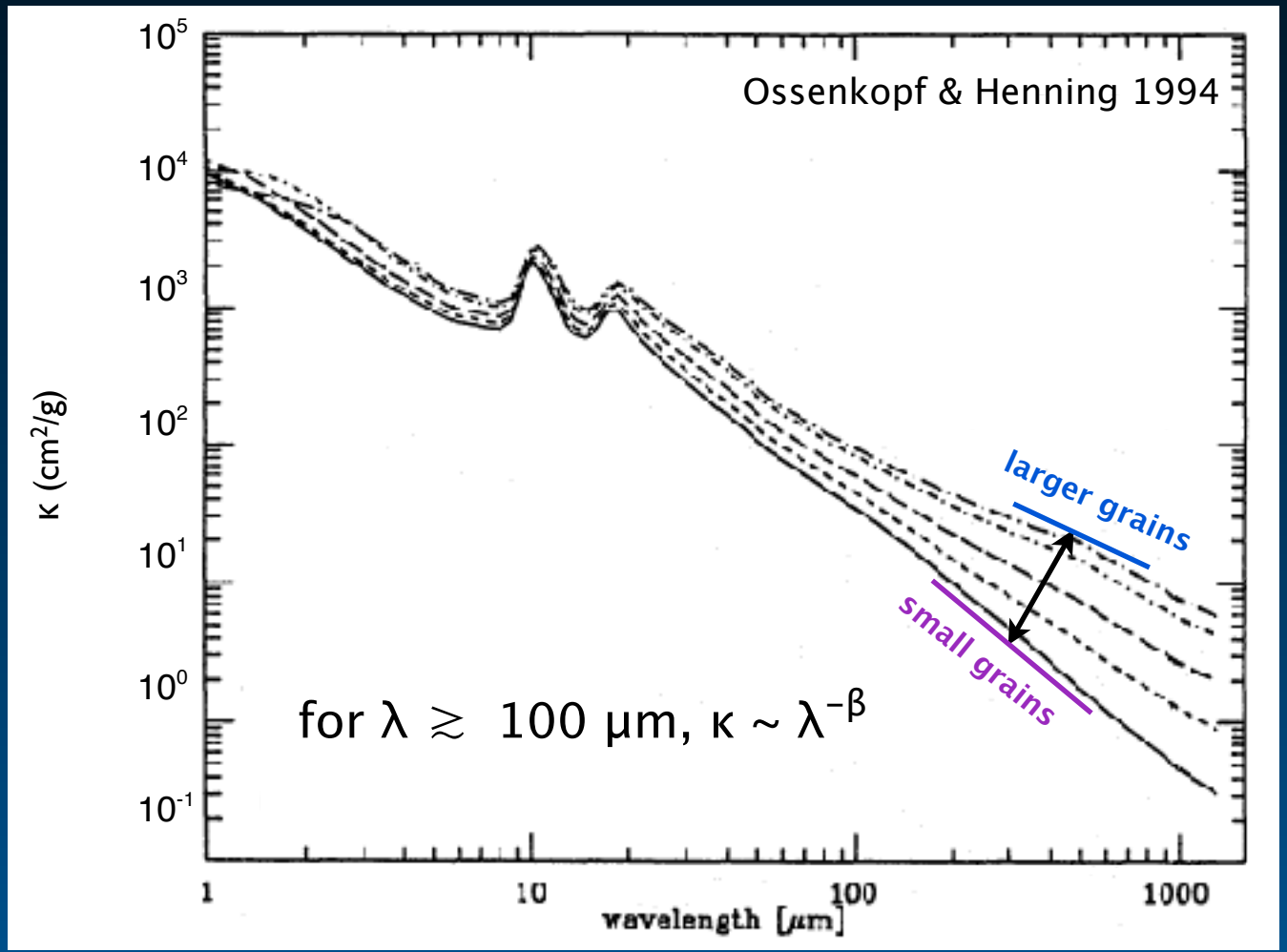


β indicates how well dust will emit at long wavelengths

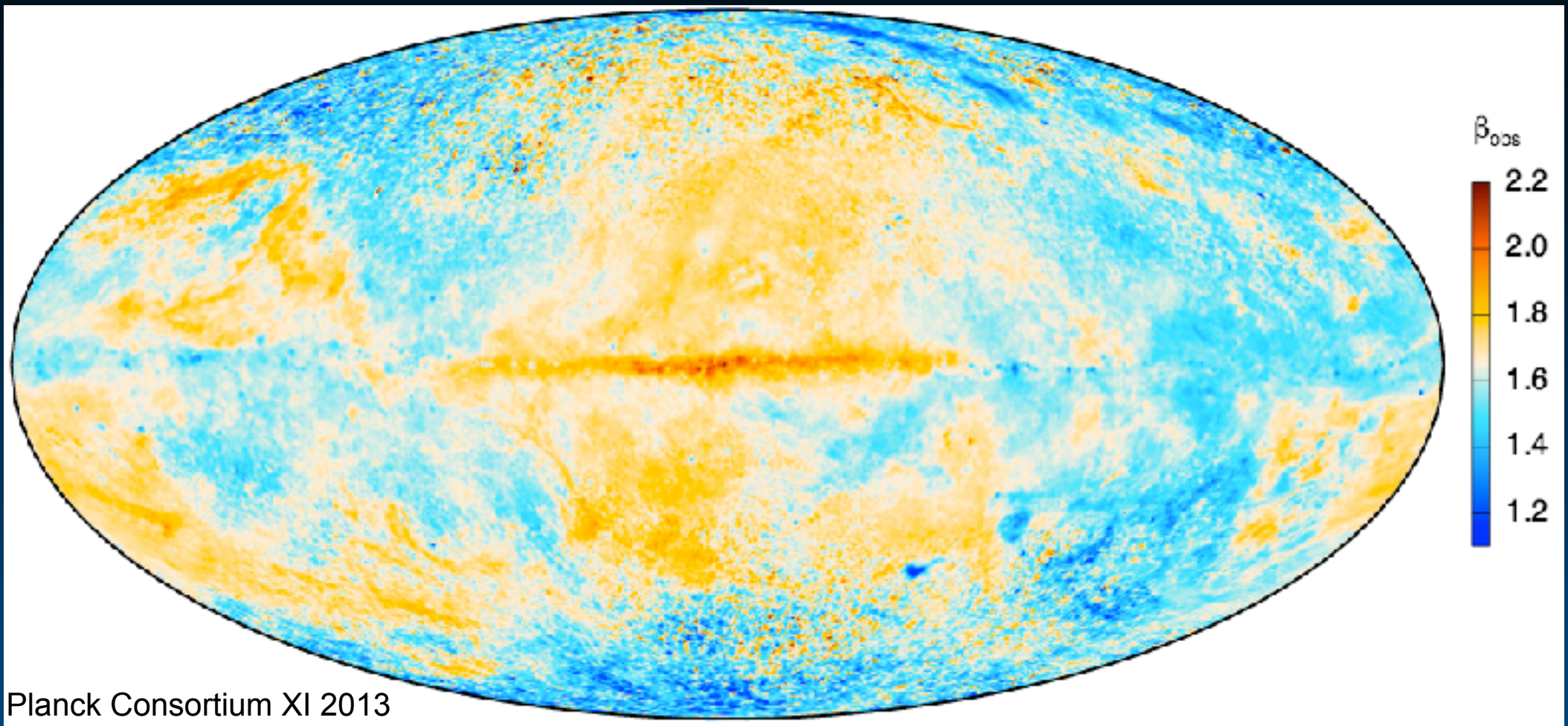
Shallow values = more efficient, implies larger grains

Steep values = less efficient, implies smaller grains

see also, e.g., Hildebrand 1983; Draine & Li 1984; Henning+ 1995; Ormel+ 2011; Testi+ 2014

Measurements of β: Clouds and Cores

Typically, clouds and cores have β ~ 1.5 – 2.0

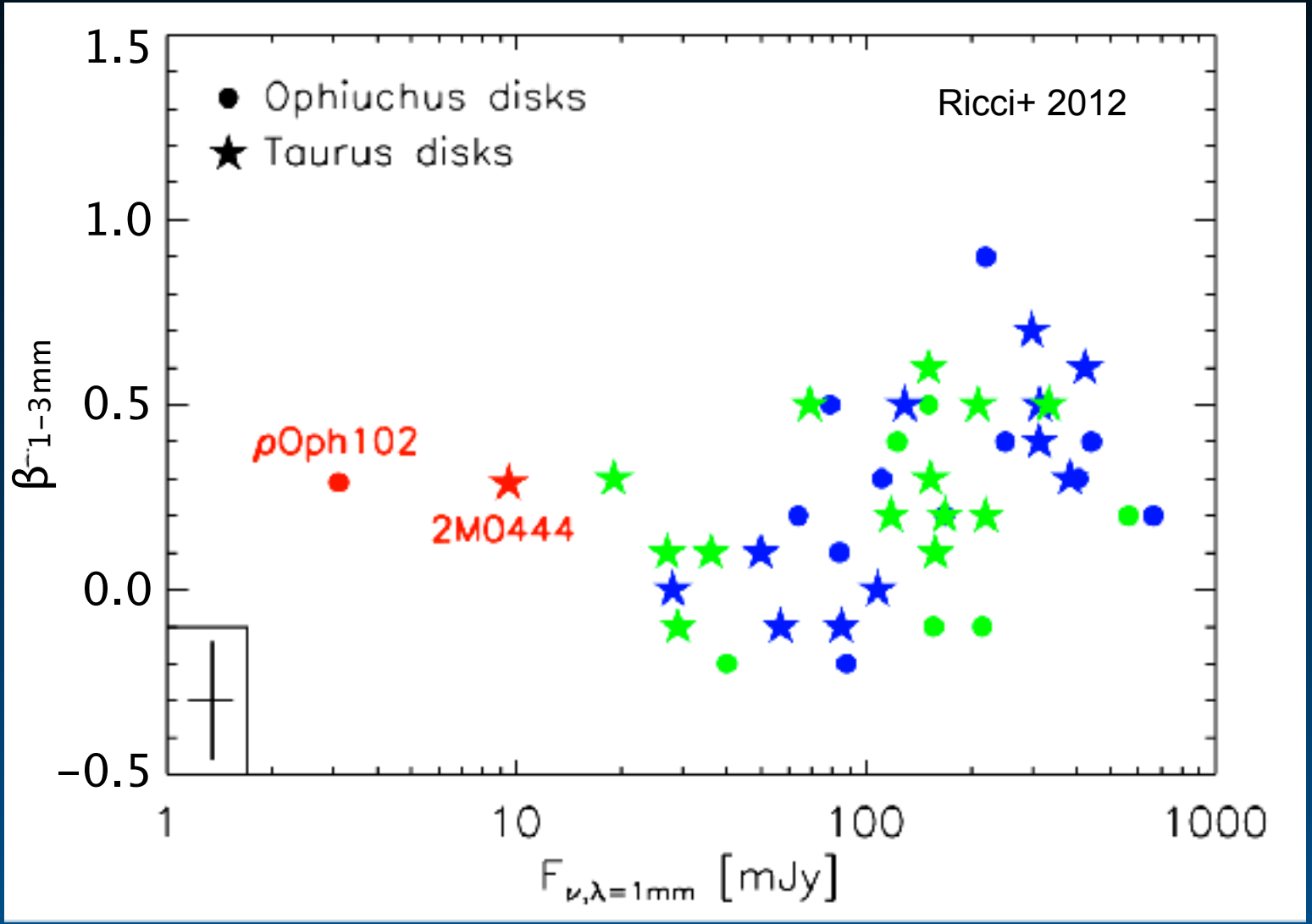


Planck Consortium XI 2013

also, Dupac+ 2003; Chiang+ 2012; Forbrich+ 2015; Sadavoy+ 2013; Ysard+ 2015; Chen+ 2016

Measurements of β: Disks

Typically, protostellar/stellar disks have β < 1



see also, Beckwith & Sargent 1991; Lommen+ 2007; Perez+ 2012; Ubach+ 2012; Wright+ 2015

The Dust Emissivity Index in OMC 2/3

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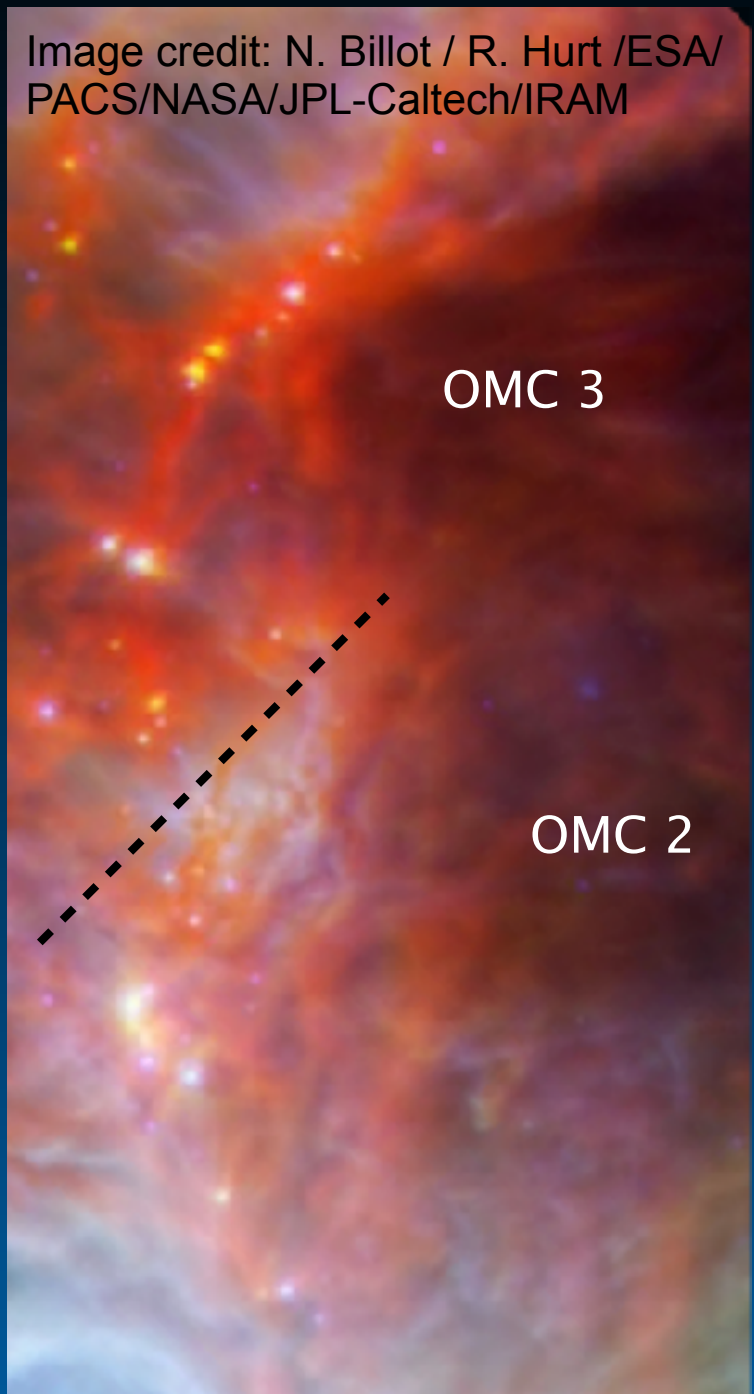
Chini+ 1997

- combined data from 350 μm – 2 mm for nine cores in OMC 2/3

- measured $1 < \beta < 2$ using modified blackbody functions



The Dust Emissivity Index in OMC 2/3

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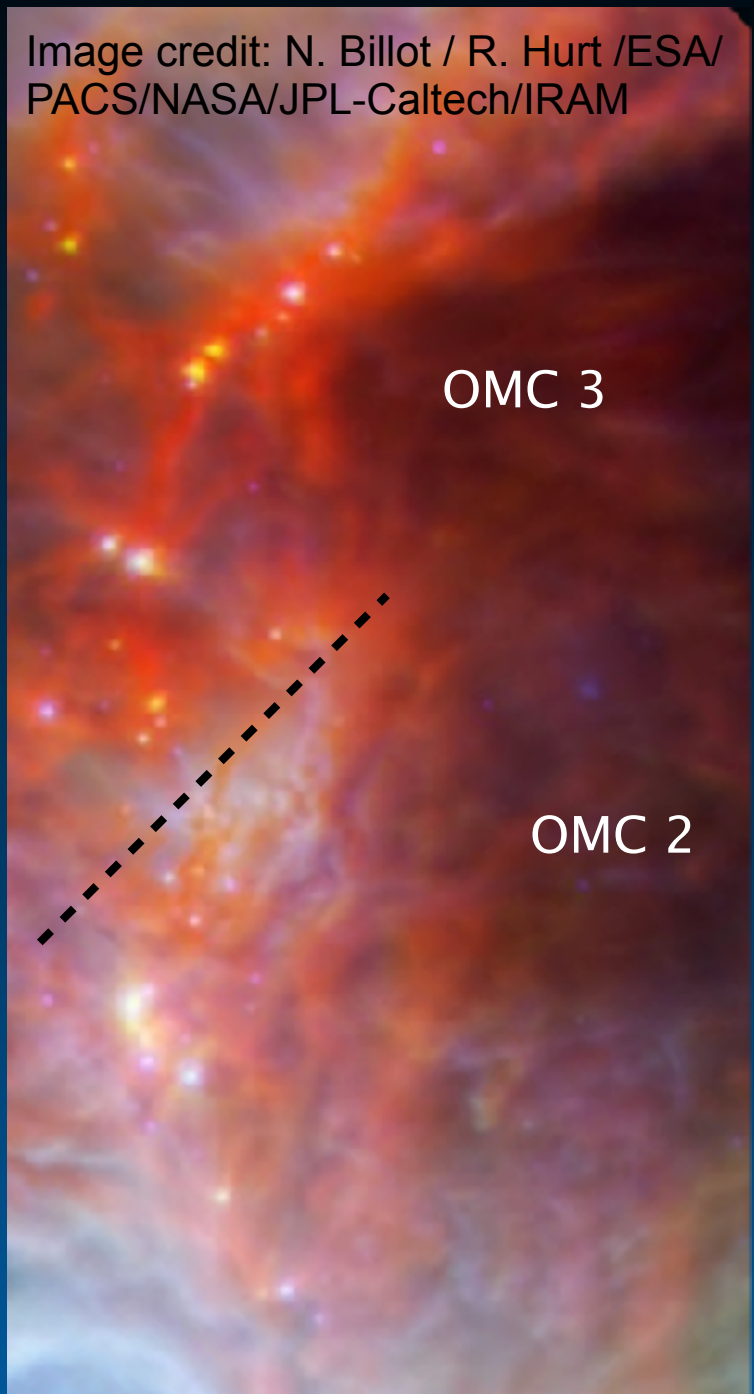
Lis+ 1998 conducted a similar analysis and found similar values

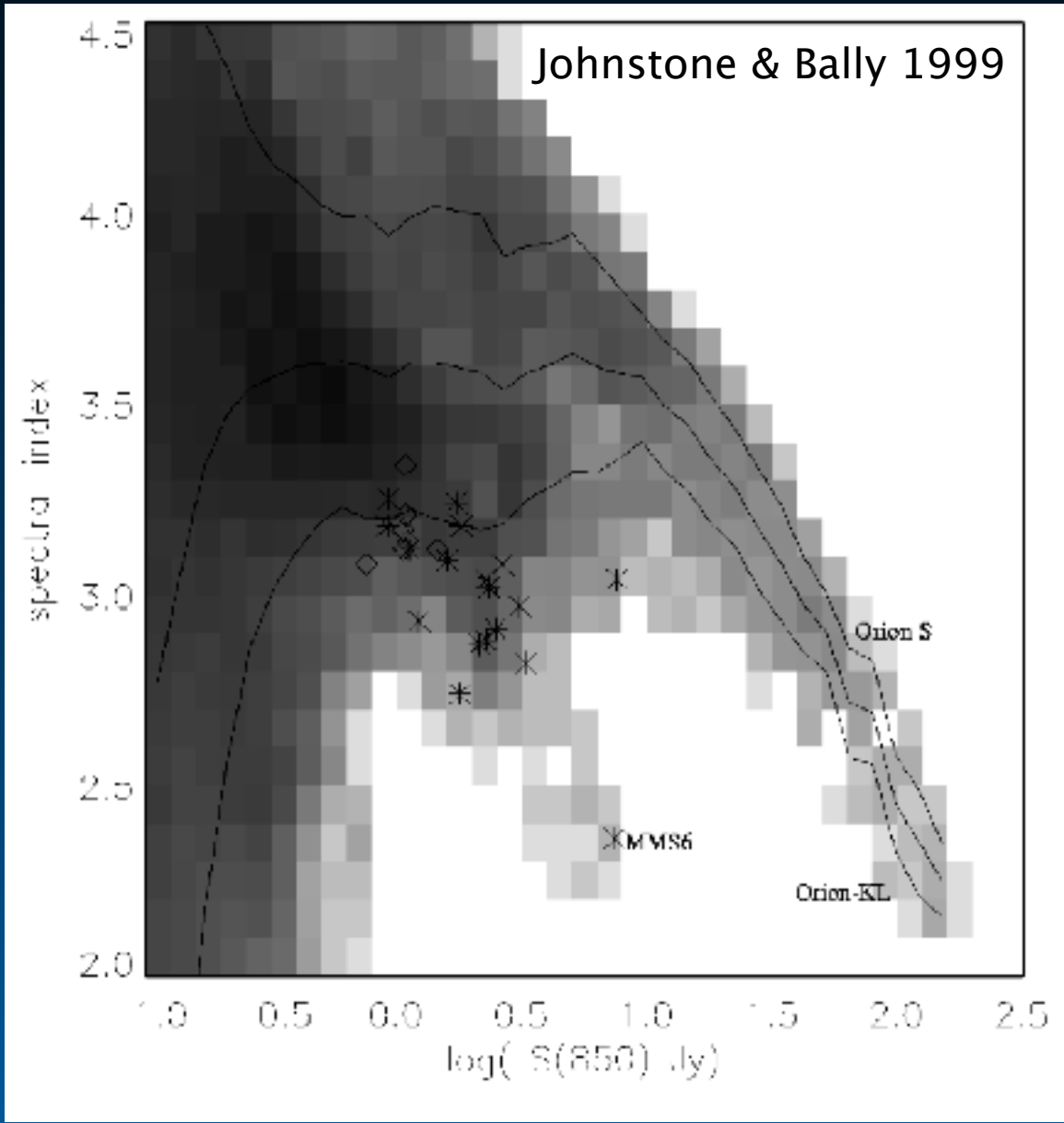


The Dust Emissivity Index in OMC 2/3

Johnstone & Bally 1999

- combined 450 μm and 850 μm data across OMC 2/3

- measured $1 < \beta < 2$ using flux ratios for $T > 10$ K



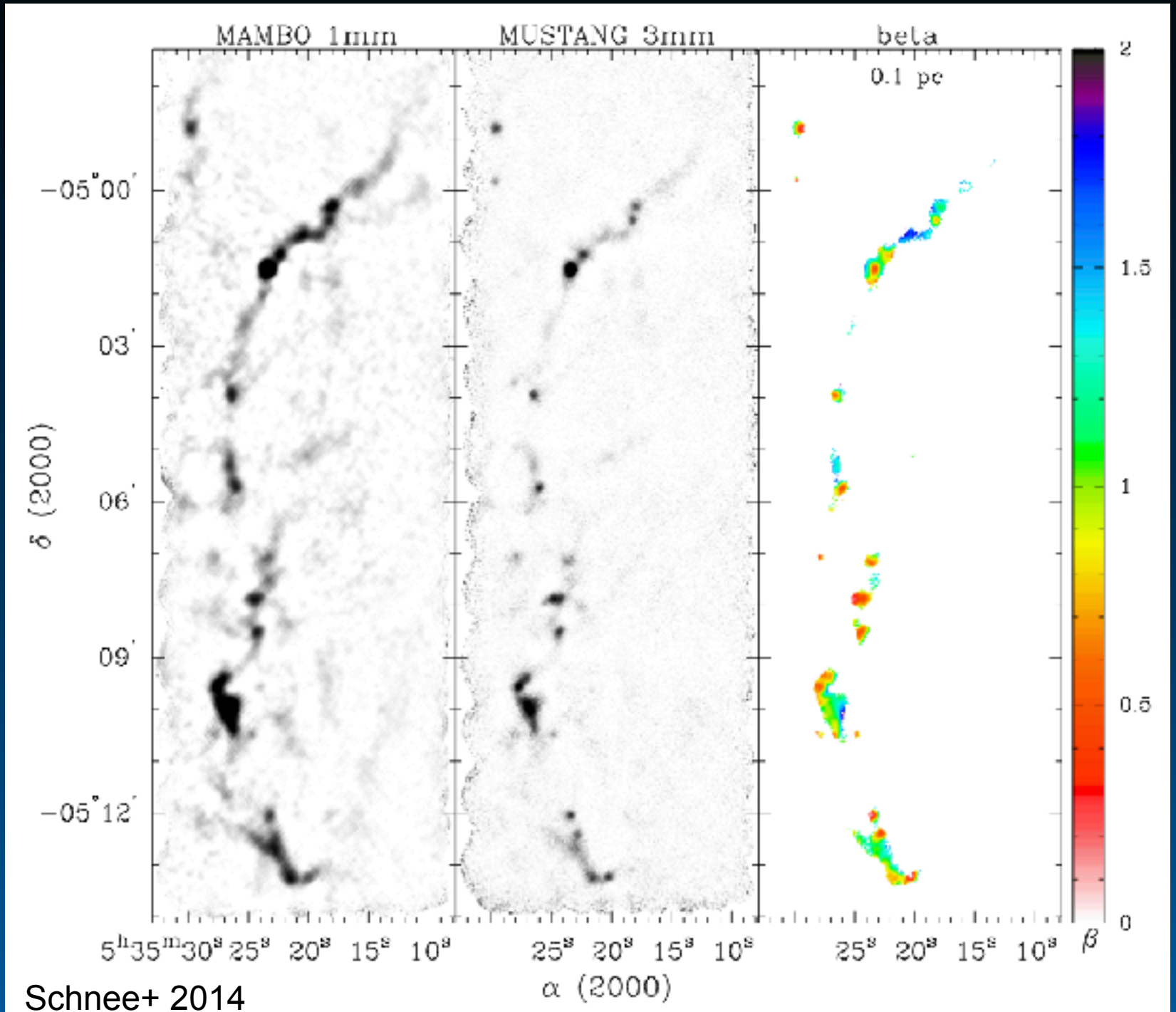
The Dust Emissivity Index in OMC 2/3

Schnee+ 2014

- combined 1.2 mm (MAMBO) and 3.3 mm (MUSTANG) data across OMC 2/3

- adopted ammonia gas temperatures from Li+ (2013) to measure β from flux ratios

The Dust Emissivity Index in OMC 2/3



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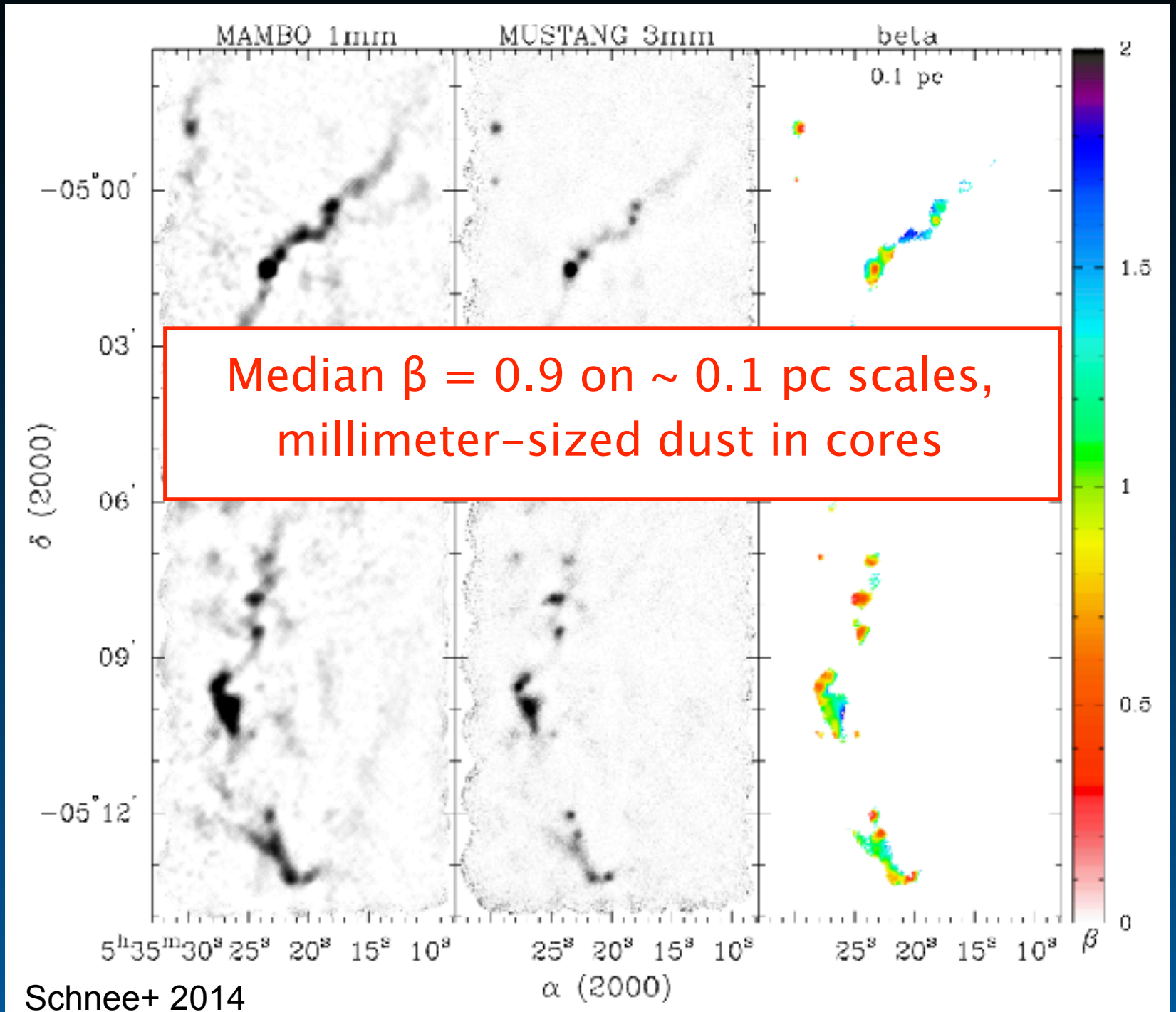
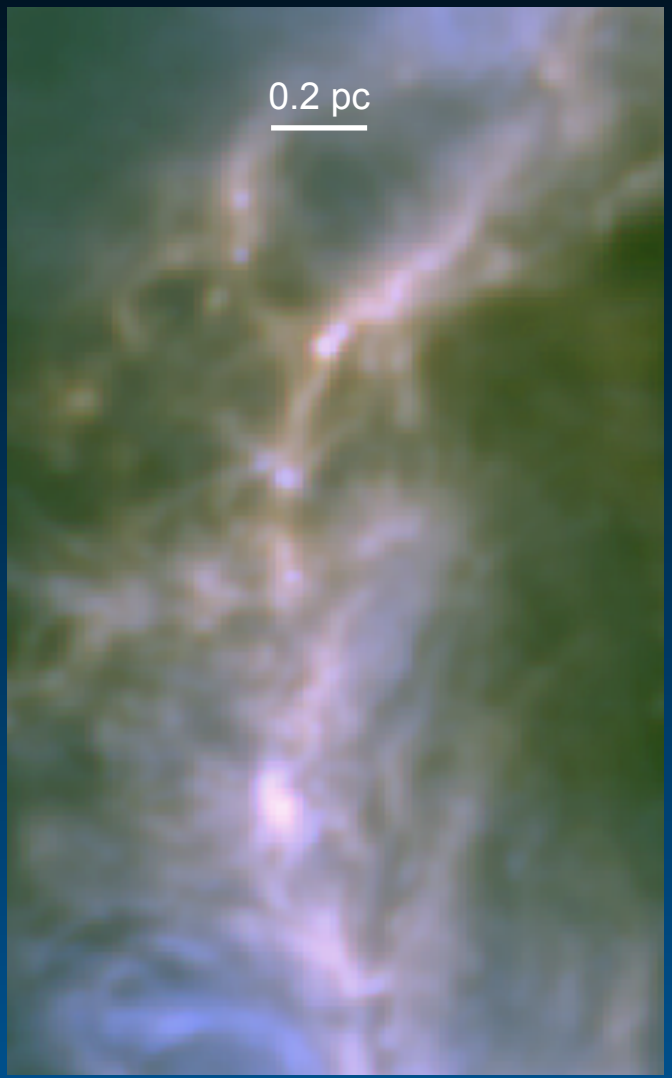


Median β = 0.9 on ~ 0.1 pc scales, millimeter-sized dust in cores

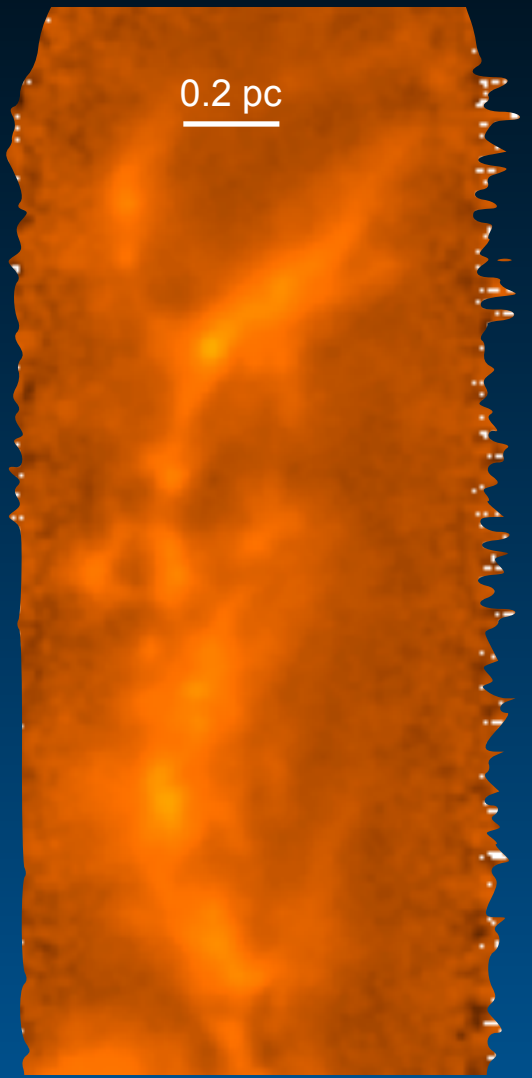
Schnee+ 2014

The Dust Emissivity Index in OMC 2/3

Sadavoy+ 2016 combined Herschel (160–500 μm) and GISMO (2 mm) data



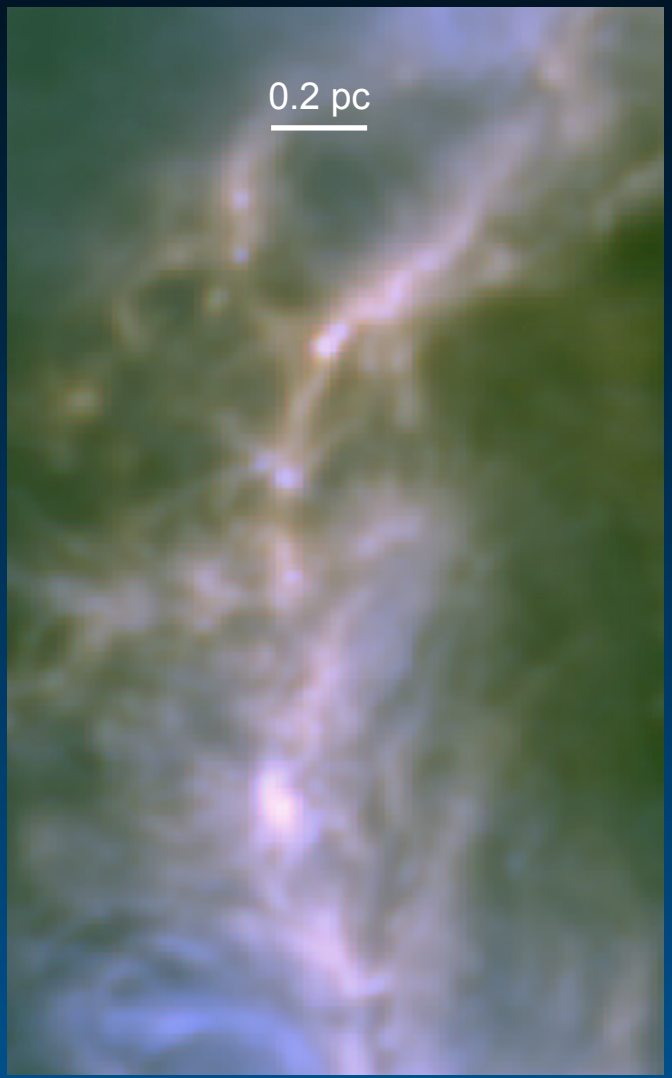
Herschel RGB(160-350 μm)
Stutz & Kainulainen 2015



GISMO 2 mm
Sadavoy+ 2016

The Dust Emissivity Index in OMC 2/3

Using modified blackbody fitting, found β ~ 1.6–1.8



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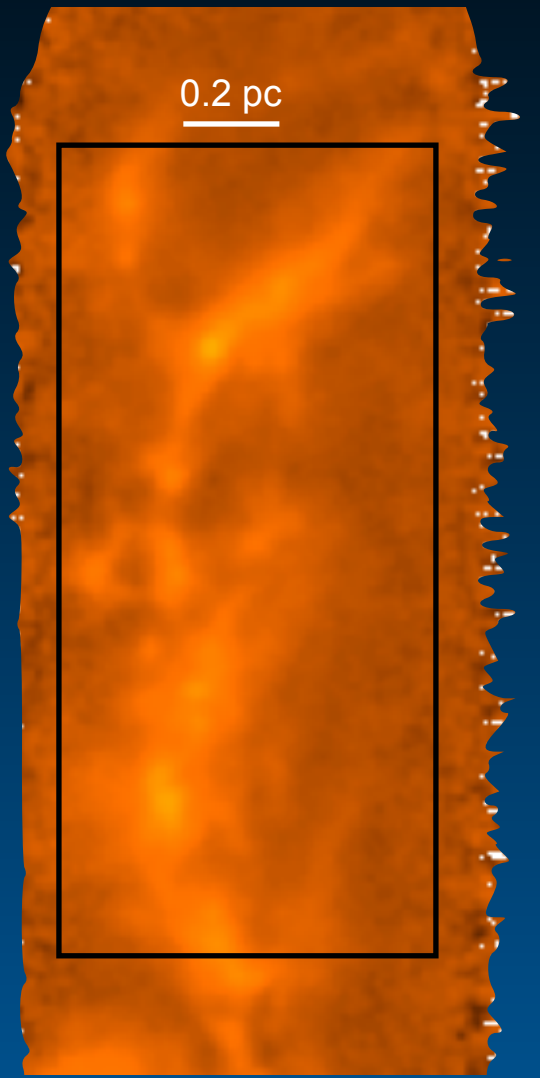

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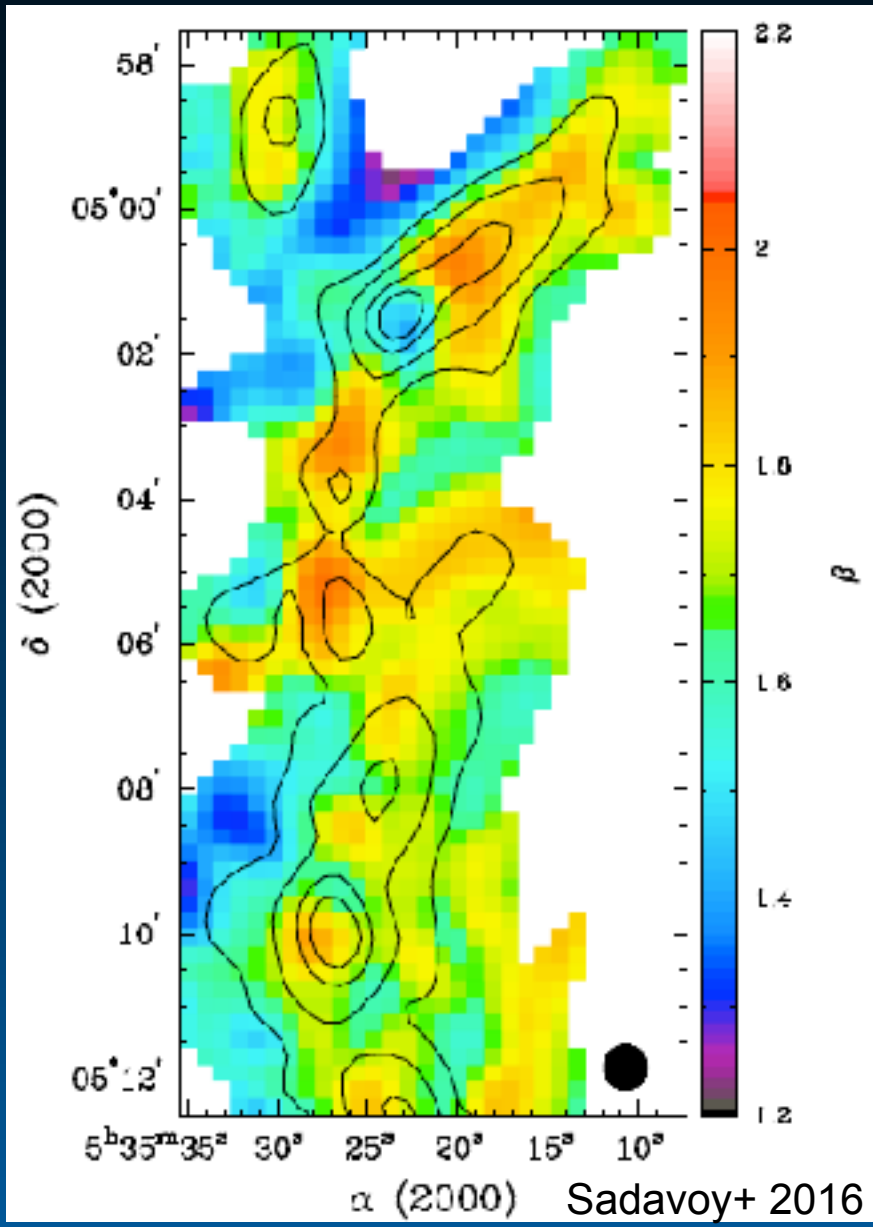

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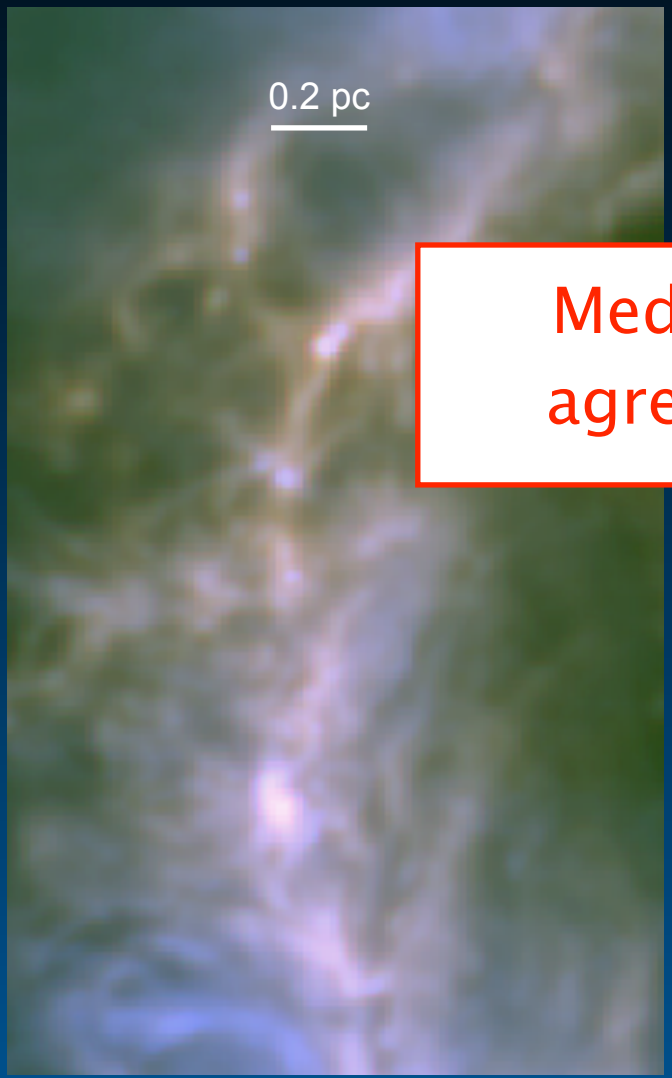

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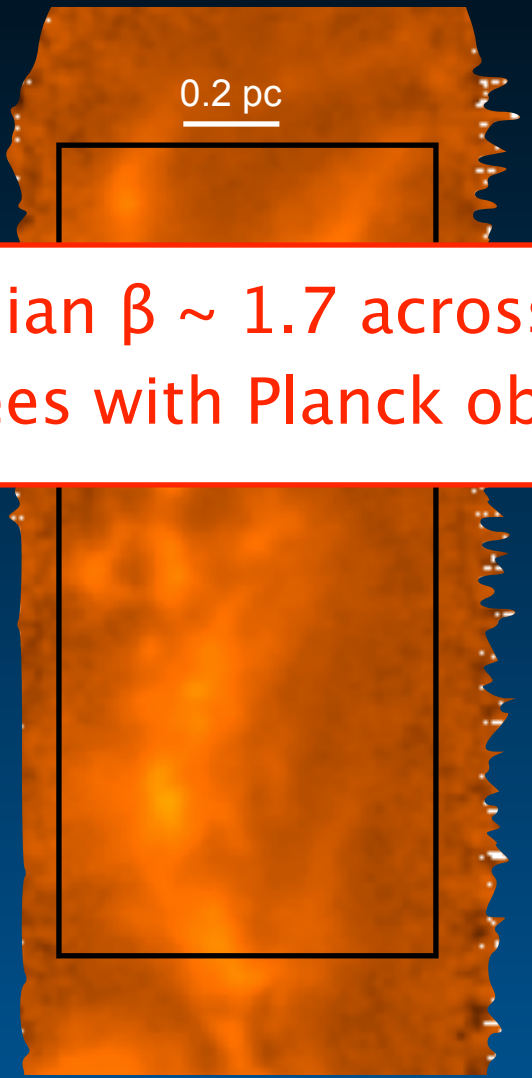
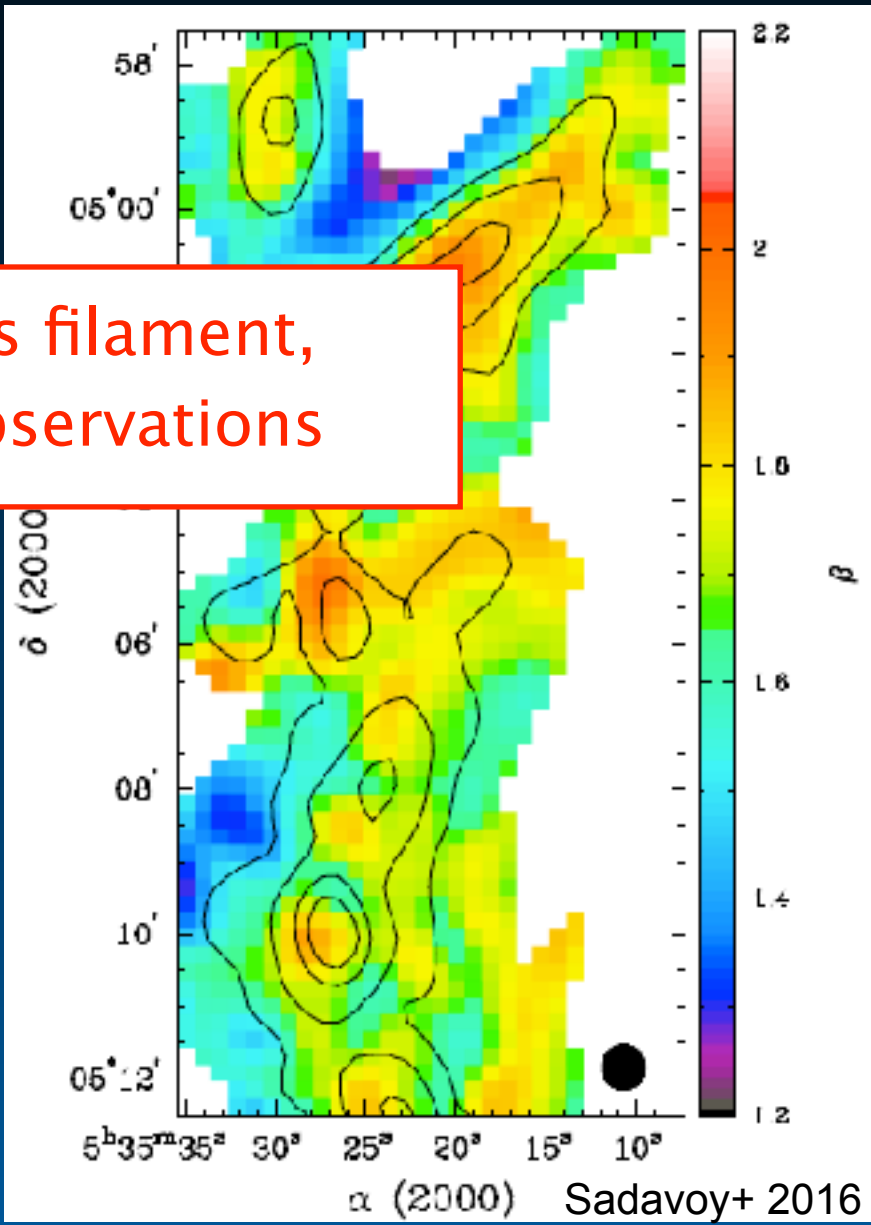


GISMO 2 mm
Sadavoy+ 2016

Median β ~ 1.7 across filament,
agrees with Planck observations



Sadavoy+ 2016

Conflicting Measurements of β

MAMBO (1.2 mm) and Mustang (3.3 mm) data give $\beta \sim 0.9$

Herschel (160–500 μm) and GISMO (2 mm) data give $\beta \sim 1.7$

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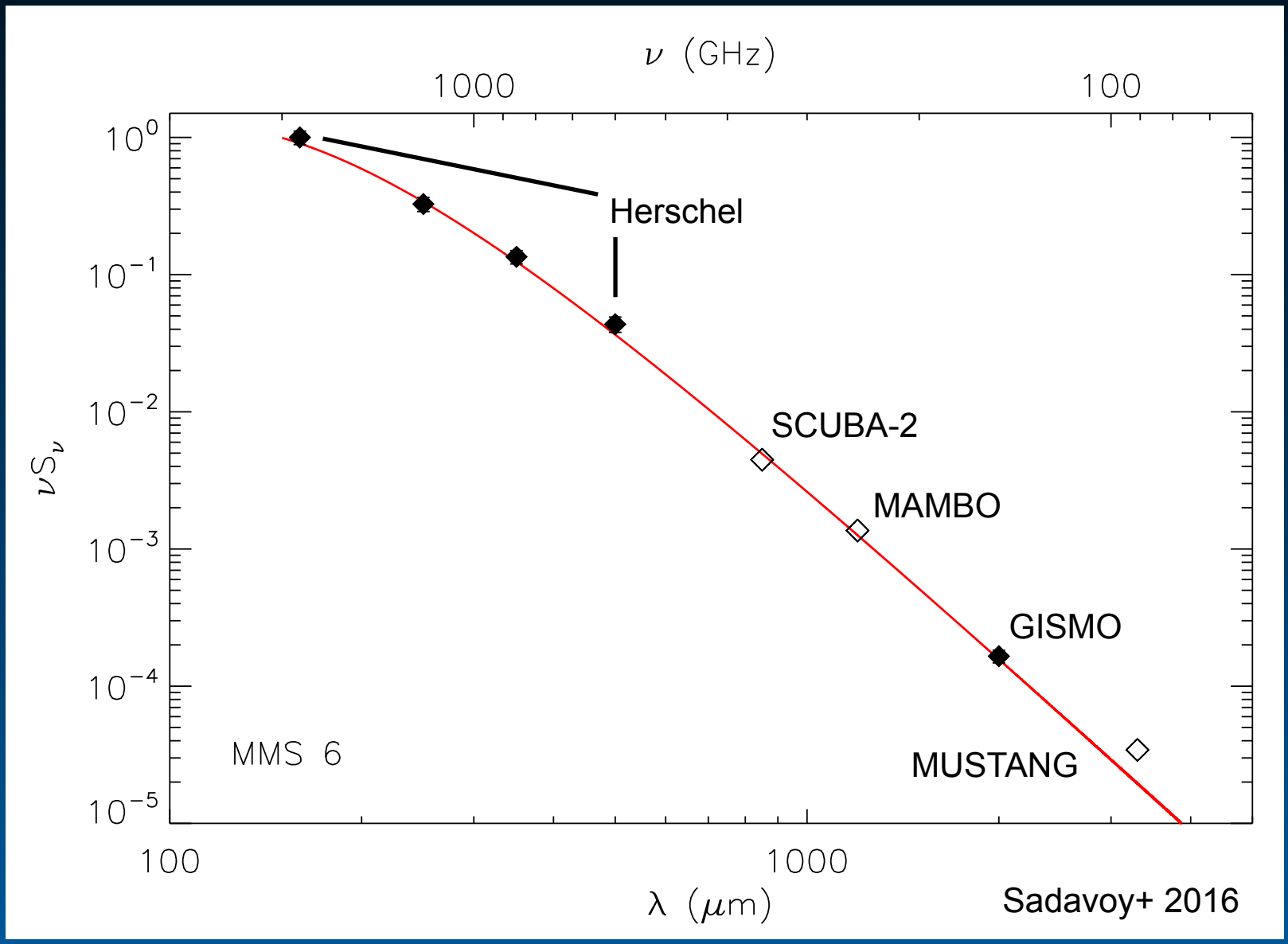
Why are we measuring very different values of β over the same regions?

Conflicting Measurements of β

OMC 2/3 has elevated 3 mm emission relative to emission at λ < 2 mm



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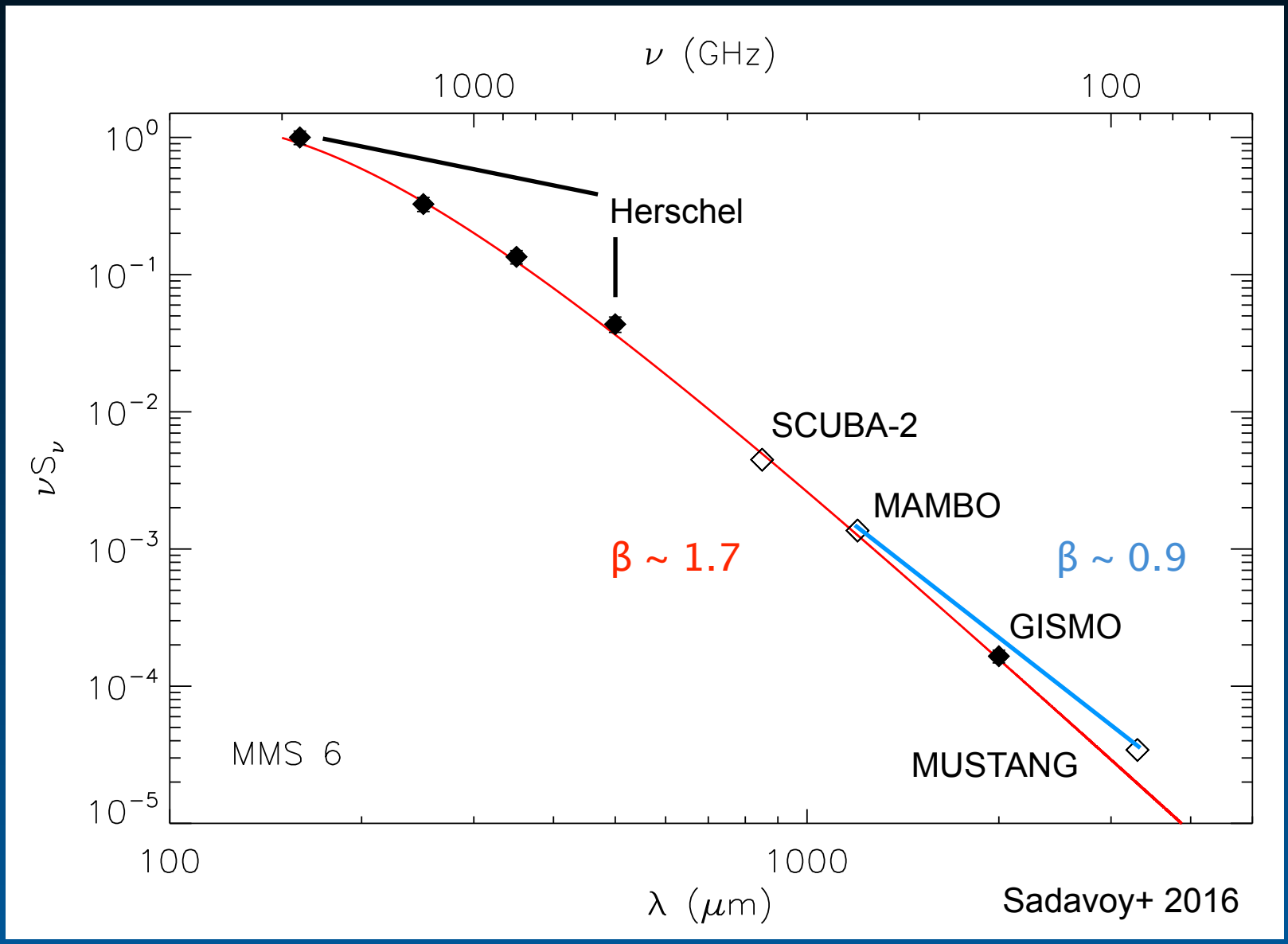

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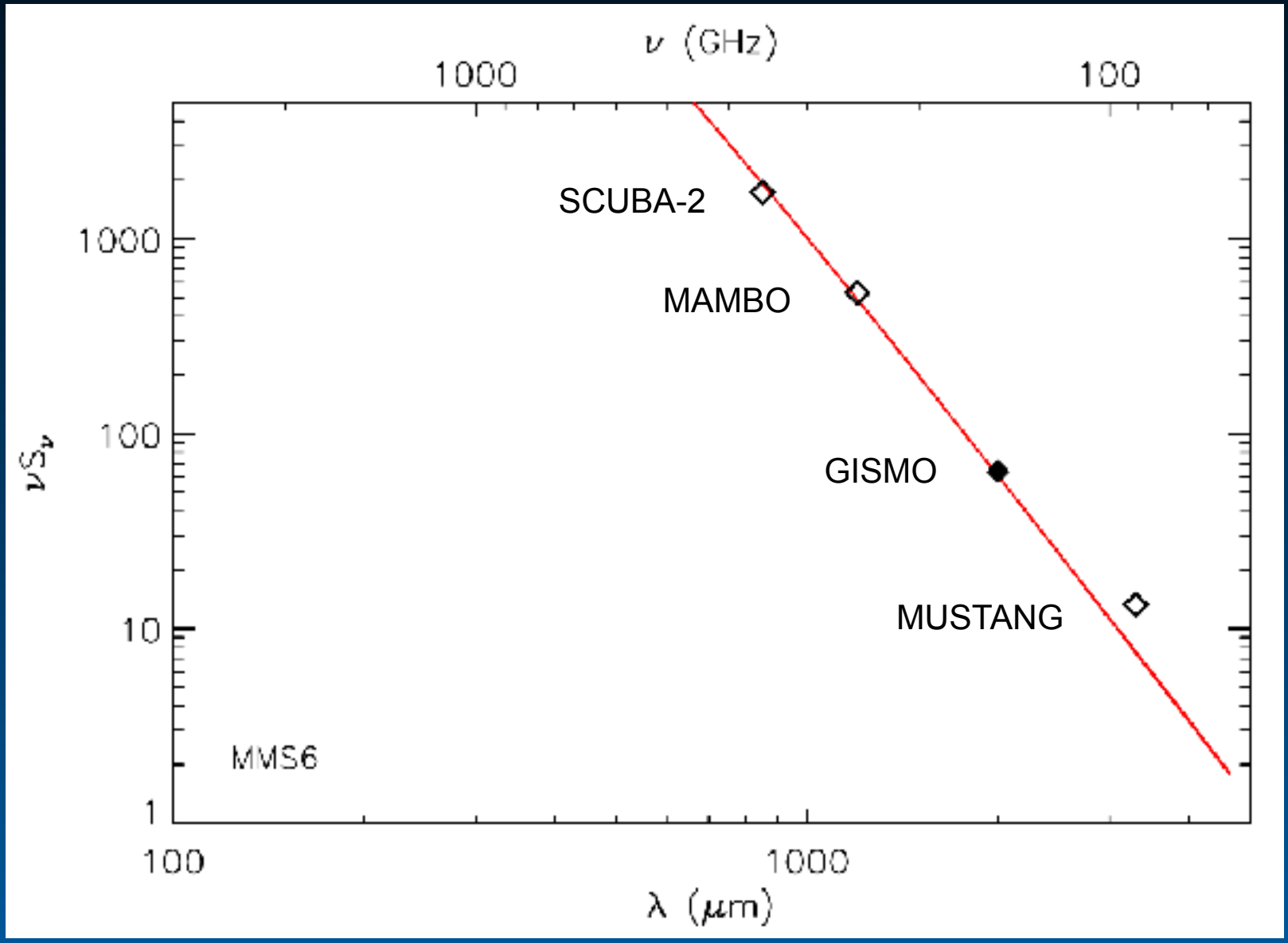
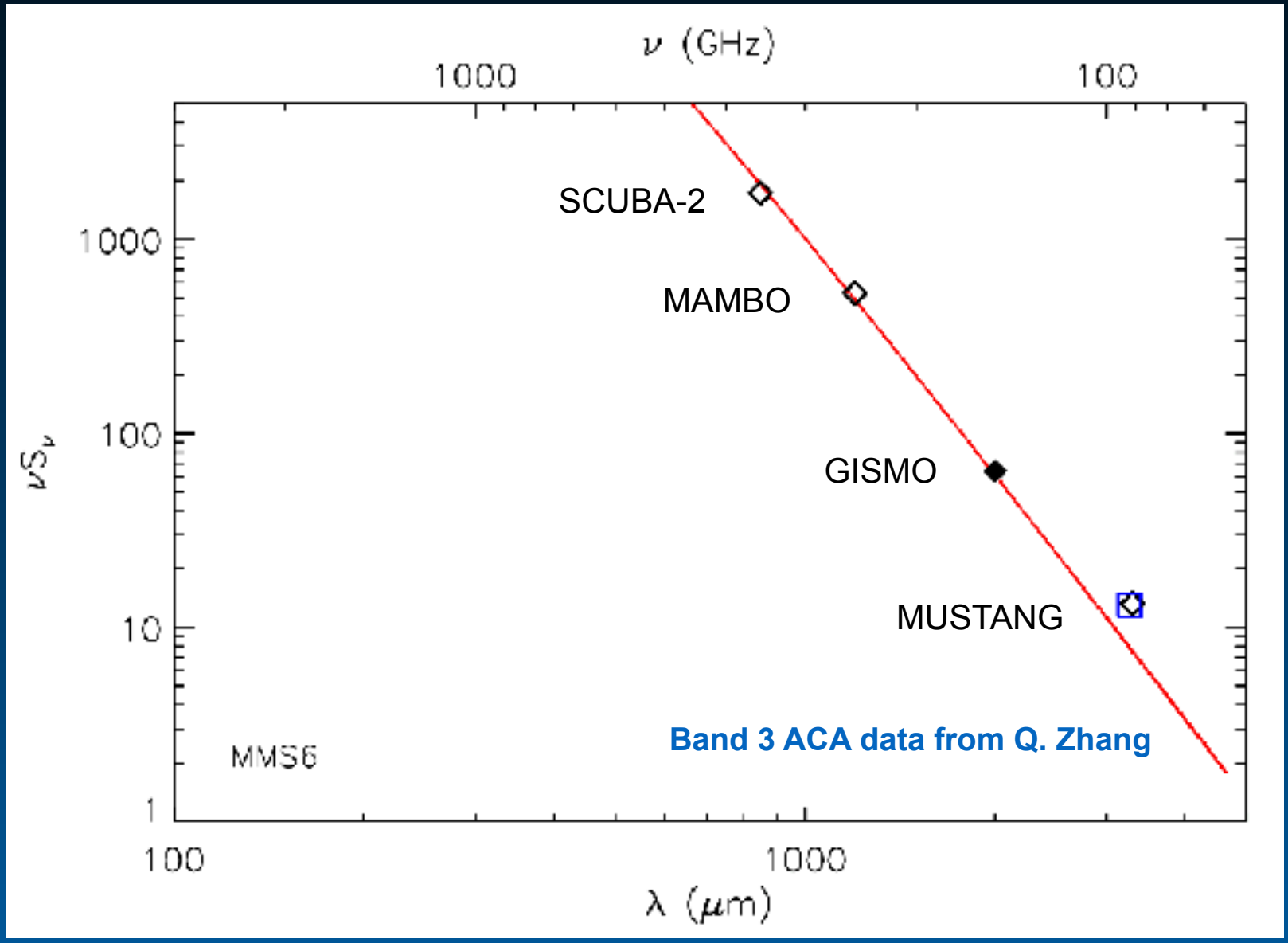


Conflicting Measurements of β

MUSTANG data matches independent 3 mm data from ALMA & Mustang-2



Conflicting Measurements of β

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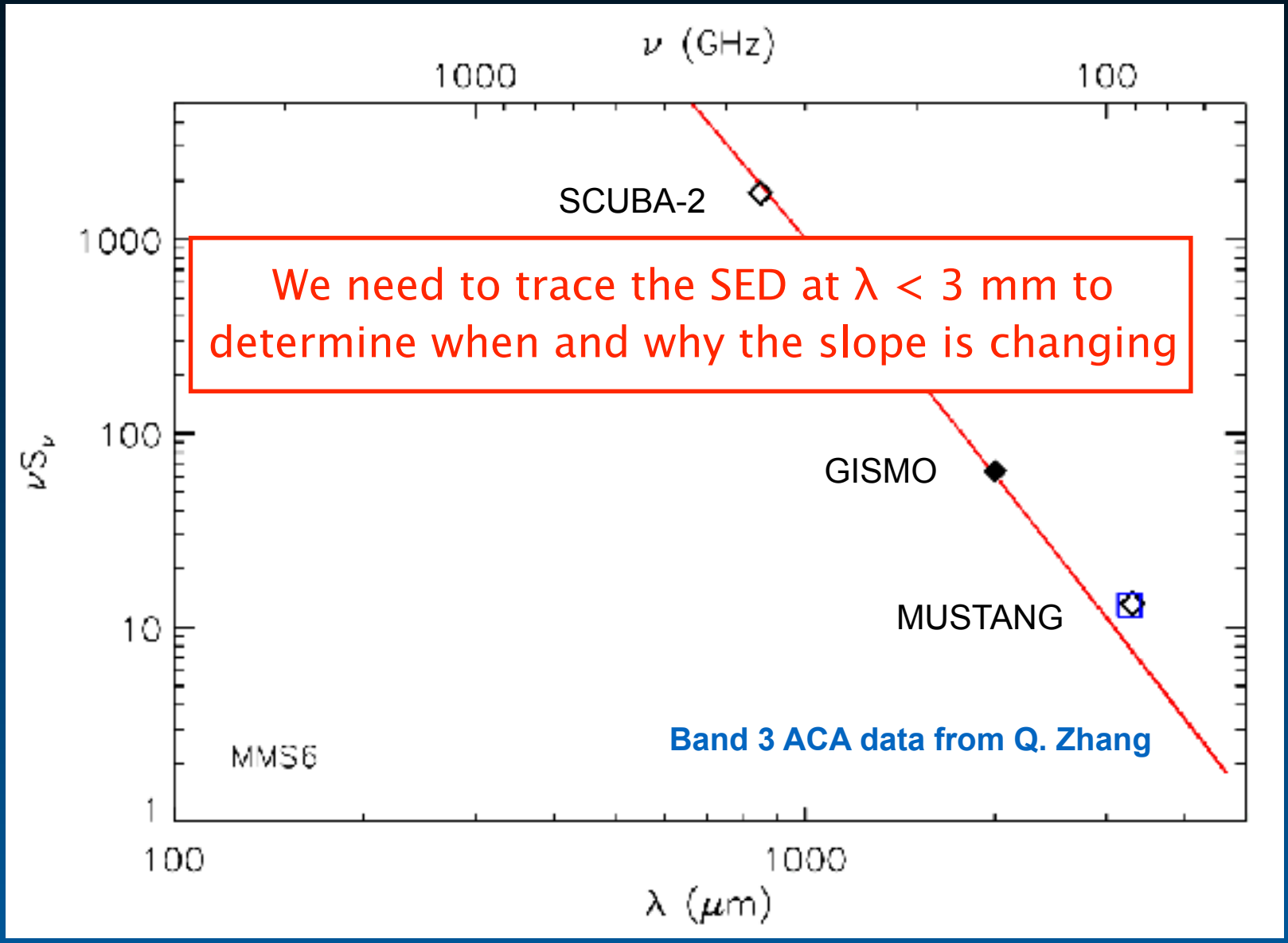


ALMA Dust Maps of OMC 2/3

Tracing the SED slope over multiple wavelengths

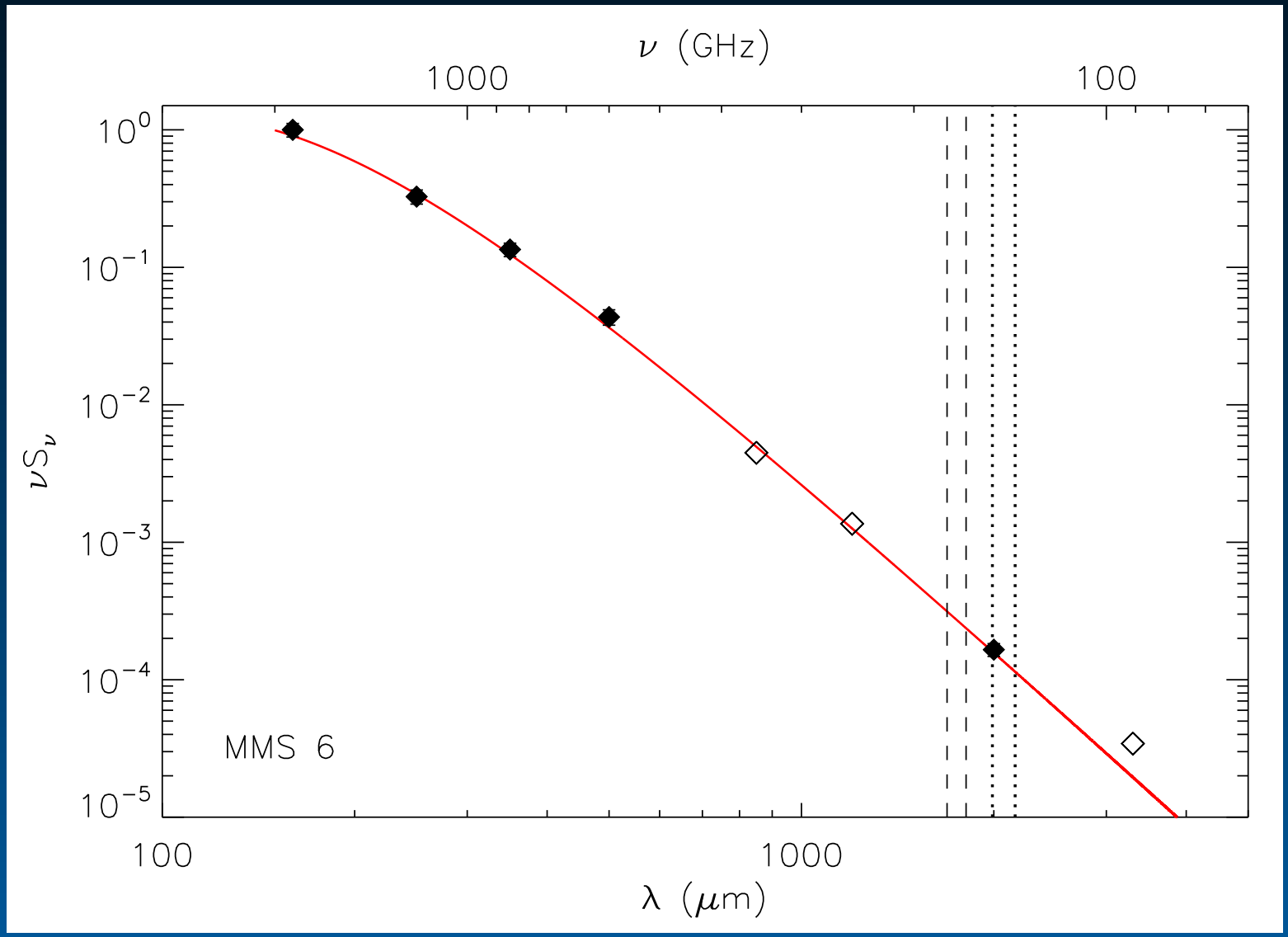
ALMA Cycle 5 project (PI Sarah Sadavoy)

- Bands 4/5 continuum maps (mosaics)
- 9.5 hours of ALMA time (delivered January 2018)
- OMC 2 in ~3' X 7' mosaic
- OMC 3 in ~3.5' X 7.5' mosaic
- ~ 1 mJy continuum sensitivity in both Bands

ALMA Dust Maps of OMC 2/3

Tracing the SED slope over multiple wavelengths

Utilize wide bandwidth to measure the SED slope between 1-3 mm



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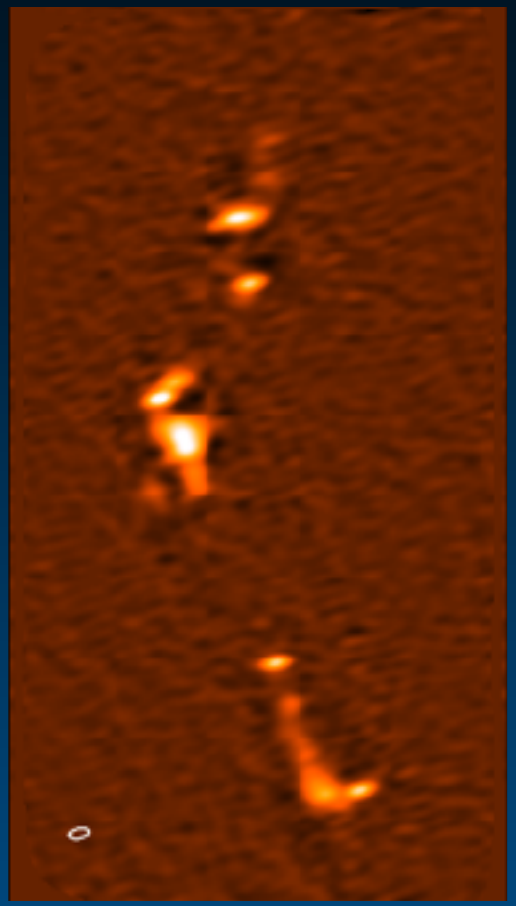
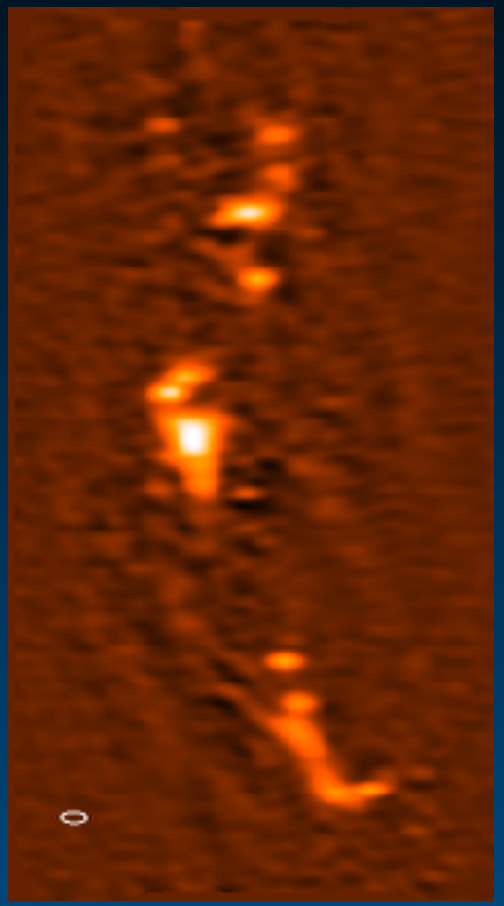
PRELIMINARY ACA Dust Maps of OMC 2/3

OMC 2 mosaic

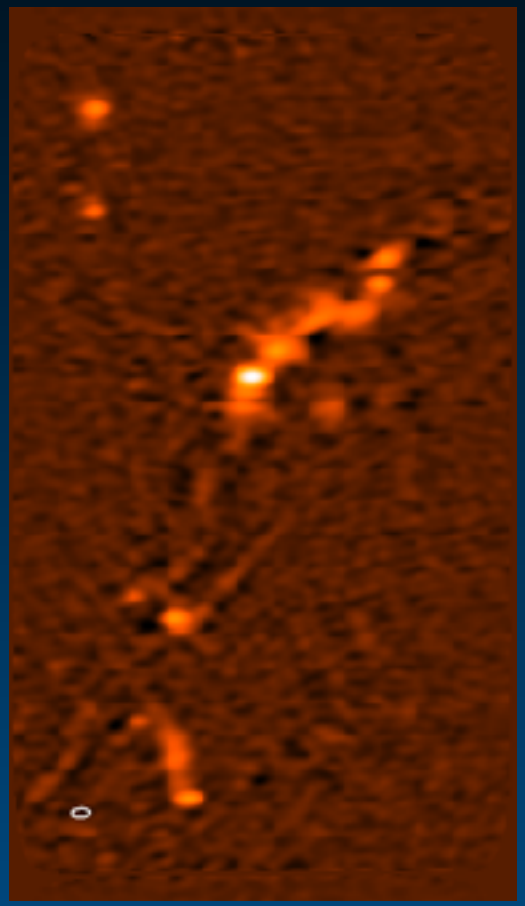


Band 5 (1.82 mm)



Band 4 (2.17 mm)

OMC 3 mosaic



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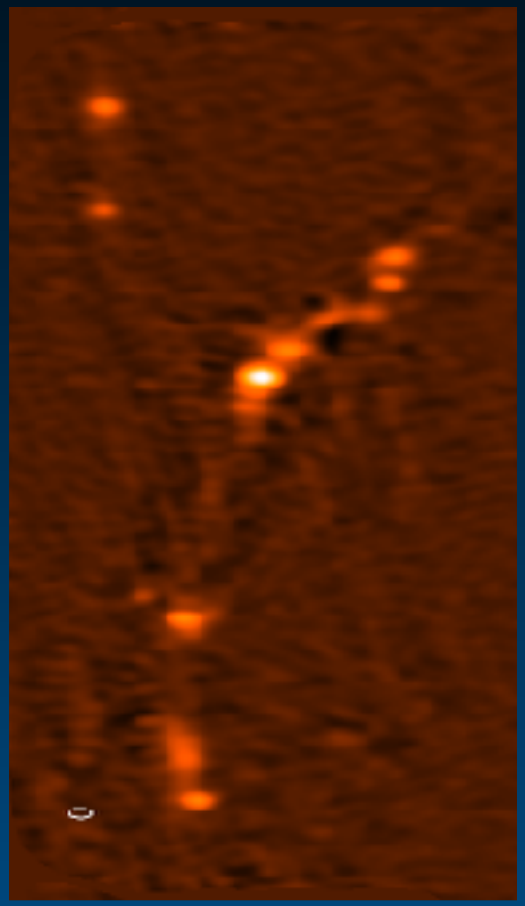

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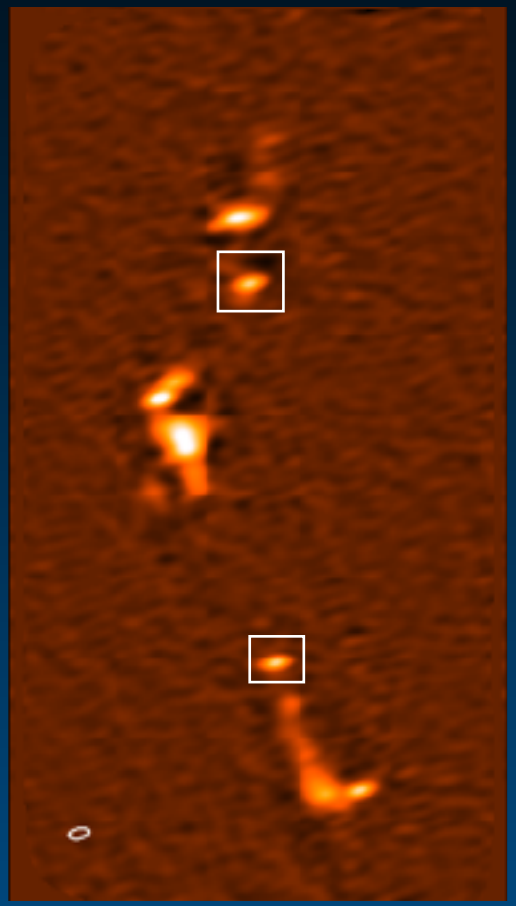

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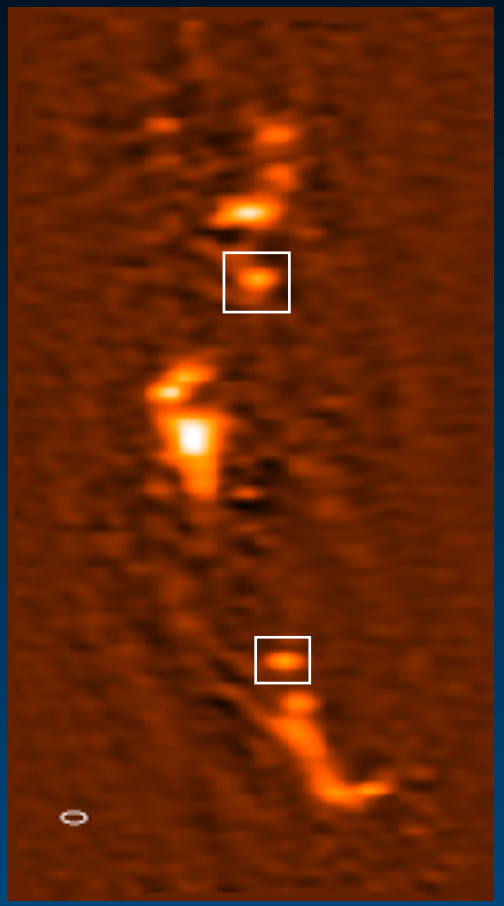

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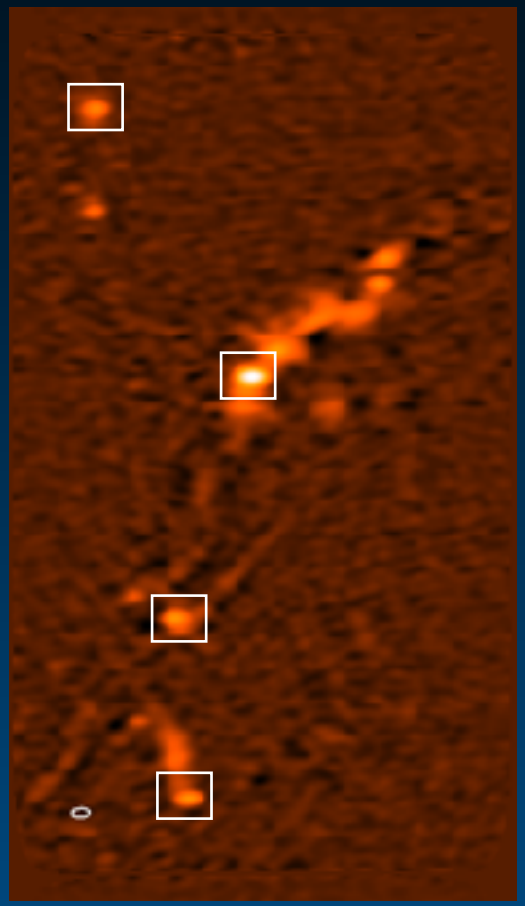

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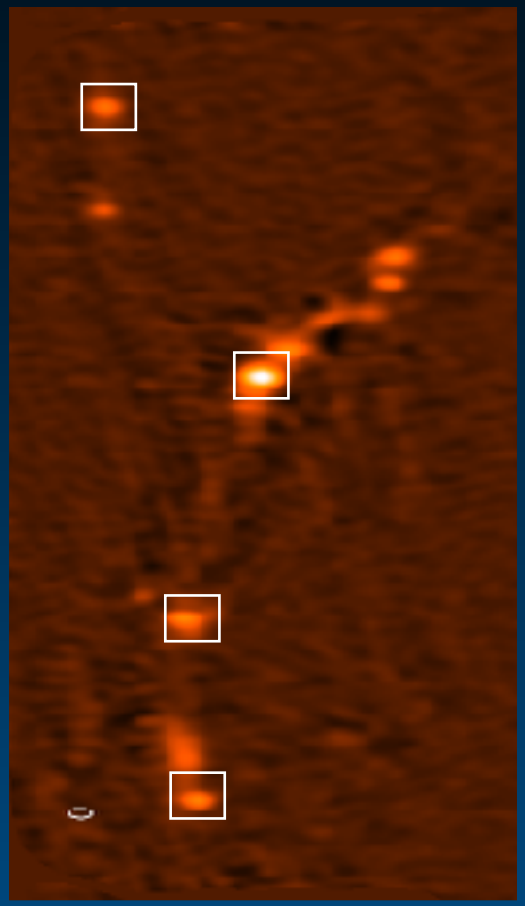
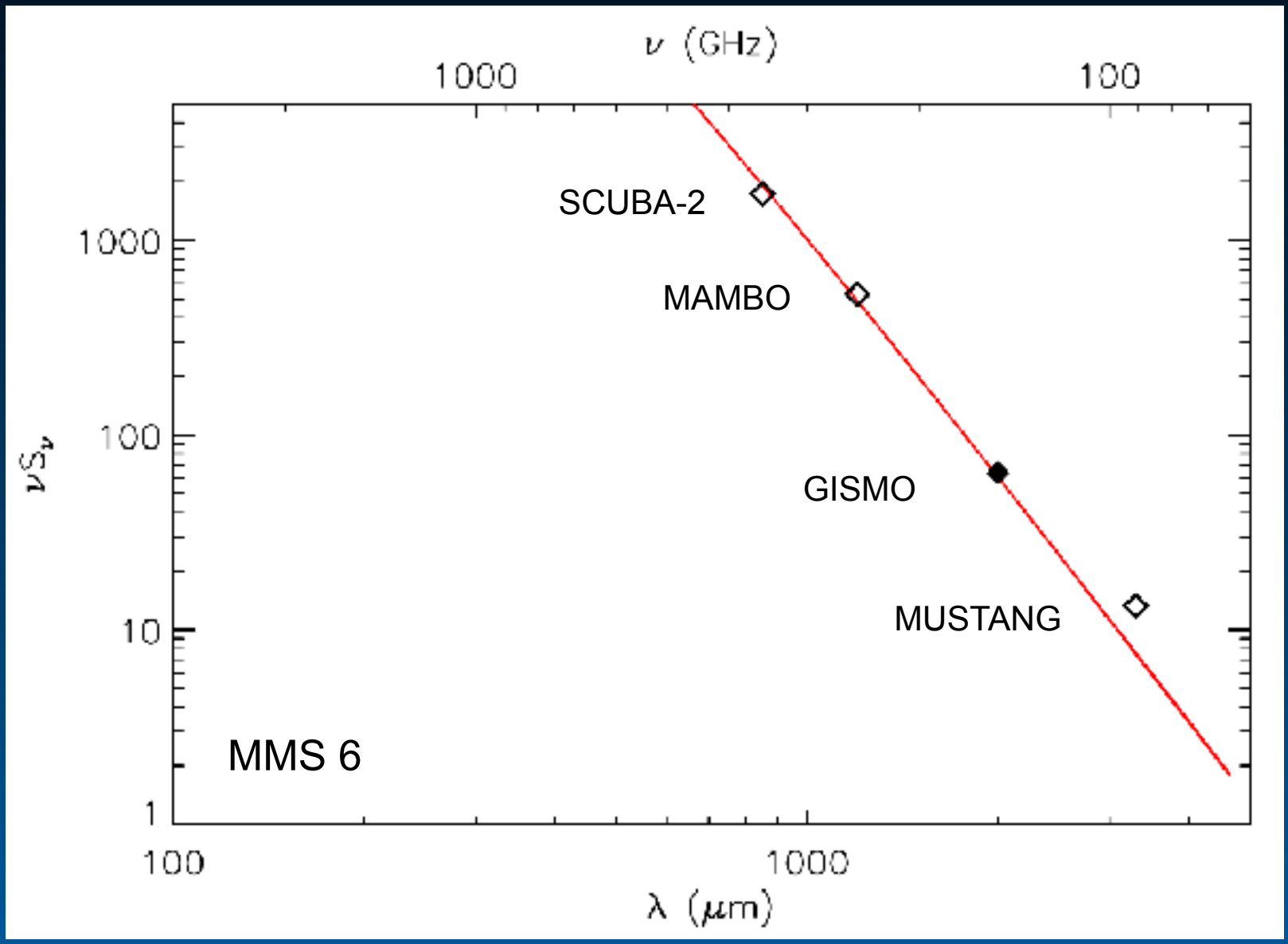


Band 4 (2.17 mm)

PRELIMINARY ACA Dust Maps of OMC 2/3

Comparison of ACA Band 4 and Band 5 data with single-dish observations



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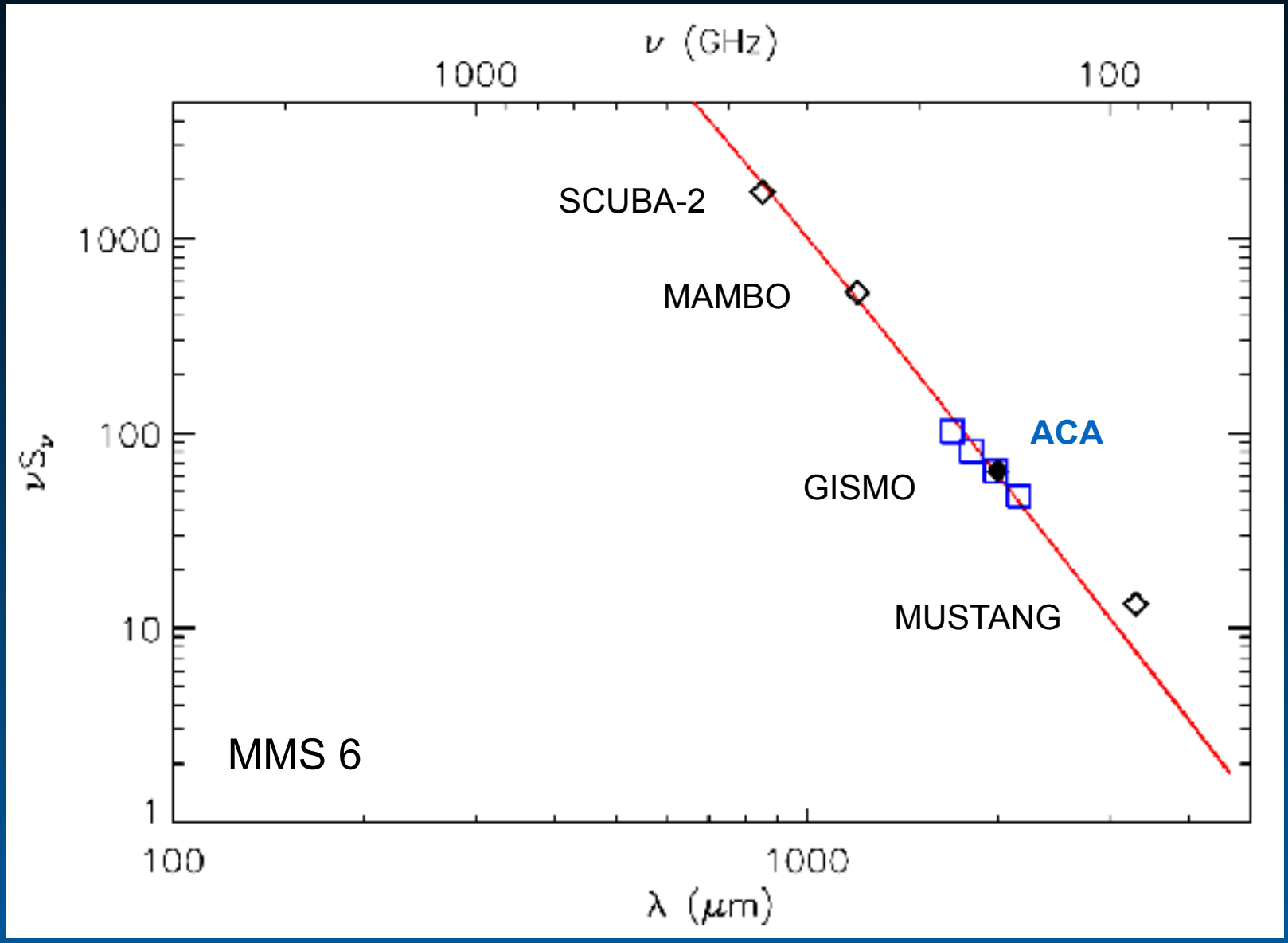
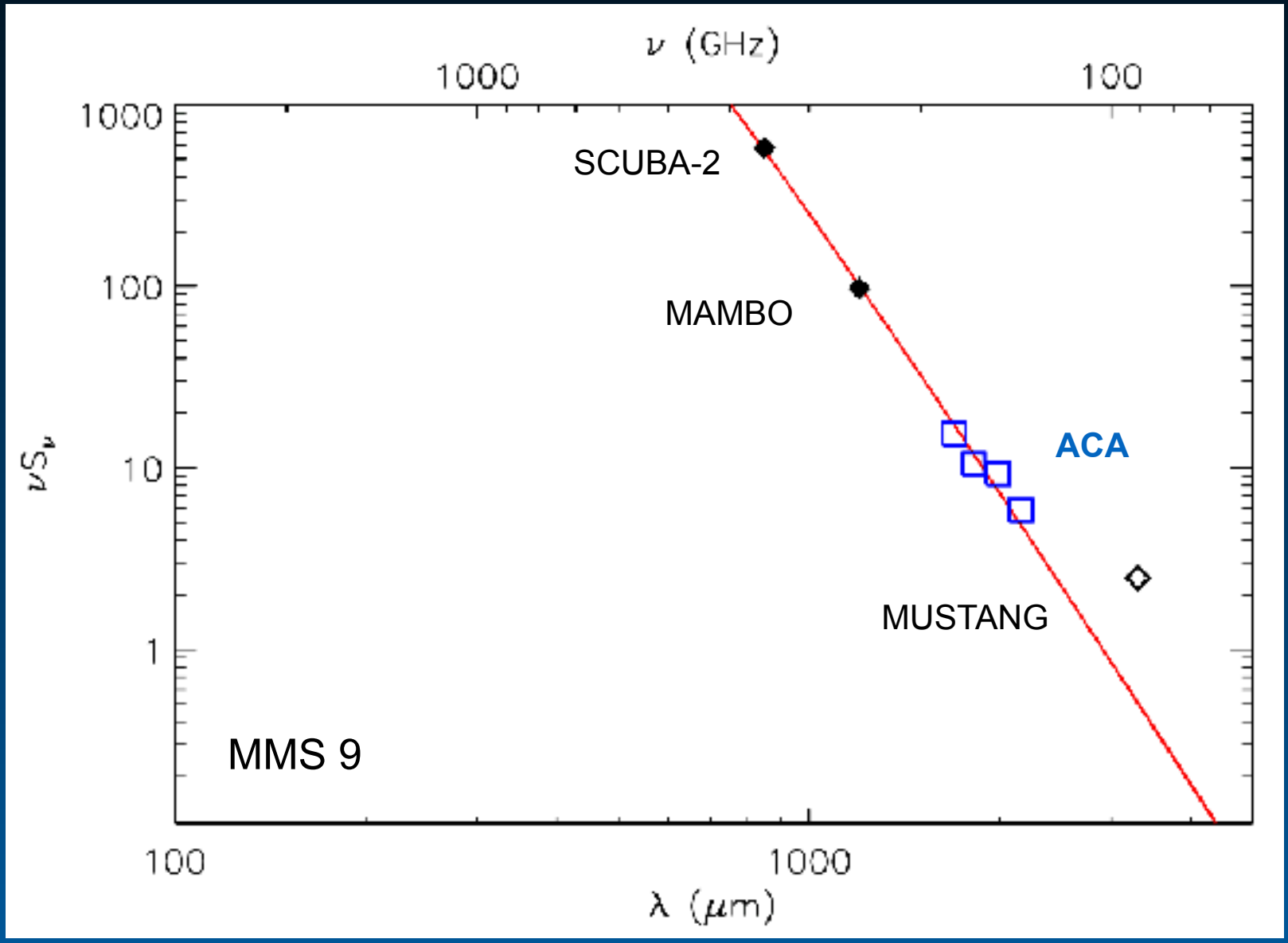


PRELIMINARY ACA Dust Maps of OMC 2/3

Comparison of ACA Band 4 and Band 5 data with single-dish observations



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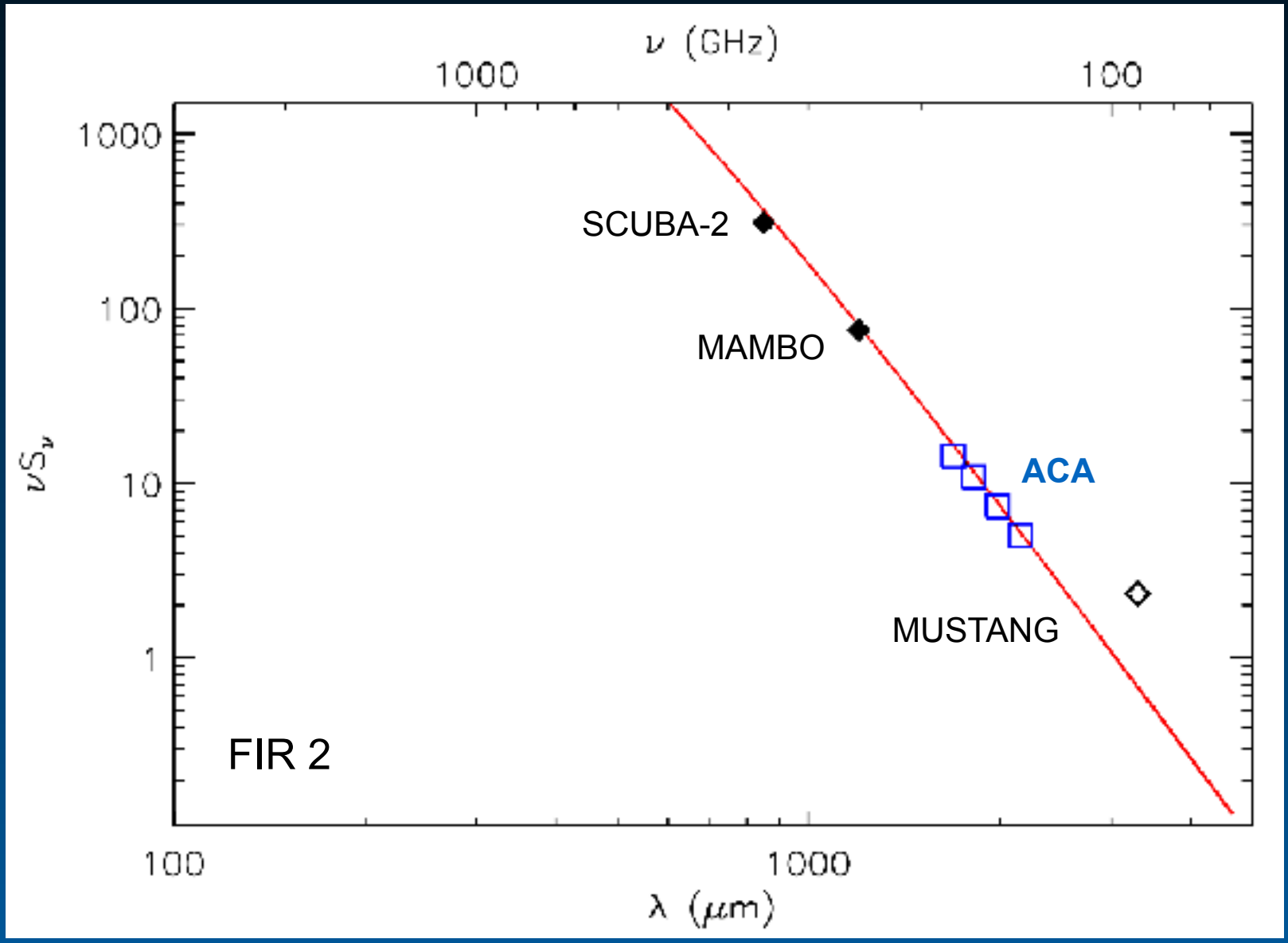

PRELIMINARY ACA Dust Maps of OMC 2/3

Preliminary results indicate that the SED slope is consistent for $\lambda < 2.2$ mm

PRELIMINARY ACA Dust Maps of OMC 2/3

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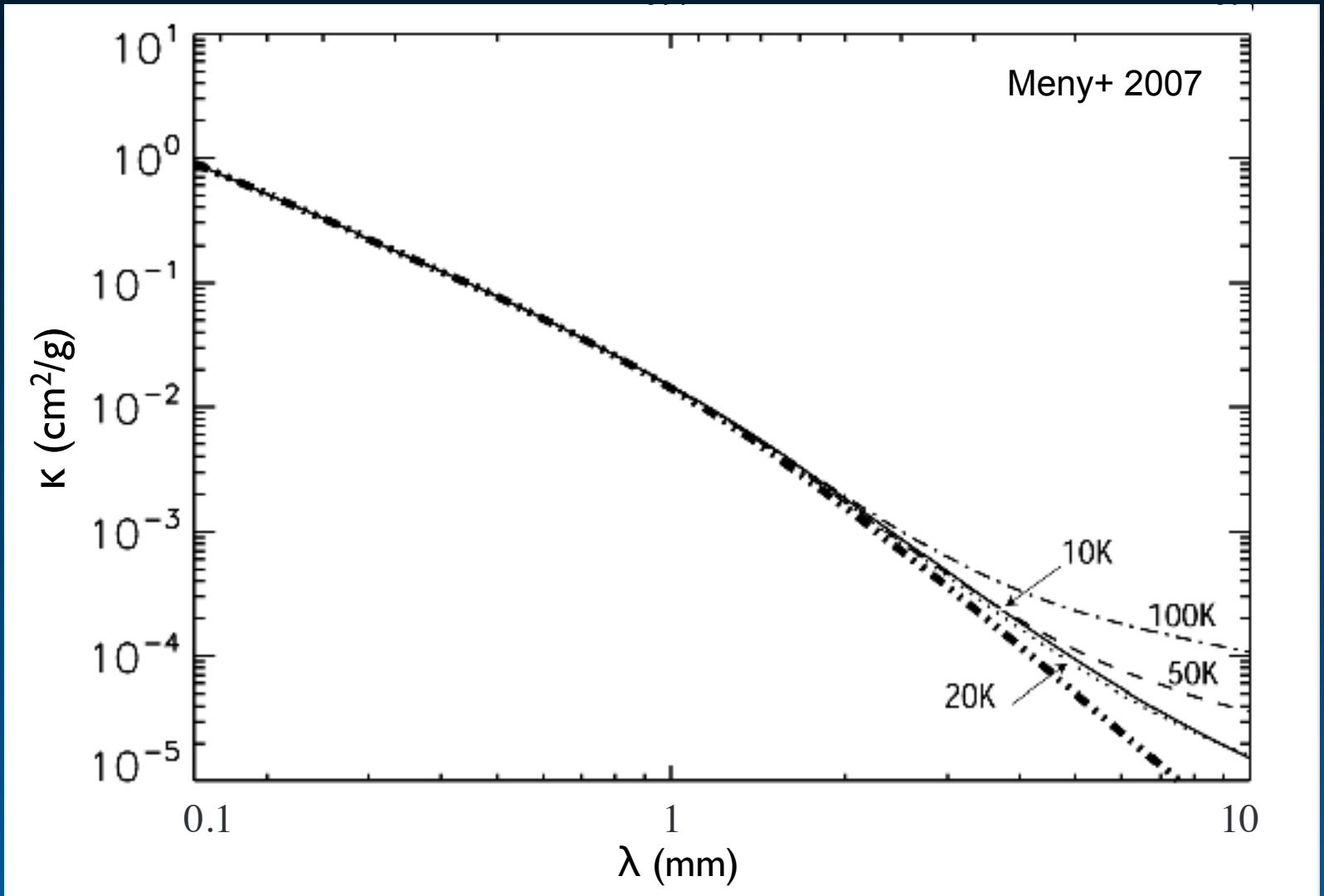
Fluxes at 3 mm are elevated (factors of 2-3) across all of OMC 2/3

Elevated 3 mm Emission Toward OMC 2/3

1) Dust emissivity index (β) does not follow a single power-law

- curvature in β seen in laboratory studies of dust
- (e.g., Reach+ 1995, Boudet+ 2005, Meny+ 2007, Coupeaud+ 2011, Demyk+ 2017)



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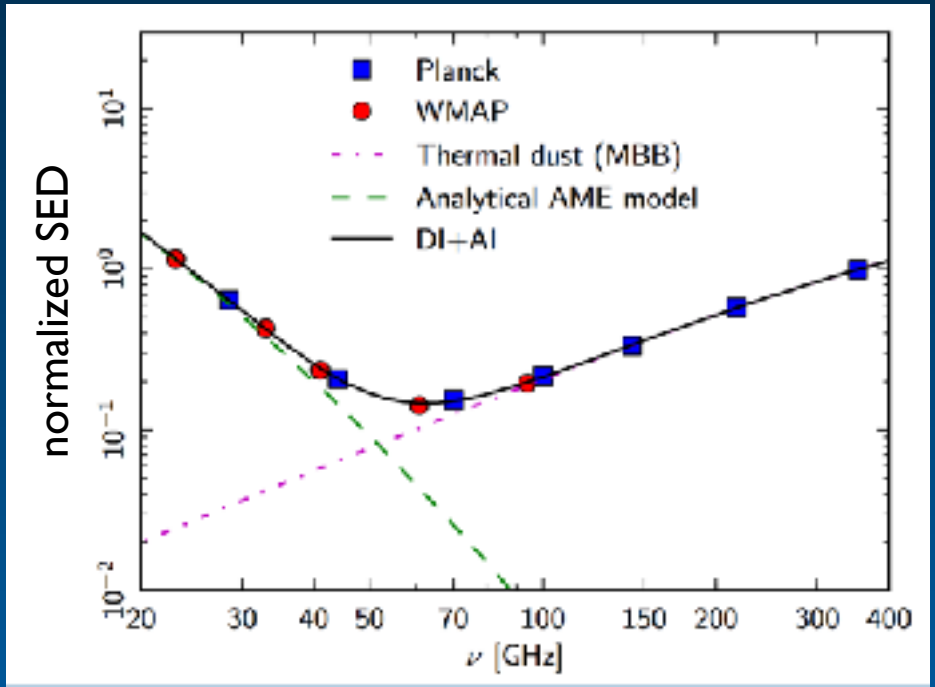
2) Contamination at 90 GHz

- free-free emission, anomalous microwave emission
- (e.g., Leitch+ 1997, Draine & Lazarian 1998, Schnee+ 2014, Planck Collab. 2016 XXV)

See Thiem's talk



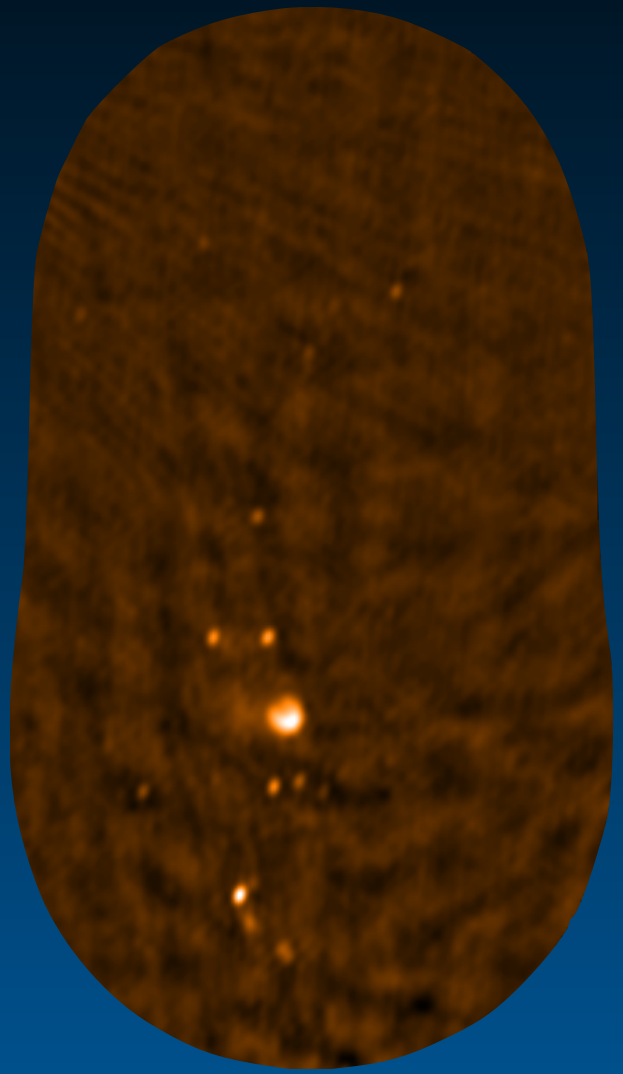
Planck Collab. 2015 XXII

Elevated 3 mm Emission Toward OMC 2/3

Need radio observations to correct for free-free emission and AME

Q-band and Ka-band (30-50 GHz) with the GBT
(DDT proposal, PI B. Mason)

Ku-band, X-band, C-band (6-15 GHz) with the VLA
(2014A project, PI S. Schnee)



C-band (preliminary)

Elevated 3 mm Emission Toward OMC 2/3

1) Dust emissivity index (β) does not follow a single power-law

- curvature in β seen in laboratory studies of dust
- (e.g., Reach+ 1995, Boudet+ 2005, Meny+ 2007, Coupeaud+ 2011, Demyk+ 2017)

2) Contamination at 90 GHz

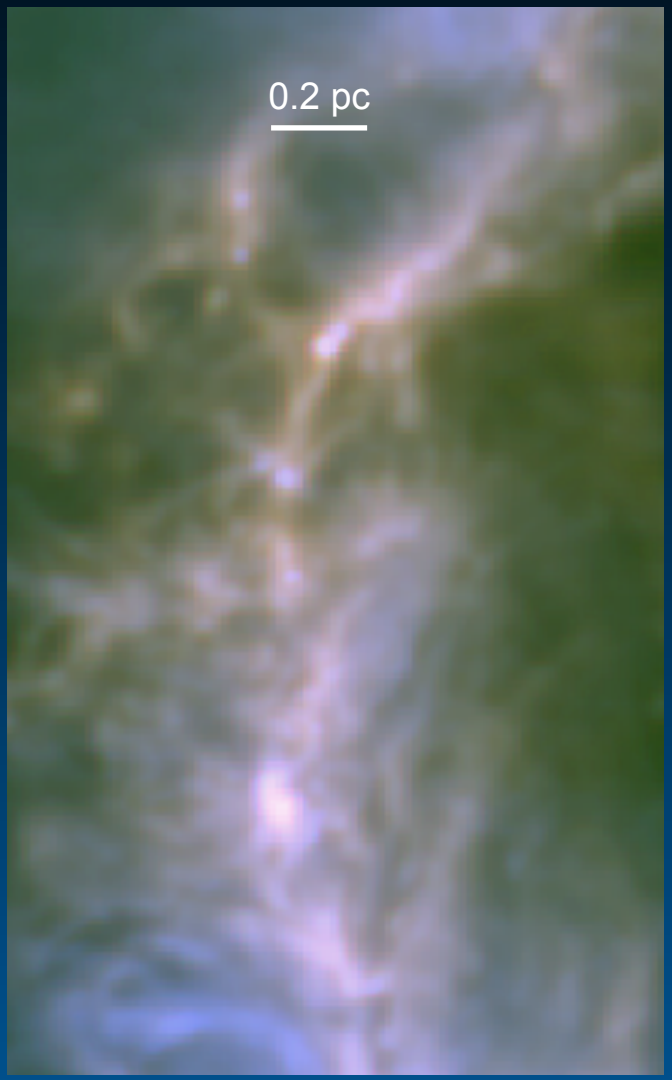
- free-free emission, anomalous microwave emission
- (e.g., Leitch+ 1997, Draine & Lazarian 1998, Schnee+ 2014, Planck Collab. 2016 XXV)

3) Something else?

- large quantity of very cold dust
- detections of large dust grains in protostellar disks

Dust Emissivity in OMC 2/3

Dust emission at ~3 mm does not follow the same trend as emission at < 2.2 mm



Herschel RGB(160-350 μm)
Stutz & Kainulainen 2015

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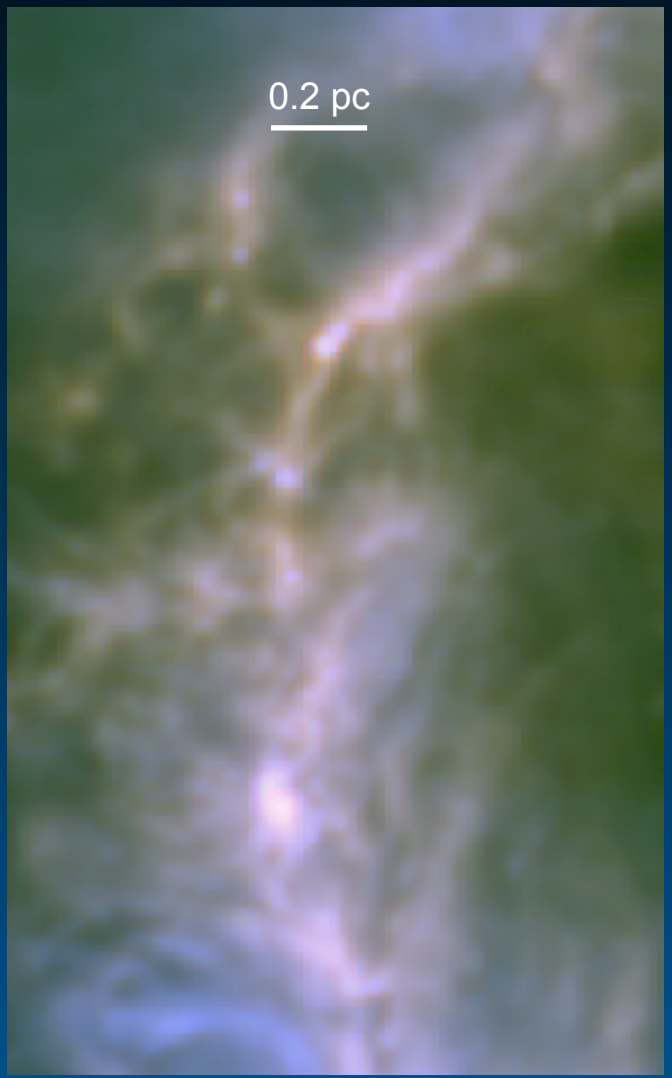

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β is ~ 1.7 for λ < 2.2 mm and decreases to < 1 at 3 mm

Change in β increases 3 mm fluxes by factors of 2-3 relative to the SED slope at shorter wavelengths

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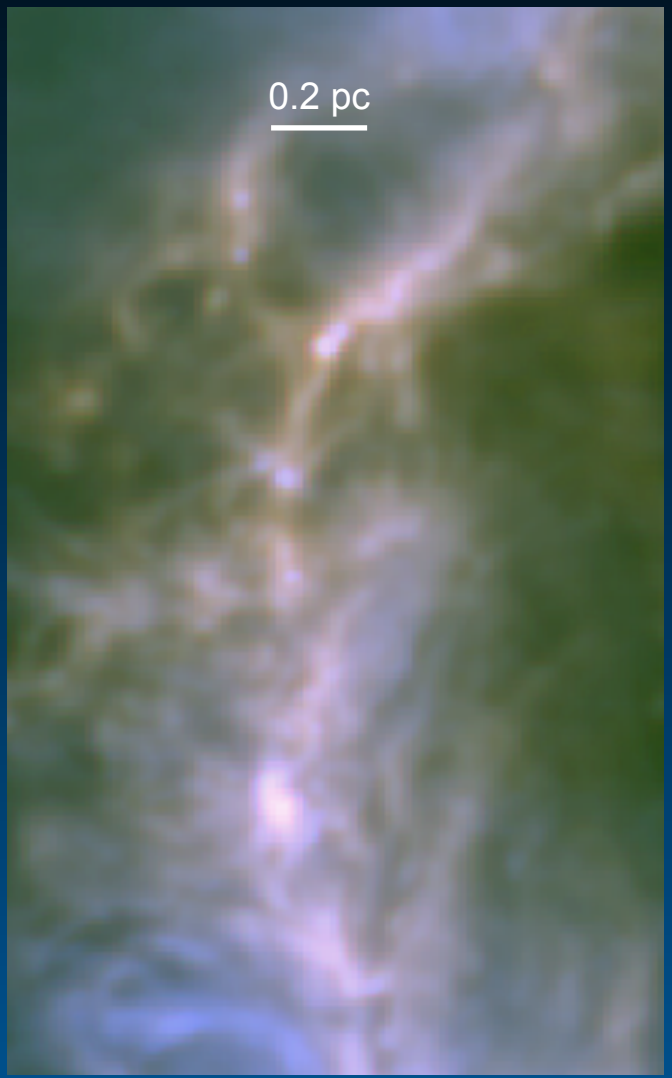

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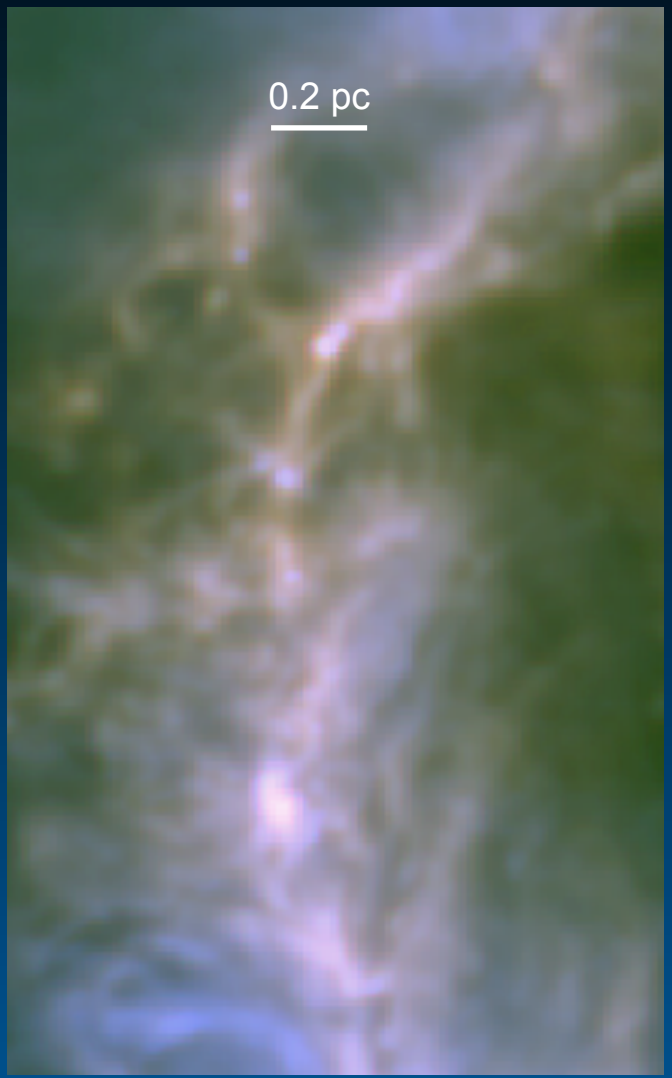

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Changing slope will affect mass estimates for OMC 2/3

Do other clouds show similar slope variations at 3 mm? If so, we need to re-evaluate Band 3 measurements