NIKA2 observations of dust grain evolution from star-forming filament to T-Tauri disk:

Results from observations of the Taurus B211/B213 filament

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On behalf of the NIKA2 Collaboration

Including GASTON Team (N., Peretto, Ph. André, A. Bacmann, A. Rigby, T.A. Duong, et al.)

Part of the Galactic Star Formation with NIKA2 (GASTON) large program.

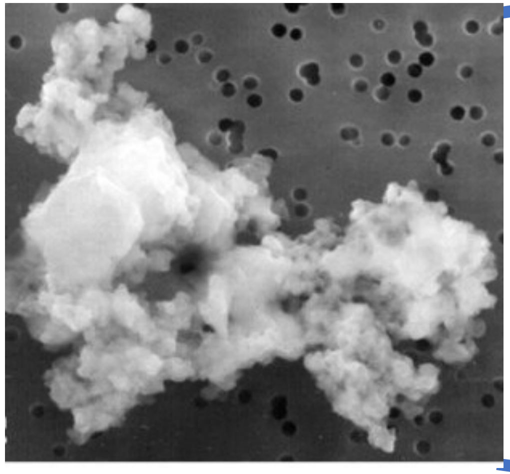
Growth of Dust Grains in Molecular Clouds?

Interplanetary dust particle

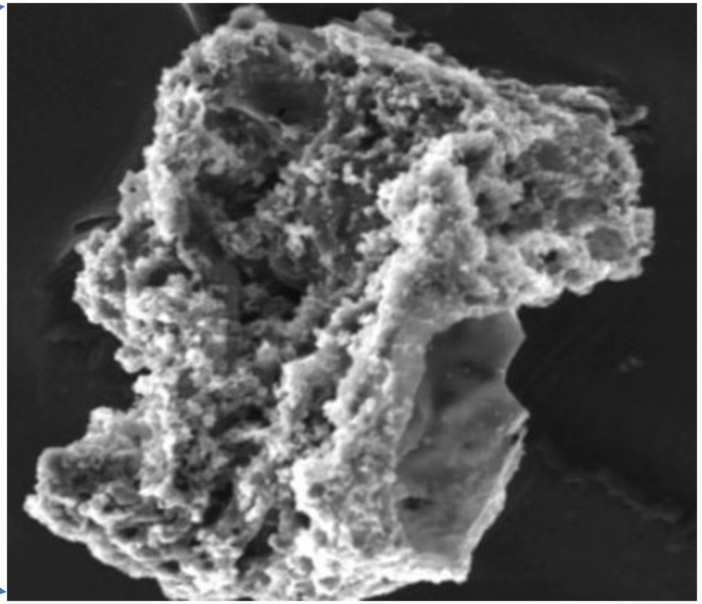
Micrometeorites

Dust opacity

$$\kappa_\nu = \kappa_0 \left(\frac{\nu}{\nu_0} \right)^\beta$$



1μm



50 μm

(*cf. Review by Engrand et al. 2023*)

Dust Emissivity Index

Small dust grains --> Large β
Large dust grains --> Small β

(*cf. Ossenkopf & Henning 1994, Stognienko, Henning, & Ossenkopf 1995; Henning & Stognienko, 1996; Ohashi et al. 2021*)

Constraining the dust emissivity index from mm and submm data

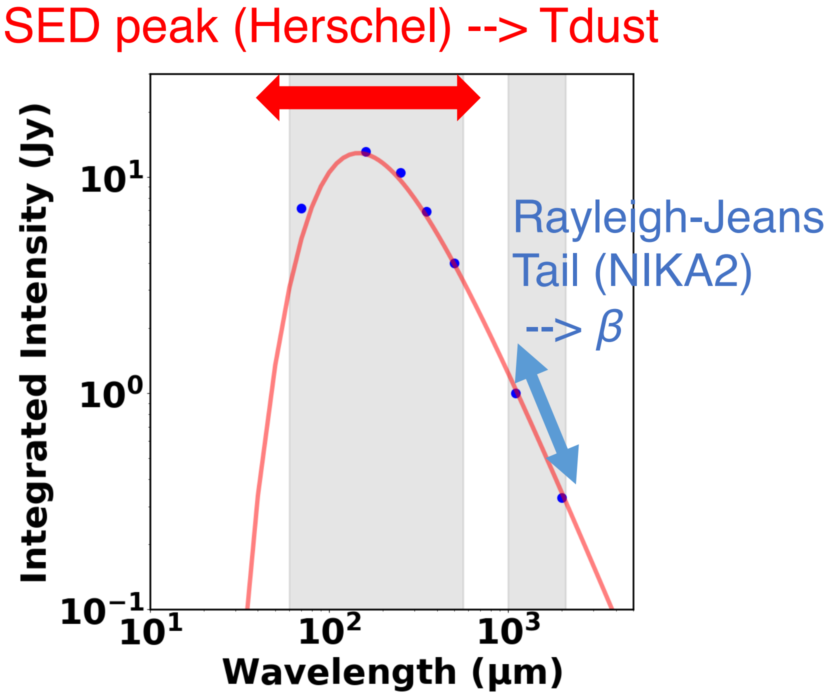
The **optically thin emission** spectrum of large dust grains can be modeled as a modified-gray body emission with the following form

$$I_\nu = \tau_\nu B_\nu(T_\mathrm{d}) = \kappa_\nu \Sigma B_\nu(T_\mathrm{d}) = \kappa_0 \left(\frac{\nu}{\nu_0}\right)^\beta \mu_{\mathrm{H}_2} m_\mathrm{H} N_{\mathrm{H}_2} B_\nu(T_\mathrm{d}),$$

$$R_{1.2\_2} = \frac{I_{1.2\mathrm{mm}}}{I_{2\mathrm{mm}}} = \left(\frac{\nu_{1.2}}{\nu_2}\right)^\beta \frac{B_{\nu_{1.2}}(T_\mathrm{d})}{B_{\nu_2}(T_\mathrm{d})},$$

$$\alpha = \frac{\ln I_1 - \ln I_2}{\ln \nu_1 - \ln \nu_2}$$

$$\beta = \log\left(R_{1.2\_2} \frac{B_{\nu_2}(T_\mathrm{d})}{B_{\nu_{1.2}}(T_\mathrm{d})}\right) / \log\left(\frac{\nu_{1.2}}{\nu_2}\right)$$

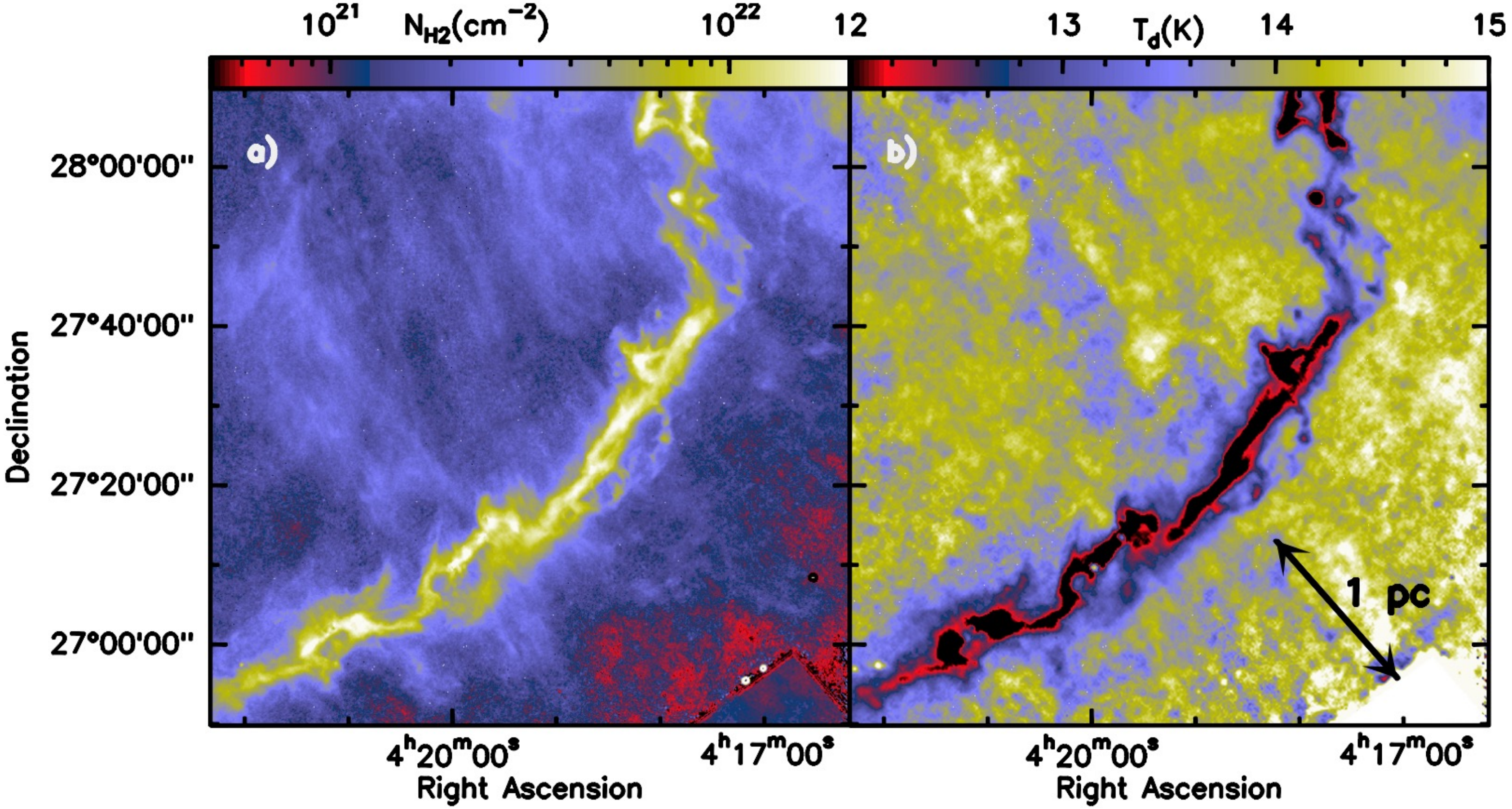


Most previous studies used the Rayleigh-Jeans Approximation (***β = α – 2***), but we do not need it since we have good temperature estimation from Herschel.

Previous studies of dust emissivity index with NIKA1 and NIKA2:

- Prestellar and protostellar cores in Taurus filament (*Bracco et al. 2017)*
- Infrared dark clouds, star-forming clumps *(Rigby et al. 2018, Rigby et al. 2021)*

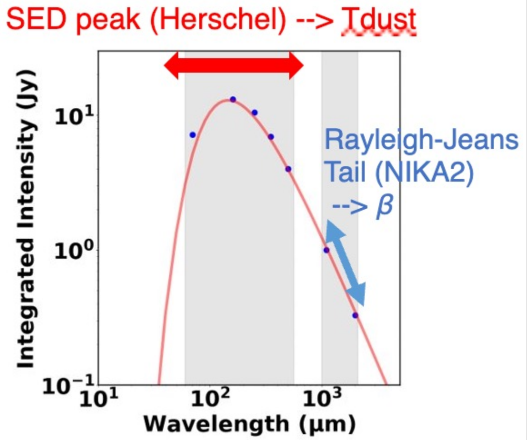
Column density and temperature maps of the Taurus B211/B213 filament as derived from Herschel data



High-resolution (18") column density map and the 36" dust temperature map

Palmeirim et al. (2013)

André, et al. (2010)
Palmeirim et al. (2013)
Marsh et al. (2017)



NIKA2 Observations of The Taurus B211/B213 Filament

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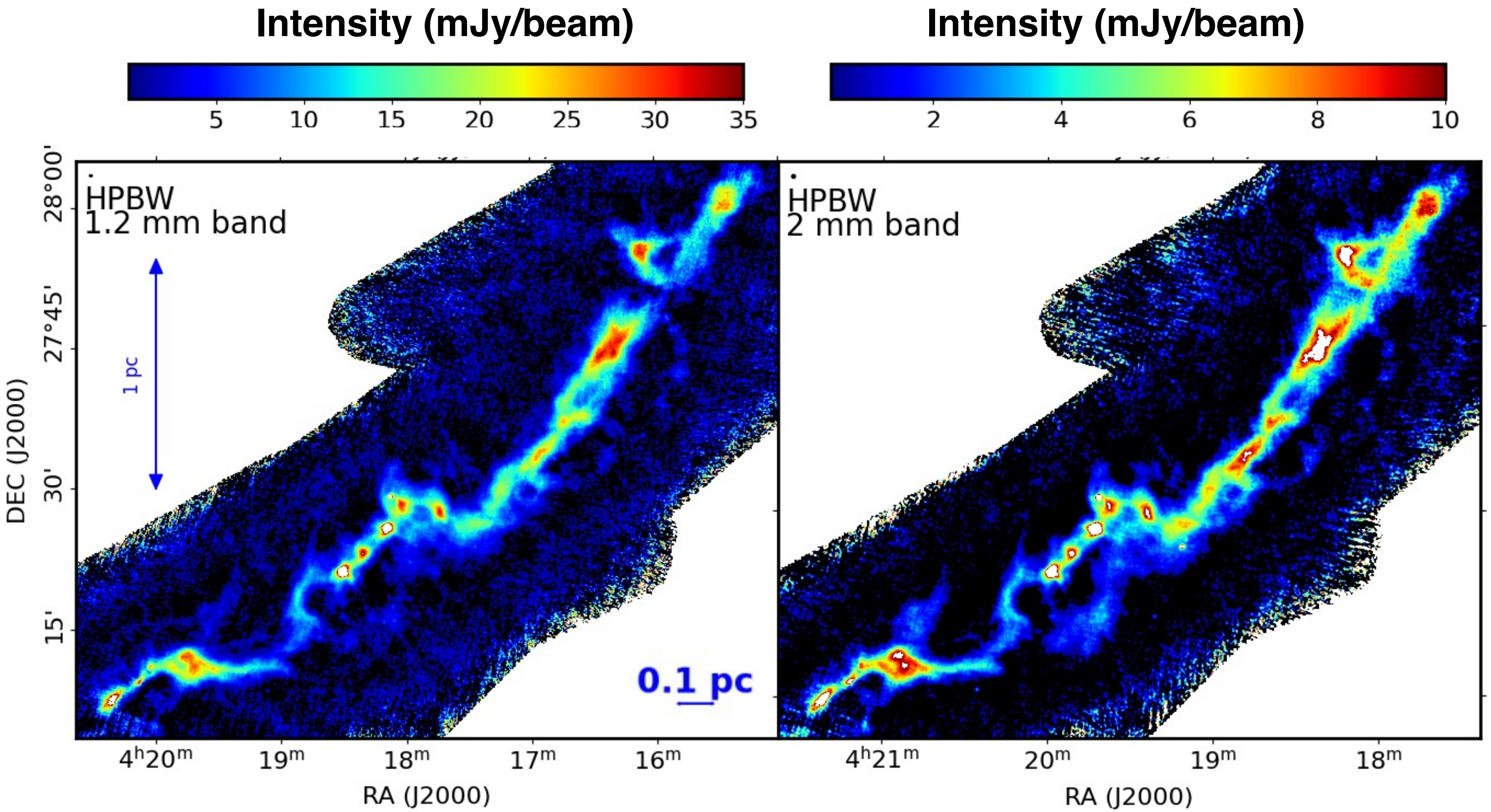


- Taurus B211/B213 observations were done in winters of 2021, 2022, 2023
- PIIC @ GILDAS (*Berta & Zylka 2022*)
- Spatial resolutions:

  11.1" or 0.007 pc at 1.2mm

  17.6" or 0.01 pc at 2mm

  (*Perotto et al. 2020*)
- RMS sensitivities:

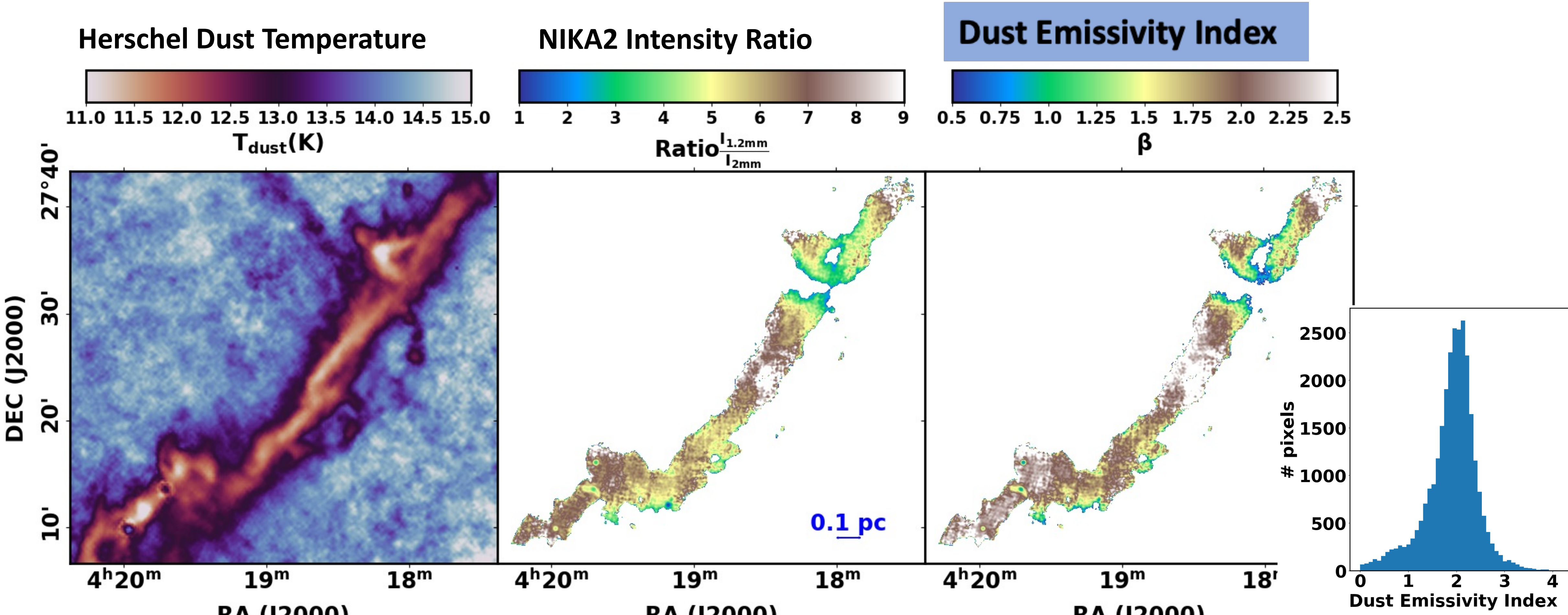
  - 1.35 mJy/11.1"-beam at 1.2 mm

  - 0.50 mJy/17.6"-beam at 2mm

NIKA2

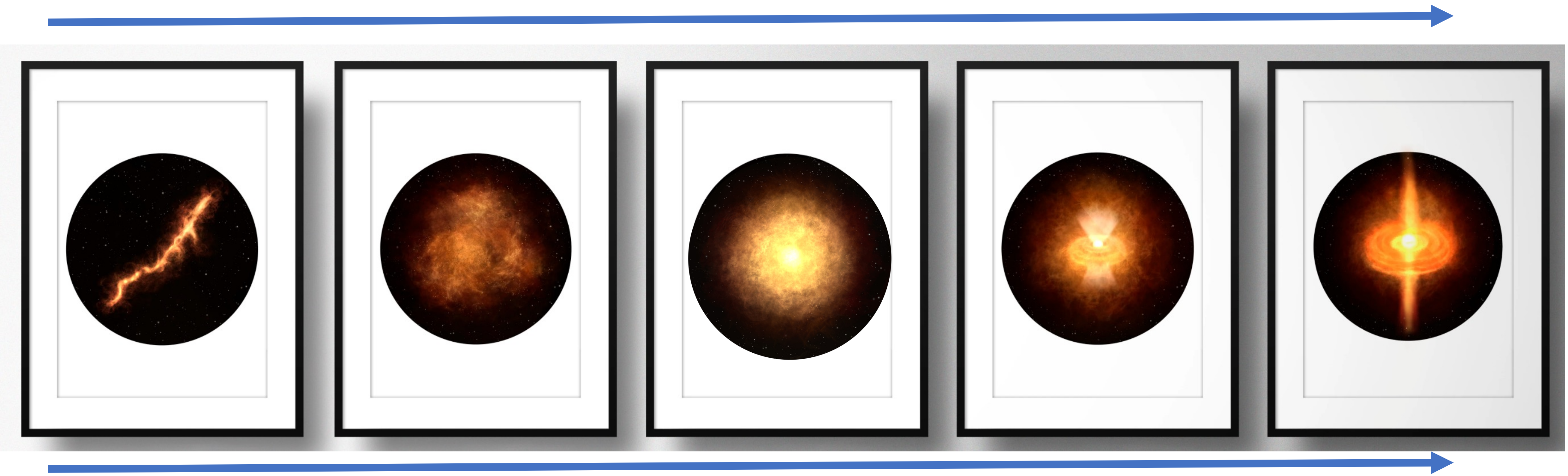
Deriving Dust Emissivity Index Map

preliminary



- Ratio derived for only pixels that have signal > 5sigma in both intensity maps
- Dust emissivity index in filament has:
  - Median β value: 1.97
  - Inter Quartile Range: [1.58-2.7]

Empirical Evolutionary Scheme from Filament to T-Tauri Star



Filament

Starless core

Prestellar core
Self-gravitating

(Class 0, I) Protostellar core
Gravitational collapse
Central protostar
Accretion Disk
Outflow

(Class II) T-Tauri star
Central T-Tauri star
Jet
Disk

(see also Carsten Kramer's talk)

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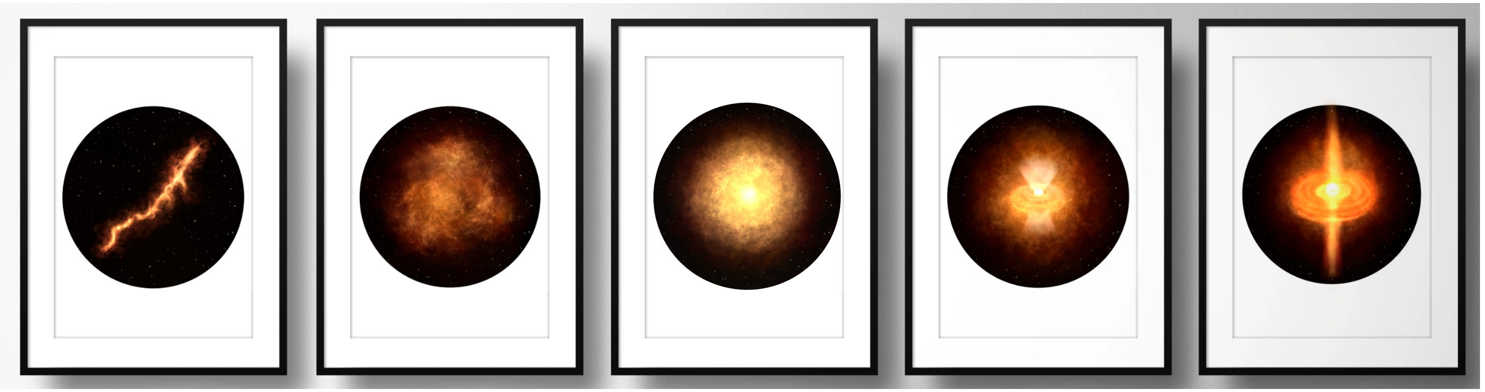
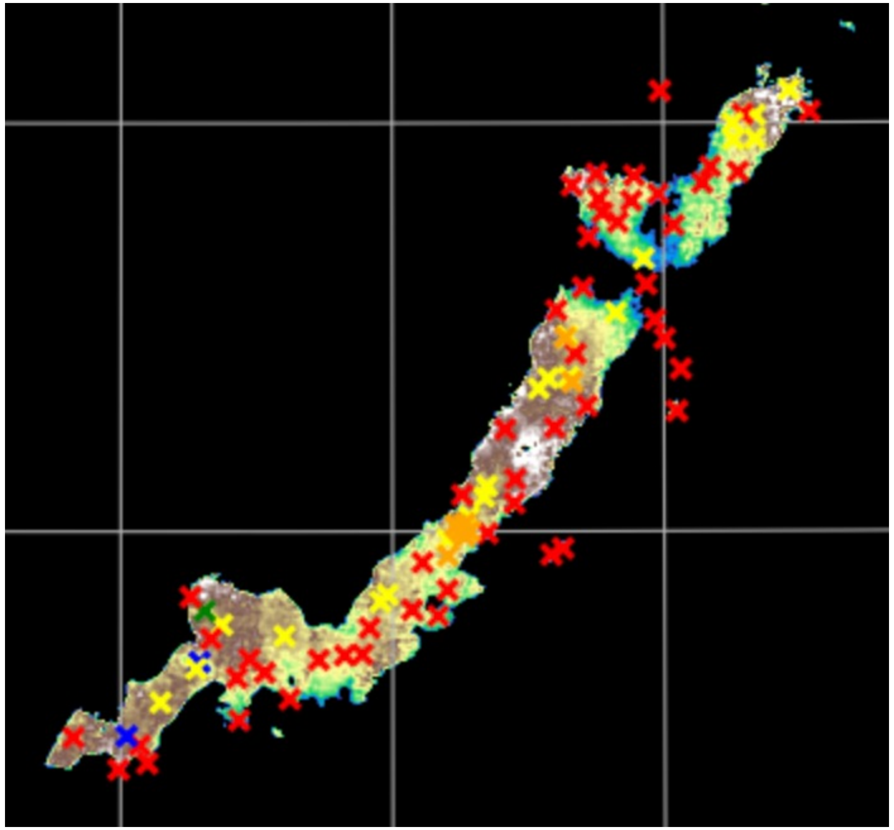
Extract Dust Emissivity Index from Dense Cores to T-Tauri Disk

- Dense cores identified with Herschel Gould-Belt Survey data (*Marsh et al. 2016*)
- Number of objects in the β map of Taurus filament



Filament	Starless core	Prestellar core	(Class 0, I) Protostellar core	(Class II) T-Tauri star
1	72	30	2	1

- Extract the overall β at the positions of the objects



Red: unbound starless cores
Black: (Candidate) Prestellar cores
Blue: Protostellar cores
Green: T-Tauri star

Dust Emissivity Index from Filament to T-Tauri Star

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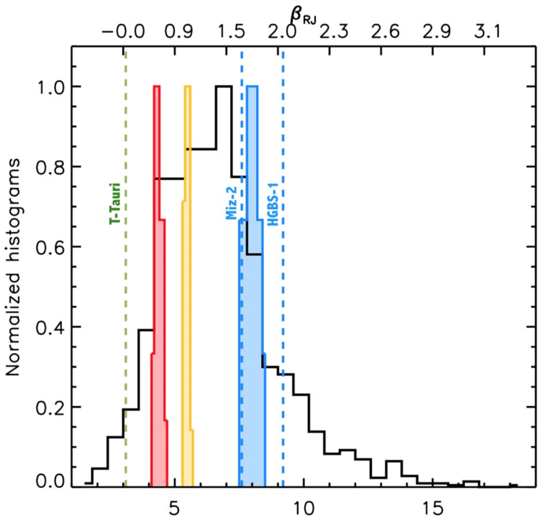
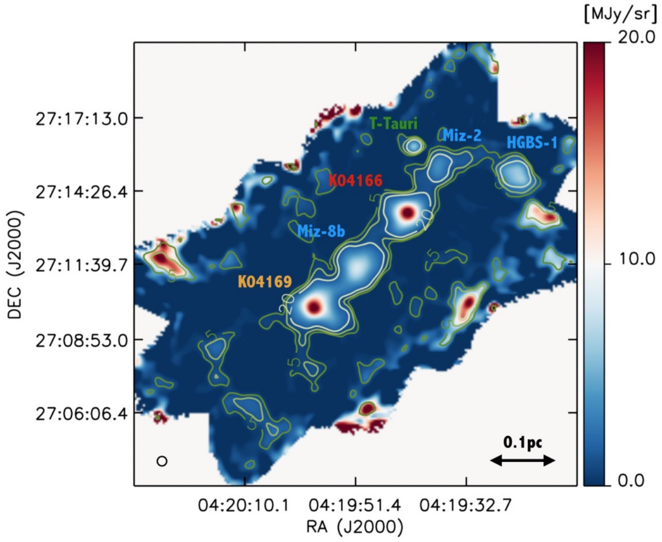
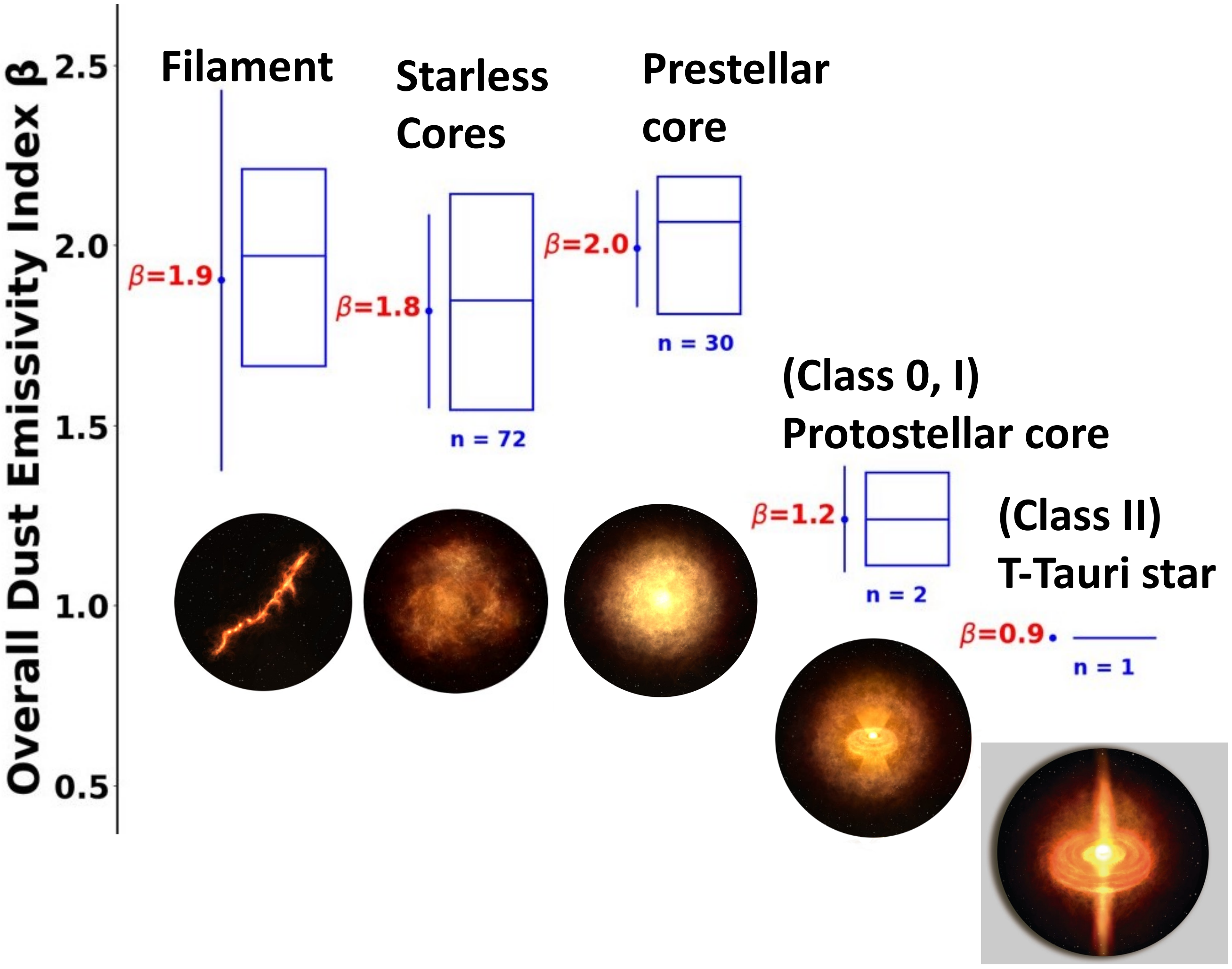
- β decreases continuously from filament and starless cores (β~2) to protostellar cores (β~ 1.2) to T Tauri stars (β<1).
- Consistent with *Bracco et al. (2017)*
- But based on a much larger sample (105 cores versus only 5 cores)
- In each evolutionary stage, β spreads over a range seen, in the Inter-Quartile Range.







(see also Carsten Kramer's talk)

Low Dust Emissivity Index from Protostellar Core to T-Tauri Star

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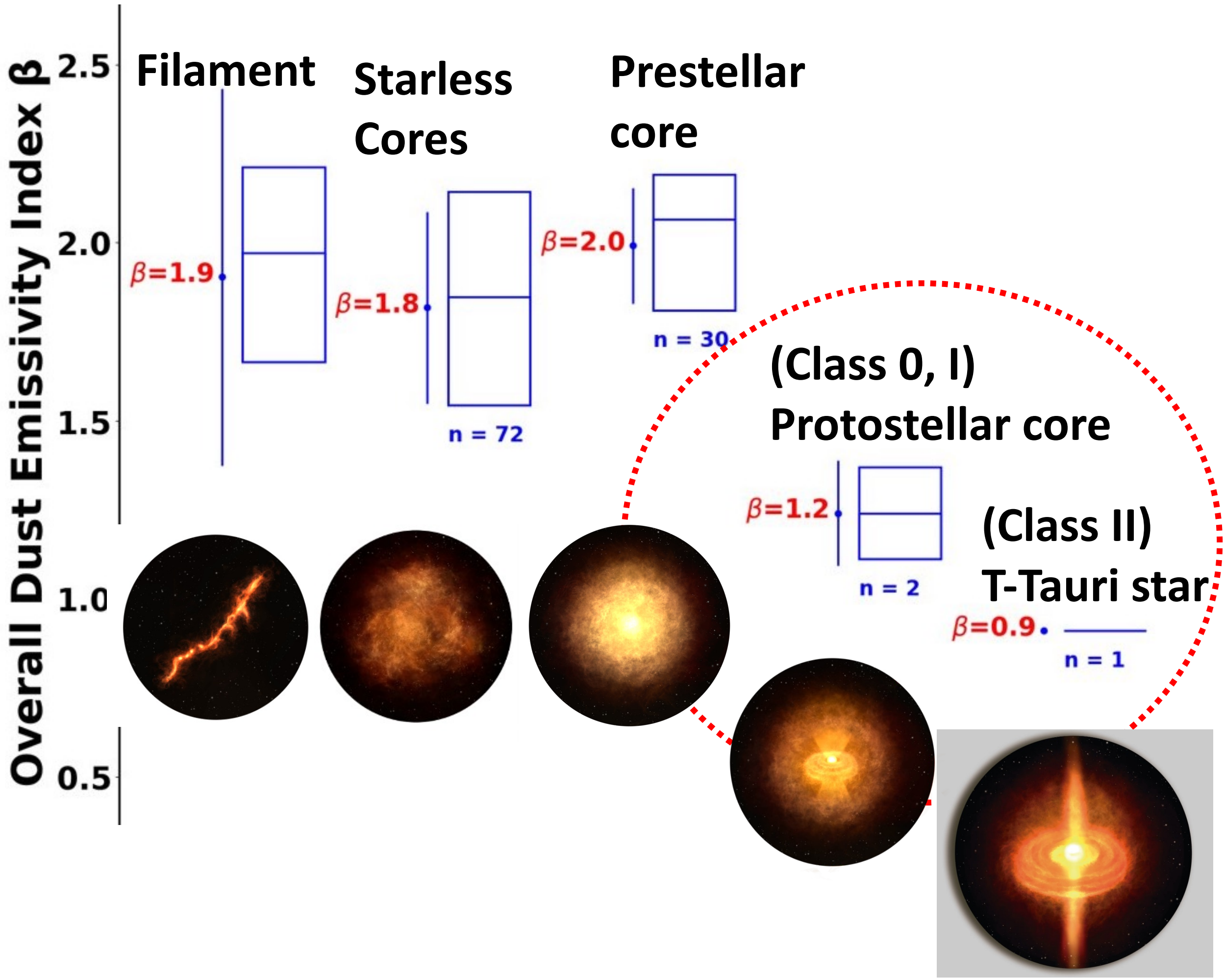
- Our low β in Taurus' protostellar cores @2000 AU are similar to β in a sample of 12 protostars ~500 AU scale, observed with PdBI in CALYPSO survey (*Galametz et al. 2019*)

- In addition, our low β in Taurus' T-Tauri disk @2000 AU scale is similar to β in a sample of 36 Lupus' T-Tauri disks ~50 AU scale, Lupus observed with ALMA (*Tazzari et al. 2021*)



A flat (β~2) dust emissivity index radial profile across filament crest

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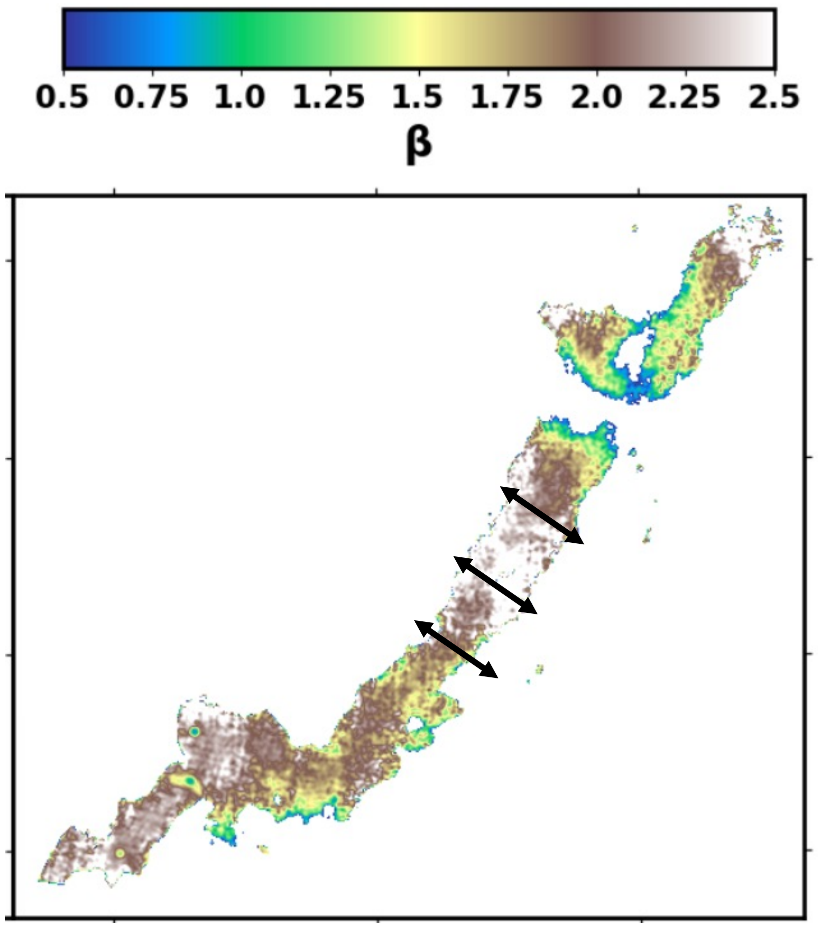

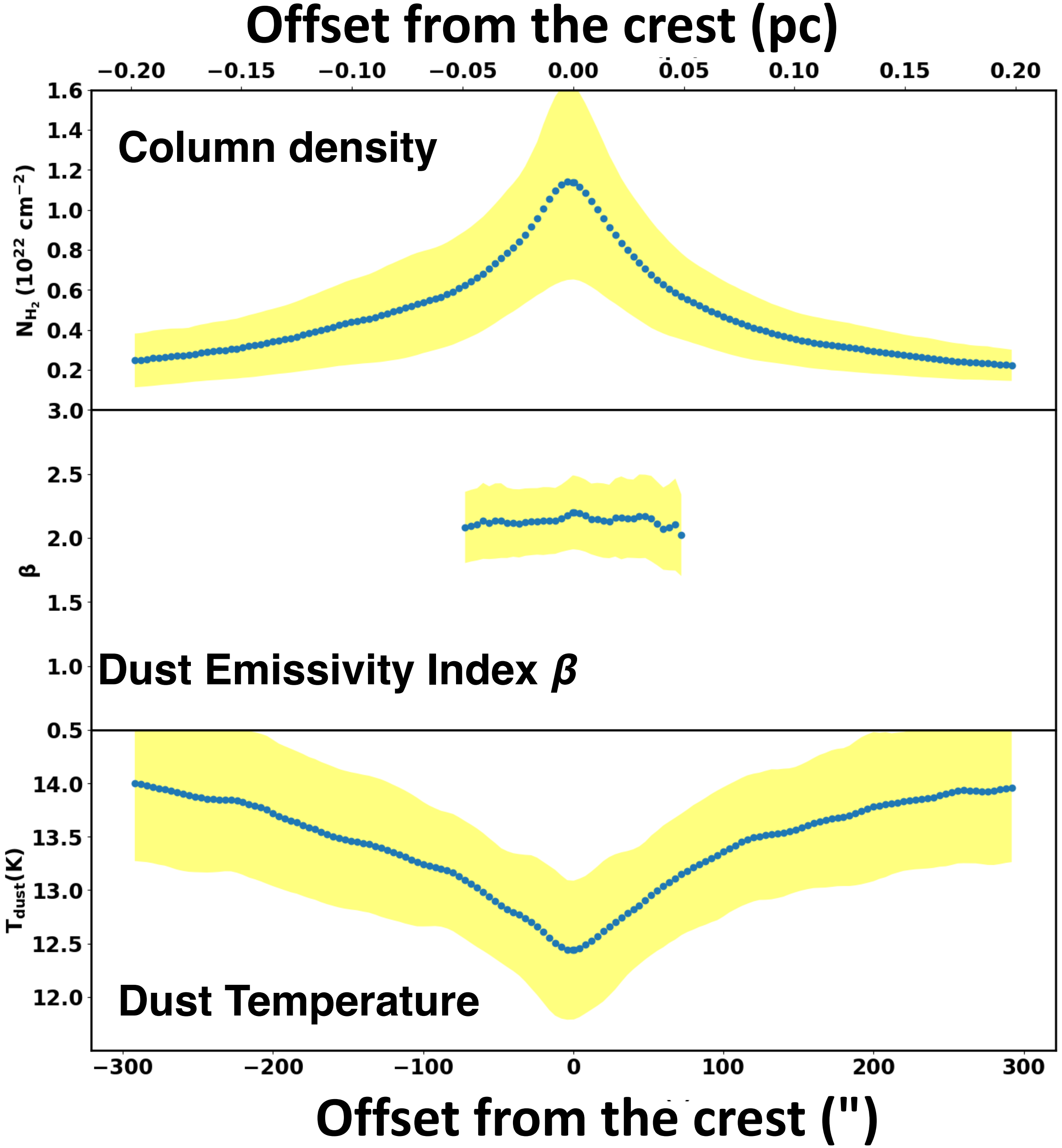

No evidence of significant β variation across the filament, β is constant~2+-0.3

Decline of the Dust Emissivity Index toward the Core Centers: Evidence of Grain Growth in the interior of protostellar cores?

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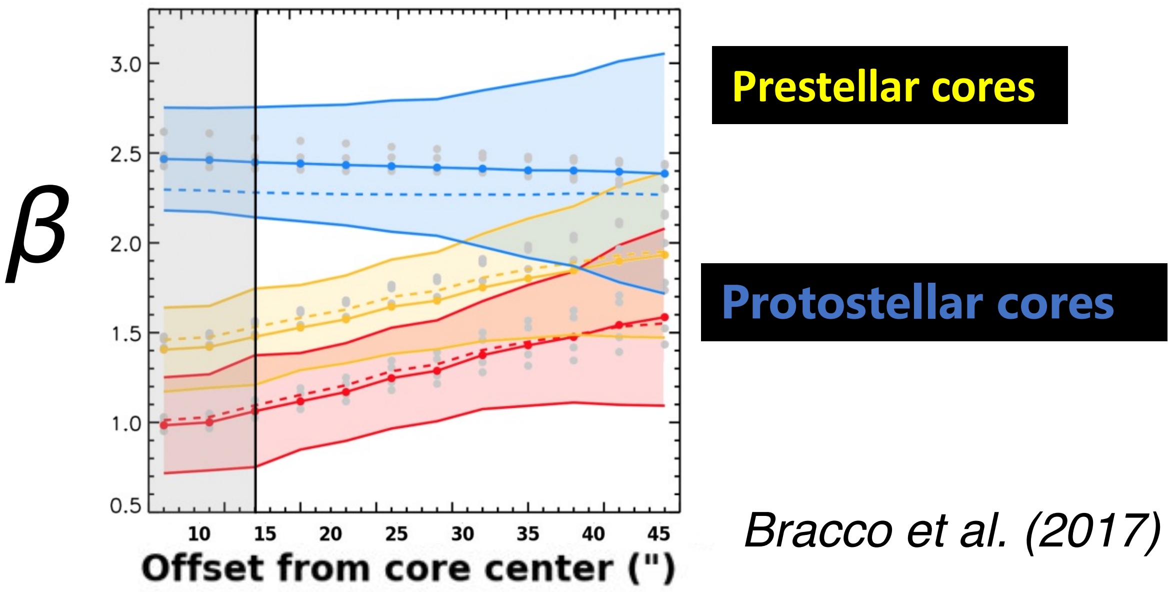
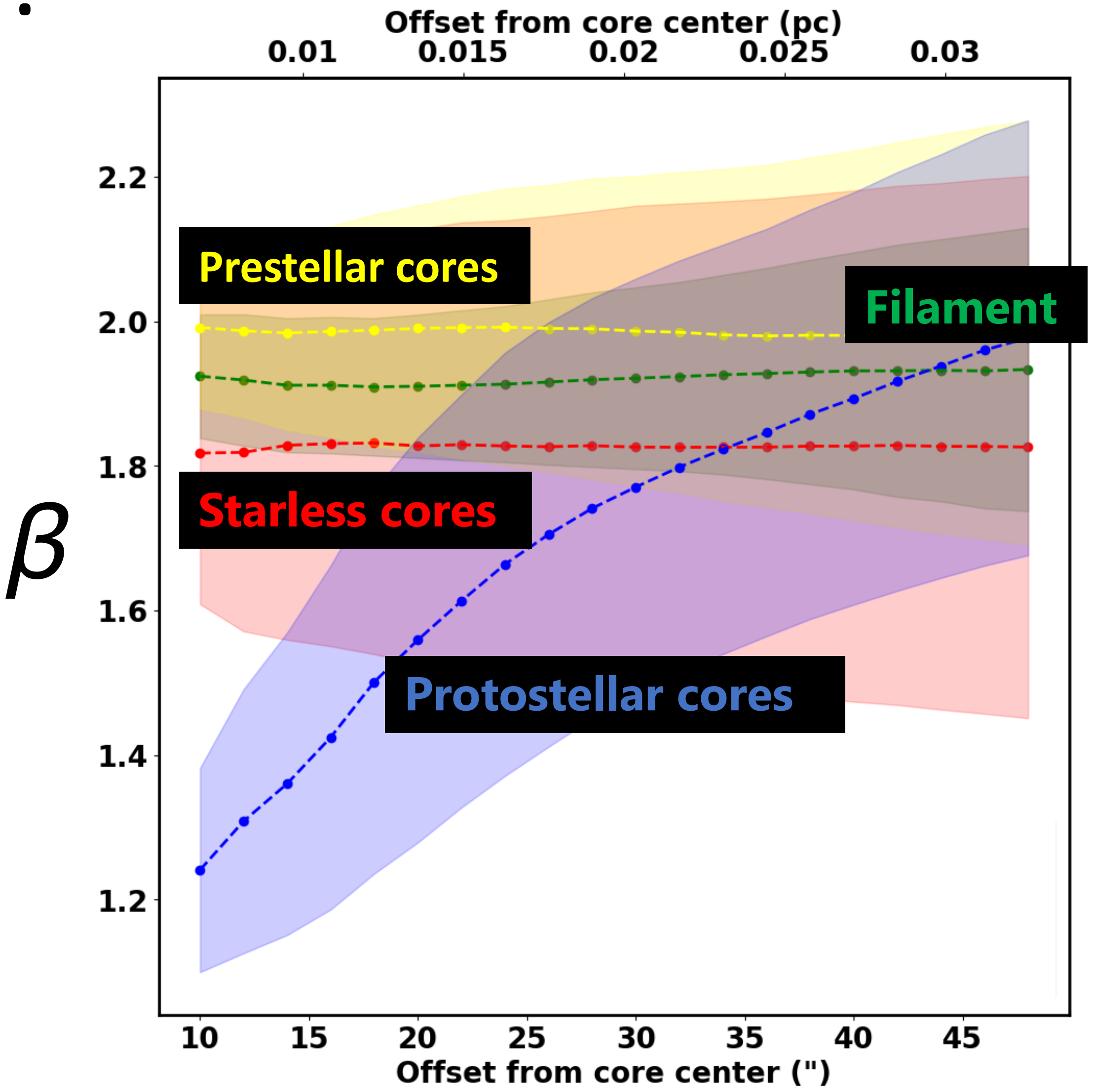
The averaged radial profiles of β within protostellar cores



Bracco et al. (2017)



- The radial profiles of β within protostellar cores show a clear decline inward (~2 outside to ~1.2 inside), consistent with the NIKA1 result of *Bracco et al. (2017)*.
- The radial profiles of β in protostellar core are contrary to that of filament profile.

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Conclusions

Dust Emissivity Index from Dense Cores to T-Tauri Disk
Our sample of 105 objects in the B211/B213 filament region indicates that the dust emissivity index β decreases from filament and prestellar cores **(β~ 2+/-0.5)** to protostellar cores **(β~ 1.2+/-0.2)** to T-Tauri protoplanetary disks **(β <1)**.

Dust Emissivity Index across Filament

The flat **(β~2+/-0.5)** profile of β across the B211/B213 Taurus filament contrasts with the beta profile of protostellar cores which declines inward and reaches a value of <1.2 in the inner part.

Possible Implication
This might imply that dust grains start to grow significantly in size only after the onset of the gravitational contraction/collapse of prestellar cores to protostars, reaching big sizes in T Tauri protoplanetary disks.