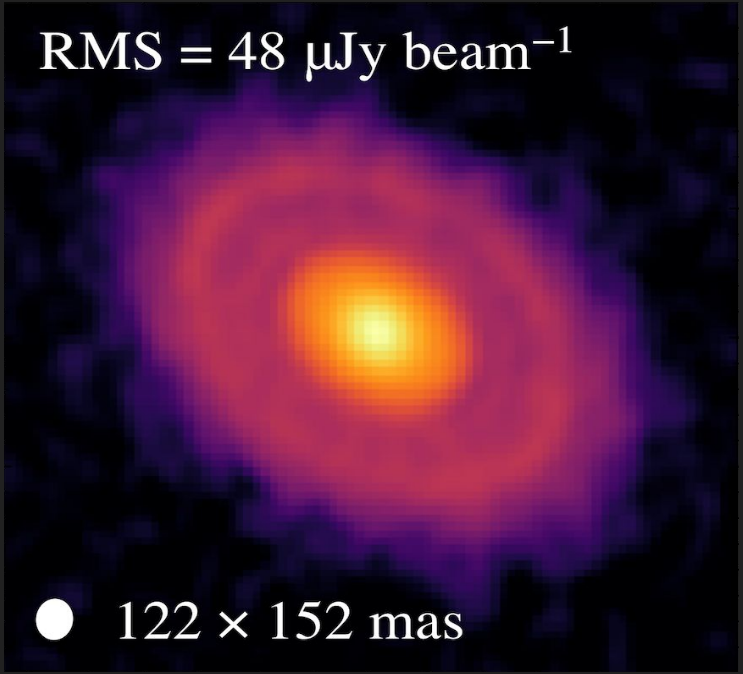
What can super-resolution imaging tell us about substructure origins?

Jeff Jennings (PhD student, IoA Cambridge)



1.33 mm (Band 6, Cycle 4) observations of DL Tau (robust +0.5, Long+18)

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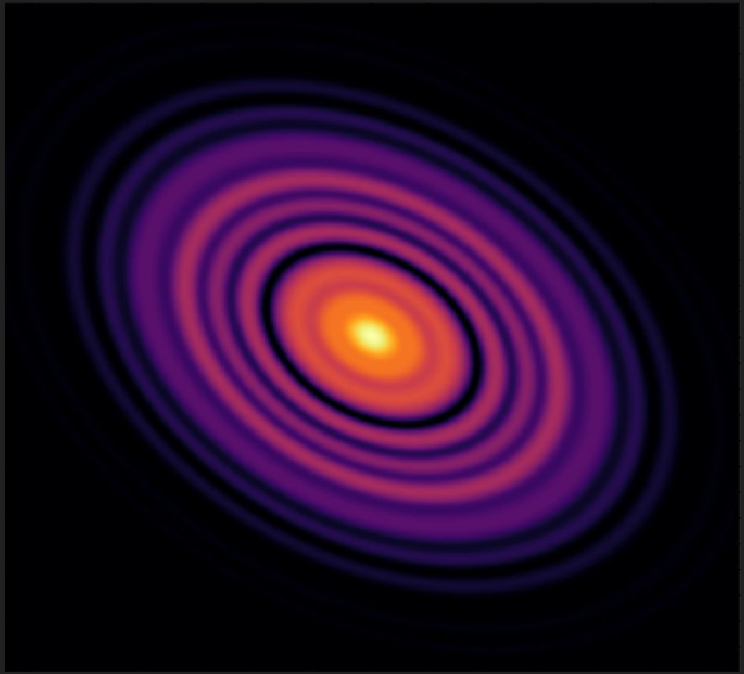


Same data, **1D** frank fit (Jennings+ submitted)

‘Frank Force Five’

Cathie Clarke

Giovanni Rosotti

Richard Booth

Marco Tazzari

Science driver

Overarching Goal:

In a population analysis, image disks to accurately measure substructure morphologies and occurrence rates; use the resulting demographics to constrain the underlying mechanisms.

Science Driver

Challenge:

To image disks, CLEAN has enabled so much.
But it does have limitations: it's procedural, uses an unphysical prior, doesn't operate natively in the data domain, and doesn't sufficiently leverage the long baseline information in modern datasets.

Long baseline information is crucial for substructure inference.

→ There are large gains to be made *on existing data* with imaging methods that can fully recover the information content instruments like ALMA (were built to) deliver.

SUPER-RESOLUTION IMAGING: it's hip to be square

GPUVMEM

Cárcamo+ 18

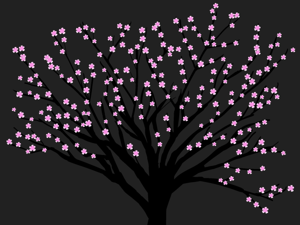
Python Module for Radio Interferometry Imaging with Sparse Modeling (PRIISM)

Nakazato+ 20

(see also EHT Collaboration+ 19)

Million Points of Light (MPoL)

Czekala+ 21 (Zenodo, v0.1.1)



galario

Tazzari+ 18

FRANKENSTEIN

Jennings+ 20

SUPER-RESOLUTION IMAGING: FRANKENSTEIN

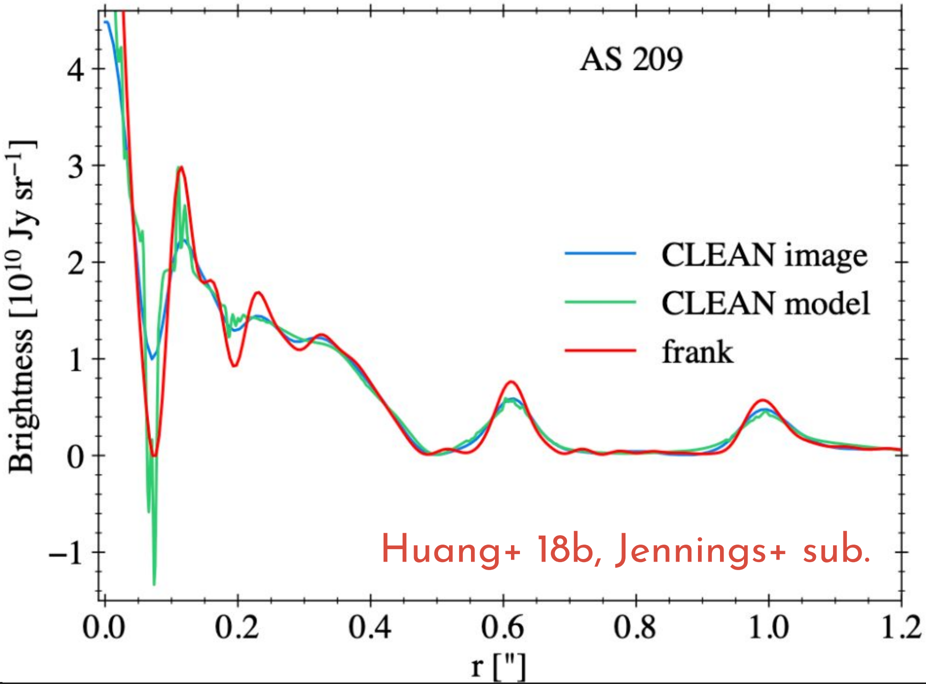
The flux reconstructor

frank OVERVIEW:

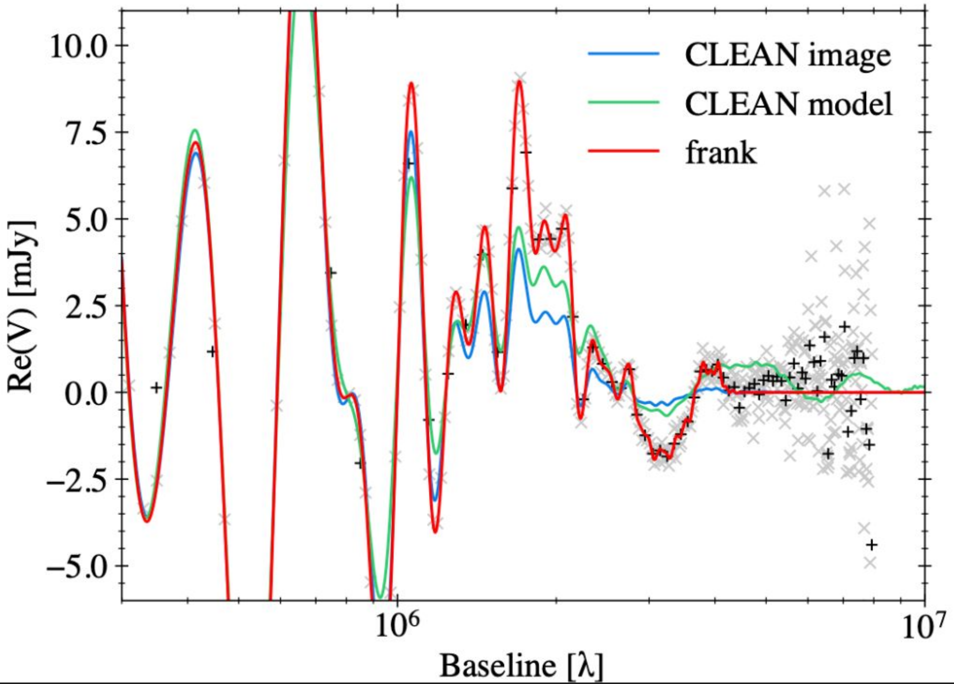
- 1D model (currently) to fit a brightness profile (so far applied to the continuum)
- Nonparametric (models the profile as a sum of Bessel functions), regularized by a nonparametric Gaussian process
- Quick (fits in 1 minute, in 1 line on terminal)
- Open source

Super-resolution imaging: why it works

In the data space, accurately recovers structure to longer baseline than the FT of the CLEAN image (and the CLEAN component model)



Huang+ 18b, Jennings+ sub.



→ Comparing models to the data is a useful step in imaging.

SUPER-RESOLUTION IMAGING: how well it works

FRANKENSTEIN

frank PERFORMANCE:

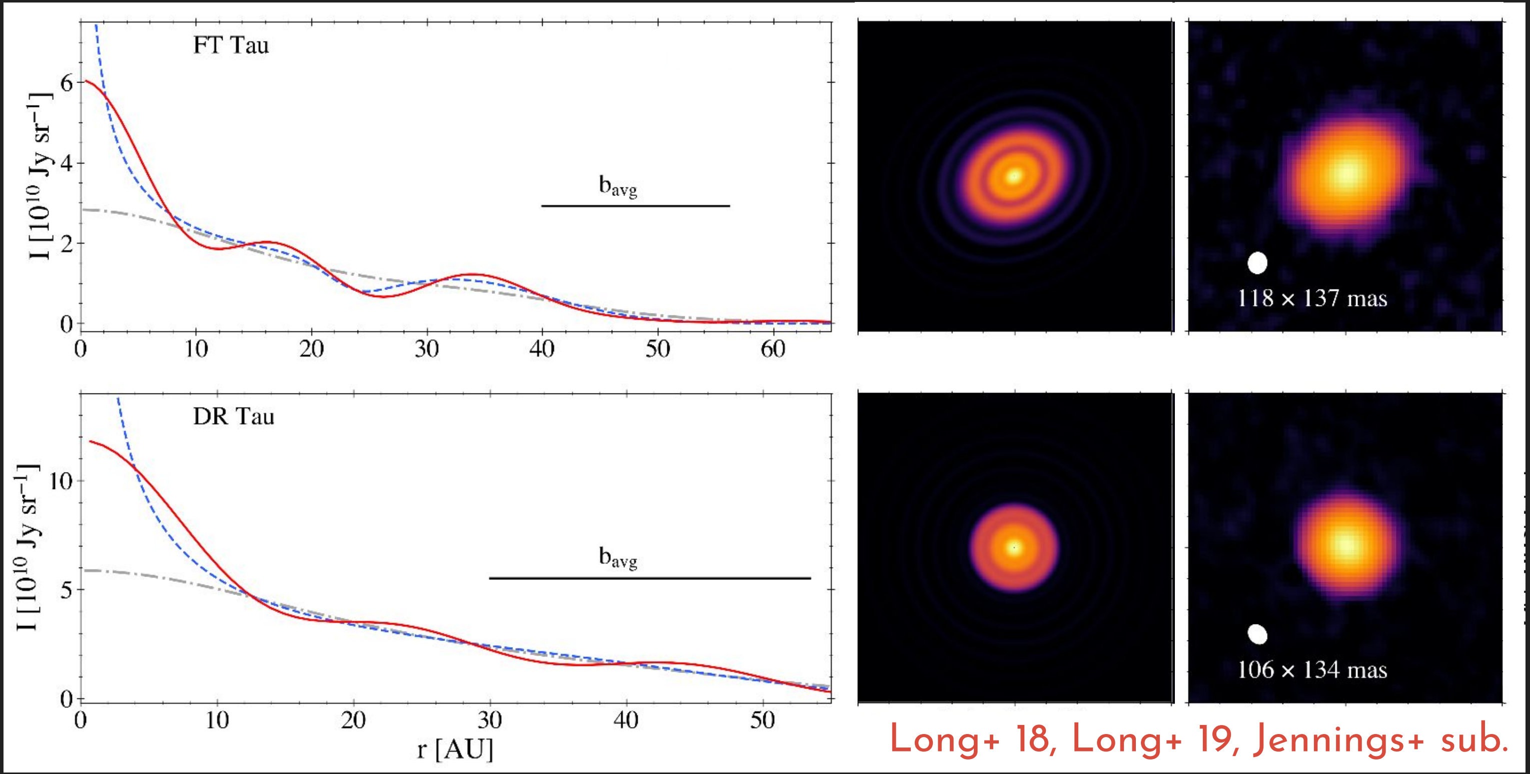
- Fits 1D visibilities accurately to an average factor of 4 (3) longer baseline than the FT of a CLEAN image (model)
- Maintains this advantage across observational resolution (e.g., from 35 mas in DSHARP to 120 mas in Taurus)
- Better resolution than uniform weighting, with sensitivity of natural weighting

SUPER-RESOLUTION IMAGING: science driver

OVERARCHING GOAL:

In a population analysis, super-resolve disk images to accurately measure substructure morphologies and occurrence rates; use the resulting demographics to constrain the underlying mechanisms.

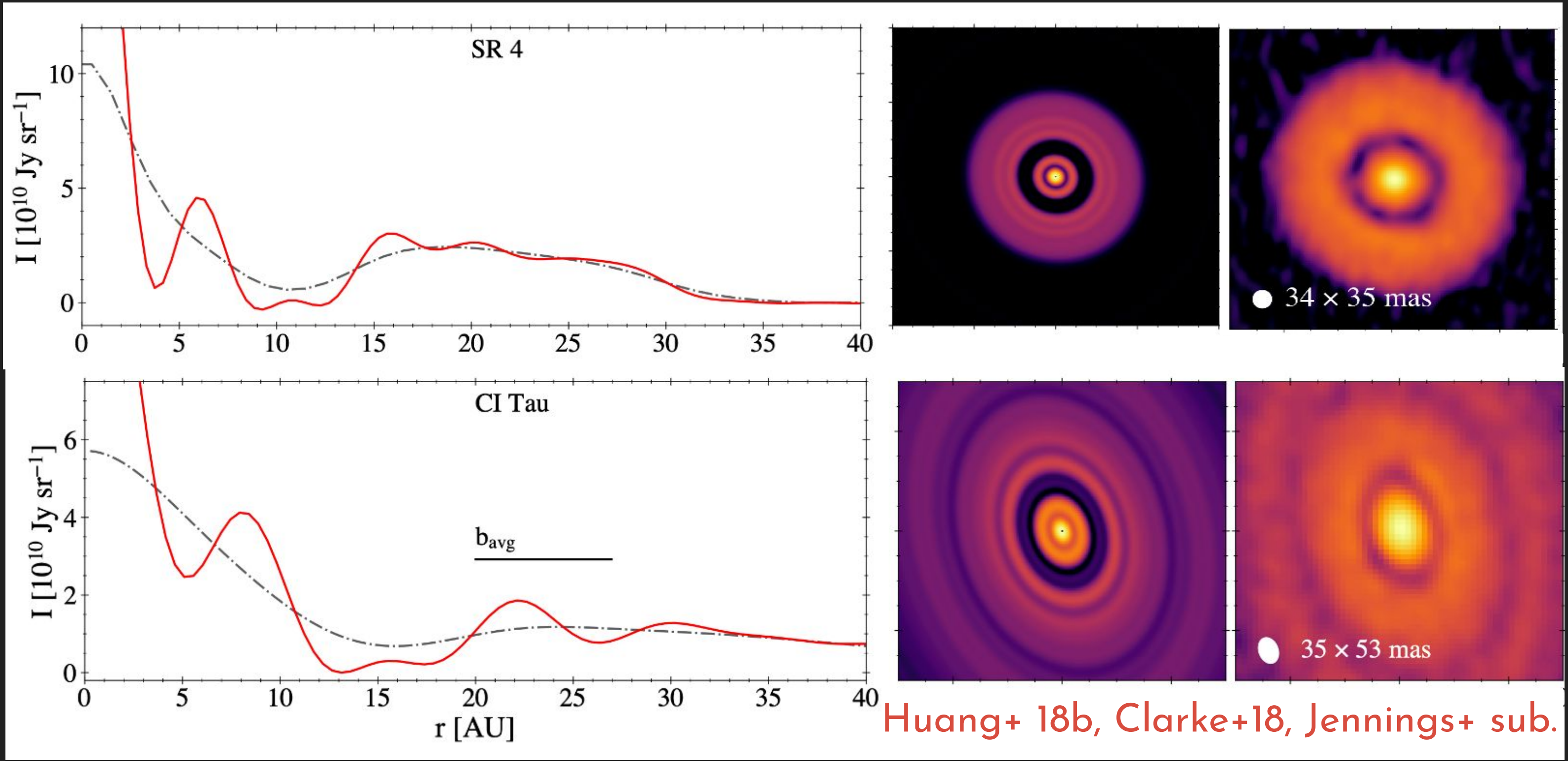
SUPER-RESOLUTION TRENDS: compact disks



Long+ 18, Long+ 19, Jennings+ sub.

Many compact disks appear smooth because of *model* resolution.

Super-resolution trends: compact disks

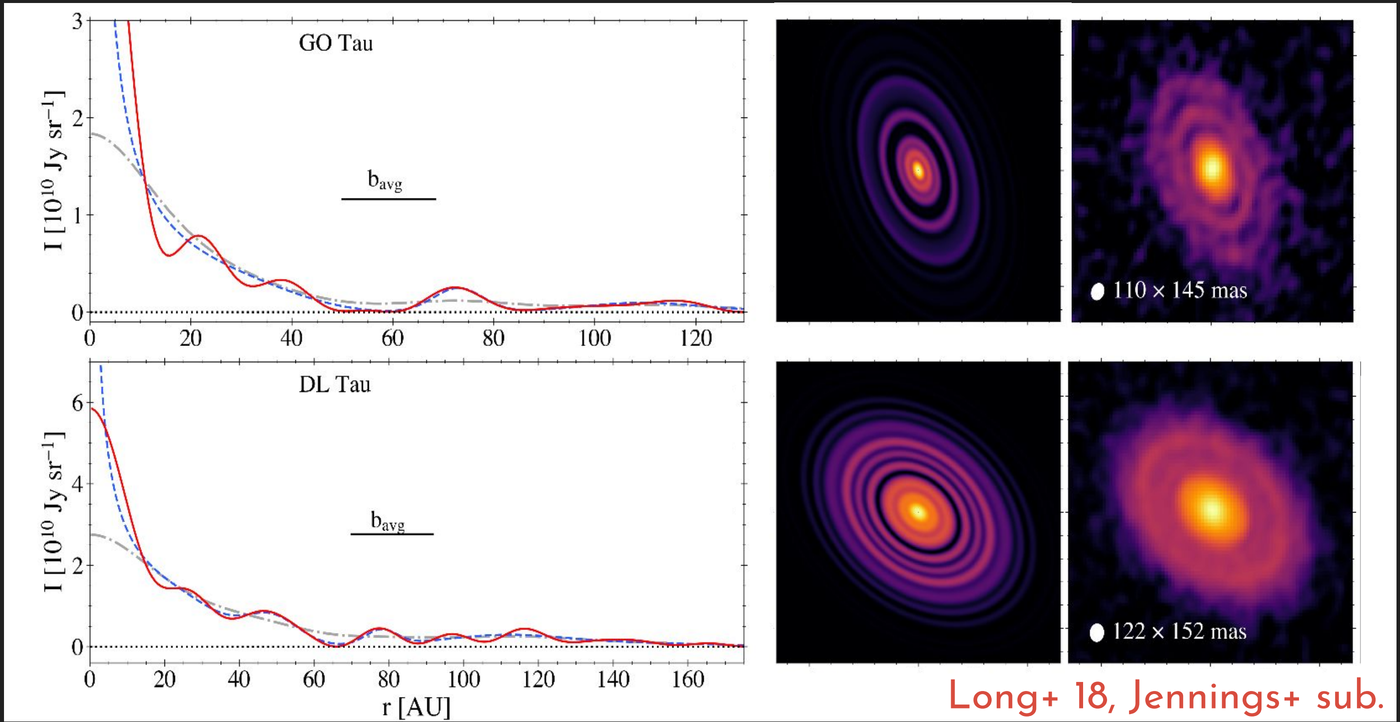


Huang+ 18b, Clarke+18, Jennings+ sub.

Substructure on ≳au scales could be common in compact disks.

→ Same evolution as extended disks?

Super-resolution trends: inner disks

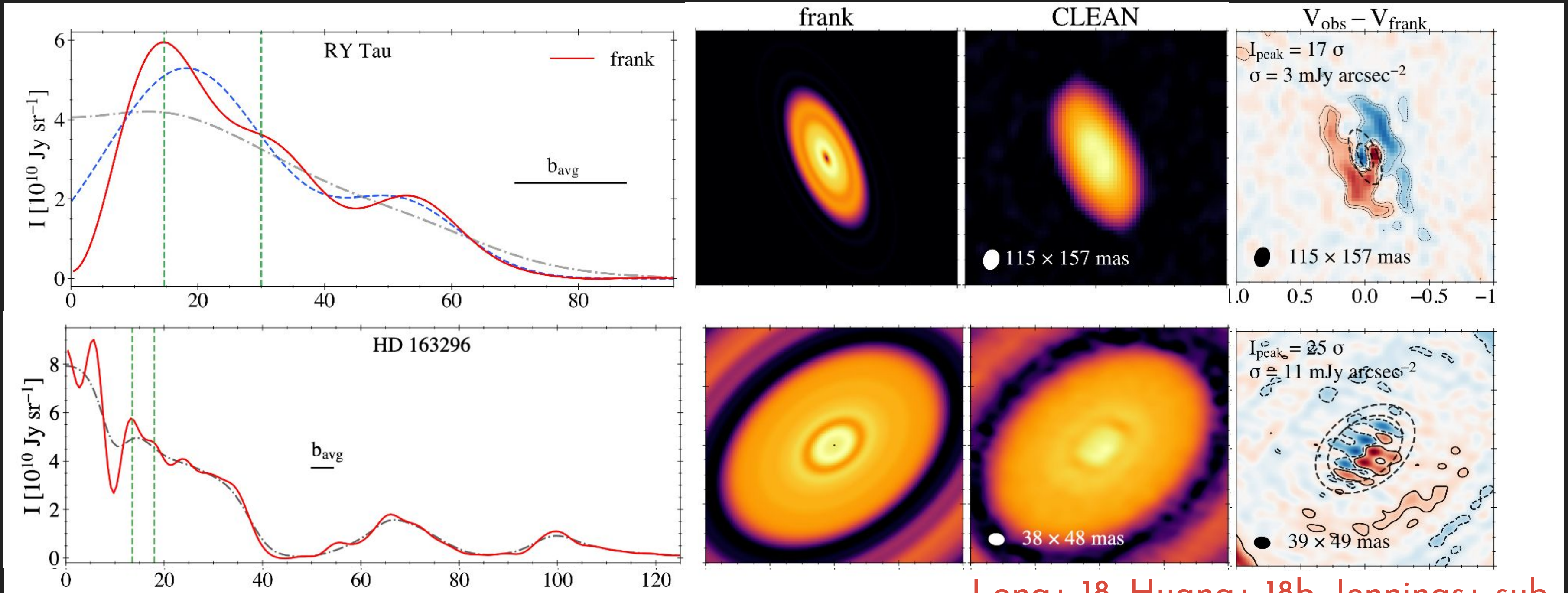


Long+ 18, Jennings+ sub.

Super-resolution fits find ~every disk ring – even in ≲35 mas observations – to be narrower and of higher contrast than in the CLEAN images.

→ At what scale (say, in [H_p]) do features resolve out?

Super-resolution trends: 'shoulders'



Long+ 18, Huang+ 18b, Jennings+ sub.

Shoulder exterior to a deep gap in the inner disk or an apparent cavity:
4 in DSHARP, 3 in Taurus, several others (e.g., GM Aur; Huang+ 20).

→ Common physical origin? (e.g., migrating planet)

NEXT STEPS: science

Characterize many tens of disks at super-resolution scales.

- Apply to archival disks that can be super-resolved on ≲30 au scales -

↓

Identify morphological trends.

- Build a super-resolution census of this large (less biased) disk sample -

↓

Constrain substructure origins.

- Compare trends to theory/simulations and complementary tracers -

Thanks!

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