Far-Infrared Luminosity Bursts Trace Mass Accretion onto Protostars

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Protostars reveal the origins of solar systems

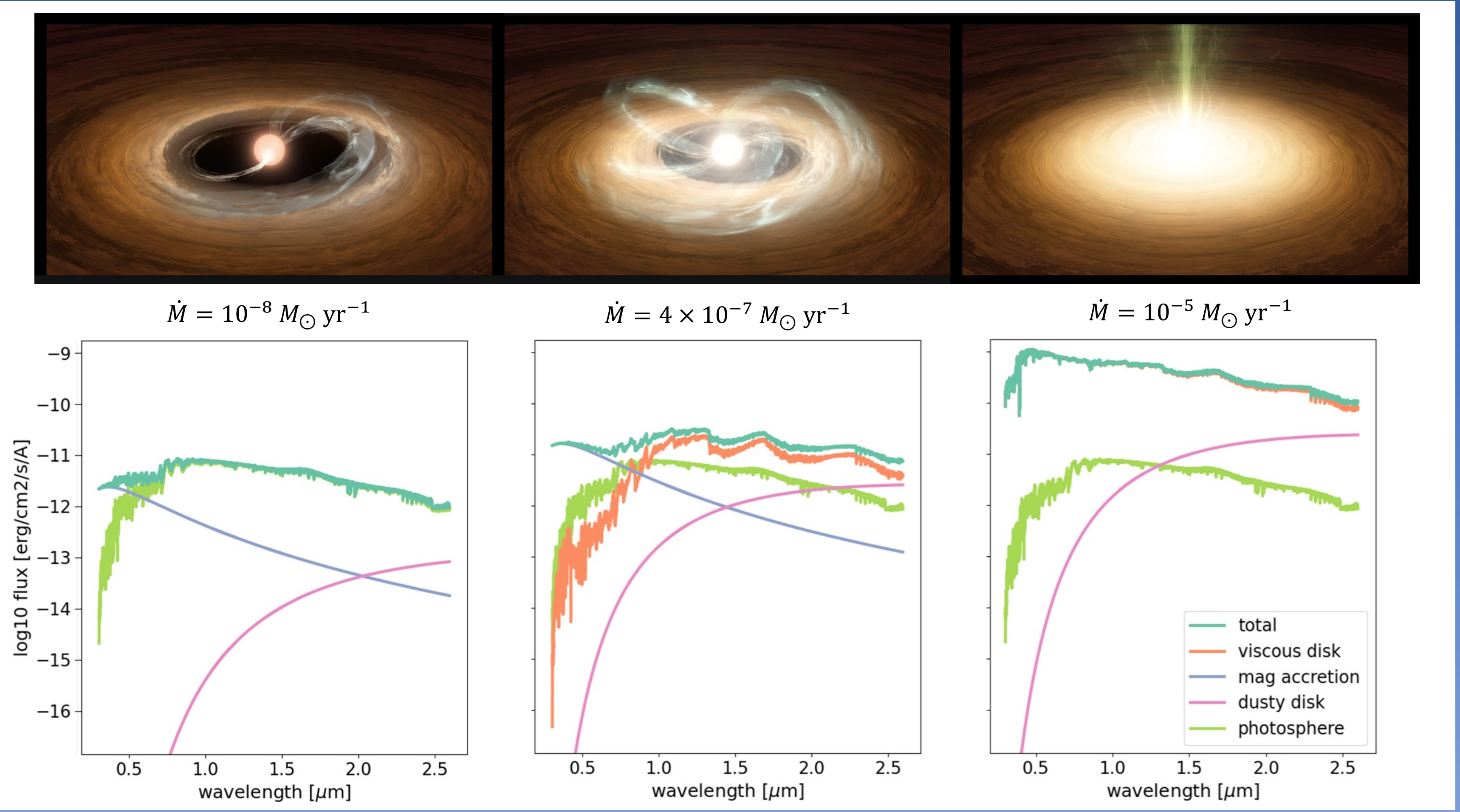
Herbig-Haro Jet HH 24

NASA and ESA • *Hubble Space Telescope* • WFC3/IR • WFPC2 • STScI-PRC15-42a

- A dense, infalling circumstellar envelope is still present
- Outflows are clearing the envelope
- A protoplanetary disk has formed
- The majority of the stellar mass is assembled
- Lifetime: ~ 0.5 Myr

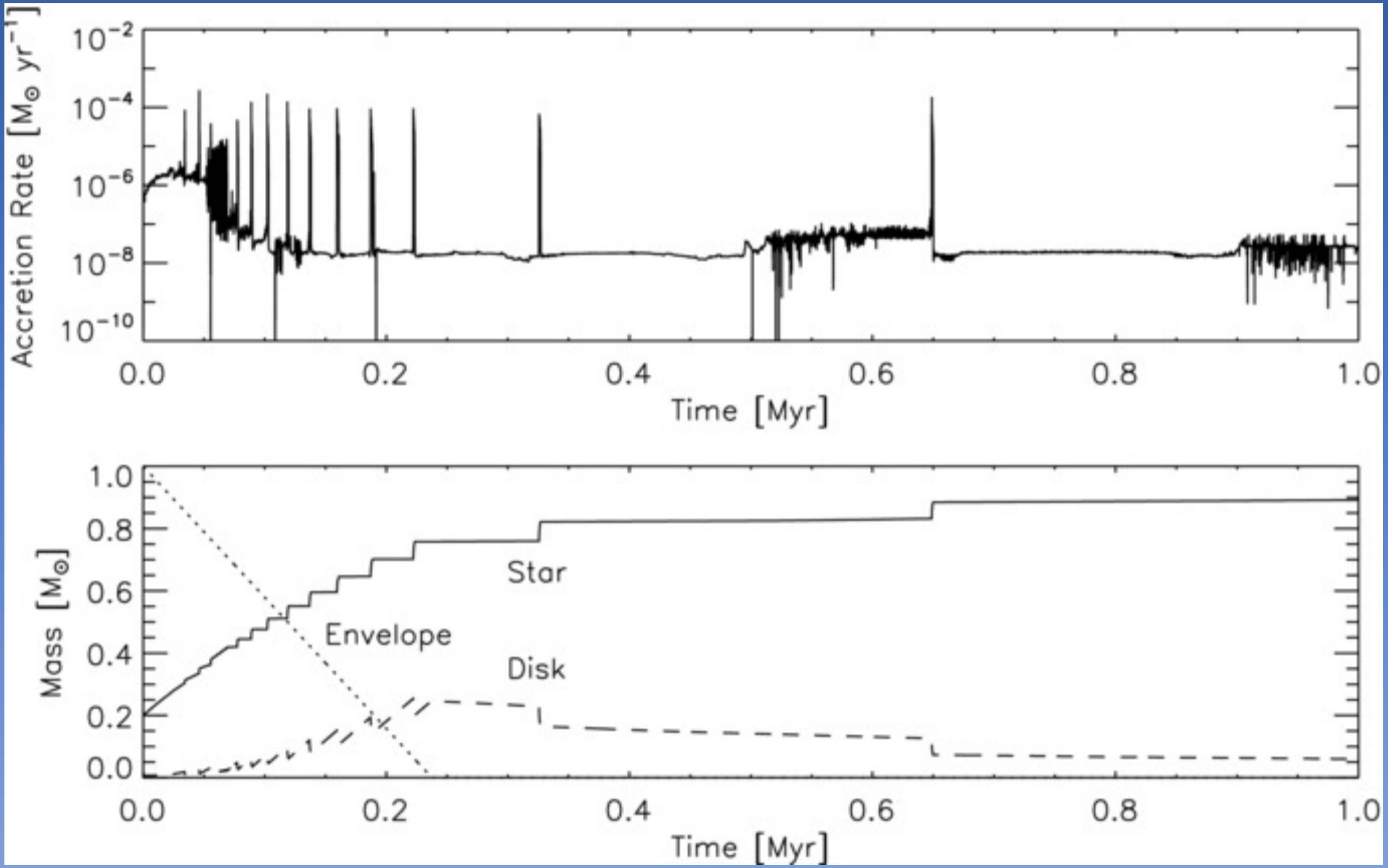
Variability: a guide to stellar mass assembly

- Variability has many causes (extinction, rotation, etc.)
- Broadband luminosity changes are due to changes in the accretion rate
- These changes tell us how the star gains mass



Art by T. Pyle (Caltech/IPAC)
Models from Liu et al. (2022)

Variability can be gradual or sudden

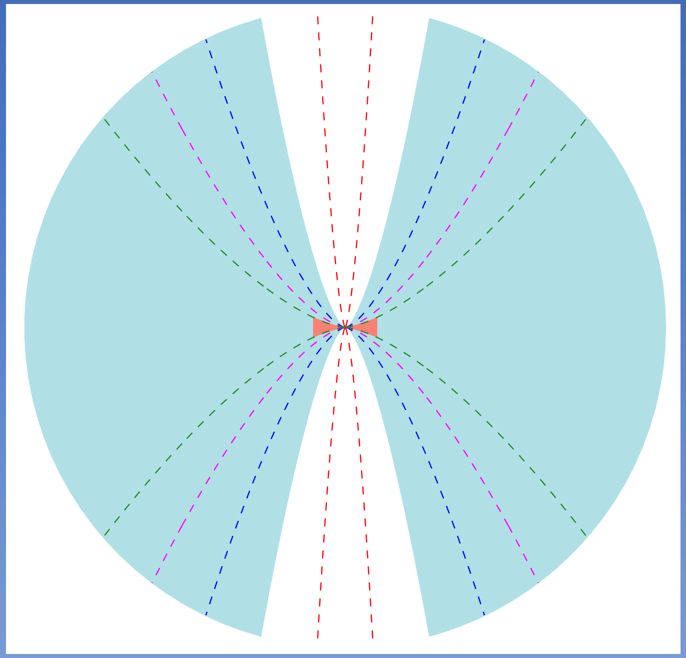


One model of the evolution of accretion rate and stellar mass (Bae et al. 2014)

- There are several types of accretion variability
  - Long-term declines in luminosity as the envelope depletes
  - Short-term low-amplitude changes
  - Sudden, short-lived bursts
- Which of these are most important for mass assembly?

Tracking mass assembly with SED modeling

Furlan et al. (2016) fit the SEDs of 319 Orion protostars with models generated by the code of Whitney et al. (2003)

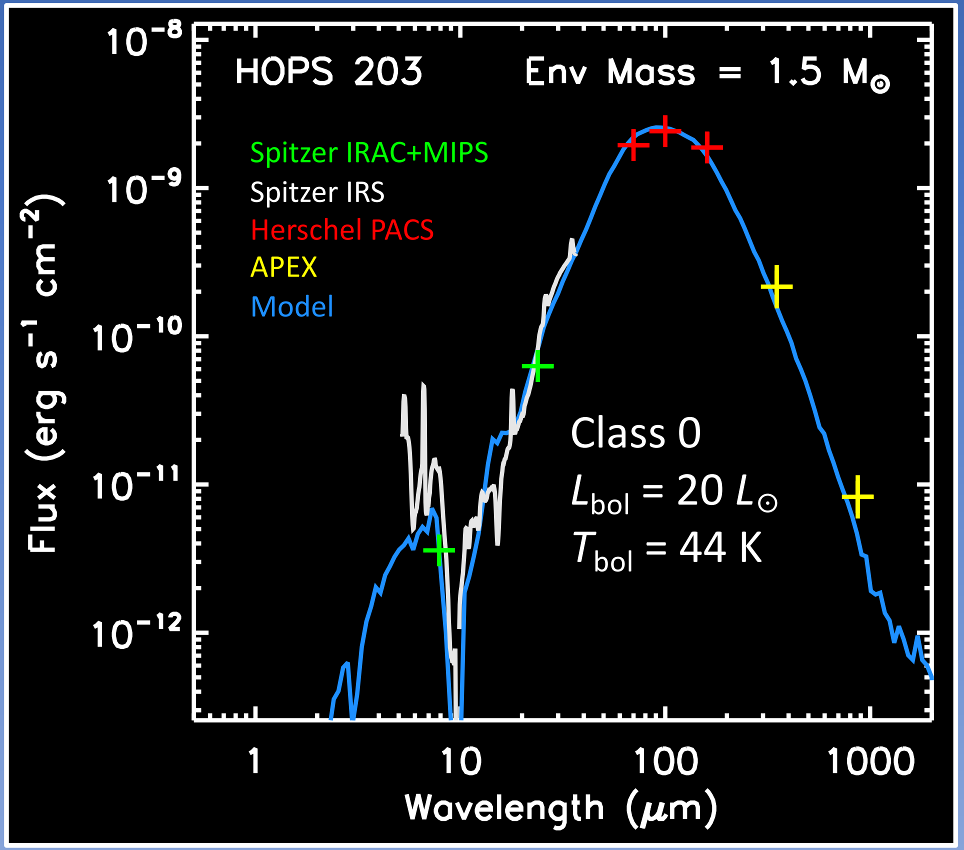


Model has a star, disk, envelope, and cavity

Main parameters

- Total luminosity
- Envelope density
- Cavity opening angle
- Inclination angle
- Foreground extinction

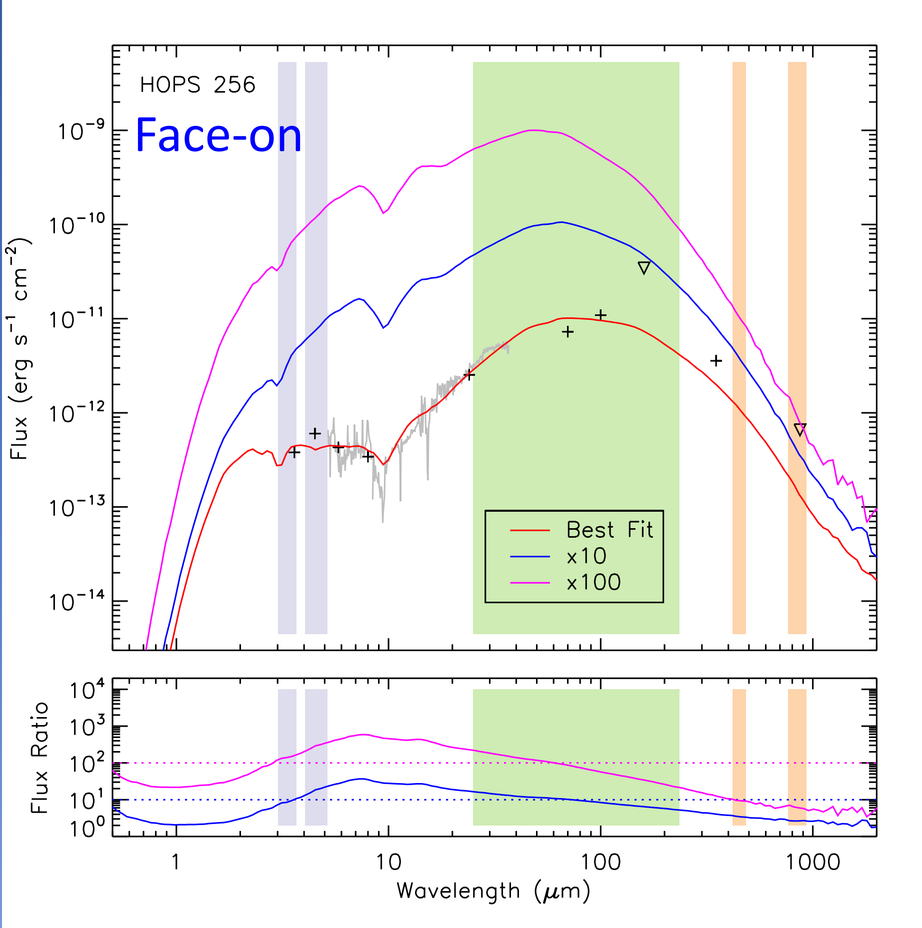
For Class 0 protostars (the least evolved numerical class), SEDs peak in the far IR



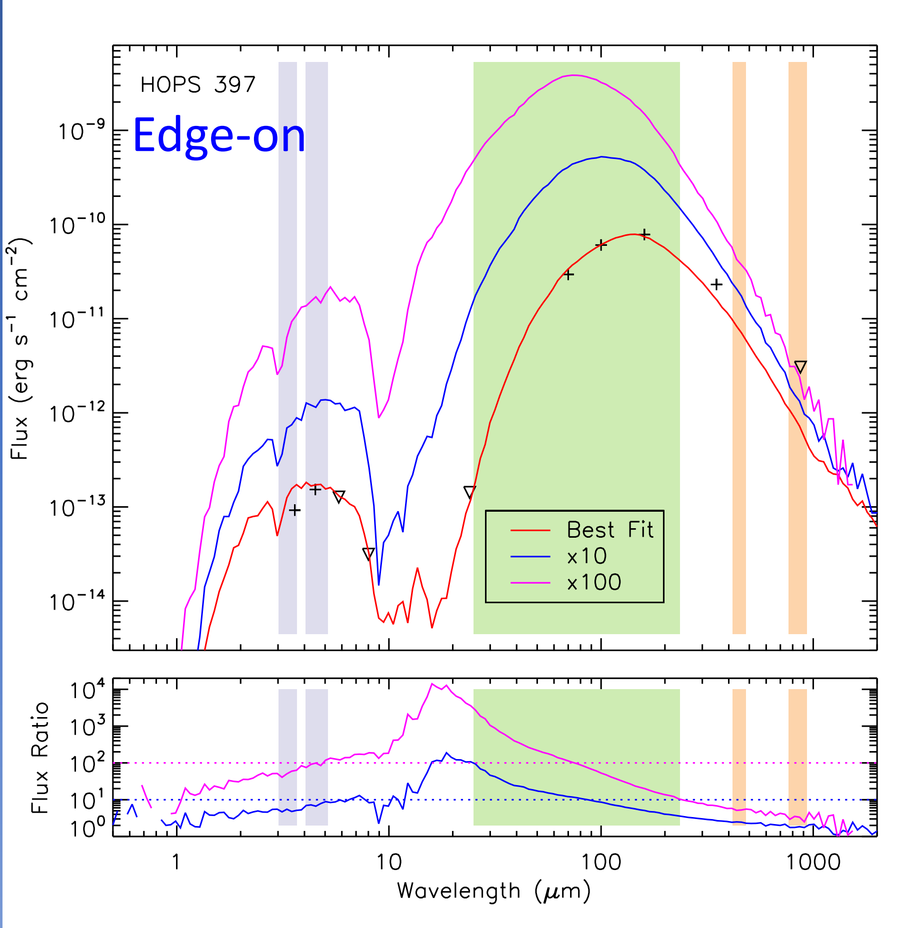
SED and model from Furlan et al. (2016)

The far IR robustly tracks changes in luminosity

- For 86 Class 0 protostars in the Furlan et al. (2016) sample, we simulated accretion bursts by turning up the luminosity of the best-fit model
- Evaluated the effect at
  - 3.4 and 4.6 µm (NEOWISE)
  - 25 – 235 µm (FIR probe)
  - 450 and 850 µm (JCMT)



- Mid-IR change is too large
- Sub-mm change is too small
- Far-IR change is just right



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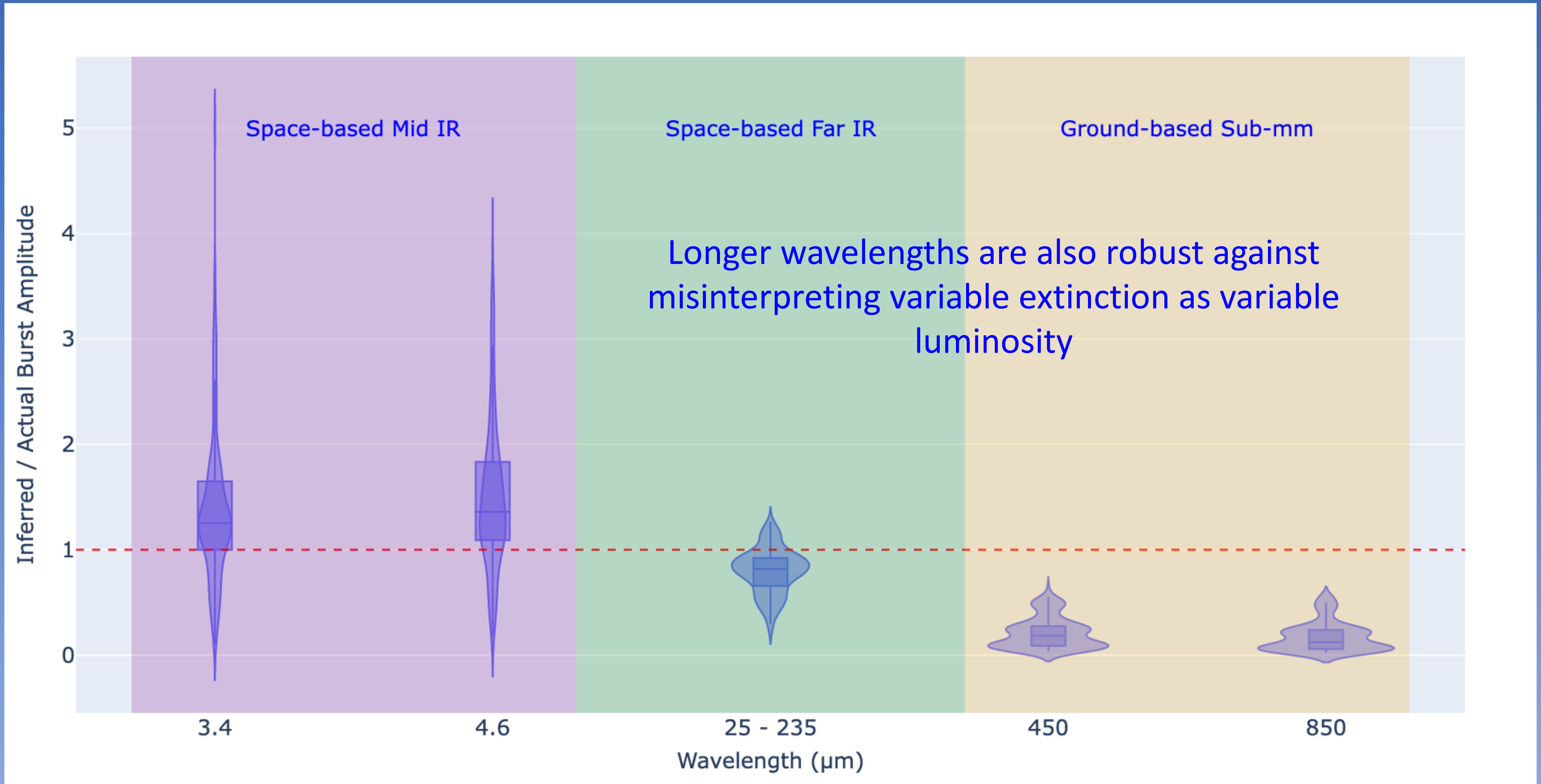
The far IR robustly tracks changes in luminosity

- In each wavelength range, measure the model flux change. This is the *inferred* burst amplitude.
- Compare this to the *actual* burst amplitude known from modeling

Mid IR: spreads are broad

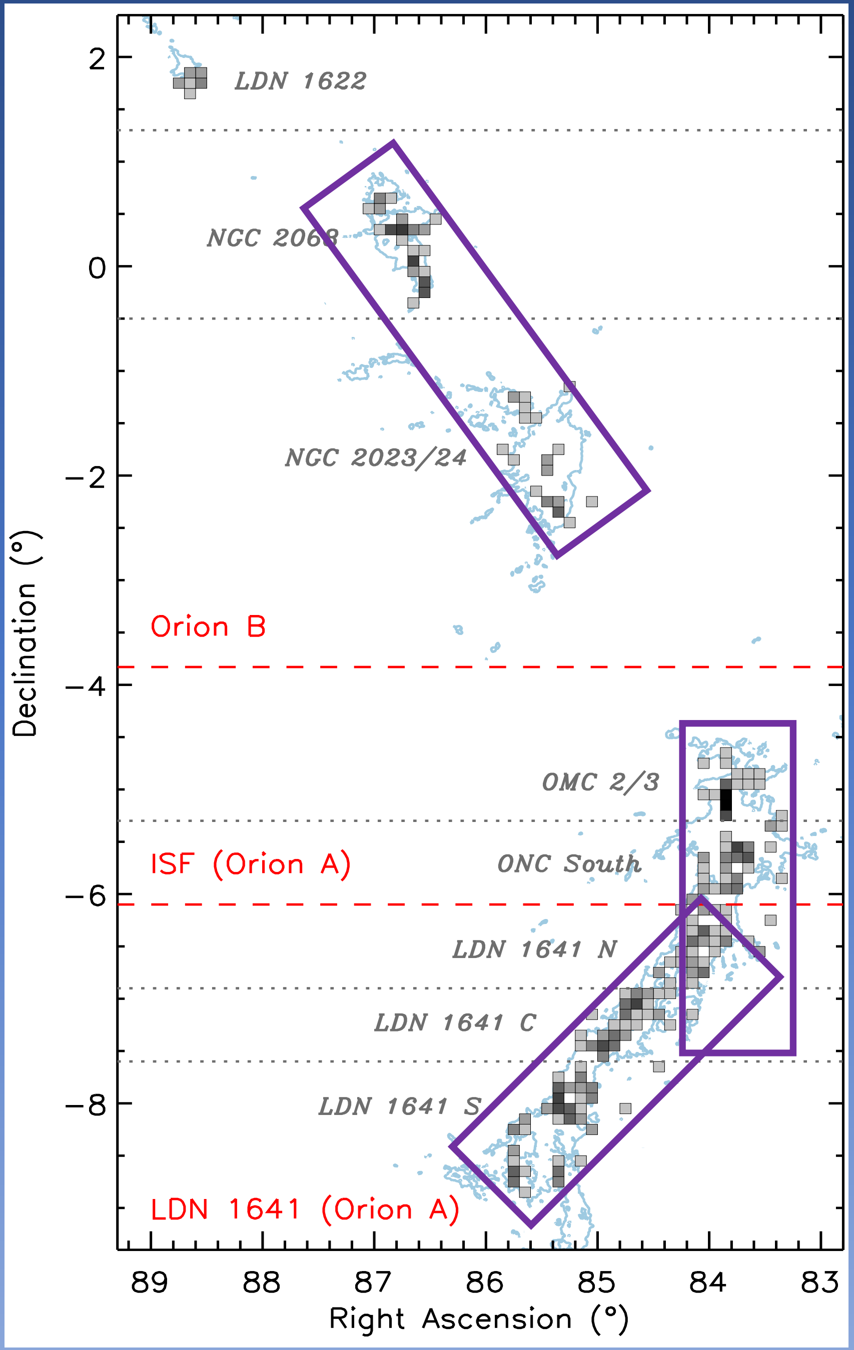


Sub-mm: amplitudes are underestimated

Far IR: tighter spreads, more reliable estimates of amplitudes

Time-domain survey

- Mapping speed is key: repeatedly image about 2000 protostars in the nearest 1.5 kpc
  - ~55 deg^2 of molecular clouds (Cygnus X, Orion, Mon R2, Aquila, Perseus, etc.)
- Long maps are most efficient since protostars lie along filaments
- Multiple visits per year
  - Sample a range of timescales from ~8 wks to the full multi-year mission
  - Combine with Herschel (~2010) to extend Δt to 25 yr
  - Explore structure in light curves to constrain physical mechanisms



Example: Mapping Orion (~10 deg^2)

Blue contours: 500 µm Herschel map (Stutz & Kainulainen 2015)

Gray boxes: Locations of 319 protostars (darker boxes contain more; Fischer et al. 2020)

Purple boxes: Plausible mapping areas

For further information

- **Far-Infrared Luminosity Bursts Trace Mass Accretion onto Protostars**, William J. Fischer, Cara Battersby, Doug Johnstone, Rachel Lee, Marta Sewiło, Henrik Beuther, Yasuhiro Hasegawa, Adam Ginsburg, & Klaus Pontoppidan, 2024, AJ, in press
- **Modeling Protostellar Accretion Variability in Stellar Mass Assembly using Monte Carlo Simulations**, Rachel Lee, Cara Battersby, Doug Johnstone, William J. Fischer, Henrik Beuther, Yasuhiro Hasegawa, Marta Sewiło, & Klaus Pontoppidan, in prep