JCMT Transient Survey

Results and update

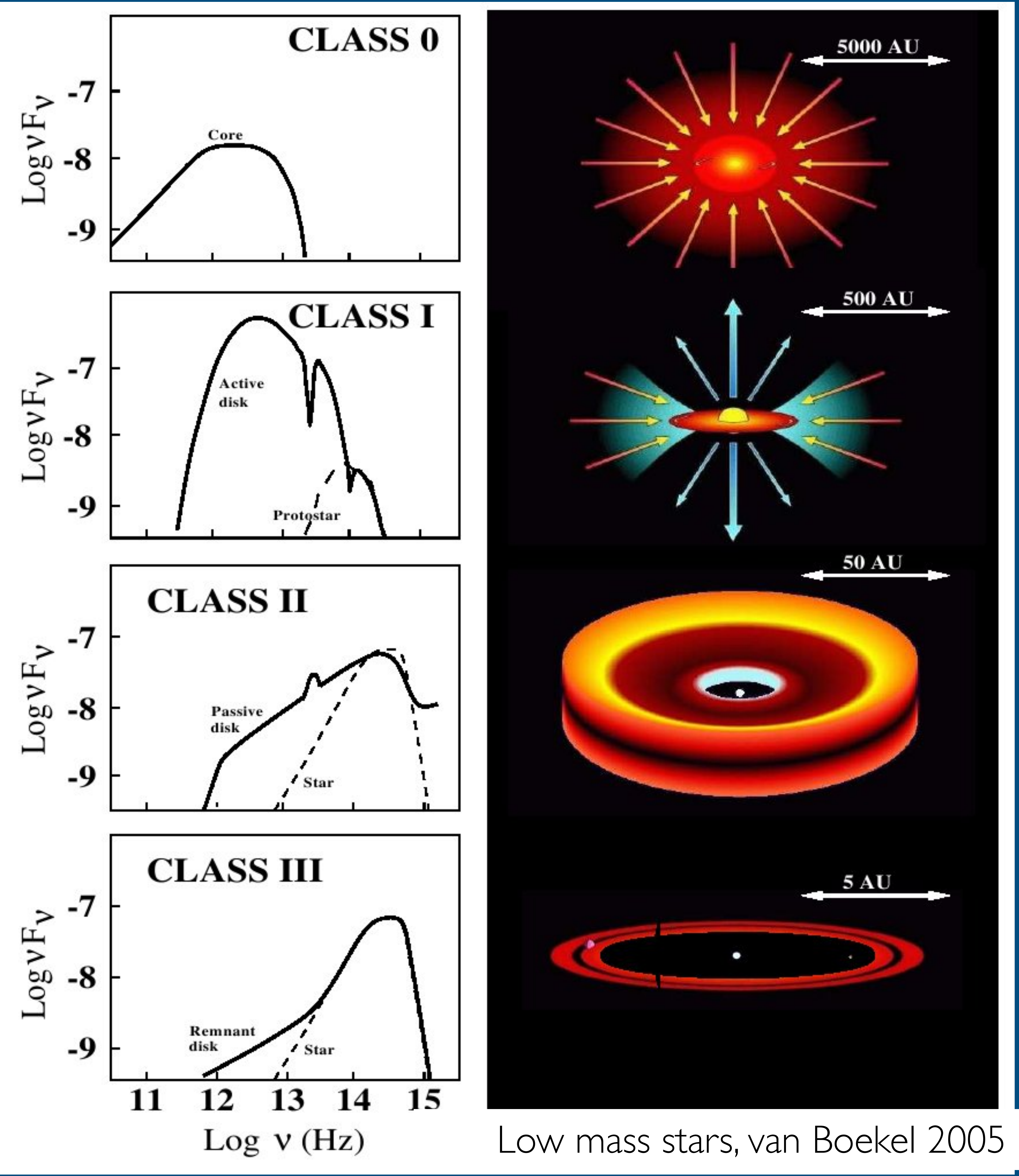
Carlos Contreras Pena (SNU/KHU), JCMT users meeting, 24 February 2022

The East Asian Observatory JCMT-Transient Survey: How do stars gain their mass?

D. Johnstone, J-E Lee, Herczeg

Other coordinators: Aikawa, Bower, V. Chen, Hatchell

Steve Mairs (SOFIA), Yong-Hee Lee (KHU), Carlos Contreras Pena (SNU), Giseon Baek (KHU), Wooseok Park (KHU), Ben MacFarlane (Lancashire), Graham Bell (EAO), Bhavna Lalchand (NCU), and many others



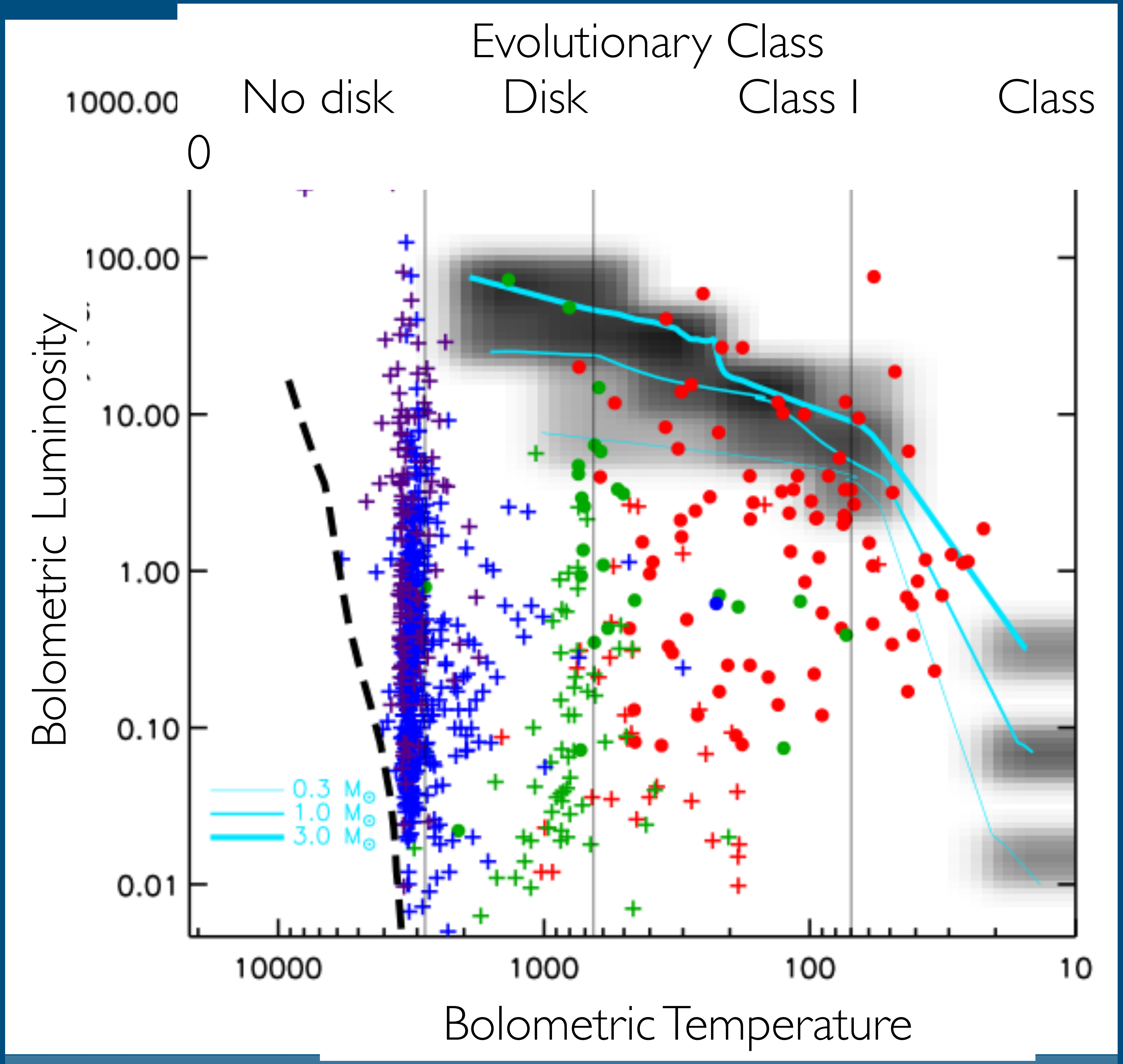
Low mass stars, van Boekel 2005

Protostars:
~few 10^5 yr
Stellar growth

Disks
~few 10^6 yr
Planet formation

Luminosity Problem

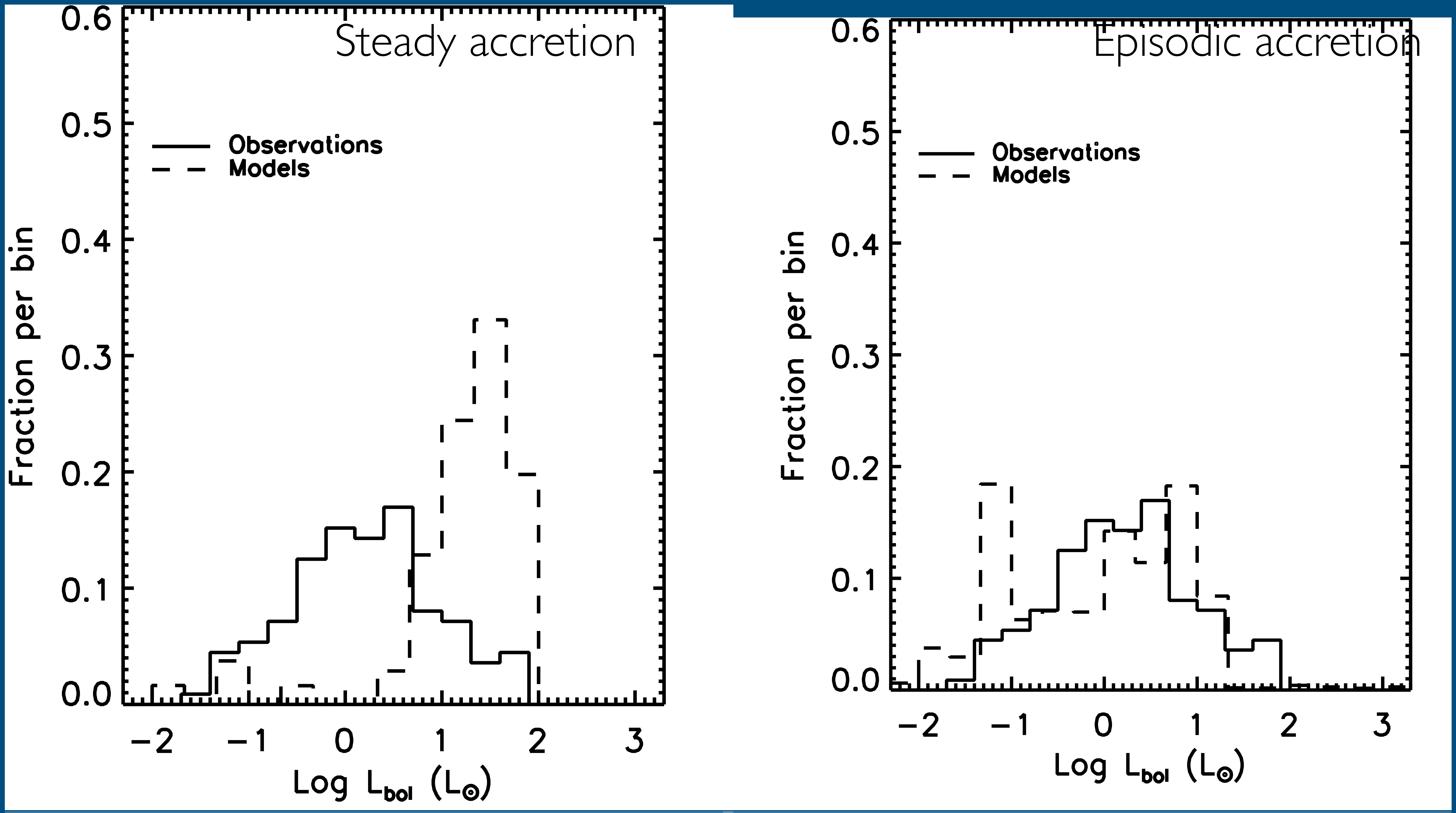
(Kenyon et al. 1990; Dunham et al. 2010)



Classical infall models: shaded region

Episodic bursts of accretion?

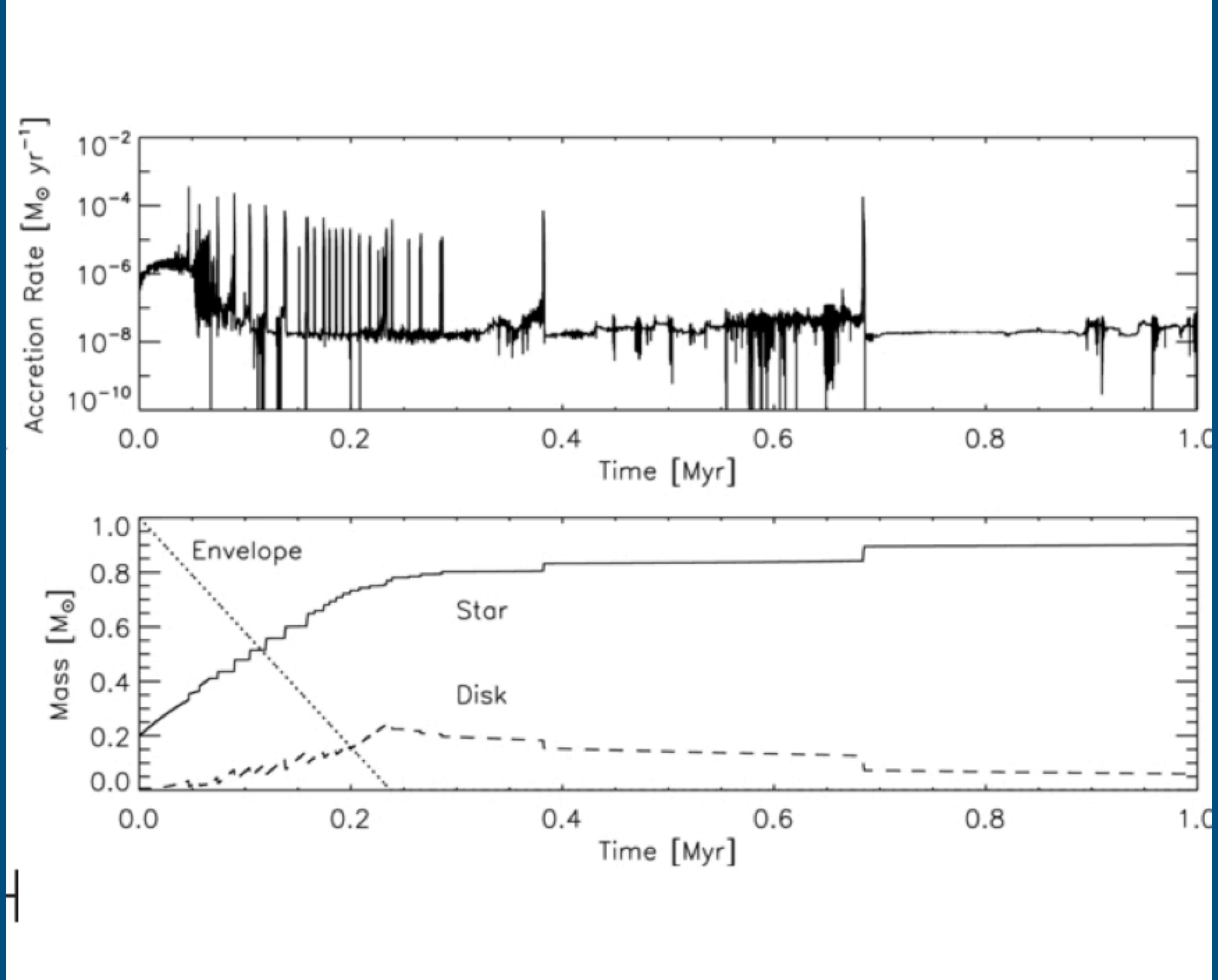
(Kenyon et al. 1990; Dunham, Evans, et al. 2009)



Stars spend most of their lifetimes in quiescent state and gain most of their mass during short-lived accretion bursts (Kenyon et al. 1990, Evans 2009).

Time dependence needed; episodic accretion is likely (but not only) solution (e.g., Offner & McKee for different assumptions; Fischer+2017 for exponential decay)

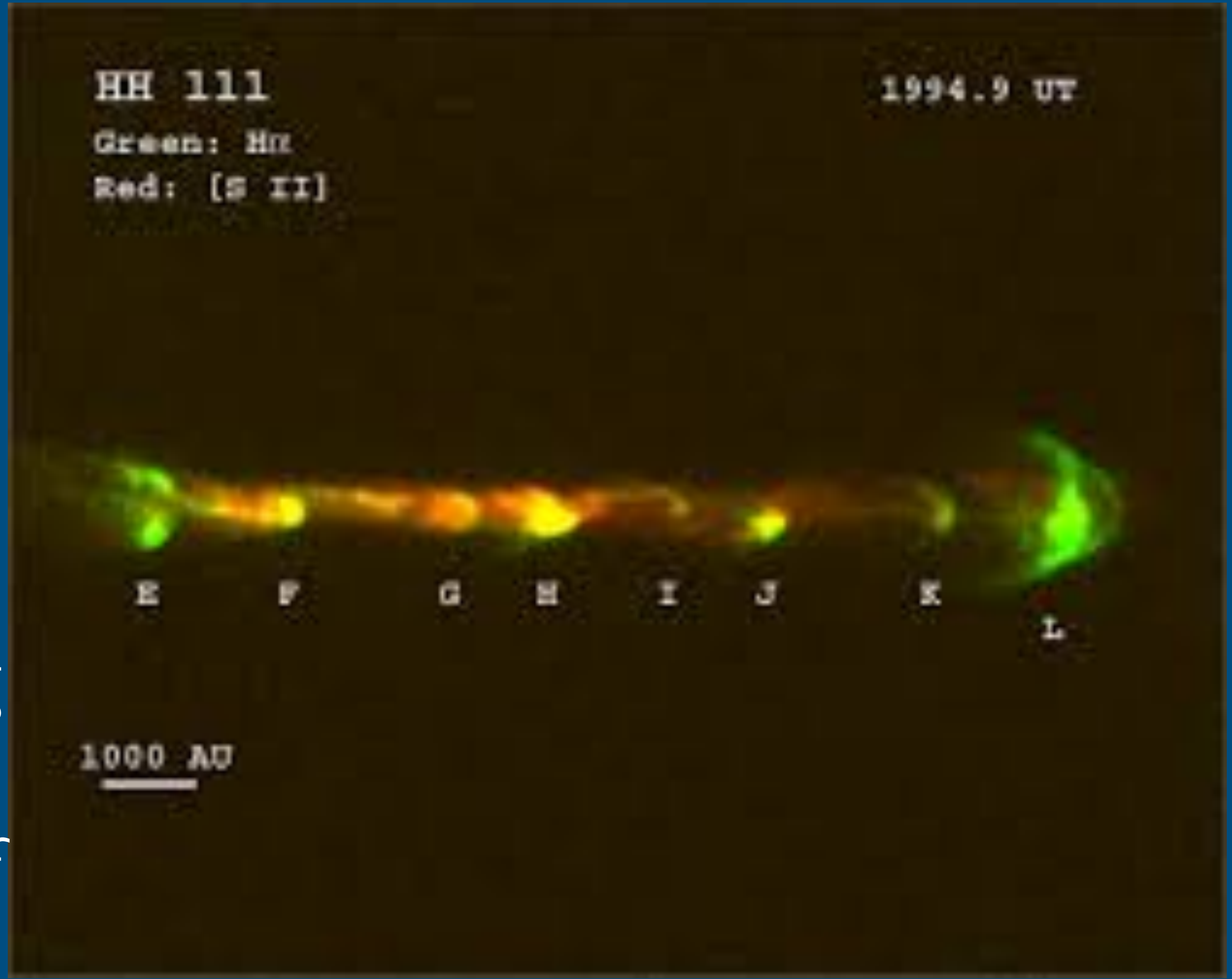
Evidence of bursts at young ages



Zhu+2010; Bae+2014

The physical mechanisms that are brought forward to explain the transport of material through the disc are unable to do so at the rate expected from infall and are likely to produce outbursts of rapid mass accretion (e.g. Zhu et al. 2009, Dunham & Vorobyov 2012, Bae et al. 2014, Vorobyov et al. 2020).

Herbig-Haro objects and knots along jets of young stellar objects (YSOs) are associated with episodes of elevated mass accretion (Reipurth & Aspin 1997, Ioannidis & Froebrich 2012, Arce 2013).

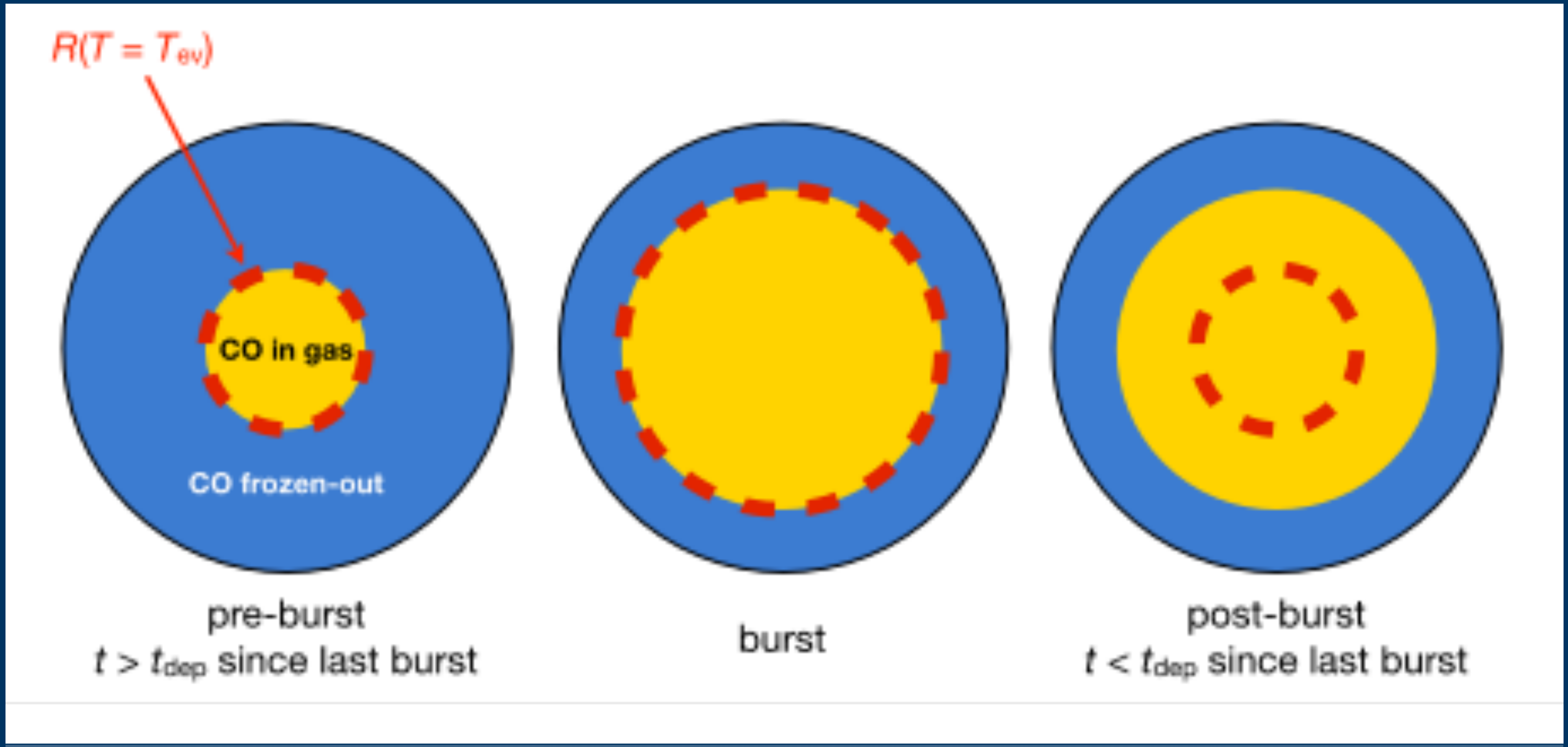


Jet shocks of YSOs
(eg Reipurth 1989; Hartigan+2011; Plunkett+2015)

Evidence of bursts at young ages

Detection of extended snowlines as indications of past outbursts.

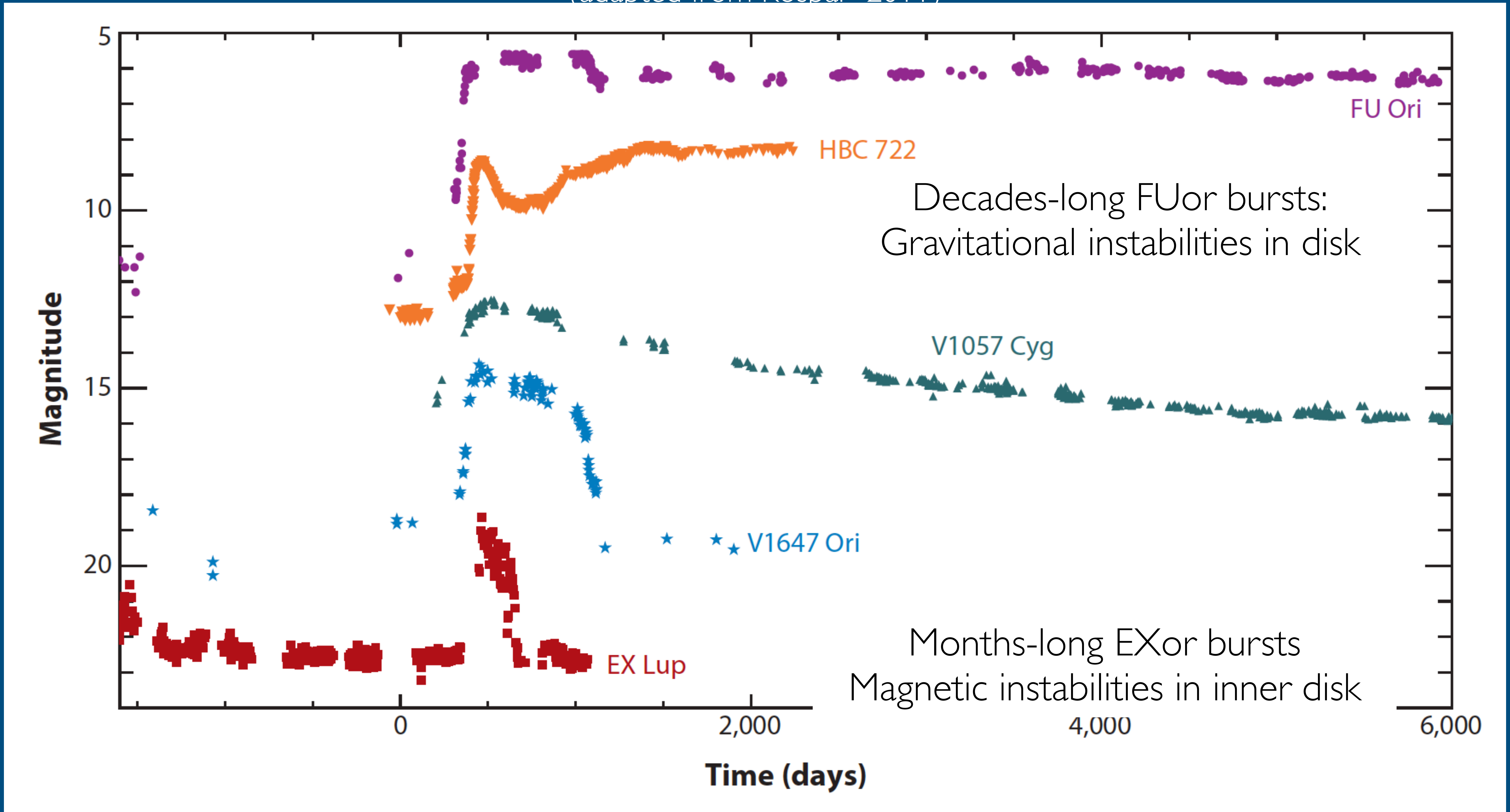
- Jorgensen et al. (2015) observes C18O J=2-1 towards 10 protostars. Five of them show extended CO emission. Outburst frequency of 20000 yrs
- Hsieh et al. (2019) observe N2H+ (1-0) and HCO+ (3-2) towards 39 protostars trace the CO and H2O snowlines respectively. Measure outburst frequency of 2000 years (Class 0) and 8000 years (Class I).



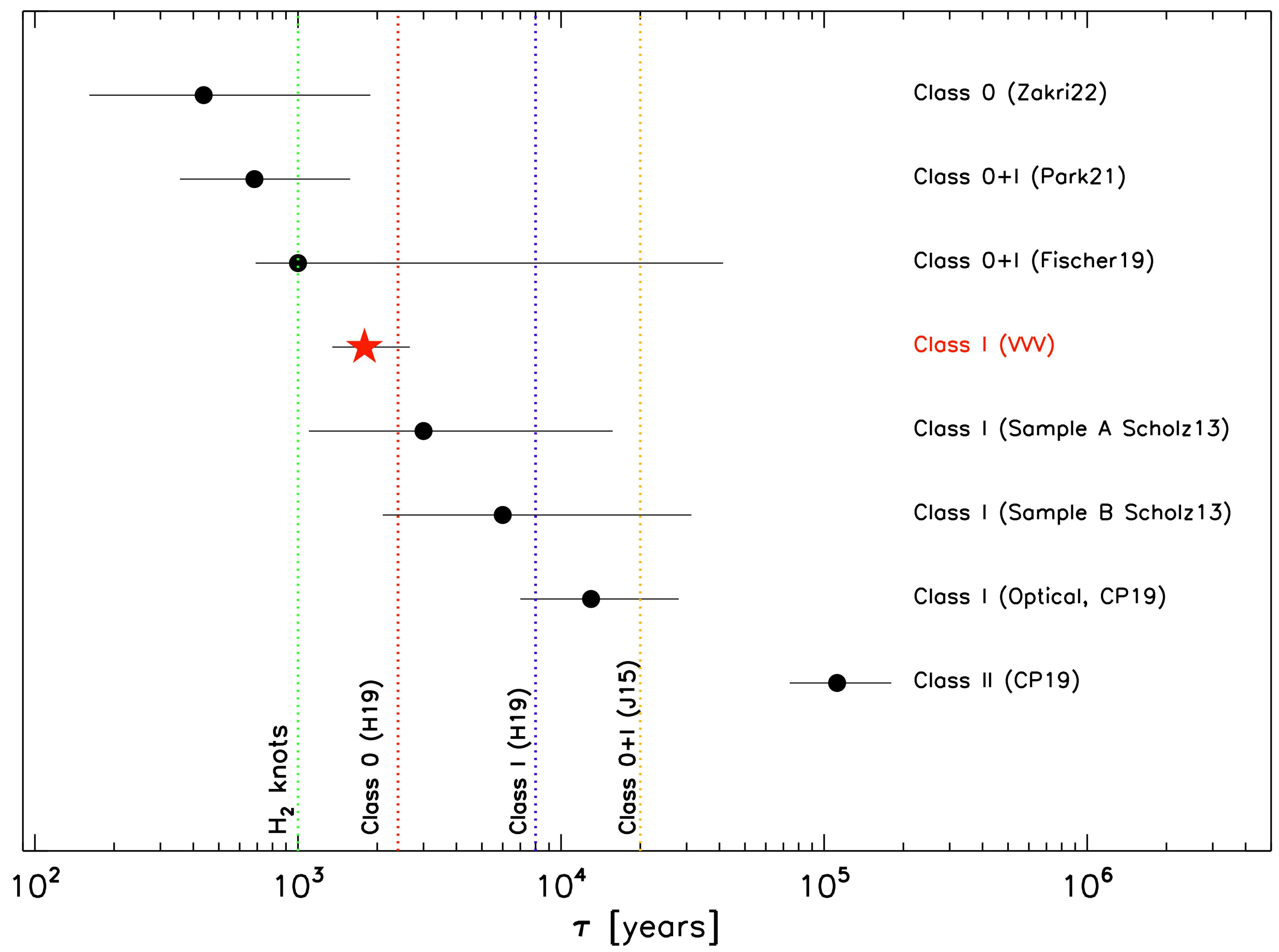
e.g. Jørgensen+2015; Hsieh+2019

FUor and EXor outbursts: discovered from optical monitoring

(adapted from Kospal+2011)



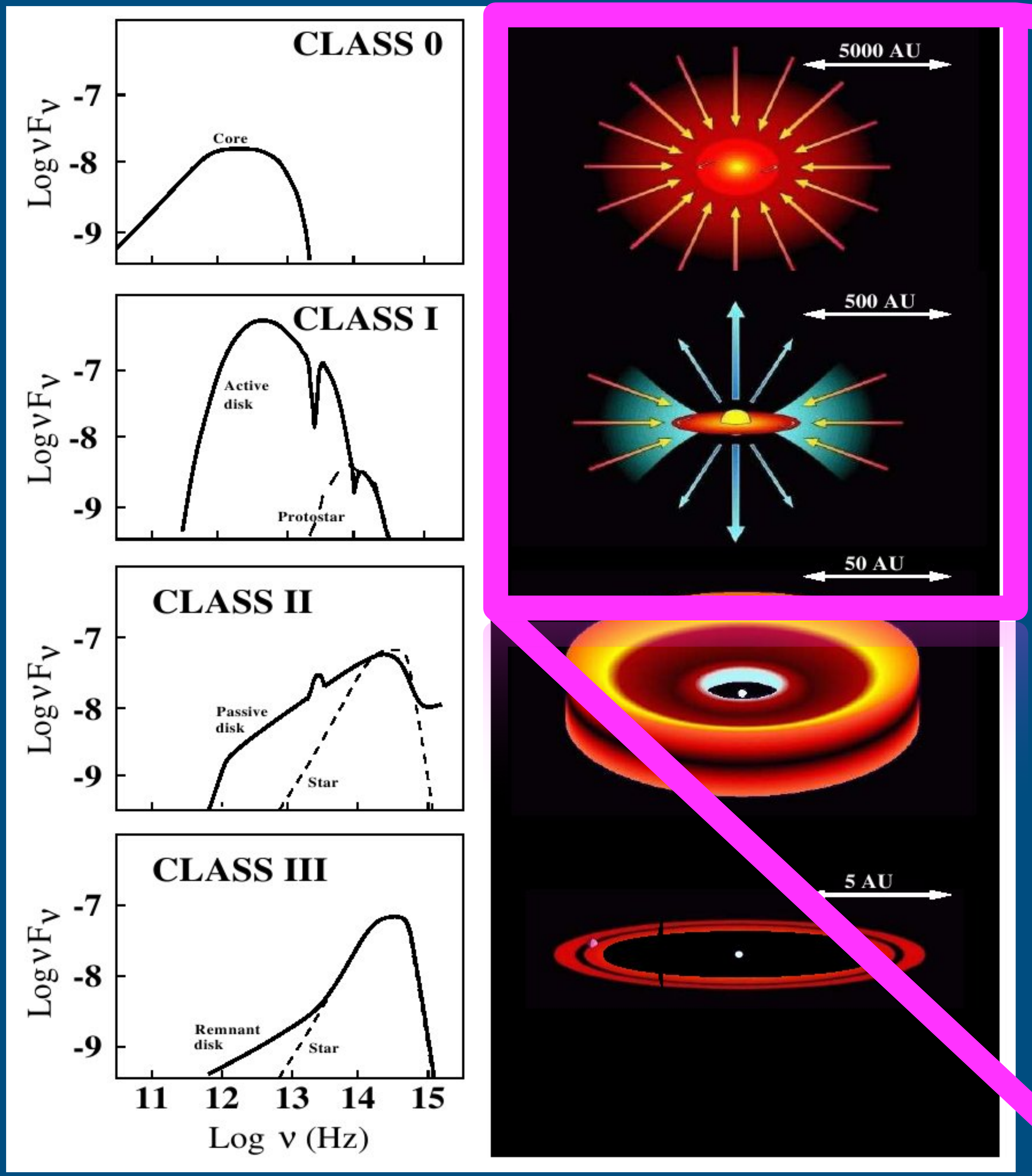
Most recent bursts found by PTF/ZTF and Gaia (e.g Hillenbrand et al. 2018). Increasing numbers with near- and mid-IR surveys (Contreras Pena et al 2017ab, Park et al. 2021)



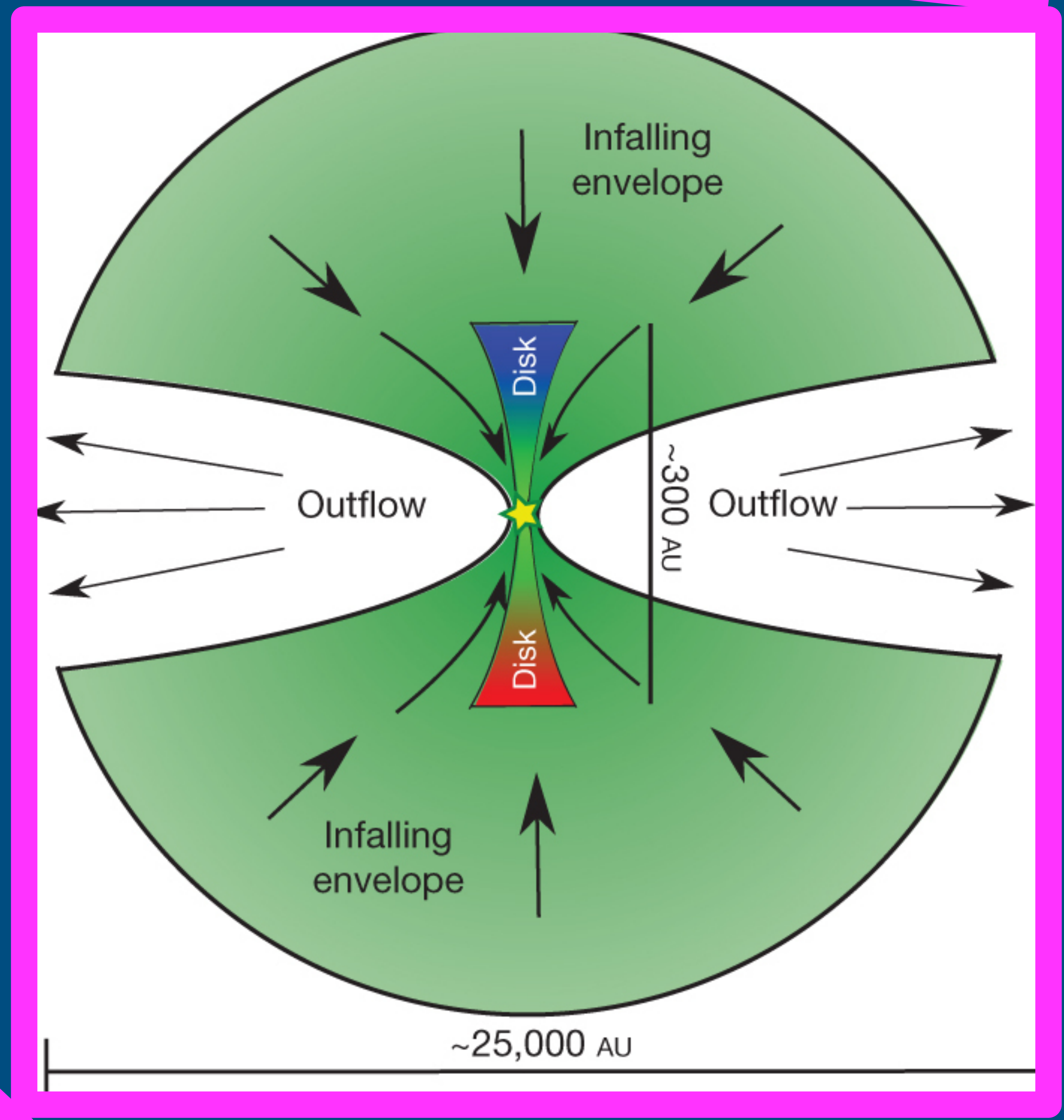
Contreras Pena et al, in prep

The frequency of outbursts can be estimated from the number of detections over time baselines of several years. These indicate that the most extreme accretion events (aka FUors) are more frequent towards the deeply embedded phase

Stars grow during protostellar phase



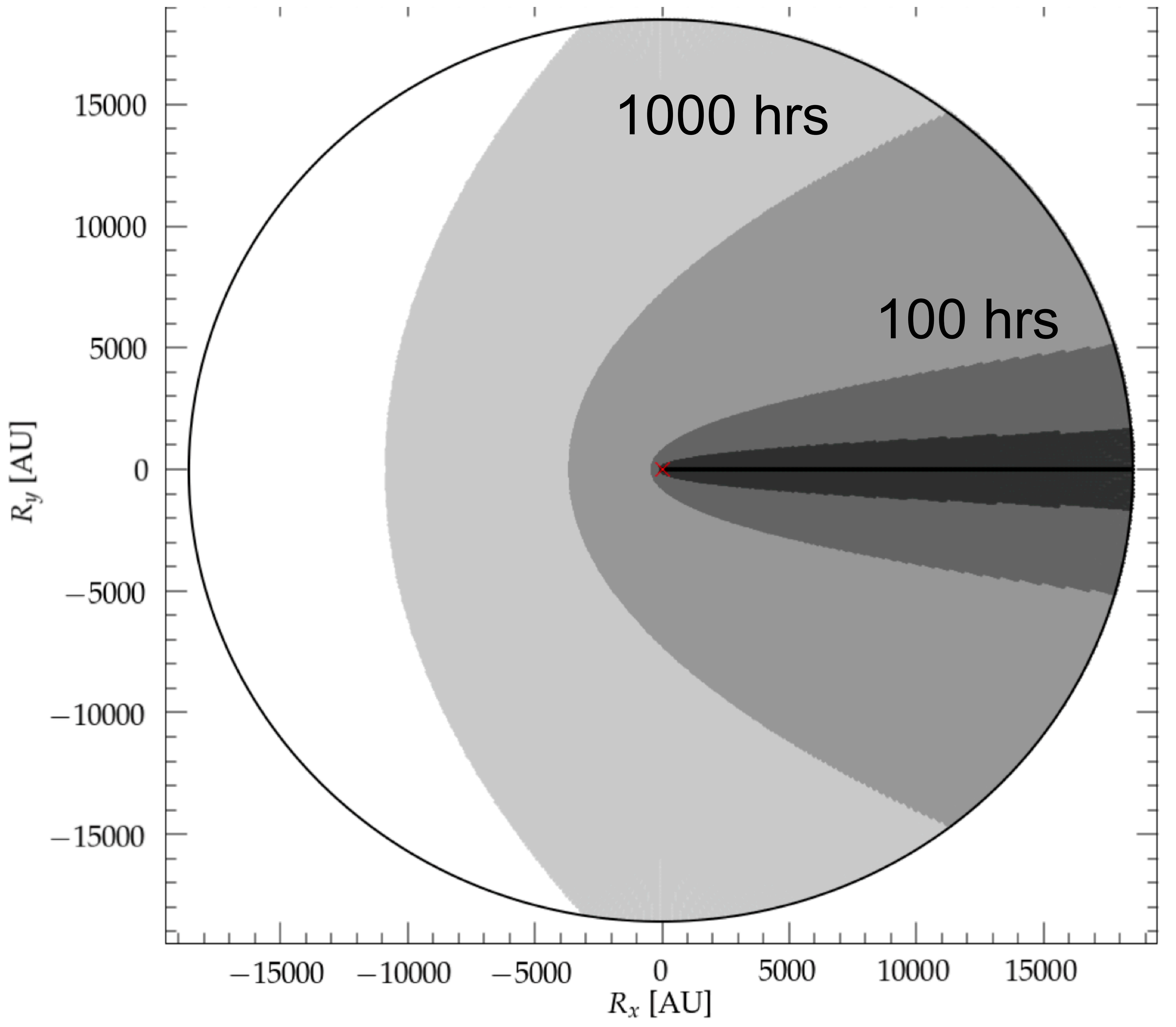
Cartoon from Isella 2006



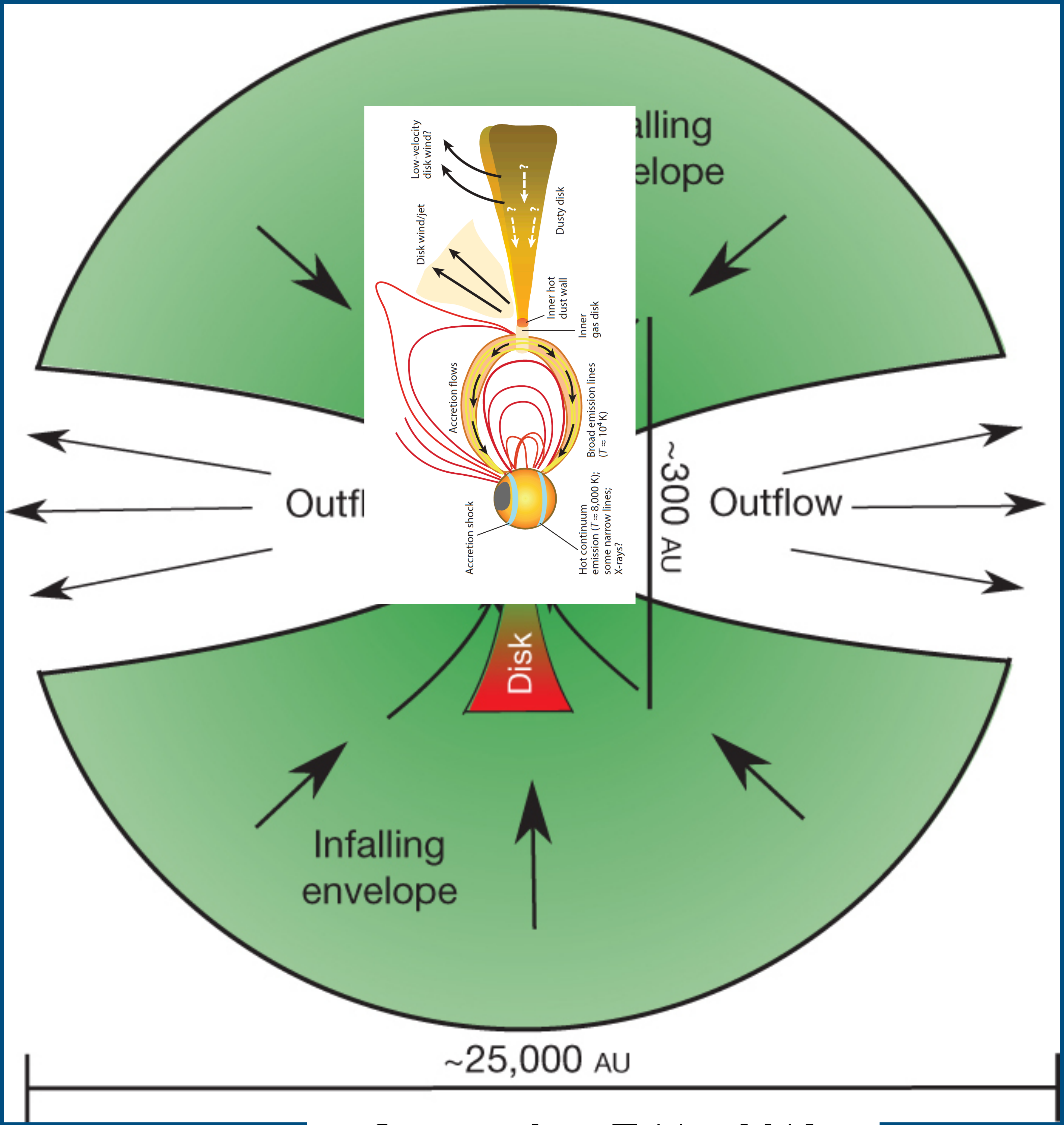
Cartoon from Tobin+2012

Stars grow during protostellar phase

Timescale for dust scattering



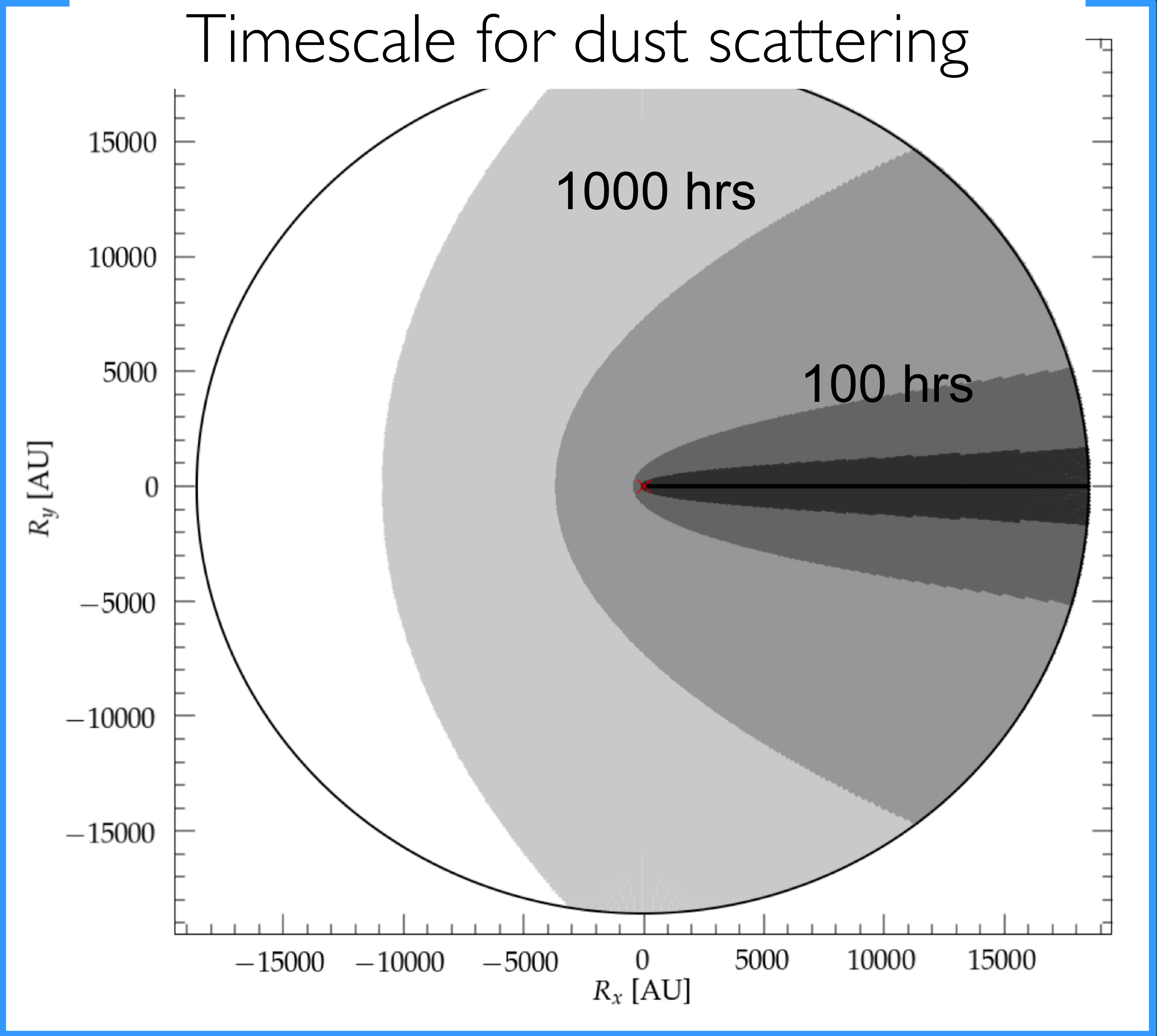
Johnstone+2013: envelope as a calorimeter



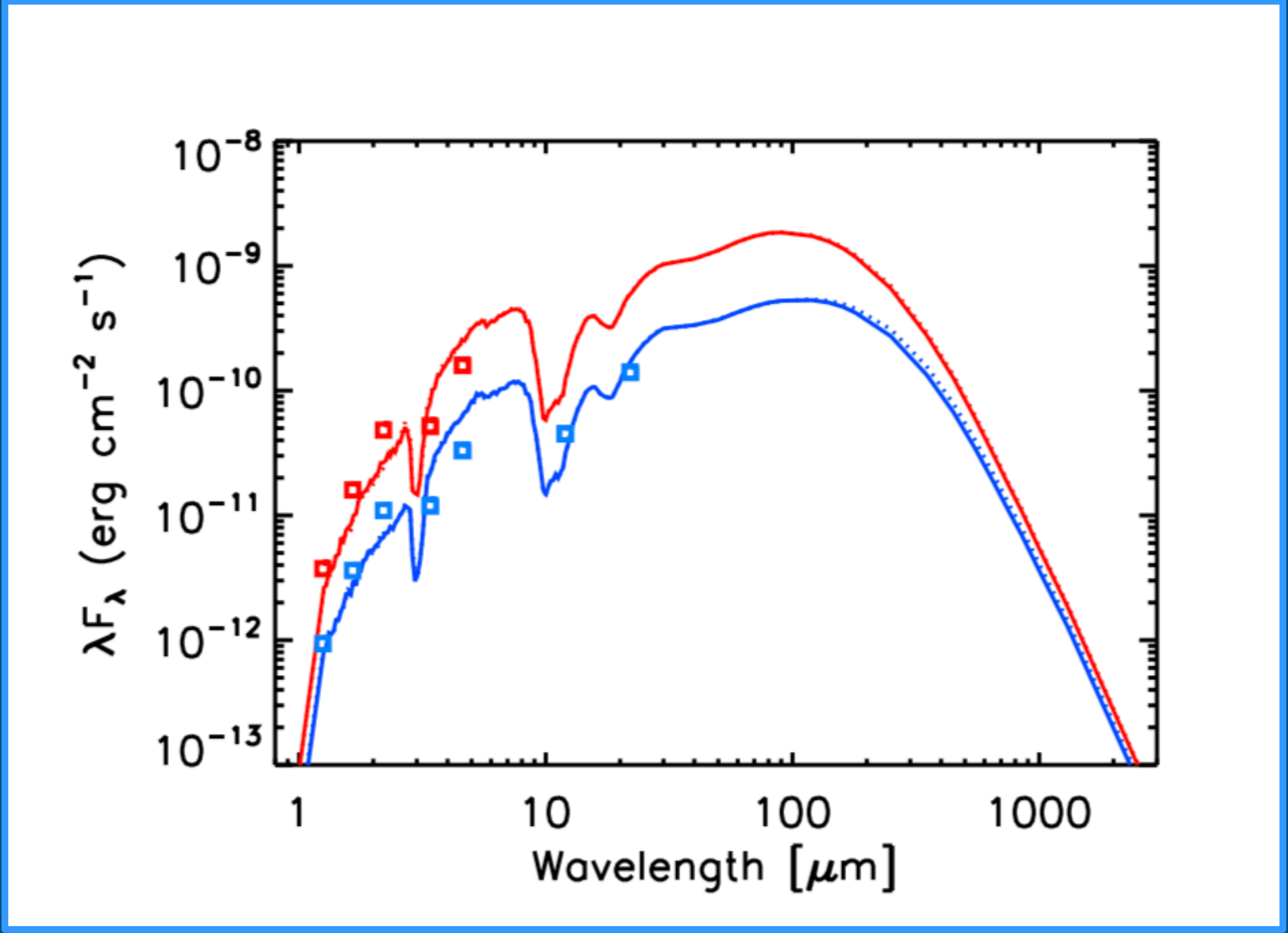
Cartoon from Tobin+2012

Stars grow during protostellar phase

- High L => high Tdust => bright sub-mm
- Geometry ~does not matter
- Short (days) timescale changes are smoothed over



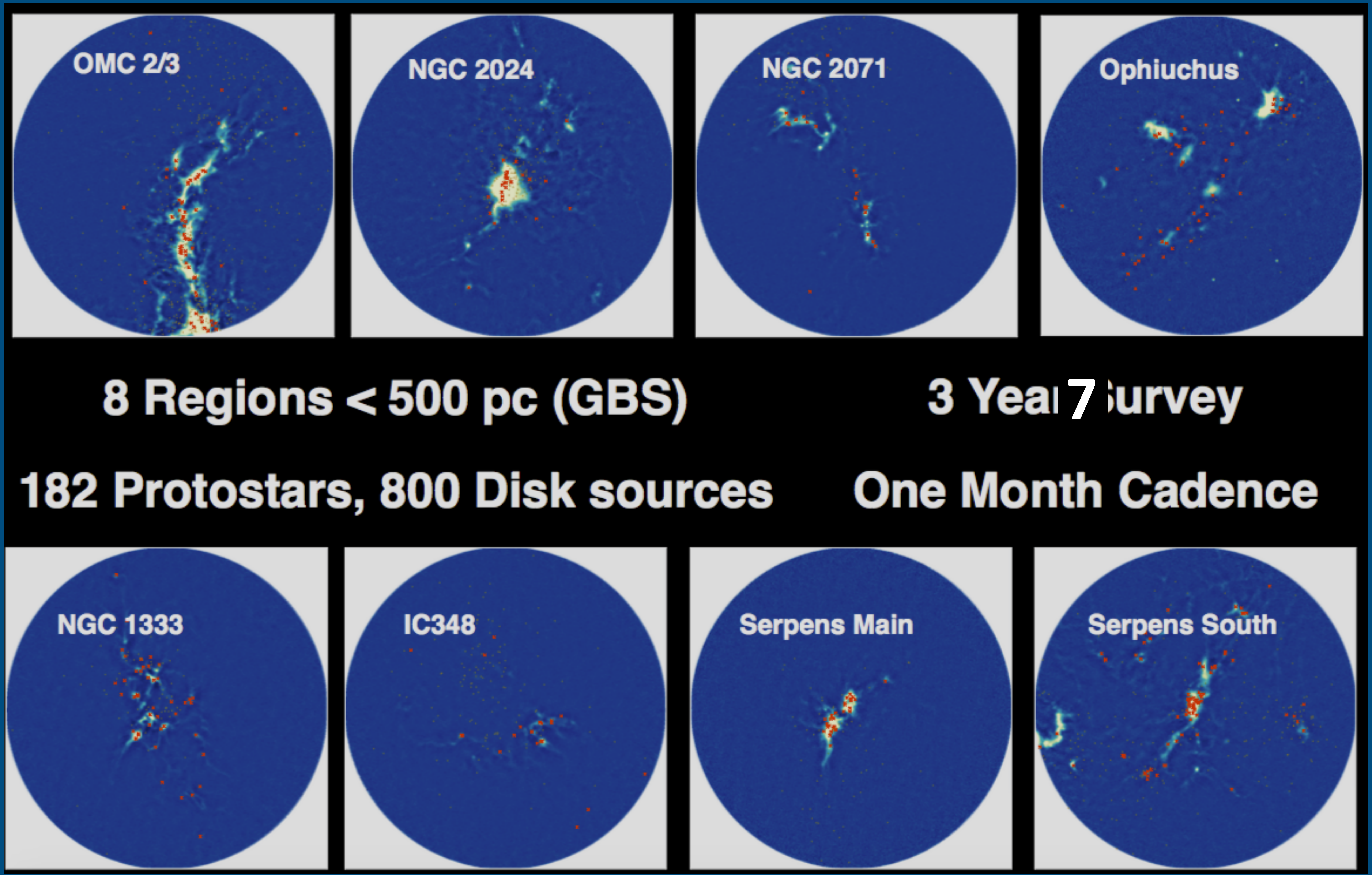
Johnstone+2013: envelope as a calorimeter



Baek et al. 2020: factor of 1.5 change in sub-mm
=> factor of 3.3 change in luminosity
See also MacFarlane+2019ab

The East Asian Observatory JCMT-Transient Survey: How do stars gain their mass?

(e.g., Herczeg+2017; Johnstone+2018; Mairs+2018, YH Lee et al. 2021)



Lightcurves from 2016.01

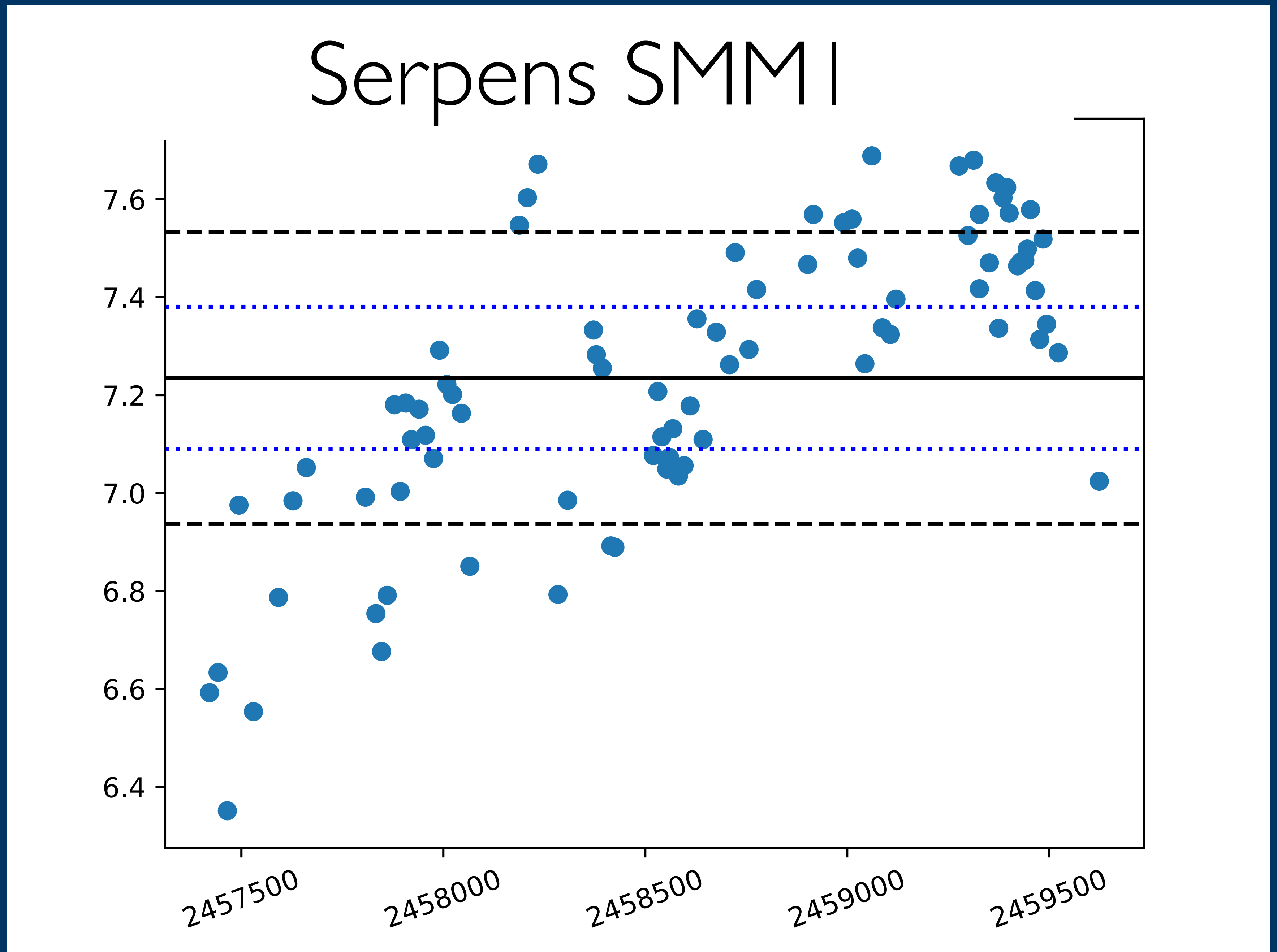
Program expansion:
2 years of monitoring intermediate mass star-forming regions
(KP Qiu, SY Liu, ZW Chen)

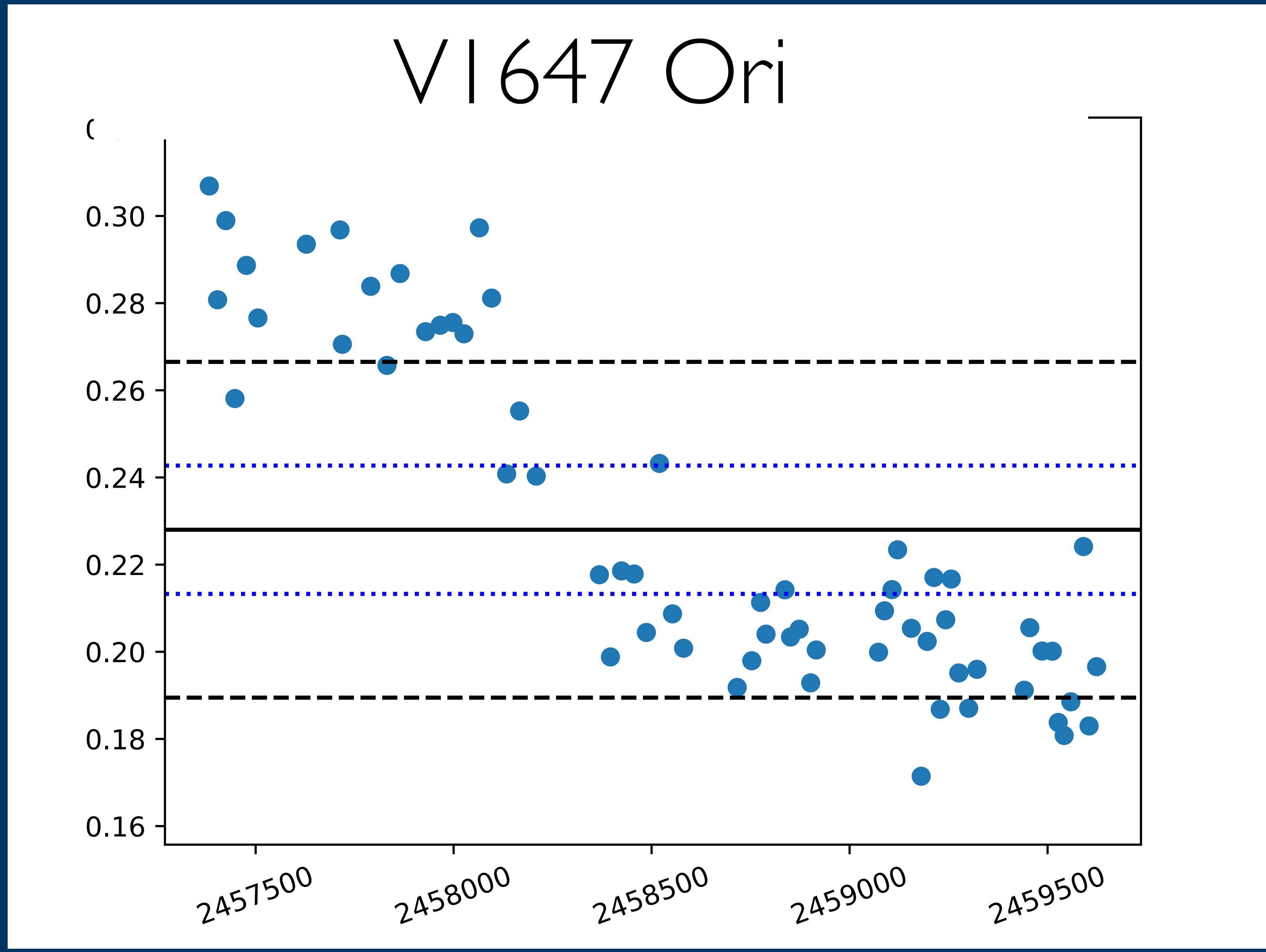
Flux calibration (Mairs et al. 2017; Mairs, Broughton, Johnstone, et al. in prep)

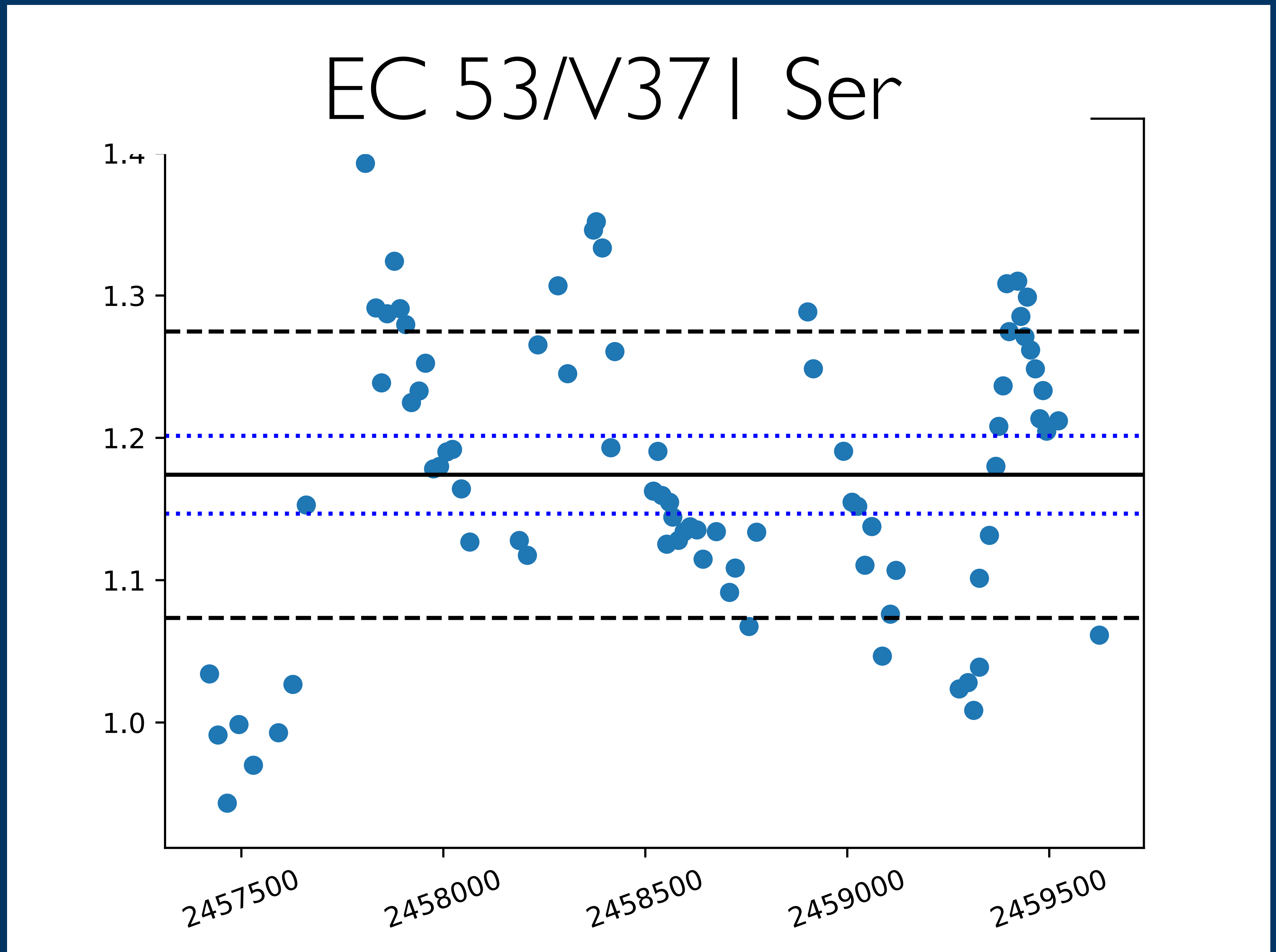
~1% at 850 microns and 3-5% at 450 microns!
(usually 7-10%; our past efforts got to 2%)

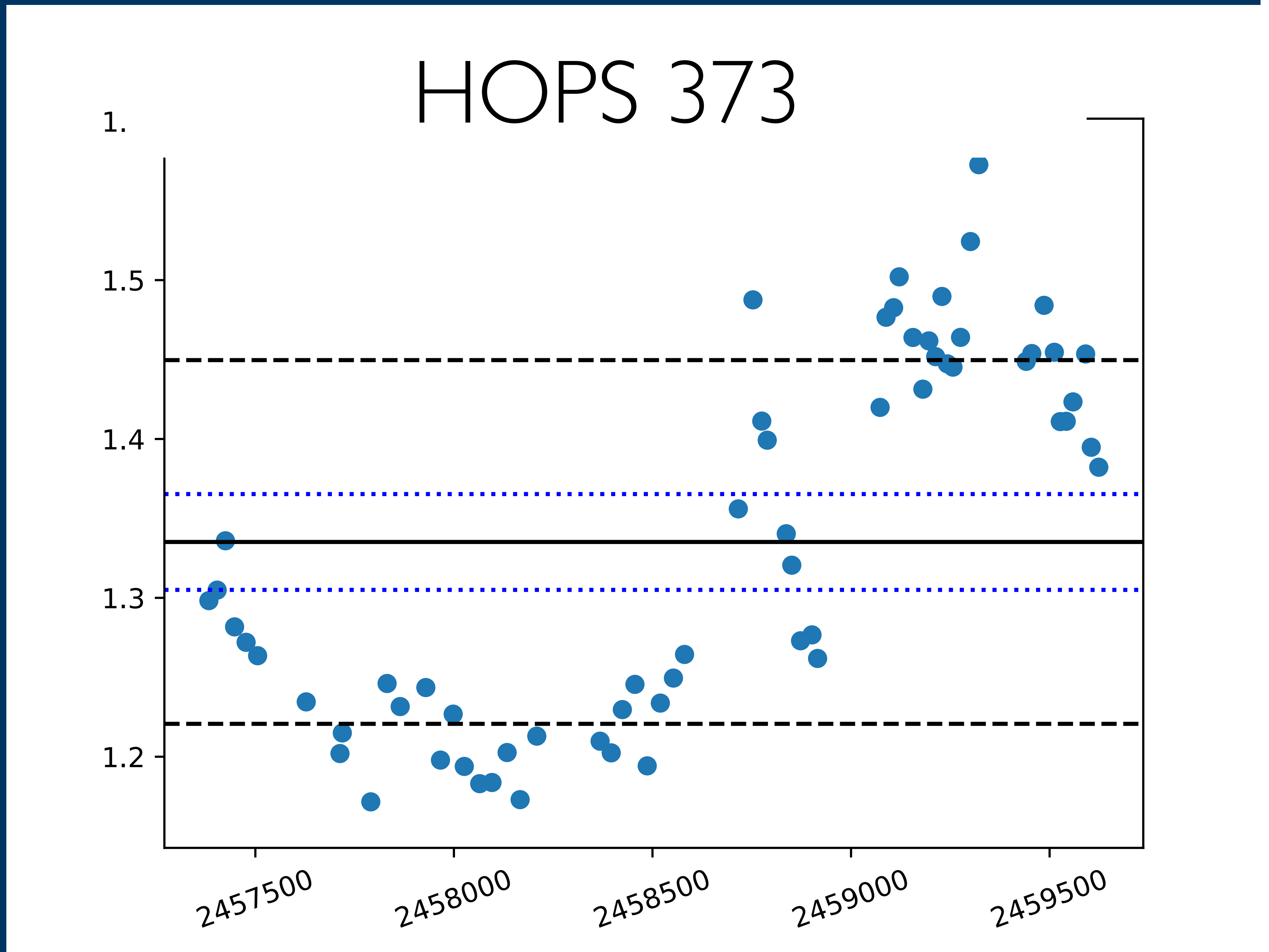
JCMT-Transient: 850 μm lightcurves

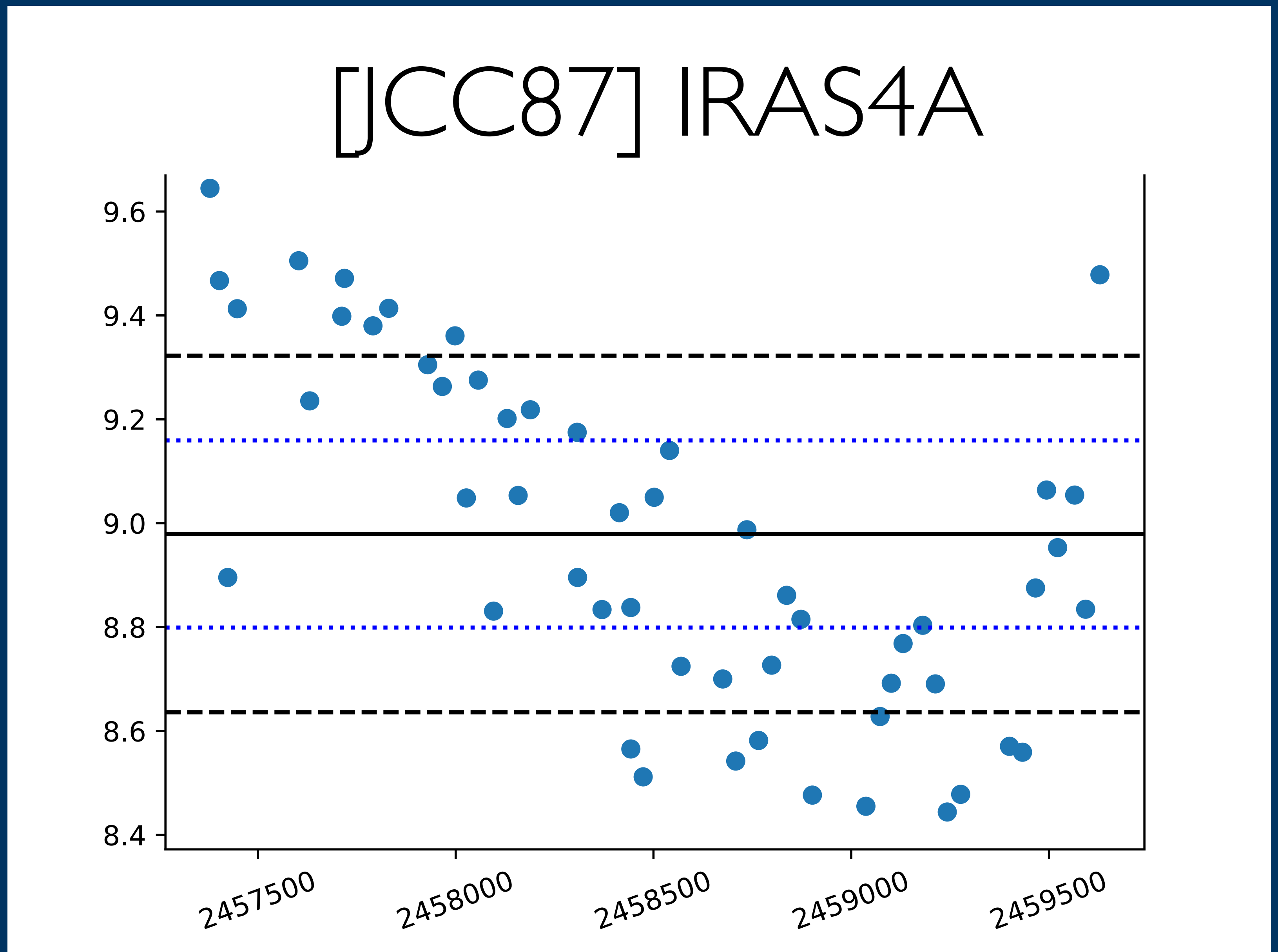
(450 μm similar, but noisier)

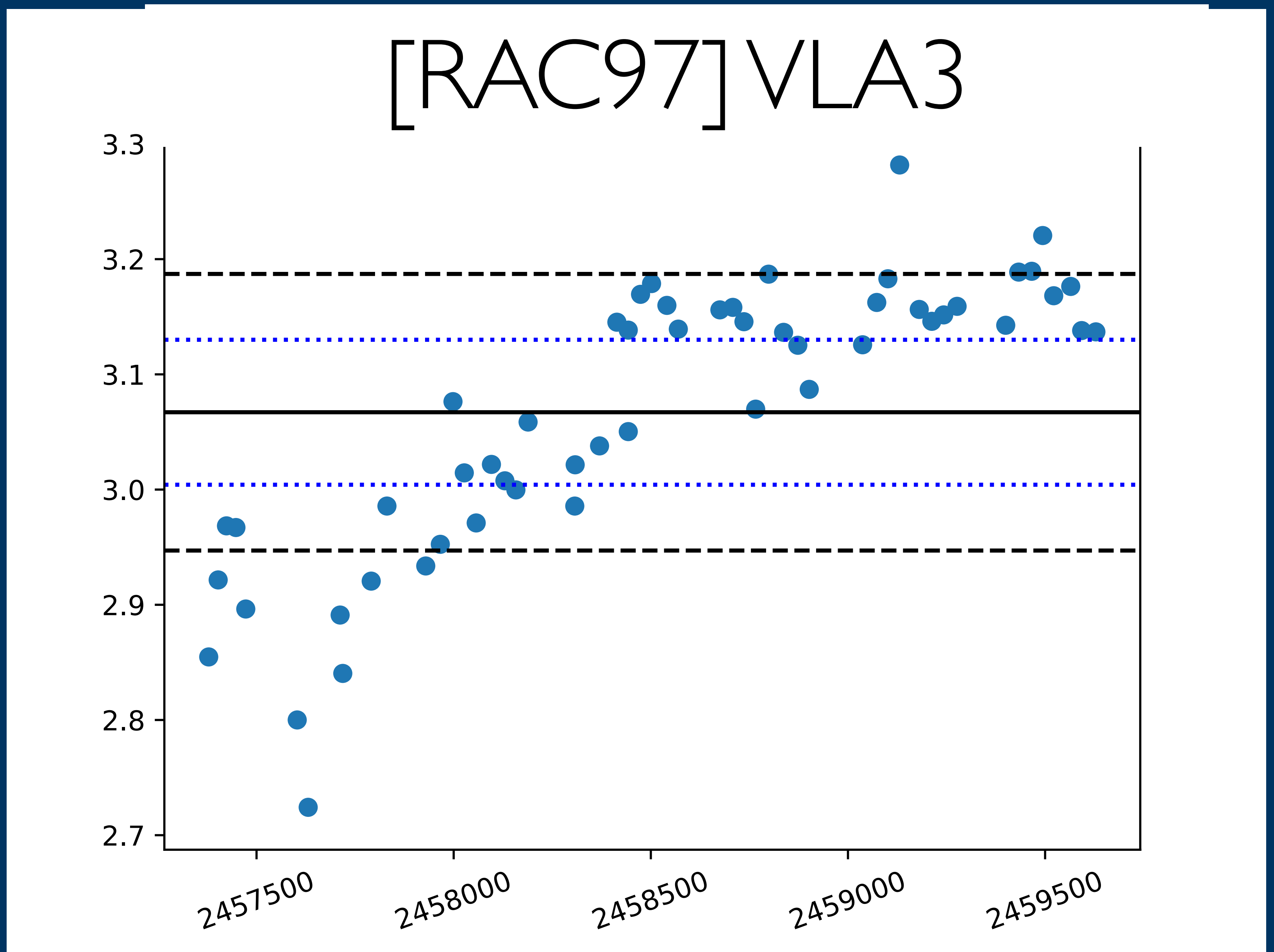


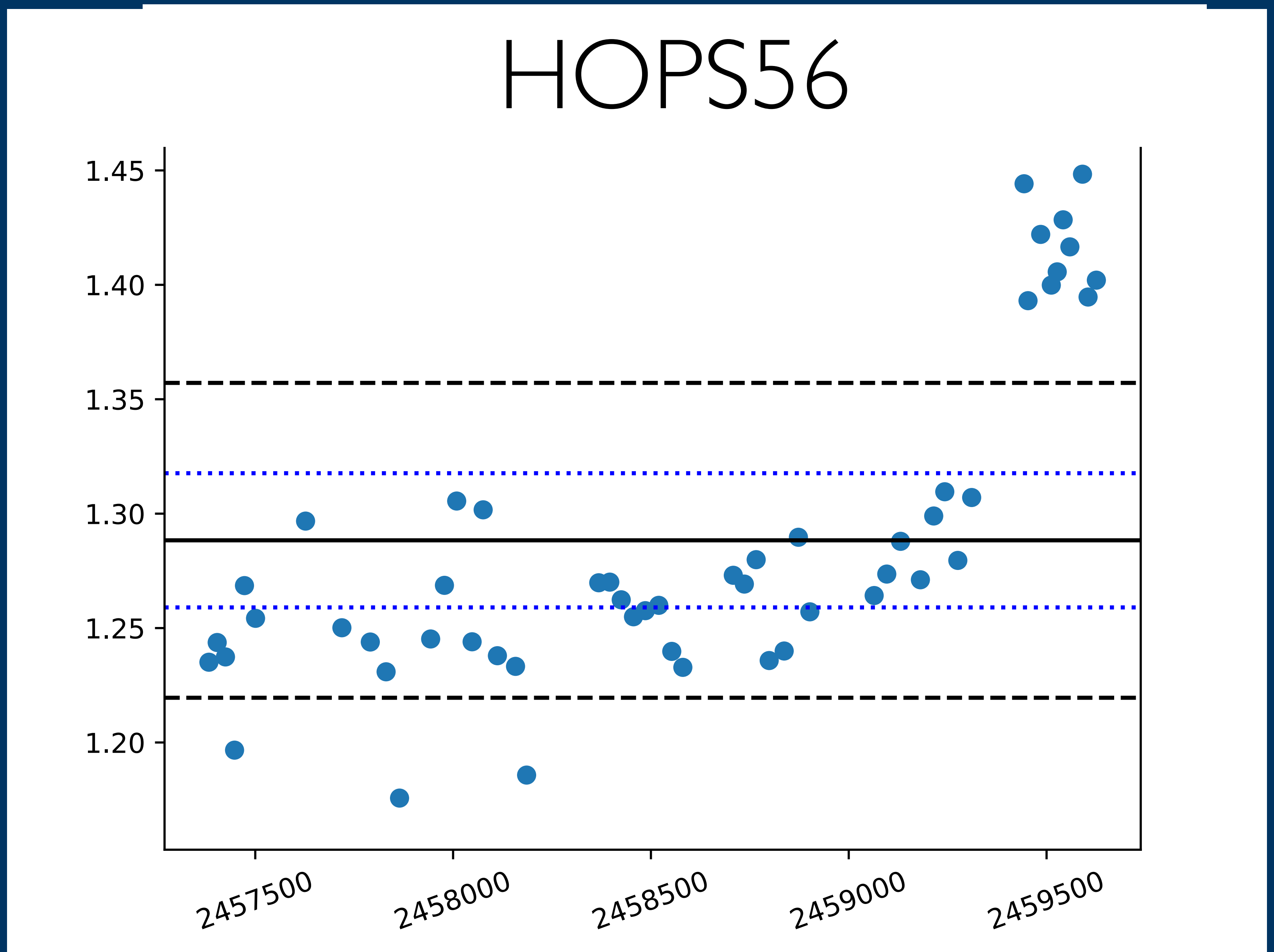


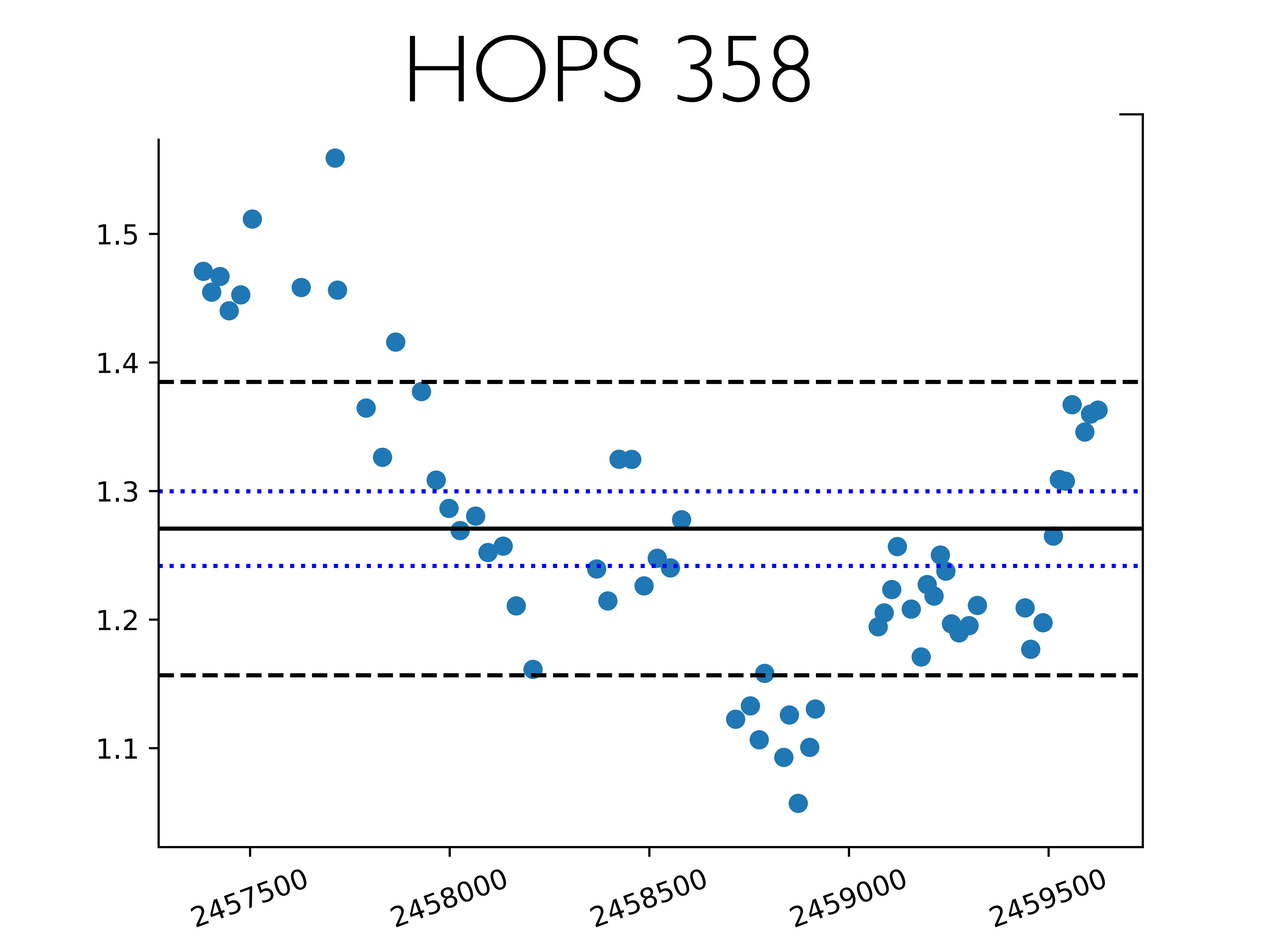


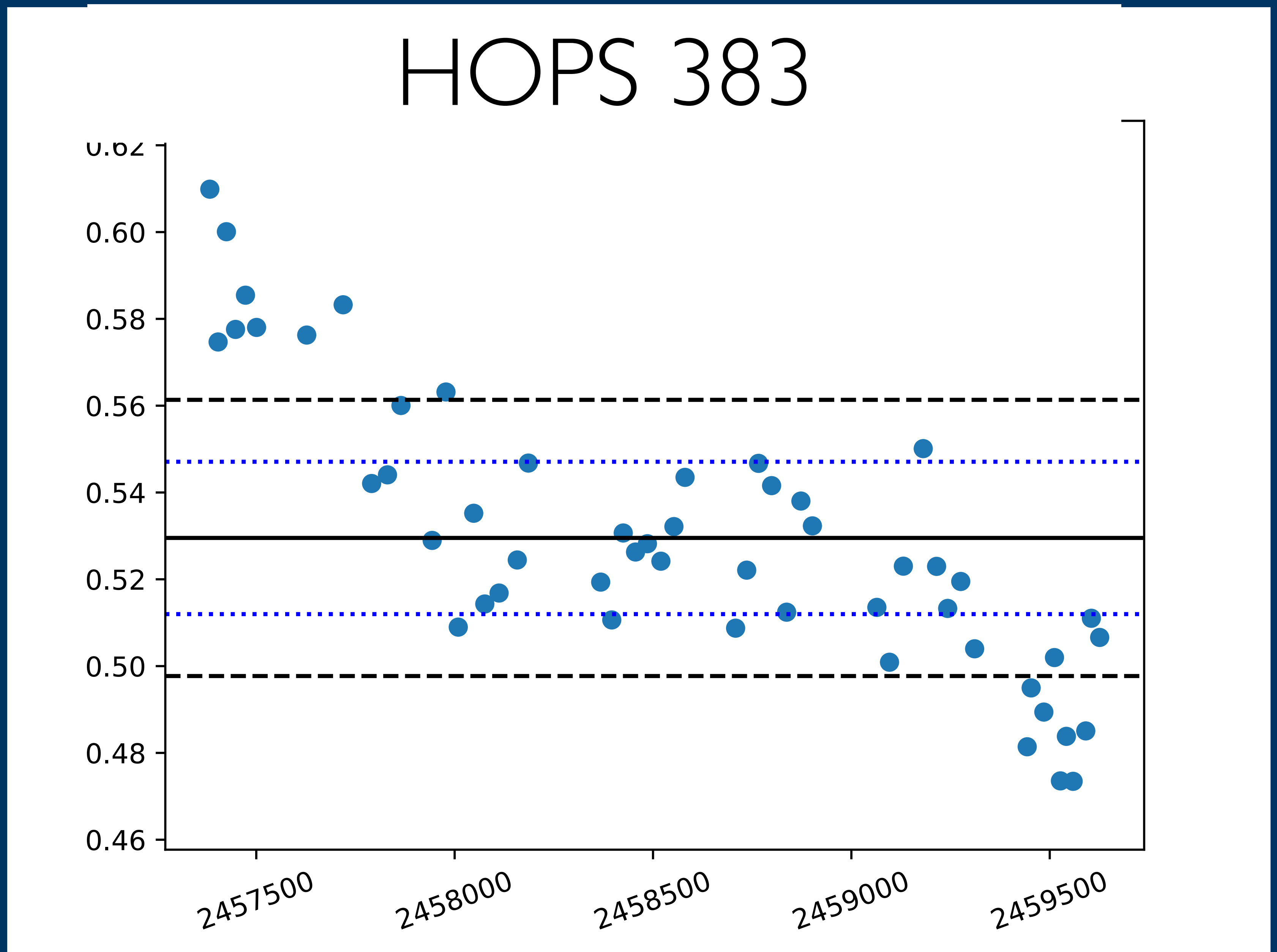



[JCC87] IRAS4A
9.6
9.4
9.2
9.0
8.8
8.6
8.4
2457500
2458000
2458500
2459000
2459500


[RAC97] VLA3
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2457500
2458000
2458500
2459000
2459500


HOPS56
1.45
1.40
1.35
1.30
1.25
1.20
2457500
2458000
2458500
2459000
2459500


HOPS 358
1.5
1.4
1.3
1.2
1.1
2457500
2458000
2458500
2459000
2459500


HOPS 383
0.60
0.58
0.56
0.54
0.52
0.50
0.48
0.46
2457500
2458000
2458500
2459000
2459500

Bright Source Secular Variability: 50 months

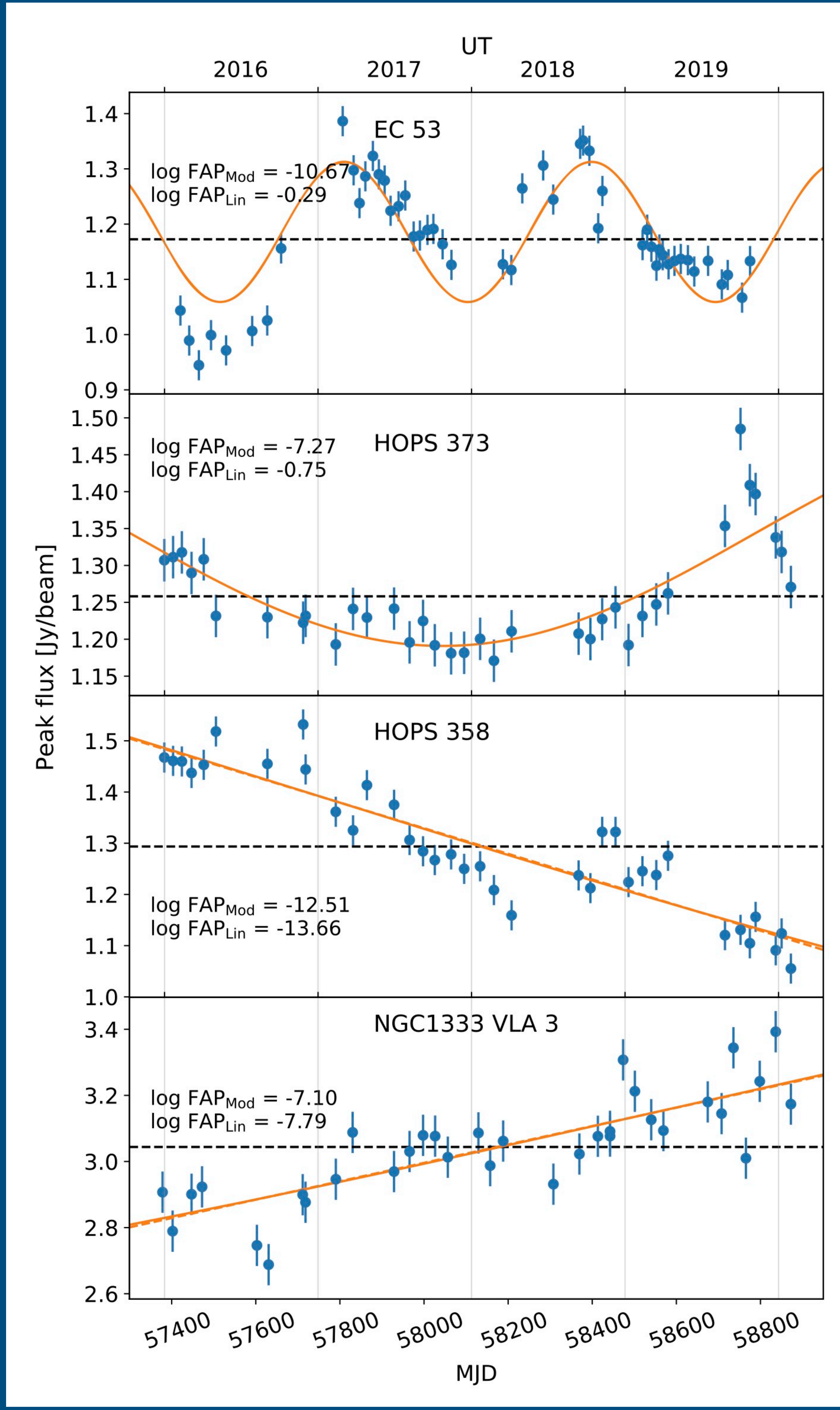
YH Lee, Johnstone, JE Lee, et al. 2021

- Light curves fit with sinusoids, lines, and stochasticity as empirical description of past behavior

- Statistical description of variability

- "periodic" sources: amplitudes of 10-20%

- ~ 60 bright protostars > 0.25 Jy/bm
  - 30% vary



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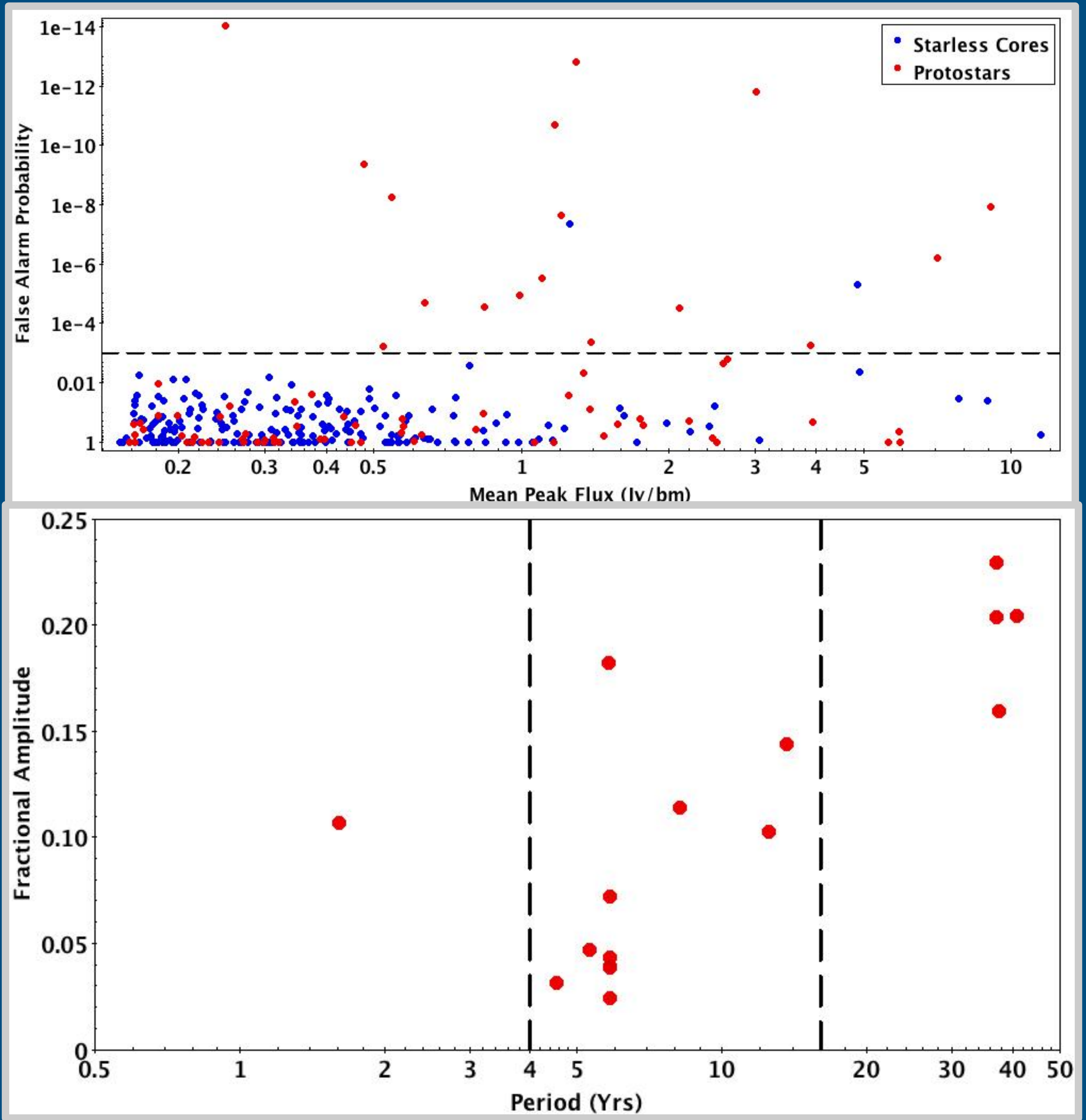
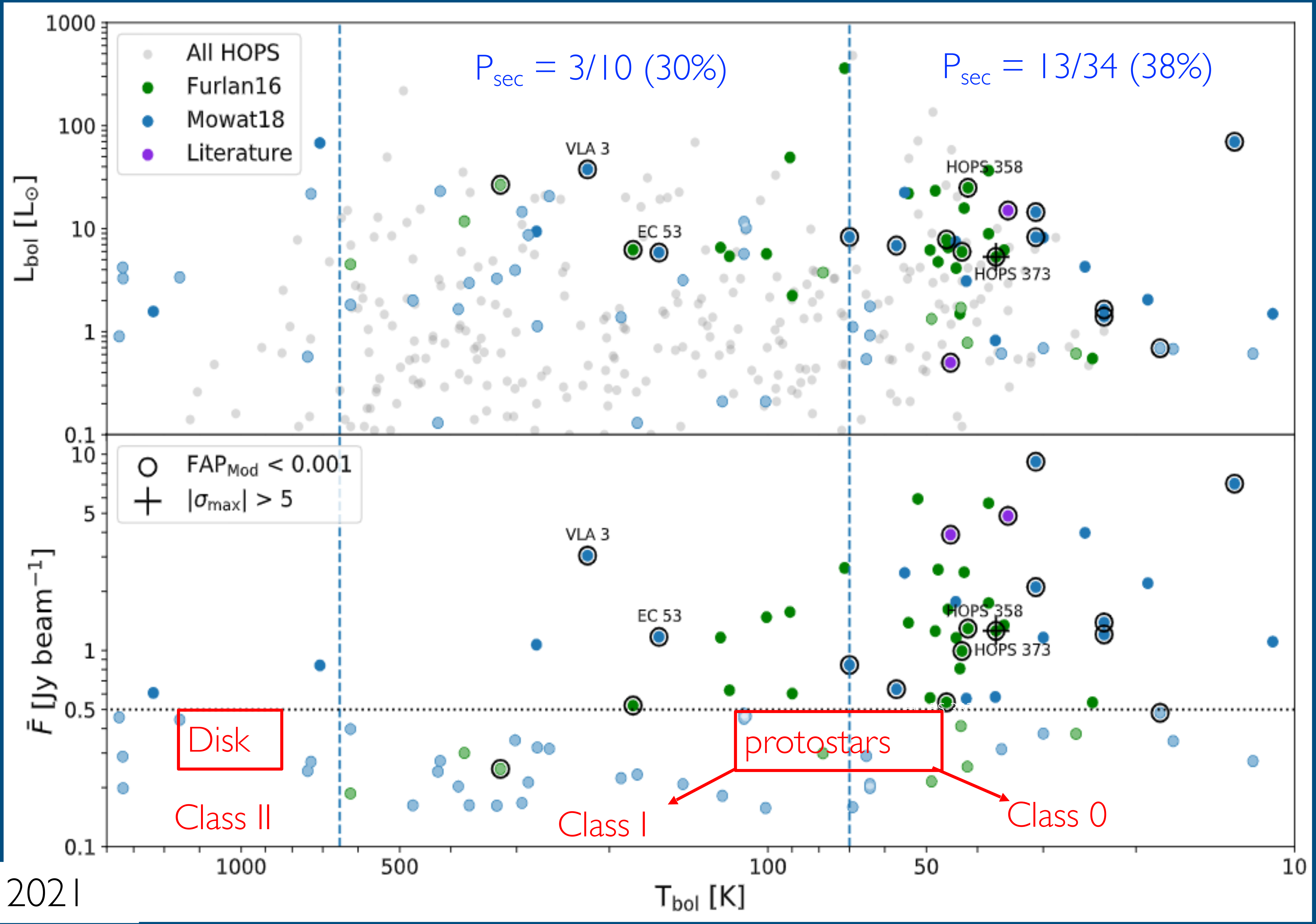
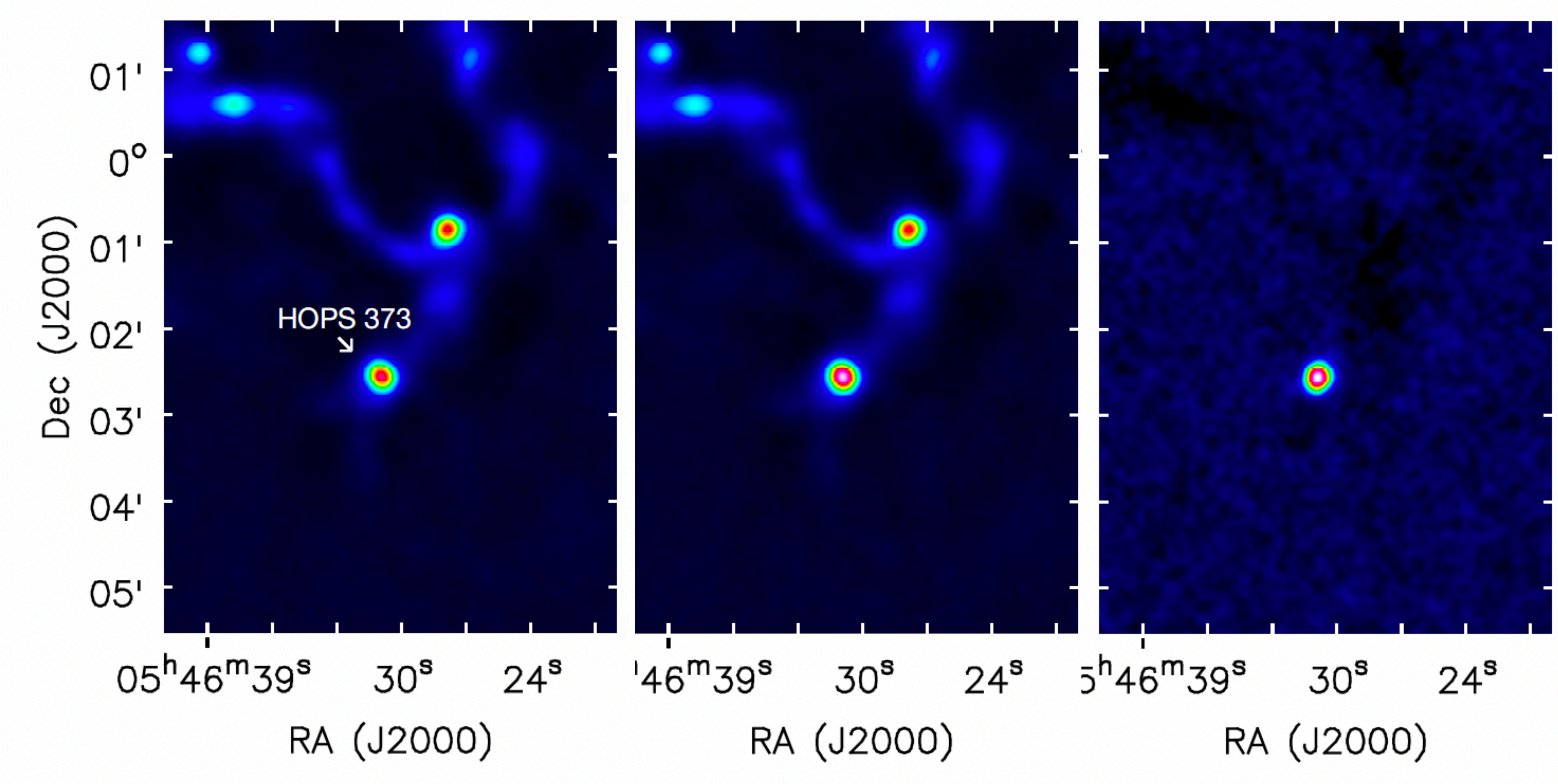


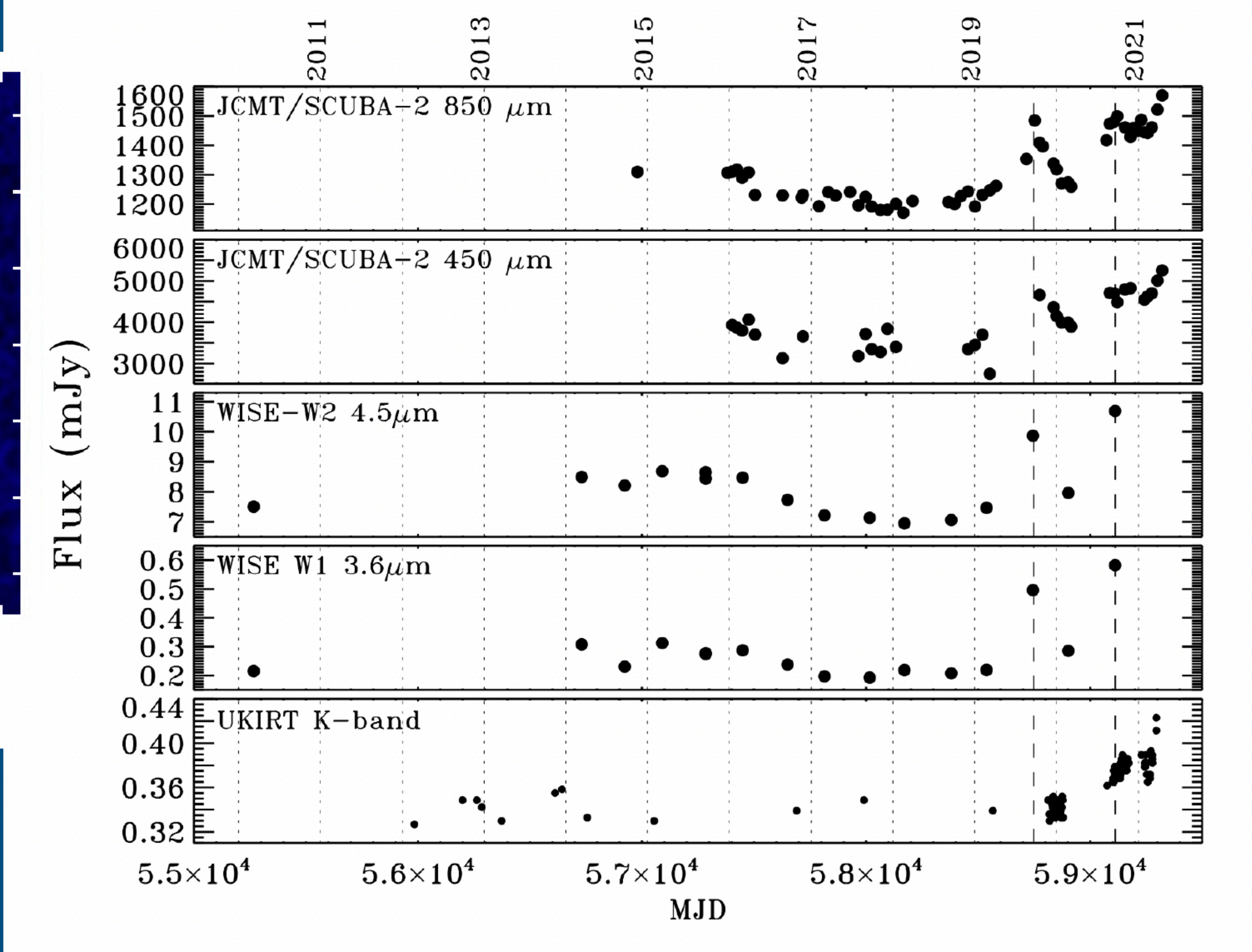
Sub-mm variability from JCMT-Transient program



YH Lee et al. 2021

HOPS 373: a modest (ongoing) accretion burst

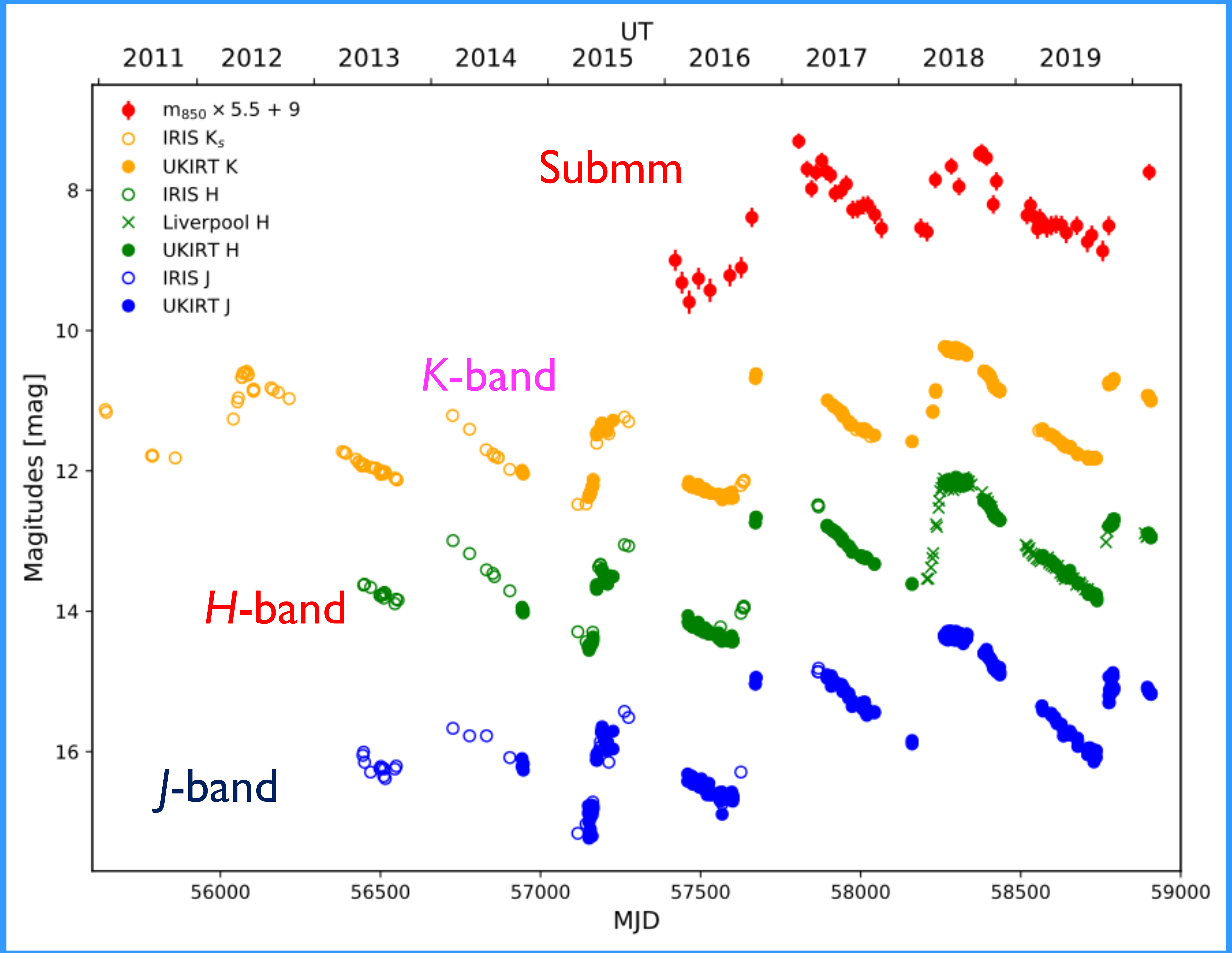




Yoon, Herczeg, JE Lee et al. 2022

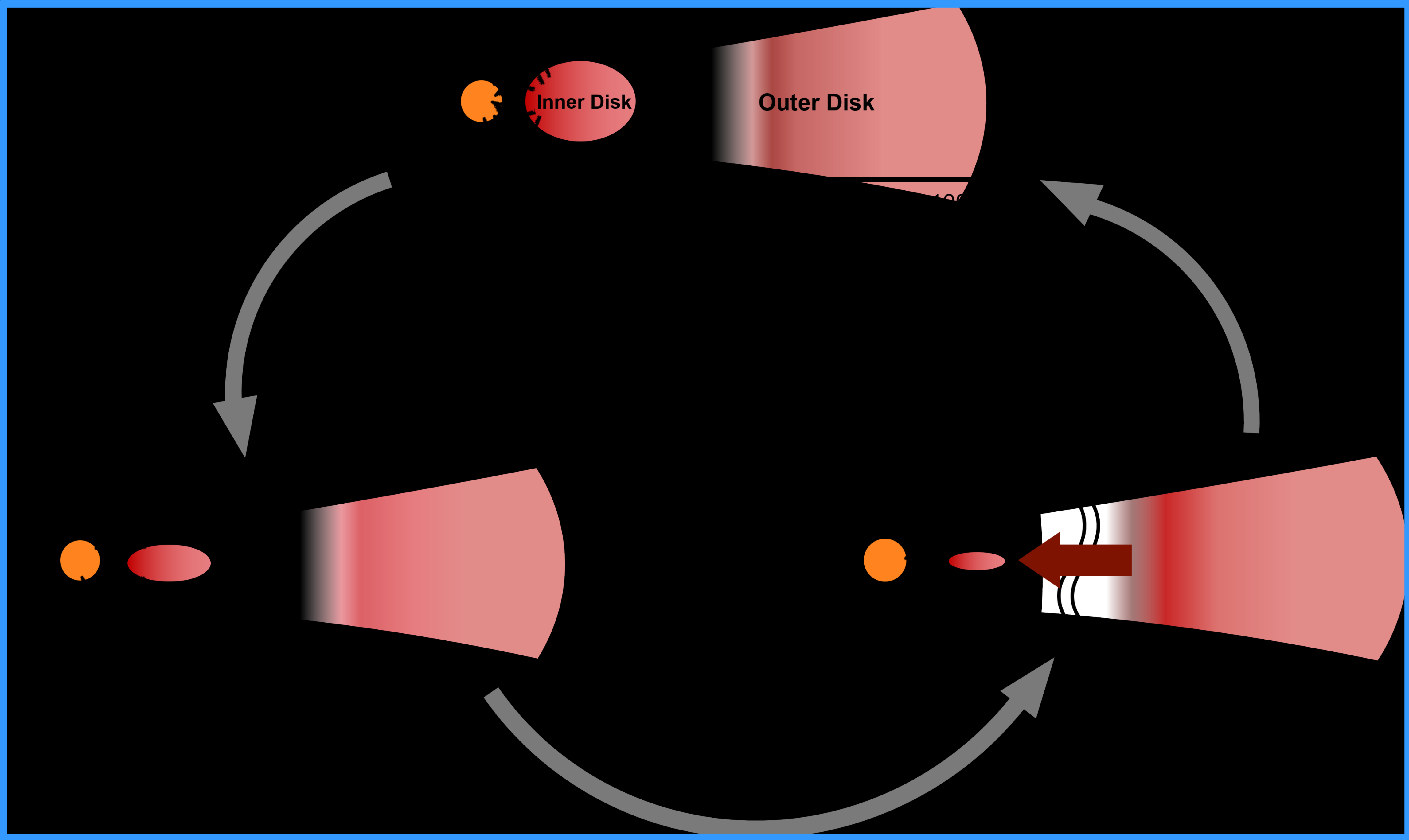
EC 53 (V371 Ser): Young Faithful

(YH Lee, Johnstone, JE Lee, et al. 2020)



Near-IR periodicity discovered by Hodapp 2012;
Source similar to Muzerolle+2011; Dahm & Hillenbrand 2020

Cycles of filling and draining the disk



Timescale (e-folding):

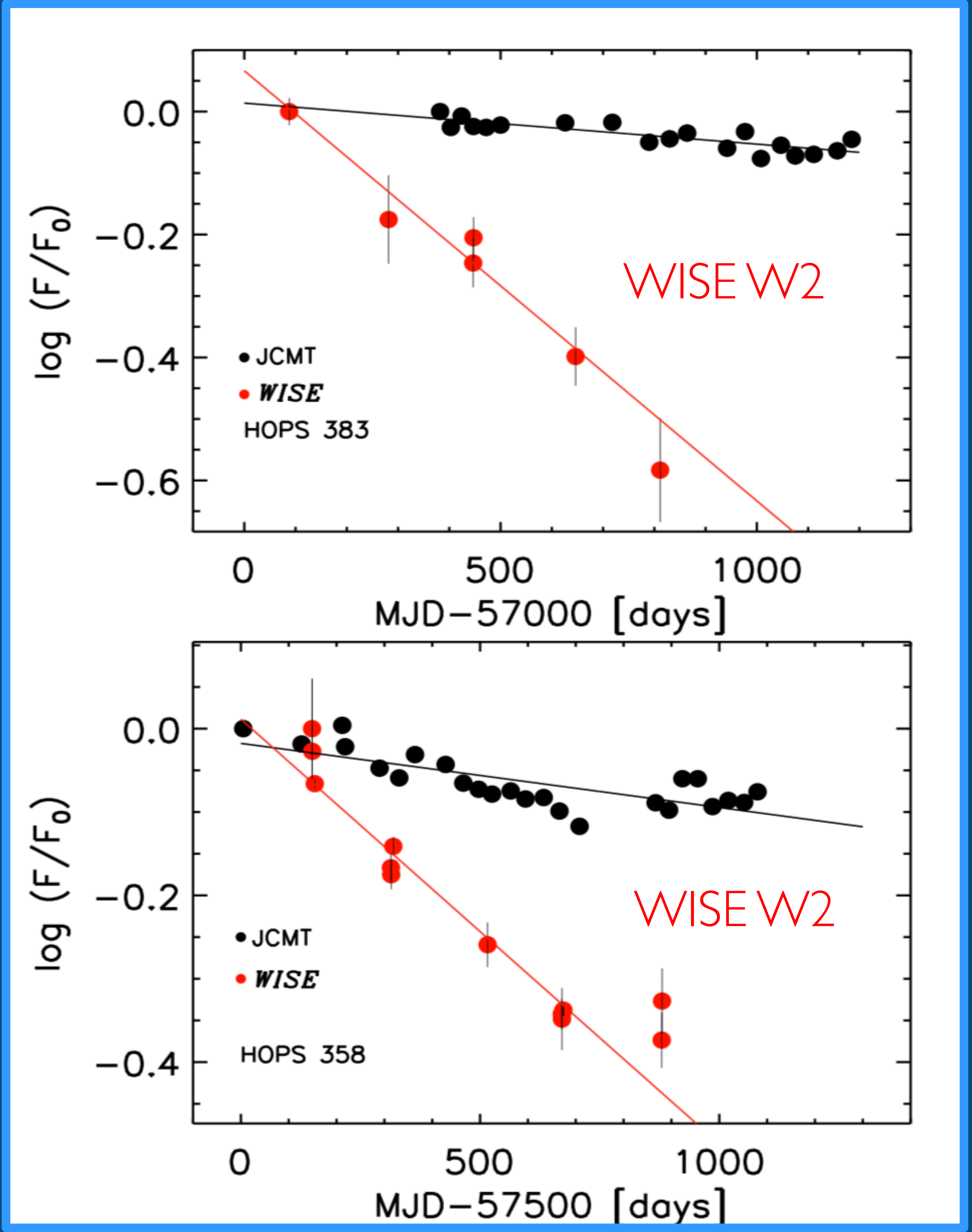
- Decay ~ 0.75 yr
- Rise ~ 0.10 yr

Accretion rate: $\dot{M}$~2.5 to 8 x 10^{-6} M_{sun}/yr

- Just before brightening: H-K is much redder (disk extinction)?

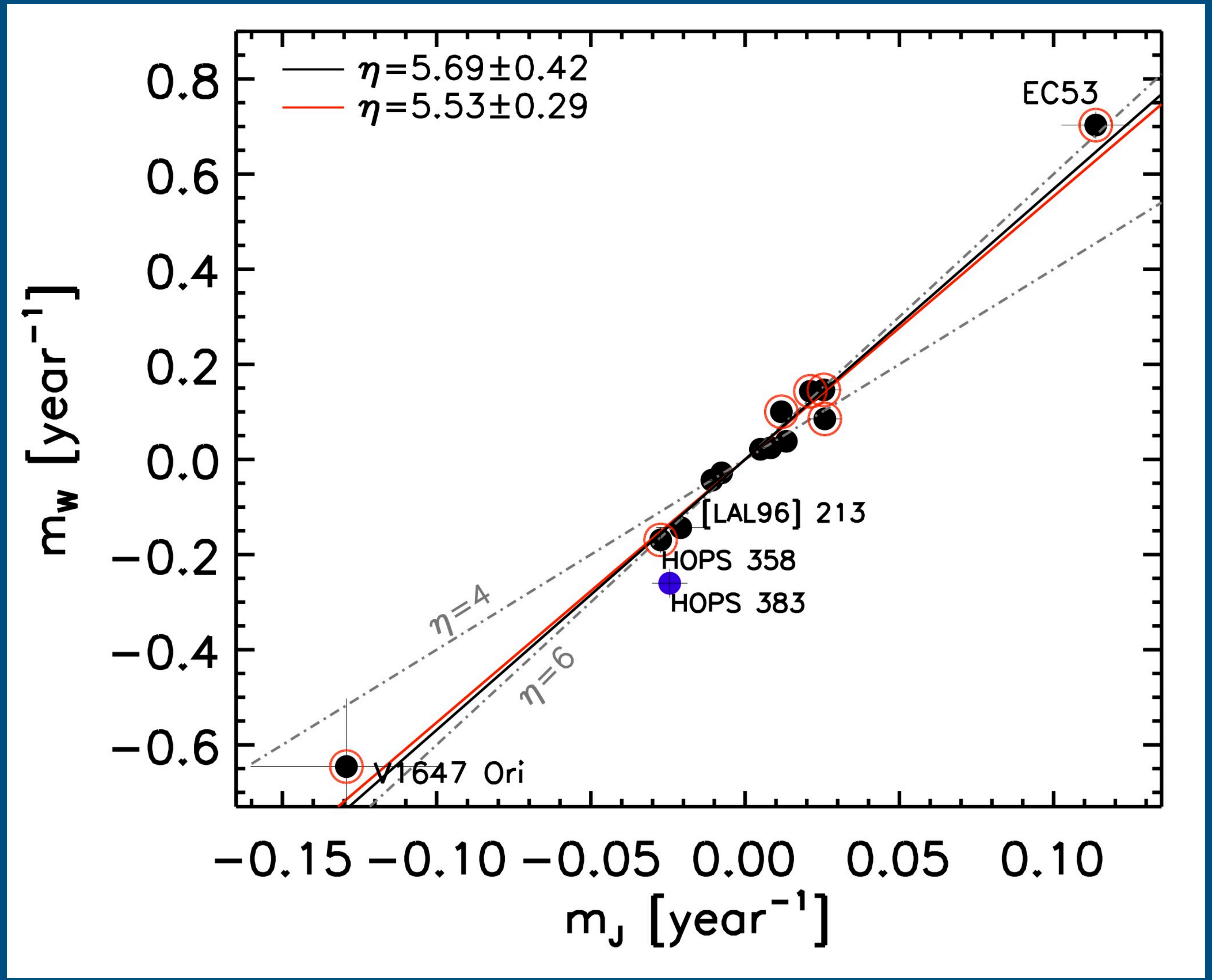
Correlation between sub-mm and NEOWISE (4.5 μm)

Contreras Pena et al. 2020



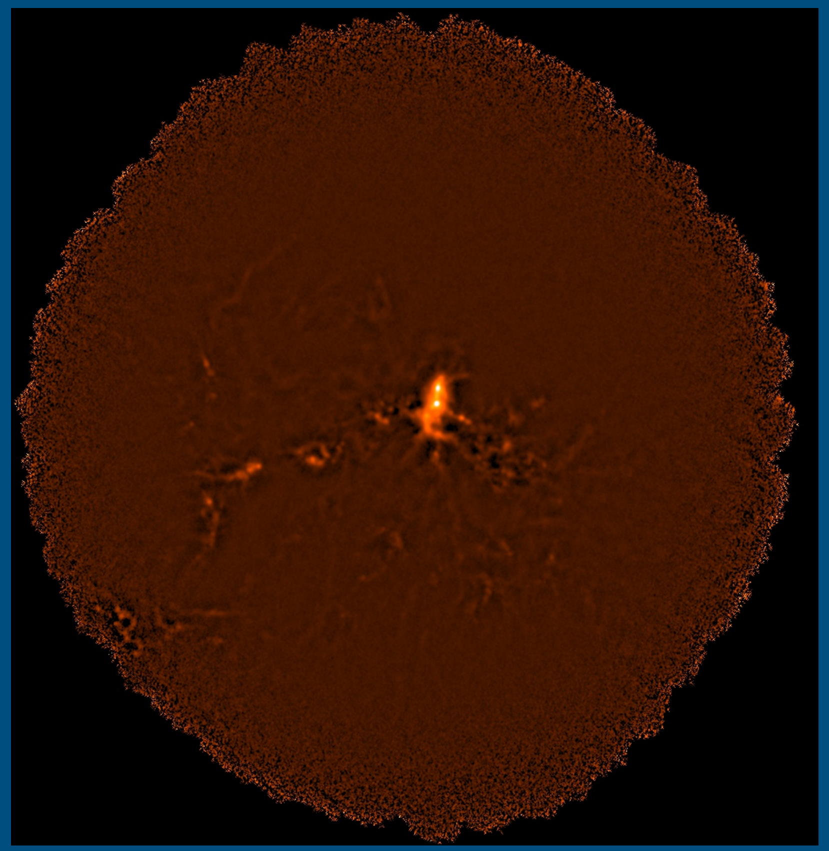
F(submm) $\propto T_{dust}$

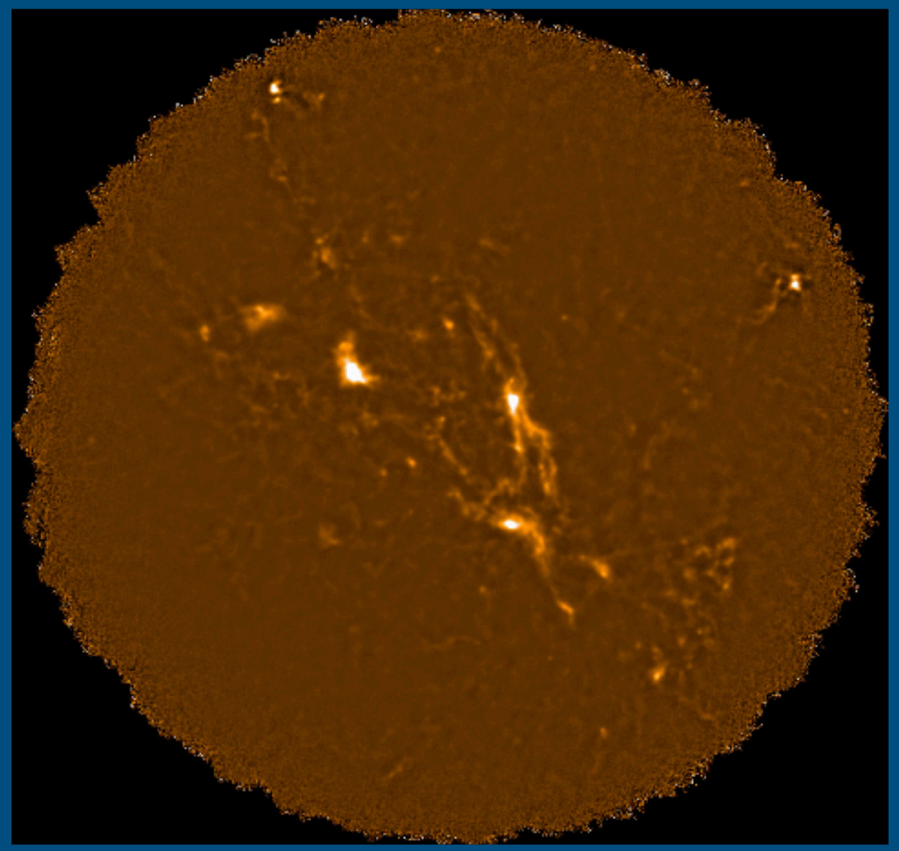
F(IR) $\propto L_{acc}$ (from disk, not certain)



Intermediate mass star-forming regions

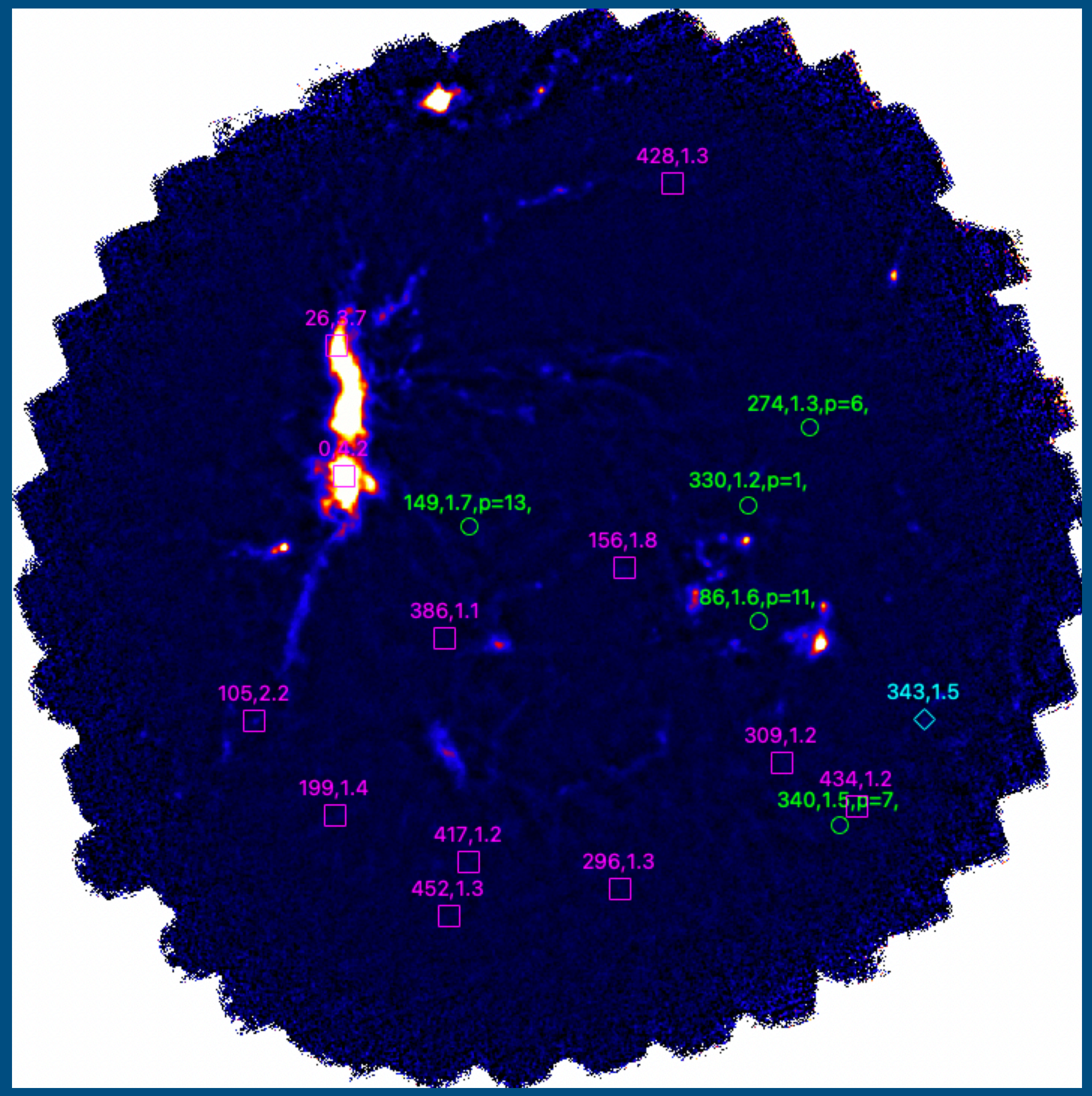
monitoring of 6 regions since 2020

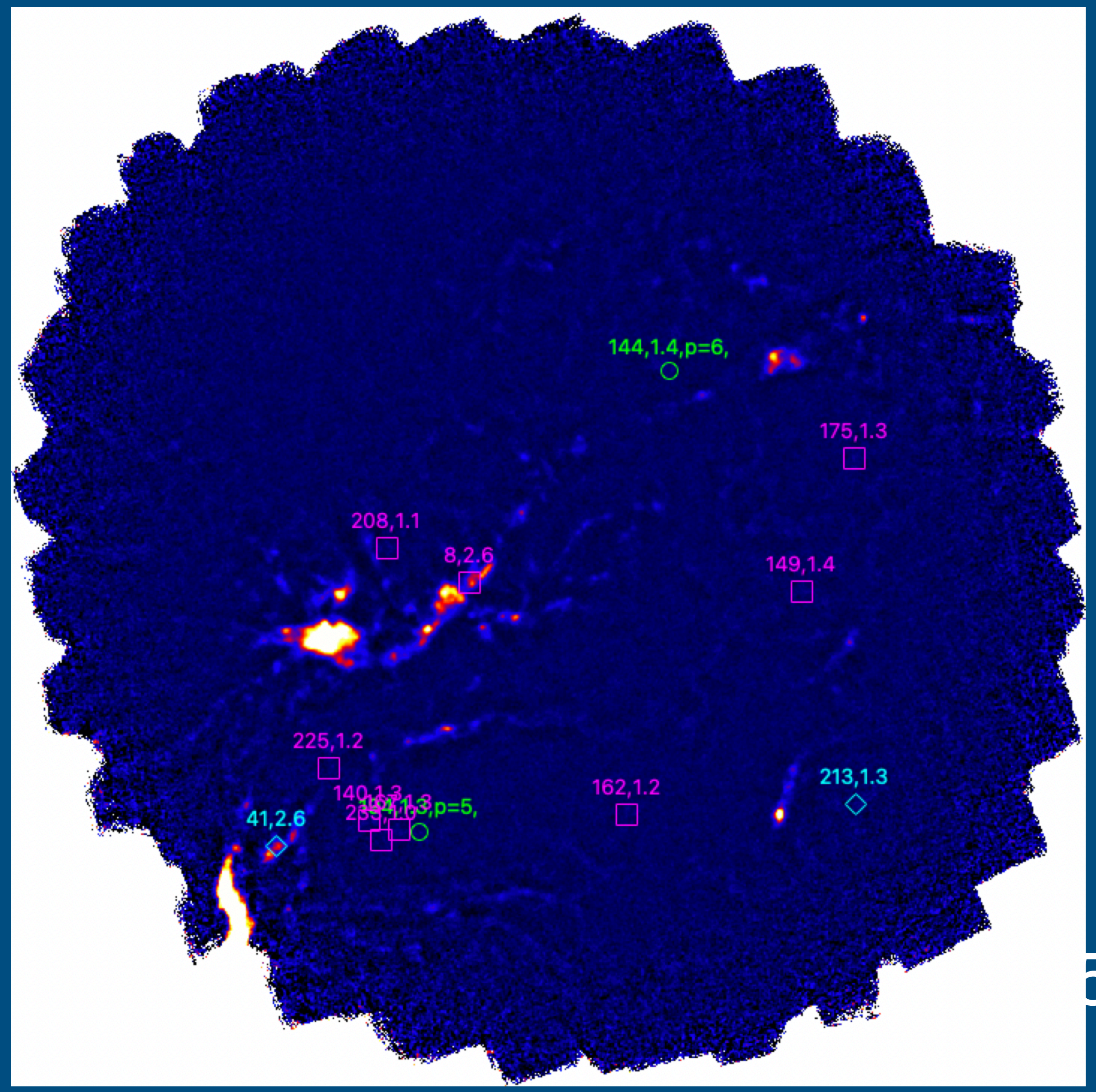


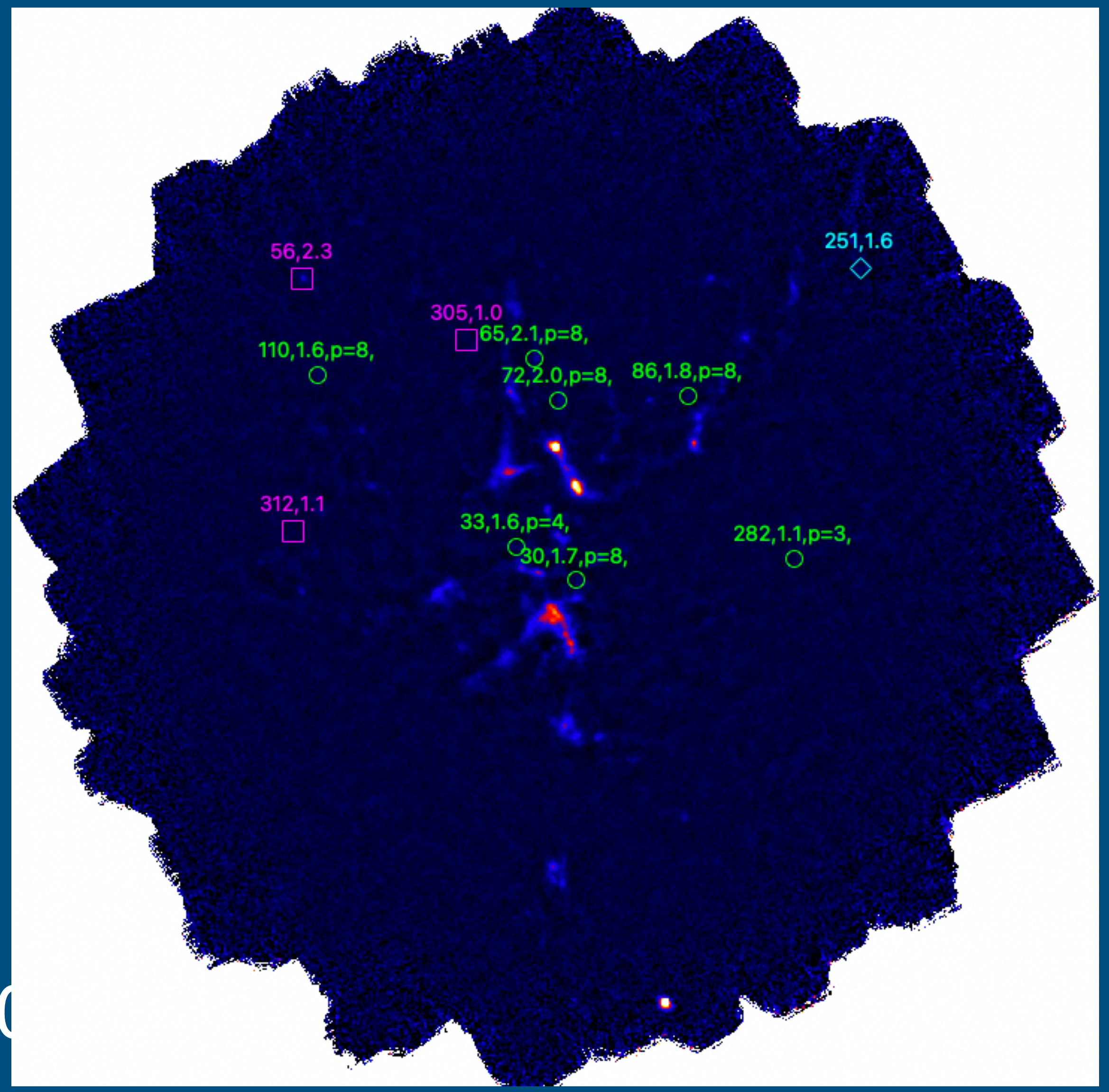


More protostars (better statistics)
also more confusion

Projects/analysis in prep led by
Wang Yao-Te (NTU), Liu Sheng-Yuan (ASIAA)
Zhang Xu, Qiu Keping (NJU)
Park Geumsook (KASI)
Chen Zhiwei (PMO)







Quantifying variability in intermediate-mass star-forming regions