Transients! in the JCMT-Transient Survey

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Transient Team

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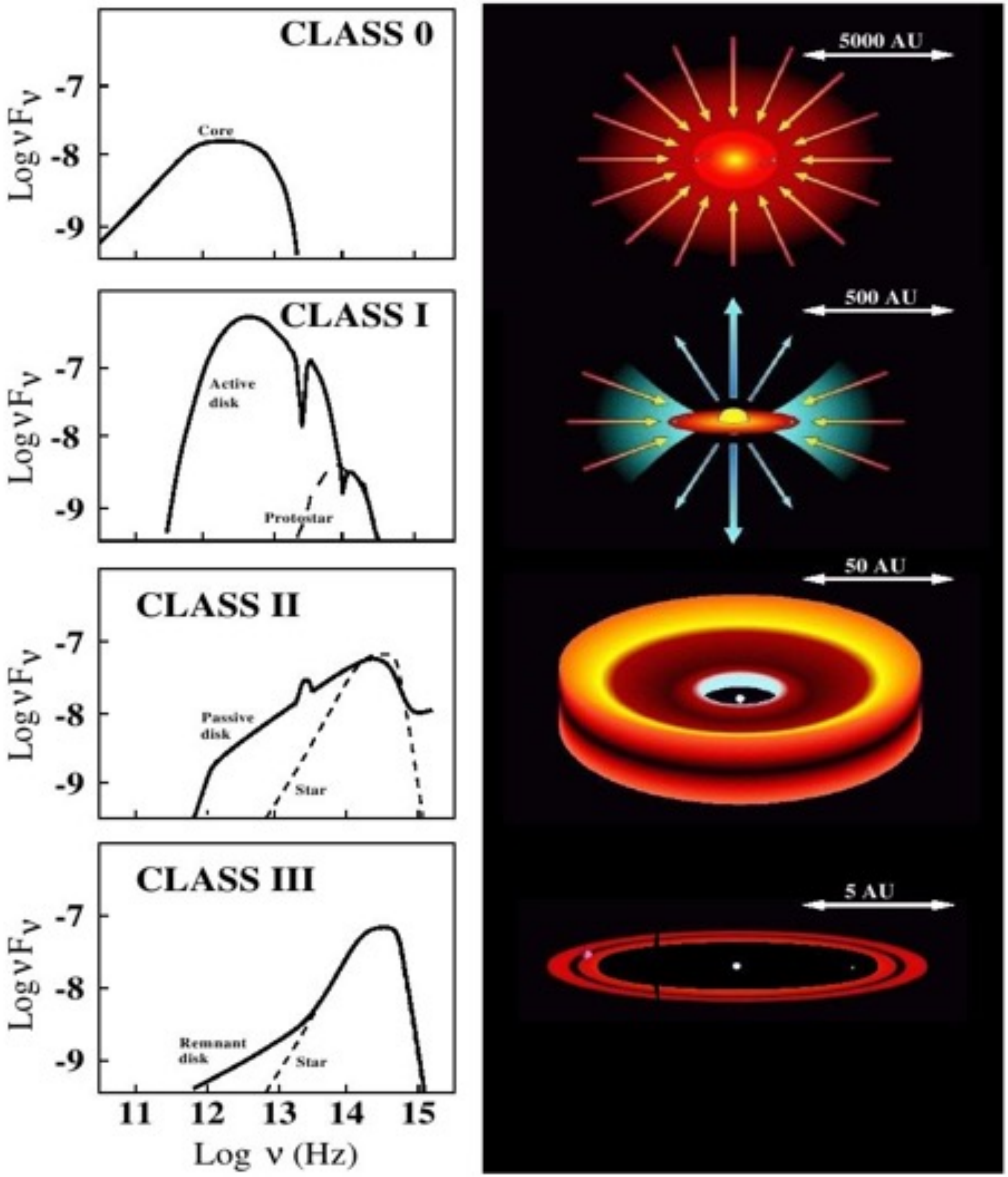
(55 people total)



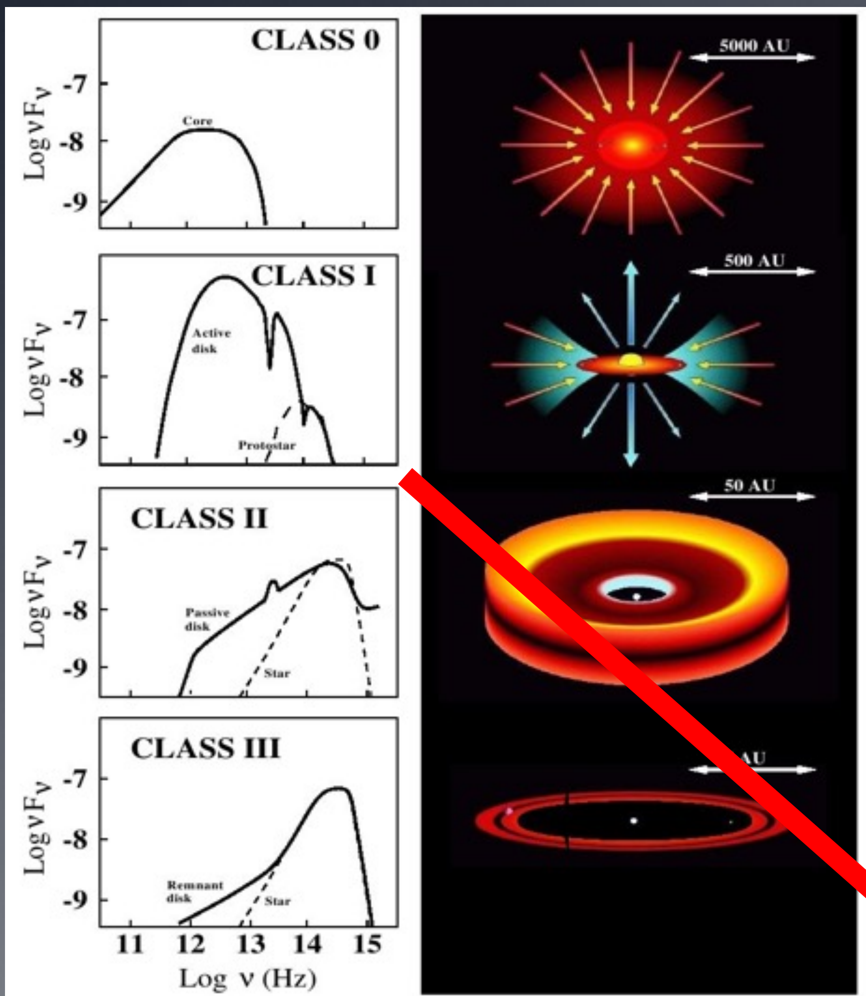
Protostellar Evolution

Cartoon from van Boekel 2005

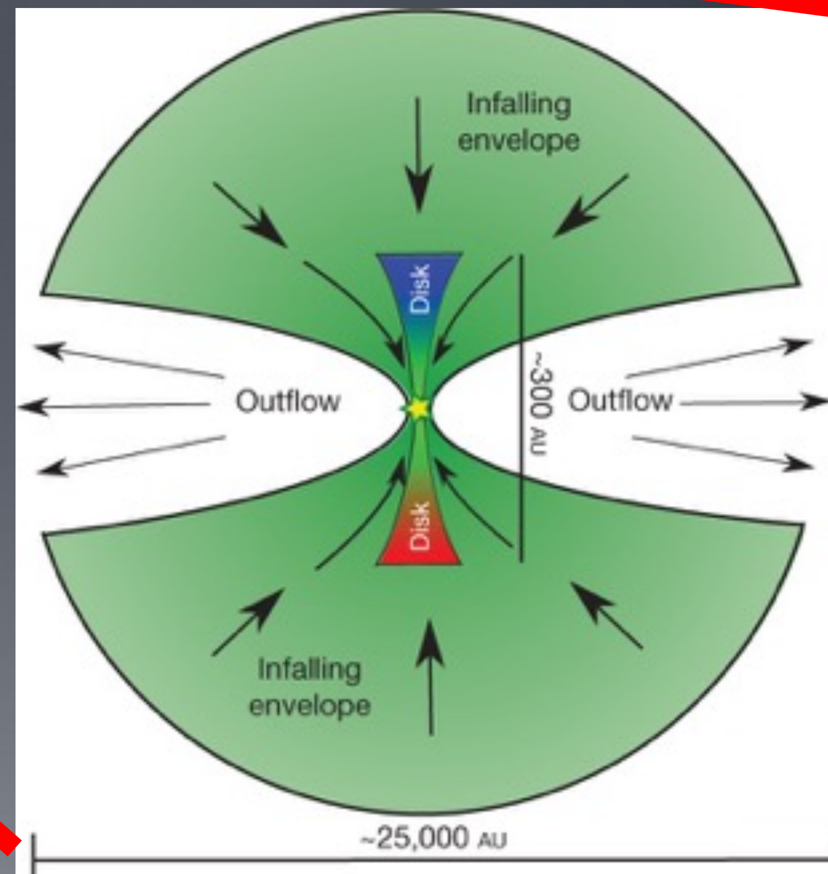
Stars grow during protostellar phase

$L_{tot}=L_{acc}+L_{phot}$

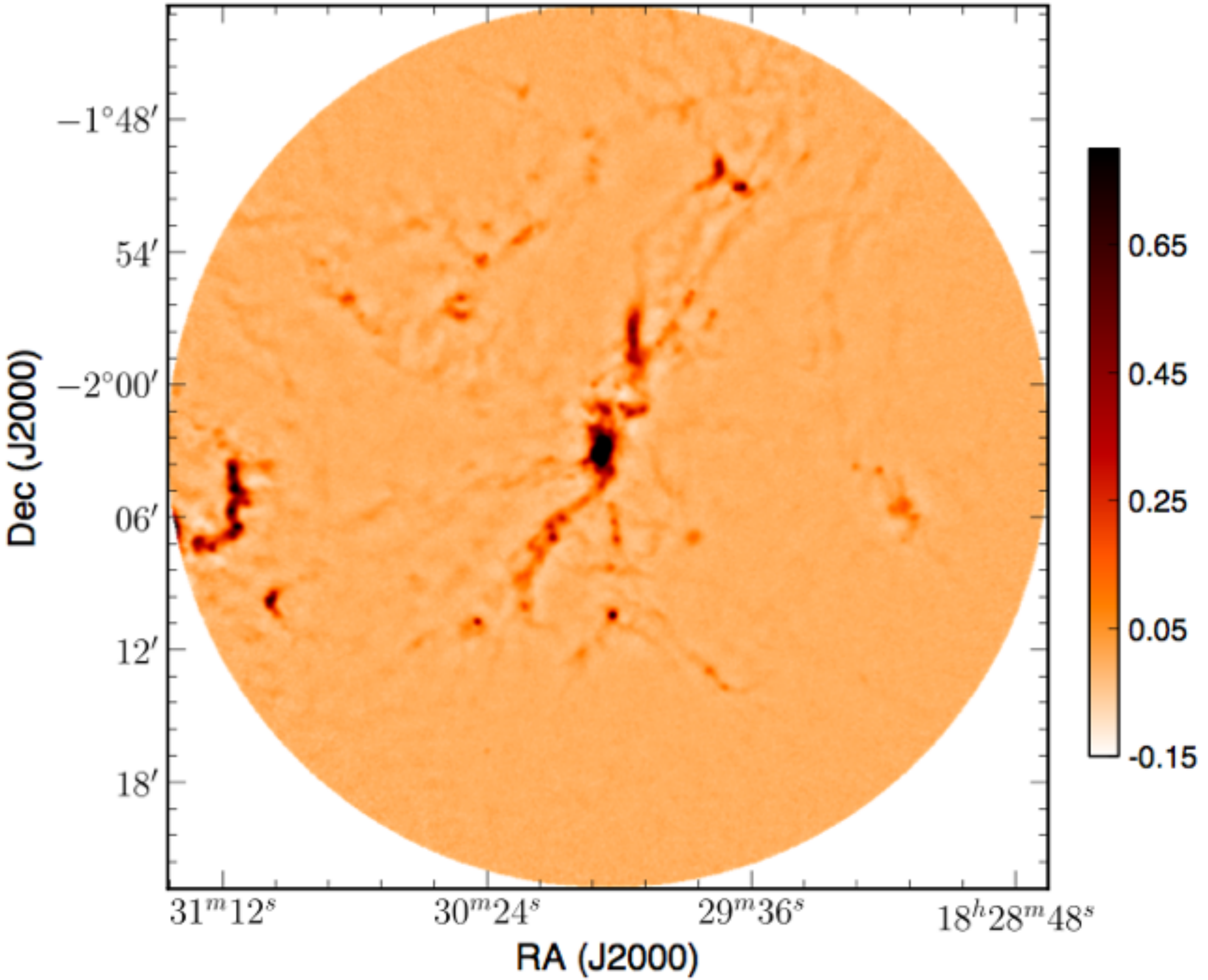
Scattered by dust



Cartoon from Isella 2006



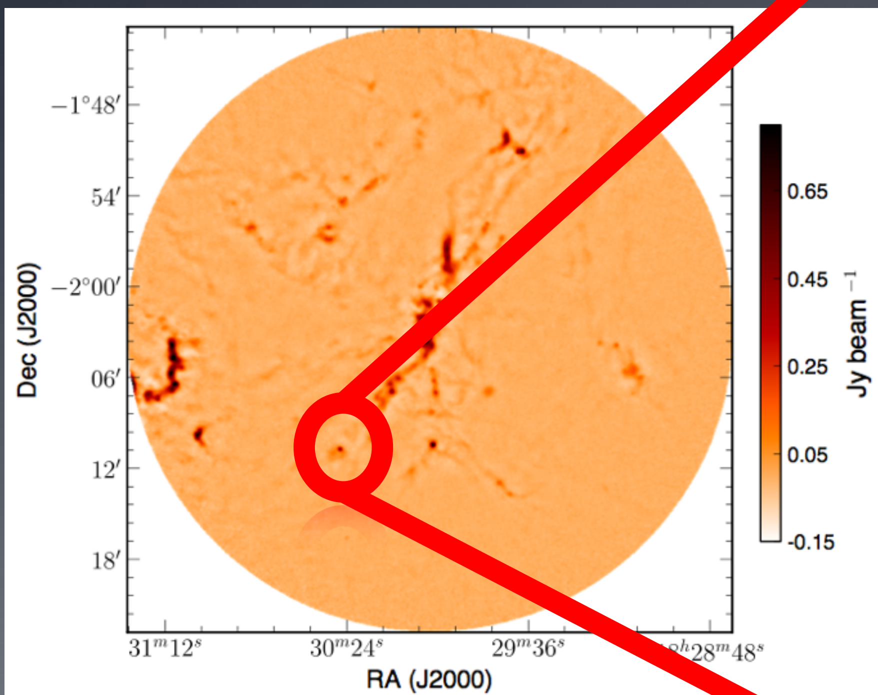
Cartoon from Tobin+2012

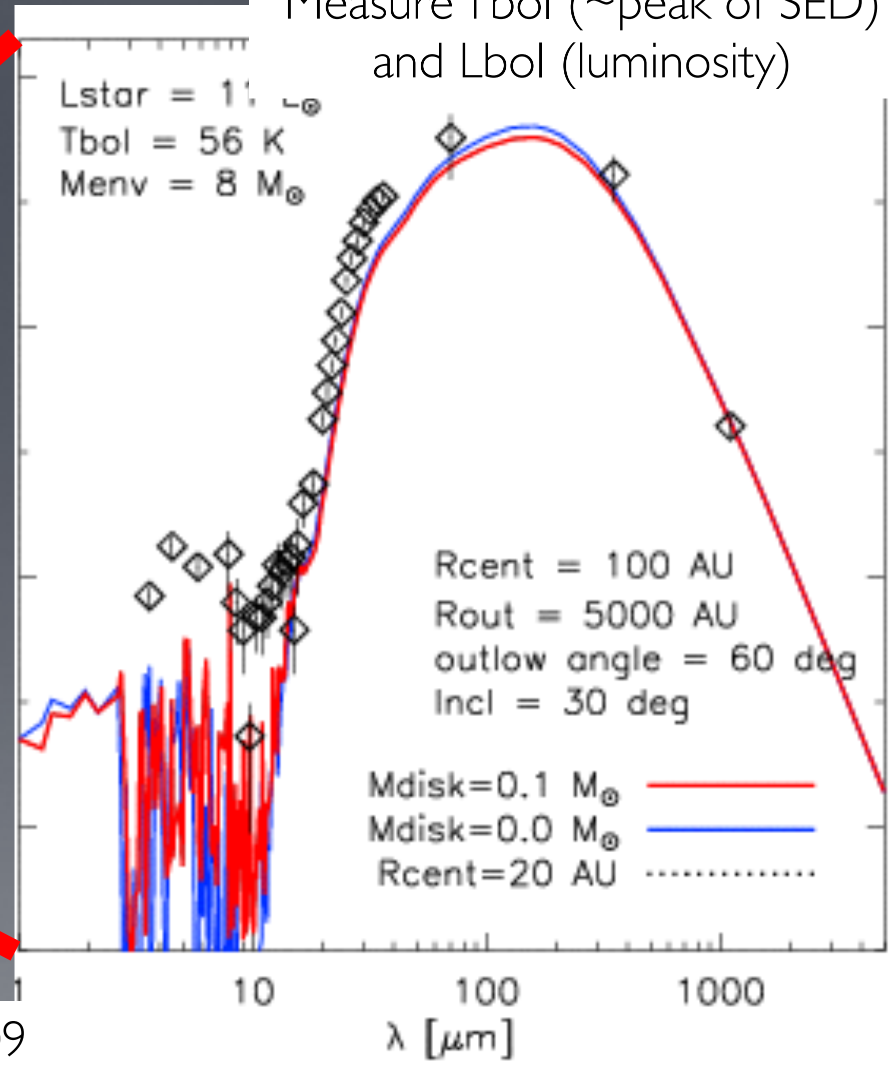


−1°48′
54′
−2°00′
06′
12′
18′
Dec (J2000)
31^{m}12^s
30^{m}24^s
29^{m}36^s
18^{h}28^{m}48^s
RA (J2000)
0.65
0.45
0.25
0.05
-0.15
Jy beam $^{-1}$

Spectral Energy Distribution

Measure Tbol (~peak of SED) and Lbol (luminosity)

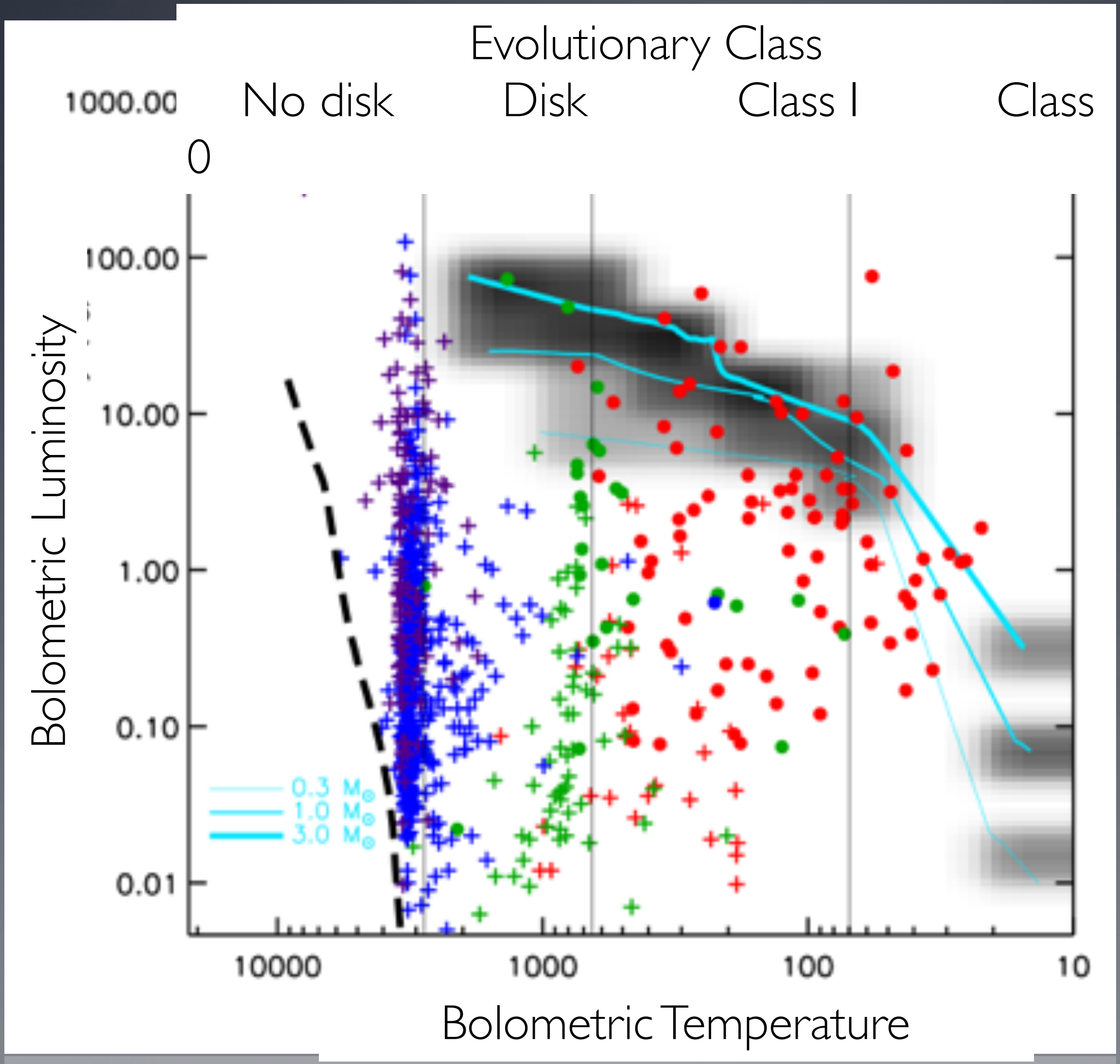




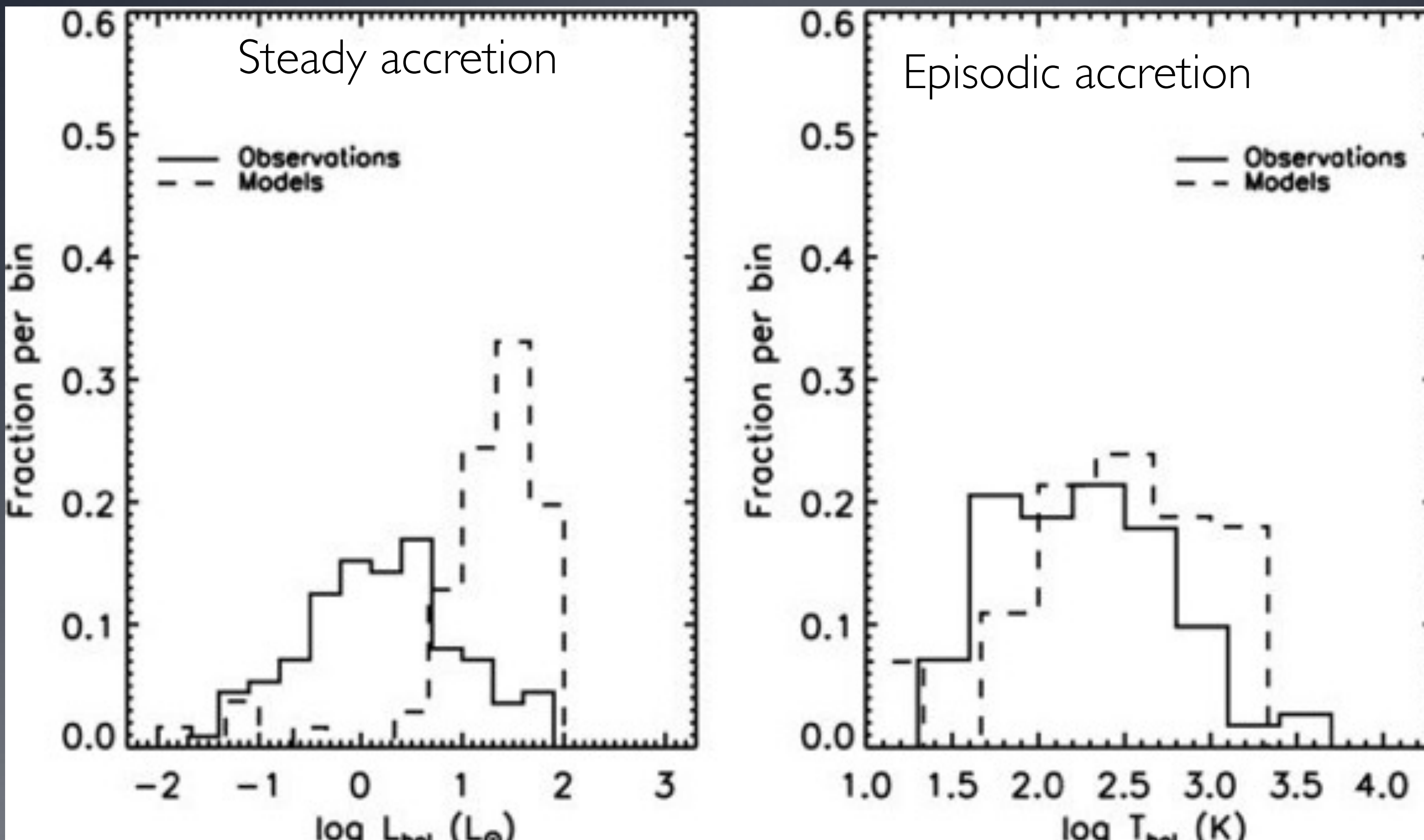
Enoch+2009

Luminosity Problem

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



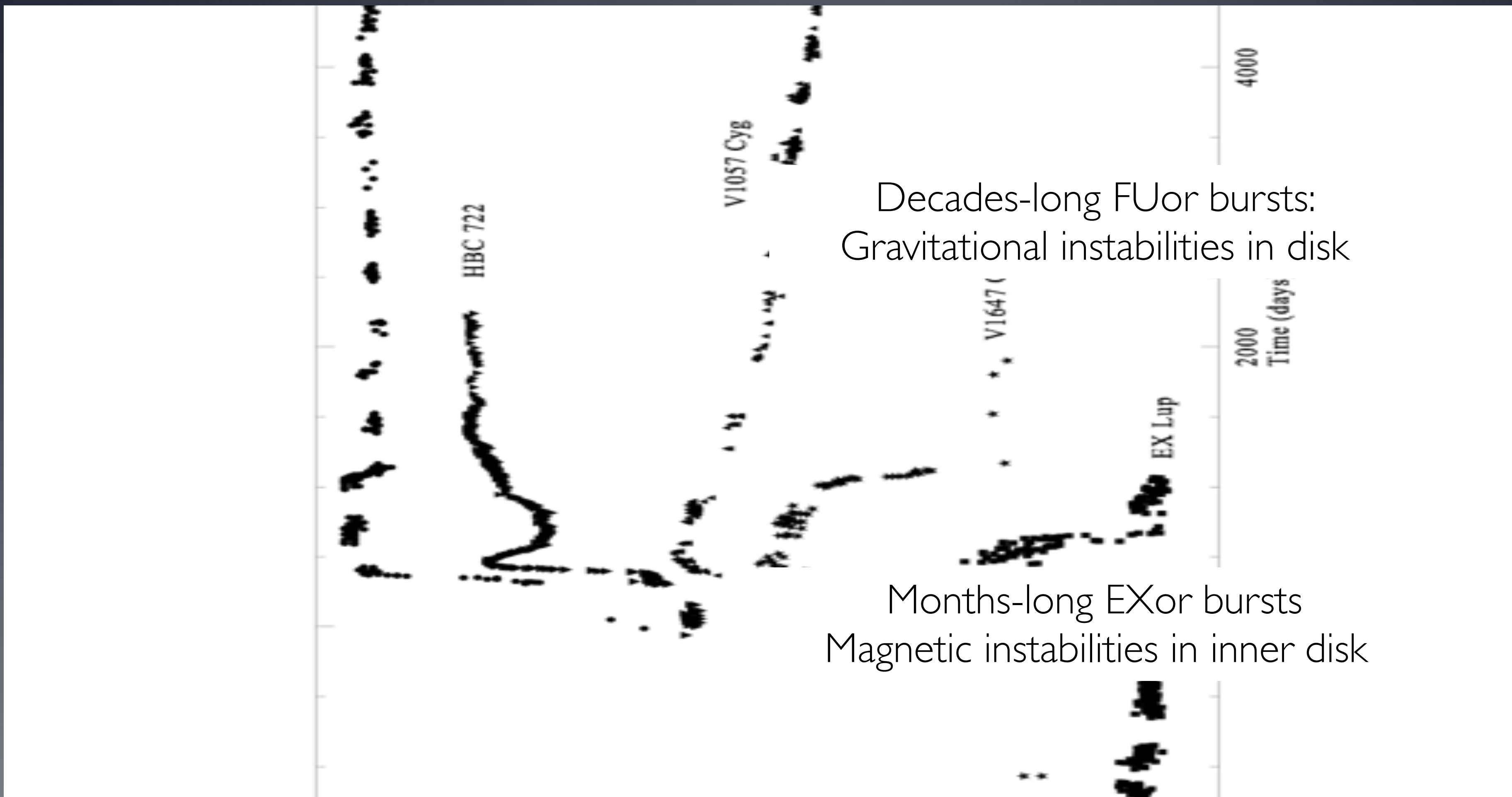
Episodic bursts of accretion
(Kenyon et al. 1990; Dunham, Evans, et al. 2009)



Time dependence needed; episodic accretion is likely (but not only) solution (e.g., Offner & McKee; see review by Hartmann, Herczeg, & Calvet 2016).

FUor and EXor outbursts

(adapted from Kospal+2011)



Decades-long FUor bursts:
Gravitational instabilities in disk

Months-long EXor bursts
Magnetic instabilities in inner disk

Accretion Variability: EX Lup

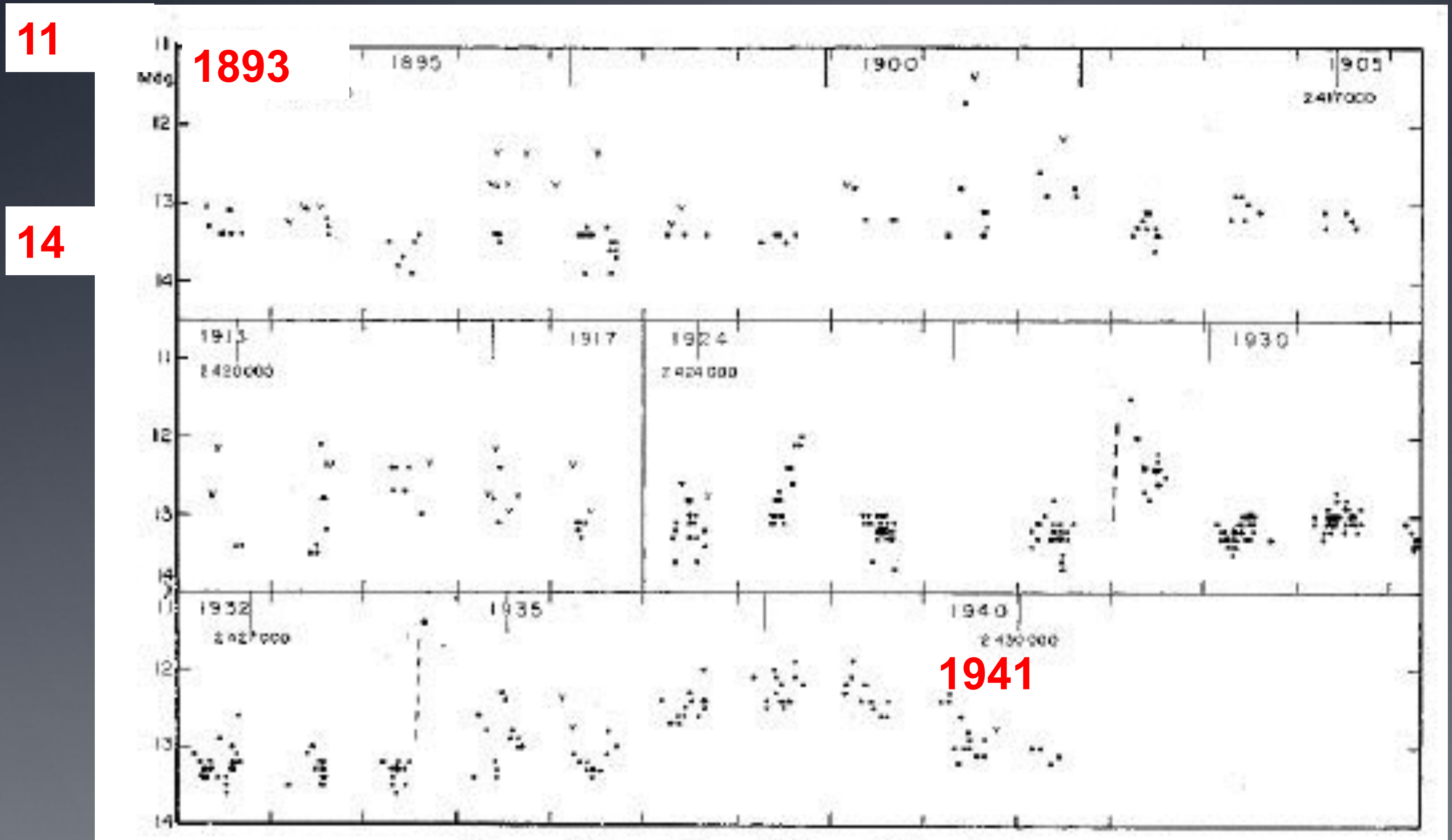


Figure 2. Light variations of HV 11976, from 1893 to 1941.

McLaughlin 1946

EX Lup: 1950-2008

THE SPECTRA OF FIVE IRREGULAR VARIABLE STARS

GEORGE H. HERBIG
Lick Observatory, University of California

The spectra of the five irregular variables listed in Table I have been obtained mainly with the 2-prism spectrograph of the 36-inch refractor and a camera of 3½ inches focal length, a combination which gives a dispersion of 130 A/mm at $H\gamma$. The spectra of four of these stars are reproduced in Plate XVII. The information contained in Table I was taken from the *General*

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HISTORY AND SPECTROSCOPY OF EXor CANDIDATES

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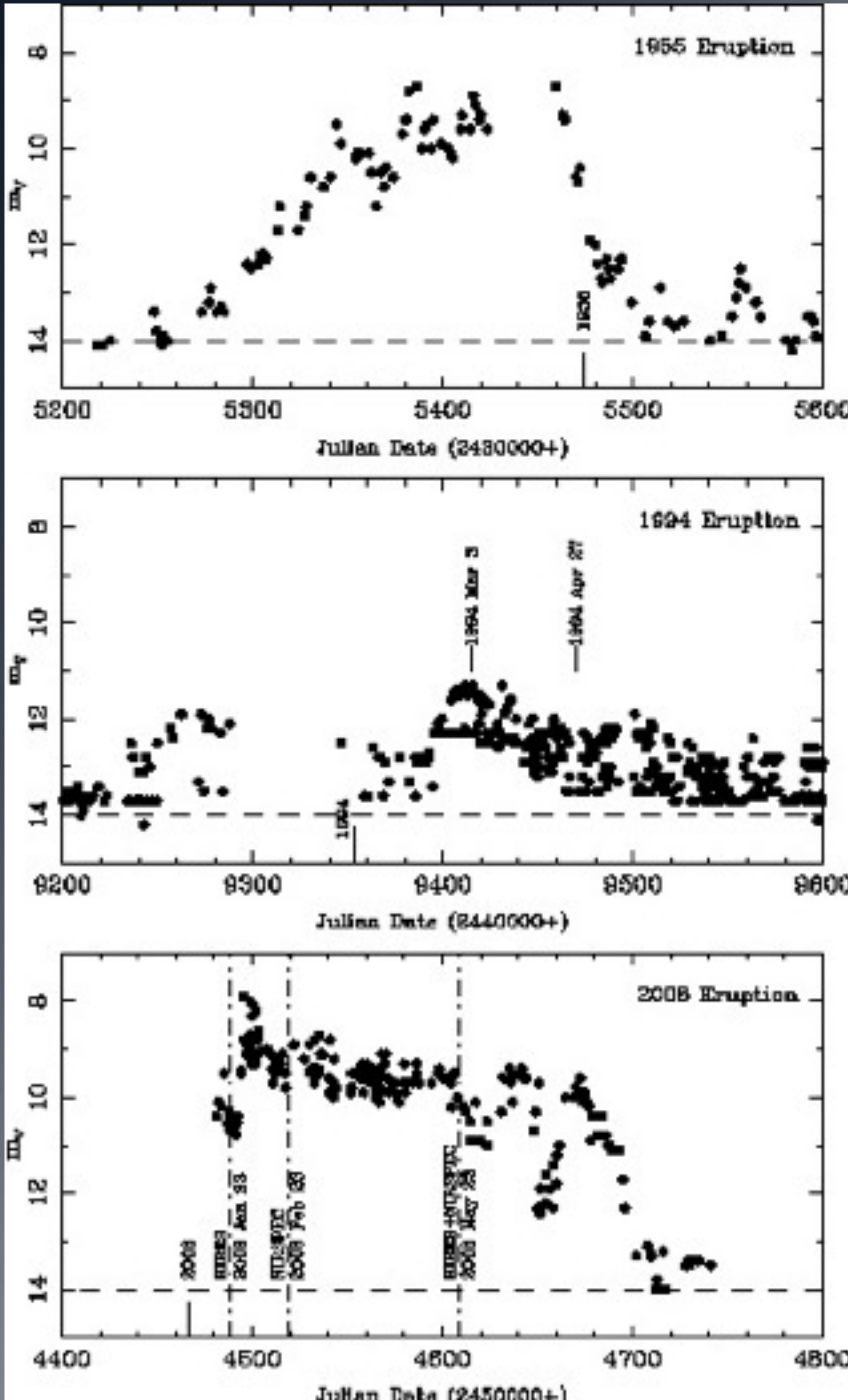
Received 2007 September 7; accepted 2007 November 25; published 2008 January 16

ABSTRACT

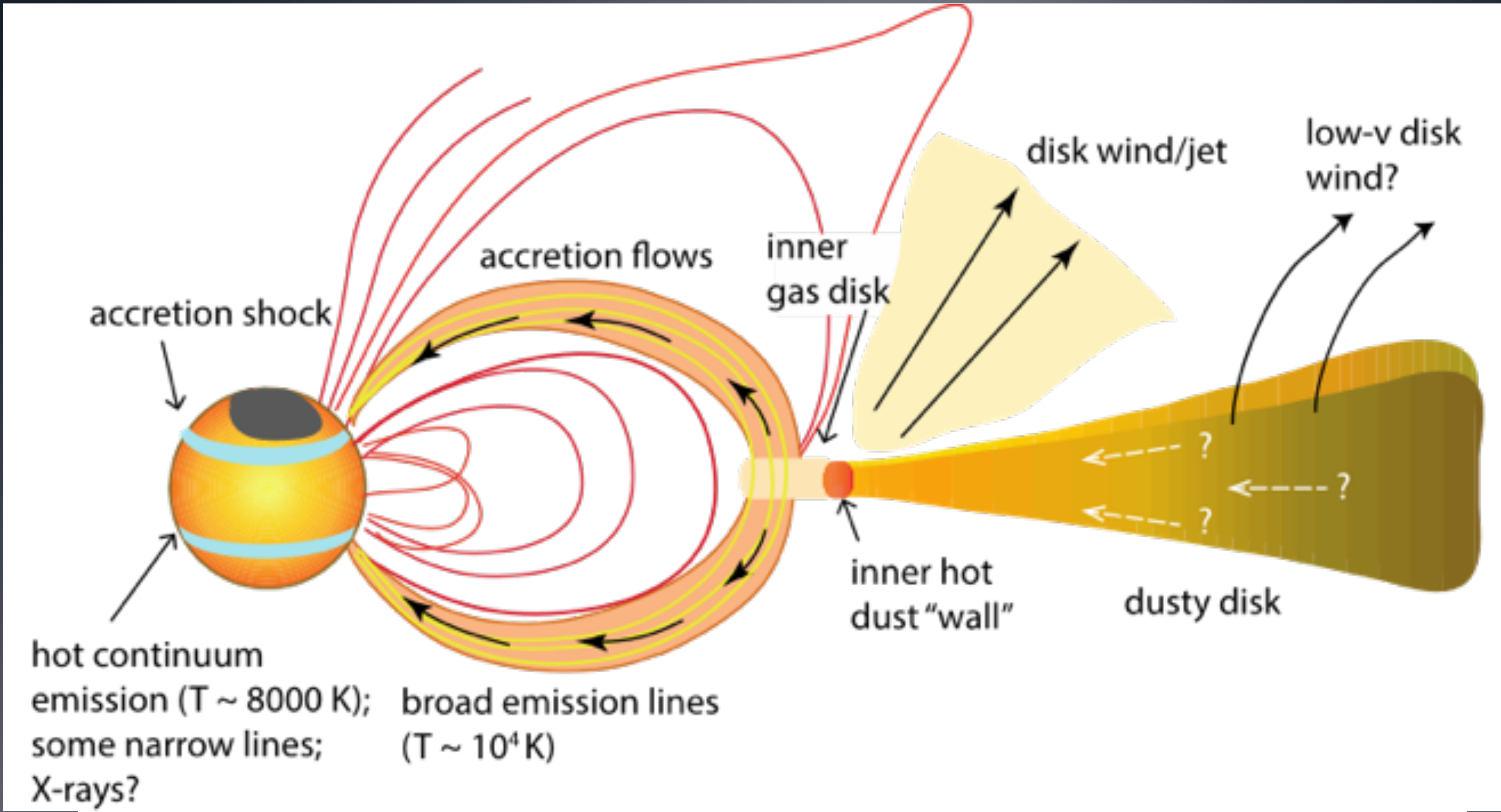
The EXors are T Tauri stars (TTSs) that occasionally flare up from minimum light, apparently as the result of a massive infall of circumstellar material. The prototype, EX Lupi, is the only example that has been examined spectroscopically in any detail, so this paper surveys what can be gleaned from the literature about five candidate EXors, and describes new observations. The aim is to clarify the nature of these objects, and to determine whether they bear a convincing resemblance to EX Lup itself. The spectroscopy was carried out with the HIRES spectrograph ($R = 48{,}000$) at the Keck I telescope between 2004 and 2007. Three of the stars examined are in or near the Orion Nebula (NY, V1118, and V1143 Ori), while V1184 Tau is in the molecular cloud CB34, and V350 Cep is at the edge



2008 Outburst of EX Lup

(Aspin+2010)

- 5-magnitude brightness
  - 2 x 10^{-7} M_{sol}/yr
  - 100 times higher than quiescence
- Lasted about half a year
  - Similar strength, duration as 1955 outburst



Cartoon from Hartmann, Herczeg, & Calvet 2016, ARAA

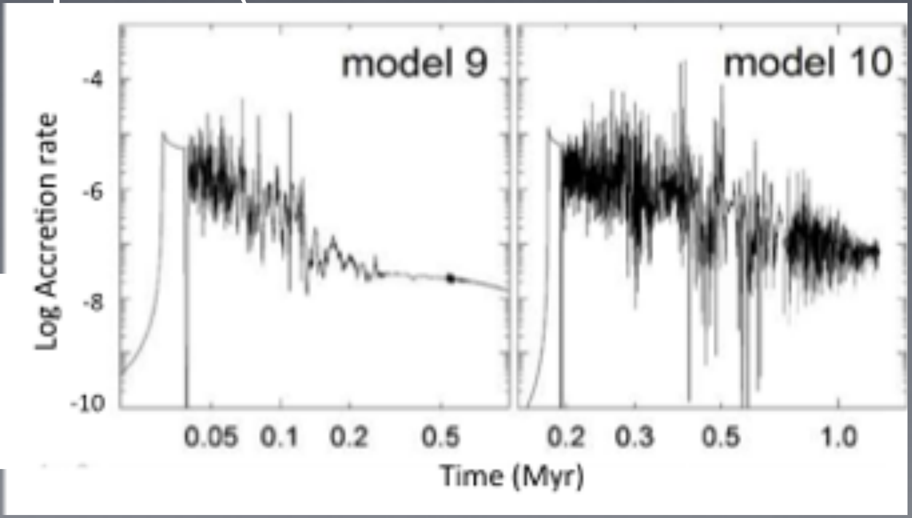
FUors: accretion rate is so large that magnetosphere gets crushed

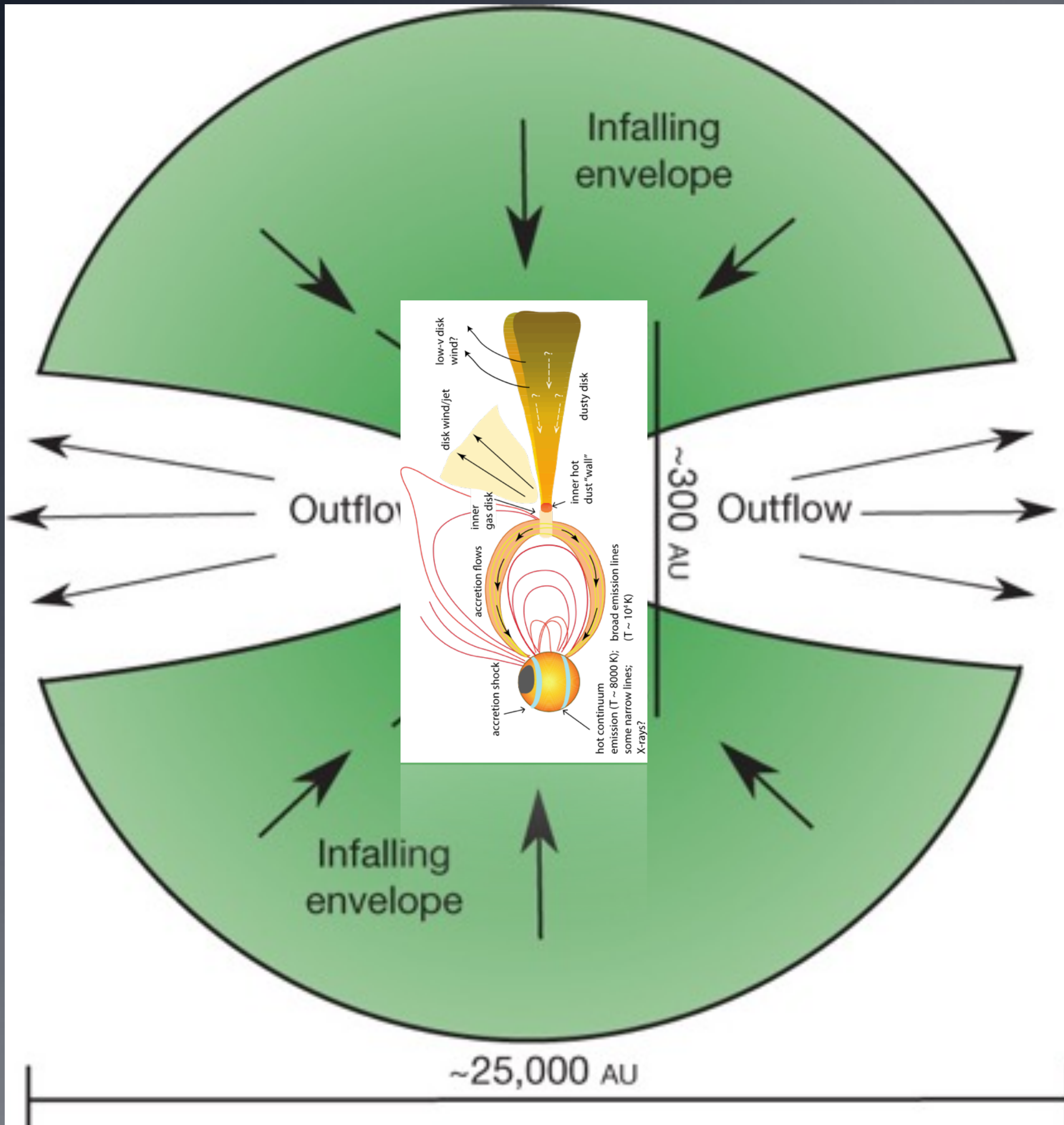
Causes of outbursts

- Disk instabilities (universal)
  - Gravitational, magneto-rotational, thermal
- Binarity (e.g. Bonnell & Bastien 1992, Reipurth 2000)
- Magnetospheric instabilities (D'Angelo & Spruit 2010, Armitage 2016)
- Tidal disruption of planets or alien weaponry (Herczeg+2016)

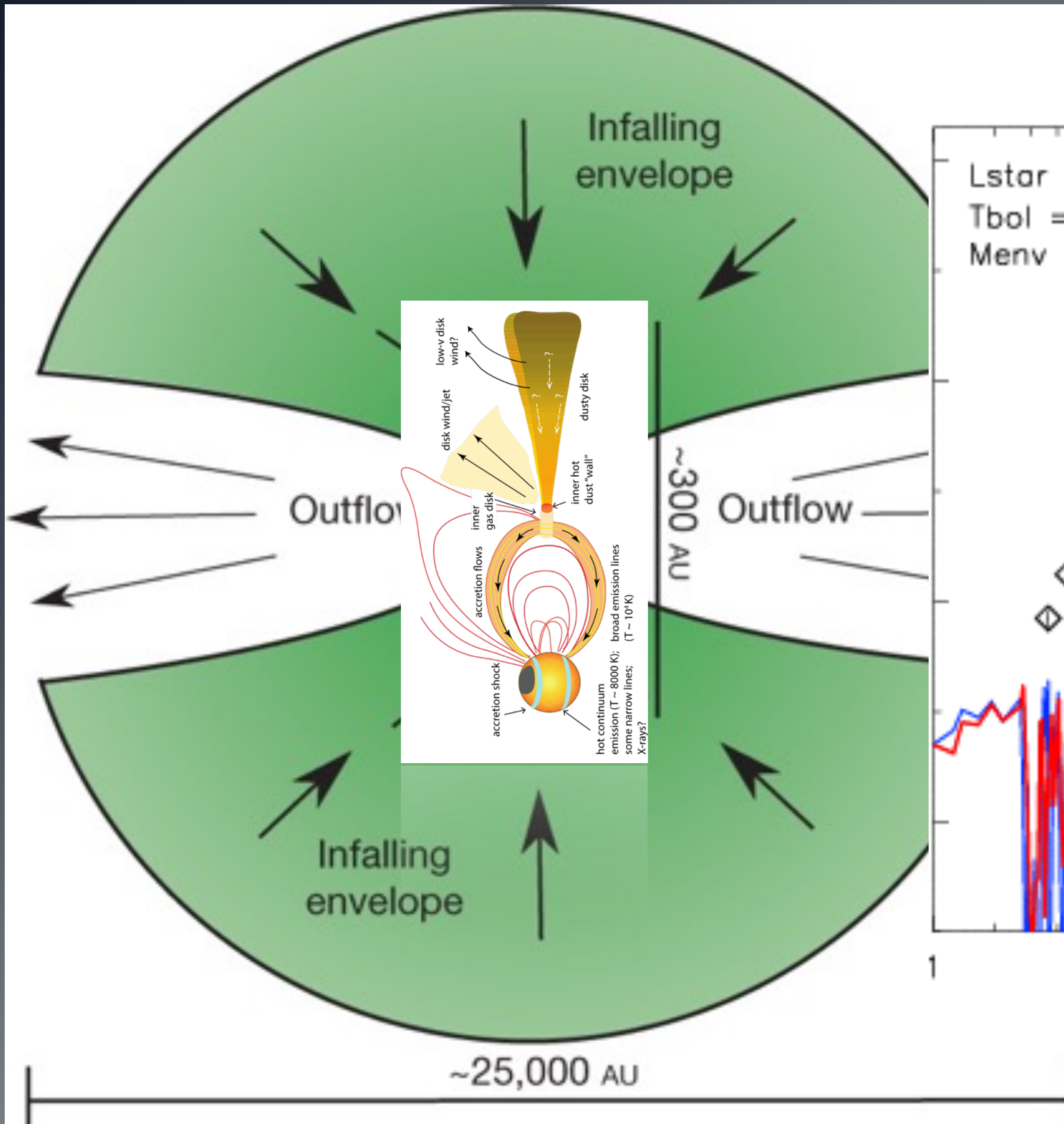
Frequency: 1 of 10^4 stars from optical (Hillenbrand & Findeisen 2015)

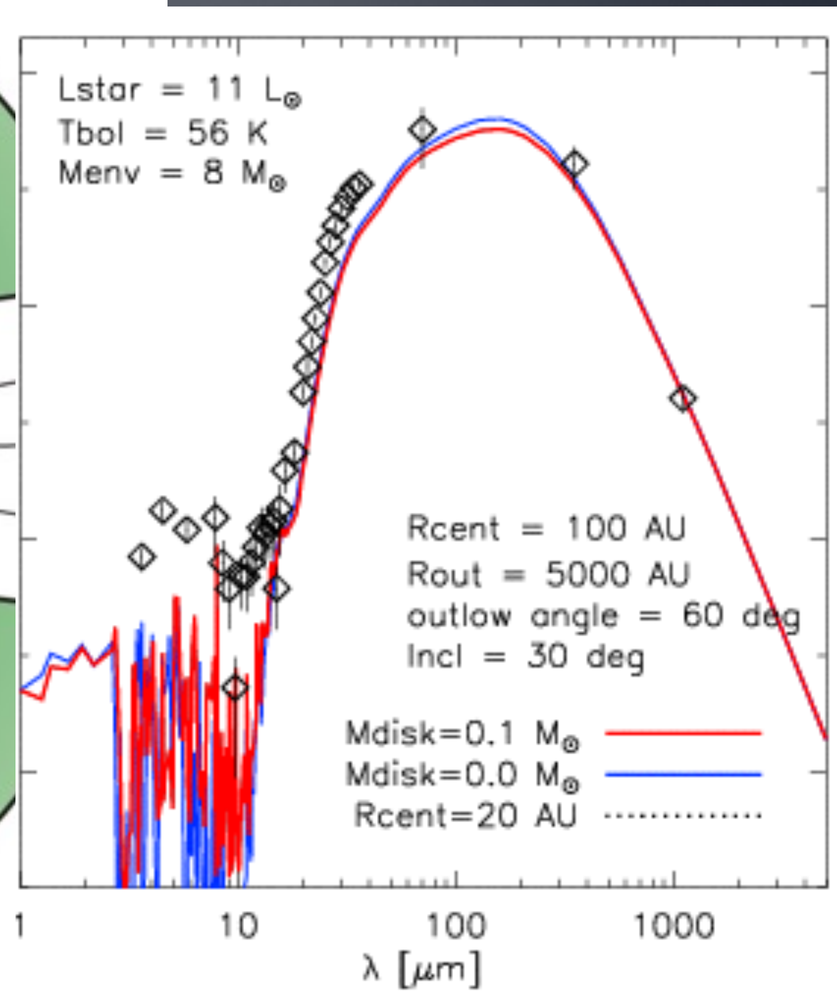
Models from Dunham & Vorobyov (2012)
See also, e.g., Zhu+, Bae+, Stamatellos+, Vorobyov+, Machida+, others





Protostars: bury accretion outburst in an envelope


Infalling envelope
Outflow
Outflow
~300 AU
Infalling envelope
~25,000 AU
low-v disk wind?
disk wind/jet
dusty disk
inner hot dust "wall"
inner gas disk
accretion flows
broad emission lines (T ~ 10⁴ K)
accretion shock
hot continuum emission (T ~ 8000 K); some narrow lines; X-rays?

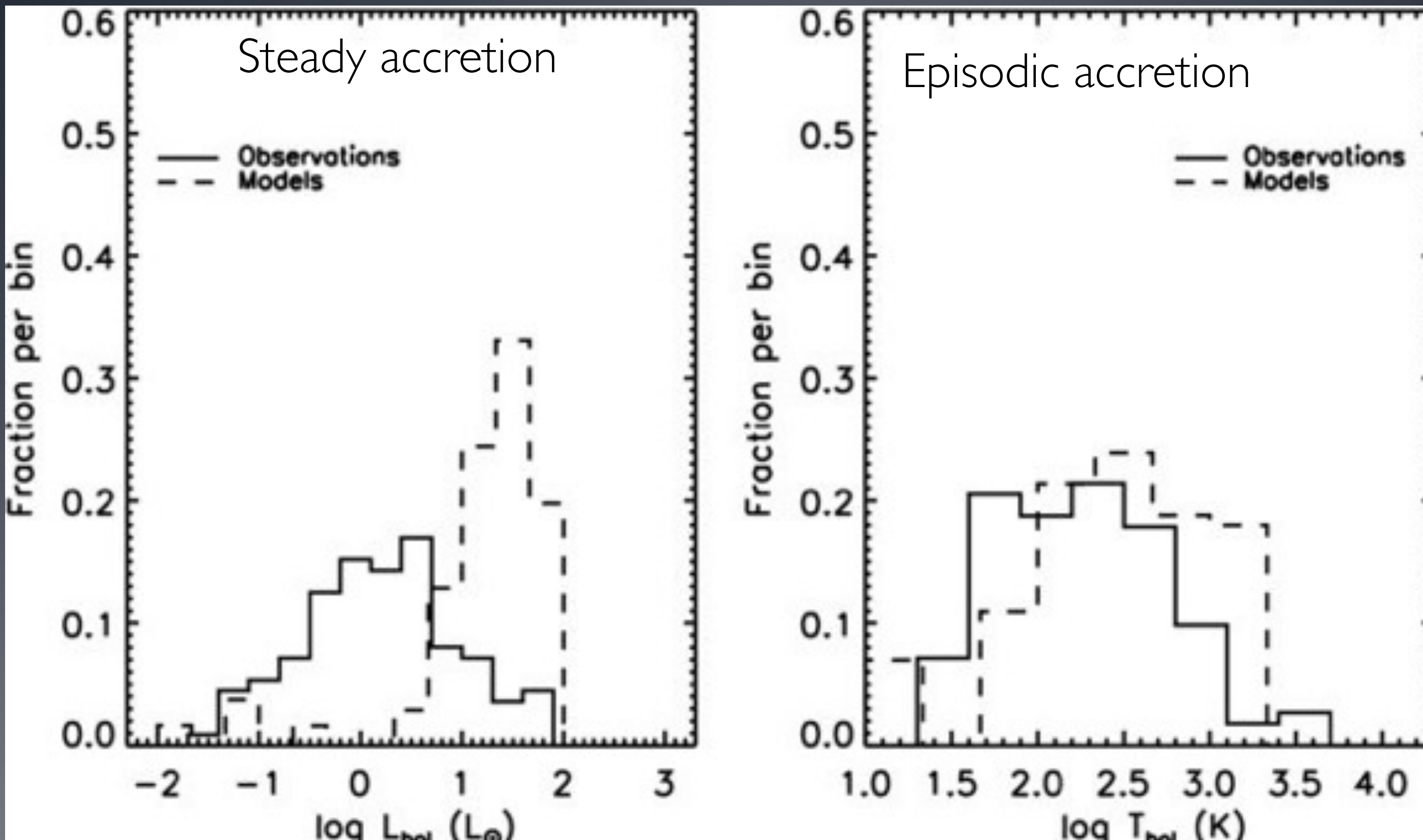

Lstar = 11 L⊙
Tbol = 56 K
Menv = 8 M⊙
Rcent = 100 AU
Rout = 5000 AU
outlow angle = 60 deg
Incl = 30 deg
Mdisk=0.1 M⊙
Mdisk=0.0 M⊙
Rcent=20 AU
1
10
100
1000
λ [μm]

Era of Transient Surveys (ASAS-SN, PTF, Gaia, LSST)

Accretion bursts in youngest stages of stellar growth:
Not detectable in optical, near-IR surveys

Episodic bursts of accretion

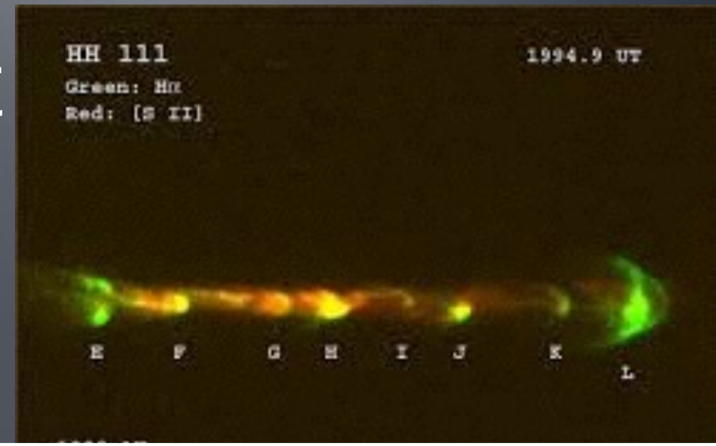
(Kenyon et al. 1990; Dunham, Evans, et al. 2009)

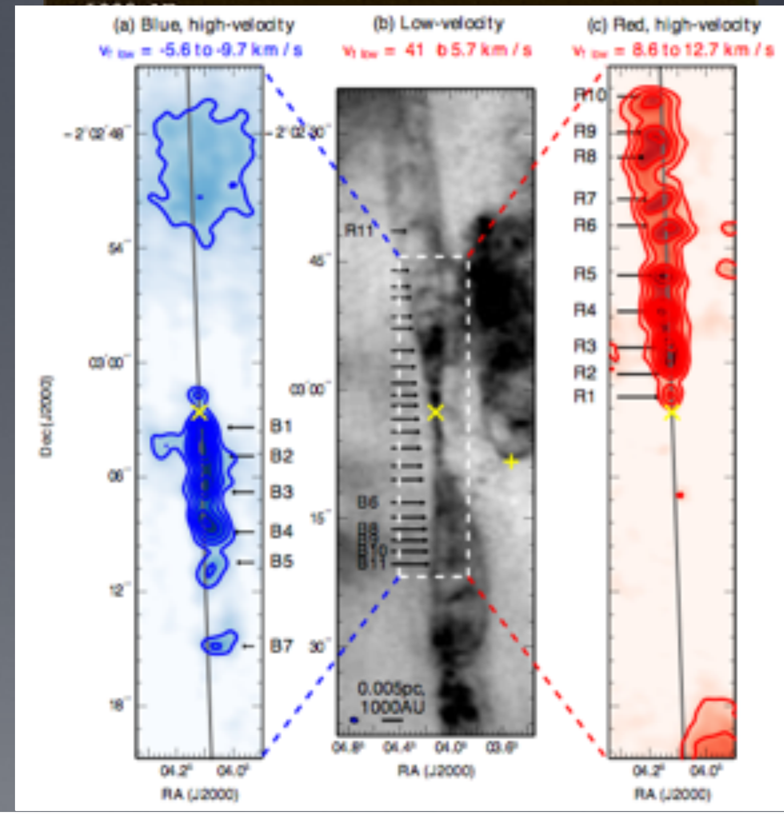


Time dependence needed; episodic accretion is likely (but not only) solution (e.g., Offner & McKee; see review by Hartmann, Herczeg, & Calvet 2016).

Evidence for episodic accretion

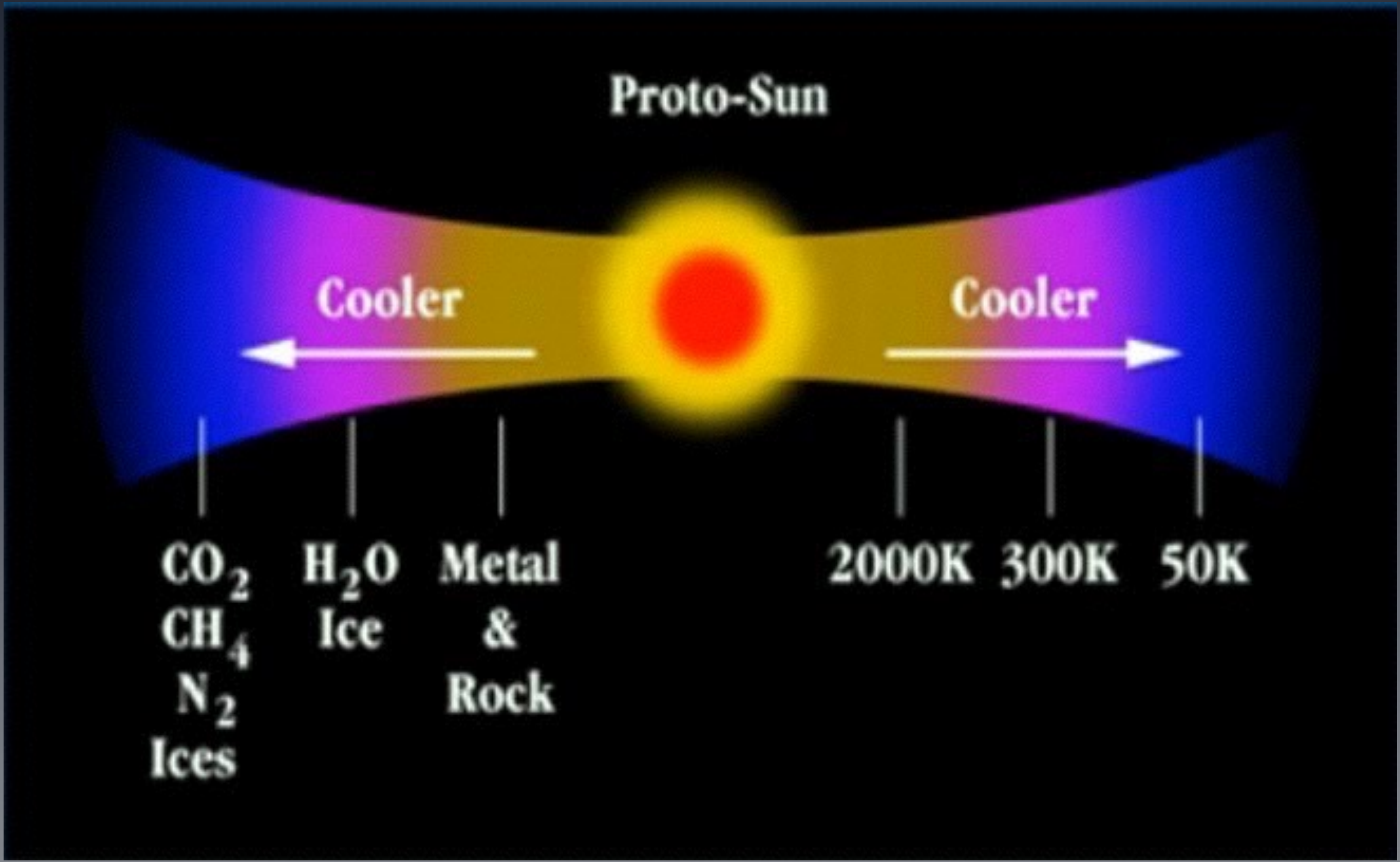
- Outbursts on more evolved protostars (FUors, EXors)
- Repeated jet shocks
- Chemical signatures of past epochs of high luminosity (e.g., Kim+2011; Jorgensen+2013)
- Models of disk instabilities



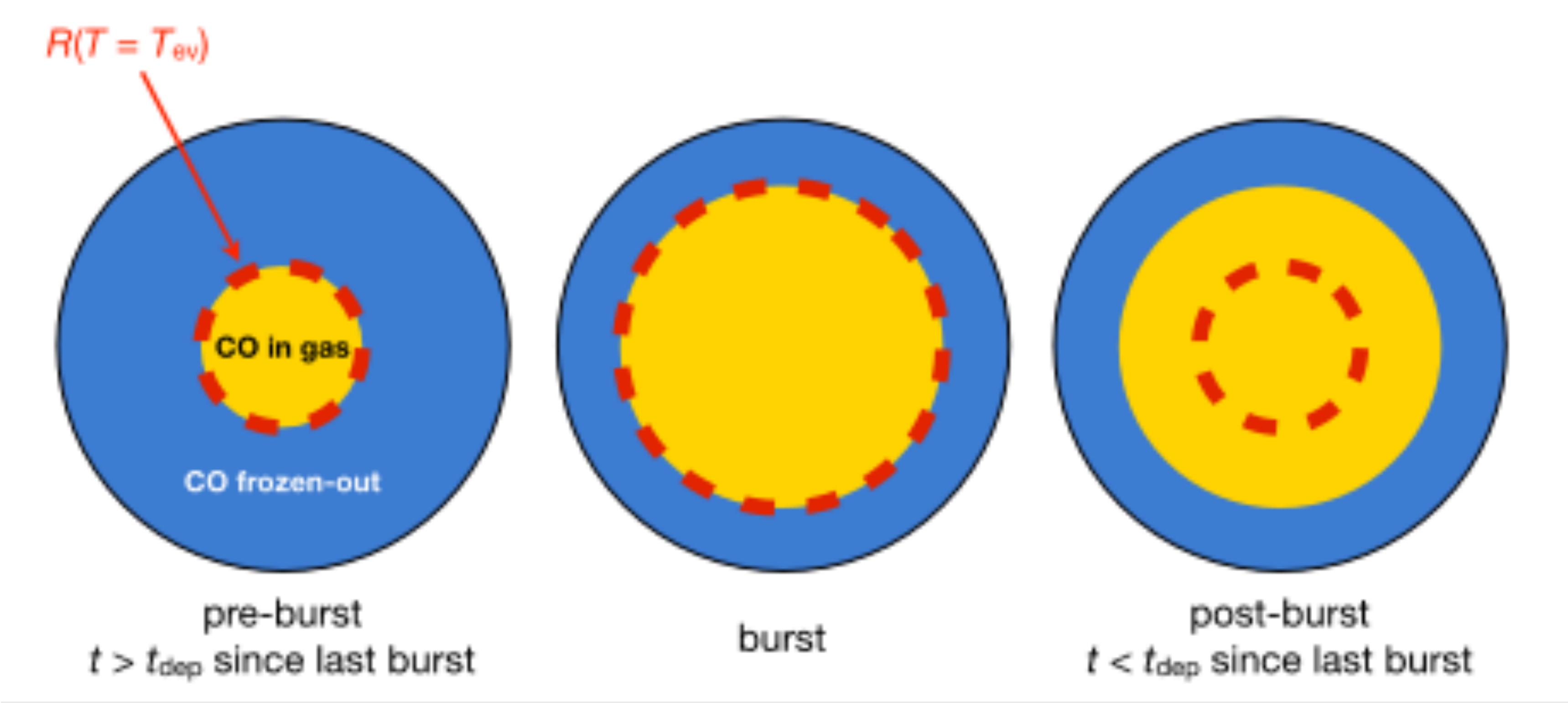


Jet shocks of YSOs
(Reipurth 1989; Hartigan+2011; Plunkett+2015)

Evidence for episodic accretion: envelope chemistry+snow line

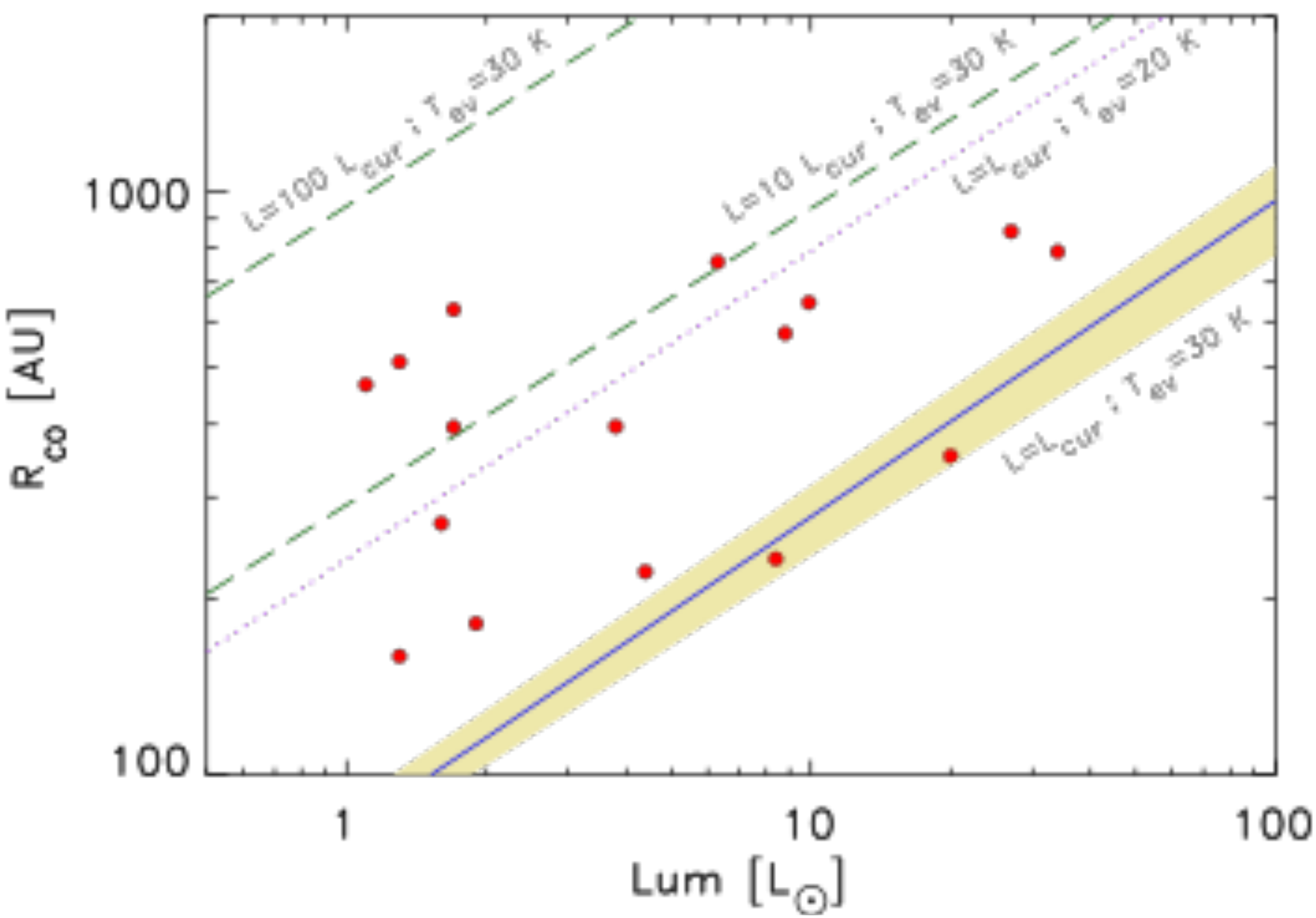


Evidence for episodic accretion: envelope chemistry+snow line



Jørgensen et al. 2015; see also, e.g., J.-E.Lee 2007

Envelope snow line and past variability



Jørgensen et al. 2015

Evidence for episodic accretion

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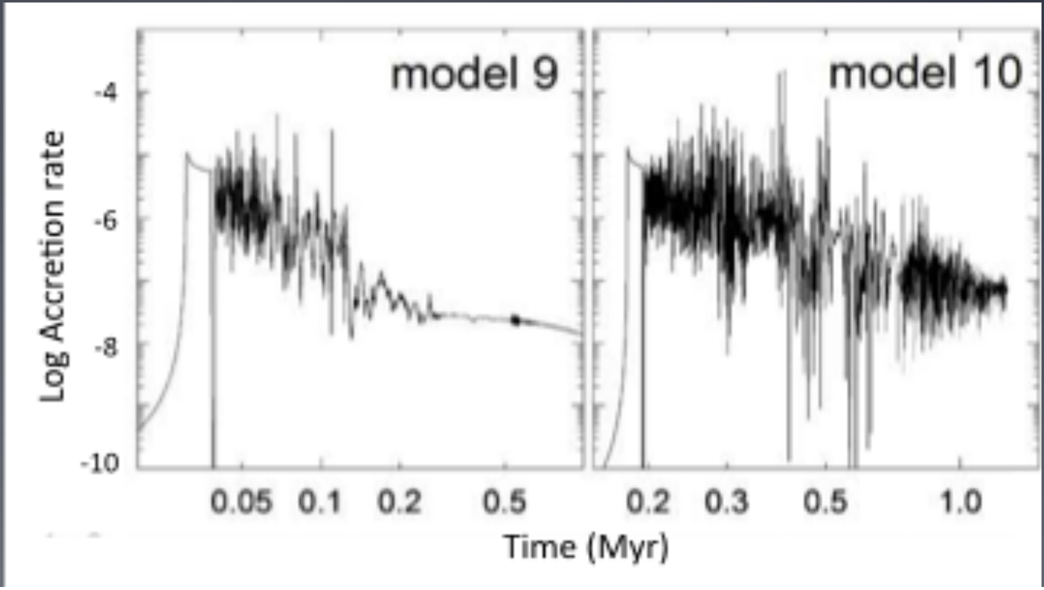
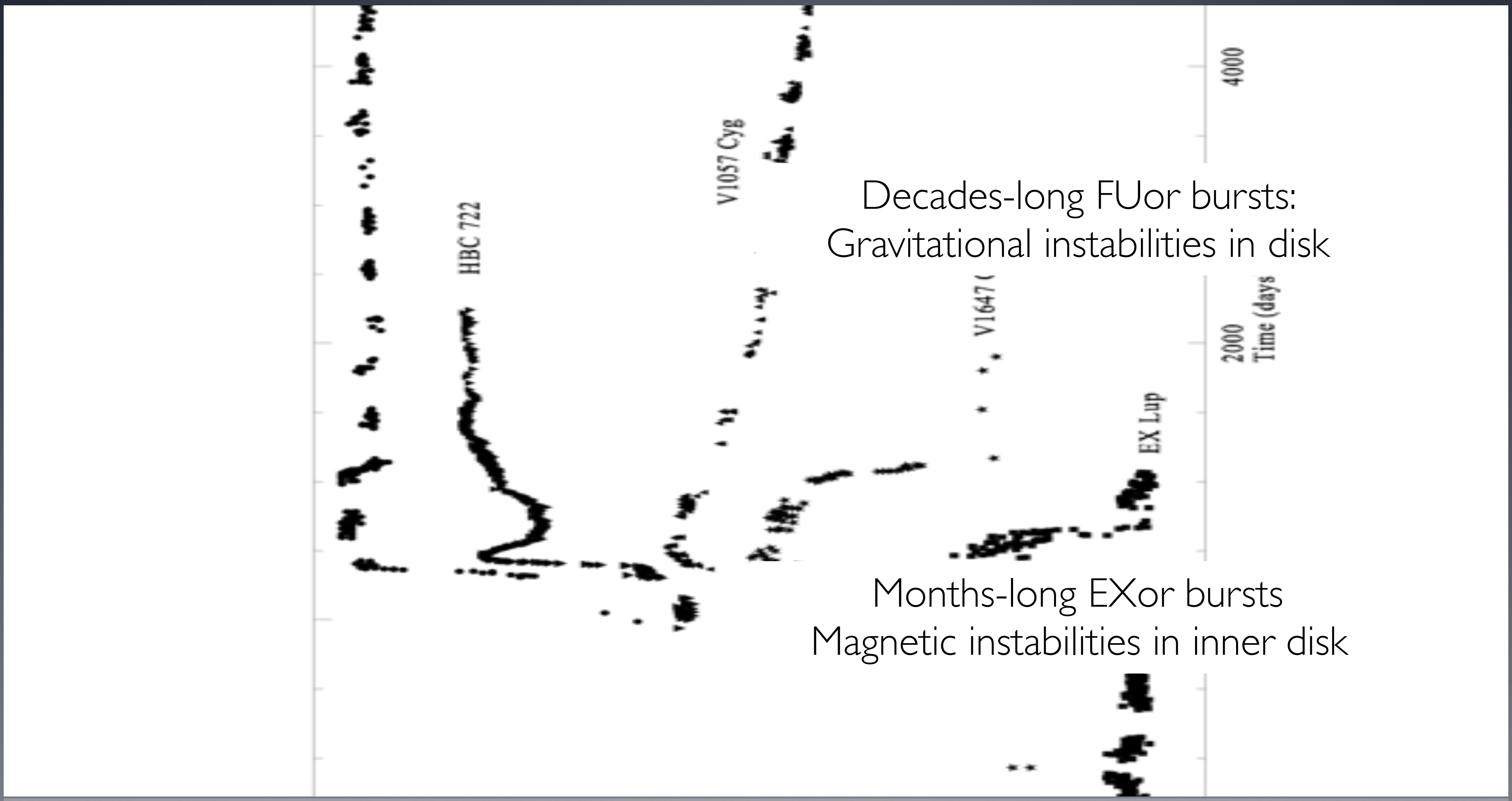
- **Models of disk instabilities**



Models from Dunham & Vorobyov (2012)
See also, e.g., Zhu+, Bae+, Stamatellos+, Vorobyov+, Machida+, others

How to detect protostellar variability?
(adapted from Kospal+2011)



Decades-long FUor bursts:
Gravitational instabilities in disk

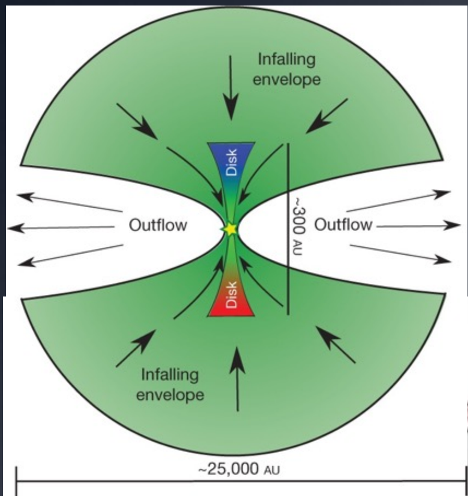
Months-long EXor bursts
Magnetic instabilities in inner disk

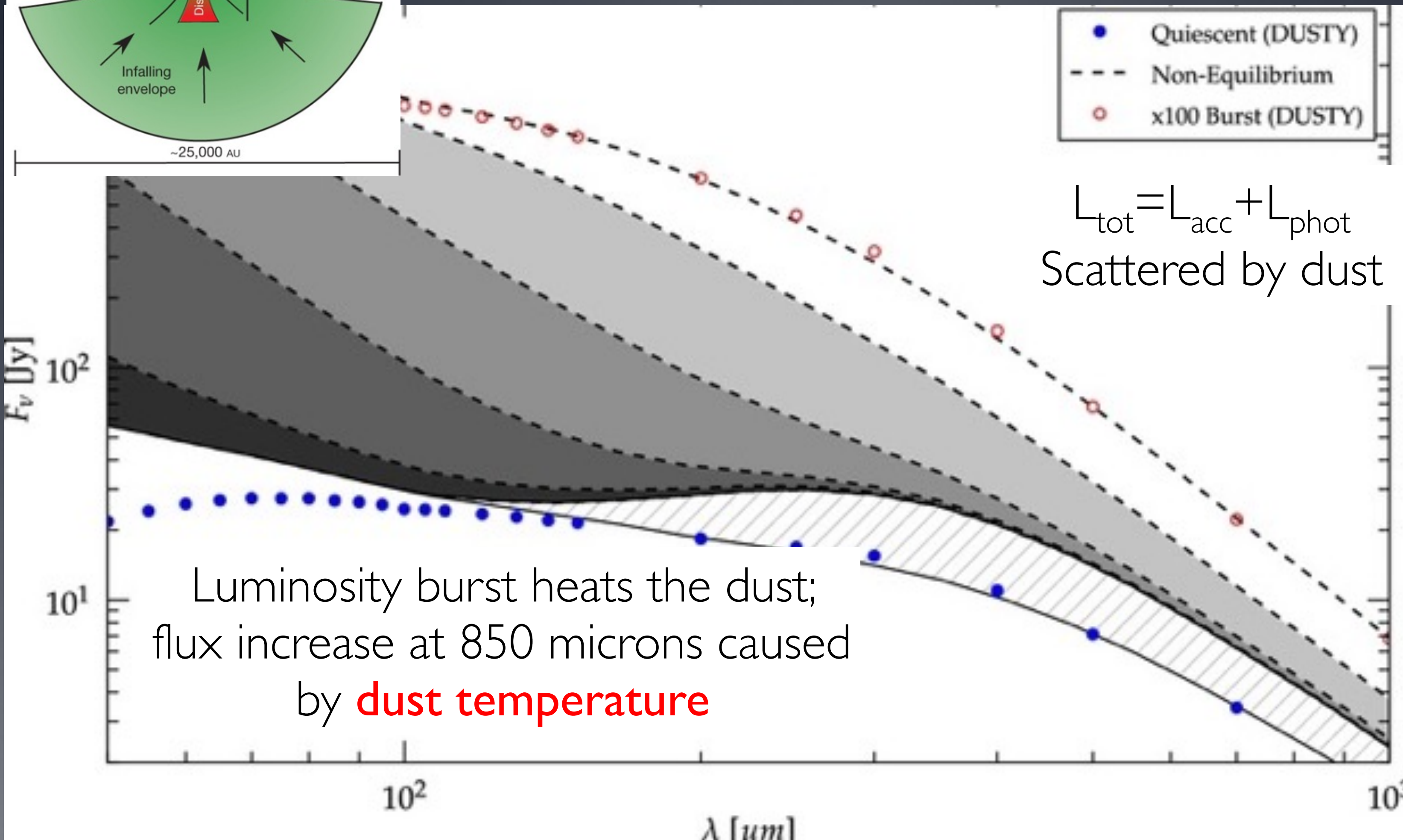
Direct detection of protostellar variability?

ASIAA Conference hosted by Sienny Shang in 2011

Radiative transfer: a burst through an envelope

(Johnstone et al. 2013)





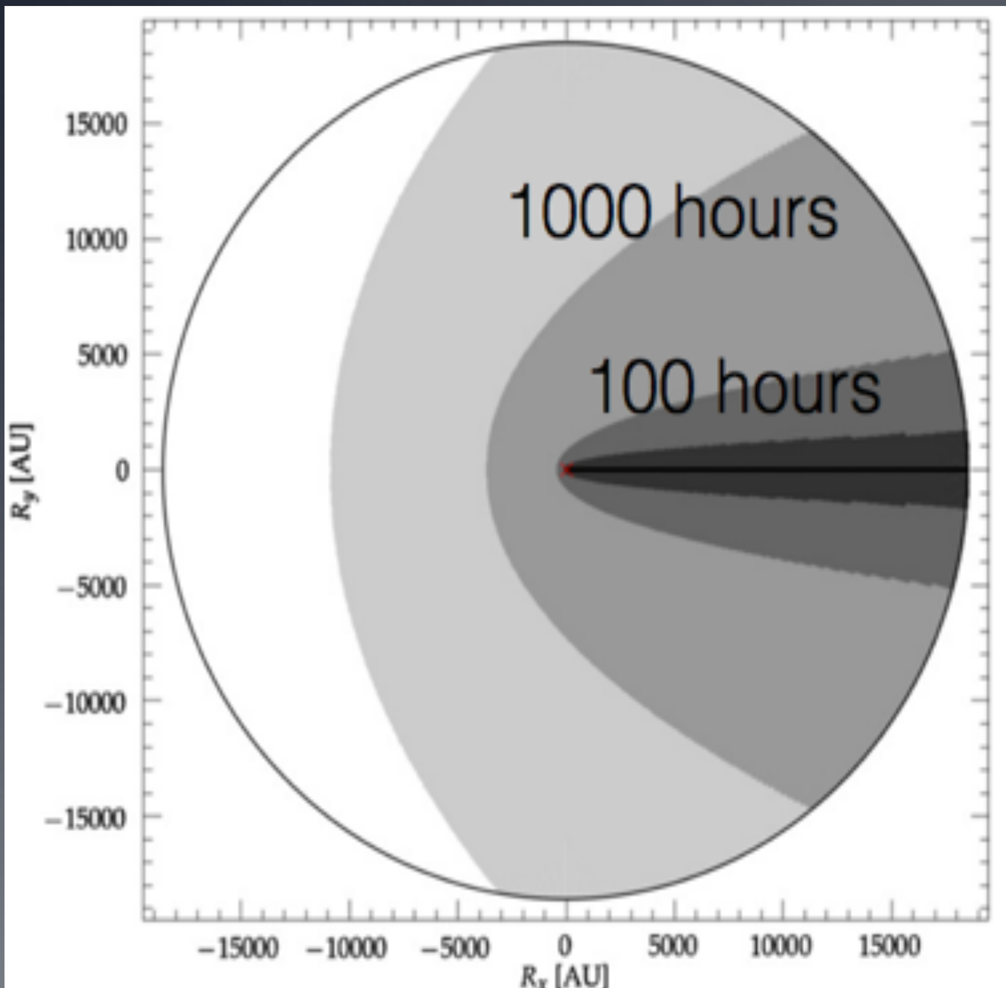
$L_{tot}=L_{acc}+L_{phot}$

Scattered by dust

Luminosity burst heats the dust; flux increase at 850 microns caused by **dust temperature**

Time delay: a few weeks (mostly light travel time)

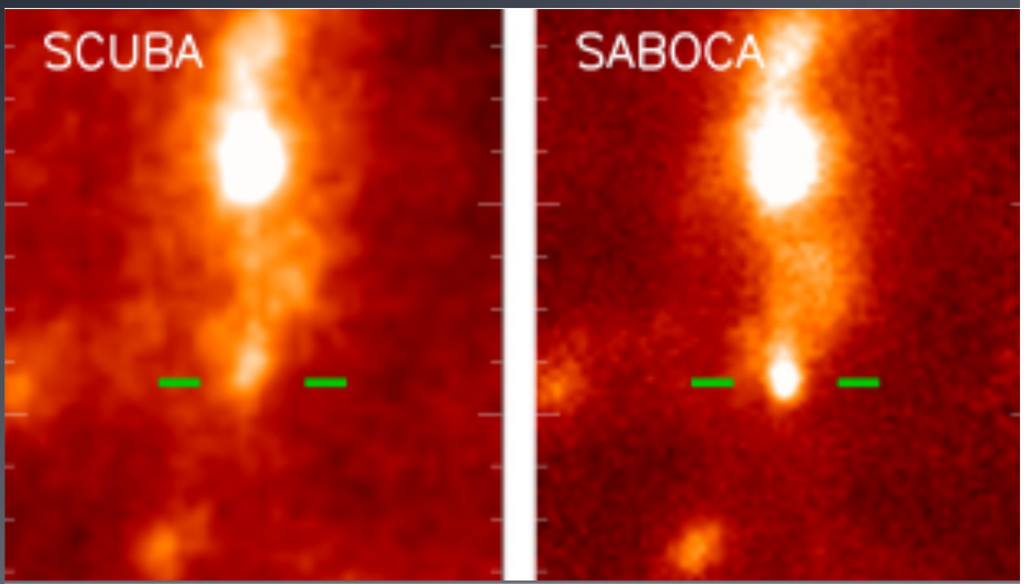
Light travel time smooths bursts

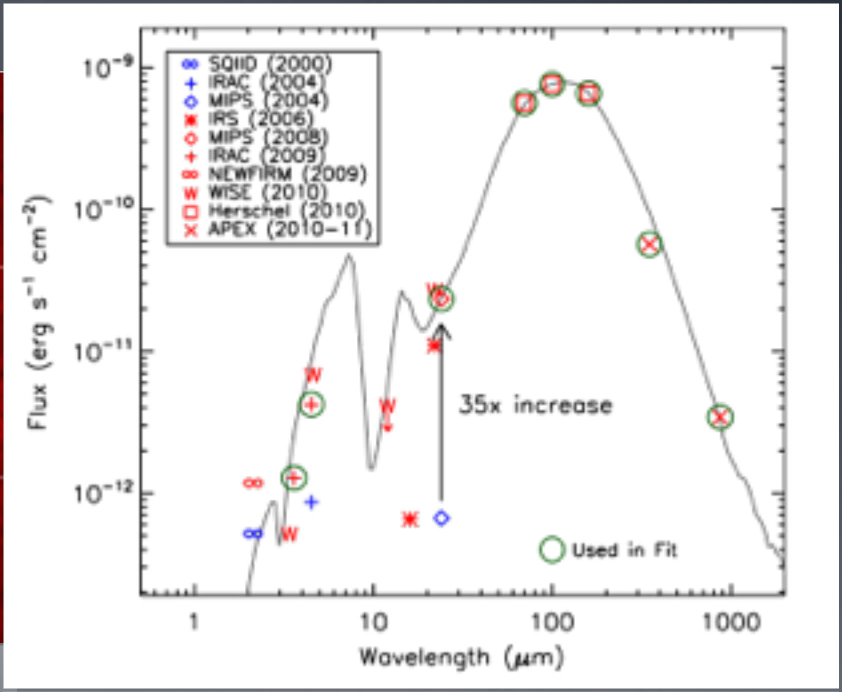


- Sub-mm continuum emission produced by dust
  - Depends on dust Temp
- Luminosity burst heats up dust, increases sub-mm emission
- Timescale for energy to propagate through envelope: weeks

Observed protostellar variability

(Safron, Fischer, et al. 2015)



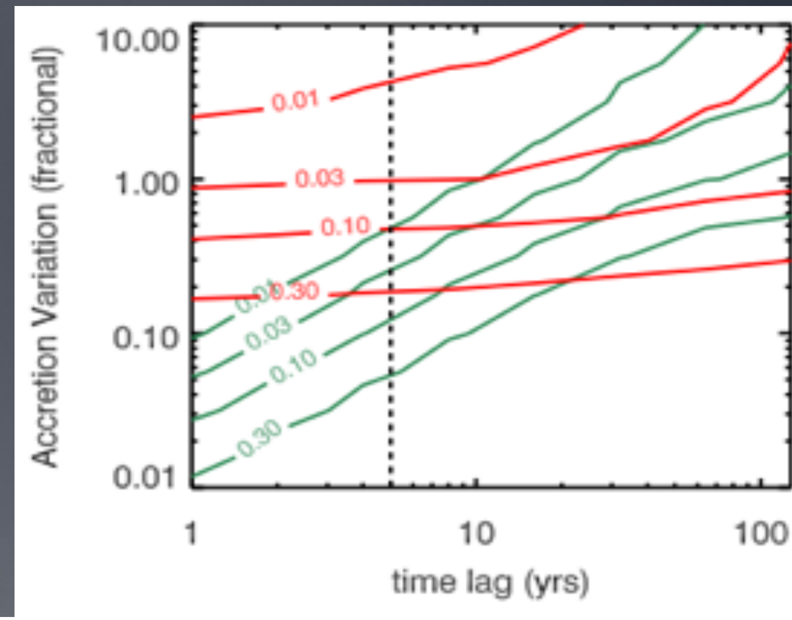


Embedded source identified in mid-IR Spitzer;
Strong sub-mm emission post-outburst

Program description

(Herczeg+subm; Mairs+accepted, Yoo+, Mairs+, Johnstone+ in prep)

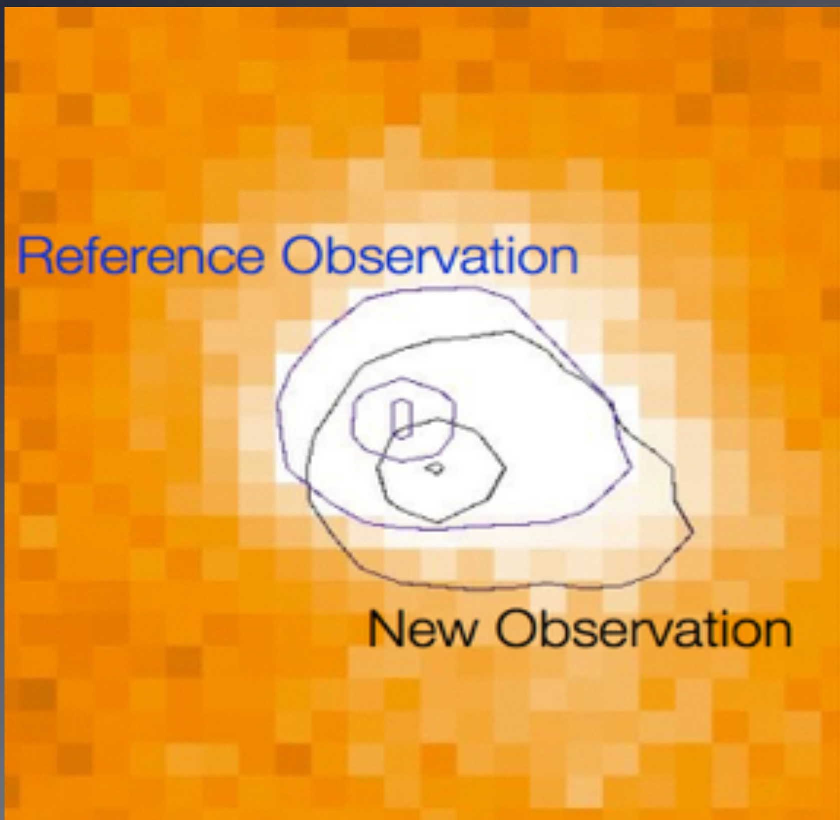
- 150 total hours spread over 8 fields of 30 arcmin (1.6 sq deg)
  - Perseus (2), Oph (1), Orion (3), Serpens (2)
  - Roughly monthly monitoring
  - Previous GBS epoch
- 105 bright clumps with ~200 protostars in fields
- 30' Pong

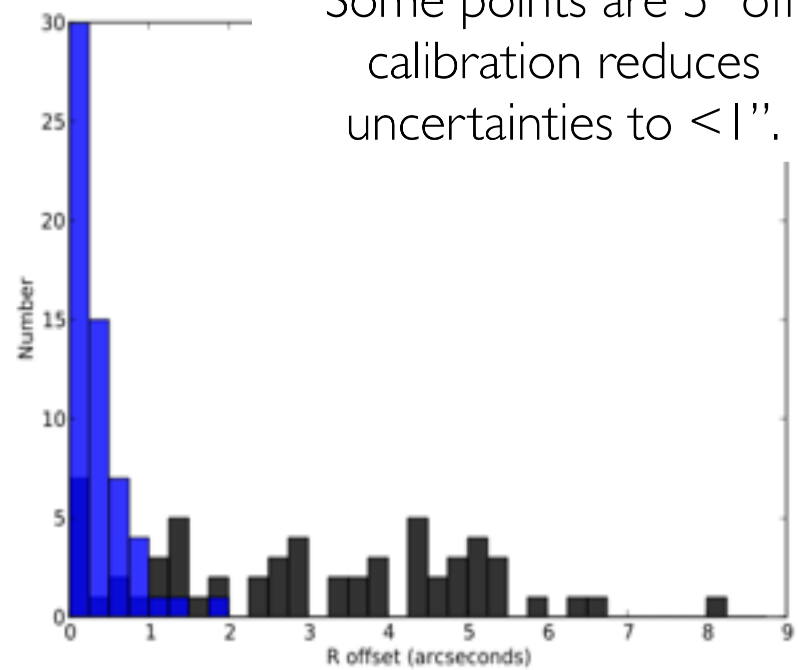


Levels of accretion variability for MRI+GI instabilities (Bae+2014, green) and GI (Vorobyov & Basu 2010, red)

Data Calibration: spatial offsets

(Mairs+accepted)



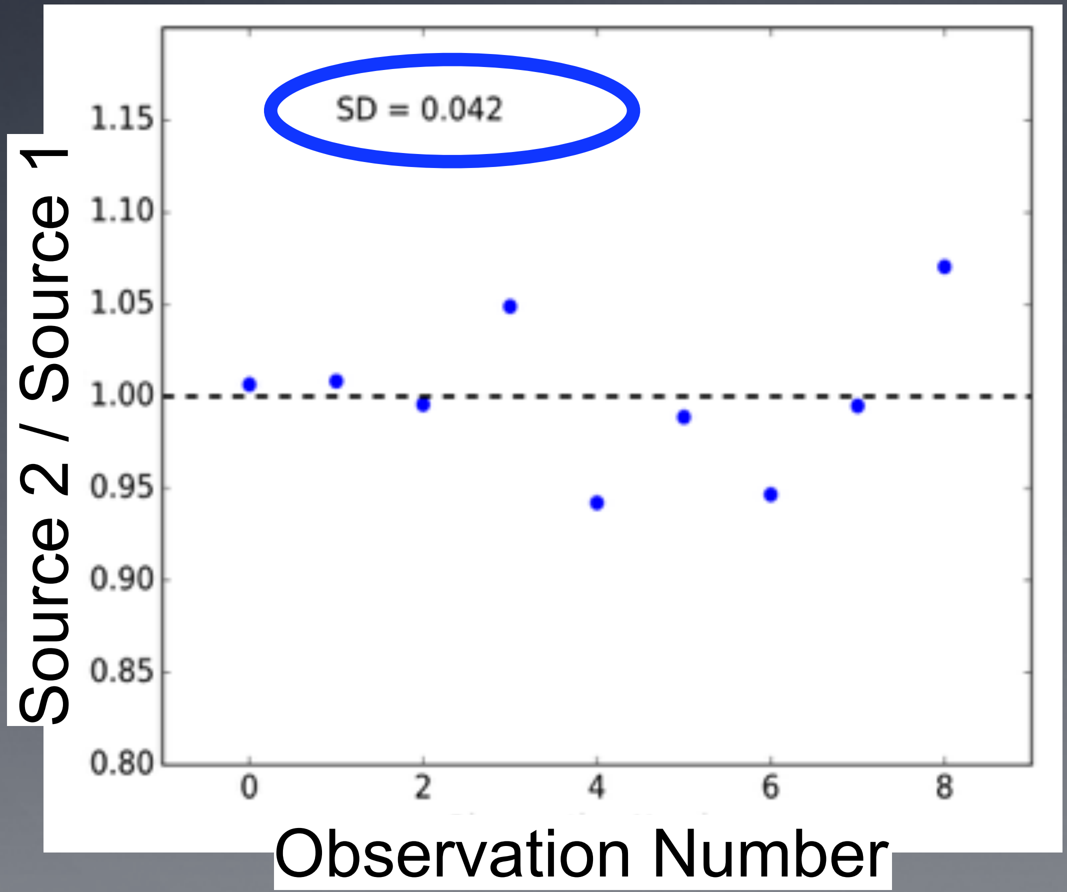


Some points are 5'' off; calibration reduces uncertainties to <1''.

Measure offset of every observation, re-reduce to same pixel scale

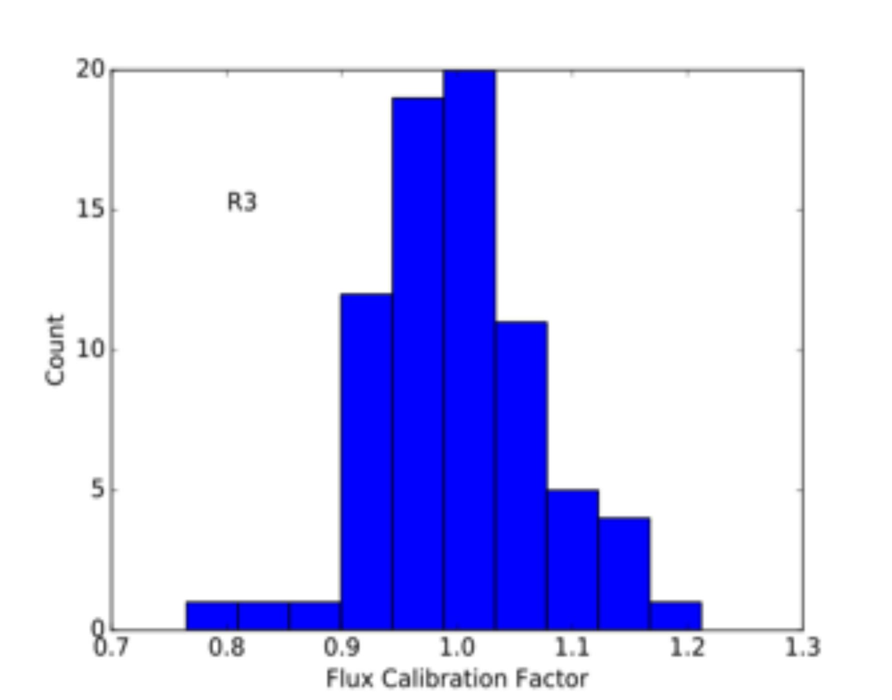
Flux calibration through differential photometry

(Mairs+ 2017)

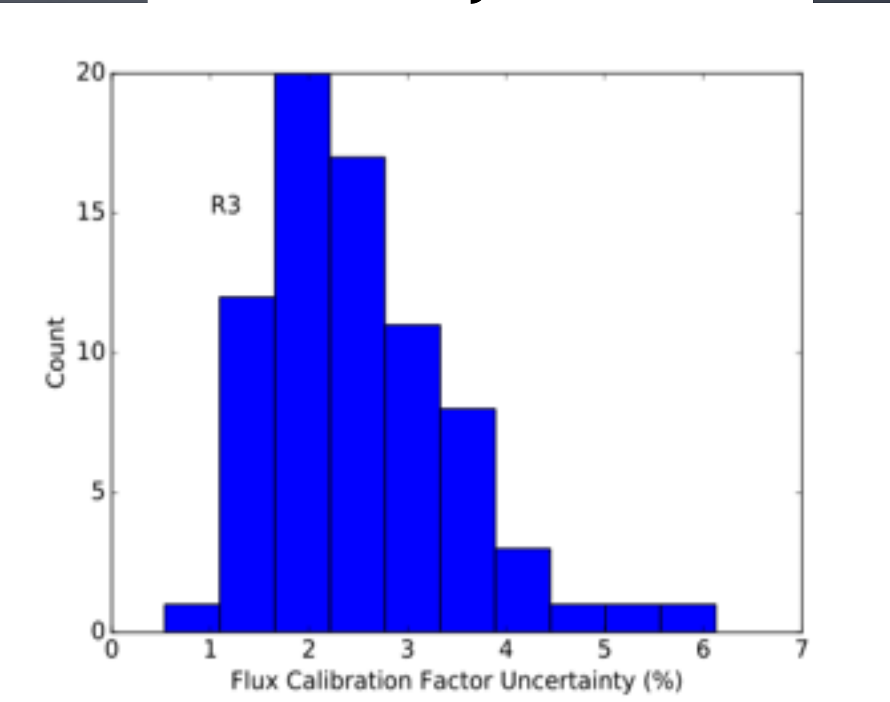


Flux calibration with differential photometry (Mairs+2017)

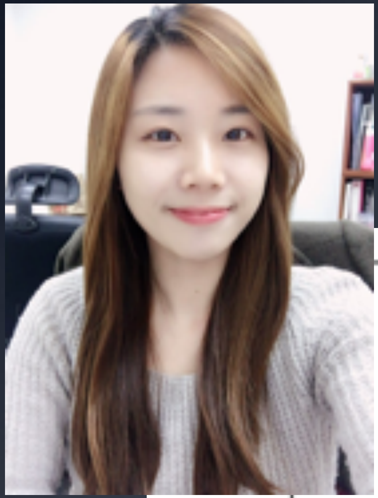
Default flux calibration uncertainty: 8% rms (see also Dempsey+2013)

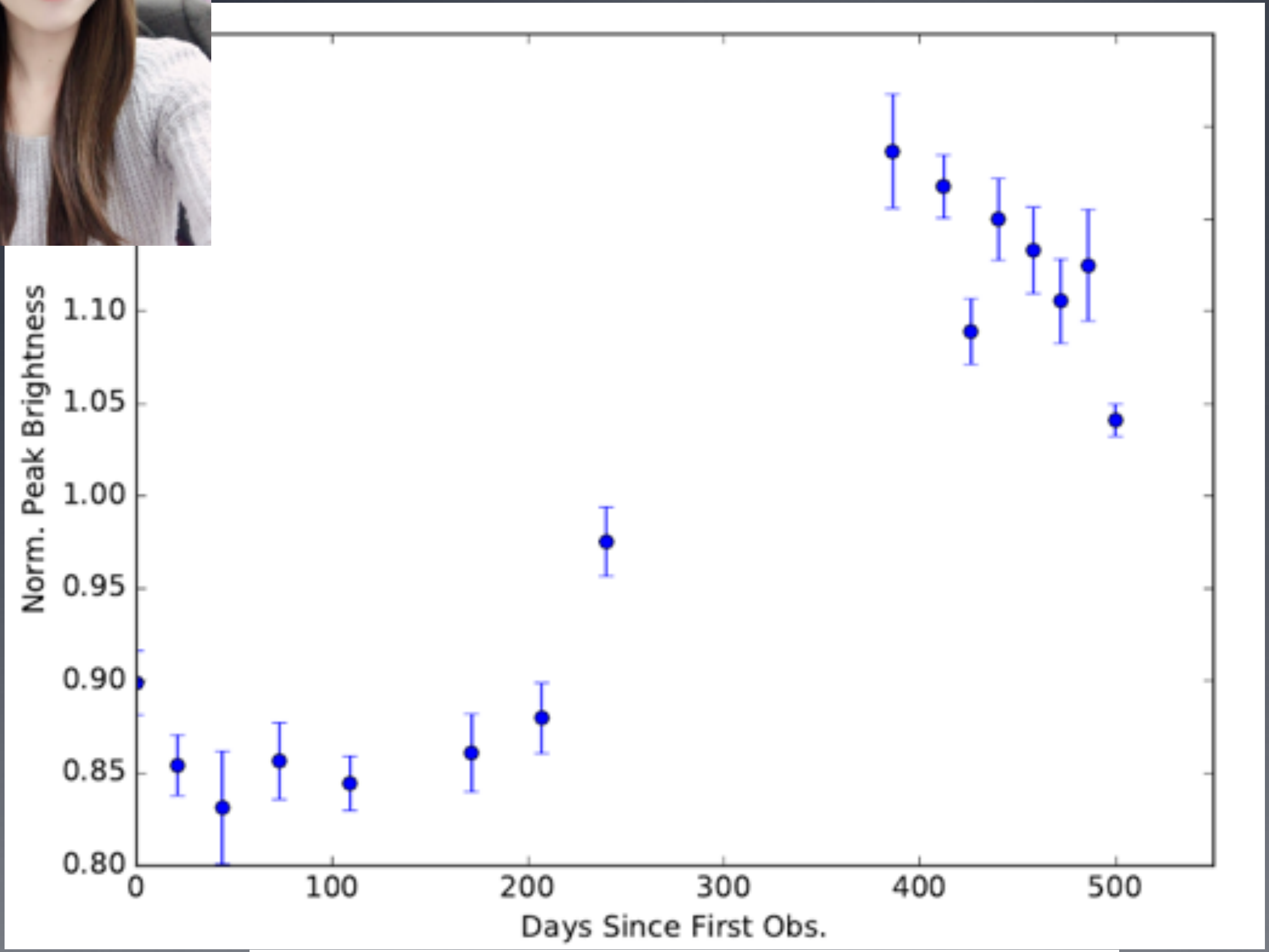


Relative flux uncertainty: ~**2.5%**



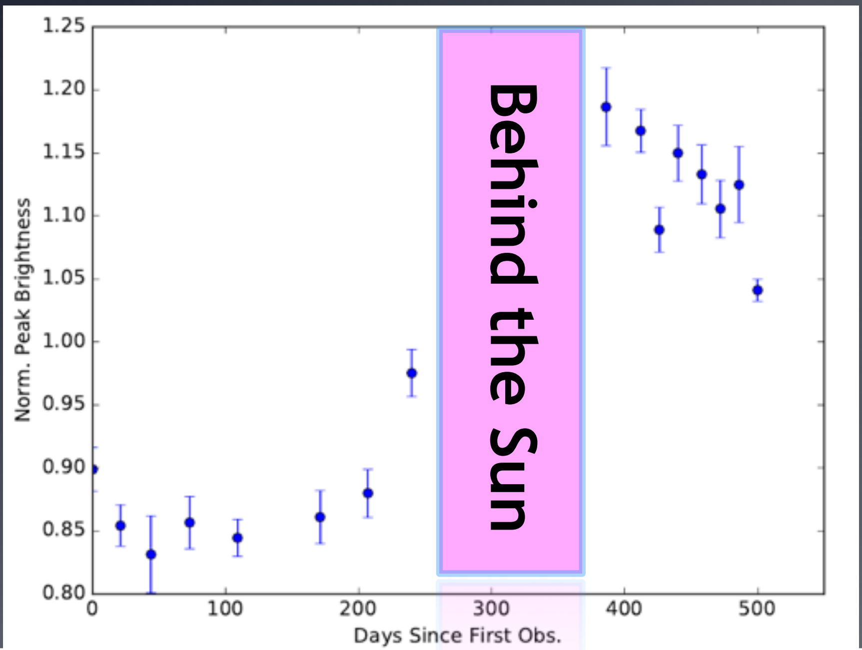
A sub-mm Transient!

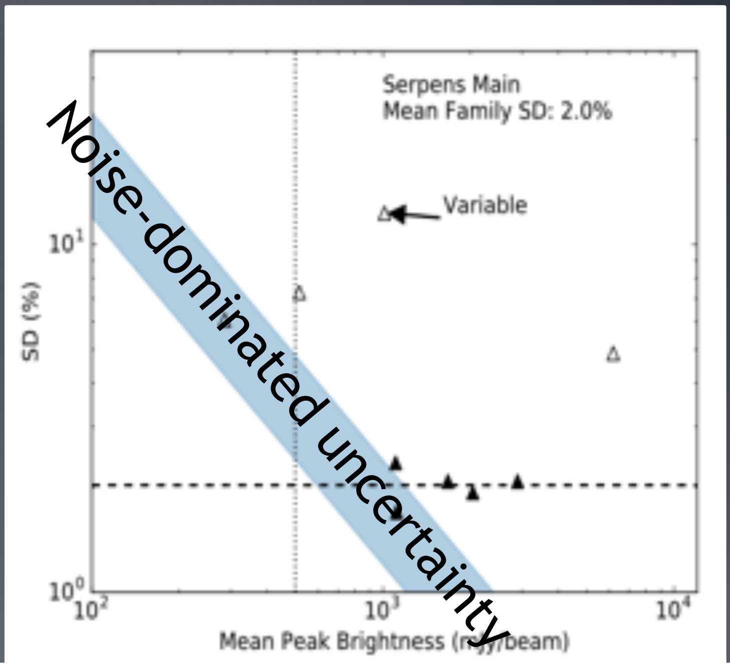


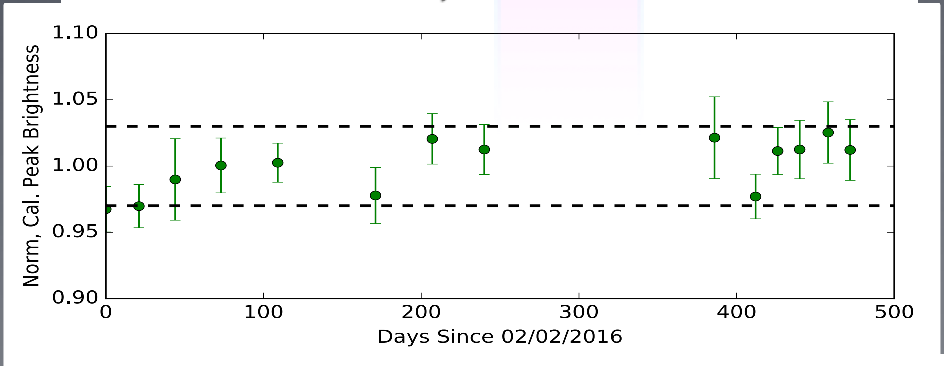


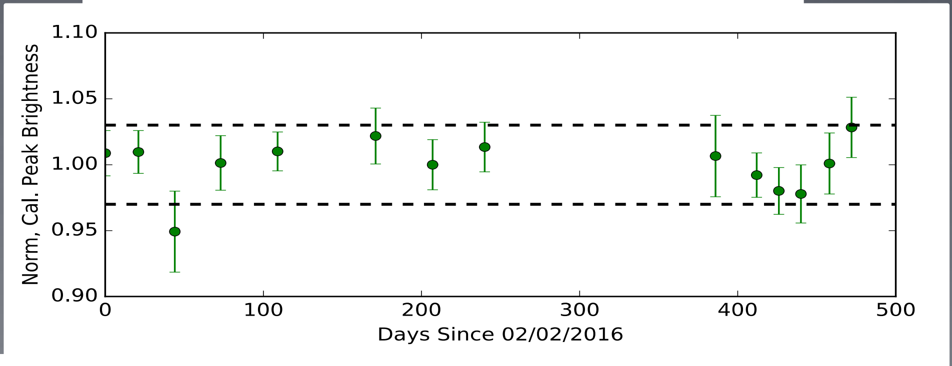
Yoo, Lee, Mairs et al., in prep

A sub-mm Transient!



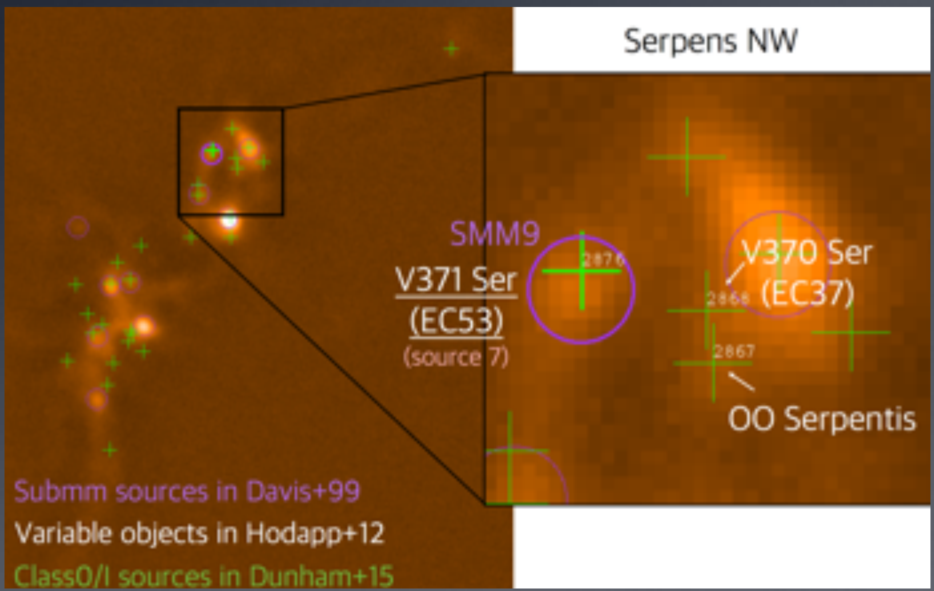


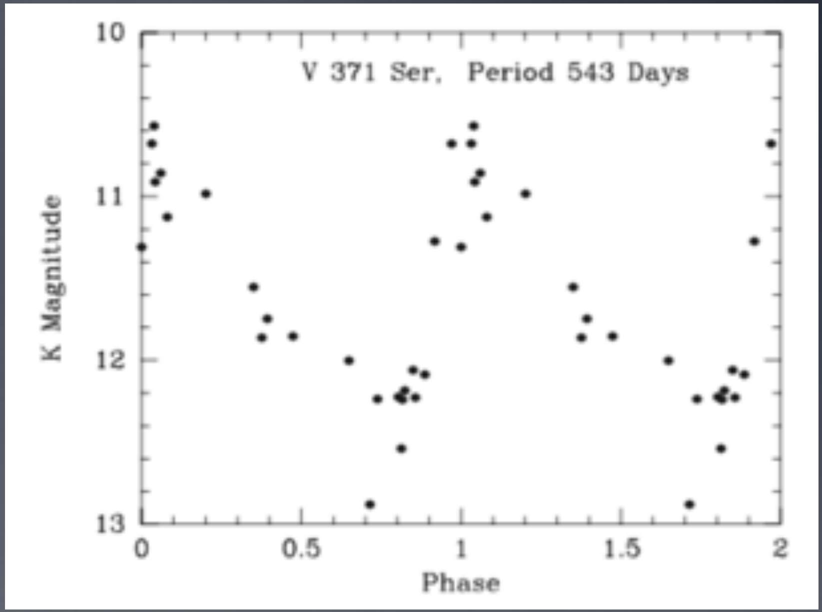




Calibrators on bottom: ~2-3% accuracy

The First JCMT Protostellar Variable

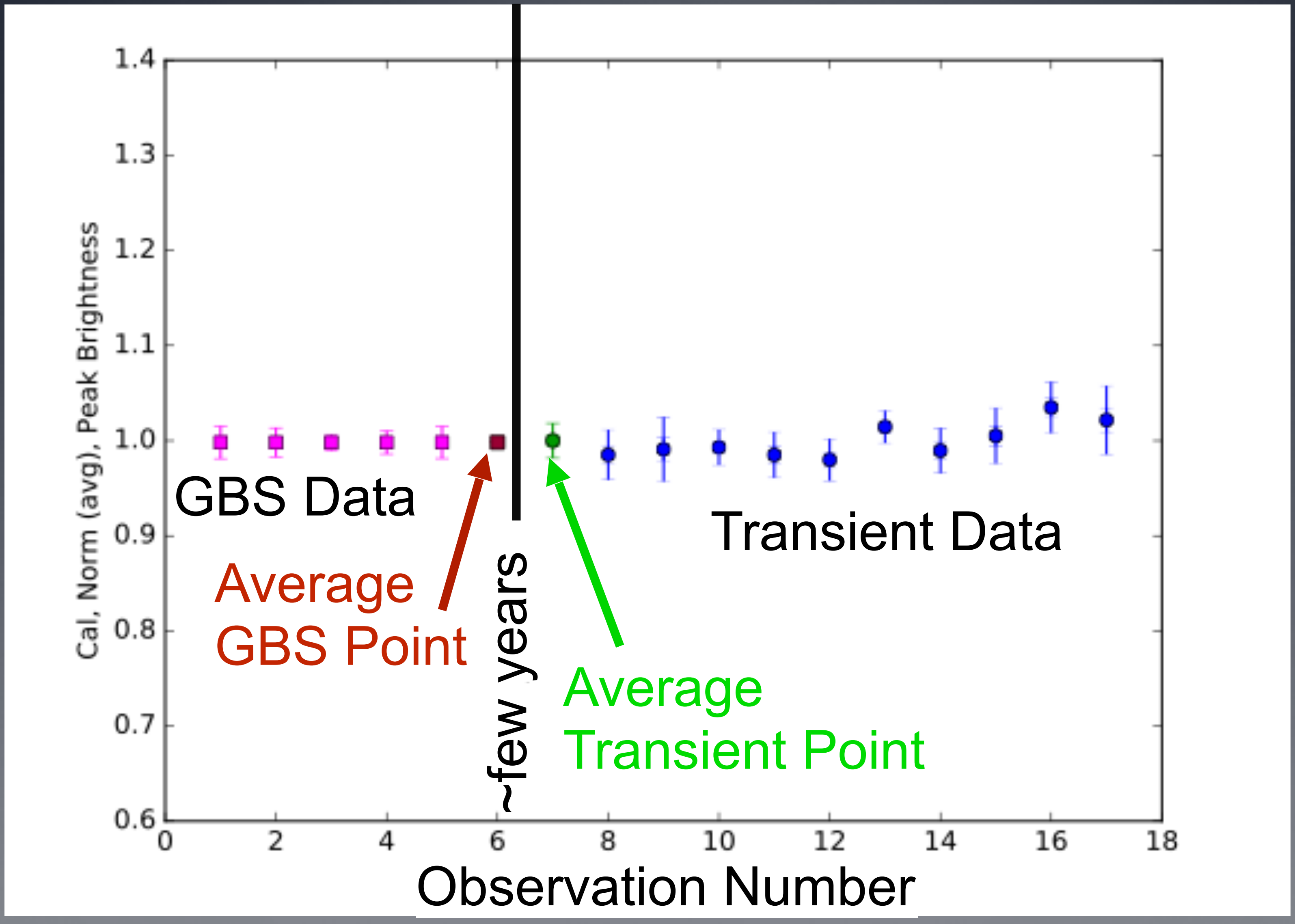




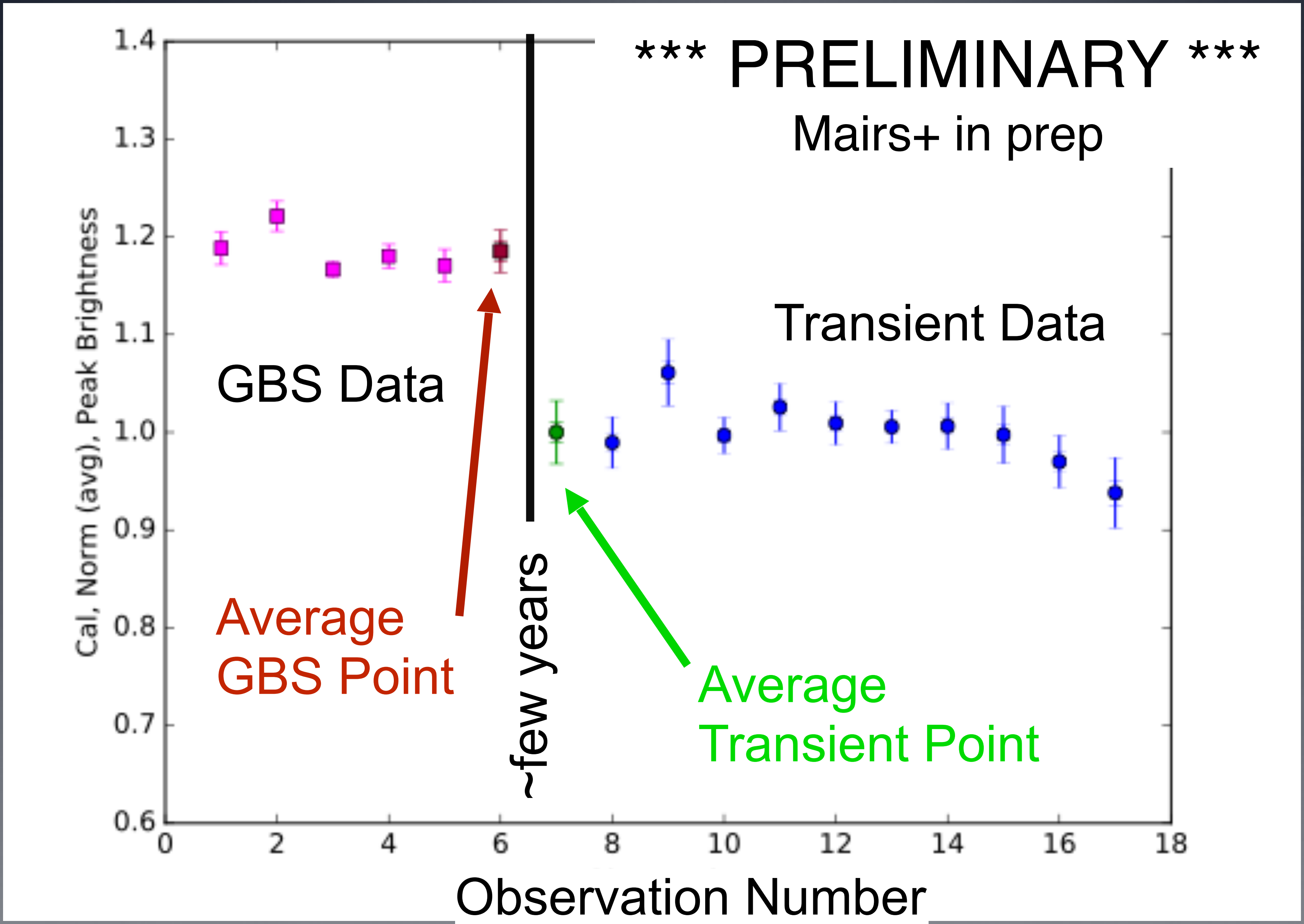
Hodapp+1999, 2012: periodic near-IR variability with 543 d period

Possible explanation: 1.5 yr eccentric binary

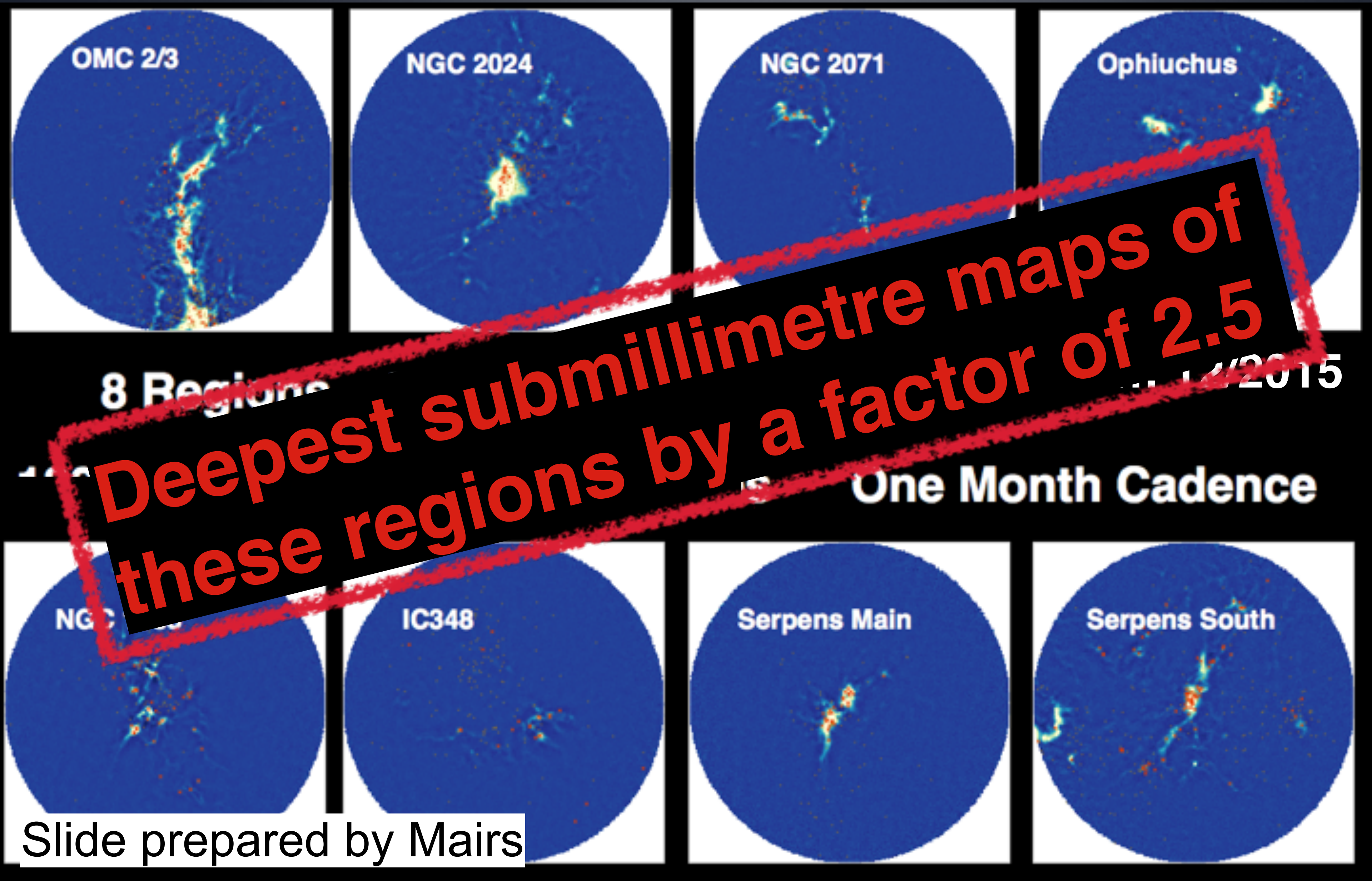
Comparison to Gould Belt Survey: ~3-yr baselines (Mairs+ in prep; Johnstone+ in prep)



A 2nd JCMT Transient?



Future of JCMT Transient Survey



Slide prepared by Mairs

The Transient Future

- Survey continues through 2018B
- Identify more transients
  - Also at 450 microns
  - Follow up transients (already JCMT, SMA, ALMA proposals)
  - Long-term variability?
- Full statistical analyses of fields
- Modelling effort
- Leverage depth for disk, filament, and VeLLO science