The Search for Outbursts in The Orion Molecular Clouds

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Amy Stutz (MPIA)
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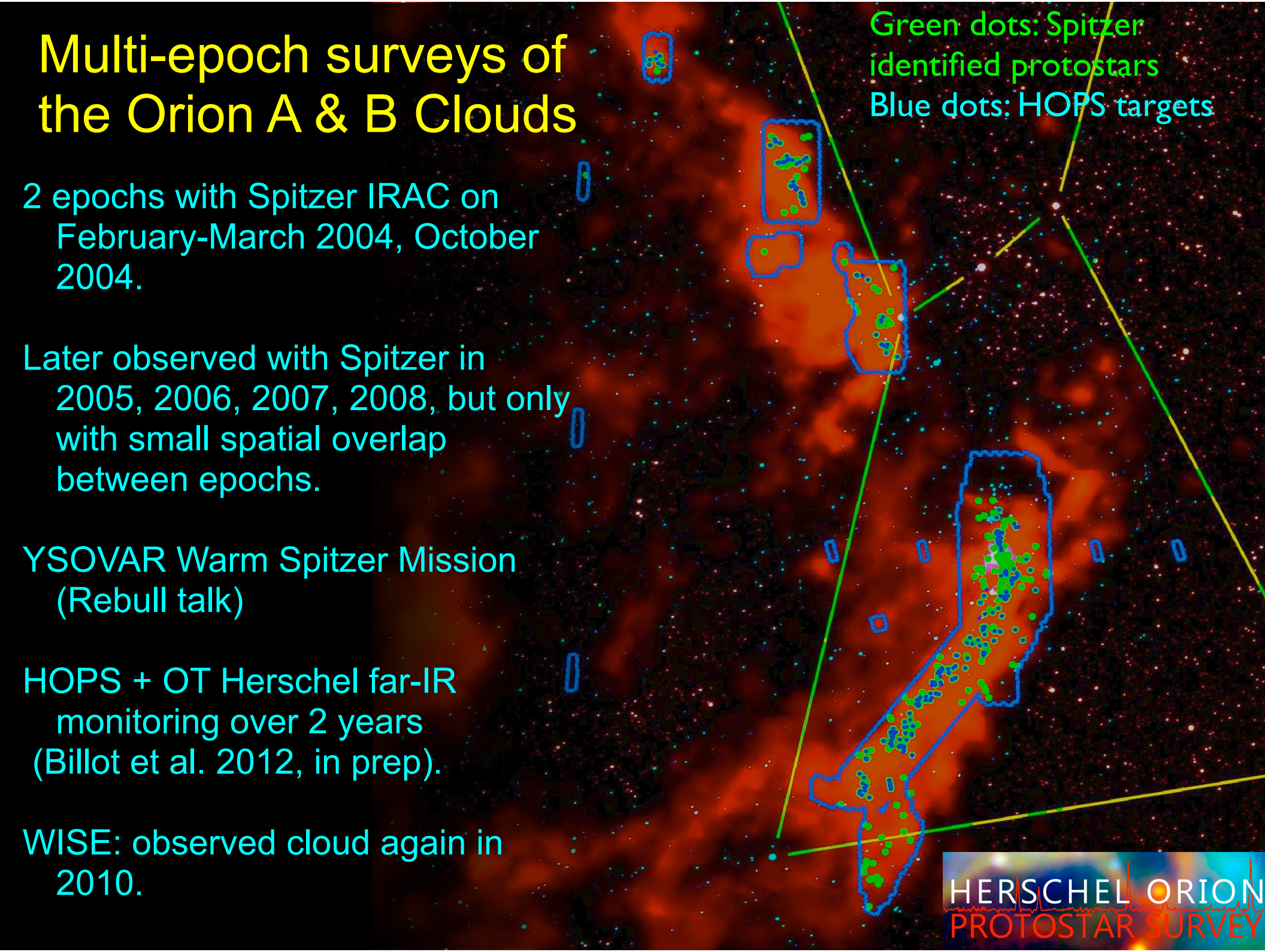
Dan Watson (U. Rochester)

and the
Herschel Orion Protostar Survey
and Spitzer Orion Survey Teams

3.6 μm
70 μm
160 μm

Multi-epoch surveys of the Orion A & B Clouds



2 epochs with Spitzer IRAC on February-March 2004, October 2004.

Later observed with Spitzer in 2005, 2006, 2007, 2008, but only with small spatial overlap between epochs.

YSOVAR Warm Spitzer Mission (Rebull talk)

HOPS + OT Herschel far-IR monitoring over 2 years (Billot et al. 2012, in prep).

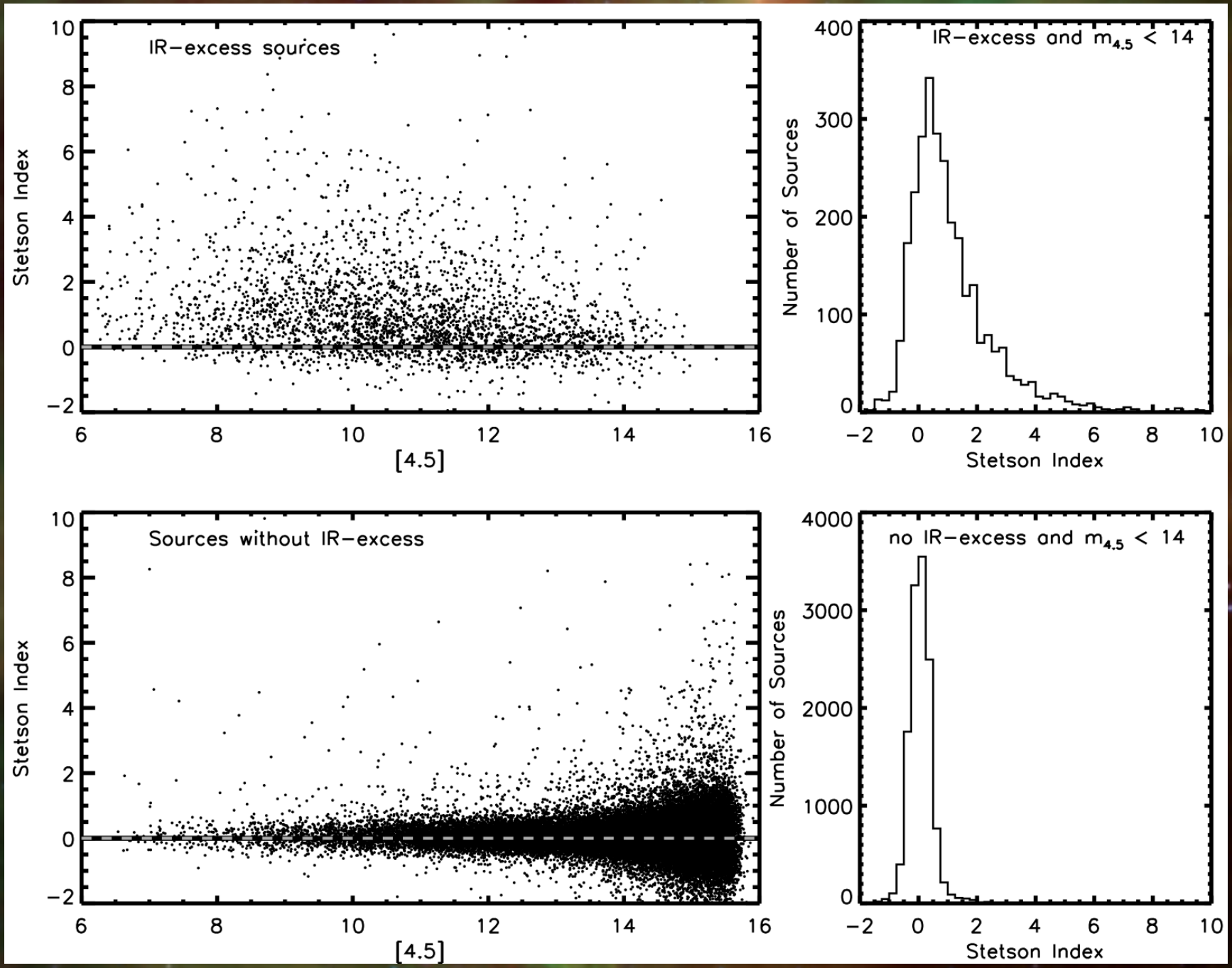
WISE: observed cloud again in 2010.

Correlated Variability at 3.6 and 4.5 μm

2 epochs, 7 months apart.

Megeath et al. 2012

Variability



Protostars Show the Highest Incidence of Variability

Table 5
Fraction of Young Stellar Objects Exhibiting Variability

	Fraction of Sources with $s > n\sigma_{\text{photo}}$				
n	Photospheres	YSOs with IR-excesses	Diskless YSOs	YSOs with Disks	Protostars
1	0.09	0.60	0.28	0.59	0.73
2	0.02	0.41	0.12	0.40	0.57
3	0.01	0.28	0.06	0.26	0.45

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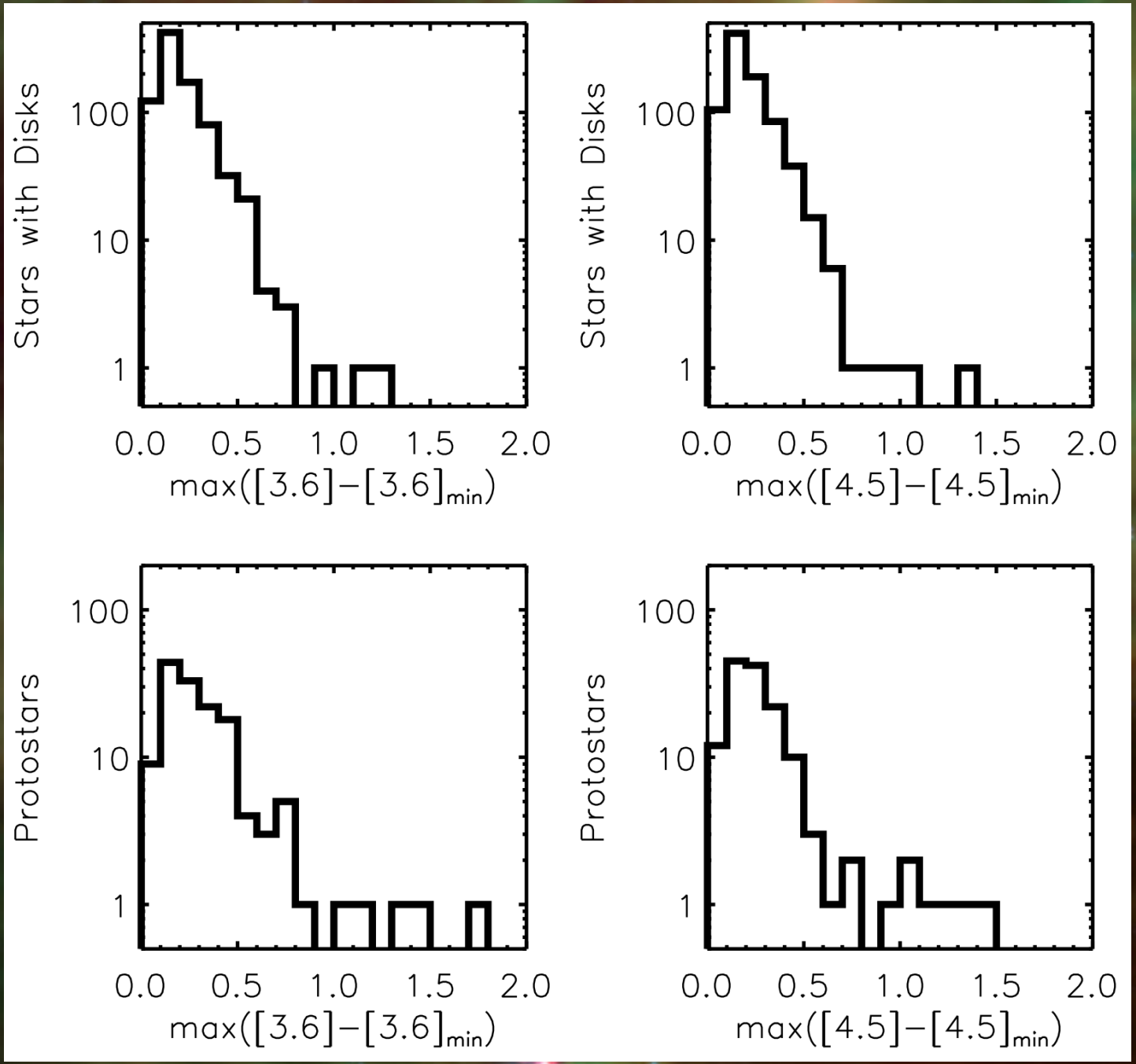
Protostars Show the Highest Level of Variability



Megeath et al. 2012

Herschel Far-IR Monitoring of
Orion Nebula & OMC 2/3 Region
(Billot et al. 2012, in prep.)
Red: 160 µm
Green: 70 µm
Blue:8-24 µm

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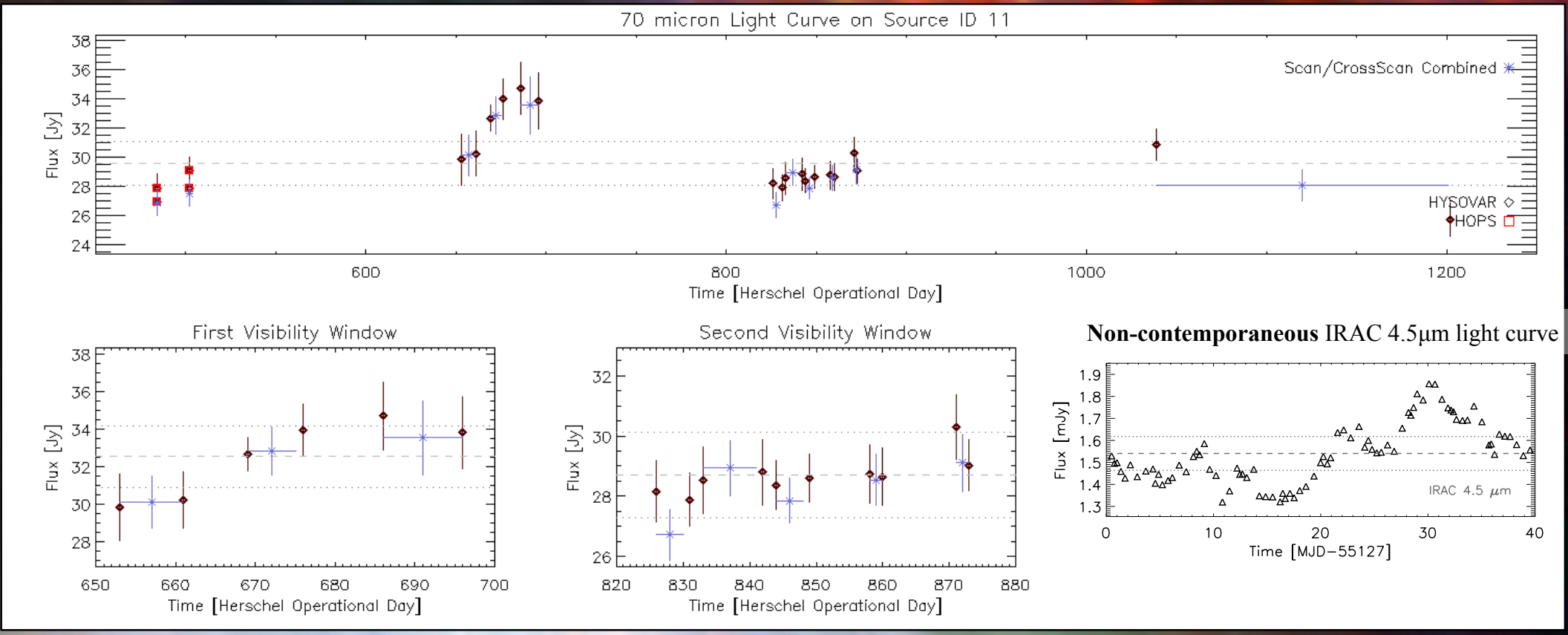


20% (8/40) show *detectable* variability over two week to two year timescales, variability 10-50%

Summary of Variability

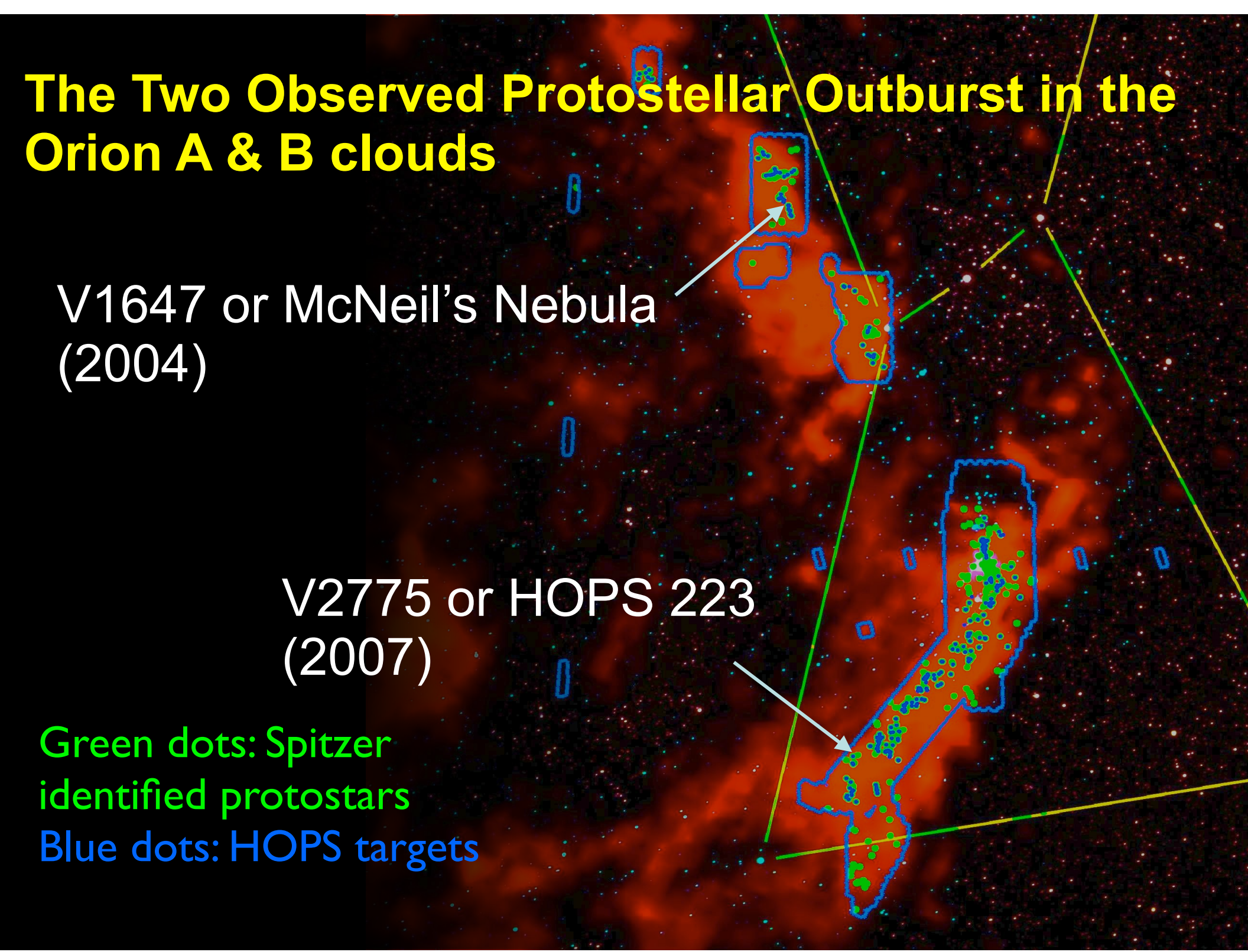
Incidence of mid-IR variability over 7 months: > 50%

Magnitude of mid-IR variability of 7 months:
50% show >22% variability, 10% show >50% variability.

Far-IR variability: >20% show variability over 2 years, with variability observed over ~1 week scales. Variability as high as 50% observed.

A modest level of variability, probably in many/most cases driven by accretion, is present.

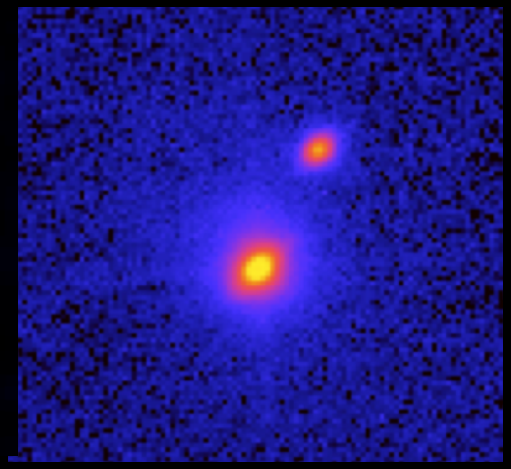
But what about luminous outbursts?


The Two Observed Protostellar Outburst in the Orion A & B clouds
V1647 or McNeil's Nebula (2004)
V2775 or HOPS 223 (2007)
Green dots: Spitzer identified protostars
Blue dots: HOPS targets

V2775 (HOPS 223): An Accretion Driven Outburst

2MASS K
(November 1998)

WHIRC K
(December 2011)



V2775 Ori
Discovered by Caratti o Garatti et al. 2011

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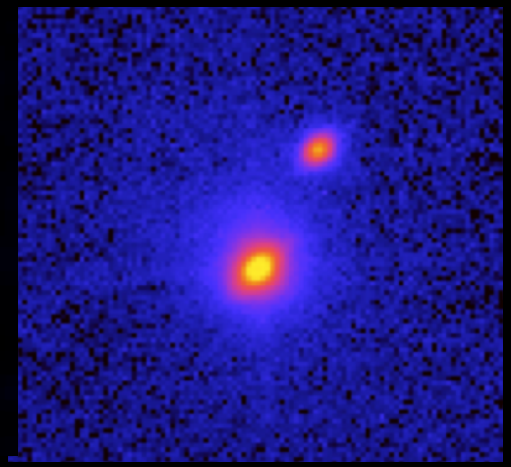


FU Ori-like or a less extreme flavor?

Herschel 70 μm

PBR

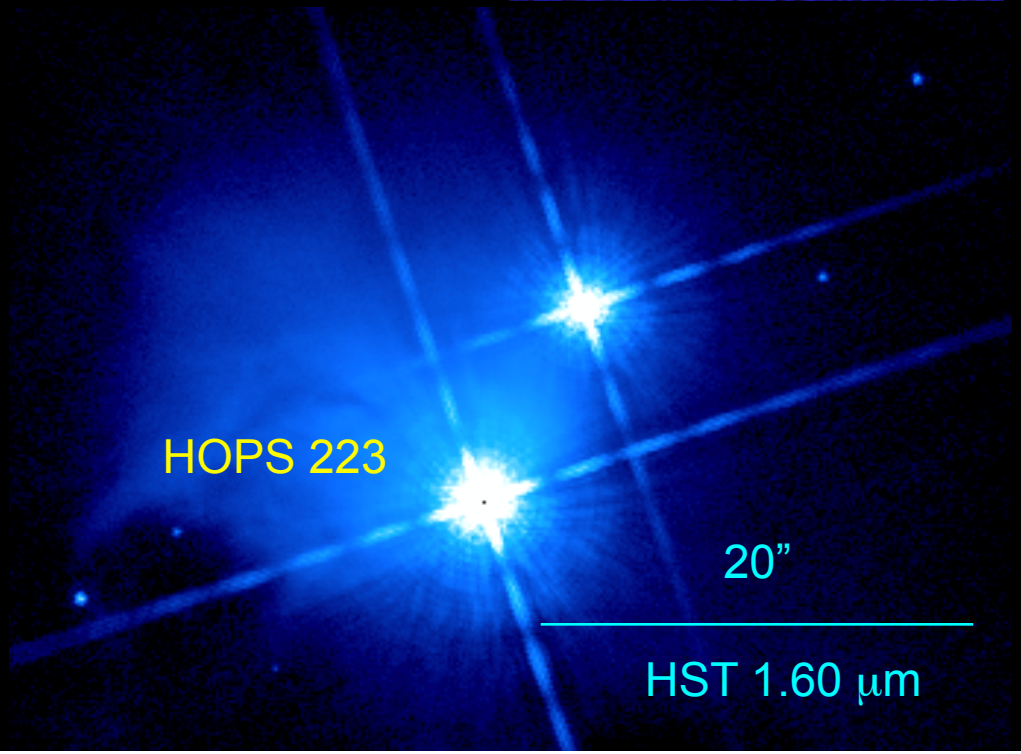
HOPS 223

HOPS 221

Herschel 160 μm

K=8.5

20”



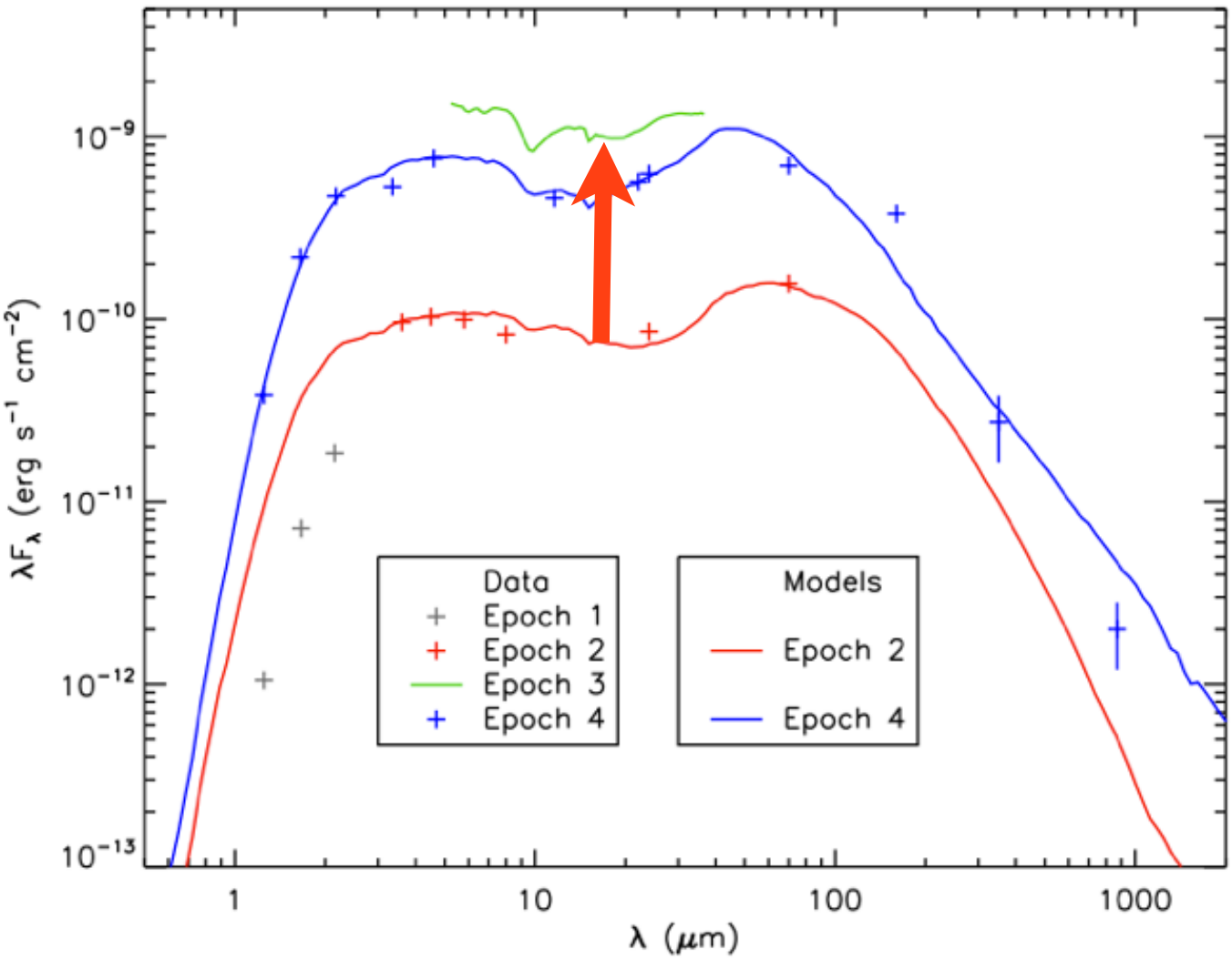
APEX 350 μm

APEX 870 μm

An FU Ori Episode Observed with Spitzer, Herschel, WISE & APEX

Fischer et al. 2011.

(V2775 Ori discovered by Caratti o Garatti 2011)



Between 2005-2007 luminosity increased from 4.5 to 51 L$\odot$.

Epoch 1: 1998

Epoch2: 2004-2005

Epoch 3: 2007

Epoch 4: 2008-2010

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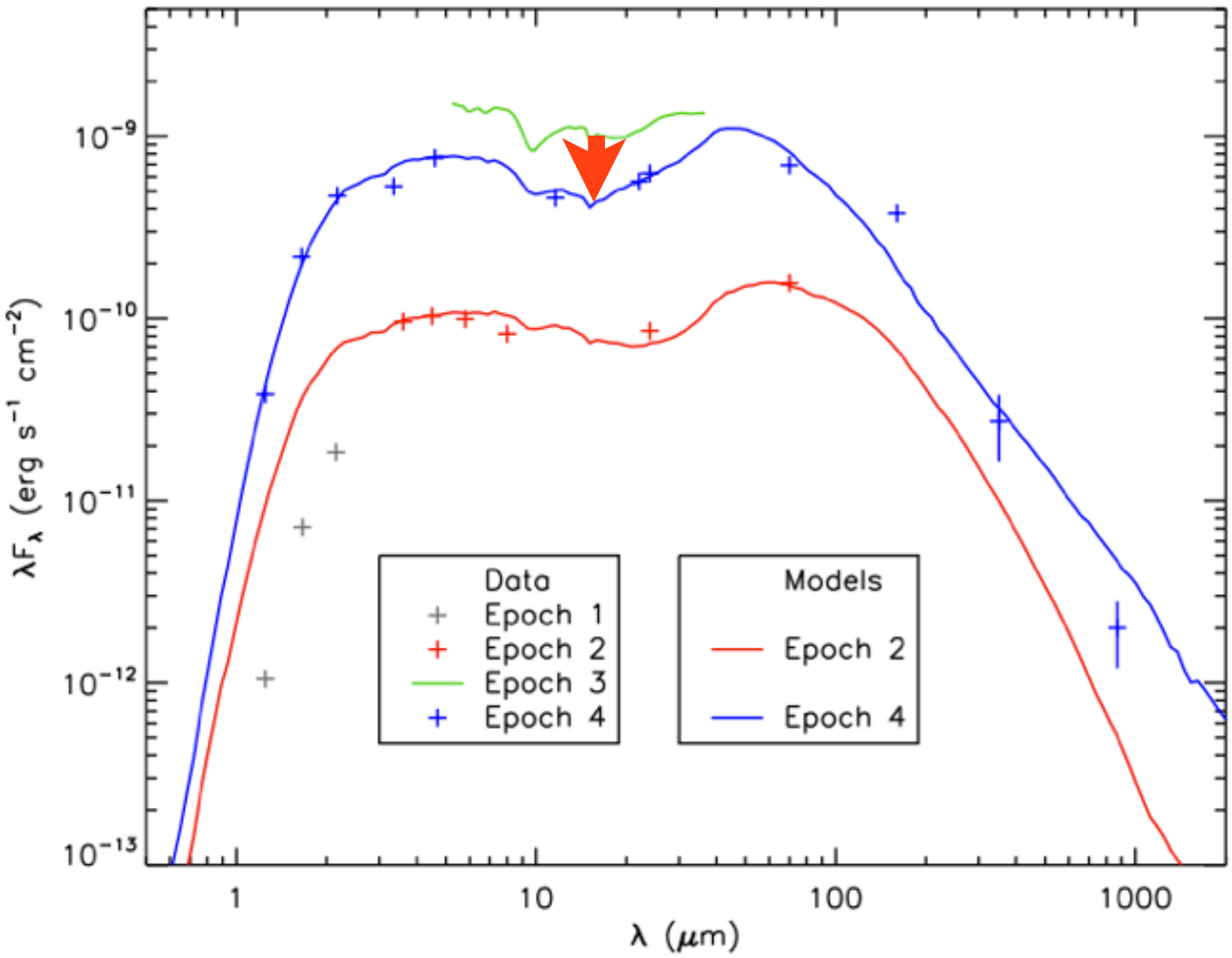


Between 2005-2007 luminosity increased from 4.5 to 51 $L_\odot$.

Between 2007-2008 luminosity decreased from 51 to 28 $L_\odot$

Accretion rate increased from:

~10^{-6} $M_\odot$ yr^{-1} to

~10^{-5} $M_\odot$ yr^{-1}

Envelope infall rate

~$7x10^{-7}$ $M_\odot$ yr^{-1}

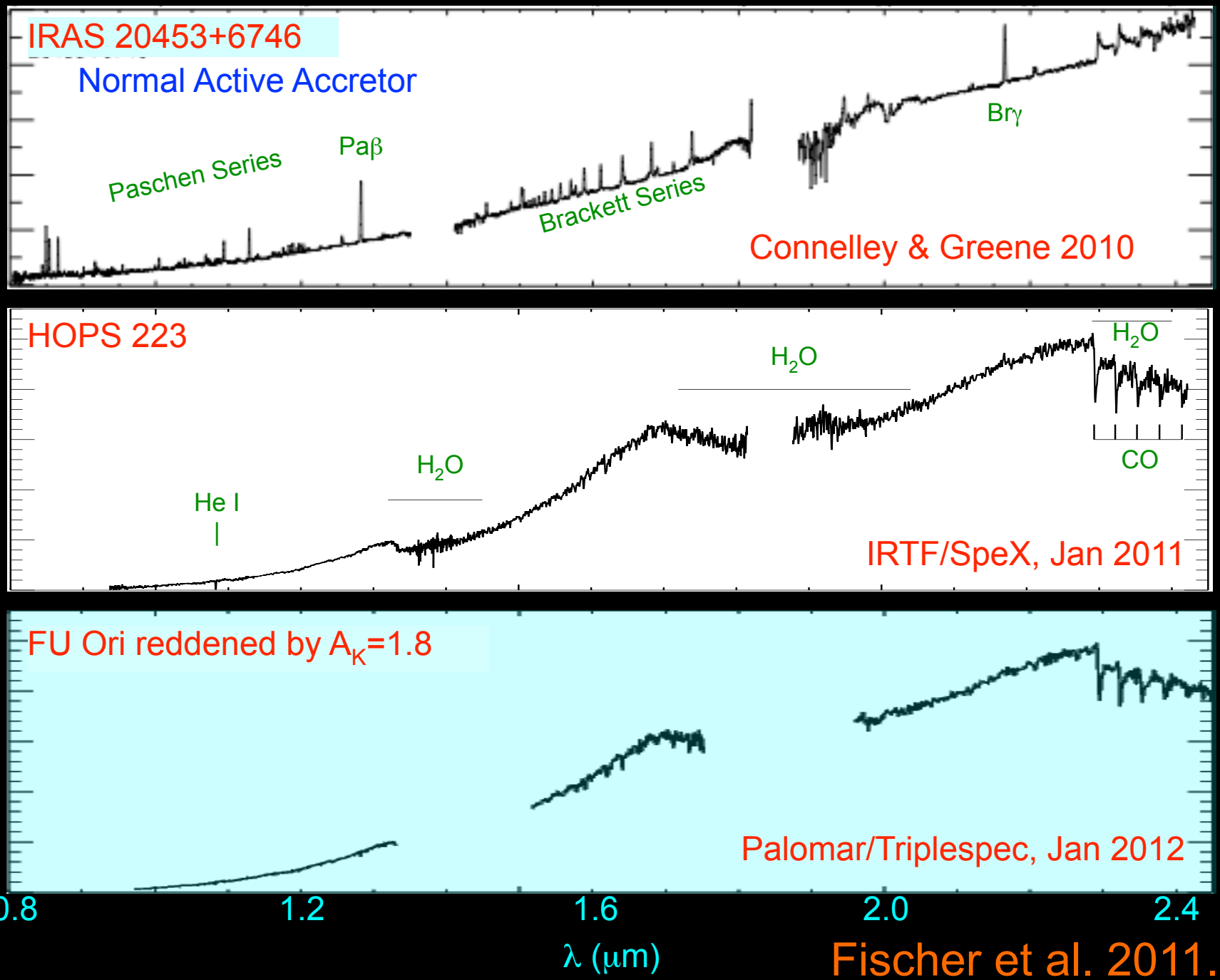
Epoch 1: 1998

Epoch2: 2004-2005

Epoch 3: 2007

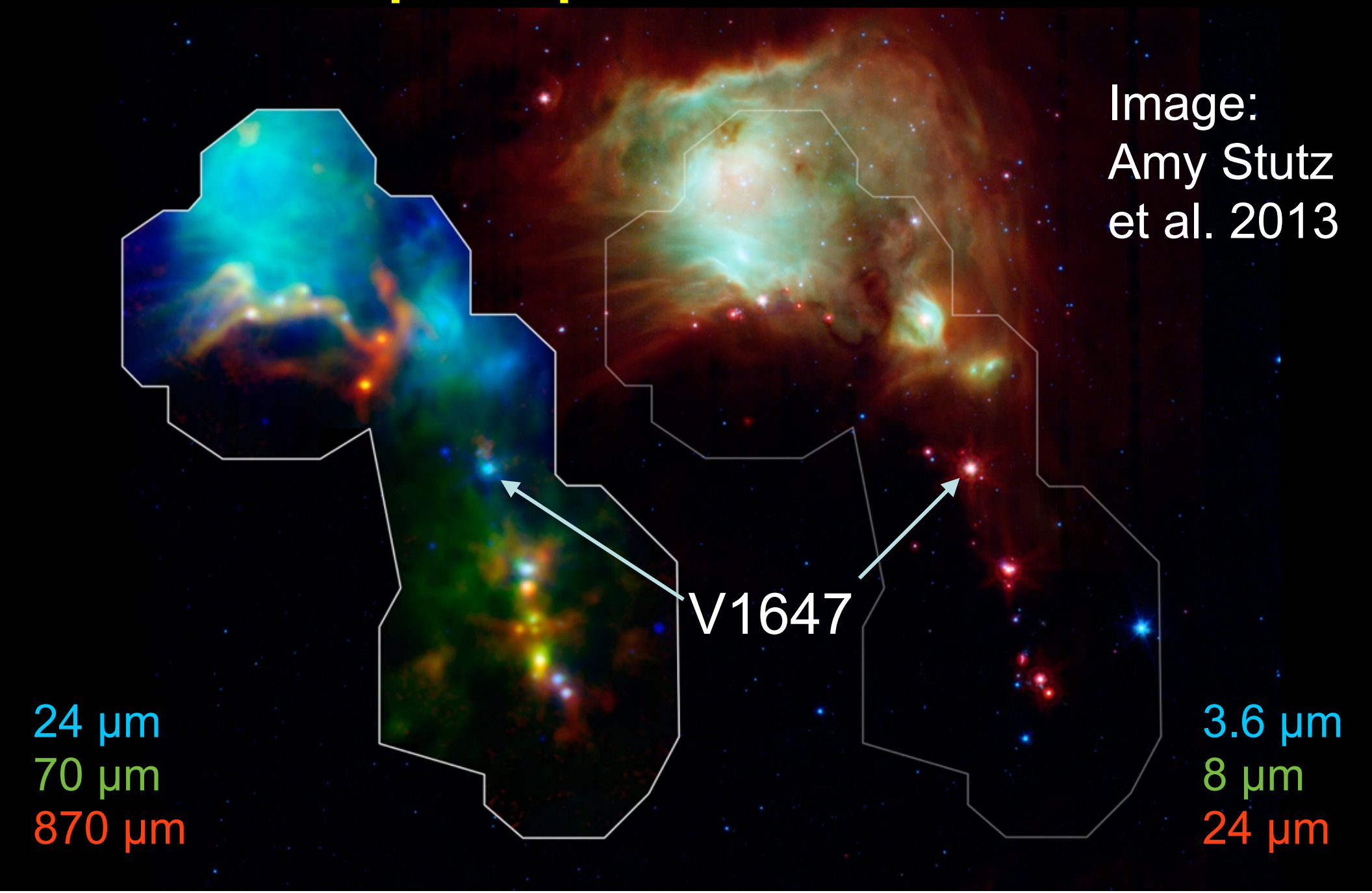
Epoch 4: 2008-2010

V2775: An FU Ori-like NIR Spectrum



Fischer et al. 2011.

V1647: discovered in January 2004, observed with Spitzer post outburst in 2004.



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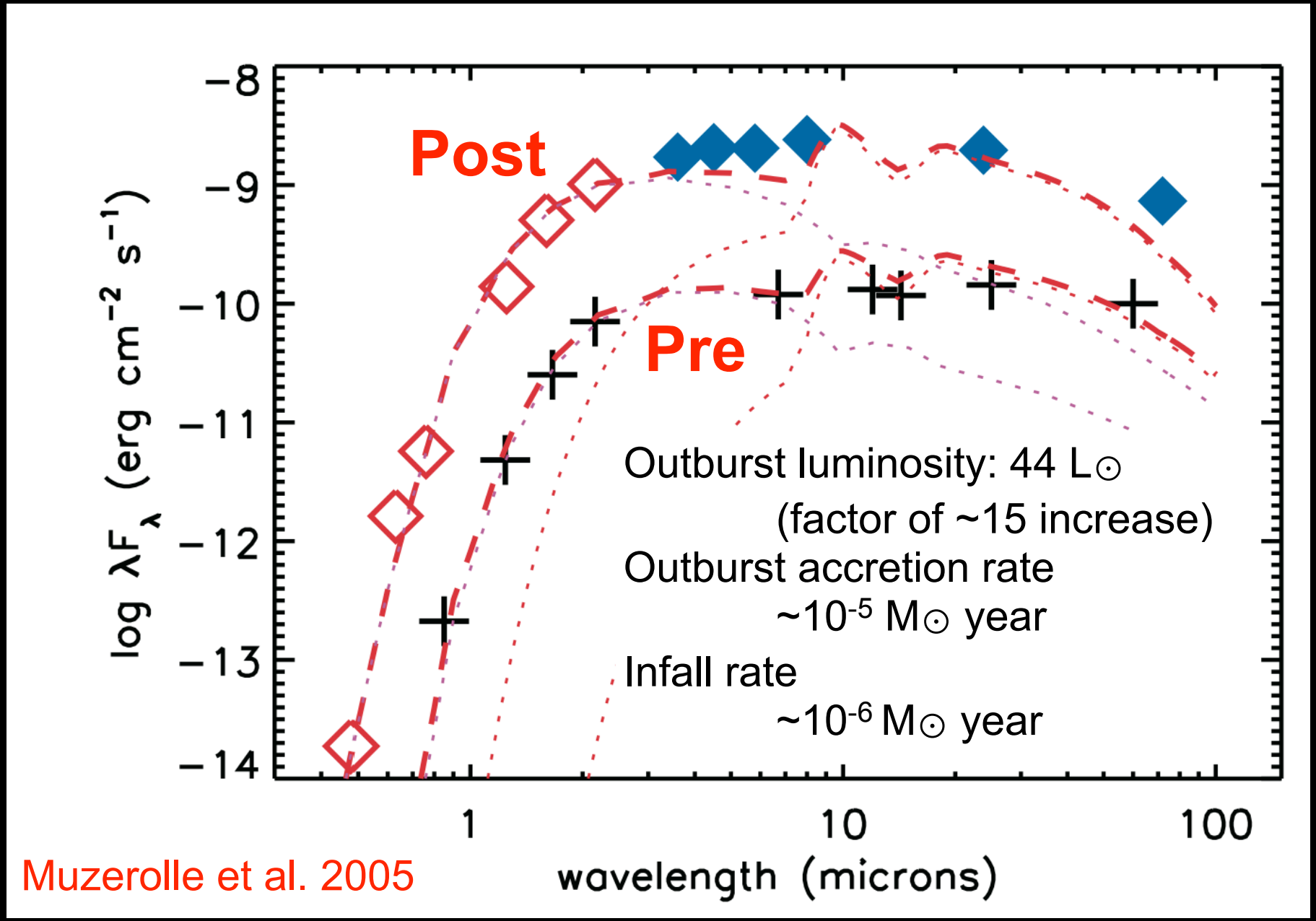
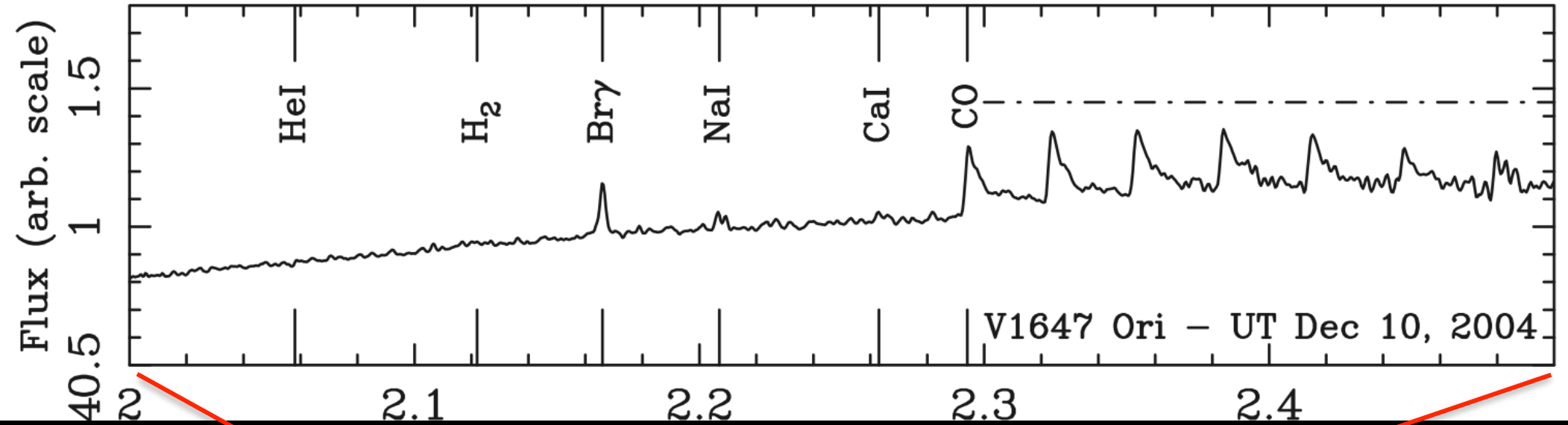
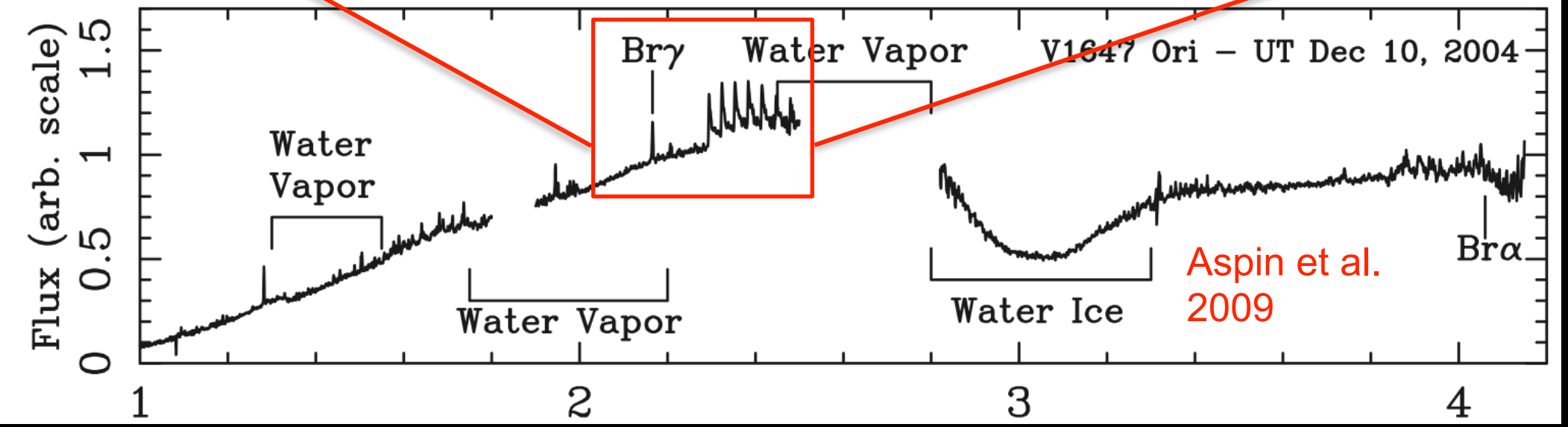


Muzerolle et al. 2005

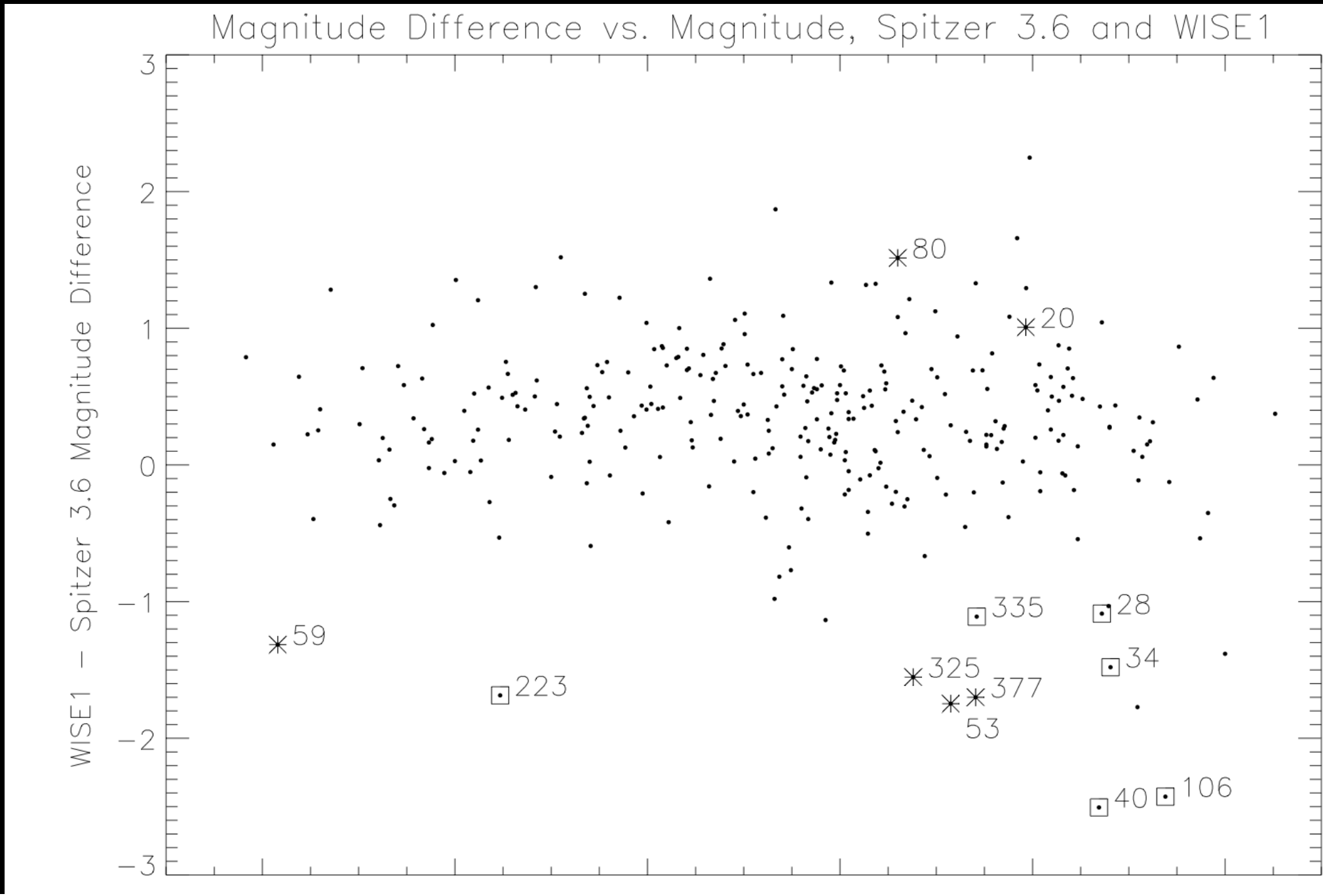
V1647 - *probably* not an FU Ori Outburst





Burst faded for one year, and then reappeared.

Are there any more outbursts? A Search of the WISE Database (Emily Safron U. Toledo)



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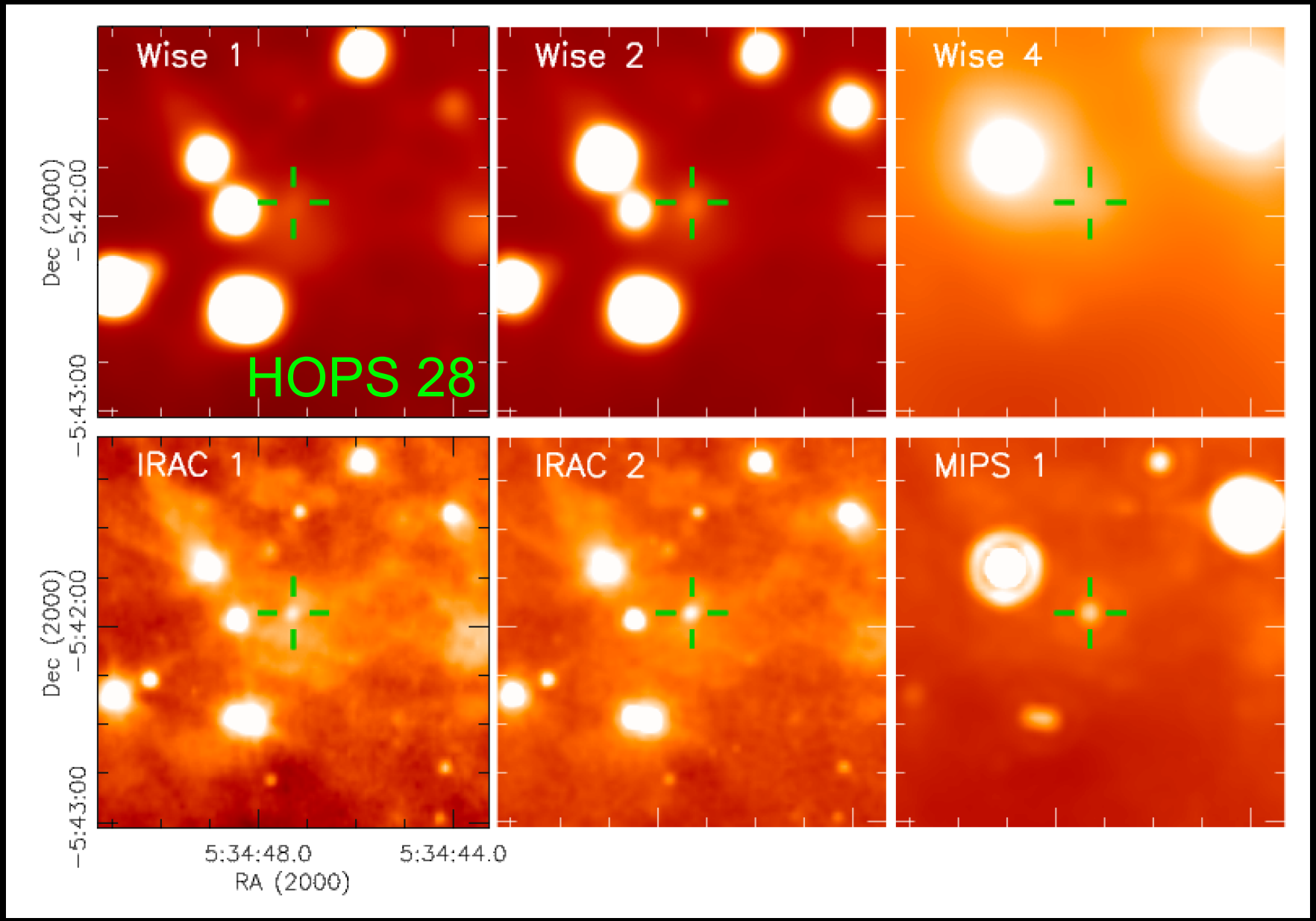

All Outburst candidates besides HOPS 223 appear spurious

What is the rate of bursts per protostar?

$$r_{burst} = \frac{N(outbursts)}{N(protostars) \times \Delta Time}$$

$$= \frac{1\ (+/-\ 1)}{356 \times 6\ years}$$

$$= 5 \times 10^{-4}\ yr^{-1}\ (0 \text{ and } 1 \times 10^{-3}\ yr^{-1})$$

interval between bursts ~ 2000 years (never, 1000 years)

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interval between bursts ~ 2000 years (never, 1000 years)

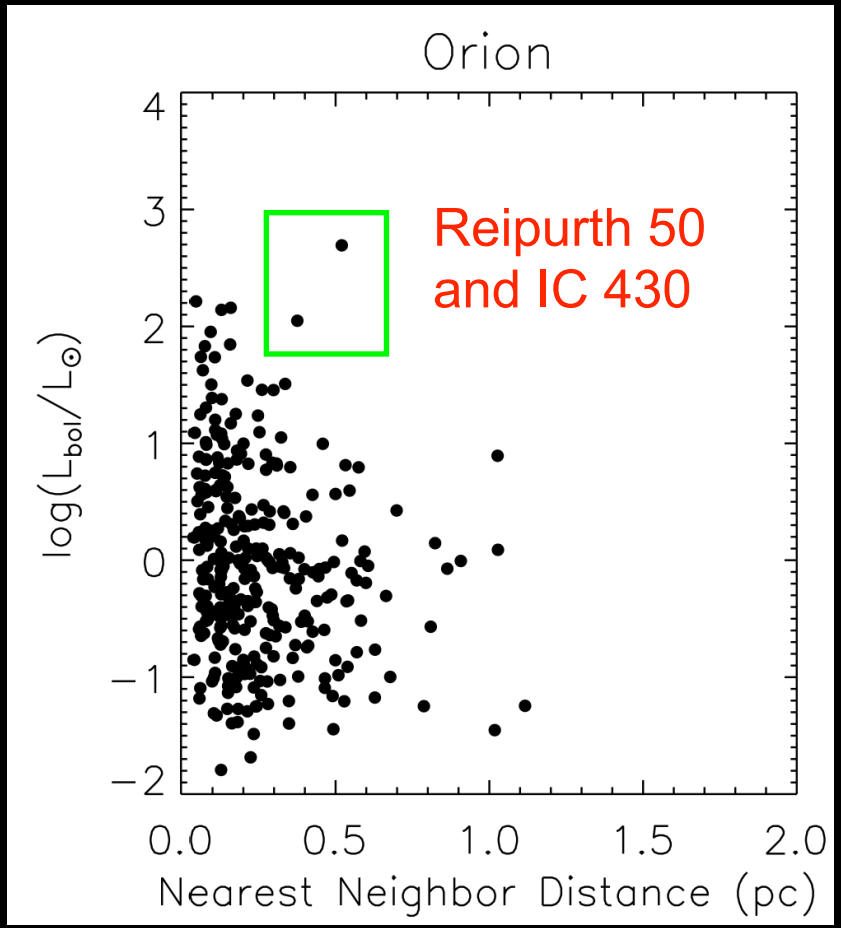
5000-20,000 years from the Schultz et al. (2013) study of 4000 dusty YSOs with WISE & Spitzer photometry

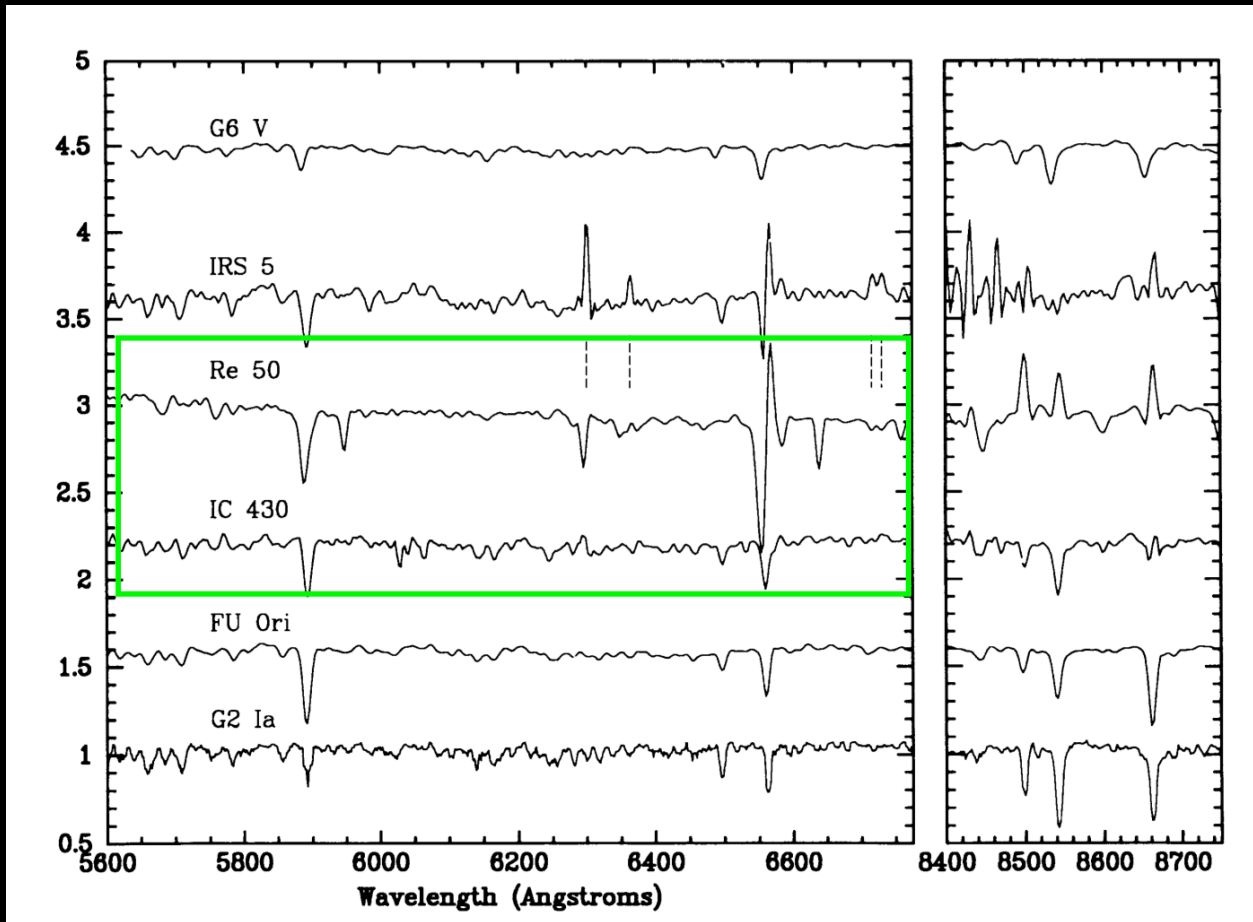
What is the duration of a burst?

$$t_{burst} = \frac{N(\text{high accretion})}{N(\text{protostars}) \times \text{Rate}}$$

$$= \frac{N(\text{high accretion})}{N(\text{outbursts})} \times \Delta\text{Time}$$

What is the Number of Ongoing Bursts in Orion i.e. N(high accretion)





Kryukova et al. 2013

Strom & Strom 1993

Number of known/candidate bursts in Orion: 4

What is the duration of a burst?

$$t_{burst} = \frac{N(\text{high accretion})}{N(\text{protostars}) \times \text{Rate}}$$

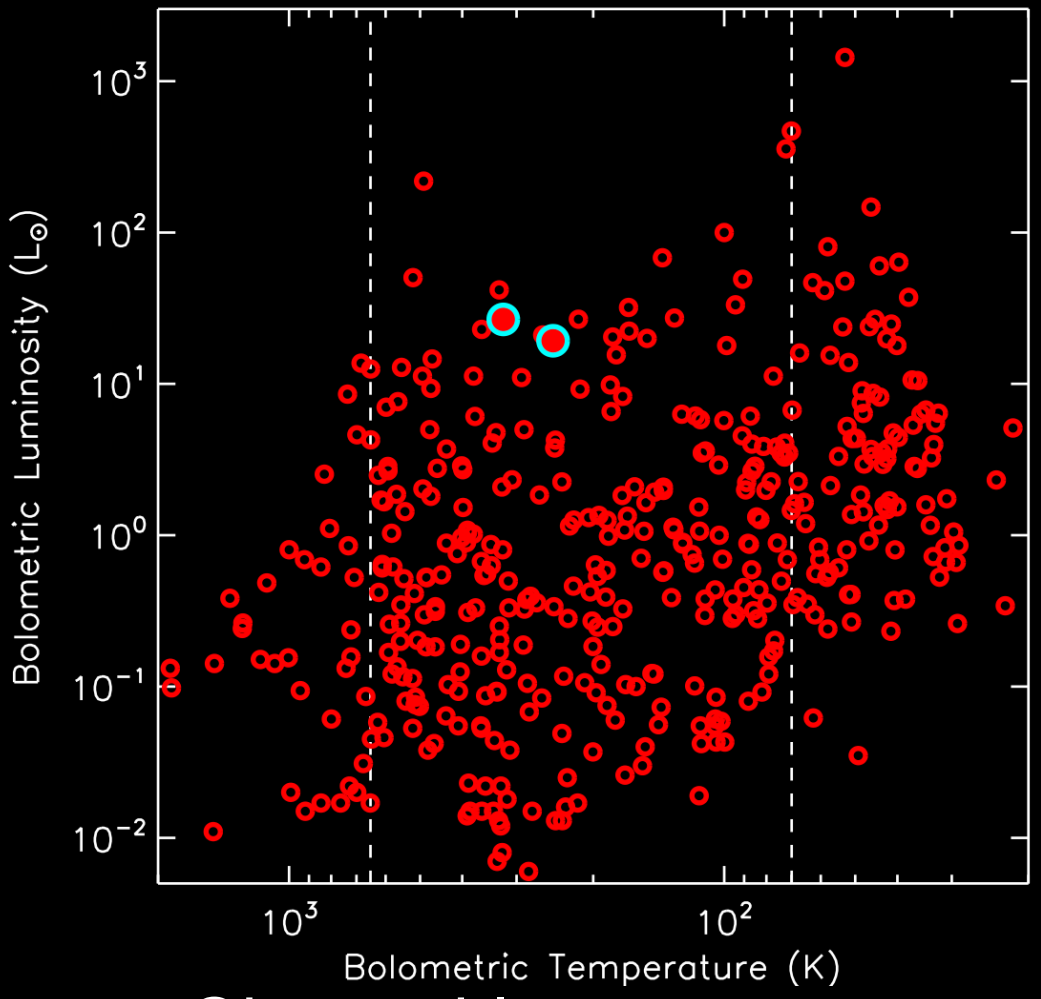
$$= \frac{N(\text{high accretion})}{N(\text{outbursts})} \times \Delta\text{Time}$$

$$= \frac{4}{1} \times 6 \text{ year}$$

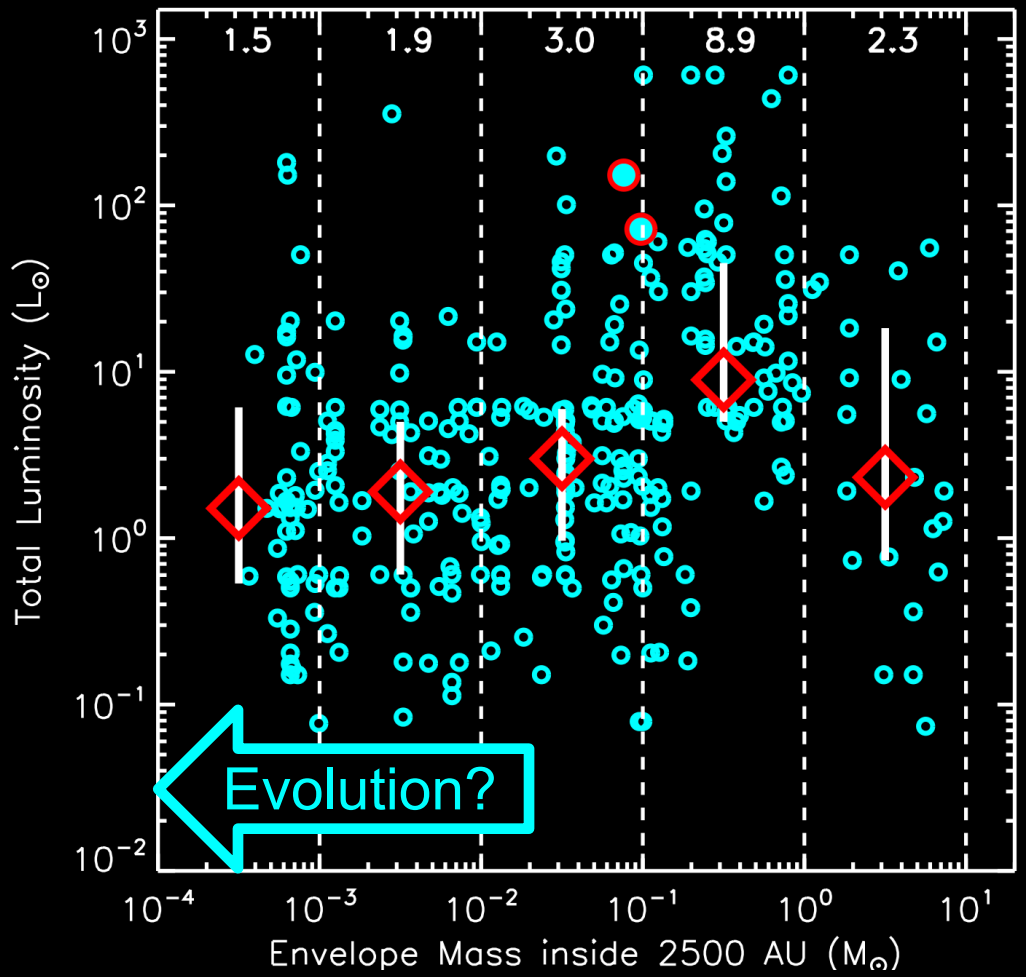
$$= 24 \text{ years}$$

What is the Upper Limit of Ongoing Bursts in Orion? i.e. N(high accretion)

Furlan et al. in prep., Ali et al. in prep., Fischer et al. in prep., Stanke et al. in prep.



Observables



SED model fit results

But is spread due to bursts or other factors?

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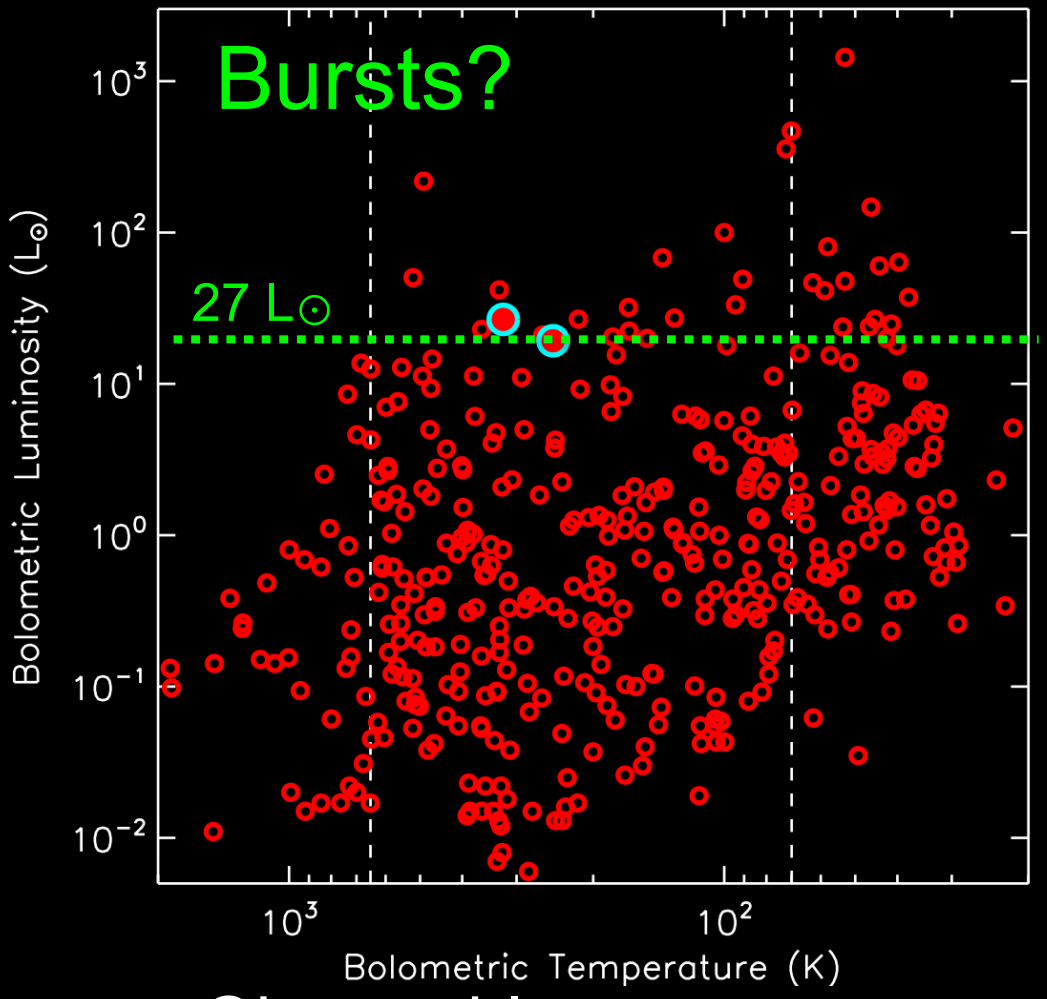

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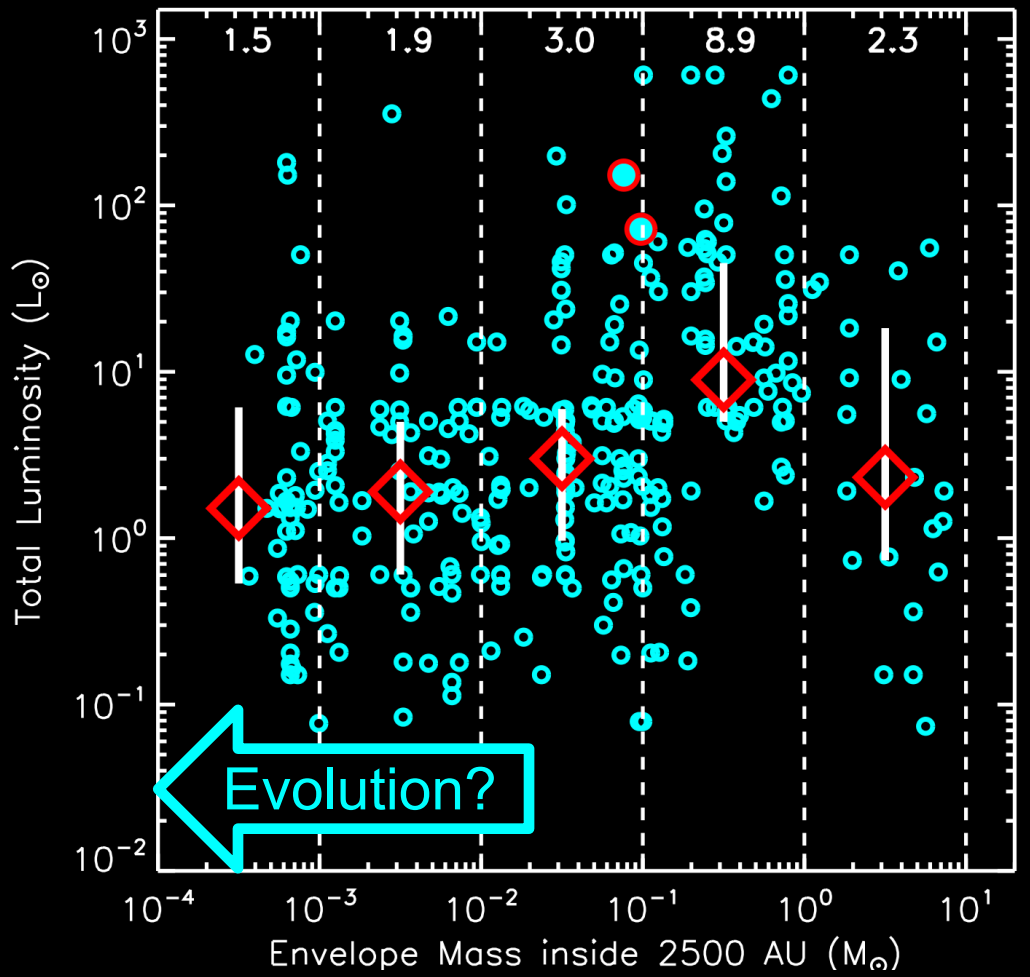

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$$= \frac{33}{1} \times 6 \text{ year}$$

$$= 198 \text{ years}$$

How much mass accreted in bursts?

$$M(\text{burst}) = r_{\text{burst}} \times t_{\text{burst}} \times \dot{M}_{\text{burst}} \times t_{\text{proto}}$$

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$$= \frac{4}{356} \times 500{,}000\ \text{yr} \times 10^{-5}\ M_{\odot}\ \text{yr}^{-1}$$

$$= 0.06\ \text{Msun}$$

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$$= \frac{33}{356} \times 500{,}000\ \text{yr} \times 10^{-5}\ M_{\odot}\ \text{yr}^{-1}$$

$$= 0.46\ M_{\text{sun}}$$

Summary

Modest level variability in mid to far-IR common for protostars, probably driven by accretion.

Constrains on burst rates of protostellar objects in Orion.

Burst rate = 5×10^{-4} yr^{-1} ($< 1 \times 10^{-3}$ yr^{-1})

Duration = 24 - 200 years

Mass accreted = 0.06 to 0.5 $M_{\odot}$ (depends on number)

Need better techniques for establishing which Orion sources are undergoing bursts.

Richer samples are needed to place more stringent. Cygnus-X?