Gaia and the recurrence timescale of long-lasting YSO outbursts

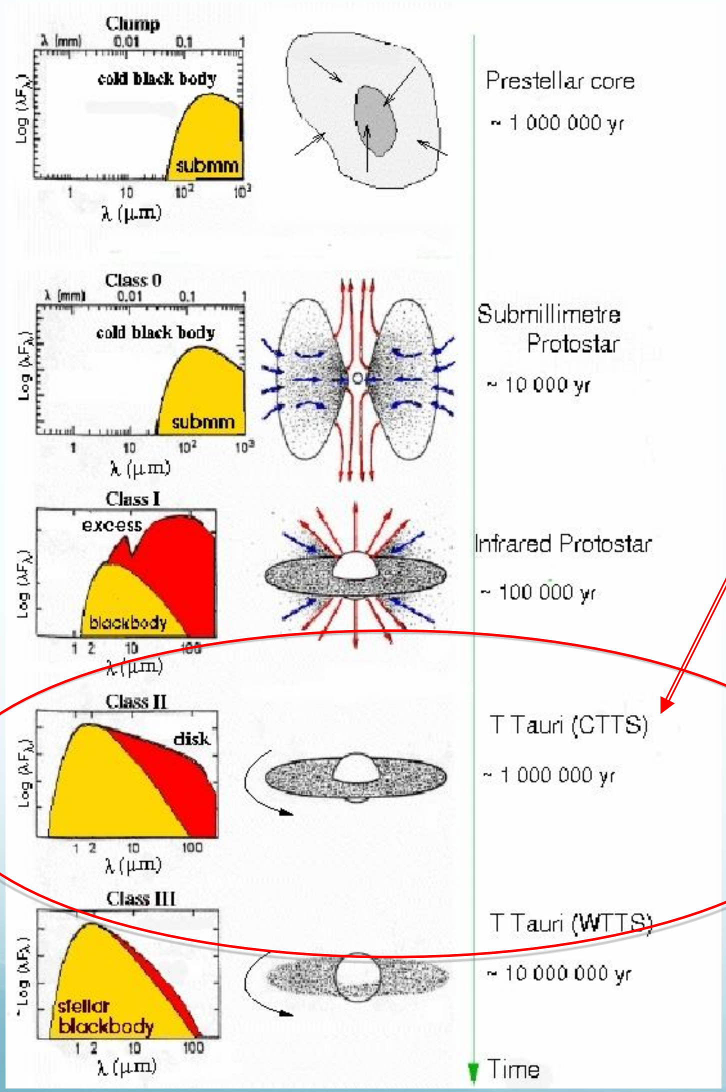
Carlos Contreras Peña, T. Naylor, S. Morrell, University of Exeter

STARRY conference, Leeds, 20 June 2019

LEVERHULME TRUST

UNIVERSITY OF EXETER

YSO evolution and Planet formation



- Planets form in protoplanetary discs.
- Crucial period for planet formation
  - 1 Myr: First planetesimals formed (Pfalzner 2015)
  - 10 Myr: protoplanetary discs around most stars have dissipated (Bell 2013)

Planet Formation

- The properties of the disc, such as surface density or temperature, play a key role in the formation and evolution of protoplanets.
  - These properties enter into migration rates and determine the location of the snowline, the latter having an impact on the surface density of solids (Cieza et al. 2017, Mordasini 2018).

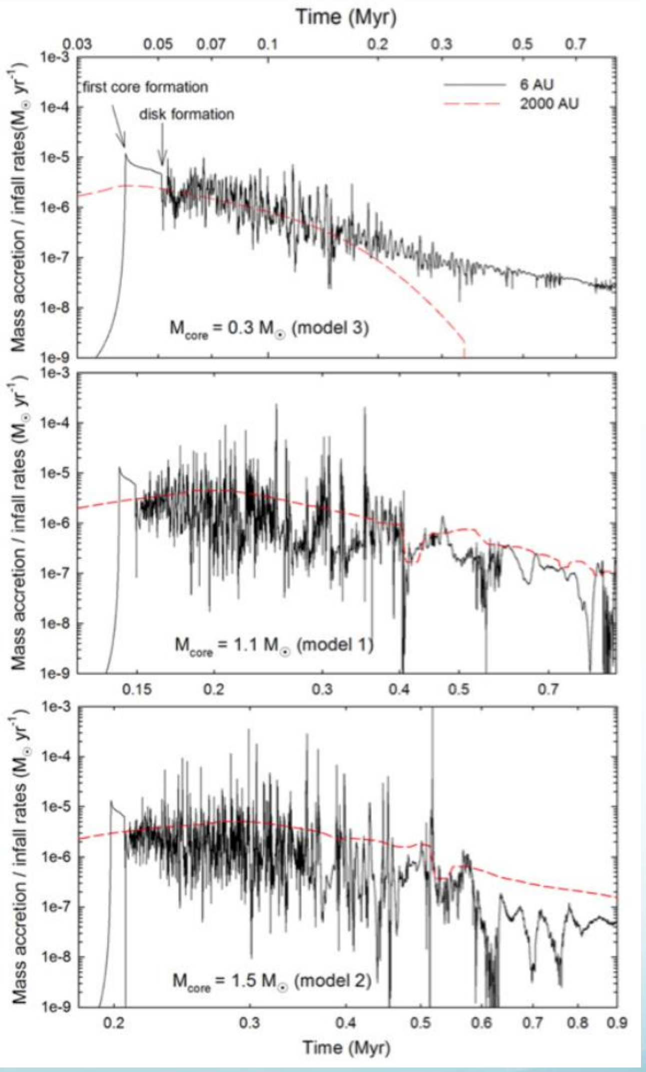
$$\Downarrow$$

- Depend on the accretion rate from the disc onto the central star.
  - Generally assumed to decrease steadily with time and some models include a dependence with the mass of the central star (Kennedy et al. 2008, Mulders et al. 2015).

Episodic accretion

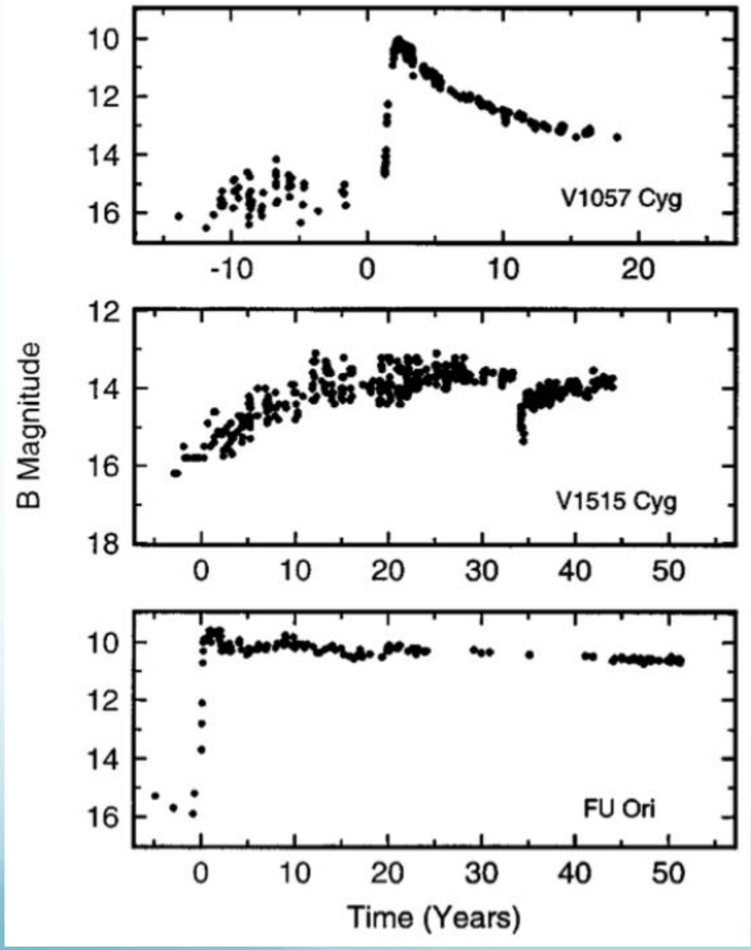
But, theoretically

- Accretion onto the central star is unlikely to be a steady process (see e.g. Vorobyov et al. 2015)



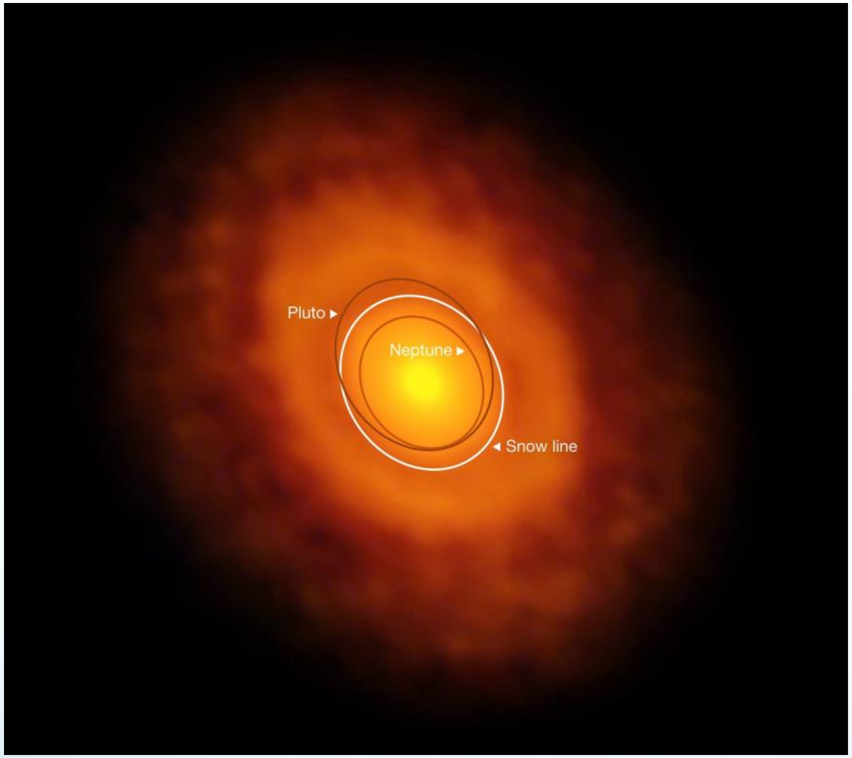
Episodic accretion

and,



- YSOs are known to go through sudden episodes of enhanced accretion that can last 100 years (e.g. Hartmann & Kenyon 1996, Audard et al. 2014; Contreras Peña et al. 2017).
- Approx. 14 long-lasting outbursts have been recorded in the past 70 years (Hillenbrand et al. 2018) .

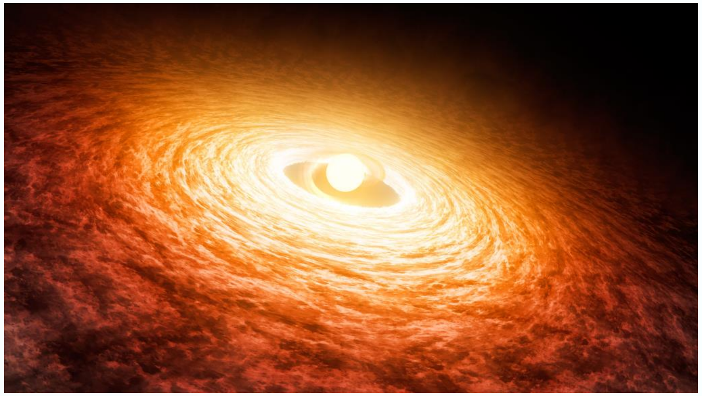
Impact on Planet Formation



ALMA (ESO/NAOJ/NRAO)/L. Cieza

- Large, long-lasting accretion events allow the in-situ formation of rocky planets even at distances ~1 AU, and will lead to planetary system architectures similar to our own (Hubbard 2017).
- Variable snowlines (V883 Ori, Cieza et al. 2017)

Outbursts



Artist's conception of FU Orionis
NASA/JPL

- It is not clear whether all stars go through episodes of enhanced accretion during their evolution (see e.g. Hartmann & Kenyon 1996).
  - Whether YSOs undergo long-lasting accretion events or not could lead to different planetary system architectures (solar vs systems with tightly packed inner planets)? (Hubbard 2017)

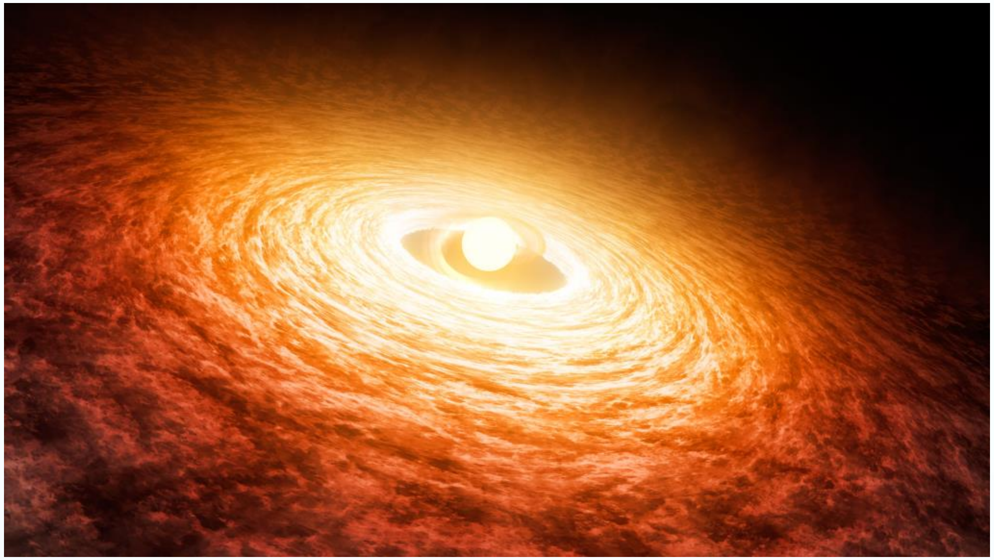
- The frequency and amplitude of the outbursts is not well constrained.
  - Scholz et al. 2013 compared WISE vs Spitzer photometry and determine an outburst rate between 5-100 kyr.

- There ~~is~~ was controversy as to whether the very largest outbursts are associated with the Class II planet building phase at all, or are just limited to the pre- planet-forming (Class 0/I) phase (c.f. Sandell & Weintraub 2001, with Miller et al. 2011).

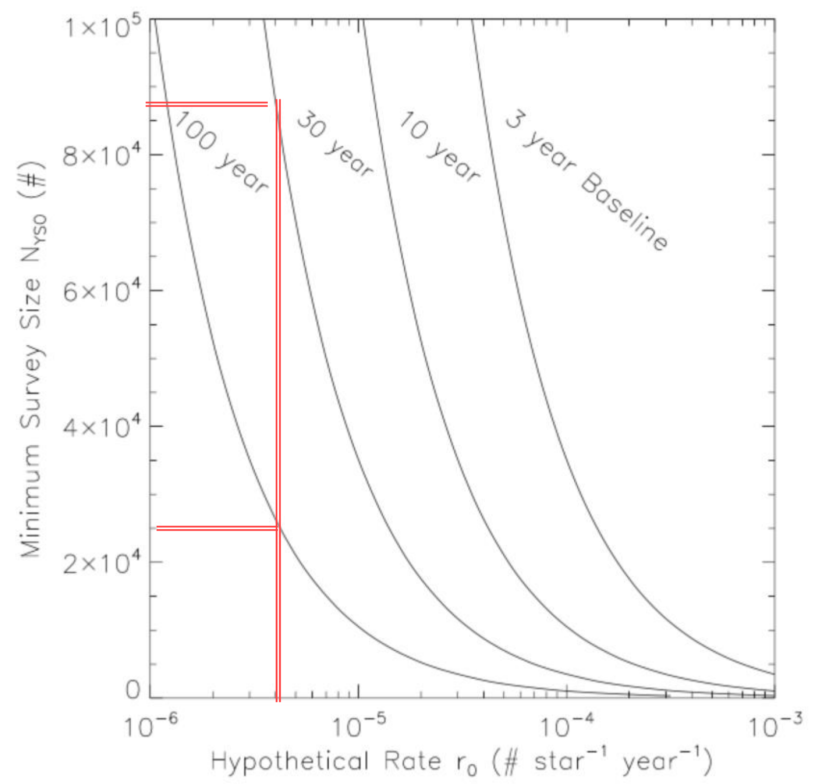
Outbursts

Artist's conception of FU Orionis

NASA/JPL



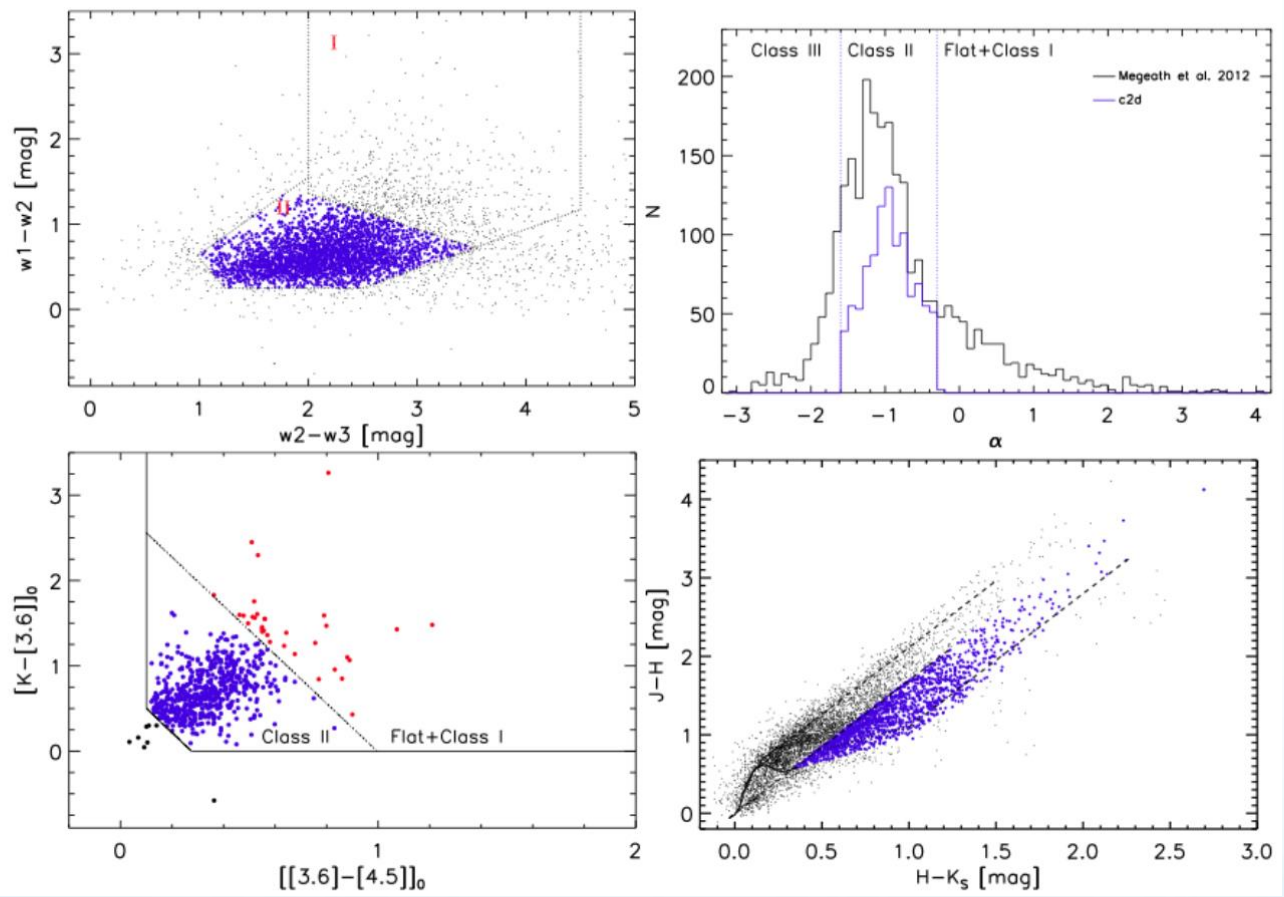
Bae et al. (2014) predict a rate of ~3x10^{-6} star^{--1} year^{--1}



To determine the outburst rate, we need to maximize both the time baseline and the number of YSOs surveyed (see e.g. Hillenbrand & Findeisen 2015).

Figure from Hillenbrand & Findeisen 2015

Sample

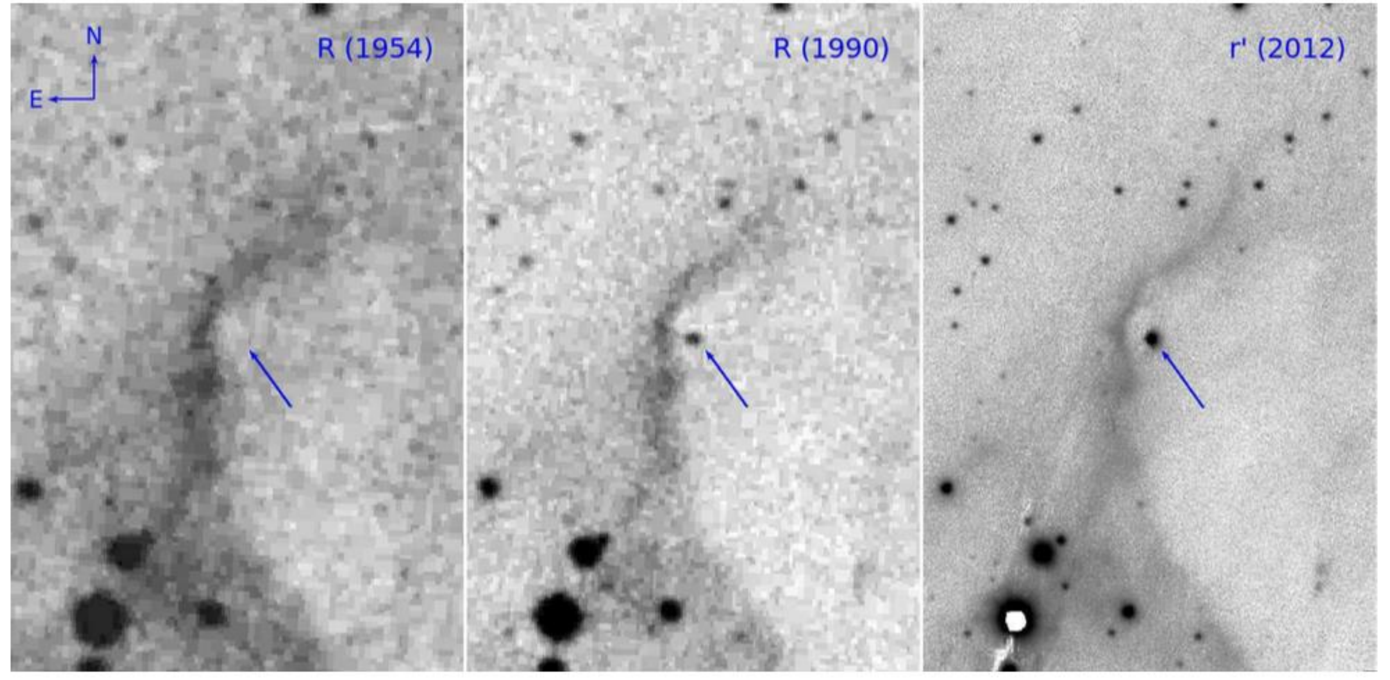


- We have constructed a sample of 15400 class II YSOs from SIMBAD (pMS, TTau, FUor, etc).

Time Baseline

- Comparison of Gaia DR2 magnitudes with those obtained from digitised photographic plates (B, R and I) by SuperCOSMOS (SSS, Hambly 2001) provided a mean baseline of 55.6 yrs.

V2492 Cyg



SuperCOSMOS POSS-I E (1954) and POSS-II R (1990) R plate images, and Pan-STARRS r′ (2012)

Method

- Compare *Gaia G* to each SSS magnitude.
- Can work out *N*-dimensional probability of variability.
- Selects 4 815 from the 15 404 Class II list at 5σ.
- Experiments with known variables (e.g. Gaia Alerts) led to
  - tightening *N*-d criterion,
- Gives 1 576 objects.

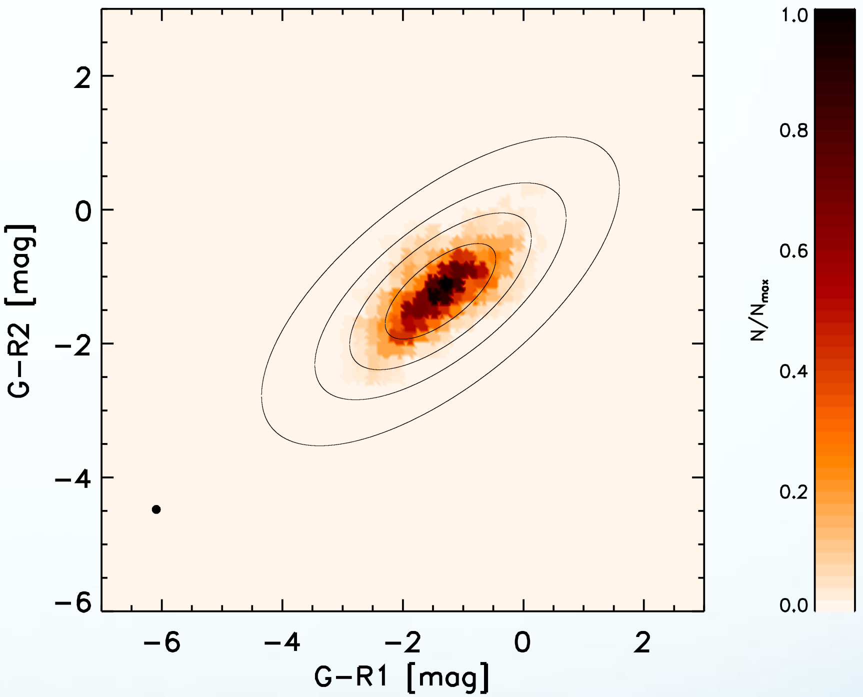
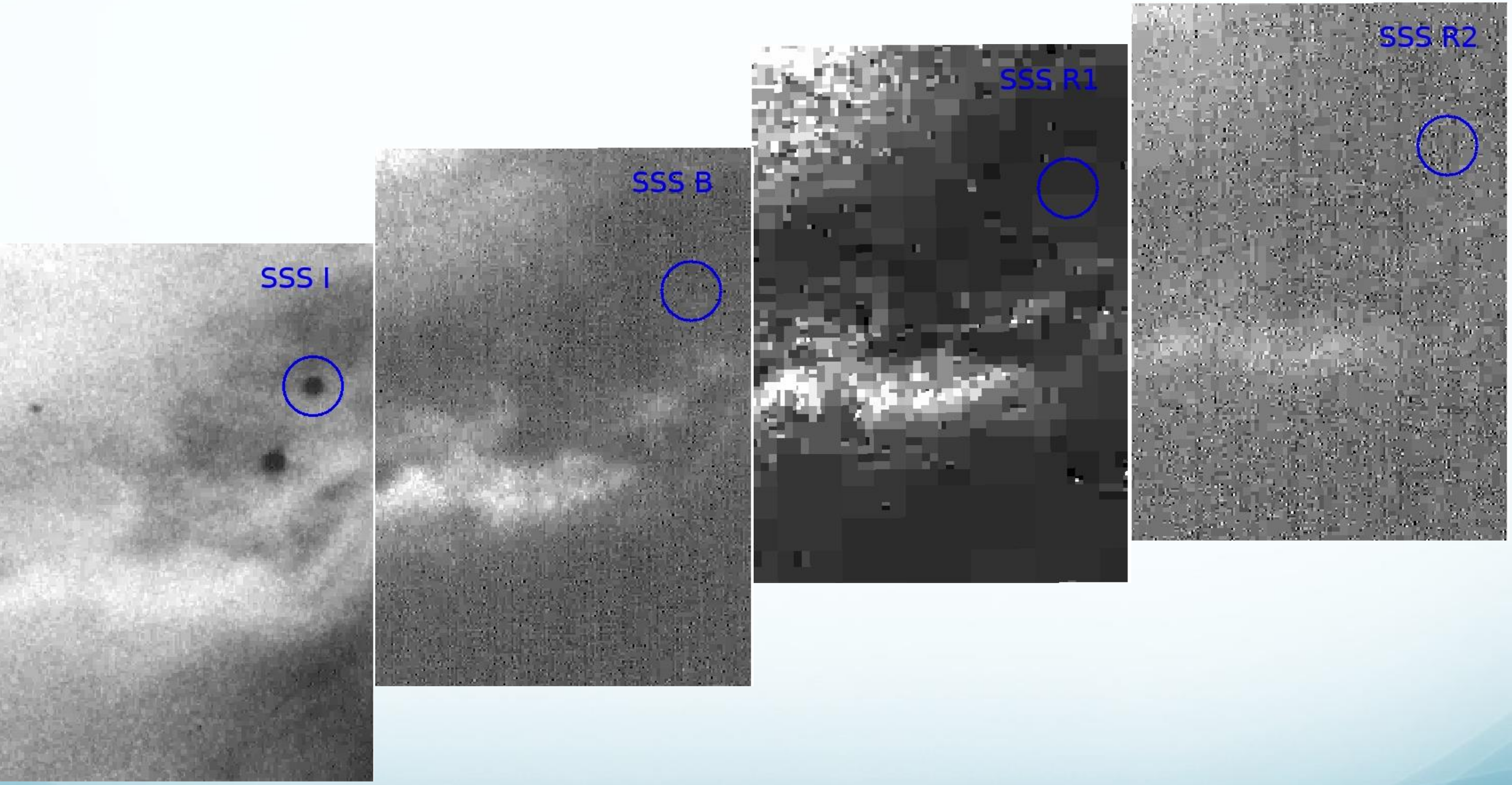


Plate problems

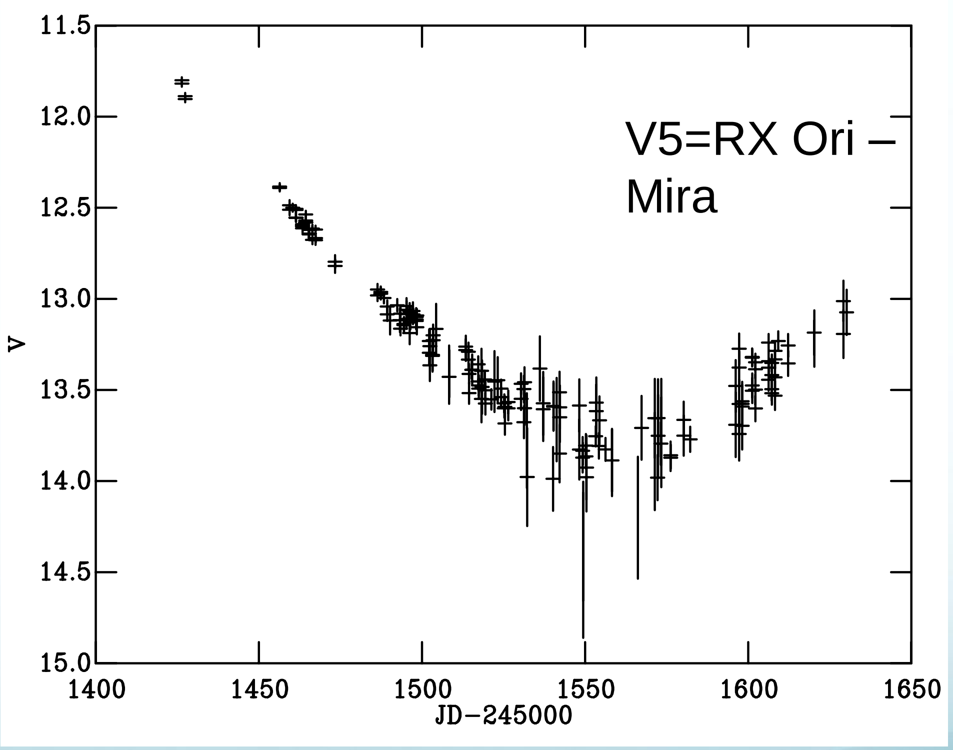


- Use $N_{\mathrm{sss}}/N_{\mathrm{Gaia}}$, in a 3’ × 3′ box.
- Remove if $N_{\mathrm{sss}}/N_{\mathrm{Gaia}} < 0.45$.
- Gives 1 075 of the 1 576 objects.

High-amplitude YSOs?

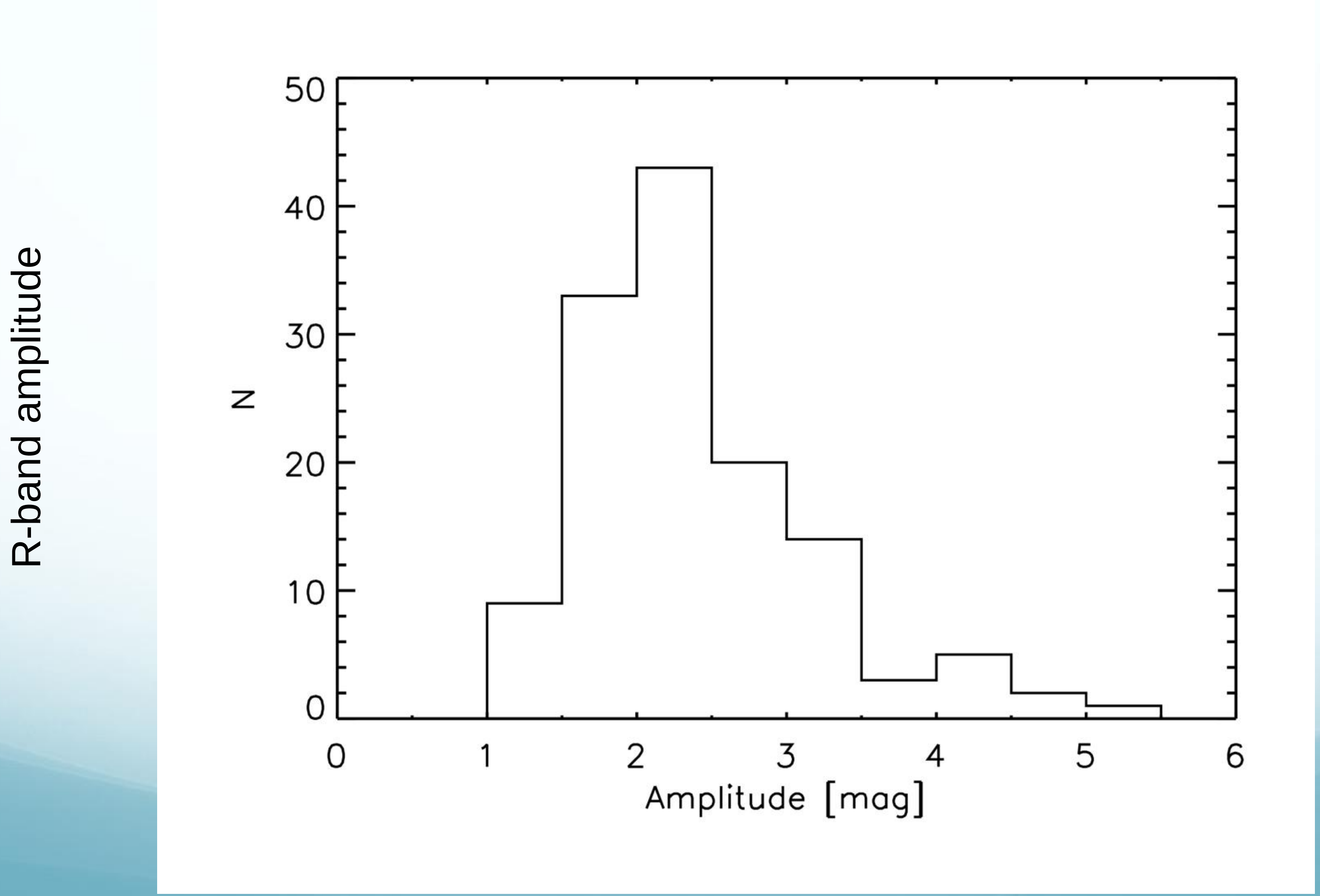
- 139 pass visual inspection for large (>1 mag) amplitude.

6 Likely non-YSOs



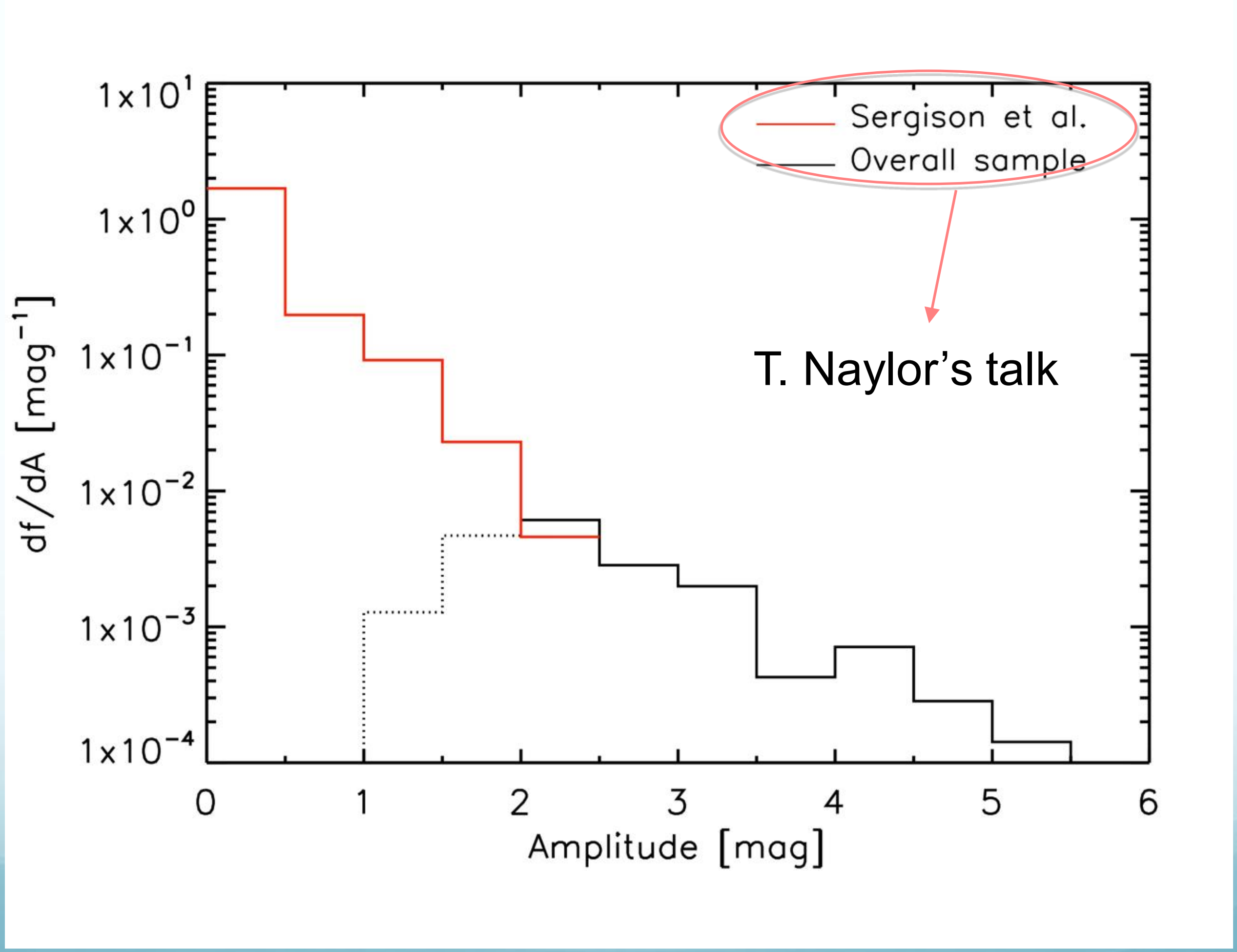
High-amplitude YSOs?

- 133 High-amplitude YSOs.

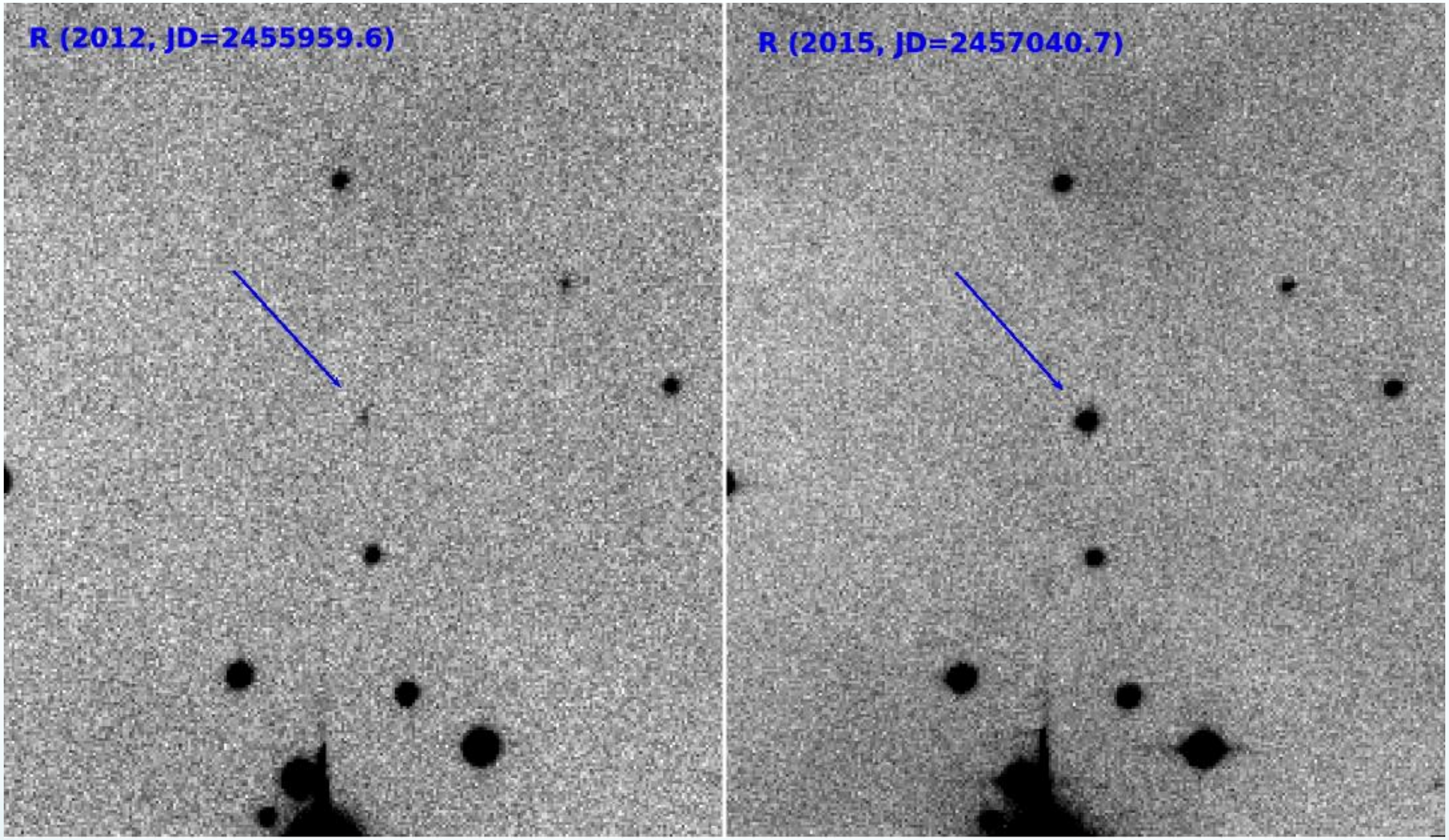


High-amplitude YSOs?

- 139 pass visual inspection for large (>1 mag) amplitude.



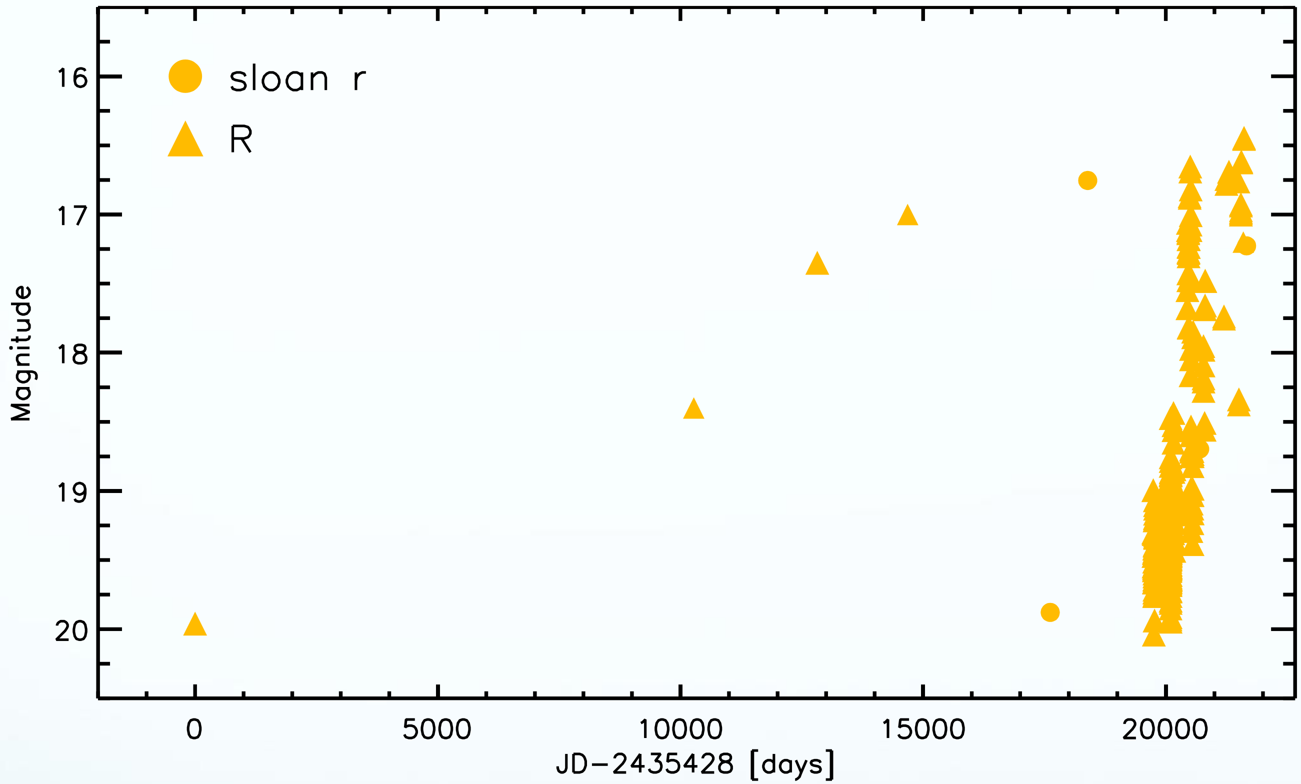
Long-lasting outbursts



V41 (V2628 Ori)

We added photometric data from past surveys such as a IPHAS (Barentsen et al. 2014), VPHAS+ (Drew et al. 2014), PTF (Ofek et al. 2012), Pan-STARRS (Chambers et al. 2016), SkyMAPPER Southern Sky Survey (Wolf et al. 2018)

Long-lasting outbursts



Collating the literature we select 9 YSOs with long-lasting outbursts

The remaining 124 YSOs

- Extreme cases of hot-spot variability (see e.g. Grankin et al. 2007)
- Variable extinction, some long-term (planet-related?)
- Short-term episodic accretion, bursters (FHO 29, Findeisen et al. 2013), exor-like (ASASSN-13db, Sicilia-Aguilar et al. 2013).

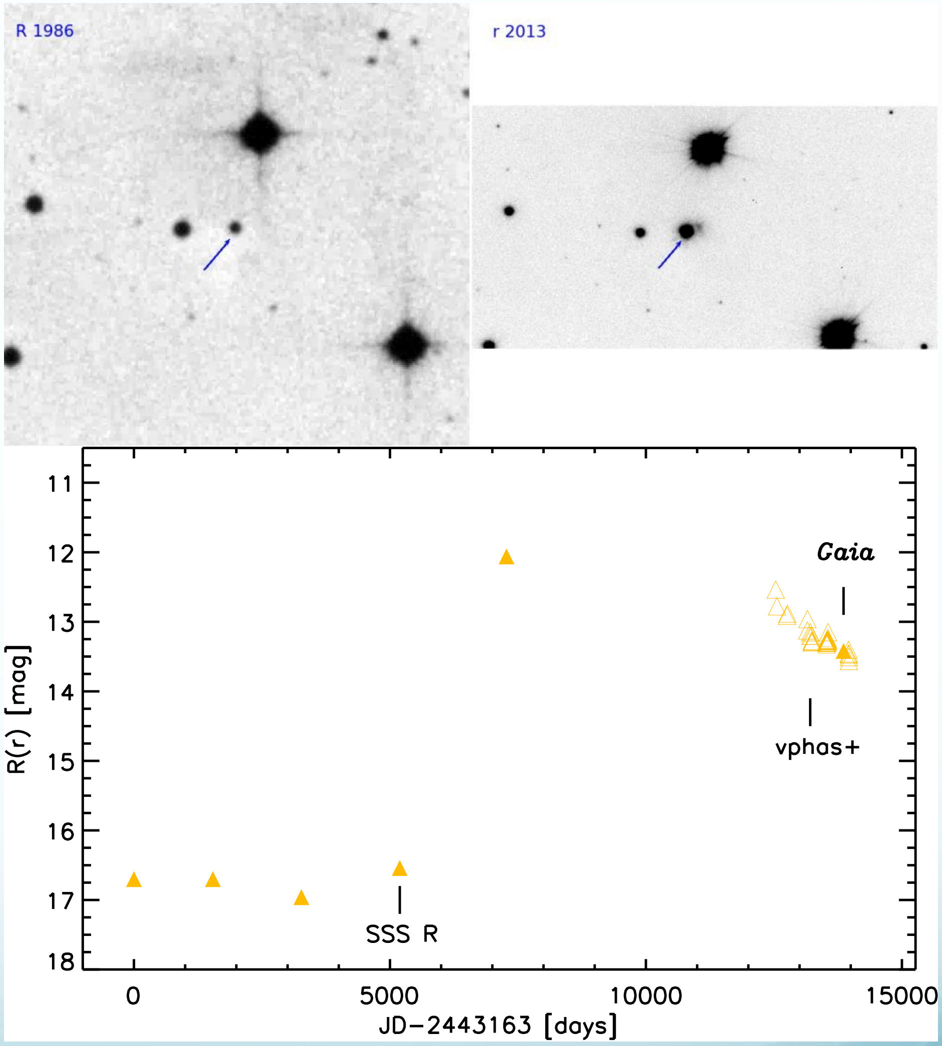
Class I Contamination

ID	Name†	α	Envelope?
V1	V1057 Cyg	–0.1	Yes (Fehér et al. 2017)
V2	HBC 722	–0.44	No (Fehér et al. 2017)
V4	2M J0233+6156	–0.4	?
V6	V350 Cep	–0.17	Yes (Muzerolle et al. 2004)
V9	2M J0841–4052	–0.23	?
V10	V733 Cep	–0.78	No (Fehér et al. 2017)
V31	V960 Mon	–0.19	Yes (Kóspál et al. 2015)
V36	V582 Aur	–0.33	No (Ábrahám et al. 2018)
V51	WRAY 15-488	–0.27	?

~1000 objects in our sample are likely class I YSOs.

Class II outbursts

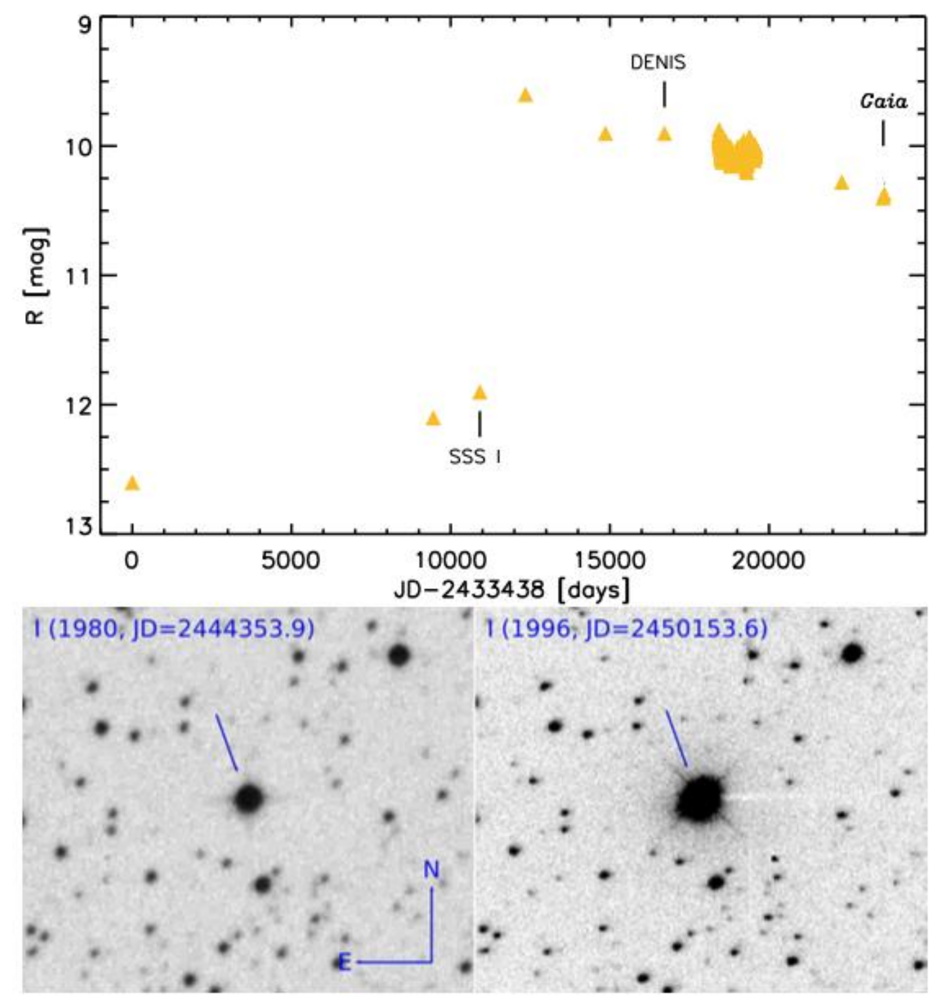
- We classify 6 objects as long-lasting class II outbursts.
- V733 Cep (Reipurth et al. 2007), V582 Aur (Abraham et al. 2018) and HBC 722 (Semkov et al. 2010)
- 3 previously unknown eruptive variable stars.



V9 (2MASS J08410676-4052174)

Class II outbursts

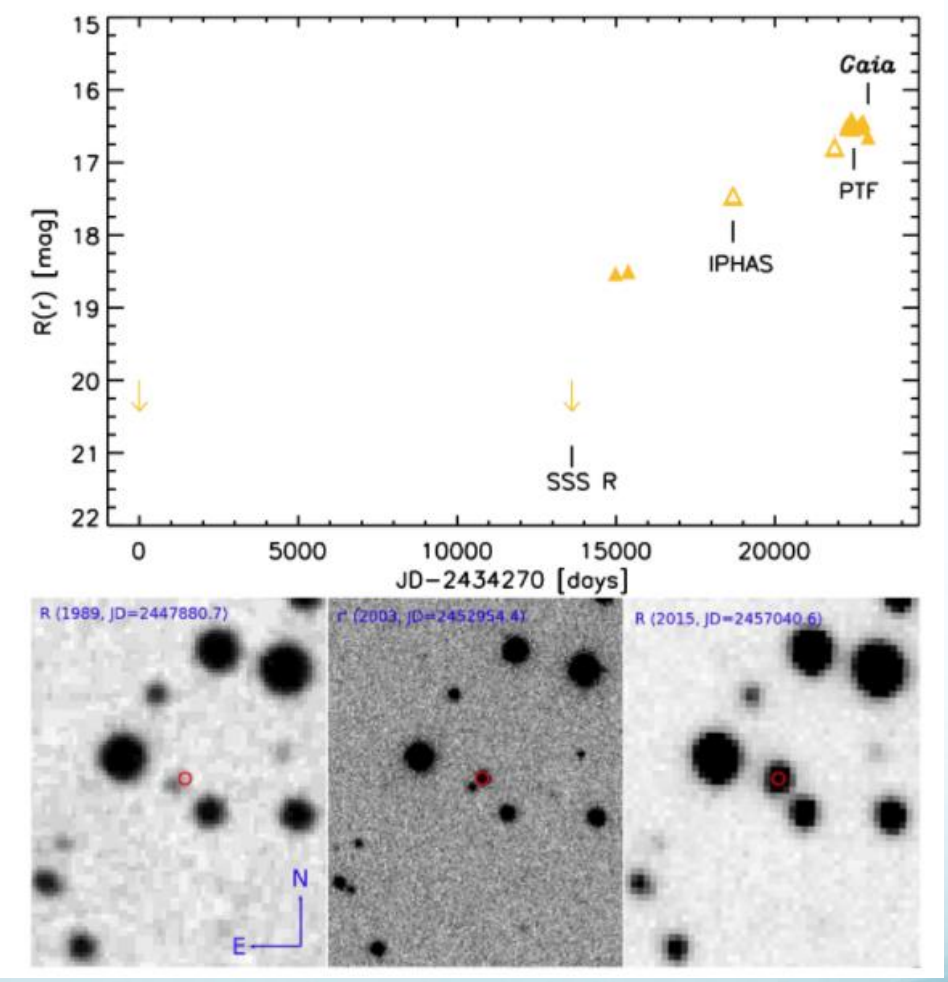
- We classify 6 objects as long-lasting class II outbursts.
- V733 Cep (Reipurth et al. 2007), V582 Aur (Abraham et al. 2018) and HBC 722 (Semkov et al. 2010)
- 3 previously unknown eruptive variable stars.



V51 (Wray 15-488)

Class II outbursts

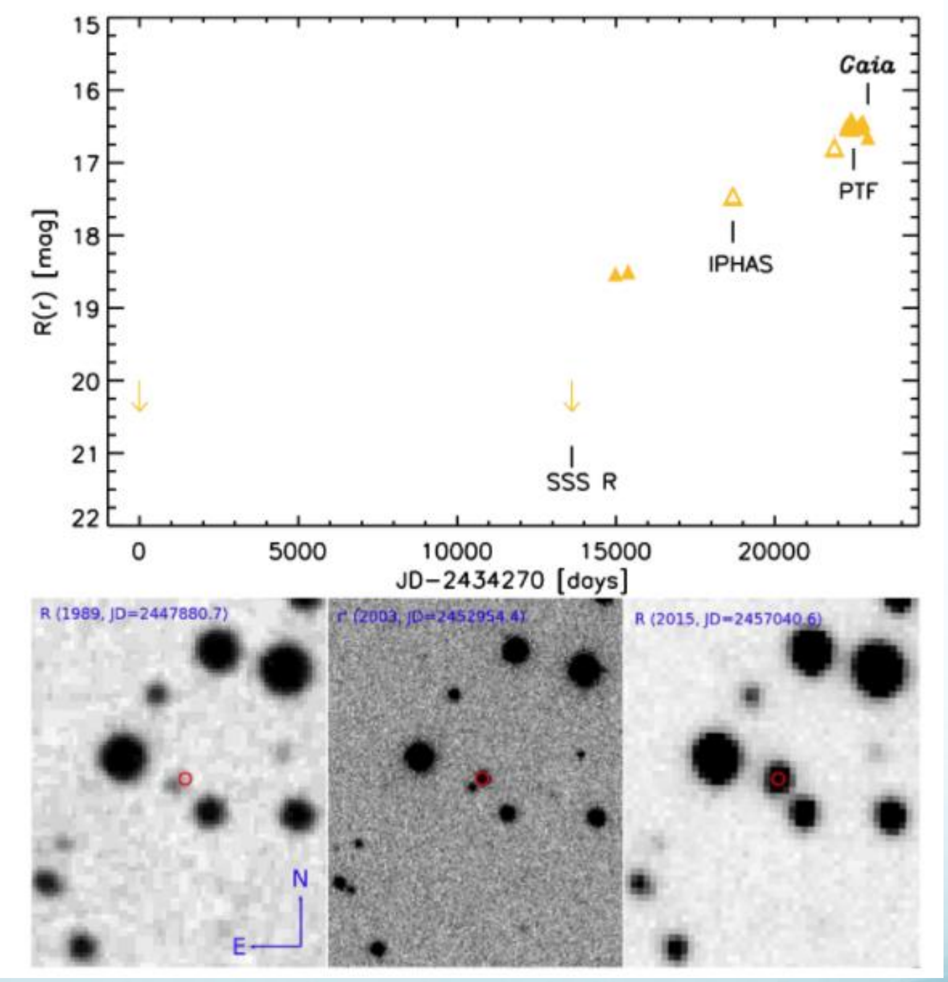
- We classify 6 objects as long-lasting class II outbursts.
- V733 Cep (Reipurth et al. 2007), V582 Aur (Abraham et al. 2018) and HBC 722 (Semkov et al. 2010)
- 3 previously unknown eruptive variable stars.



V4 (2MASS J02335340+6156501)

Inter-outburst interval

- We determine, for the first time, that class II YSOs do in fact undergo large and long-lasting accretion events, with 74 to 180 kyr inter-outburst intervals (depending on prior).
- From the contamination from class I YSOs we estimate a rate of 7-28 kyr for the class I stage,



V4 (2MASS J02335340+6156501)

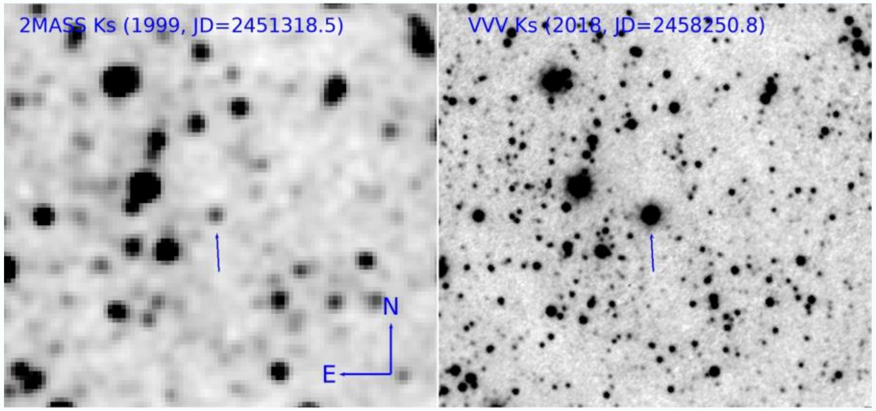
Previous estimates

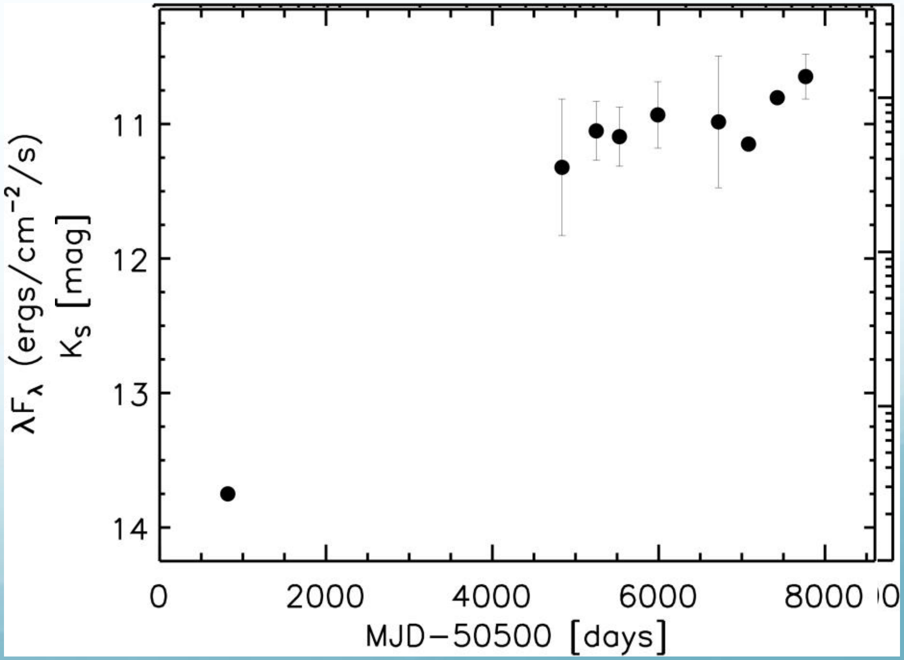
- Scholz et al. 2013 -> from WISE vs Spitzer analysis discover three outbursts which yields an outburst rate of 5-100 kyr, but the sample includes both class I and class II YSOs.
- We re-analysed their sample to estimate the fraction of Class II and Class I YSOs.
- Also, only 2 outbursts are likely to be long-term
  - V2492 Cyg, a known eruptive Class I YSO
  - 2MASS J16443712-4604017, likely a Class I YSO

Outburst rate in the Class II stage is longer than 8 kyr

Between 3 to 30 kyr in Class I YSOs

2MASS J16443712-4604017

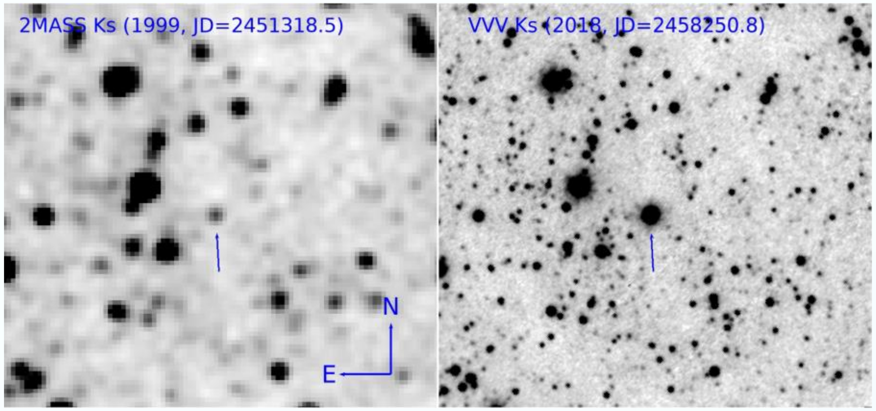


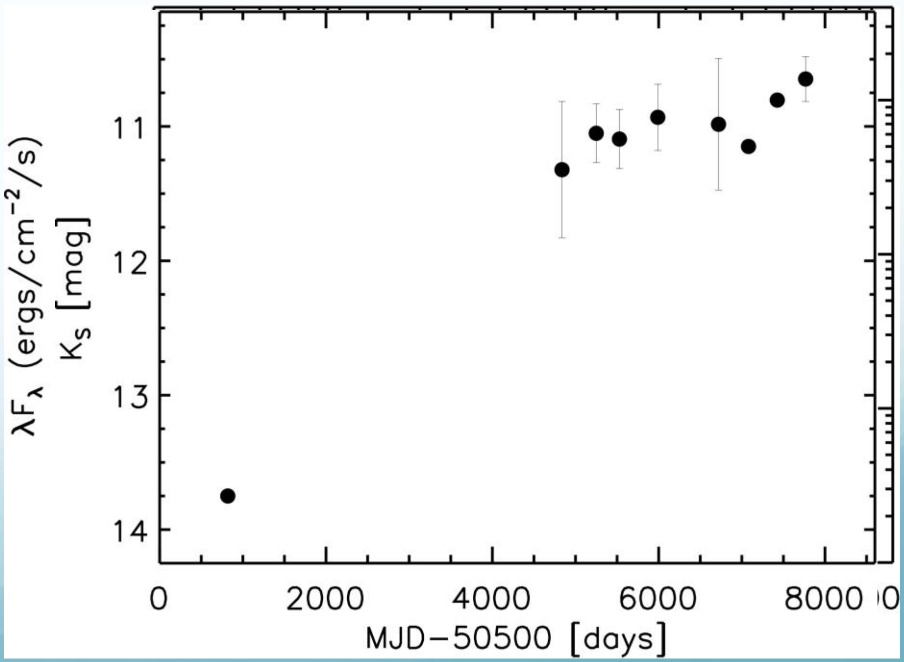


Previous estimates

- Fischer et al. 2019 determine an outburst rate of 1000 yr (90% confidence interval between 690 to 40300 yr) from the mid-infrared variability of 319 protostars (class 0, I and flat-spectrum YSOs) in Orion.
- Time between ejection events determined from the observed gaps between H_2 knots is ~1000 yr (e.g. Makin & Froebrich 2018).
- Gravitational + magnetorotational (GI+MRI) instability models of Bae et al. 2014 predict 12.5 and 333 kyr for the class I and II stages, respectively.

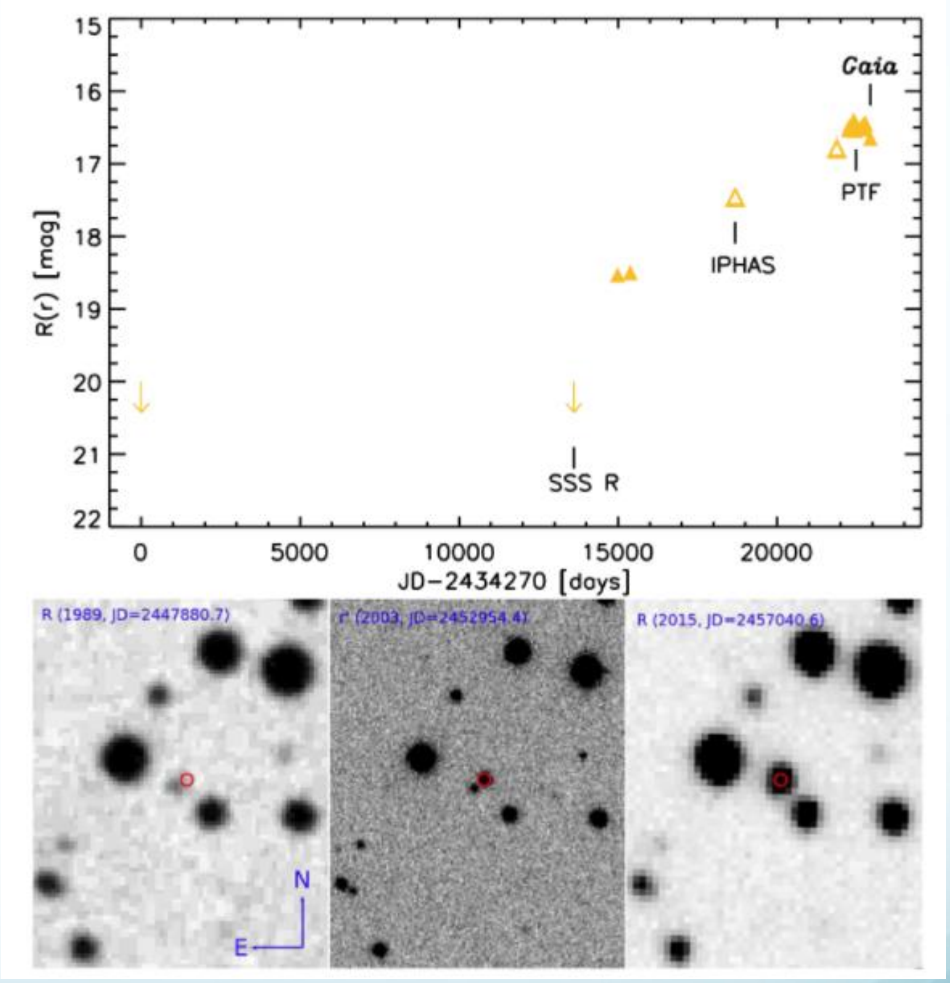
2MASS J16443712-4604017





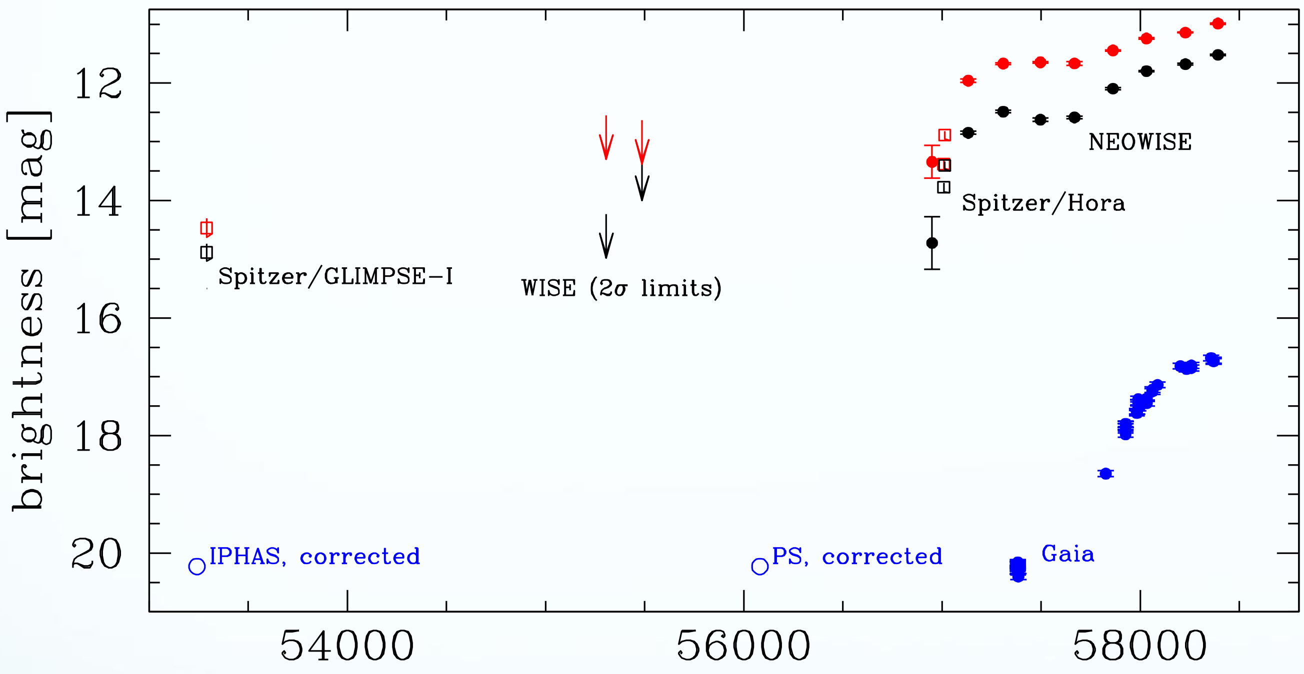
Mechanism

- Reservations - this is an average, perhaps over many mechanisms.
- Gravitational instabilities and fragmentation e.g. Vorobyov & Basu (2015), ApJ 805, 115, produce Class I but probably not Class II interval.
- Planet "daming" – maybe 10^4 years; Lodato & Clarke (2004), MNRAS, 353, 841.
- Combined MRI/GI instabilities – maybe, e.g. Bae et al (2013), ApJ 764, 141.



V4 (2MASS J02335340+6156501)

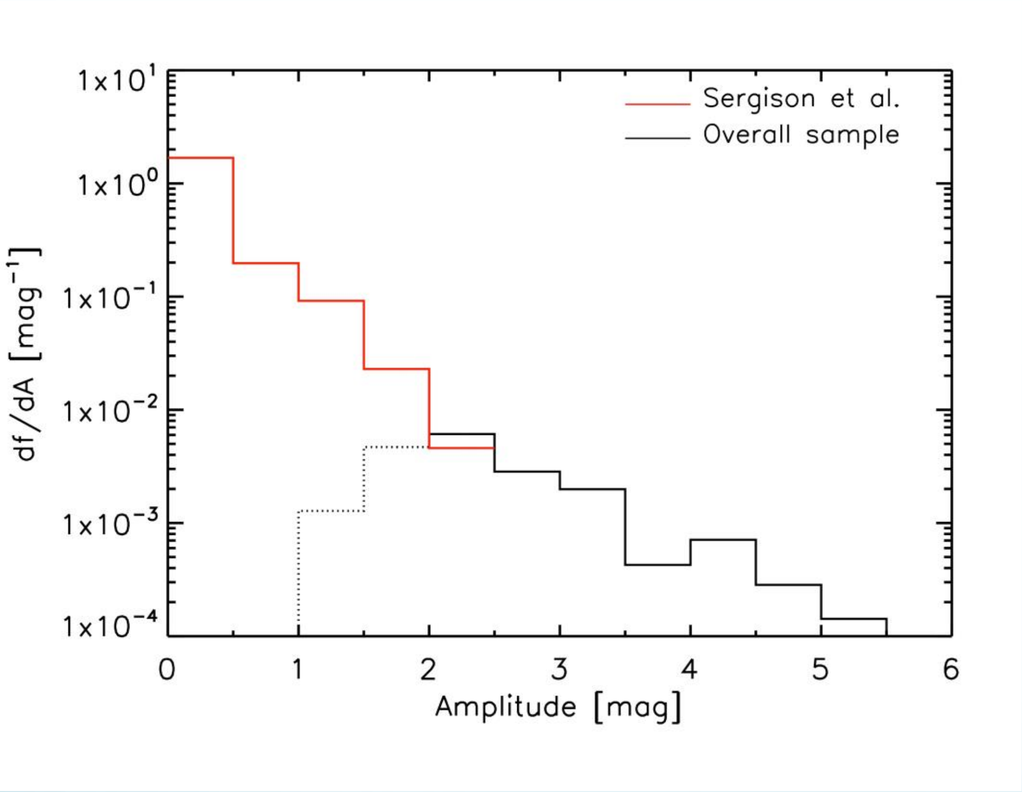
Predictions



Gaia17bpi (see Hillenbrand , Contreras Peña, et al. 2018, ApJ, 869, 146)

- LSST single exposure depth *r*=24.5, corresponds to *G*=25. Maybe 32x bigger sample?
- This would imply 4 class II YSO outbursts per year (as well as ~10 class I outbursts per year).
- 1 year of LSST observations would provide the current number of YSO outbursts.

Conclusions



- 133 High-amplitude YSOs, complete for ΔR>2 mag.
- We have studied ~800000 YSO years and determined that long-lasting accretion related outburst do occur during the class II planet-building phase.
- Outburst rates of ~100000 and ~10000 years for the class II and class I stages respectively.

Contreras Peña, Naylor & Morrell 2019, MNRAS, 486, 4590

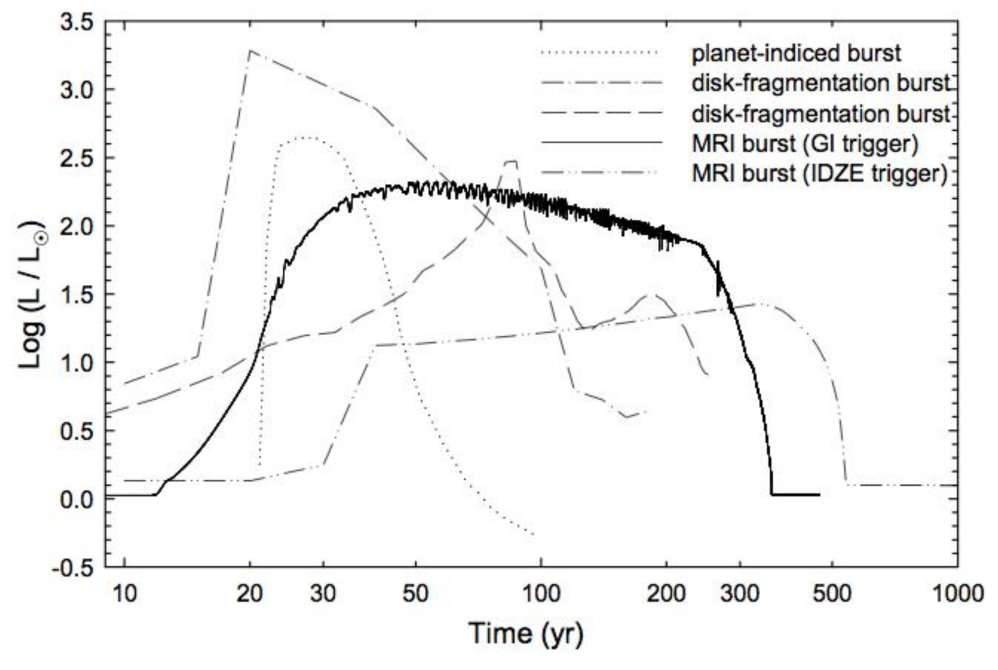
Thank you!

What about non-detections?

- Many objects in our sample are not detected in SuperCOSMOS.
- Instinct - throw away anything without *Gaia* detection.
- But, object at G=22.5, brightens by 2 magnitudes, would be detected.
- So, how much of sample is fainter than G=22.5?
- Estimate this from *r*, *J* and *K* photometry.
- 14 086 objects remain.

LSST

- LSST will provide a unique opportunity to characterize YSO outbursts



Audard et al. 2014,
Protostars & Planets VI

Rise times are slower for inside-out outbursts (Hartmann & Kenyon et al. 1996).

Decay times can constrain the viscosity parameter α(Cannizzo & Mattei 1998, Cannizzo, Chen & Livio 1995).