Determining the recurrence timescale of YSO outbursts (a.k.a FUors)

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Great Barriers in Planet Formation, Palm Cove, 24 July 2019

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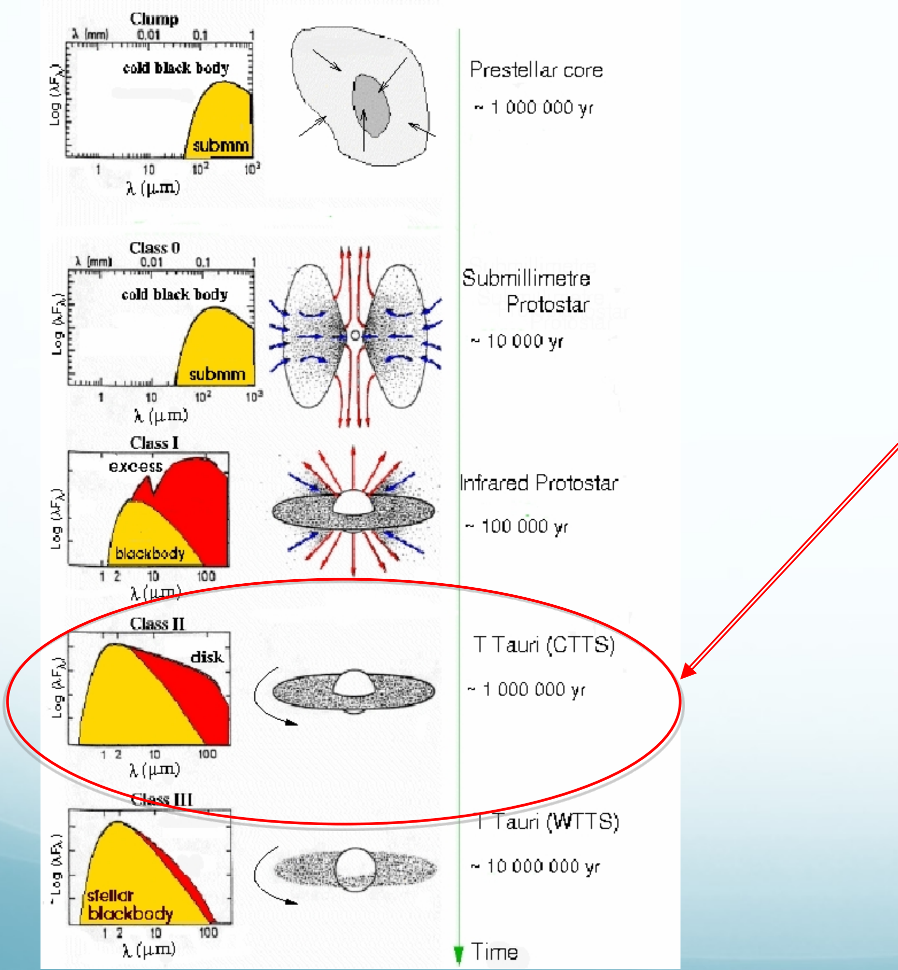
YSO evolution and Planet formation



- 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

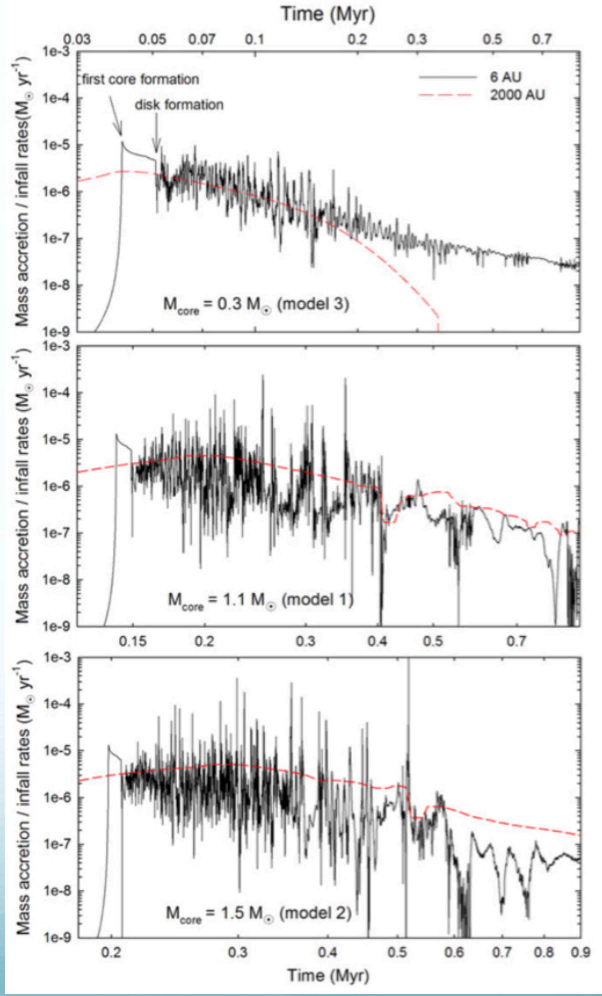
- The properties of the disc, such as surface density or temperature, play a key role in the formation and evolution of protoplanets.
  - These properties enter into migration rates and determine the location of the snowline, the latter having an impact on the surface density of solids (Cieza et al.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

- 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

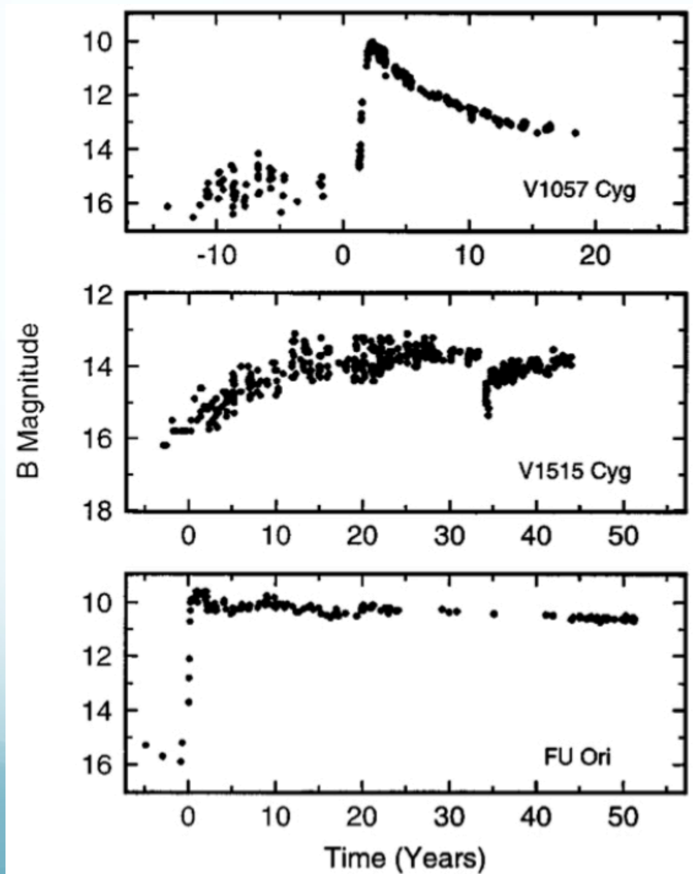
But, theoretically

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



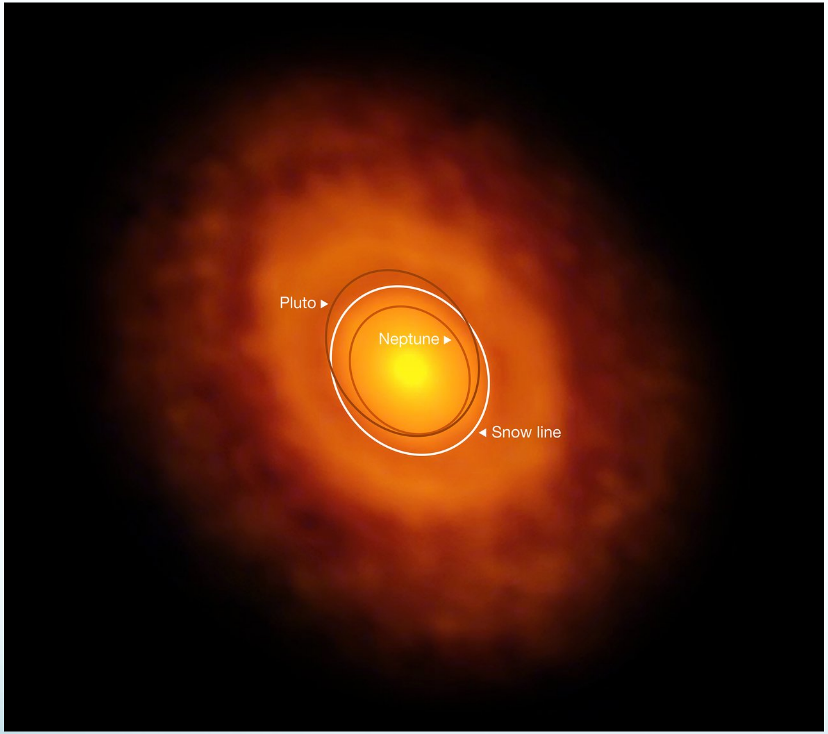
Episodic accretion

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. 15 long-lasting outbursts have been recorded in the past 70 years (Hillenbrand et al. 2018) .

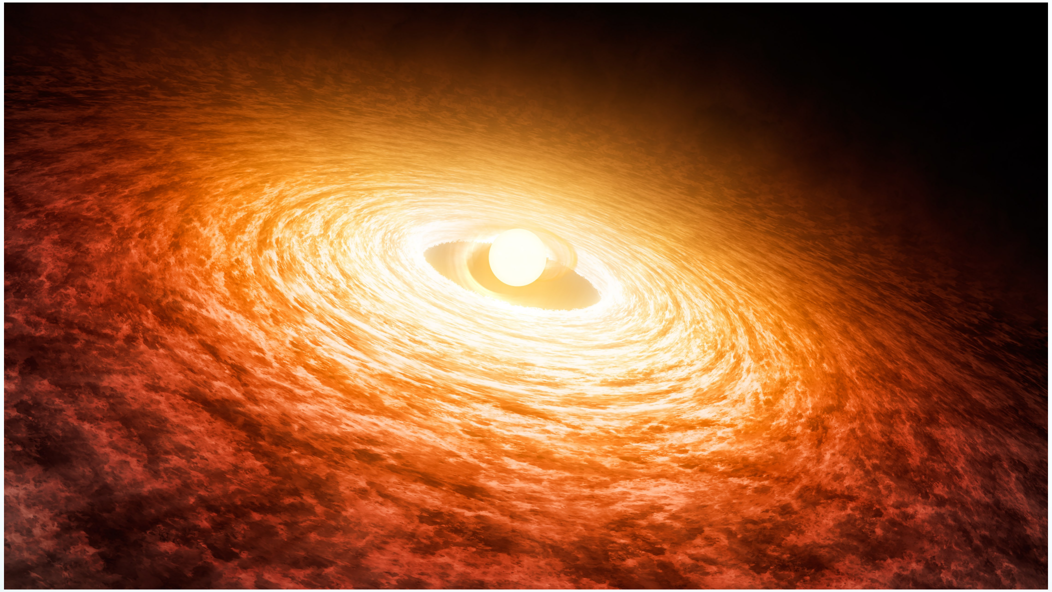
Impact on Planet Formation



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).
- Protoplanets survive the outburst, but it might affect orbital evolution (Boss 2013)
- Variable snowlines (V883 Ori, Cieza et al. 2017)

Outbursts

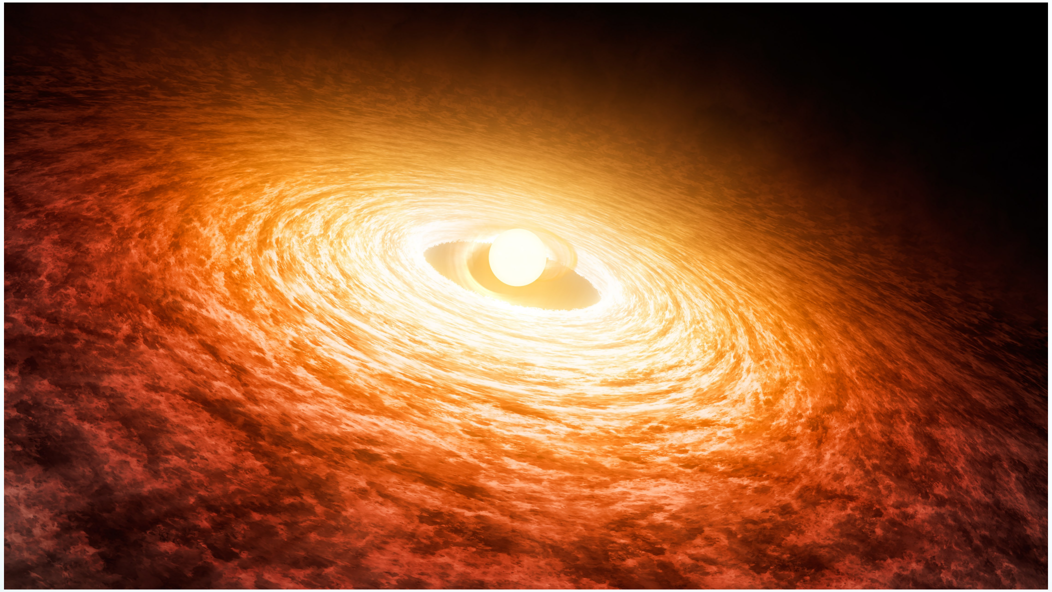


Artist's conception of FU Orionis

NASA/JPL

- It is not clear whether all stars go through episodes of enhanced accretion during their evolution (see e.g. Hartmann & Kenyon 1996).

Outbursts



Artist's conception of FU Orionis

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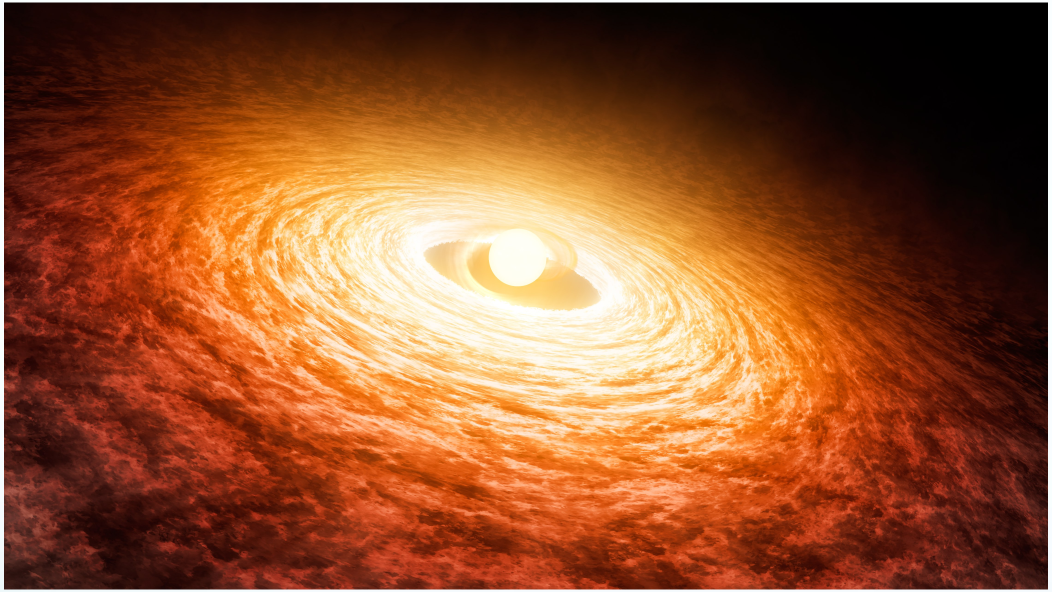
- The frequency and amplitude of the outbursts is not well constrained.
  - Scholz et al. 2013 compared WISE vs Spitzer photometry and determine an outburst rate between 5-100 kyr.

Outbursts



Artist's conception of FU Orionis

NASA/JPL

- There is 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).

Outburst rate

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).

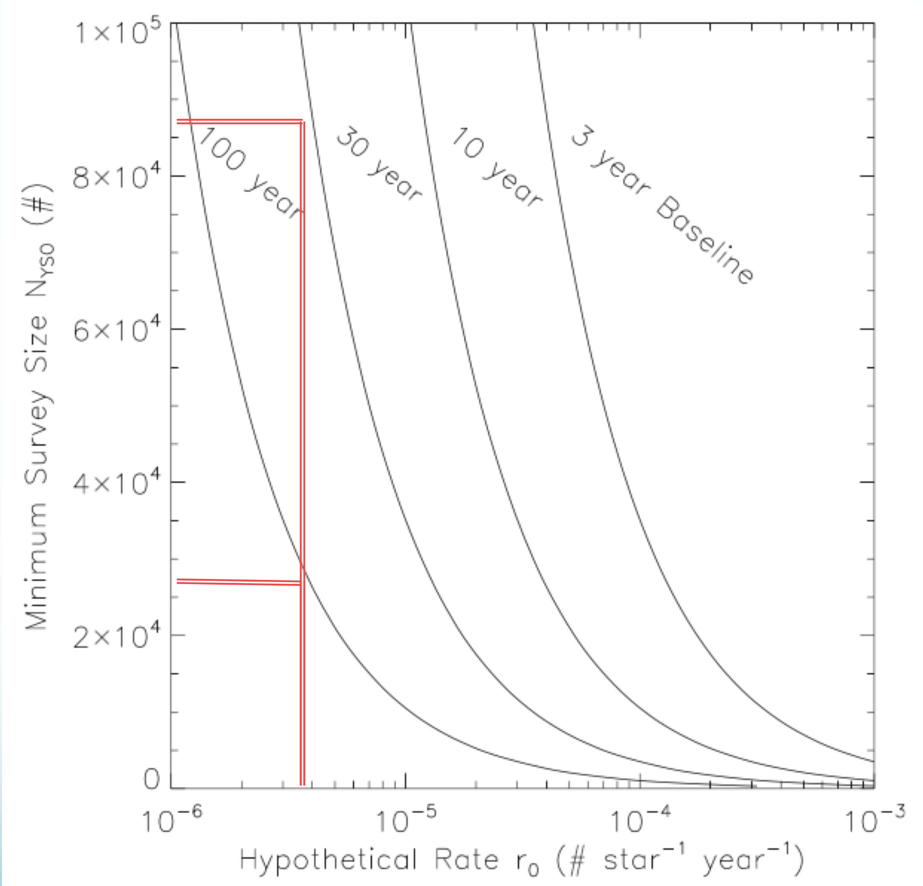
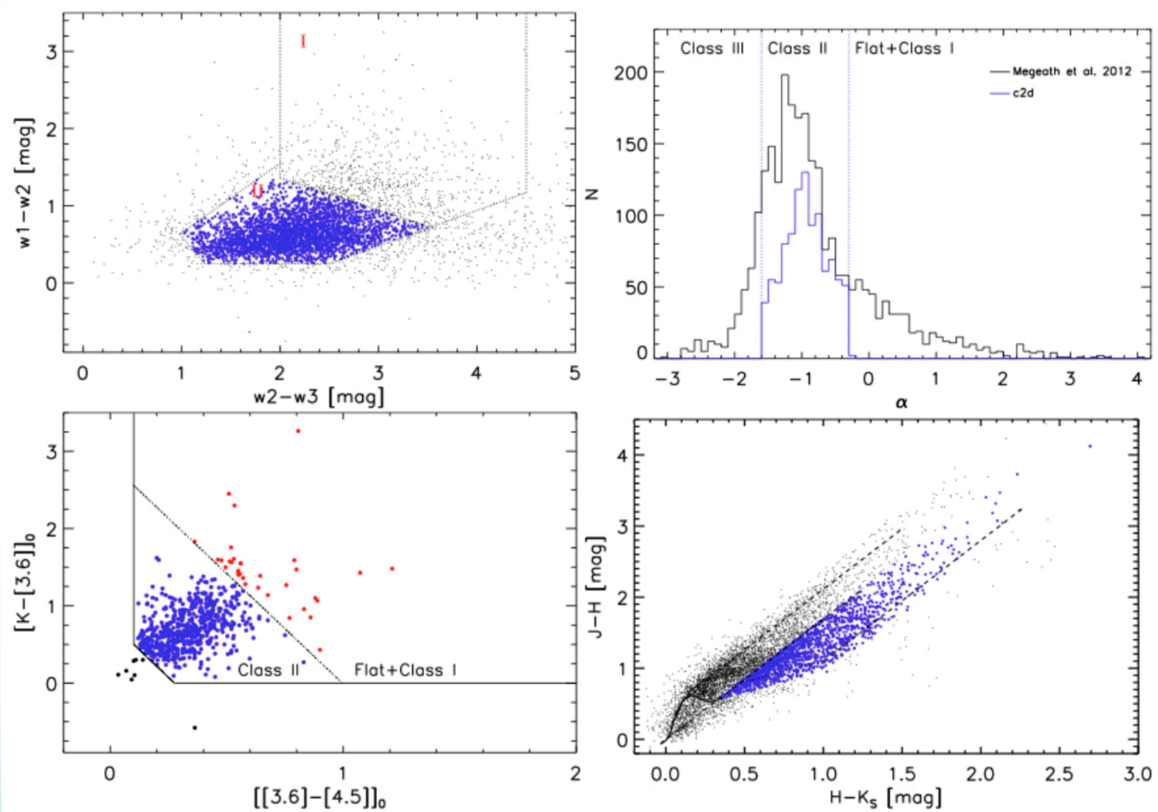


Figure from Hillenbrand & Findeisen 2015

Bae et al. (2014) predict a rate of ~3×10^{-6} $star^{-1}$ $year^{-1}$ (or 1 outburst every 300 000 years for the class II stage)

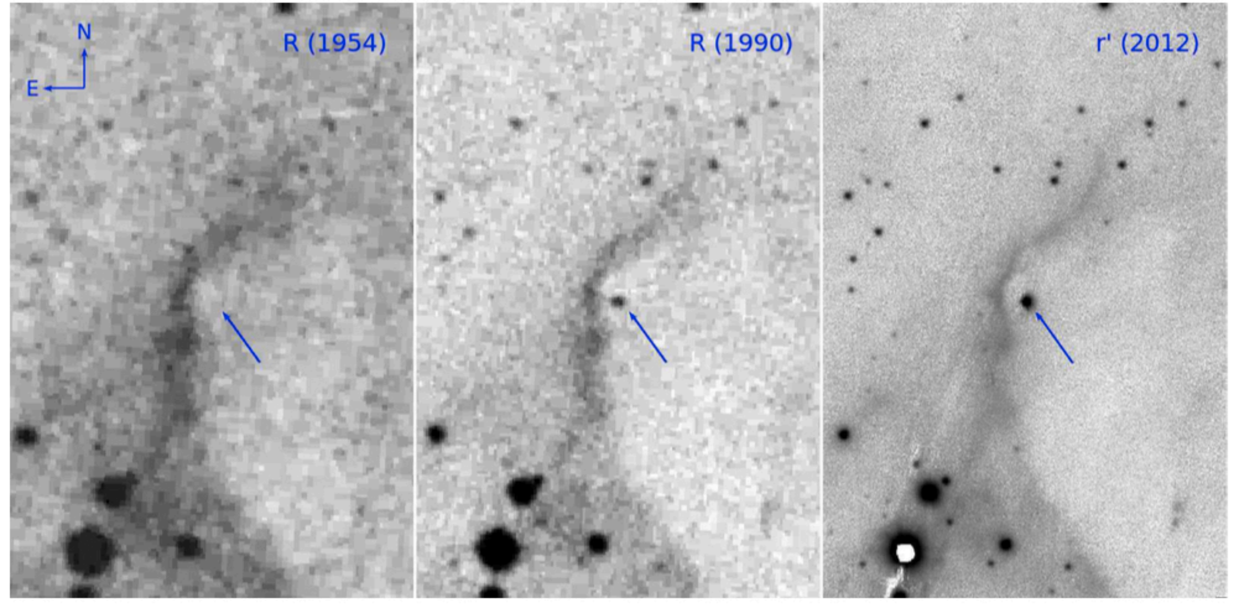
Sample



- 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.

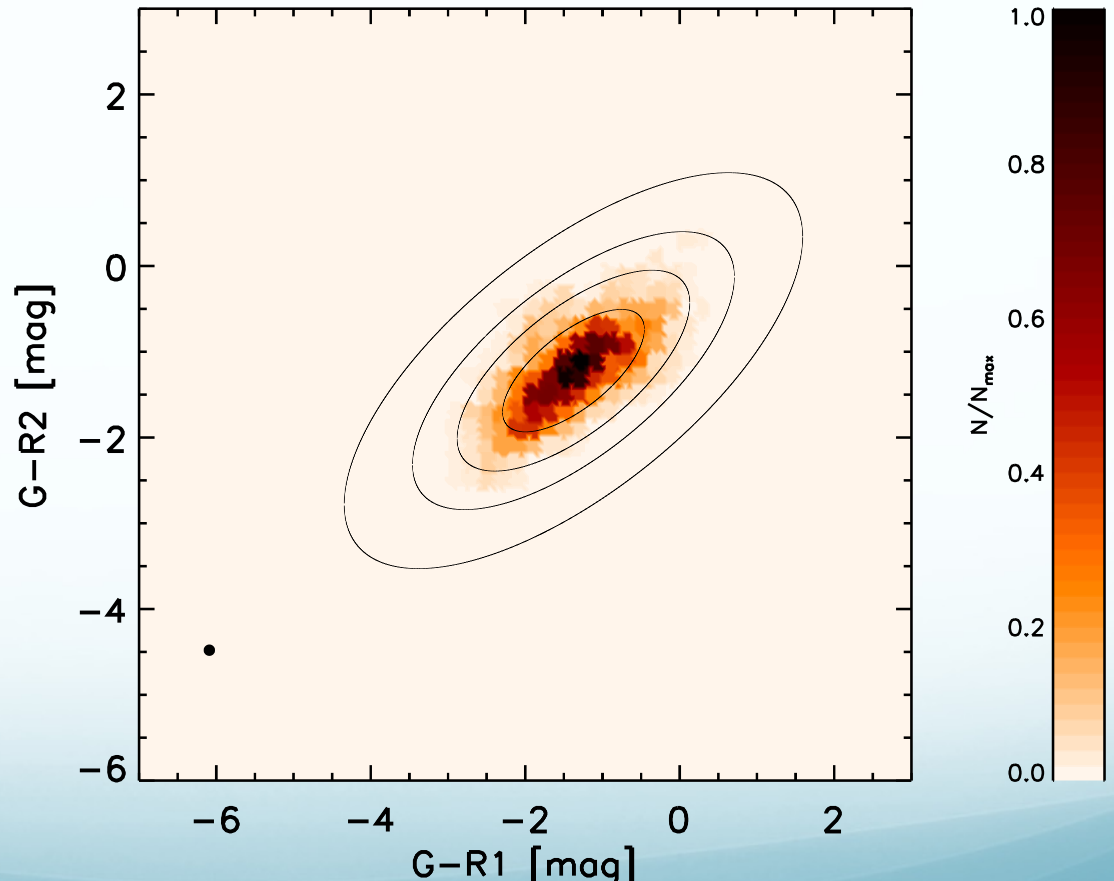


V2492 Cyg

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

Method

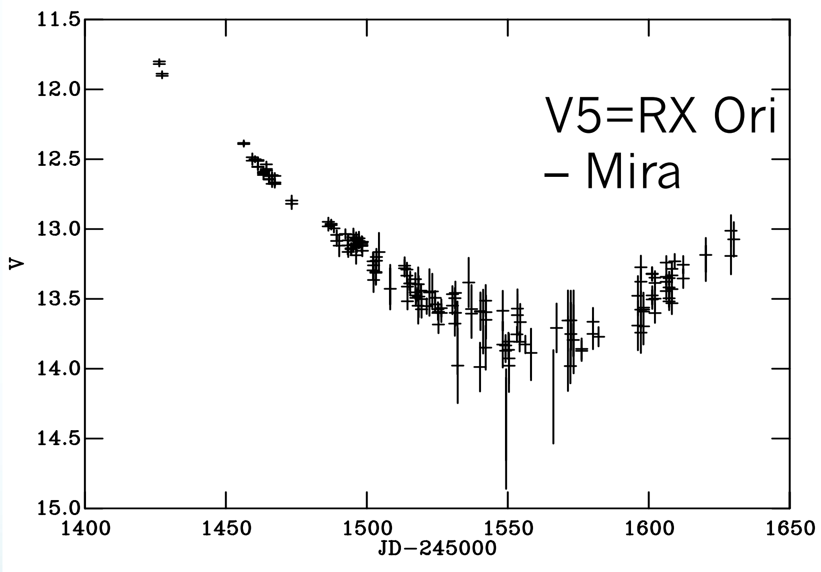
- Compare *Gaia* *G* to each SSS magnitude.
- Can work out *N*-dimensional probability of variability.
- 1075 candidates



High-amplitude YSOs?

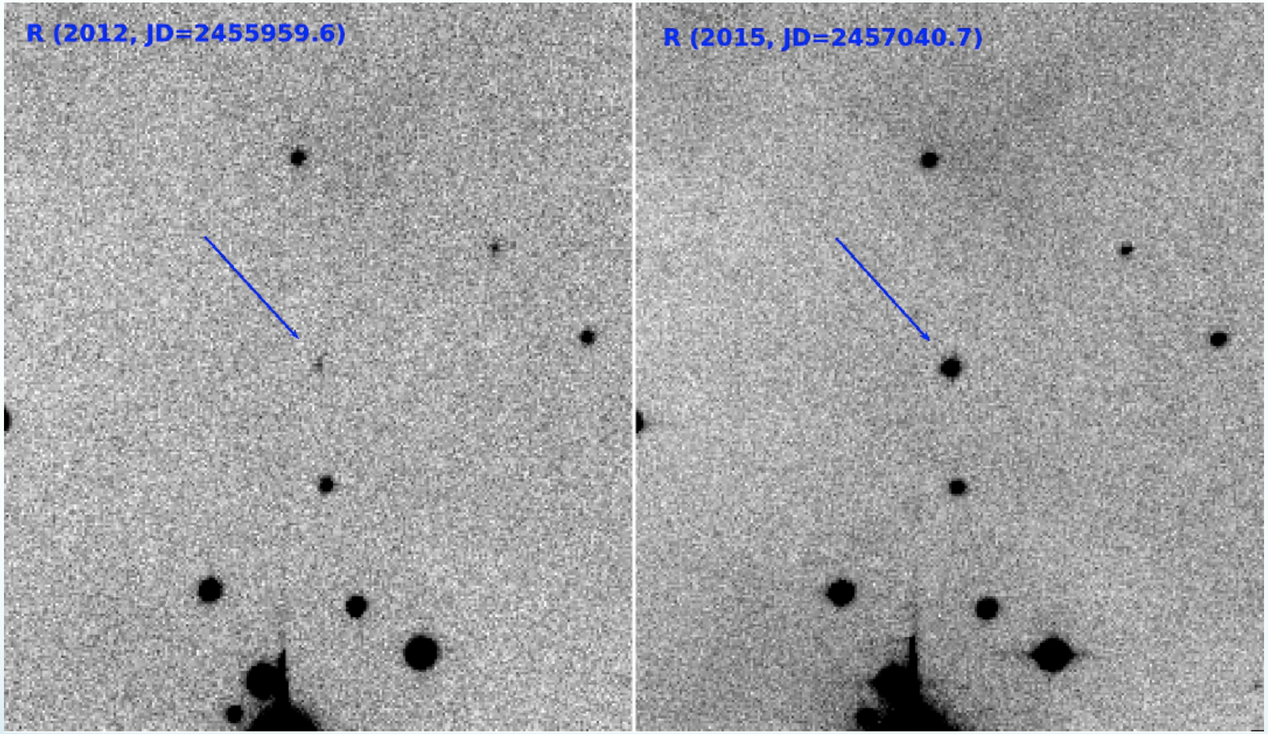
- 139 pass visual inspection for large (>1 mag) amplitude.

6 Likely non-YSOs



- 133 high-amplitude YSOs.
  - How many of them show light curves of long-lasting accretion driven outbursts?

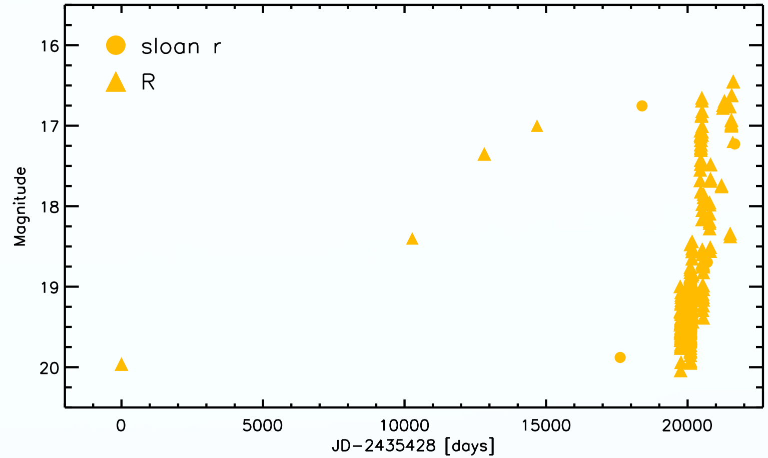
Long-lasting outbursts



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

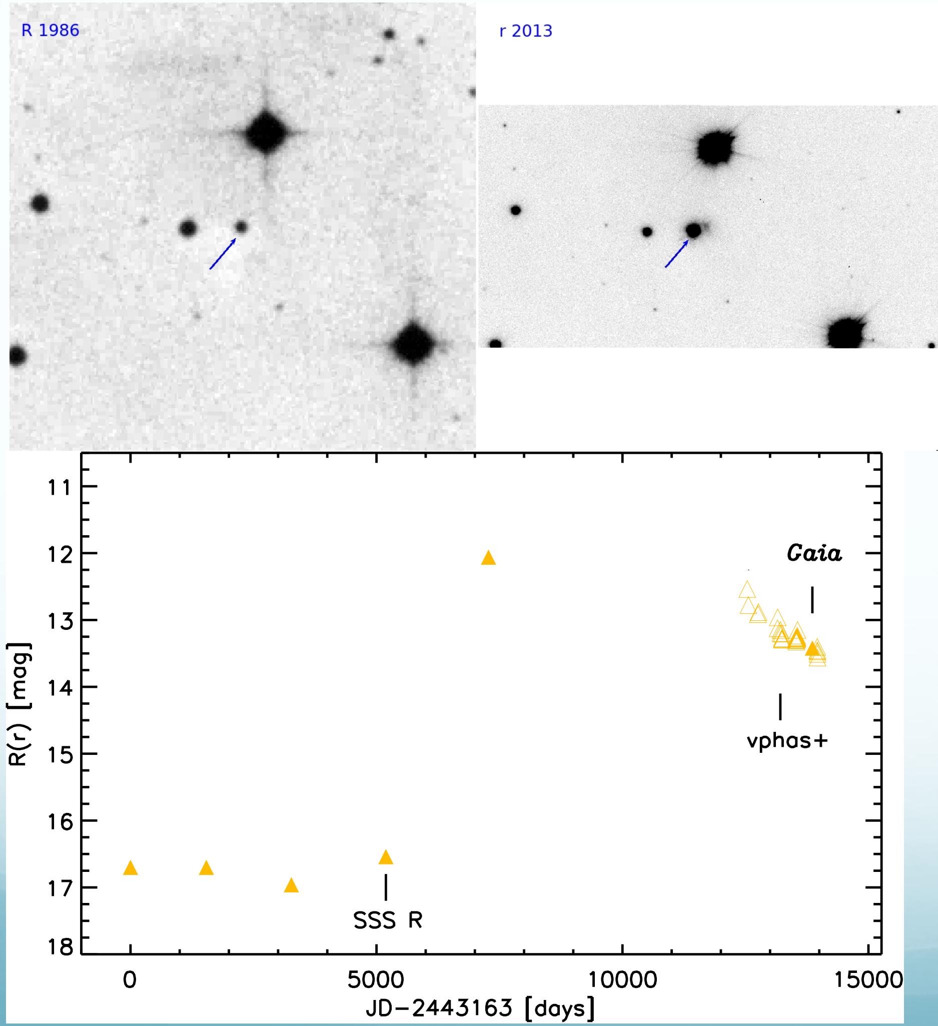
	ID	Name[a]	α	Envelope?
Class I ⟷	V1	V1057 Cyg	– 0.1	Yes (Fehér et al. 2017)
	V2	HBC 722	– 0.44	No (Fehér et al. 2017)
	V4	2M J0233 + 6156	– 0.4	?
Class I ⟷	V6	V350 Cep	– 0.17	Yes (Muzerolle et al. 2004)
	V9	2M J0841 – 4052	– 0.23	?
	V10	V733 Cep	– 0.78	No (Fehér et al. 2017)
Class I ⟷	V31	V960 Mon	– 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 full sample are likely class I YSOs.

Class II outbursts

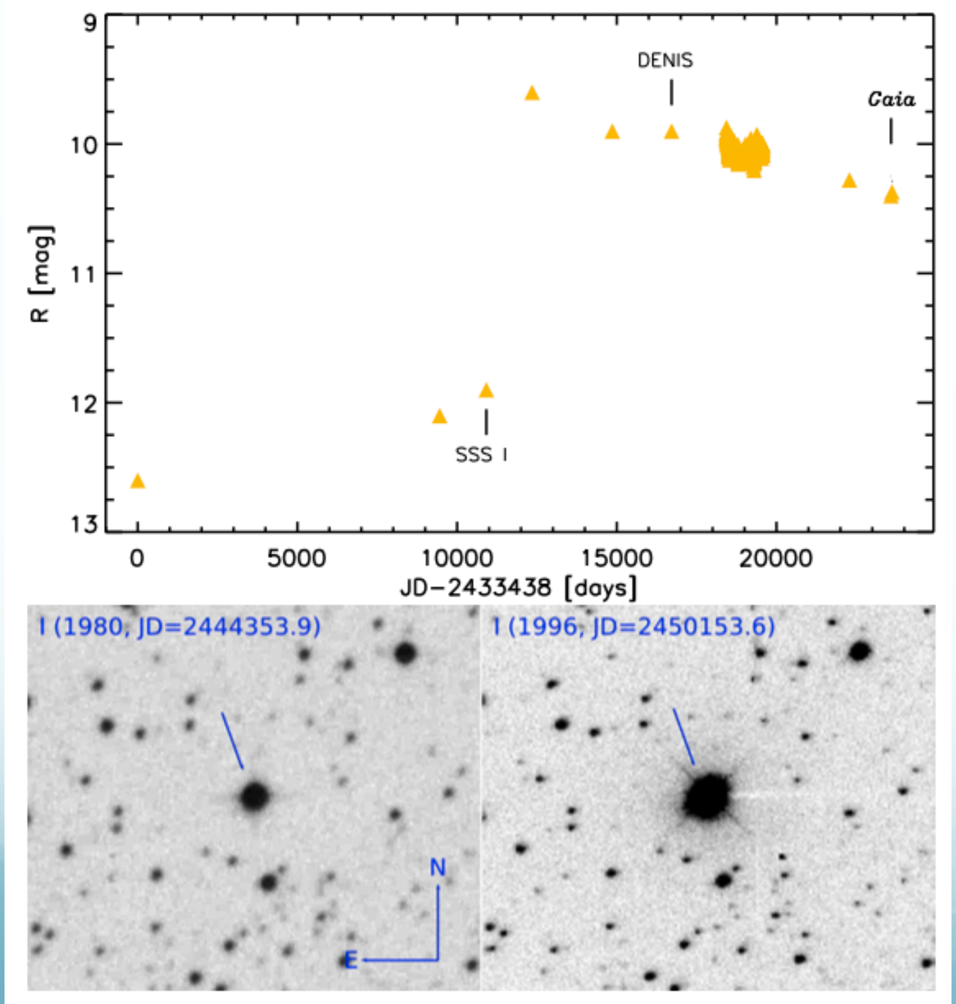
- We classify 6 objects as long-lasting class II outbursts.
- V733 Cep (Reipurth et al. 2007), V582 Aur (Abraham et al. 2018) and HBC 722 (Semkov et al. 2010).
- 3 previously unknown eruptive variable stars.

Class II outbursts



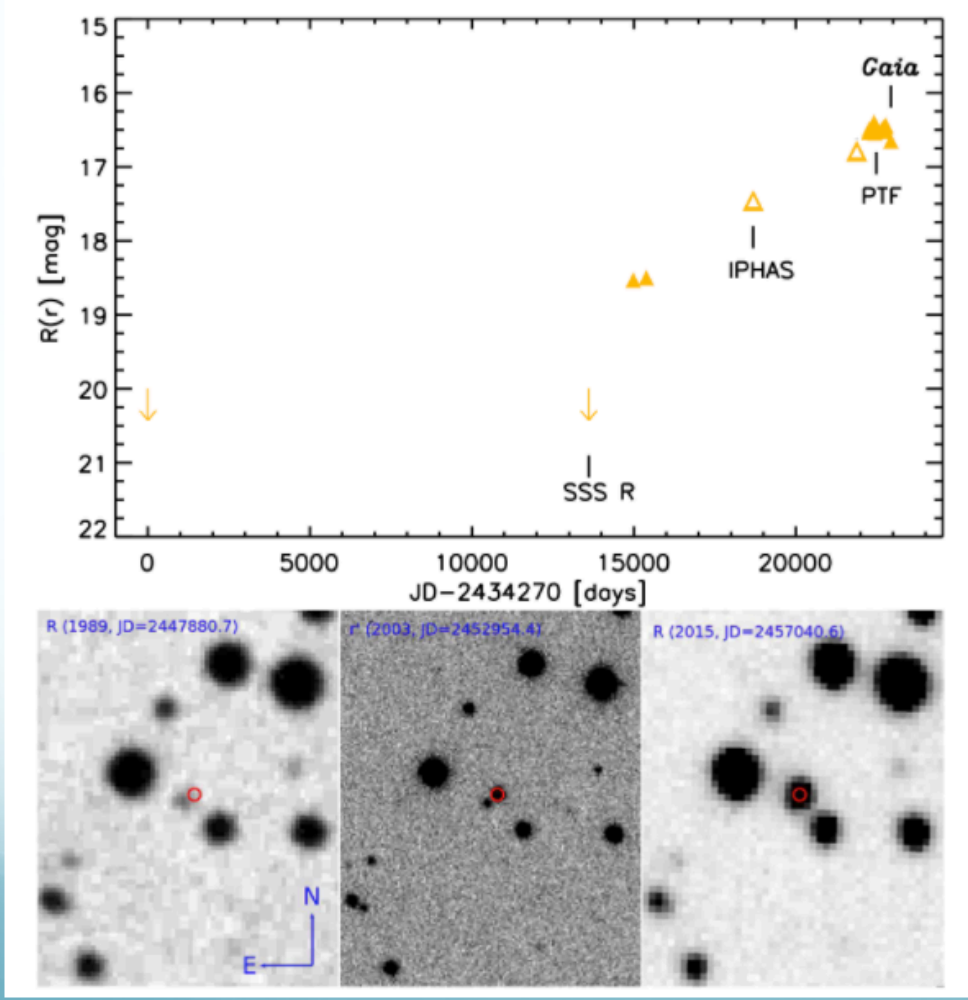
V9 (2MASS J08410676-4052174)

Class II outbursts



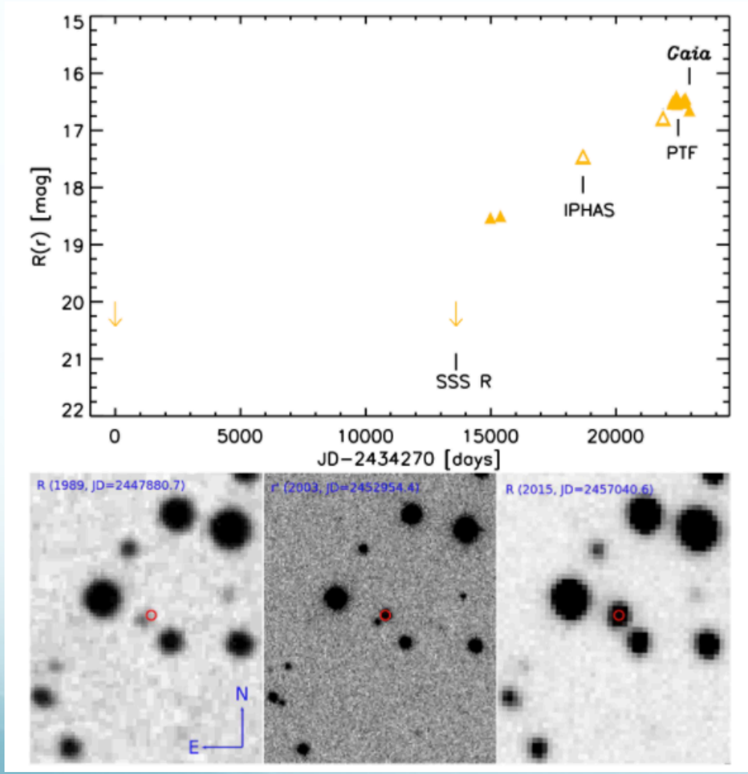
V51 (Wray 15-488)

Class II outbursts



V4 (2MASS J02335340+6156501)

Inter-outburst interval



- $\boldsymbol{\tau}=(N_{YSO} \times \boldsymbol{\Delta}t)/N_{outbursts}=112$ kyr
- 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.

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.
- Two outbursts in the Scholz et al 2013 sample 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

Previous estimates

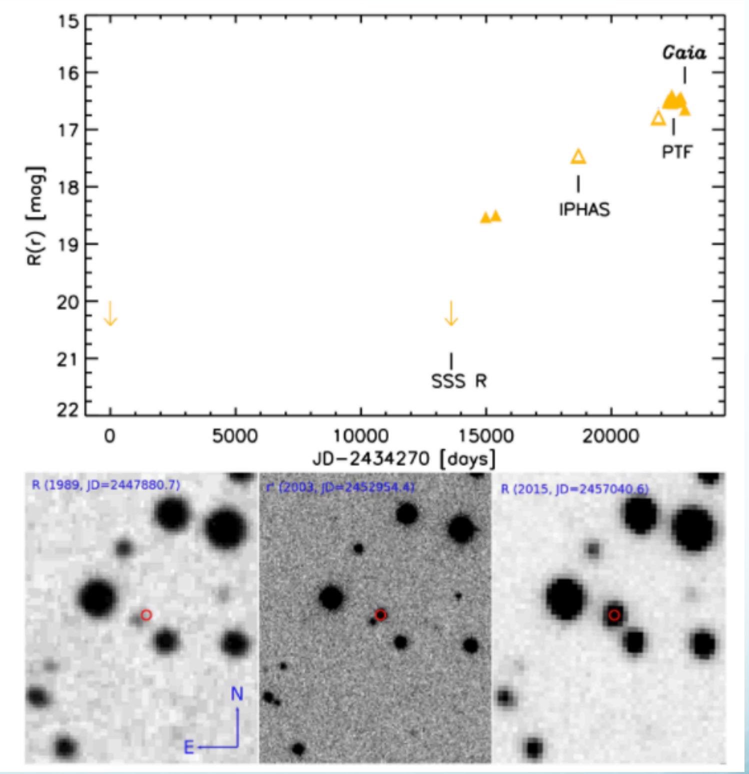
- Fischer et al. 2019 determine an outburst rate of 1000 yr (90% confidence interval between 690 to 40300 yr) from the mid-infrared variability of 319 protostars (class 0, I and flat-spectrum YSOs) in Orion.

- 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.

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.
- Binary interaction, flybys (Bonnell & Bastien 1992, Cuello et al. 2018)



Take home messages

- We have studied ~800000 YSO years and determined that long-lasting accretion related outbursts do occur during the class II planet-building phase (and discovered three previously unknown YSO outbursts).
- Outburst rates of ~100 000 years for the class II stage.
- ~10 000 years for the class I stage (our sample, Scholz et al. 2013, Fischer et al. 2019).

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

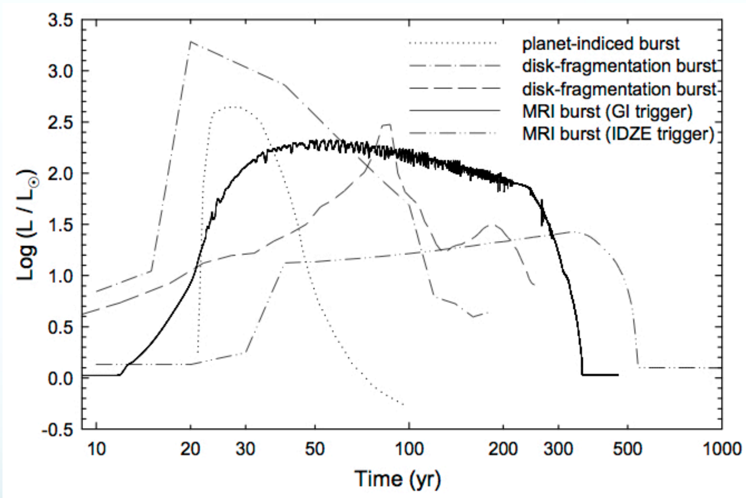
Thank you!

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).