Dynamic young stars and their disks: a temporal view

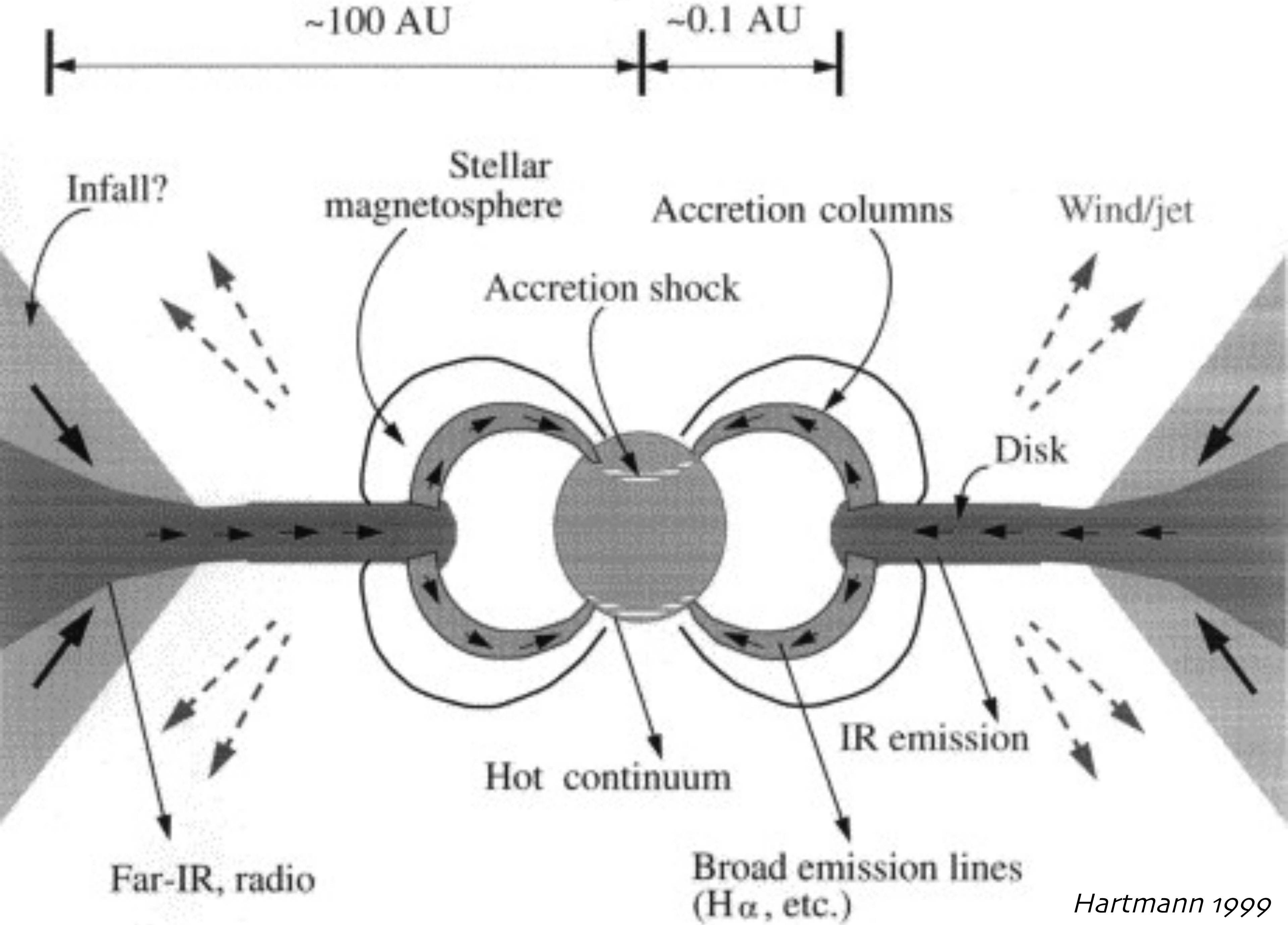
Ann Marie Cody, IPAC/Caltech

Thanks to many collaborators…

At Caltech: Lynne Hillenbrand, John Stauffer, Luisa Rebull, John Carpenter, Peter Plavchan, Krzysztof Findeisen

And many other institutions:

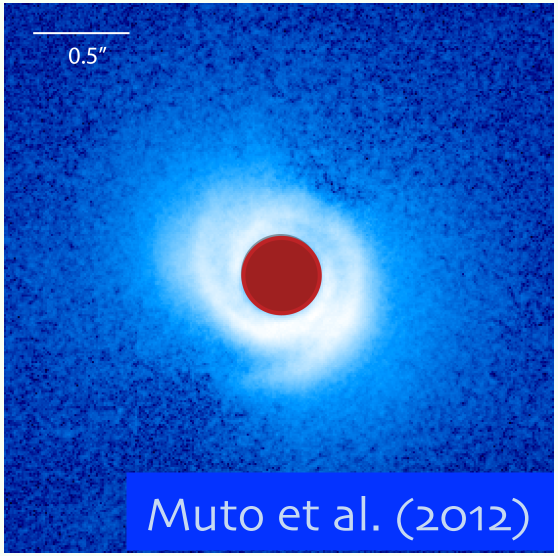
The CSI 2264 team: csi2264.ipac.caltech.edu



Hartmann 1999

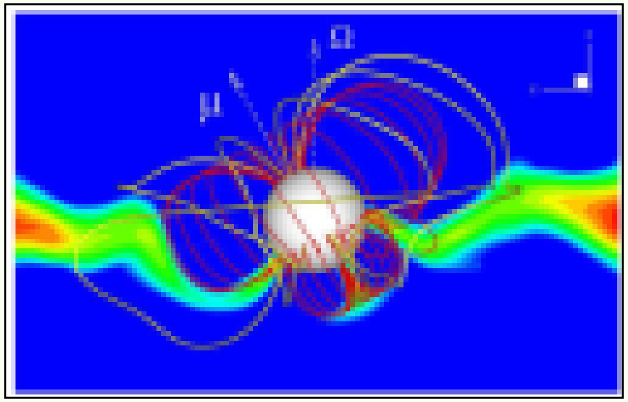
What's missing from our picture of young stars and the inner disk?

Disk structure



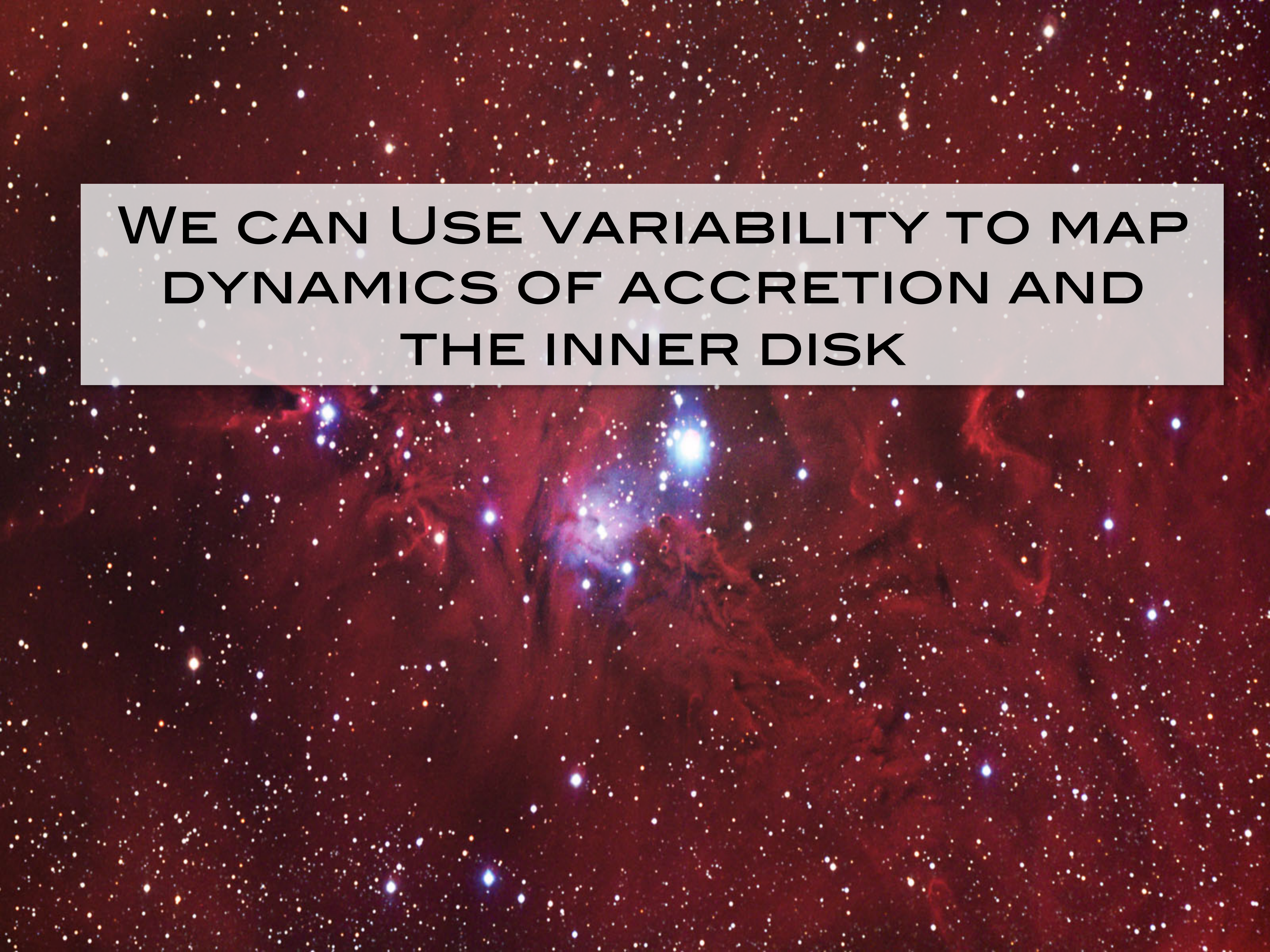
Dust properties

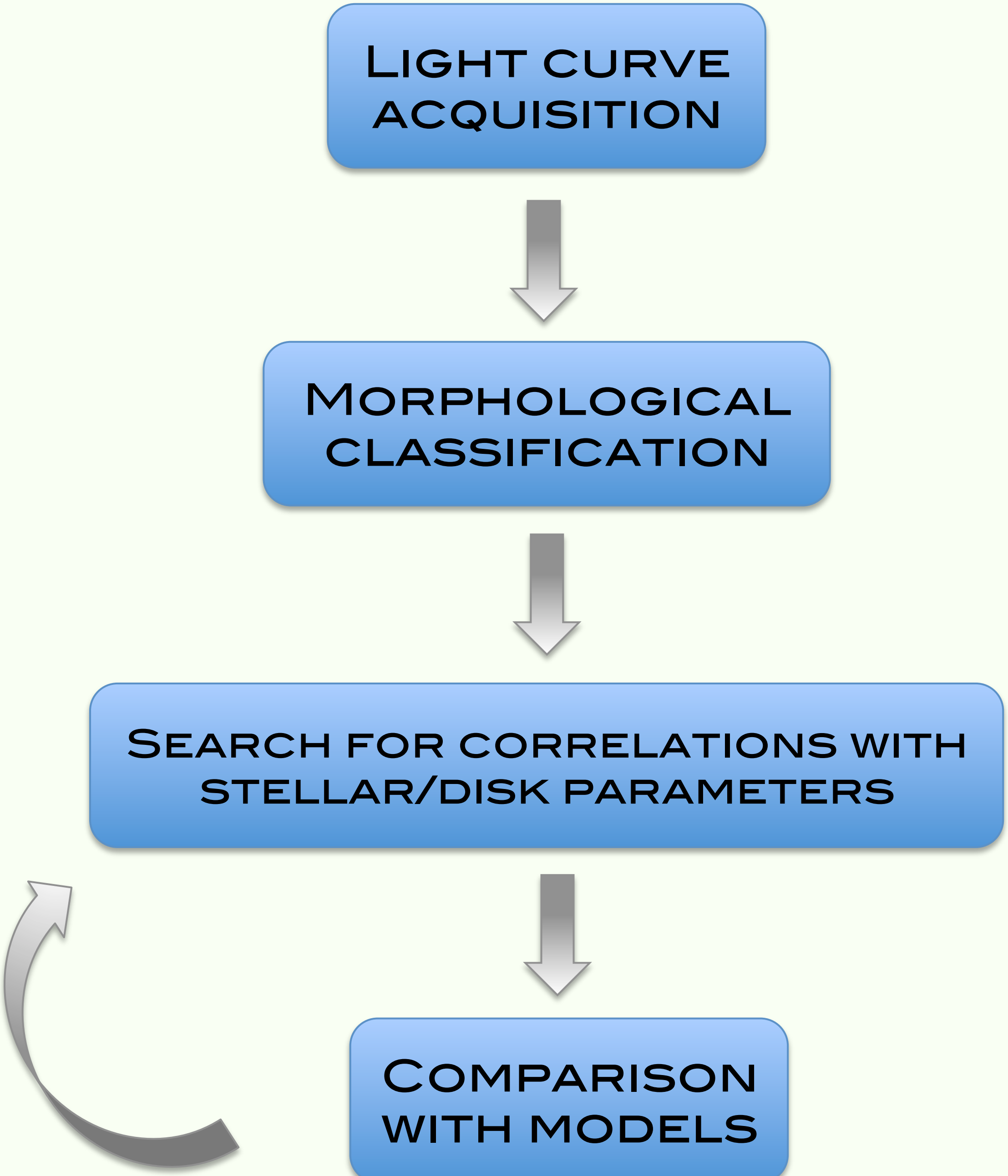
Star-disk connection



Long et al. (2007)

We can Use variability to map dynamics of accretion and the inner disk

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Search for correlations with stellar/disk parameters
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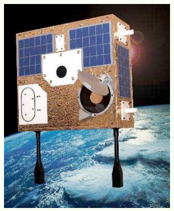
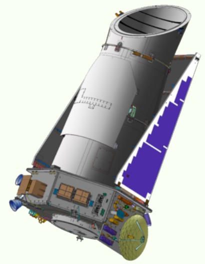
A revolution in time series Monitoring of young stars

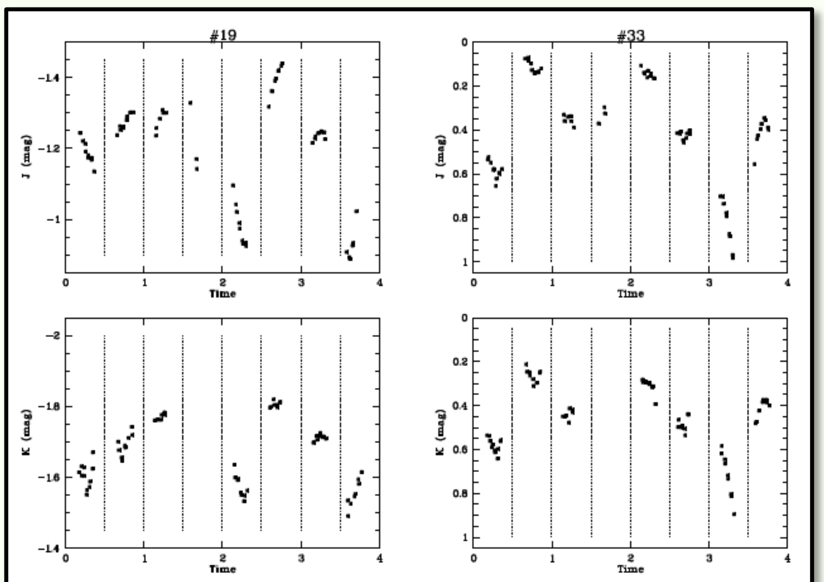


MOST

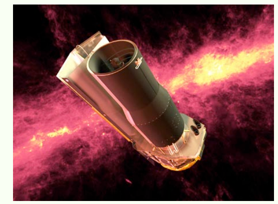
CoRoT



Kepler/K2



Optical

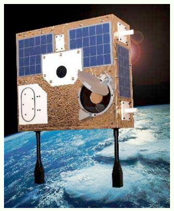


Spitzer

?

INFRARED

A revolution in time series Monitoring of young stars



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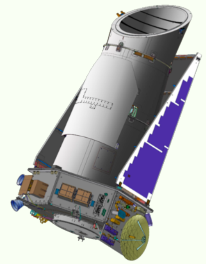

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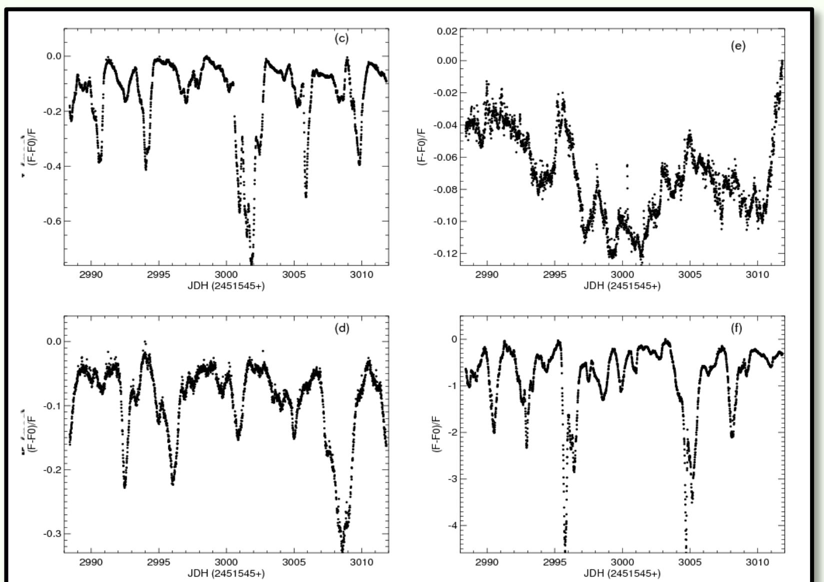
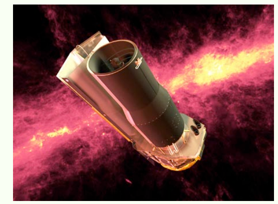


Alencar et al. (2010)

Optical



Spitzer

?

infrared

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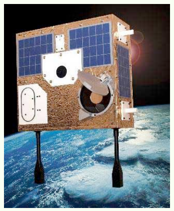
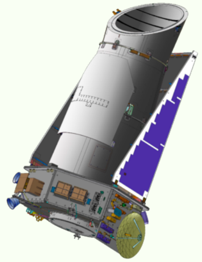
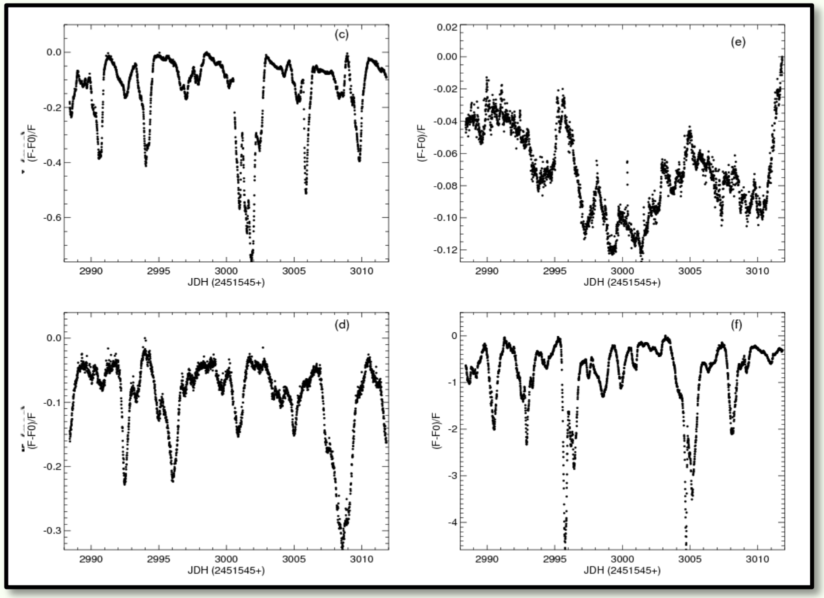


MOST

CoRoT



Kepler/K2



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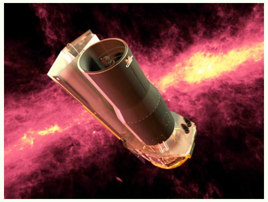
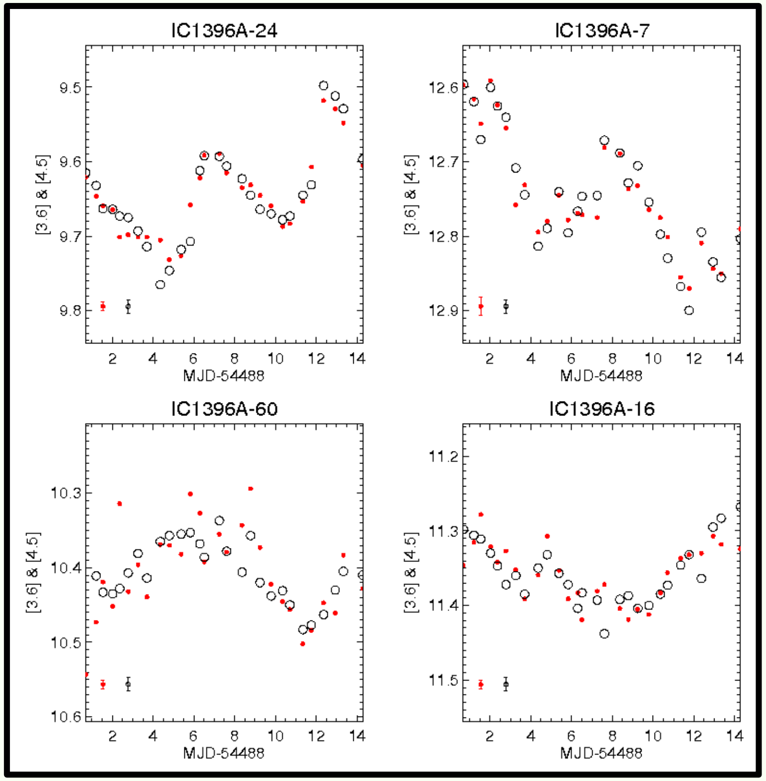
Optical



Spitzer

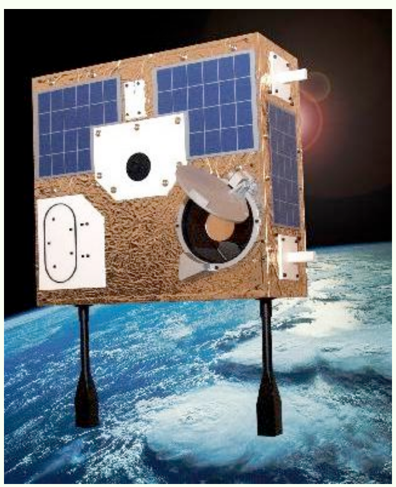


INFRARED

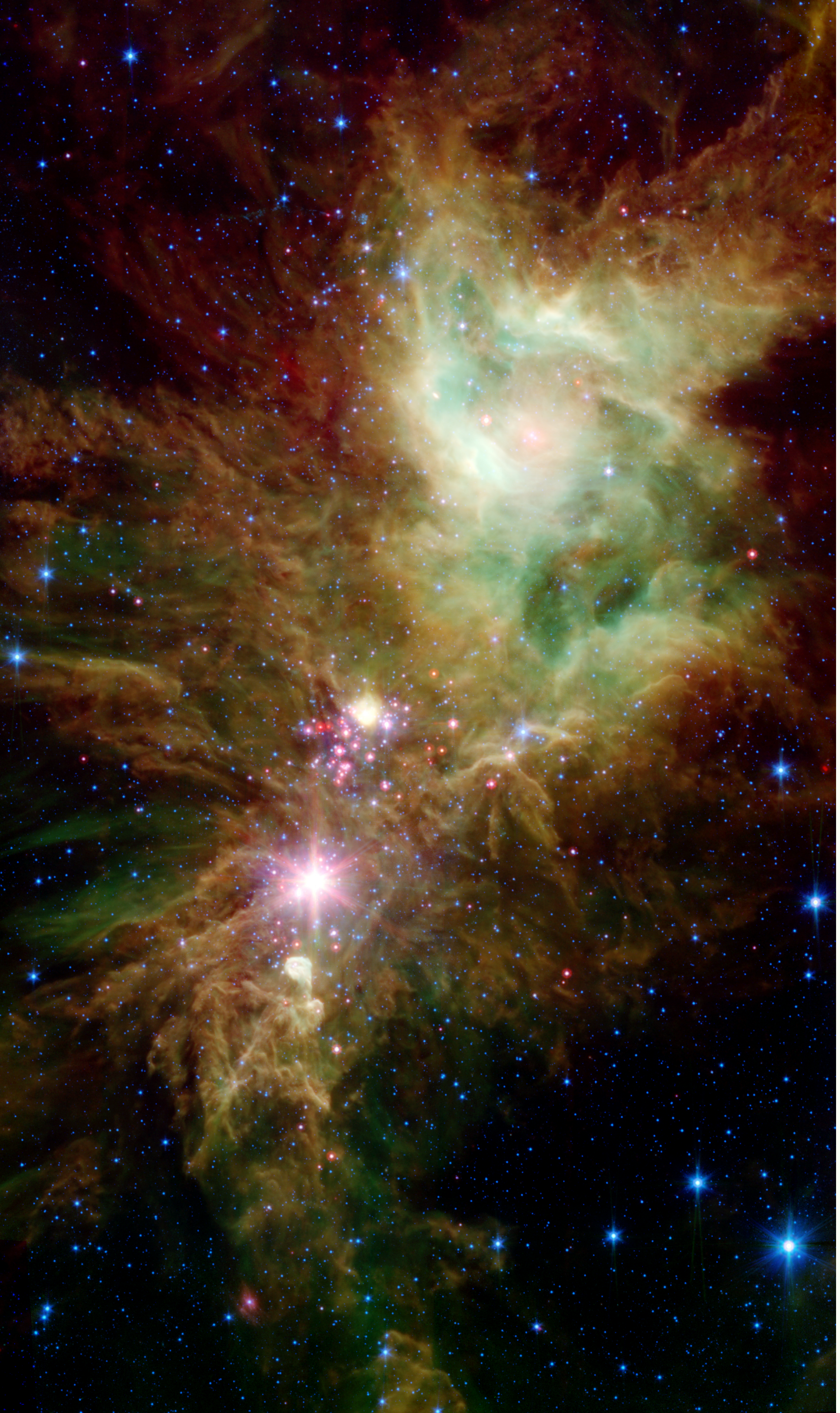
Morales-Calderón et al. (2009)

Coordinated Synoptic Investigation of NGC 2264

- Spitzer: 30 days, 3.6-4.5 μm
- CoRoT: 40 days, optical
- Chandra/ACIS: 300ks (3.5 days)
- MOST: 40 days, optical
- VLT/Flames: ~20 epochs
- Ground-based monitoring
  U-K bands: ~3 months

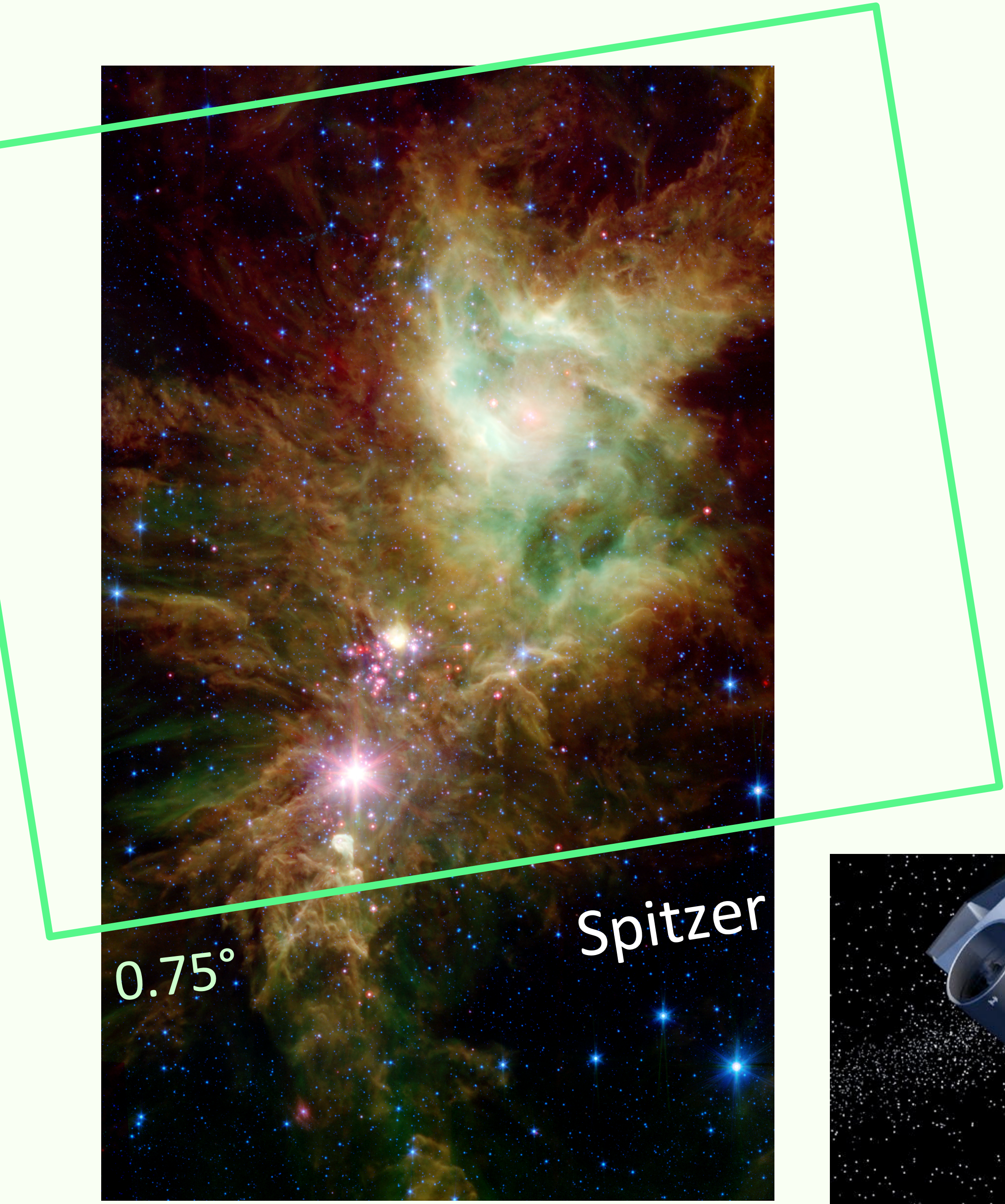


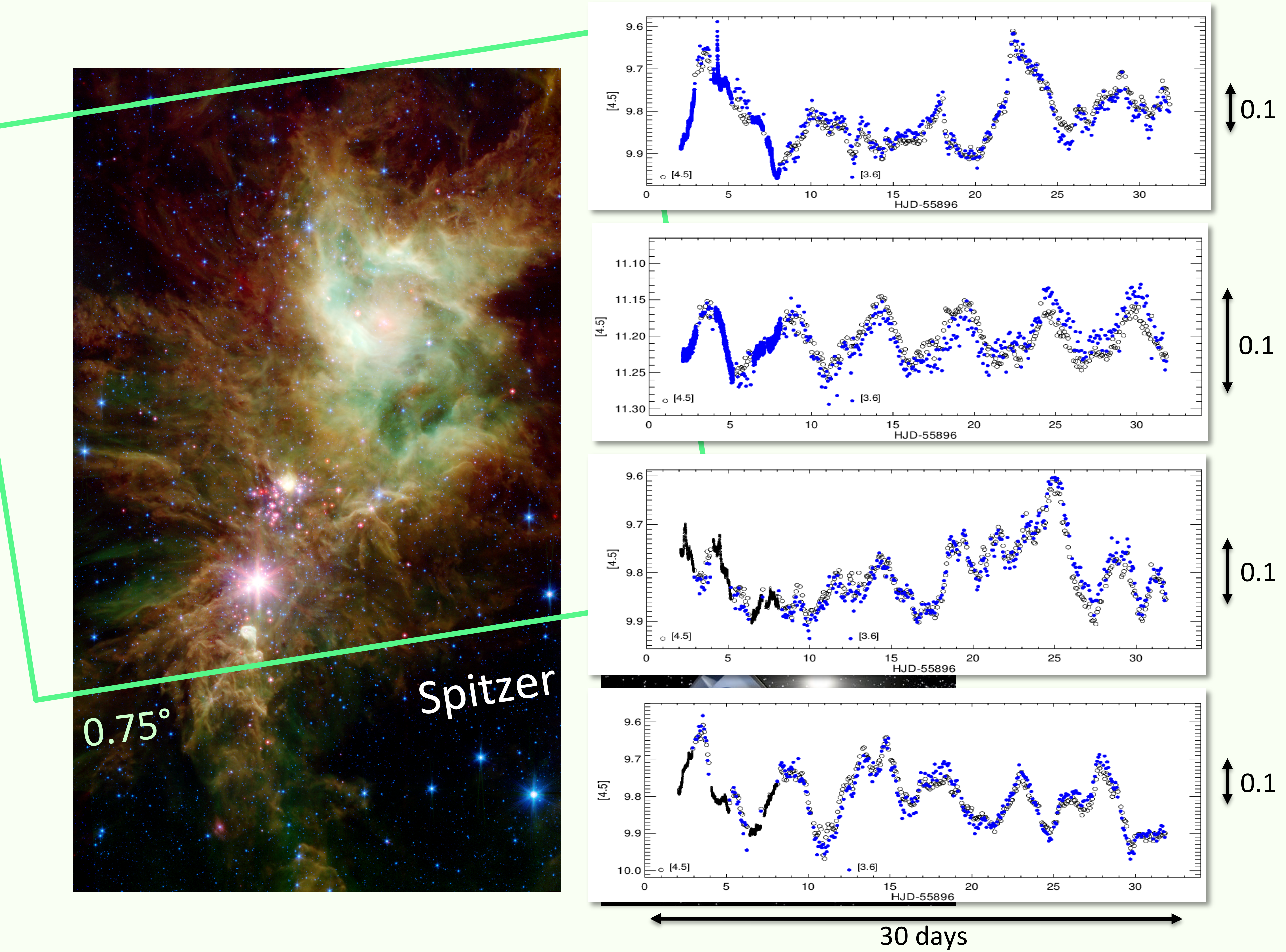
Cody+ 2014



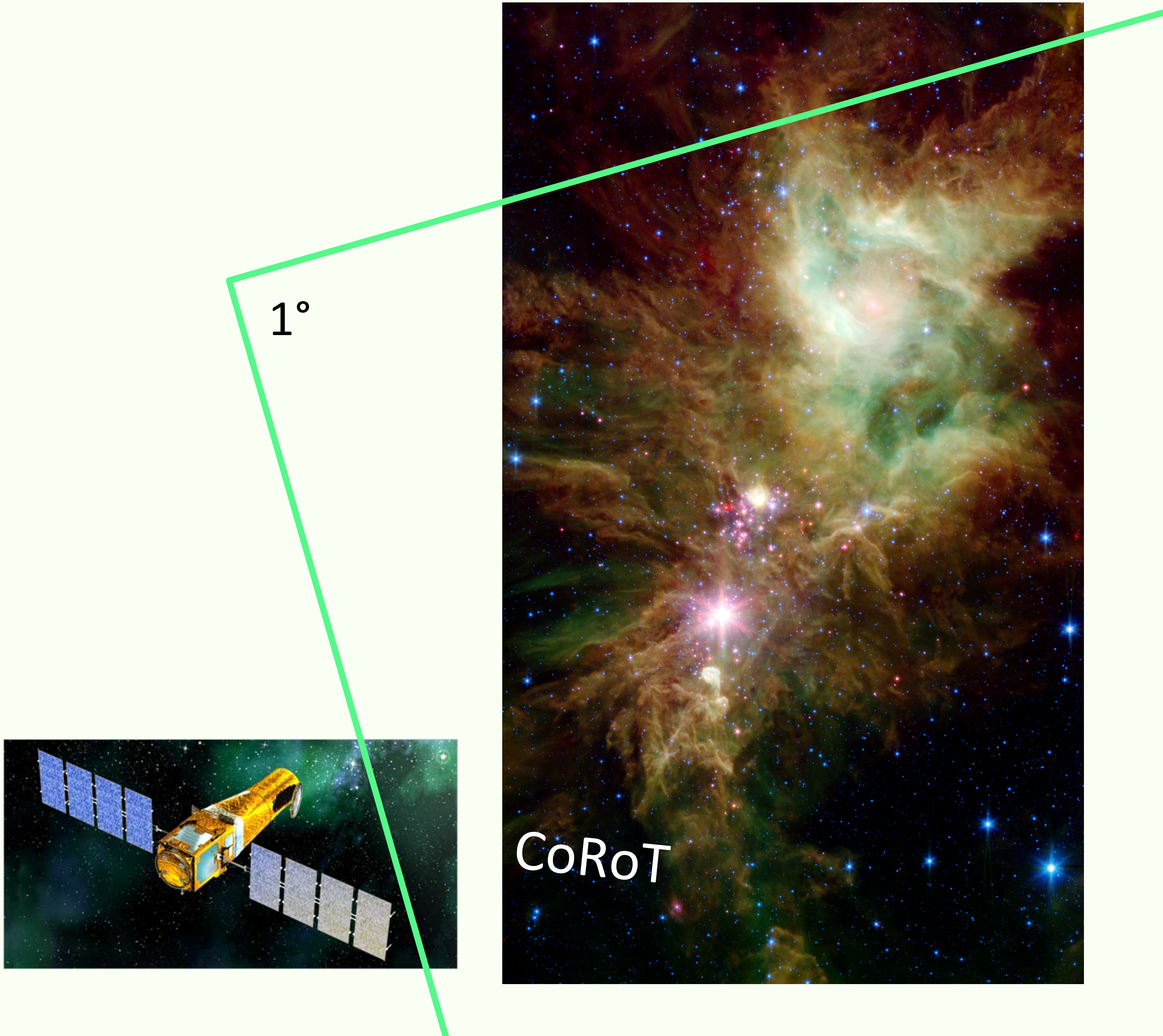
The target: NGC 2264

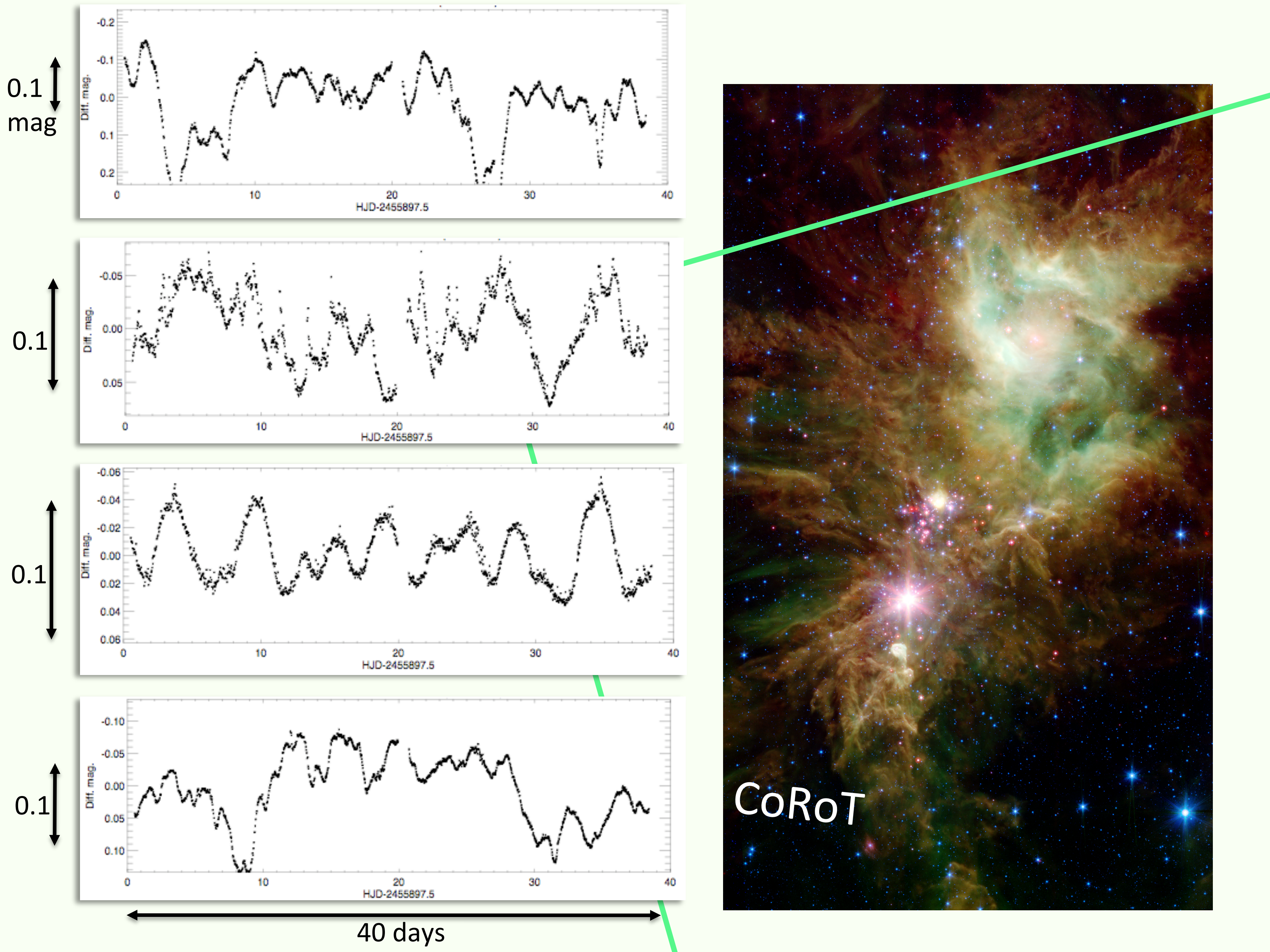
- Distance ~ 760 pc
- Age ~ 2-4 Myr
- Known members: ~1500
- Large photometric & spectroscopic database
- Many stars with disks


Spitzer
0.75°

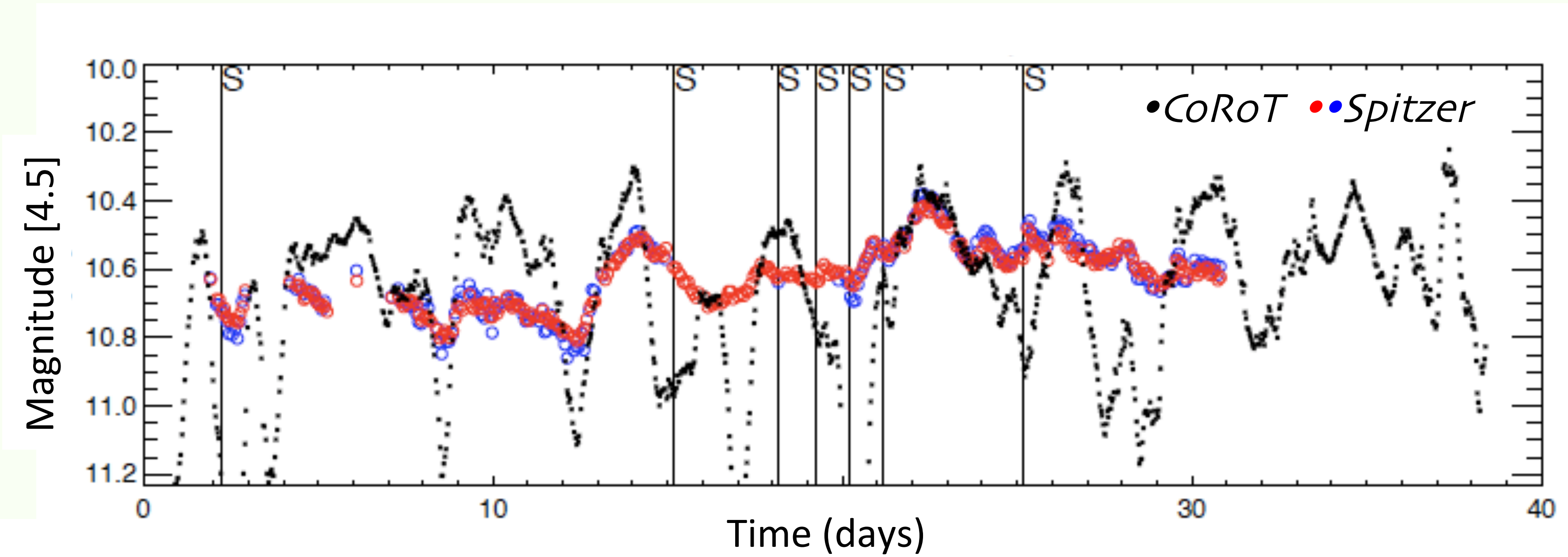


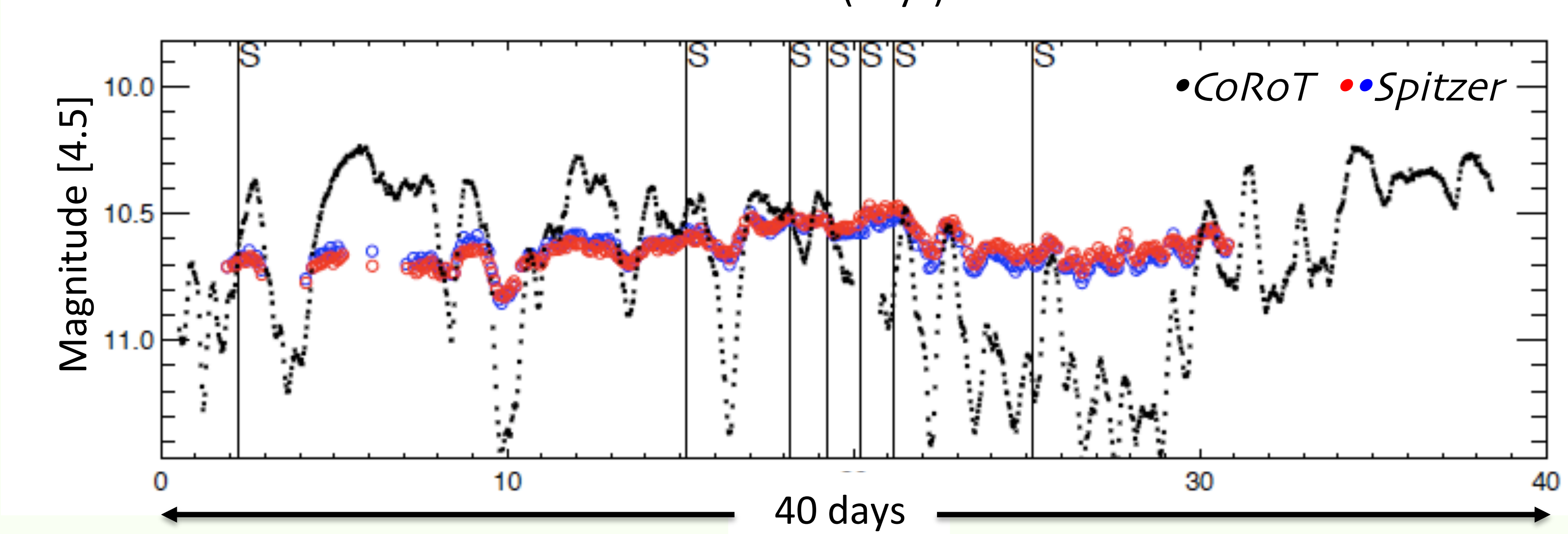
Spitzer
0.75°
[4.5]
HJD-55896
[3.6]
0.1
30 days


1°
CoRoT

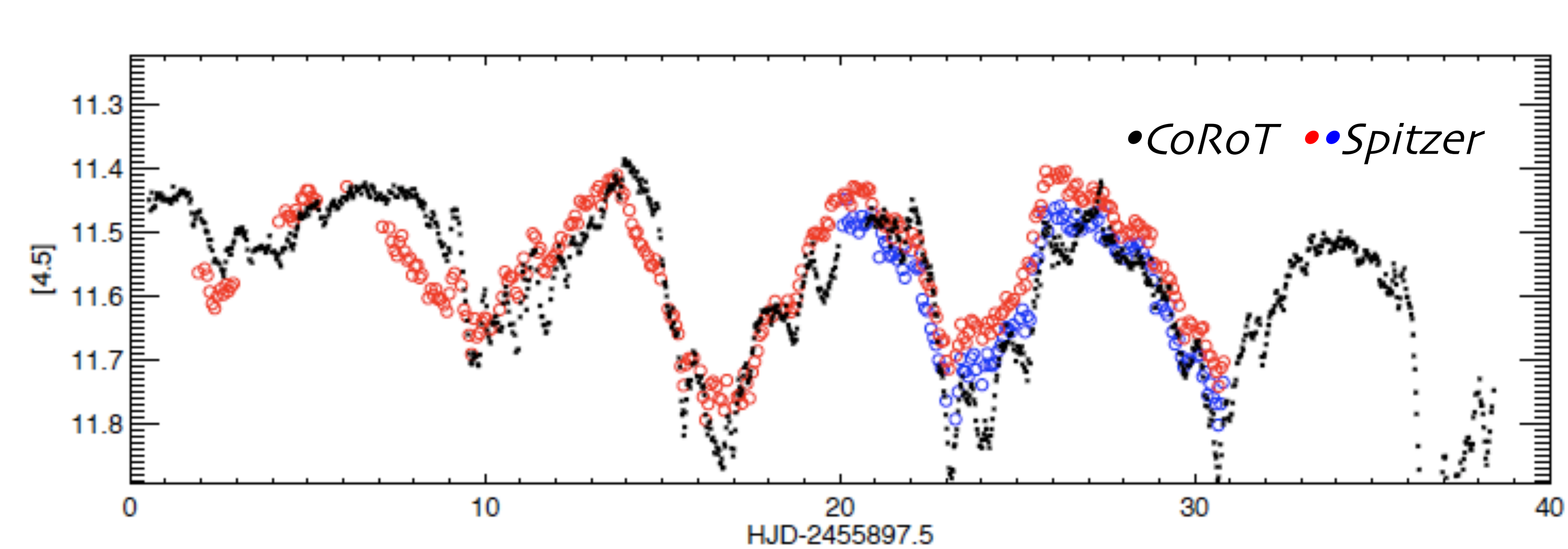

0.1 mag
0.1
0.1
0.1
Diff. mag.
HJD-2455897.5
40 days
CoRoT

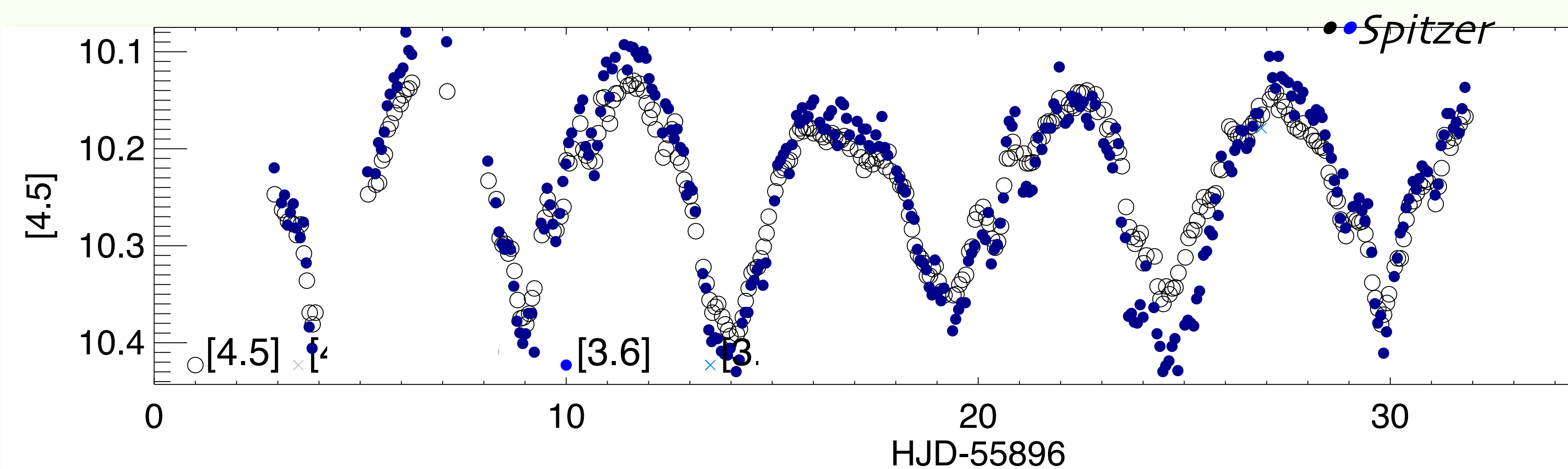
A zoo of light curves



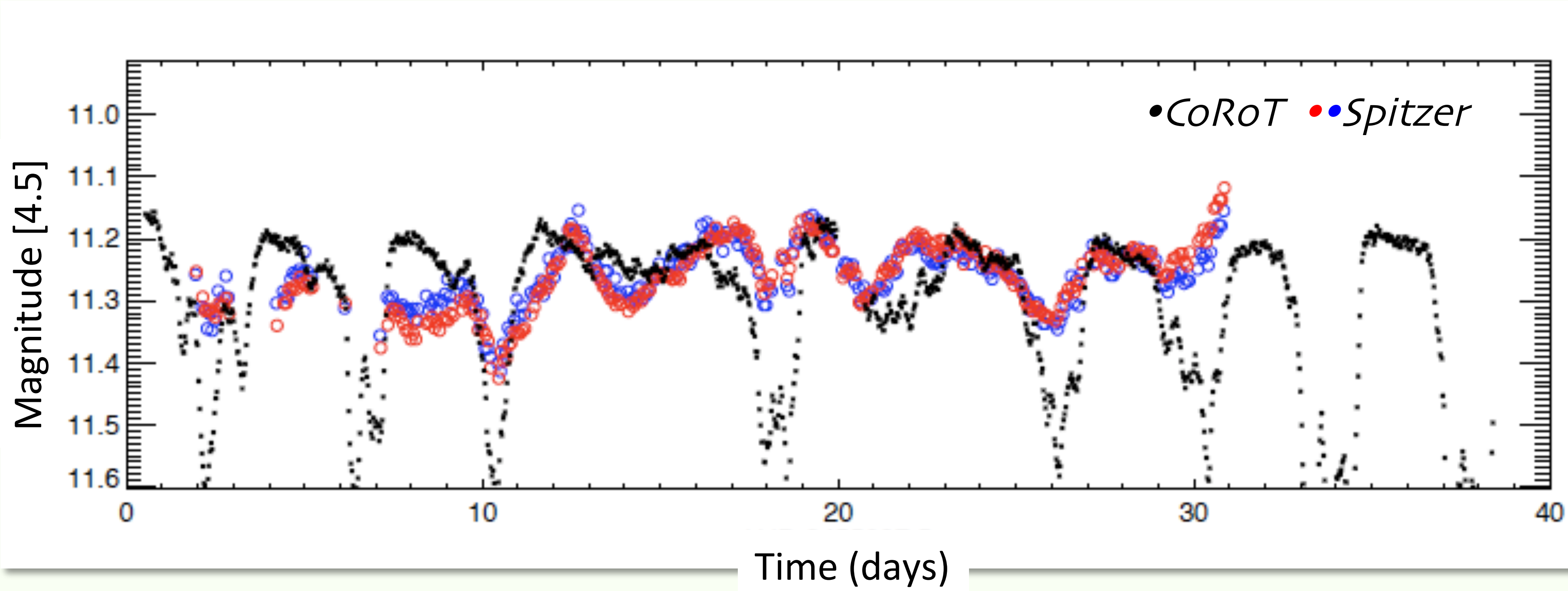


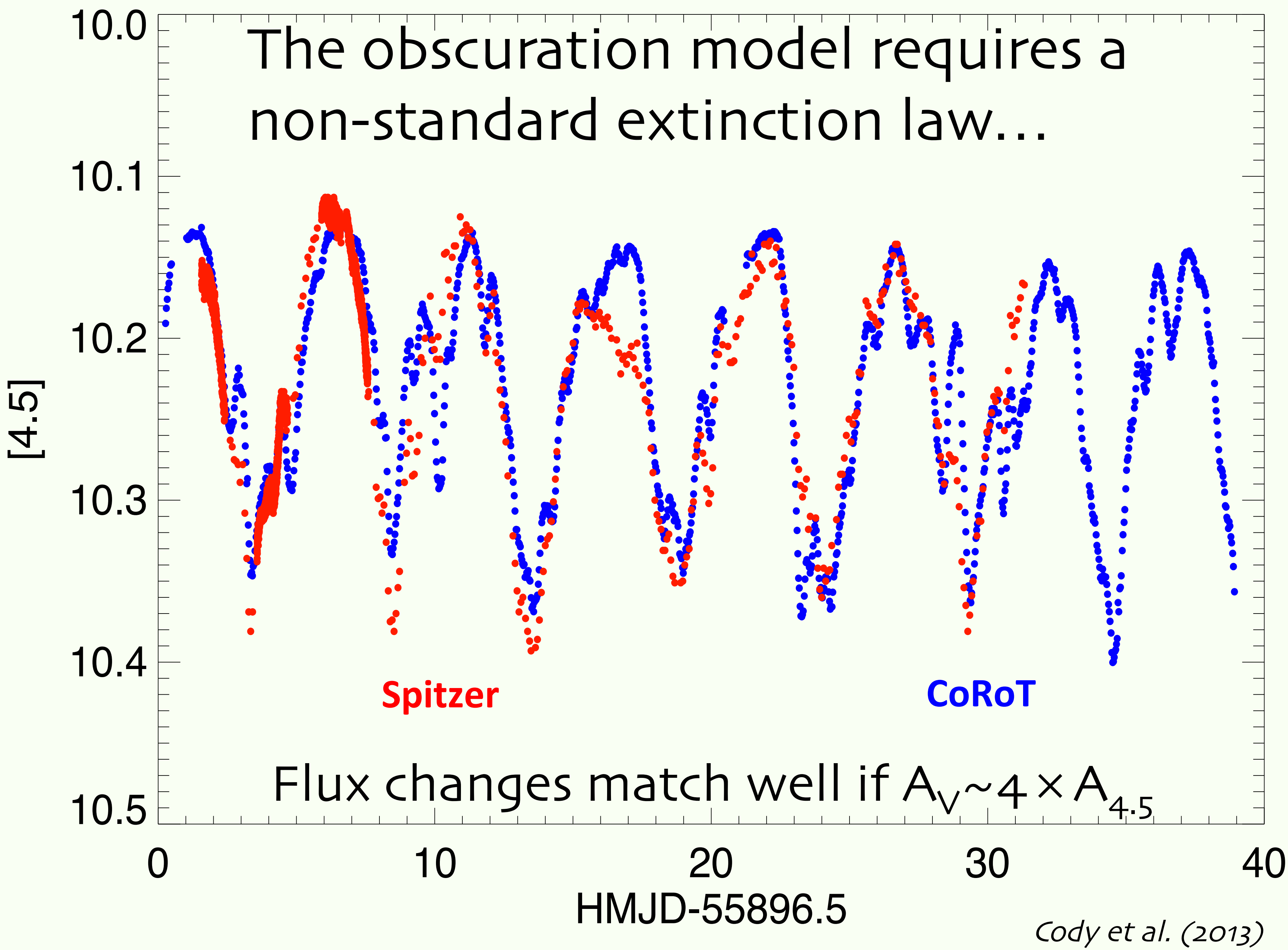
DISK-BEARING STARS: UNEXPLAINED PERIODIC BEHAVIOR



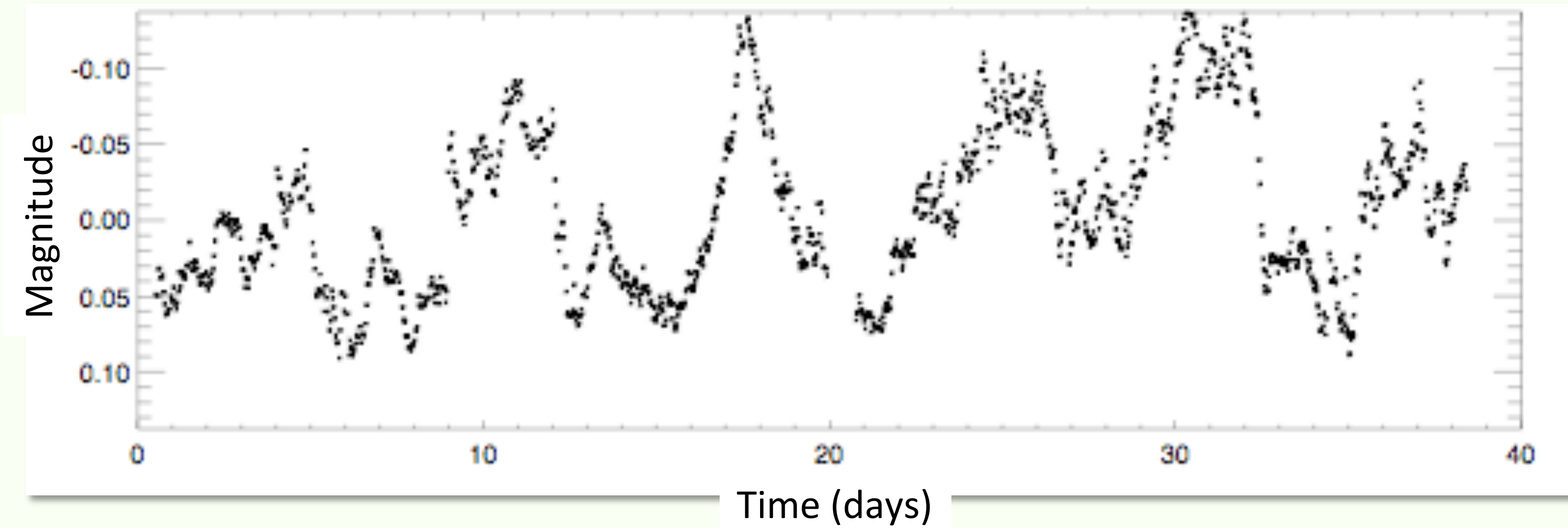


Quasi-periodic flux dips: Disk blobs or warps



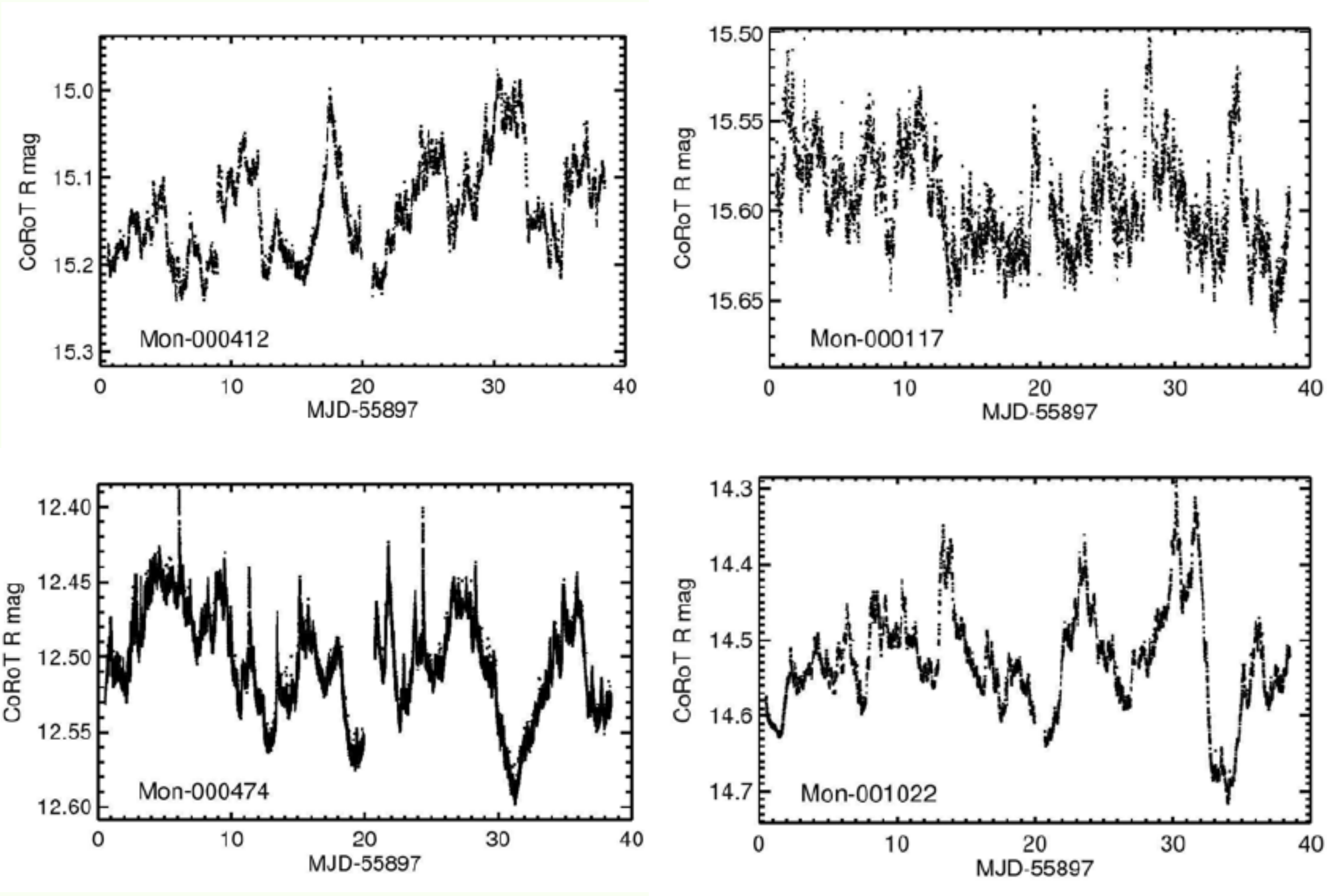

The obscuration model requires a non-standard extinction law...
10.0
10.1
10.2
10.3
10.4
10.5
[4.5]
Spitzer
CoRoT
Flux changes match well if $A_V \sim 4 \times A_{4.5}$
0
10
20
30
40
HMJD-55896.5
Cody et al. (2013)

Corot data reveals Flux events that may be accretion bursts

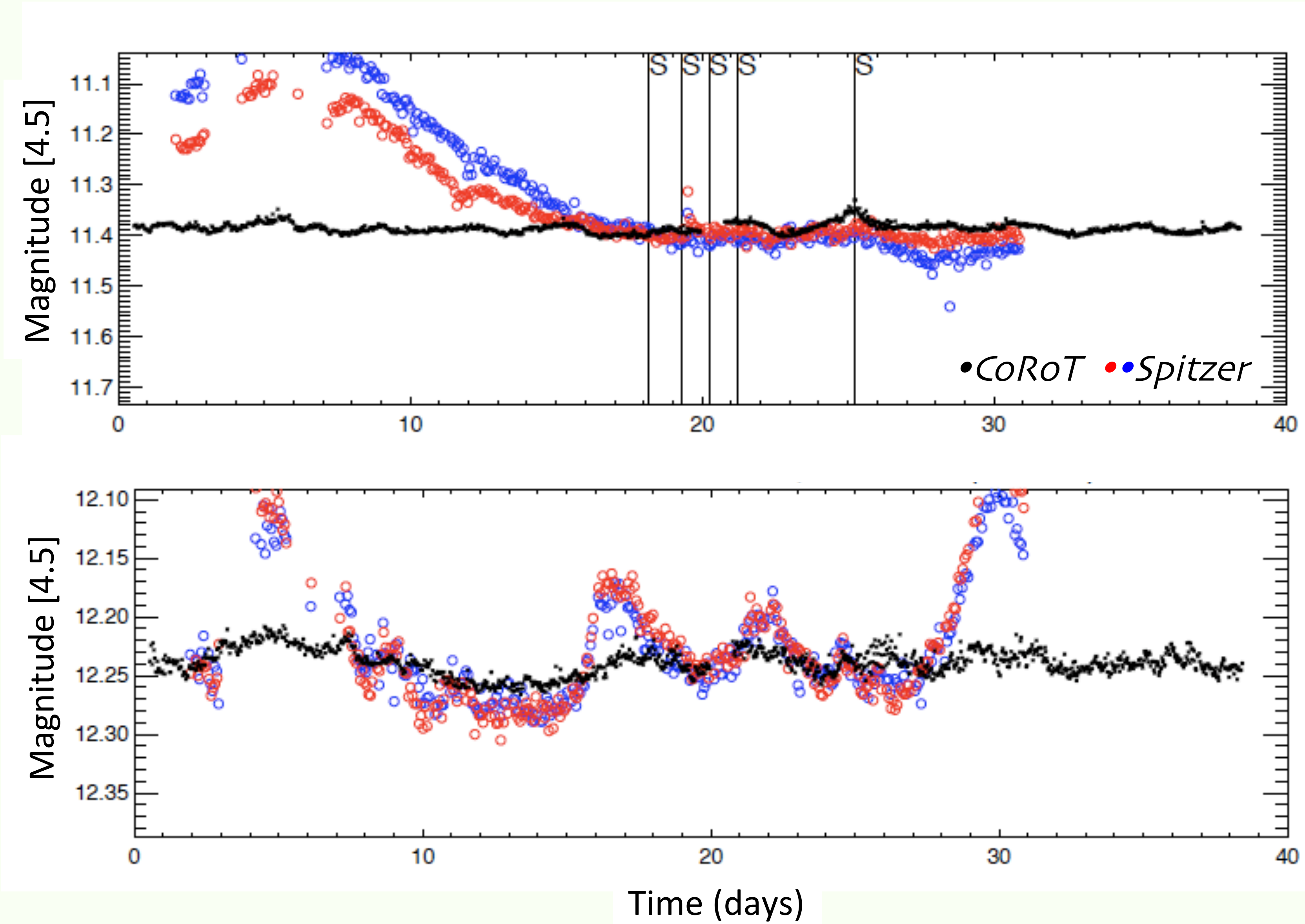


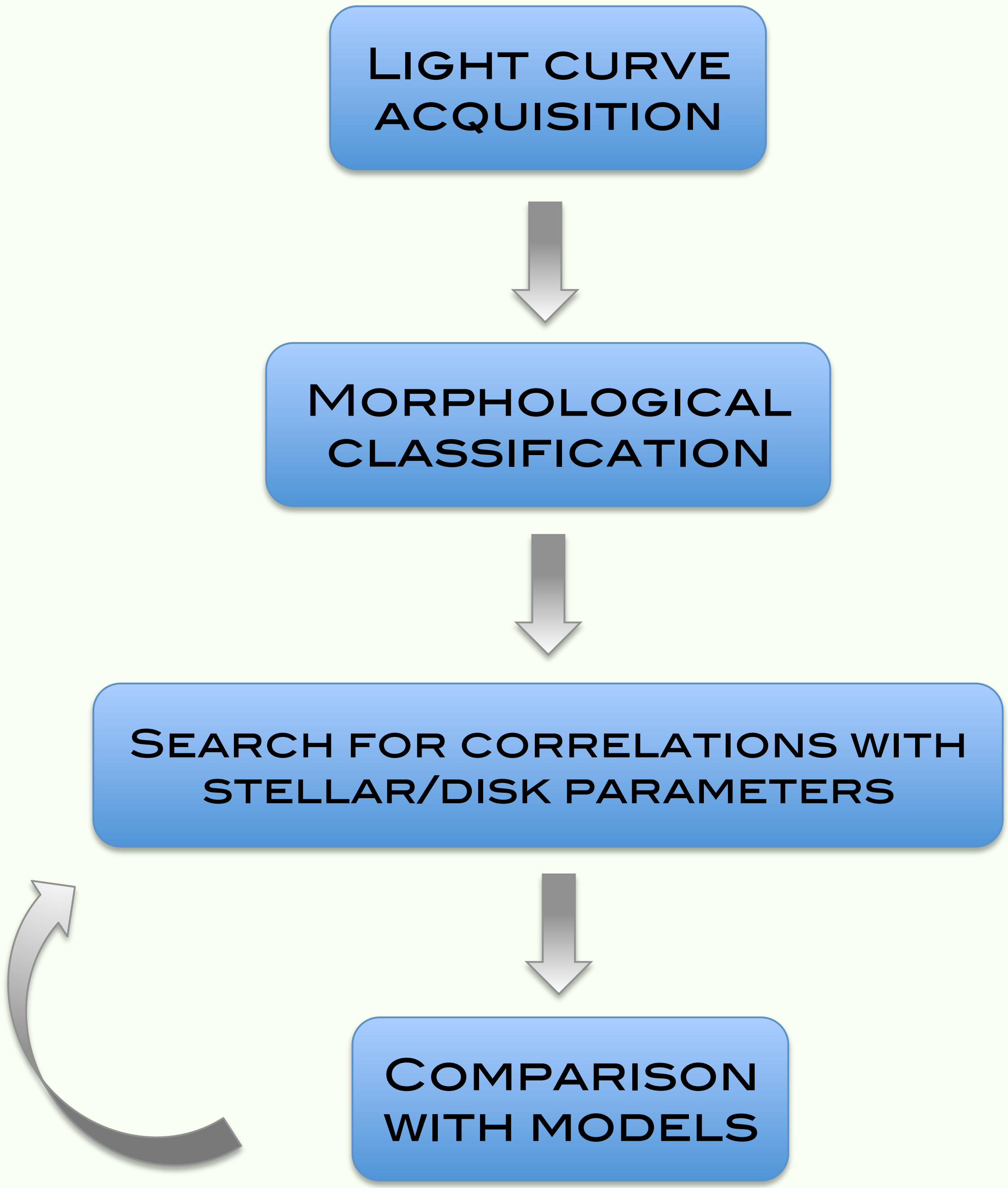
→ These objects have preferentially high UV excesses and Hα emission indicative of strong accretion.

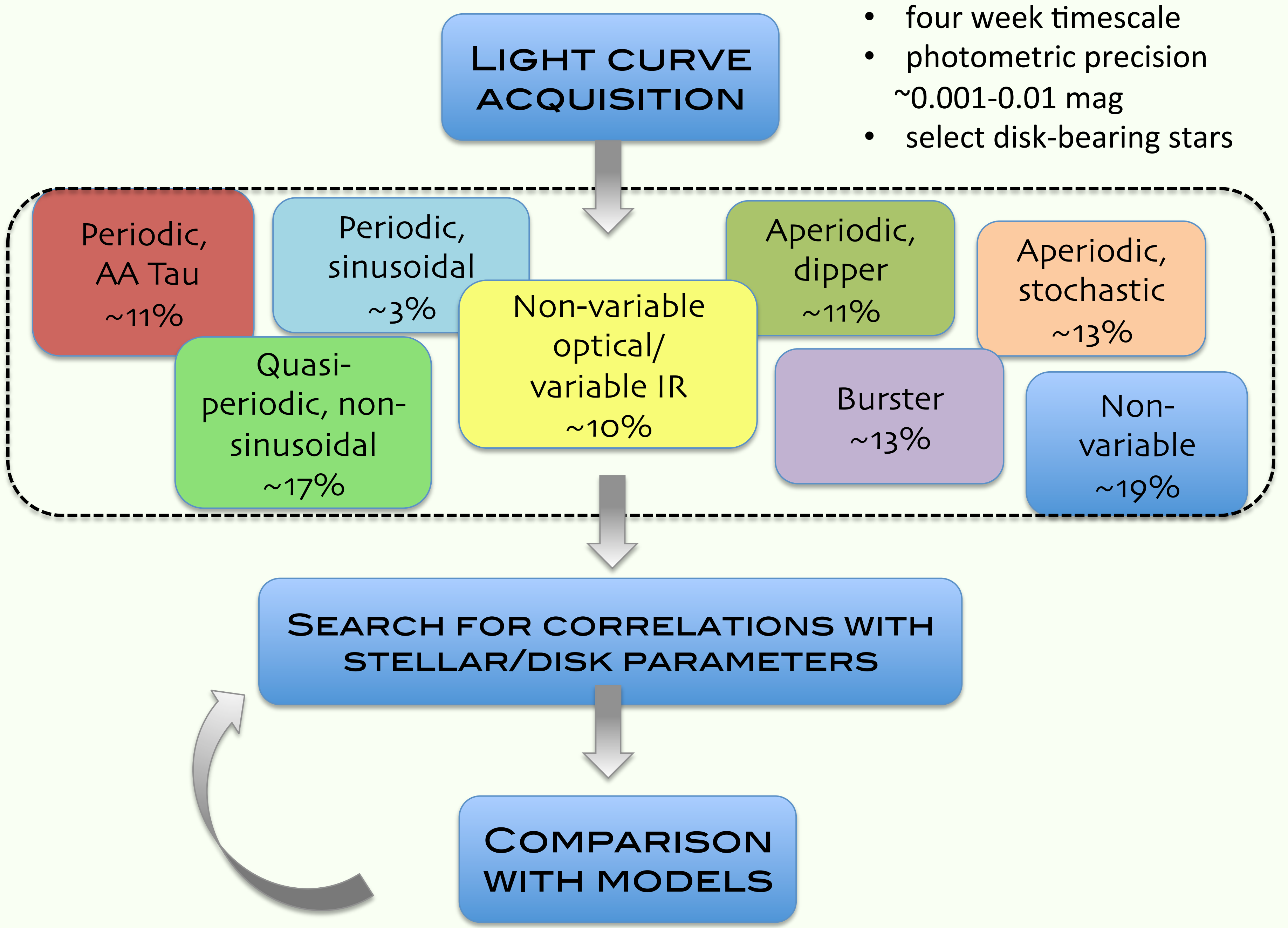
Stauffer, Cody+ 2014


Mon-000412
CoRoT R mag
MJD-55897
Mon-000117
CoRoT R mag
MJD-55897
Mon-000474
CoRoT R mag
MJD-55897
Mon-001022
CoRoT R mag
MJD-55897

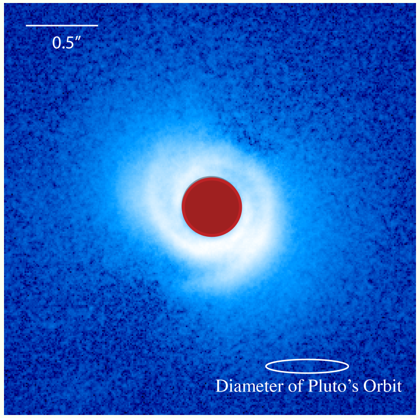
At least 10% of disk-bearing stars show High-amplitude behavior in the IR only




Light curve acquisition
Morphological classification
Search for correlations with stellar/disk parameters
Comparison with models

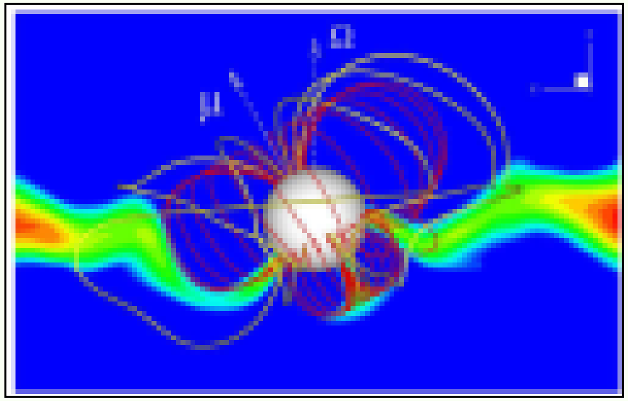

Light curve acquisition
four week timescale
photometric precision ~0.001-0.01 mag
select disk-bearing stars
Periodic, AA Tau ~11%
Periodic, sinusoidal ~3%
Quasi-periodic, non-sinusoidal ~17%
Non-variable optical/ variable IR ~10%
Aperiodic, dipper ~11%
Aperiodic, stochastic ~13%
Burster ~13%
Non-variable ~19%
Search for correlations with stellar/disk parameters
Comparison with models

What have we learned?



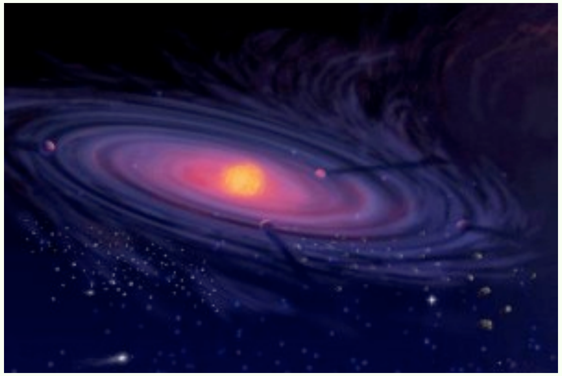
Inner Disk structure

- ➢Azimuthal asymmetries common
- ➢Changes on day to week timescales



STAR-disk connection

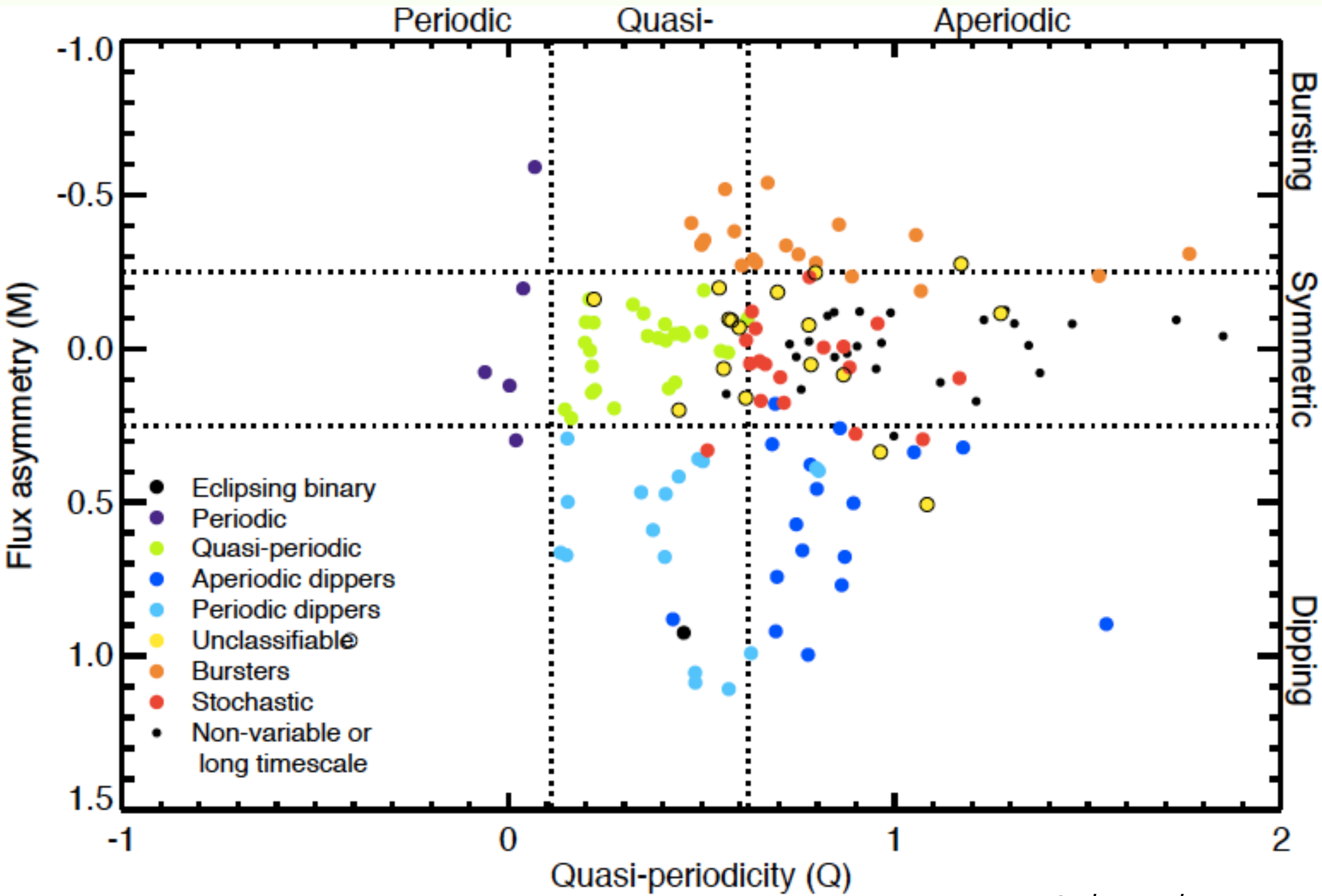
- ➢We are likely observing unsteady accretion flow, including bursts



Dust properties

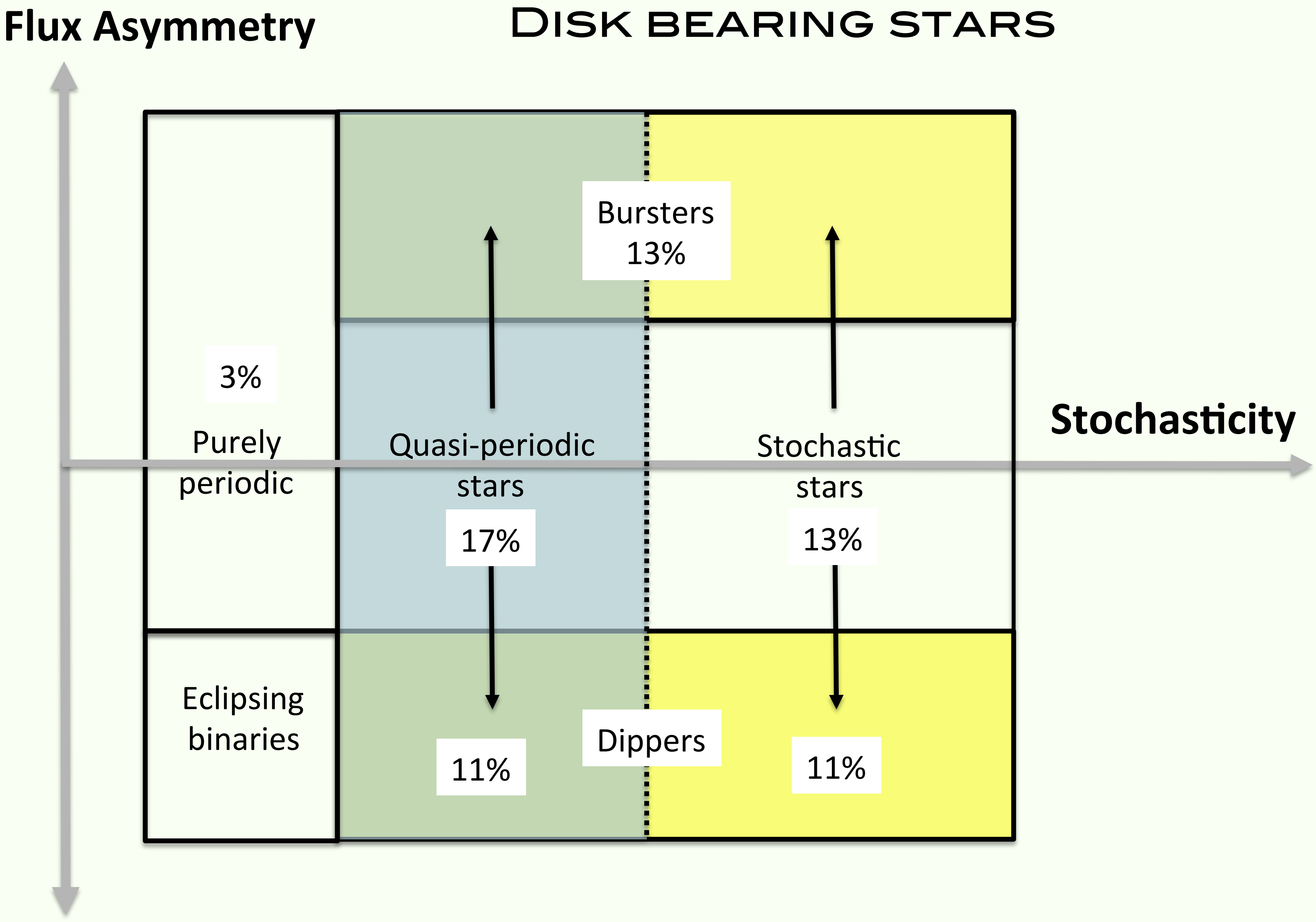
- ➢Obscuration events suggest extinction properties quite different from ISM material, and may depend on stellar mass

CLASSES CAN NOW BE SELECTED STATISTICALLY!



Cody et al. 2014

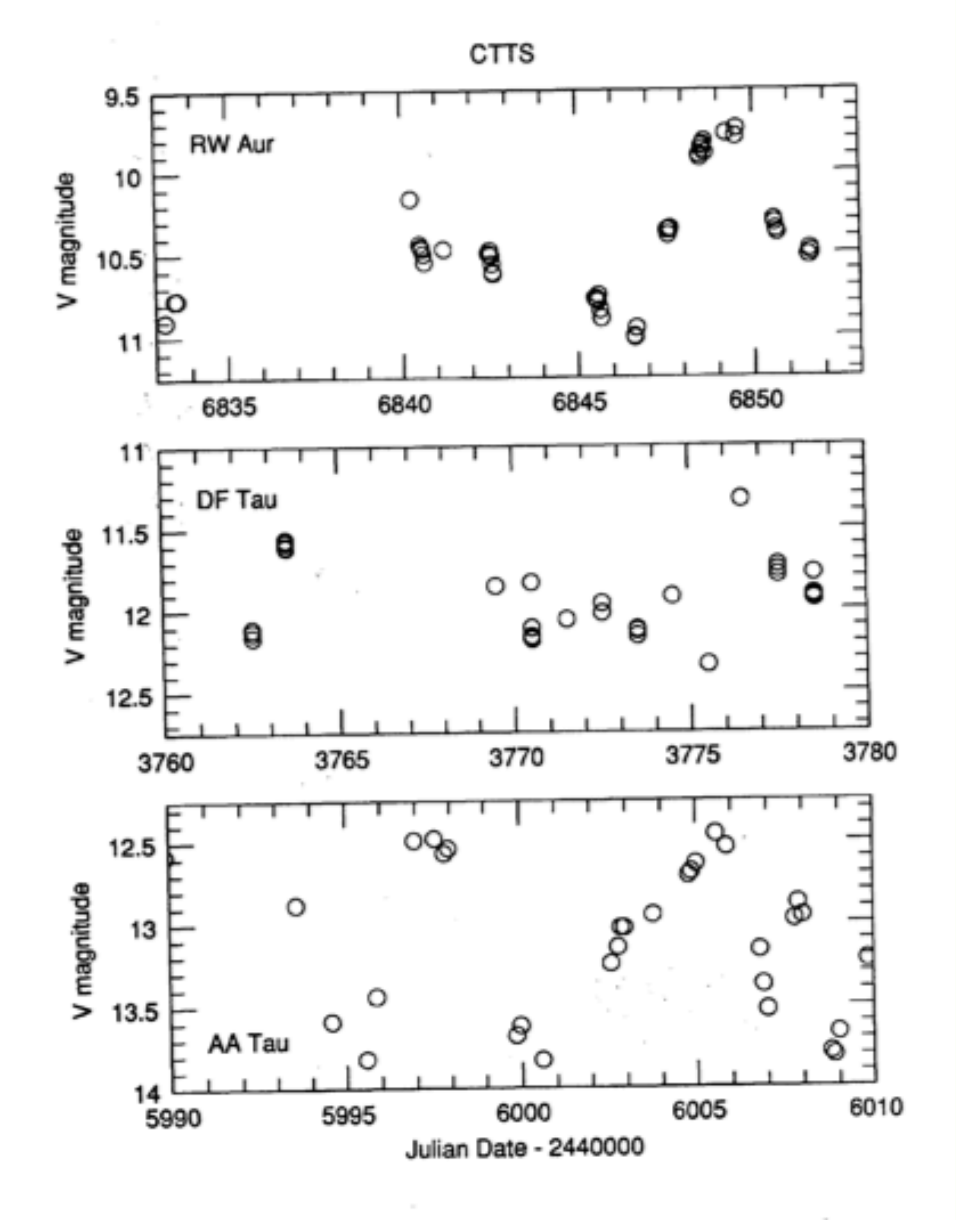
New light curve classes for Disk bearing stars



LIGHT CURVE CLASSES:
PRIOR TO THE SPACE PHOTOMETRY REVOLUTION

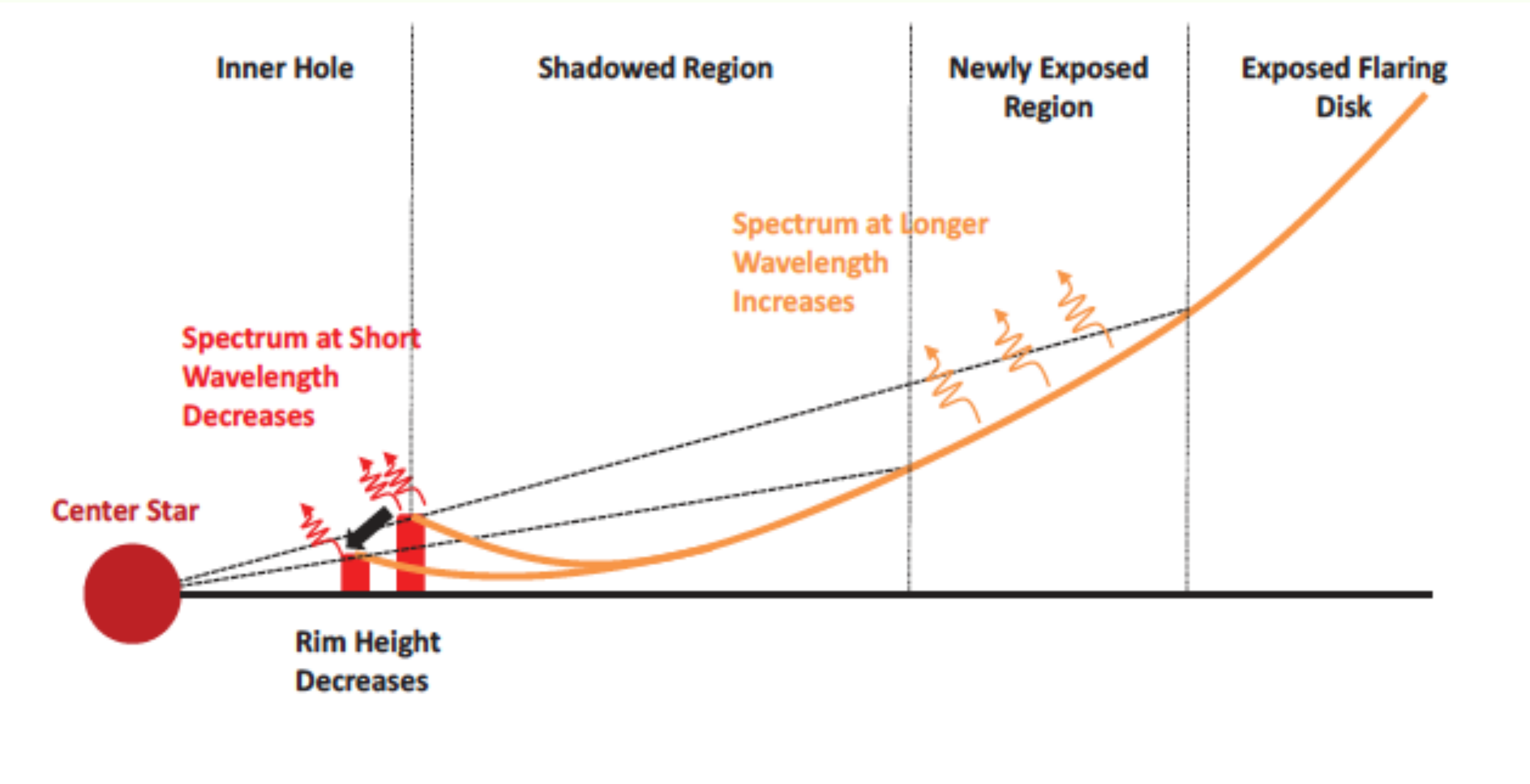
Periodic	Aperiodic
Eclipsing binaries	UX Ori stars

How can we translate light curve behavior into physics?



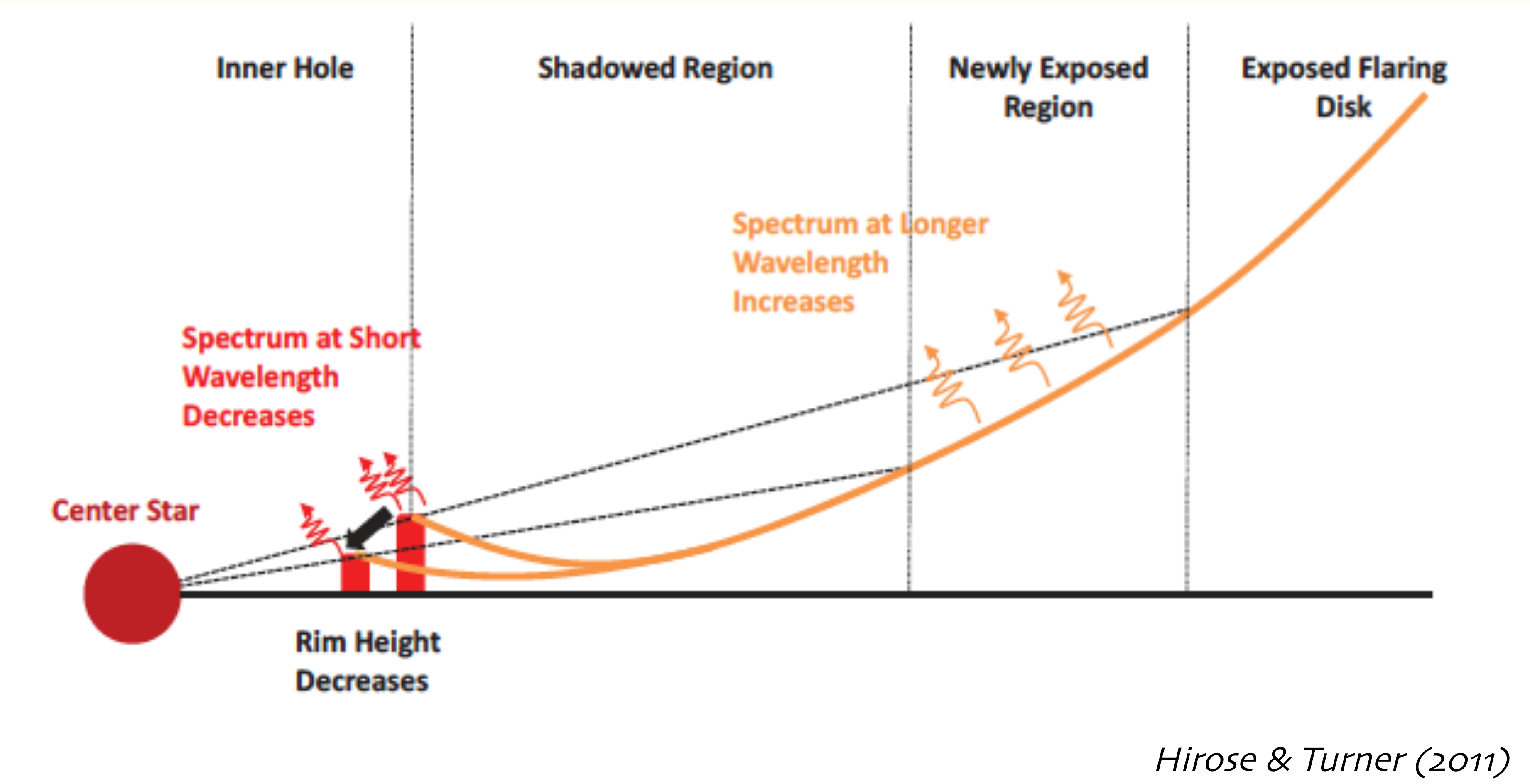
Classical T Tauri stars from Herbst et al. (1994)

What could be causing infrared variability ?



What could be causing infrared variability ?

Changes in inner disk scale height may be responsible.

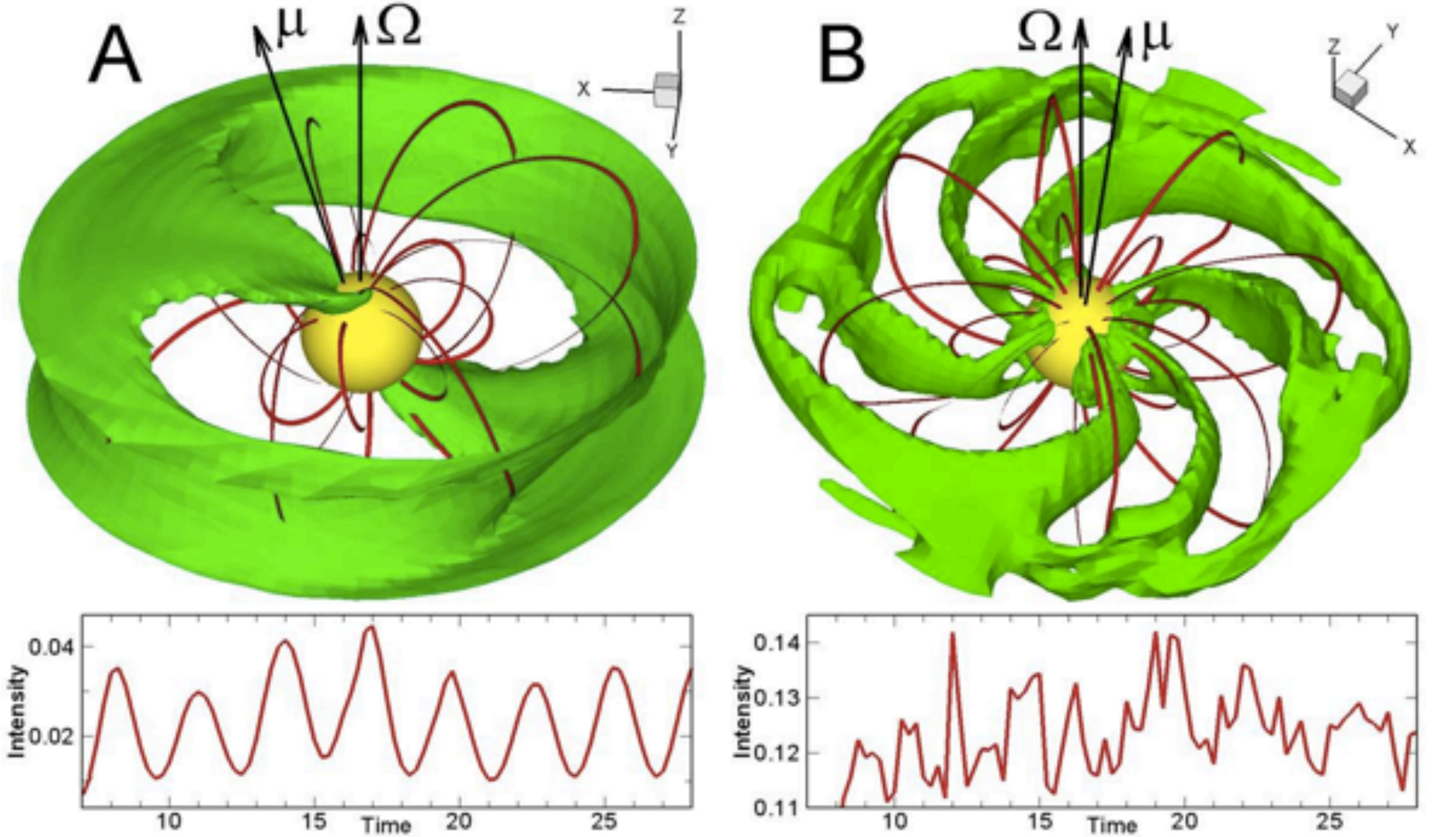


Hirose & Turner (2011)
Flaherty et al. (2012)
Ke, Huang & Lin (2012)

Looking toward the future

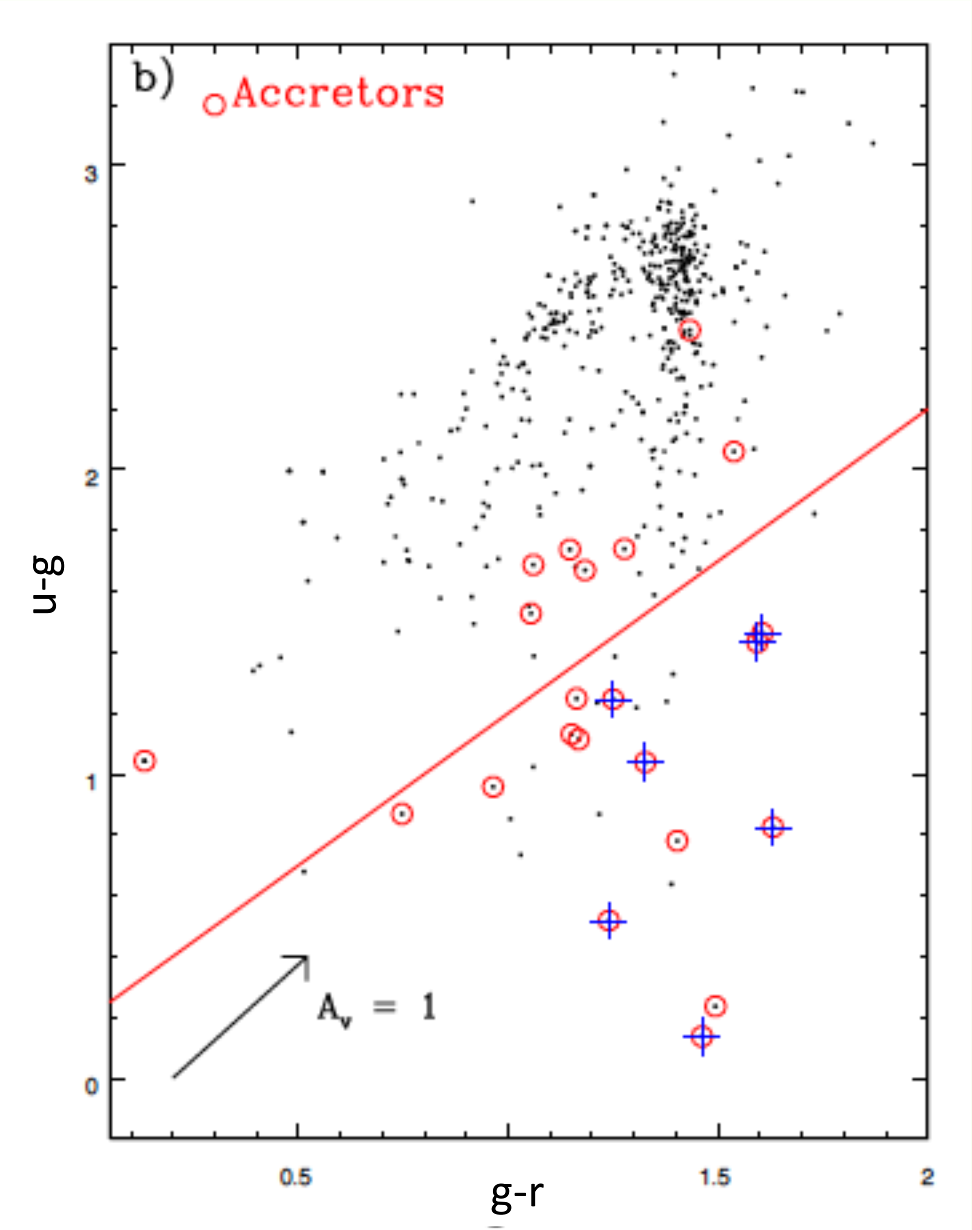
- Thanks to CoRoT and Spitzer, we now know that not only are young stars highly variable, but so are their disks!
- Some of the infrared variability could be from reprocessed starlight… but in many cases it doesn't correlate at all with stellar variations!
- Changes in height of the inner disk rim are one potential mid-infrared variability mechanism, but other explanations await.
- We have developed a new light curve classification scheme which can now be applied to additional datasets
- Stay tuned for further results from the CSI project, as well as new monitoring with K2

Can we detect different accretion regimes photometrically?



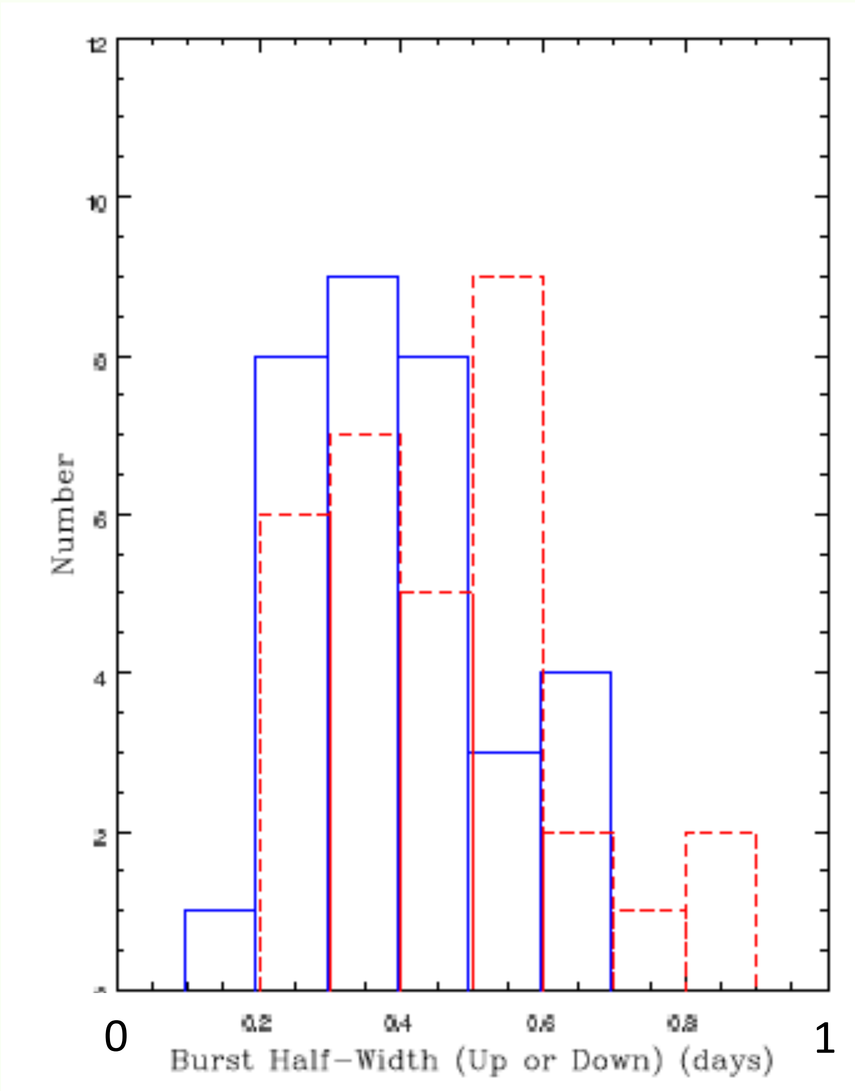
M. Romanova

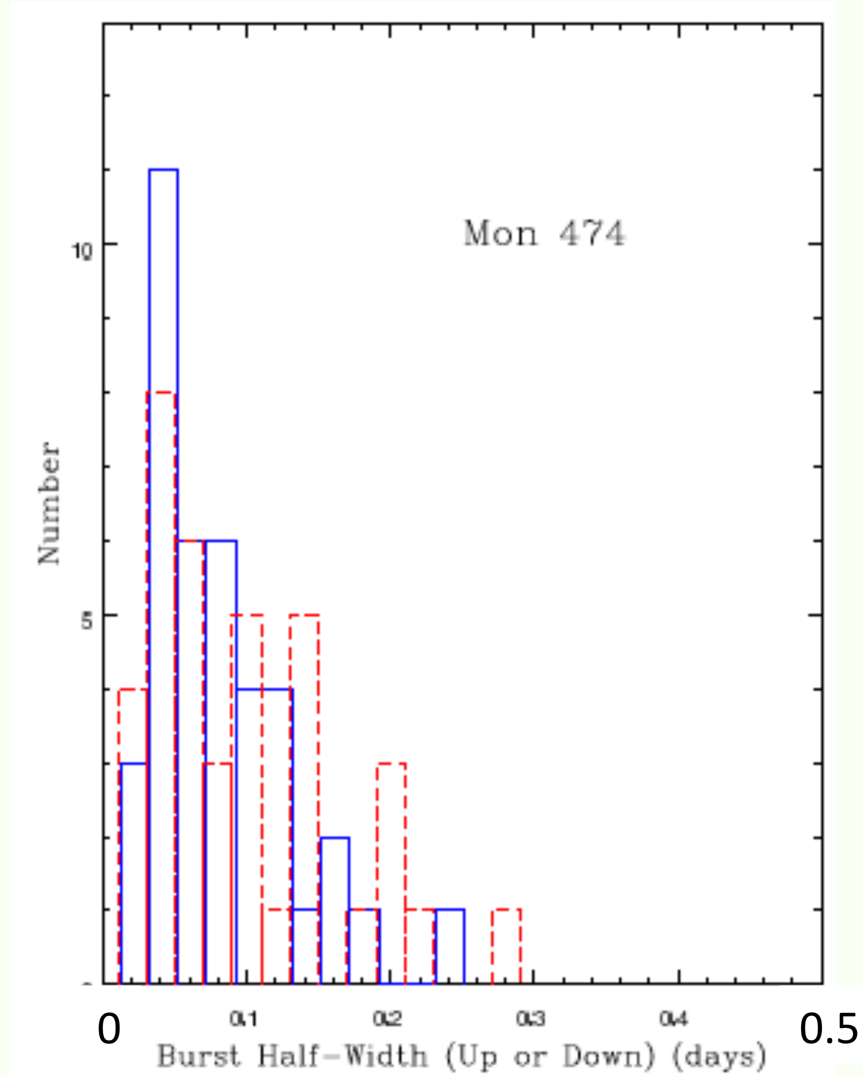
Evidence that short duration bursts are due to stochastic accretion



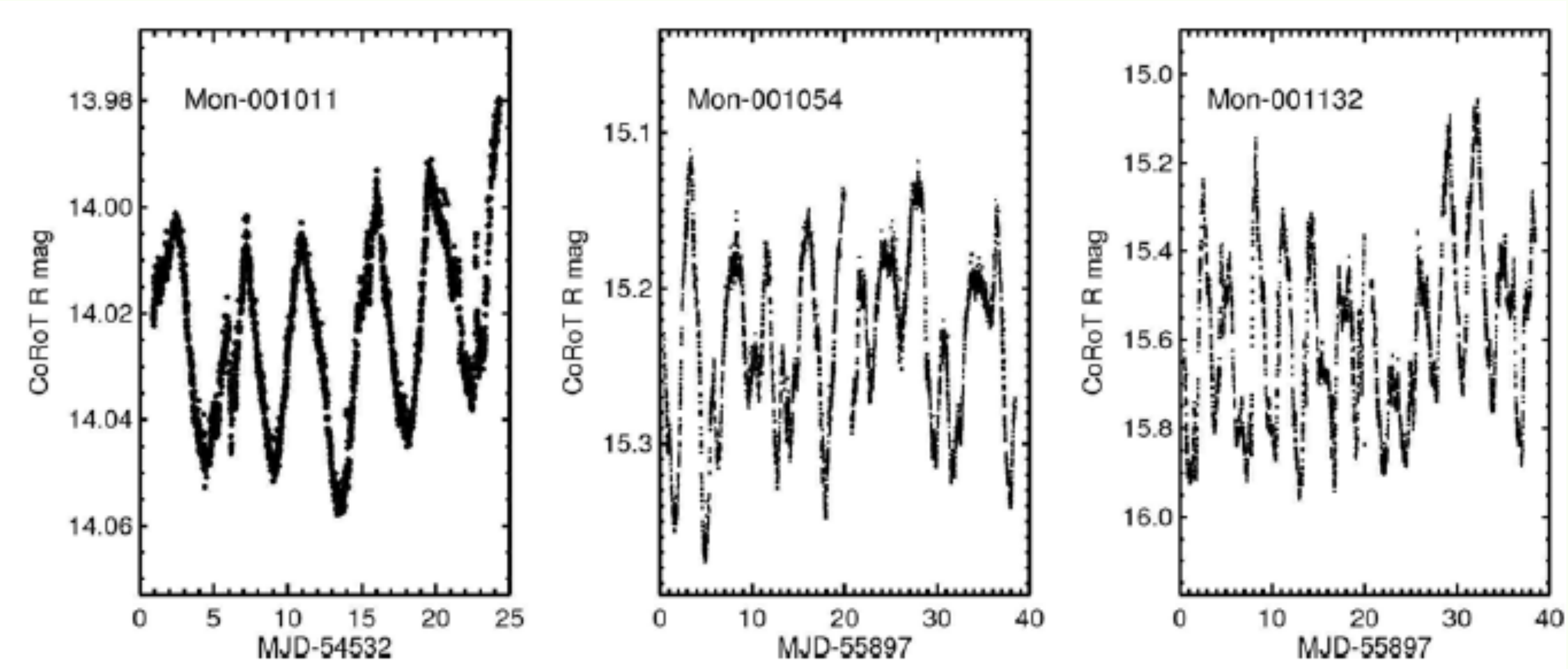
These objects have preferentially high UV excesses and H α emission indicative of strong accretion.

Burst durations: 0.1-1 day





Where are the hotspot dominated variables?



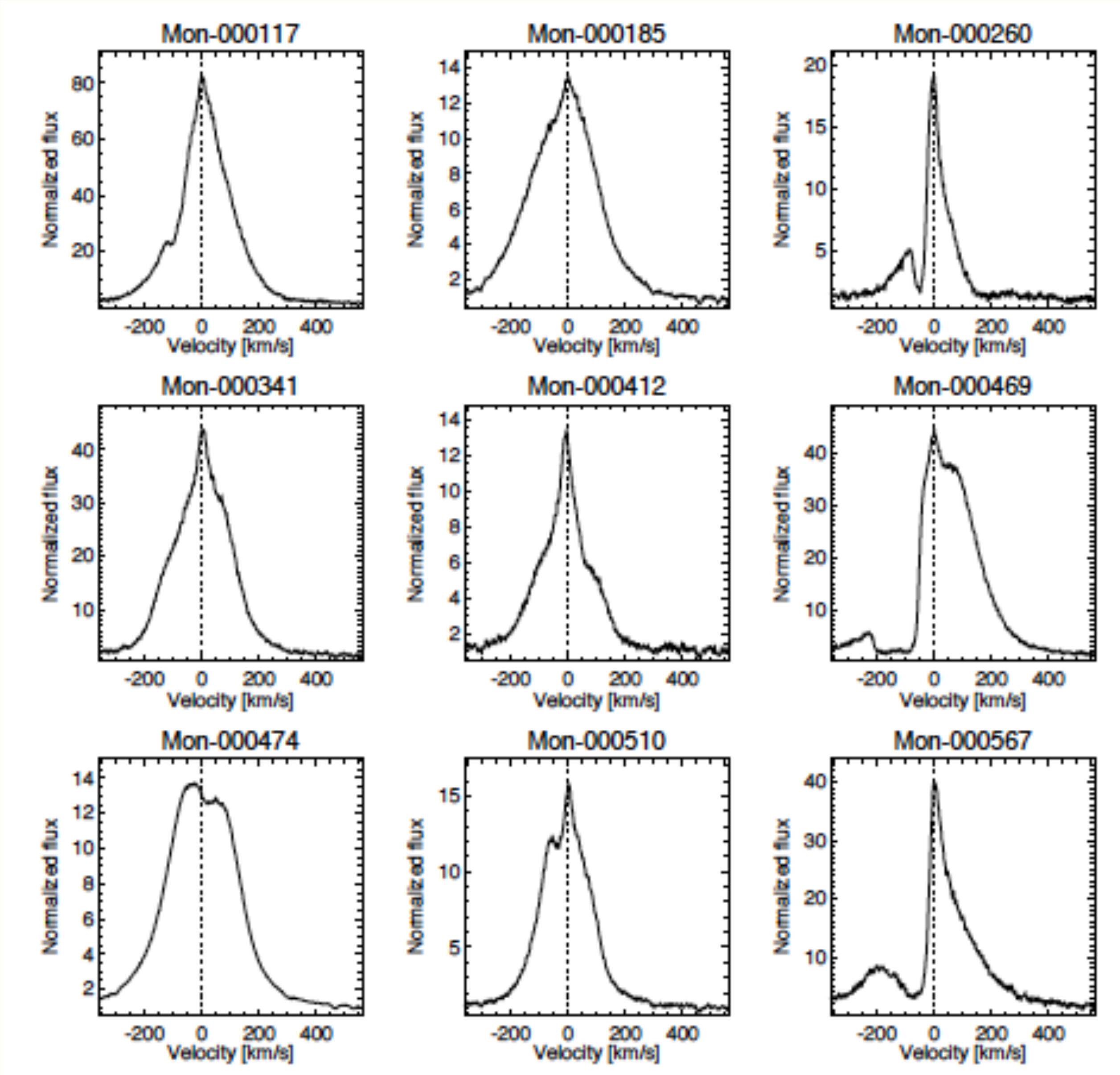
SUMMARY

Using high precision, high cadence space-based time series data, we have identified a collection of accreting stars that display rapid (<1 day) flux bursts in their optical light curves.

The correlation of these light curves with large UV excesses suggests that these are the **most heavily accreting stars in the cluster**.

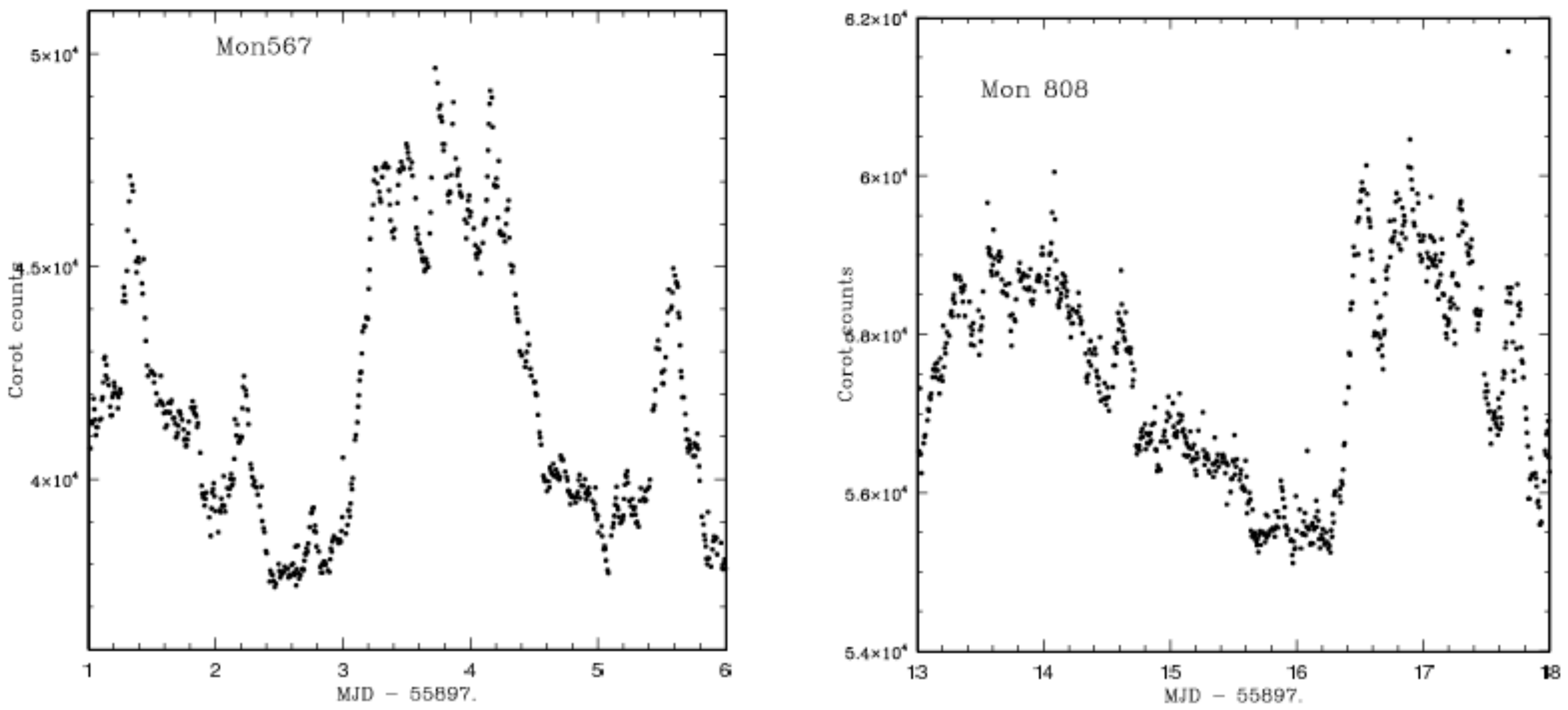
These results concur with the recent simulations of Romanova et al. and signal a shift from the paradigm of steady accretion flow along stable funnels.

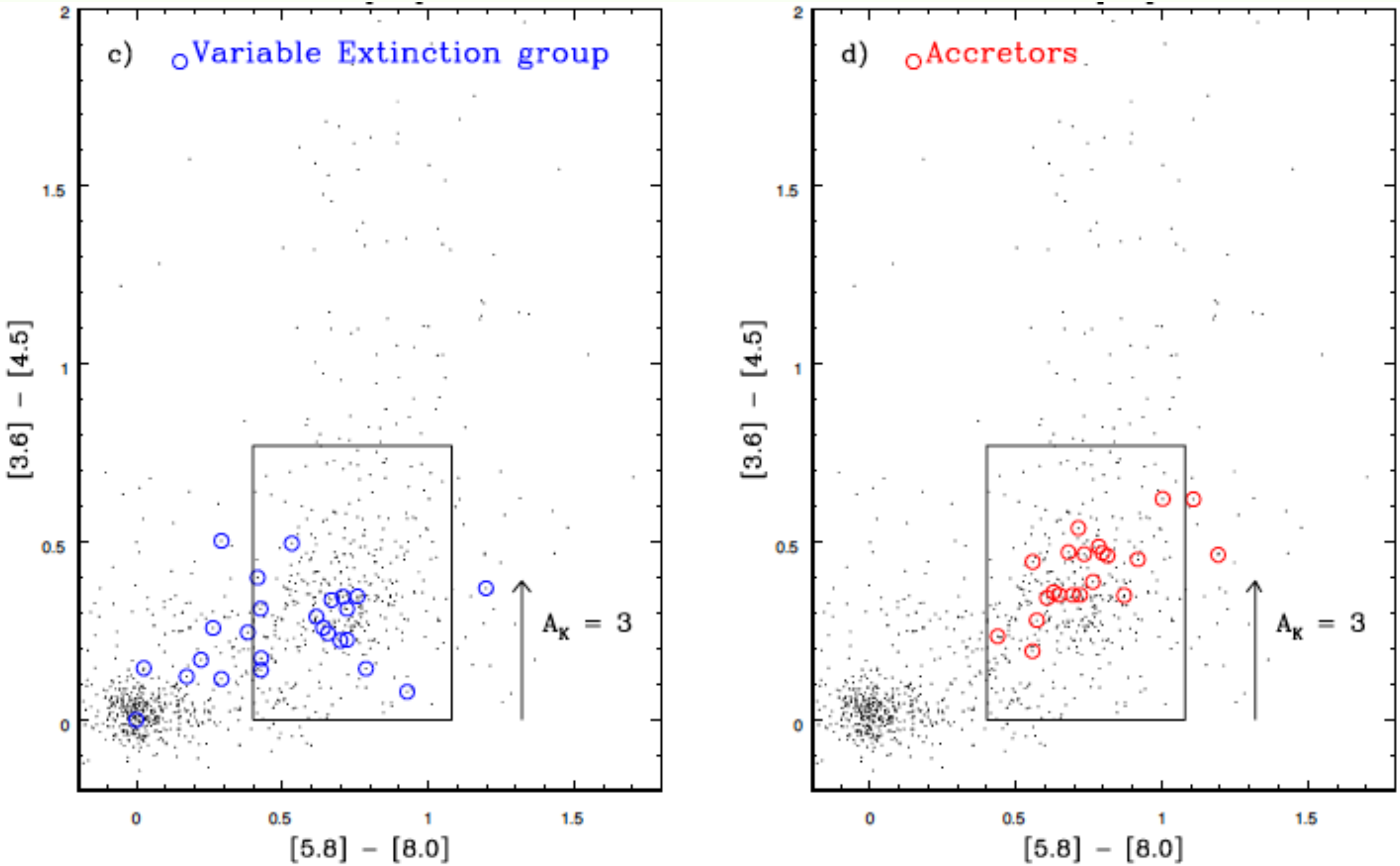
Hα PROFILES



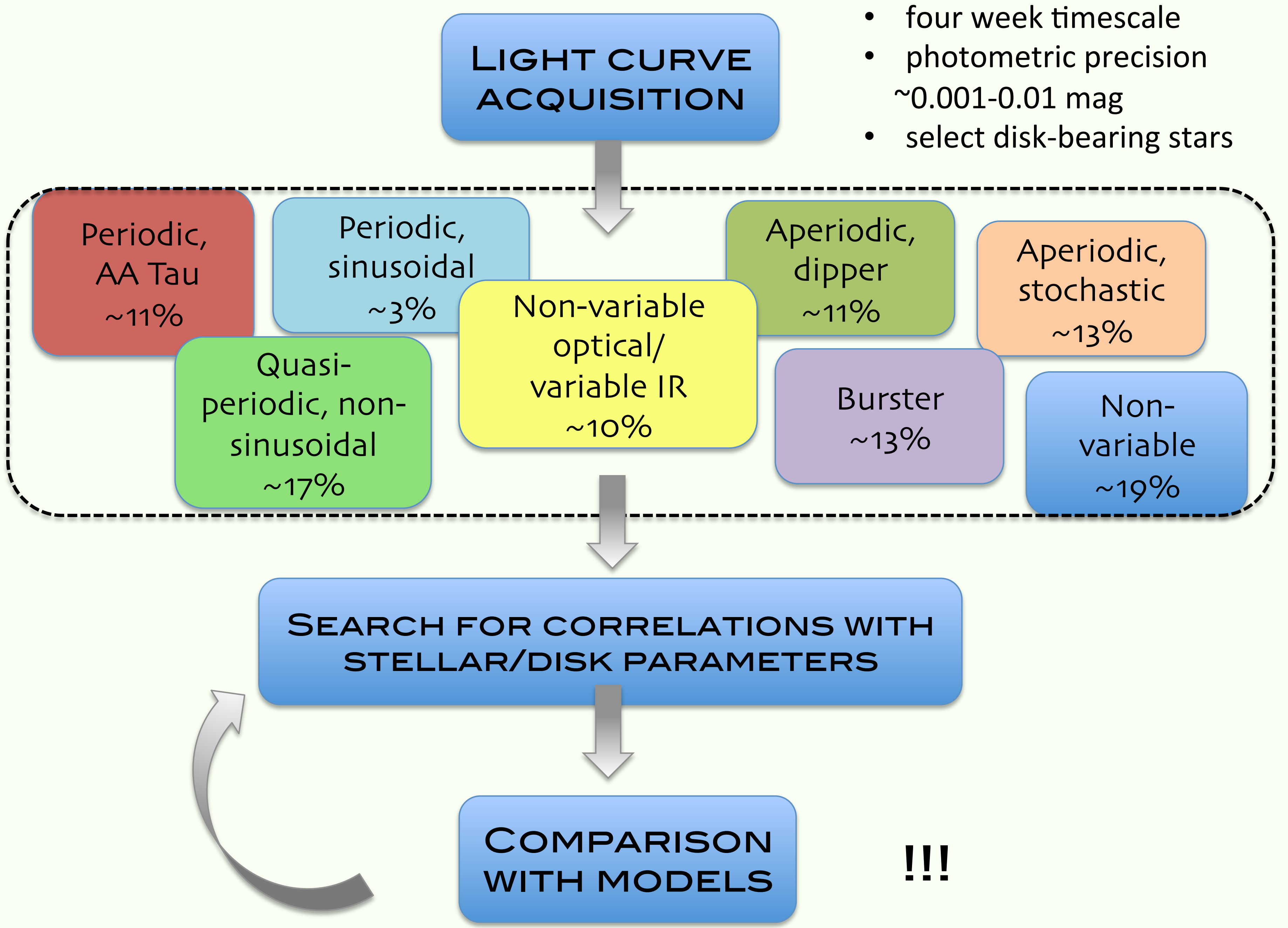
Mon-000117
Mon-000185
Mon-000260
Mon-000341
Mon-000412
Mon-000469
Mon-000474
Mon-000510
Mon-000567
Normalized flux
Velocity [km/s]

Zoom in on a flux burst





c)
Variable Extinction group
[3.6] − [4.5]
[5.8] − [8.0]
A_K = 3
d)
Accretors
[3.6] − [4.5]
[5.8] − [8.0]
A_K = 3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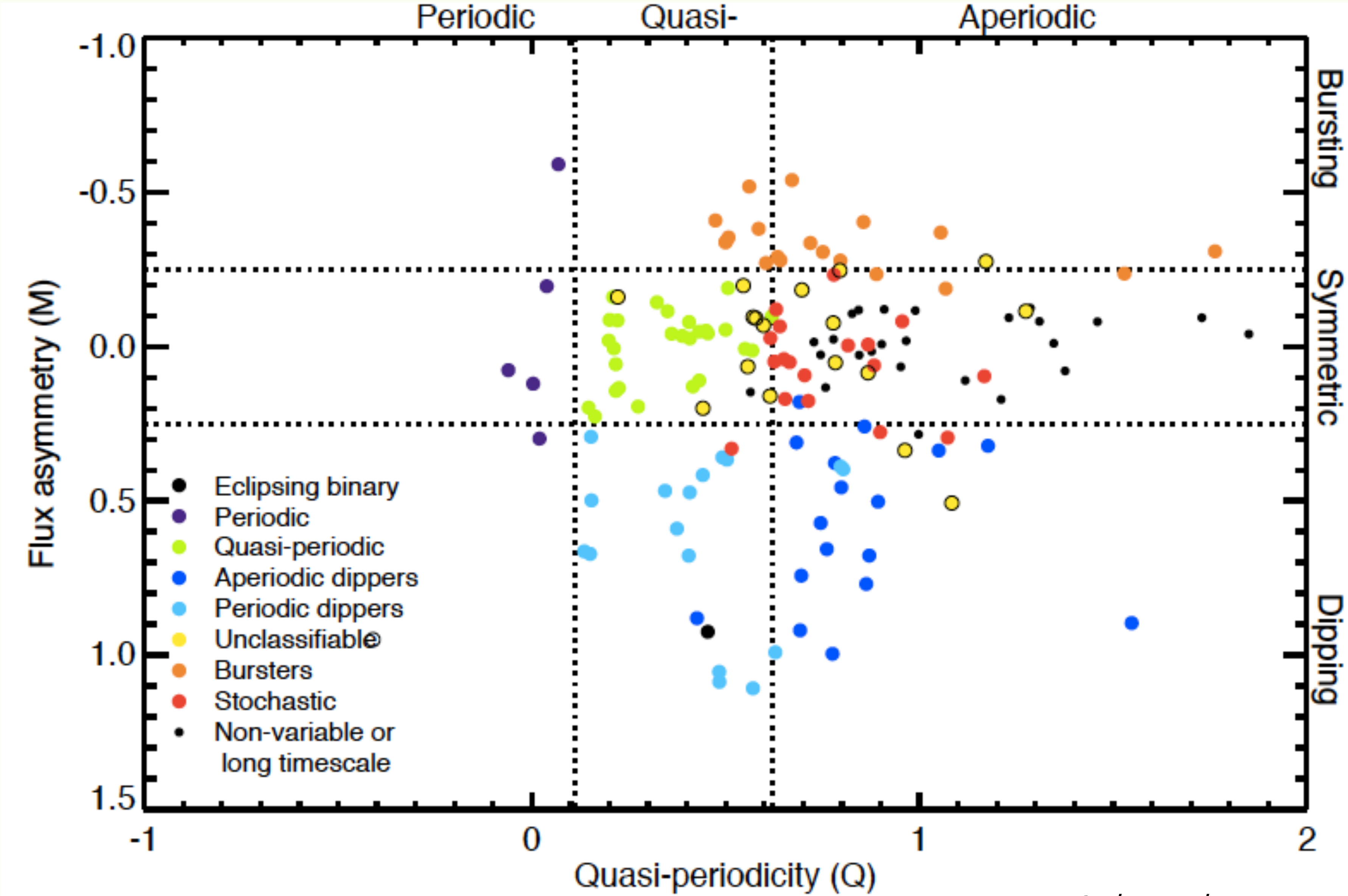
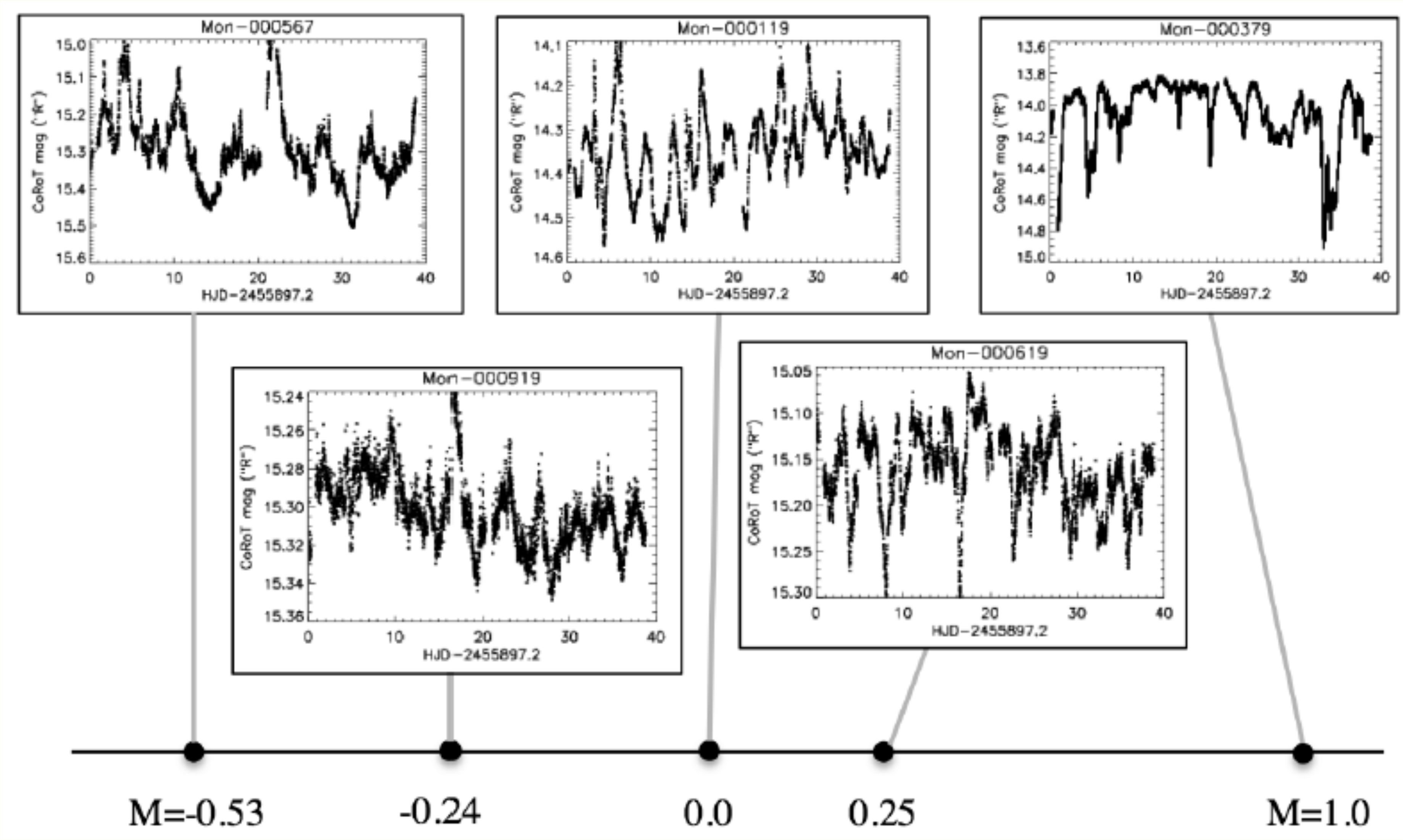
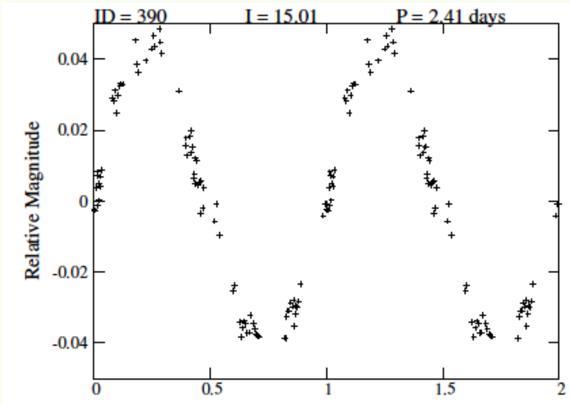


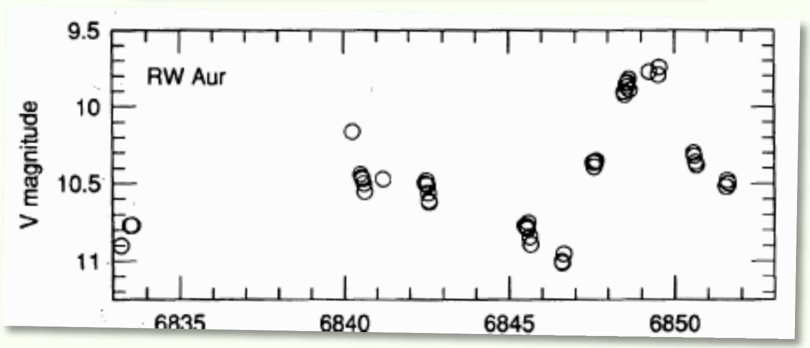
Cody et al. 2014

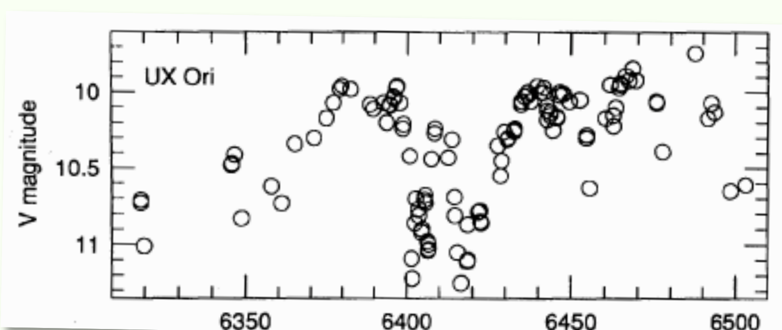
The spectrum of light curve flux asymmetry



Classification of variability: the picture prior to 2000







Herbst et al. (1994) paradigm:

I. Periodic-
Spots on the stellar surface

II. Irregular-
Variable accretion

III. Early type variables (K1-A0)-
Circumstellar obscuration?