Watching brown dwarfs go round and round *

Rotation and variability from stars to planets

Aleks Scholz
(St Andrews)

Plus many students and collaborators

* Thanks to John Lennon and Scott Wolk

Brown dwarfs are extreme

Central object: <0.08 $M_\odot$

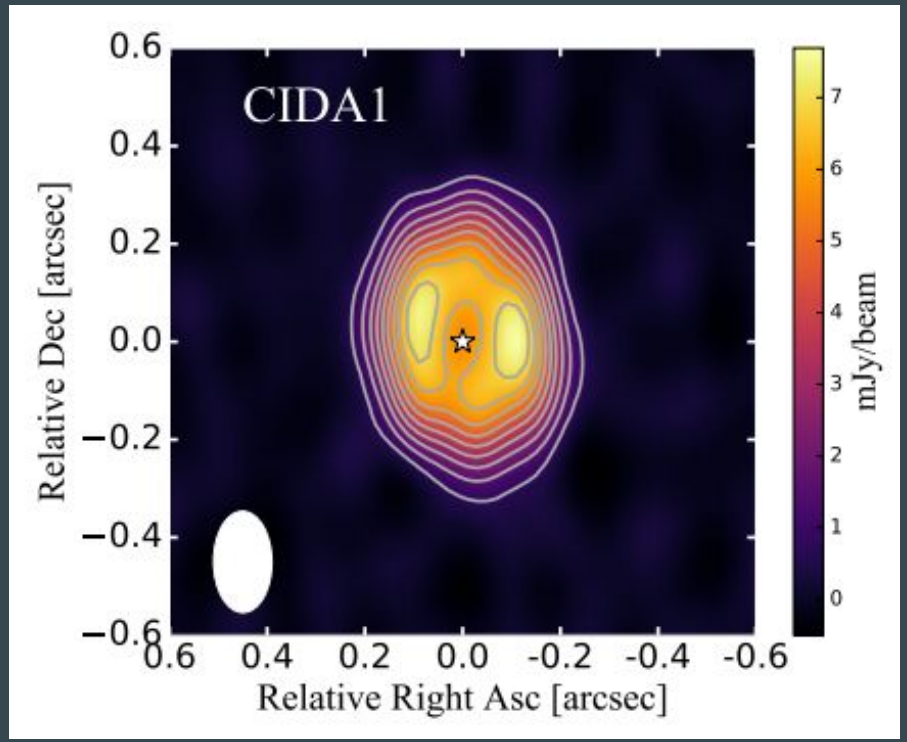
J-band mag >12 (L<0.05 $L_\odot$)

Disk masses: ≲ Jupiter mass

Dust masses: ≲ few Earth masses

Most disk sizes: <25 AU

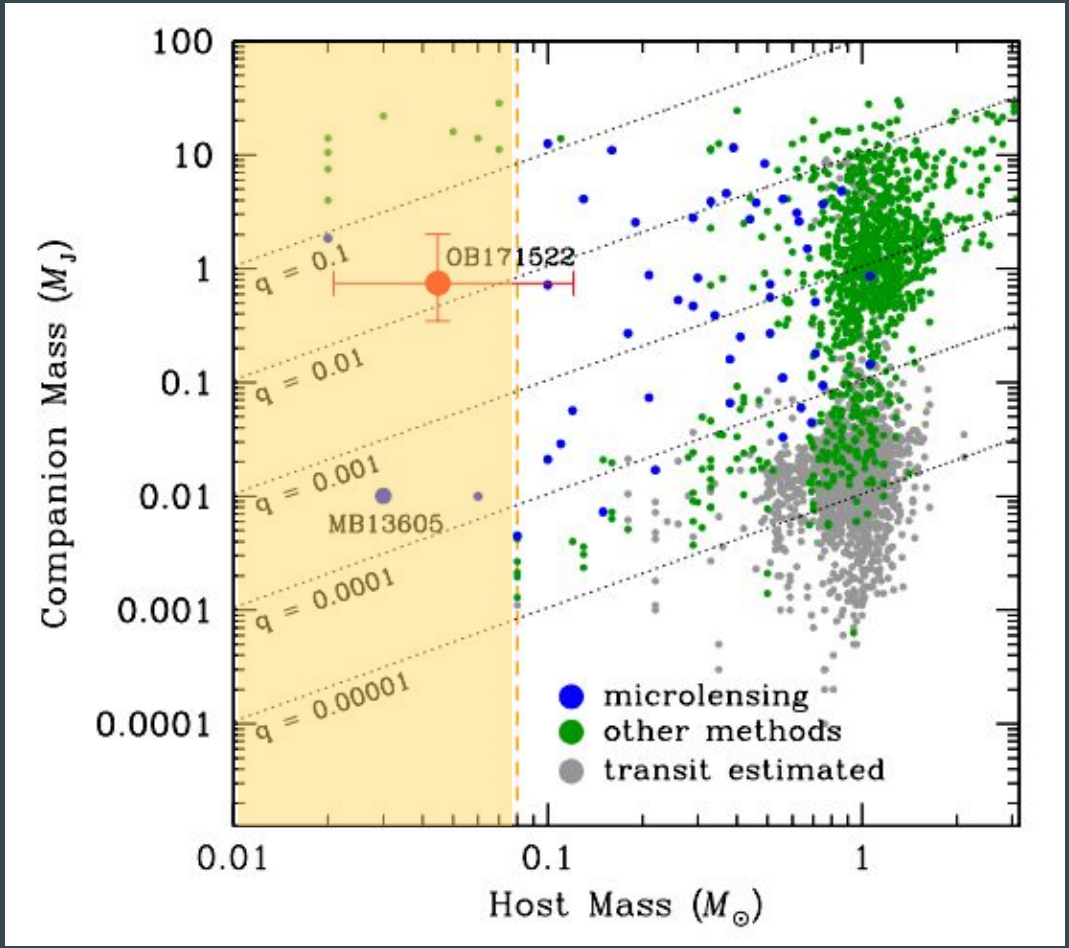
Accretion rates: <10^{-9} $M_\odot$/yr



Pinilla et al. 2018

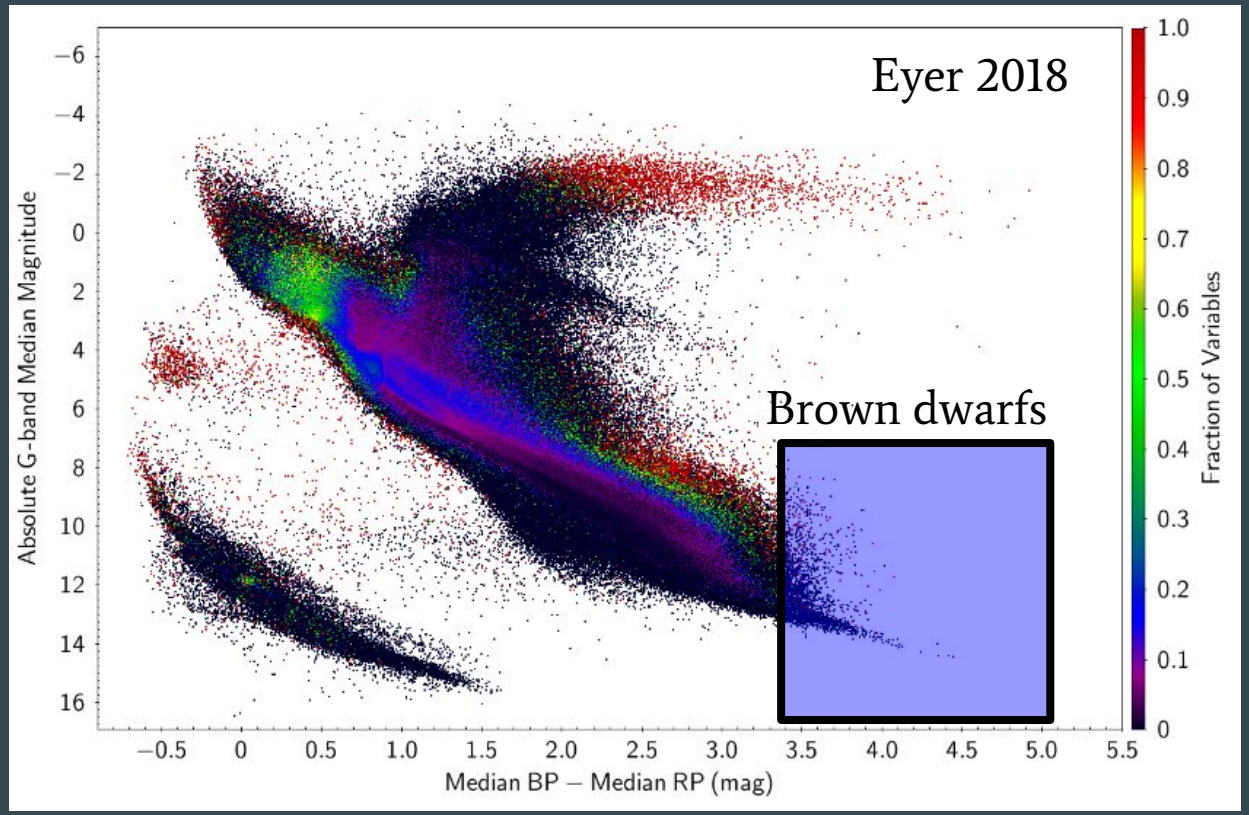
Variability is a really useful tool for faint sources.

Brown dwarf planets

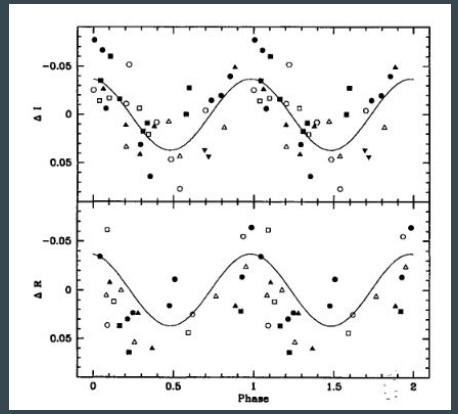


Jung et al. 2018

Gaia CMD of variable stars



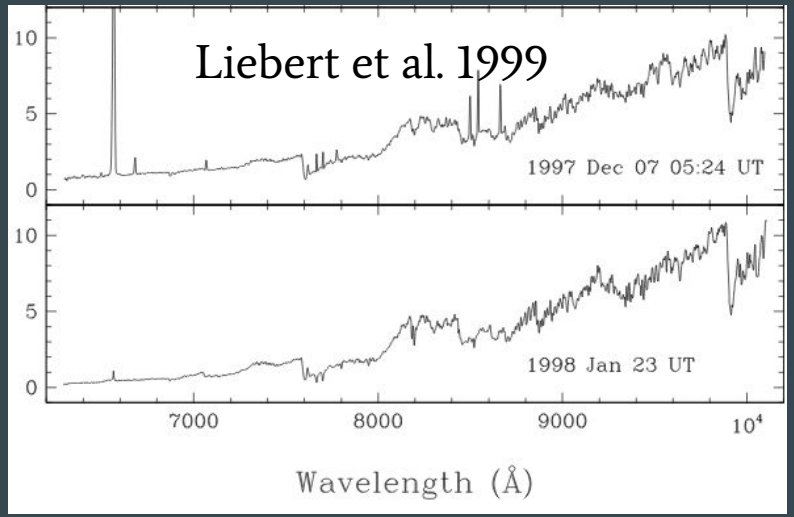
20 years ago: first brown dwarf variability papers



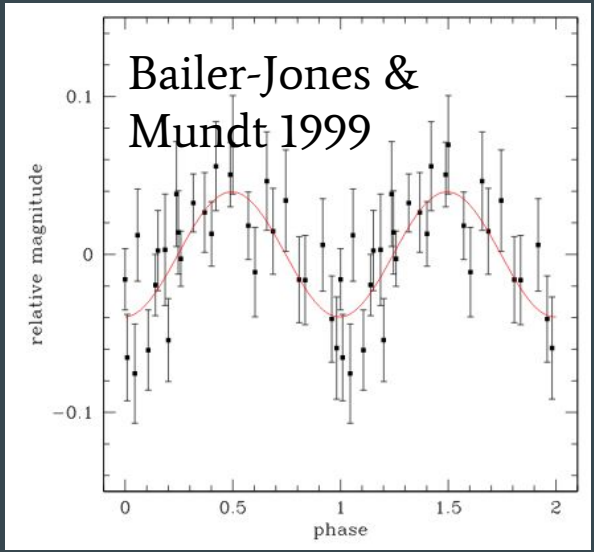
Martin et al. 1997

spots

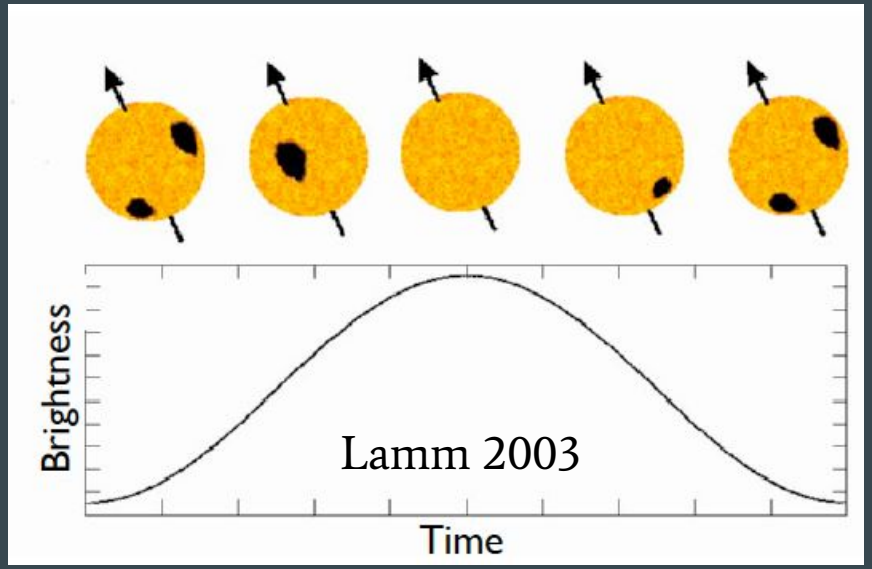
flares

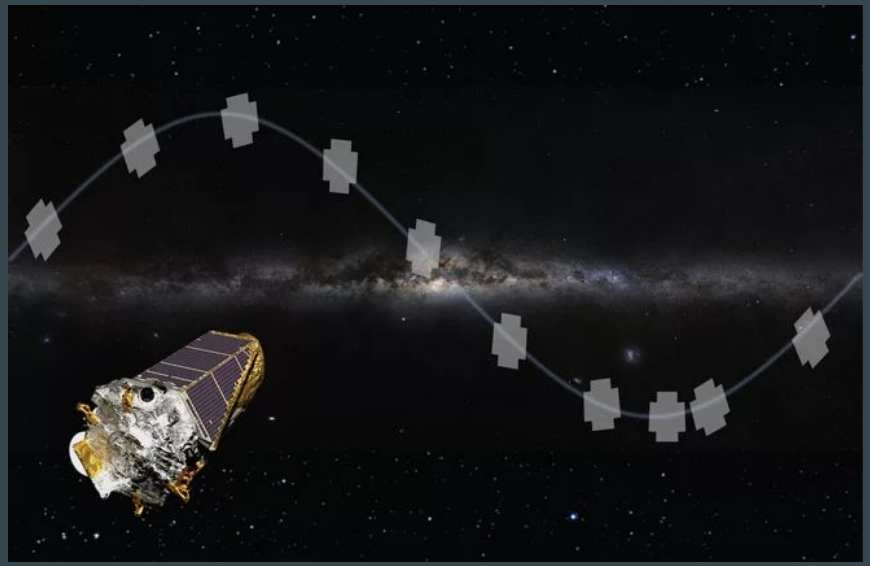


clouds

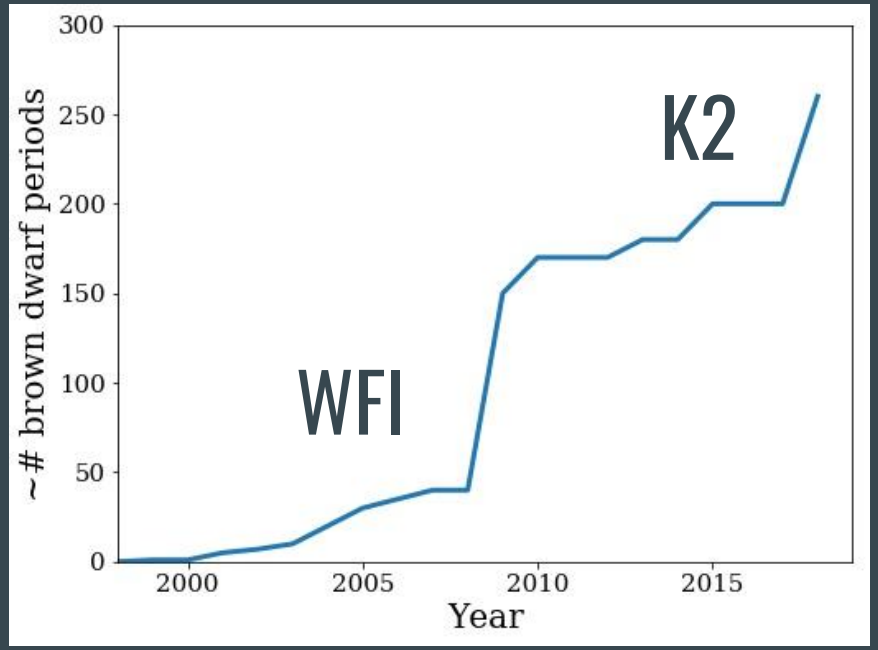


Rotation period: fundamental parameter at <1% accuracy





Brown dwarf rotation: the database for 0.02-0.08 Msol

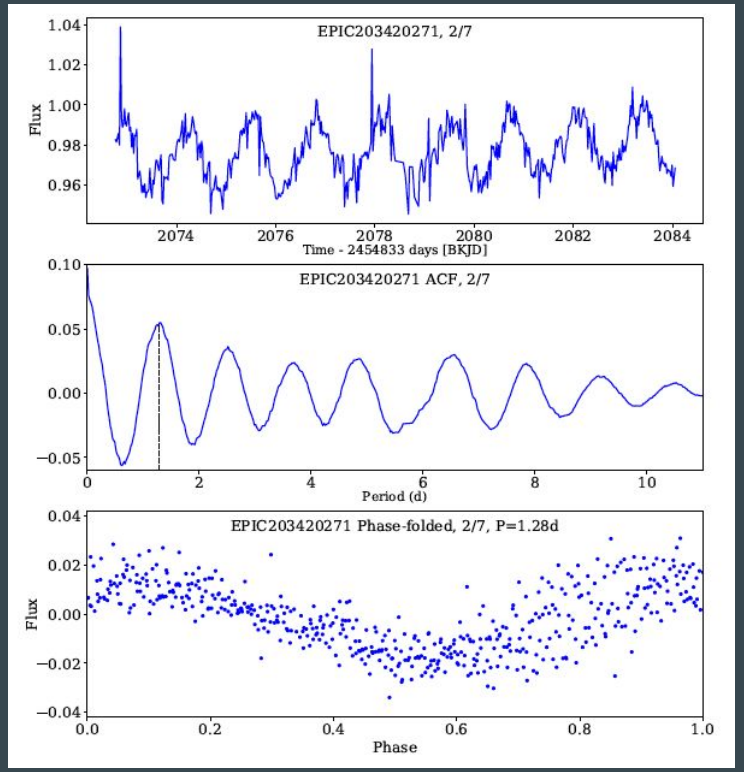


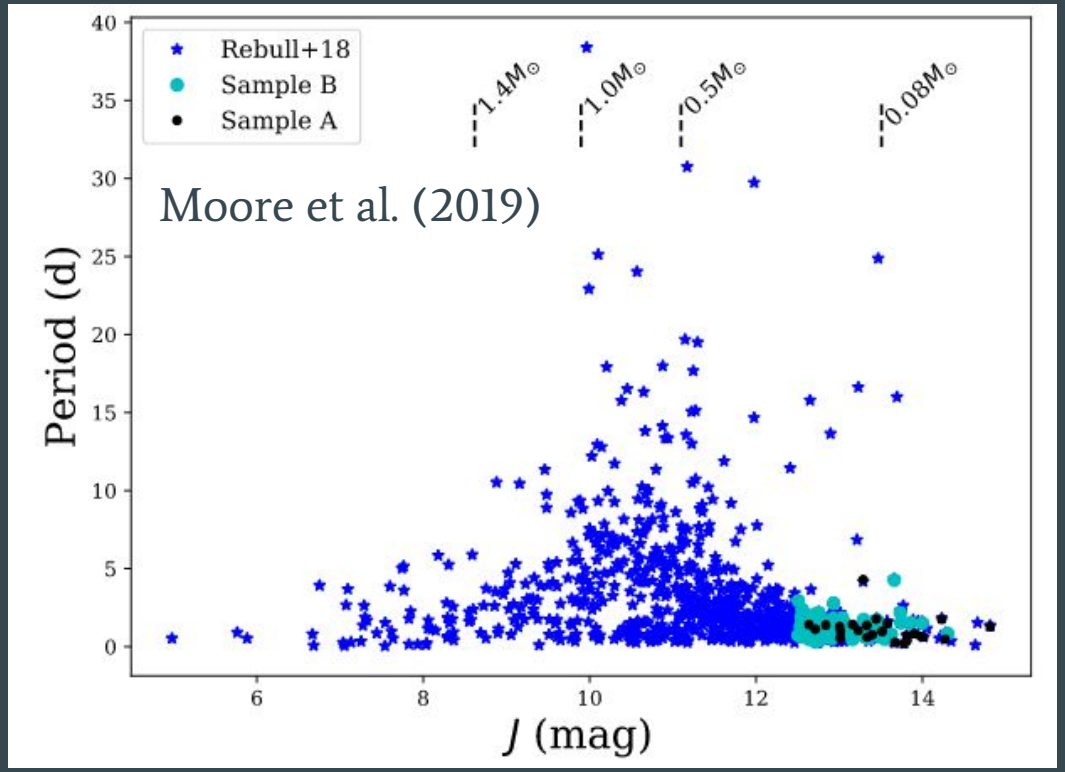
1-2 Myr: ~120 periods
Rodriguez Ledesma 2009, ***Scholz 2018, +***

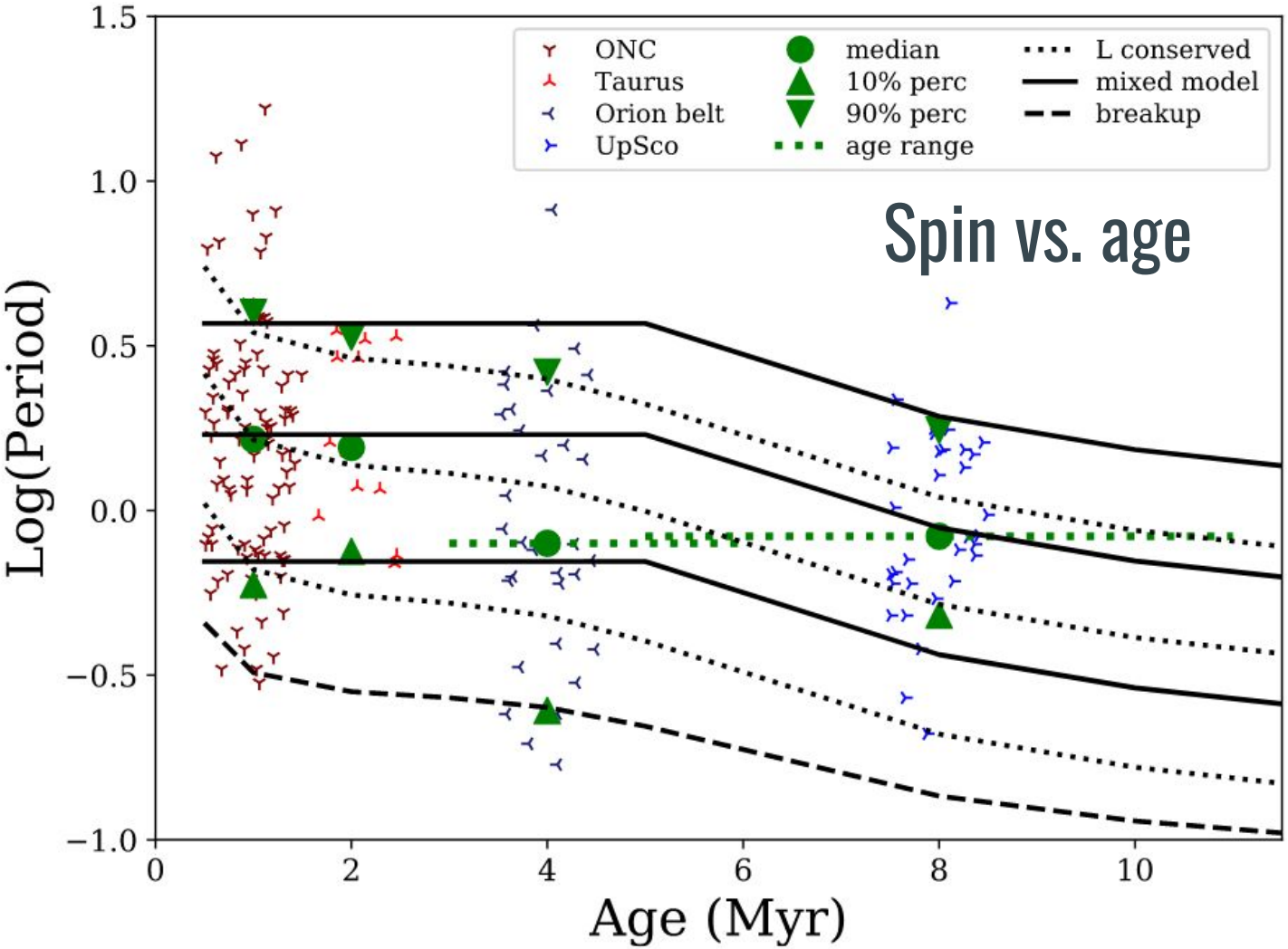
3-20 Myr: ~100 periods
Scholz 2004/05, Cody 2010, ***Scholz 2015***, Rebull 2018, ***Moore 2019, +***

Field: ~20 periods, plus vsini
Many papers

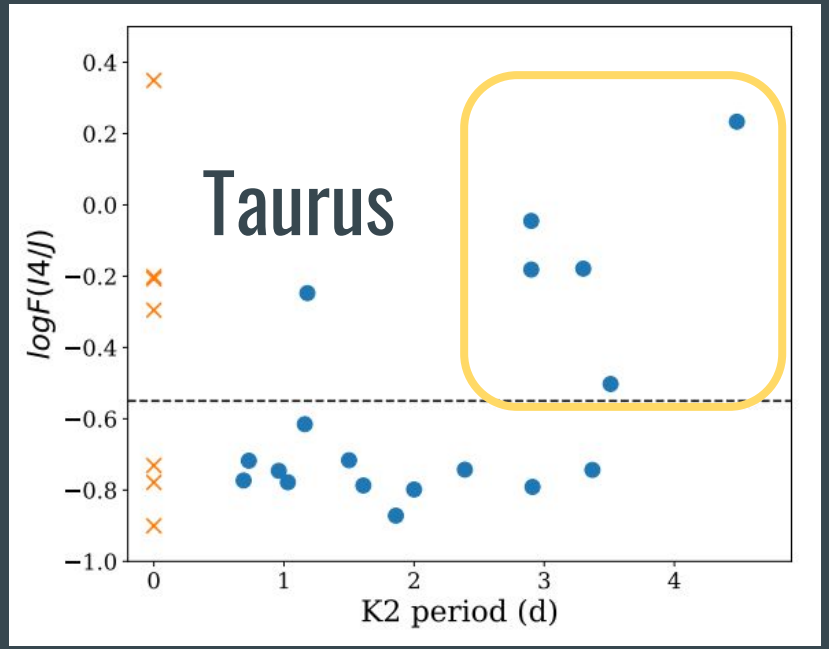
K2 brown dwarf periods in Upper Scorpius

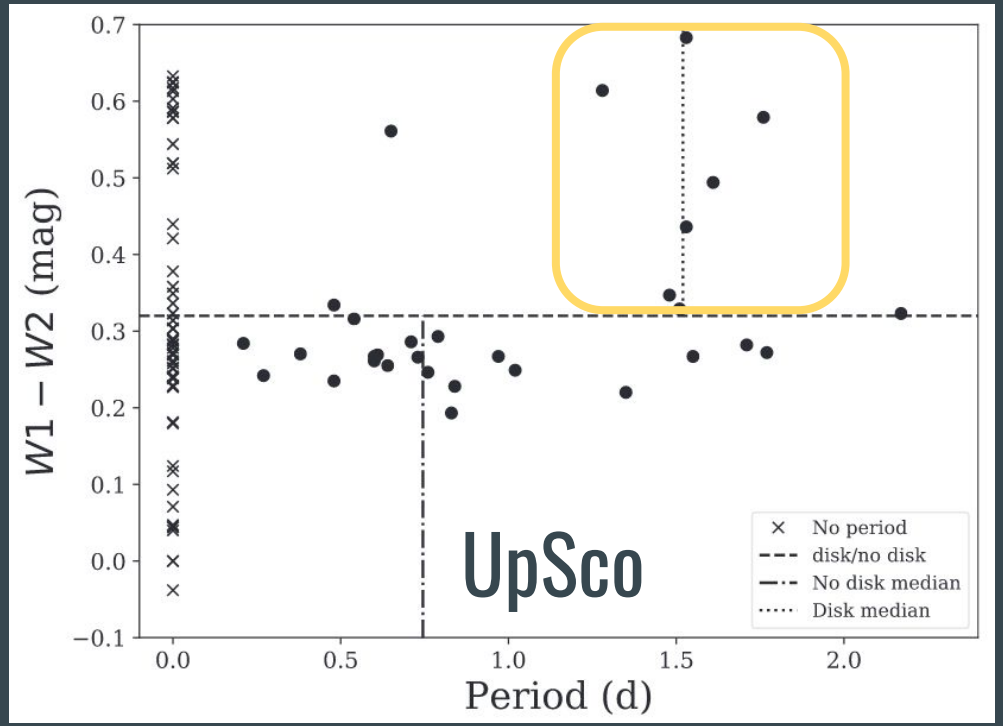





ONC
Taurus
Orion belt
UpSco
median
10% perc
90% perc
age range
L conserved
mixed model
breakup
Spin vs. age
Log(Period)
Age (Myr)
1.5
1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10

Slow rotation and presence of disks

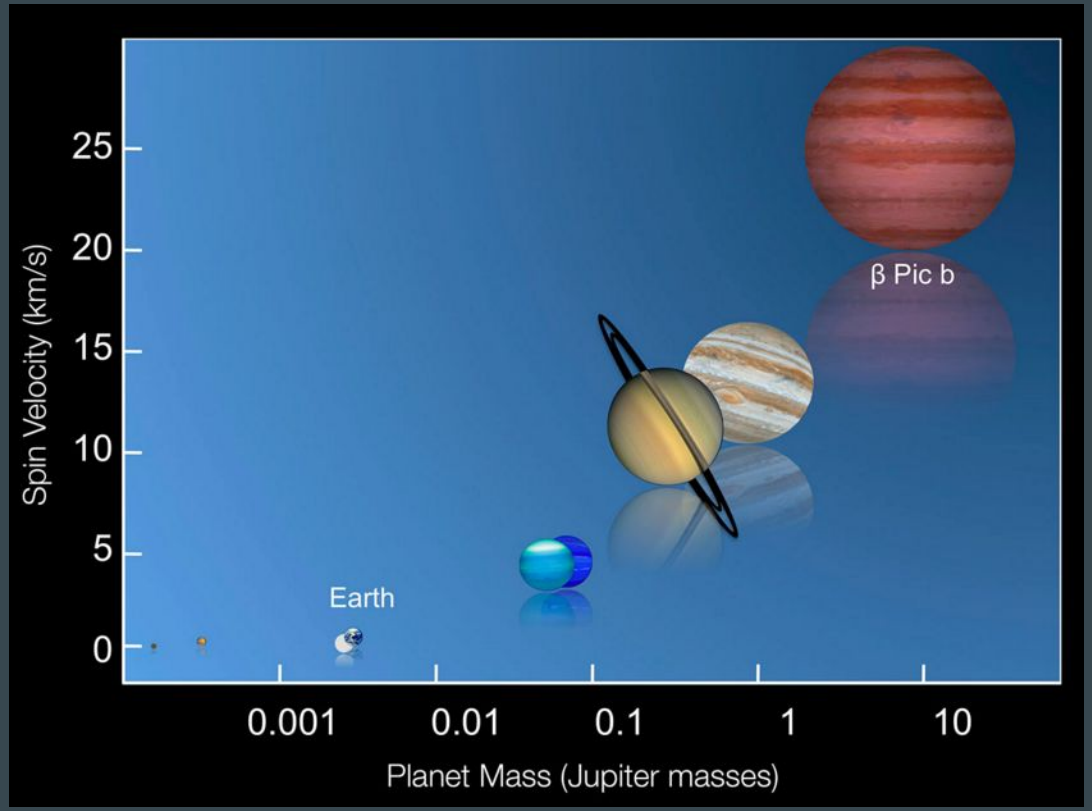




Disk braking works for a few Myr. *

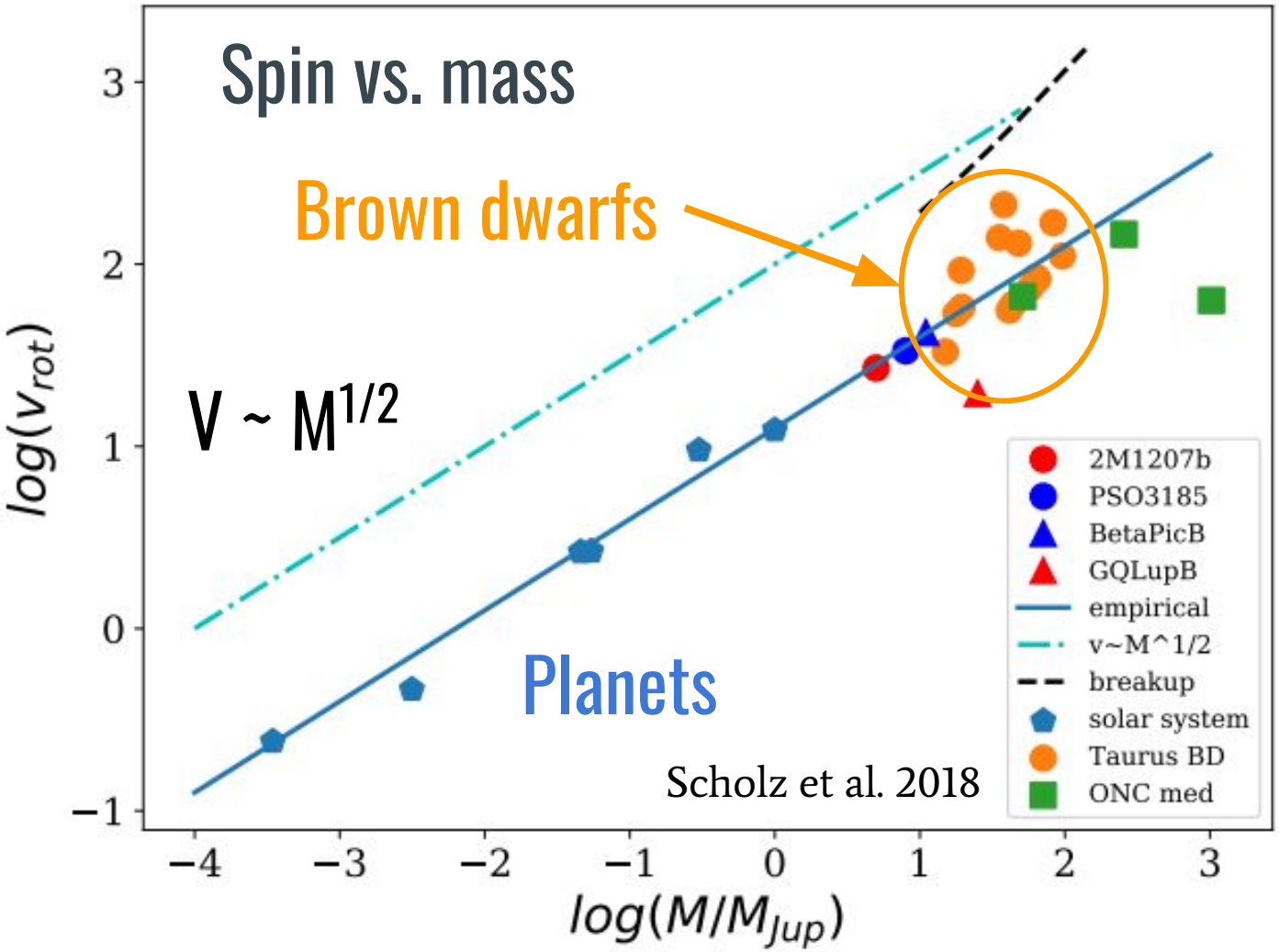
* Moore, Scholz, & Jayawardhana, ApJ, 2019

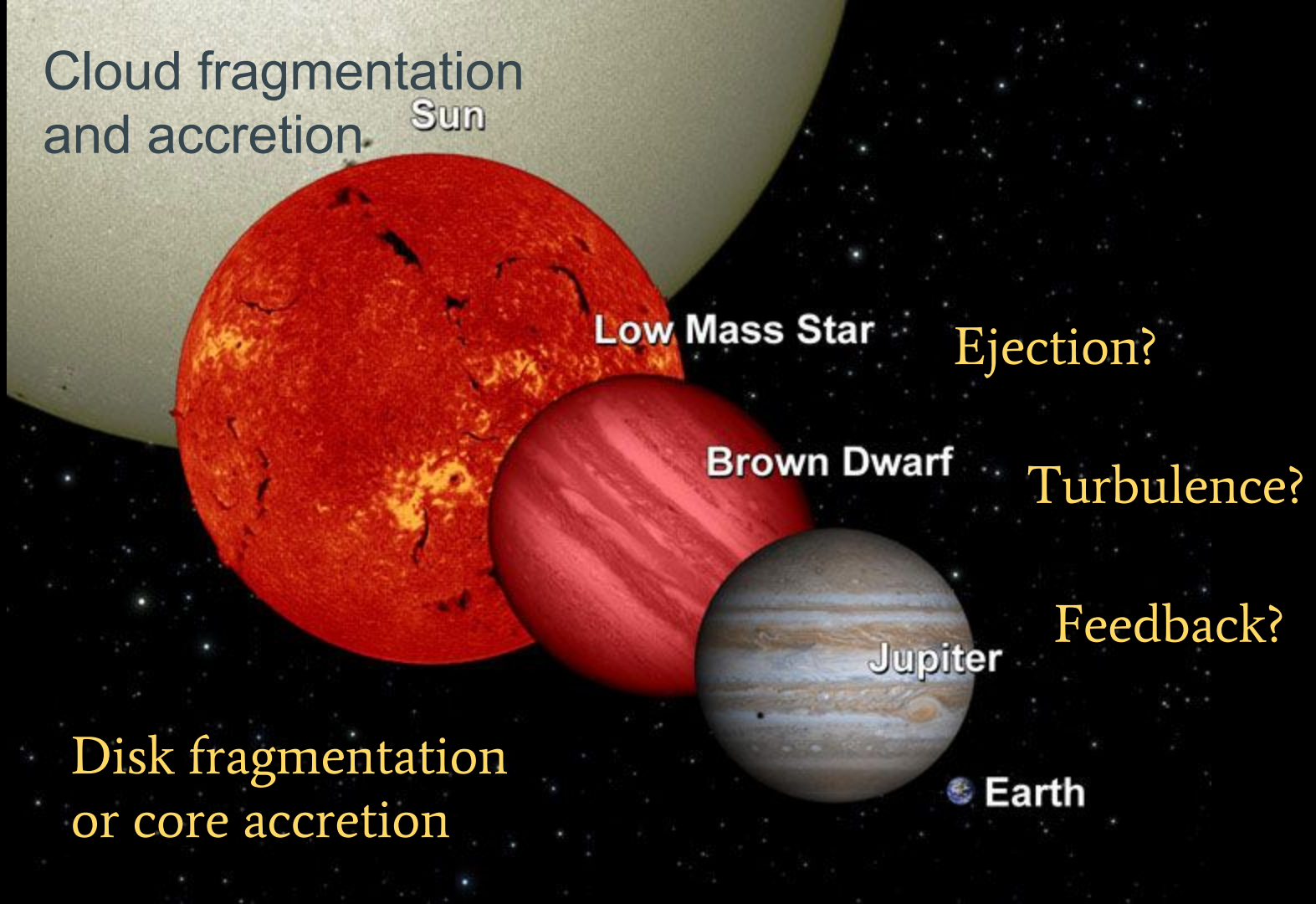
The planetary spin-mass relation



Snellen et al. 2014: first exoplanet spin rate

Power law relation between spin and mass from rocky planets to gas giants

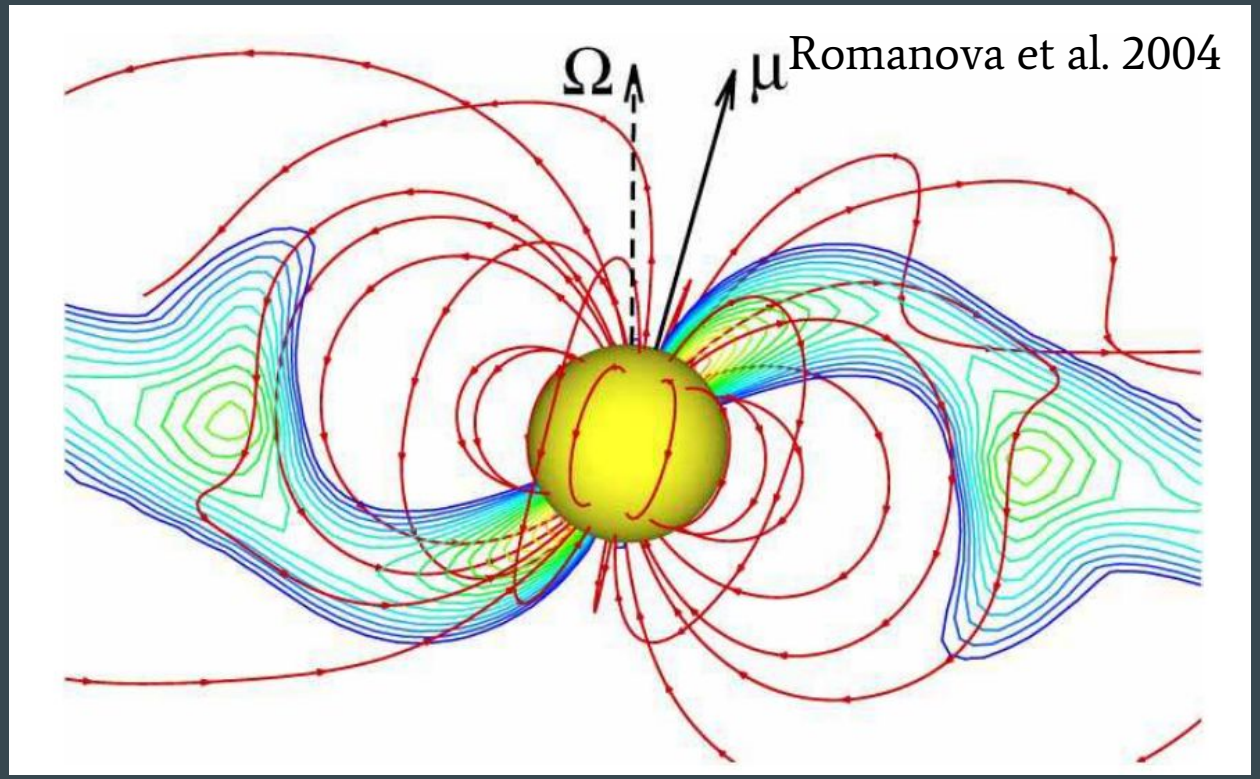

Spin vs. mass
Brown dwarfs
V ~ M^1/2
Planets
Scholz et al. 2018
2M1207b
PSO3185
BetaPicB
GQLupB
empirical
v~M^1/2
breakup
solar system
Taurus BD
ONC med
log(v_rot)
log(M/M_Jup)
3
2
1
0
−1
−4
−3
−2
−1
0
1
2
3


Cloud fragmentation
and accretion
Sun
Low Mass Star
Ejection?
Brown Dwarf
Turbulence?
Feedback?
Jupiter
Earth
Disk fragmentation
or core accretion

A universal spin-mass relation - constraints on formation? *

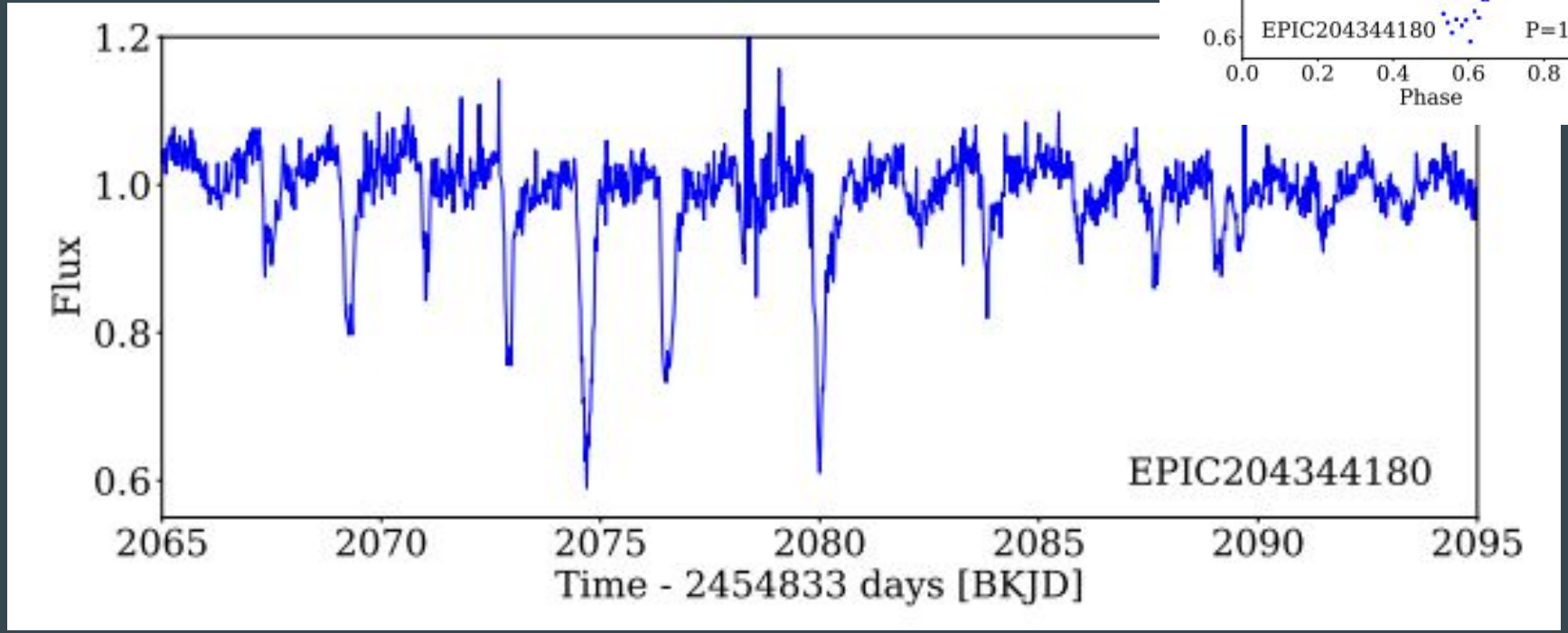
* Scholz et al., ApJ, 2018

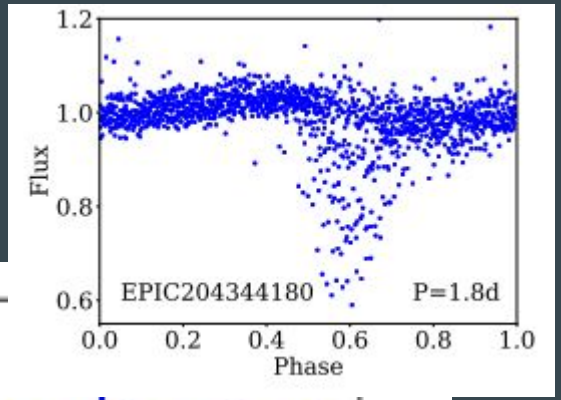
Inclined dipole + accretion column = complex variability



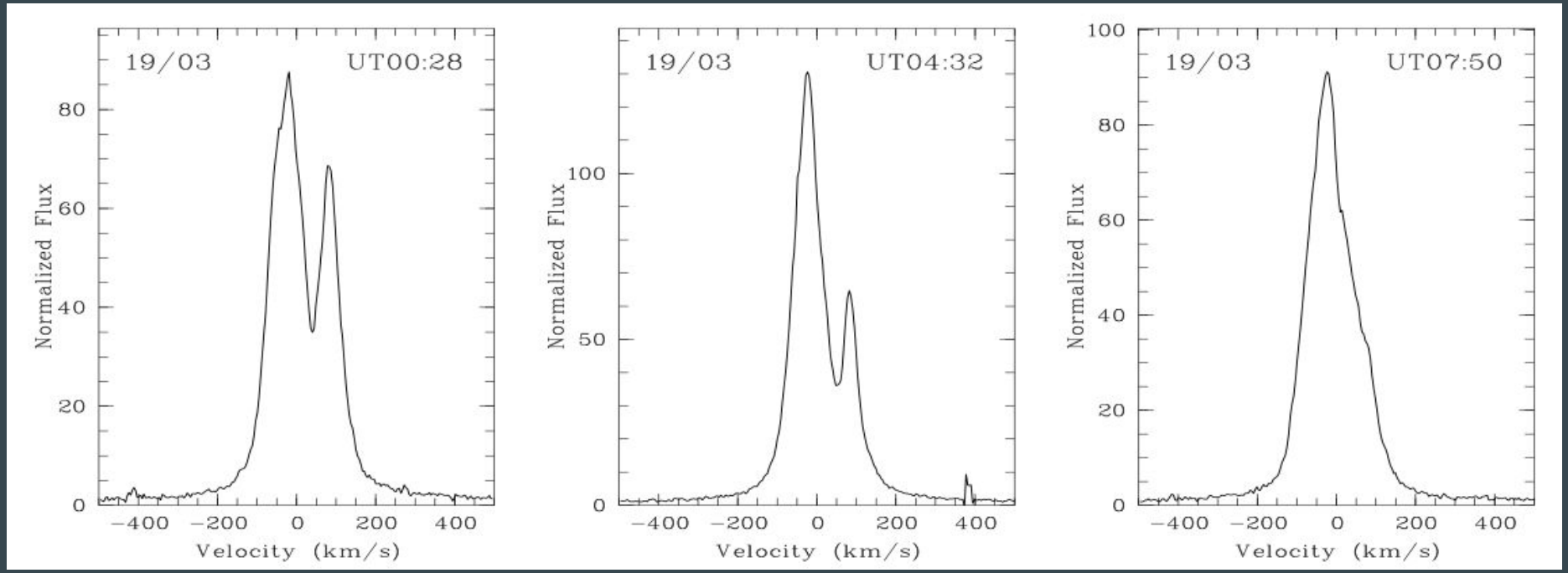
Romanova et al. 2004

AA Tau-like dippers among BDs



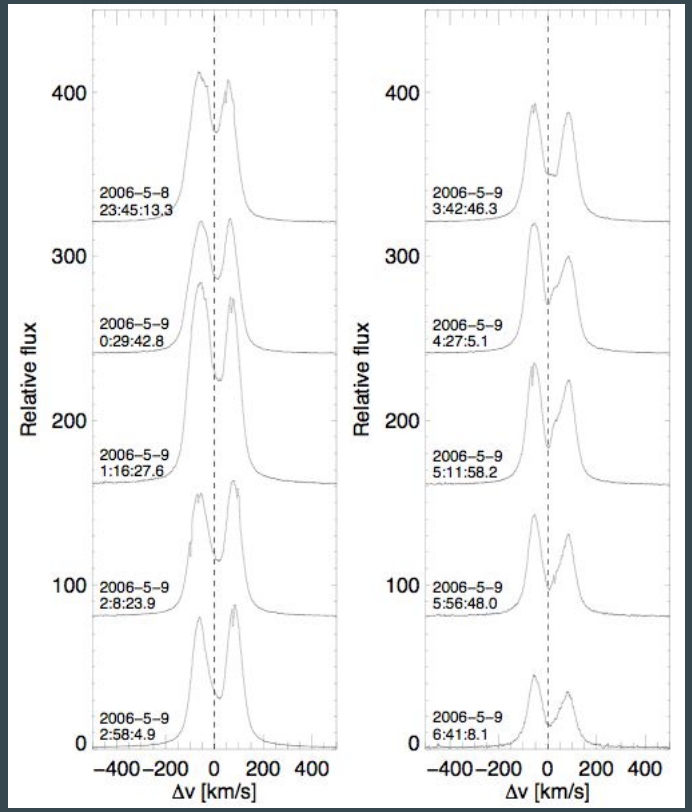


Spectroscopic variability in 2M1207

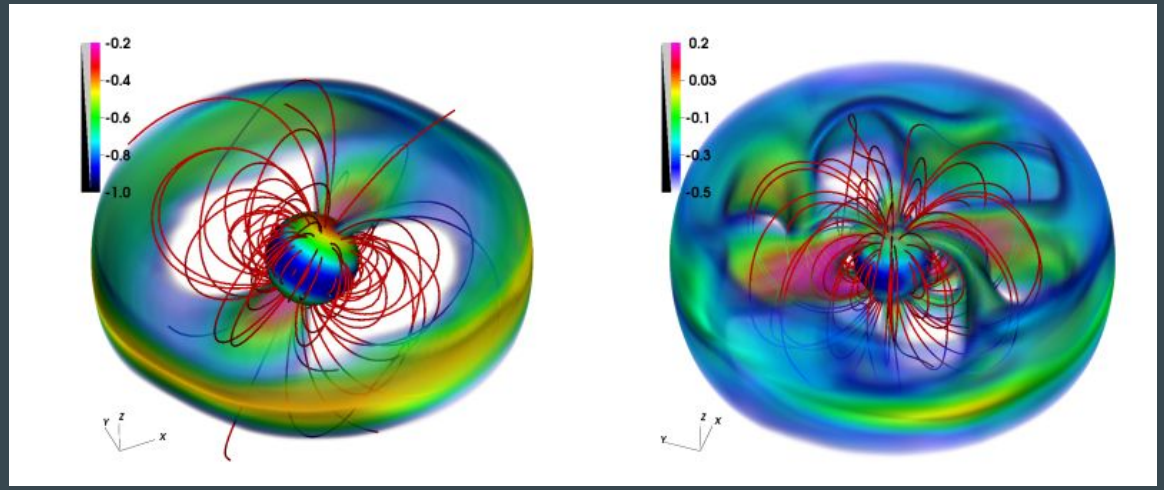


Scholz et al. 2005

2M1207: stable in 2005 vs. unstable in 2006

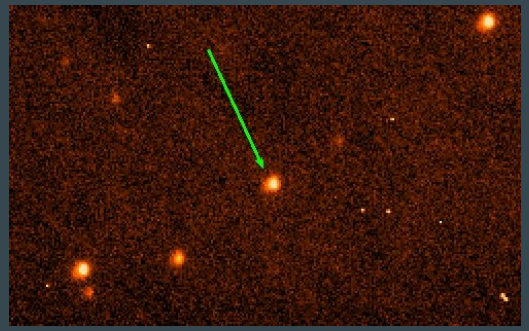


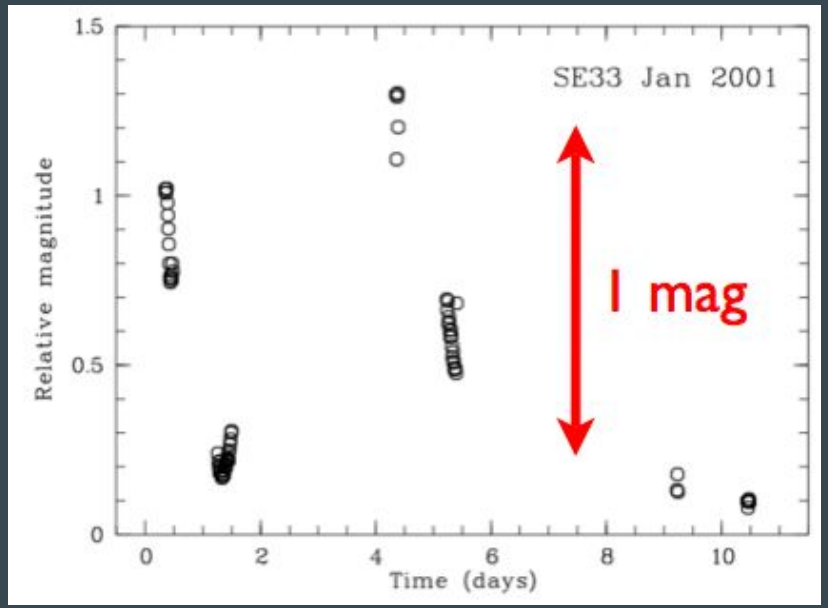
Stelzer et al. 2007



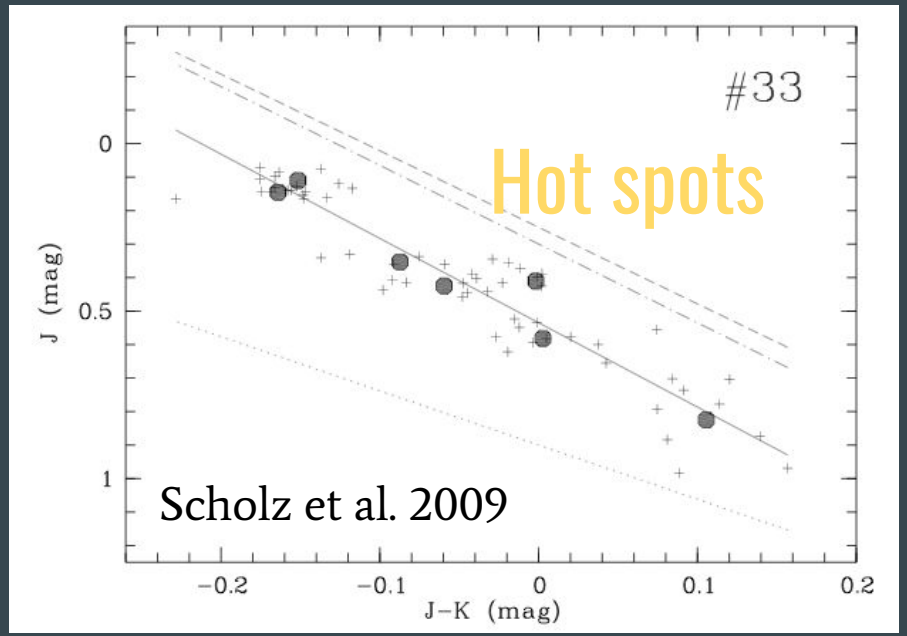
Kurosawa & Romanova 2013

V2737: unstable, face-on, like TW Hya?



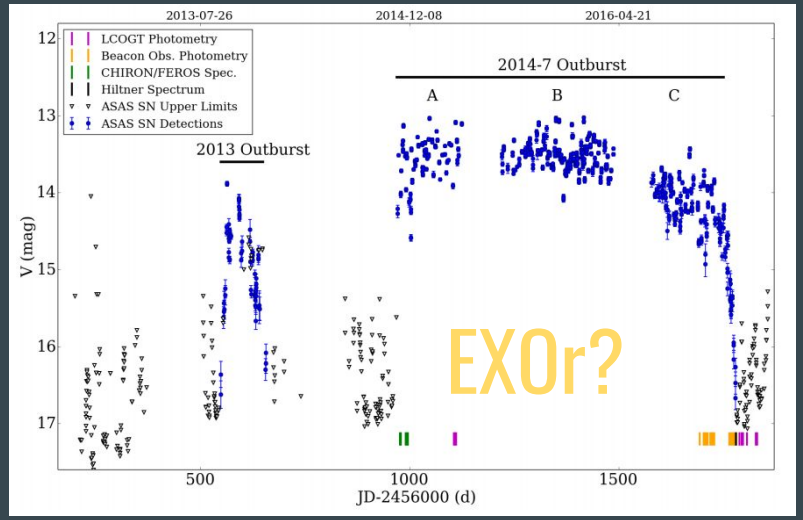


Scholz & Eislöffel 2004

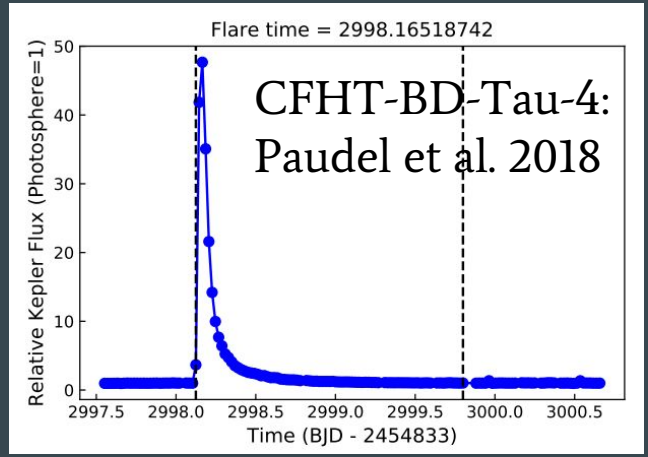


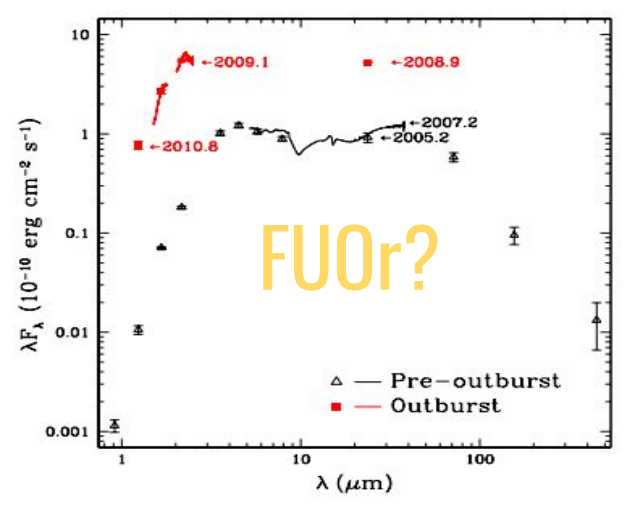
Scholz et al. 2009

Accretion bursts in VLM objects



Sicilia Aguilar et al. 2017



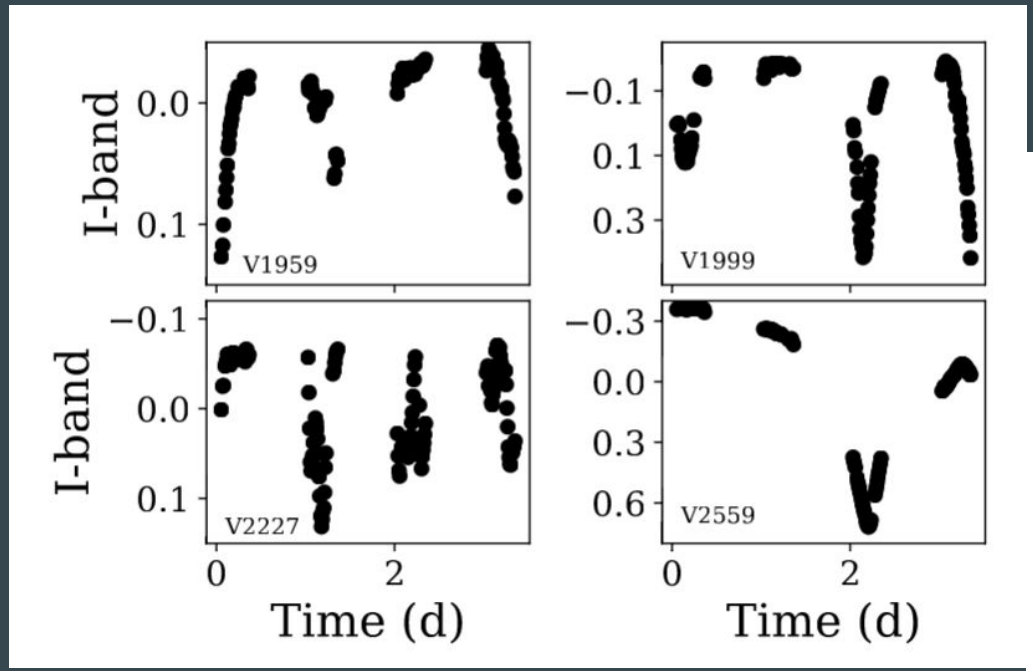


Caratti o Garatti et al. 2013

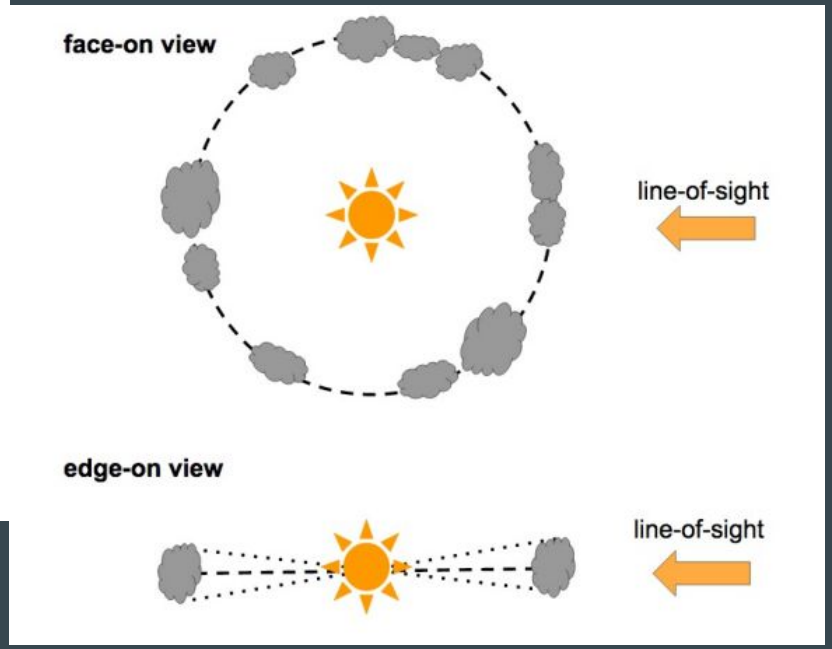
The same paradigm seems to work for low-mass stars and brown dwarfs.

Among M stars: Dippers without accretion

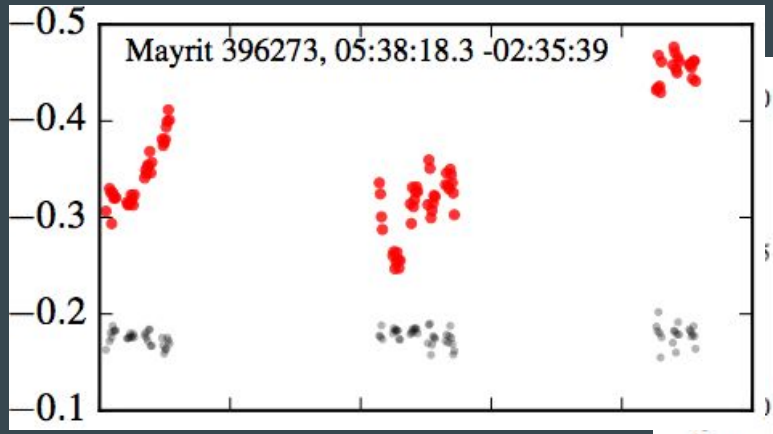
See also:
David 2017
Stauffer 2017, 2018
Zhan et al. today

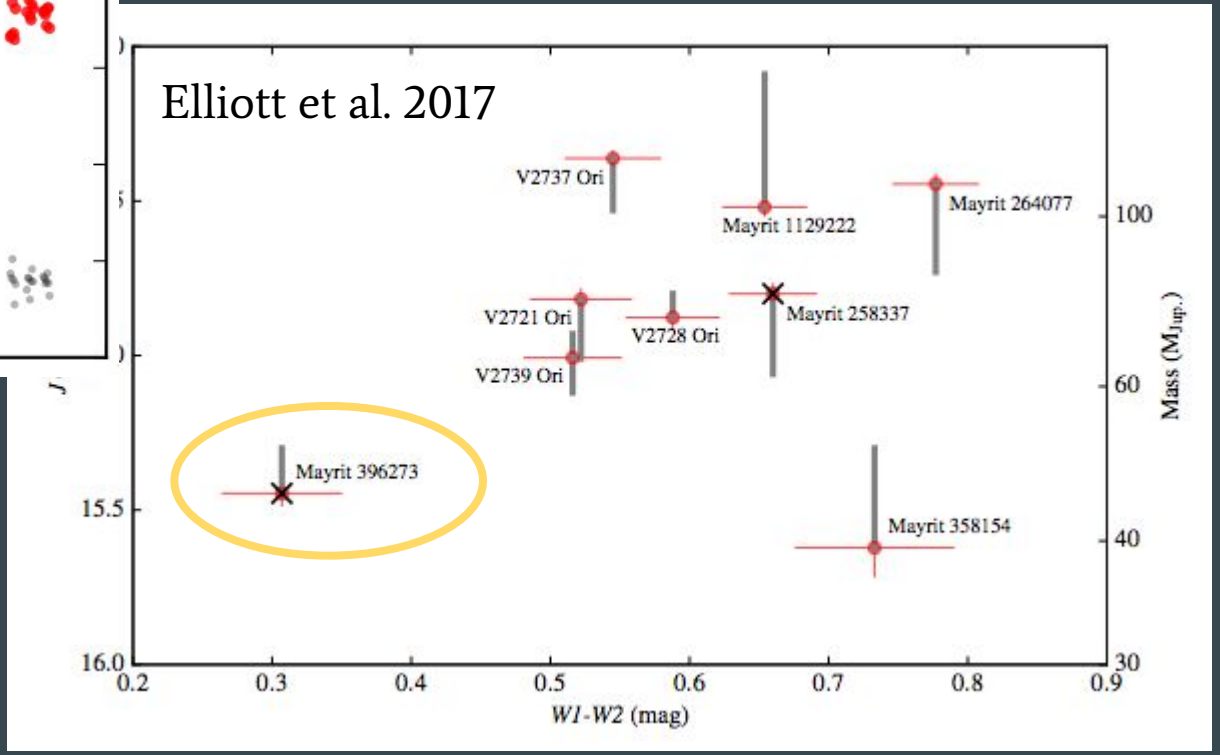


Scholz, Natta et al. 2019



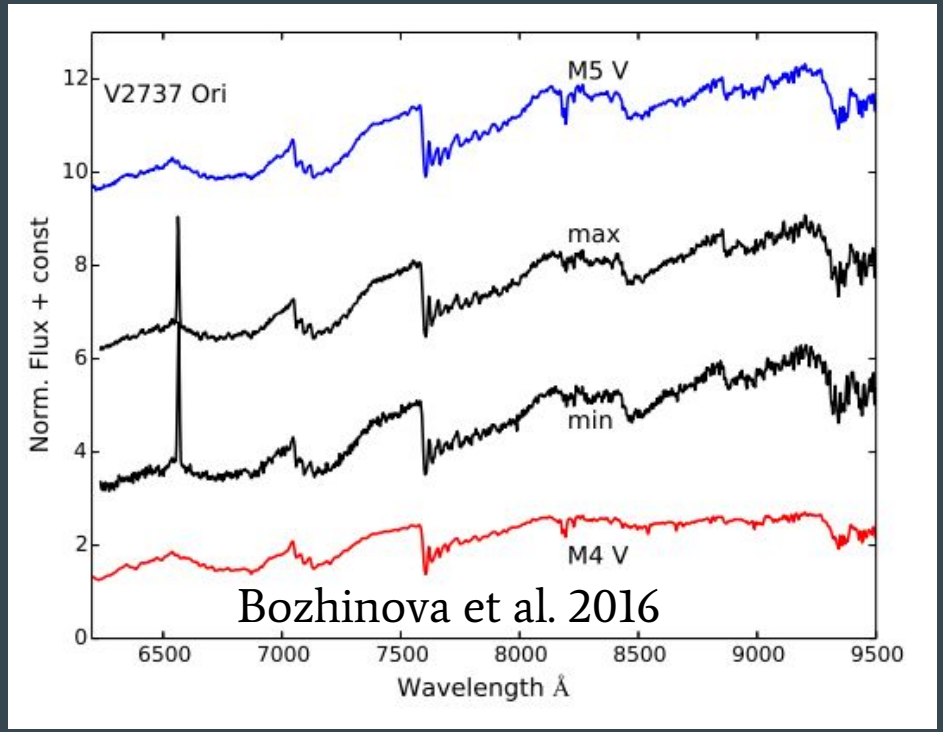
A sample of highly variable VLM objects in Sigma Ori





Strong aperiodic variability without disk

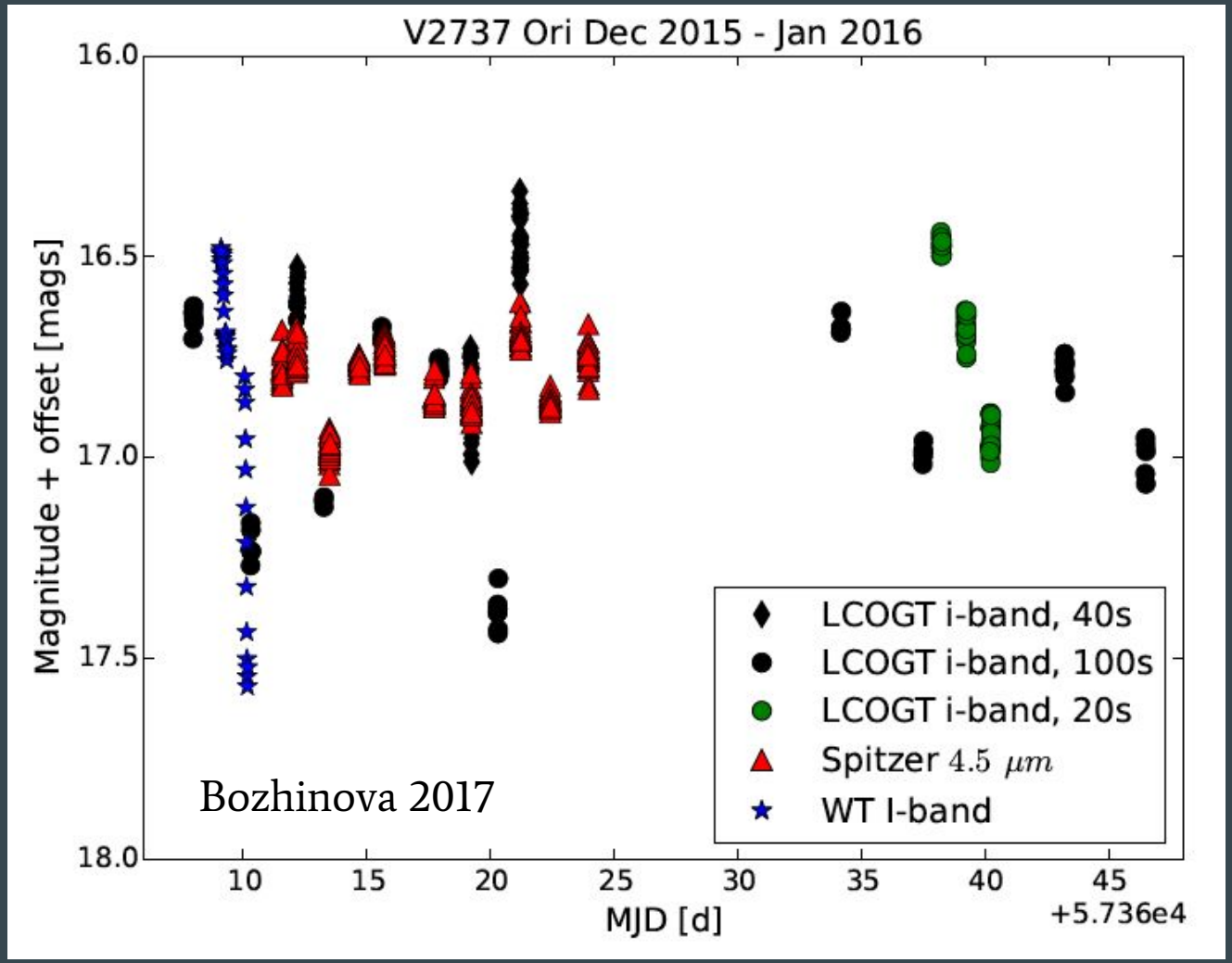
High variability without spectral changes



Bozhinova et al. 2016

Hot spots, but only a few 100K above photosphere?

Filling factor 20-40%?


V2737 Ori Dec 2015 - Jan 2016
Magnitude + offset [mags]
16.0
16.5
17.0
17.5
18.0
10
15
20
25
30
35
40
45
+5.736e4
MJD [d]
LCOGT i-band, 40s
LCOGT i-band, 100s
LCOGT i-band, 20s
Spitzer 4.5 μm
WT I-band
Bozhinova 2017

Variability tends to make things more complicated.

Still to be discovered

Accretion bursts

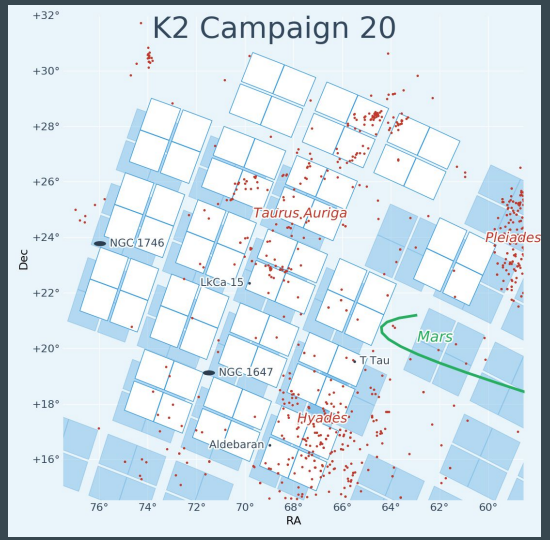
Long disk eclipses

Non-accretion dippers

Circumsecondary disks

Transiting exoplanets

Needed: deep, wide, multi-filter survey with fast cadence



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