Stellar magnetic activity cycles in X-rays: Results from Chandra, XMM, and Swift

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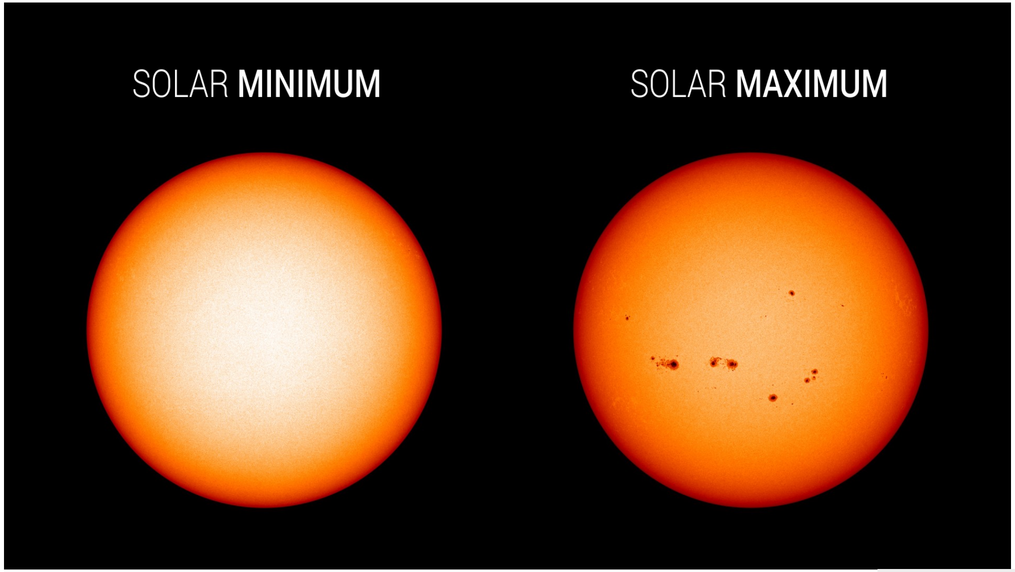
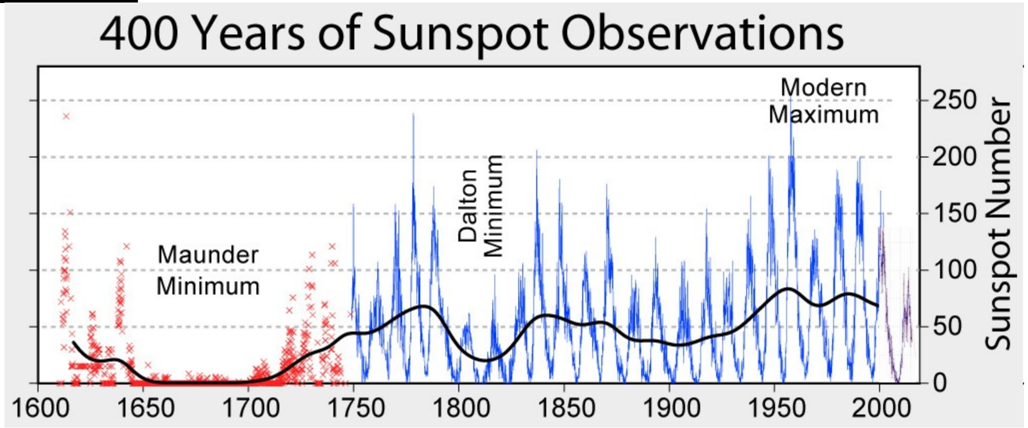
Solar Cycle

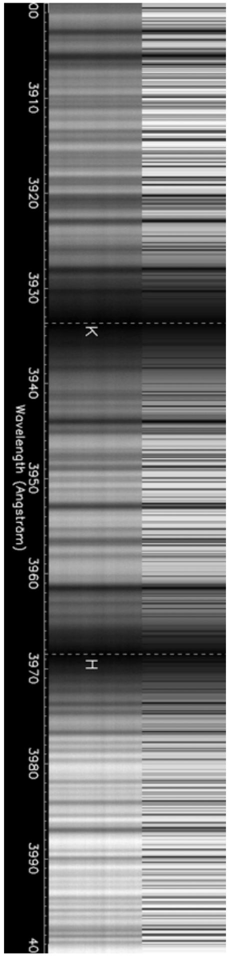


- 0.1% brightness variation.
- In other stars, photospheric brightness may or may not be in sync with magnetic cycle—depends on balance of dark sunspots and bright faculae, which depends on stellar type and activity level.

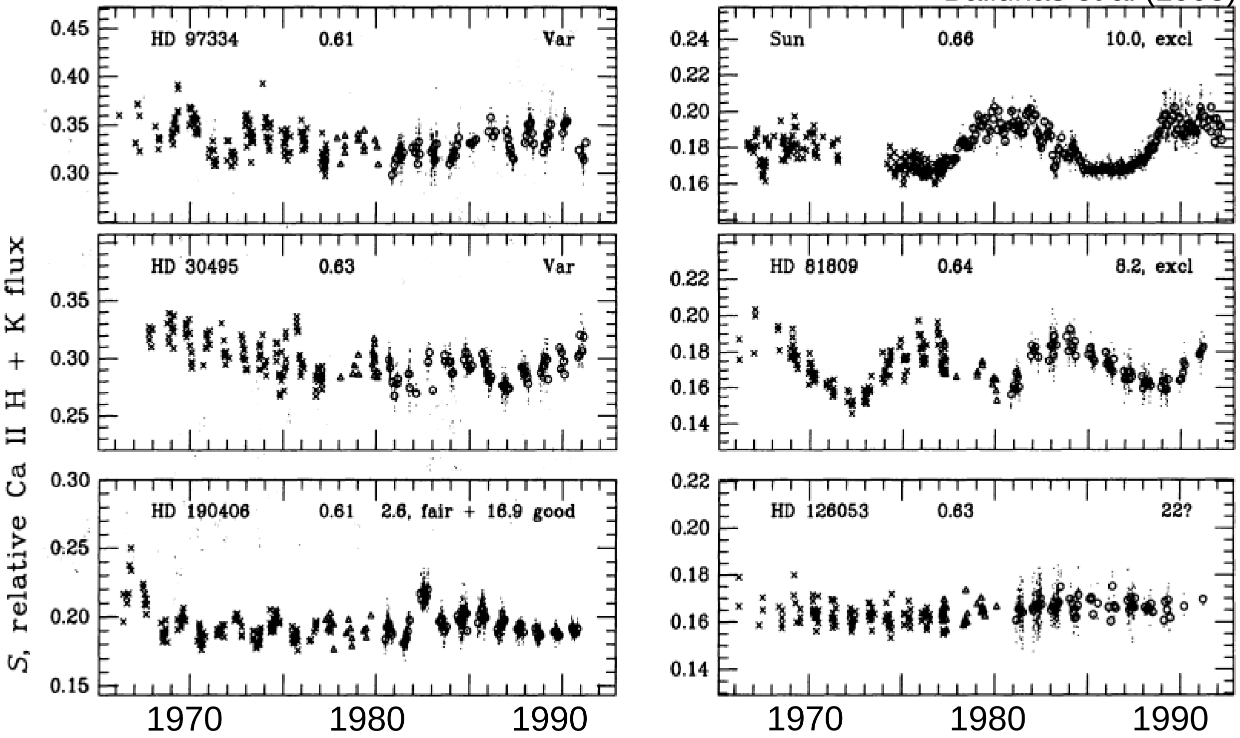


- Roughly 50 stars have been observed with photometric cycles.
- Typical amplitude ~1%.

Mt Wilson HK Project – chromospheric CaII H&K lines



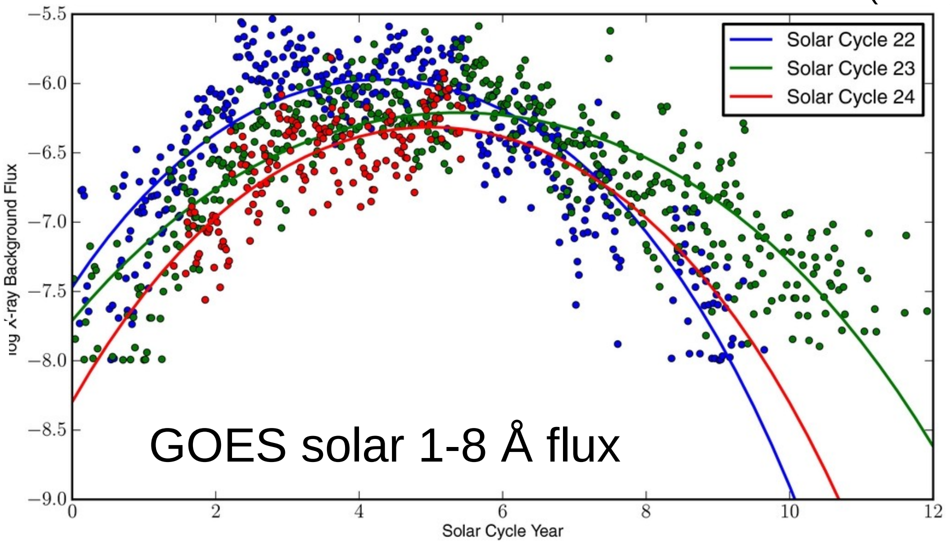
Baliunas et al (1995)



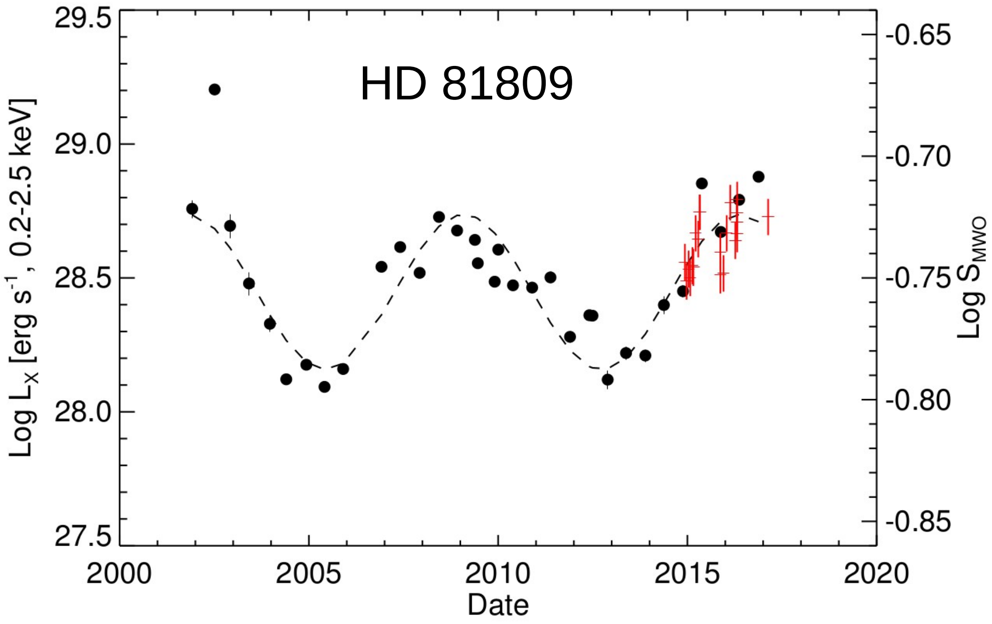
- 100 stars (later 300) monitored – roughly 40% had cycles.
- Only 1 M star included—M’s dim, hard to study.
- Typical amplitude ~10% (in phase with mag. cycle)

X-ray Cycles—Coronal Emission

Winter and Balasubramaniam (2014)



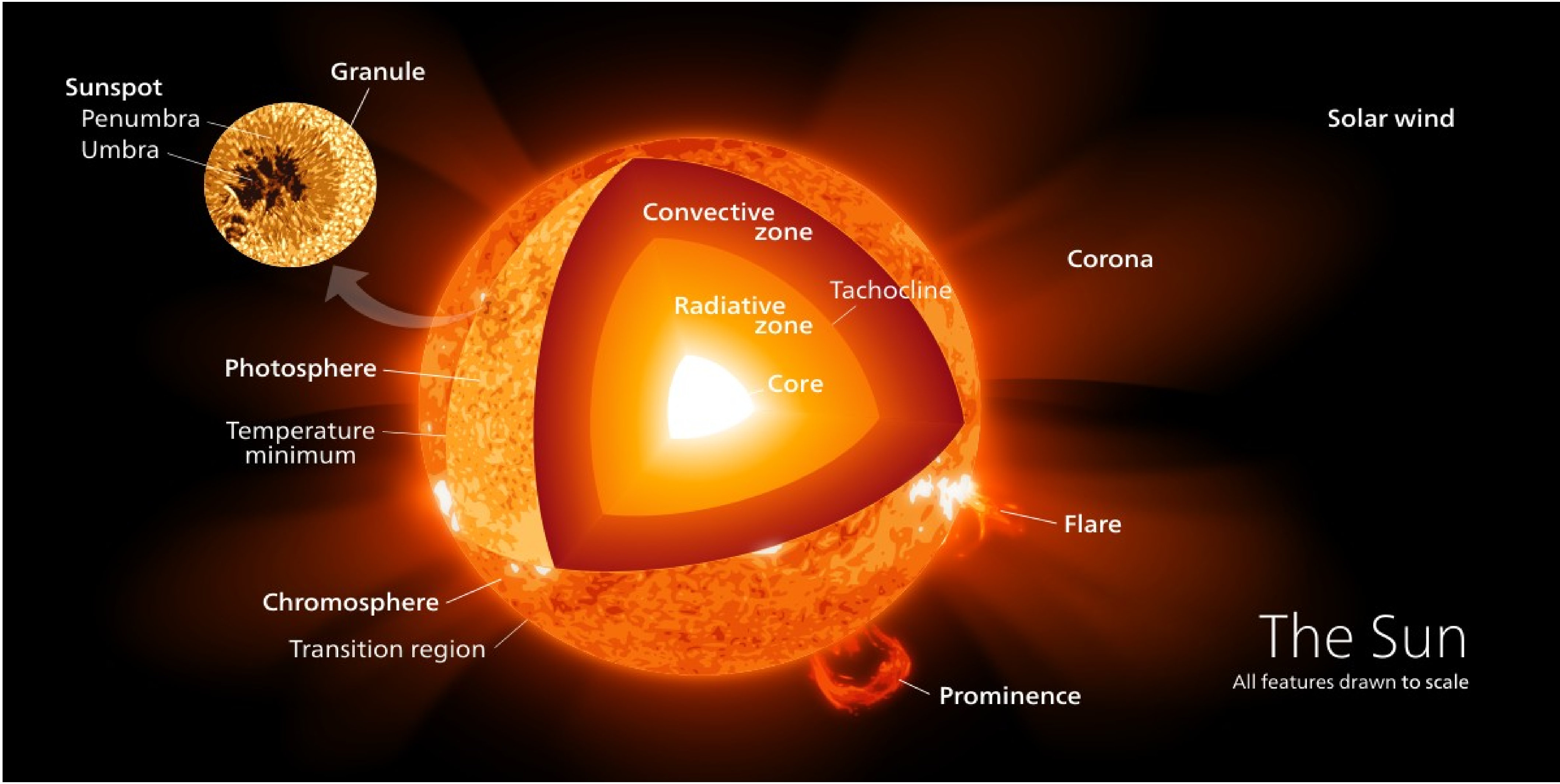
Orlando et al (2017)



- Amplitudes of factor of a few. (~100x for the Sun in harder GOES band.)
- In phase with magnetic cycle.
- Only ~10 stars measured.

Why does the magnetic field cycle?

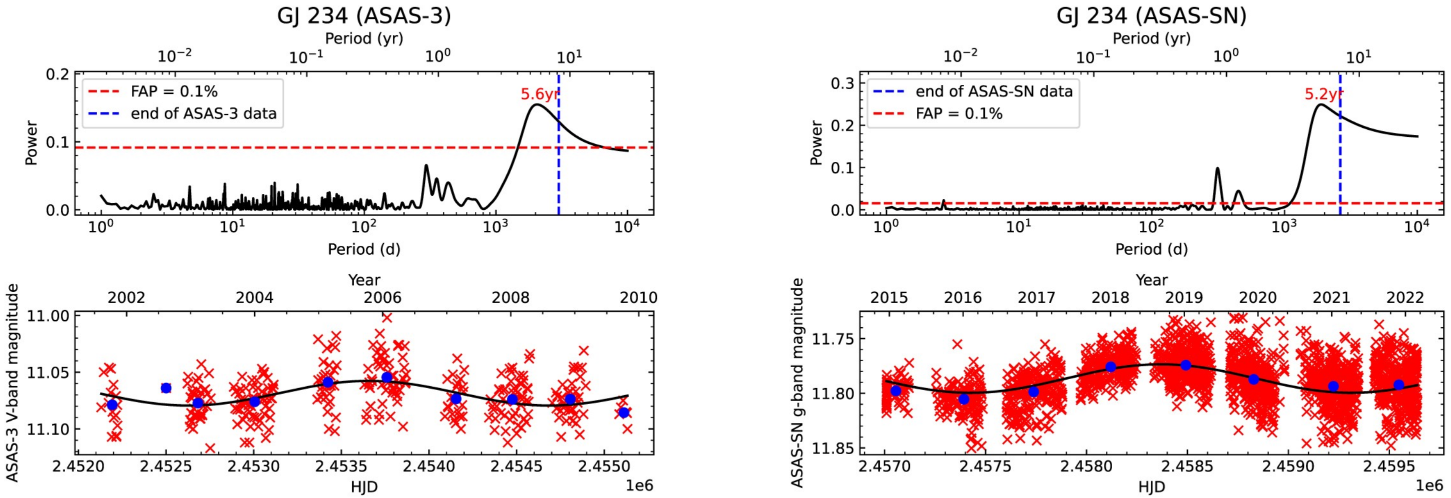
- $\alpha\Omega$ dynamo
- Driven by differential rotation and shear at tachocline (radiative/convective boundary)
- Magnetic power cycles between poloidal and toroidal fields. The Sun has an 11-yr sunspot (Schwabe) cycle and 22-yr (Hale) magnetic cycle.


Sunspot
Granule
Penumbra
Umbra
Solar wind
Convective zone
Corona
Tachocline
Radiative zone
Photosphere
Core
Temperature minimum
Flare
Chromosphere
Transition region
The Sun
All features drawn to scale
Prominence

Why does the magnetic field cycle?

- αΩ dynamo
- Driven by differential rotation and shear at tachocline (radiative/convective boundary)
- Magnetic power cycles between poloidal and toroidal fields. The Sun has an 11-yr sunspot (Schwabe) cycle and 22-yr (Hale) magnetic cycle.
- M3.5-F5 stars have tachoclines; smaller stars are fully convective, don't have αΩ dynamos (presumed αα turbulent dynamos instead), and therefore can't(?) cycle. **But some do!**

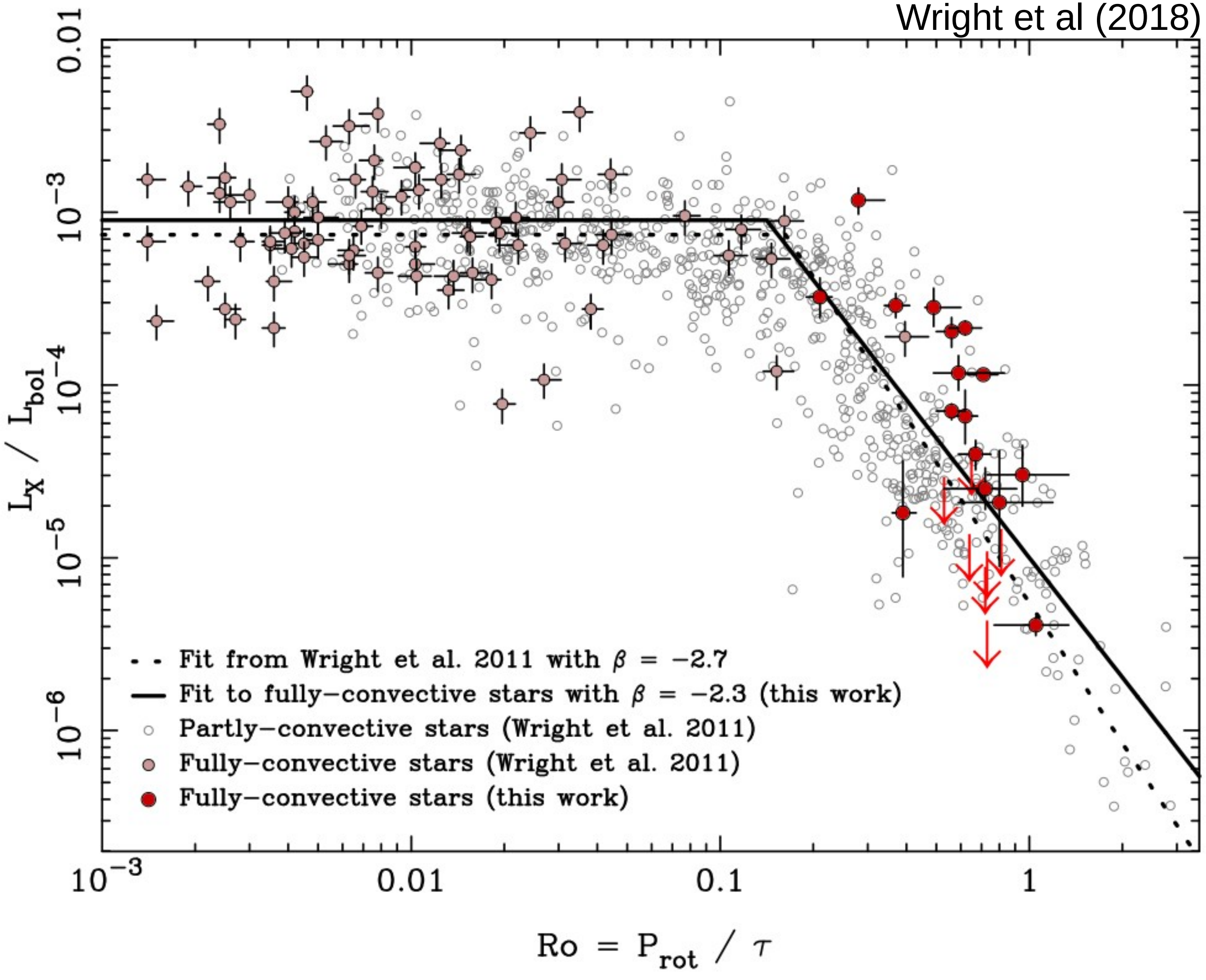
Cycles in fully convective stars



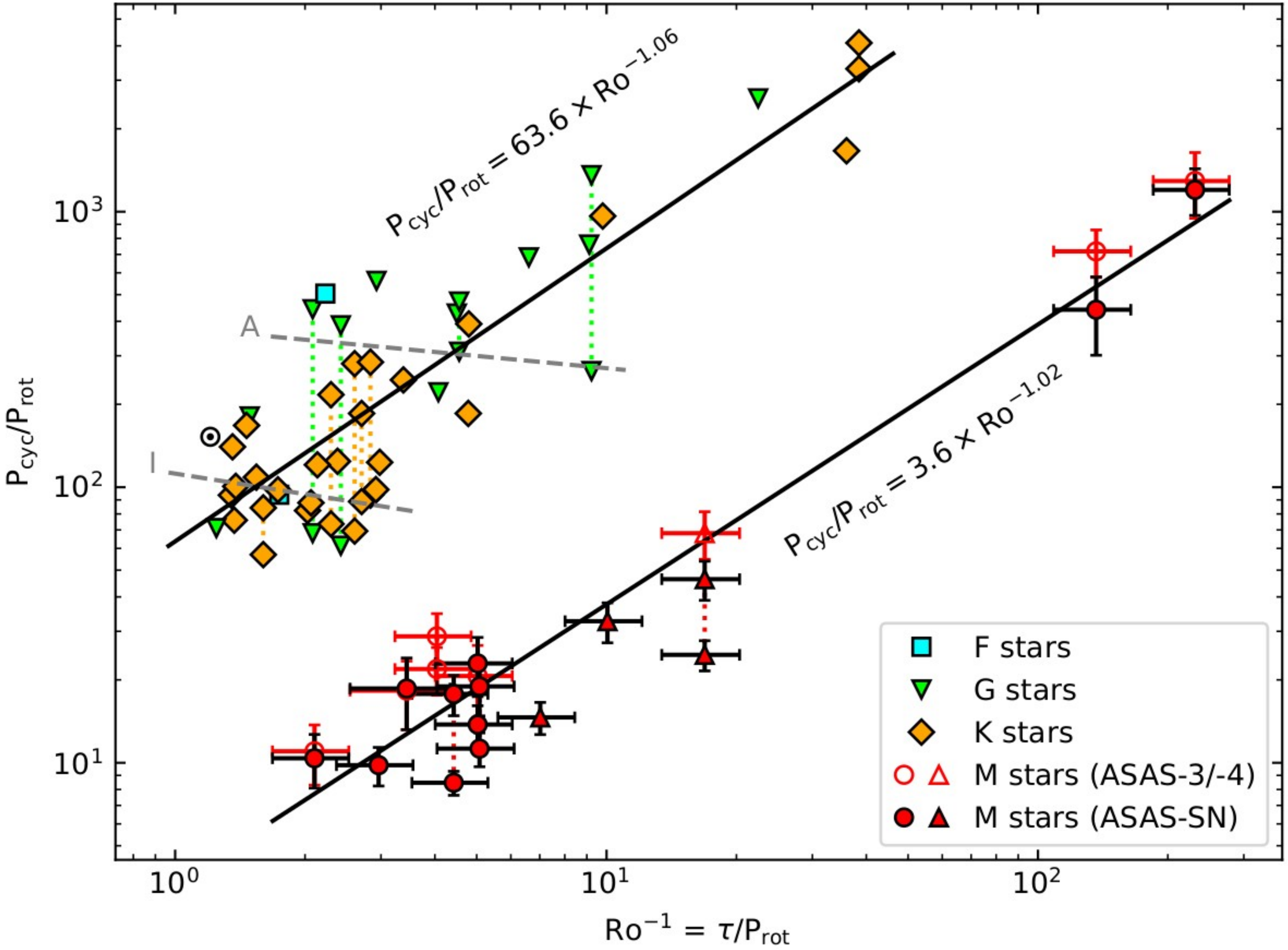
- All Sky Automated Survey (ASAS; Pojmanski 1997) -- 2000 to 2010+
- ASAS for SuperNovae (ASAS-SN; Shappee et al 2014) – 2014-present
- Suarez-Mascareno et al. (2016) found cycles in ~50 stars from ASAS data, including about a dozen fully convective
- Those dozen confirmed by Irving et al. (2023), adding ASAS-SN data

No apparent change in X-ray behavior between partial and fully convective

Wright et al (2018)



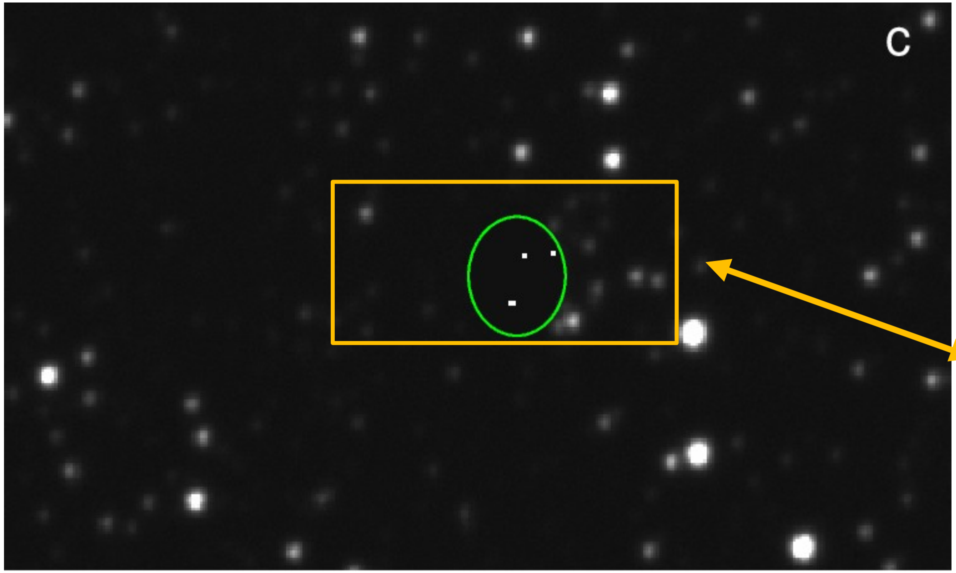
On the other hand….



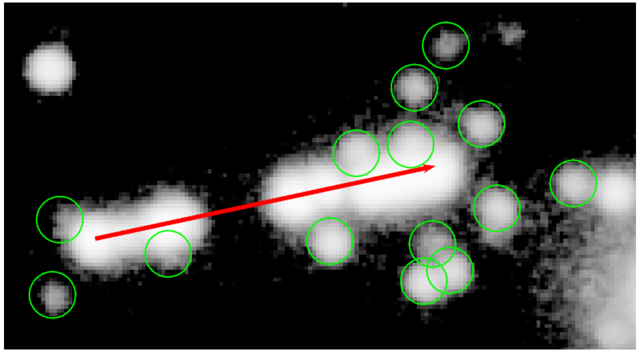
Proxima Centauri (M5.5)

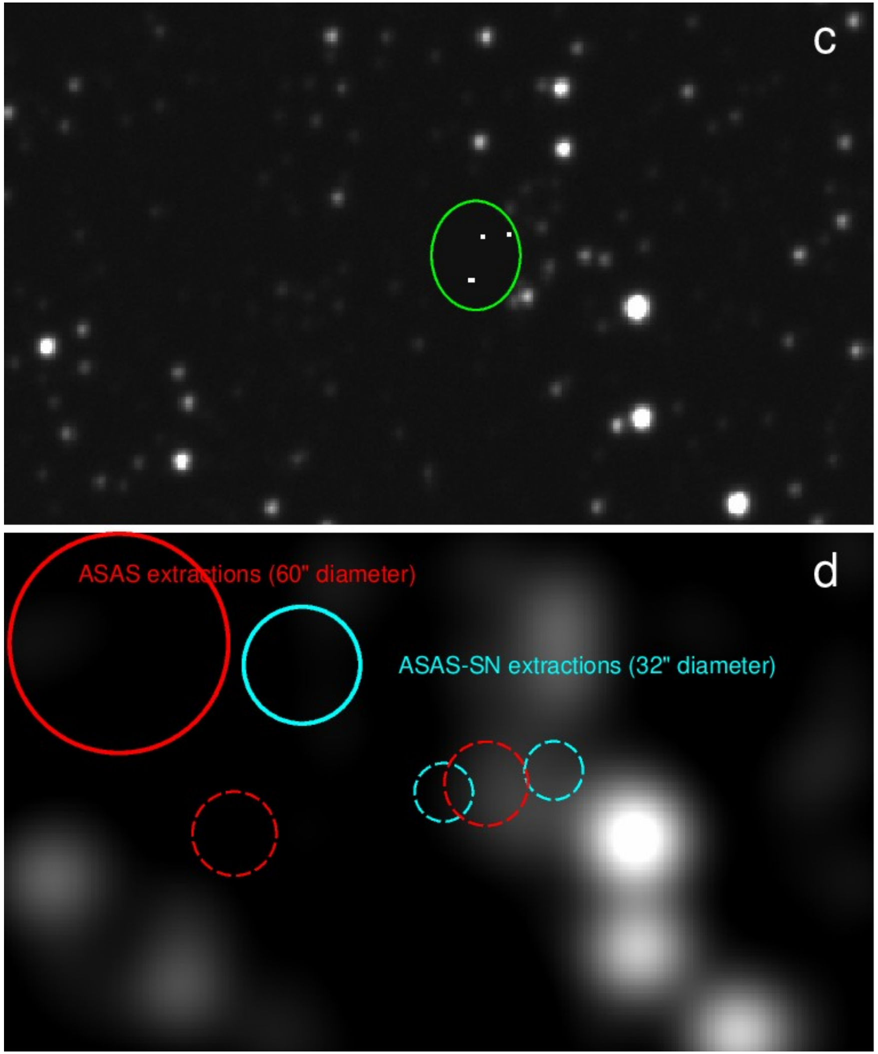
- One of the dozen M stars with cycles
- Best example (longest photometry monitoring, plus X-ray/UV)
- Only 2 deg off Galactic Plane and high proper motion—moving through crowded field
- ASAS and ASAS-SN spatial resolution is (intentionally) poor—23” and 16” FWHM
- Flares a LOT—harder to measure “baseline” X-ray and UV emission

Optical SkyMapper g-band

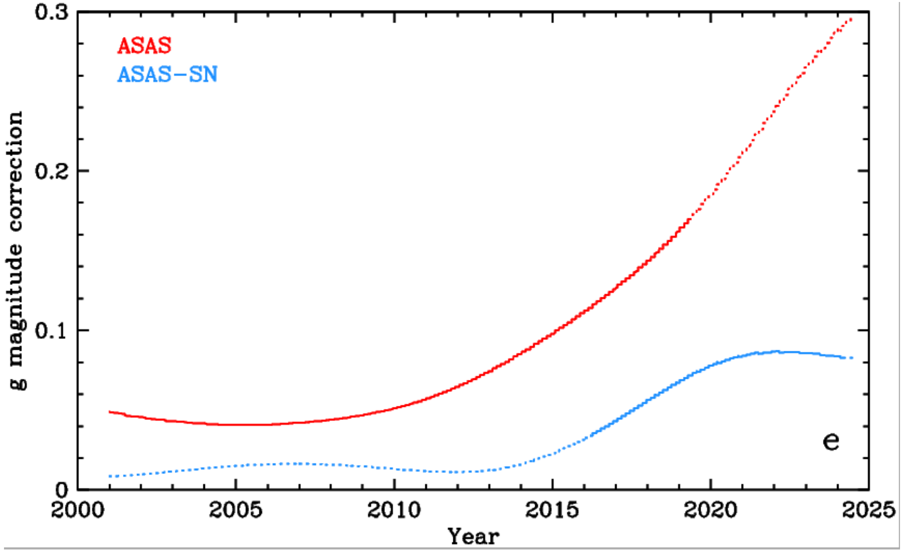


Swift UVOT/W1 (~2800 Å). PSF 2.5” FWHM

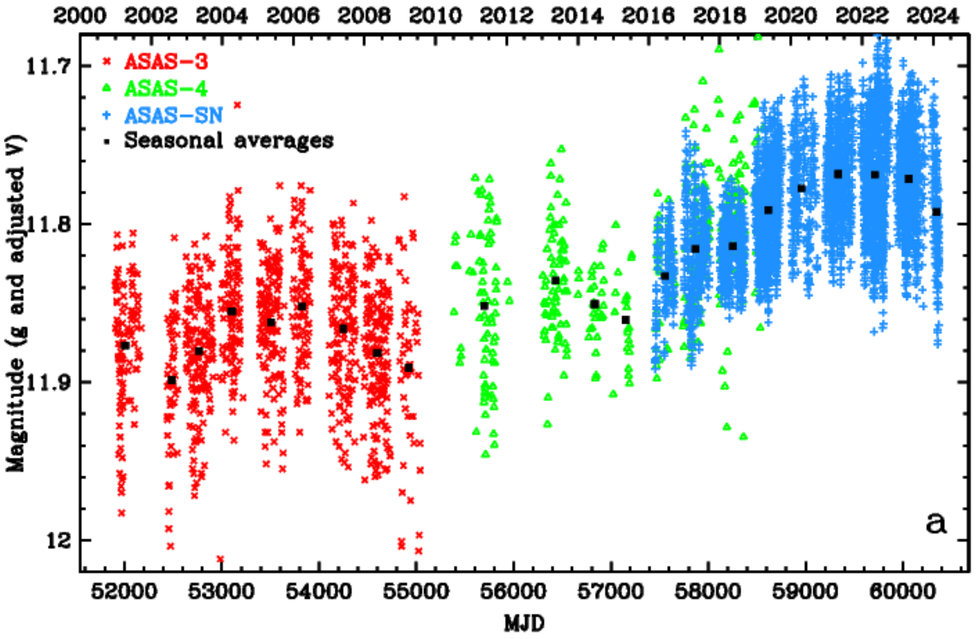




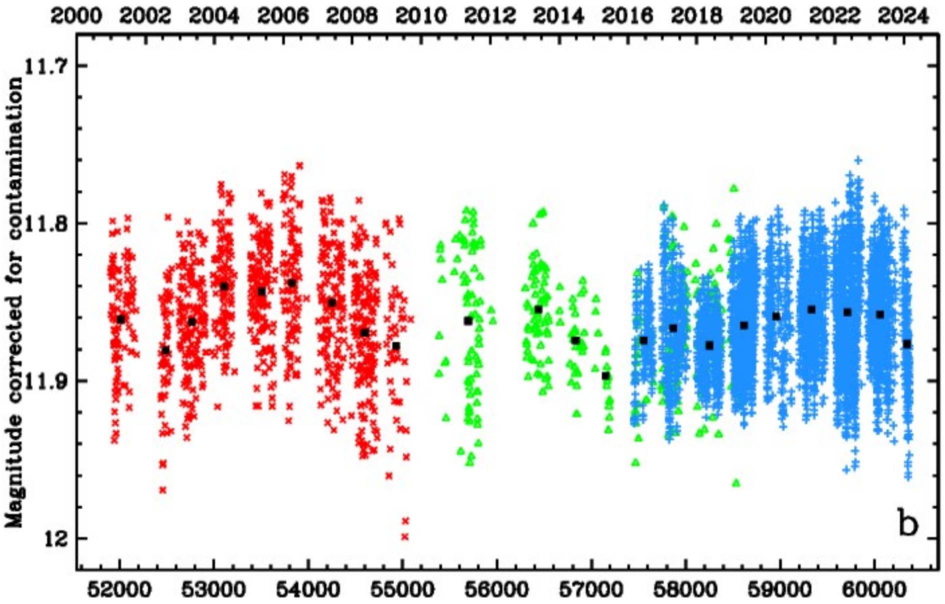
- Convolve high-res image with ASAS(-SN) PSF.
- Determine contamination of Proxima extractions as it moves through the field.



Uncorrected ASAS(-SN) data



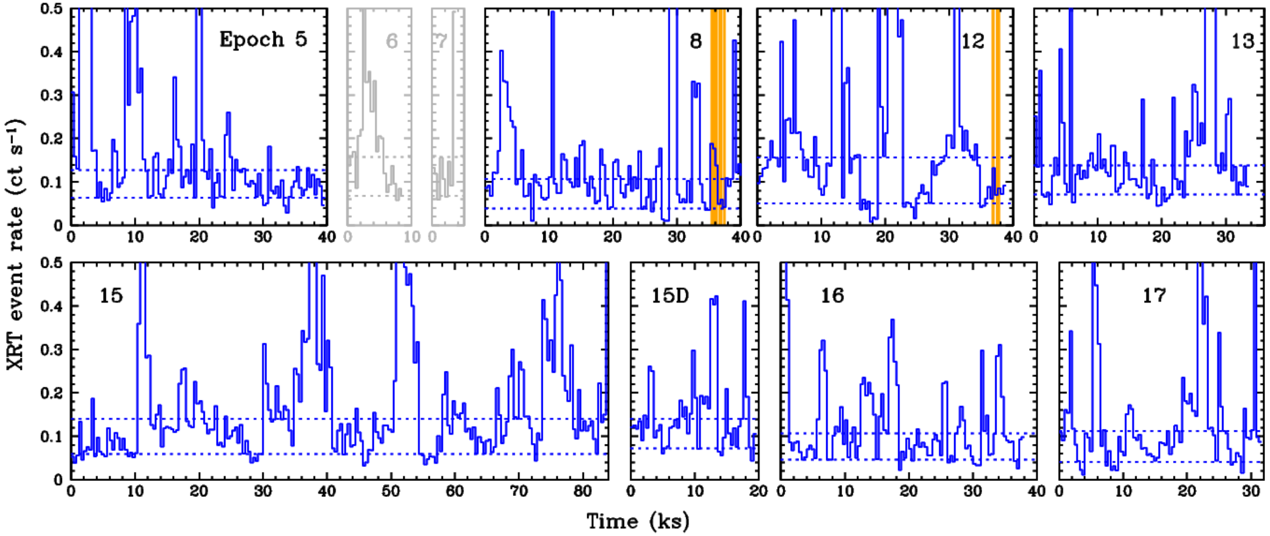
Decontaminated



So much flaring!

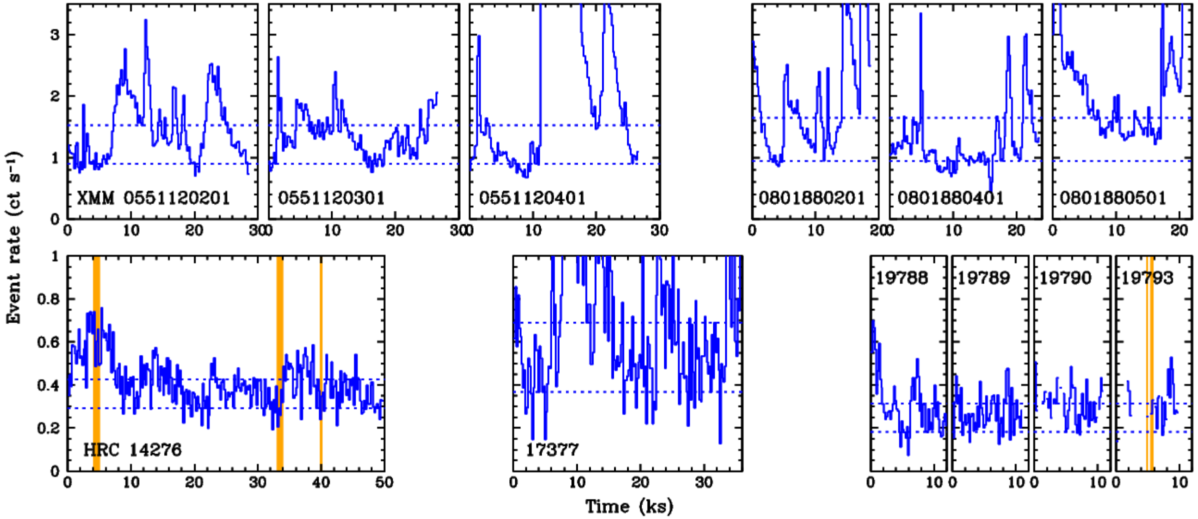
Swift 2009-2021. Short snapshots provide nearly random sampling.

(Orange vertical bars = simultaneous Swift/HRC, allowing cross calibration)

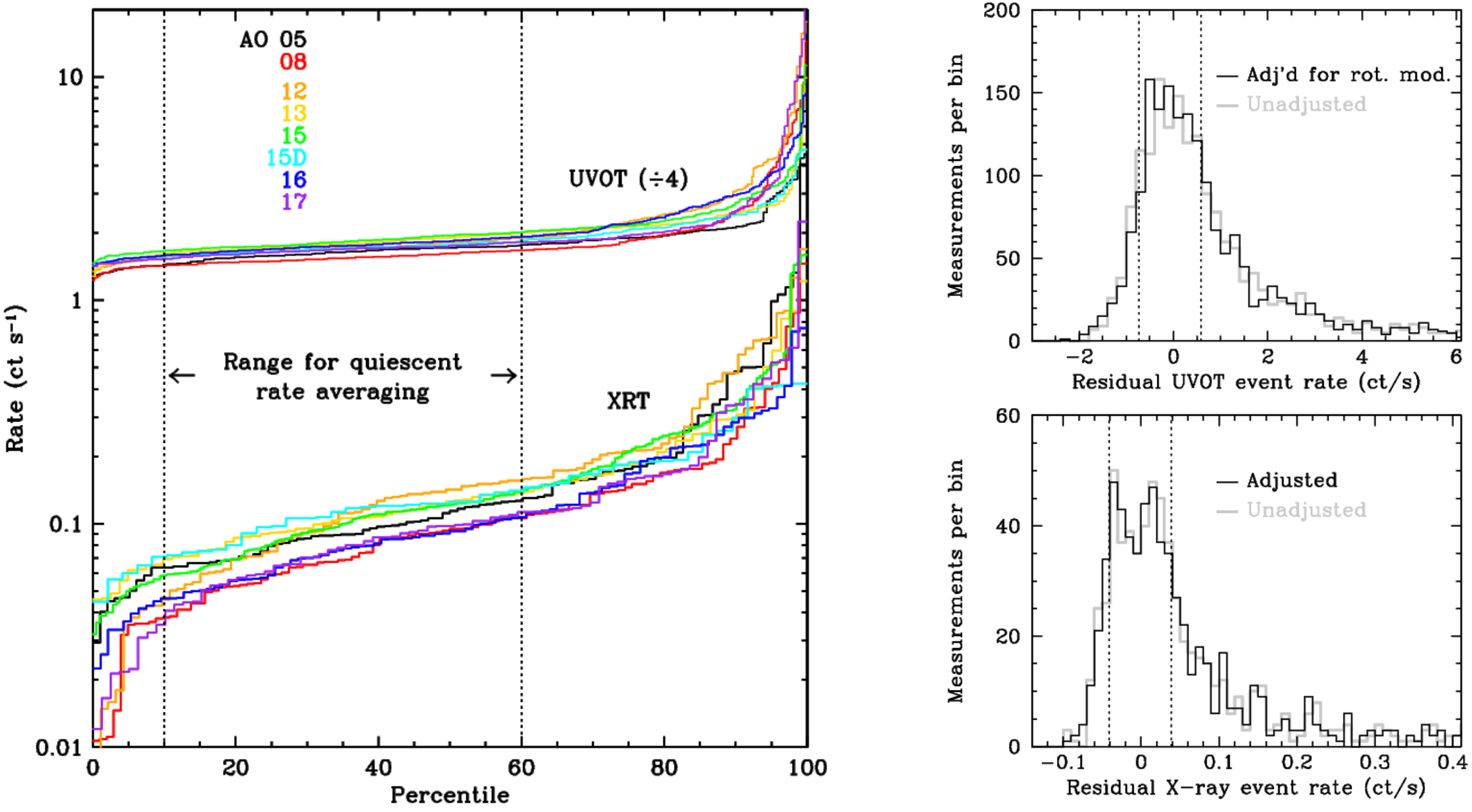


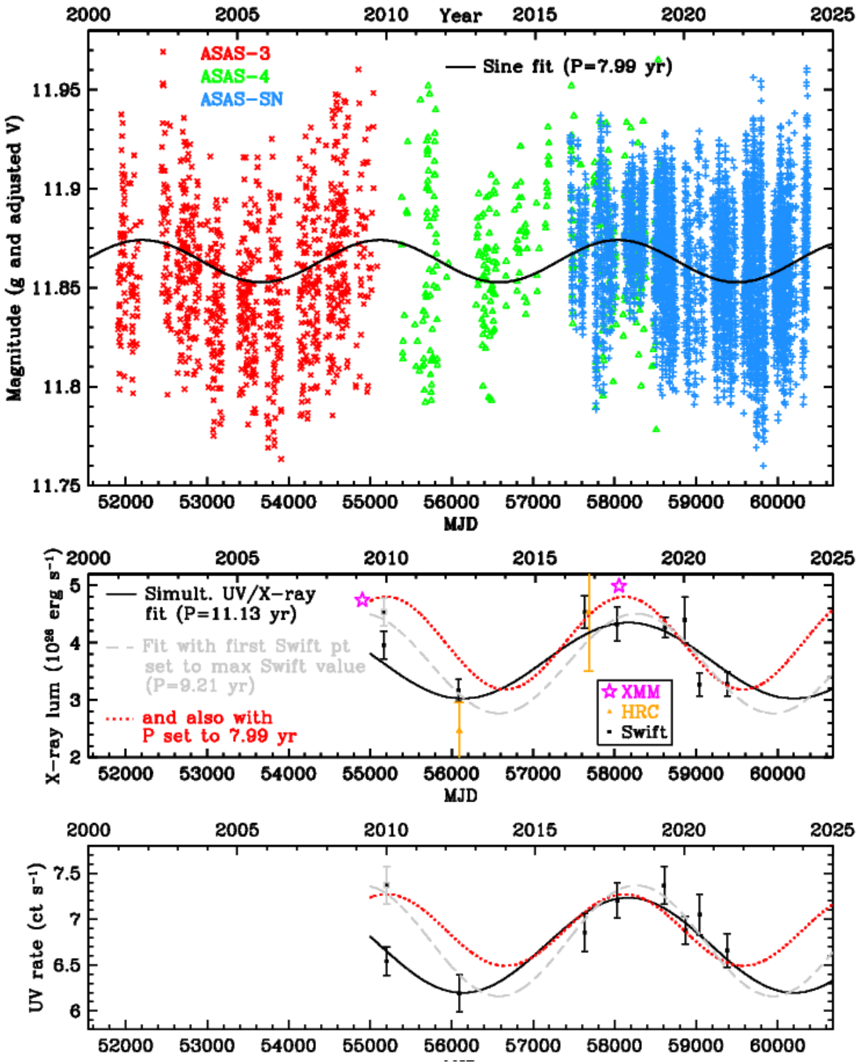
XMM 2009, 2017/18

HRC-I 2012, 2015, 2016



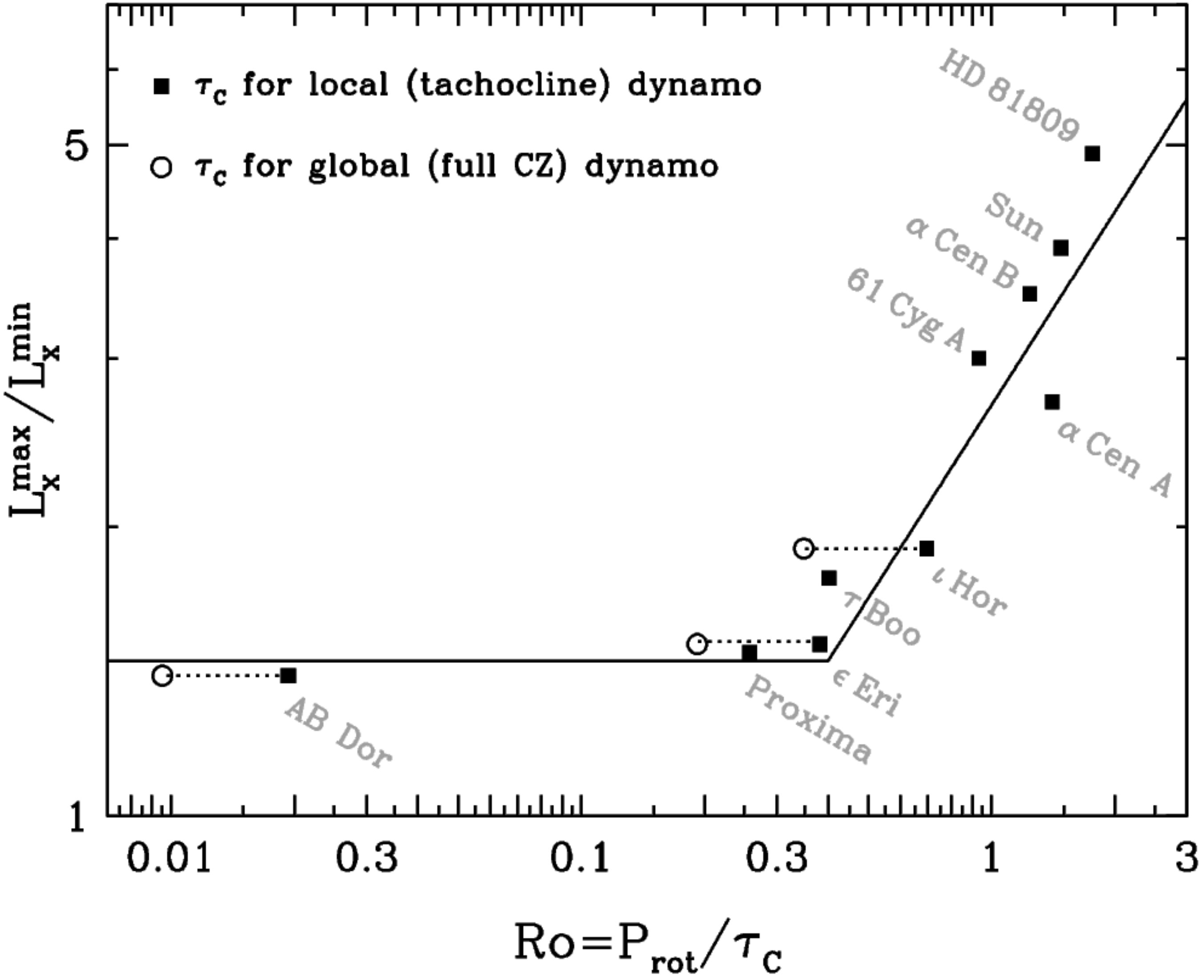
Swift XRT and UVOT rate distributions





- Optical: 8.0 yr, 2% max-to-min ampl
- UV: ~15% ampl
- X-ray: factor of ~1.5 ampl
- UV/X-ray periods 9-11 yr depending on how the first measurement is treated. (Weak first cycle?)

Only a few X-ray cycles measured but there is a correlation between amplitude and Ro.



4 or 5 years
of Chandra
and XMM
observations
of 3 low-Ro
stars ready
to analyze