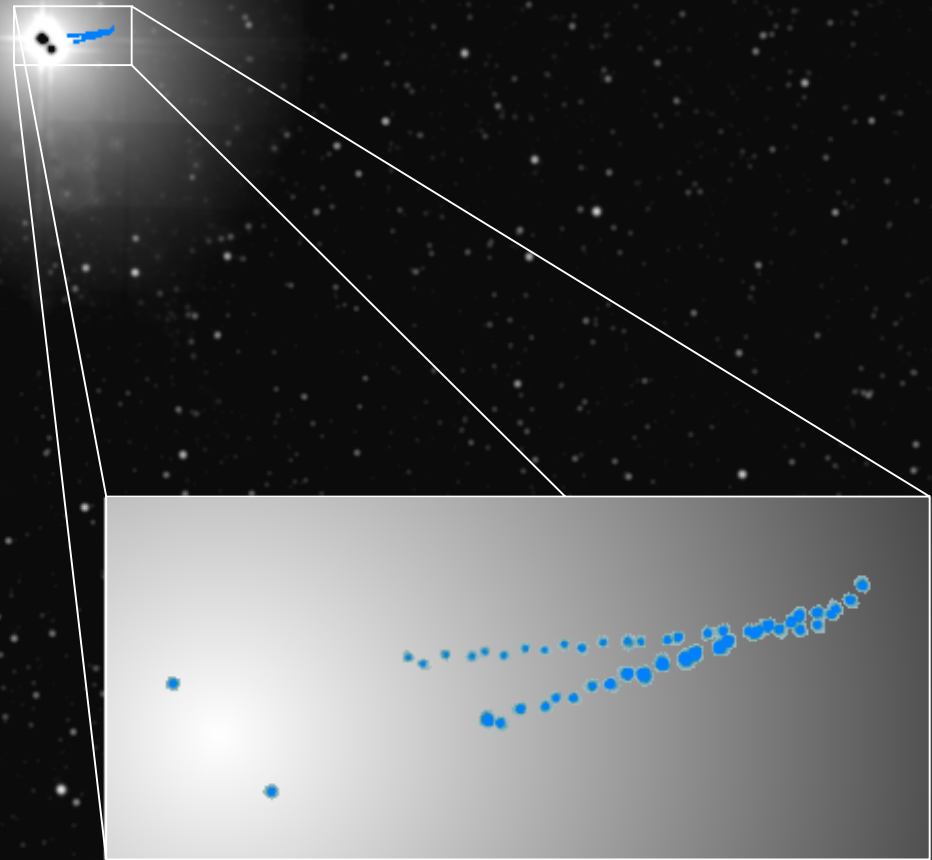


Curious Coronal Conundrum of Procyon: Lessons for IRIS?



Tom Ayres (CASA)

Contributed Talk

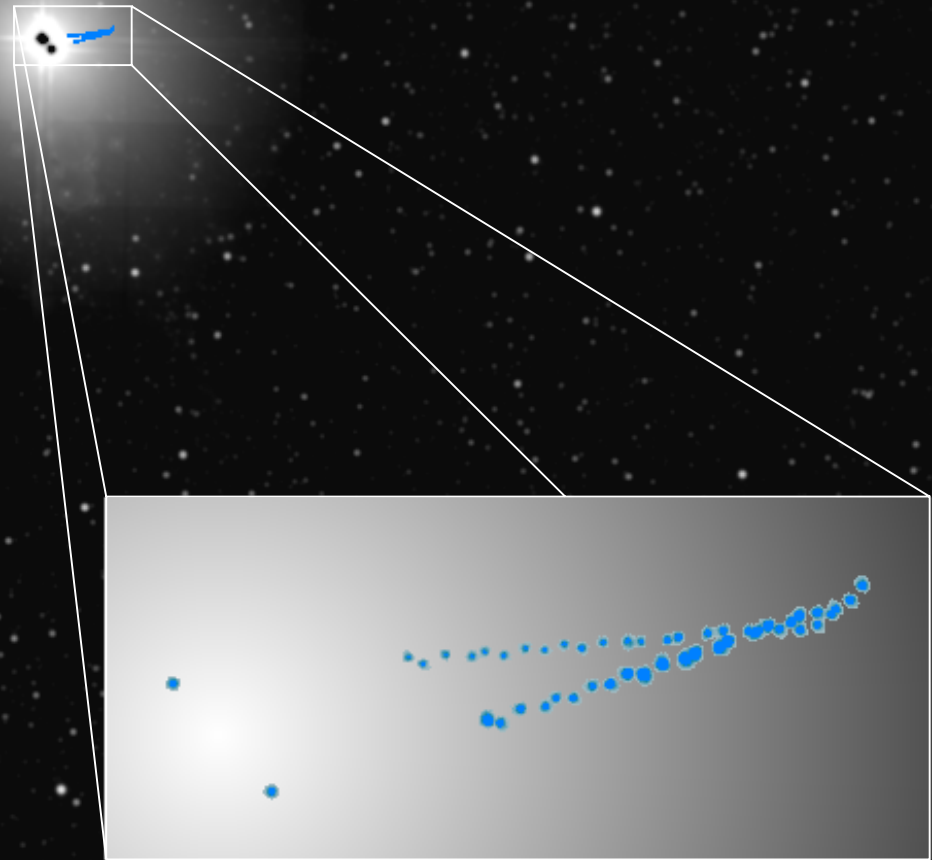
1. Fundamental physical processes and modeling

The Curious Conundrum of the Corona of the Mid-F Subgiant Procyon: a Lesson for IRIS?

T. Ayres

Procyon (α Canis Minoris: F5 IV-V) is a nearby late-type subgiant (only 3.5 pc away) that is similar to the Sun in some respects, but different in others (especially its more advanced evolutionary status, although the rotation periods are similar). Studies with the initial generation UV spectrograph on *Hubble Space Telescope* ("GHRs") suggested that the otherwise solar-intensity "transition zone" emissions of Procyon, such as Si IV 1393 Å and C IV 1548 Å seemed to lack the bimodal lineshapes seen in more closely solar-like α Centauri A (G2 V) and B (K1 V), and the Sun itself; displaying instead a more purely Gaussian character. At the same time, X-ray pointings by the Chandra Observatory have shown that the F subgiant has had a nearly constant coronal X-ray brightness over the past decade, perhaps something like a Maunder Minimum, except that the contemporary X-ray-to-bolometric luminosity levels of Procyon are comparable to the Sun at *Solar Maximum*. This creates a curious conundrum in the sense that the Maunder Sun's corona, and transition zone, should have been dominated – in the absence of active regions – by the supergranulation network, but this is exactly where on the Sun the bimodal TZ emission lines are thought to arise. However, the earlier UV assessment of Procyon was based on lower resolution and lower S/N FUV spectra than have become available recently, thanks to *Hubble's* later generation Space Telescope Imaging Spectrograph (STIS). The surprising results of a new analysis of the STIS FUV spectra, of relevance to *IRIS* observations of the same spectral features on the Sun, will be presented.

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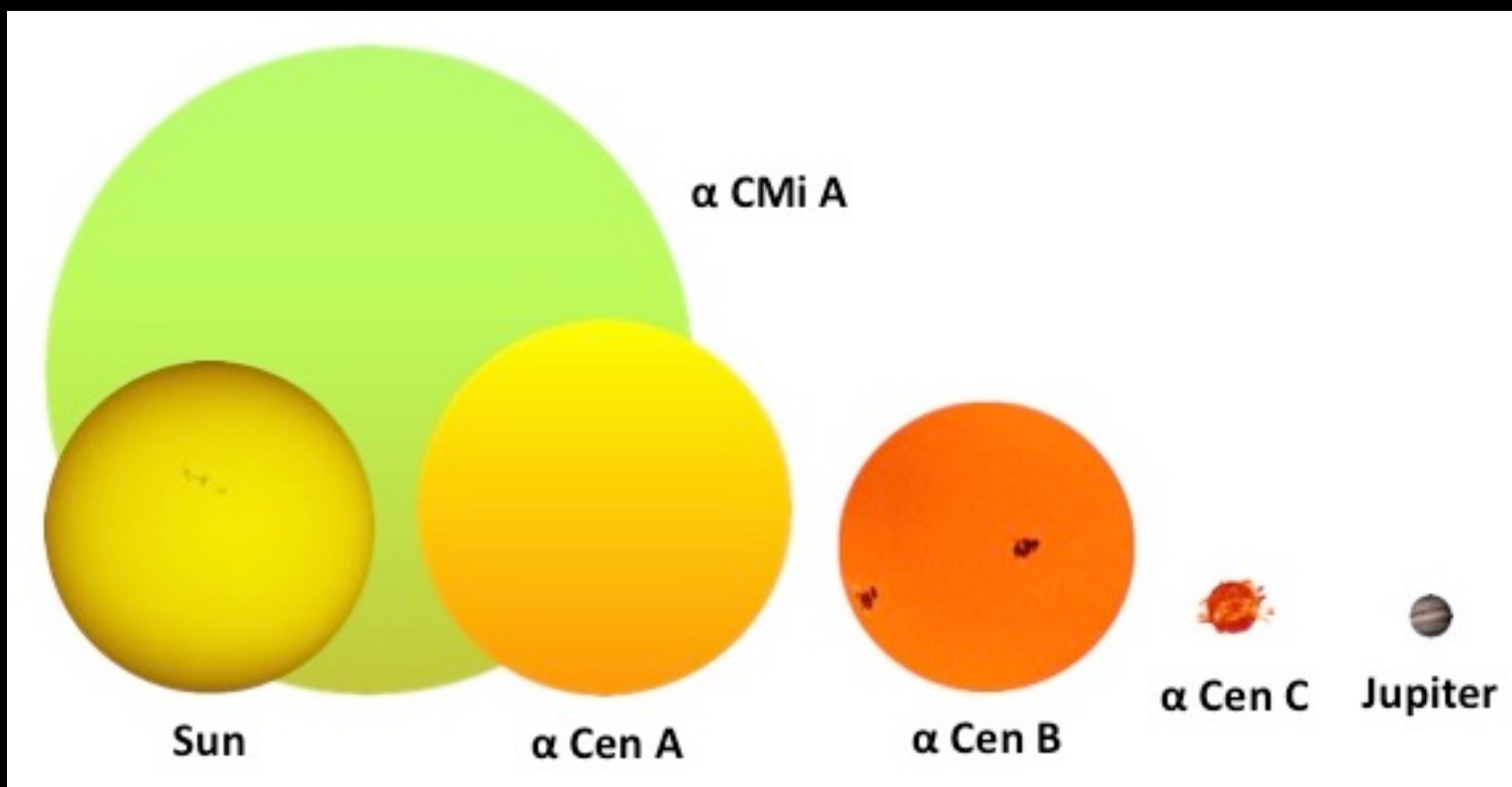
- F subgiant Procyon *next Sun-like star* beyond Alpha Centauri AB (also solar proxies)
- X-rays best gauge of coronal activity– Procyon: *flat activity, high, but “X-ray deficient;”* α Cen AB: *Sun-like cycling*
- FUV hot-line profiles-- Procyon: *broad comp dominated; α Cen AB: split broad/narrow*

P
R
O
C
Y
O
N

$Z/Z_{\odot} \sim 1$
 $P_{\text{rot}} \sim 23 \text{ d}$
 Age $\sim 2 \text{ Gyr}$

A
L
P
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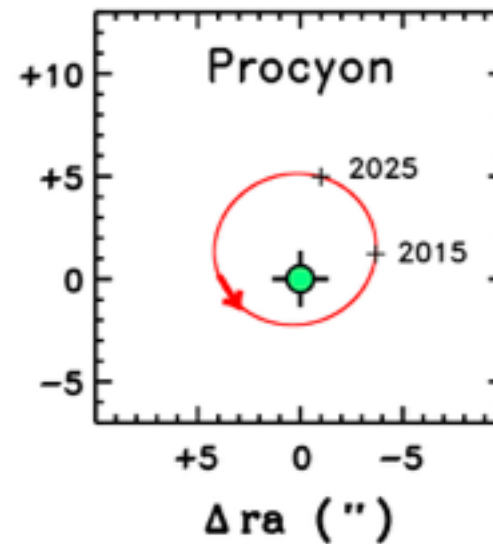
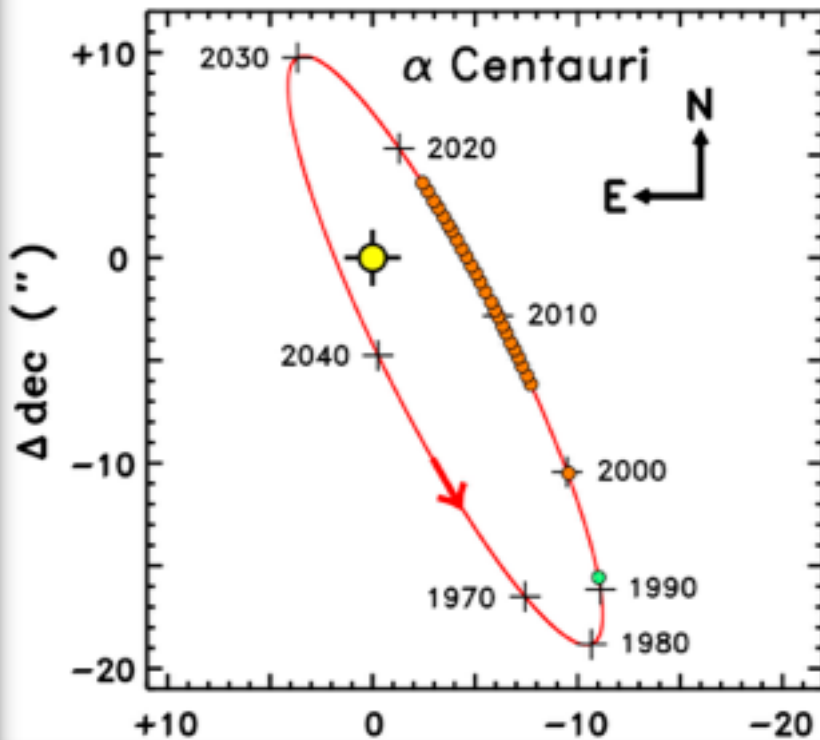
$Z/Z_{\odot} \sim 2$
 22, 36 d
 Age $\sim 6 \text{ Gyr}$



Object	M/M_{\odot}	R/R_{\odot}	L/L_{\odot}	T (K) [Type]
SUN	1	1	1	5772 [G2V]
α CMi	1.50	2.1	6.9	6500 [F5 IV]
α Cen A	1.10	1.22	1.52	5790 [G2V]
α Cen B	0.91	0.86	0.50	5260 [K1V]
α Cen C	0.12	0.14	0.002	3040 [M6V]
Jupiter	0.001	0.10	10^{-9}	165 [--]

Pairing	Distance (AU)	Orbital Period (yr)
Sun - Jupiter	5.0 - 5.5	11.9
A - B	11 - 36	80
AB - C	4,000 - 13,000	600,000
Sun - α Cen	276,200 (1.34 pc)	--
Sun - Procyon	3.51 pc	--

$P_{\text{ORB}} \sim 80 \text{ yr}$



α CMi B [WD: DQZ]

$P_{\text{ORB}} \sim 41 \text{ yr}$

X-rays and FUV

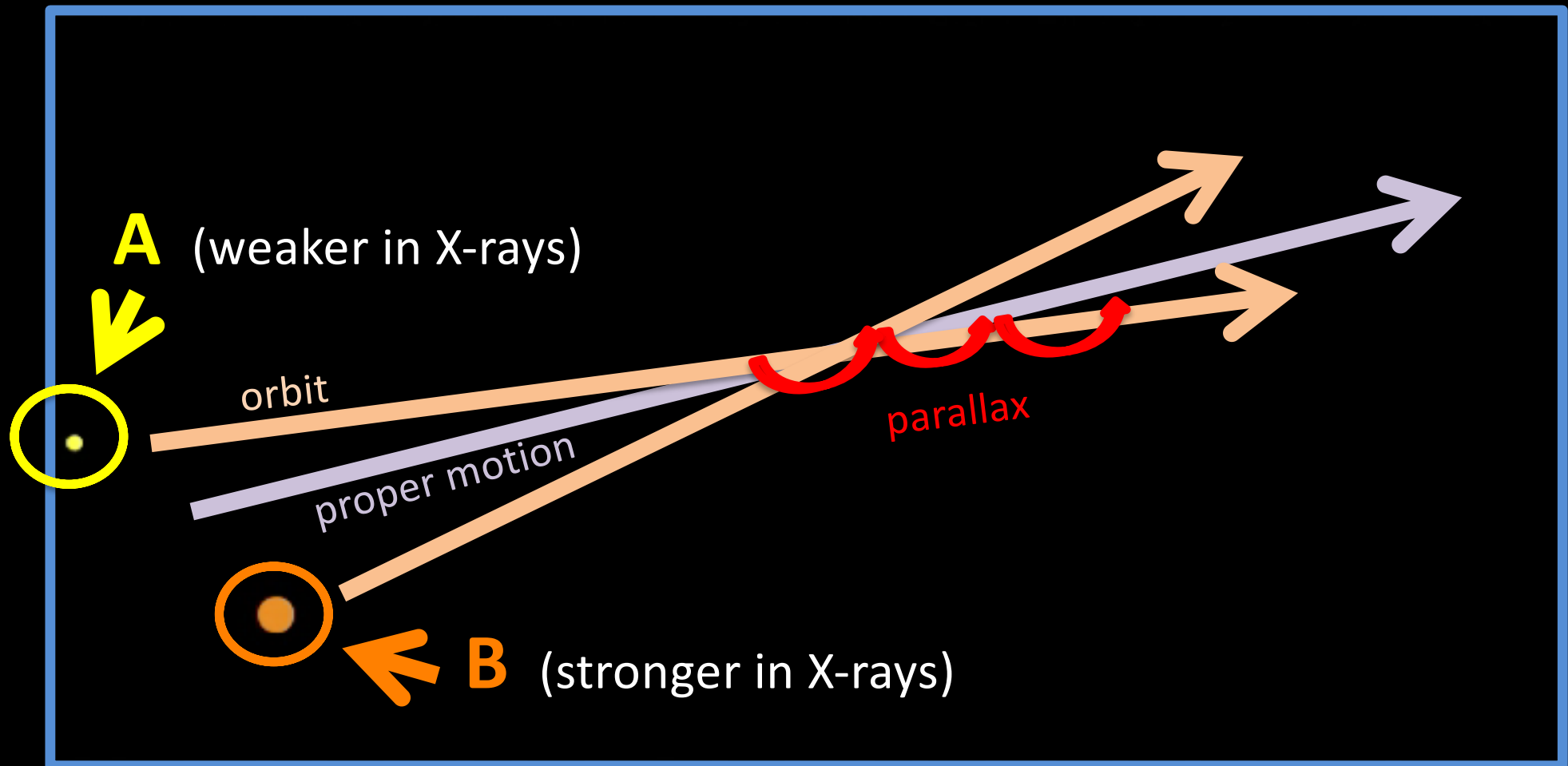
High contrast: Ca II HK $\sim 15\%$ over cycle; FUV factors of ~ 2 ; X-rays factor of *several* $\rightarrow 10$. X-rays respond strongly to changes in active region temperatures

Far-UV high-resolution spectra provide dynamical information missing from broad-band X-rays

Need spacecraft observations (but short exposures, semi-annual OK for cycle studies)

α Cen AB: 13 yr dedicated *Chandra* HRC, ~ 25 yr total (incl. *ROSAT*, *XMM*); Procyon: 3 yr dedicated HRC, ~ 20 yr total (*CXO* only); *HST* STIS: 9 yr α Cen AB; 3 yr α CMi (+)

Chandra X-ray Observations of Alpha Cen



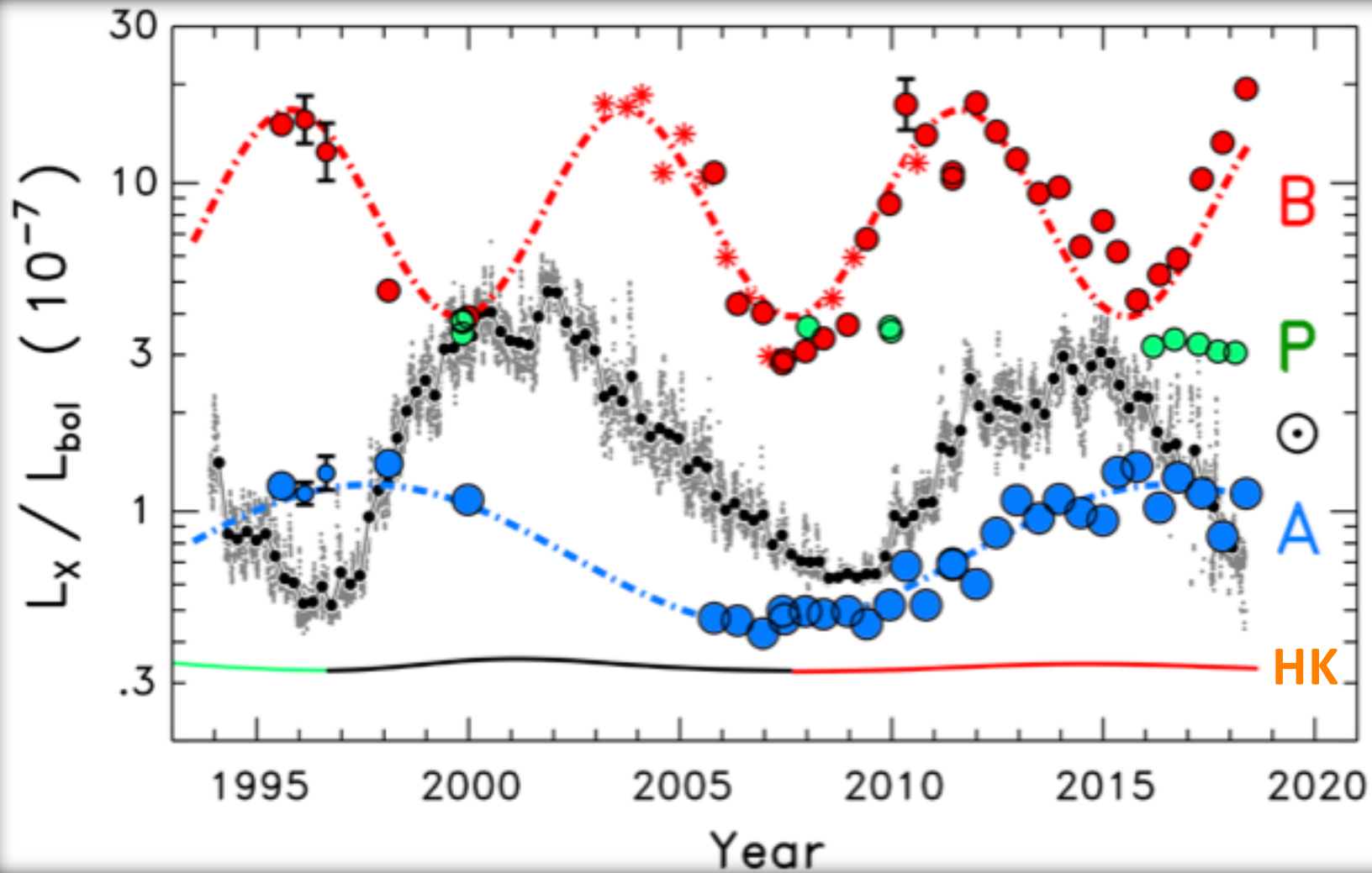
13 year time span: last obs May 2018; High Res Camera;
only *Chandra* can separate AB; dot size → X-ray intensity

Chandra X-ray Observations of Alpha Cen

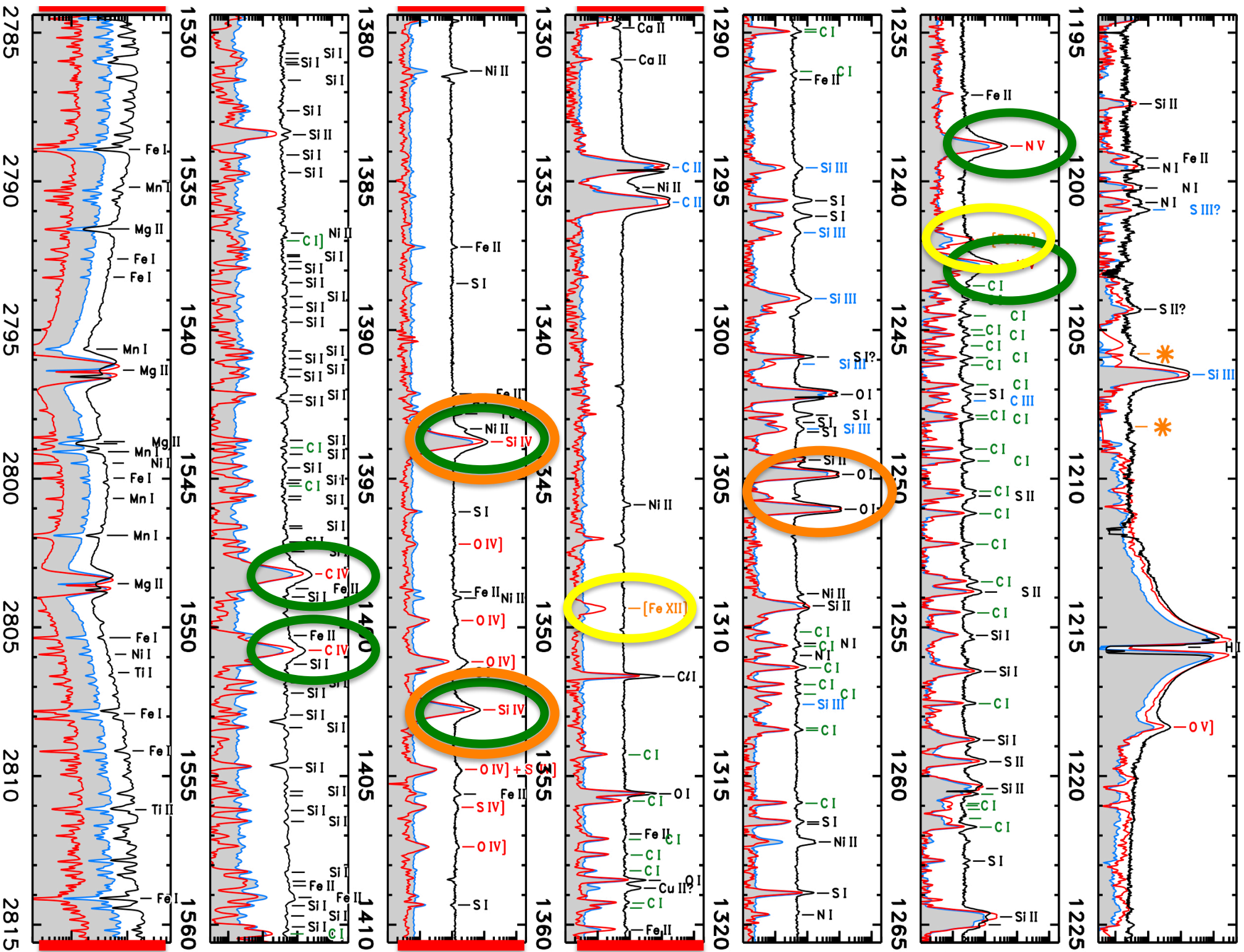


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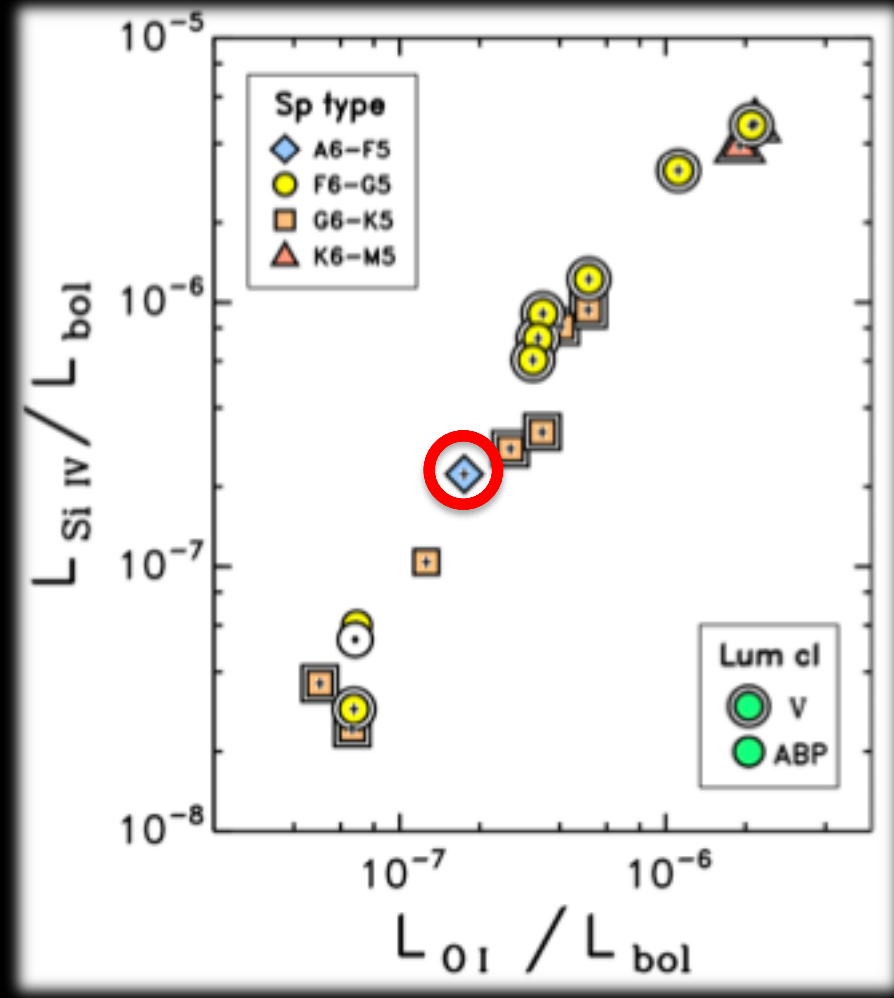
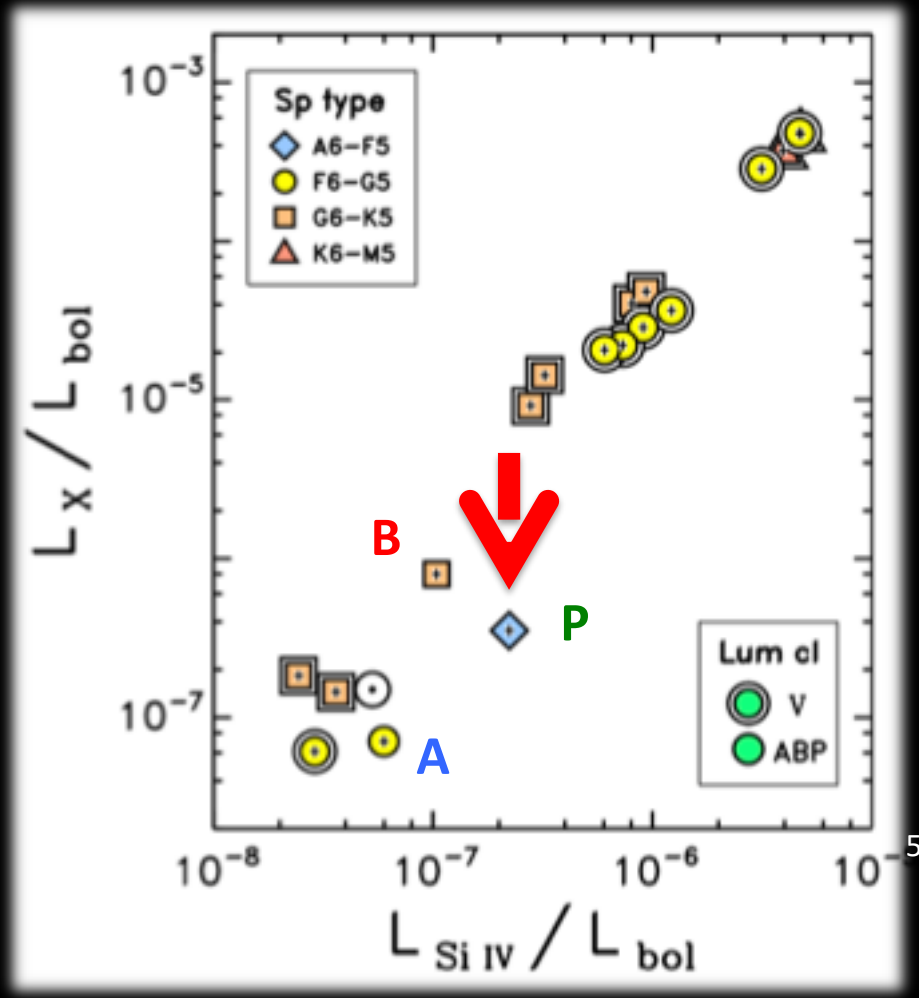
Ups & Downs of Alpha Cen and Procyon



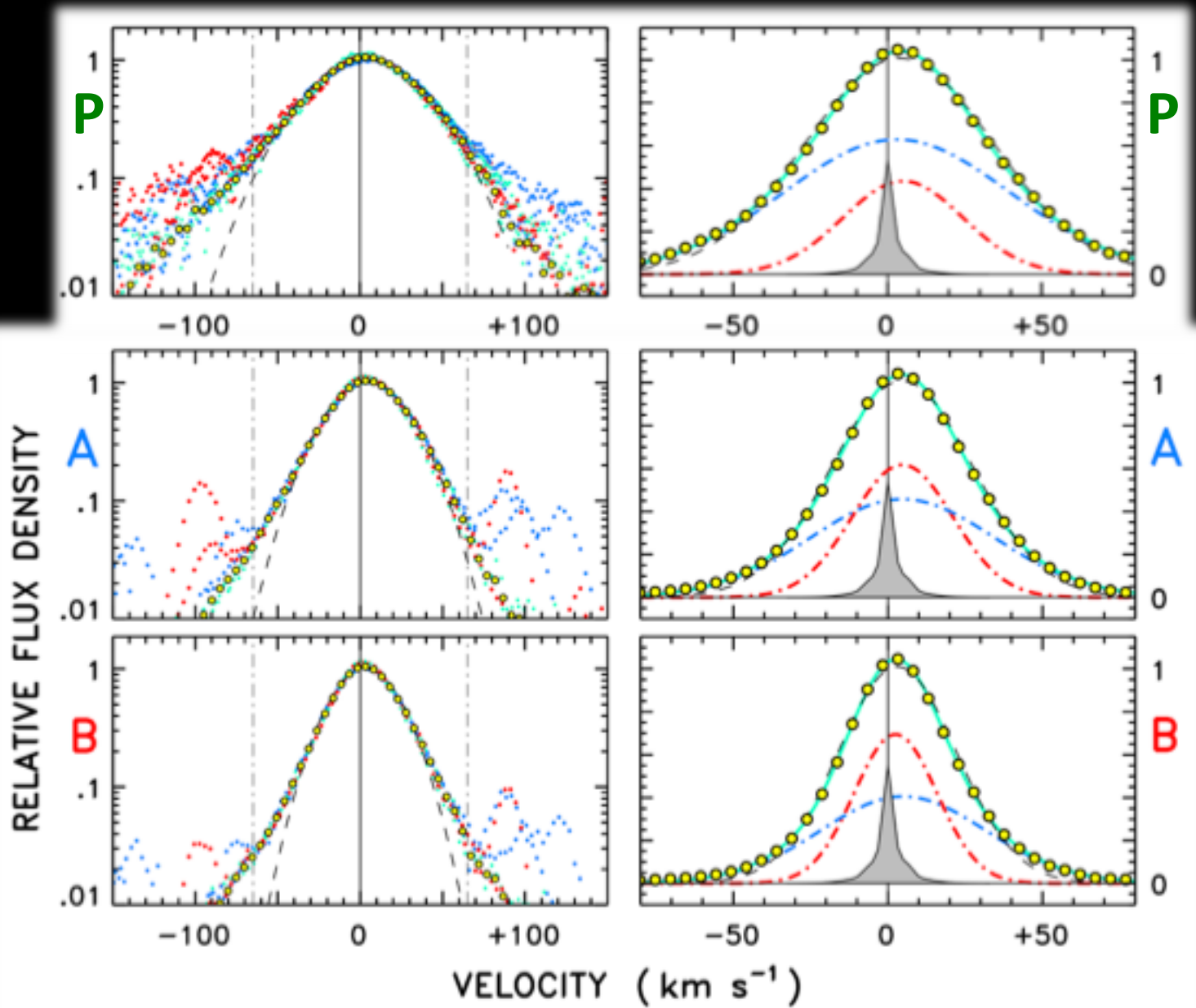
ⓘ X-ray Index L_X/L_{bol} proportional to Hab Zone Irrad



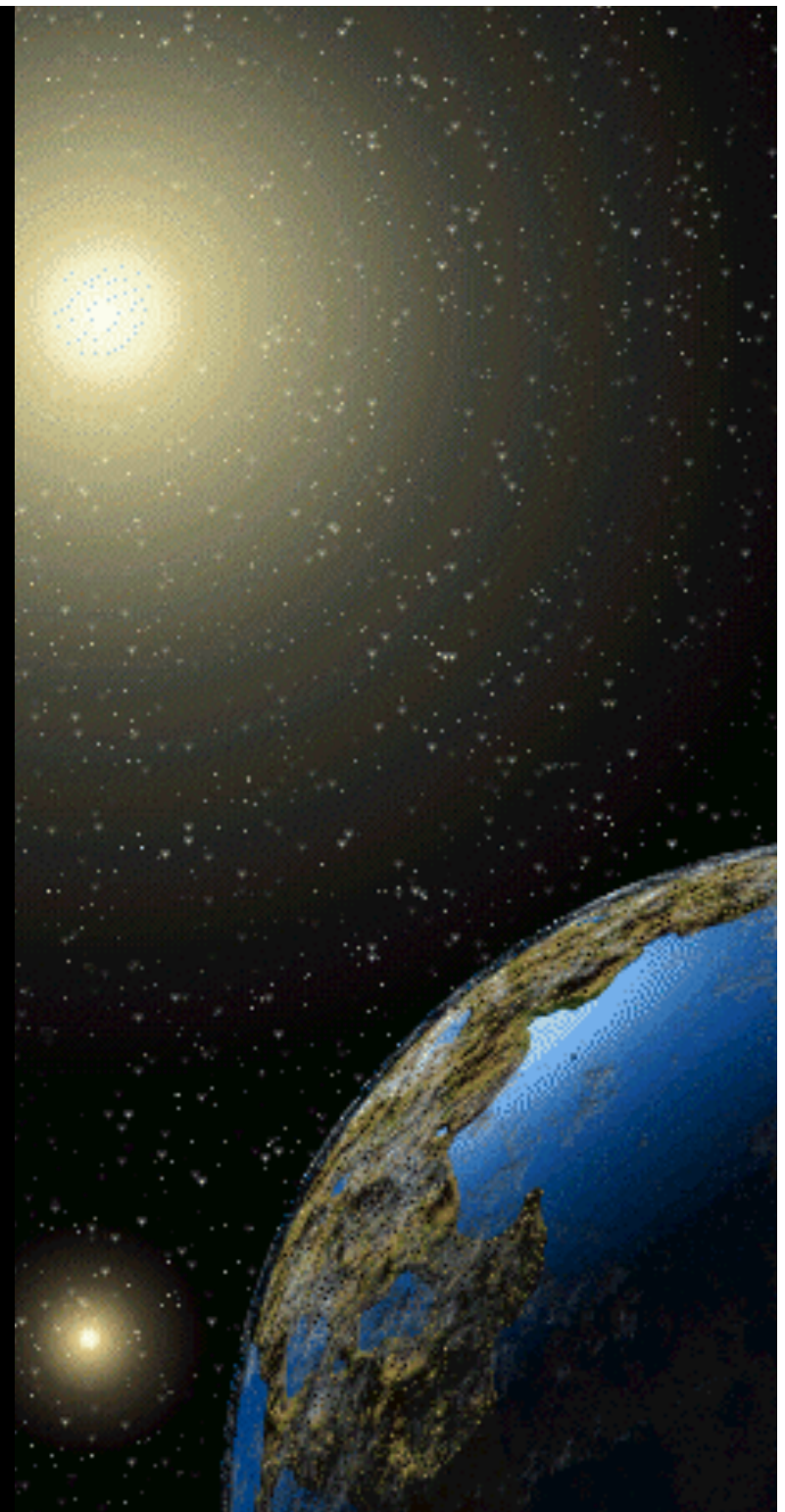
Corona / TZ / Chromosphere Flux-Flux Correlations



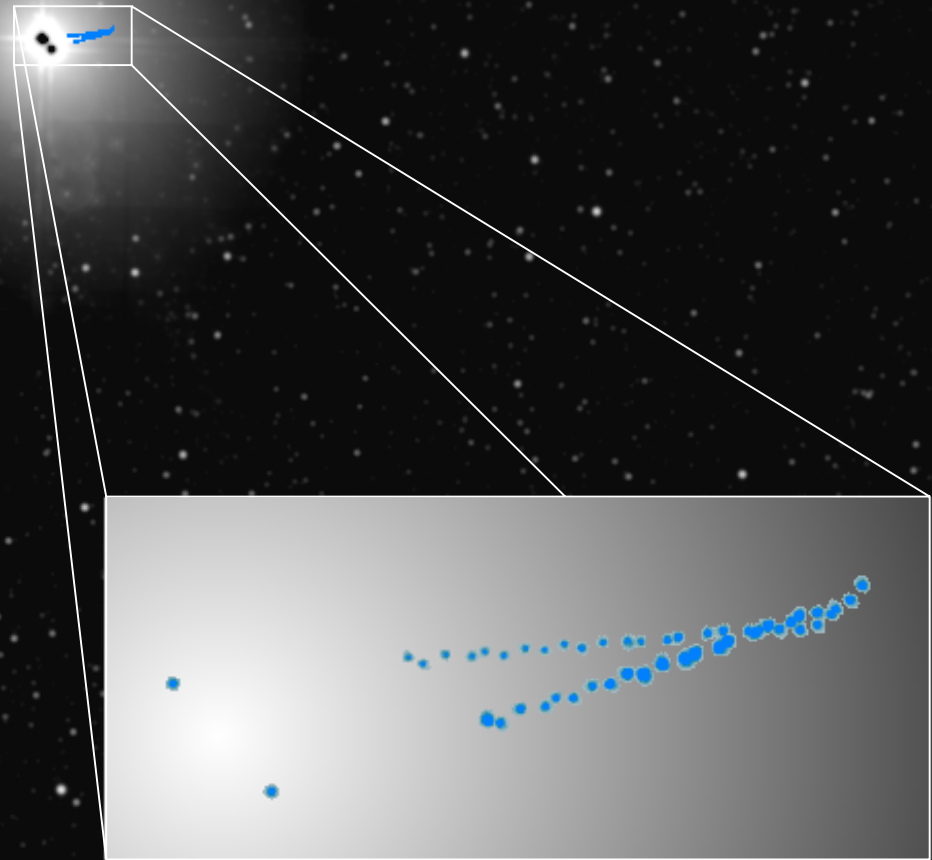
Hybrid Transition Zone Profiles: N V + Si IV + C IV



- Procyon's corona: *simpler* than Sun or α Cen AB ?? (*X-ray deficient + flat activity vs. Sun-like cycling*)
- Procyon's ave TZ lineshape: *wider, dominated by broad component, but still red-shifted by ~ 5 km/s* (connections to *IRIS* sol obs??)
- Procyon's corona *scaled-up, more powerful version* of solar supergranulation network ?? (*thin, more vigorous CZ ??*)

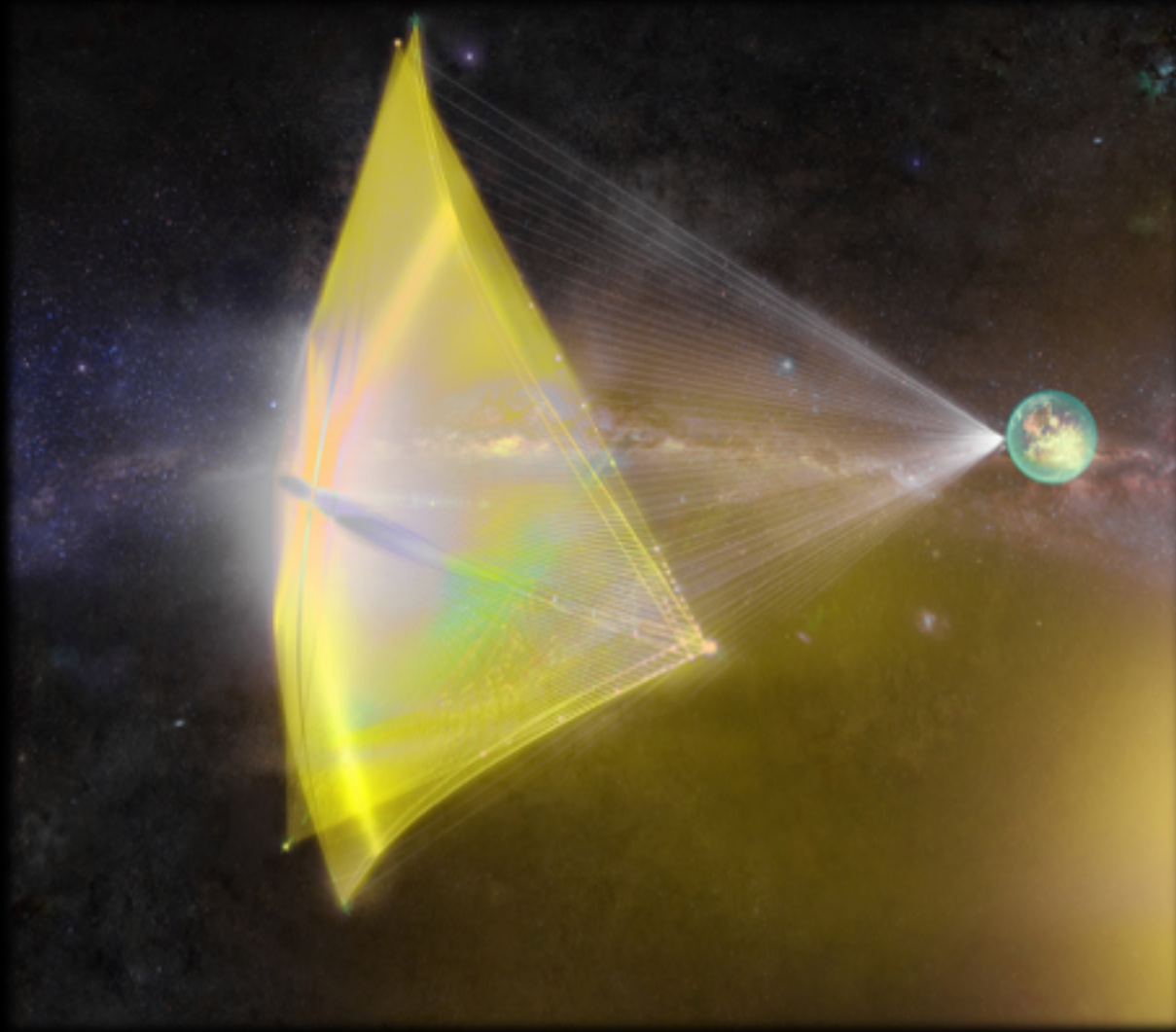


Alpha Centauri at a Crossroads



Chandra Spring
2017 Newsletter

Breakthrough *Starshot*



To boldly go where no nanobot has gone before...