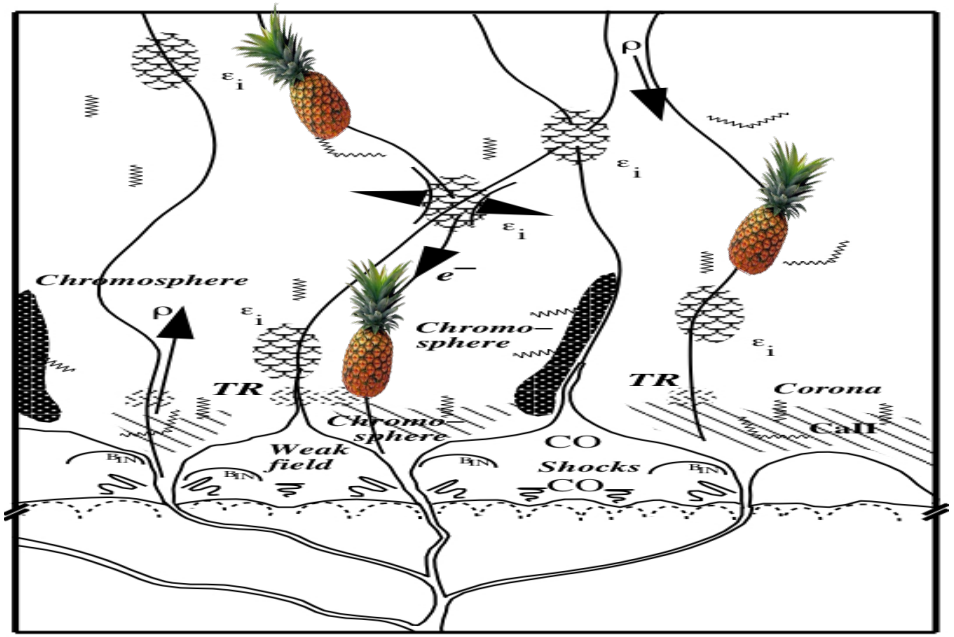
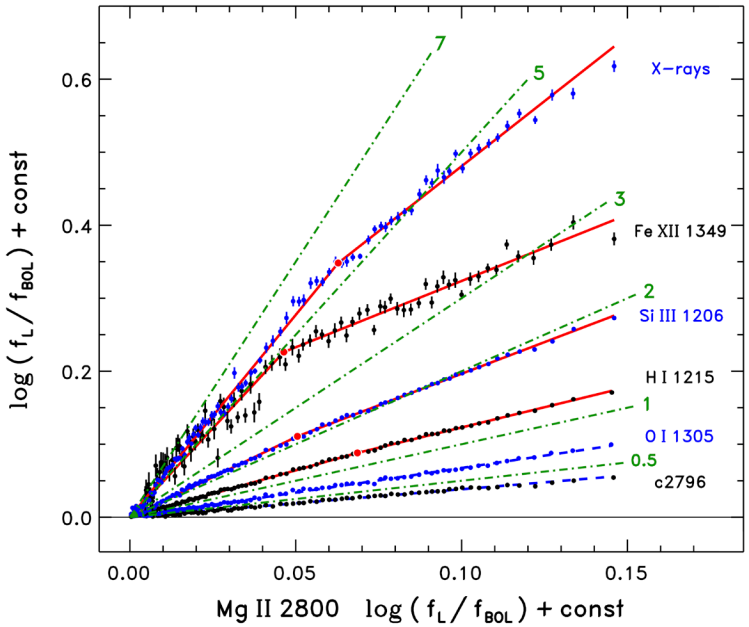
Seeking the Quiet Sun Among the Stars

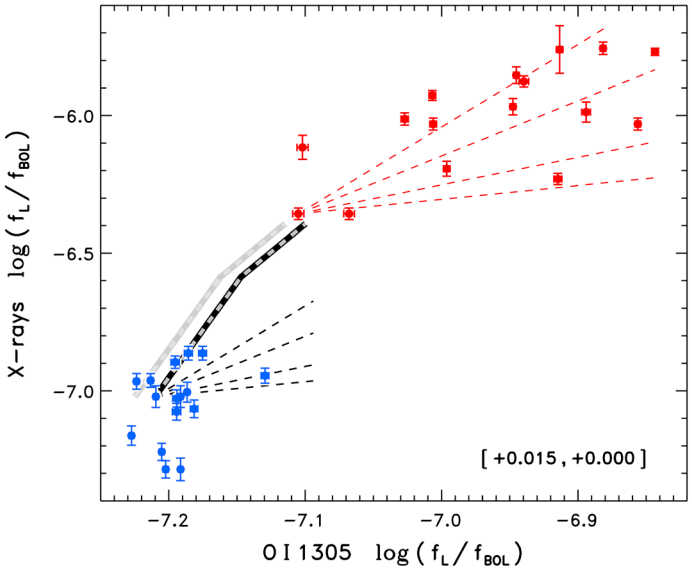
Tom Ayres (University of Colorado, CASA)



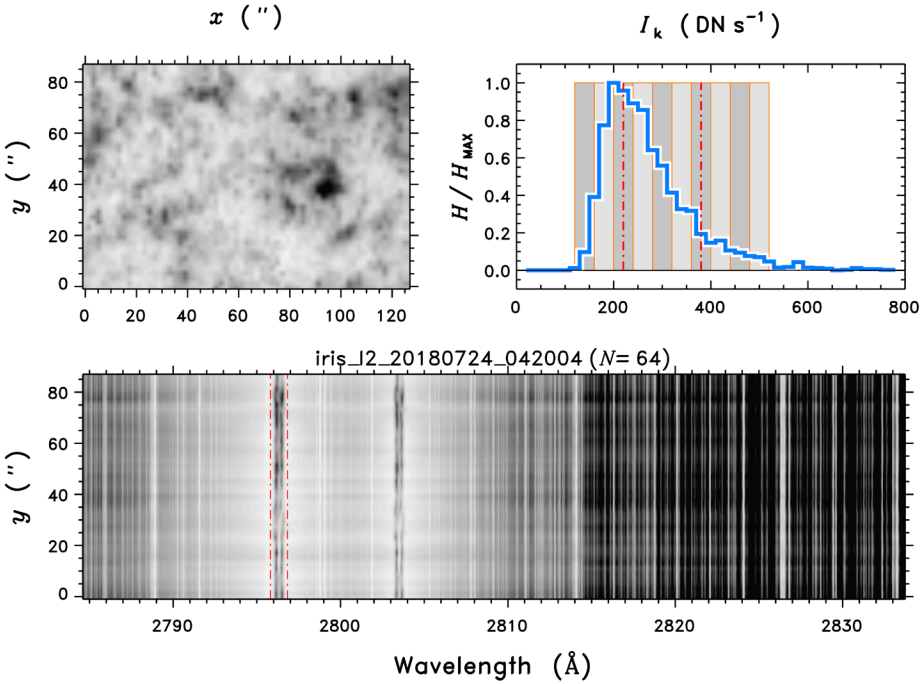
In the Trenches of the Solar-Stellar Connection:

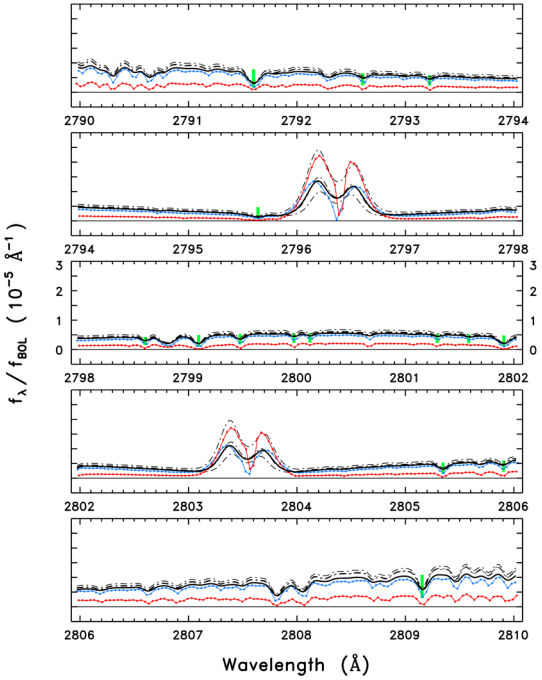
Flux-Flux Correlations over the Activity Cycles of Alpha Cen AB and the Sun





How I Found the Quietest Sun Hidden, in Plain Sight, in the Quiet Sun Itself





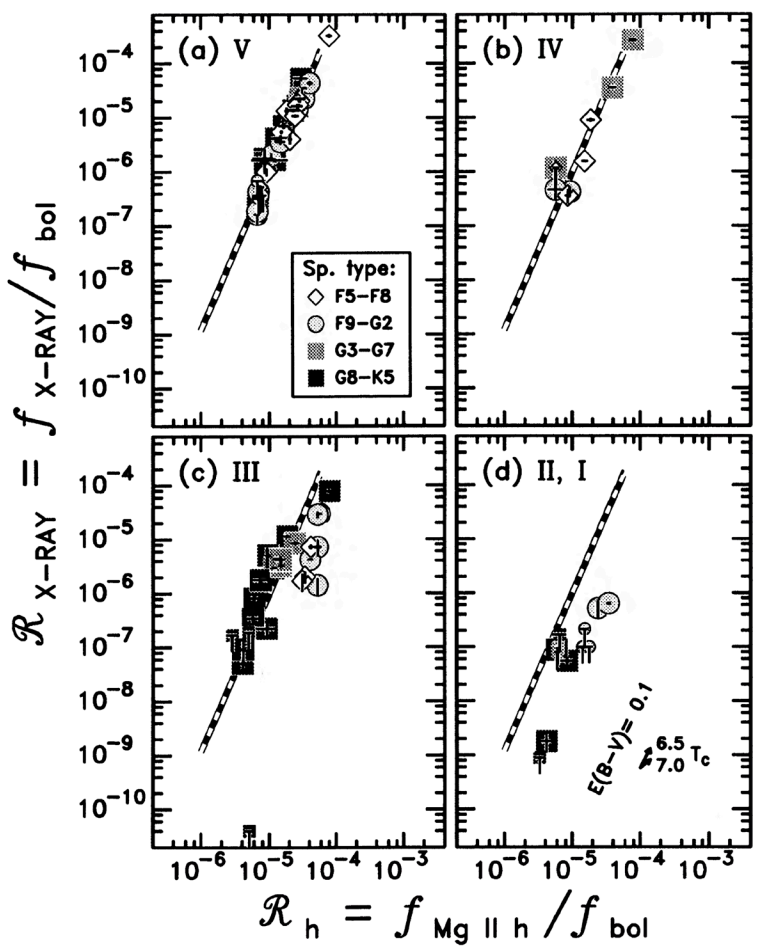
Background

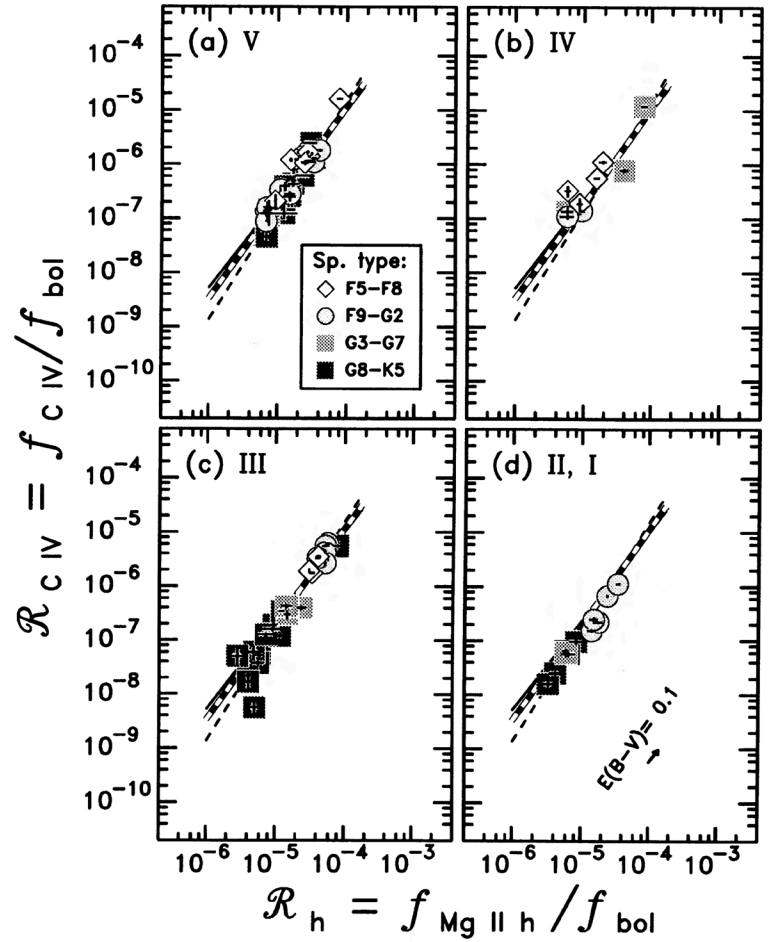
✪ **Flux-Flux correlation diagrams (“correlagrams”), pitting, say, coronal X-rays (1 MK) vs. chromospheric Mg II emission (10,000 K), in past have been based on *moderate-size surveys* of sunlike stars**

✪ **Stellar flux-flux diagrams typically show *power-law correlations* with *slopes increasing with ionization energy*. For example, the X-ray/Mg II slope is ~2.9, whereas C IV/Mg II is ~1.8**

✪ **Correlagrams allow one to extrapolate high-energy activity indicators into lower activity regimes, for example the UV/X-ray state of the quietest possible Quiet Sun, perhaps like the solar conditions in the “spotless” Maunder Minimum; or low-activity exoplanet hosts**

✪ **An alternative to heterogenous surveys is to follow one star through its activity cycle. Three sunlike stars have the requisite long-term datasets: Alpha Cen A (G2V) and B (K1V), from *Chandra+HST*; and the Sun (G2V) from *SORCE* (SOLSTICE+XPS) and IRIS**





Stellar correlagrams from "RIASS Coronathon" **(Ayres+1995). Normalizing observed fluxes by bolometric flux ("stellar irradiance") mitigates against the different stellar sizes and distances. (f_{BOL} is derived from stellar visual magnitude and color-dependent B.C.)**

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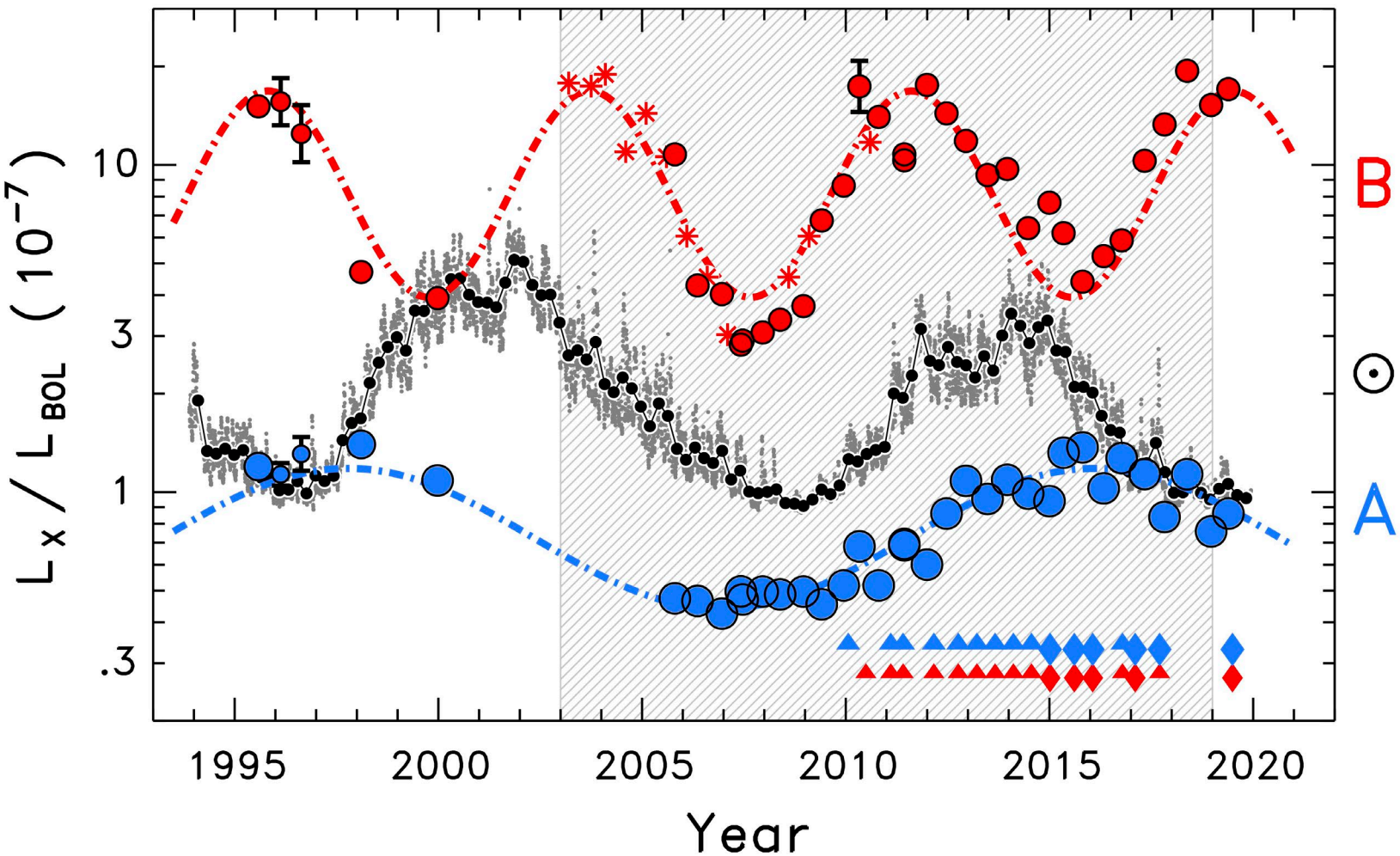


X-ray cycles (0.2-2 keV) of α Cen A+B over past 15 years. **Blue & red triangles mark *HST*-STIS FUV pointings on AB, respectively; diamonds: FUV + NUV. 2003-2019 is *SORCE* UV/X-ray coverage.**

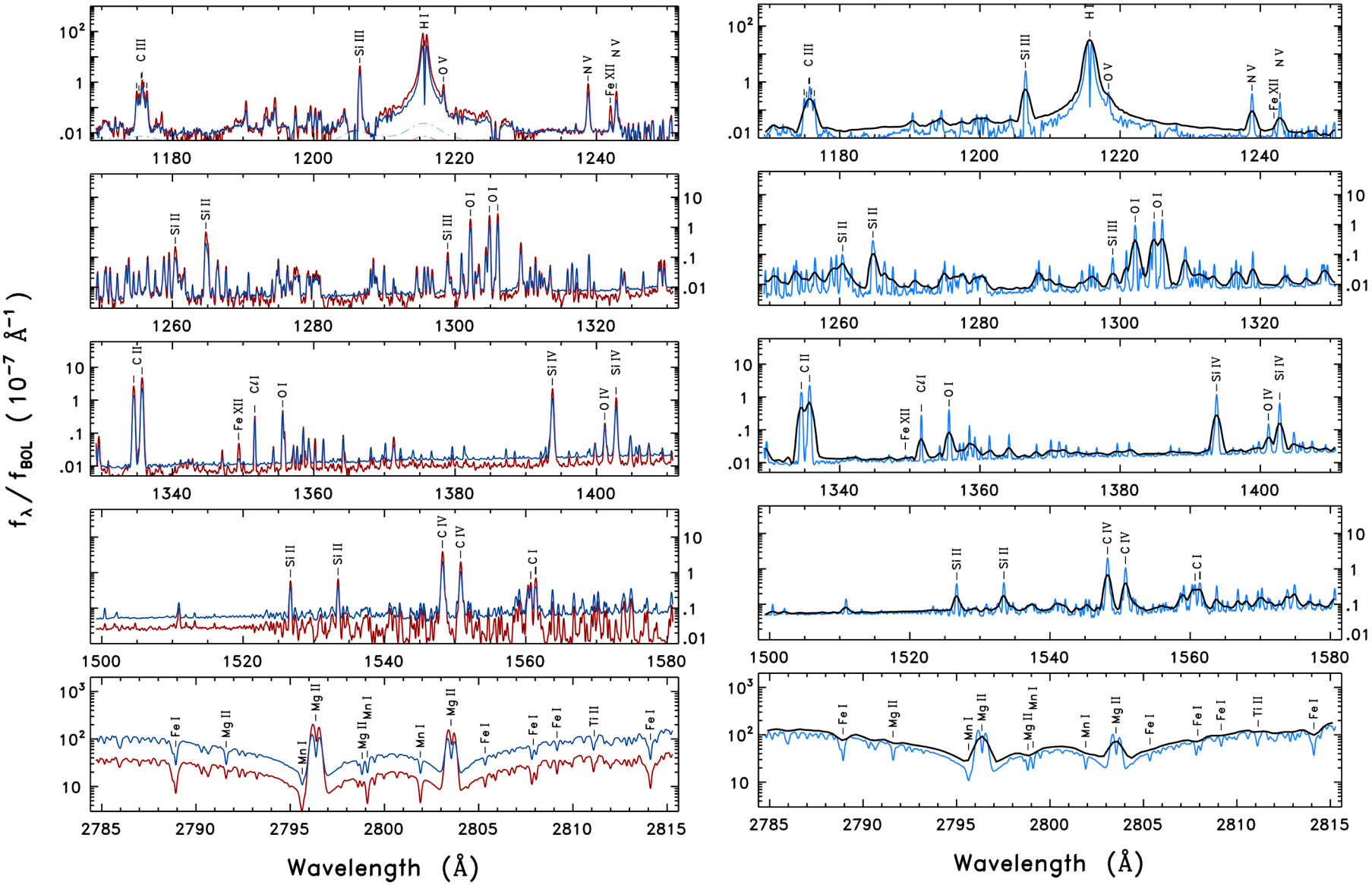
Results

✪ **Solar correlagrams show unexpected *broken power laws* for corona versus chromosphere, and curious *inversions in activity hierarchy* : Si III more active than N V. (Good luck, theorists!)**

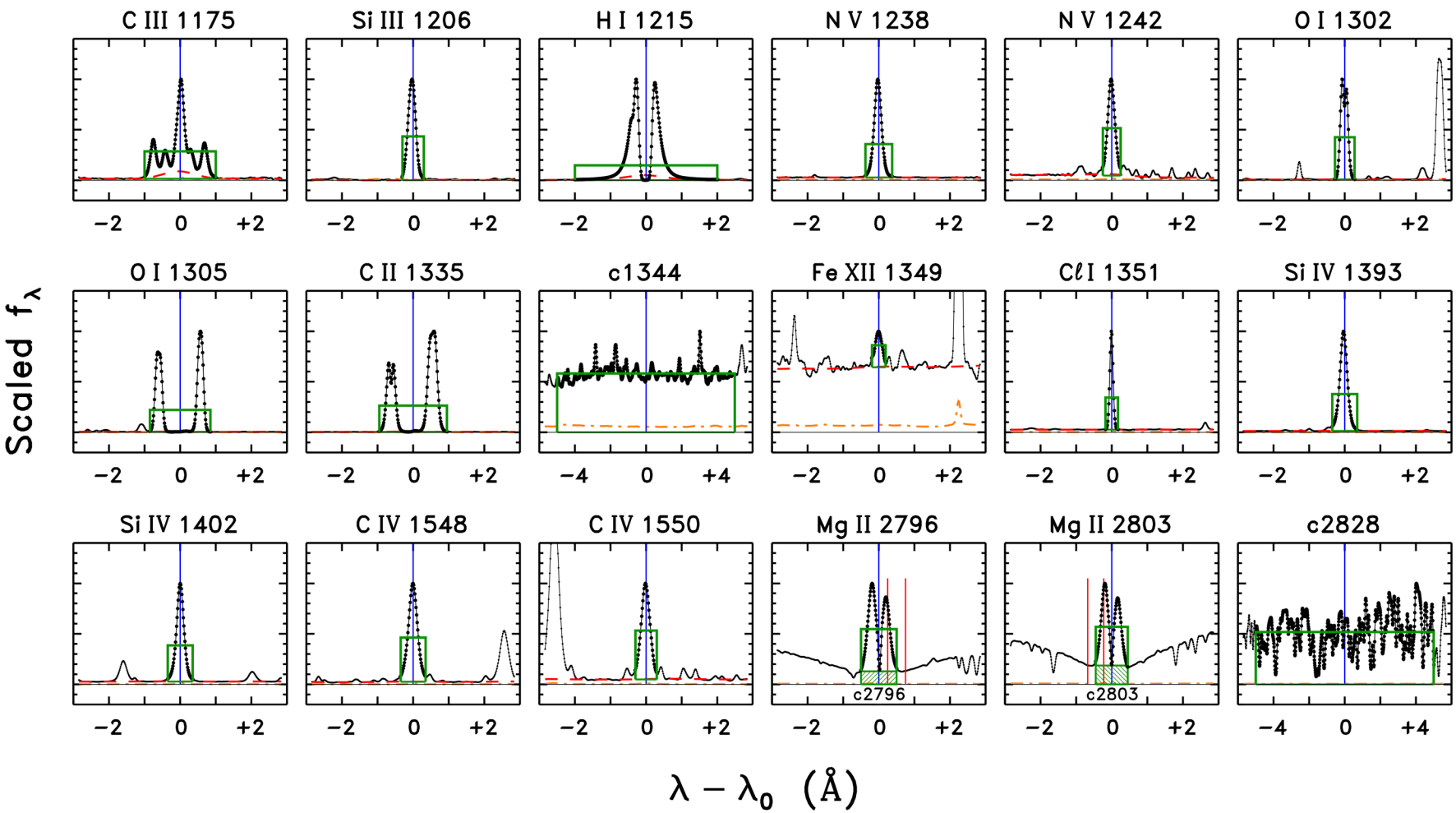
✪ **The unusual solar behavior also afflicts solar twin Alpha Cen A; but somewhat more active companion Alp Cen B appears to follow power-laws and excitation hierarchy seen in earlier stellar surveys**

✪ **Chromospheric Mg II emission displays systematic trends with stellar effective temperature. The Sun falls near the bottom boundary of the relation, and low-brightness components of the Quiet Sun, obtained by histogramming IRIS k-line rasters, fall below. Further, a disk-average Mg II profile assembled from Quiet-Sun scans falls under the Cycle-minimum Mg II flux indicated by SOLSTICE**

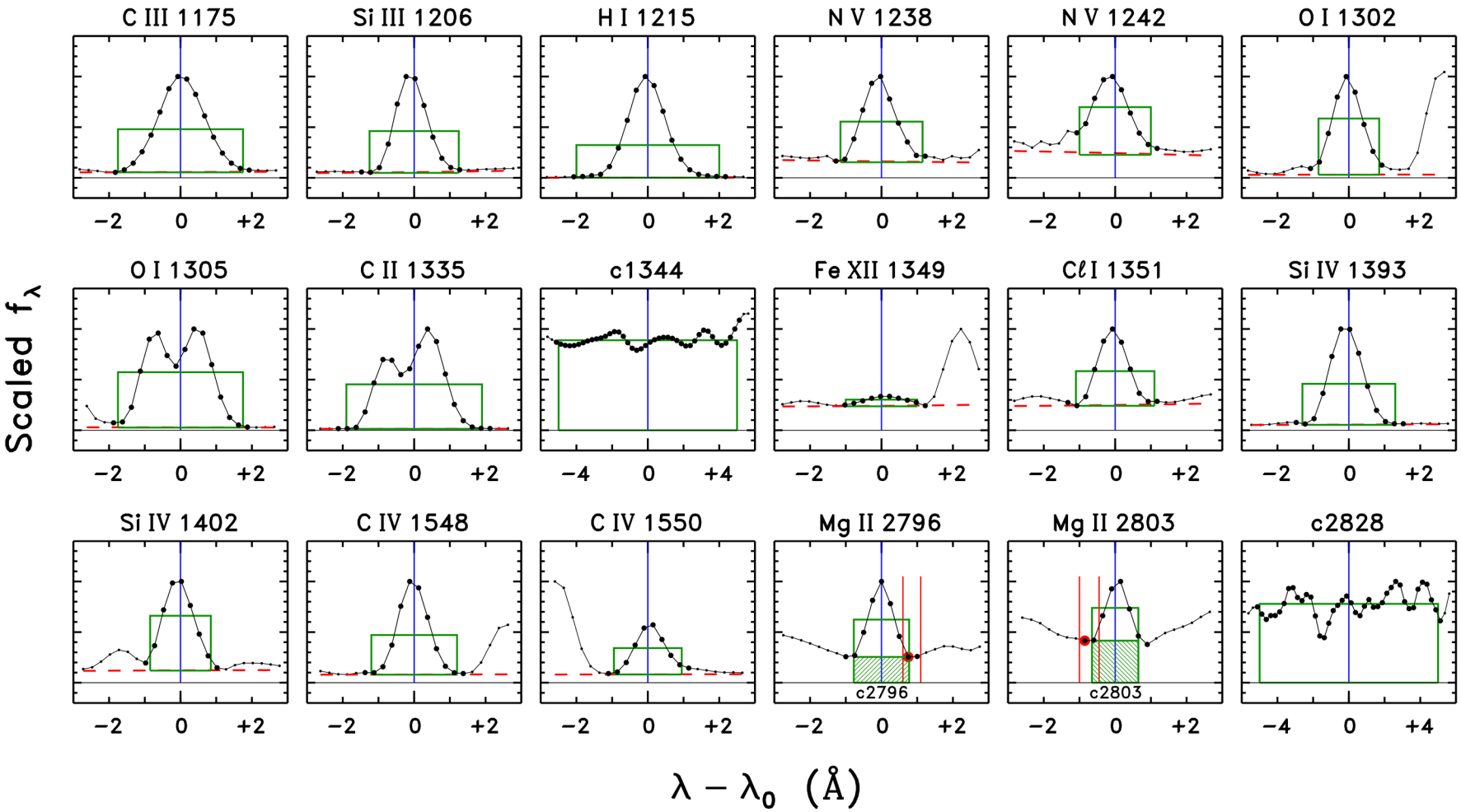
✪ **The IRIS disk-average Mg II Quiet Sun profile is consistent with the lowest hk flux seen among the stars, so likely represents the minimum possible activity level on the Sun: shocked BPs and SGN elements.**



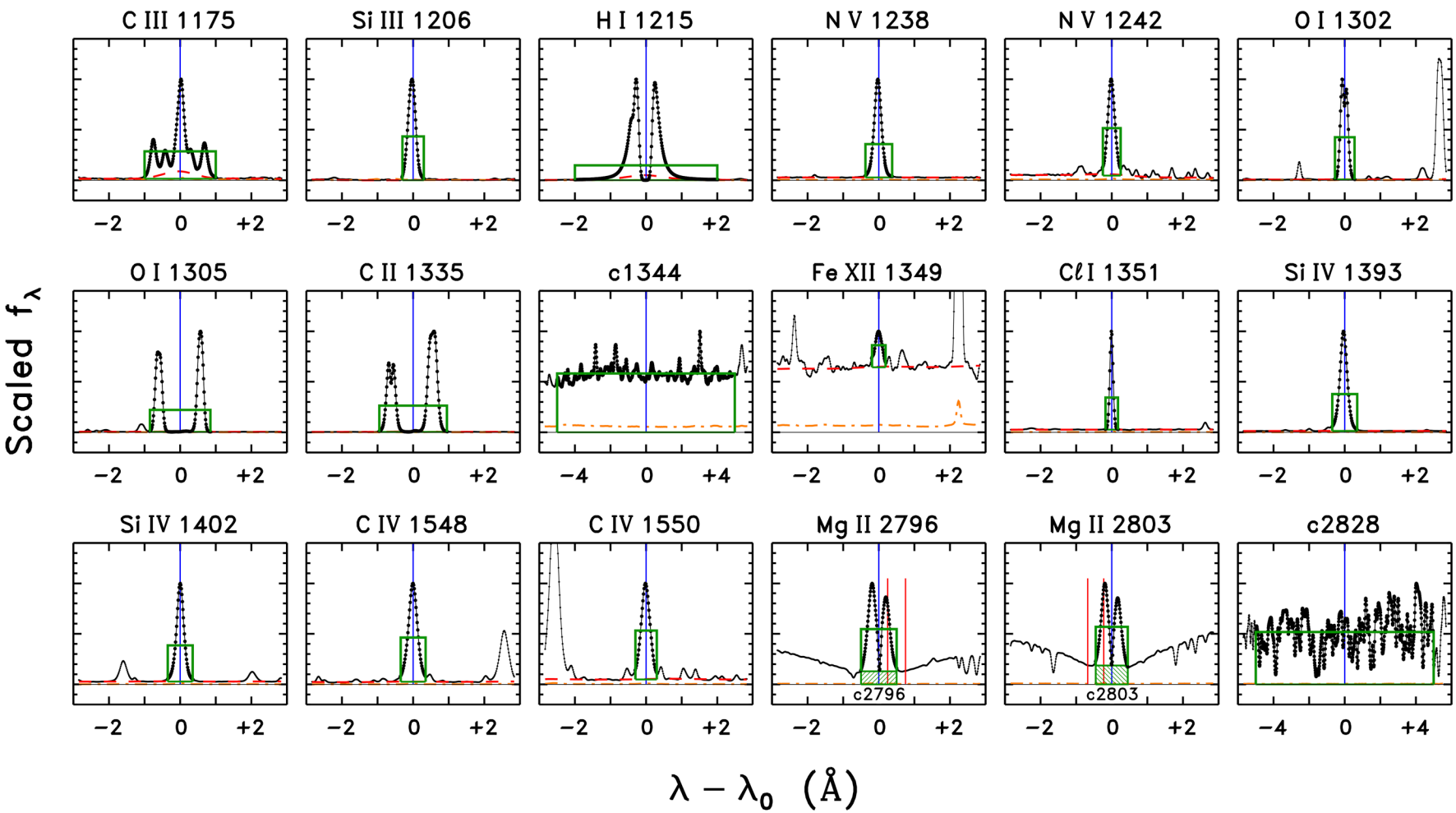
High-resolution STIS UV spectra of α Cen A+B (blue, red) on left; SOLSTICE (black) + α Cen A (blue) on right



Measurements of high-resolution STIS UV spectra of α Cen A: emission lines integrated above "continuum."



Measurements of low-resolution SOLSTICE spectra



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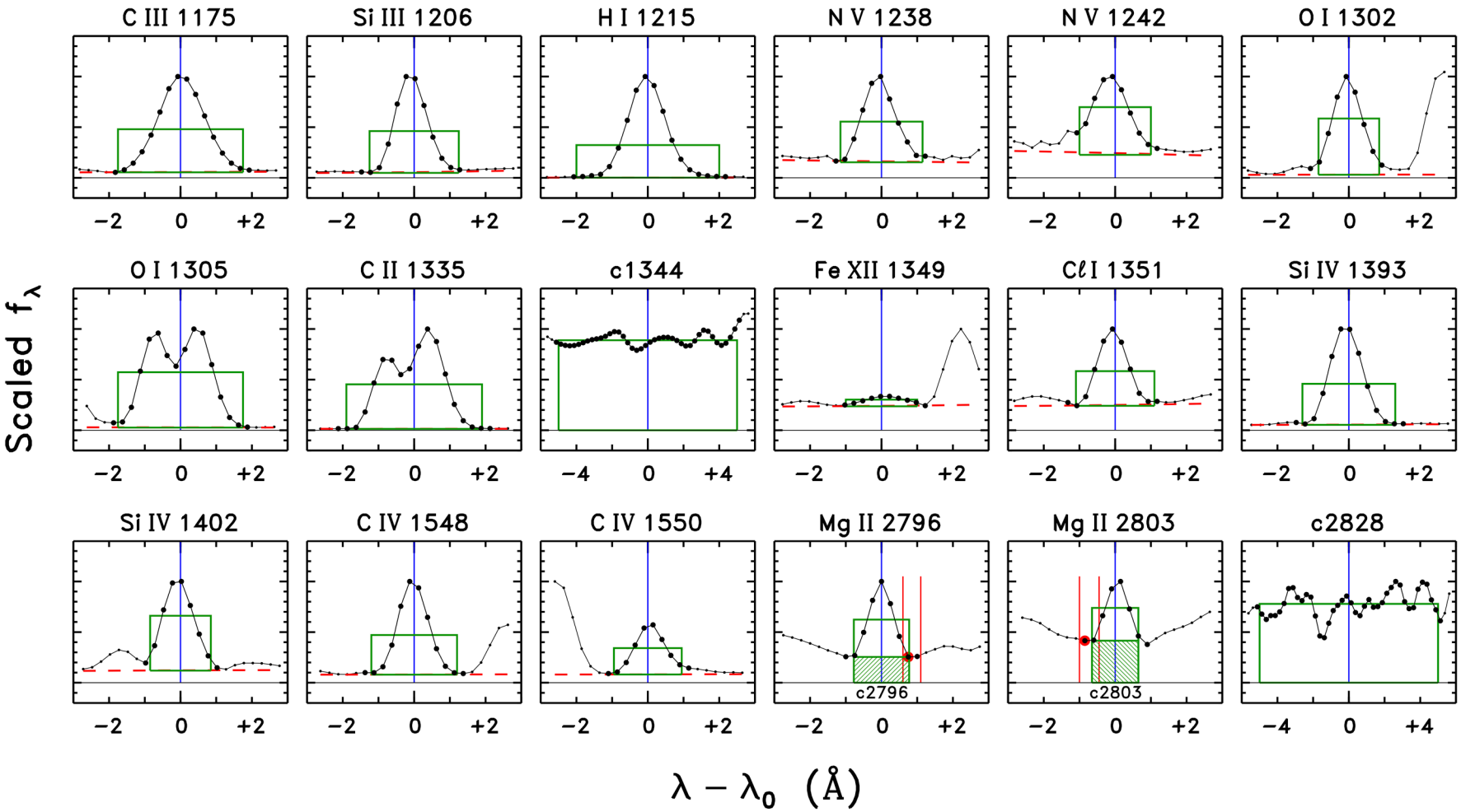

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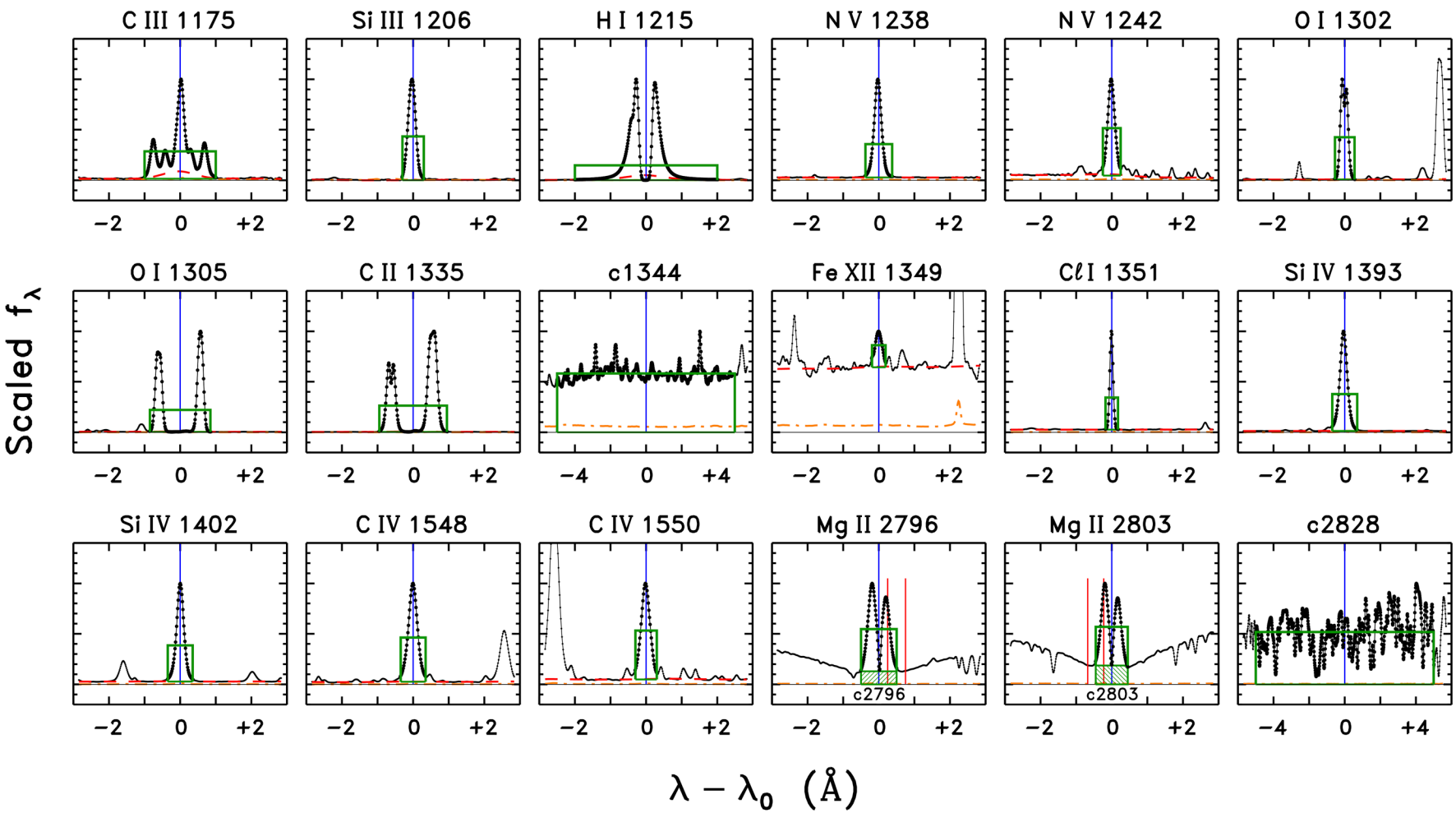
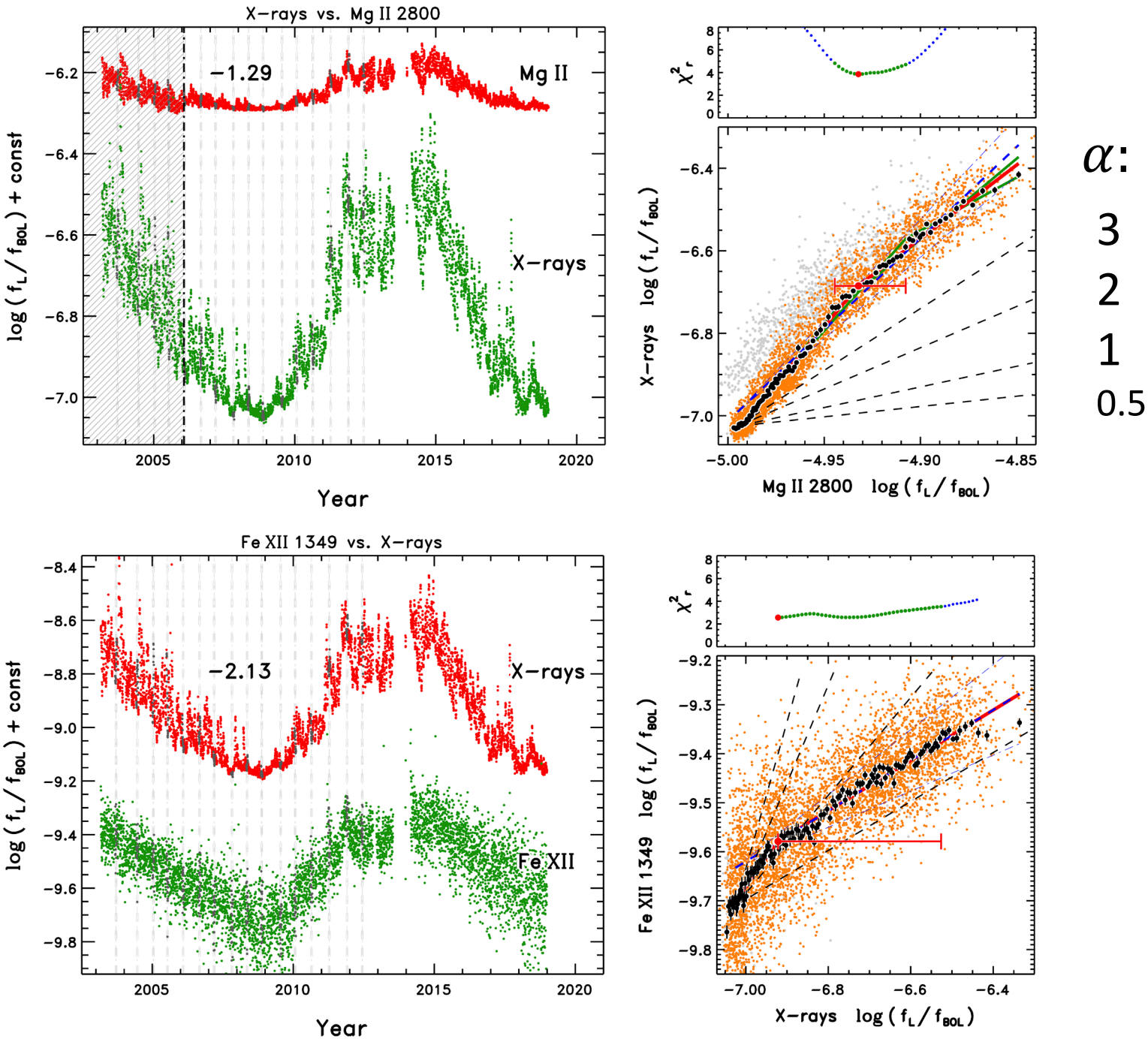
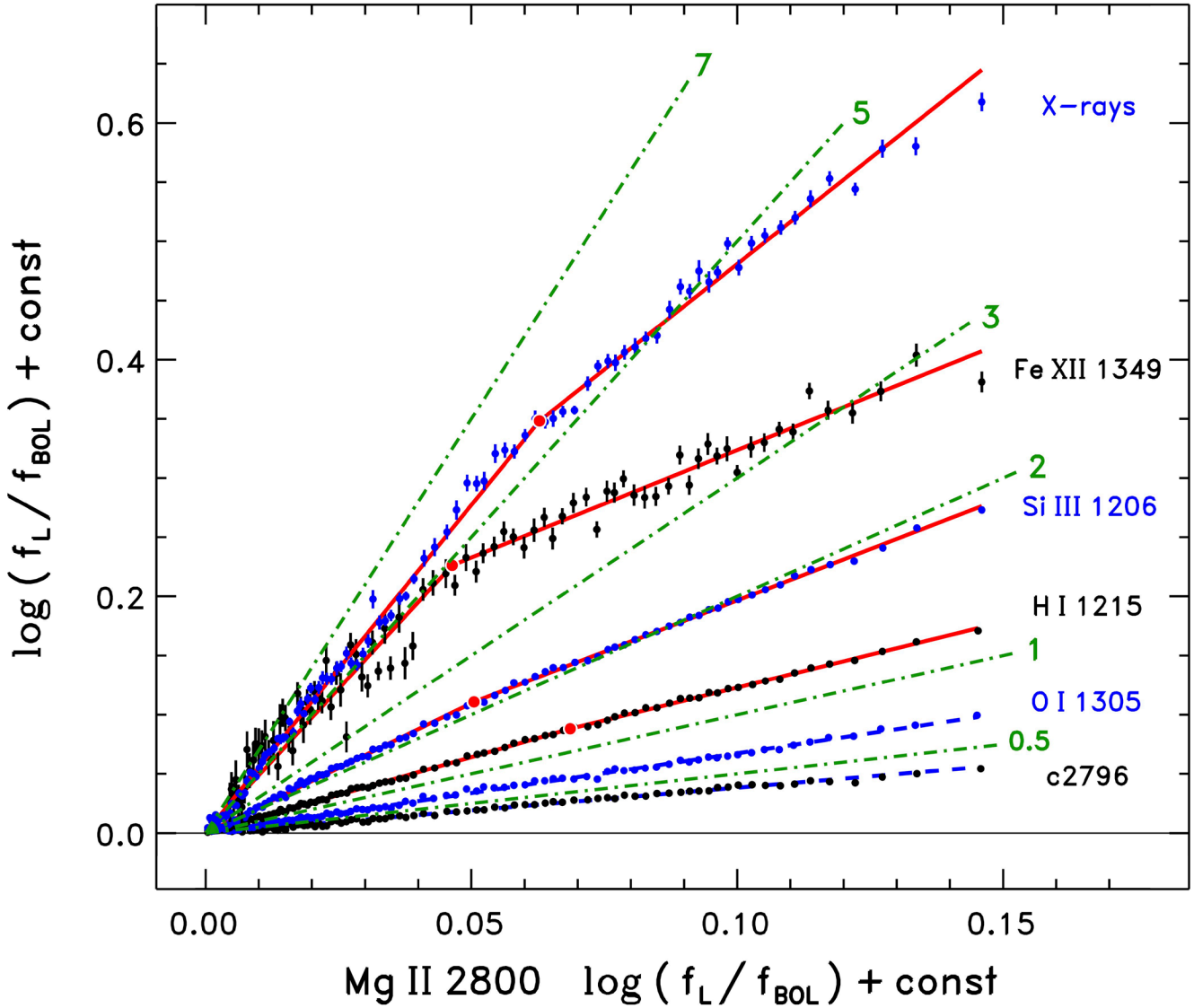


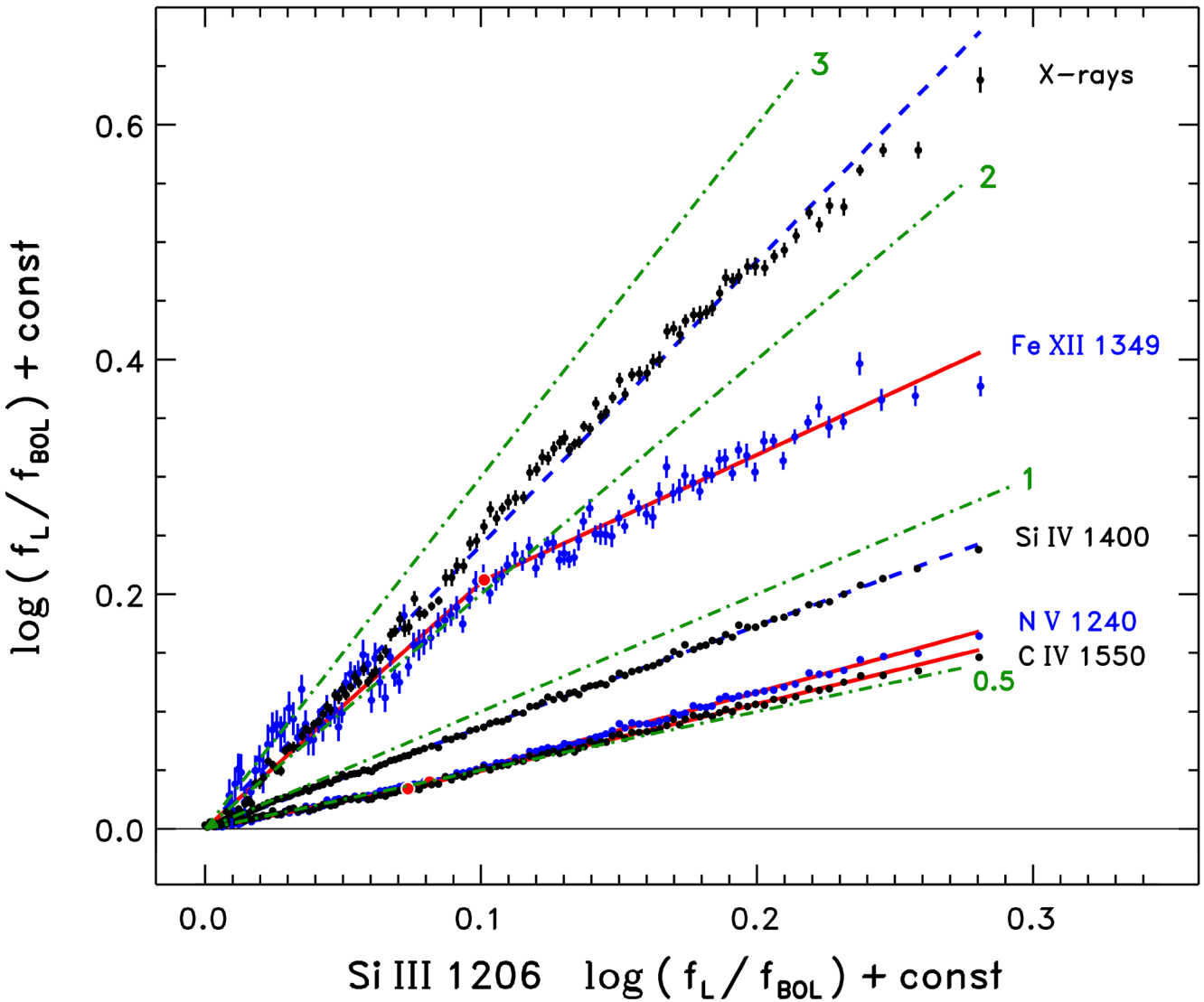
Measurements of high-resolution STIS UV spectra of α Cen A: emission lines integrated above "continuum."


X−rays vs. Mg II 2800
−1.29
Mg II
X−rays
log (f_L / f_BOL) + const
Year
χ²_r
X−rays log (f_L / f_BOL)
Mg II 2800 log (f_L / f_BOL)
α:
3
2
1
0.5
Fe XII 1349 vs. X−rays
−2.13
X−rays
Fe XII
log (f_L / f_BOL) + const
Year
χ²_r
Fe XII 1349 log (f_L / f_BOL)
X−rays log (f_L / f_BOL)



Note broken power laws for the coronal emissions vs. chromsopheric Mg II.

Something happens to corona at minimum activity: ***Global Coronal Cooling ??***



Now, broken power law mainly for Fe XII. But, high-excitation species Si IV, C IV, N V (0.8–2× 10^5 K) show ***suppressed behavior*** relative to Si III 1206 Å (5× 10^4 K)

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✪ Chromospheric Mg II emission displays systematic trends with stellar effective temperature. The Sun falls near the bottom boundary of the relation, and low-brightness components of the Quiet Sun, obtained by histogramming IRIS k-line rasters, fall below. Further, a disk-average Mg II profile assembled from Quiet-Sun scans falls under the Cycle-minimum Mg II flux indicated by SOLSTICE

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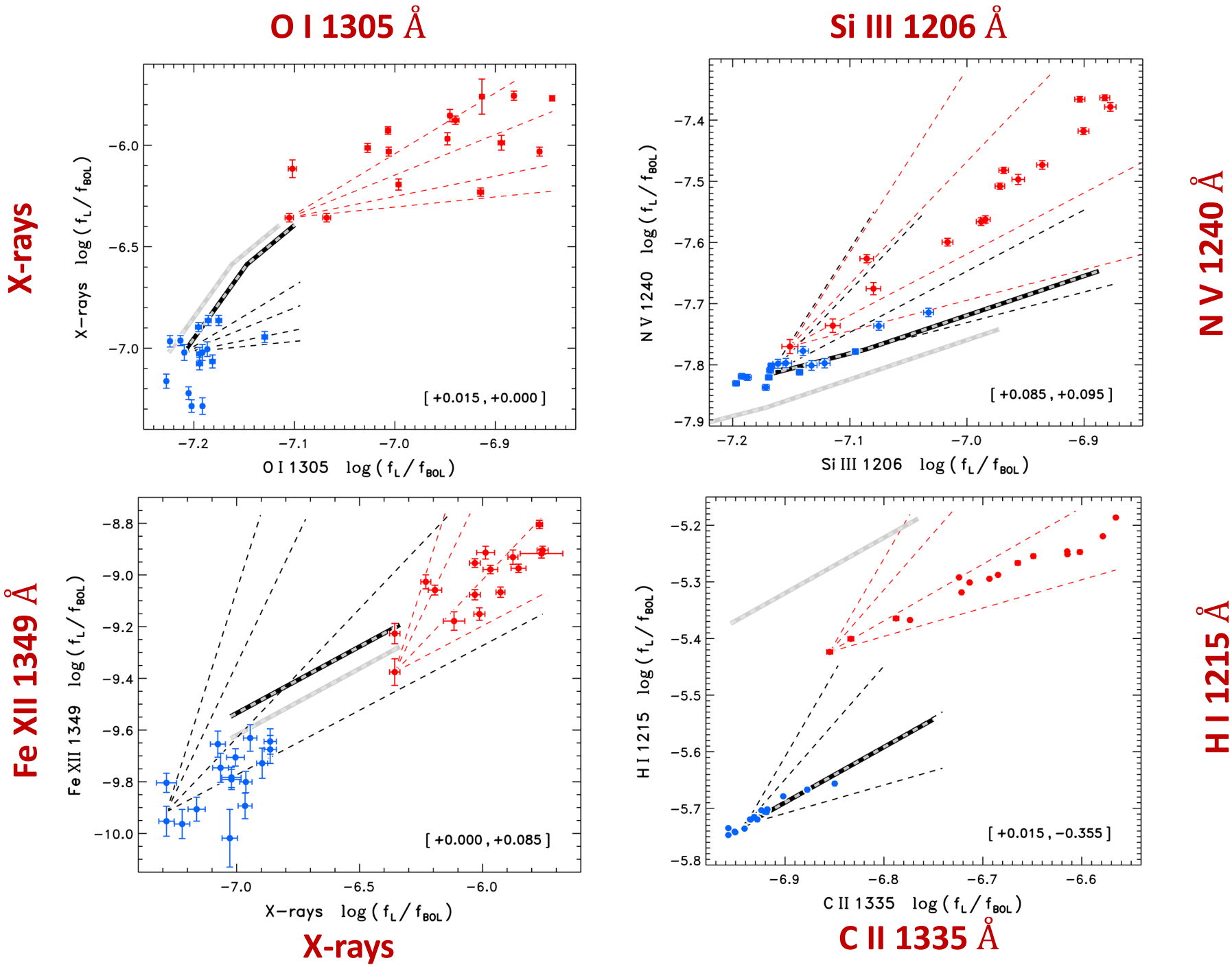
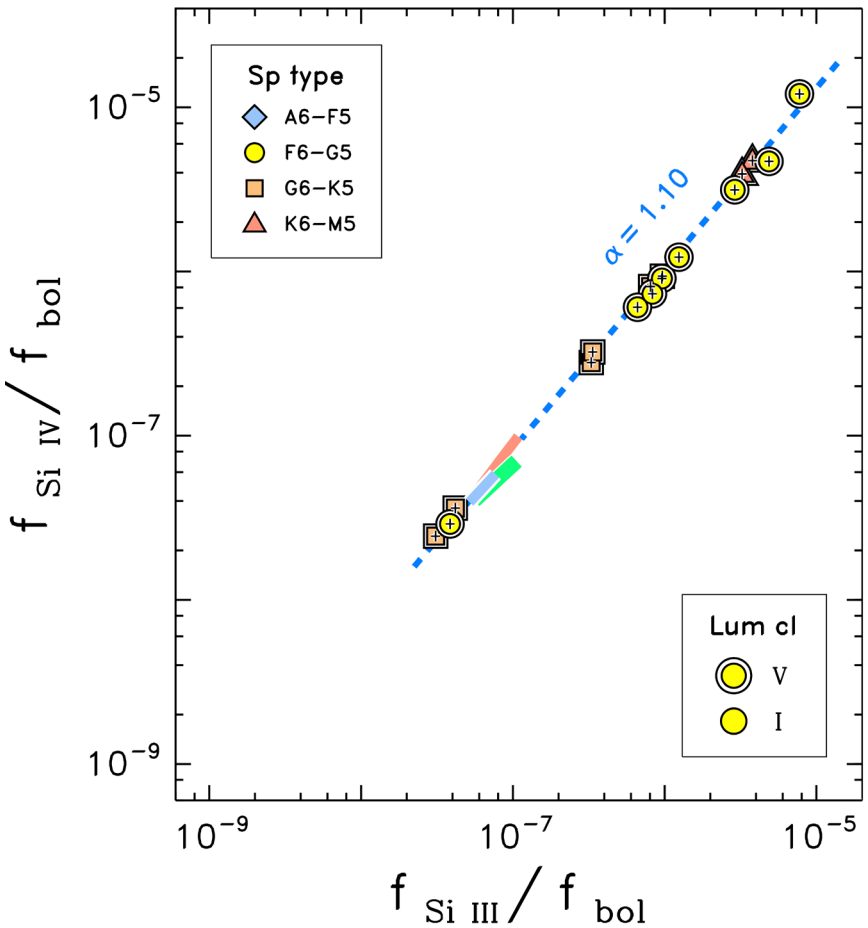
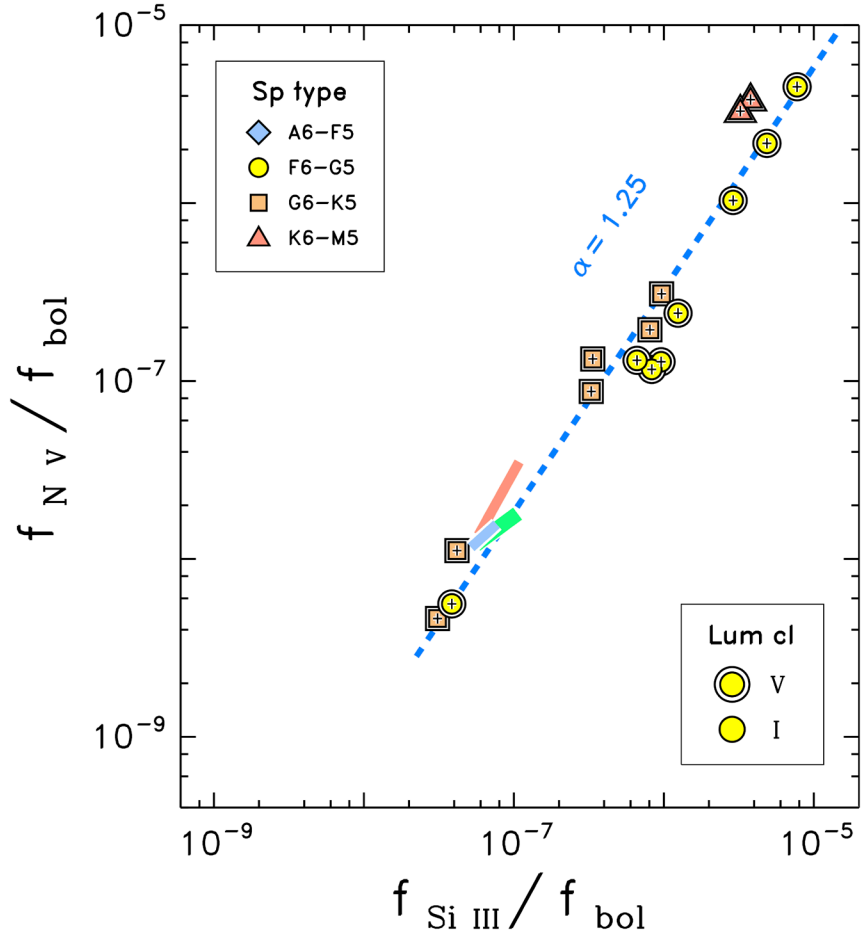

O I 1305 Å
Si III 1206 Å
X-rays
N V 1240 Å
Fe XII 1349 Å
H I 1215 Å
X-rays
C II 1335 Å
X−rays log (f_L / f_BOL)
O I 1305 log (f_L / f_BOL)
[+0.015 , +0.000]
N V 1240 log (f_L / f_BOL)
Si III 1206 log (f_L / f_BOL)
[+0.085 , +0.095]
Fe XII 1349 log (f_L / f_BOL)
X−rays log (f_L / f_BOL)
[+0.000 , +0.085]
H I 1215 log (f_L / f_BOL)
C II 1335 log (f_L / f_BOL)
[+0.015 , −0.355]





Stellar flux-flux power laws over wide range of activity. Green bar shows solar behavior over *SORCE*-SOLSTICE era; blue bar, STIS **α** Cen A; rose bar, **α** Cen B. The disparate behaviors could not be guessed from the heterogenous stellar sample. ***Note that the Sun and the α Cen stars fall near the bottom of activity heap.***

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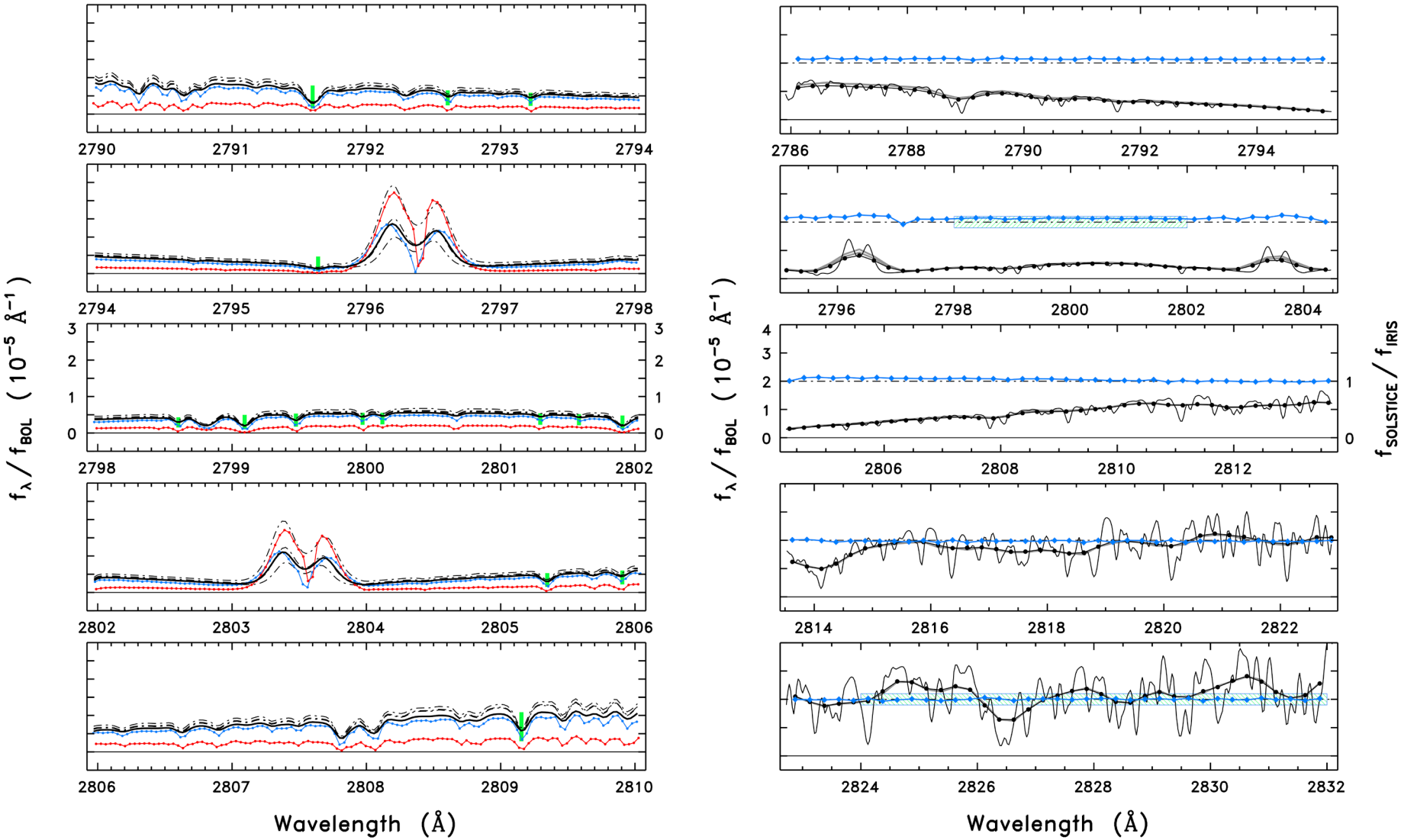
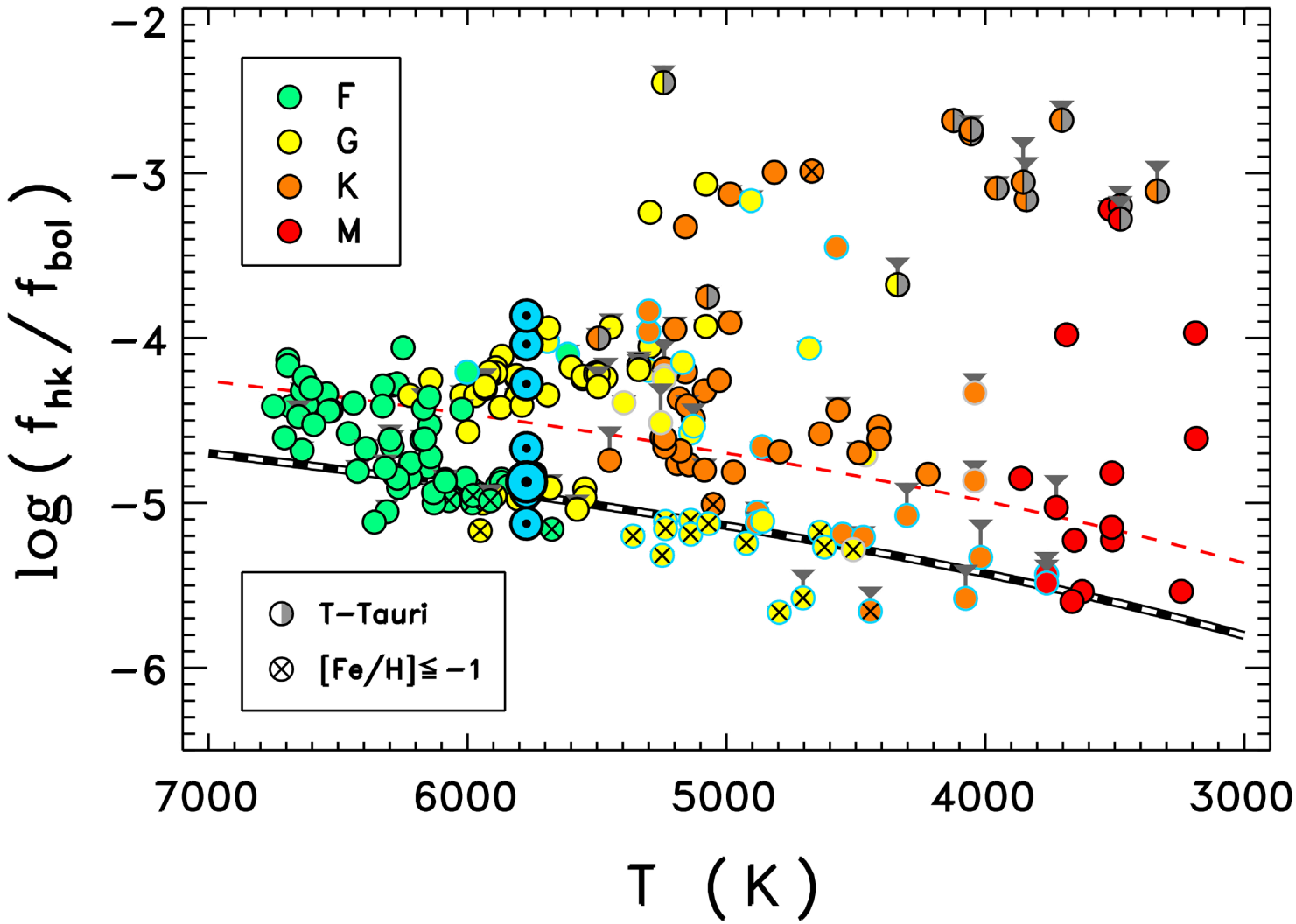
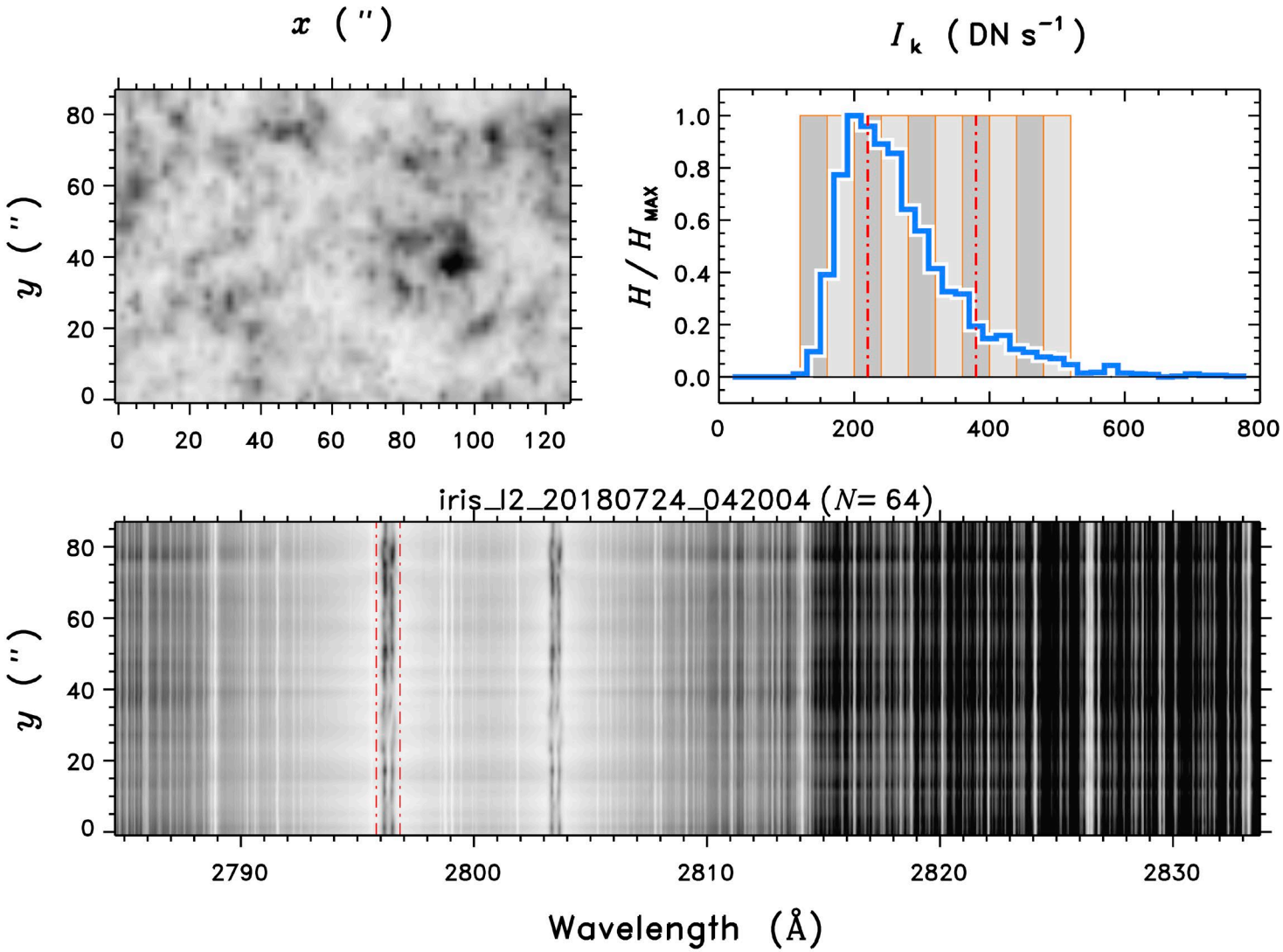


Left hand panel depicts IRIS profiles of Mg II brightness components of quiet-Sun (low, medium, high: dot-dashed); and disk-average (thick solid). STIS **α** Cen A is blue curve; **α** Cen B is red. ***Right panel is calibration of IRIS "flux" vs. SOLSTICE.***



Stellar Mg II emission vs. effective temperature. Blue dots show range of solar Mg II brightness components derived from IRIS NUV histograms, from low-quiet (bottom) to bright-plage (top). Larger dot in middle depicts span of solar cycle. ***IRIS quiet-Sun disk average falls slightly below: the true "quietest quiet-Sun??"***



Example of IRIS histogram analysis. Spectral frame is one of 64, which were used to build up the k-line "filtergram," above left; and intensity histogram, above right. Latter divided into 3 brightness levels: low, medium, high-(quiet). ***The k-line image represents the quietest-Sun: shocked BPs and SG-Network.***

Conclusions

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That’s all Folks:

Have a Nice L(a)unch!