CHIANTI and Solar-C

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CHIANTI is an Atomic Database and Software Package

- CHIANTI was first released in 1996 and made freely available to all
- For modeling emission lines and continua from ionized atoms
- Database contains atomic rates, energies and wavelengths for ions of elements up to zinc
- IDL software package continues to be the “master”
  - Ken Dere maintains ChiantiPy
  - Will Barnes has alternative FIASCO Python package
- CHIANTI papers have received over 4500 citations

https://chiantidatabase.org

CHIANTI Team

United States

Peter Young (NASA GSFC)

Ken Dere (GMU)

Enrico Landi (Univ. Michigan)

Will Barnes (American Univ., NASA GSFC)

United Kingdom (Cambridge University)

Giulio Del Zanna

Roger Dufresne

[Helen Mason]

How is CHIANTI used?

1. For deriving plasma parameters from spectroscopic data
2. For deriving radiative emissions from 3D modeling codes
3. For predicting count rates during instrument development
4. For deriving response functions (e.g., AIA) and radiometric calibration (e.g., EIS)

CHIANTI and Hinode/EIS

- CHIANTI has been critical to the success of EIS
- 58% of EIS papers cite a CHIANTI paper
- CHIANTI was used to update the radiometric calibration in orbit

EIS has been important for improving CHIANTI

- Many new line identifications
- Testing atomic data accuracy
- Improving density diagnostic accuracy

Name	No. of papers
Del Zanna, G	23
Brooks, D	21
Harra, L	18
Warren, H	16
Doschek, G	15
Young, P	15
Landi, E	13
Baker, D	12
Hahn, M	10
Tripathi, D	9

CHIANTI team have been major users of EIS data!

Topics

CHIANTI-related topics

- Fe VII and Fe IX wavelengths
- Wavelength accuracy (Mg VII & Si VII)
- Advanced models for transition region ions

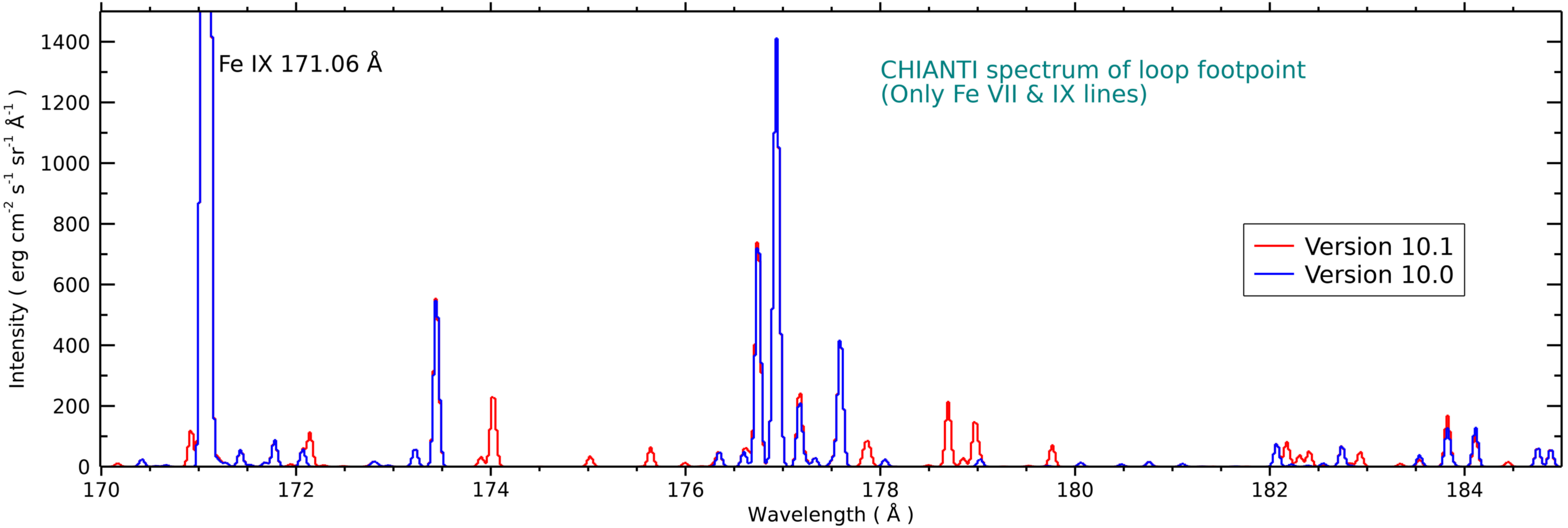
Other topics

- Large Doppler shifts
- Scattered light
- Radiometric calibration

Fe VII and Fe IX Line Identifications and Wavelengths

- Fe VII and Fe IX have complex spectra in 150-250 Å range due to complex atomic configurations
- Laboratory spectra of A. Ryabtsev (Moscow) have yielded a number of new identifications [Young et al. (2021), Kramida et al. (2022), Ryabtsev et al. (2022)]
- Ions were updated with CHIANTI 10.1 (2023)
- If EUVST has good effective area in 170-185 Å range, then should be some useful diagnostics

Fe VII and Fe IX Lines (170-185 Å)



Red lines have new observed wavelengths following laboratory work

(Peak of Fe IX 171 Å is 24,200)

Wavelength Accuracy

- Use EIS spectra to update reference wavelengths for Mg VII & Si VII
- Two sources of reference wavelengths:
  - NIST database
  - B. Edlén compilations (1980s)
- Comparisons with EIS spectra suggested problems with both for Mg VII & Si VII

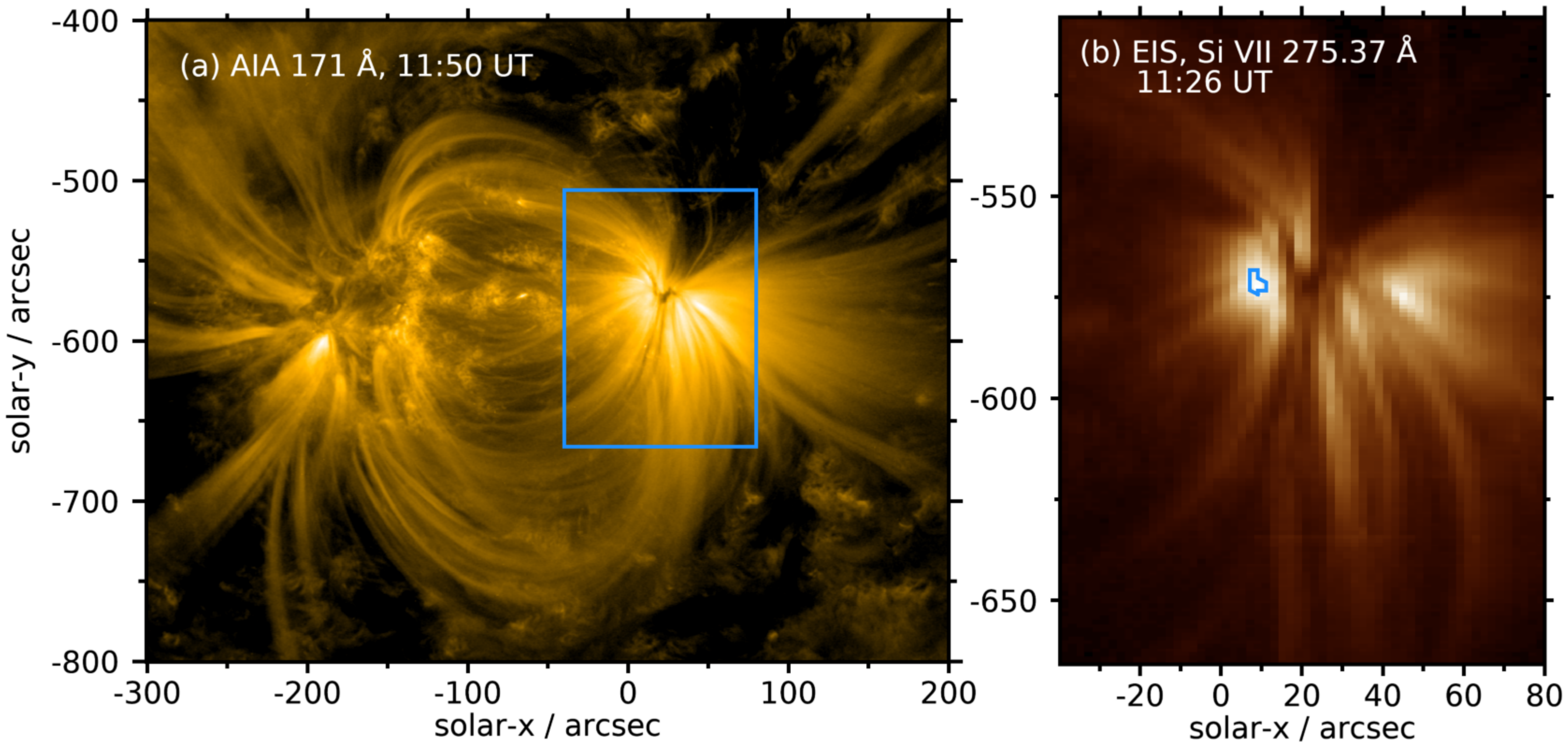
Line	NIST	Edlén	Difference
Si VII 275.3 Å	275.353	275.361	+9 km/s
Mg VII 276.4 Å	276.154	276.138	-17 km/s

EIS absolute accuracy is 5 km/s; relative accuracy is 1 km/s

Young, 2023, ApJ

Use Loop Footpoints to Measure Lines

Mg VII & Si VII lines enhanced by factors >10 at these locations



Young, 2023, ApJ

Results

Ion	Configurations	Terms	$\Delta\lambda^{a}/\text{Å}$	Wavelengths (Å)			
				Measured[a]	Ritz[a]	ASD	Edlén
Si VII	$2s^22p^4$–$2s2p^5$	$^3P_2$–$^3P_1$	−2.7105(9)	272.658 (4)	272.658 (3)	272.639	272.647
		$^3P_1$–$^3P_0$	−1.1804(13)	274.188 (4)	274.188 (4)	274.175	274.180
		$^3P_2$–$^3P_2$	0.0000	275.368 (4)	275.368 (3)	275.353	275.361
		$^3P_1$–$^3P_1$	+0.3158(8)	275.684 (4)	275.685 (3)	275.667	275.675
		$^3P_0$–$^3P_1$	…	…	276.860 (3)	276.839	276.850
		$^3P_1$–$^3P_2$	+3.0877(27)	278.456 (5)	278.456 (3)	278.443	278.449
Mg VII	$2s^22p^2$–$2s2p^3$	$^3P_0$–$^3S_1$	+0.7739(10)	276.142 (4)	276.142 (3)	276.154	276.138
		$^3P_1$–$^3S_1$	…	…	276.993 (3)	277.001	276.993
		$^3P_2$–$^3S_1$	+3.0261(18)	278.394 (4)	278.394 (3)	278.402	278.393
		$^1D_2$–$^1P_1$	+5.3613(14)	280.729 (4)	280.729 (4)	280.737	280.722

- Mg VII & Si VII results should be valuable for MUSE (284 Å channel)
- CHIANTI team will need to assess accuracy of wavelengths for EUVST lines in long-wavelength channels

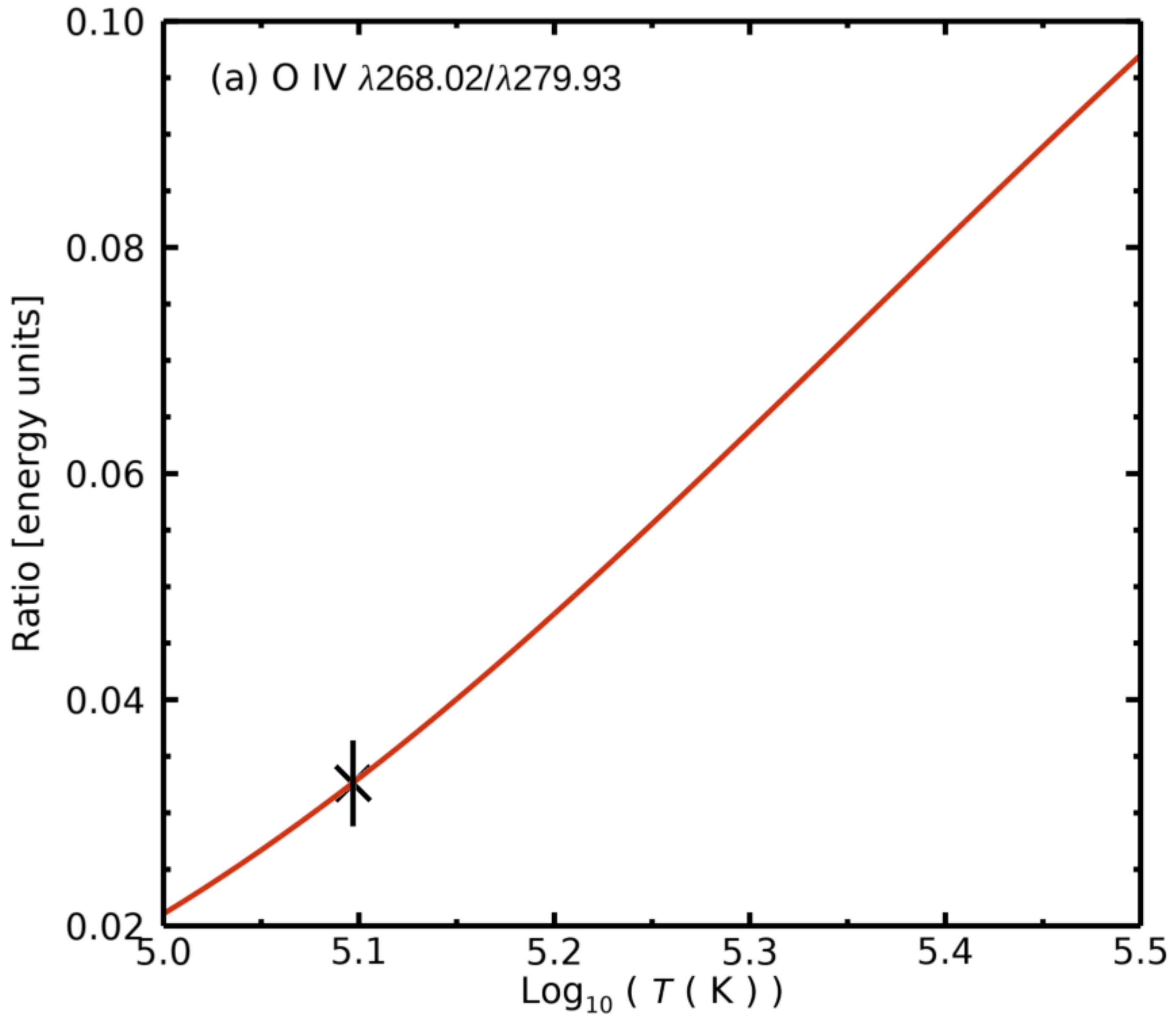
Young, 2023, ApJ

Advanced Models for Transition Region

- R. Dufresne and G. Del Zanna have developed new atomic models for transition region ions
- Additional processes
  - Level-resolved ionization and recombination
  - Suppression of dielectronic recombination at high densities
  - Charge transfer (model-dependent)
- Generally leads to ions being formed at lower temperatures
- CHIANTI version 11 will include these advanced models

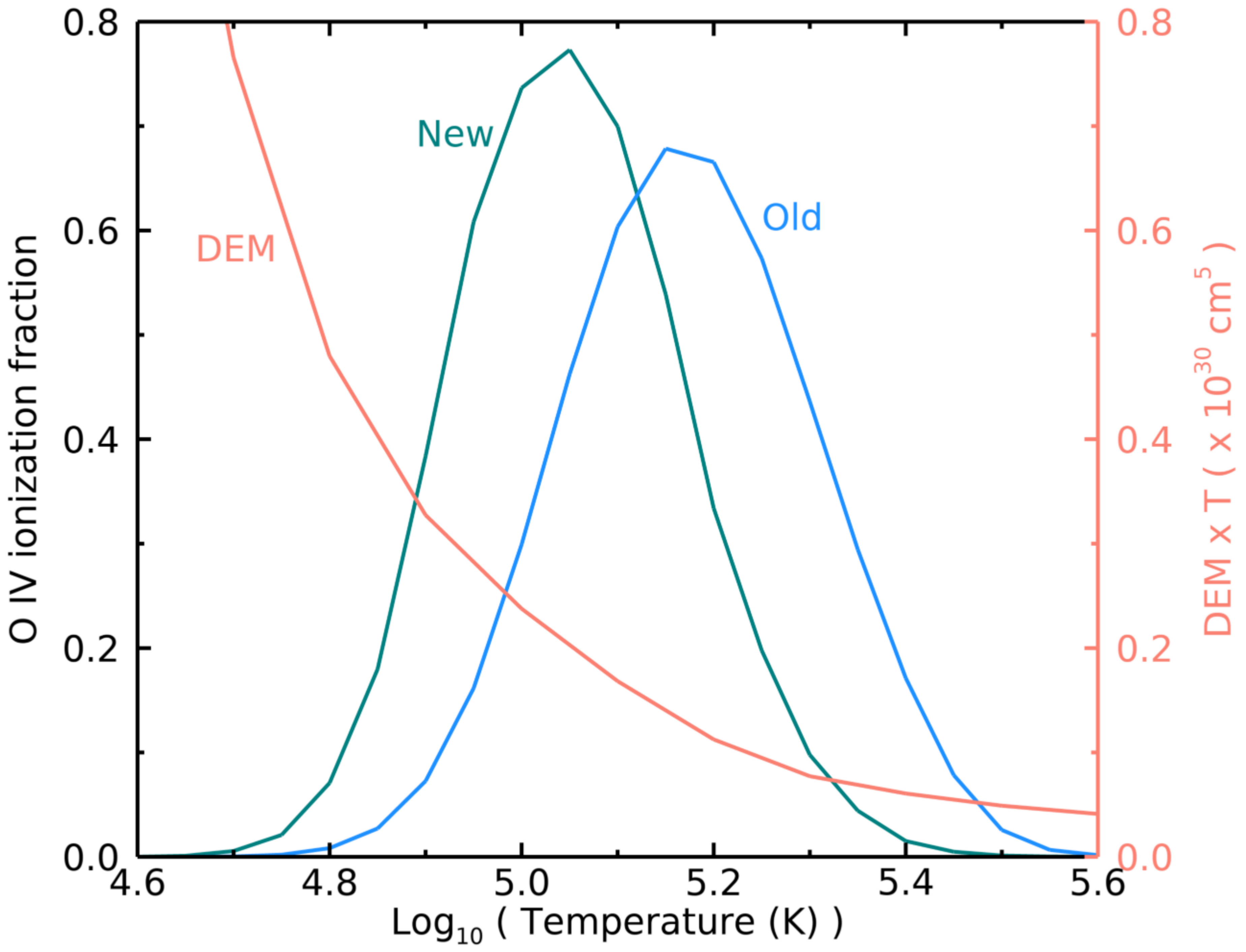
Dufresne et al., 2023, MNRAS; Dufresne & Del Zanna, 2019, A&A

Example: EIS O IV Lines from a Flare



EIS λ268.02/λ279.93 ratio gives log T = 5.10

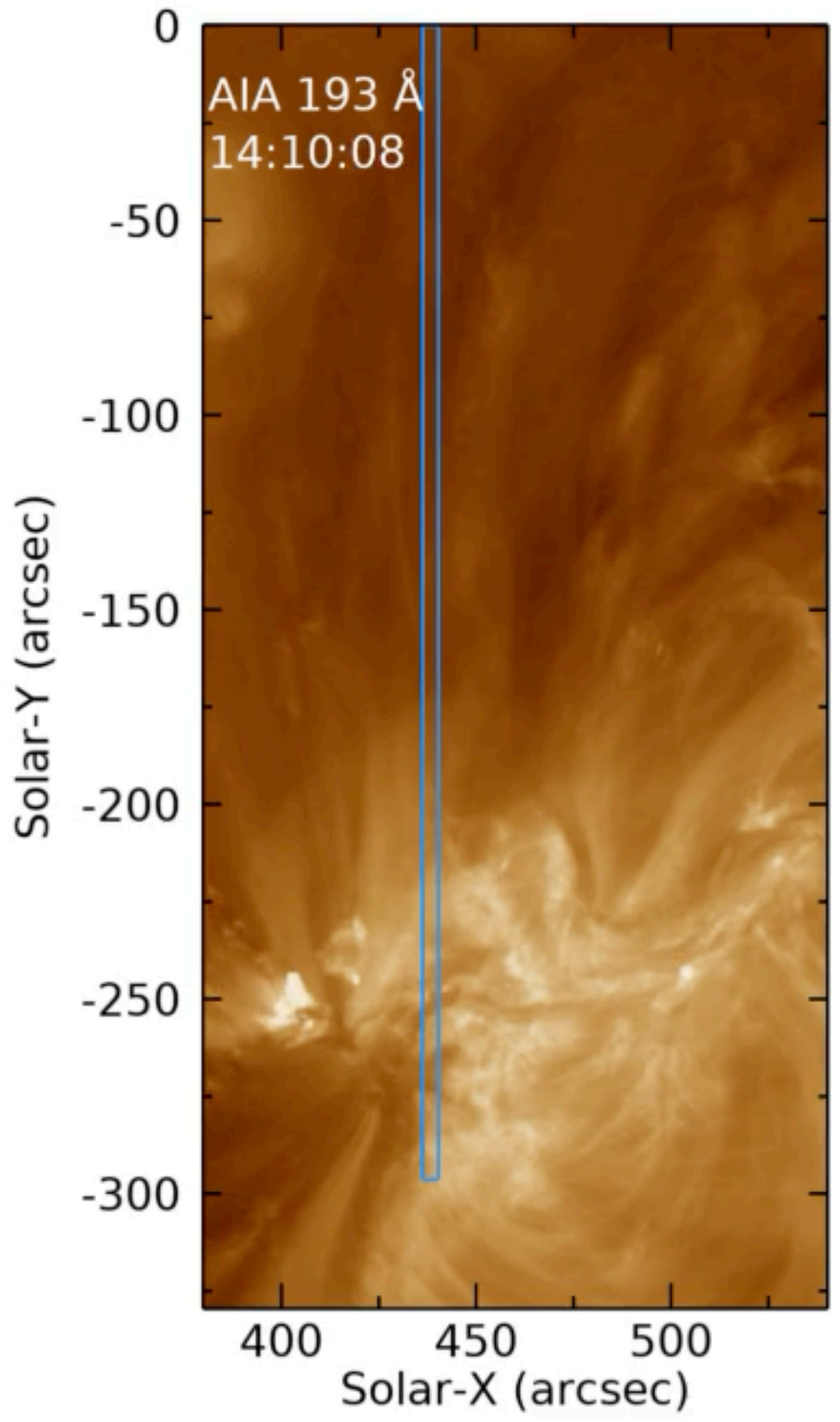
Lines' contribution functions peak at log T = 5.25

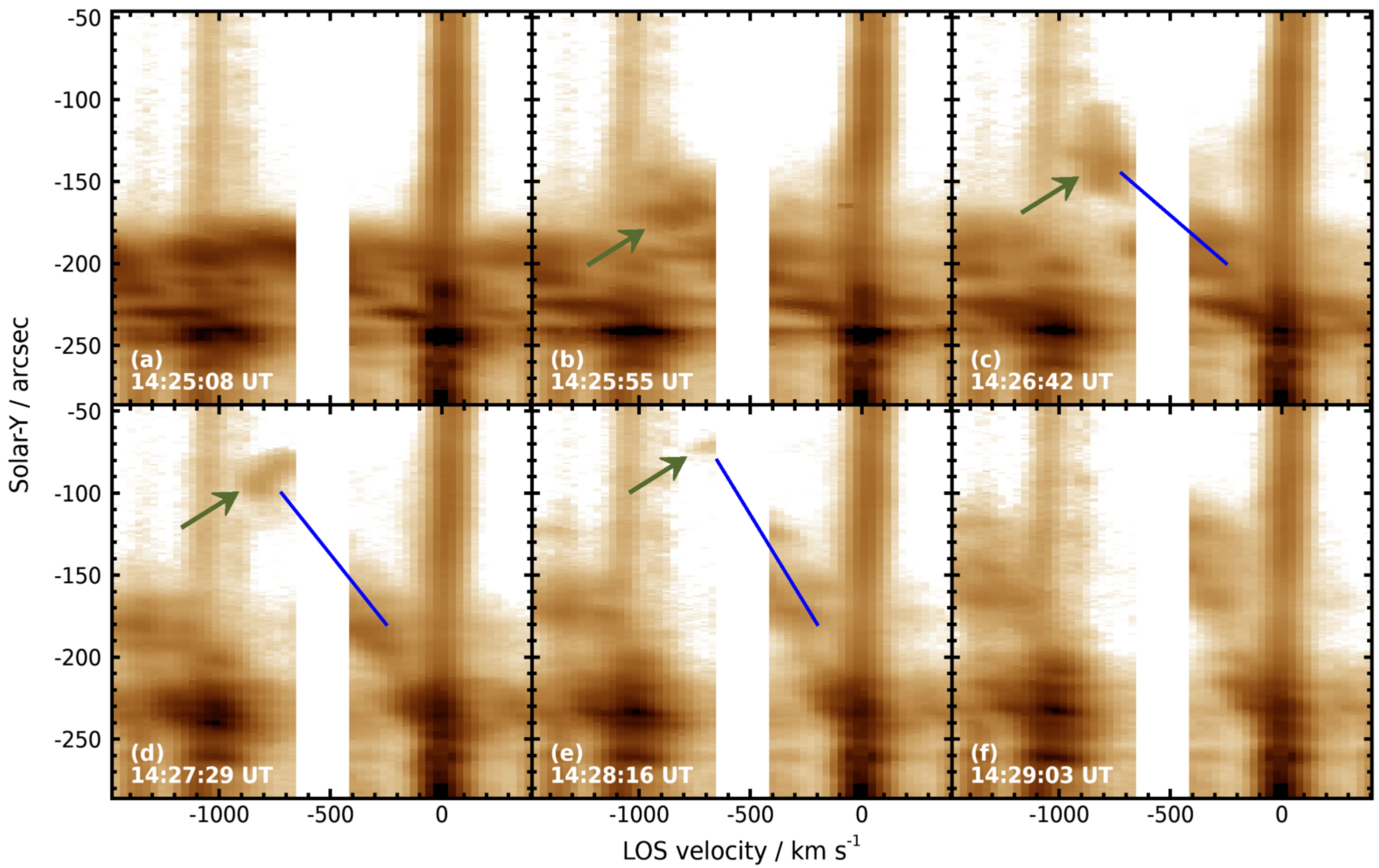


Explained by strongly-sloped DEM and new ionization equilibrium curve for O IV

Young, 2024, arXiv

Large Doppler Shifts





- Doppler shift of 850 km/s measured from Fe XII
- EUVST wavelength windows will need to be large to capture eruption dynamics

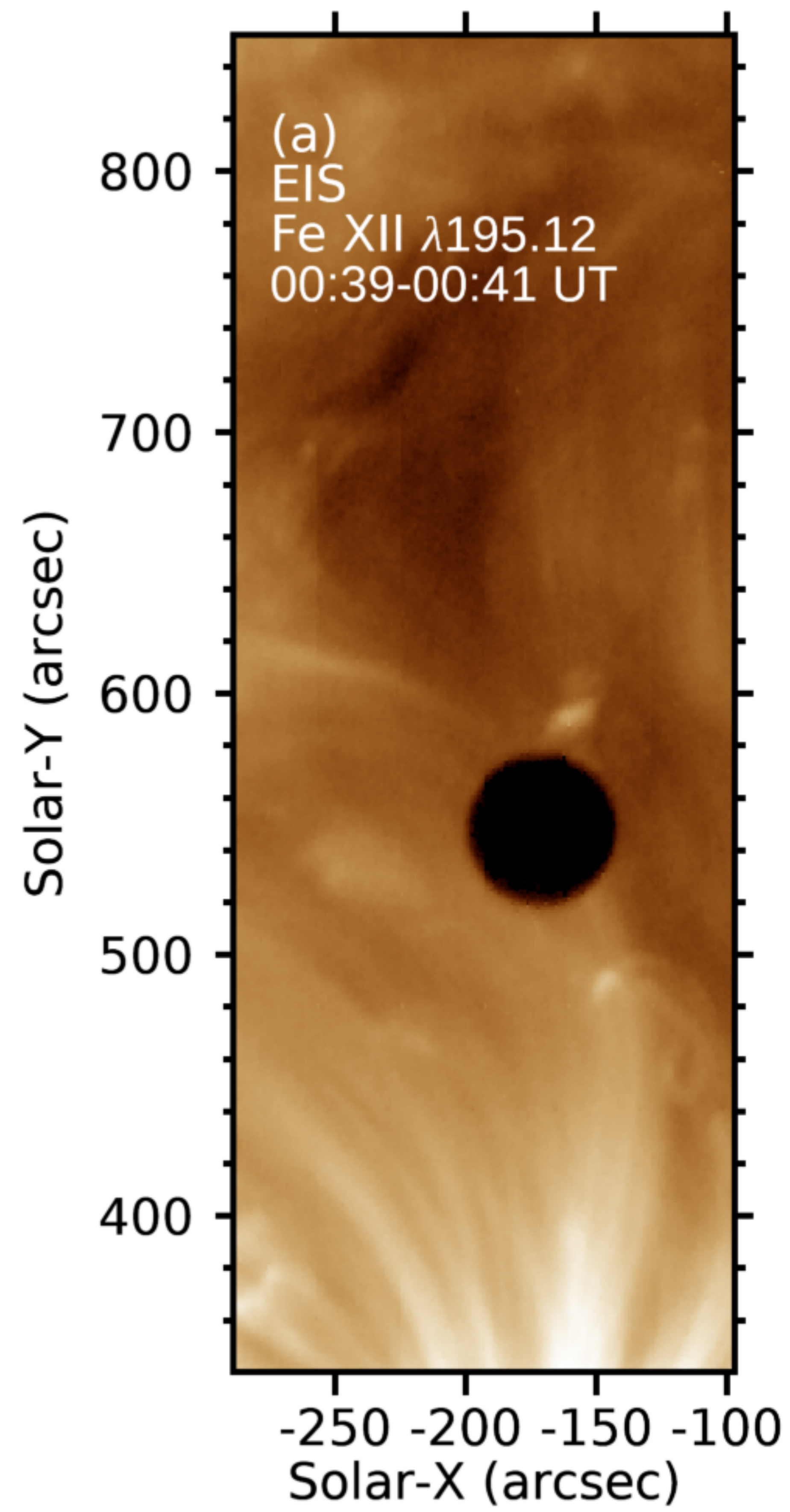
Young, 2023, Adv. Sp. Res.

Scattered Light

- Derived empirical formula for scattered light for EIS Fe XII λ195.12 using slot data
  - Used Venus transit data from 2012

$$I_{\mathrm{scatt}} = \frac{I_{\mathrm{ann}}}{6.6} + \frac{I_{\mathrm{fd}}}{34}$$

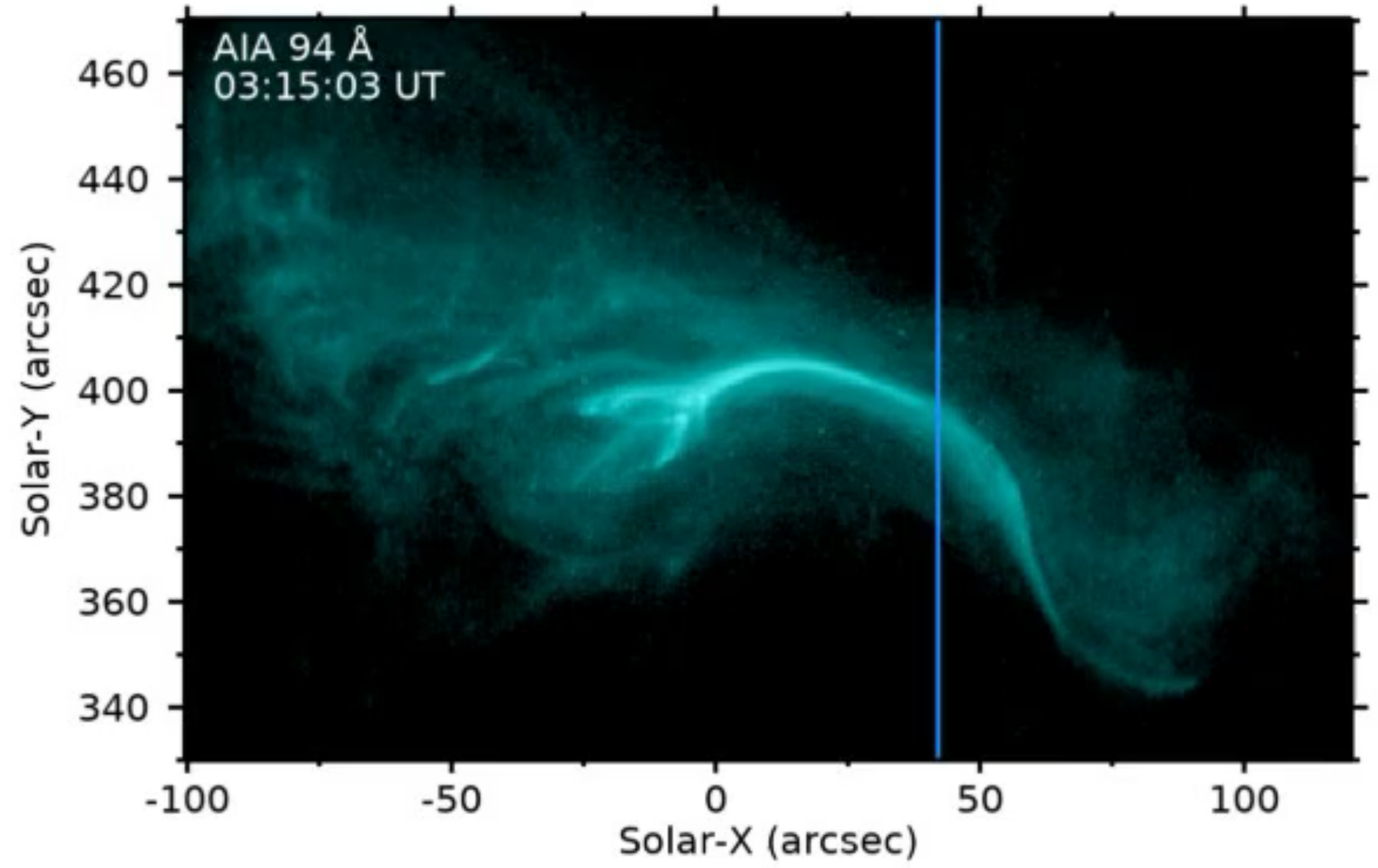
- Long-range scattered light often dominates in on-disk coronal holes
- Recommend characterizing this for EUVST on the ground
  - No slot for EUVST and no Venus transit!



Young & Viall, 2022, ApJ

CHIANTI Needs from Solar-C

- *Spectral atlas data should be a high priority from day one!*
  - Crucial for assessing sensitivity degradation
  - Needed for line identification and checking atomic data
  - Should cycle through a range of targets (on-disk, off-limb, AR, QS, CH)
- A flare spectral atlas is a goldmine of diagnostic information
  - Should be part of flare observation strategy
- Long-exposure data (e.g., 300 s) valuable for investigating weak lines



Rare example of EIS flare spectral atlas (9-Mar-2012)

Final Thoughts

- CHIANTI will be an essential tool for the success of Solar-C
- Solar-C data will also lead to improvements in CHIANTI
- Solar-C team members should sign up to the CHIANTI Google Group
  - https://groups.google.com/g/chianti
- Invite CHIANTI team members to Solar-C Science Meetings!

This talk available at https://pyoung.org/talks