Correlation between chromospheric and coronal heating

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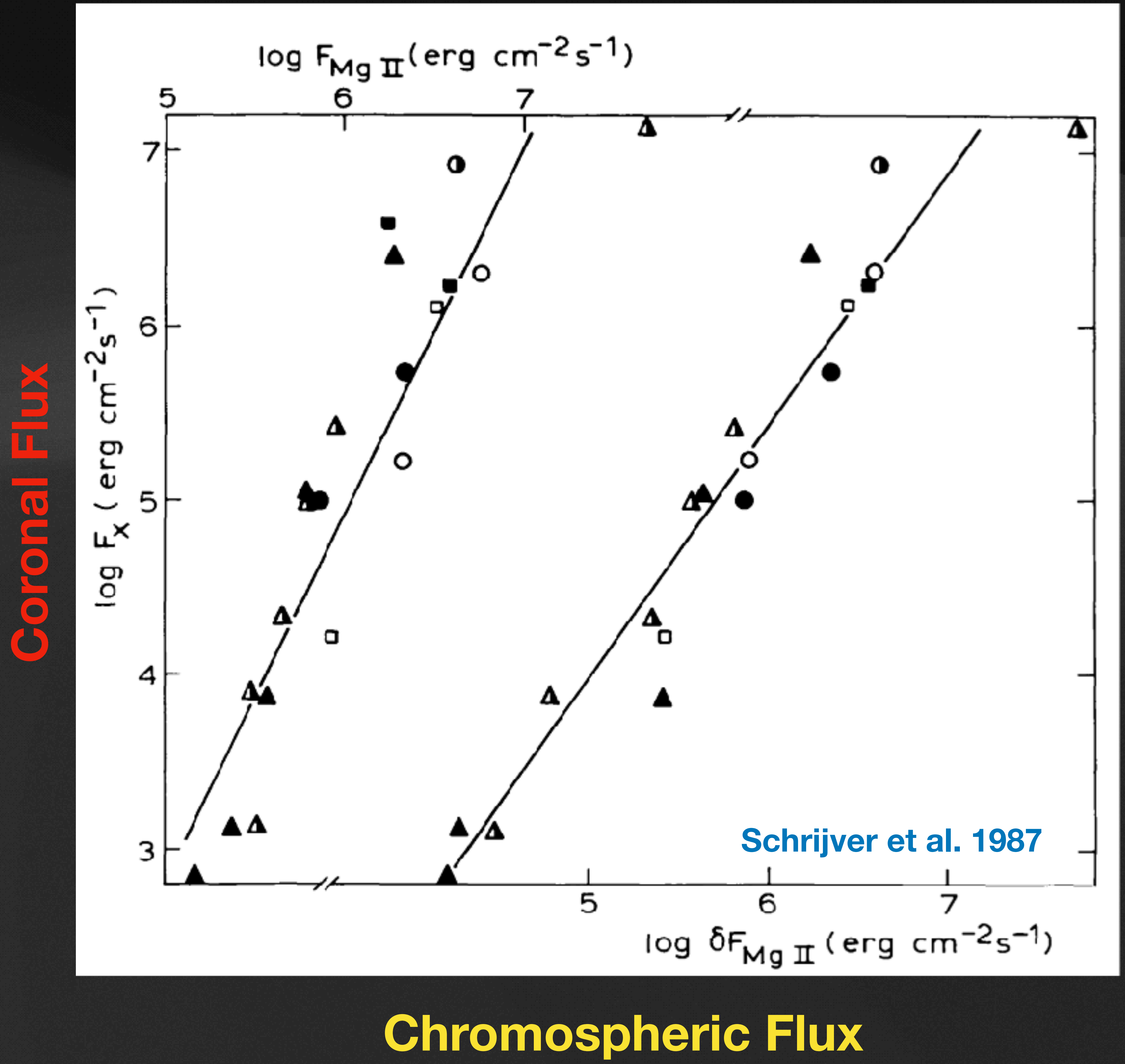
Bose et al. 2022 arXiv:2211.08579

Motivated from Stellar Studies

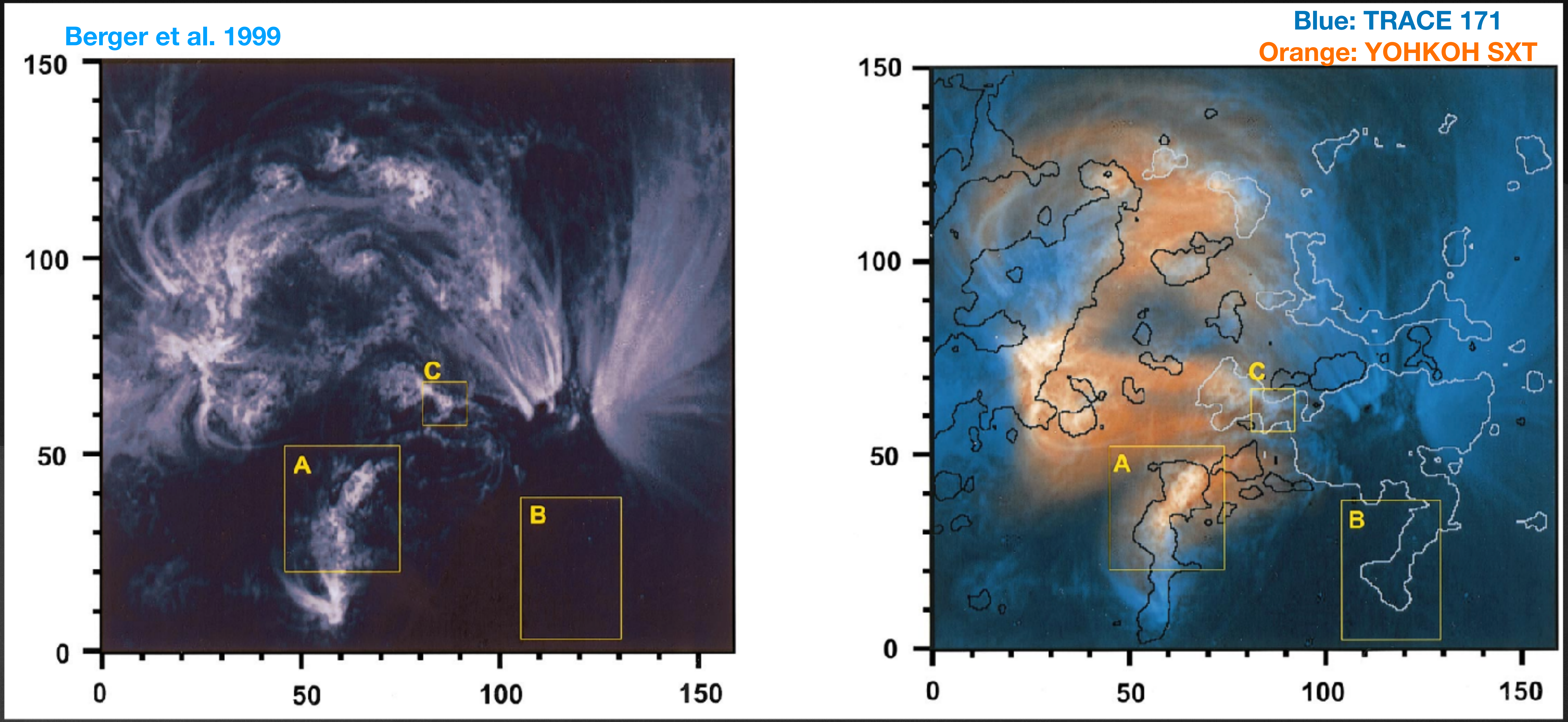
Analysis of Sun-like stars

- Tight power law relationship between flux densities.
- Chromospheric and coronal emission **correlated** on a global scale.



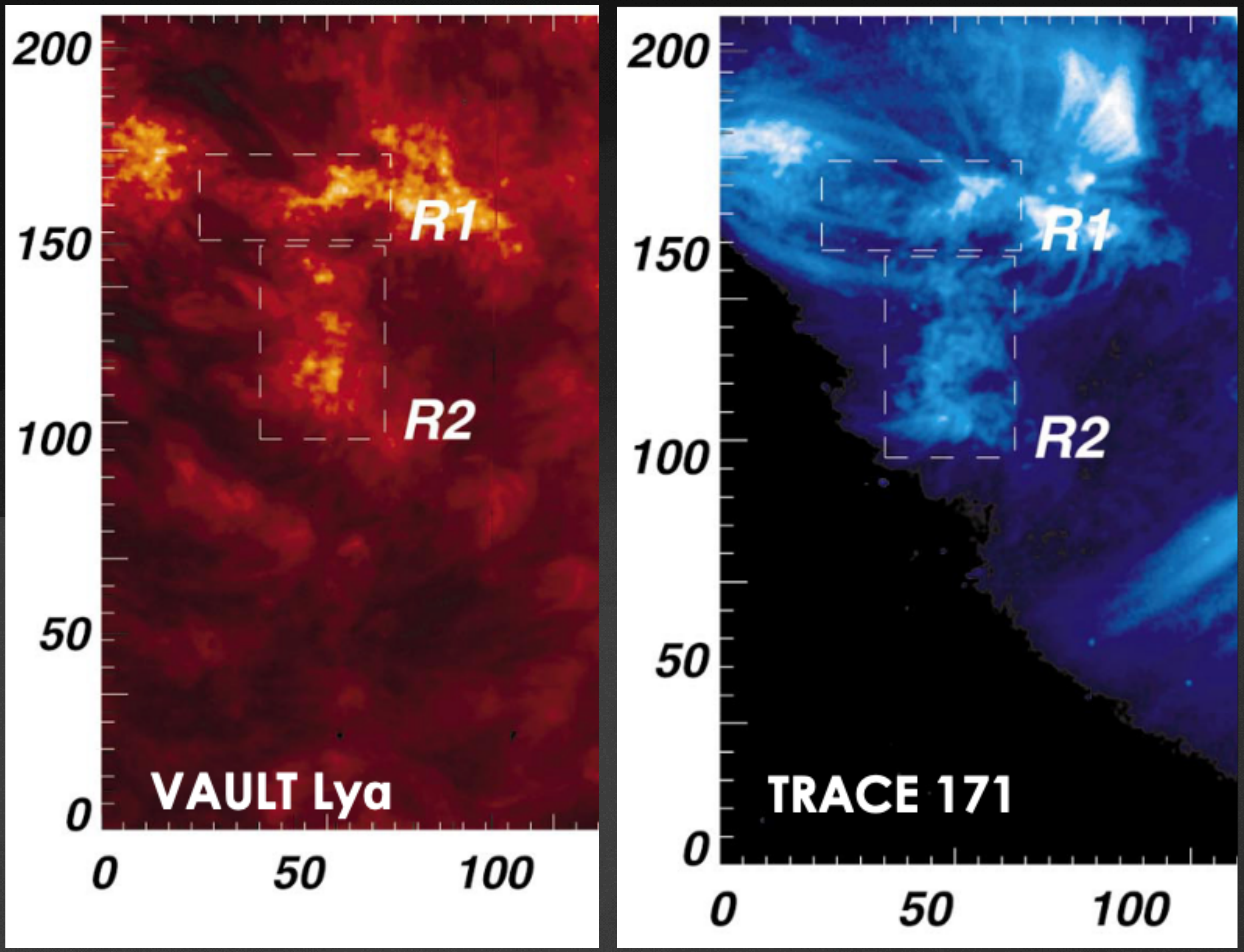
Can this be readily extended to the Sun?

Moss

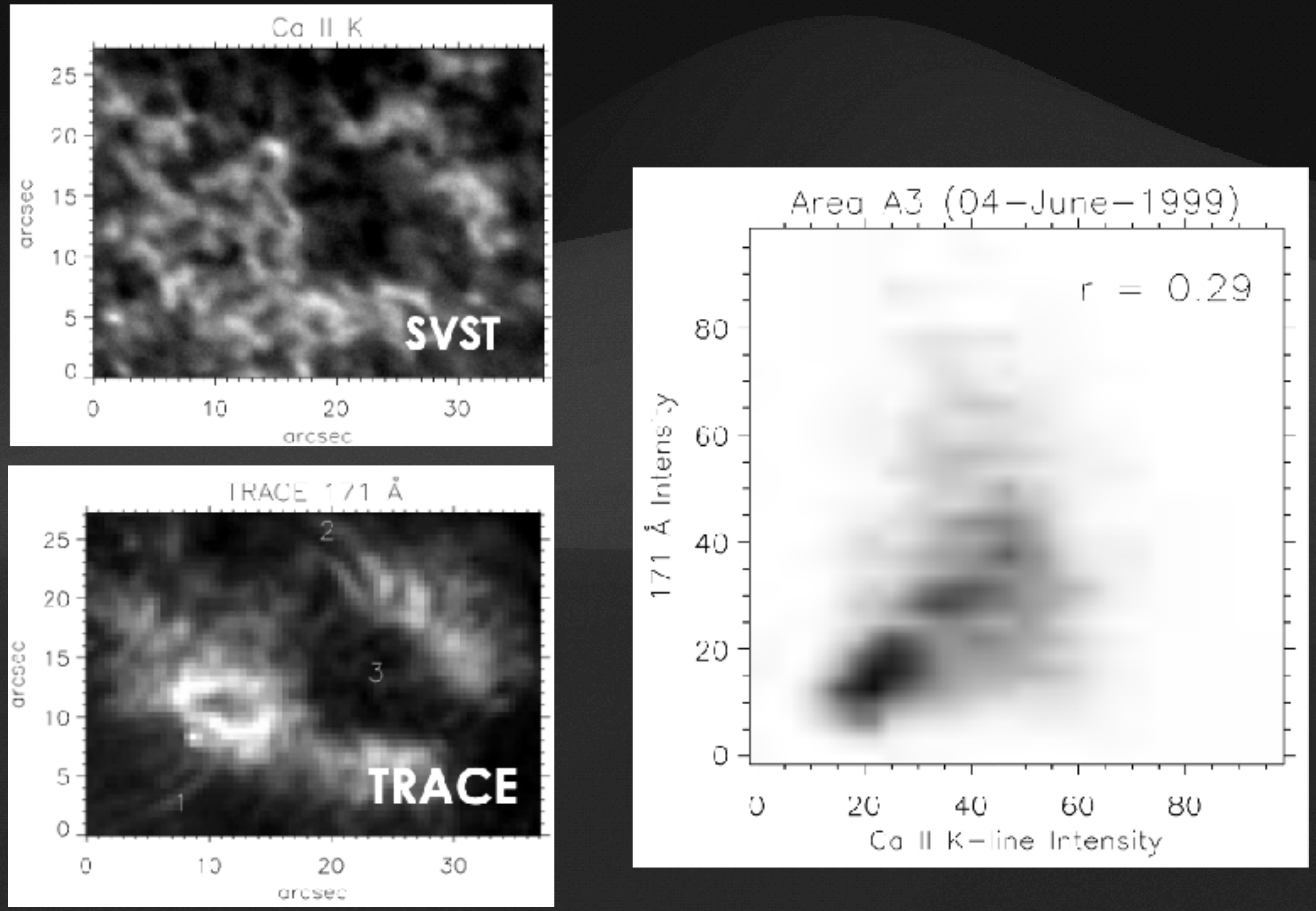


- Bright reticulated emission pattern above an AR plage (Berger et al. 2000).
- Footpoints of hot (2–5 x 10^5 K) and high density coronal loops (Fletcher & De Pontieu 1999).

Correlation: studies so far

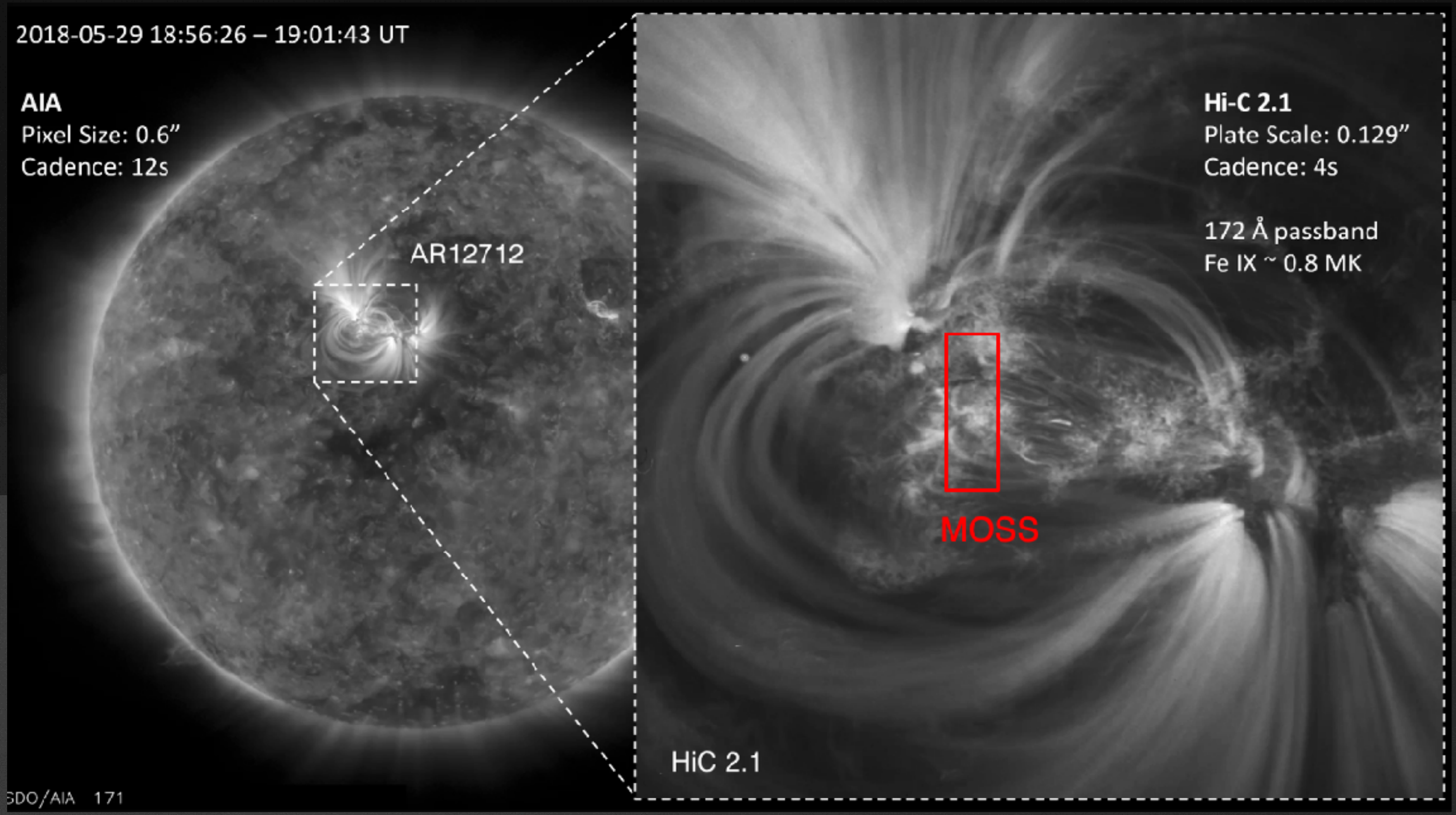


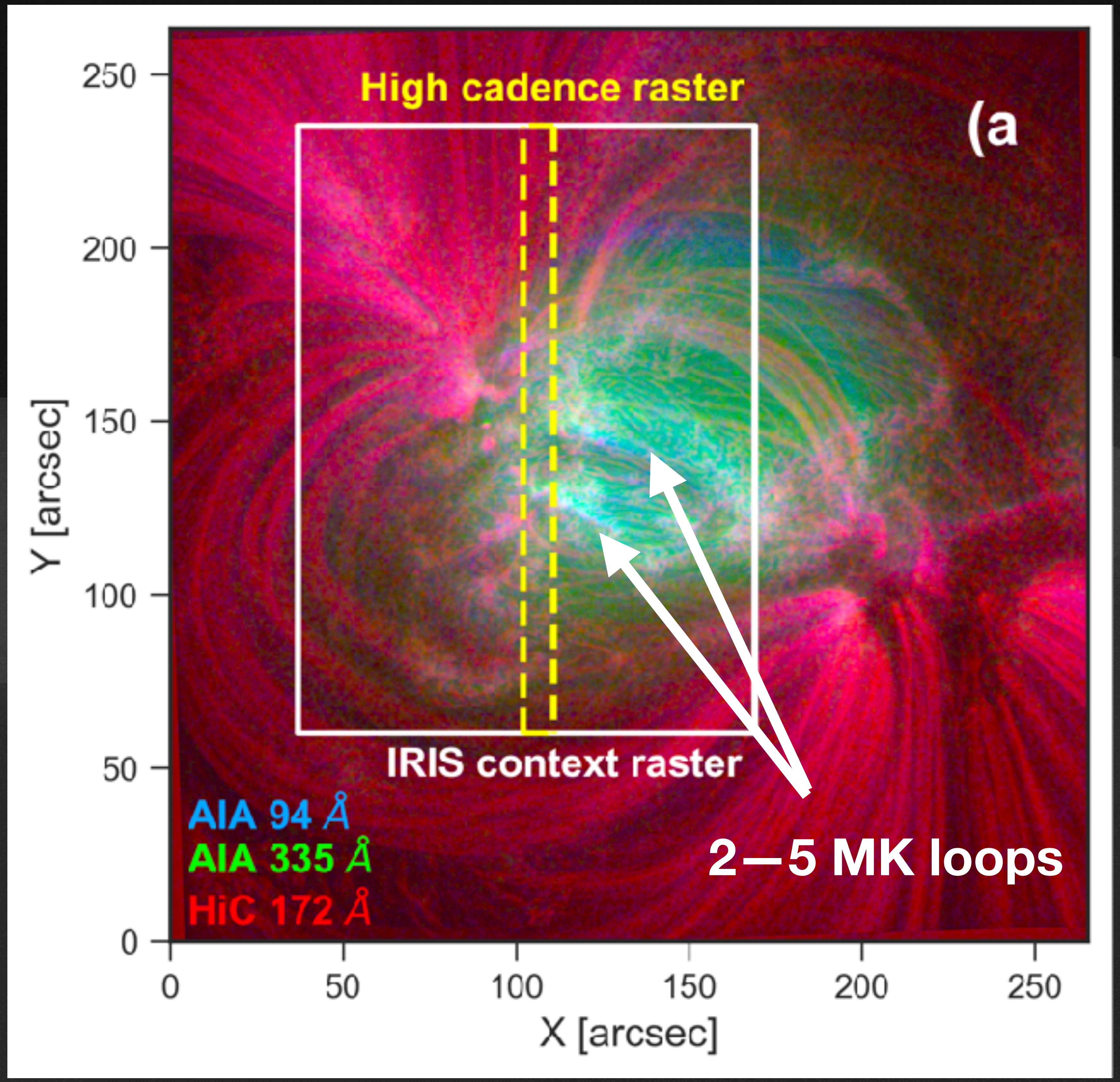
Visually well-correlated (Vourlidas et al. 2001)



- Correlation on smaller (sub)arc second scaled did not resemble global studies (e.g. De Pontieu et al. 2003)

Enter HiC 2.1 and IRIS

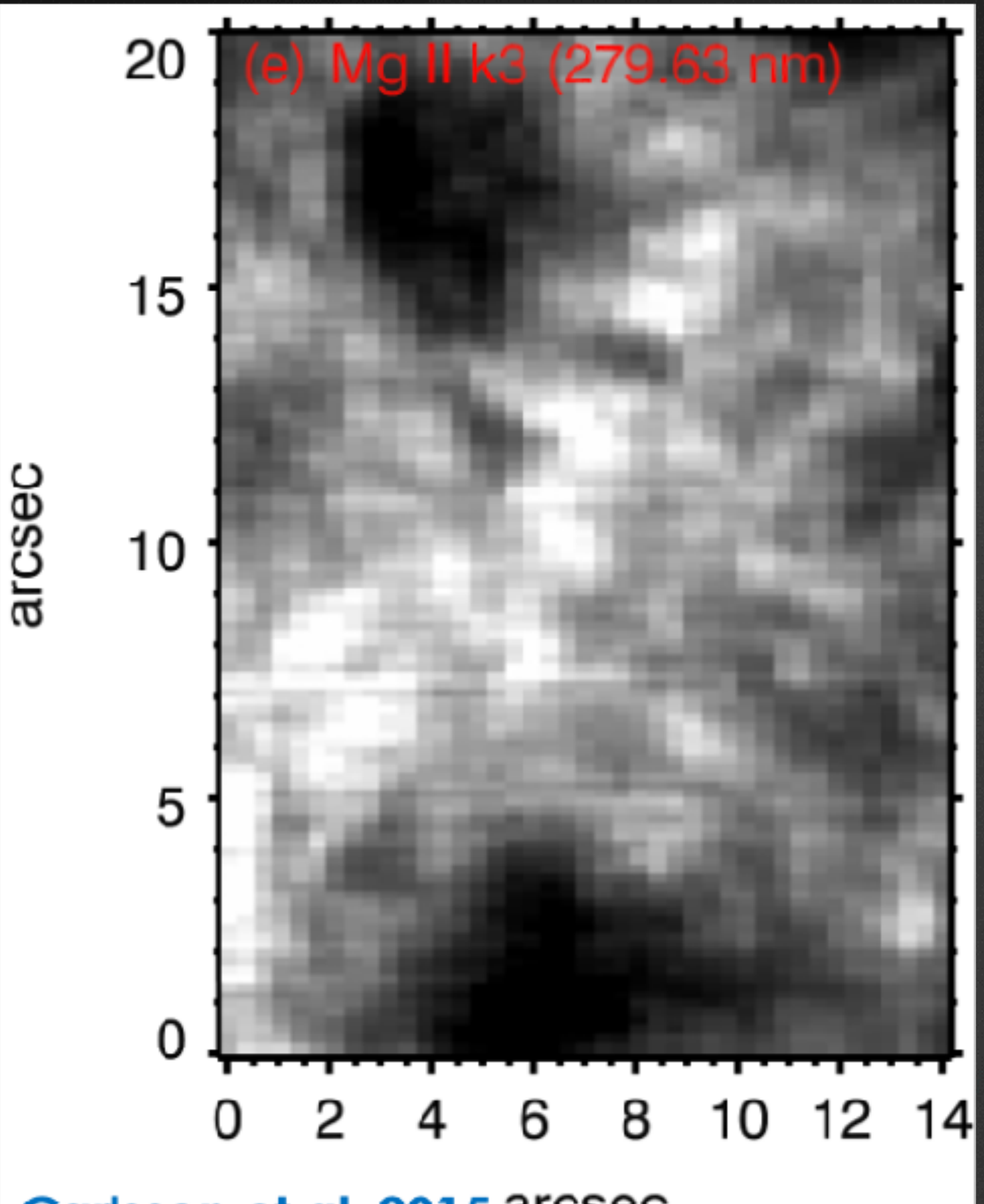




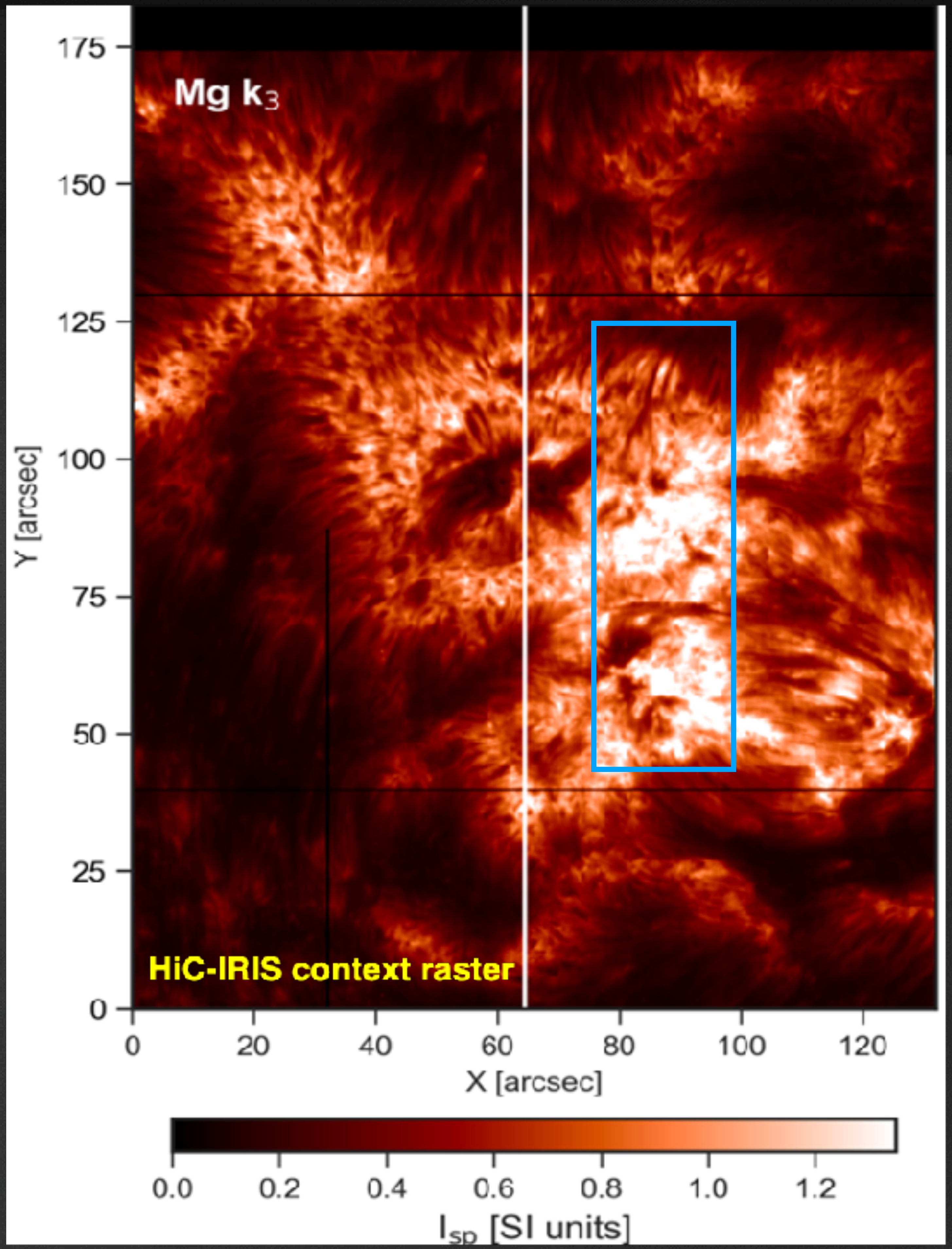
- Sounding rocket mission launched in 2018 lasting ~ 5.5 mins.
- Unprecedented high-**spatial** (**0.3”**) and temporal resolution (~ **4s**).
- IRIS coordination: very large sparse 8-step raster + dense 400-step context raster

Chromosphere underneath the moss

IRIS Mg II k observations

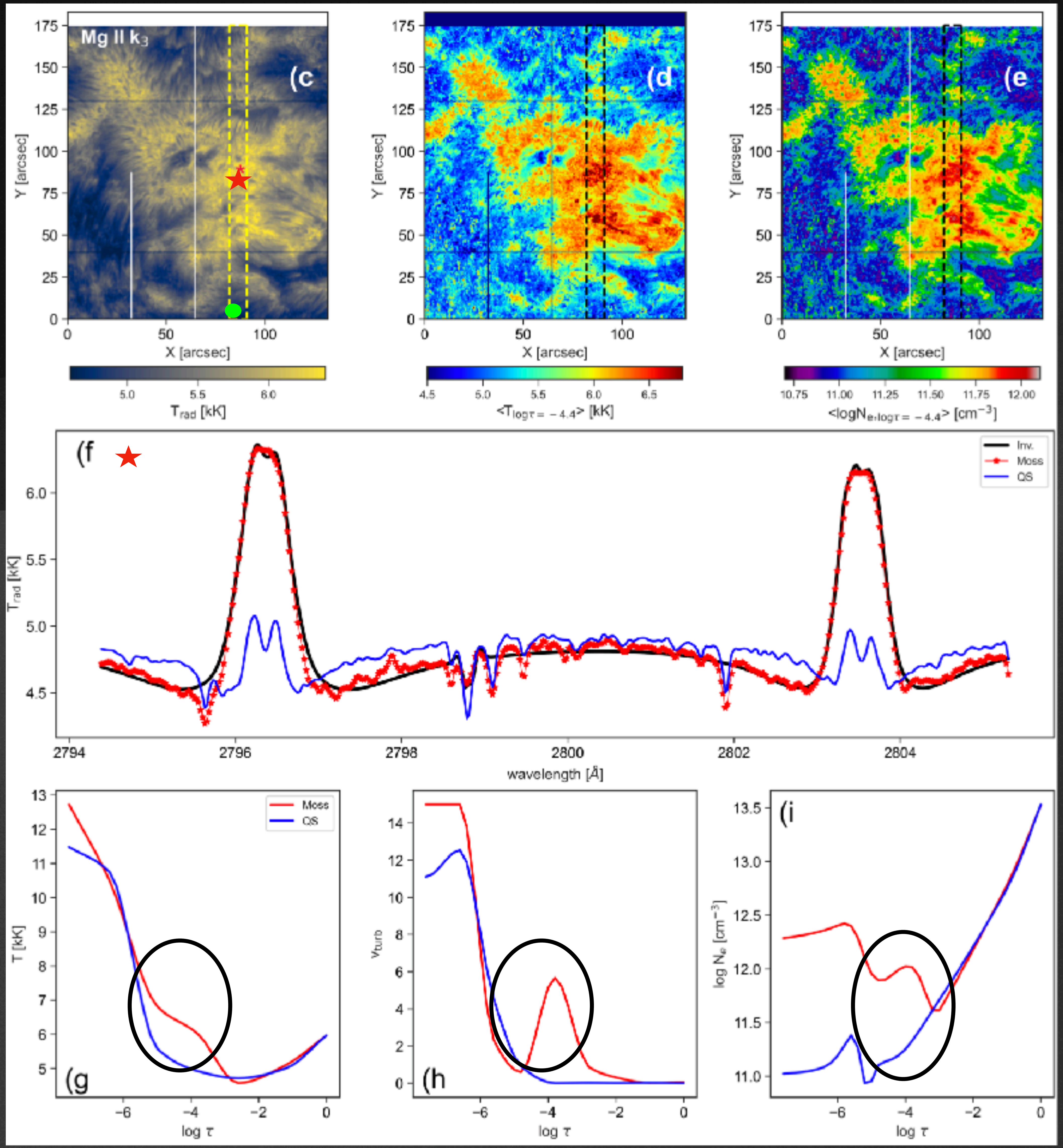


Carlsson et al. 2015



- Moss "occurs" where the Mg II k_3 shows enhanced brightness.
- Enhanced temperature and density (Carlsson et al. 2015).
- Implications of strong chromospheric heating.

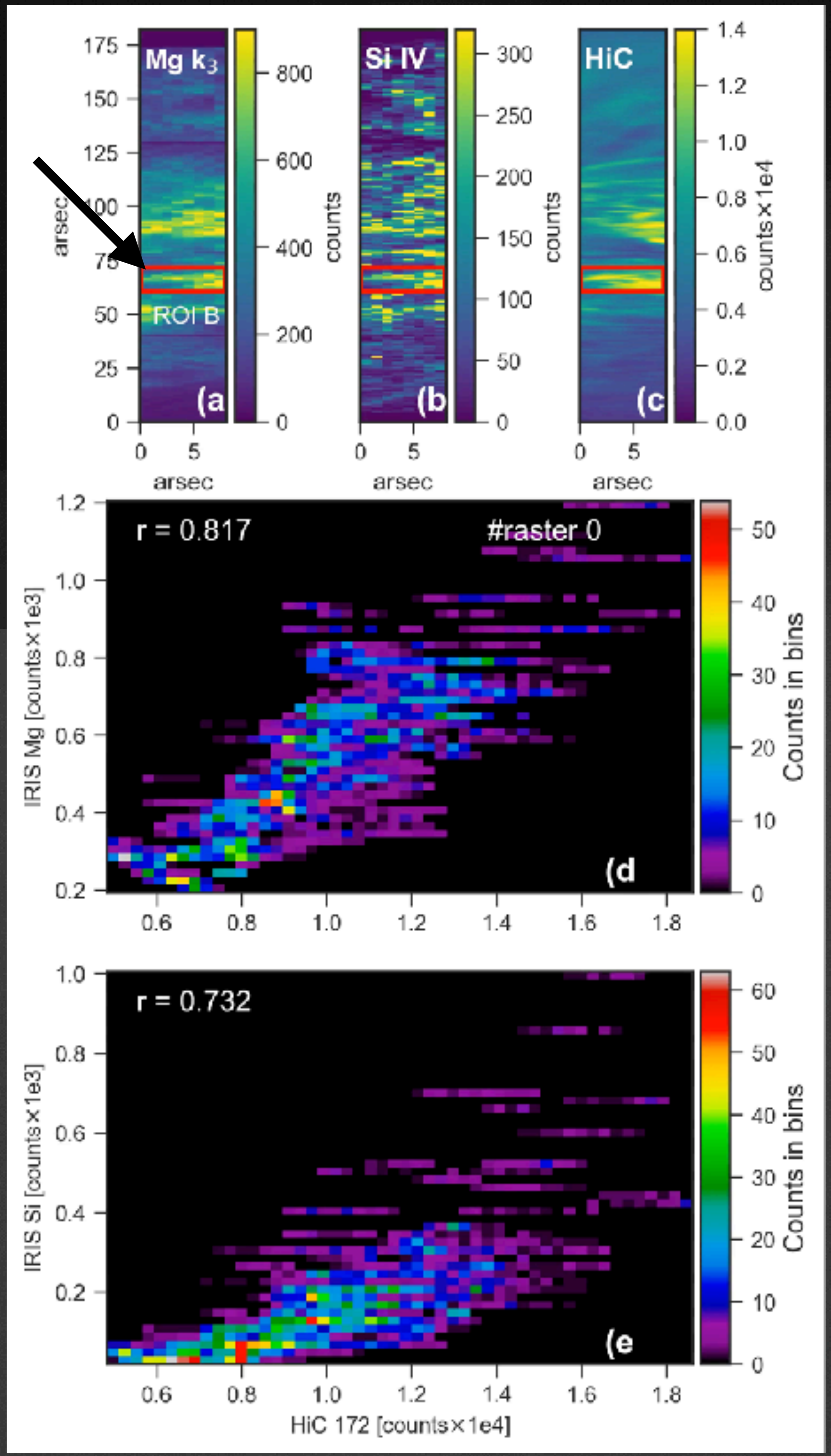
Multi-line inversions (*IRIS*$^{2+}$)



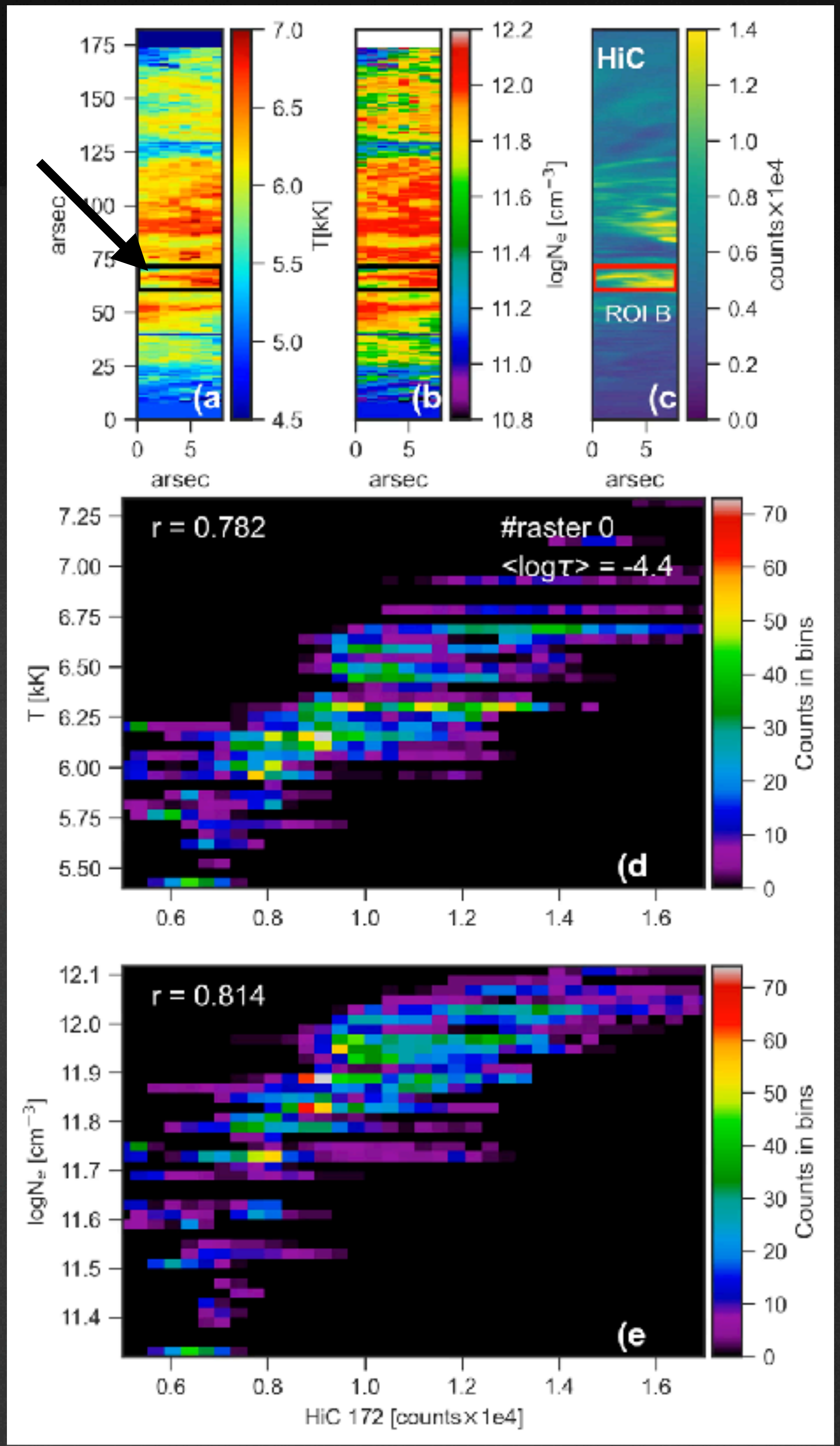
- *IRIS*$^{2+}$ inversions (Sainz Dalda et al. 2022) performed by combining C II, Mg II h&k, Mg II UV triplet, and the **photospheric** Fe I 2793 and Ni 2815 Å lines.
- Canonical spectral profiles: little-to-no self reversals in k_3 (Carlsson et al. 2015, Bose et al. 2022).
- Inversions show high density and enhanced temperature below the moss.

Spatio-temporal correlation analysis

Intensity correlation



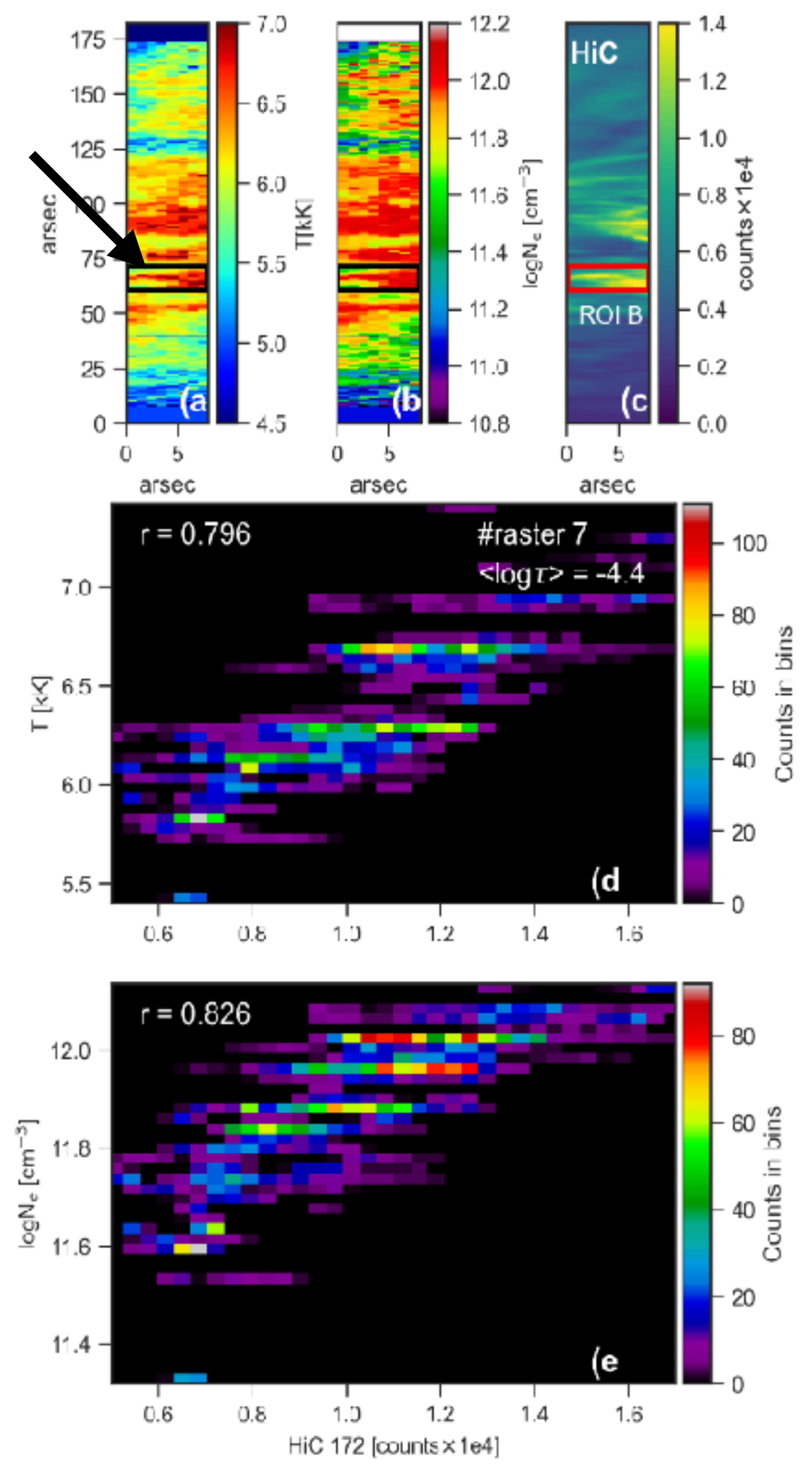
Thermodynamic correlation

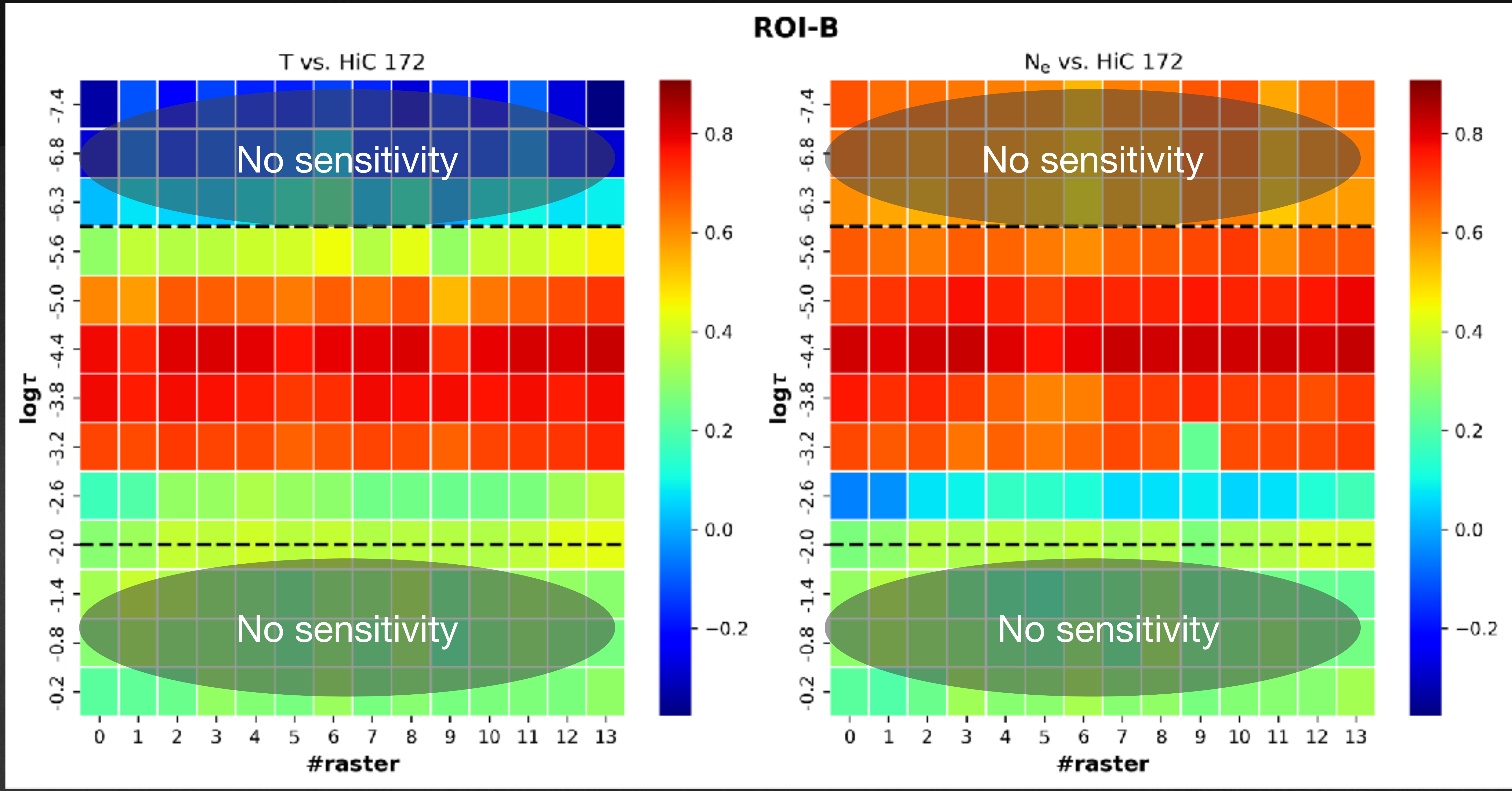


- Good correlation between IRIS and HiC intensities all through the chromosphere and TR.
- Coronal (HiC) emission well correlated with inferred T and density.
- **(Quasi)steady** non-impulsive heating pattern (unlike electron beams; see Testa et al. 2013, 2020)

Height dependence of the correlation

Thermodynamic correlation





- **Strong correlation** with HiC 172 Å well down to $log\ \tau = -3.2$ **(~ T minimum).**
- Thermal conduction is **negligible** at such temperatures (5 kK<T<6 kK) in the low chromosphere.
- Suggestive of a ***common*** heating mechanism.

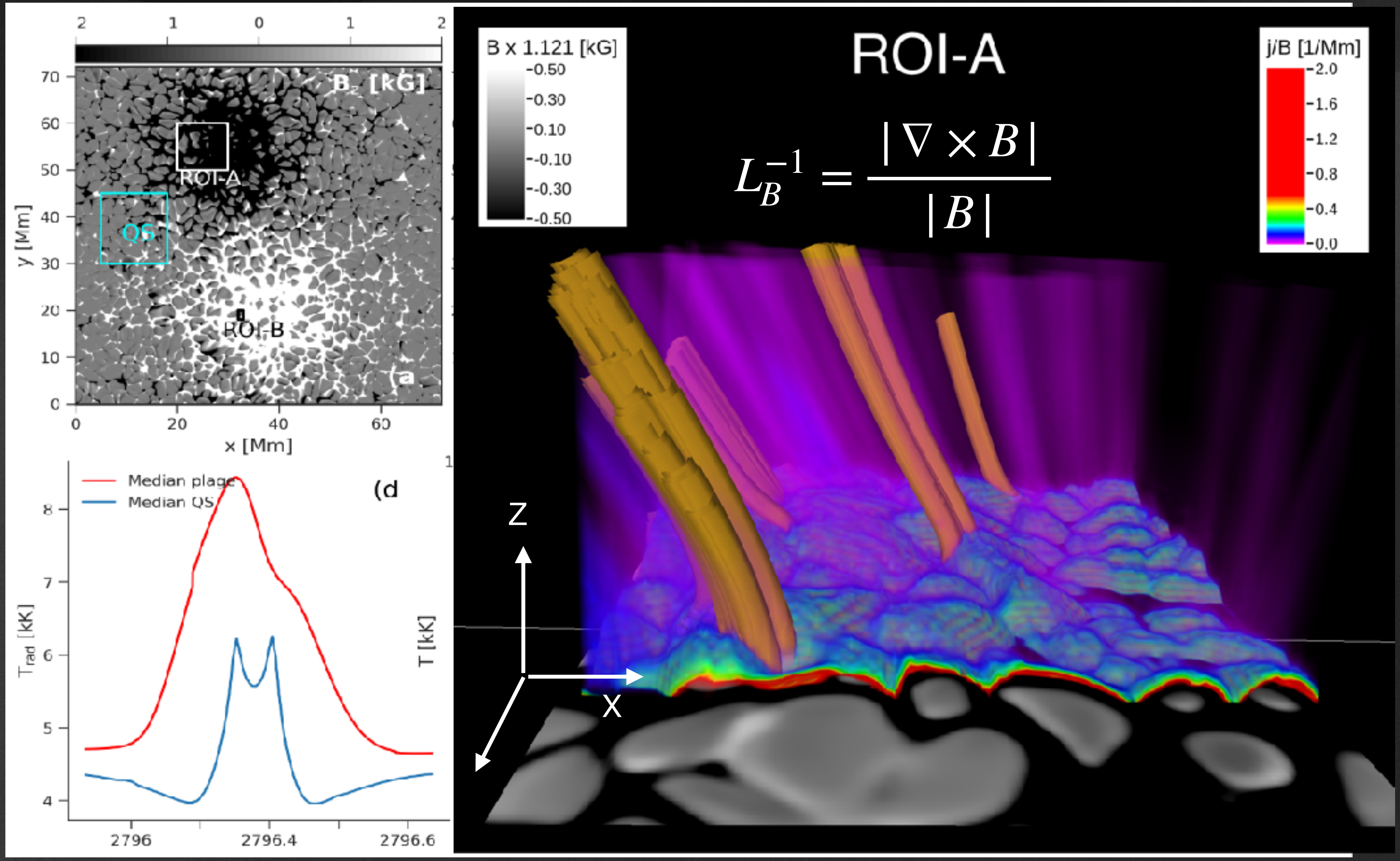
So what causes the heating?

Insights from a 3D MHD Bifrost simulation

- Observations **rule out** the possibility of thermal conduction and non-thermal electron beams.

3D simulation of a Plage

Good correspondence with observations



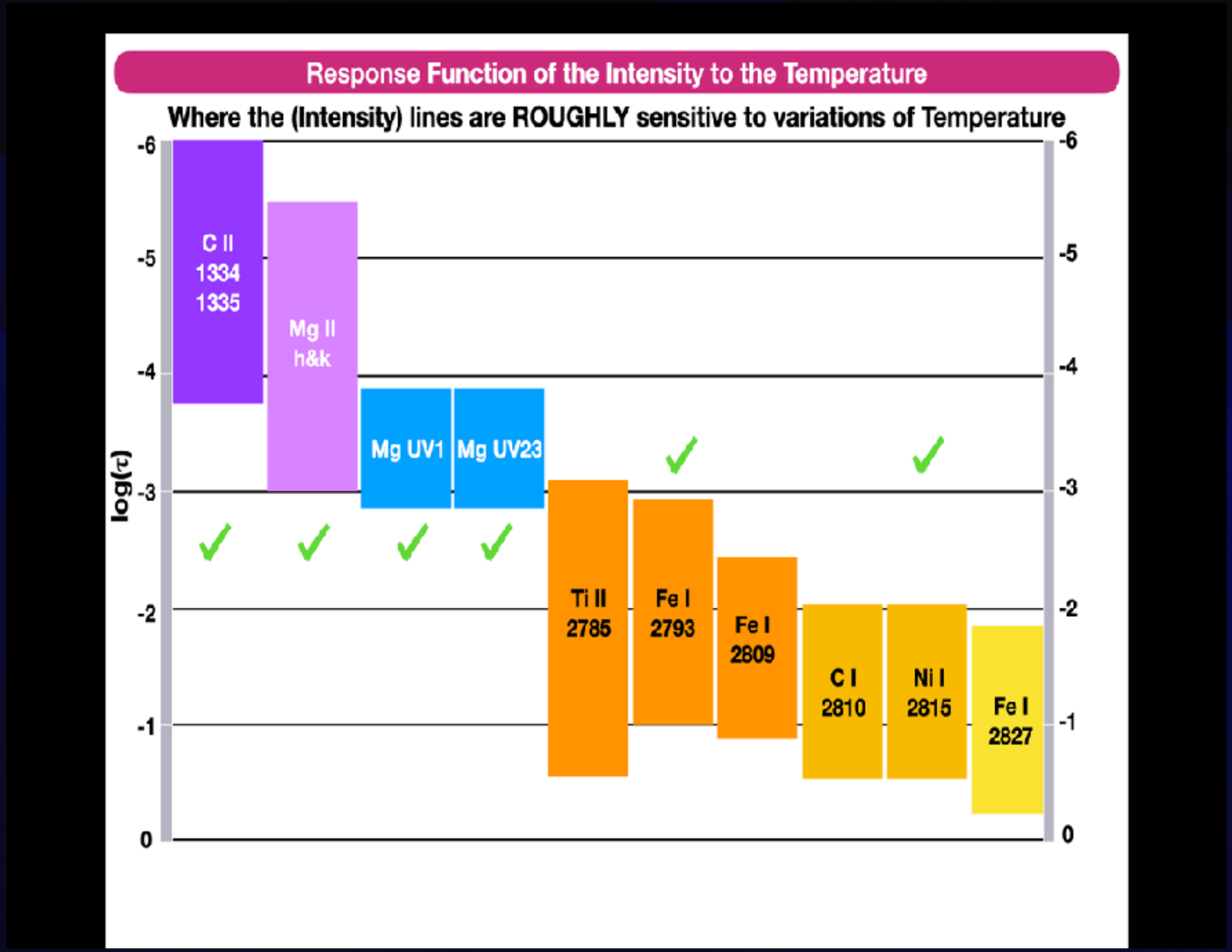
Current dissipation from braiding

Key takeaways

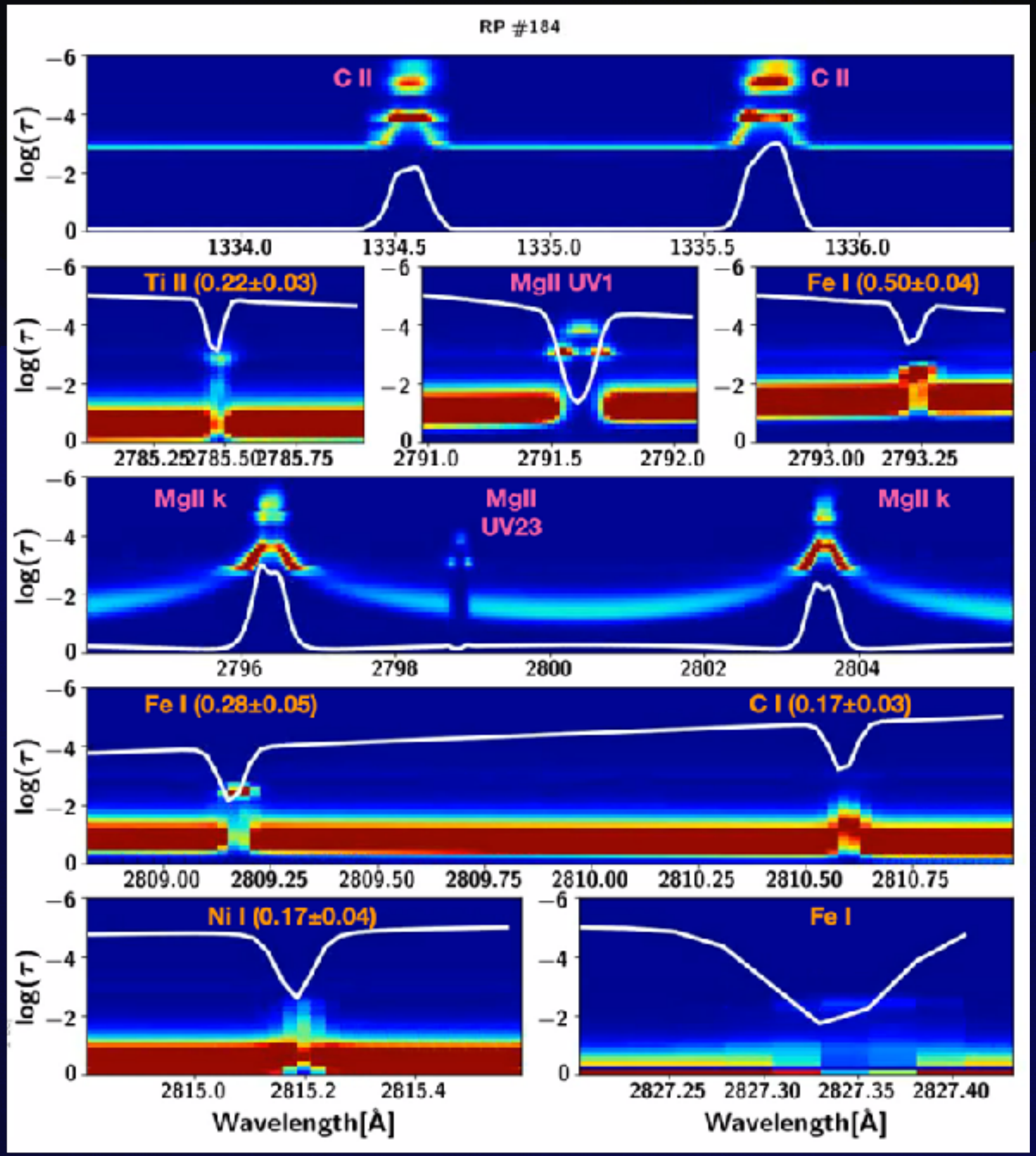
- Chromospheric and coronal heating **well correlated** in moss.
- (Quasi) steady heating pattern is observed in small-scales.
- No longer restricted to “proxies” of heating signatures (inversions to the rescue).
- Heating mechanism compatible with predictions from **braiding** models (thermal conduction and electron beams unlikely.)
- Need more statistics! (MUSE & EUI can help).



Back ups

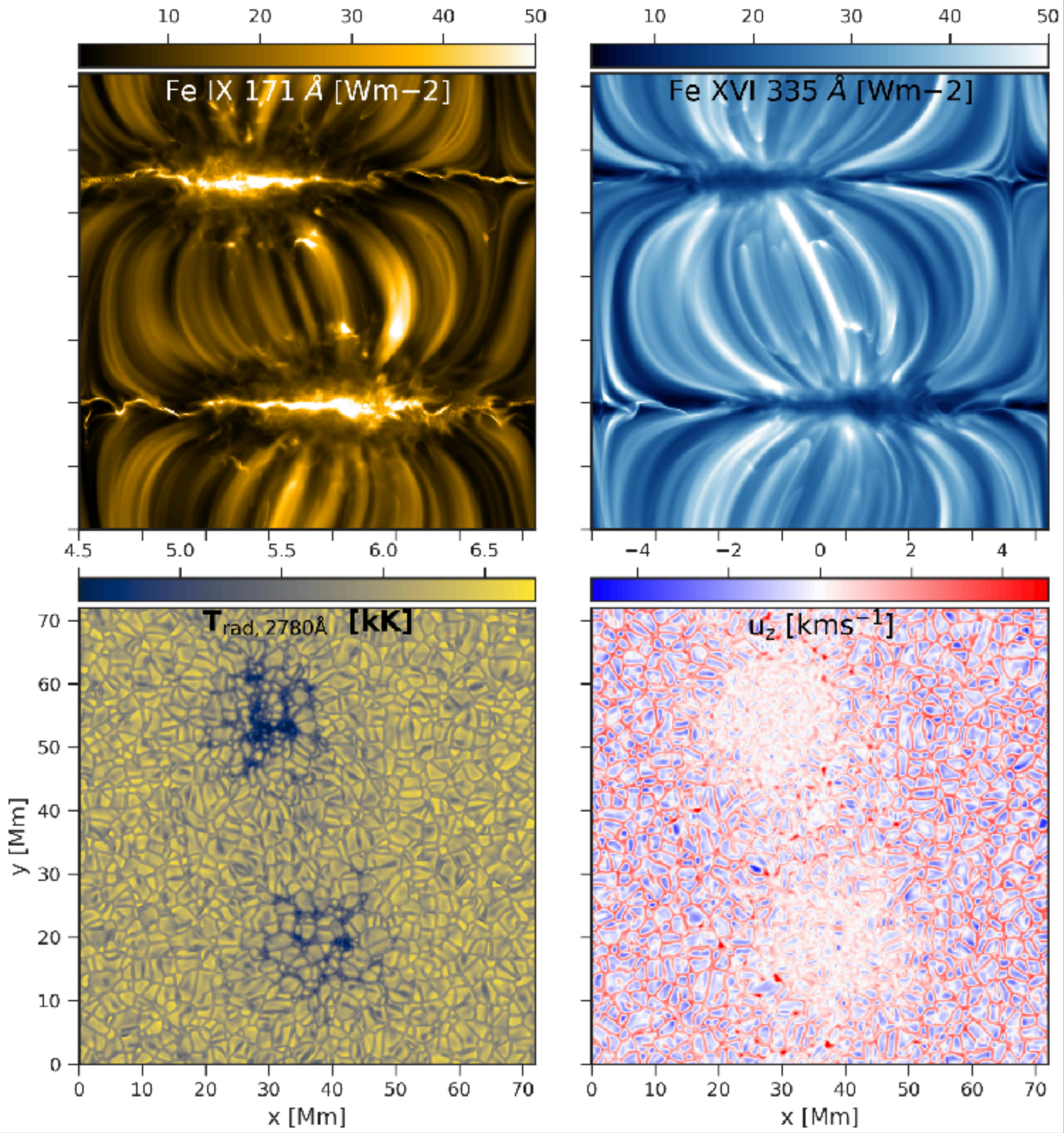


Response Function of the Intensity to the Temperature
Where the (Intensity) lines are ROUGHLY sensitive to variations of Temperature
log(τ)
C II 1334 1335
Mg II h&k
Mg UV1
Mg UV23
Ti II 2785
Fe I 2793
Fe I 2809
C I 2810
Ni I 2815
Fe I 2827

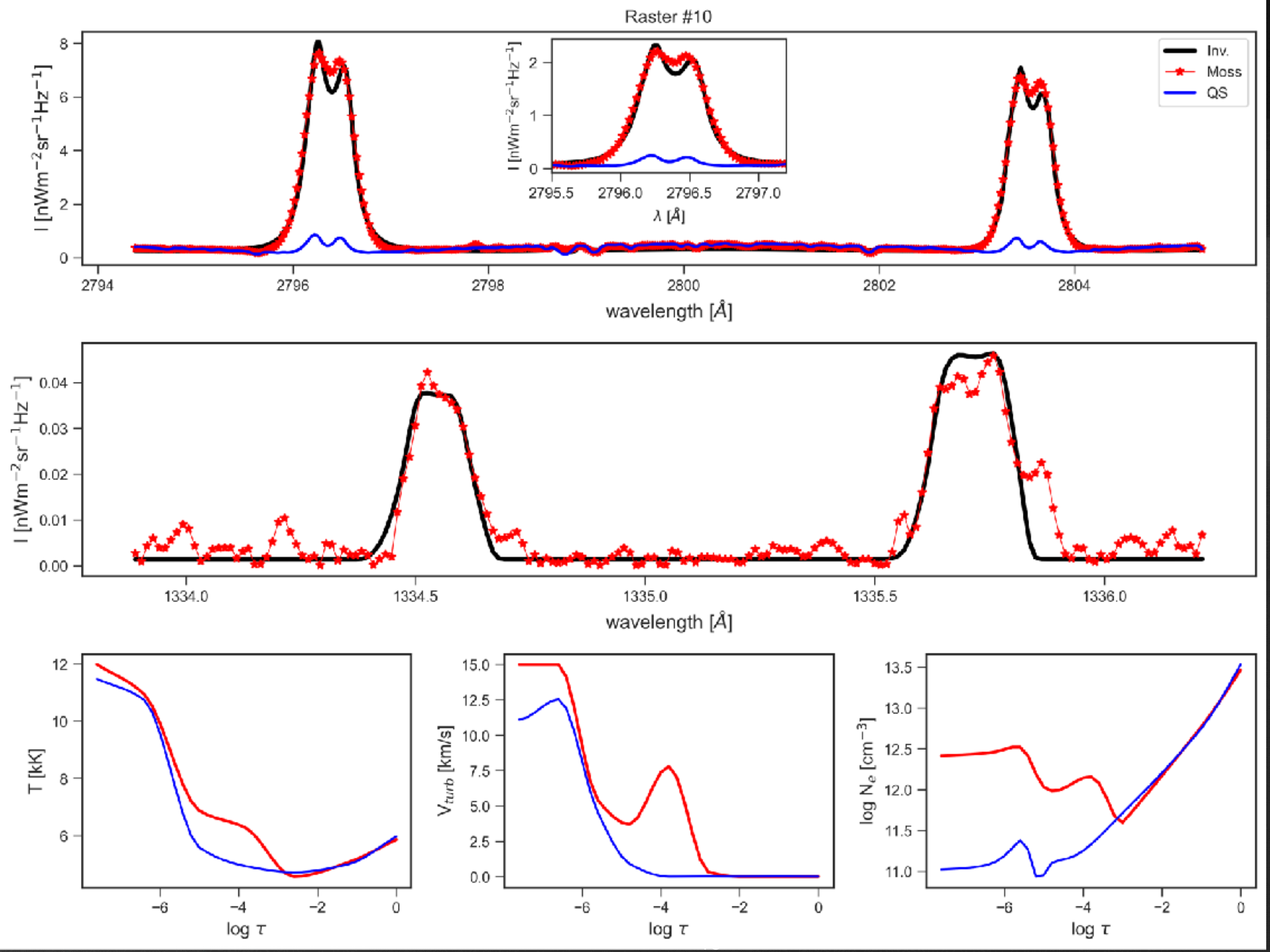


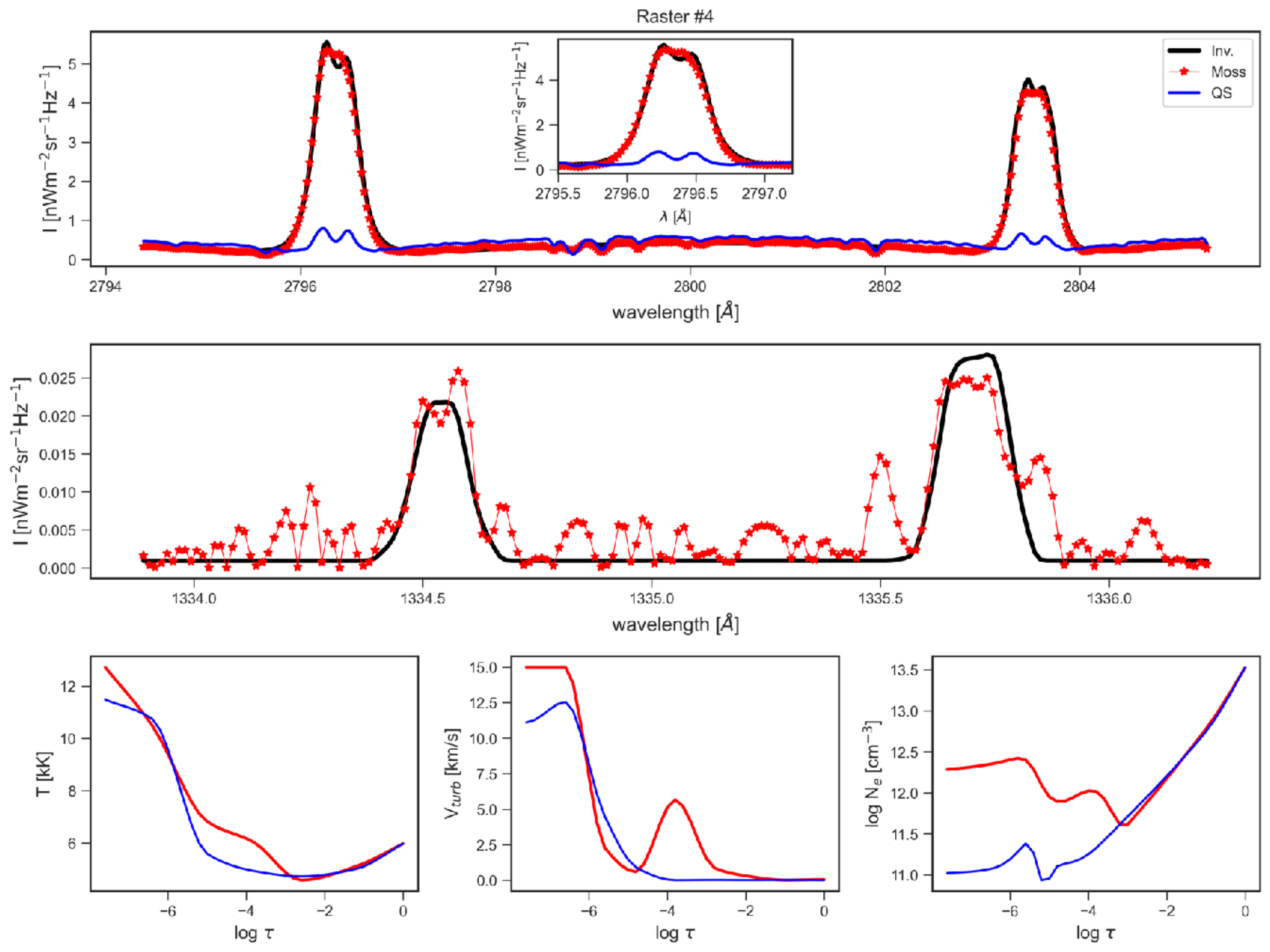
RP #184
C II
C II
Ti II (0.22±0.03)
MgII UV1
Fe I (0.50±0.04)
MgII k
MgII UV23
MgII k
Fe I (0.28±0.05)
C I (0.17±0.03)
Ni I (0.17±0.04)
Fe I
log(τ)
Wavelength[Å]

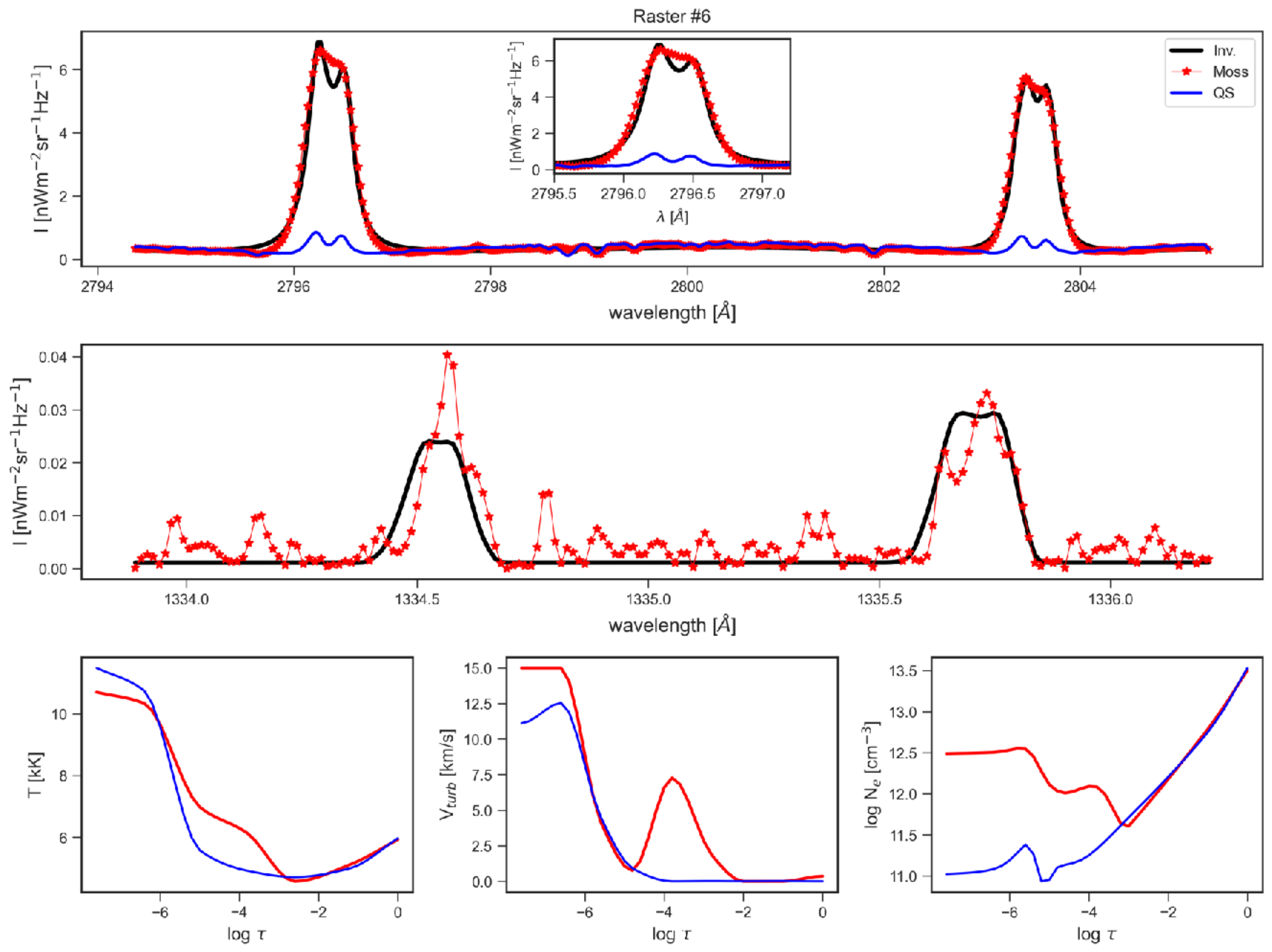
Photosphere and the corona



$IRIS^{2+}$ inversions — more examples




Raster #4
Inv.
Moss
QS
I [nWm−2sr−1Hz−1]
wavelength [Å]
λ [Å]
T [kK]
Vturb [km/s]
log Ne [cm−3]
log τ

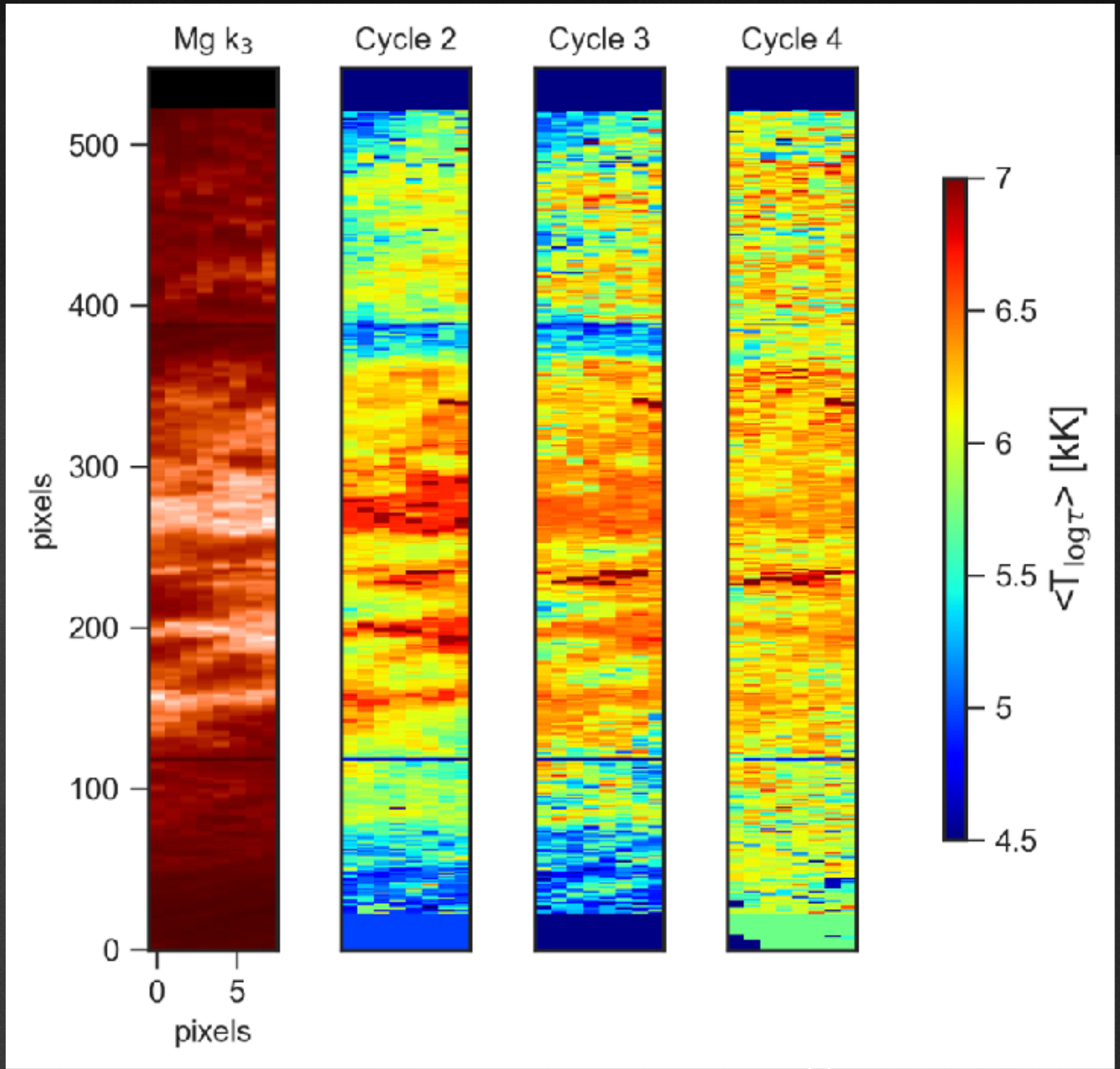


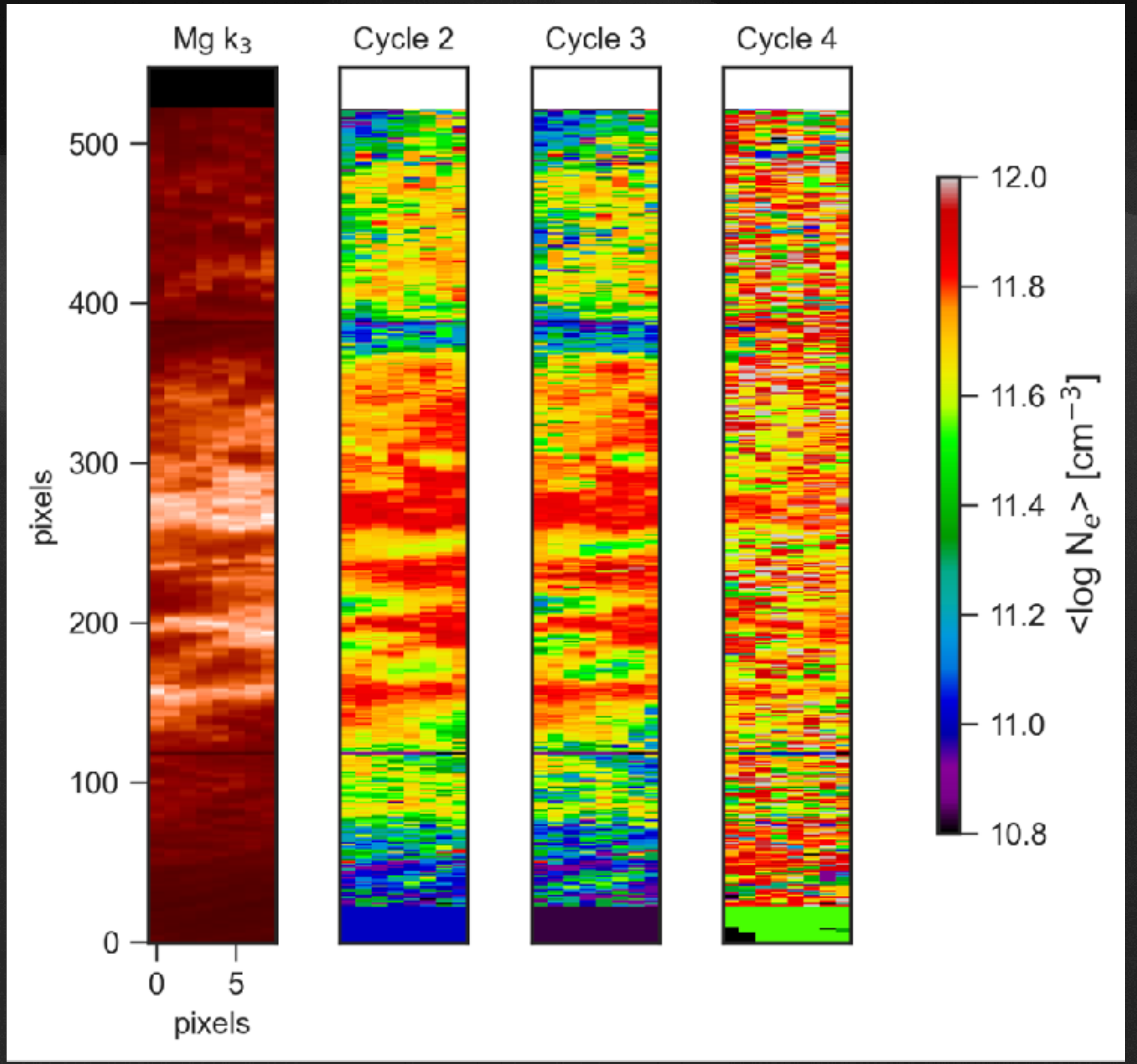
Raster #6
Inv.
Moss
QS
I [nWm^{-2}sr^{-1}Hz^{-1}]
λ [Å]
wavelength [Å]
T [kK]
V_{turb} [km/s]
log N_e [cm^{-3}]
log τ

$IRIS^{2+}$ inversions — comparison of multiple cycles

T, vturb, vlos

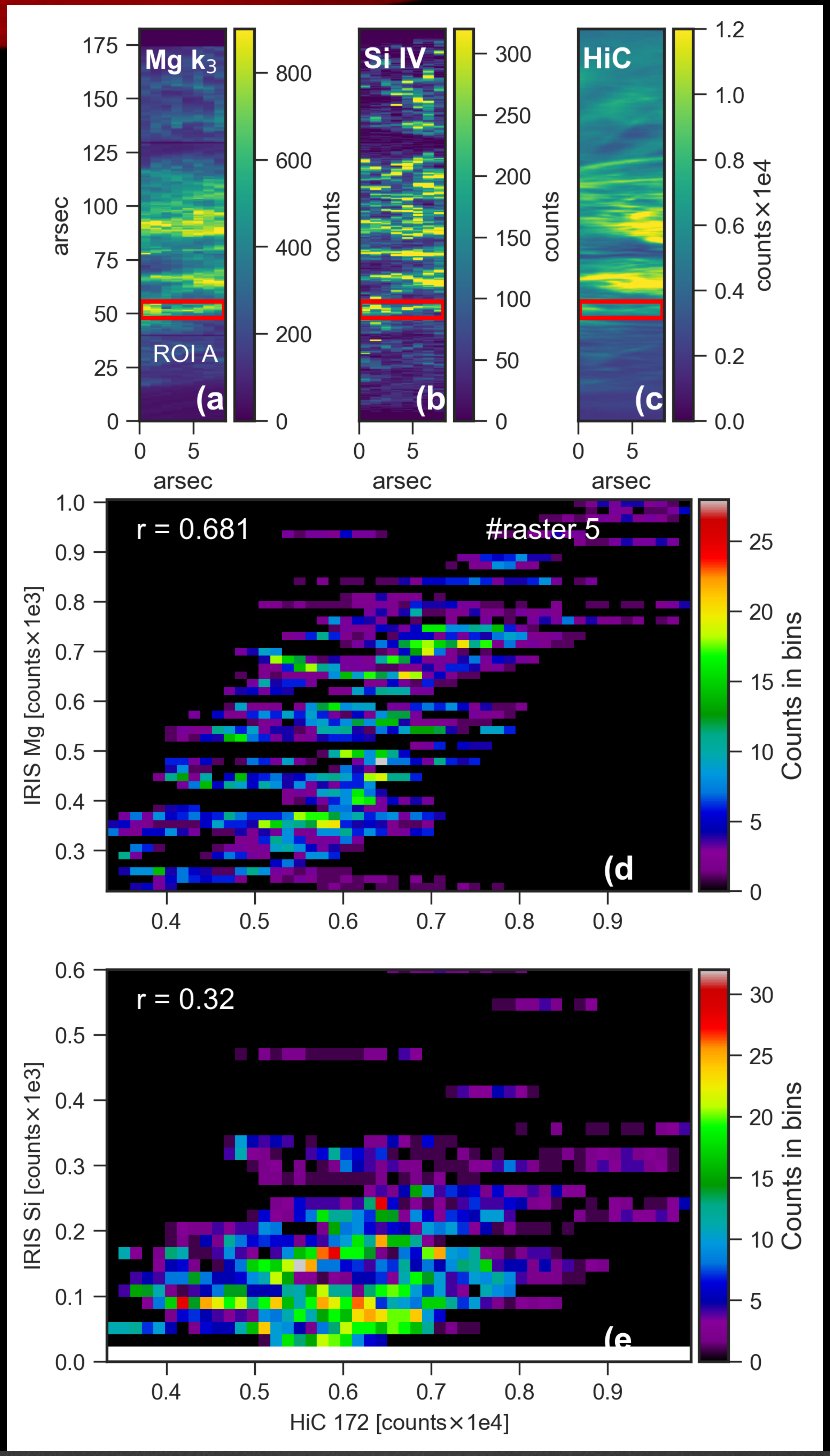
C1 = 4, 2, 2
C2 = 7, 4, 4
C3 = 7, 9, 9
C4 = 13,13,13



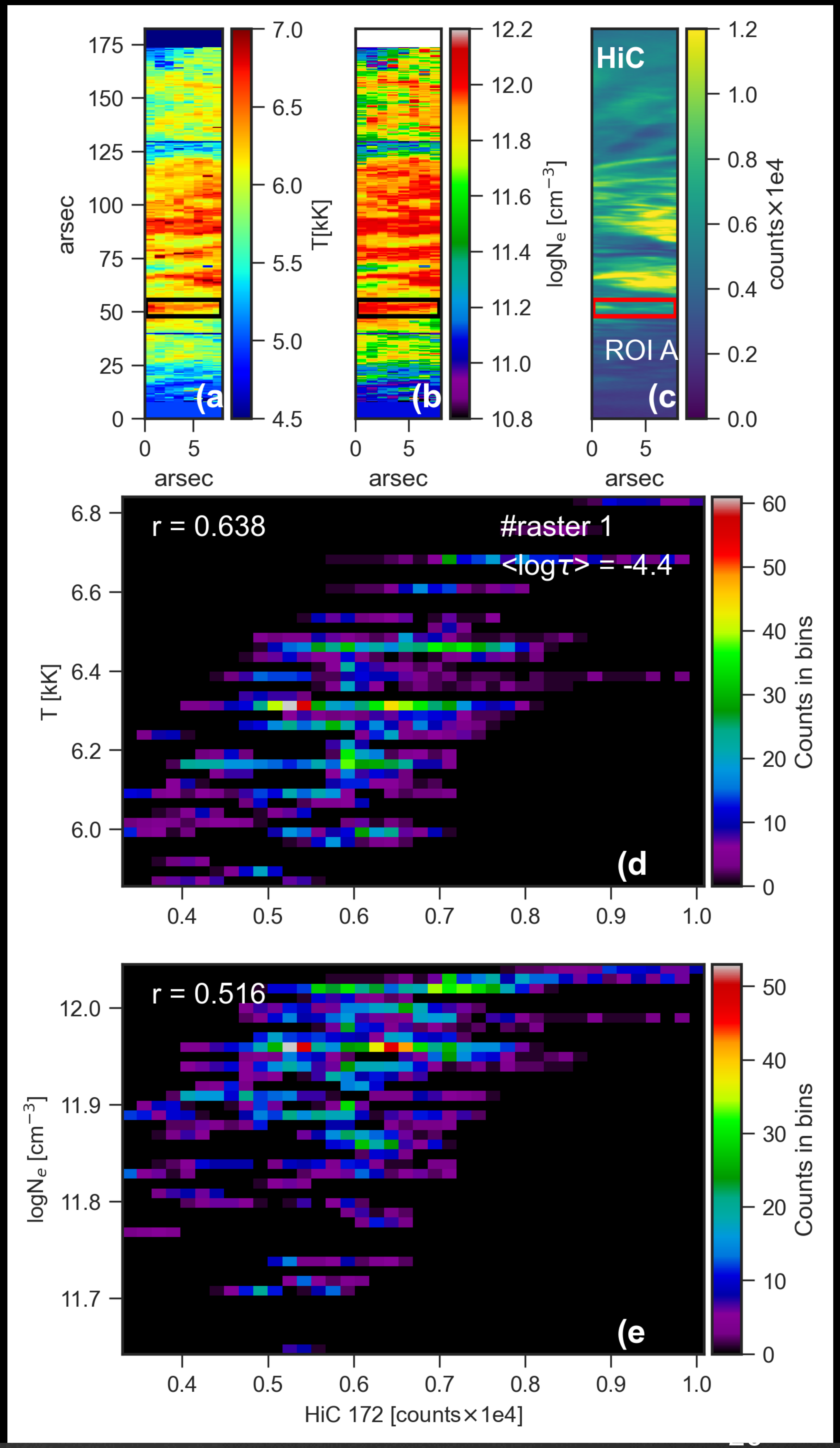


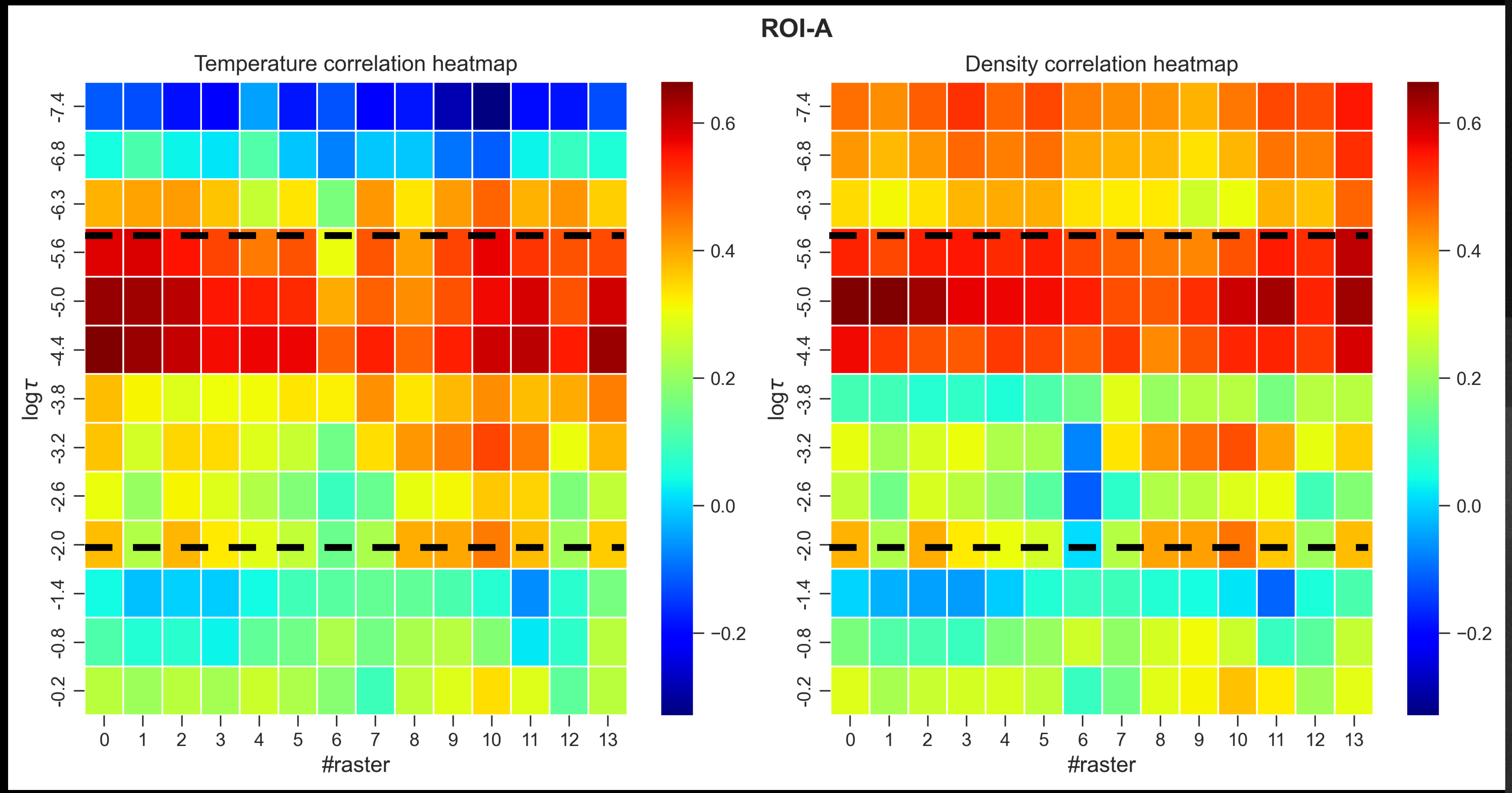
WHAT ABOUT OTHER FOVS?

Intensity correlation



Thermodynamic correlation





- Reasonable correlation down to log tau ~ -4 (where 5kK<T< 6kK).
- Thermal conduction **inefficient** to cause heating at such temperatures.
- Implies a ***common*** heating mechanism.