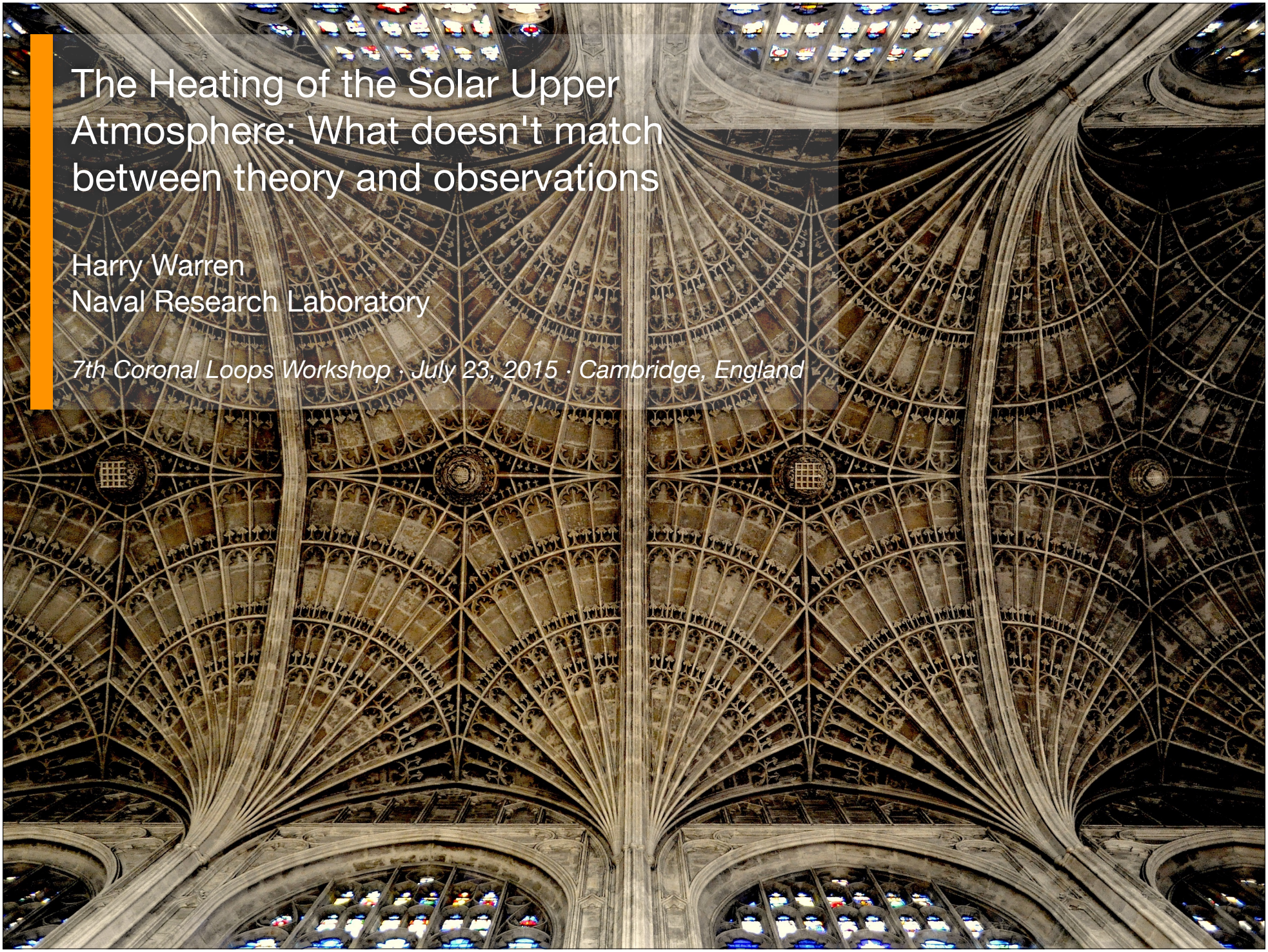
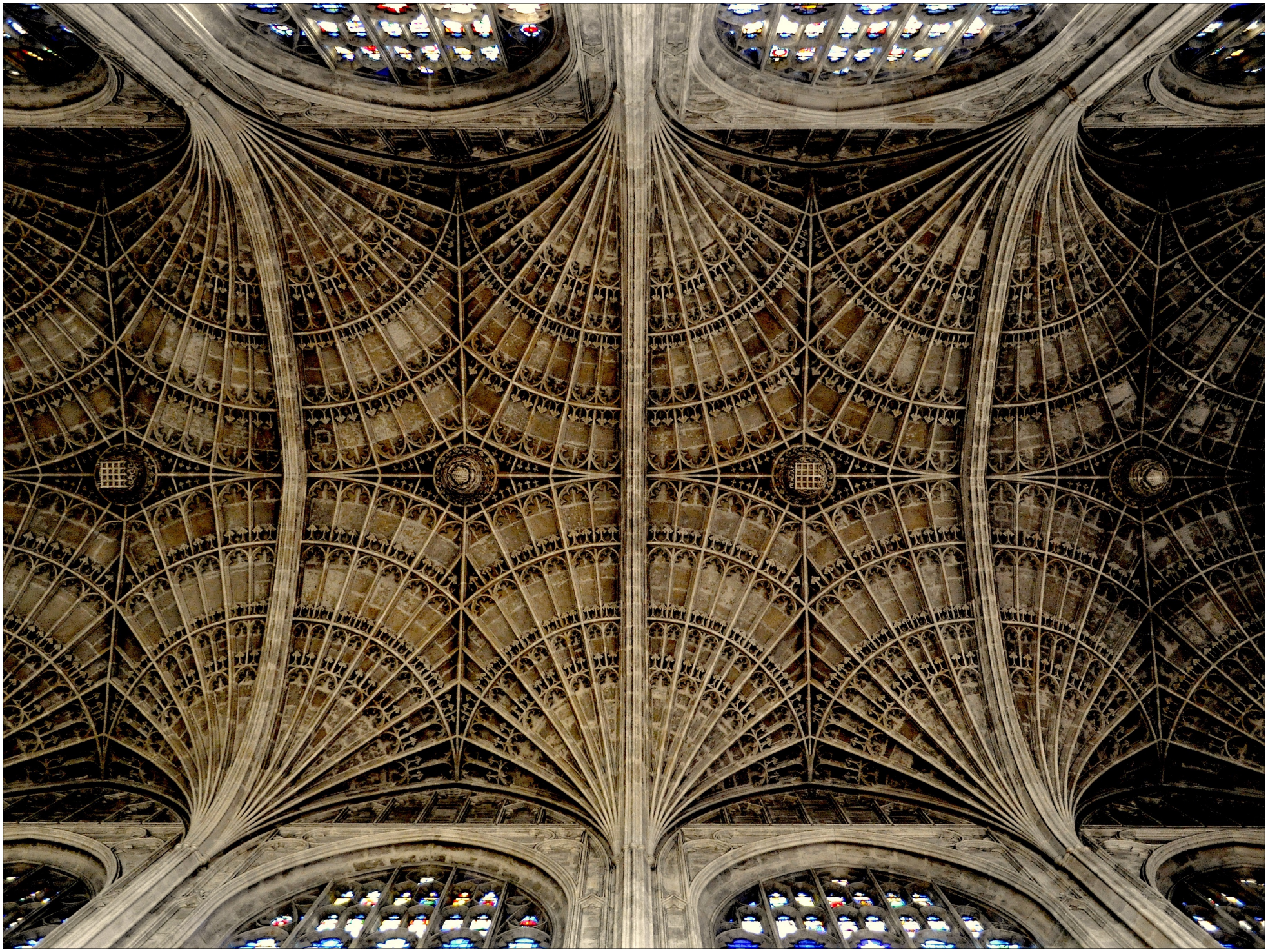
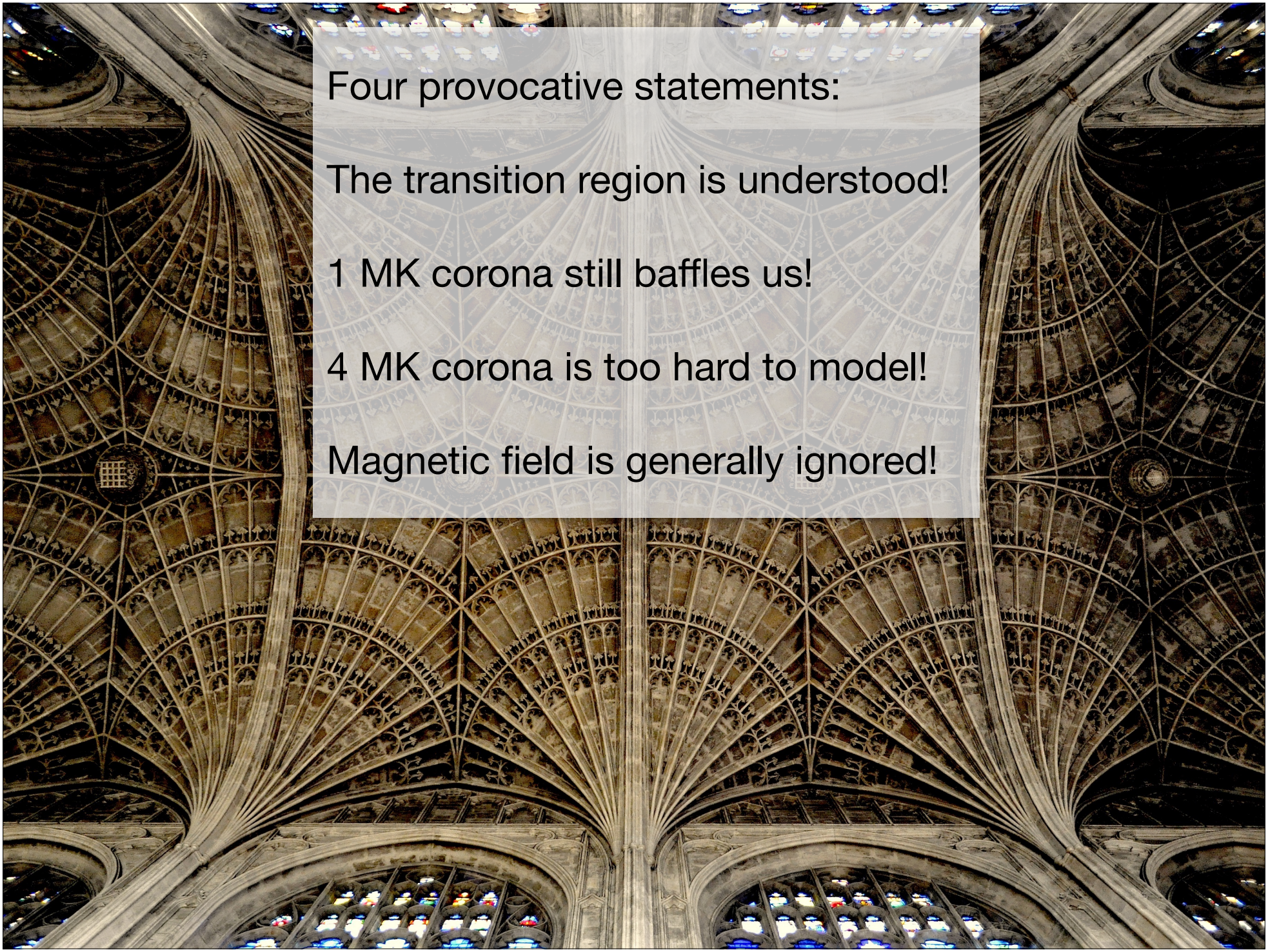


The Heating of the Solar Upper Atmosphere: What doesn't match between theory and observations

Harry Warren
Naval Research Laboratory

7th Coronal Loops Workshop · July 23, 2015 · Cambridge, England




Four provocative statements:
The transition region is understood!
1 MK corona still baffles us!
4 MK corona is too hard to model!
Magnetic field is generally ignored!

The Transition Region

Skylab

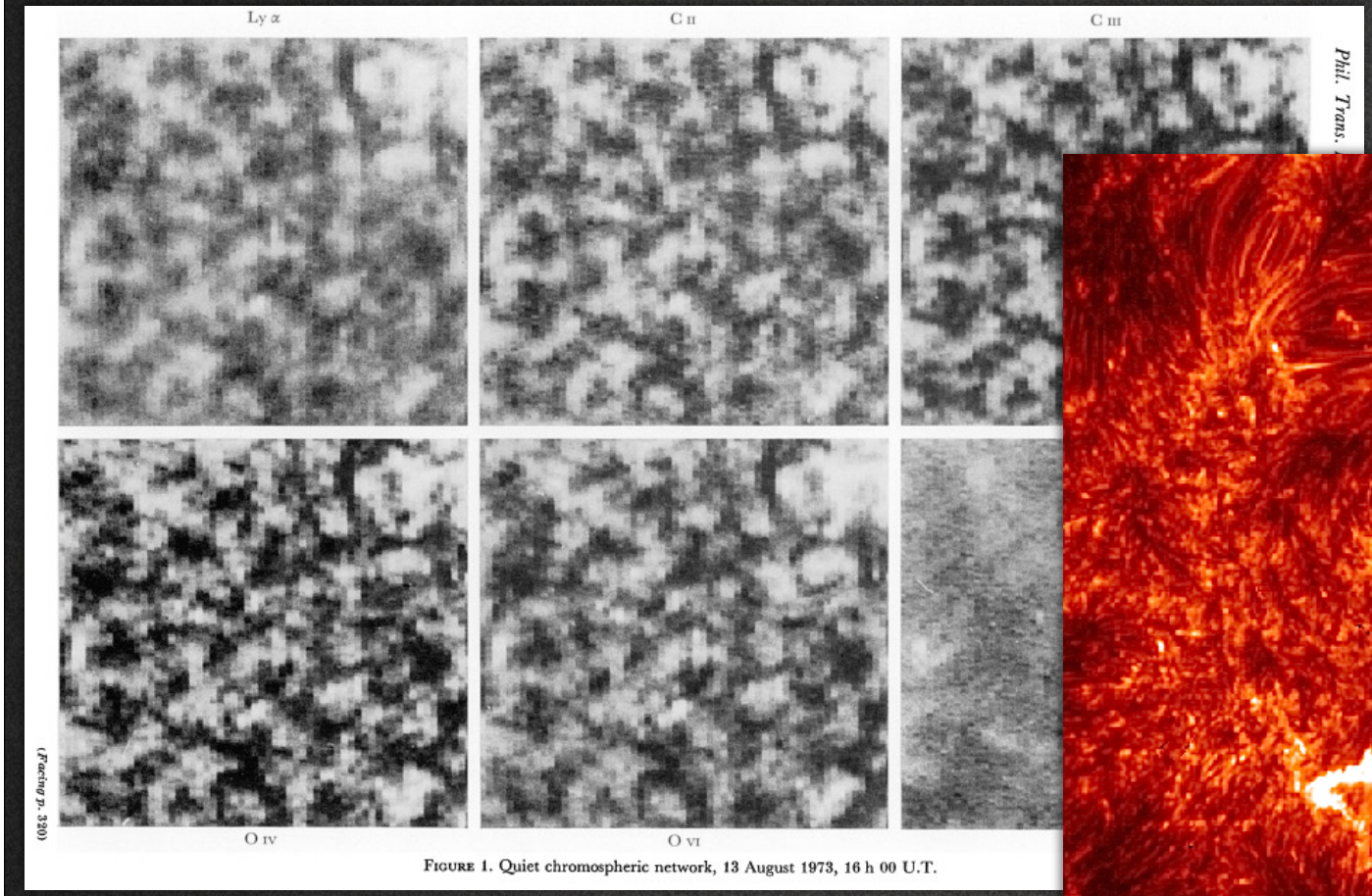
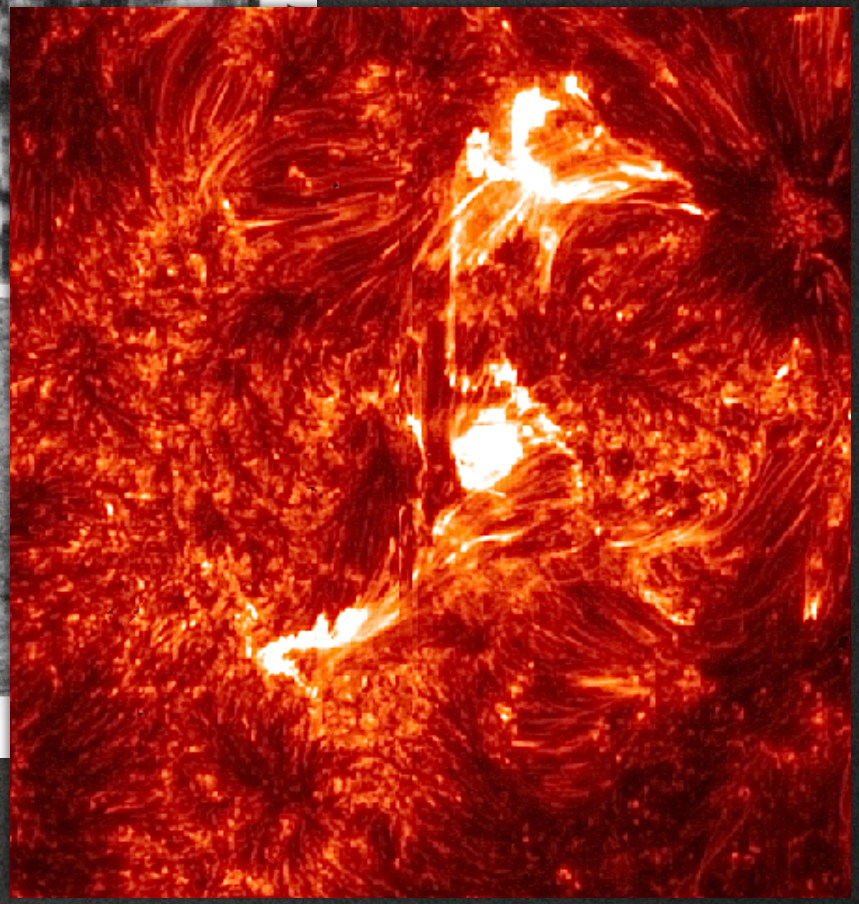


FIGURE 1. Quiet chromospheric network, 13 August 1973, 16 h 00 U.T.

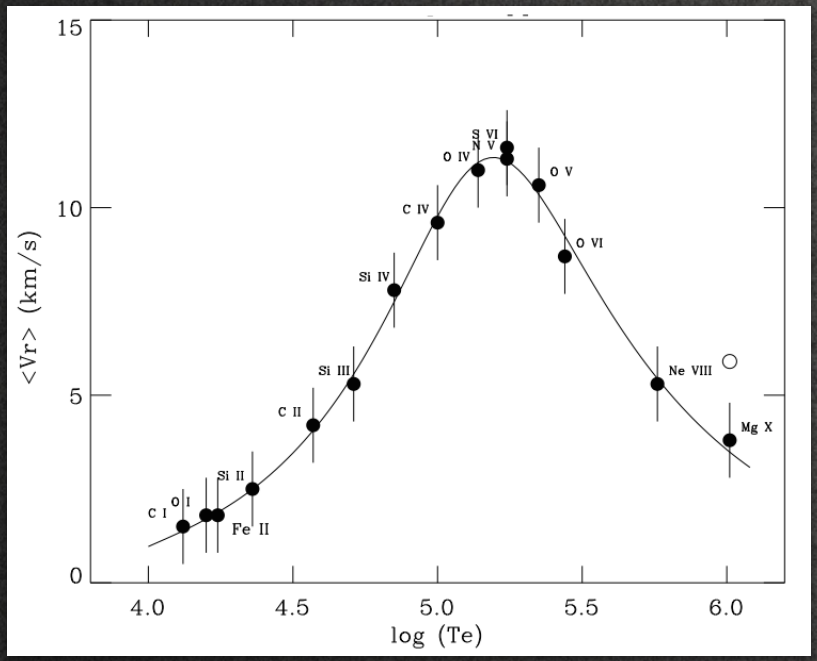
IRIS



e.g., Reeves, Vernazza, & Withbroe (1976)

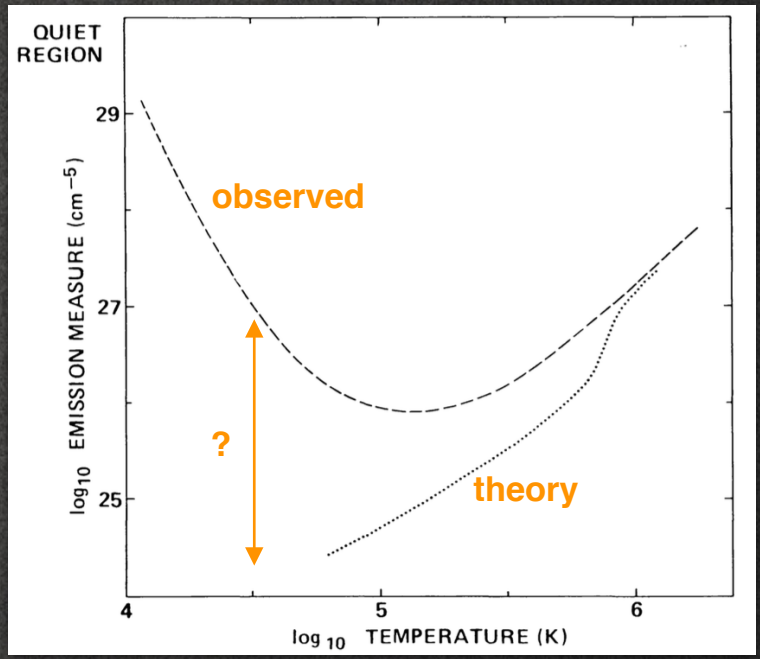
The Transition Region: Observational Problems

Emission is systematically redshifted



e.g., Chae, Yun, & Poland (1998)

Emission measure below ~ 10^6 is too high

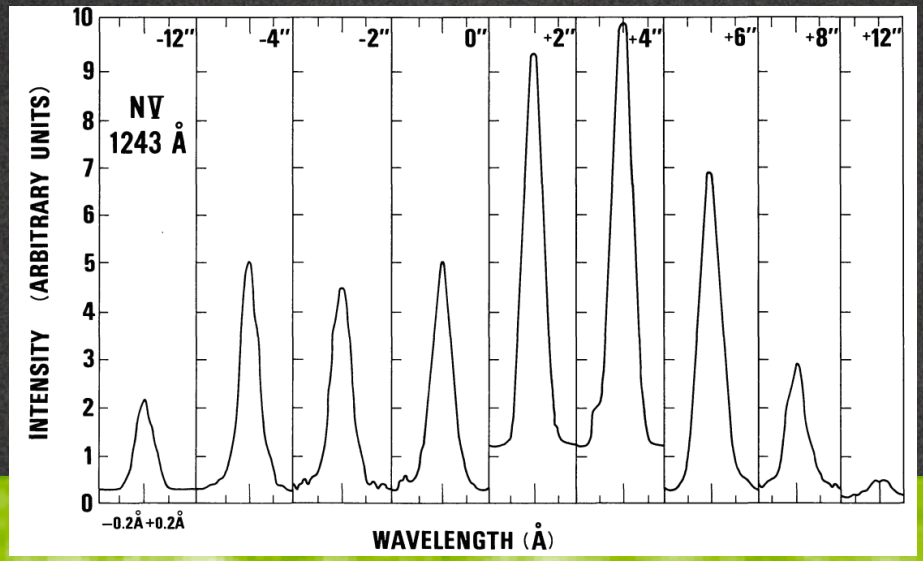


e.g., Dowdy, Rabin, & Moore (1986)

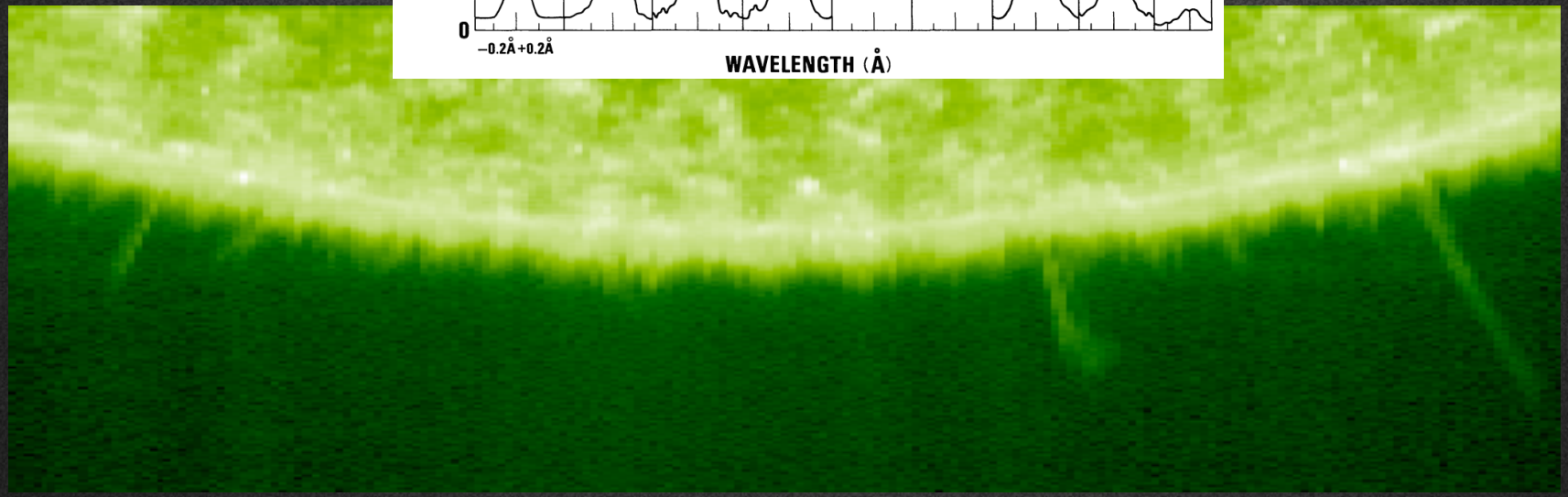
The Transition Region: Observational Problems

Emission scale height is too large:
not ~100 km, but ~1000 km

e.g., Doschek et al. (1976)

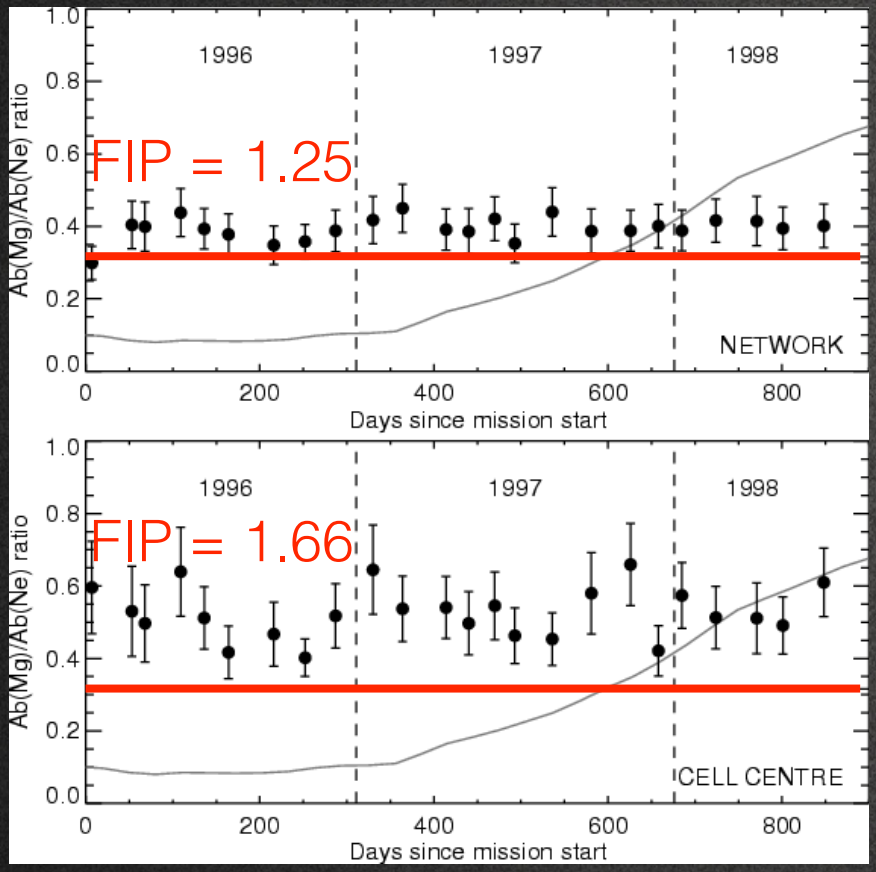


SUMER N V 1243 Å

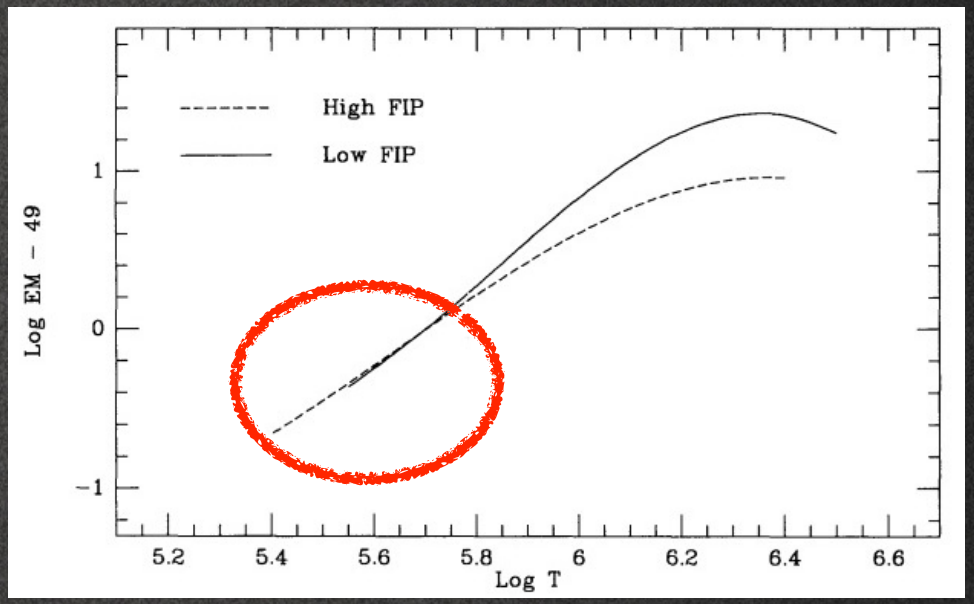


The Transition Region: Observational Problems

Composition is not coronal,
but close to photospheric



Young, A&A, 2005



Laming, Drake, & Widing, ApJ, 1995

The Transition Region: The "Junkyard" Model?

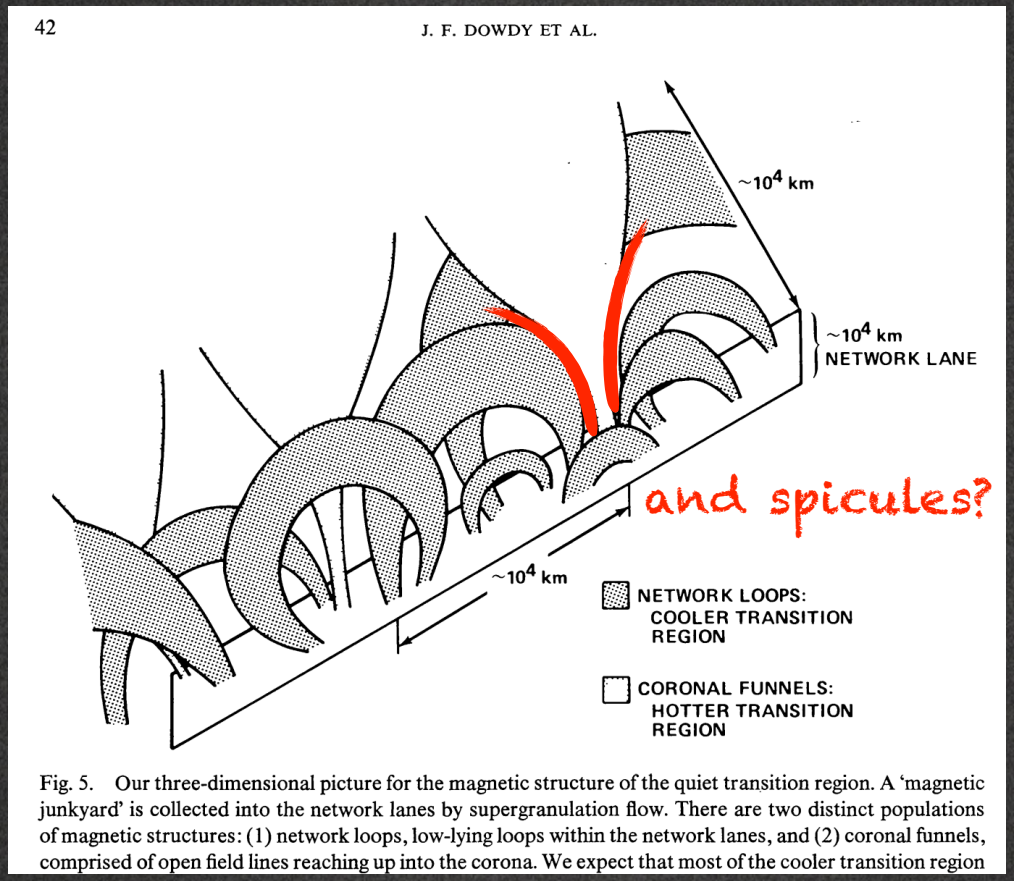


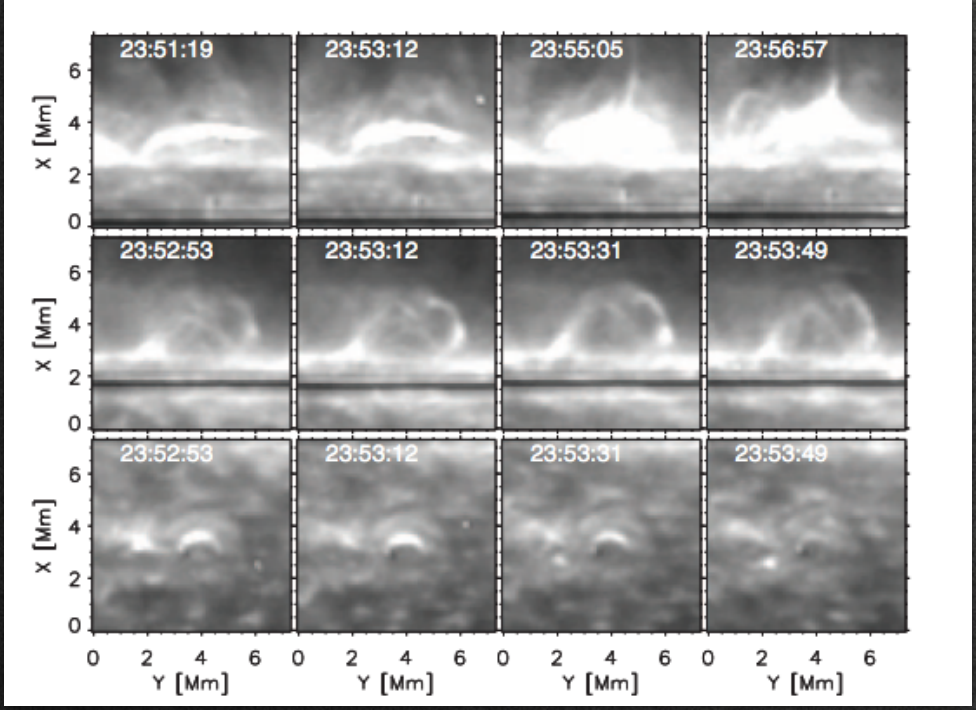
Fig. 5. Our three-dimensional picture for the magnetic structure of the quiet transition region. A 'magnetic junkyard' is collected into the network lanes by supergranulation flow. There are two distinct populations of magnetic structures: (1) network loops, low-lying loops within the network lanes, and (2) coronal funnels, comprised of open field lines reaching up into the corona. We expect that most of the cooler transition region

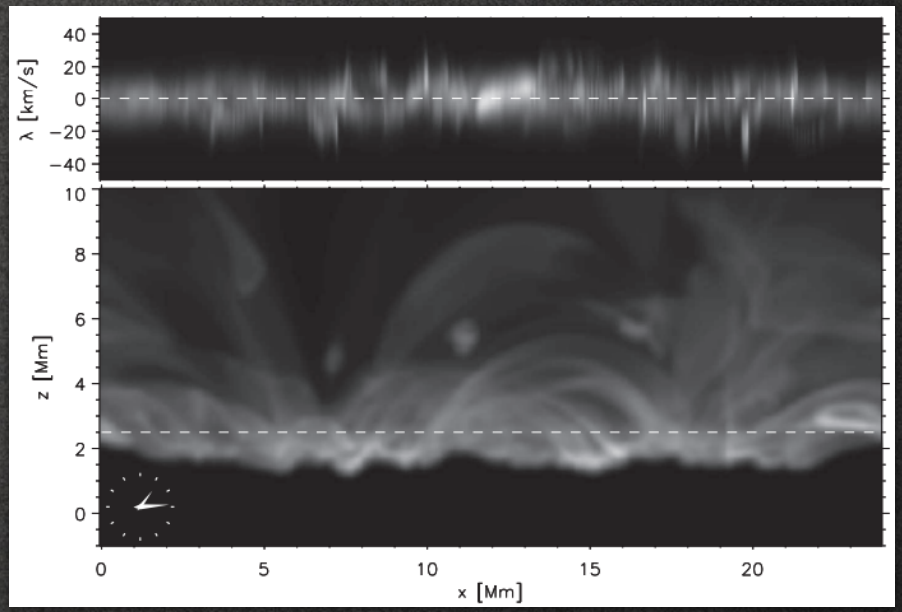
Dowdy, Rabin, & Moore (1986)

The Transition Region: Unresolved Fine Structure?

"The high spatial and temporal resolution observations with the Interface Region Imaging Spectrograph (IRIS) at the solar limb reveal a plethora of short, low-lying loops or loop segments at transition-region temperatures that vary rapidly, on the time scales of minutes. We argue that the existence of these loops solves a long-standing observational mystery."

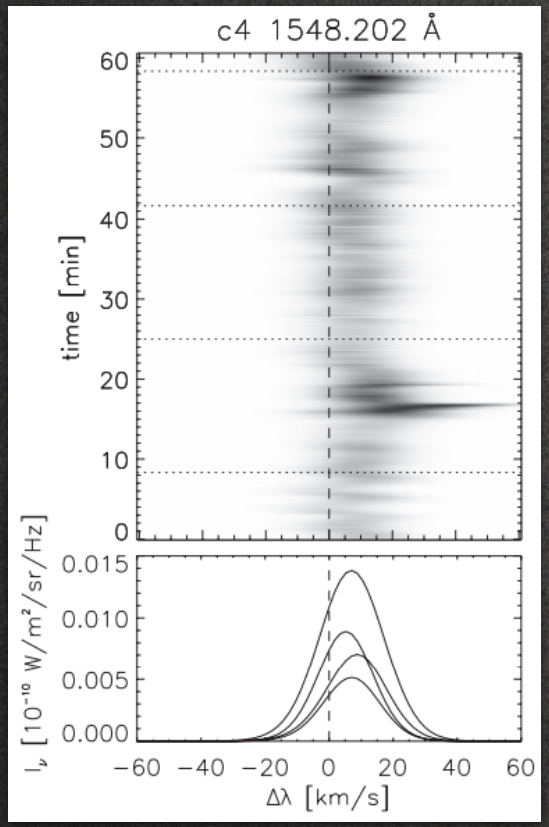
- Hansteen et al., Science, 2014

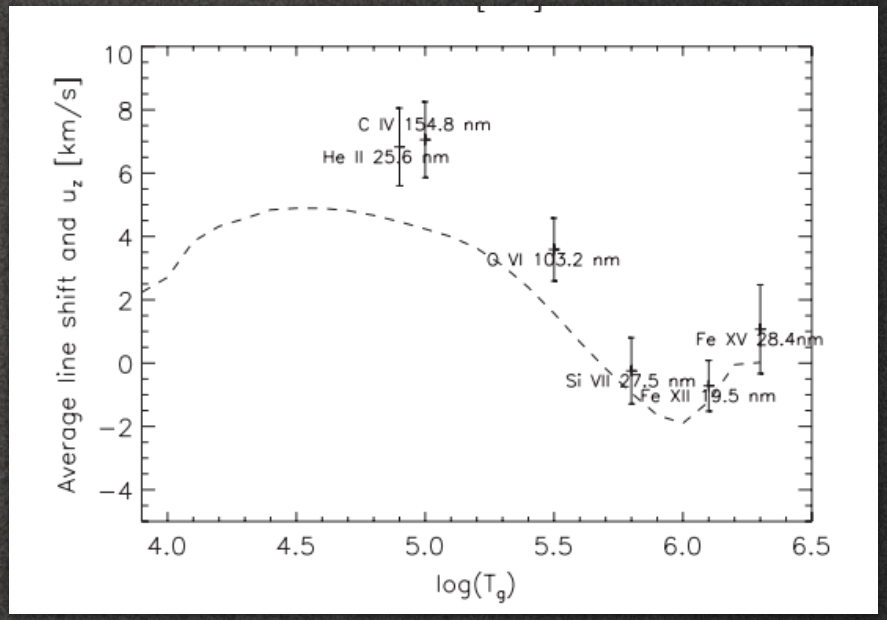




The Transition Region: Impulsive Heating and Flows?

"We show that rapid, episodic heating, at low heights of the upper chromospheric plasma to coronal temperatures naturally produces downflows in TR lines . . . with similar amplitudes to those observed with EUV/UV spectrographs."
- Hansteen et al., ApJ 2010





Also, Peter et al. 2004, 2006; Binger & Peter 2011; Zacharias et al. 2009, 2011; Bourdin et al 2013; Olluri et al. 2015

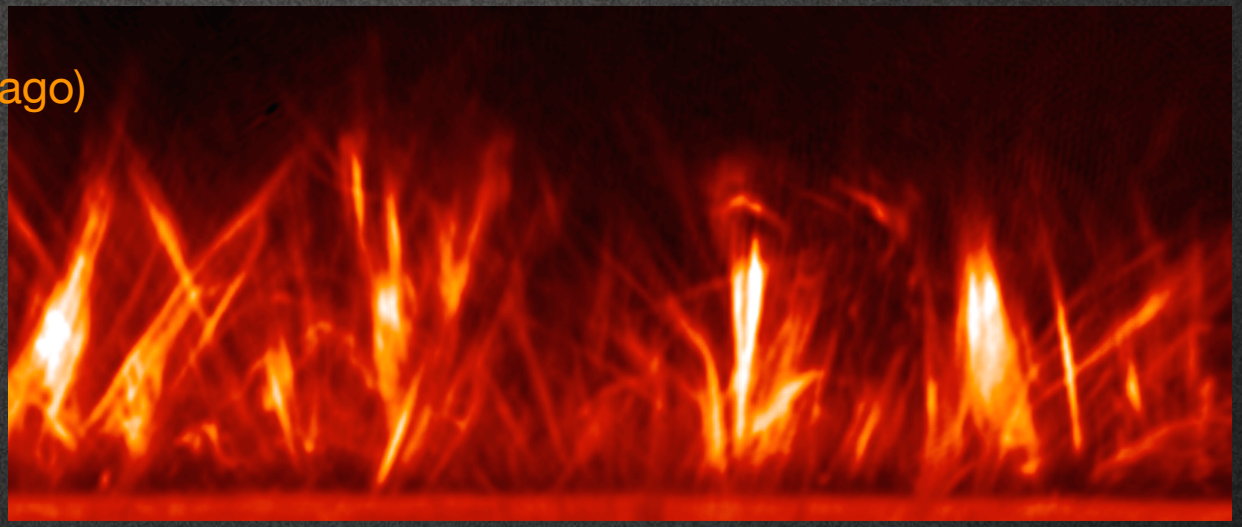
Is the Transition Region Understood?

If “transition region emission is dominated by small scale, impulsively heated structures,” that could explain

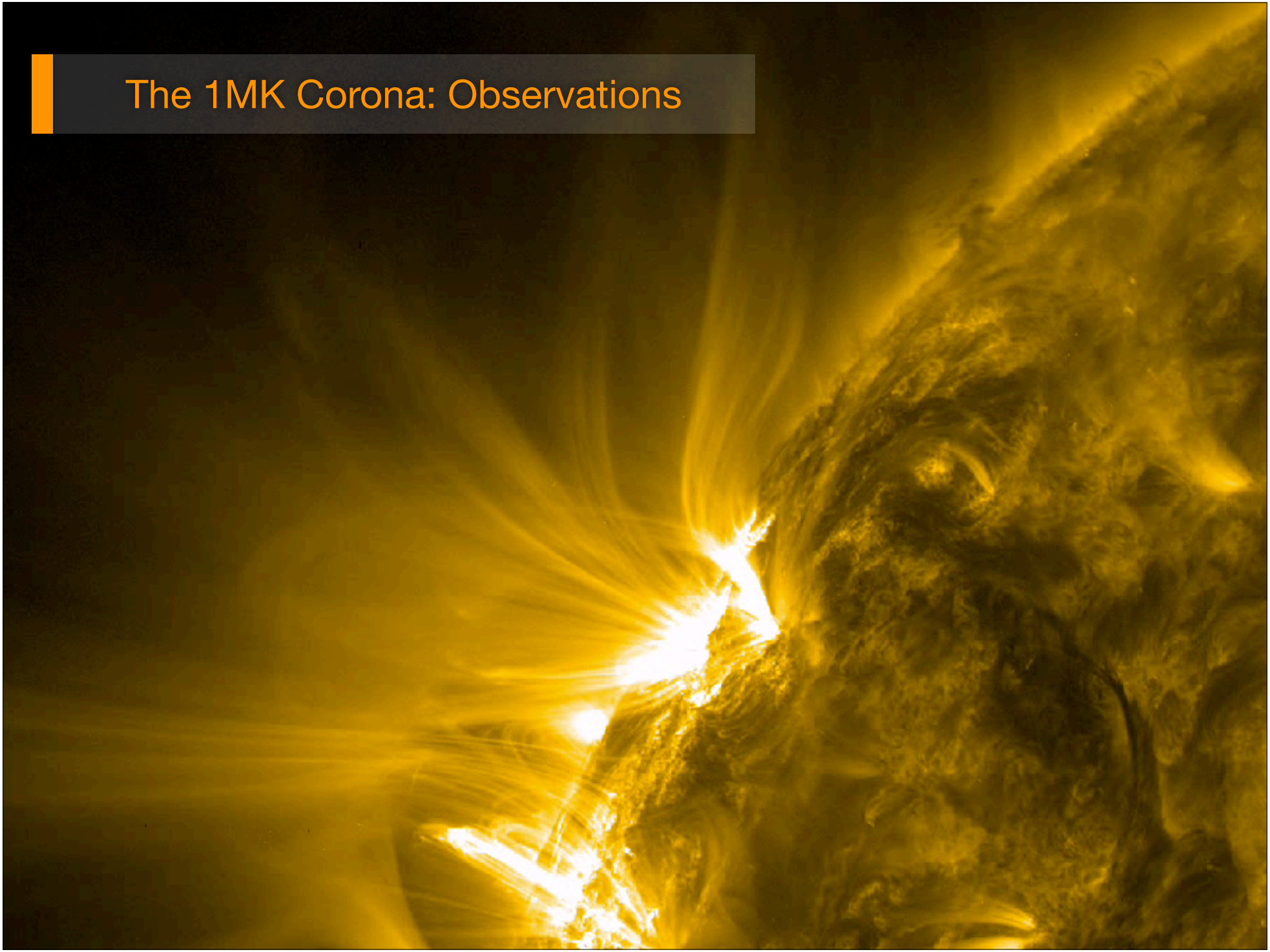
- Systematic red-shifts
- Excess DEM at ~ 10^5 K
- Excess emission scale height
- Photospheric composition (needs time-dependent modeling to confirm)

What’s left? . . . Spicules could contribute significantly to the small scale transition region

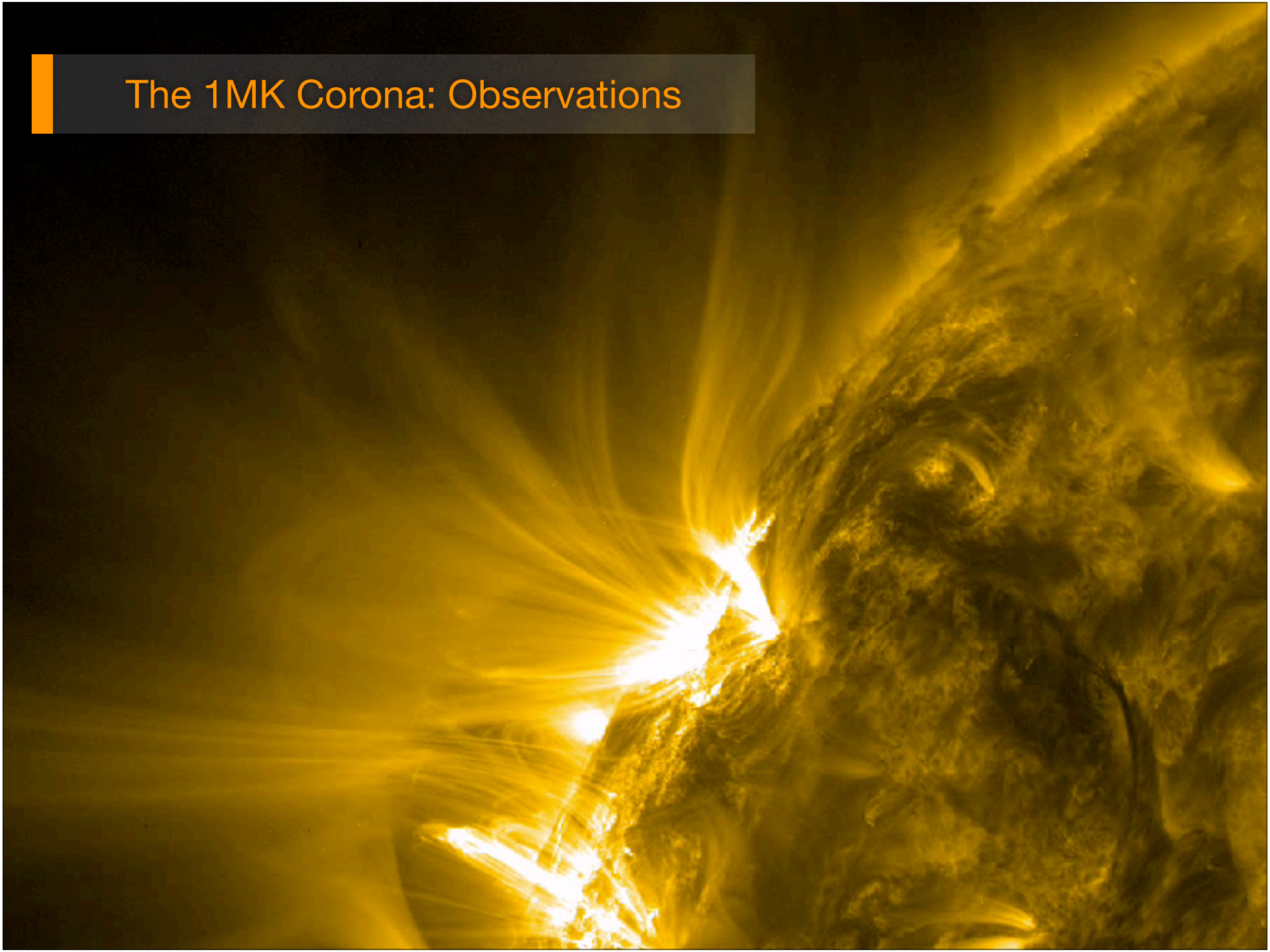
- Great observations (Tiago)
- No accepted theories!



The 1MK Corona: Observations

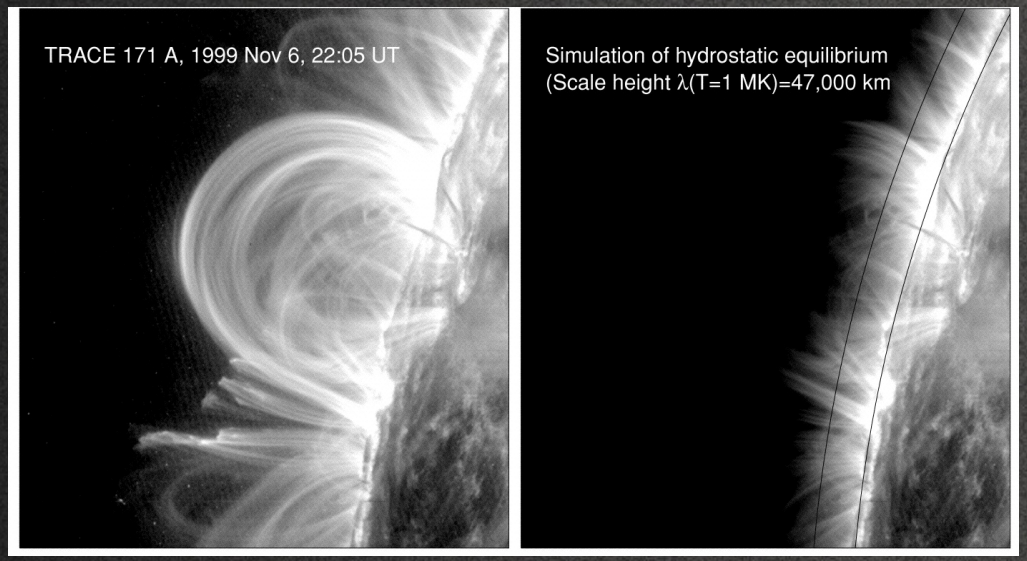


The 1MK Corona: Observations



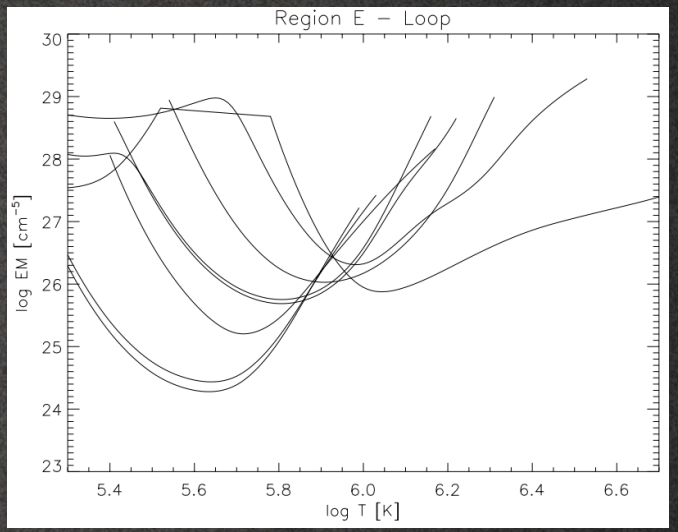
The 1MK Corona: Observational Problems

Loops are Overdense



Aschwanden et al. (2001)
Lenz et al. (1999)

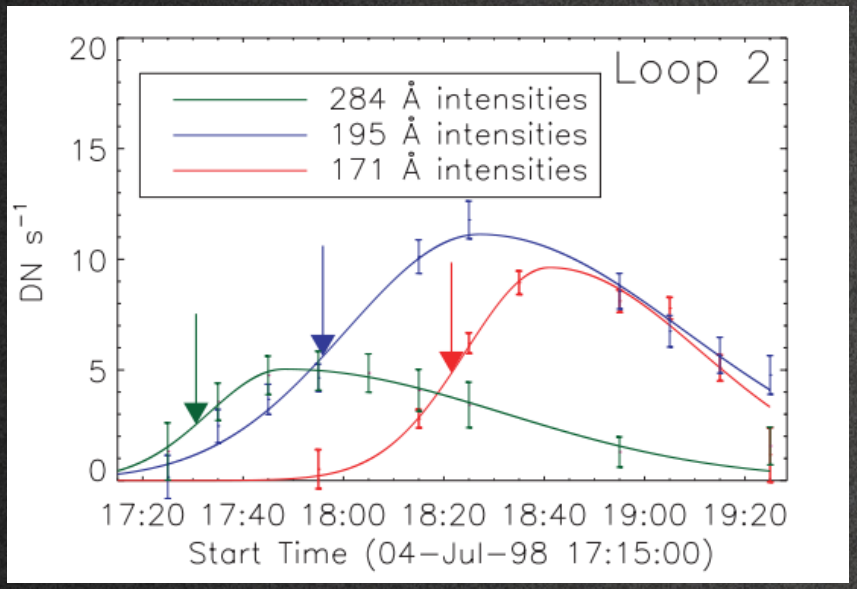
DEMs are Narrow



Del Zanna & Mason (2003)
Brooks et al. (2012)

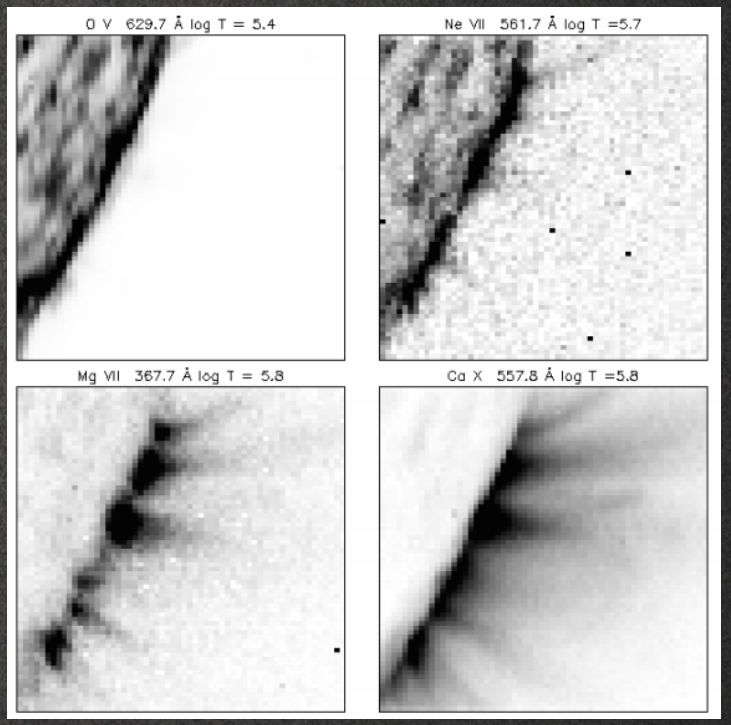
The 1MK Corona: Observational Problems

Loop Lifetimes are Long



Winebarger et al. (2003)
Lenz et al. (1999)
Vial et al. (2012)

Composition is Coronal



Del Zanna & Mason (2003)

The 1MK Corona: No Solution Yet?

Multiple Strand Impulsive Heating

Overdensity from: slow draining

Problem:
Light curves generally not observed
(e.g., Winebarger delay studies)

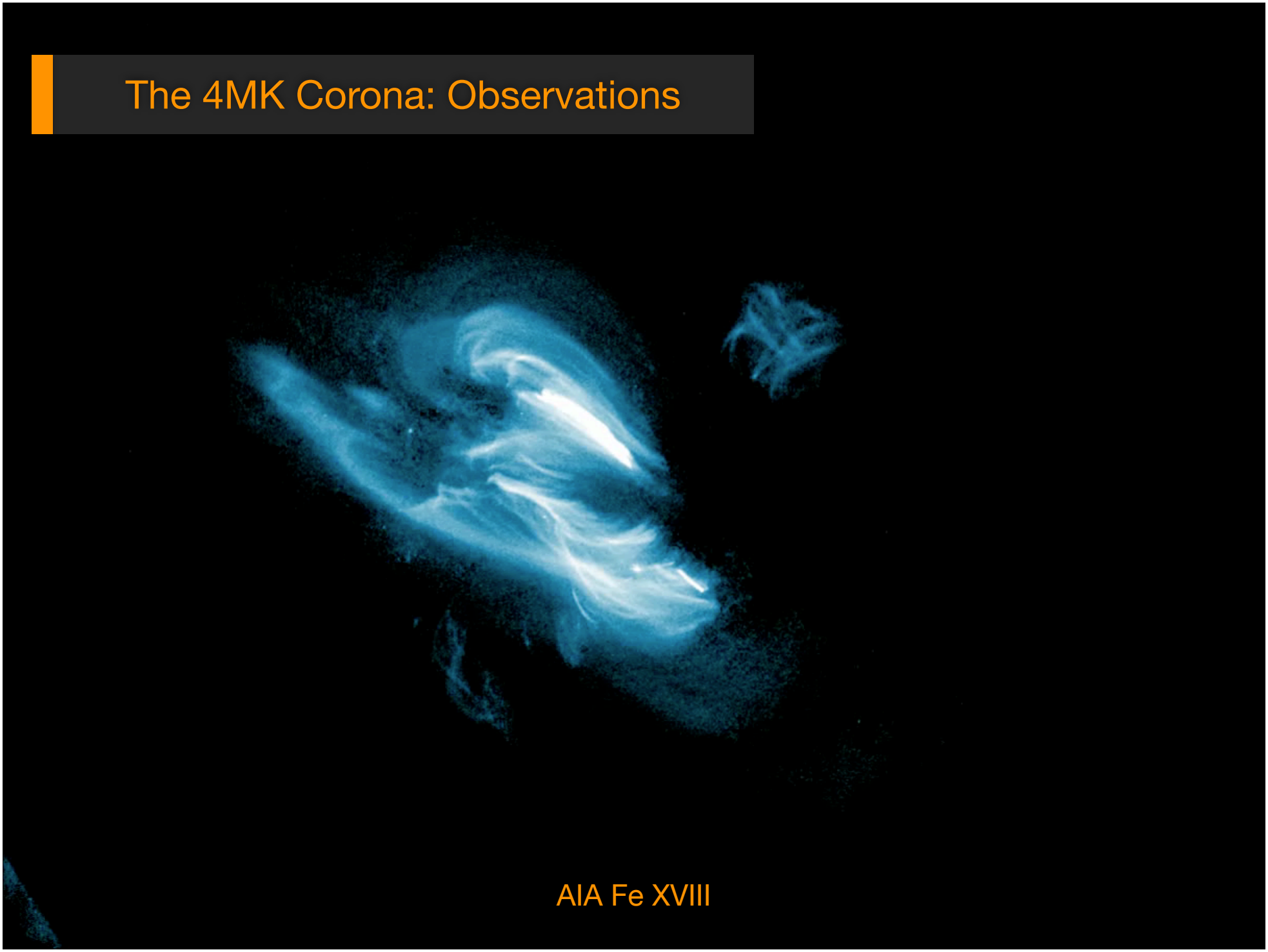
Thermal Non-Equilibrium

Overdensity from: footpoint heating

Problem:
Conditions for TNE rare?
(e.g., Froment study)

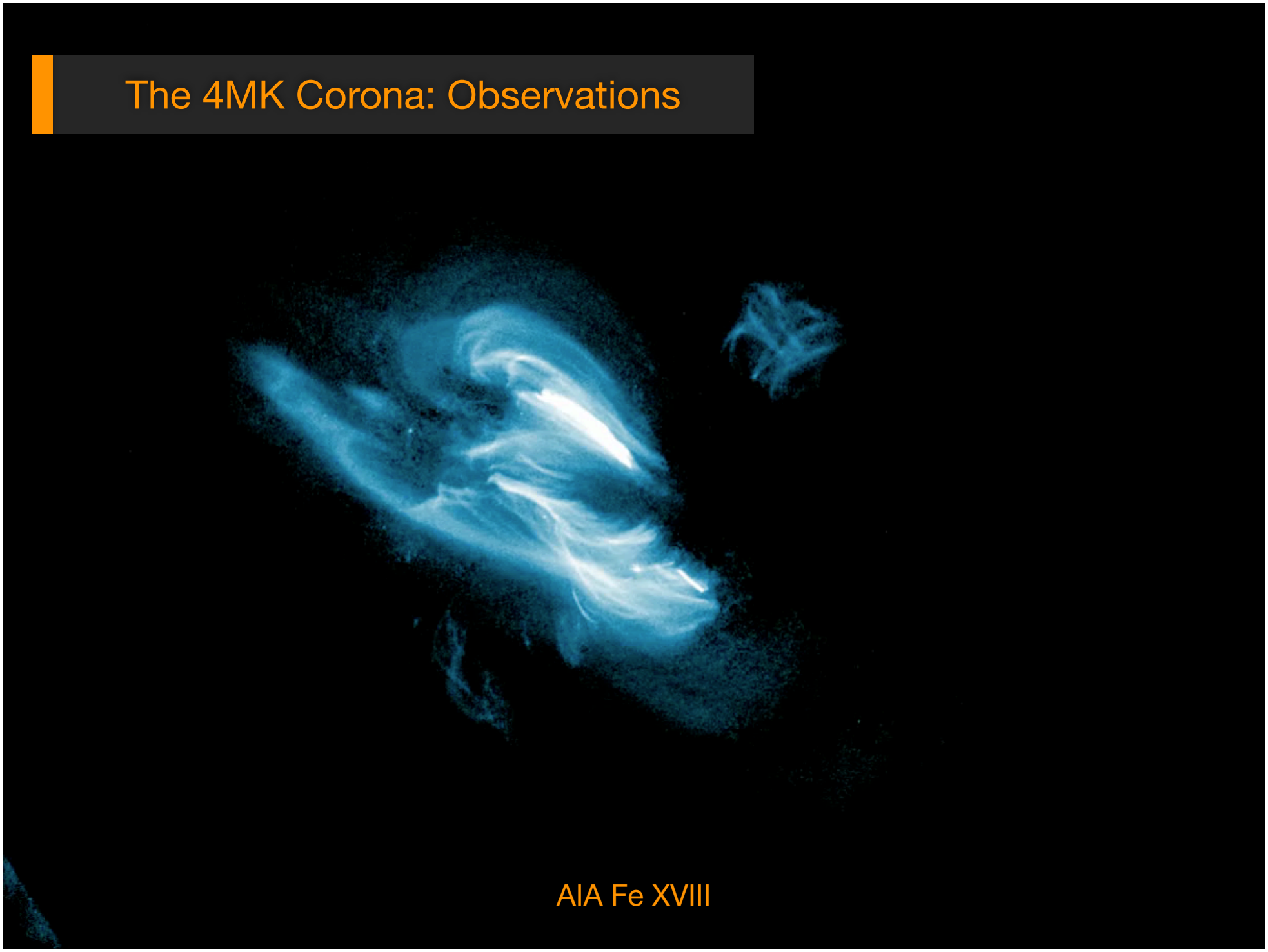
NEI?
Kappa Distributions?
Loop Geometry?

The 4MK Corona: Observations



AIA Fe XVIII

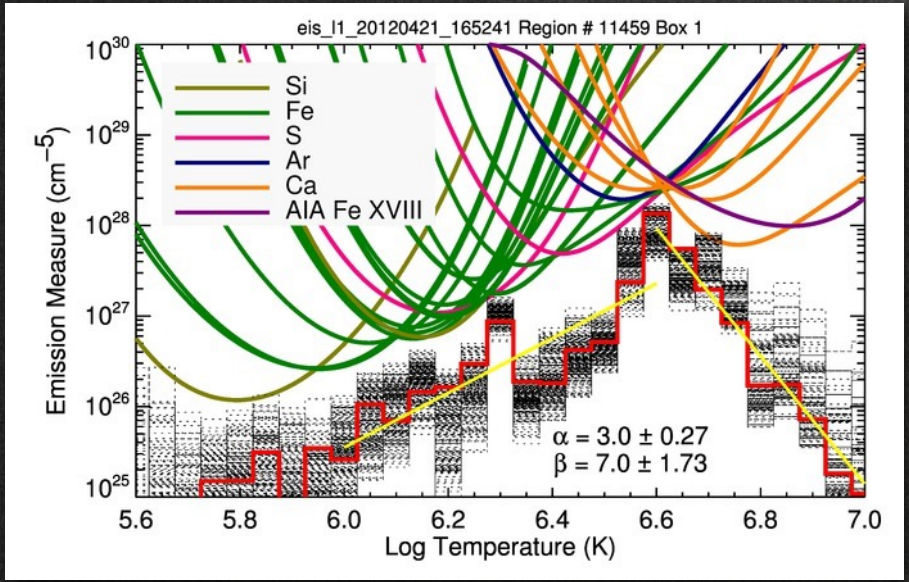
The 4MK Corona: Observations



AIA Fe XVIII

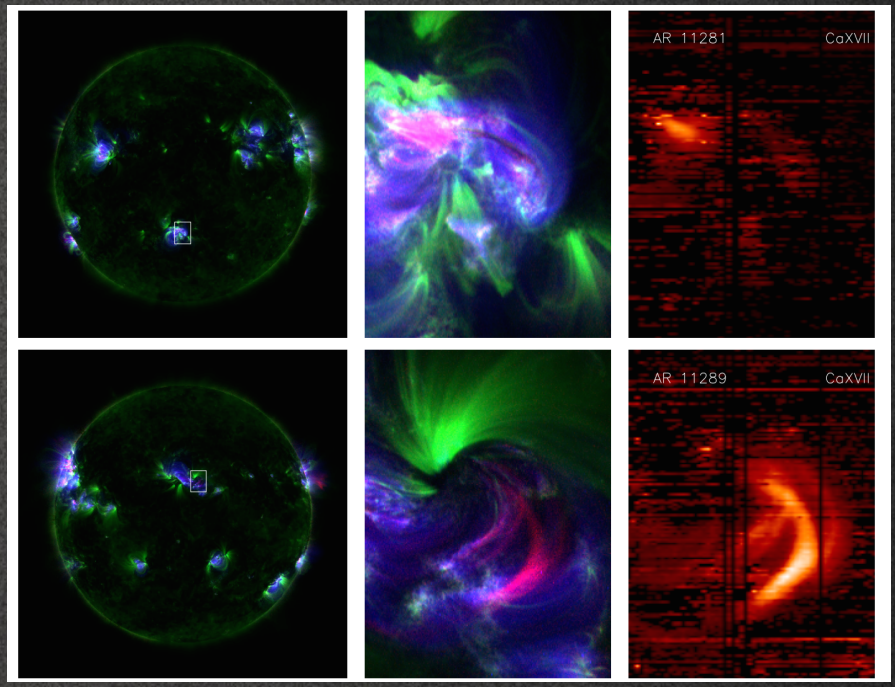
The 4MK Corona: Observations

DEMs are narrow



Warren et al. (2012)
Del Zanna et al (2015)

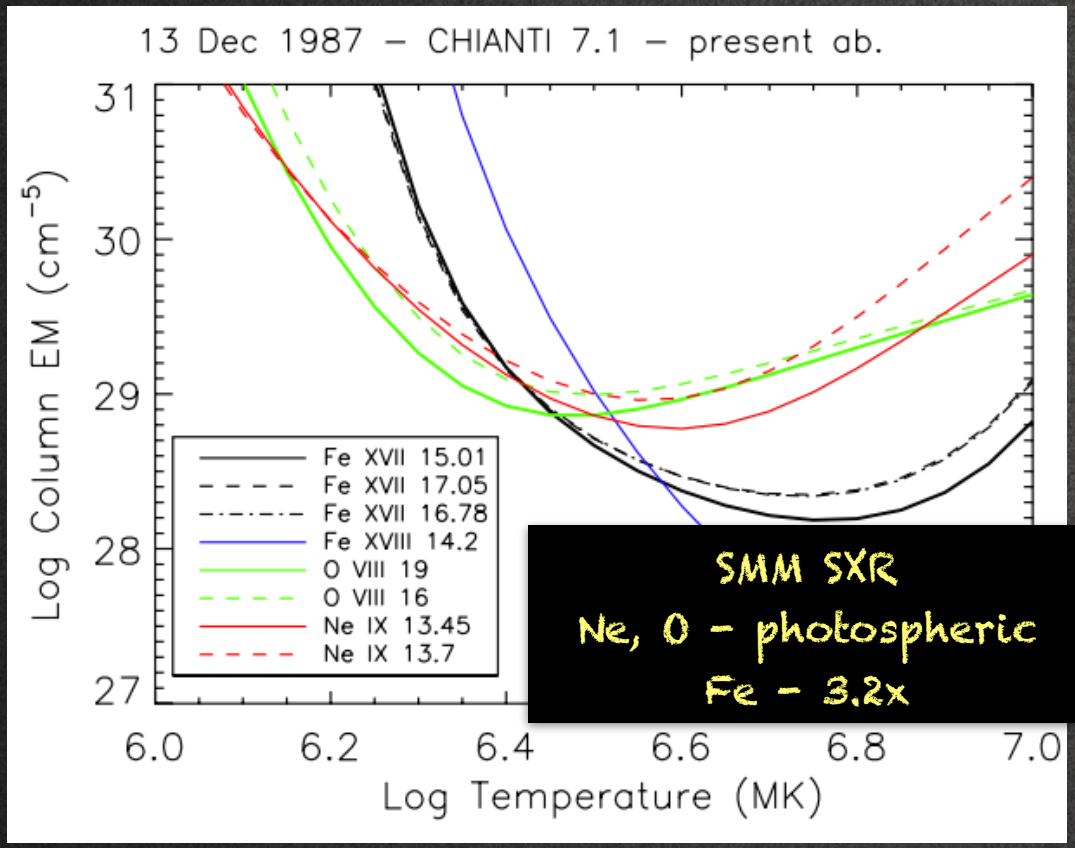
Amount of 5 MK Plasma is Small



Testa & Reale (2012)
Del Zanna & Mason (2015)

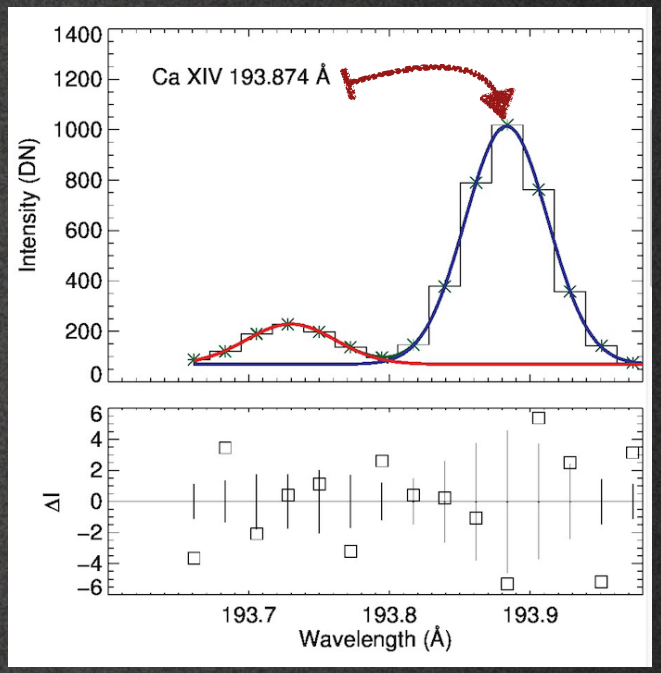
The 4MK Corona: Observations

Composition is Coronal



Del Zanna & Mason (2015)
Warren et al. (2012)

Non-thermal Velocities are Small (~ 18 km/s)

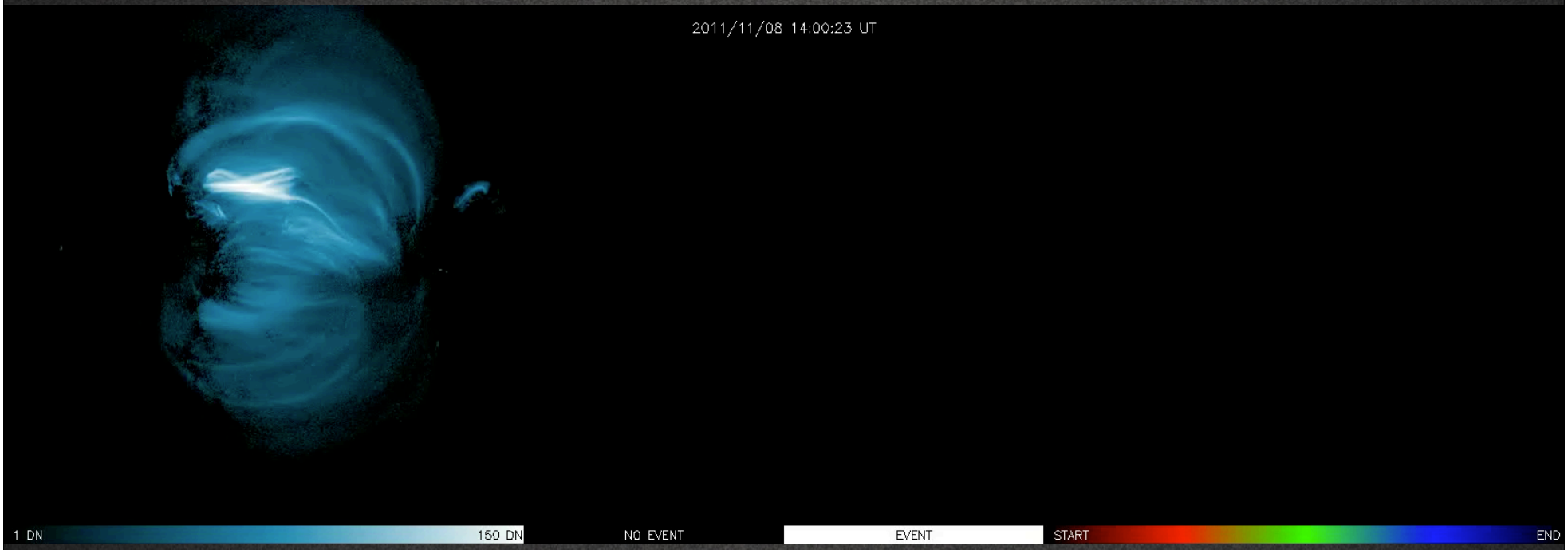


Imada et. al. (2009)
Brooks et al. (2015)

Bart: IRIS O I 1355 Å
VNT ~7 km/s

The 4MK Corona: Observations

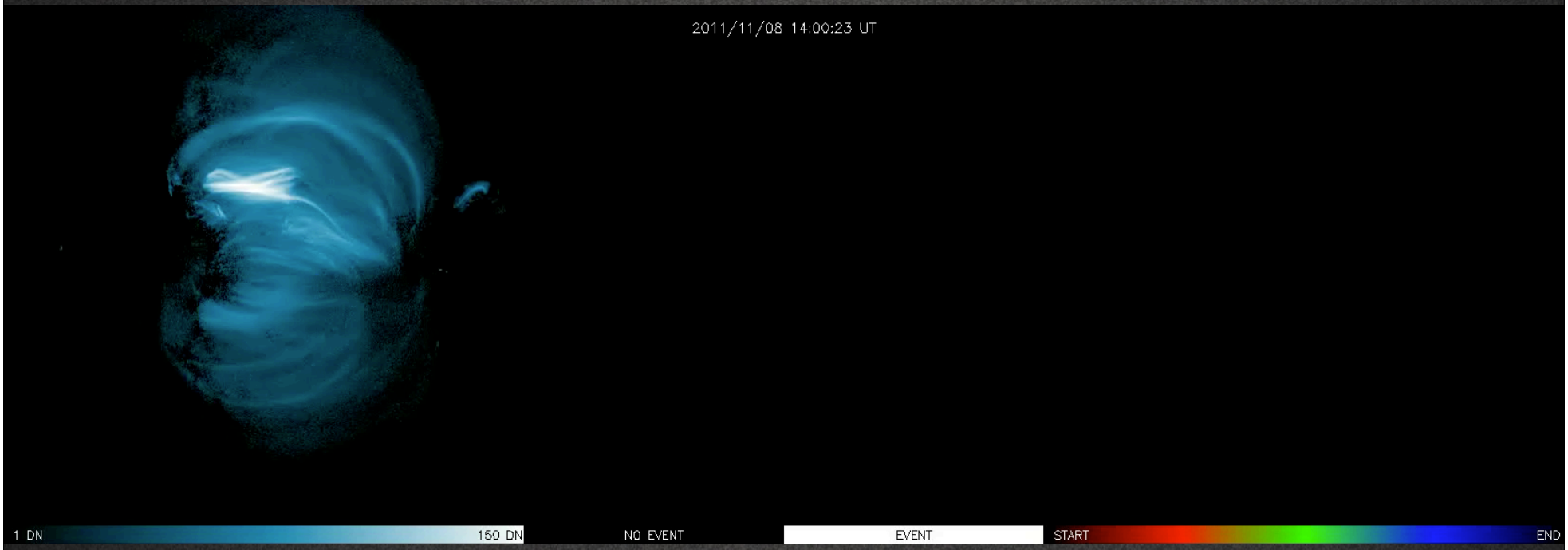
Fe XVIII emission is not steady



Ugarte-Urra & Warren (2014)

The 4MK Corona: Observations

Fe XVIII emission is not steady



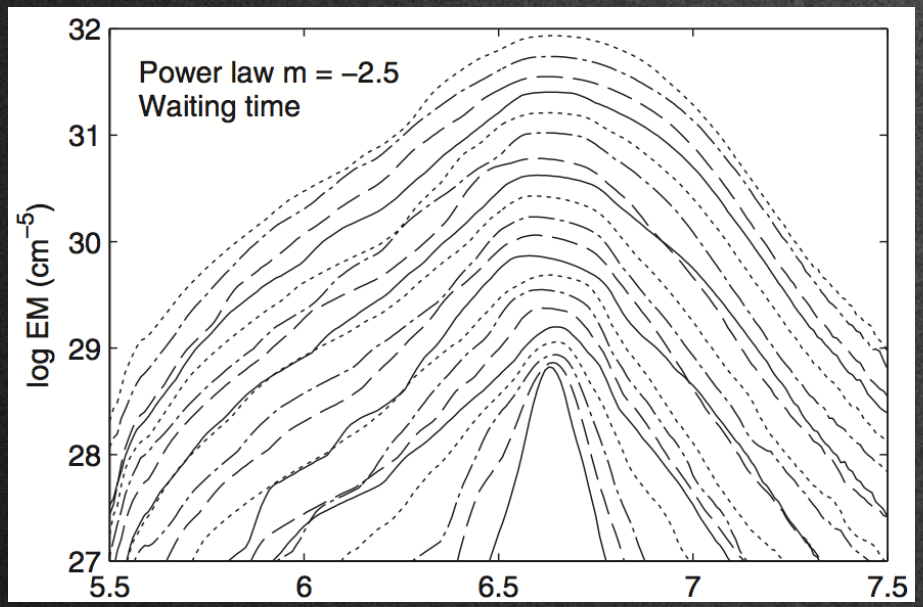
Ugarte-Urra & Warren (2014)

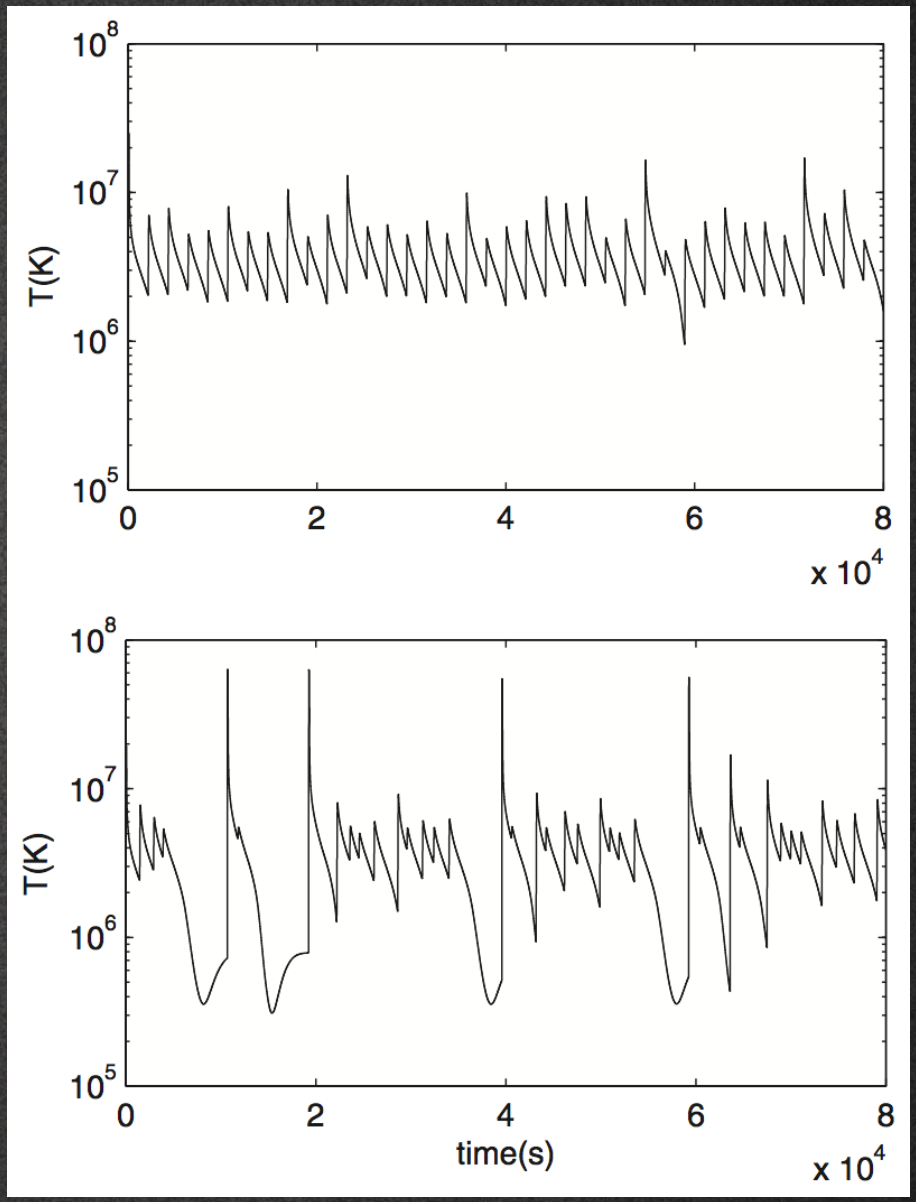
The 4MK Corona: 0D Simulations

Lack of 4 MK 3D MHD simulations is not a physics problem, but a computational problem (Viggo?)

"Super Stepping" (Meyer MNRAS 2012)
C. Johnston Poster (P2.6)

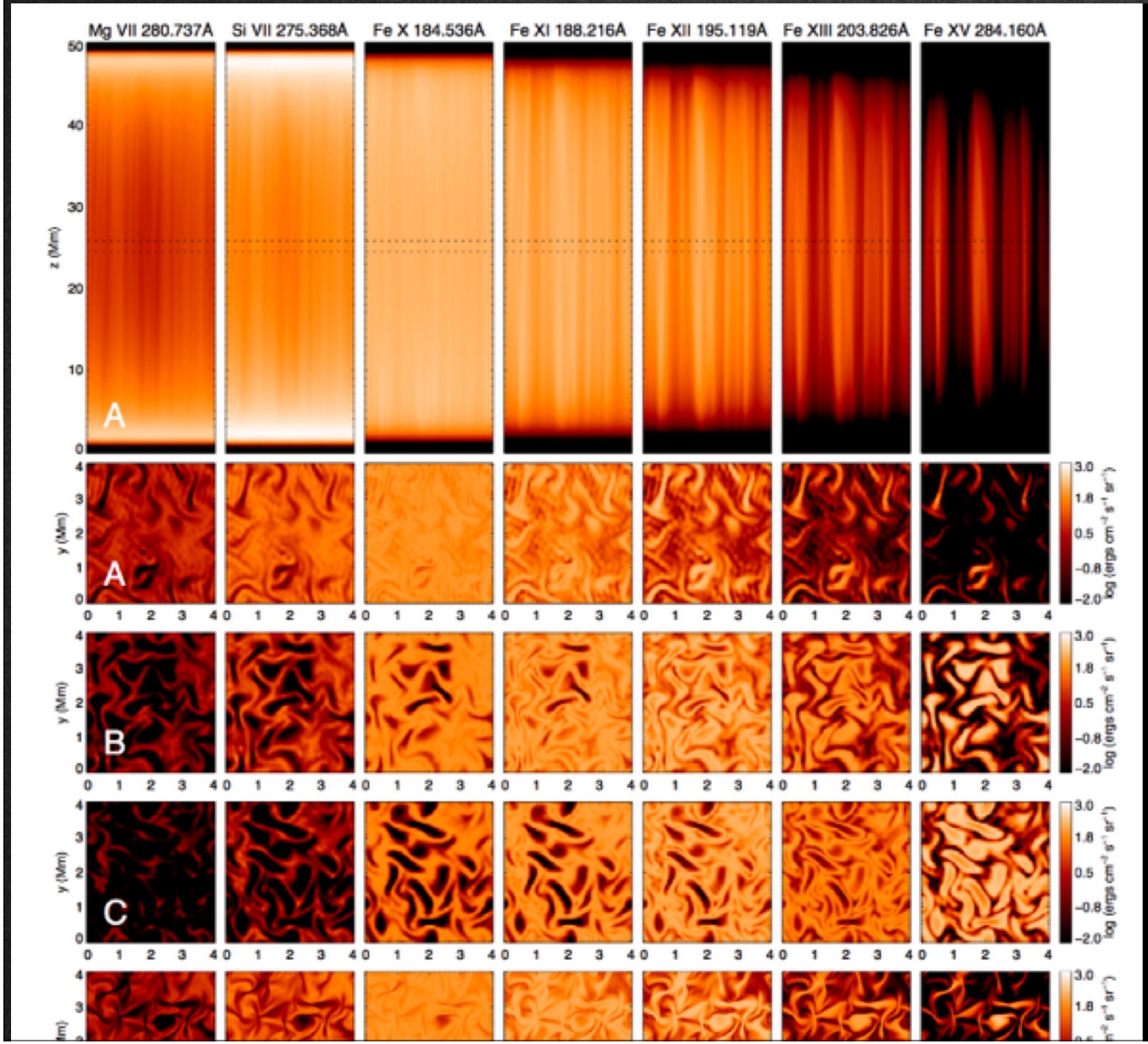
Cargill (2014); Also Fabio's Talk

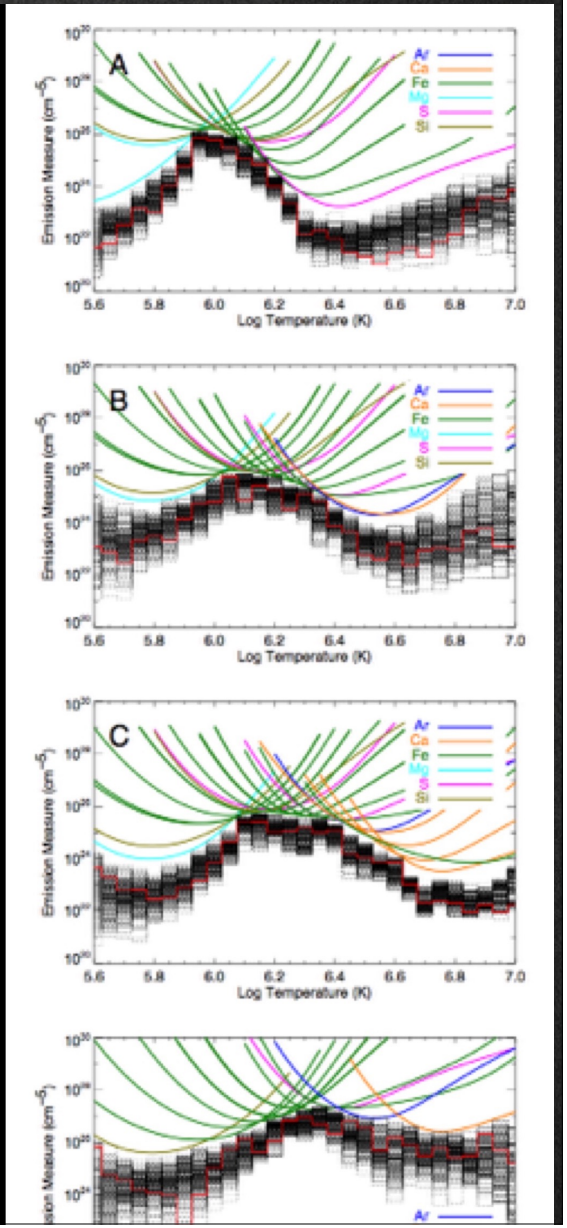




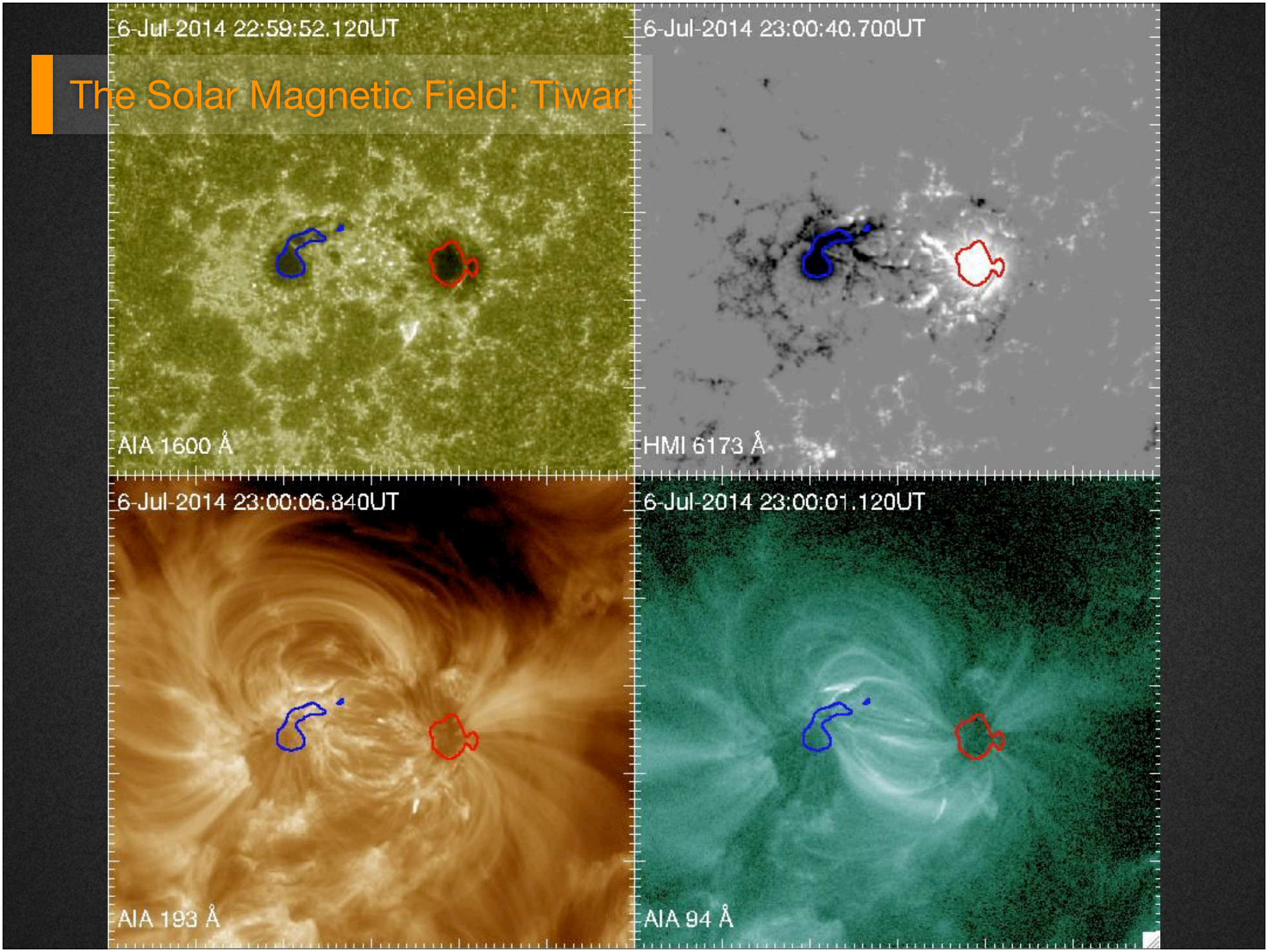
The (almost) 4MK Corona: 3D MHD Simulations

Dahlburg et al Submitted





The Solar Magnetic Field: Tiwari



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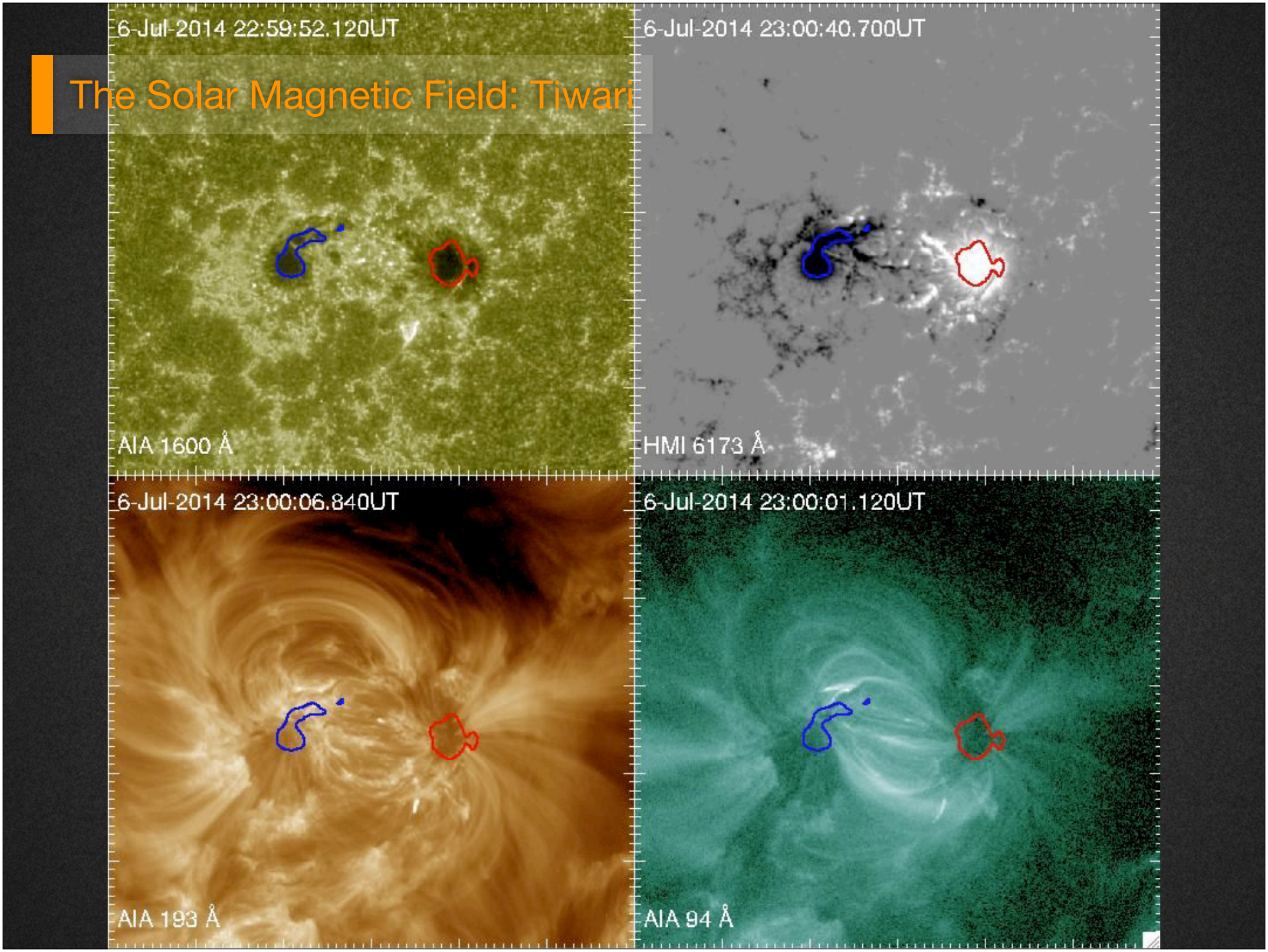
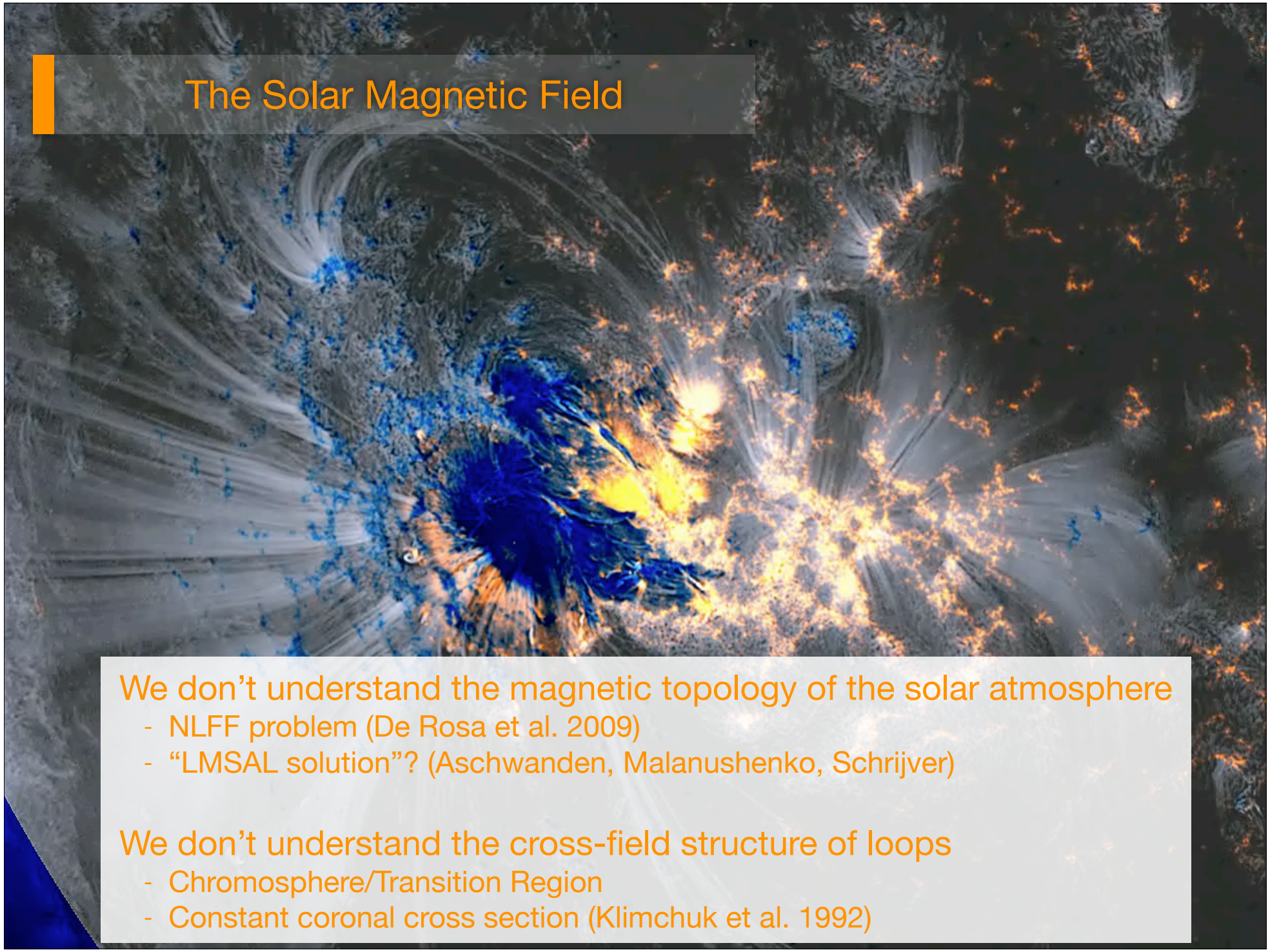


The Solar Magnetic Field



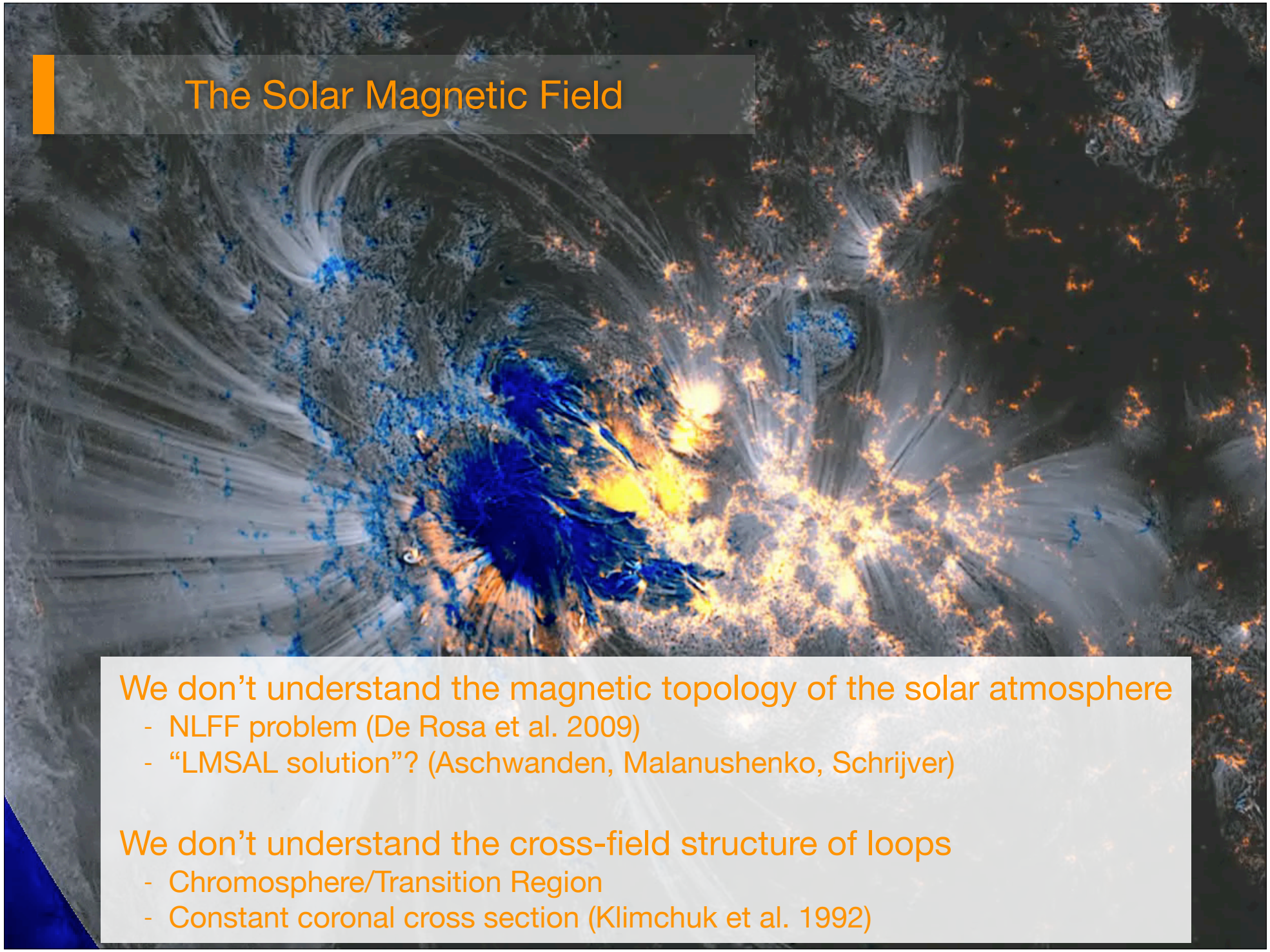
We don't understand the magnetic topology of the solar atmosphere

- NLFF problem (De Rosa et al. 2009)
- "LMSAL solution"? (Aschwanden, Malanushenko, Schrijver)

We don't understand the cross-field structure of loops

- Chromosphere/Transition Region
- Constant coronal cross section (Klimchuk et al. 1992)

The Solar Magnetic Field



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