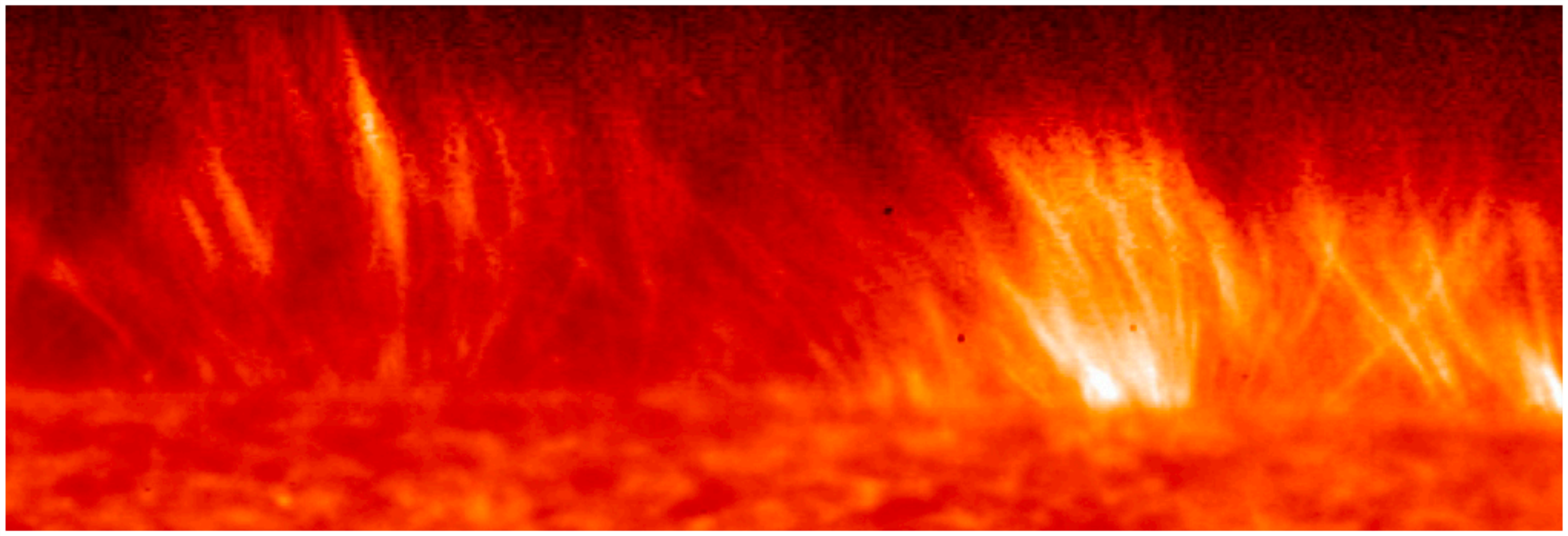


Chromospheric Magnetic Fields

Andreas Lagg
MPI for Solar System research, Göttingen

IRIS-9, Göttingen, 25-29 June 2018

Invited Talk

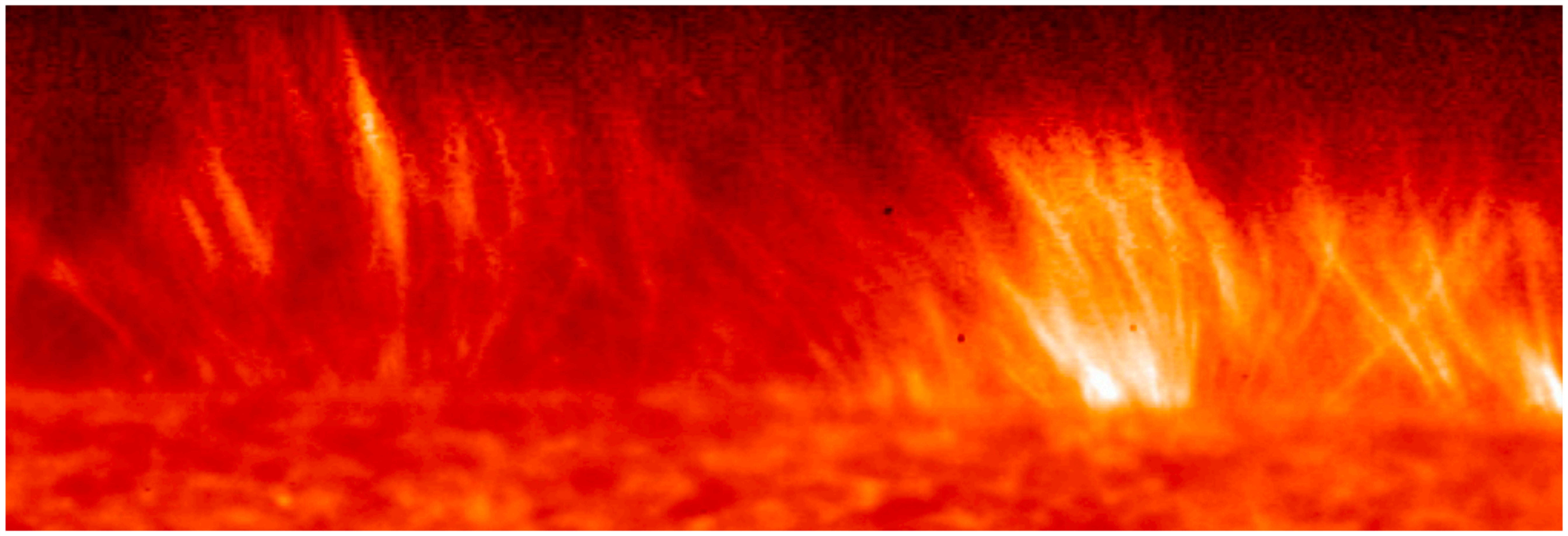
2. Chromospheric heating and dynamics

Magnetic field in the chromosphere

Andreas Lagg[1]

[1] *Max Planck Institute for Solar System Research, Göttingen, Germany*

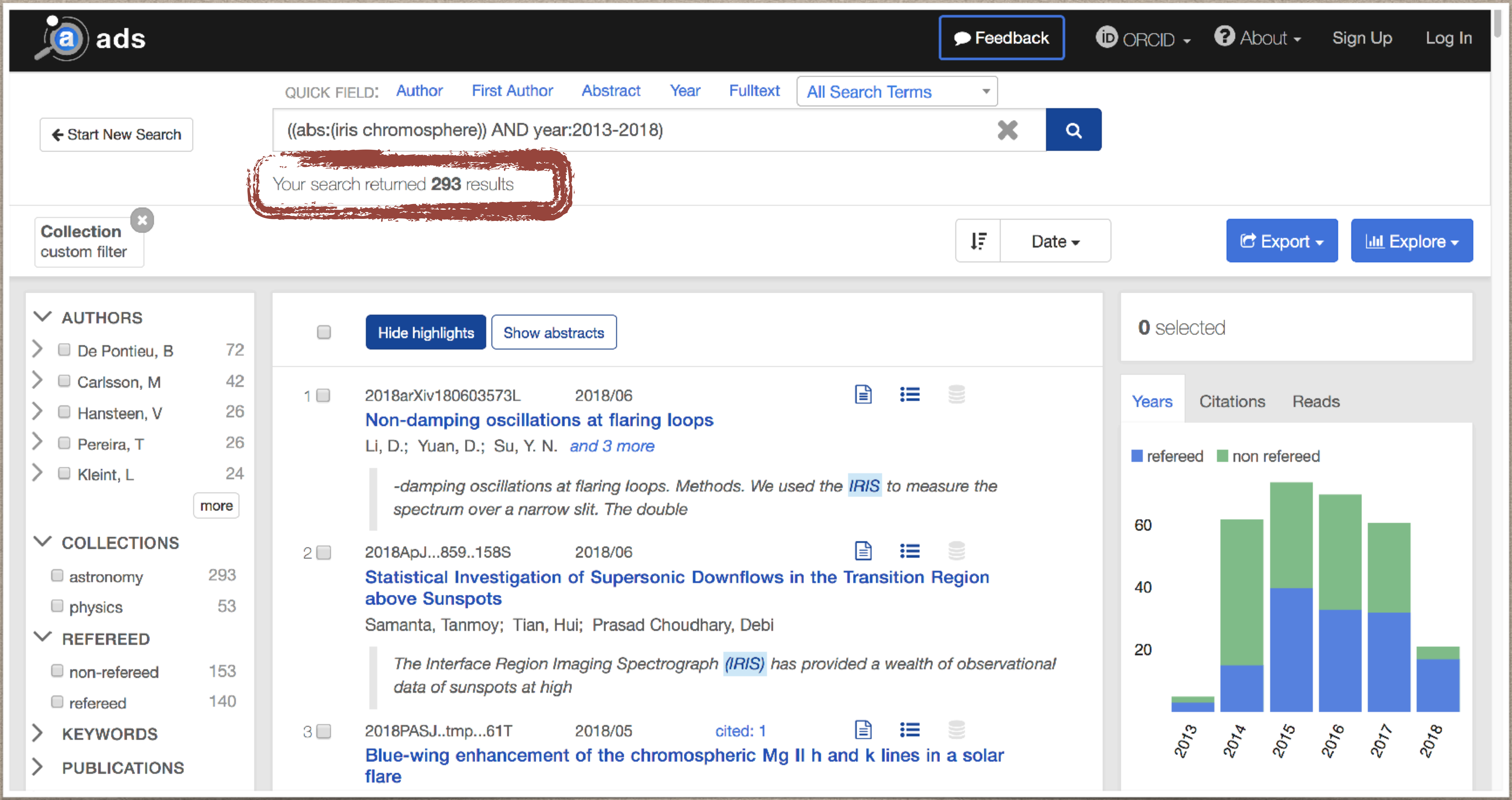
Measuring the chromospheric magnetic field is a challenging endeavor. In this layer, the fields are typically weak and require highly sensitive spectropolarimetric observations; the gas and plasma motions occur at very high velocities and demand for a high temporal cadence, and the fine structure, visible for example in the Hα filaments, a high spatial resolution. In addition, low plasma densities and the anisotropy of the radiation field lead to a high level of complexity in the physics of the chromosphere. Sophisticated instrumentation installed in ground-based and space observatories, here especially the IRIS mission, have led to a significant improvement of the understanding of the chromosphere during the last decade. In this talk I will highlight some of the recent advances, based on measurements in the He 10830Å triplet and the Ca infrared lines, the Mg data of the IRIS and the Sunrise missions, and give an outlook to future observatories and instruments aimed for improving the understanding this important layer connecting the photosphere and the corona.



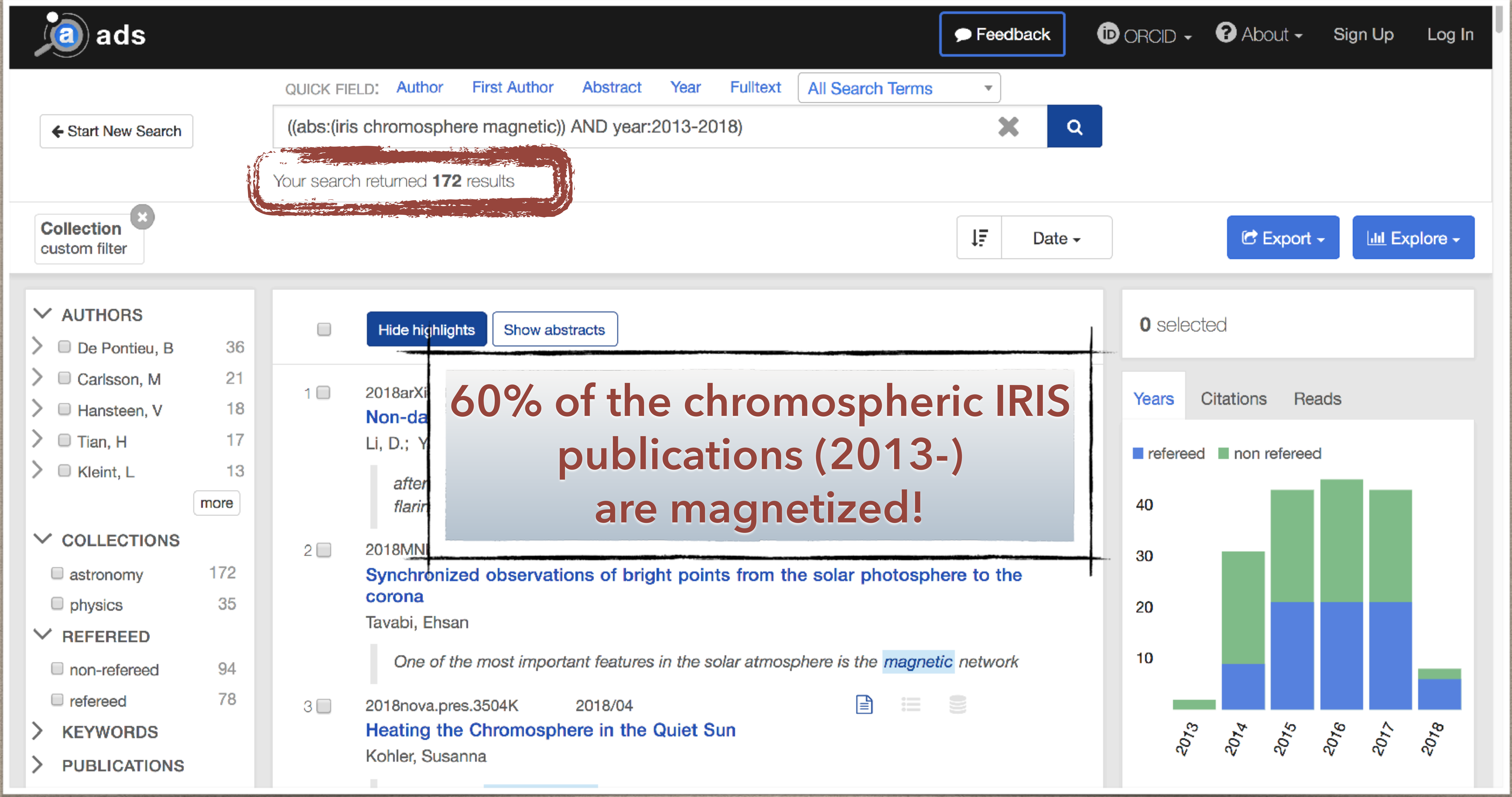
Chromospheric Magnetic Fields

Andreas Lagg
MPI for Solar System research, Göttingen

ADS: IRIS + Chromosphere in Abstract



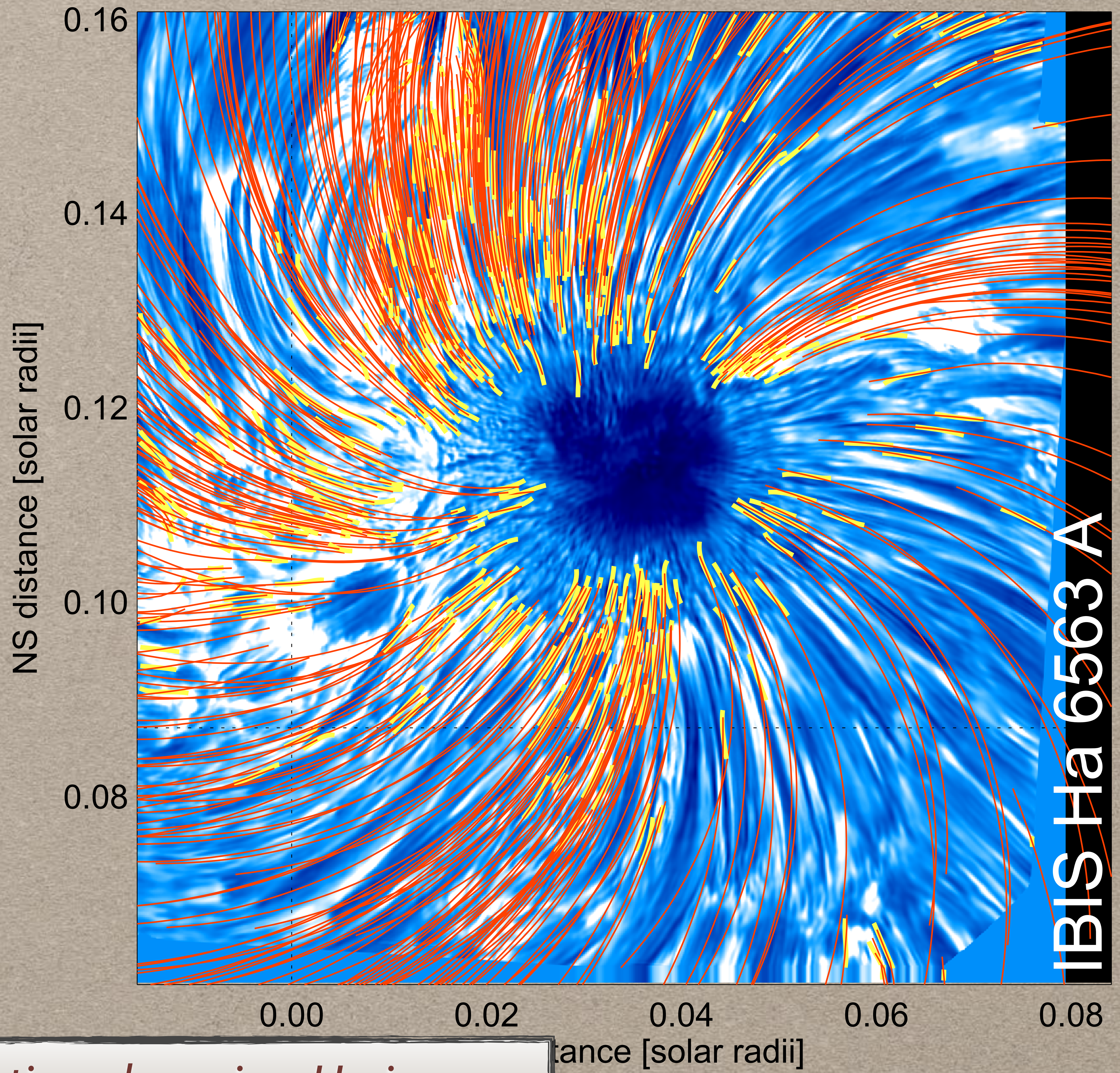
ADS: IRIS + Chromosphere + Magnetic in Abstract



60% of the chromospheric IRIS publications (2013-) are magnetized!

Aschwanden et al. (2016):
Tracing the chromospheric and coronal magnetic field with AIA, IRIS, IBIS and ROSA data

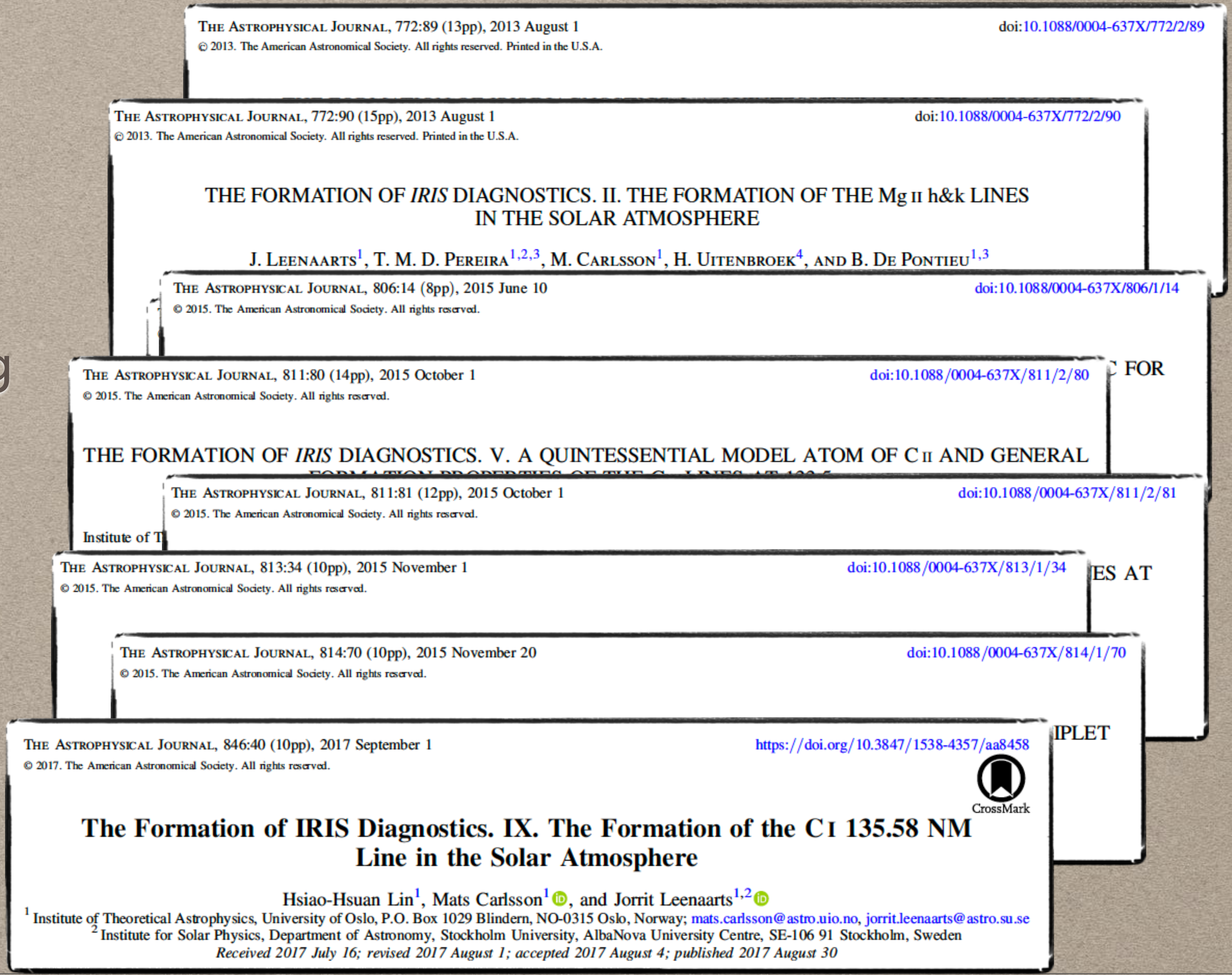
- Alignment of curvi-linear structures to magnetic field
- Compute free energy: 2-4 times higher than from coronal estimates
- Determine height range of chromospheric features (h≤4000 km, corona: up to 35 Mm)
- Determine plasma-β 10^{-5}–10^{-1}



Also: Wiegelmann et al. (2008): Improving NLFF Extrapolations by using Hα-images

IRIS Diagnostics: (see also tutorials yesterday)

- Mg II h&k model atom
- Mg II h&k formation
- Mg II h&k IRIS images
- Mg II h&k for chrom. heating
- C II 133.5nm model atom
- C II 133.5 diag. potential
- O I 135.56nm formation
- C II 133.5 IRIS observations
- C I 135.58 nm formation


The Astrophysical Journal, 772:89 (13pp), 2013 August 1 doi:10.1088/0004-637X/772/2/89
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The Astrophysical Journal, 772:90 (15pp), 2013 August 1 doi:10.1088/0004-637X/772/2/90
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THE FORMATION OF *IRIS* DIAGNOSTICS. II. THE FORMATION OF THE Mg II h&k LINES IN THE SOLAR ATMOSPHERE

J. Leenaarts[1], T. M. D. Pereira[1,2,3], M. Carlsson[1], H. Uitenbroek[4], and B. De Pontieu[1,3]

The Astrophysical Journal, 806:14 (8pp), 2015 June 10 doi:10.1088/0004-637X/806/1/14
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The Astrophysical Journal, 811:80 (14pp), 2015 October 1 doi:10.1088/0004-637X/811/2/80
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THE FORMATION OF *IRIS* DIAGNOSTICS. V. A QUINTESSENTIAL MODEL ATOM OF C II AND GENERAL

The Astrophysical Journal, 811:81 (12pp), 2015 October 1 doi:10.1088/0004-637X/811/2/81
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The Astrophysical Journal, 813:34 (10pp), 2015 November 1 doi:10.1088/0004-637X/813/1/34
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The Astrophysical Journal, 814:70 (10pp), 2015 November 20 doi:10.1088/0004-637X/814/1/70
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The Astrophysical Journal, 846:40 (10pp), 2017 September 1 https://doi.org/10.3847/1538-4357/aa8458
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The Formation of IRIS Diagnostics. IX. The Formation of the C I 135.58 NM Line in the Solar Atmosphere

Hsiao-Hsuan Lin[1], Mats Carlsson[1], and Jorrit Leenaarts[1,2]
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What questions do we ask to the chromospheric magnetic field?

Simulations / Modelling

Observations

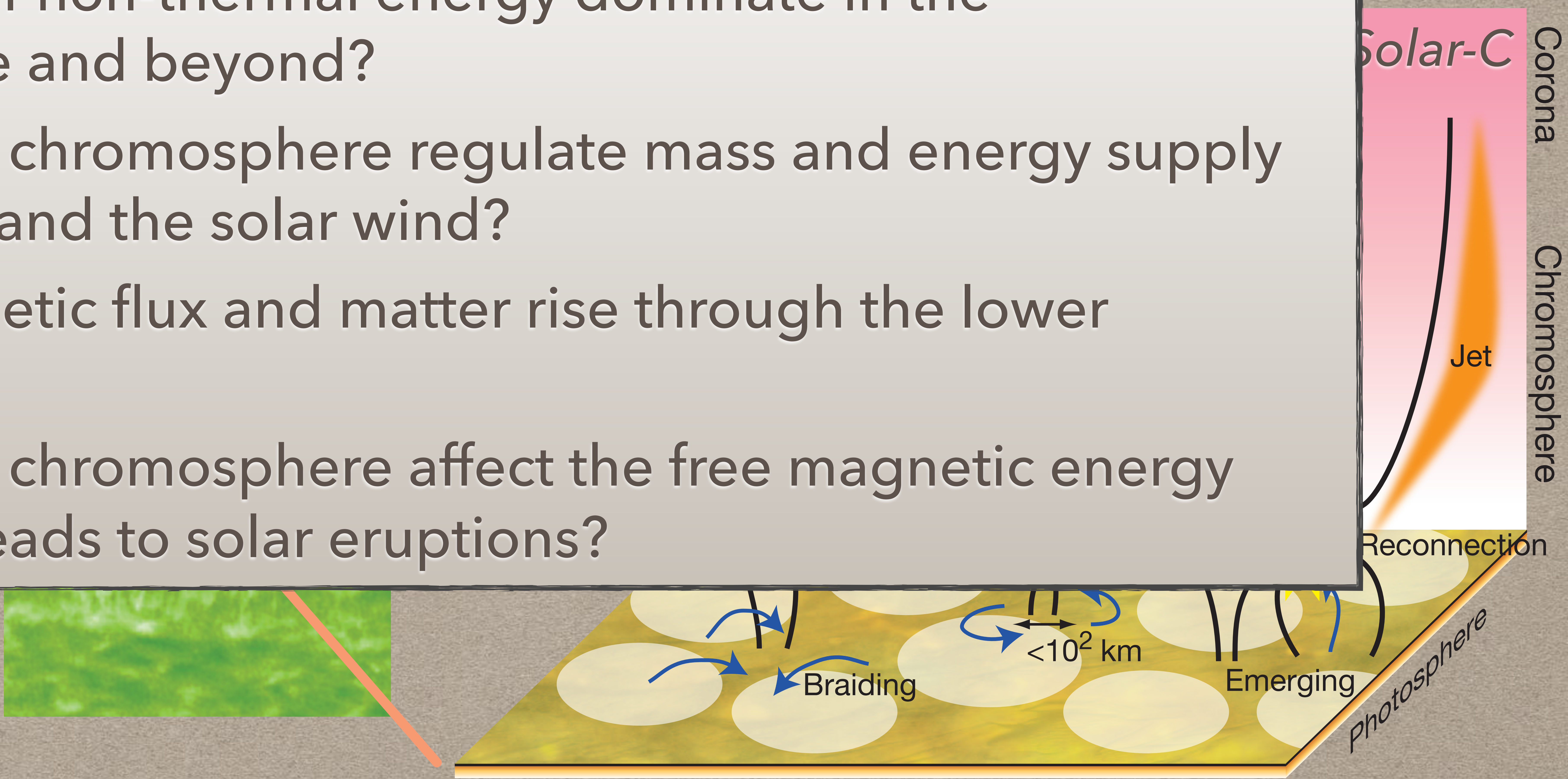
Inversions

Questions

Main topic: Energy transfer photosphere → chromosphere → corona

Oslo SAM project (2011/2016)

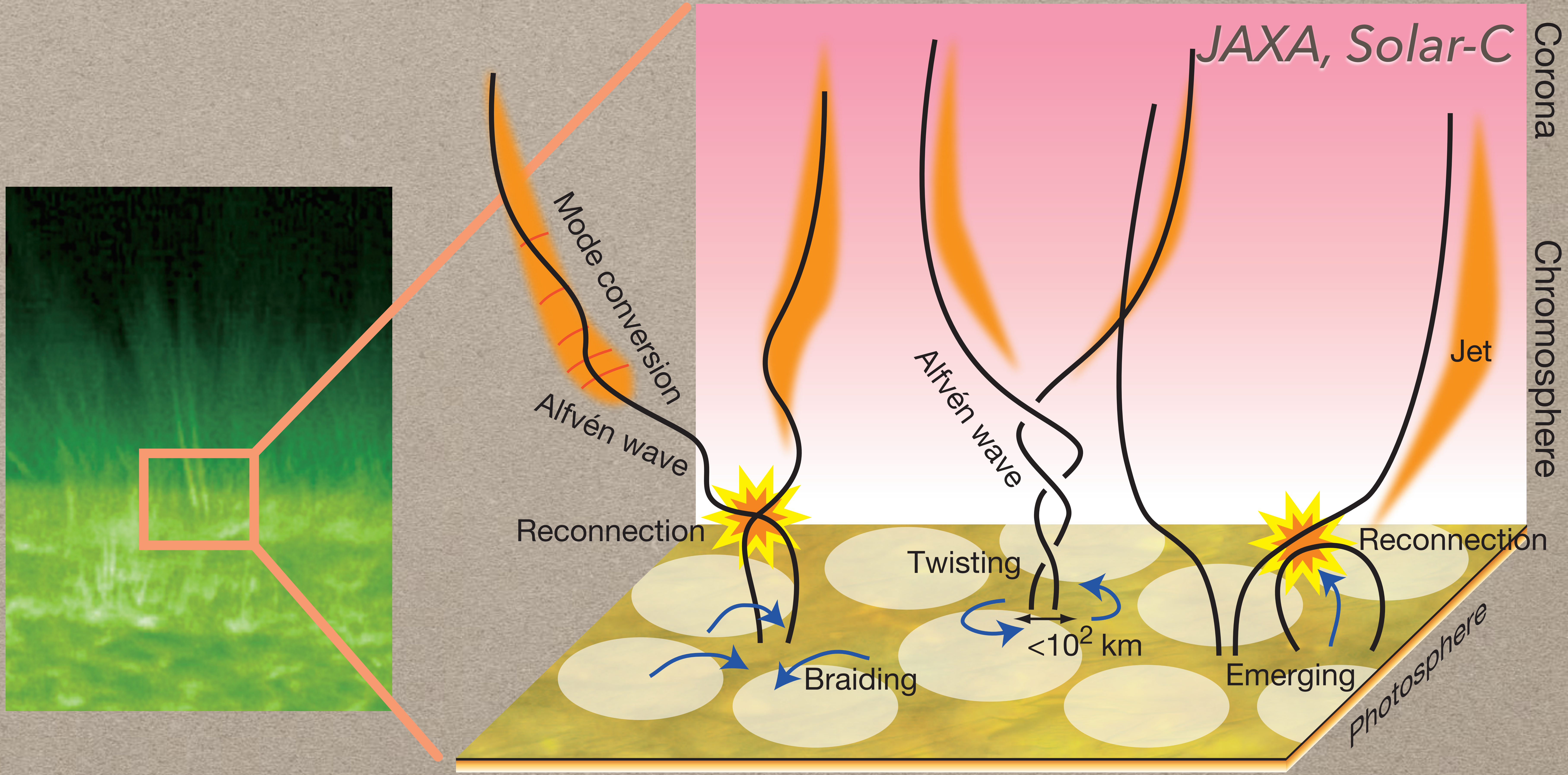
- Which types of non-thermal energy dominate in the chromosphere and beyond?
- How does the chromosphere regulate mass and energy supply to the corona and the solar wind?
- How do magnetic flux and matter rise through the lower atmosphere?
- How does the chromosphere affect the free magnetic energy loading that leads to solar eruptions?



Questions

Main topic: Energy transfer photosphere → chromosphere → corona

- Reveal the details of spicules
- Verify nano flare hypothesis
- Verify wave heating
- Energy build-up & triggers for flares, CMEs
- ...



Talks

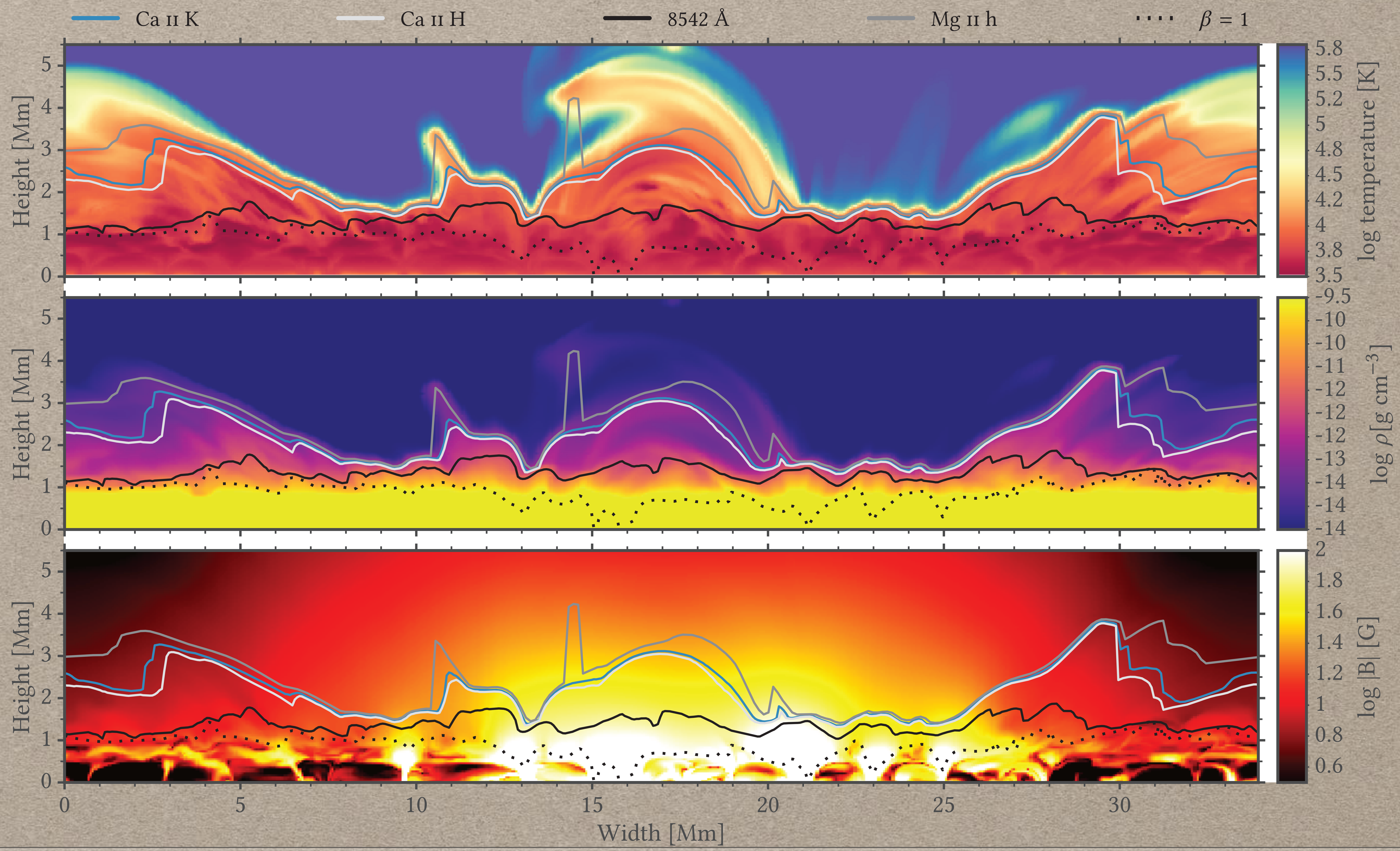
1. Fundamental physical processes and modeling

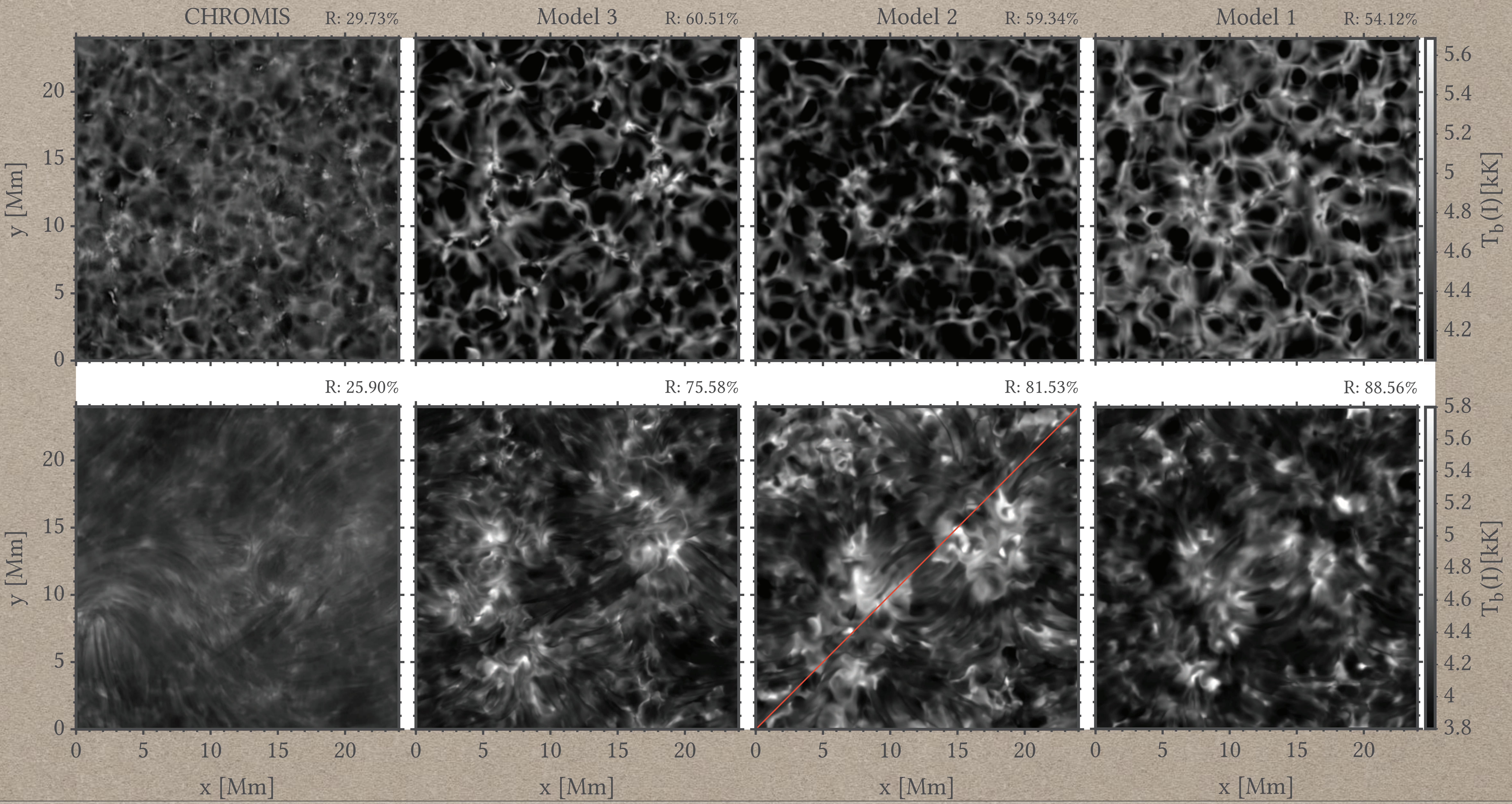
Tue	09:45	J. Martinez-Sykora	Chromospheric modeling on ion-neutral interaction effects and non-equilibrium ionization	1
Tue	10:15	J. Leenaarts	Studying radiation-MHD simulations in the Lagrangian frame	2
Tue	10:30	A. Sukhorukov	Simulating CLASP-IRIS co-observations in H I Ly-α and Mg II h	3
Tue	11:45	L. Ni	Magnetic reconnection in strongly magnetized regions around the solar TMR	4
Tue				
Tue				
Tue	15:00	J. Warnecke	Twisted currents of coronal loops in 3D MHD simulations	9
Tue	15:15	C. Gontikakis	Resonant scattering processes at work in an active region as detected in the transition region Si IV lines near 140 nm with IRIS	10
Tue	15:30	J. Dudík	Transition-Region lines with strong wings: Non-Maxwellian analysis of line profiles and intensities	11

Wed	11:45	M. Carlsson	An IRIS Optically Thin View of the Dynamics of the Solar Chromosphere	19
Wed	12:00	J. Bjørgen	Three-dimensional modeling of chromospheric spectral lines in a simulated active region	20
Wed	12:15	K. Barczynski	A disturbance propagating from the chromosphere into a heated coronal loop	21

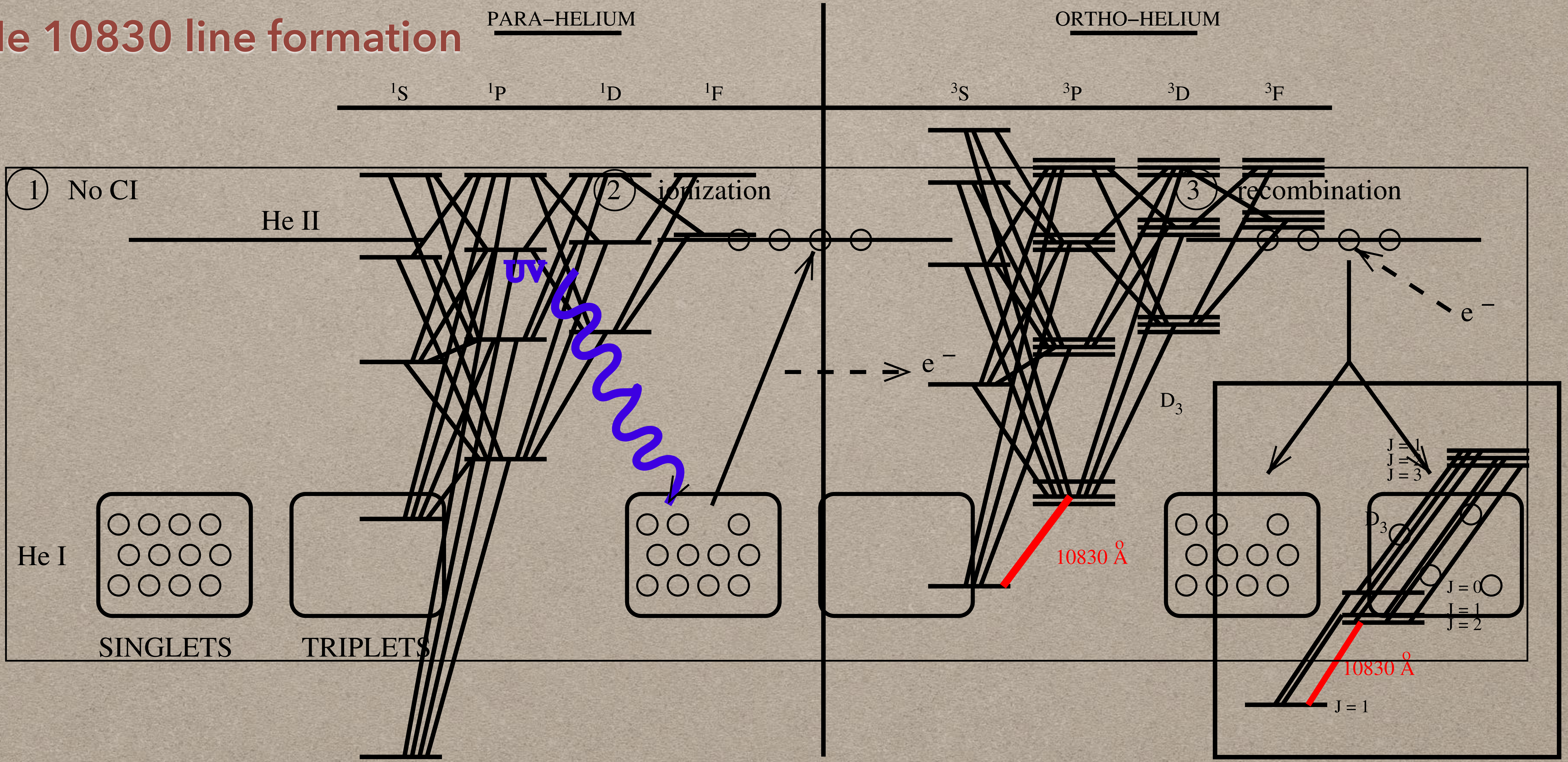
Three-dimensional modelling of the Ca II H and K lines in the solar atmosphere, Bjørgen et al. 2018

- Based on Bifrost (Gudiksen et al. 2011)
- Compute line profiles
- Compare with hi-res observations (CHROMIS/SST, Scharmer et al. 2018)



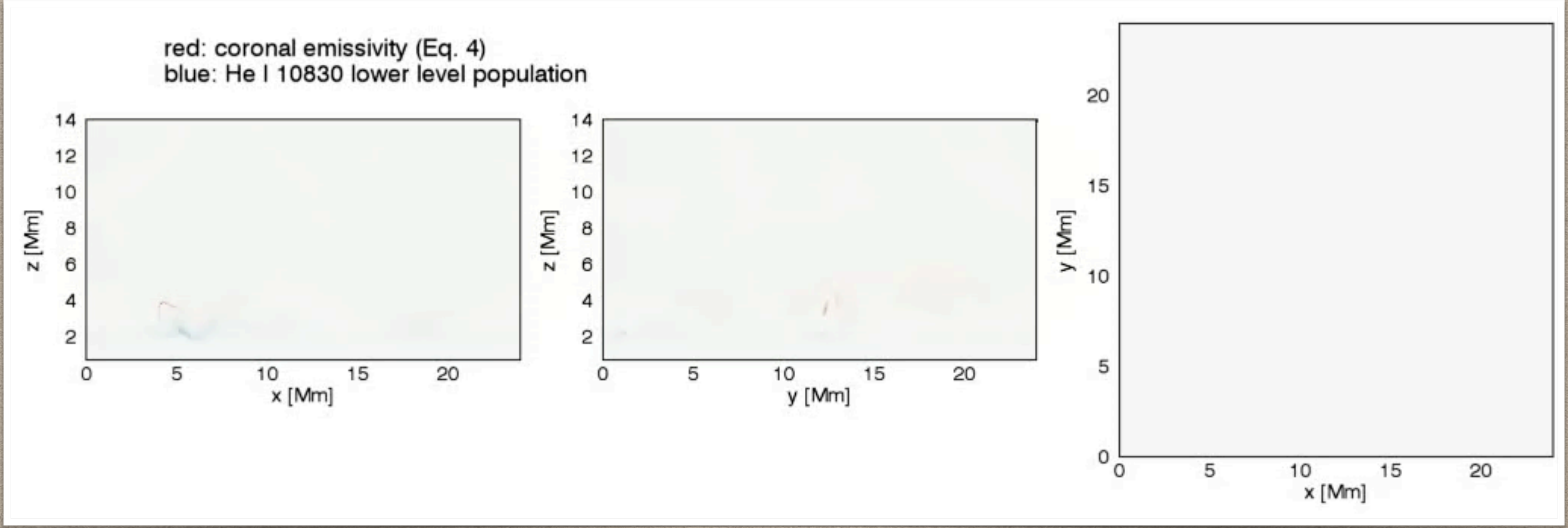

CHROMIS
R: 29.73%
Model 3
R: 60.51%
Model 2
R: 59.34%
Model 1
R: 54.12%
R: 25.90%
R: 75.58%
R: 81.53%
R: 88.56%
y [Mm]
x [Mm]
$T_b(I)$[kK]

He 10830 line formation



The cause of spatial structure in solar He I 1083 images (Leenaarts et al., 2016)

- He images show fine structure at the resolution limit (<100km)
- Result of the complex 3D structure of the chromosphere and corona
- 2 sources of ionising radiation: coronal (0.5-2 MK) & TR (80-200 kK)

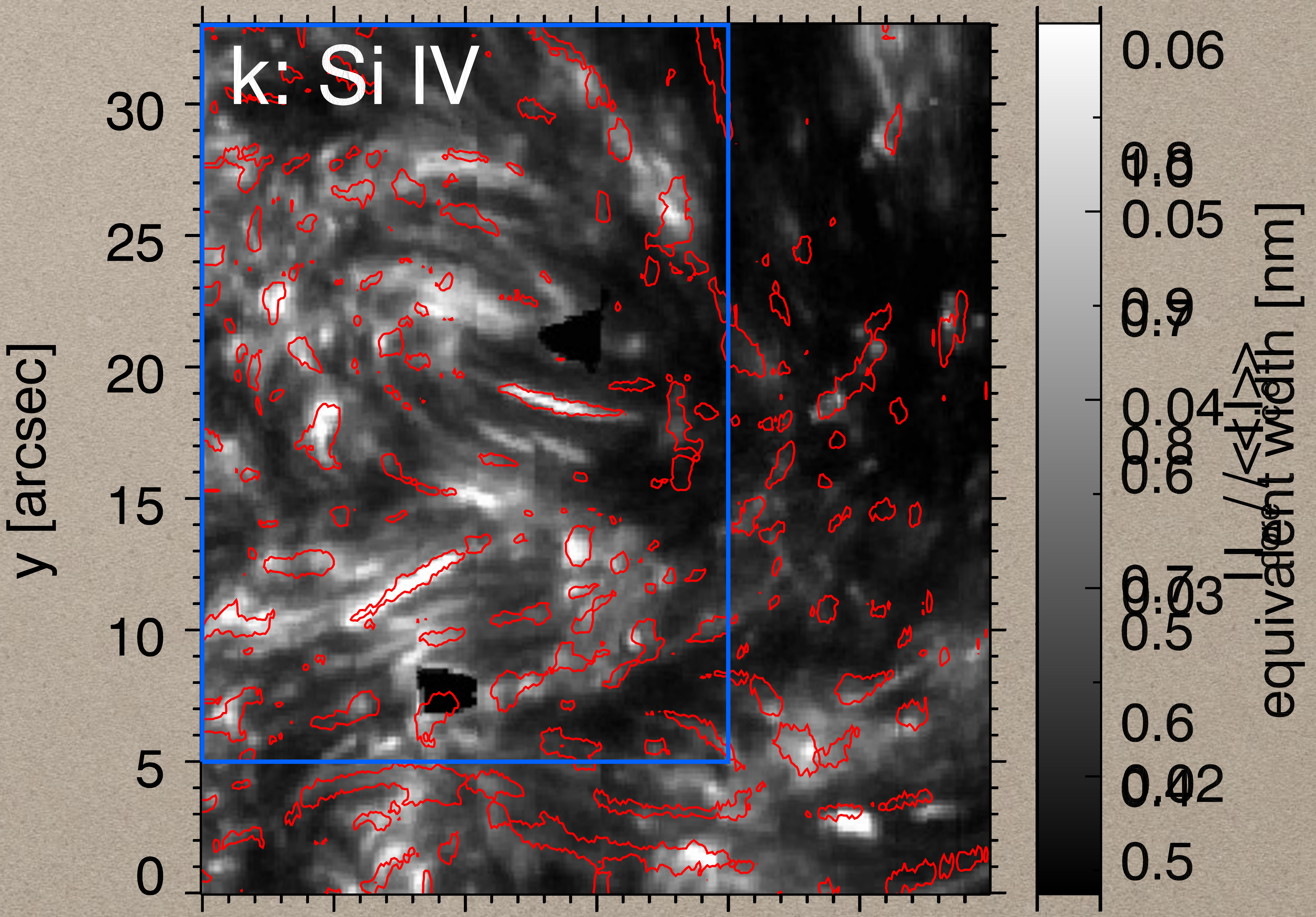


HE 10830 LINE FORMATION

The cause of spatial structure in solar He I 1083 images (Leenaarts et al., 2016)

Comparison
He 10830 ↔ Si IV 139.38

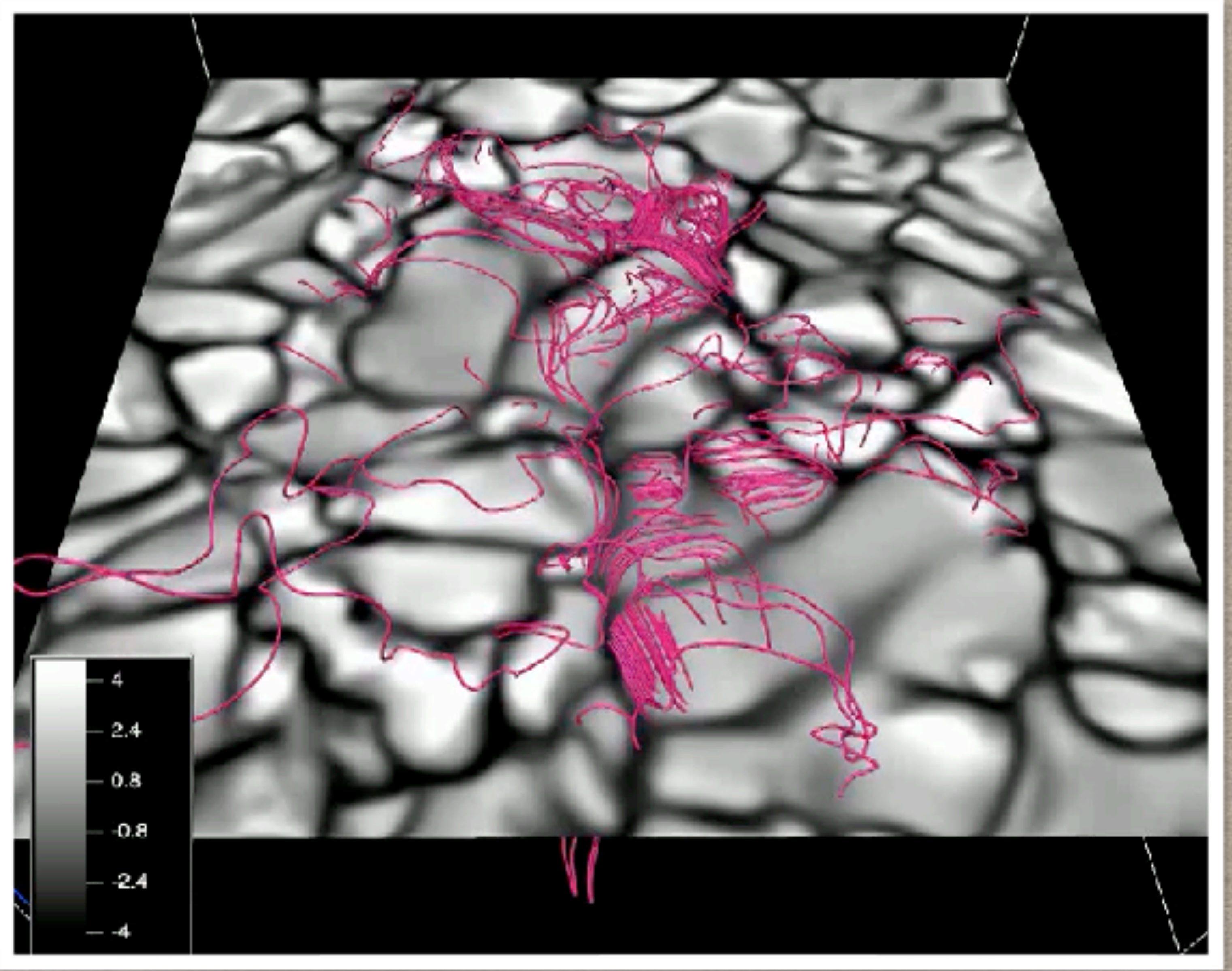
- Samples 80 kK
  → TR source for ionisation
- Good correlation of small-scale He patches with Si IV emission
- Correlation absent in AR filament

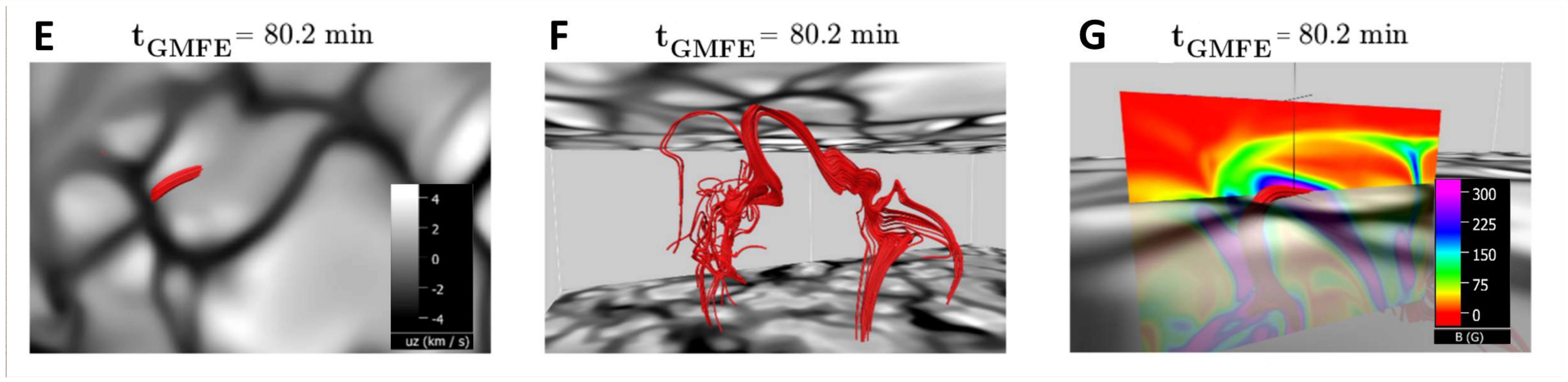


Tools for Chrom. B-Diagnostic: Sim/Mod

Small-Scale Flux Emergence in the Quiet Sun (Moreno-Insertis et al. 2018)

- Based on Bifrost (Gudiksen et al., 2011)
- Two types of flux emergence: sheets & tubes
- Tubes: observed since 10 years
- Sheets only recently confirmed by observations (Sunrise-II quiet-sun granule-covering flux sheets, Centeno et al.2017)





Tools for Chrom. B-Diagnostic: Inversions

- Milic 2018: SNAPI

Spectropolarimetric NLTE inversion code SNAPI

I. Milić[1] and M. van Noort[1]

Max-Planck-Institut für Sonnersystemforschung, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany
e-mail: milic@mps.mpg.de; vannoort@mps.mpg.de

Inversions are the bridge between simulations / modelling and observations.

- De la Cruz Rodríguez

IPLET LINES

…SENSIO RAMOS[2,3]
[1] Institute for Solar Physics, Dept. of Astronomy, Stockholm University, AlbaNova University Centre, SE-106 91 Stockholm Sweden
[2] Instituto de Astrofísica de Canarias, E-38205, La Laguna, Tenerife, Spain
[3] Departamento de Astrofísica, Universidad de La Laguna, E-38205 La Laguna, Tenerife, Spain

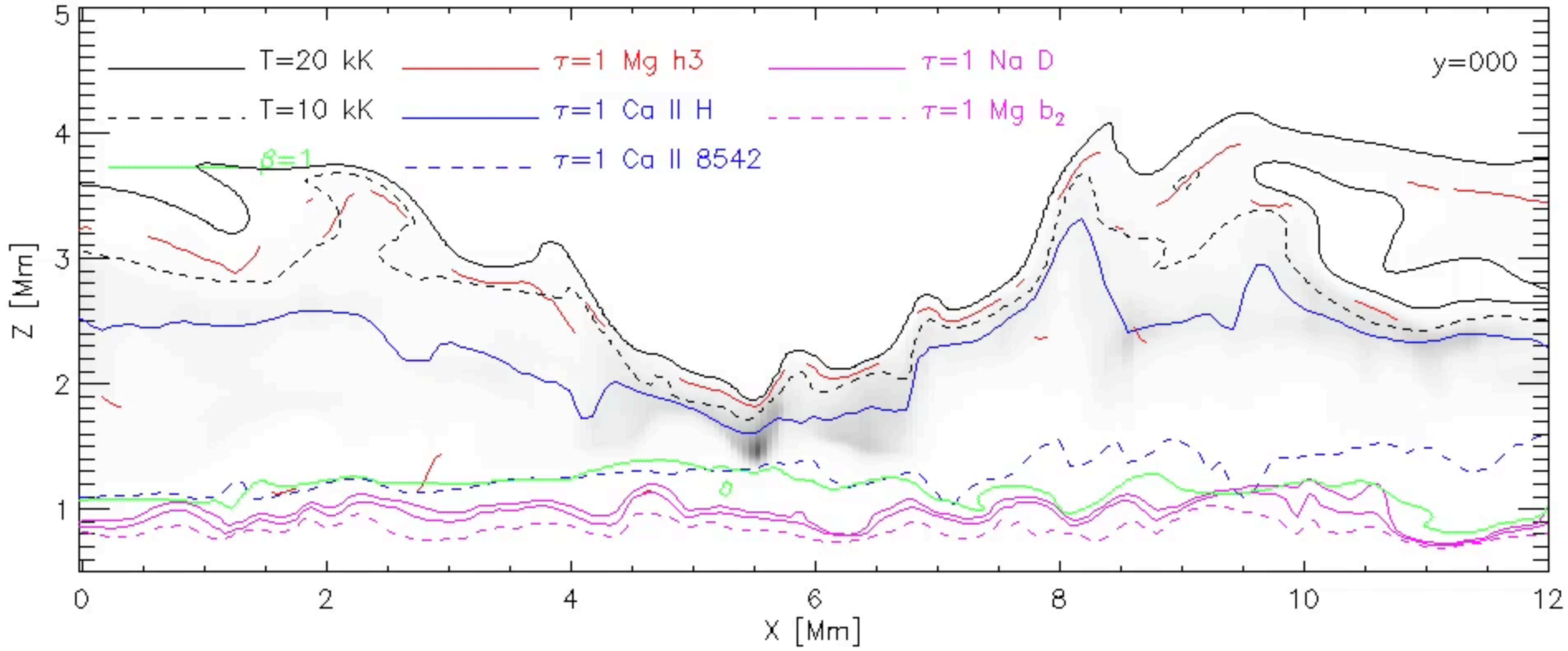
… 29; published 2016 October 18

Required: High-quality observations. What makes it so difficult?

- Socas-Navarro: NICOLE

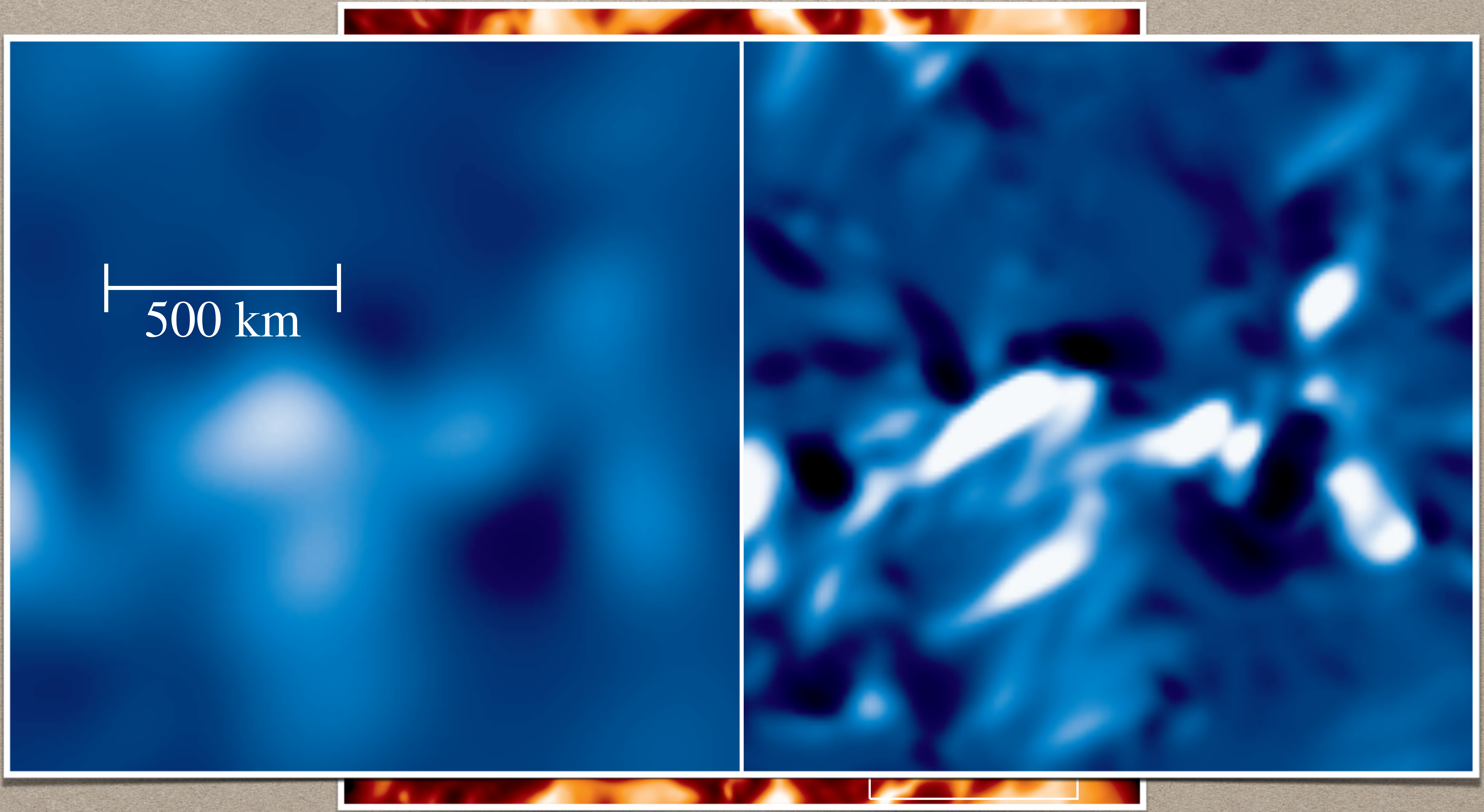
An open-source, massively parallel code for non-LTE synthesis and inversion of spectral lines and Zeeman-induced Stokes profiles★

H. Socas-Navarro[1,2], J. de la Cruz Rodríguez[3], A. Asensio Ramos[1,2], J. Trujillo Bueno[1,2,4], and B. Ruiz Cobo[1,2]

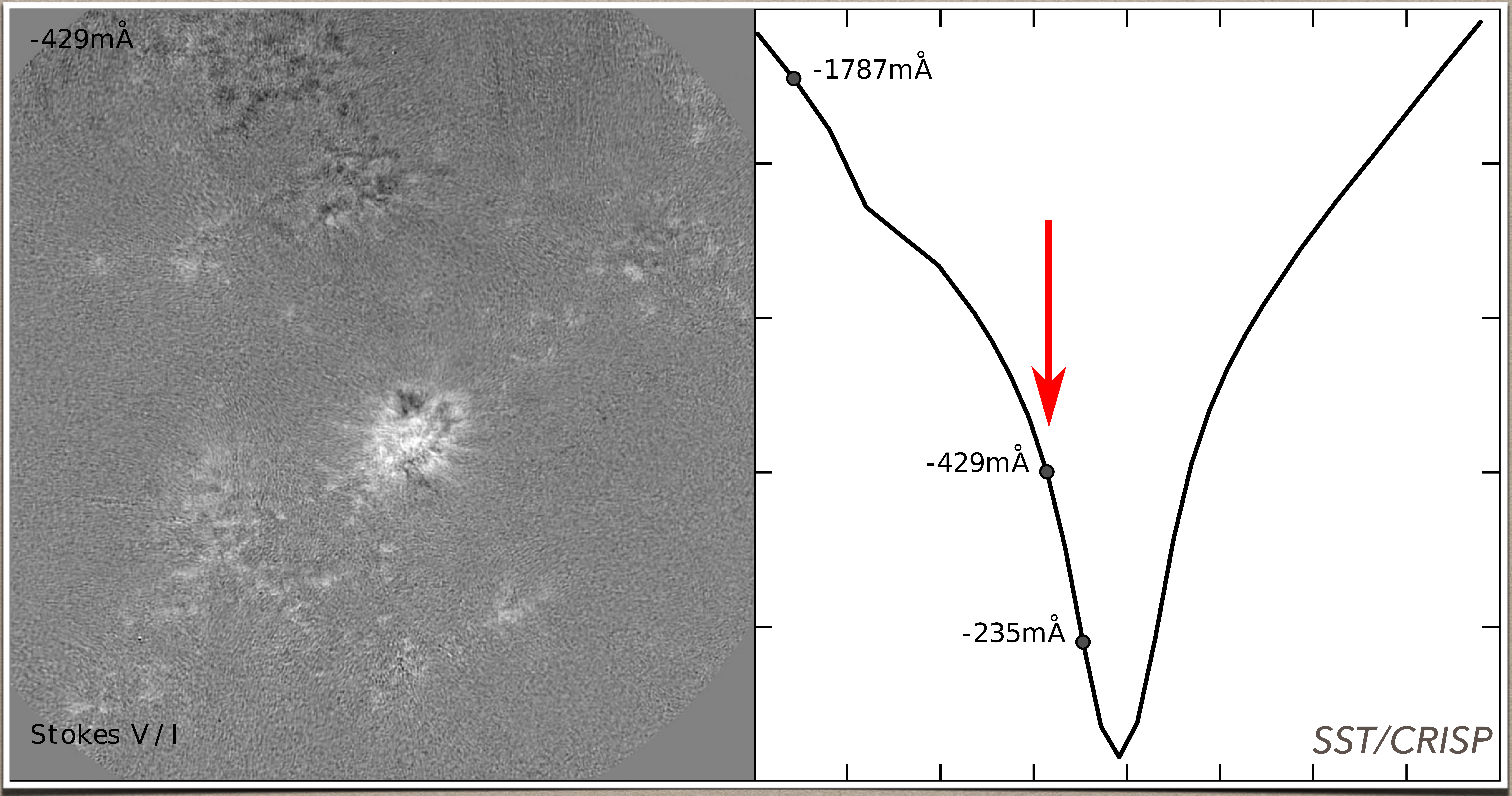


Courtesy: Mats Carlsson

The Challenges for Spectropolarimetry



The Challenges: Photon Budget

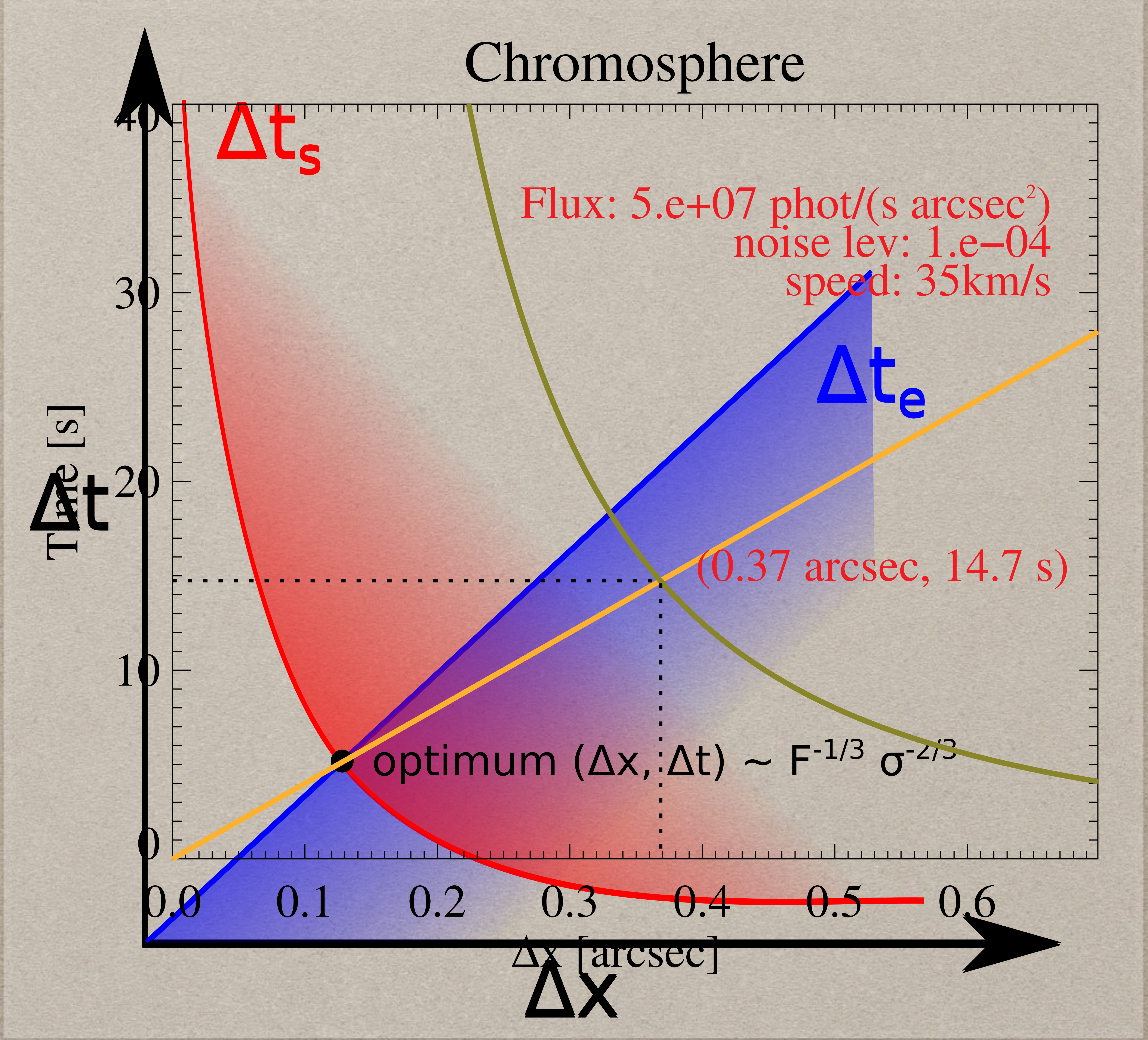


- Maximum integration time allowed by solar evolution:

$$\Delta t_e = \frac{2\,\Delta x}{v}$$

- Minimum integration time to reach a given required rms noise level

$$\Delta t_s = \frac{1}{F\sigma^2\Delta x^2}$$



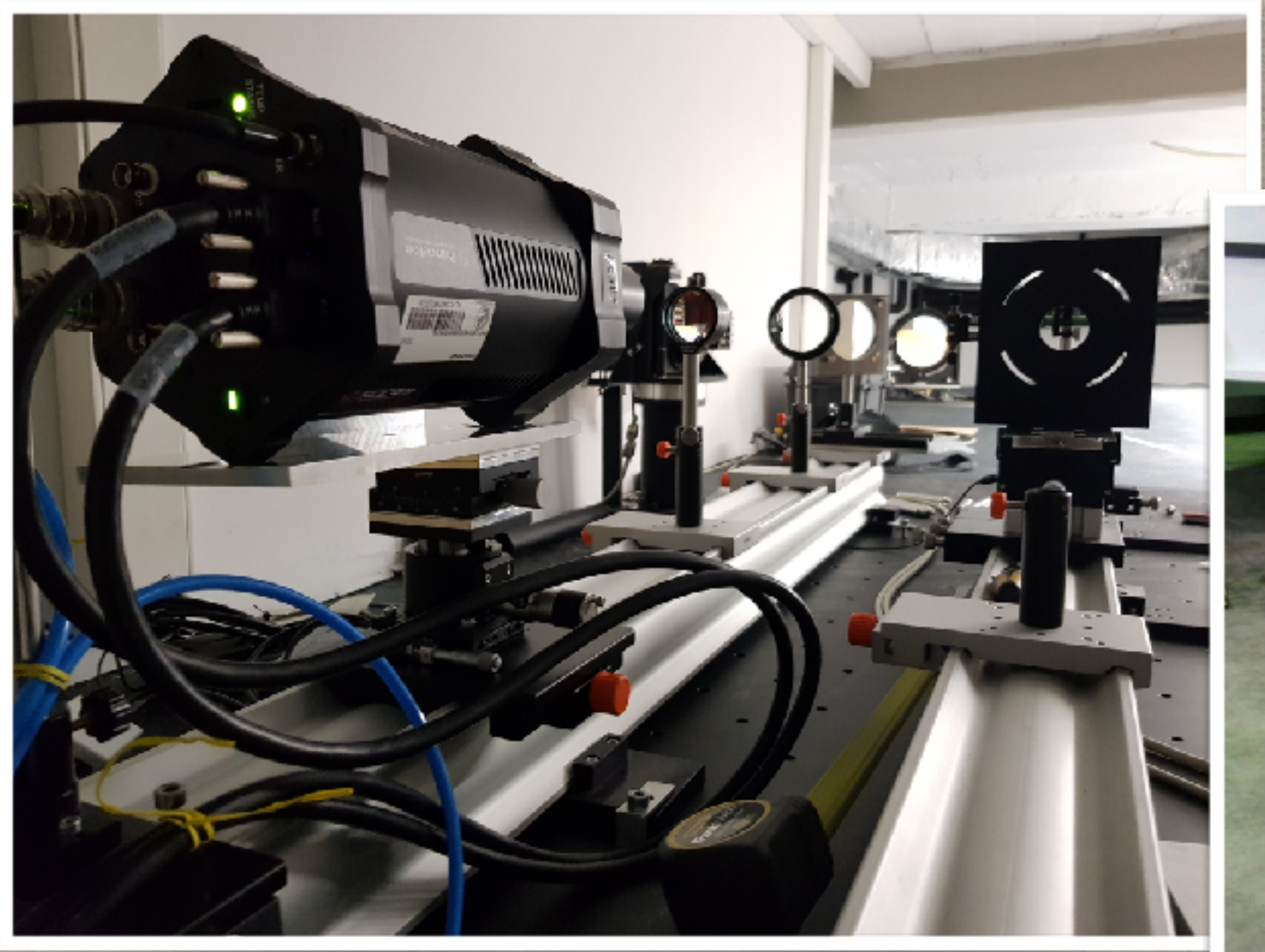
The Solution: Improve Instrumentation

Existing instruments / observatories

- IRIS
- FISS@GST
- GRIS@GREGOR
- CRISP & CHROMIS @SST
- FIRS @DST
- ALMA: See special session on Thursday

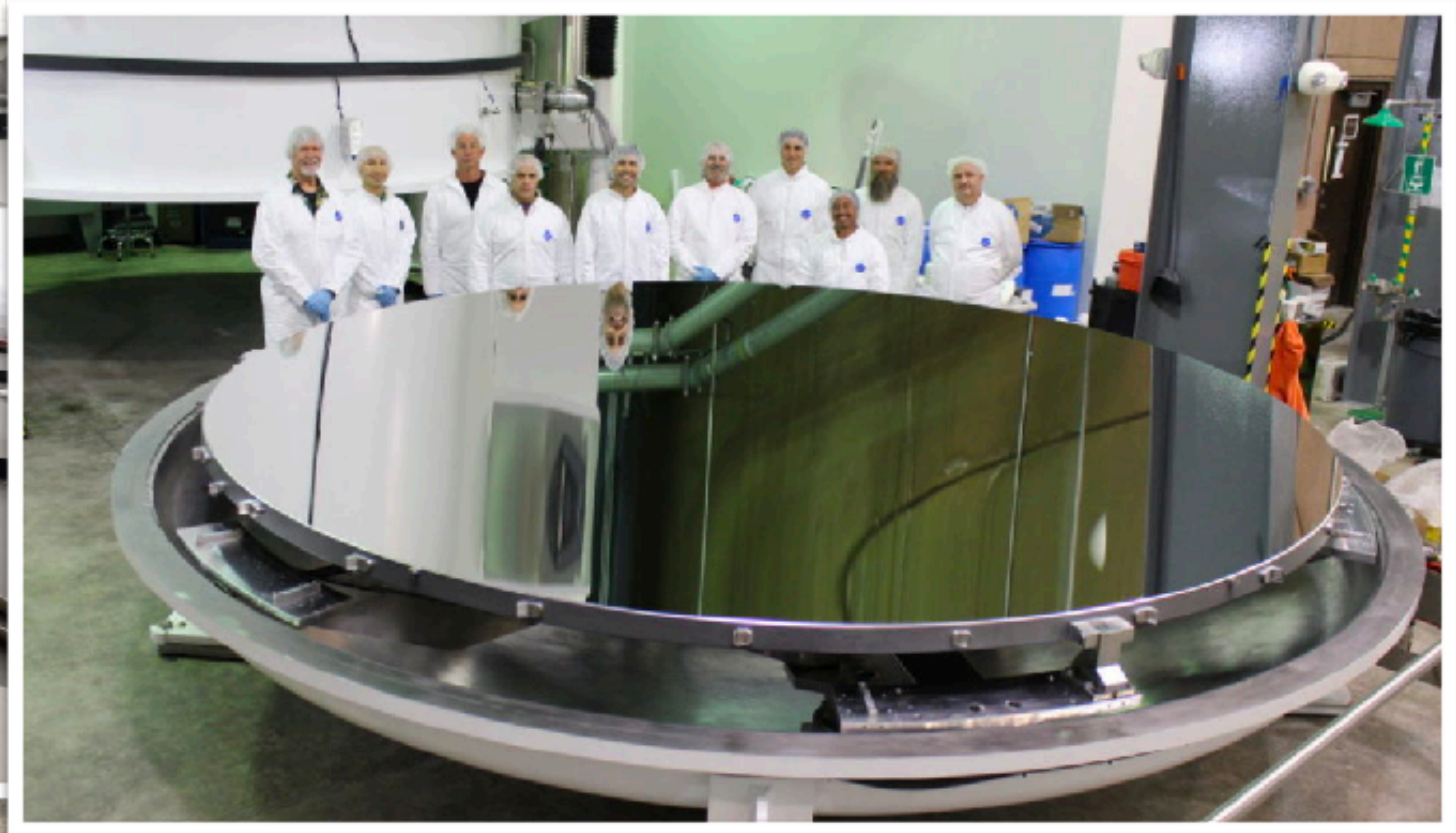
This year

- GRIS+ @GREGOR
- HeSP @SST

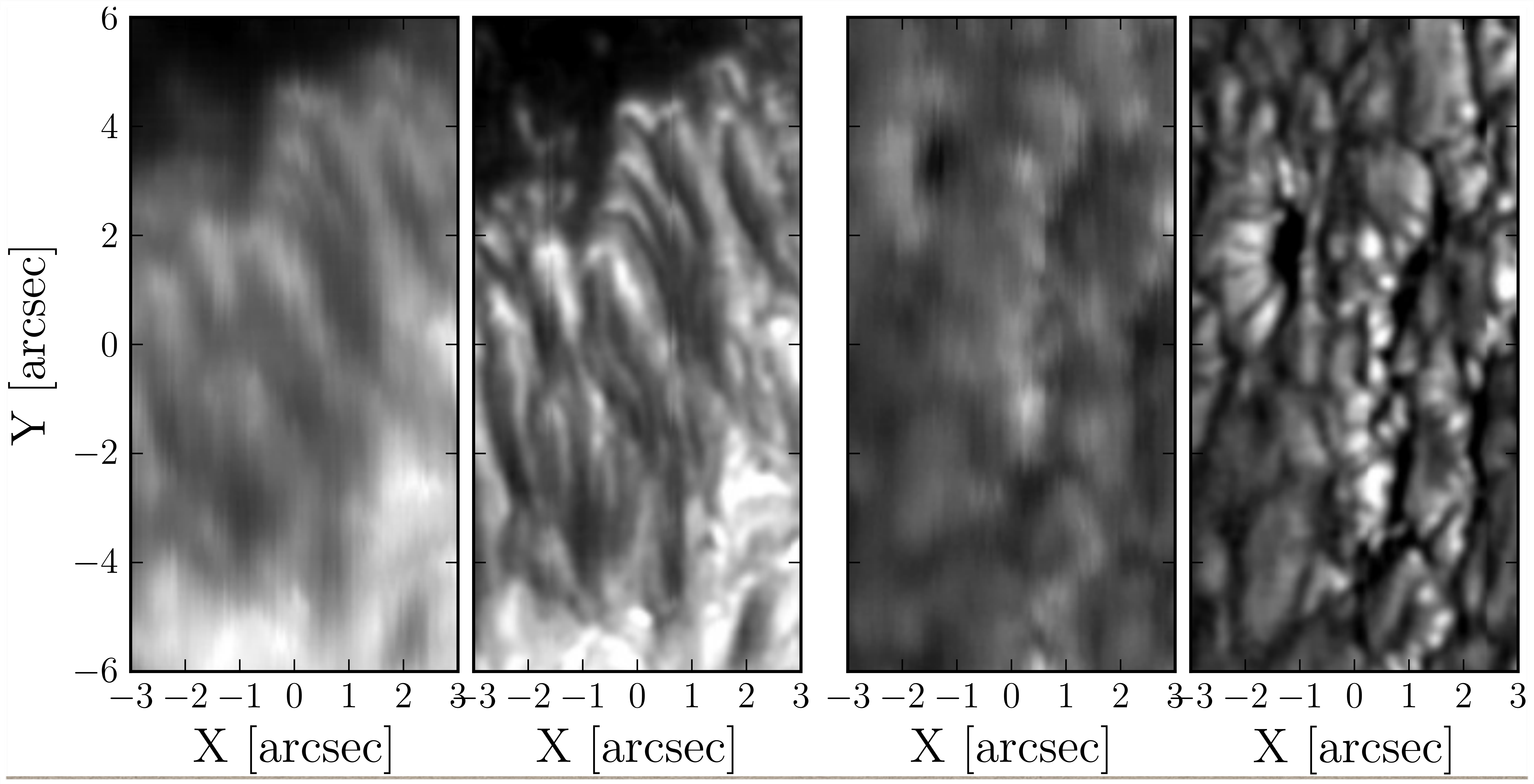


Future

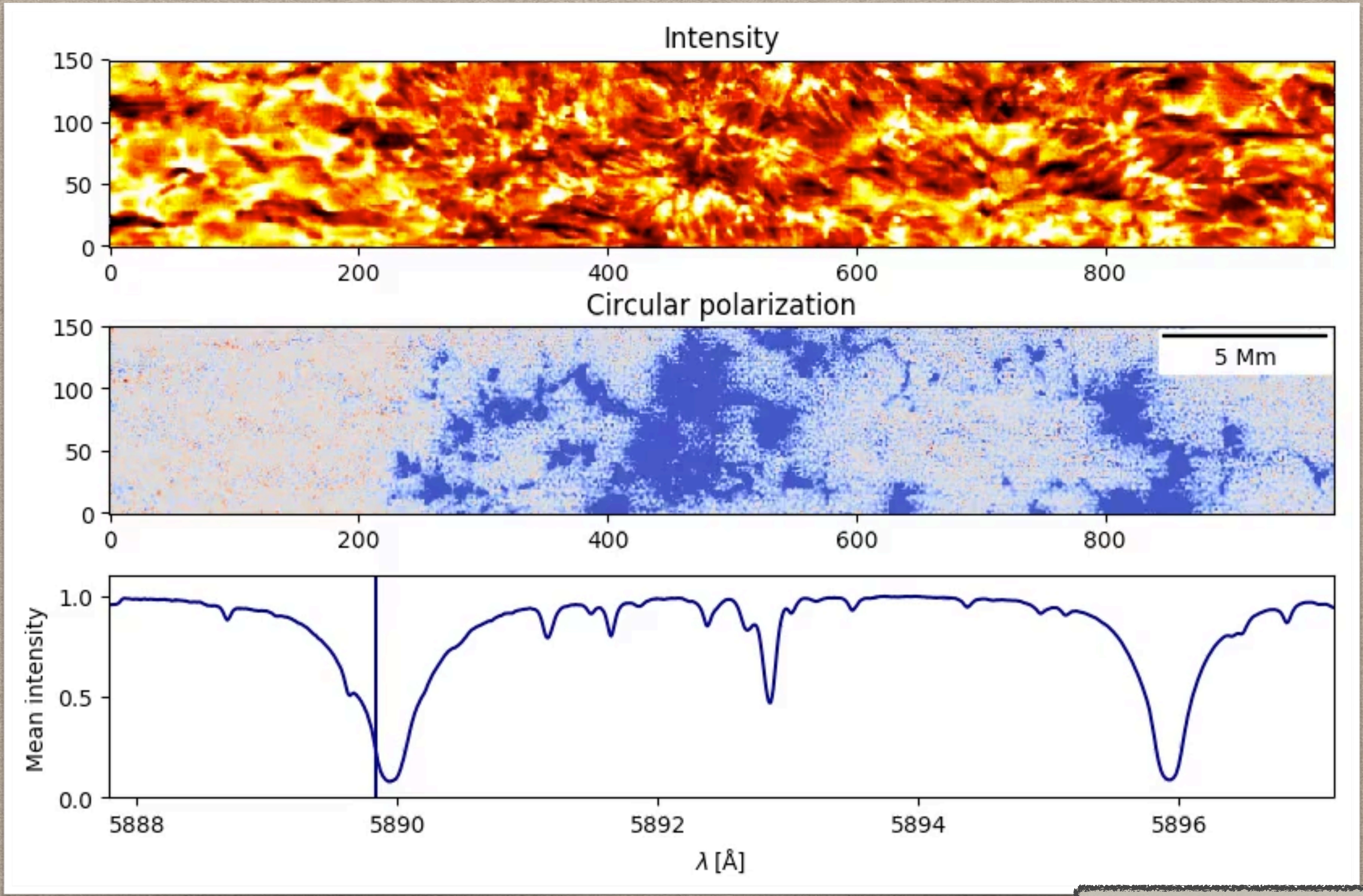
- DKIST: whole suite of instruments dedicated to chromosphere
- Sunrise-III



Spectral Restoration: van Noort (2017)

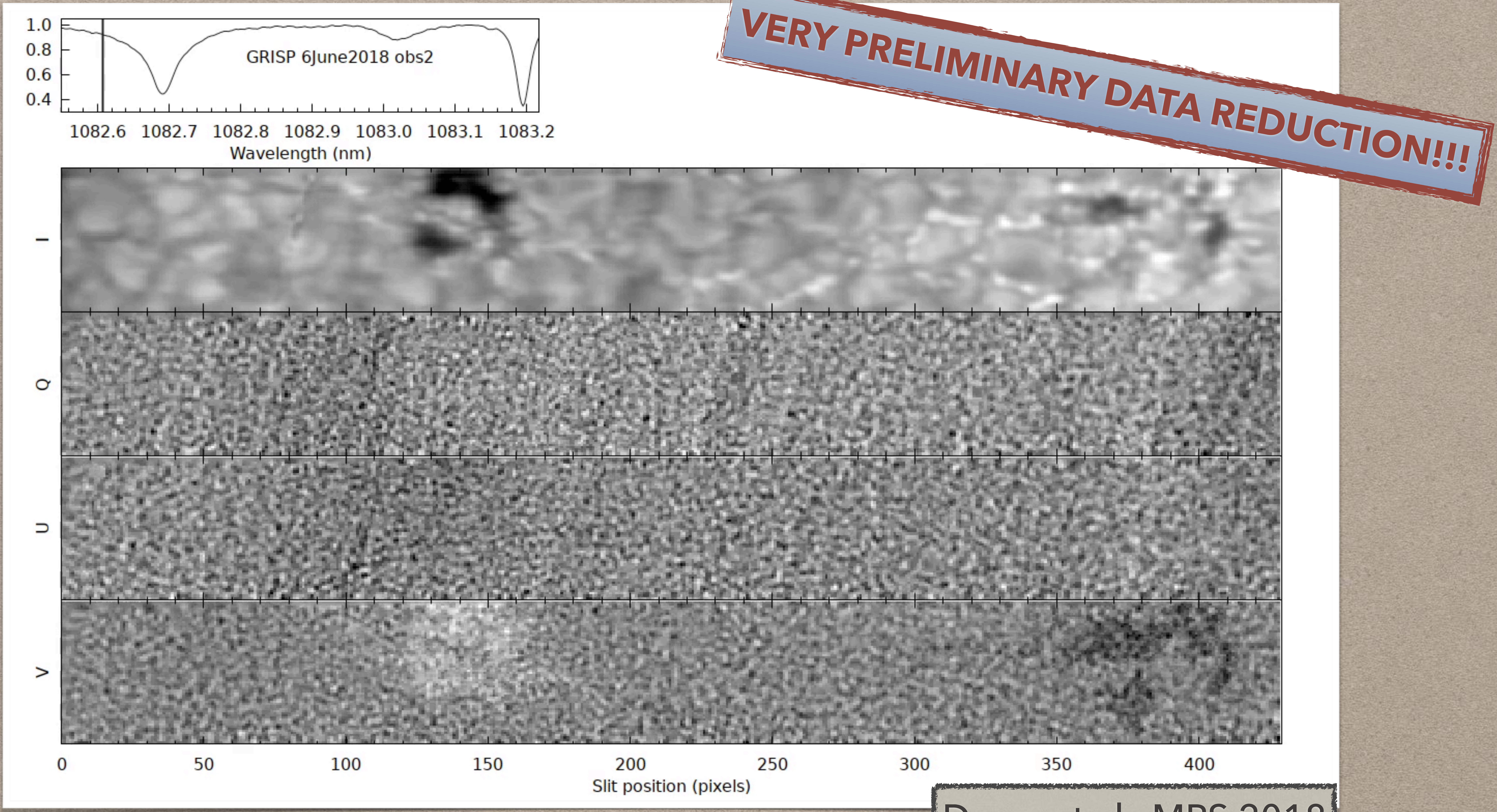


Spectral Restoration: Na I Stokes V (SST)



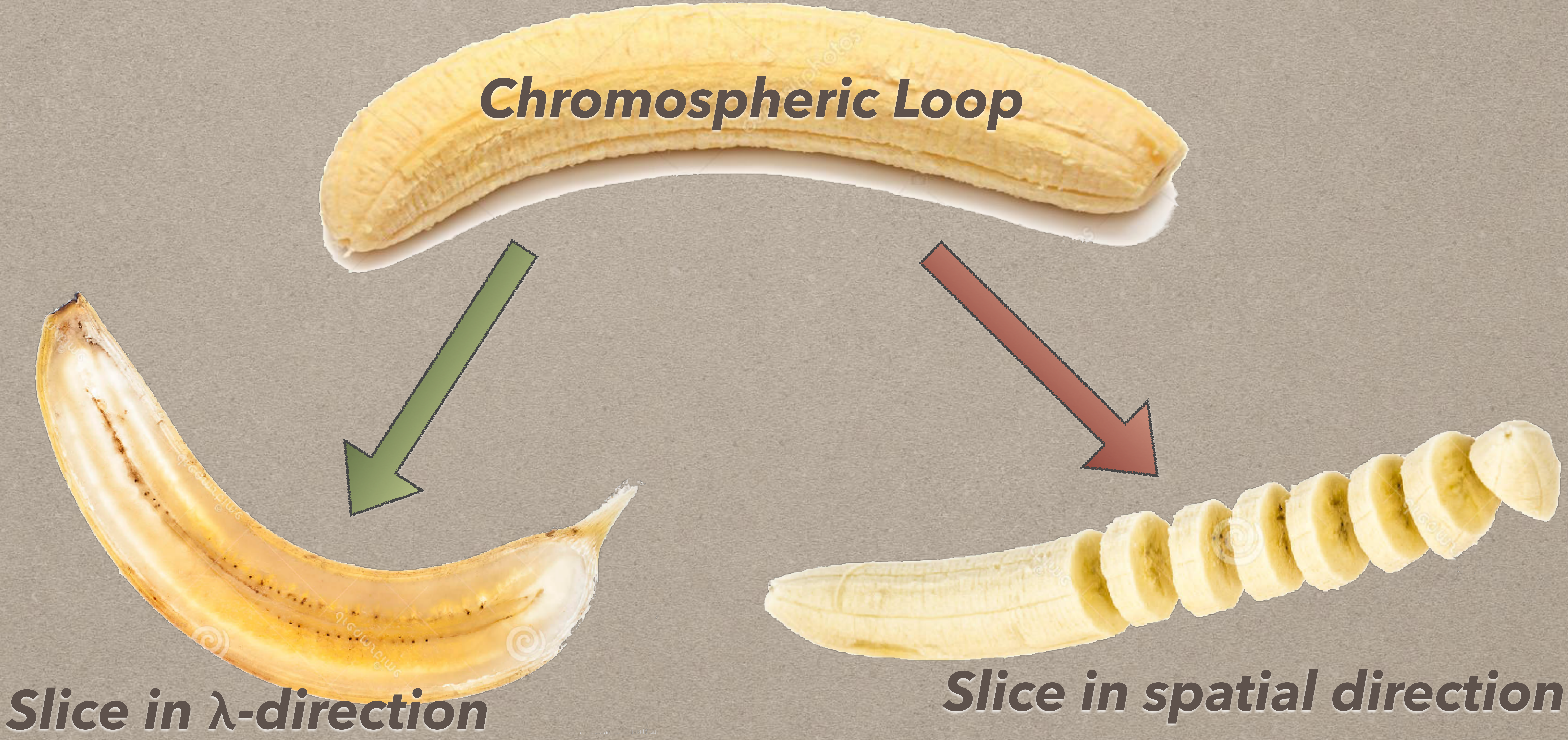
Van Noort et al., MPS 2018

Spectral Restoration: He 10830 (GREGOR)

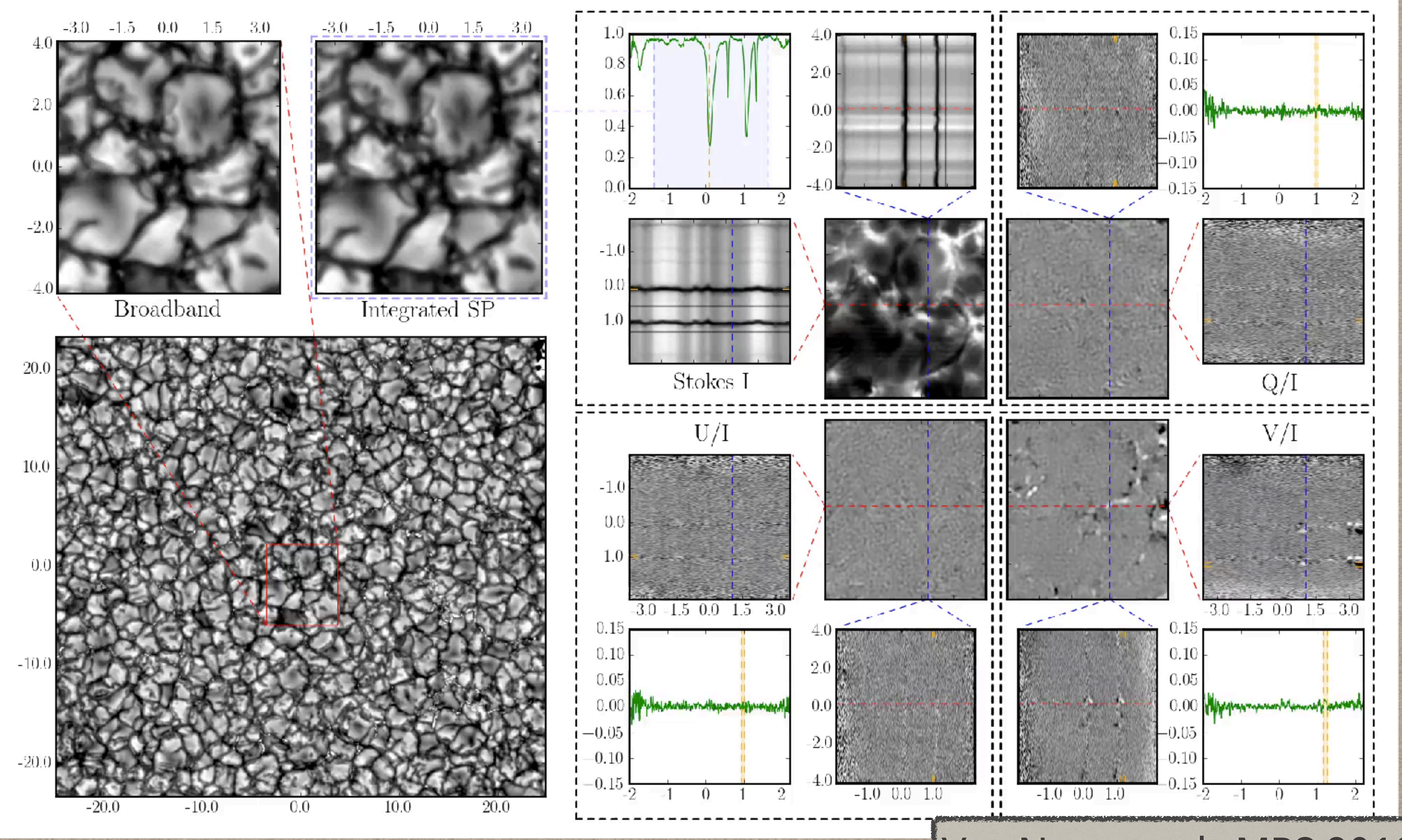


Doerr et al., MPS 2018

Future of Chromospheric Observations: 3D

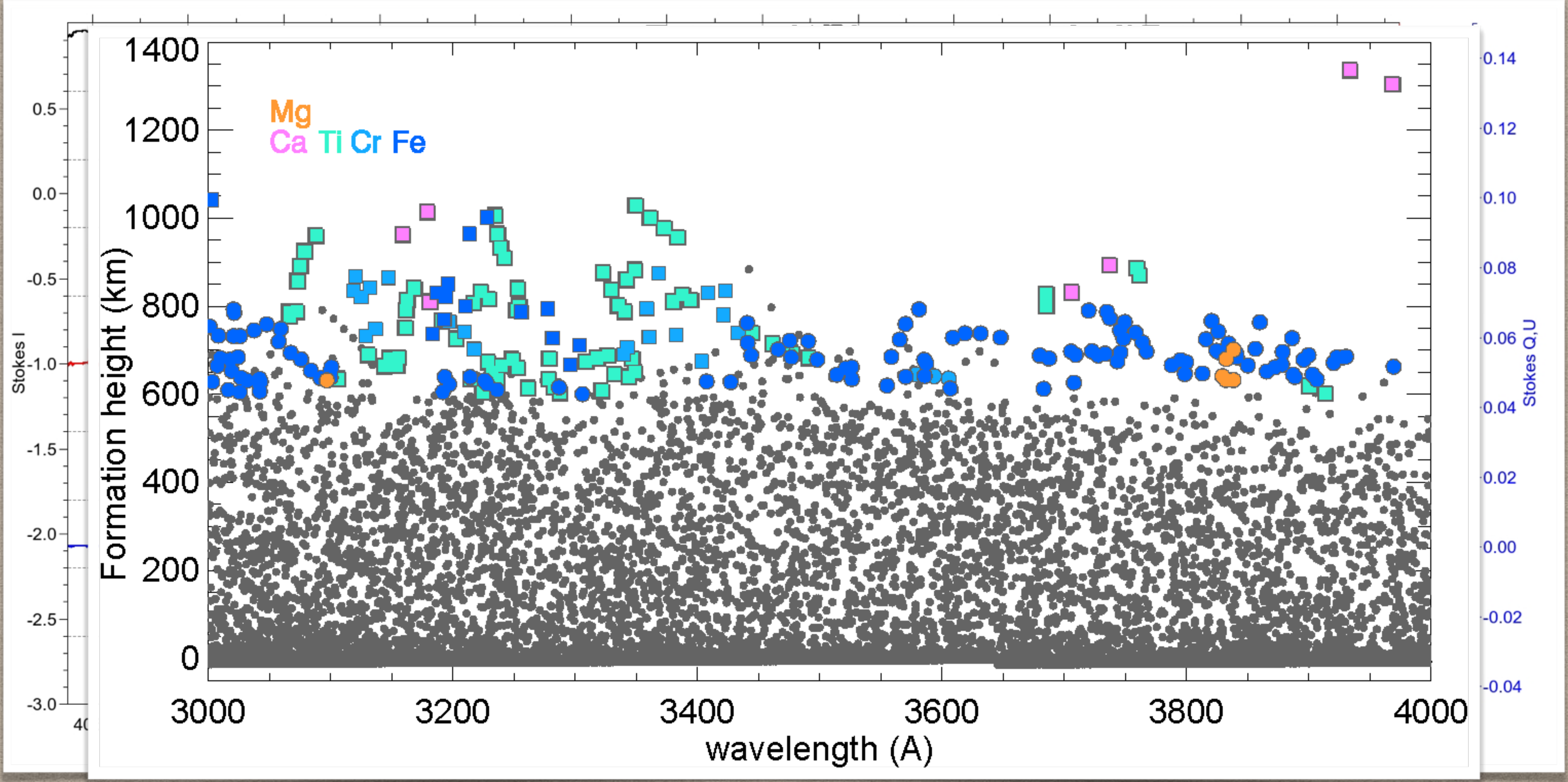


3D Spectropolarimeter MiHI (soon HeSP)



Van Noort et al., MPS 2018

Sunrise-III: Seamless Phot -> Chrom. Measurements



Riethmueller, Manso-Sainz, MPS 2018

Summary

- The chromospheric diagnostics of IRIS significantly deepened our understanding of the chromosphere
- Important side-effect: huge benefit for numerical simulations (MHD, radiative transfer)
  → essential prerequisite to understand the chromosphere
- Only now available: Instrumentation allowing for hi-res (temporal, spatial, spectral) reliable chromospheric magnetic field measurements