

# Visible & near IR DKIST Diagnostics

Gianna Cauzzi

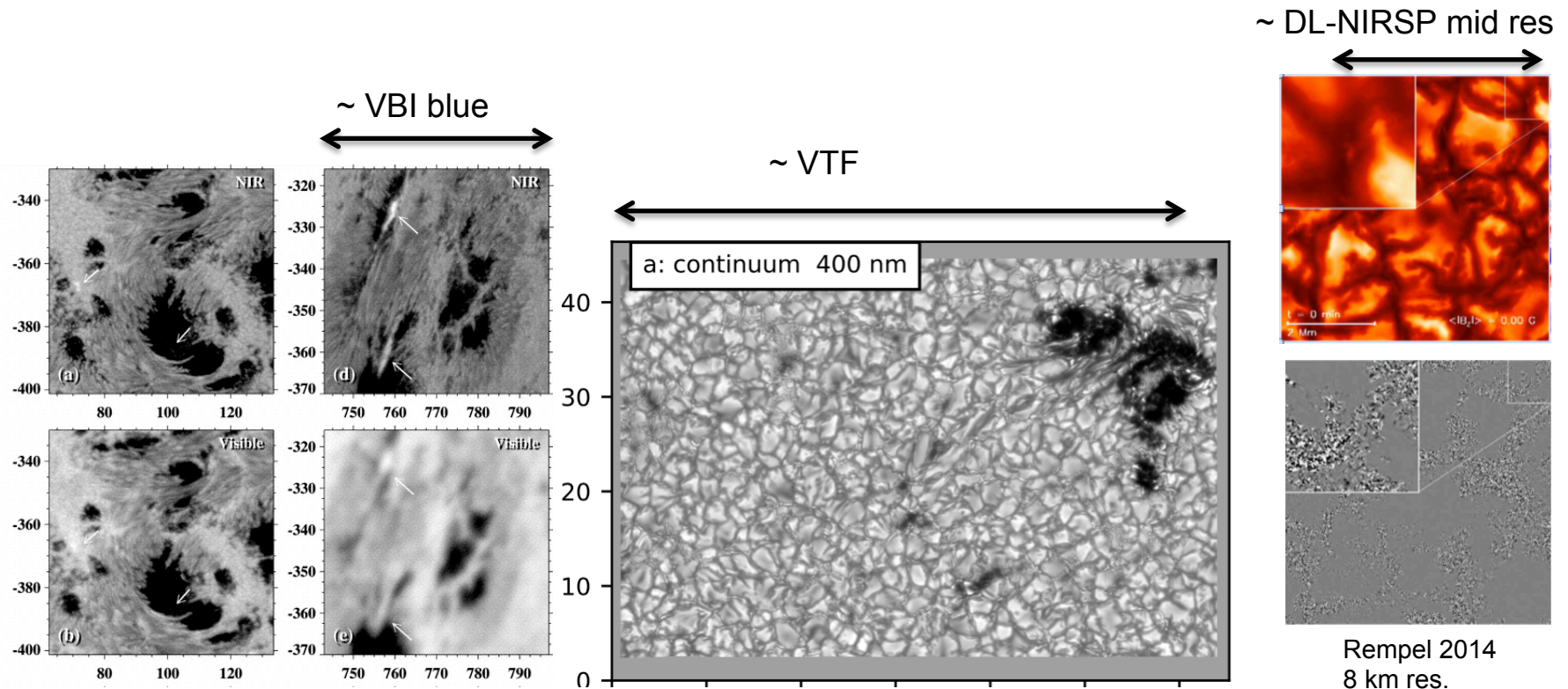
- *Continua*
- *Molecular bands*
- *Photospheric & Chromospheric lines*
- *Coronal diagnostics*



# 1. Continua

- Visible continuum formed at “base of photosphere”:  $h \sim 0$  km ( $\tau_{5000} = 1$ )
- IR continuum at  $\sim 1.5 \mu\text{m}$  forms at continuum opacity minimum –  $h \sim -50$  km

*Granulation, intergranular “bright points” (magnetic?), horizontal motions. Occasionally, WL flares*

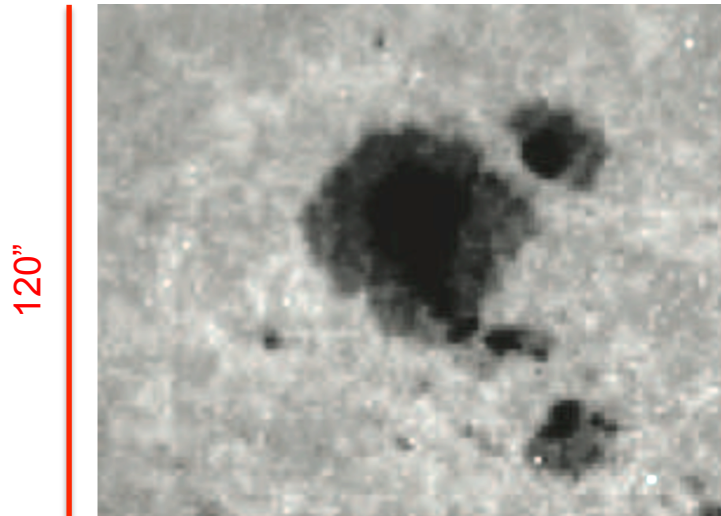


# 1. Continua

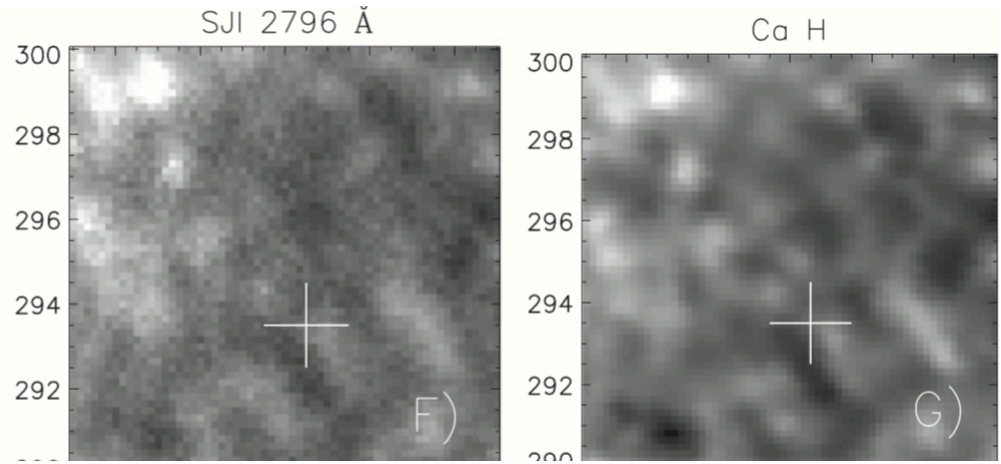
- IR continuum ( $\sim 3\text{-}4\ \mu\text{m}$  and above) forms higher in the atmosphere,  $\sim$  mid-photosphere (like, e.g. 170nm channel of AIA, or IRIS SJI 279.6)

*Reverse granulation, waves, shocks*

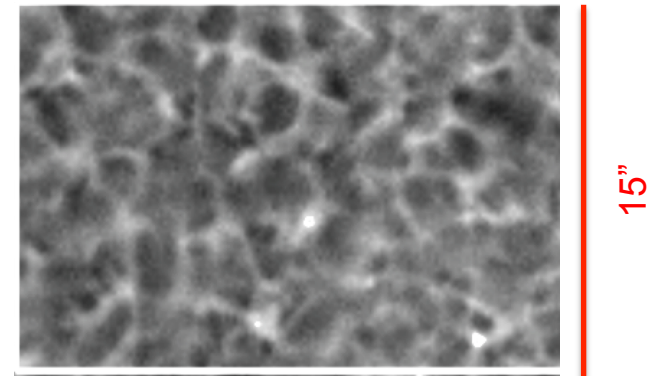
**UV vs. Ca II H filter**  
Martinez-Sykora et al 2015,



Penn et al 2016,  $5\ \mu\text{m}$



Janssen & Cauzzi, 2006,  
Ca II 854.2 wing;



# 1. Continua: DKIST instruments

---

<u>Spectral Window</u>	<u>Spatial Resolution (*)</u>	<u>DKIST Instrument</u>
450.3 nm	0.022" ; 16 km	VBI
668.4 nm	0.034" ; 25 km	VBI
590, 630, 660, 860 nm	0.030 – 0.043"; 20-40 km	VTF (broad band)
860, 1080 nm	0.06", 0.15" ; 43, 108 km	DL-NIRSP
1565 nm	0.08", 0.15" ; 60, 108 km	DL-NIRSP
1080, [2300, 3000,] 3900, 4600 nm	0.24 x 0.30" ; 175 x 215 km	Cryo-NIRSP [ <i>not at first light</i> ]
1080, 1250, 3900, 4600 nm	0.10–0.23" ; 75 – 165 km	Cryo-NIRSP Context Imager
390 – 900 nm	0.04" x 0.06" ; 30 x 40 km	ViSP

---

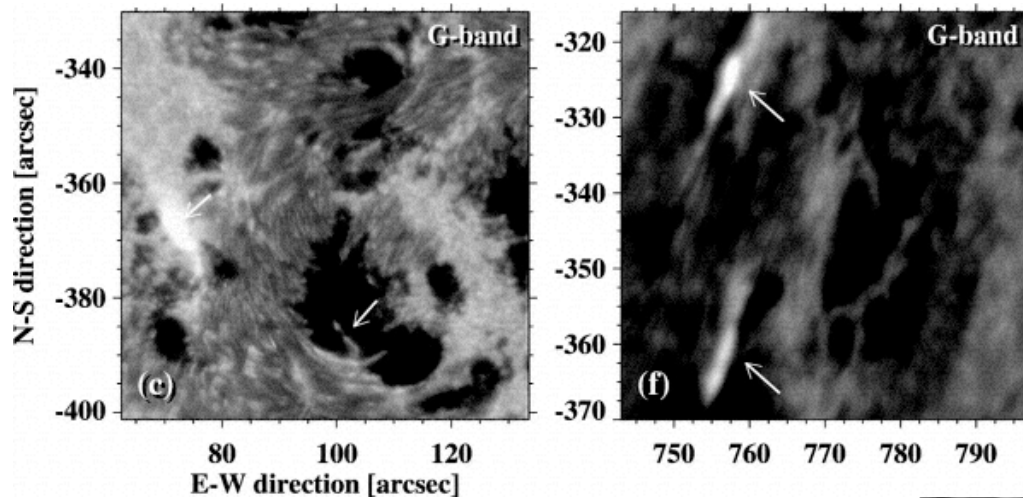
(\*) nominal diffraction limit of a 4-m telescope at that wavelength



## 2. Molecular lines, bands

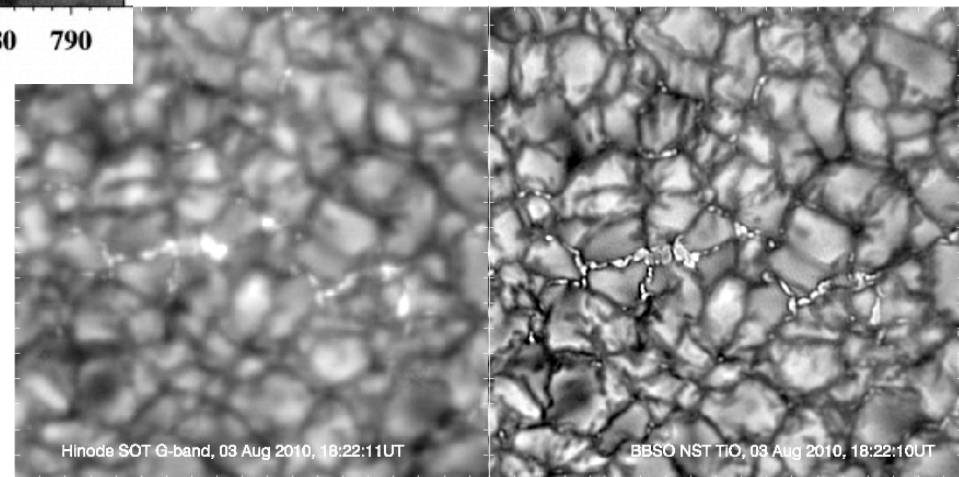
- Formed in the low photosphere, provide large intensity contrast for “hot” vs. “cold” structures (strong T dependence of opacity). E.g. TiO, CN (G-band), CH.

*Granulation, intergranular “bright points”, horizontal motions. Occasionally, WL flares.*



Xu et al 2006

Hinode G-band vs. NST TiO (2010)

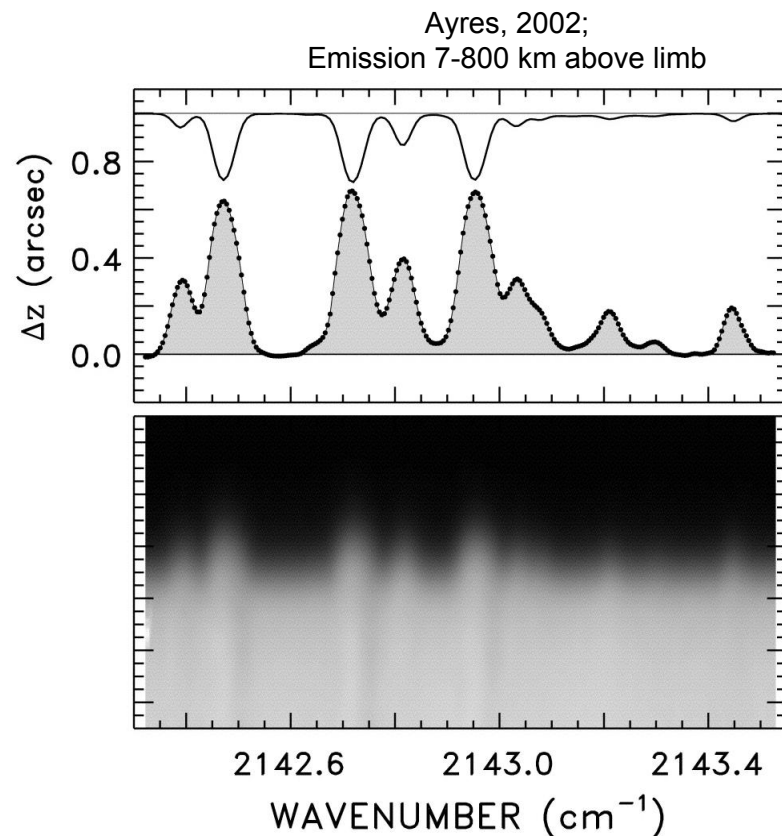
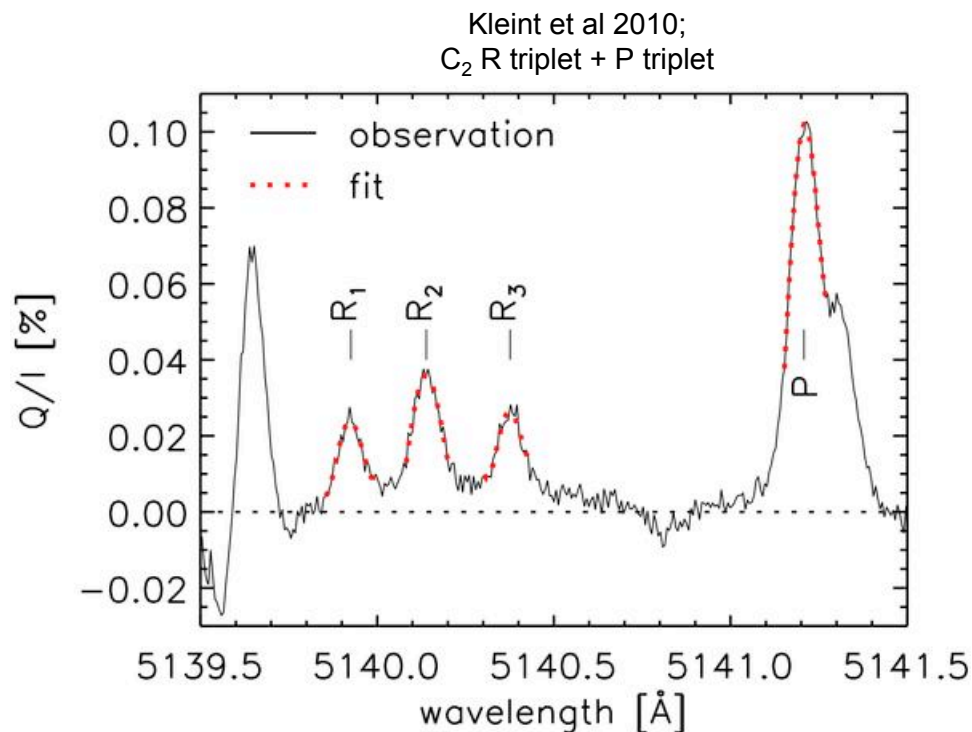


## 2. Molecular lines, bands

- Sensitive to Hanle effect, e.g. MgH, C<sub>2</sub> lines.
- Presence of molecular lines indicate low temperatures – e.g. CO roto-vibration transitions at 4.7 μm, require T<sub>e</sub> < 3700 K.

*Investigate small scale, tangled magnetic fields in the photosphere (e.g. via differential Hanle effect)*

*Investigate spatio-temporal structure of low chromosphere, presence of cold bubbles ?*



## 2. Molecular lines: DKIST instruments

---

<u>Spectral Window</u>	<u>Spatial Resolution (*)</u>	<u>DKIST Instrument</u>
430.5 nm – G-band (CH)	0.022" ; < 20 km	VBI
707.8 nm – TiO	0.034" ; 25 km	VBI
2326 nm – CO (1 <sup>st</sup> overtone)	0.24 x 0.30" ; 175 x 215 km	Cryo-NIRSP <i>not at first light</i>
4651 nm– CO (fundamental)	0.24 x 0.30" ; 175 x 215 km	Cryo-NIRSP Spectrograph
4651 nm– CO (fundamental)	0.23" ; 165km	Cryo-NIRSP Context Imager
390 – 900 nm (CH, TiO, others)	0.04" x 0.06" ; 30 x 40 km	ViSP

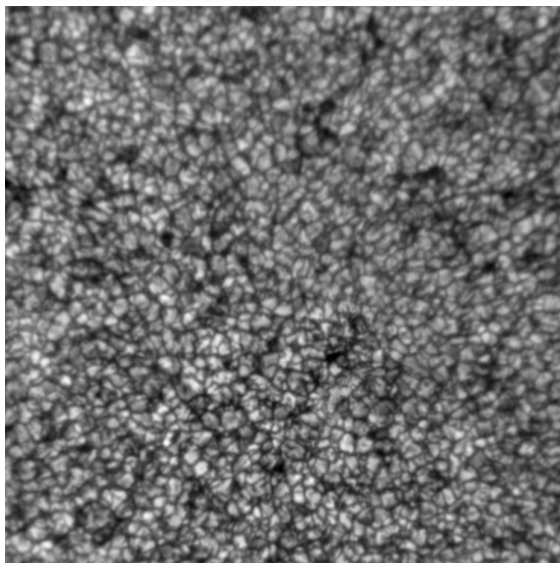
---

(\*) nominal diffraction limit of a 4-m telescope at that wavelength

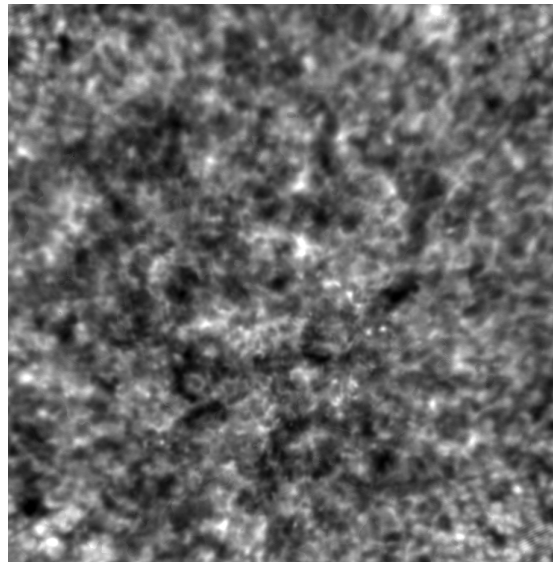
### 3. Non-magnetic photospheric lines

- Several photospheric lines have  $g_L = 0$  and are not influenced by the presence of magnetic fields. Can be formed over a large span of photospheric heights (e.g. Fe II 512.3 Fe I 543.4, Fe I 567.6; Fe I 709.0, Fe II 722.4, Ti I 839.7 nm). *Accurate thermo-dynamical structure of atmosphere, waves through  $T_{min}$*

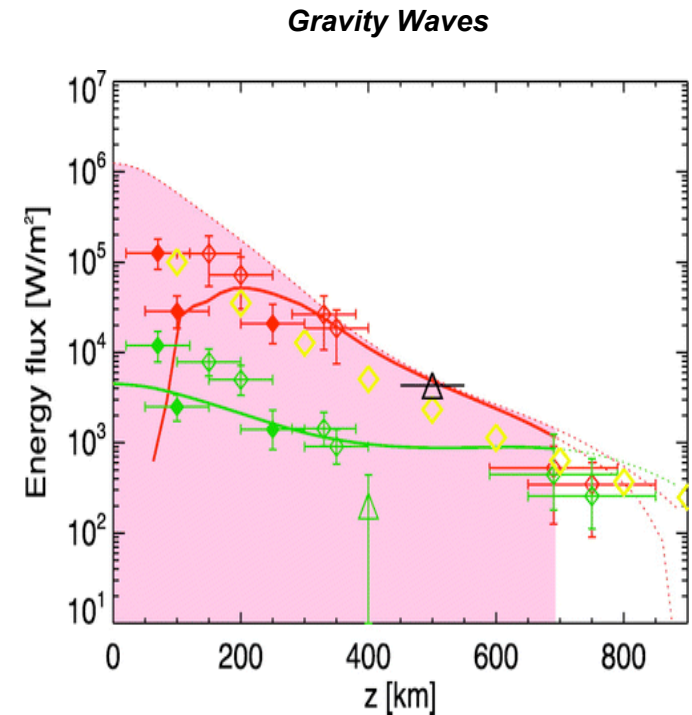
95''



Whitelight (IBIS)



Fe I 543.4 nm Line Core (IBIS)



Straus et al 2008

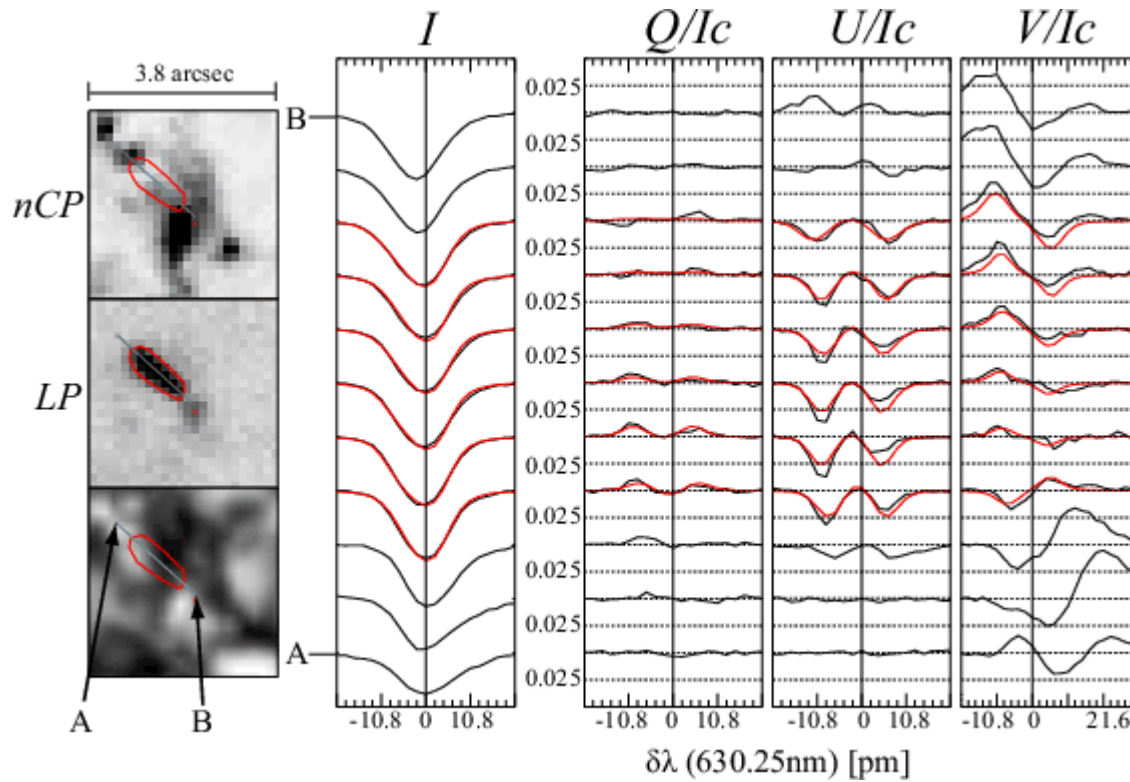
### 3. Non-magnetic photospheric lines: DKIST instruments

---

<u>Lines</u>	<u>Spatial Resolution</u>	<u>DKIST Instrument</u>
Fe I 709.9 nm	0.035"; 26 km	VTF – <i>not at first light</i>
390 – 900 nm	0.04" x 0.06" ; 30 x 40 km	ViSP

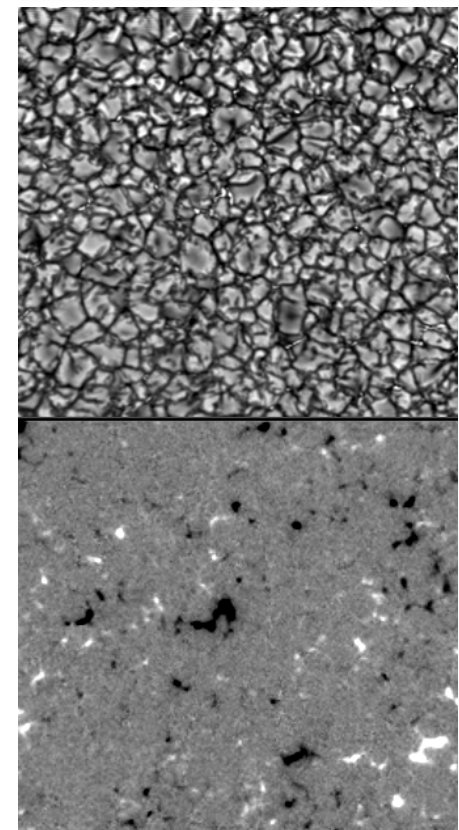
---

# 4. Zeeman-sensitive photospheric lines



Ishikawa, et al., 2008

30"



IBIS – White Light and Circular polarization



## 4. Zeeman-sensitive photospheric lines

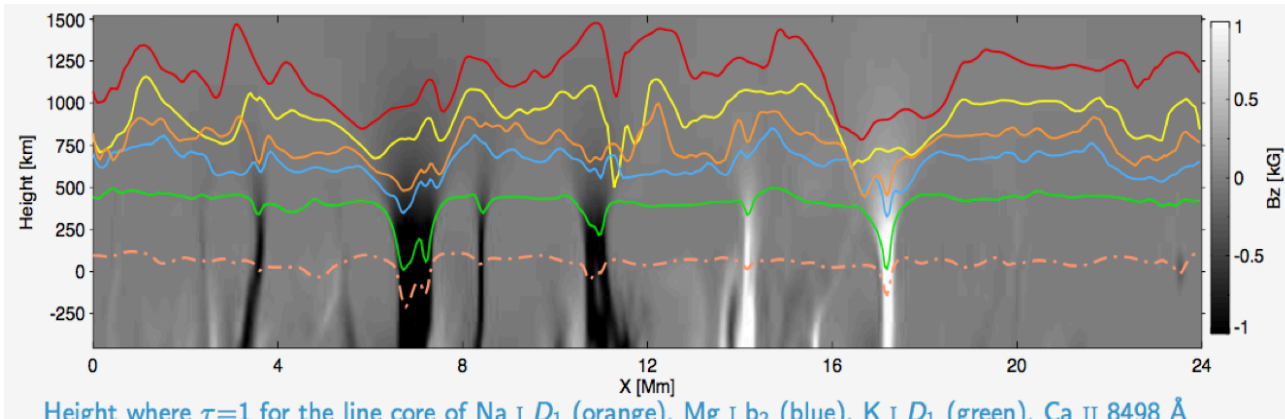
---

<u>Lines</u>	<u>Used By</u>	<u>DKIST Instrument</u>
Fe I 524.7, 525.0 nm	IMaX	ViSP, VTF – <i>not at first light</i>
Fe I 617.3 nm	HMI, IBIS	ViSP
Fe I 630.1, 630.2 nm	ASP, Hinode SOT/SP, IBIS	ViSP, VTF
Fe I 846.8, 851.4 nm		ViSP
Si I 1082.7 nm	FIRS	DL-NIRSP, Cryo-NIRSP
Fe I 1564.8, 1565 nm	FIRS	DL-NIRSP
390 – 900 nm		ViSP

# 4.5 Magnetic middle-atmospheric lines

- Resonance lines of alkali – e.g. Na I  $D_1$ ,  $D_2$ ; K I  $D_1$  (small  $g_L$  but sensitive to velocity)

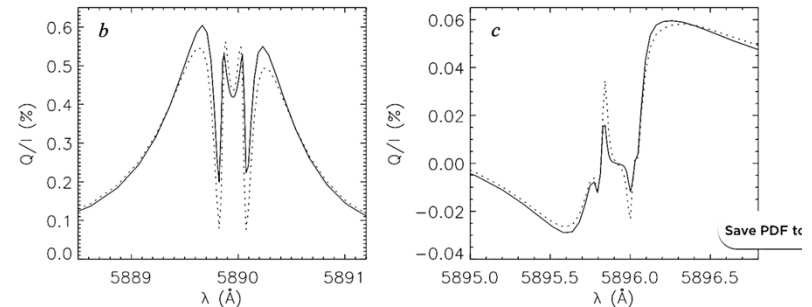
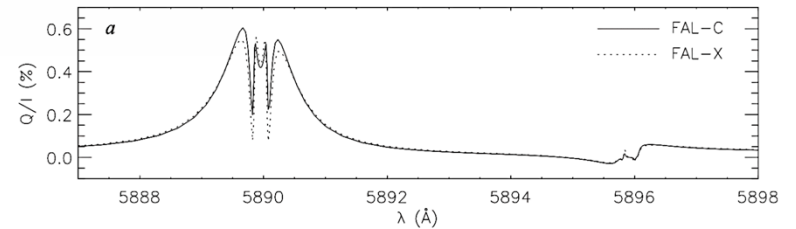
Scattering polarization; magnetism at  $T_{min}$ , flares



Quintero Noda 2018

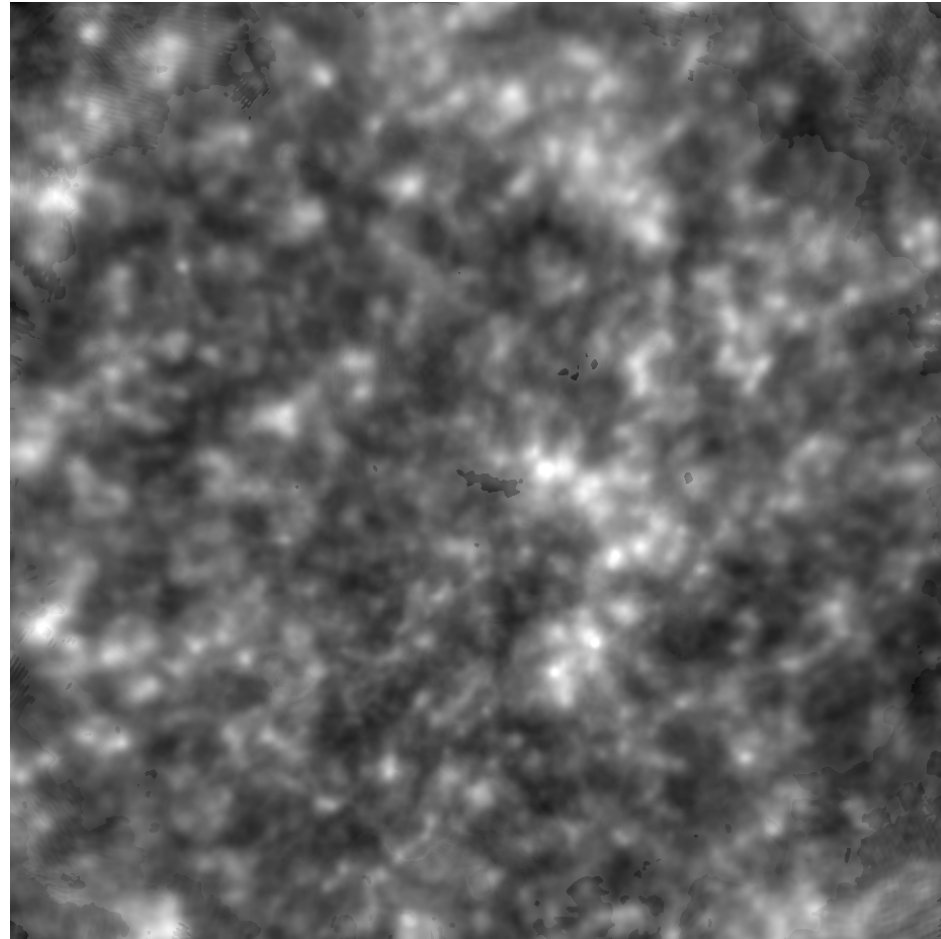
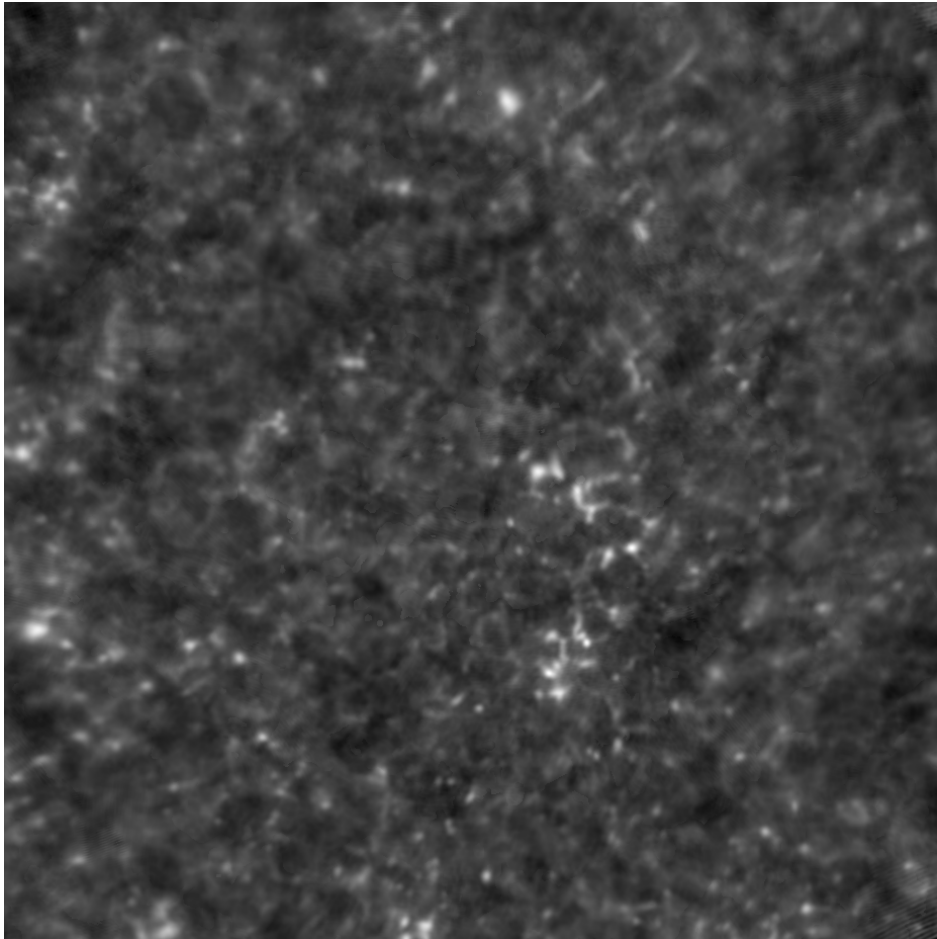
Height where  $\tau=1$  for the line core of Na I  $D_1$  (orange), Mg I  $b_2$  (blue), K I  $D_1$  (green), Ca II 8498 Å (yellow), and 8542 Å (red). Dashed orange to  $\tau=1$  at continuum wavelengths.

Belluzzi et al 2015  
Scattering polarization in Na D lines



K I 7699 Å

Na D<sub>1</sub> 5896 Å



IBIS data

## 4.5 Magnetic middle-atmospheric lines: DKIST instruments

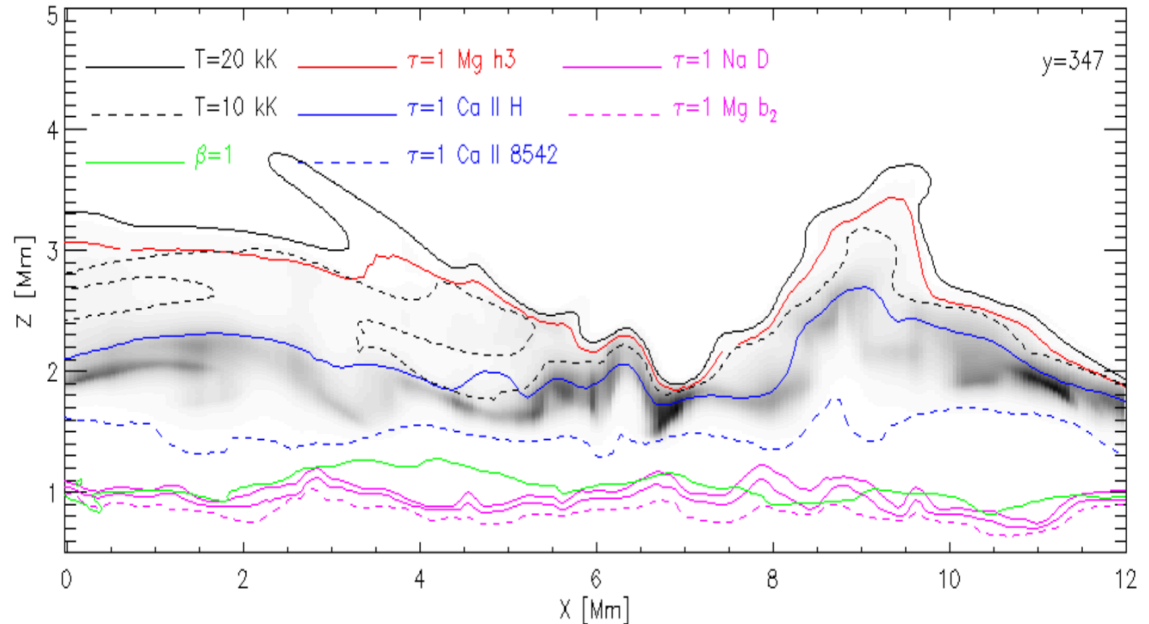
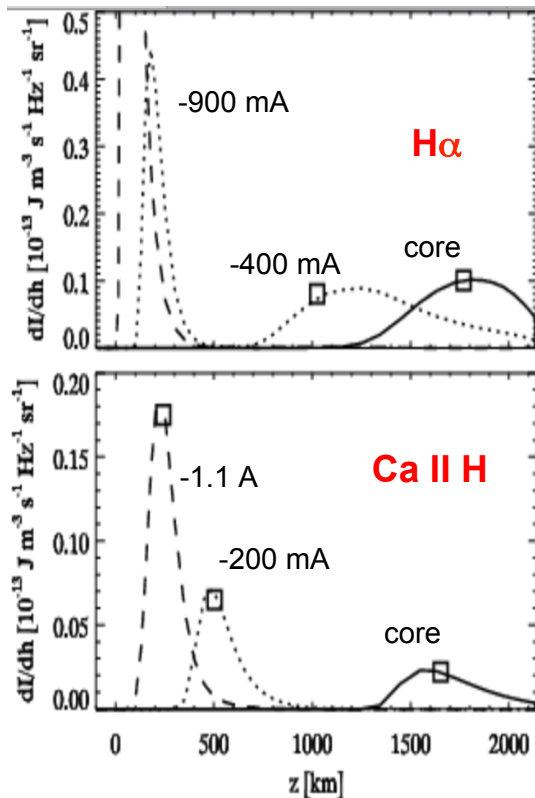
---

<u>Lines</u>	<u>Spatial Resolution</u>	<u>DKIST Instrument</u>
Na I 589.0 nm	0.03"; 22 km	VTF
Na I 589.0 nm Na I 589.6 nm K I 769.9 nm Mg I 517.3 nm  390 – 900 nm	0.04" x 0.06" ; 30 x 40 km	ViSP

---

# 5. Chromospheric lines

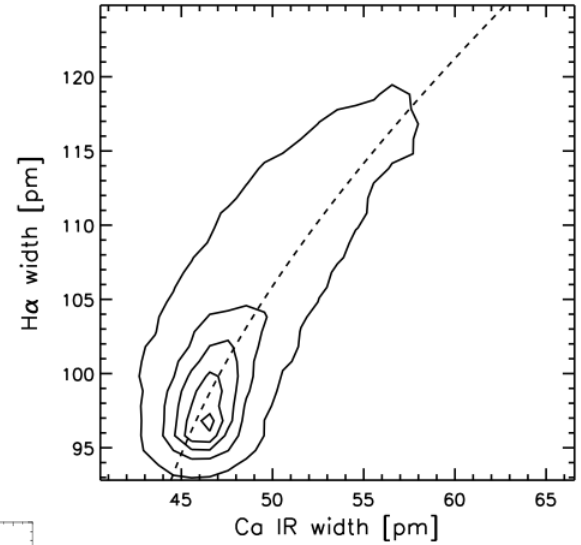
- Chromosphere is optically thin in most of the visible/near IR, apart from few strong lines: Balmer and Paschen series, CaII resonance (H&K) and subordinate triplet (849.8, 854.2, 866.2 nm), HeI triplet (1083 nm), subordinate HeI D<sub>3</sub> (587.6 nm)
- “Height of formation” is an over-simplification. Lines form over a large span, and heavily depend on local spatio-temporal conditions. HeI also strongly depends on local UV irradiation.



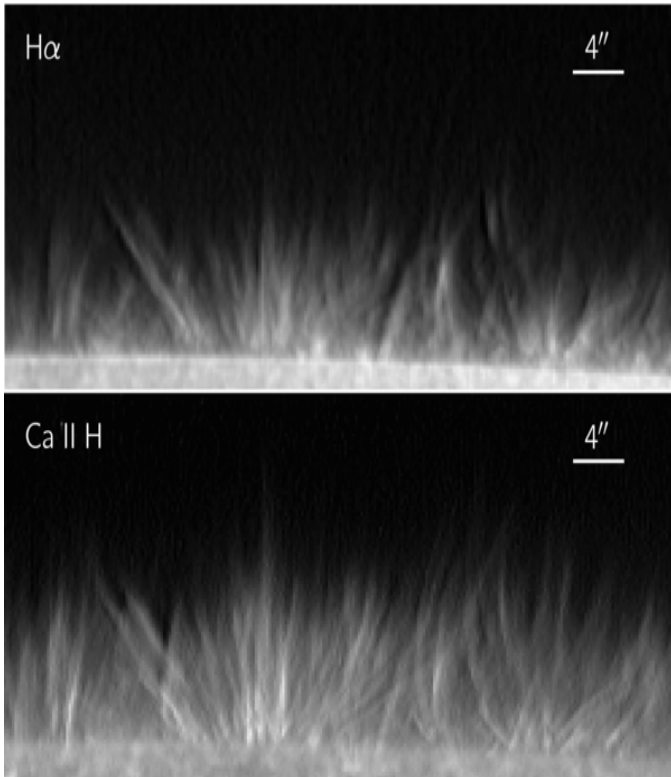
Courtesy of M. Carlsson

# 5. Chromospheric lines

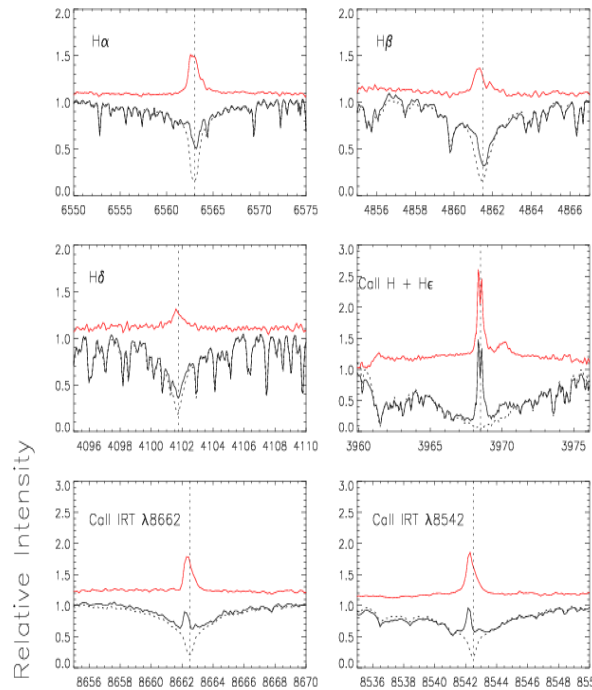
- $H\alpha$ , Balmer series: dynamics, temperature, density, depth of TR
- Paschen lines: electric fields
- Call lines: chromospheric dynamics, temperature, chrom. mag. fields
- HeI: dynamics, density in flares (esp.  $D_3$ ), chromospheric mag. fields



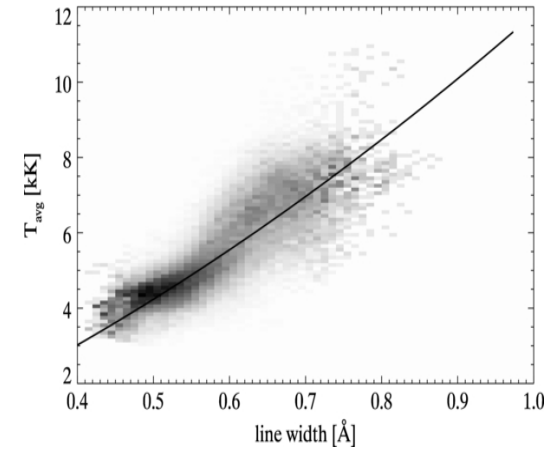
Cauzzi et al. 2009



Pereira et al 2013



Garcia Alvarez et al 2005

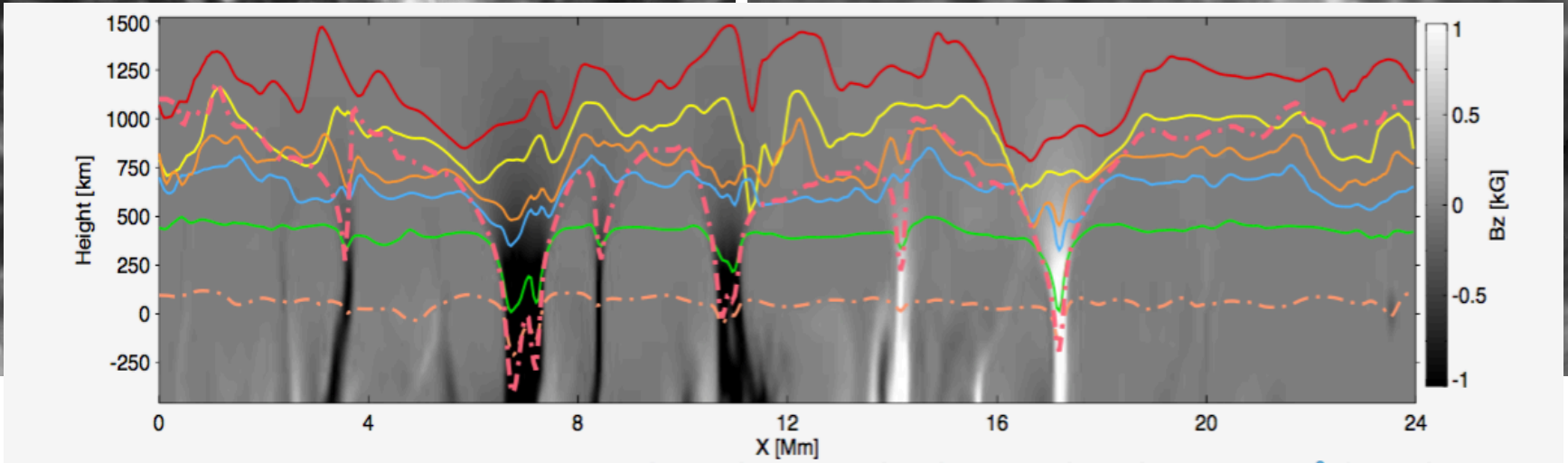
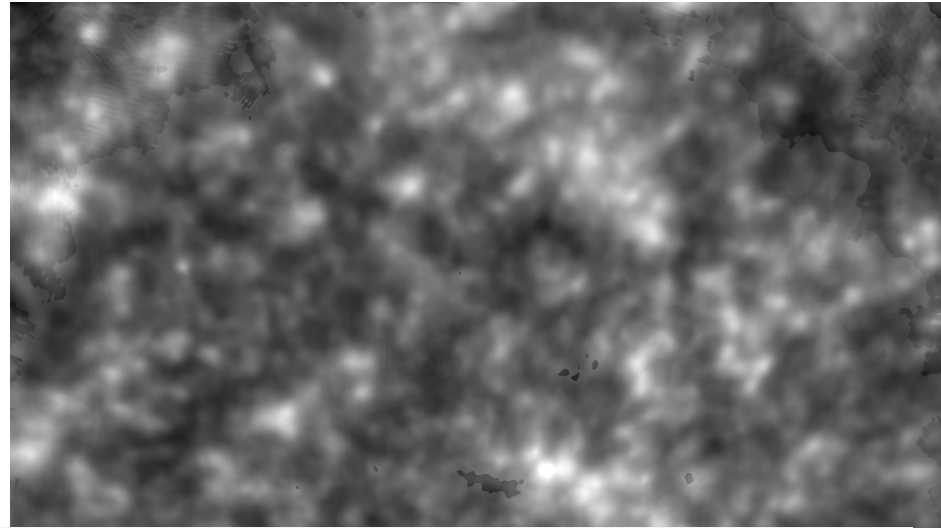
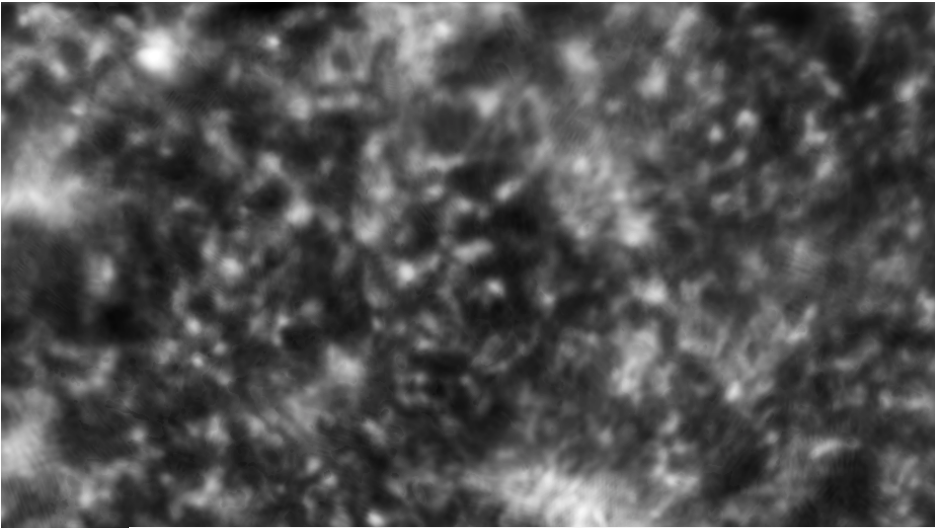


Leenaarts et al 2012



Ca II 8542 Å

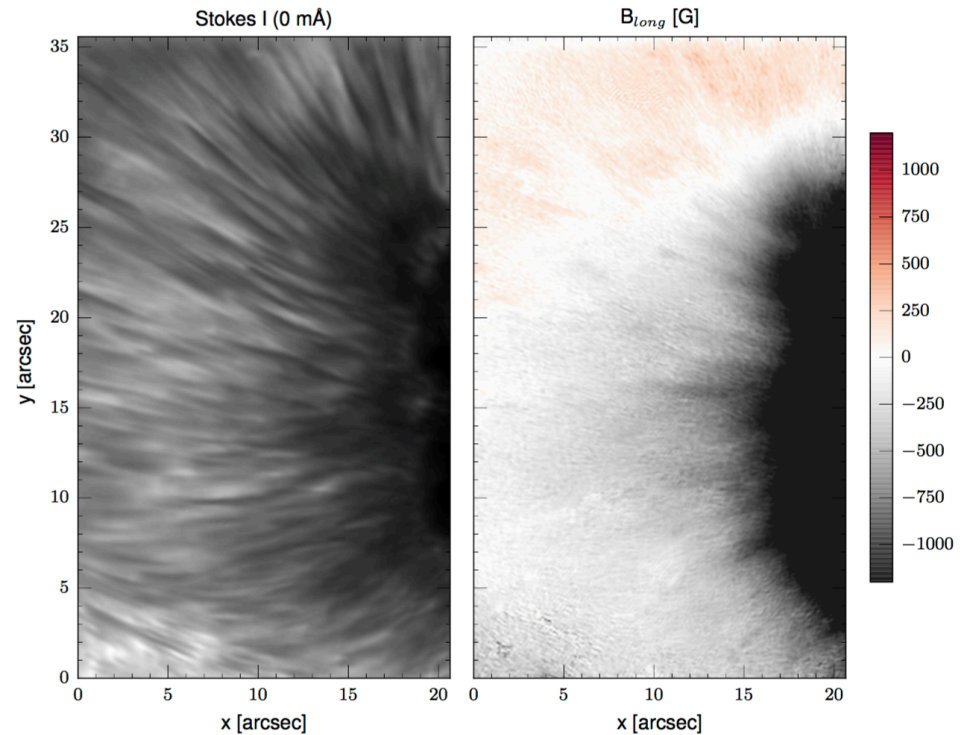
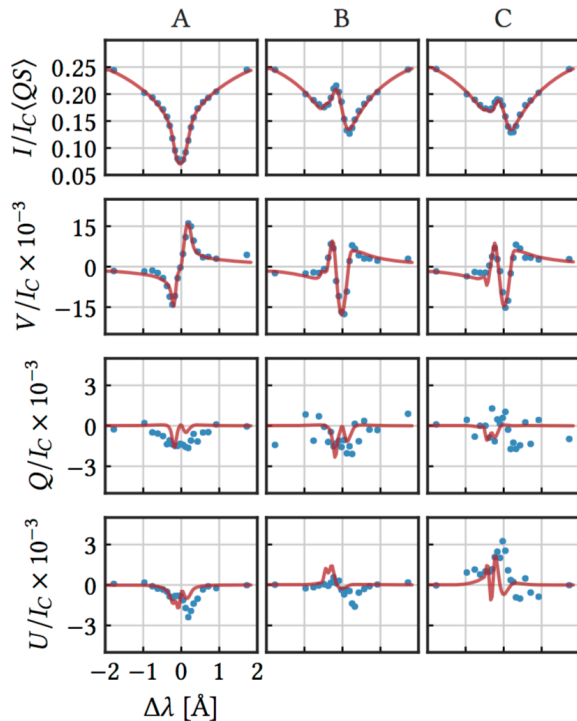
Na D<sub>1</sub> 5896 Å



Quintero Noda 2018; dot-dashed pink line is  $\beta=1$  surface; red represents  $\tau=1$  for Ca II 854.2 core

# Call 854.2 nm

- Sensitive to Zeeman effect ( $g_L=1.1$ )
- Sensitive to temperature stratification
- Encodes velocity gradients
- Essentially the ONLY line currently used to diagnose magnetic field in mid-chromosphere

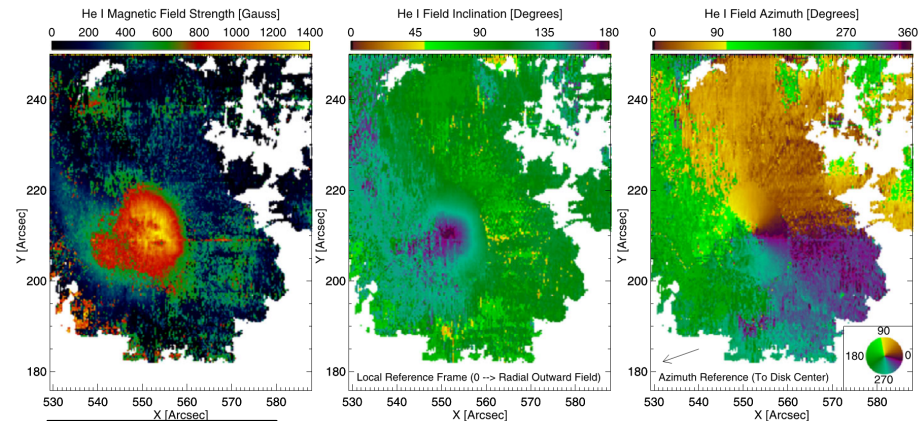


de la Cruz Rodriguez et al. 2013 (using WFA)

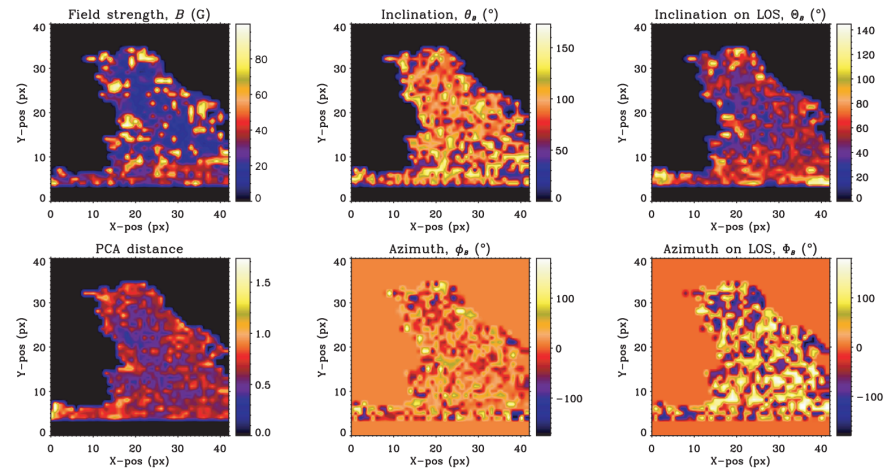
Joshi & de la Cruz Rodriguez (2018)

# He I Infrared triplet (1083 nm)

- The He I Triplet system has well-known advantages for chromospheric polarimetry. Formed by PR mechanism, sensitive to *both* chromosphere and coronal conditions.
- Formed in a (relatively) thin and localized range of heights -> slab model.
- Strongest transitions at 1083 nm and 587.6 nm (D3) have Hanle sensitivity up to 10 and 50 Gauss respectively.
- Useful for active region magnetic field mapping in the chromosphere as well as cool material in the corona!



Schad et al. (2015)



Casini and Lopez-Ariste (2002)

## 5. Chromospheric lines: DKIST instruments

---

### Hydrogen Lines

<u>Spectral Window</u>	<u>Observing Mode</u>	<u>Spatial Resolution</u>	<u>DKIST Instrument</u>
656.3 nm	spectral scan	0.033" ; 25 km	VTF
656,3 nm	filtergram	0.034" ; 25 km	VBI
486.1 nm	filtergram	0.024" ; 18 km	VBI
656.3, 486.1, 434.0, 410.1, 397.0 nm	spectrograph	0.04" x 0.06" ; 30 x 40 km	ViSP
P <sub>11</sub> and higher, 820.4 (Paschen limit)	spectrograph	0.04" x 0.06" ; 30 x 40 km	ViSP

## 5. Chromospheric lines: DKIST instruments

### Calcium Lines

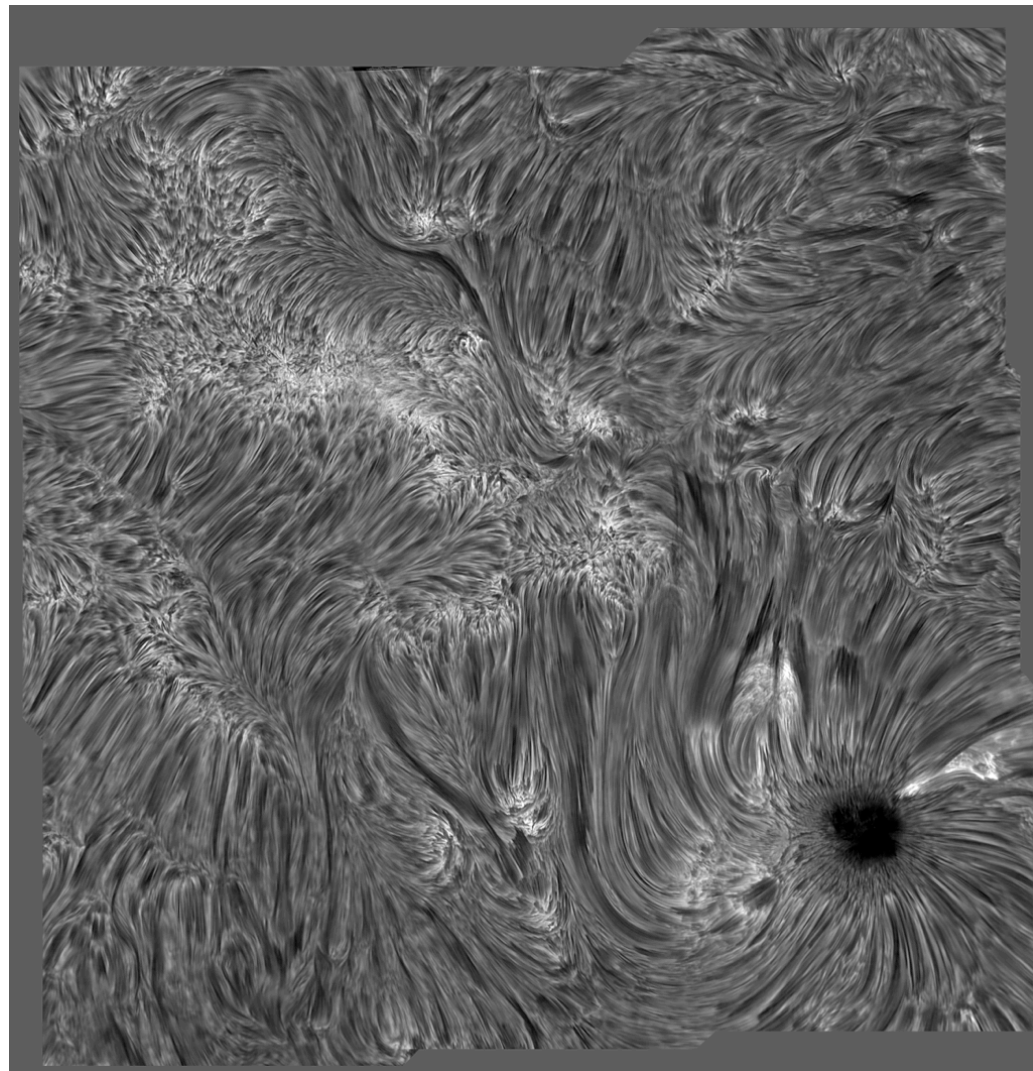
<u>Spectral Window</u>	<u>Observing Mode</u>	<u>Spatial Resolution</u>	<u>DKIST Instrument</u>
393.3 nm	filtergram	0.022" ; 16km	VBI
393.3, 396.8 nm	spectrograph	0.04" x 0.06" ; 30 x 40 km	ViSP
854.2 nm	spectral scan	0.043" ; 30 km	VTF
854.2 nm	imaging spectrograph	0.06", 0.15" ; 43, 108 km	DL-NIRSP
854.2, 849.8, 866.2 nm	spectrograph	0.04" x 0.06" ; 30 x 40 km	ViSP

### Helium Lines

<u>Spectral Window</u>	<u>Observing Mode</u>	<u>Spatial Resolution</u>	<u>DKIST Instrument</u>
1083.0 nm	imaging spectrograph	0.06", 0.15" ; 43, 108 km	DL-NIRSP
1083.0 nm	spectrograph	0.24 x 0.30" ; 175 x 215 km	Cryo-NIRSP
587.6 nm	spectrograph	0.04" x 0.06" ; 30 x 40 km	ViSP

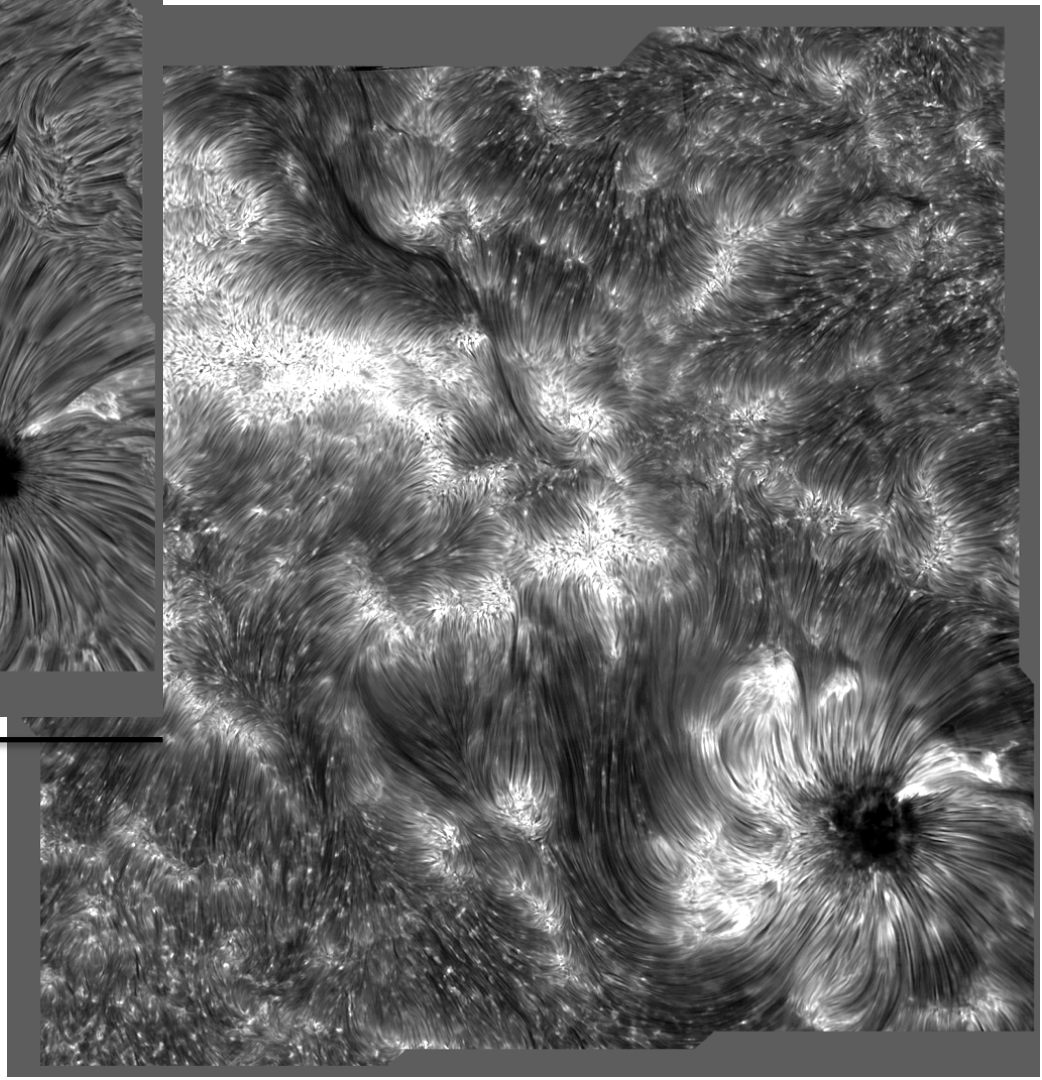


**IBIS**  
**Ca II 8542 Å**



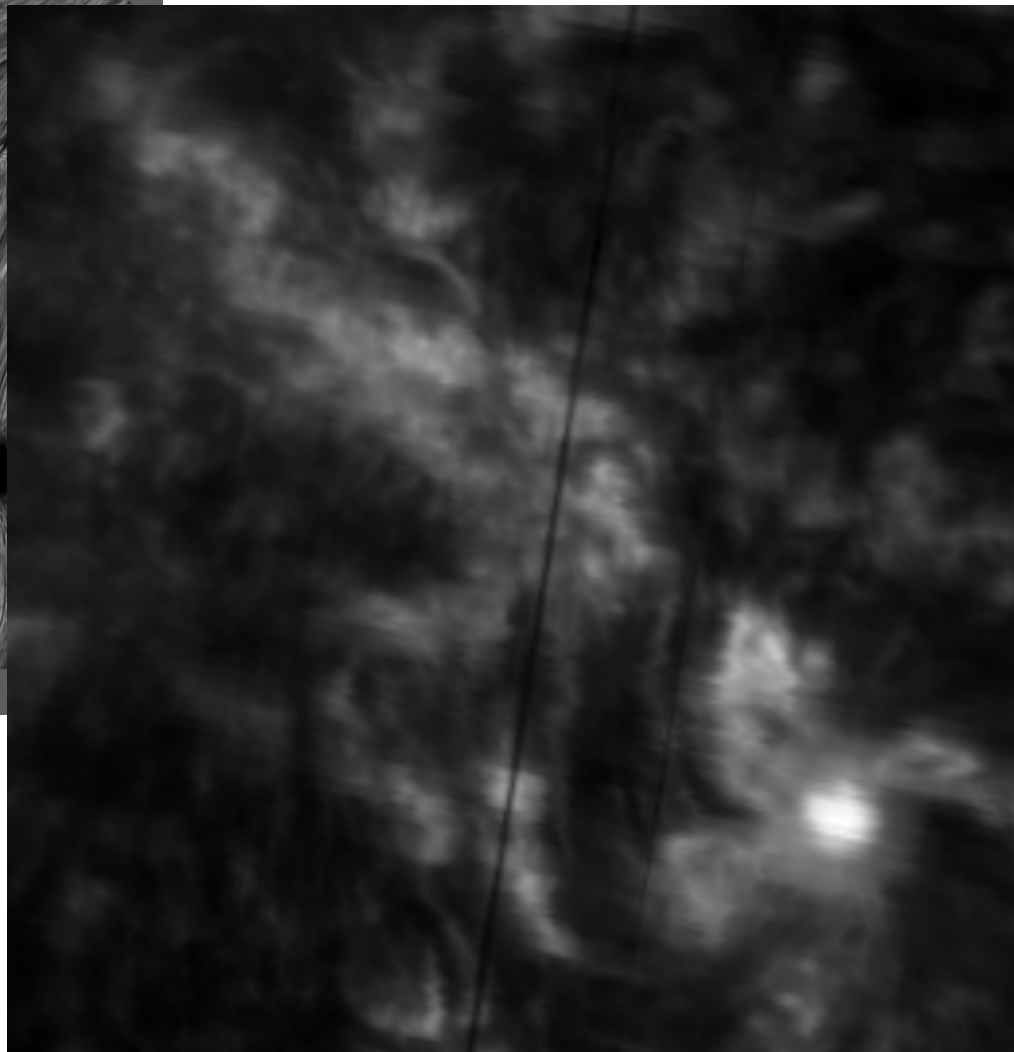
240"

**IBIS**  
**H $\alpha$  6563 Å**





SOLIS He I 10830 Å



H $\alpha$  6563 Å

