宇宙からの次世代
彩層磁場観測

石川遼子（国立天文台）

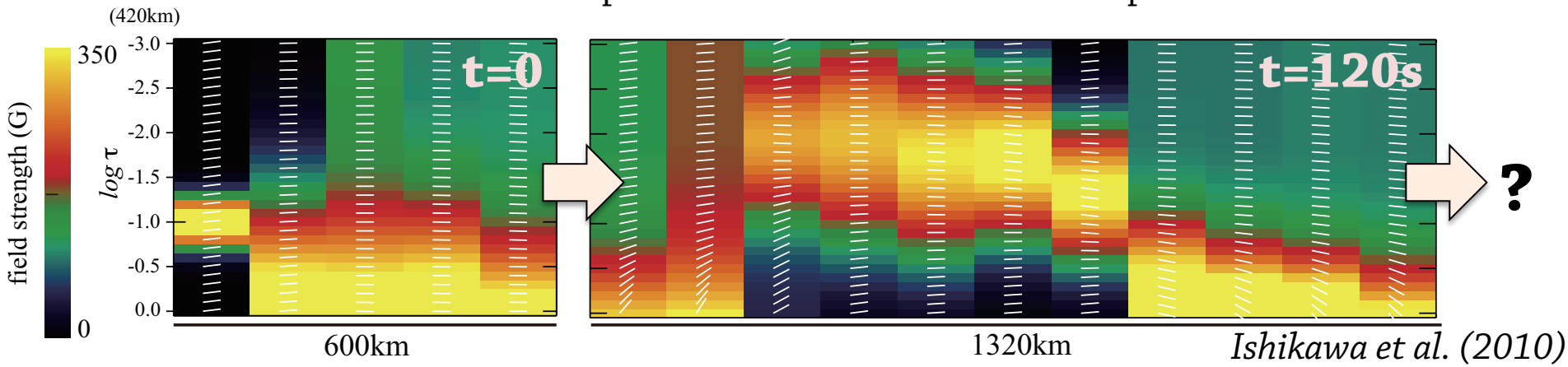
Advantages of space-based obs.

- UV range
  - Impossible to access from the ground
- Blue side of the spectrum
  - Adaptive optics system does not work
  - Higher diffraction limit than that in red & IR
- Capable of long exposure (high polarization sensitivity) keeping the high spatial resolution
  - Lessons learned from Hinode/SP

Requirements to spectral lines

- Emitted from **low β** region
- Enable to observe the **vector** magnetic field
  - Magnetic fields are inclined in the chromosphere
- Sensitive to **less than 10 G** for vector field
  - Transient granular-size horizontal fields: B_{phot}=400G @ photosphere *(Ishikawa et al. 2008)*
  - @ upper chromosphere [h=2000km ~ 8 H_p]

$$P_{chro} \sim \exp(-8) P_{phot} \Rightarrow \mathbf{B_{chro}} \sim \exp(-4) B_{phot} \sim \underline{\mathbf{7G}}$$



Ishikawa et al. (2010)

Limitation of Zeeman effect

- Hard to achieve high sensitivity to transverse magnetic field

$$B_{\text{long}} = 4348\left(\frac{V}{I}\right)$$

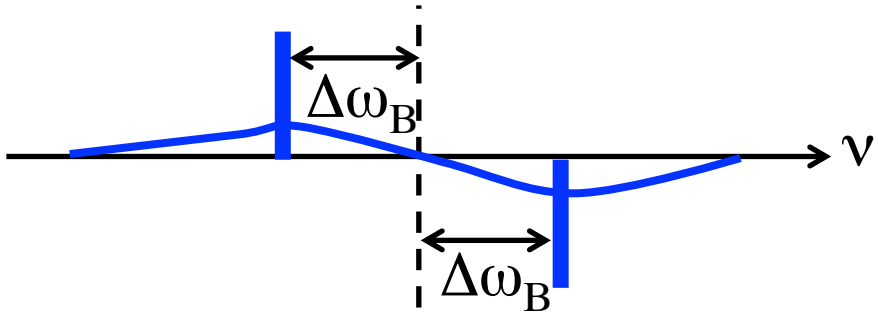
$$B_{\text{tran}} = 3371\left(\frac{Q}{I}\right)^{\frac{1}{2}}$$

Polarization sensitivity of 10^{-3} gives at FeI 6302A

- B_{long} = 4G & B_{tran} = 100G

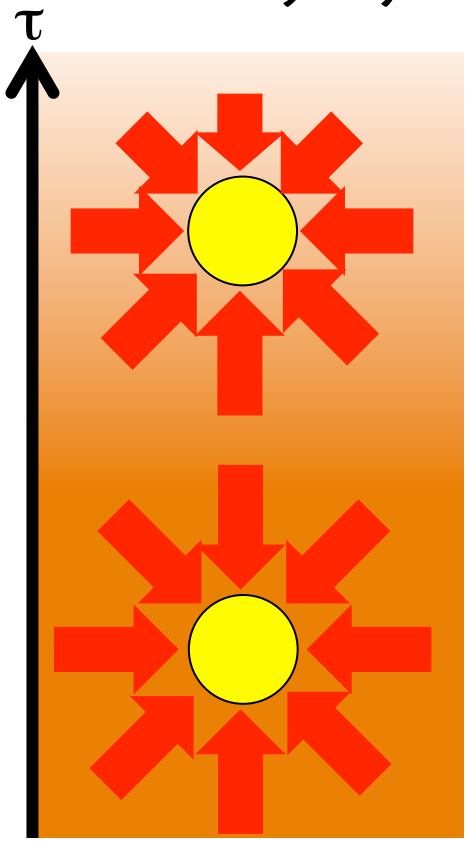
Landi Degl'Innocenti & Landolfi (2004)

- Very weak signals because of large Doppler broadening in the chromosphere and above

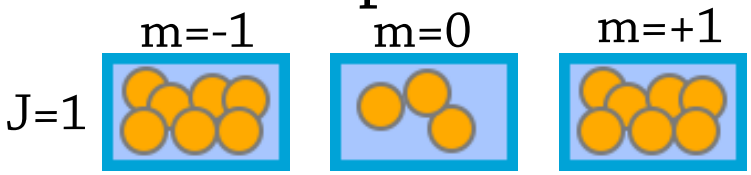


Atomic polarization

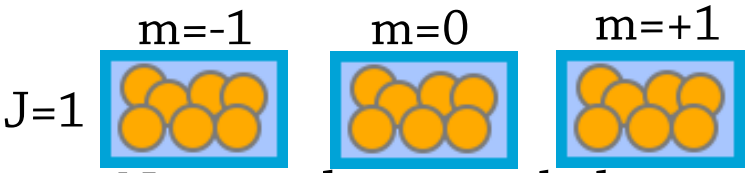
- *Population imbalance* between magnetic sublevels induced by *anisotropic radiation*
- *Quantum coherency* by rotation of quantization axes



Anisotropic radiation



Uniform radiation



No population imbalance,
no atomic polarization!

Hanle effect

- Magnetic fields *dephase & decrease coherence*

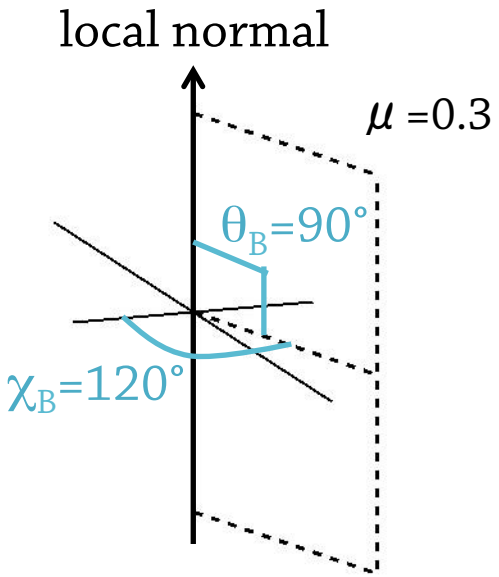
Operates at $\omega_B \sim A$

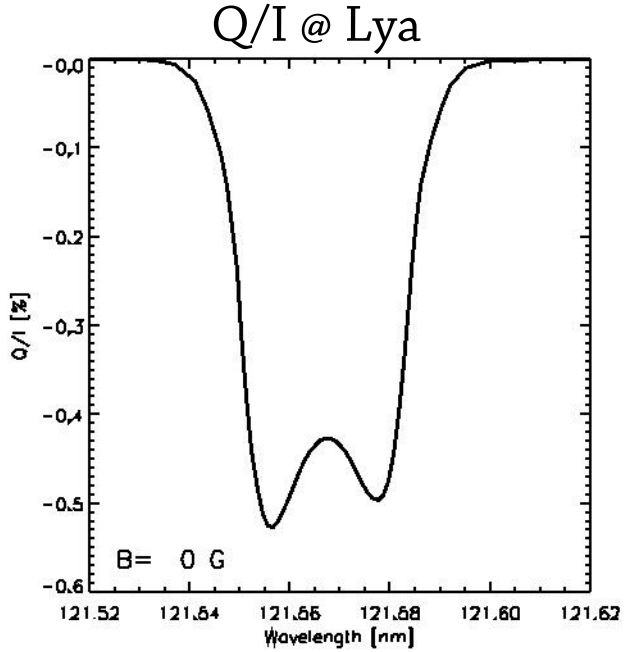
$\omega_B = \frac{e}{2m} gB$: Larmor frequency

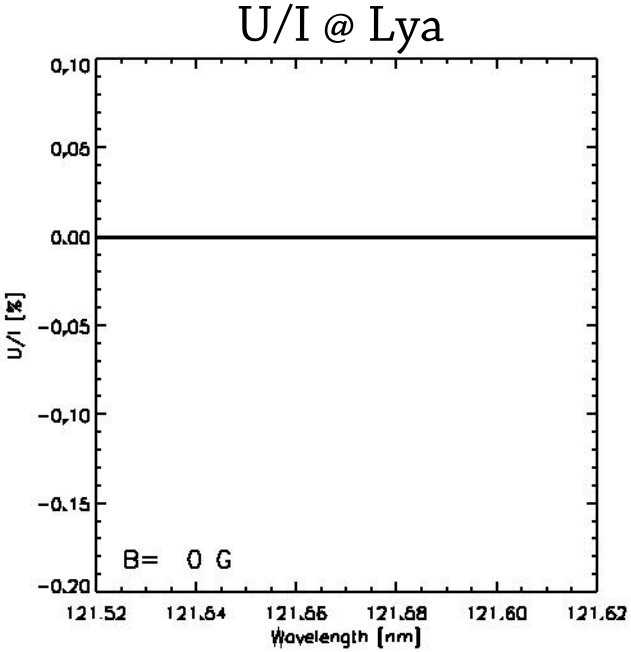
A : Einstein coefficient

Large A (Lya, MgII k, ...)→ Large B_H

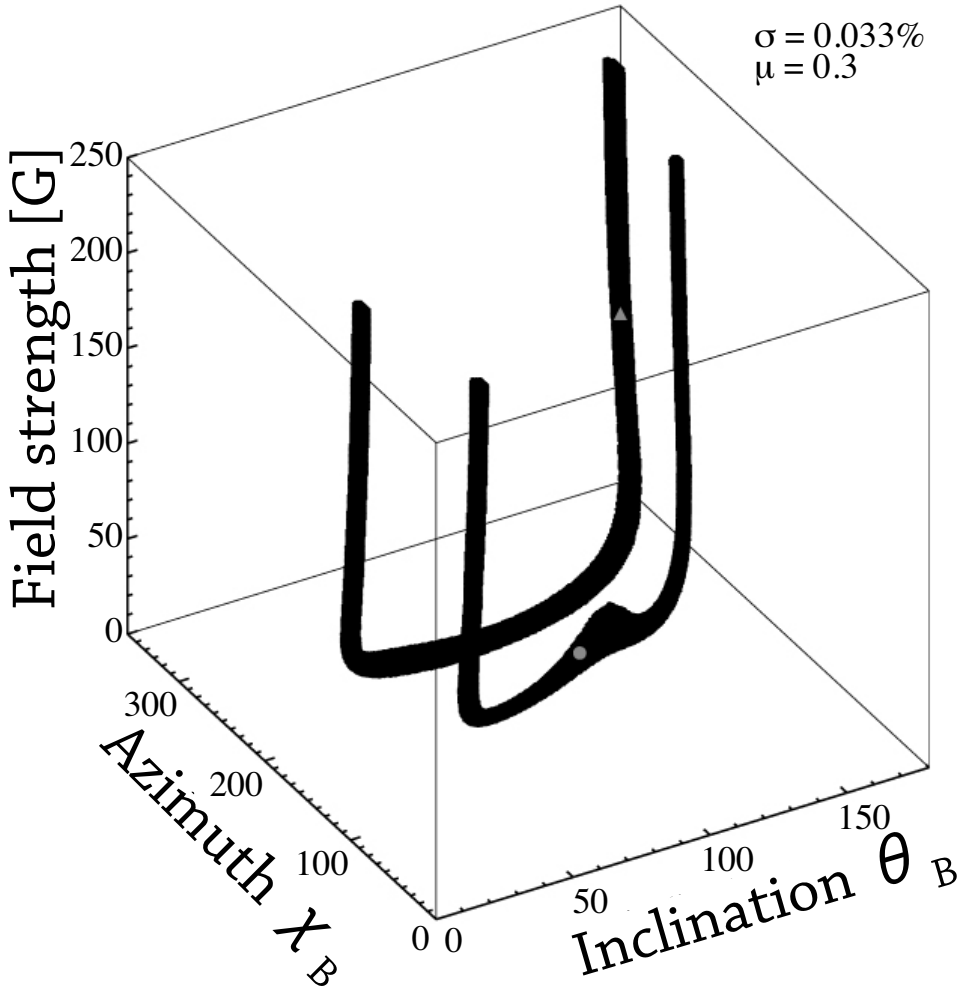
Small A (e.g., forbidden line) → Small B_H







Inversion of Hanle effect

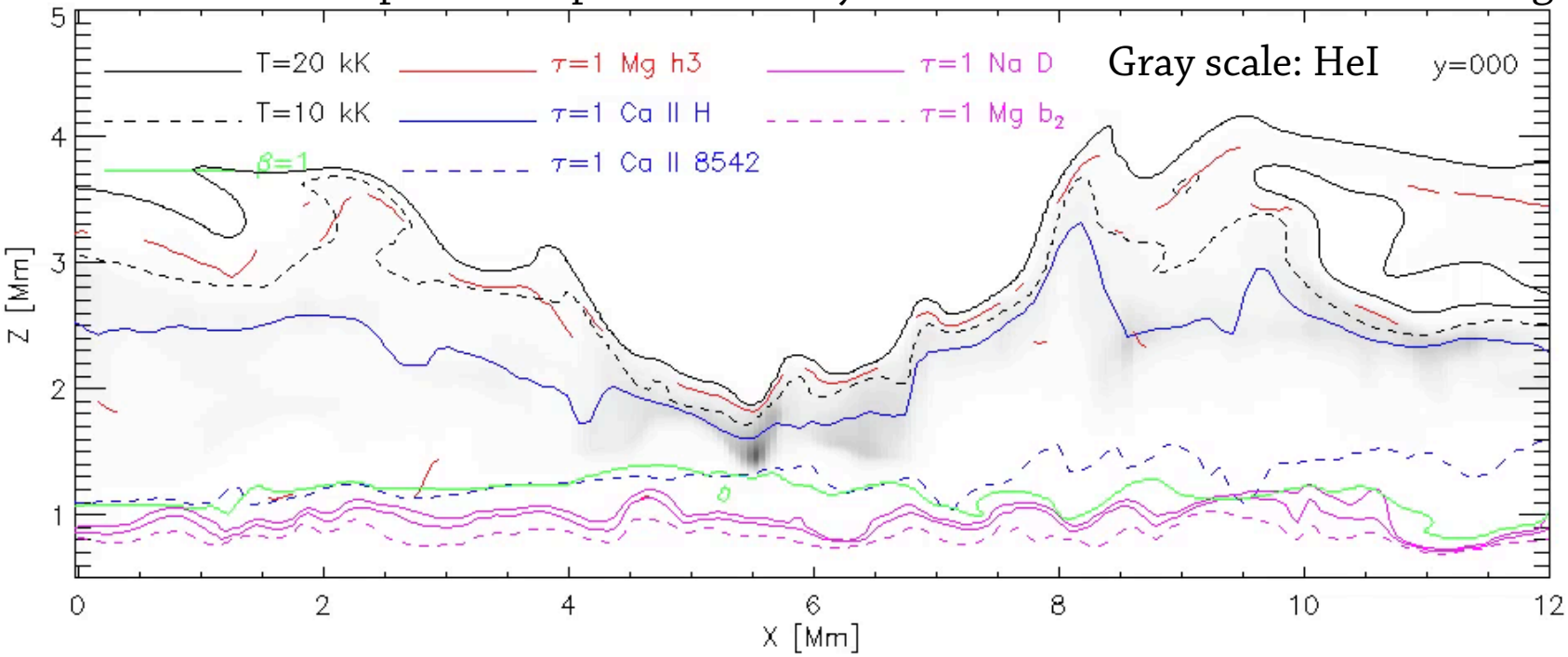


Ishikawa et al. (2014)

- Hanle effect only does not allow to uniquely determine the three components of magnetic field.
- Additional information (Stokes V from Zeeman, simultaneous Hanle measurement with other line,….) is required.

Formation Height

Adopted from presentation by Carlsson in SOLAR-C science meeting 2013



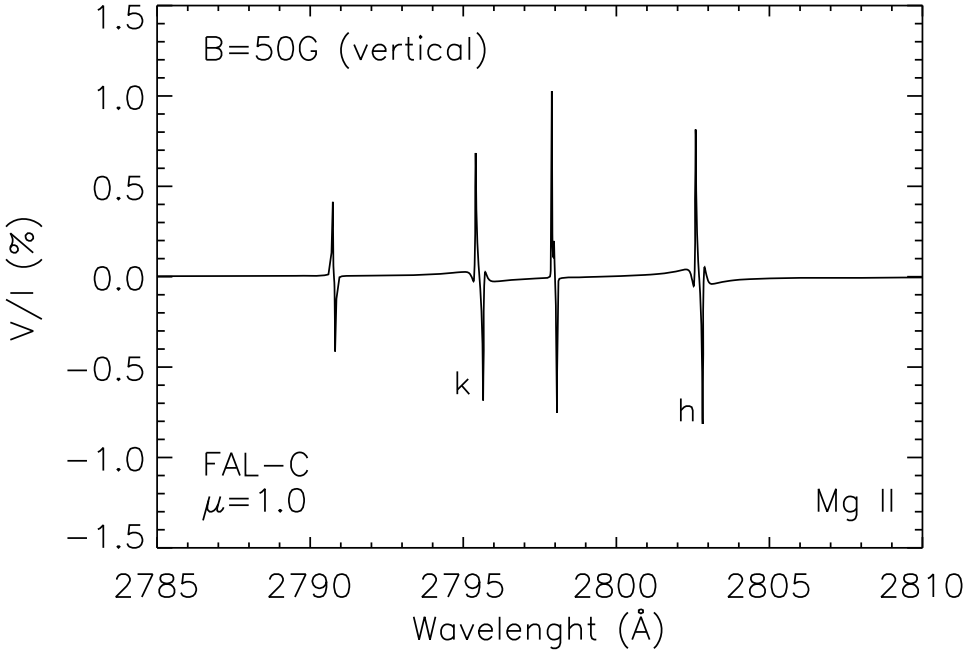
CaII 8542 (triplet) β~1 << HeI ~ CaII h(k) < MgII h(k) β<<1

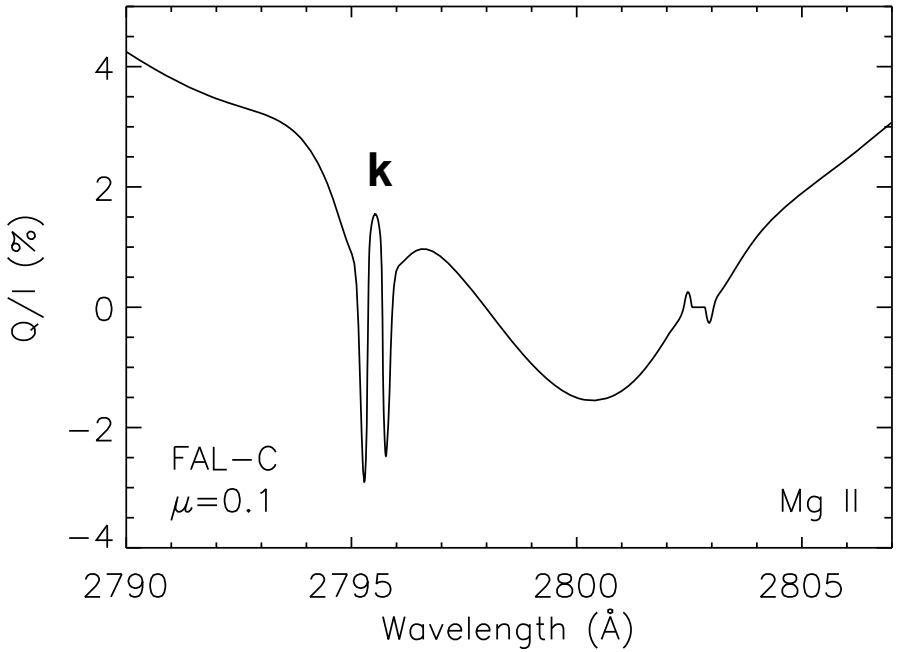
- HeI is observed everywhere in QS???? Other candidates are MgII k and CaII k.

Pressure scale height : 500km @ 10^4 K

Mg II k

Adopted from presentation by Belluzzi in SOLAR-C science meeting 2012

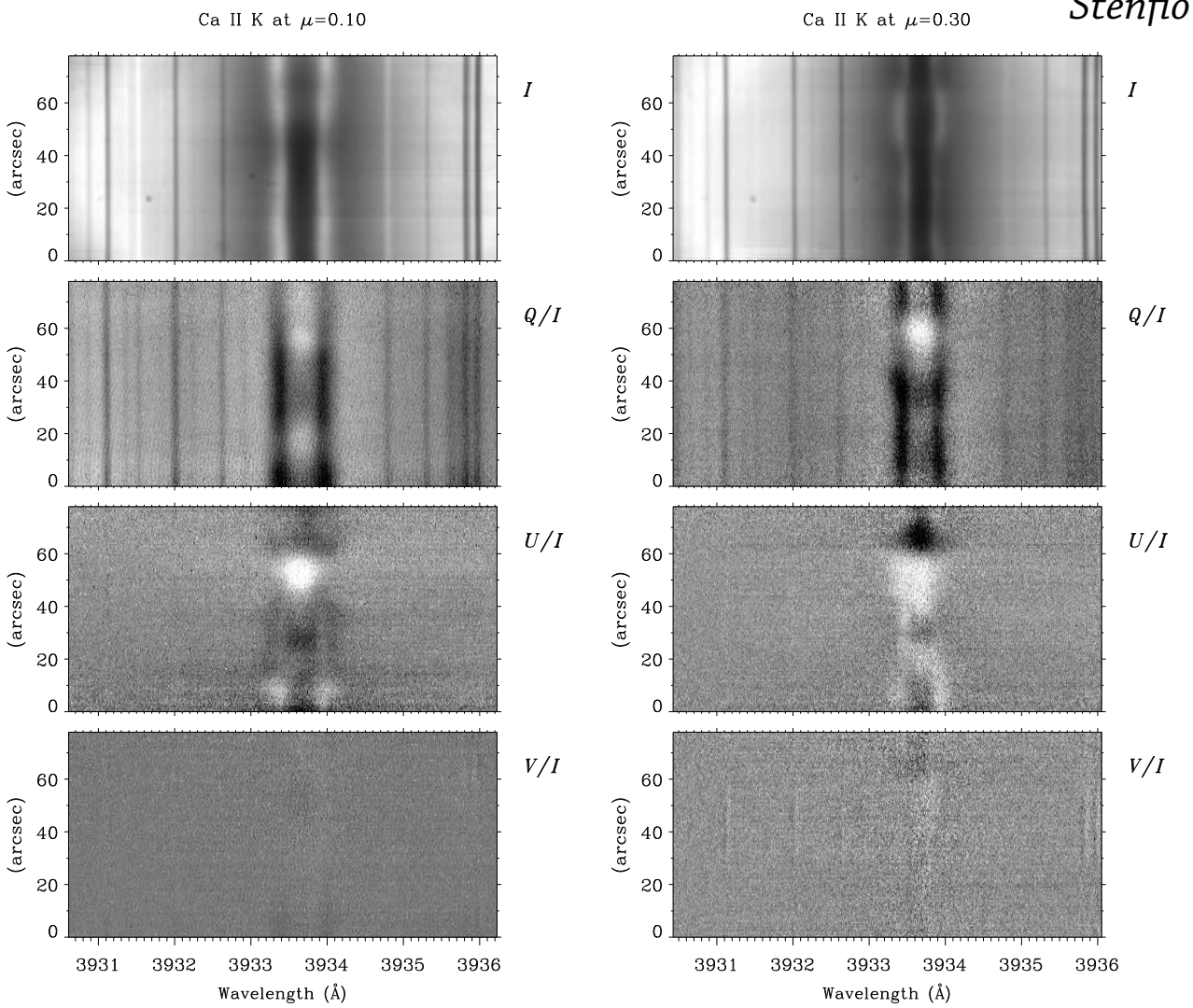




- Up to now, there is no observation of atomic polarization in this line. However, the atomic system and the line formation height are similar to hydrogen Lyα, and CLASP observation in 2015 will greatly help us to understand this line!

Ca II k

Stenflo (2004)



Candidates of spectral lines for SUVIT+ sensitive to **Hanle**

UPPER CHROMOSPHERIC LINES ONLY!

Spectral line (A)	1.22/D [arcsec]	Response height[km]		Zeeman effect		Hanle effect	
		T_e	V	B_{long}[G]	B_{tran}[G]	Range[G]	P [%]
HeII 304	-	Transition region		-	-	85 - 850	1.5
Lyα 1216	-	Transition region		-	-	0.5 - 50	0.5
MgII k 2796	0.046	1300	1400	130	2100	0.3 - 25	1.5
CaII k 3933	0.065	1000	1200	81	1700	0.2 - 15	1.5
HI β 4861	0.080	1500	1000	19	1300	Collisional depolarization??	
HI α 4861	0.108	1500	1300	9.9	910		
CaII 8498	0.140	700	1000	5.6	280	10^{-3} - 10	0.01
CaII 8542	0.141	800	1200	6.1	330	10^{-3} – 10^{-2}	0.4
CaII 8662	0.143	700	1000	7.6	410		0.4
HeI 10830 (QS)	0.179	1800	1800	20	400	Blue: 10^{-2}-10^{-1} Red: 10^{-1}-1	Blue:0.03 Red:0.15
HeI 10830 (AR)	0.179	1800	1800	10	280		

Information of the Hanle effect is added to the updated table in MPD.

Trade-Off

Spectral line	Formation height	Zeeman sensitivity		Hanle effect			
		B_{long}	B_{tran}	Sensitive B range	Atomic pol.	Interpretation	
						Atmos. model	3D effect
Lyα 1216	◎	×	×	○	△	△?	△?
MgII k 2796A	○	△	×	○	○	△?	△?
CaII k 3933A	○	△	×	○	○	△?	△?
CaII 8498A	×	○	×	△	×	△?	△?
CaII 8542A	×	○	×	×	△	△?	△?
CaII 8662A	×	○	×		△	△?	△?
HeI 10830A (QS)	○	×?	×	×	△	○?	○?
HeI 10830A (AR)	○	○	×				

Summary

- It may be risky to rely on the HeI 10830 since it is not visible everywhere in the quiet Sun (especially in the internetwork region).
- Alternative plan is the spectro-polarimetric observations in CaII k and MgII k. These are new generation of space-based observations (CLASP, CLASP+, small satellite mission….)!
- For the SUVIT line selection, the trade off is necessary.
  - Organize an international task force.