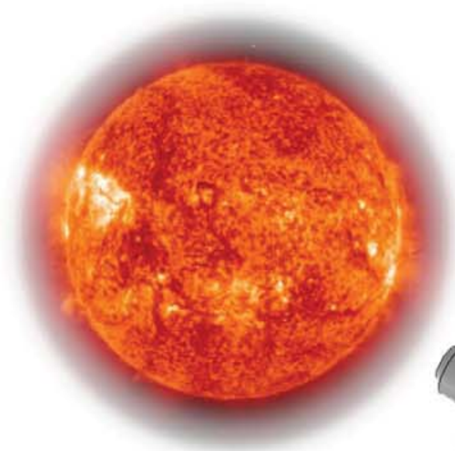
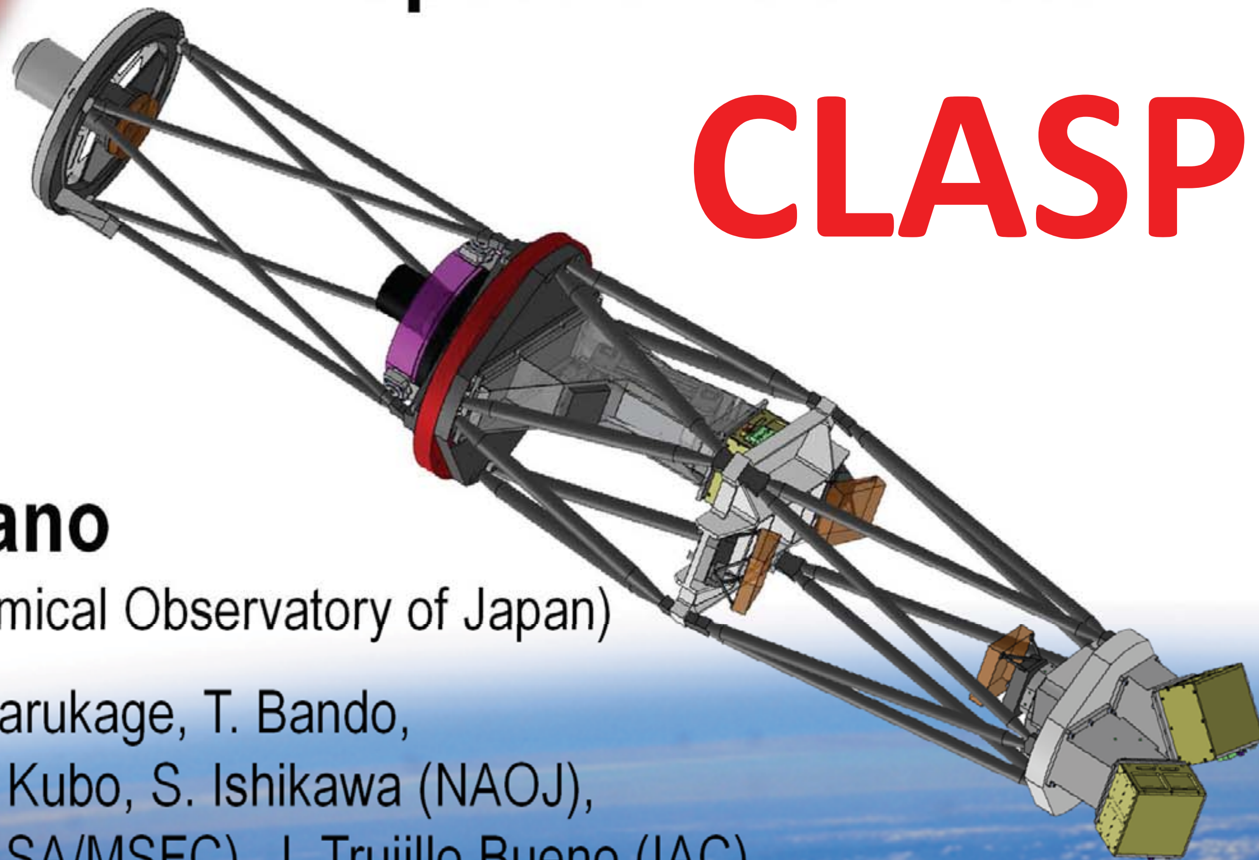


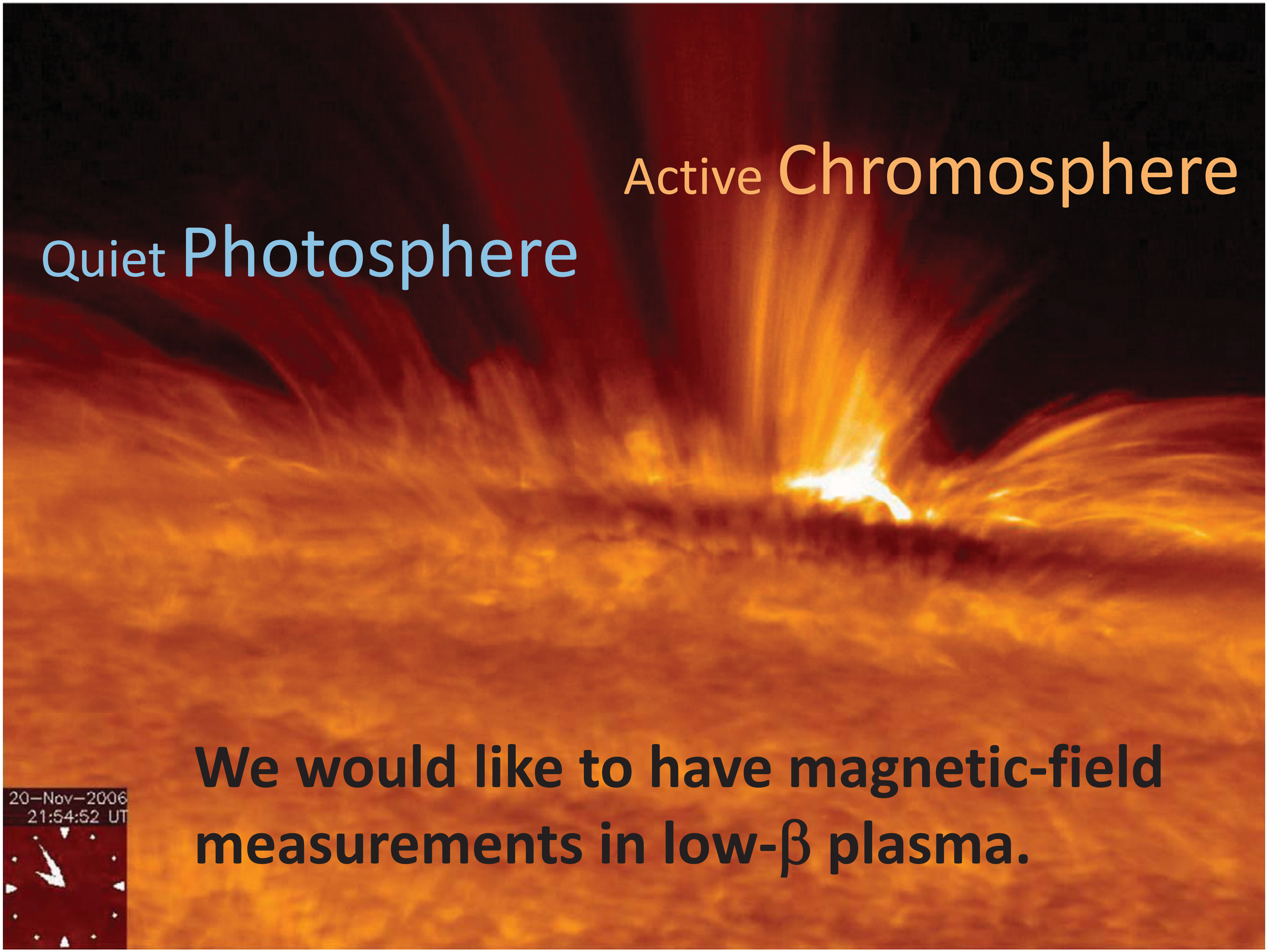
Chromospheric Lyman-Alpha Spectro-Polarimeter

CLASP



Ryouhei Kano
(National Astronomical Observatory of Japan)

R. Ishikawa, N. Narukage, T. Bando,
Y. Katsukawa, M. Kubo, S. Ishikawa (NAOJ),
K. Kobayashi (NASA/MSFC), J. Trujillo Bueno (IAC),
F. Auchère (IAS), with the CLASP team


Active Chromosphere
Quiet Photosphere
We would like to have magnetic-field measurements in low-β plasma.
20–Nov–2006
21:54:52 UT

Chromospheric **L**yman-**A**lpha **S**pectro-**P**olarimeter (CLASP)

A sounding rocket experiment aiming the followings:

- **high-precision (0.1%)** measurements of linear **polarizations in vacuum-UV (VUV) lights**,
- the **first measurement** of the linear polarization induced by **atomic polarization and Hanle effect in the Lyman-alpha line (121.567nm)**, and
- the **first exploration** of **magnetic fields** in the upper chromosphere and transition region of the Sun.

The CLASP project was accepted by NASA in 2012, and CLASP will fly with NASA's sounding rocket in 2015!

International Collaboration in **CLASP**

12 institutes in 5 countries

Japan : **R.Kano (PI,** NAOJ**)**

- **All of CLASP science instrument** (except **CCD camera system** and **concave grating**)
- Development of empirical tool to diagnose ch.-magnetic fields.

USA: **K. Kobayashi (PI,** NASA/MSF**C)**

- CCD camera system
- Sounding rocket & operation

France : **F. Auchère (PI,** IAS**)**

- Concave grating

Collaborations

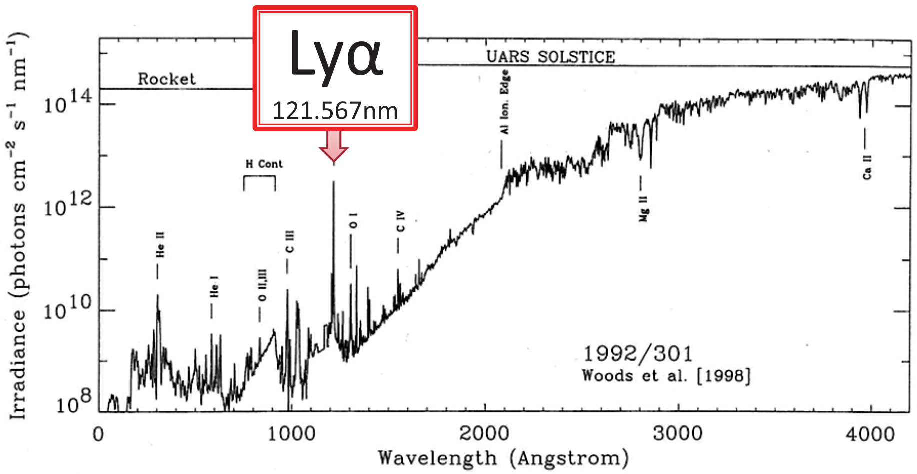
Norway : **M. Carlsson (**Oslo U.**)**

- 3D modeling of solar atmo-sphere

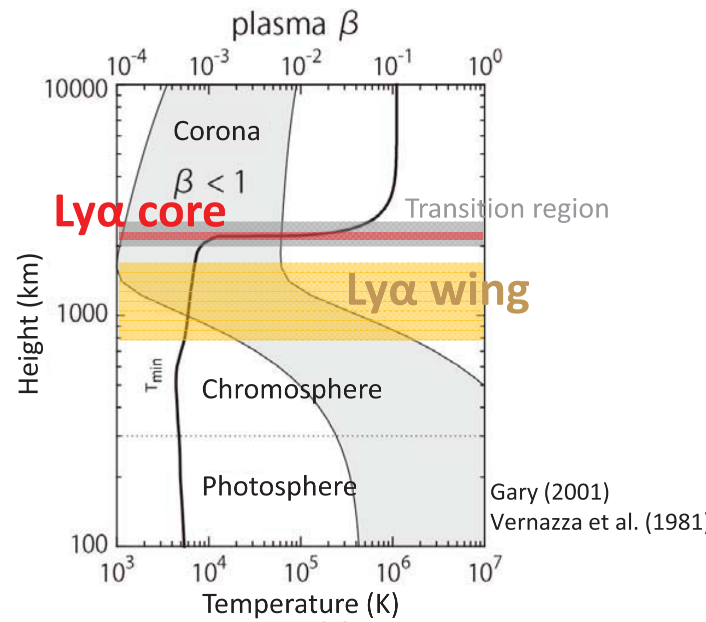
Spain : **J. Trujillo Bueno (PI,** IAC**)**

- Modeling of spectro-polarimetric profile in Lyman-alpha with Hanle effect

Why Lyα line?



Solar spectrum in VUV range



Plasma-β and formation height of Lyα in the solar atmosphere

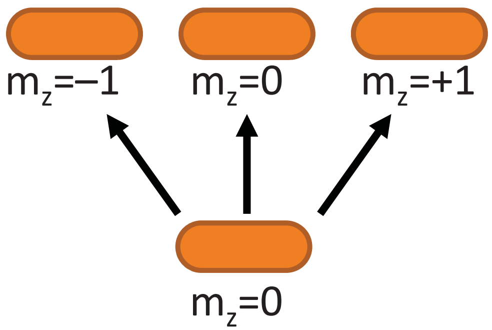
- Brightest line in VUV chromospheric emission lines.
- Bright even in quiet Sun as well as active regions.
- Line core is emitted by the plasma located between higher chromosphere and **transition region**.
- Good sensitivity to magnetic field of 10 – 250 G via Hanle effect.

➔ Lyα line is a best candidate to infer magnetic fields in low-β plasma (β<1) over the entire solar disk.

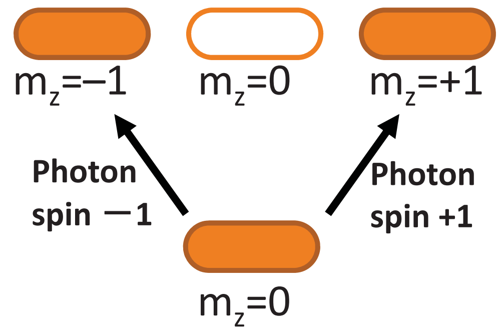
Origin of linear polarization in scattered lights

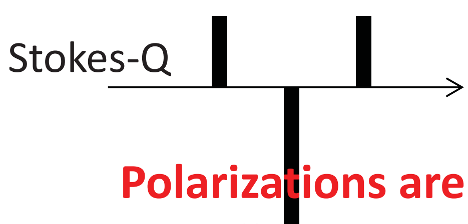
Step 1: Population imbalance between atomic sublevels induced by **anisotropic radiation** illuminating atom.

isotropic radiation



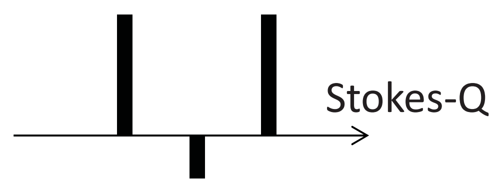
anisotropic radiation





Polarizations are cancelled out.

If Doppler width is wider than Zeeman spliting,

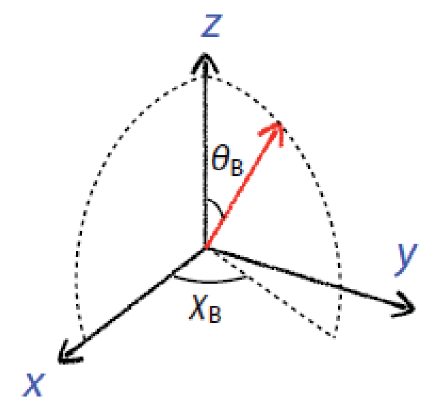


Polarizations remain even after cancellation.

Origin of linear polarization in scattered lights

Step2: Quantum coherency by rotation of quantization axes.

Step3: Magnetic fields dephase and decrease the coherence (Hanle effect). It is a competition between Larmor motion and de-escitation.



$$\frac{1}{\omega_0} \quad \textbf{VS.} \quad \frac{1}{A}$$

time scale to change coherency — time scale for de-excitation

$\frac{1}{\omega_0} \sim \frac{1}{A}$ **marginal field:** depolarization & rotation of linear polarization

***B*~54G @ Ly-alpha**

$\frac{1}{\omega_0} \ll \frac{1}{A}$ **strong field (saturation regime):** depolarization

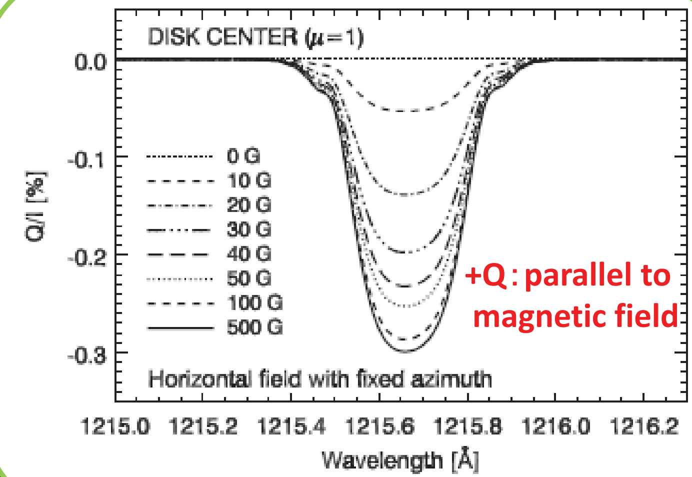
$\omega_0 = \frac{e}{2m} gB$: Larmor frequency

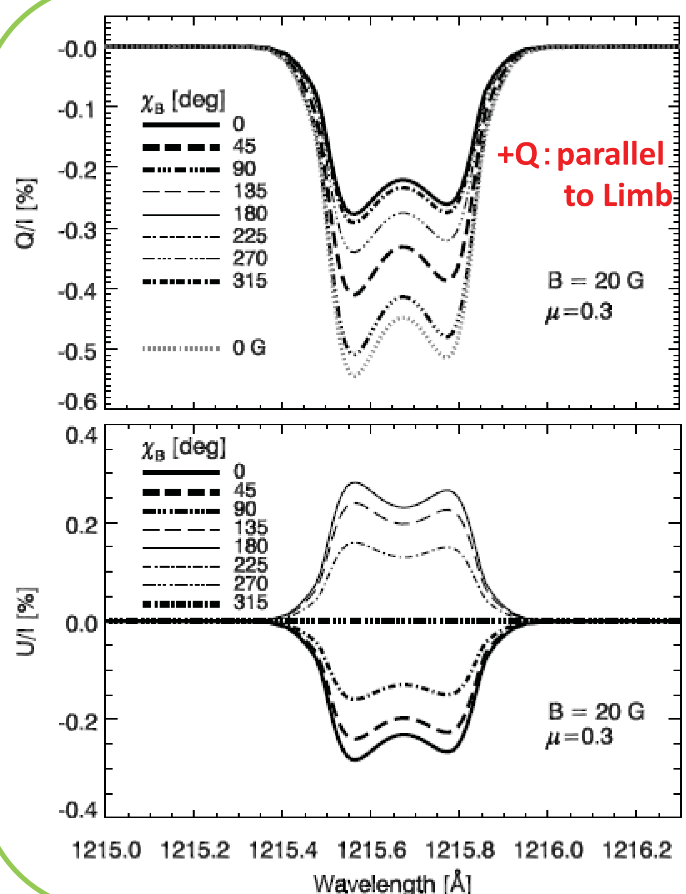
A: Einstein coefficient for spontaneous decay

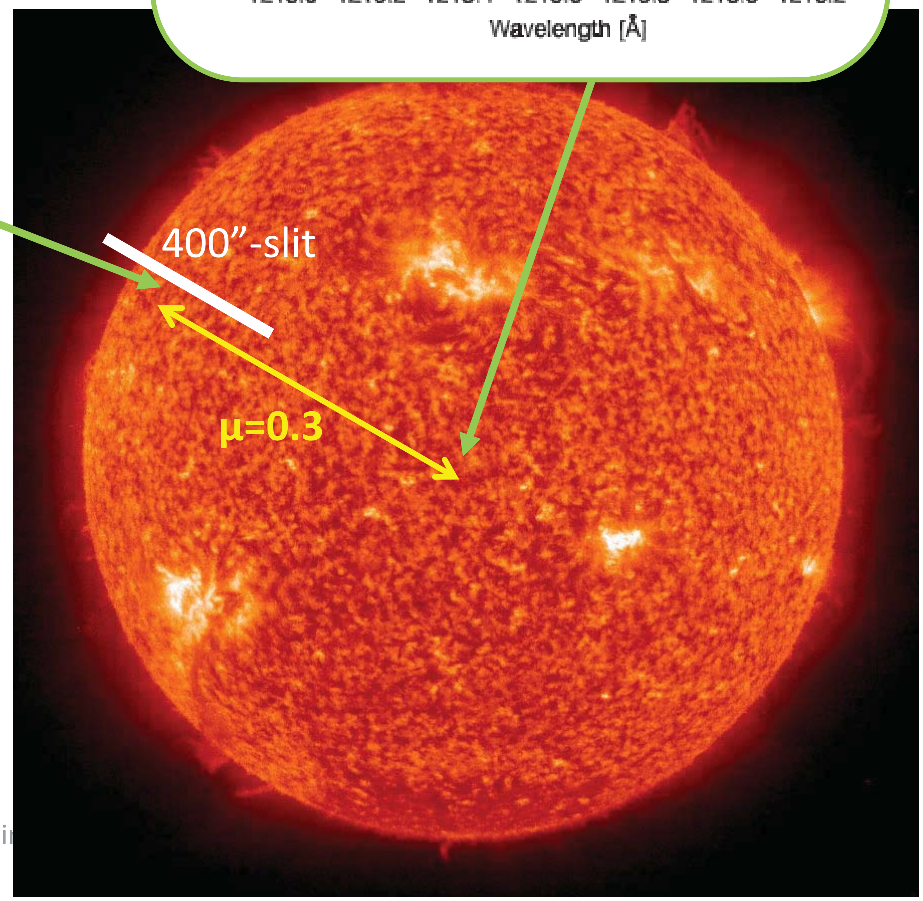
Polarization of Hanle effect in Lyα

based on **FAL-C model** & **CRD scattering**

(Trujillo Bueno et al. 2011, ApJ)



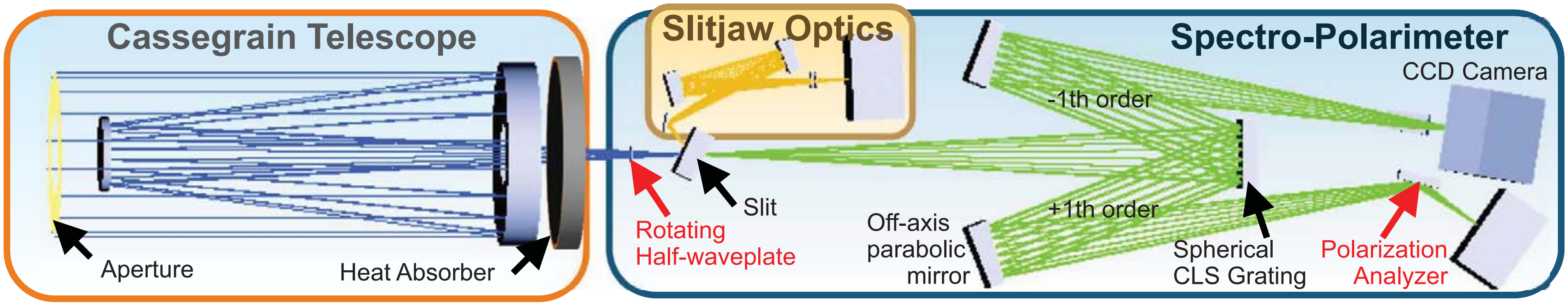




COSPAR i

CLASP Instrument: Optics

Narukage,N. et al. (2014, Applied Optics, in preparation)



Cassegrain Telescope	
Aperture	ϕ270.0 mm
Effective Focal Length	2614 mm (F/9.68)
Visible light rejection	"Cold Mirror" coating on primary mirror

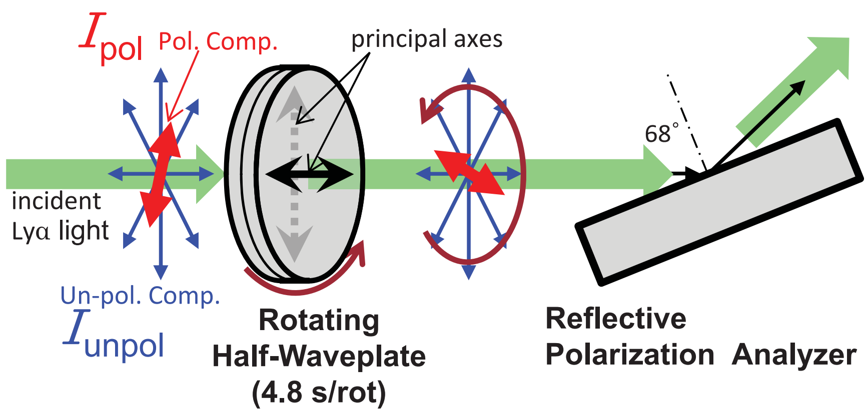
Slitjaw Optics	
Wavelength	121.567 nm (narrowband filter)
Plate scale	1.03''/pixel
FoV	527'' × 527''

Spectro-Polarimeter		
Optics	**Dual beam** of Inverse Wadsworth mounting	
Wavelength	121.567 ± 0.61 nm	
Slit	1.45'' (width), 400'' (length)	
Grating	Spherical constant-line-spacing, 3000 lines/mm	
CCD camera	512 × 512 pixel	13μm/pixel
Plate scale	0.0048 nm/pixel	1.11''/pixel
Resolution	**0.01nm**	3''
Sensitivity	**0.1%**	

Polarization Measurement

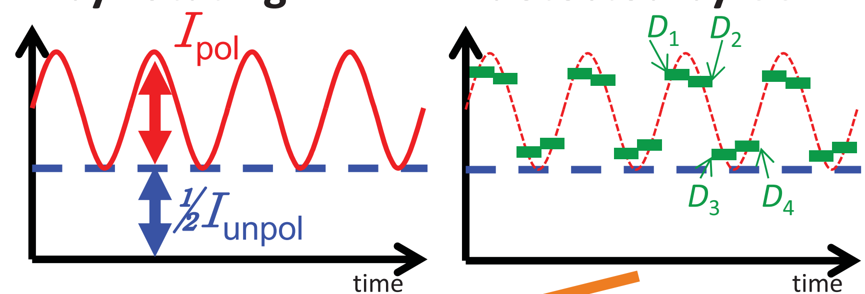
- CLASP is optimized for linear polarization, because V/I is expected to be too small (~0.005% @10G in the Ly-alpha by Zeeman effect).

CLASP Polarimeter



Modulation

by rotating WP **detected by CCD**



Demodulation

from CCD exposures

$$Q = aK\{(D_1 - D_2 - D_3 + D_4) + \ldots\}$$

$$U = aK\{(D_2 - D_3 - D_4 + D_5) + \ldots\}$$

$$I = K\{(D_1 + D_2 + D_3 + D_4) + \ldots\}$$

a: modulation coefficient
K: throughput value

Dual-beam demodulation

- It will reduce spurious polarizations from time variations.

	t1	t2	t3	t4	…
Ch1	I+aQ+aU	I−aQ+aU	I−aQ−aU	I+aQ−aU	…
Ch2	I−aQ−aU	I+aQ−aU	I+aQ+aU	I−aQ+aU	…

Error term

$$\frac{Q}{I} = \left[\frac{Q}{I}\right]_0 + \frac{\Delta^2}{2a} \cdot \frac{1}{I_0} \frac{d^2 I}{dt^2} \cdot \frac{K_2 - K_1}{K_2 + K_1}$$

Difference of throughput K between 2 Ch

- We expect that the symmetric optics reduces the difference .

Time variation of intensity of targets

- The modulation/demodulation scheme removes a sensitivity to the linear change.
- The 1.2s period to take one set for the demodulation (i.e. 4 exposures) may be short enough.

Δ: exposure interval (~0.3s)

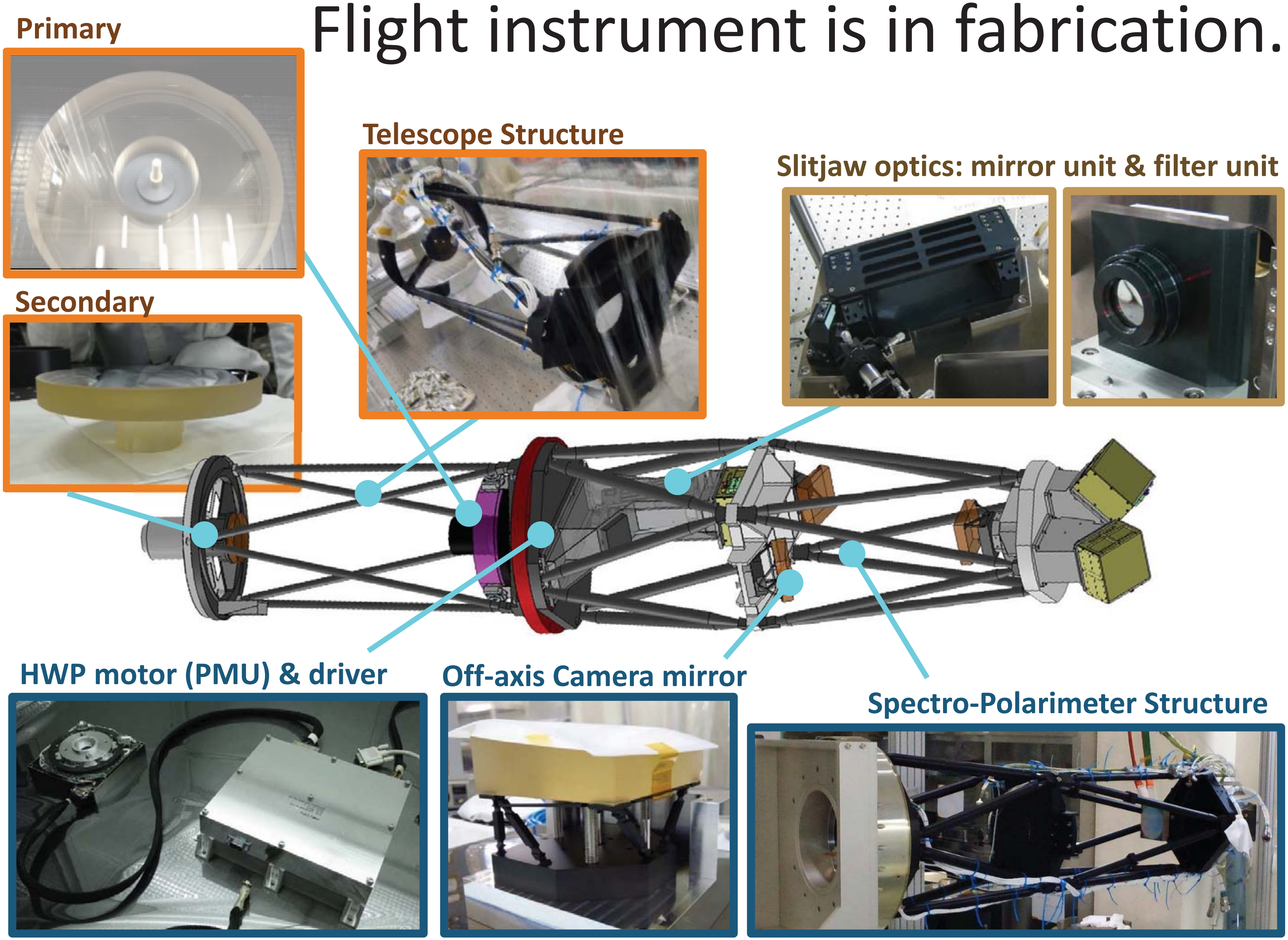
Error budget for spurious polarization

Ishikawa,R., et al. (2014, Solar Physics, in press)

Cause of error		error (1σ)
Random noise	**Photon noise at Ly-a center** (*10”* along slit and *200s* obs. period)	***0.026%***
	Readout noise of CCD cameras	**0.011%**
	Fluctuation of exposure durations	5×10^{-5}%
$\frac{dI}{dt}$	Time variation of source intensity	<0.018%† (~0%)
	Intensity variation from pointing jitter	<0.018%† (~0%)
	Image shift from waveplate rotation	~0%
Tel.	Off-axis incidence with 200’’	~10^{-4}%
	Non-uniformity of coating on primary	10^{-3}%
SP	**Error in polarization calibration**	**0.017%**
RSS		***<0.042% (~0.033%)***

†: These values are the case for the single channel demodulation, and can be reduced by dual channel modulations.

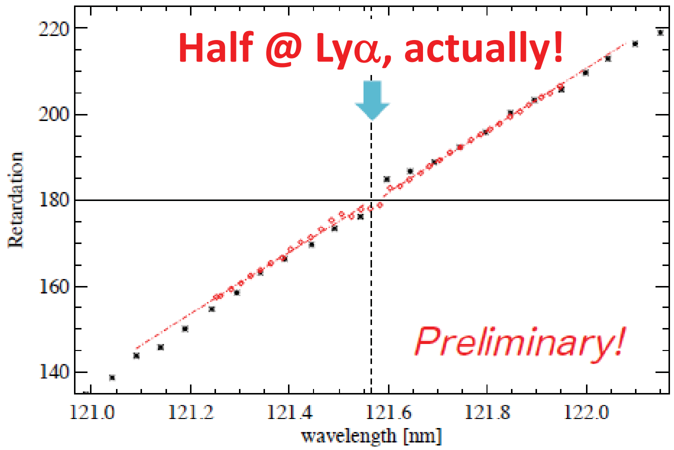
Flight instrument is in fabrication.



Measurements of flight components are also in progress.

Half waveplate

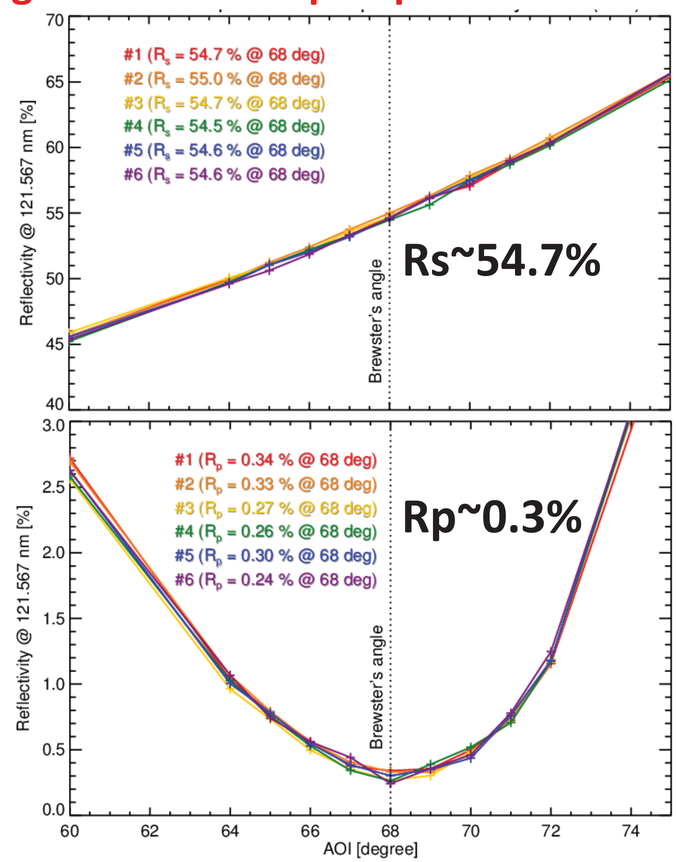
MgF_2 WP optimized by Ishikawa,R. et al. (2013, Applied Optics)



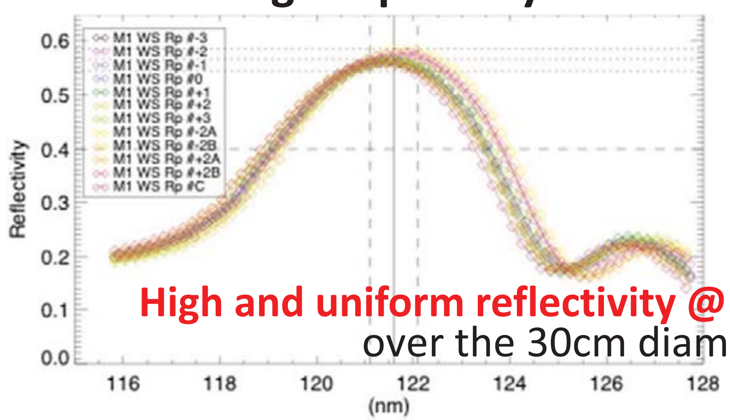
Reflective pol. analyzer

Multi-layer designed by Bridou et al.(2011. Applied Physics A)

High and uniform pol.-power = 98.9%



"Cold mirror" coating for primary mirror



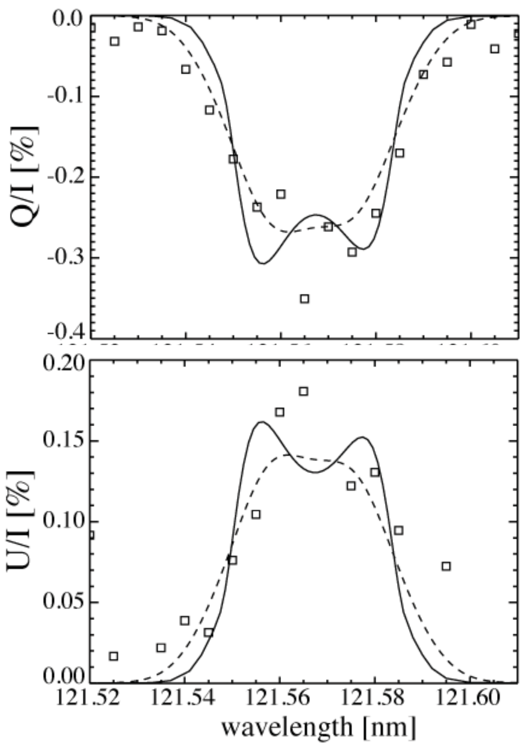
High and uniform reflectivity @ Lyα over the 30cm diameter

How ambiguous is *B*-inversion? How to solve the ambiguity?

Ishikawa,R. et al. (2014, ApJ 787, 159)

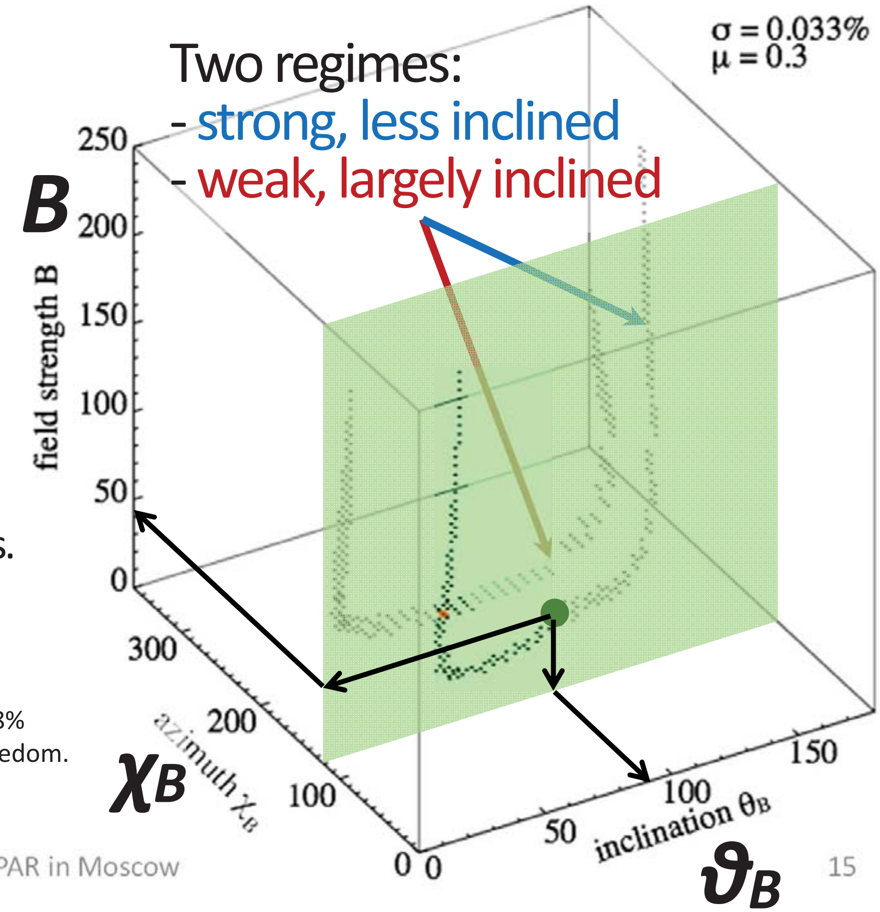
Close-to-limb (μ=0.3) obs. of ***B***=50G, θ_B=90˚, χ_B=120˚

Simulated observation
- λ-res.: σ=0.013nm
- noise : σ=0.033%

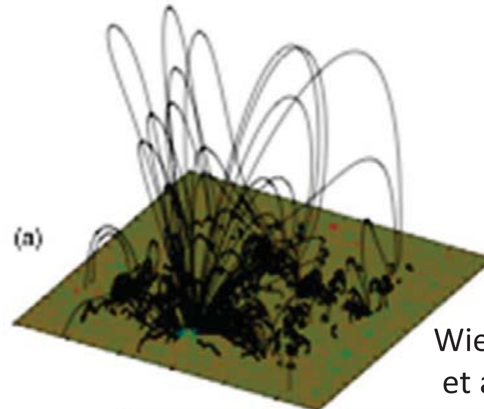


Take χ^2 with all synthetic profiles.

Black dots:
$\Delta\chi^2 \equiv \chi^2 - \chi^2_{min} \leq 3.53$,
which corresponds the confidence level of 63.8% (1σ) for 3-degree of freedom.



Procedure to infer magnetic fields



Wiegelmann et al. (2010)

Estimate azimuth χ_B using fibril and thread structures from IRIS, CLASP SJ, ground-based obs

χ_B

Estimate B, ϑ_B, and χ_B from extrapolations using photospheric magnetic field measurement from Hinode/SP and HMI etc

Determine B and ϑ_B from the inversion by fixing azimuth χ_B

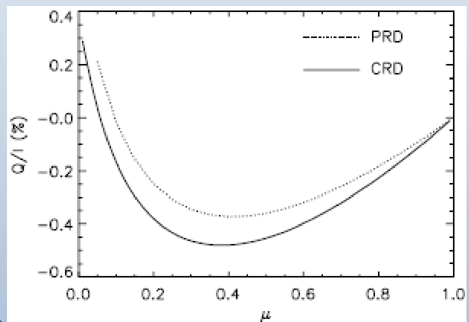
B, ϑ_B

Plots: Trujillo Bueno et al. (2011, ApJ; etc.)

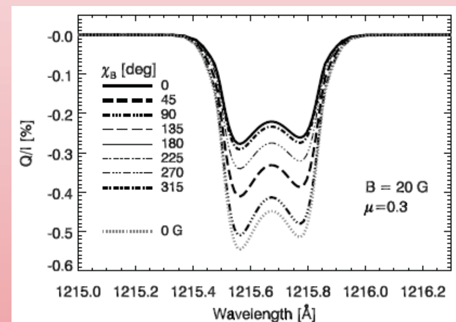
What will CLASP observe?

Observables

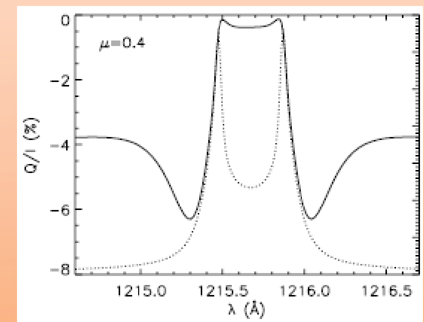
C-to-L Variation of Polarization



Polarization in Line Core



Polarization in Line Wing



?

Solar Atmosphere

Global Structure
$T(h), \rho(h)$

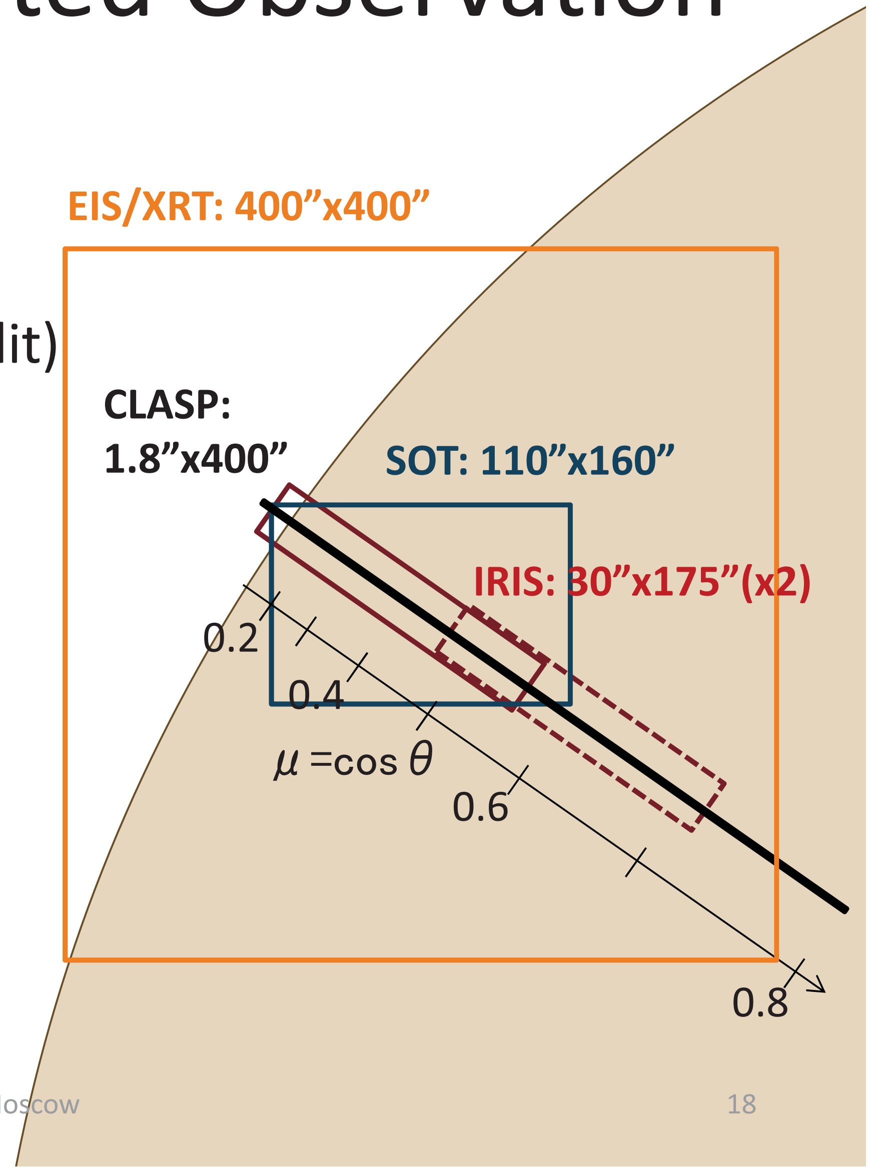
Magnetic fields in Chrom. & TR
B, ϑ_B, χ_B

Local Structure
$T(\vec{x}), \rho(\vec{x})$

Draft for Coordinated Observation

IRIS
- during the CLASP flight
  - Raster scan of 30”(scan)x175”(slit)
  - Near the limb: μ~0.4 and 0.6 (Scat-pol is maximum at μ~0.4.)
  - Mg II h&k observation.

Hinode/SOT
- before/after the CLASP flight
  - Near the limb: μ~0.4.
  - Hα imaging & Photospheric Vector magnetic fields by SP.



Summary

- The CLASP project is on-going **to infer magnetic fields in upper-chromosphere and transition region**.
- The CLASP, a sounding rocket experiment, will be performed **in 2015 summer at White Sands** in USA.
- Coordinated imaging observations of chromosphere and photospheric magnetic fields are necessary.
- A quick inversion based on plane-parallel atmospheres will be tried at first, but will be followed by precise analysis collaborated with 3D simulations.