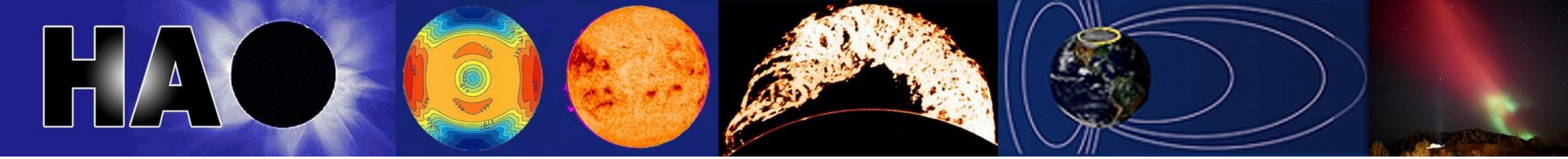
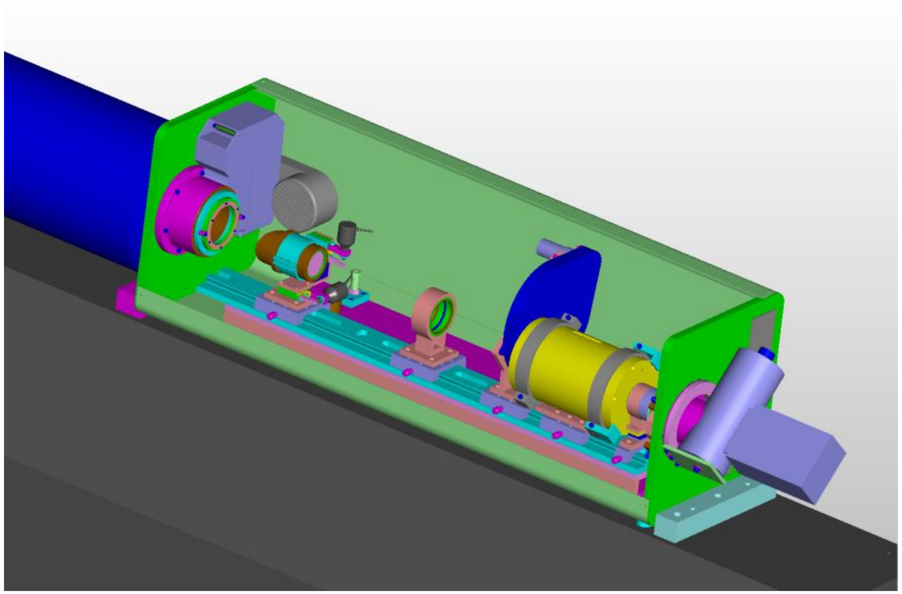
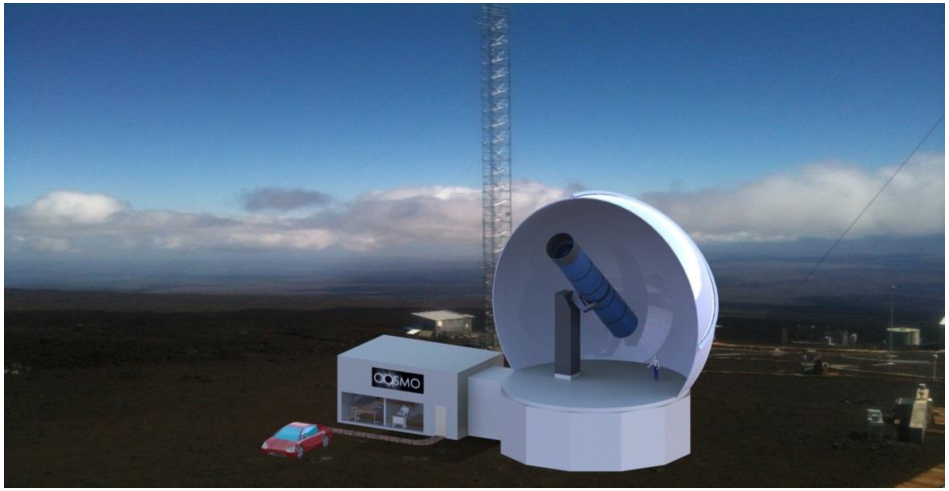


Polarimetry of the Solar Corona with the FeXIII Near-IR Lines





Steven Tomczyk
High Altitude Observatory, NCAR

High Altitude Observatory (HAO) – National Center for Atmospheric Research (NCAR)

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NCAR

Coronal Magnetic Field Measurements

Corona is 10^5 -10^6 times fainter than photosphere

Scattered light can be significant

Need coronagraph

Coronal magnetic fields are weak 1-10 Gauss

Coronal lines are much broader than in photosphere

Need high S/N - lots of photons

Coronal features are large

Need large field-of-view, ~1º

Very Difficult Measurement

Why the FeXIII near-IR Lines?

Judge et al. (NCAR Tech Note 446, 2001):

FeXIII has the best expected S/N based on line intensity, magnetic sensitivity and sky background levels

Ion	λ μm	Log I erg cm^{-2} s^{-1} sr^{-1}	Figure of merit (max s/n (V))	Max V/I	Log T_e
Fe XIII	1.0746	1.35	23.8	5.6-4	6.22
Si IX	3.9346	-0.17	23.4	1.5-3	6.04
Si X	1.4300	0.73	11.4	4.5-4	6.13
Mg VIII	3.027	-0.36	7.2	5.6-4	5.92
Fe XIII	1.0797	0.72	6.9	2.3-4	6.22
Fe XIV	0.5303	1.36	5.8	1.5-4	6.30
Fe XI	0.7891	0.96	5.8	1.8-4	6.10
Fe X	0.6374	1.12	5.2	1.5-4	6.03
S IX	1.252	-0.07	1.7	7.2-5	6.0
Si VII	2.481	-0.71	1.1	7.0-5	5.8

Methodology

Line-of-Sight Field Strength derived from Longitudinal Zeeman effect in Circular Polarization (V/I 10^{-4} / G)

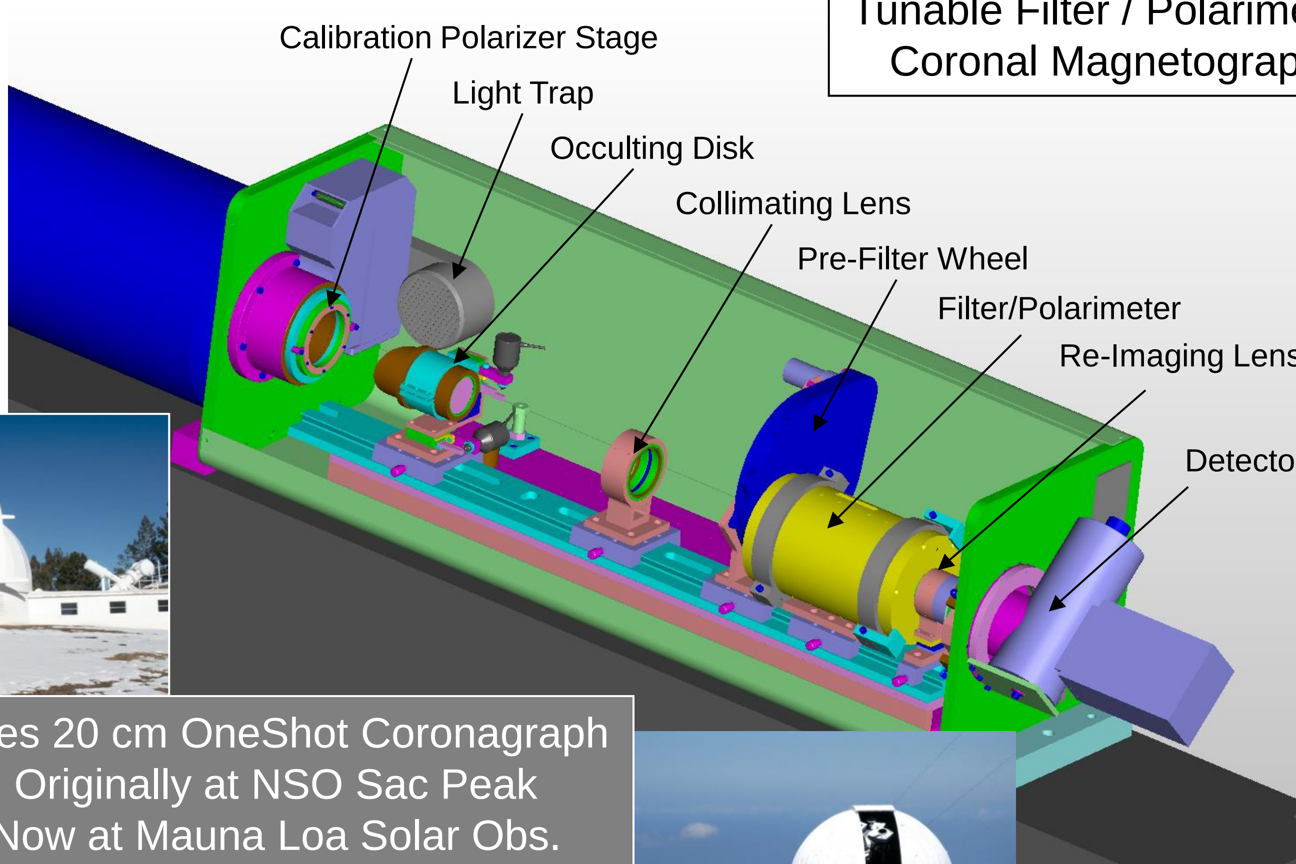
Plane-of-Sky Direction derived from Resonance Scattering effect in Linear Polarization (Q/I, U/I 5-10%)

Line-of-Sight Velocity derived from Doppler effect in Intensity

Plasma Density derived from line Intensity Ratio

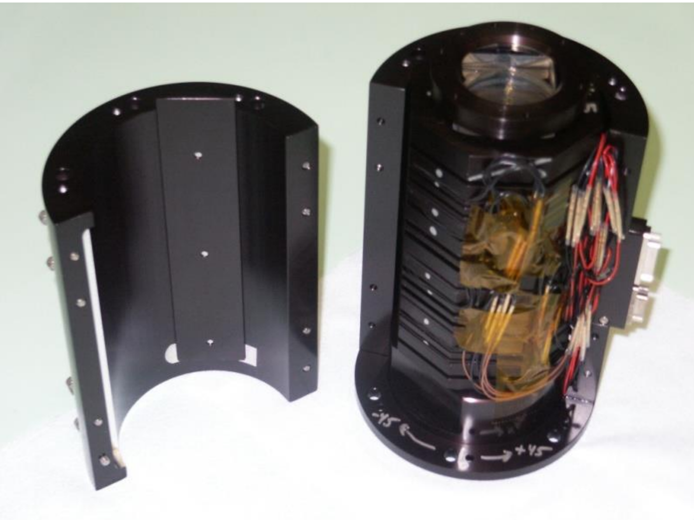
Coronal Multi-channel Polarimeter (CoMP)

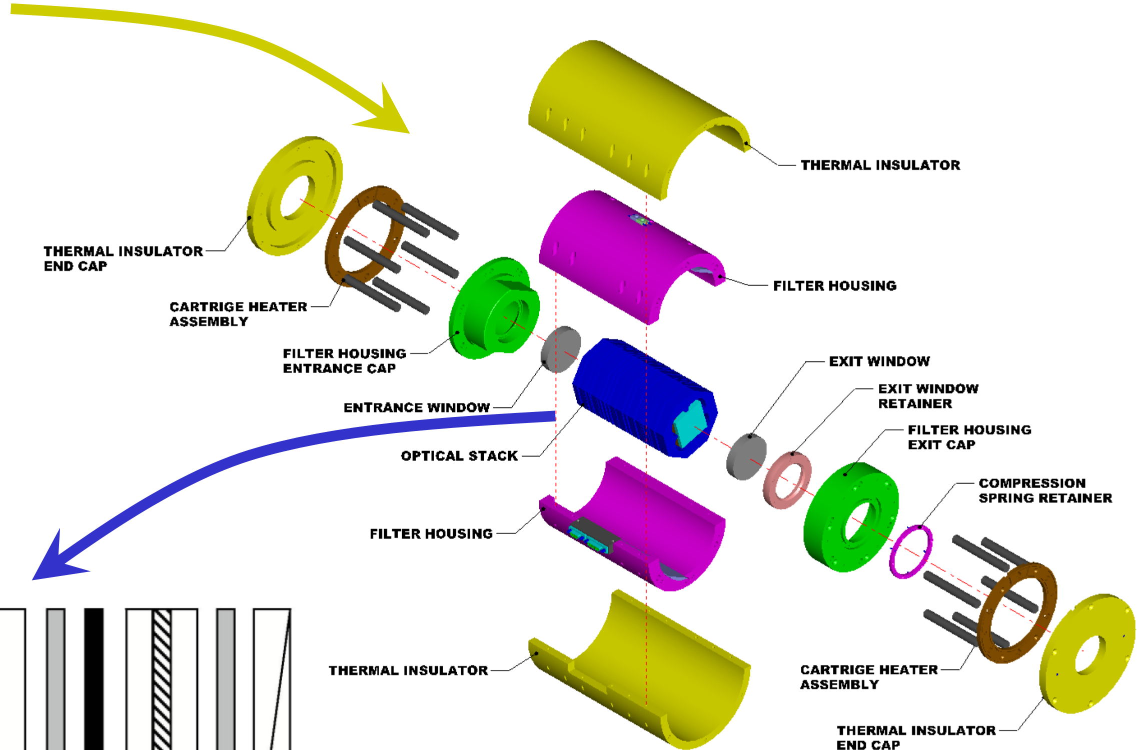
Tunable Filter / Polarimeter
Coronal Magnetograph

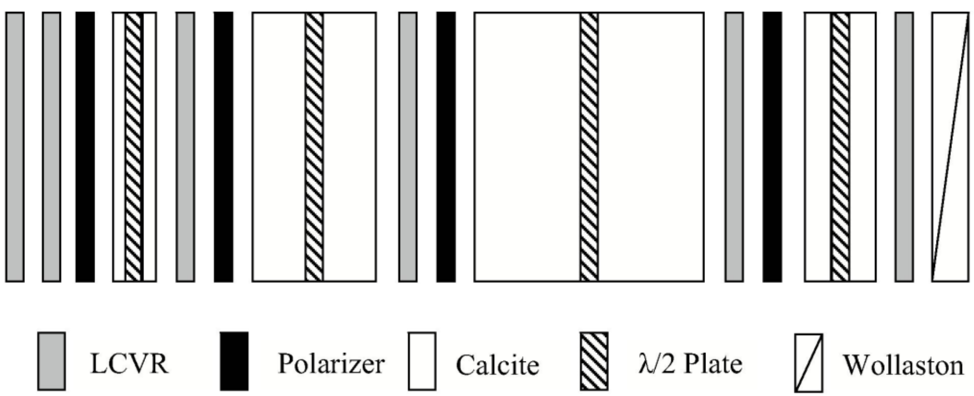


Uses 20 cm OneShot Coronagraph
Originally at NSO Sac Peak
Now at Mauna Loa Solar Obs.

CoMP Filter/Polarimeter







Wollaston Prism for Two Beam Output (line and continuum)

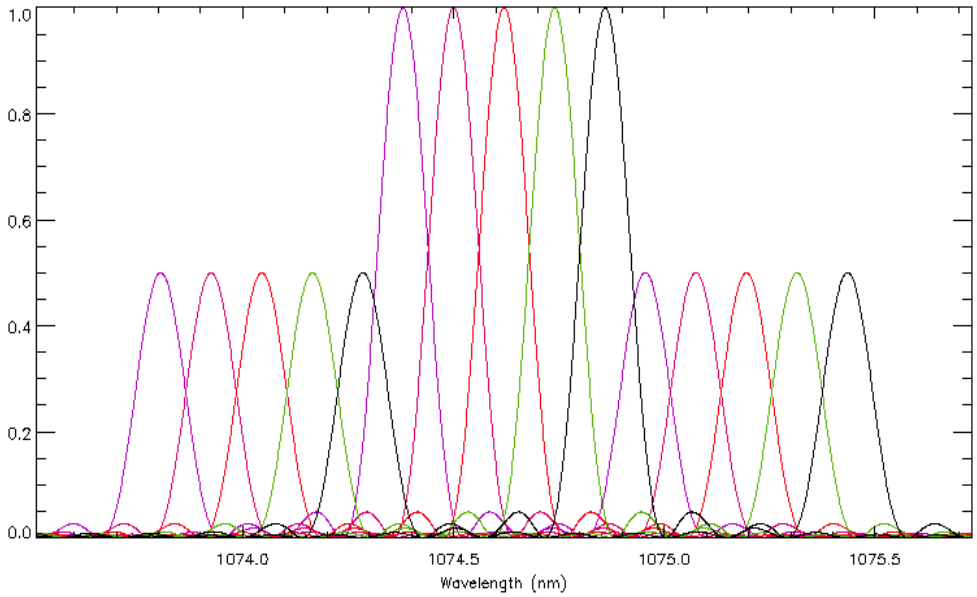
CoMP Filter/Polarimeter

Combination Tunable Filter and Polarimeter

Measures the Complete Polarization State (Stokes I,Q,U,V)

Dual Beam Output Simultaneous Corona and Continuum Images

Bandpass and Polarization State Selected with Liquid Crystals



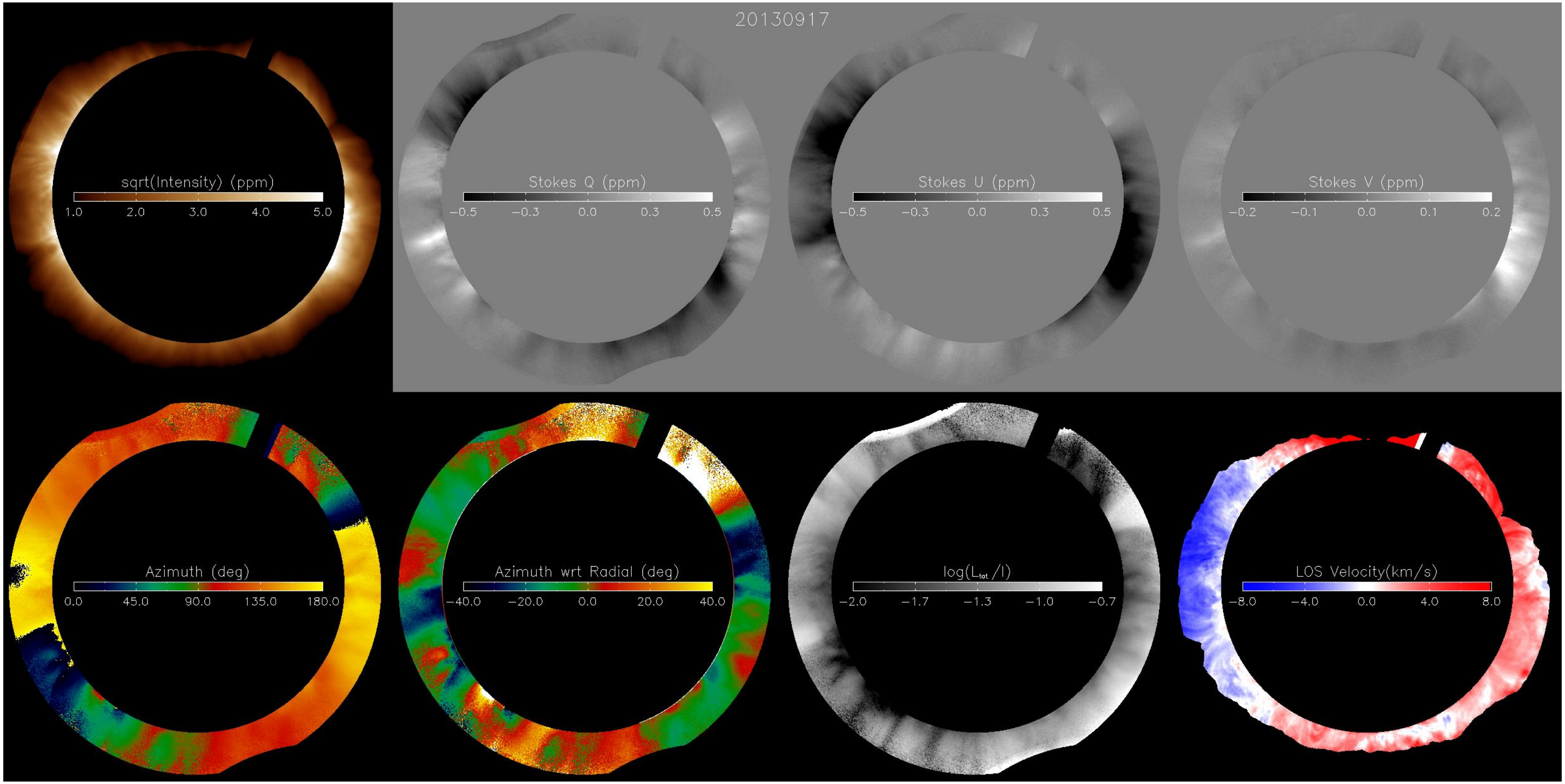
2.8 R_{sun} Full FOV Images

FeXIII 1074.7 and 1079.8 nm, HeI 1083.0 nm

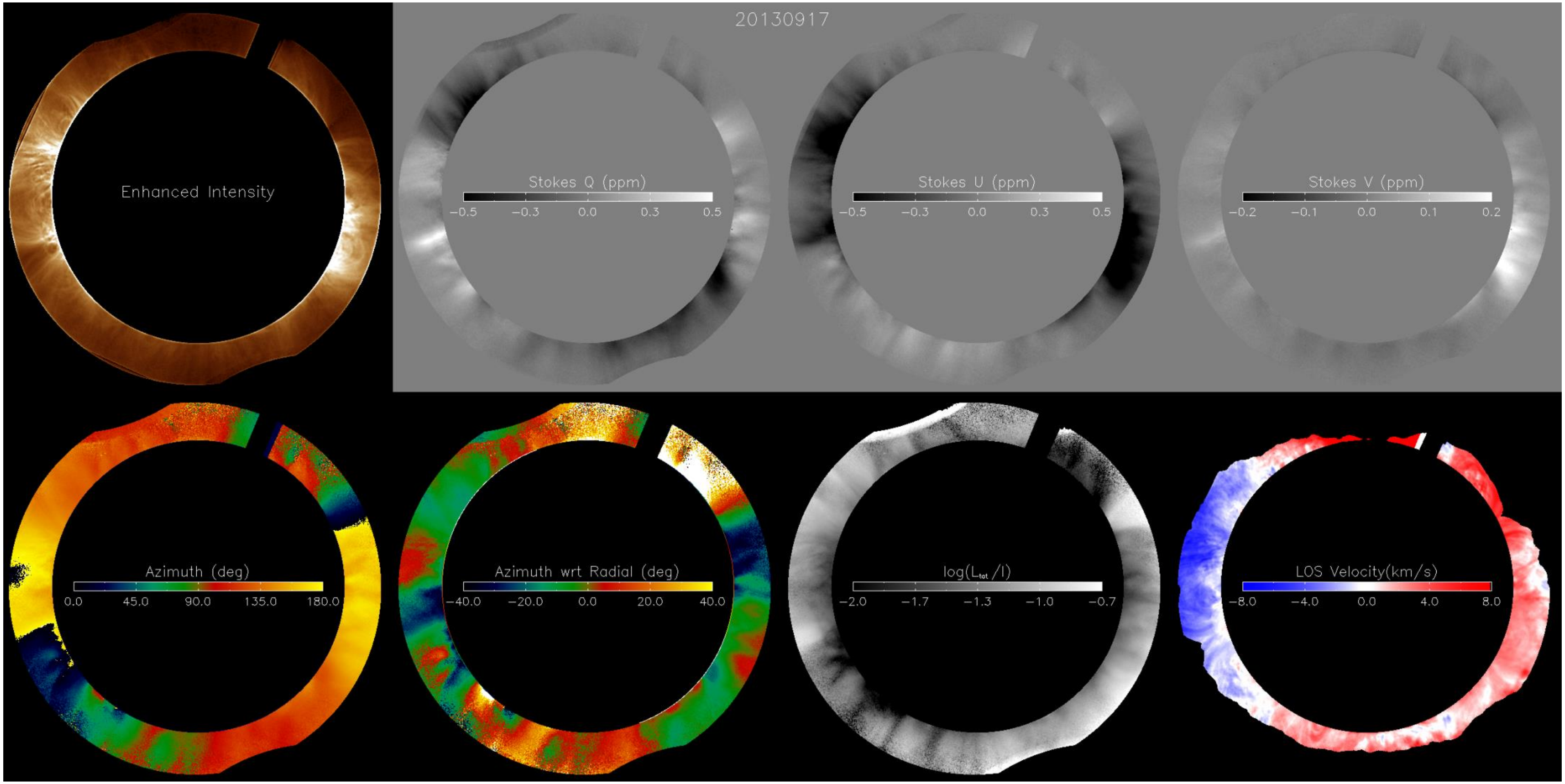
0.14 nm bandpass

4.5 arcsec/pixel

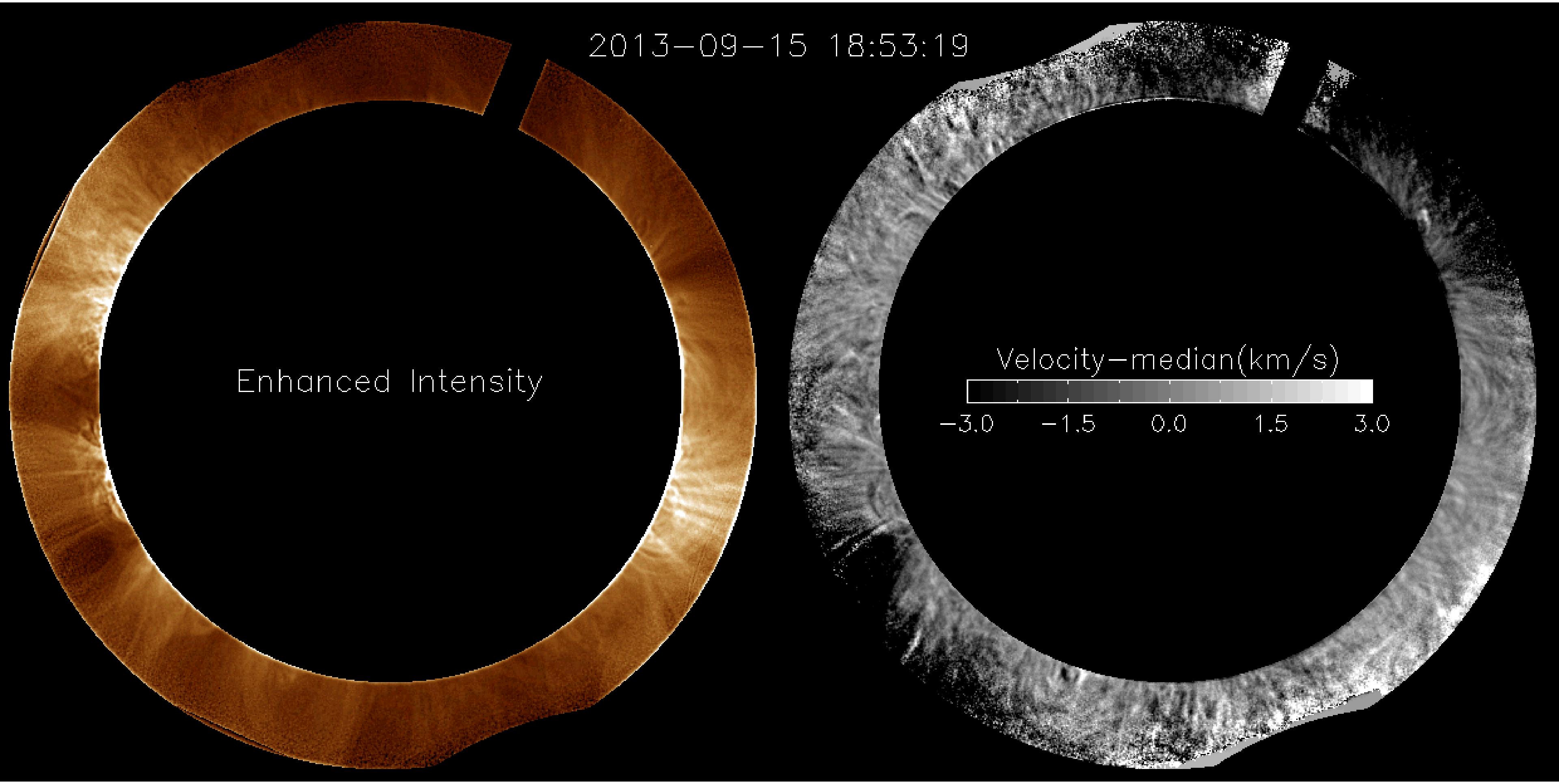
CoMP Measurements



CoMP Measurements



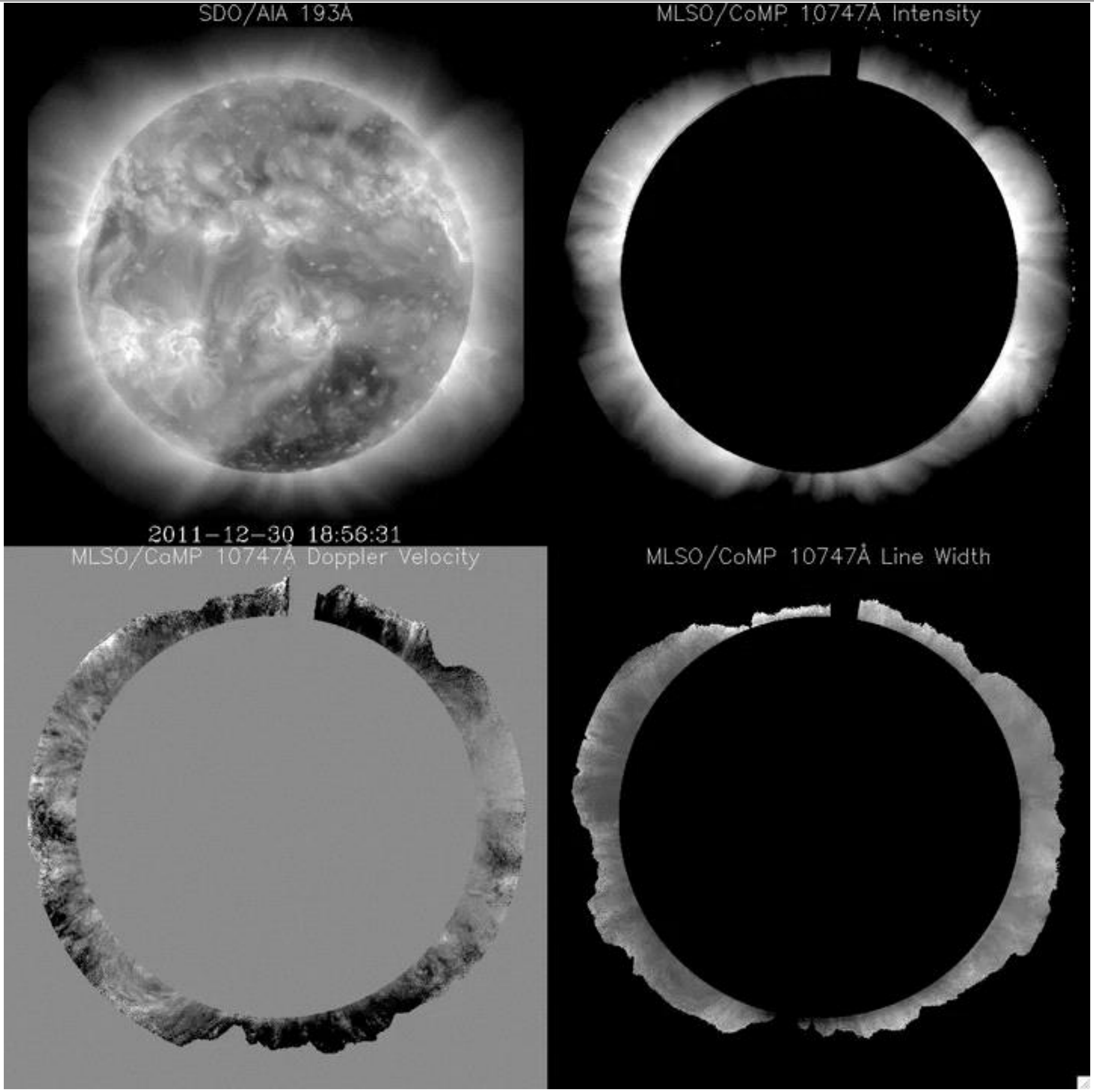
CoMP Observations of Ubiquitous Alfvén Waves

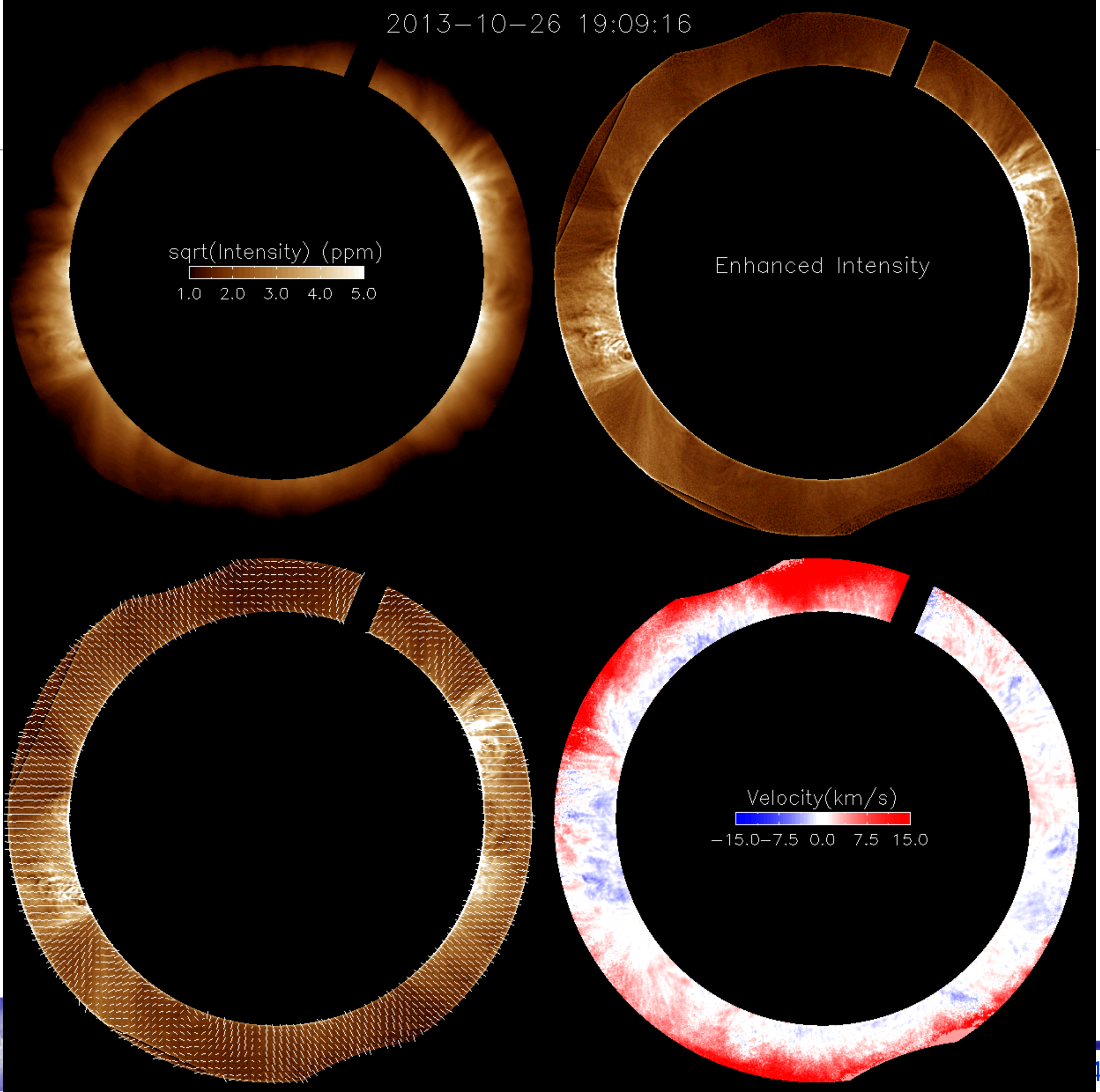


CoMP Observations of Ubiquitous Alfvén Waves

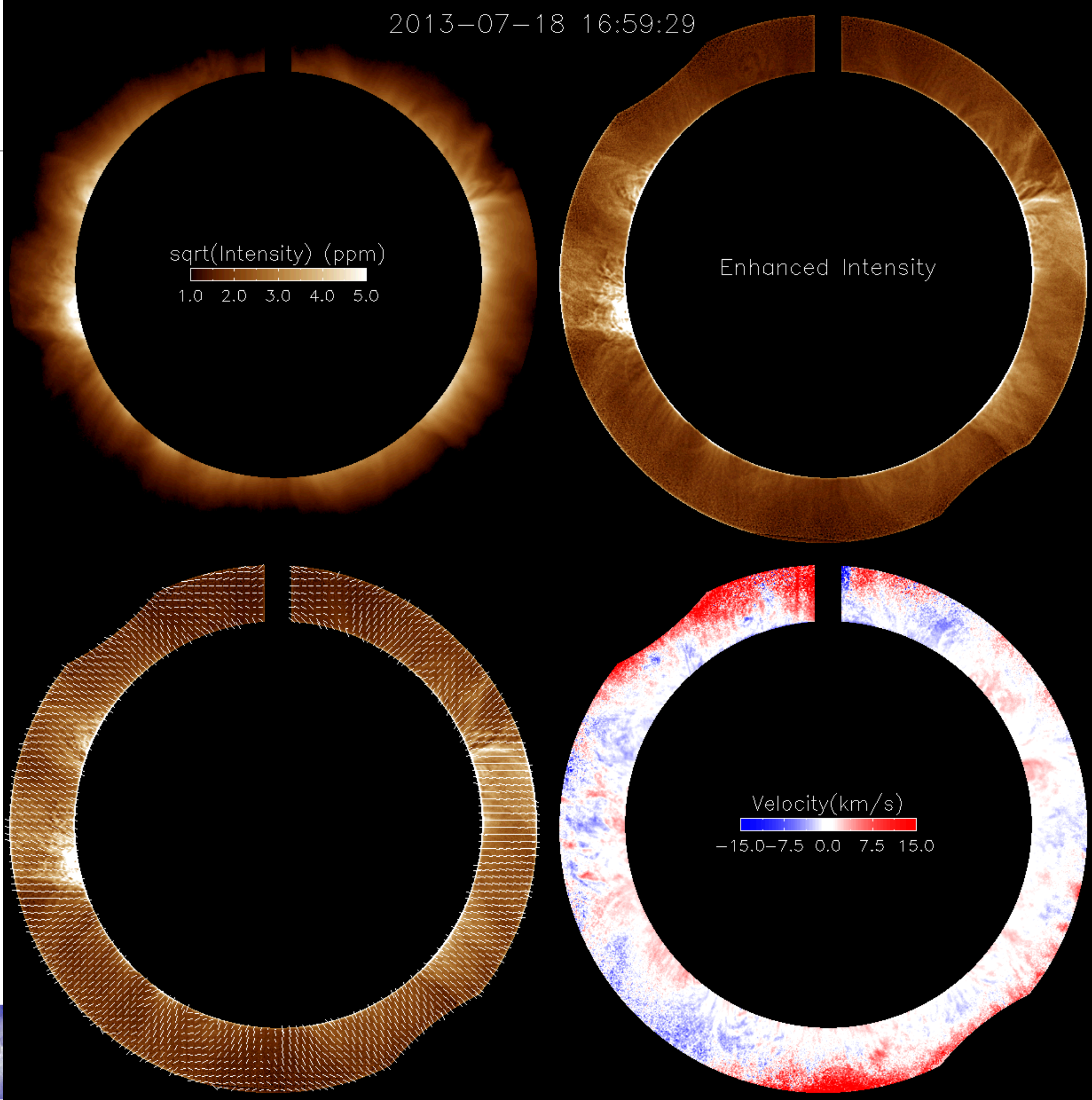
- Wave observations allow determination of coronal magnetic field strength and direction via coronal seismology
- Waves provide complementary information to Zeeman effect
- Zeeman - LOS field strength vs.
- Waves - Transverse field strength
- Combination has potential to provide vector magnetic field

CoMP Observes CMEs

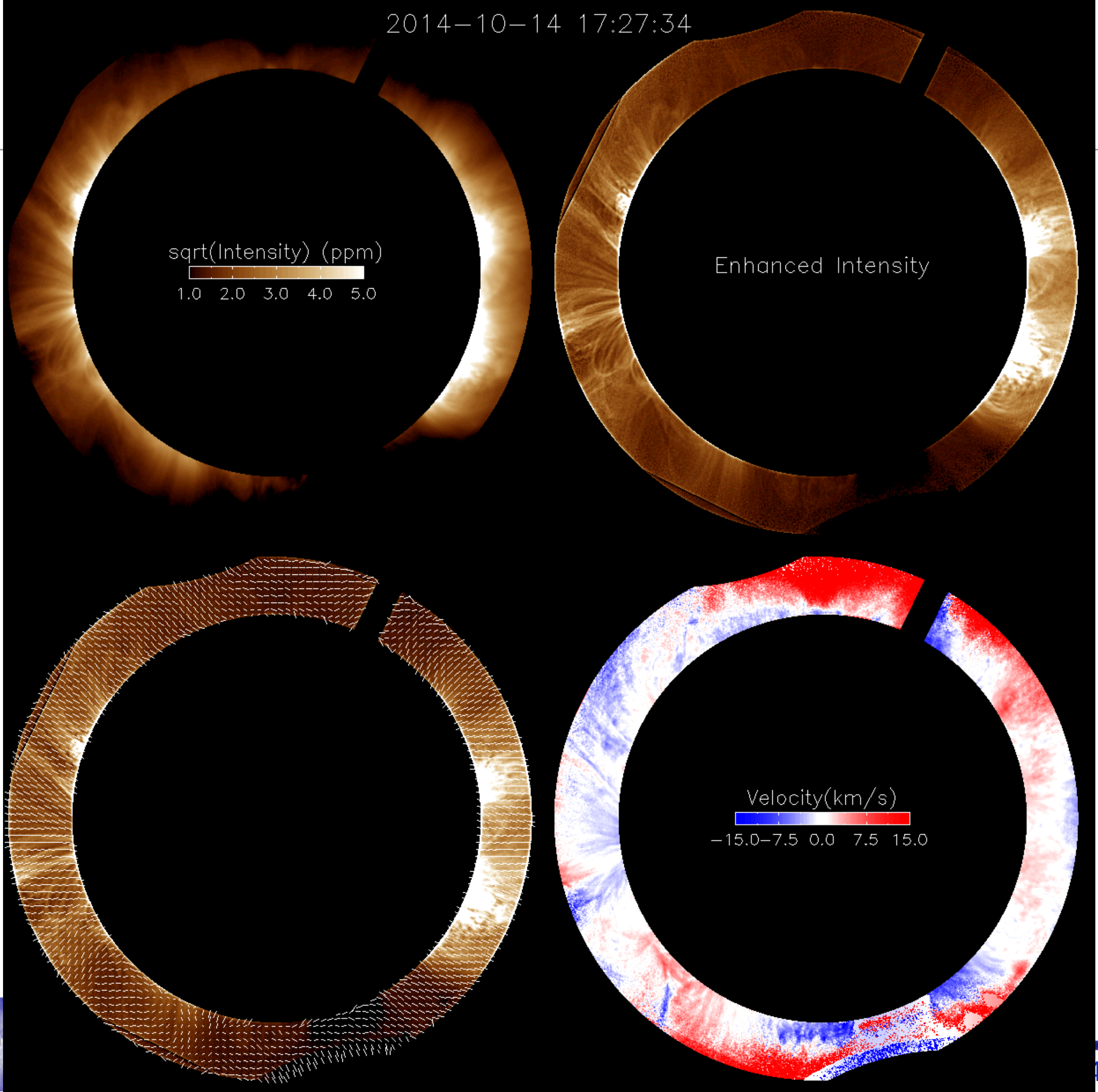




2013−10−26 19:09:16
sqrt(Intensity) (ppm)
1.0 2.0 3.0 4.0 5.0
Enhanced Intensity
Velocity(km/s)
−15.0−7.5 0.0 7.5 15.0



2013−07−18 16:59:29
sqrt(Intensity) (ppm)
1.0 2.0 3.0 4.0 5.0
Enhanced Intensity
Velocity(km/s)
−15.0−7.5 0.0 7.5 15.0


2014–10–14 17:27:34
sqrt(Intensity) (ppm)
1.0 2.0 3.0 4.0 5.0
Enhanced Intensity
Velocity(km/s)
–15.0–7.5 0.0 7.5 15.0

Magnetic Field Noise

Photon limited LOS magnetic field noise is given by:

$$\sigma_B = \frac{k}{\sqrt{I_C}}\left(1+2\frac{I_B}{I_C}\right)^{\frac{1}{2}}$$

k ~ 8500 G for 1074.7 nm FeXIII line

I_B, I_C = photons in background, corona

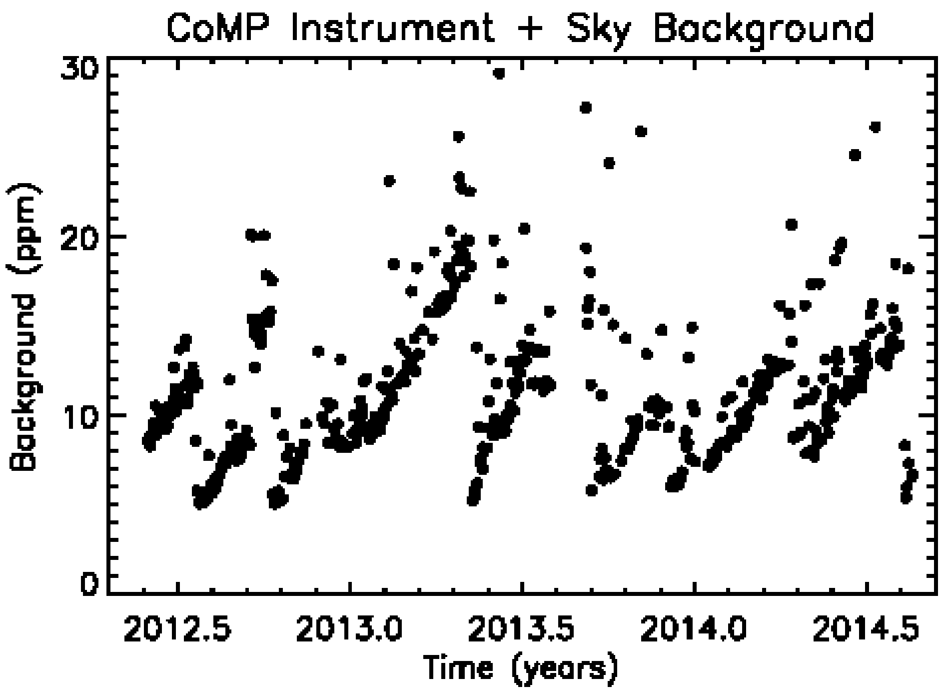
Other noise sources: polarimeter efficiency, seeing induced polarization, dark and flat noise.

Systematic errors are important

CoMP observes 3500 photons s^{-1} ppm^{-1}

Other considerations: V signal is in wings, duty cycle limited

Limitations of Small Ground-based Telescopes



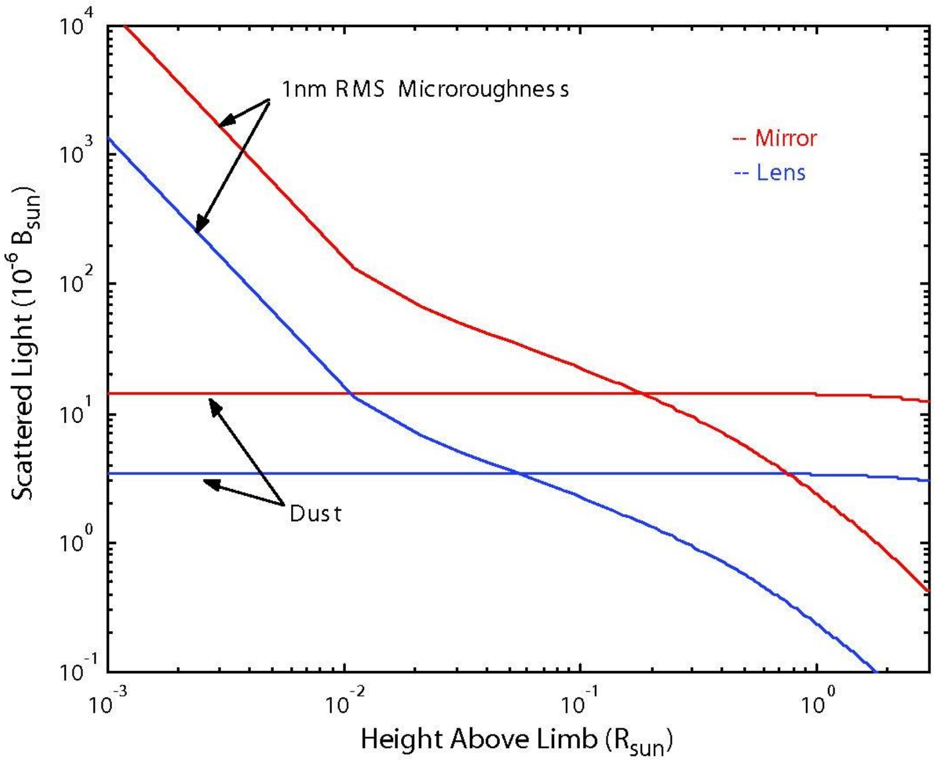
Often, the sky conditions and number of available hours will not allow meaningful measurements of B on any given day.

Ground-based coronal B measurements are not routine, especially with a 20 cm aperture telescope

COSMO LC Design Drivers

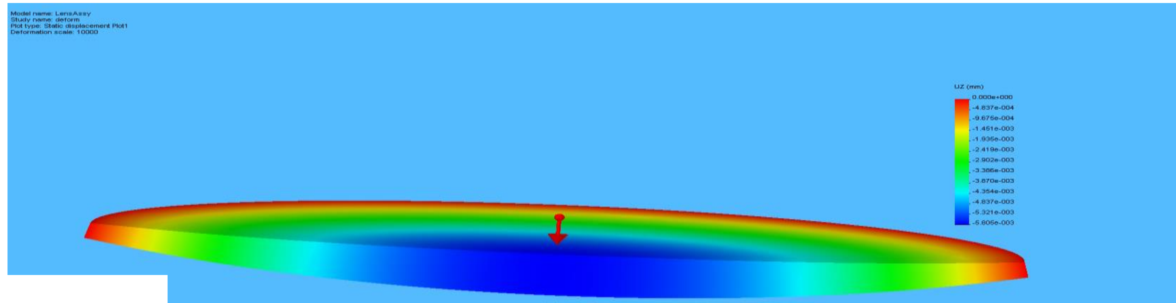
- Large aperture
  - Need to collect photons (V/I ~ 10^{-4} / Gauss)
- Low scattered light
  - Lens better than mirror (microroughness and dust)
- High efficiency - no reflections
  - ATST 10, EST 14 reflections before coude instruments
- Symmetrical on-axis optical system - Makes polarimetry easier
- Large Field-of-View - Coronal structures are large - aberrations are easier to control with a lens than a mirror
- Pressurized Dome Design
  - HEPA filtering - maintain cleanliness

What Kind of Coronagraph?

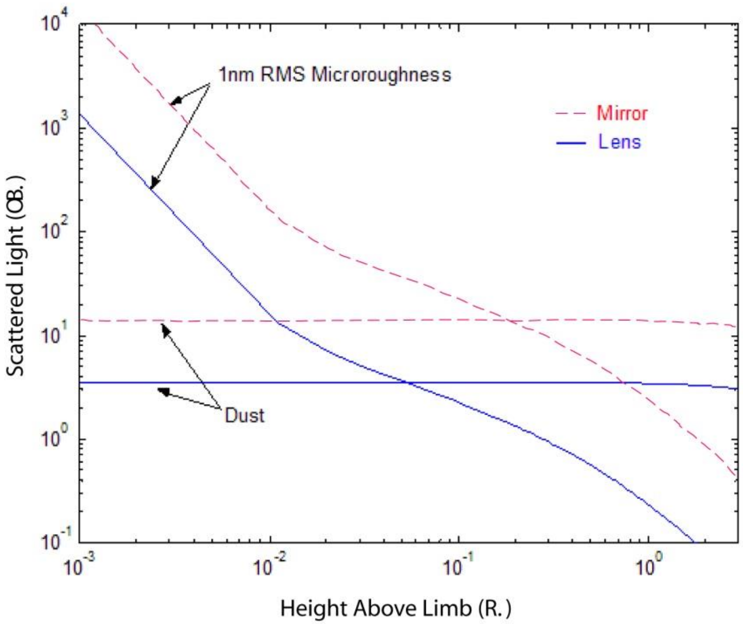


Lens has much less scattering than mirror
10x less from microroughness, 4x less from dust
Can achieve 1º FOV easier with lens (asphere)

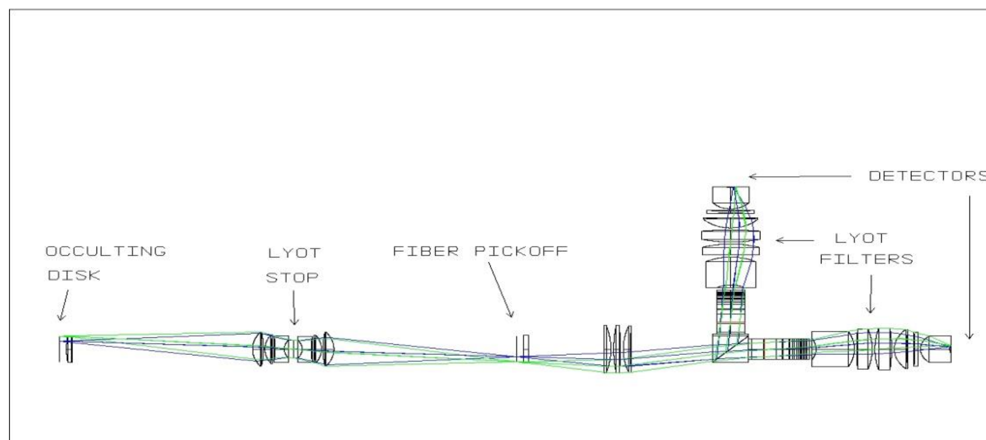
Conclusion: 1.5-m Refracting Coronagraph



Finite Element Analysis of Lens

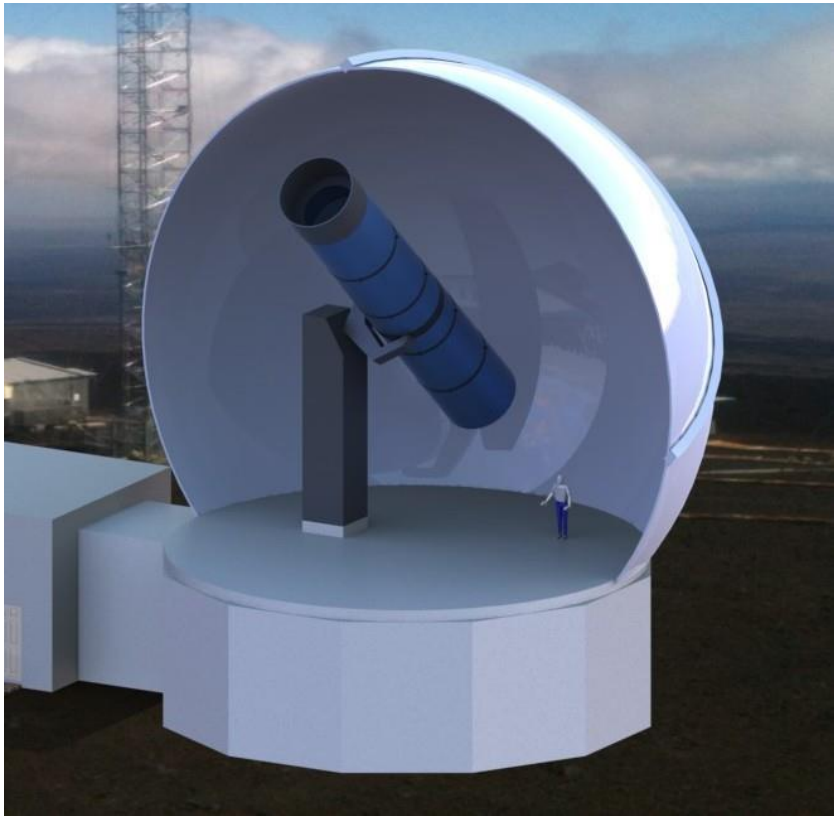


Scattered Light Analysis



Optical Design

COSMO Large Coronagraph



1.5 m refractive coronagraph

1º field-of-view

Low scattered light

Synoptic operation

Will obtain measurements of Coronal B with 1 Gauss precision in 10 minutes, 5 arcsecond spatial resolution

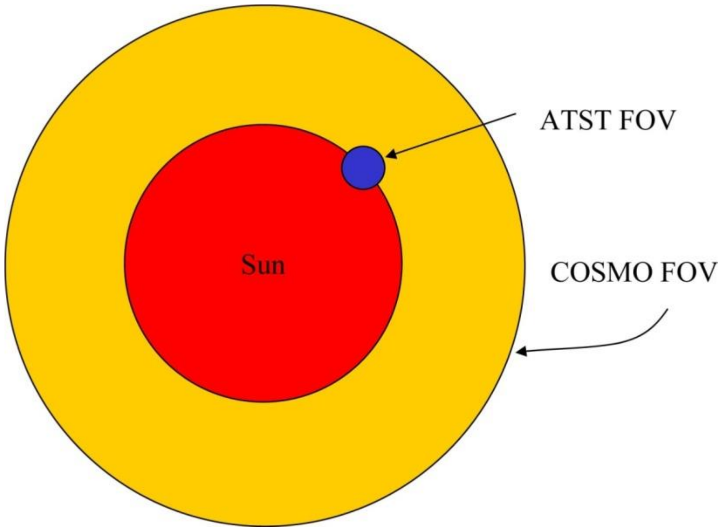
Would be the largest refracting telescope in the world, $25M

COSMO is Complementary to the DKIST

$$\sigma_B \propto \frac{\sqrt{background}}{\sqrt{time} \cdot telescope\,aperture}$$

ATST: $I_B = 25$ µB
COSMO: $I_B = 5$ µB

ATST aperture advantage is mitigated by better scattering of COSMO



Solid angle FOV_{COSMO}/FOV_{ATST} ~100

The COSMO coronagraph will have a light gathering power (étendue) that exceeds that of the ATST by a factor of 15.

COSMO LC is Complementary

There is currently many ground-based solar telescopes under construction or development:

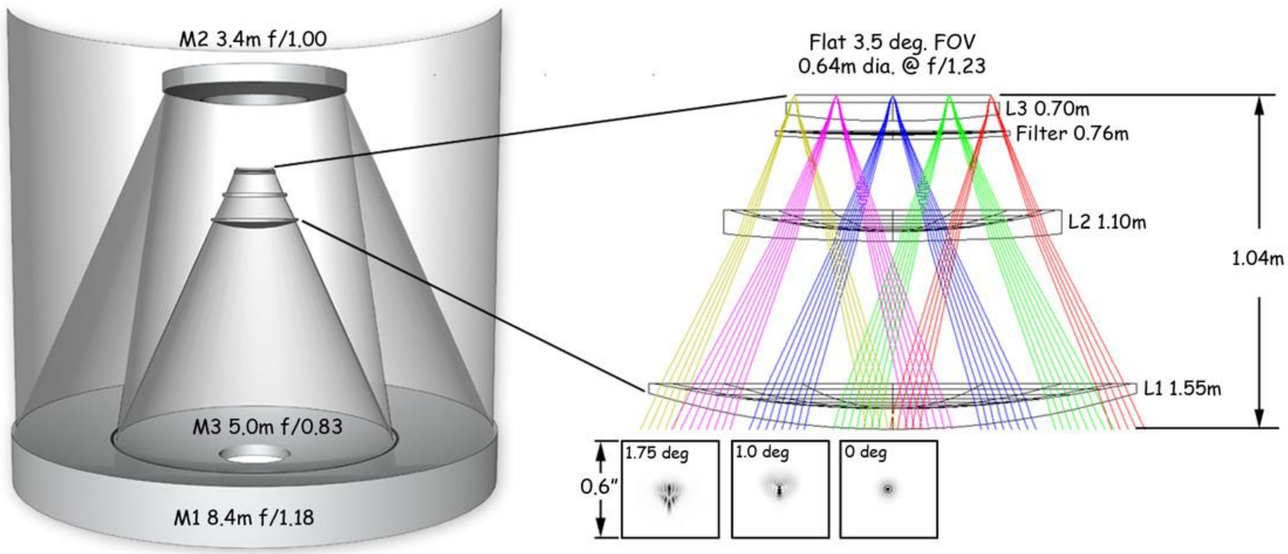
- 8-m CGST (China)
- 4-m ATST (USA)
- 4-m EST (Europe)
- 2-m NLST (India)
- 1.6-m NST (USA)
- 1.5-m GREGOR (Germany)
- 1-m Yunnan (China)
- 0.5-m MAST (India)

These telescopes are optimized for high spatial resolution science

COSMO LC is unique and complementary

Large Synoptic Survey Telescope

LSST has unique combination of aperture and FOV → Étendue
light collecting power = collecting area x solid angle FOV = 319 m^2 deg^2



LSST will have a 1.6 m diameter lens and a 1.1 m lens!

COSMO LC Status

- COSMO Large Coronagraph Conceptual Design,
  Feasibility Study Complete
- COSMO Now an International Project
  US/China Collaboration on Design Development
- COSMO Endorsed by US 2012 Heliophysics Decadal Survey!
- Preliminary Design Review – Feb 2015
- Proposals for Construction

CoMP Data Available at MLSO website

http://mlso.hao.ucar.edu/