A Large Coronagraph for Solar Coronal Magnetic Field Measurements

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Motivation

Our vulnerability to solar activity is increasing

- Manned Space Flight
- Power Grids
- Communications
- GPS Navigation
Motivation

The corona is a magnetically dominated system
Coronal magnetism is the source of Space Weather

- Coronal Mass Ejections
- Energetic Particle Acceleration
- Coronal Heating
- Solar Wind Acceleration

Are not understood and will remain so until we are able to obtain routine measurements of coronal magnetic fields
Coronal Magnetic Field Measurements

Gyroresonant Emission: Radio observations (B > 250 G)
(Kundu, Schmahl, Gerassimenko 1980)

Hanle Effect: EUV emission lines (O VI 103.2 nm)
(Sahal-Bréchot et al. 1986)

Longitudinal Zeeman Effect: Vis, IR emission lines (Line-of-Sight B)
(Harvey 1968; Lin, Penn and Tomczyk 2000)

Resonance Scattering: Vis, IR emission lines (Plane-of-Sky Direction)
(KELP Instrument: Querfeld and Smartt 1984)

Few Measurements Exist
Coronal Magnetometry

Judge et al. (NCAR Tech Note 446, 2001): Visible/IR magnetometry most promising. FeXIII has the best expected S/N for Zeeman measurement based on line intensity, magnetic sensitivity and sky background levels.

<table>
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<tr>
<th>Ion</th>
<th>λ ((\mu m))</th>
<th>Log I (erg cm(^{-2}) s(^{-1}) sr(^{-1}))</th>
<th>Figure of merit (max s/n ((V)))</th>
<th>Max V/I</th>
<th>Log (T_e)</th>
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Coronal Magnetic Field Measurements

- Corona is $10^5 - 10^6$ times fainter than photosphere
  Scattered light is 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, $\sim 1^\circ$

Very Difficult Measurement
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
Heritage

- Harvey (1968) – coronal V measurement
- KELP Instrument (Querfeld 1974) 1074 nm linear polarization only
- Solar-C/OFIS (Lin et al., 2000, 2004) 1074nm linear and circular
- CoMP (Tomczyk et al. 2008) 1074nm linear and circular
COSMO (COronal Solar Magnetism Observatory) is a proposed facility dedicated to synoptically studying solar magnetic fields and their role in driving solar activity such as coronal mass ejections. It comprises:

- 1.5 m Aperture Coronagraph (Corona)
- Disk Imager / Polarimeter - ChroMag (Chromosphere/Photosphere)
- K-coronagraph (CME)

1.5-m coronagraph pictured here
COSMO LC Design Drivers

- Large aperture
  - Need to collect photons ($V/I \sim 10^{-4} / \text{Gauss}$)
- Low scattered light
- High efficiency
  - No reflections - ATST 10, EST 14 reflections to coude
- High polarimetric precision
  - Symmetrical on-axis optical system
- Large field-of-View
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

Is preferred
And is feasible

Finite Element Analysis of Lens

Scattered Light Analysis

Optical Design

Steven Tomczyk
COSMO
1 December 2014
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 Highly Complementary

Most existing and planned solar telescopes have small FOV, and will observe at high spatial resolution and are not synoptic.

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

There are currently many ground-based solar telescopes recently constructed, under construction or proposed:

- 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
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 2012 Heliophysics Decadal Survey
- Preliminary Design Review – Feb 2014
- Proposals for Construction