Coronal Observations at MLSO and their Importance for Space Weather

G. de Toma and the MLSO and COSMO teams

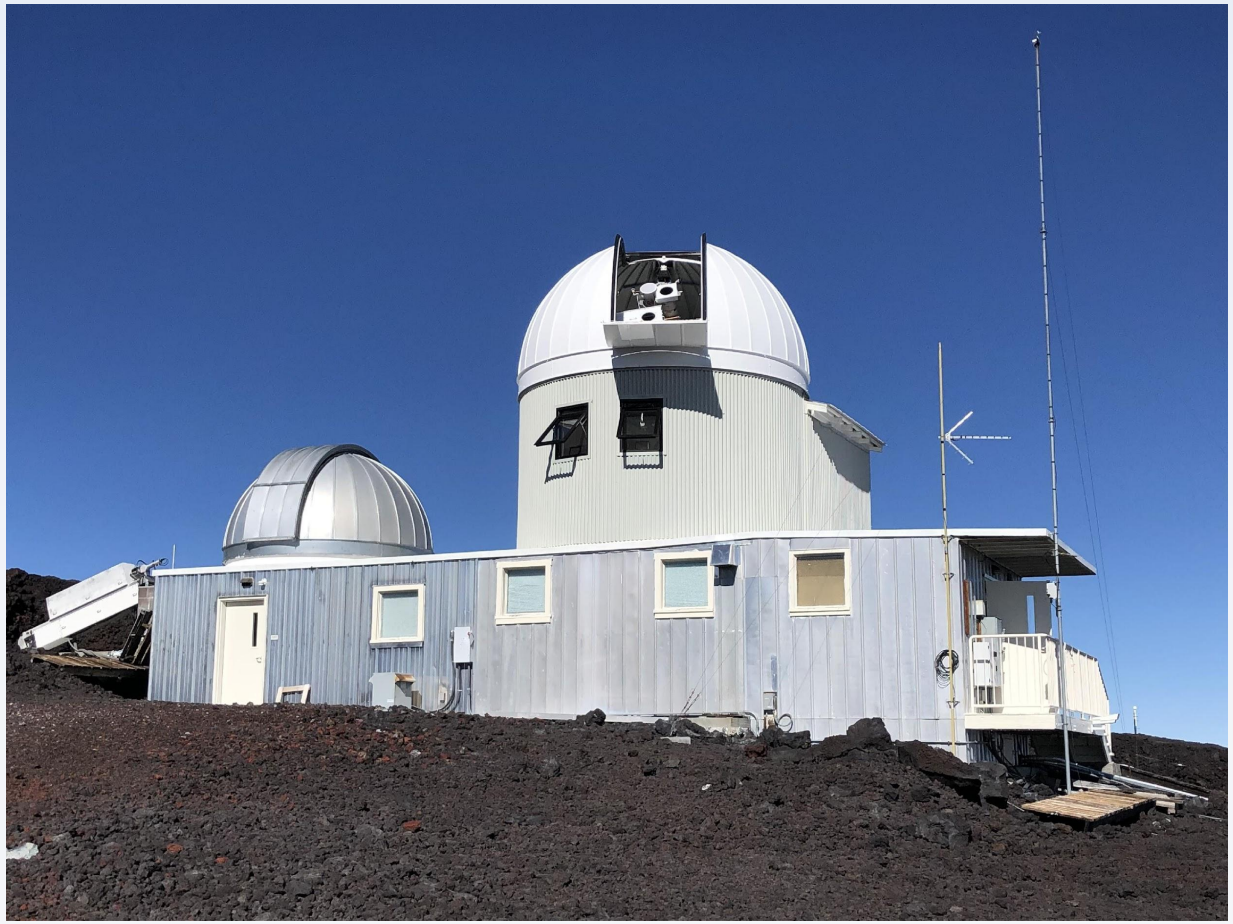
2025 Community Space Weather Modeling and Data Assimilation Workshop

Ground-based instruments are key to developing and testing innovative technology

MLSO instruments: K-Cor and UCoMP coronagraphs
+ ChroMag (under testing in Boulder)

Future facilities: COSMO
network of coronagraphs
space opportunities

Mauna Loa Solar Observatory (MLSO)



NSF/NCAR facility to observe
the solar corona

located in the Big Island of Hawaii
on the flank of the Mauna Loa mountain
at 3394m elevation

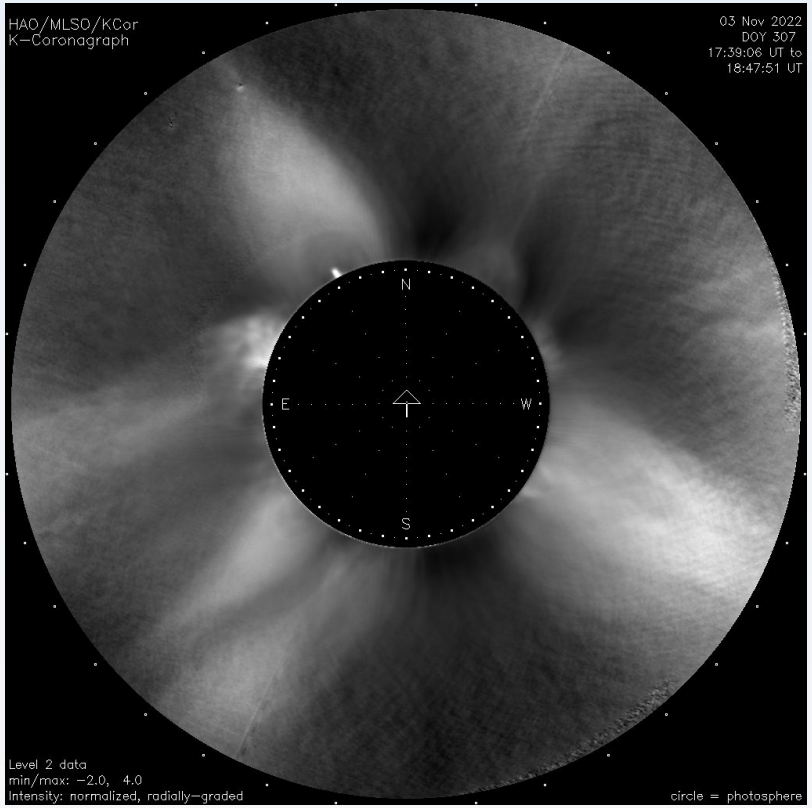
dark sky/high altitude
dry conditions
low dust/aerosols
clear sky
stable atmosphere/low turbulence

K-Cor (COSMO K-coronagraph)

J. Burkepile et al.

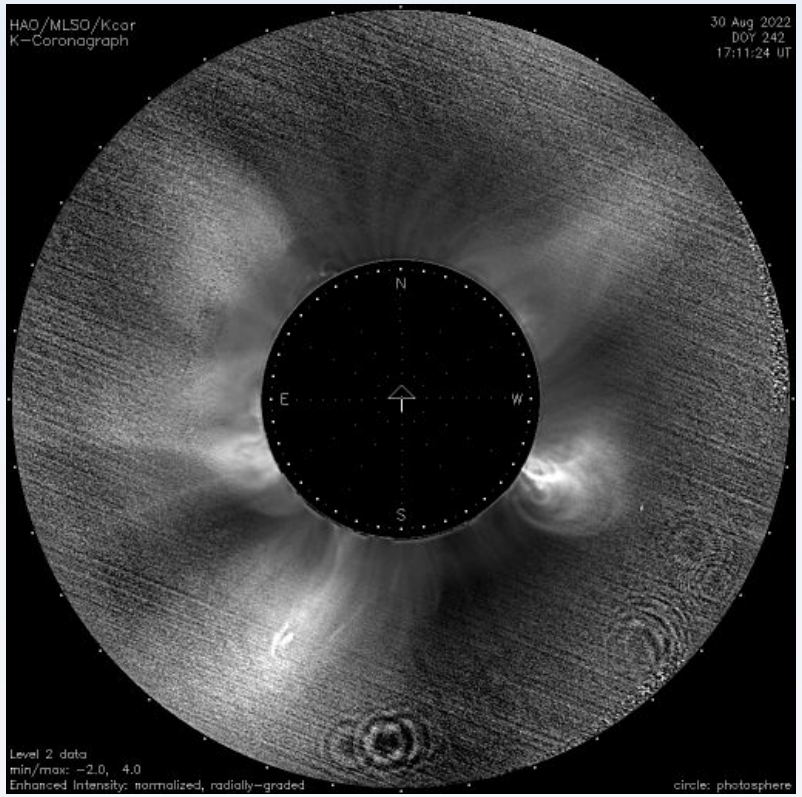
designed to observe the formation and acceleration of CMEs

near IR broad-band filter (720-750nm)
observable: polarization brightness (pB)
fov: 1.05-3 solar radii
spatial resolution: 5.5arcsec/pixel
cadence: 15s
data latency: ~2.5m



K-Cor CME observations

Aug 8 2022



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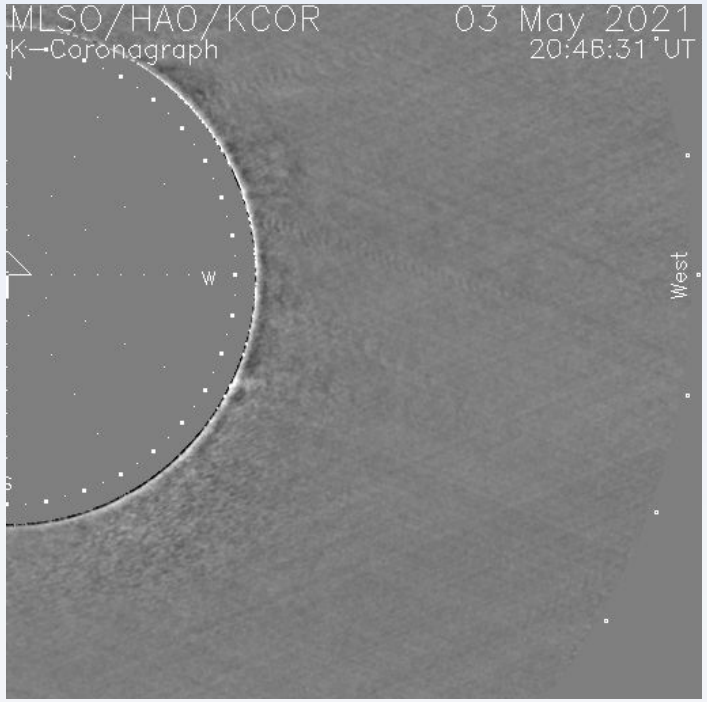
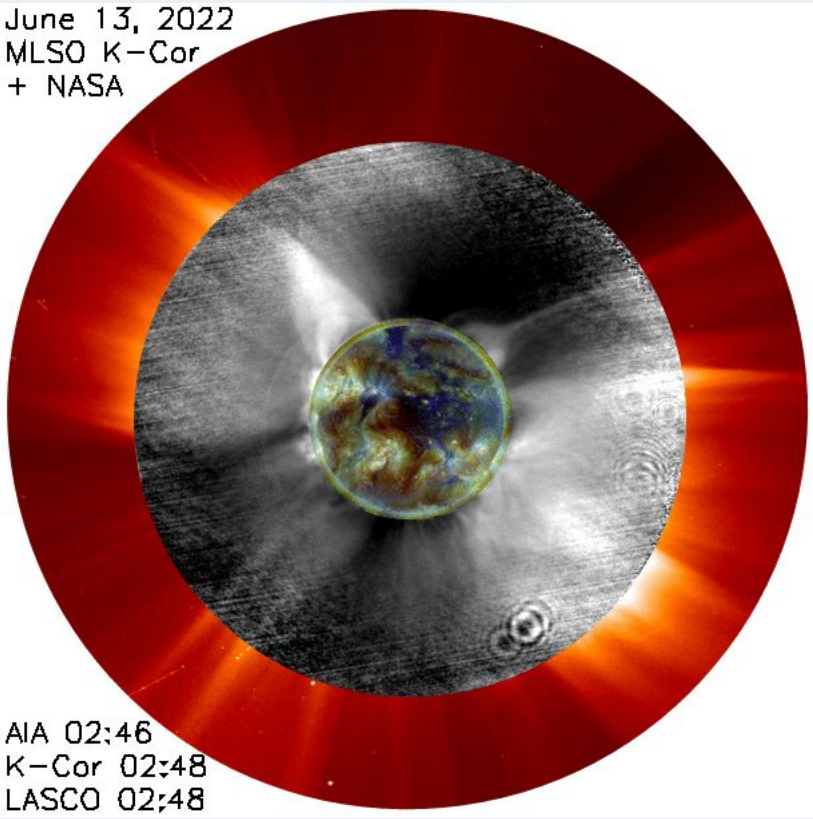


difference movie

June 12-13 2013



K-Cor CME/SEP automatic alerts

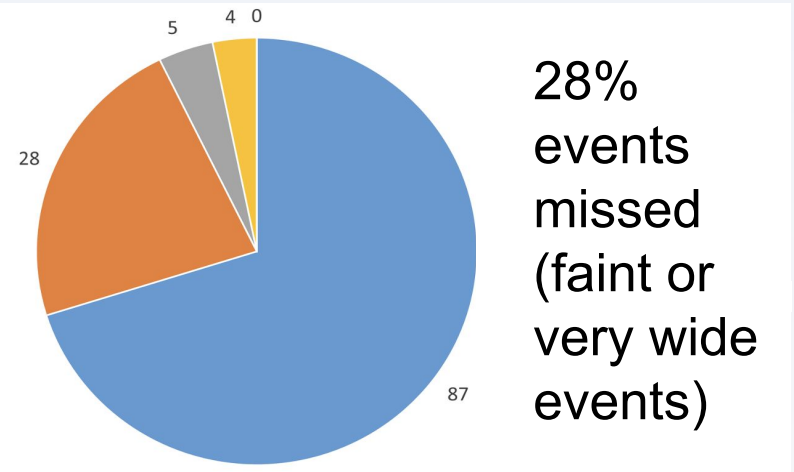
K-Cor data is fully processed within 2.5m of acquisition by an automated data pipeline

CME detection algorithm developed by B. Thompson based on the Solar Eruptive Event Detection System (SEEDS) software runs in real time, gives time, height, and speed of CME

K-Cor alerts go out before the CME is seen by LASCO 78% of the time

on average, K-Cor alerts are available 55m before LASCO images are available to forecasters

	cadence	inner fov	data latency
K-Cor	15s	~1.05Rsun	2.5m
LASCO	12m	~2.1Rsun	>40m
CCOR	15m	>3.6Rsun	15-30m



Ground-based Network of Coronagraphs

heritage: GONG magnetograph network

advantages:

- high duty cycle
- low latency data for operational SW
  e.g. near real time CME/SEP alerts
- low cost compared to space missions
- long lifetime
- upgradable
- improved CMEs coverage
- improved, no data gaps, science products
  (synoptic maps, rotational tomography)

challenges:

- ~5-6 coronal sites for 24/7 coverage
  (site survey for COSMO,
  international collaborations)
- capability to operate autonomously
  in remote locations
  (solar power, robotic operation without
  constant human supervision, etc.)

COSMO site survey

S. Gibson, M. Wiltberger, R. Casini, S. Sewell, D. Farrell et al.

location	altitude	longitude
MLSO	3400m	155.6W
Cerro Tololo, CHILE	2200m	70.8W
Felix Aguilar, Argentina	2400m	69.3W
Magdalena Ridge, NM	3200m	107.2W
Barcroft Station, CA	3800m	118.2W
El Teide, Canary Islands	2400m	16.6W
Pic du Midi, France	2900m	0.1E
Lomnicky Stit, Slovakia	2600m	47.4E
Concordia Station, Antartica	3300m	123.3E

COSMO site survey studied 6 possible coronal sites in the Western hemisphere

Coronal network needs suitable sites in the Asia pacific area

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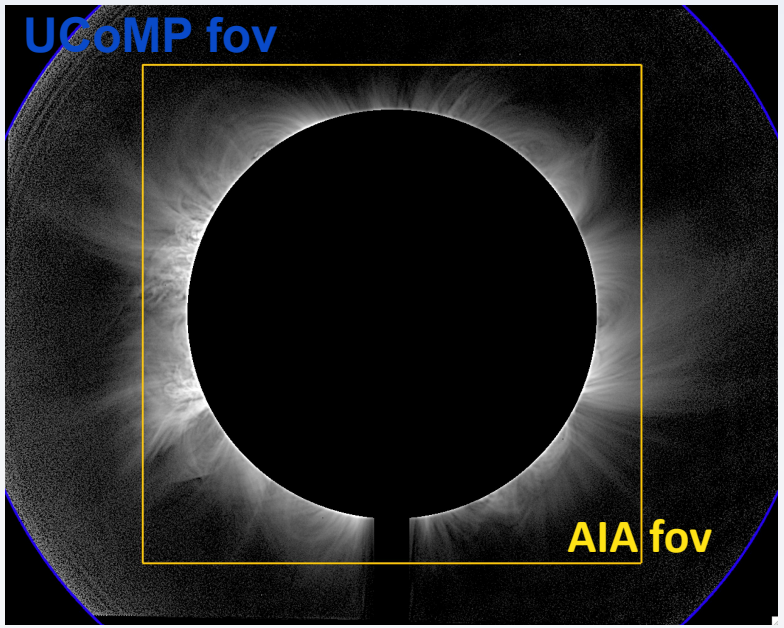
UCoMP (Updated Coronal Multichannel Polarimeter)

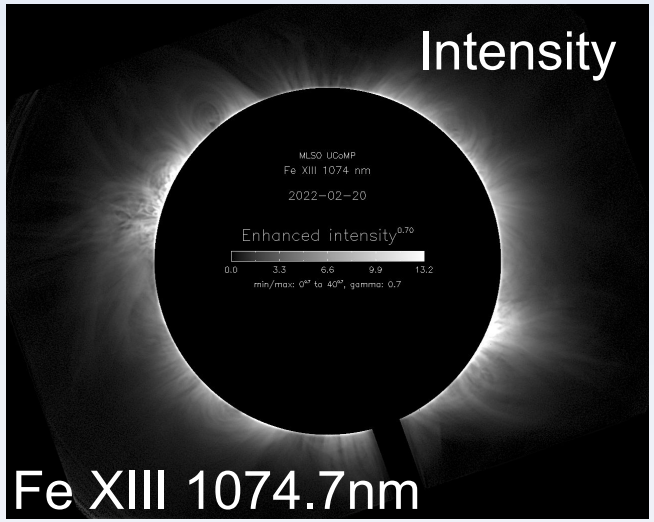
S. Tomczyck, E. Landi et al.

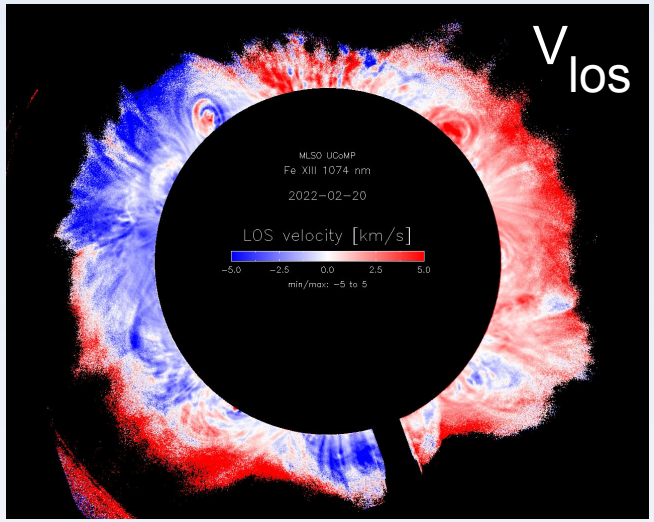
imager spectro-polarimeter designed to measure the plasma and magnetic properties of the solar corona

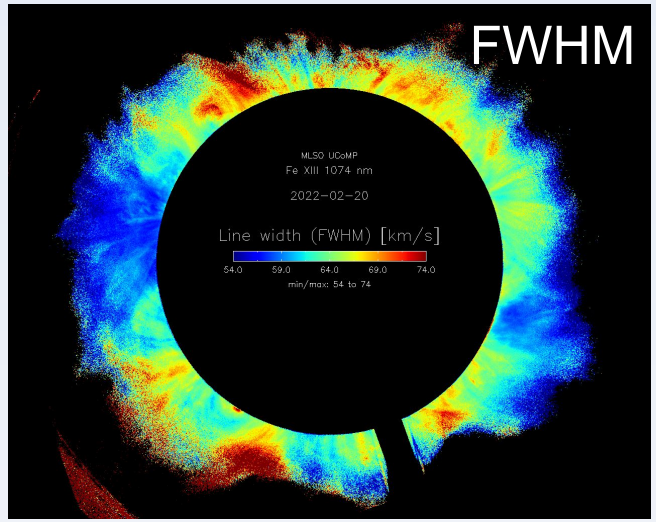
visible/near IR tunable filter (530-1083nm)
fov: 1.03-2.1 solar radii
spatial resolution: ~3arcsec/pixel
cadence: 30s – 2.5m
observables: Stokes I, Q, U, V
science products: intensity, line width, $V_{los,}$ N_e
B_{pos} direction



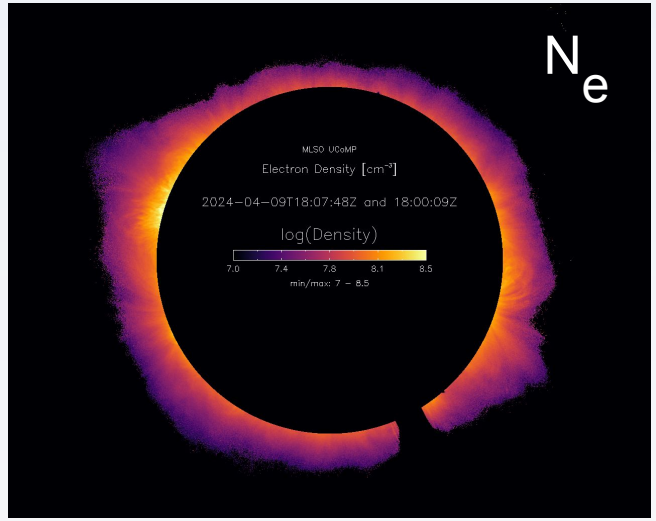
UCoMP science products (spectroscopy)





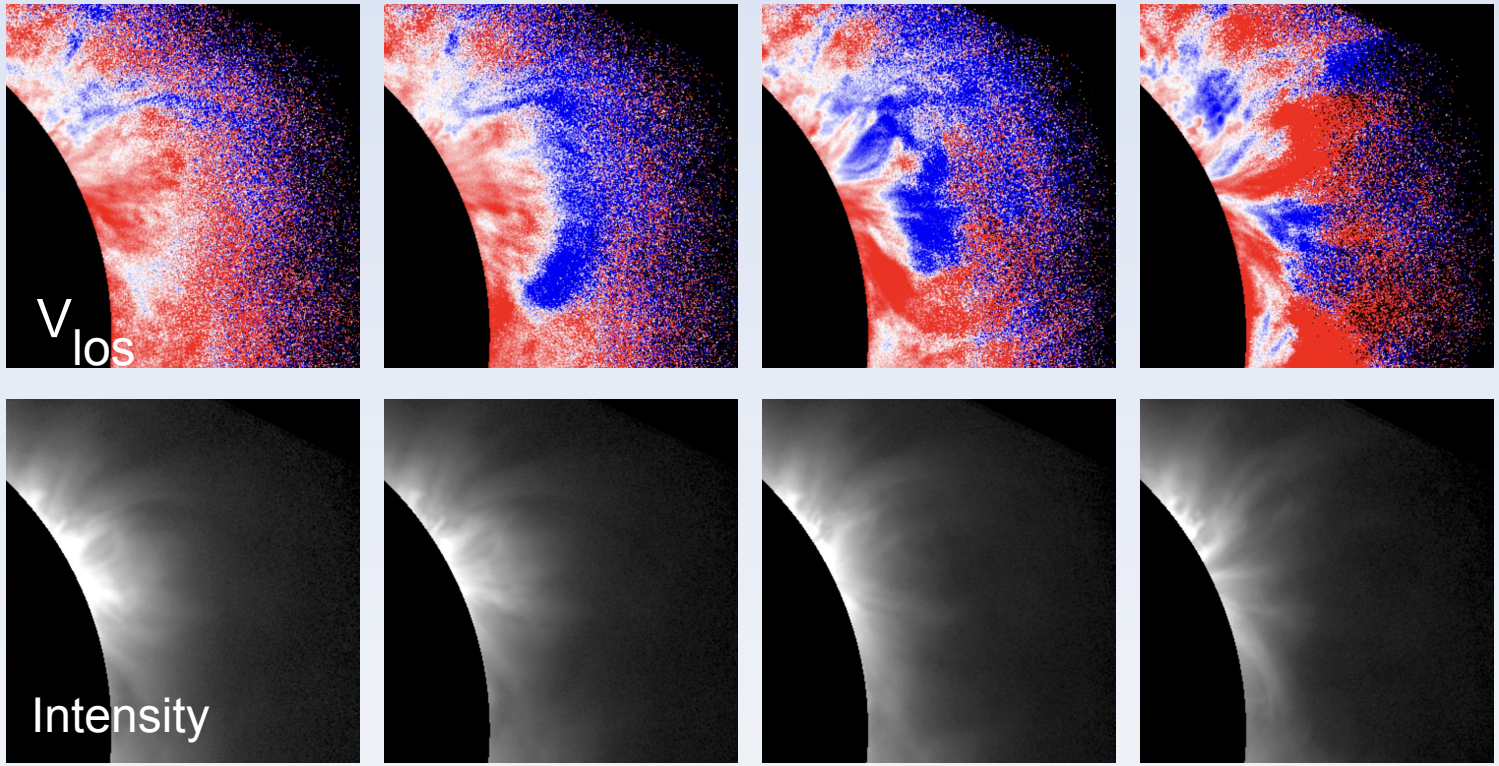


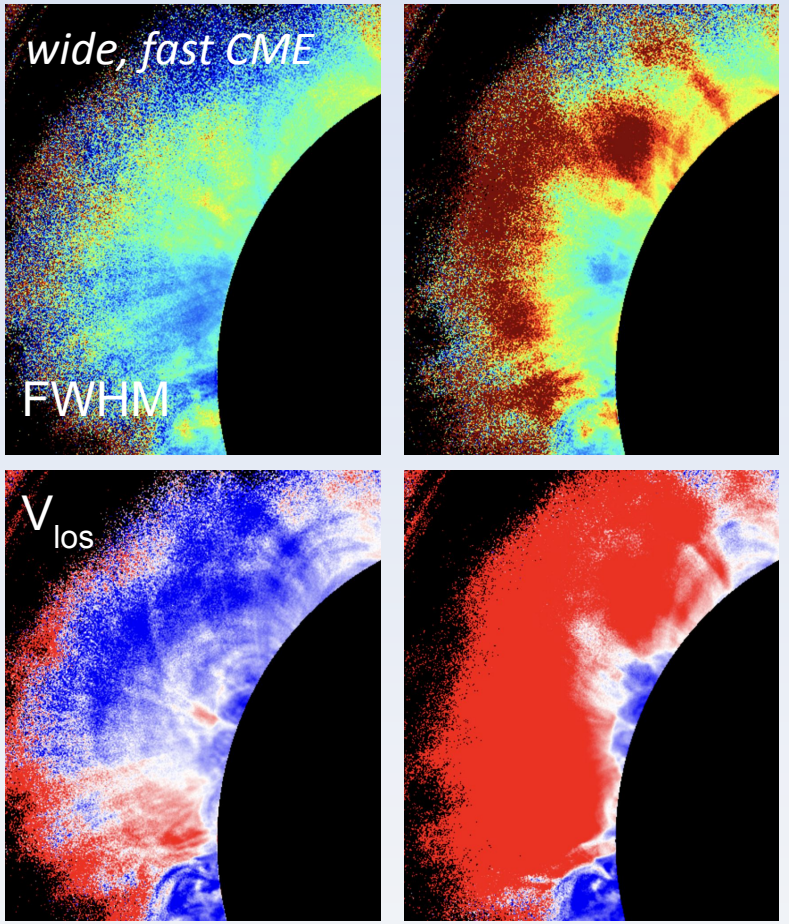
multi-wavelengths instrument
can scan the emission lines and measure:
- intensity,
- line-of-sight velocity and line width,
- density and temperature from line ratios



density
from
Fe XIII
line ratio:
1074.7nm
1079.8nm

UCoMP CME observations

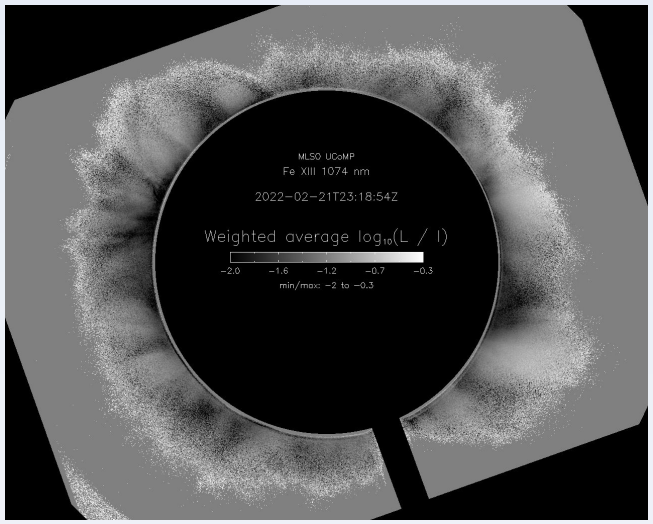


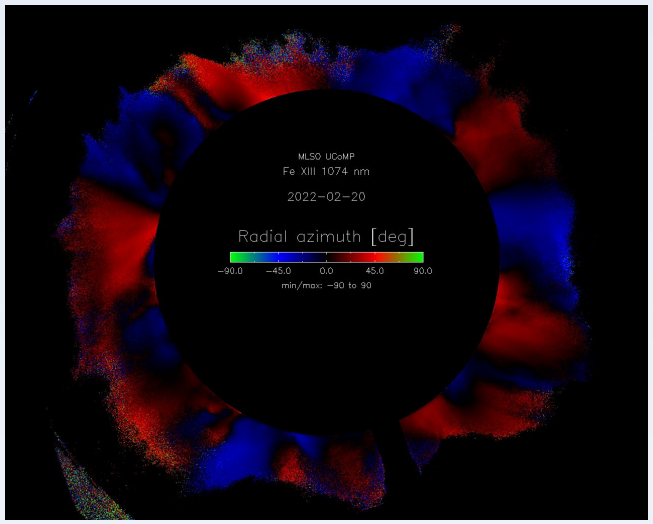


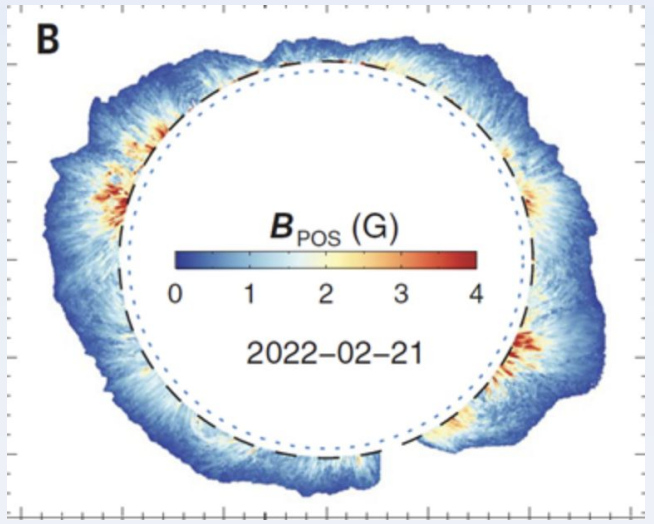
pre-CME during CME

CMEs visible in more than just intensity!

UCoMP science products (polarimetry)







linear polarization

B_{pos} direction

B_{pos} strength from corona seismology

Scattering polarization gives information on the plane-of-the-sky magnetic field
Stokes Q and U (linear polarization) are a few % of the intensity signal in Fe XIII 1074.7nm

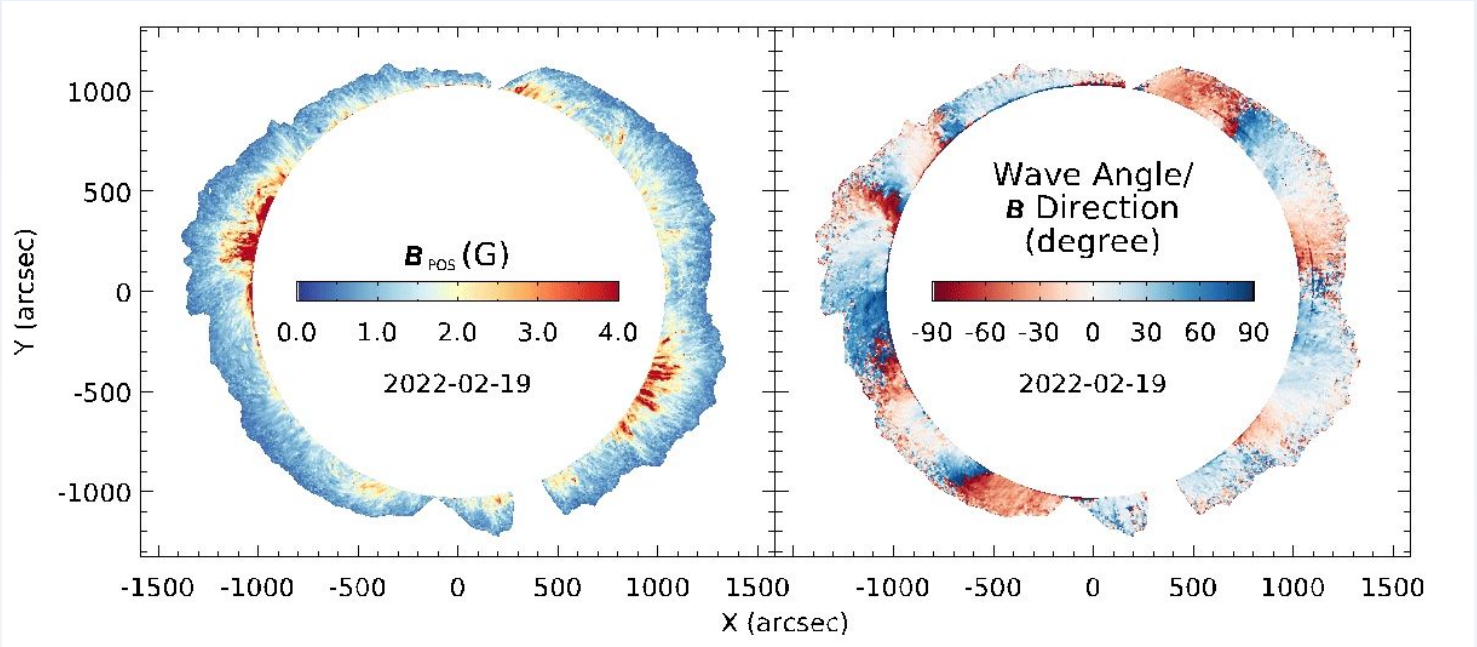
Zeeman effect gives the line-of-sight magnetic field

Stoke V (circular polarization) → much harder to measure (V/I is 10^{-4} /G)

UCoMP-like instrument in space

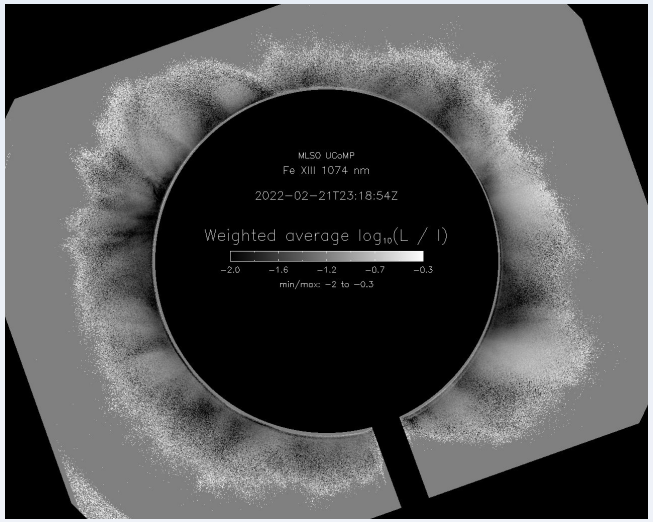
a UCoMP-like instrument at L5 would measure the magnetic field along the Sun-Earth direction

UCoMP sees ubiquitous waves in the solar corona
phase speed of waves V_{ph} is related to the magnetic field:
$V_{ph} = B / \mathrm{sqrt}(4\pi\rho)$

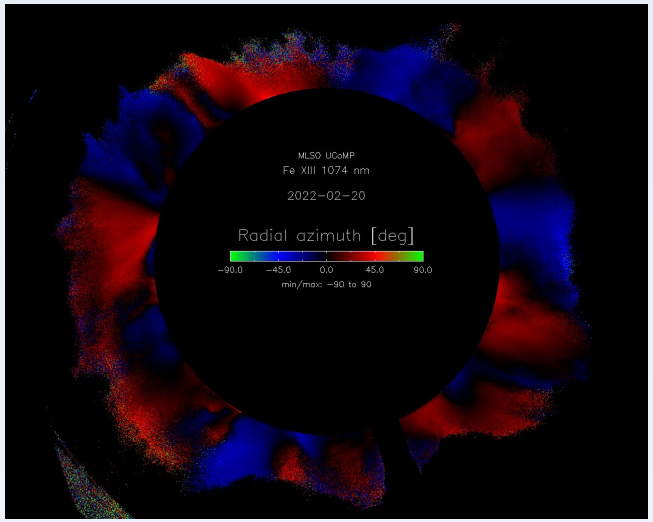


UCoMP magnetic field movie Courtesy of Zihao Yang

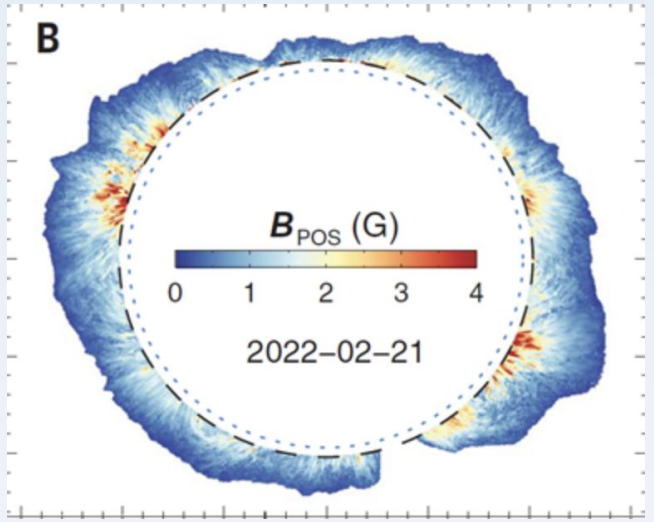
UCoMP science products (polarimetry)



linear polarization



B_{pos} direction



B_{pos} strength from waves

Zeeman effect gives the line-of-sight magnetic field

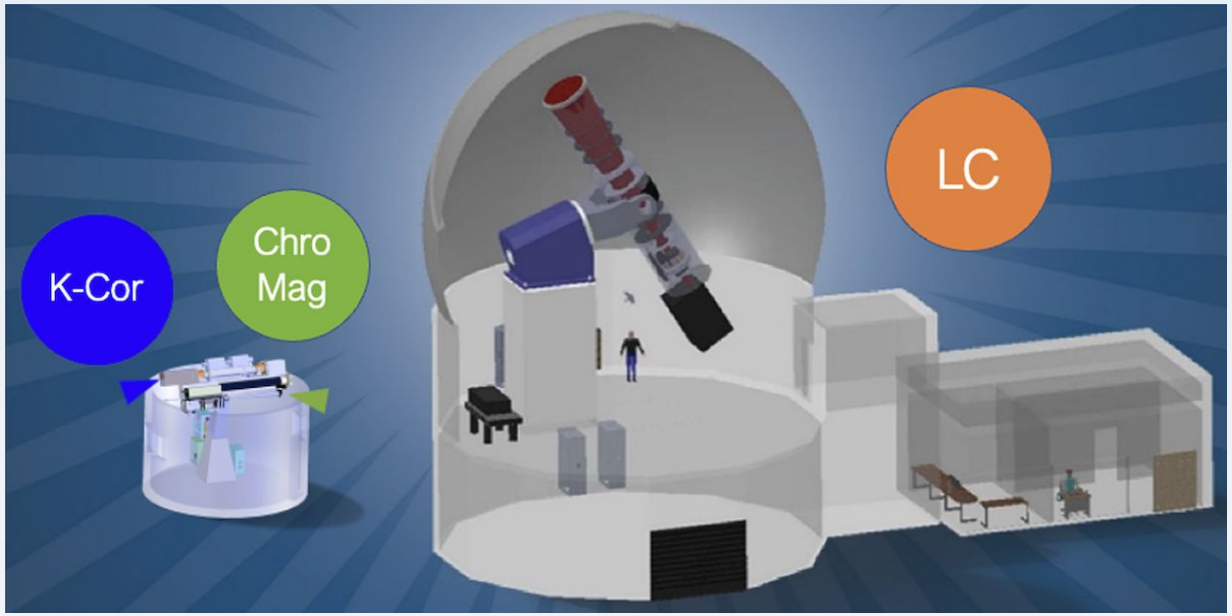
Stoke V (circular polarization) → much harder to measure (V/I is 10^{-4} /G)

We need to measure Stoke V to obtain the 3D magnetic field vector

The COronal Solar Magnetism Observatory COSMO

Ground-based facility proposed by HAO and University partners for synoptic observations of the corona and chromosphere

The Large Coronagraph (LC) is a ~1.4m telescope at the core of COSMO



COSMO will advance our current understanding of the magnetic drivers of solar eruptions, the sources of coronal heating, and the global coronal magnetic evolution

COSMO Large Coronagraph (LC)

Final design was completed in April 2025 by NCAR and EIE (European Industrial Engineering)

LC large ~1.4m aperture is required to detect Zeeman induced circular polarization in coronal lines to measure the line-of-sight magnetic field

LC will use a super polished lens instead of a mirror to reduce stray light making it one of the largest lenses ever built

The instrument behind the LC is an improved version of UCoMP, uses a similar LiNbO3 Lyot filter (530-1500nm – to include SiX line at 1430nm) and a larger 4kx4k detector (1 arcsec/pixel)

COSMO as a synoptic facility

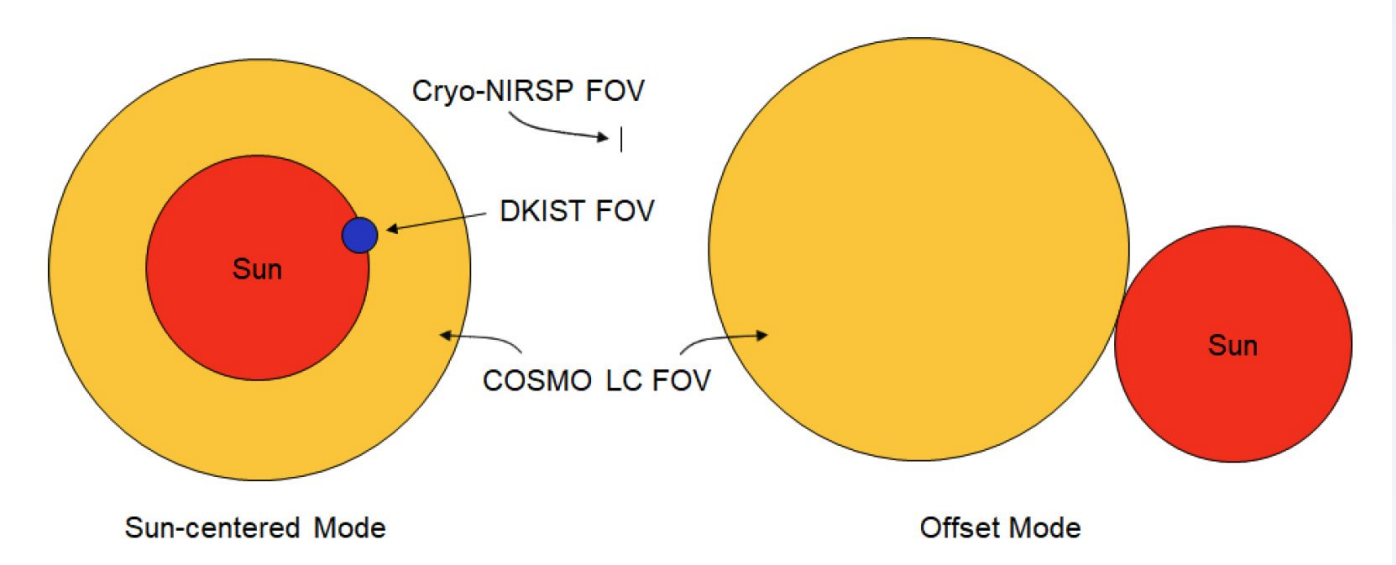
COSMO is a synoptic facility with a large field-of-view up to 2 solar radii and the capability of off-pointing to follow CMEs even further out

will provide routine measurements of the global coronal magnetic field:

1m cadence for B_{pos}

12m cadence for B_{los} of 1Gauss

complementary to DKIST and other observatories designed to study the small scale structure of the Sun



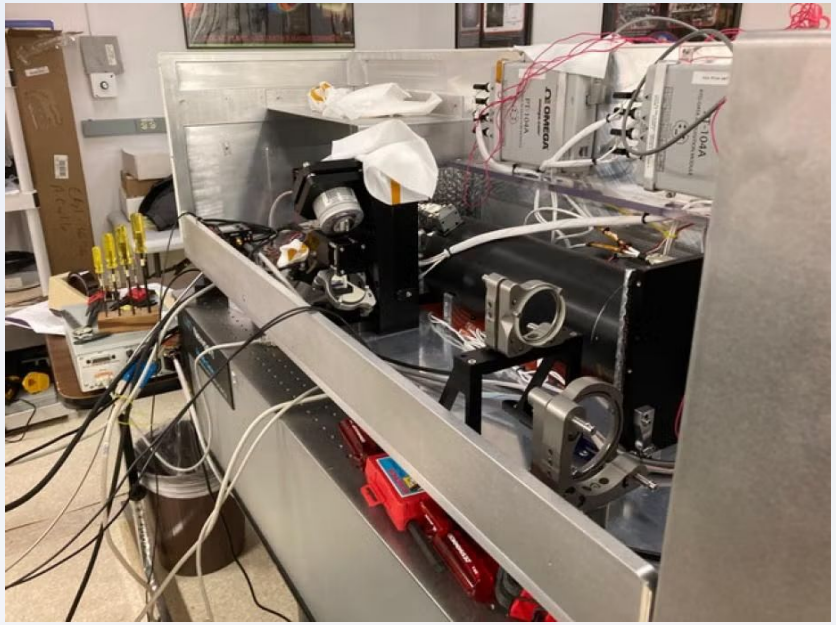
Backup Slides

ChroMag

A. de Wijn

designed to measure the 3D magnetic field in the photosphere and chromosphere

visible/near IR tunable filter
fov: disk, off-limb up to 2.25 solar radii
spatial resolution: ~1.2arcsec/pixel
(tip/tilt image stabilization system)
cadence: <1m
observables: Stokes I, Q, U, V



instrument is built, undergoing testing and calibration in Boulder

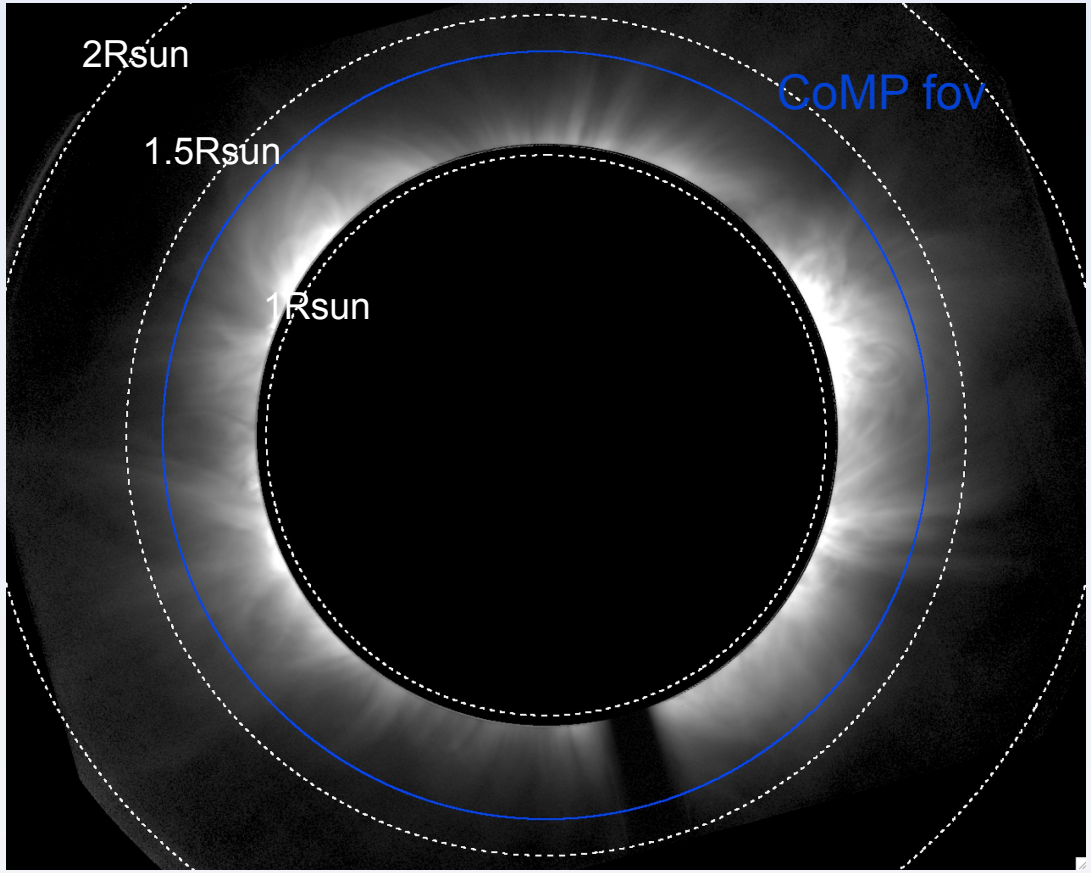
MLSO site re-opening

Waiting for DOT to sign contract to restore the portion of the road destroyed by the lava (~3months project)

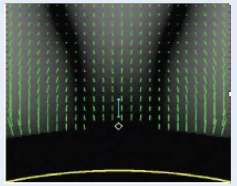
Solar panels and batteries already on-site ready to be installed (~3weeks)

Process	Physical-state dependency	Observation	Magnetic quantity probed
Thomson scattering	electron density	White-light pB, TB	Plasma structured by field (e.g. closed vs. open field boundaries, flux surfaces)
Collisional excitation	electron density, temperature	IR/Visible/EUV/SXR emission	Plasma structured by field (incl. loops, closed/open boundaries, flux surfaces)
Continuum absorption	chromospheric population density, electron density, temperature	EUV absorption features	Can indicate magnetic geometry suitable for prominence formation
Resonance scattering; polarization	electron density, temperature, vector magnetic field	Visible/IR spectra	B_{los} from Stokes V; Magnetic field direction from Stokes Q, U
Doppler shift	electron density, temperature, velocity	Visible/IR spectra	B_{pos} and field line direction from waves; flux surfaces from bulk flows
Thermal bremstrahllung	electron density, temperature, vector magnetic field	Radio emission (intensity and circular polarization) as a function of frequency	B_{los} from Stokes V
Gyroresonance	electron density, temperature, vector magnetic field	Radio emission (intensity and circular polarization) as a function of frequency	Surfaces of constant magnetic field strength at each frequency
Faraday rotation	electron density, temperature, vector magnetic field	Rotation of plane of polarization	B_{los} from rotation measure

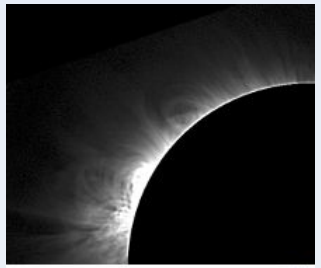
Courtesy of S. Gibson



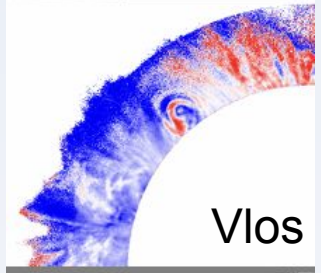
Wavelength (nm)	UCoMP Line	Temperature (MK)	
530.3	FeXIV	1.90	removed Nov 22
637.4	FeX	1.10	whole mission
656.3	HI	0.02	removed Nov 22
670.2	NiXV	2.50	added Nov 22
691.8	ArXI	1.90	removed Nov 22
706.2	FeXV	2.20	whole mission
761.2	SXII	2.20	added Nov 22
789.4	FeXI	1.30	whole mission
802.4	NiXV	2.50	added Nov 22
991.3	SVIII	0.80	added Nov 22
1074.7	FeXIII	1.80	whole mission
1079.8	FeXIII	1.80	whole mission
1083.0	HeI	0.02	removed Nov 22

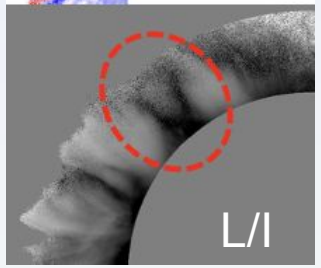


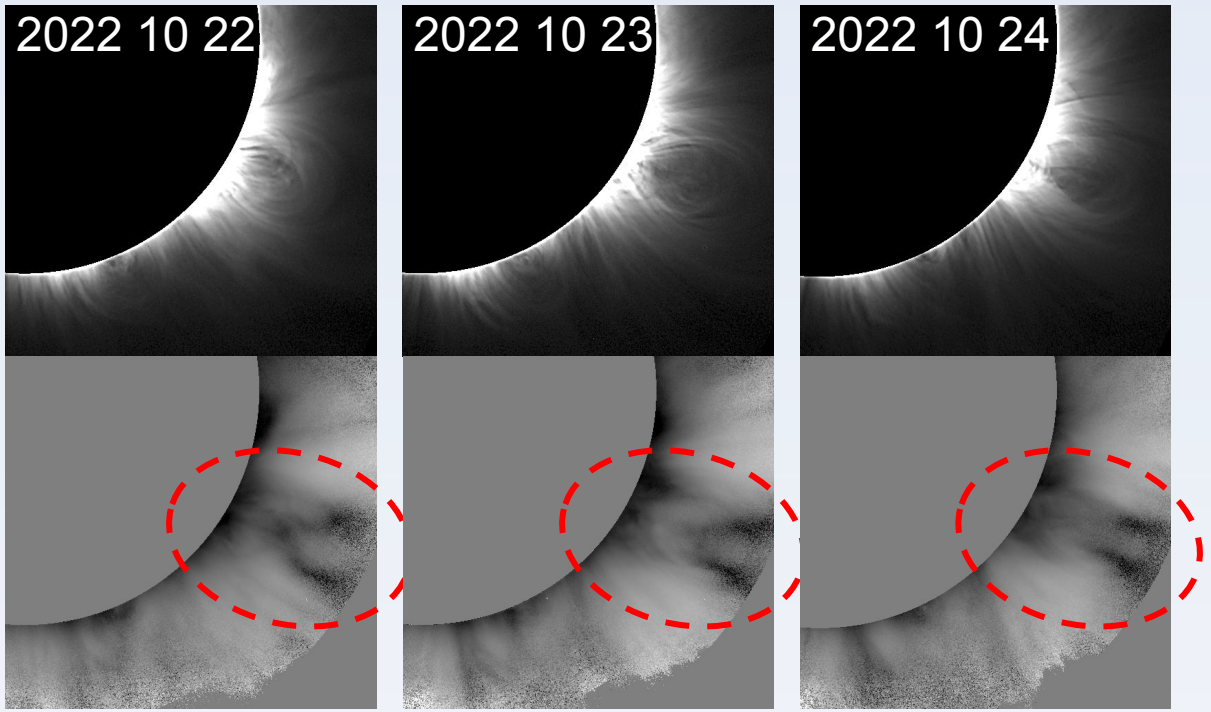
modeled L/I
in a cavity



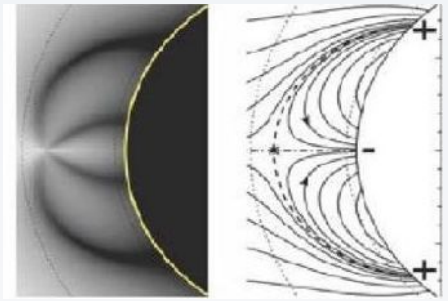
UCOMP
observation
in a cavity



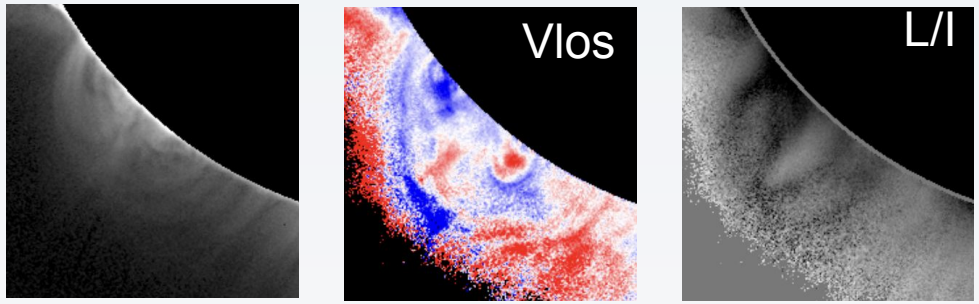




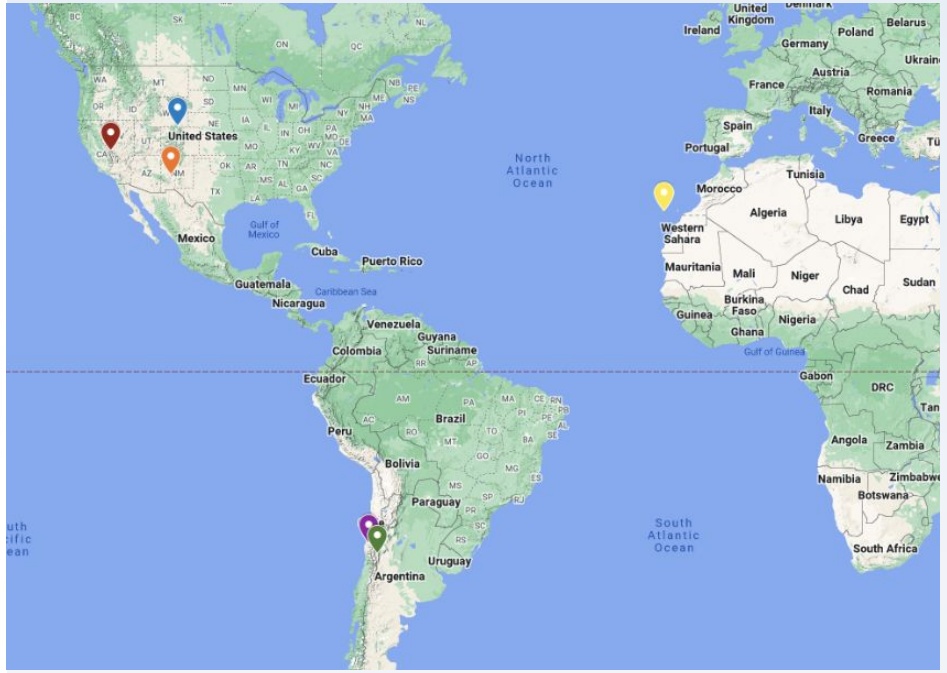
modeled pseudo-streamer



observed pseudo-streamer



Jelm Mountain Observatory	Coronal skies uncertainty: annual number of days; wildfires? Other
Magdalena Ridge Observatory	Coronal skies uncertainty: annual number of days: wildfires? Solid engagement with indigenous population
Barcroft Station	Coronal skies: initial observations encouraging (but sparse!) Site Access is a major challenge
CTIO – Chile	High quality coronal skies AURA has been challenging to work with
El Leoncito – Argentina	High quality coronal skies Inflation and political climate are major concerns
Izana – Tenerife	Meets requirements coronal skies and atmos. seeing Very willing to work with us



Scientific Quality

- Coronal Skies
- (Phase 1)
- Atmospheric seeing (Phase 2)

Infrastructure

- Cost of Construction
- Primary & backup power

Natural Hazards & Climate Risk

- Earthquake
- Wildfire

Geopolitical

- Political Instability
- Opportunities for collaboration

Human Factors

- Compliance with international wage and benefits

Weather & Site Accessibility

- Cost of maintaining site access

Health and Safety

- Access to EMS
- Cell phone access

Local Community & Indigenous Populations

- Expressions of support
- Impact to cultural lands

Legal

- Intellectual Property
- Export control

Contracts and Administration

- Ease of payment
- Foreign Corrupt Practices Act

Environmental Assessment Process

- Complexity of EIA process

Operating Costs

- Magnitude of annual costs