PROSPECTS FOR CORONAL MAGNETIC FIELD MEASUREMENTS FROM SPACE

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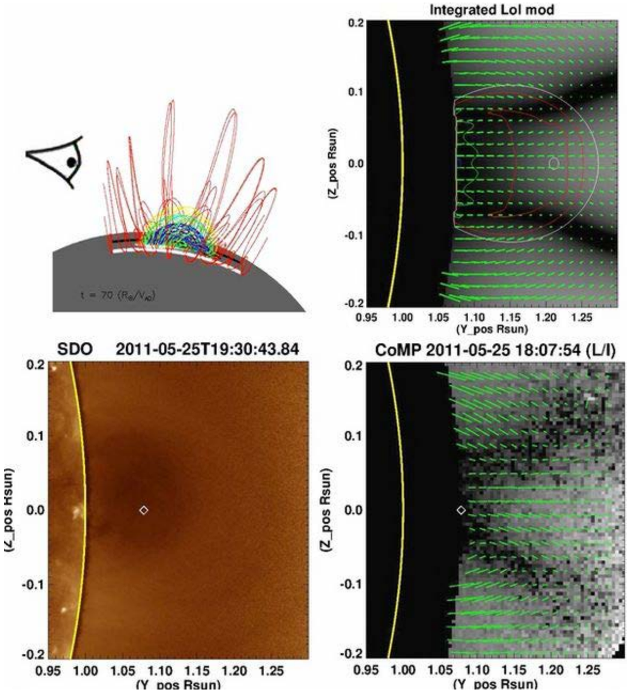
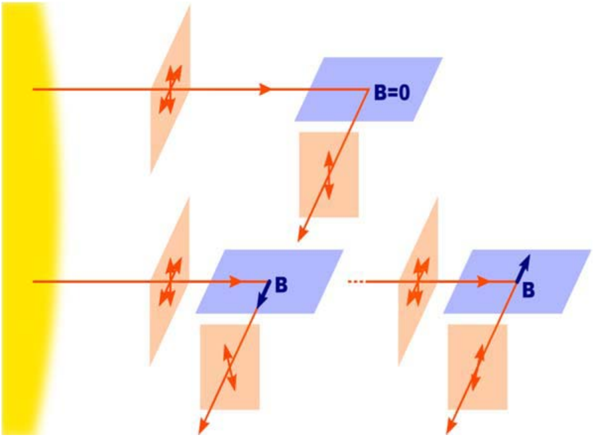
How to measure the coronal magnetic field ?

- **Coronal seismology**
  - **B** form properties of transverse loop oscillations
- **Radio observations**
  - Limited resolution,
- **Zeeman effect**
  - Compared to photospheric conditions
    - B_{corona} ↘, Zeeman splitting ↘
    - T_{corona} ↗, Line width ↗
- **Hanle effect**
  - Modification of the linearly polarized scattered radiation by the magnetic field
  - Sensitive to weaker fields
- **Combination of both**



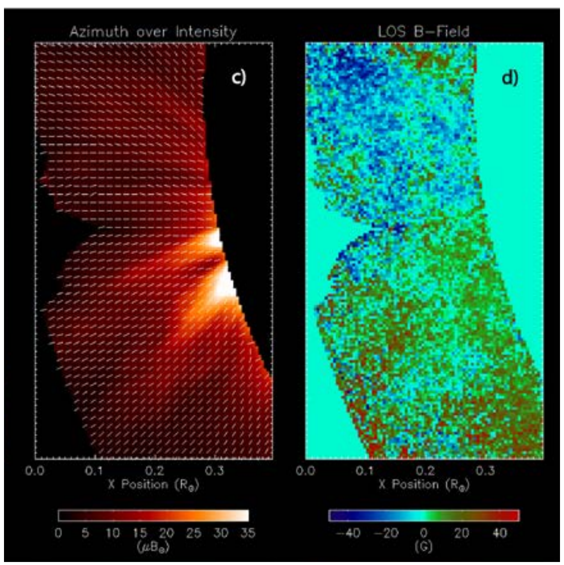
Bak et al. 2013

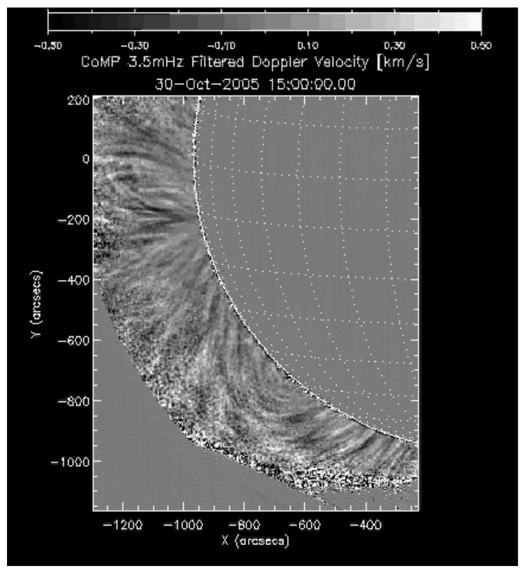


Trujillo Bueno et al. 2005

WAMIS (Waves and Magnetism in the Solar Atmosphere)

- **High altitude balloon proposal**
  - Led by NRL (D. Moses)
  - A version of CoMP (Tomczyk et al. 2008)
    - B strength & azimuth
    - Doppler velocity
  - Launch in 2018 ?



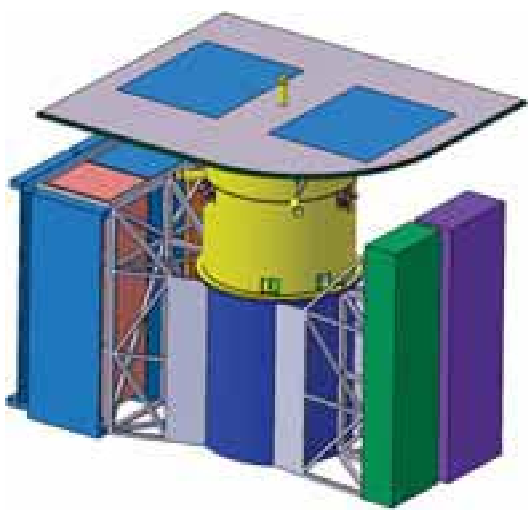


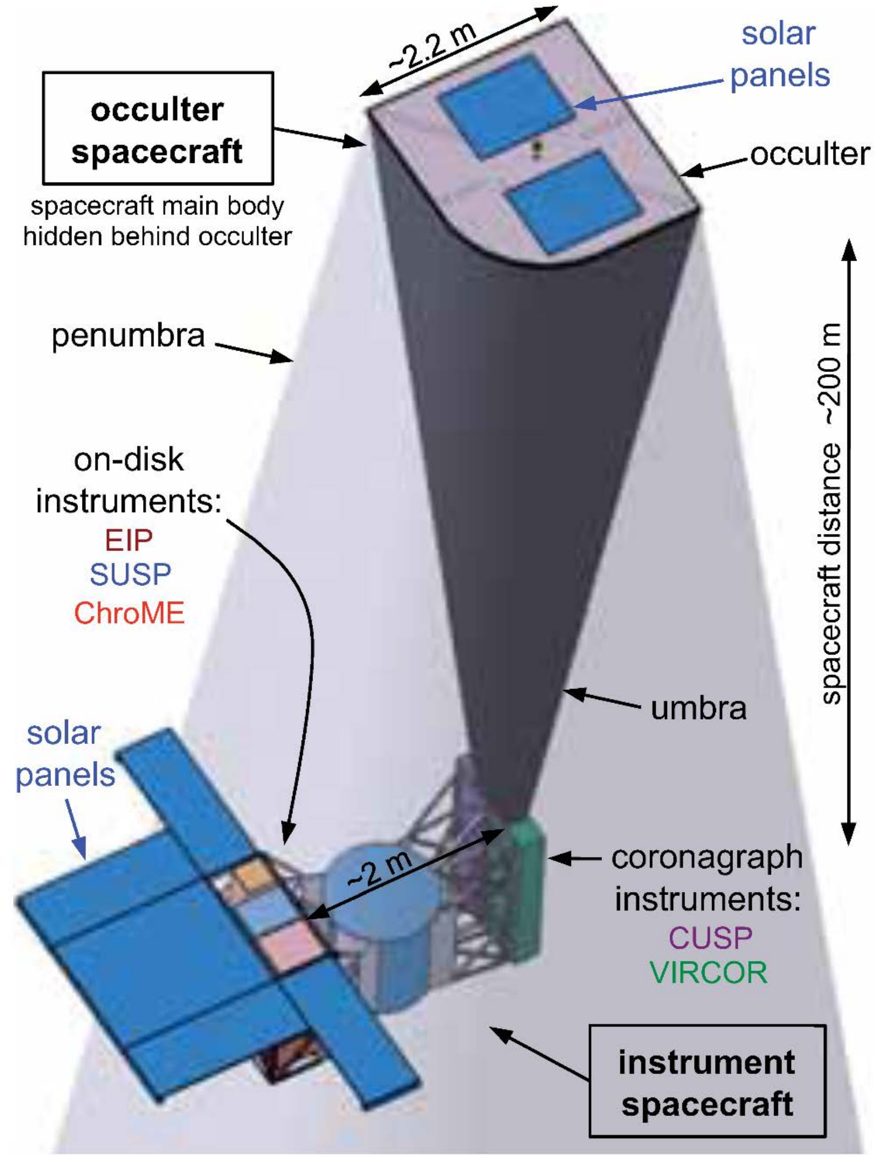
Telescope type	Internally occulted Lyot coronagraph
Objective lens	f/10 singlet, aperture 20cm, focal length 203.3cm
Objective Stray Light	<0.2 $\mu B_\odot$ goal 1.2-2.8 $R_\odot$
Overall Throughput	≈5%
$B_\odot$	9.34×10^6 erg/cm^2/s/sr/nm
Plate Scale	4.5"/pixel low mag. 1.5"/pixel high mag.
Fe XIII (1074.7nm) Count Rate @ 1.1 $R_\odot$	1×10^5 photons/pixel/sec @1.5"/pixel magnification
Detector	Goodrich camera 15 micron pixels, 1280x1024 format
Inner FOV Limit	1.02 $R_\odot$
Outer FOV	±2.8 $R_\odot$ @4.5"/pixel Sun Centered
	1.8 $R_\odot$ @1.5"/pixel Limb Centered
Primary Lines of Interest	Fe XIII (1074.7, 1079.8 nm) Fe X (637.5 nm) He I (1083.0 nm)
Filter	Tunable Lyot filter, 3.8cm aperture 530 – 1083 nm range
Duration of Continuous Observational Sequence	2 weeks minimum ≥4 week optimum

SolMEx (Solar Magnetism Explorer)

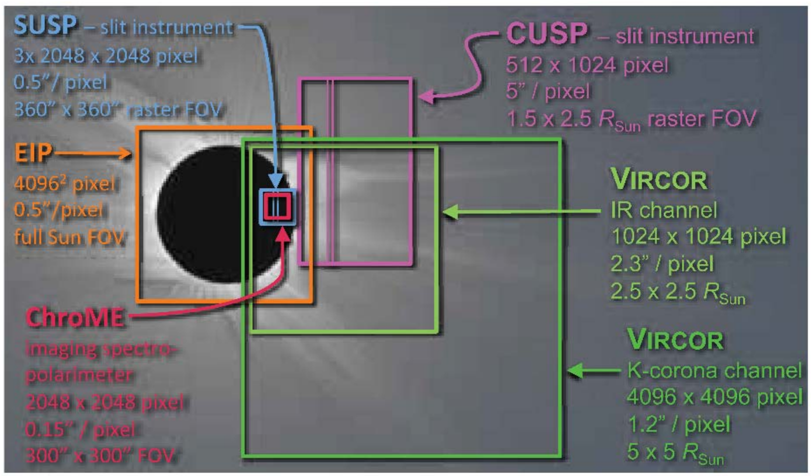
- **ESA M3 proposal**
  - Led by MPS (H. Peter)
  - First proposed as COMPASS (M2)

  - Zeeman & Hanle polarimetry from chromosphere to corona





SolMEx Instruments



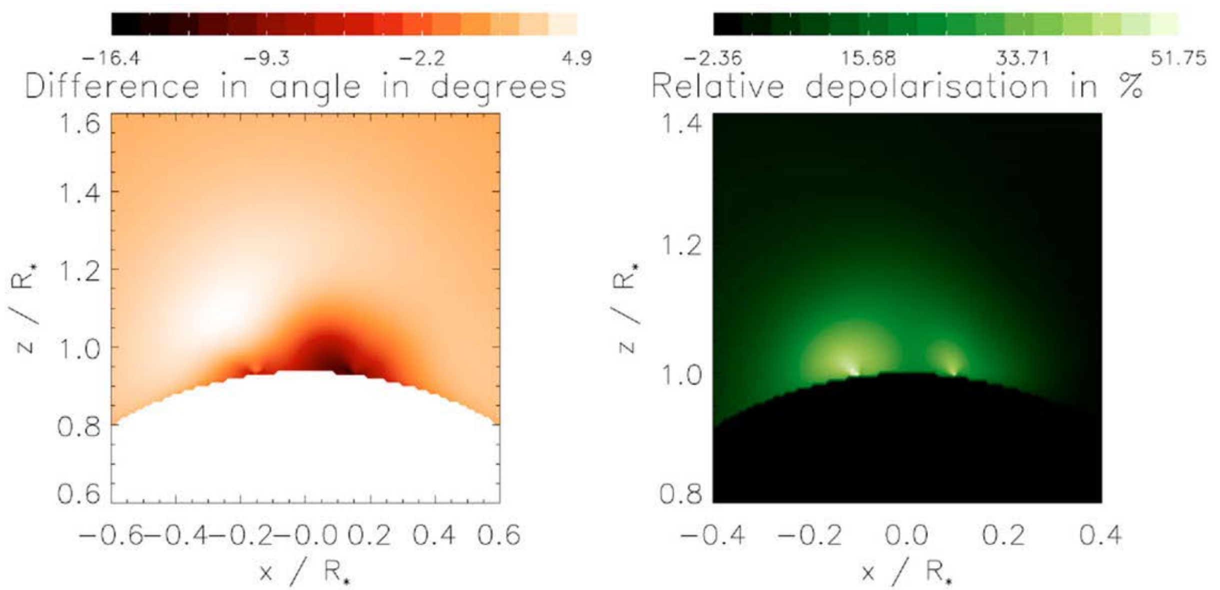
	off-limb		*on-disk*		
instrument specifications	**CUSP** coronagraphic UV spectro-polarimeter	**VIRCOR** visible light & IR coronagraph	**EIP** EUV imaging polarimeter	**SUSP** Scanning UV spectro-polarimeter	**ChroME** Chromospheric Magnetism Explorer
spectral lines or band	Ly-α, β, γ (121, 102, 97 nm) O VI (103 nm)	Fe XIII 1.07 μm He I 1.08 μm vis: ~ 400 nm	Fe X (17.4 nm)	115nm–155 nm incl. Ly-α, C IV (121, 150 nm)	Mg II (279 nm) Fe I (525 nm)
detector size: [pxl]	512x1024 photon counting	IR: 1024^2 vis: 4096^2	4096^2	3x 2048^2 * photon counting	Mg: 2048^2 Fe: 1024^2
spatial sampling	5"/pxl	IR: 2.3"/pxl vis: 1.2"/pxl	0.55"/pxl	0.5"/pxl	Mg: 0.15"/pxl Fe: 0.3"/pxl
field of view	slit: 10" x 0.7° raster: 0.4°x0.7°	IR: 0.6°x0.6° vis: 1.3°x1.3°	0.6°x0.6°	slit: 1"x360" raster:360"x360"	300"x300"
spectral sampling	9 pm / pixel	IR: 0.2 nm vis: broad band	0.35 nm FWHM band	6.6 pm / pixel	Mg: 5 pm Fe: 9 pm
polarimetric accuracy †	10^{-2} linear	10^{-4} linear & circular	10^{-3} linear	10^{-3} linear & circular	10^{-3} linear & circular
exposure times ‡	10 s – 4 h	IR: 5 s vis: 1 s	3 s (N-P) 1 min (POL)	<1 s (N-P) 7s–6min (POL)	0.5 s
observation cadence §	30 s – 8 hours	IR: 30 s vis: 3 s – 5 min	3 s – 3 min	10 s – 12 min	30 s
data rate kbit/s *(total: 2 Mbit/s)*	150	300	550	300	700
effective focal length mm	1000	IR: 1600 vis: 2100	4400	1200	Mg: 13750 Fe: 7360
aperture	25 x 30 cm^2	⌀ 20 cm	⌀ 28 cm	15 x 10 cm^2	⌀ 25 cm
dimension cm^3	180 x 60 x 30	180 x 50 x 25	100 x 30 x 30	160 x 50 x 40	150 x 45 x 50
mass kg *(total: 290 kg)*	70	60	40	68	52
power W *(total: 210 W)*	30	50	50	25	55
absolute pointing *x-y* / roll	5' 15'	2' 5'	0.5'	2' 1'	2' 1'
pointing stability *x-y* / roll	1" / 15 min 1' / 15 min	1" / 3 min 1' / 3 min	0.2" / 15 min	1" / 15 min 1' / 15 min	int. stabilization 5" / 5 s

* only the central 720 pixel in the spatial direction are read out
† for typical exposure times ‡ (N-P): non-polarimetric, (POL): polarimetric observation mode
§ typical cadence for one full set of data, e.g., exposures for all necessary polarization states.

Hanle effect for the H Lyman series

- **The Hanle effect is sensitive to weaker fields than the Zeeman effect**
  - [5, 500] G for H I Ly-α (1216 Å)
  - [1, 160] G for H I Ly-β (1026 Å)
  - [0.5, 70] G for H I Ly-γ (992 Å)

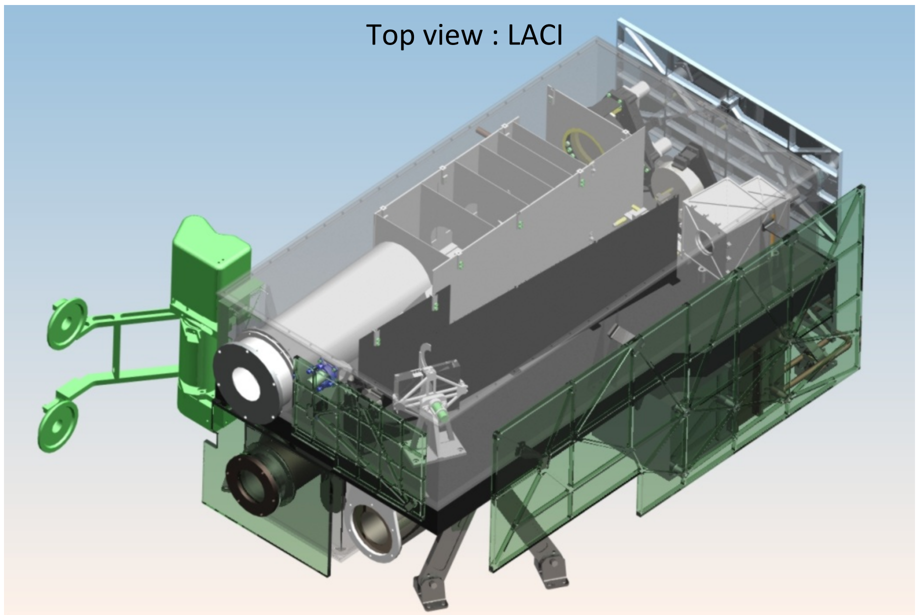
- **Lyman α is the prime candidate for the first measurements**
  - Strongest coronal UV line
  - The physics is well understood (e.g. Bommier & Sahal-Bréchot 1982)
  - The technology is available (efficient optics, detectors)
  - Strong expected signal

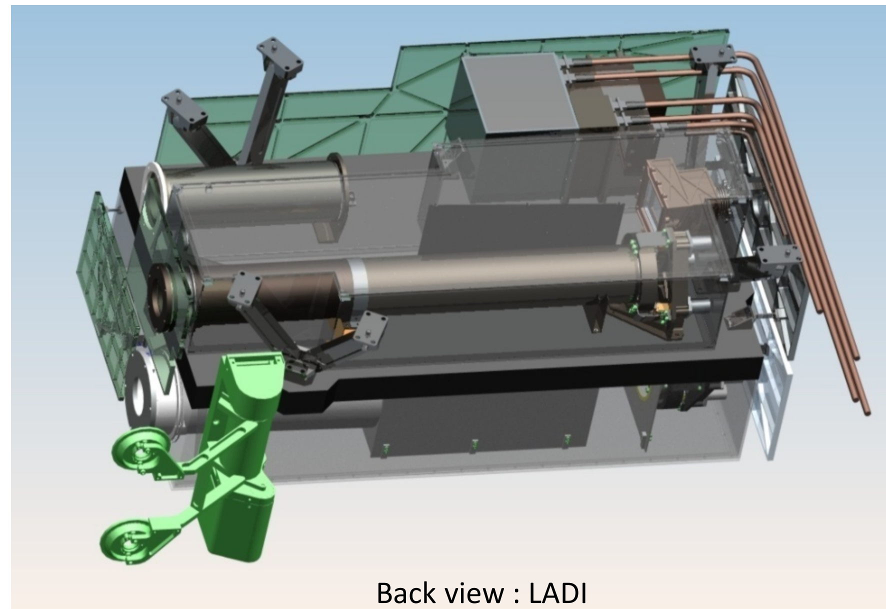


Khan & Landi degl'Innocenti 2011

LYOT(Lyman Orbiting Telescopes)

- LYOT = Lyman □disk imager + Lyman □coronagraph + polarimeter
- Studied up to phase A for the SMESE Franco-Chinese mission
- IAS, MPS, CSL, LAM, Florence, RAL





- LYOT went through a phase A study and successfully passed its PDR
- SMESE stopped in 2008 for funding reasons
- Several similar proposals since: ECLIPSE, SIGMA, MASC …

MASC: Magnetic Activity of the Solar Corona

- Small mission to be proposed in response to the upcoming ESA / CAS AO

Hui Li, Weiqun Gan, Jian Wu,
Jingwei Li, Qiusheng Du - ***Purple Mountain Obs, Nanjing, China***

Cheng Fang, Yang Guo - ***Nanjing University, Nanjing, China***

Xin Meng - ***National Space Science Center, China***

Haiying Zhang – ***Nanjing Institute of Atronomical Optics & Technology, China***

Frédéric Auchère, Jean-Claude Vial - ***Institut d'Astrophysique Spatiale, France***

Silvano Fineschi - ***INAF-Osservatorio Astrofisico di Torino, Italy***

Marco Romoli, Federico Landini - ***University of Florence, Italy***

Petr Heinzel - ***Astronomical Institute of the Academy of Sciences of the Czech Republic***

Hardi Peter - ***Max-Planck-Institut für Sonnensystem-forschung, Germany***

Andrei Zhukov, Susanna Parenti - ***Royal Observatory of Belgium, Belgium***

Pierre Rochus – ***Centre Spatial de Liège, Belgium***

Manolis Georgoulis - ***Academy of Athens, Greece***

Thanassis Katsianis - ***National Observatory of Athens, Greece***

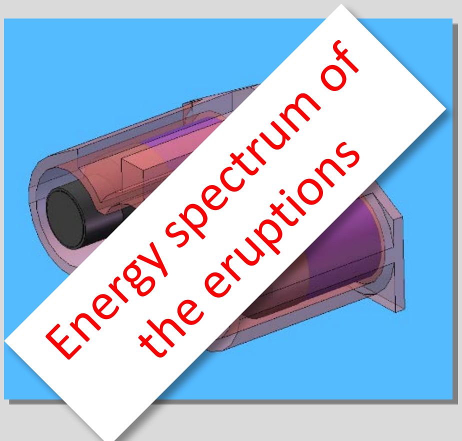
Spiros Patsourakos - ***University of Ioannina, Greece***

MASC (Magnetic Activity of the Solar Corona)

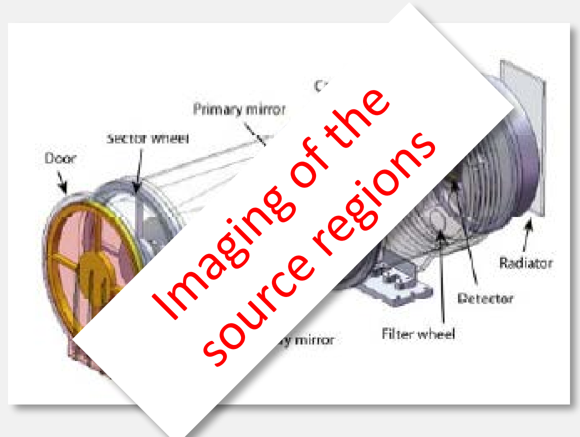
Objectives:

1. What is the global magnetic field configuration in the corona?
2. What is the role of the magnetic field in the triggering of flares and CMEs?
3. What is the link between magnetic configuration and energy release?

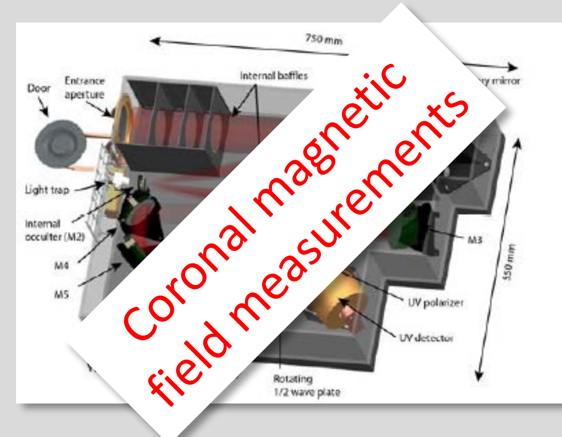
HXR spectrometer (HESP)



UV/EUV Imager (WIFI)



Coronagraph (MAGIC)

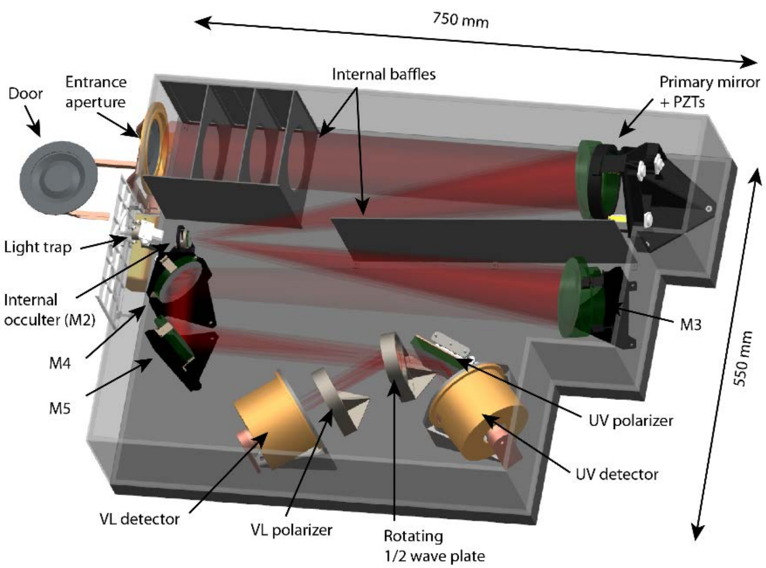


Payload: Magnetic Imaging of the Corona (MagIC)

Measurements: magnetic field, electron density & Hydrogen outflow velocity

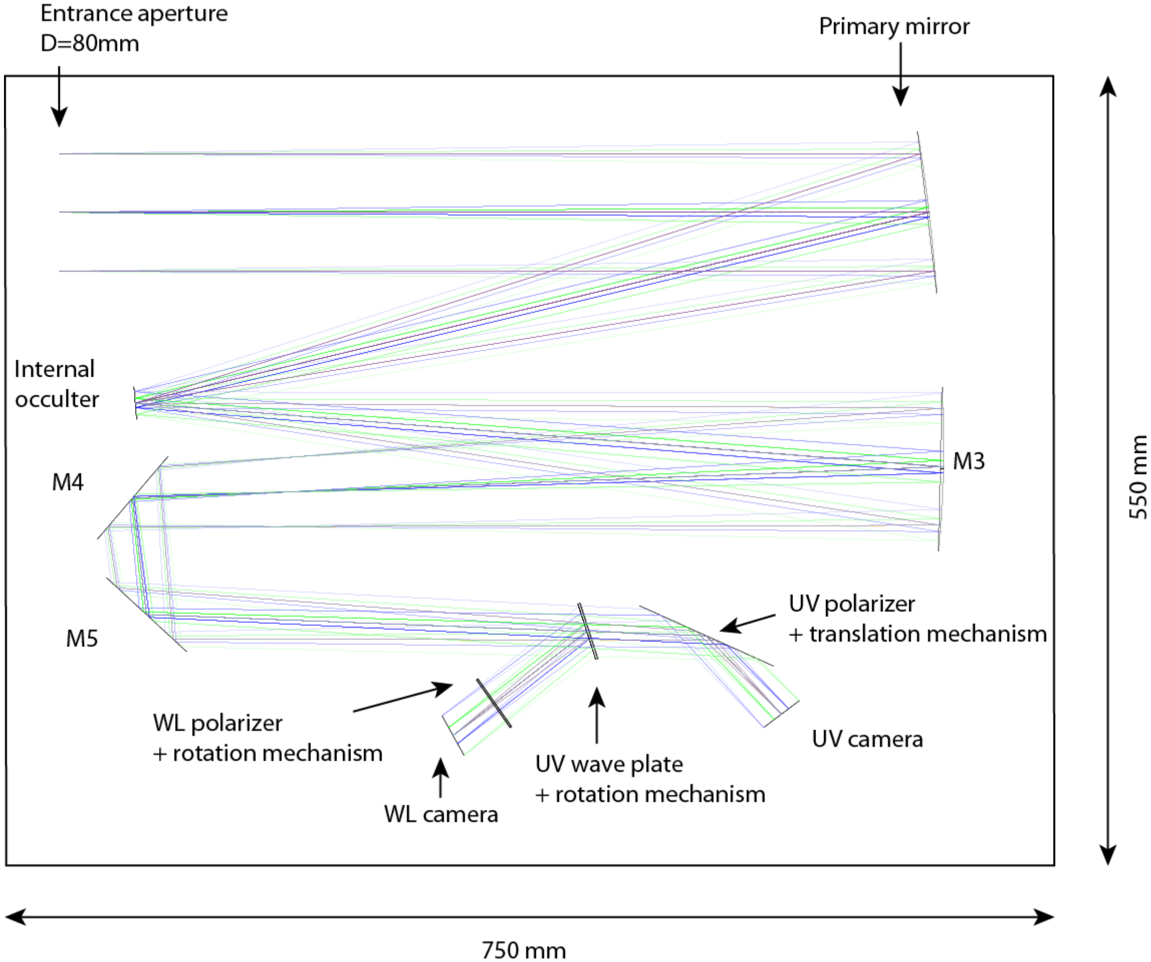
Main characteristics

- Field of view: 1.15 to 3 Rs
- Passbands: Visible light & Lyman α
- Linear polarization in VL & Lyman α
- Cadence: 2 min
- Resolution: 2.8'' (2048 × 2048)
- Mass: 26 kg
- Power: 20 W
- Volume: 75 x 55 x 20 cm^3



Consortium

- Management, optics, structure, PA/QA, AIT/AIV
- Door
- Stray light analysis, polarizers
- Flight software
- Cameras, electronics
- Possible contributions from China



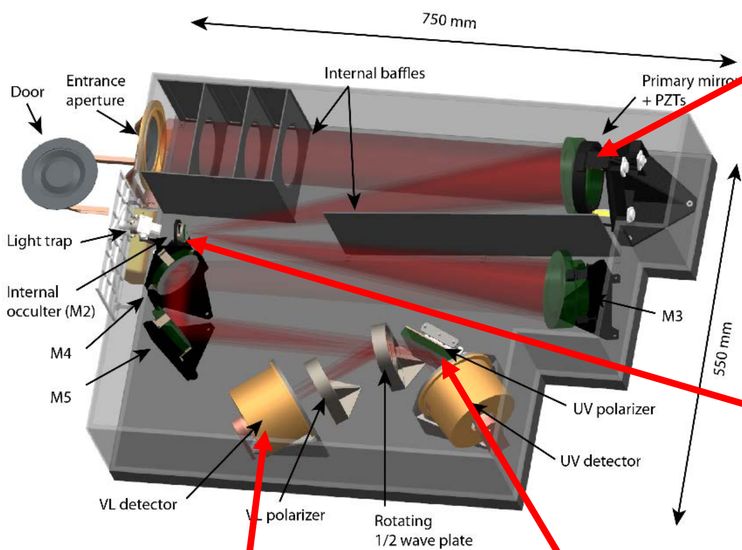
Aperture: 80 mm

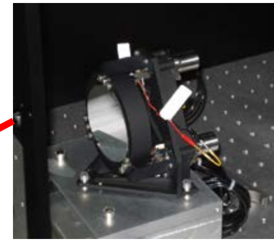
Focal length: 1100 mm

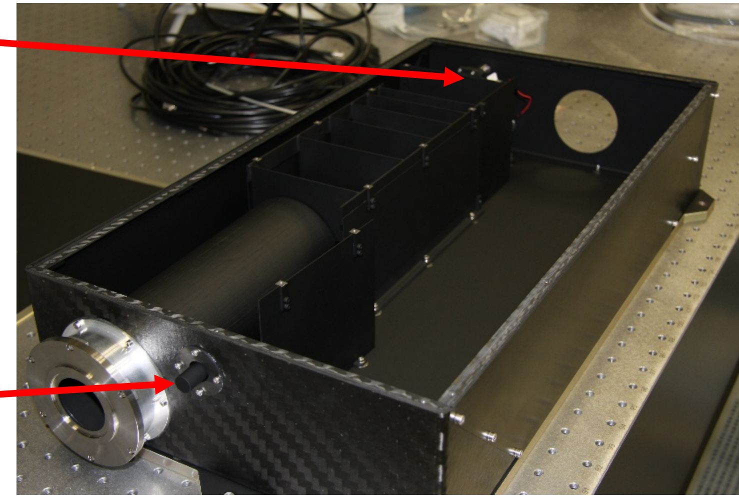
Focal plane: 2k x 2k with pixel size 15 µm x 15 µm

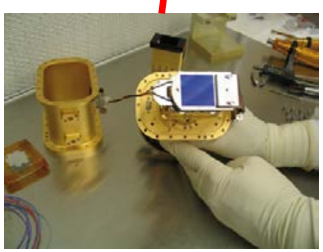
Volume ~ 750 x 550 x 150 (mm^3)

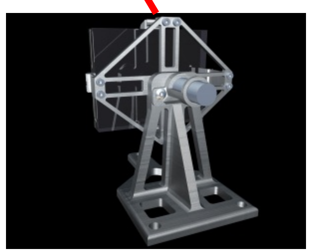
MagIC status







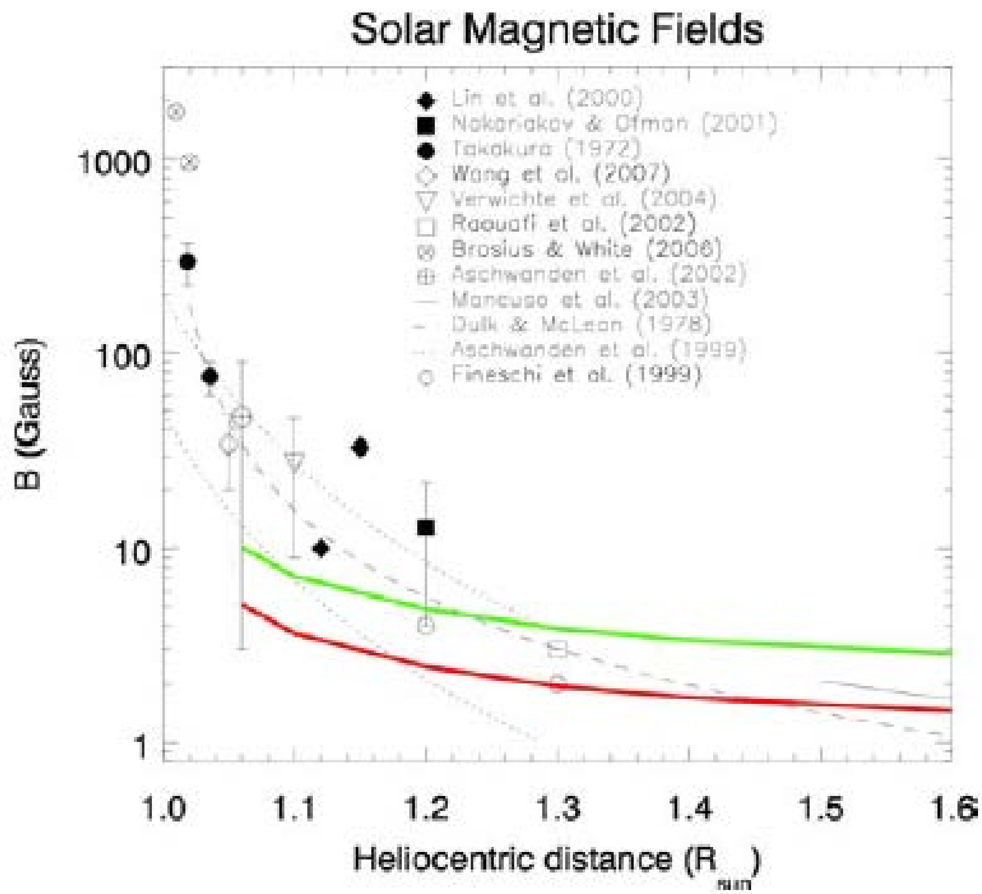




- Developments since 2000+: LYOT/SMESE, ECLIPSE, SIGMA, etc.
- All critical components (mirrors, polarizers, detectors) have benefited from CNES R&Ts
- Stray light levels validated on a mock-up

TRL >6

UV polarization sensitivity



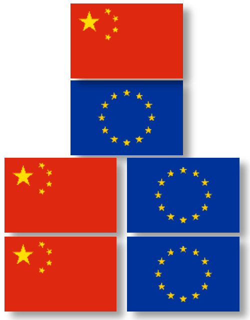
Minimum field-strength detectable via the Hanle effect measurements in H I Lyα assuming SNR of 100 and 200 in the polarimetric measurements. (Fineschi et al.)

MASC mission overview

Requirements

- (Quasi)-continuous view of the Sun
- ~4 Mbit/s telemetry (High resolution, high cadence)
- Dawn-dusk SSO or geo-synchronous orbit
- Launch in 2021, three year nominal mission

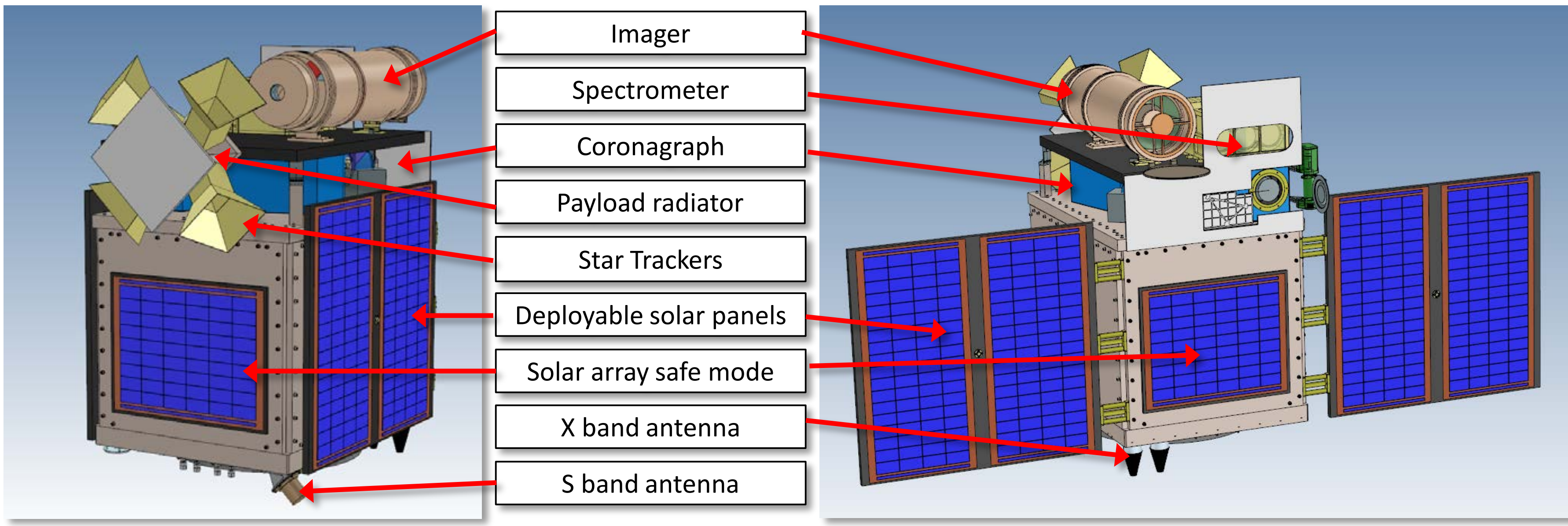
Implementation



- Chinese launch, dedicated or possibly as a piggy back payload
- European platform (Proba, Myriad Evo, etc.)
- Dual ground segment
- Joint science operations center

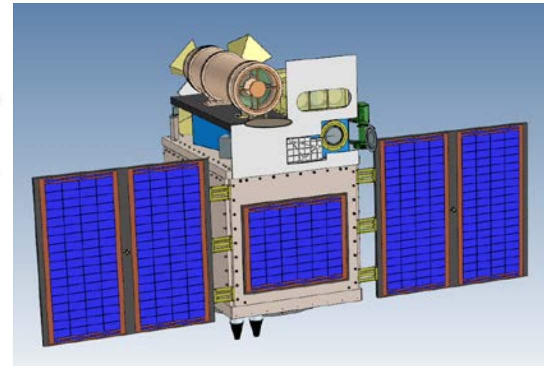
Accommodation Study

- Based on the PROBA series of platforms (TRL ≥ 8)
- PROBA is being "ITAR freed"
- Total S/C mass: ~250 kg (including payload)



- Confirms previous analyses: the concept is mature and fits a small mission
  - SMESE Franco / Chinese project phase A study (2006-2008)
  - SIGMA shortlisted for ESA's small missions (2012)

Joint ground segment



Data Telemetry

Kiruna/Miyun

Data Telemetry

Spacecraft & Instrument Commanding

MOC

or

Science Telemetry and auxilliary

Instruments commanding

MASC Mission archives

ESAC

PMO

Joint SOC

Instrument commanding	Public data archive
SOC data handling	Mission website

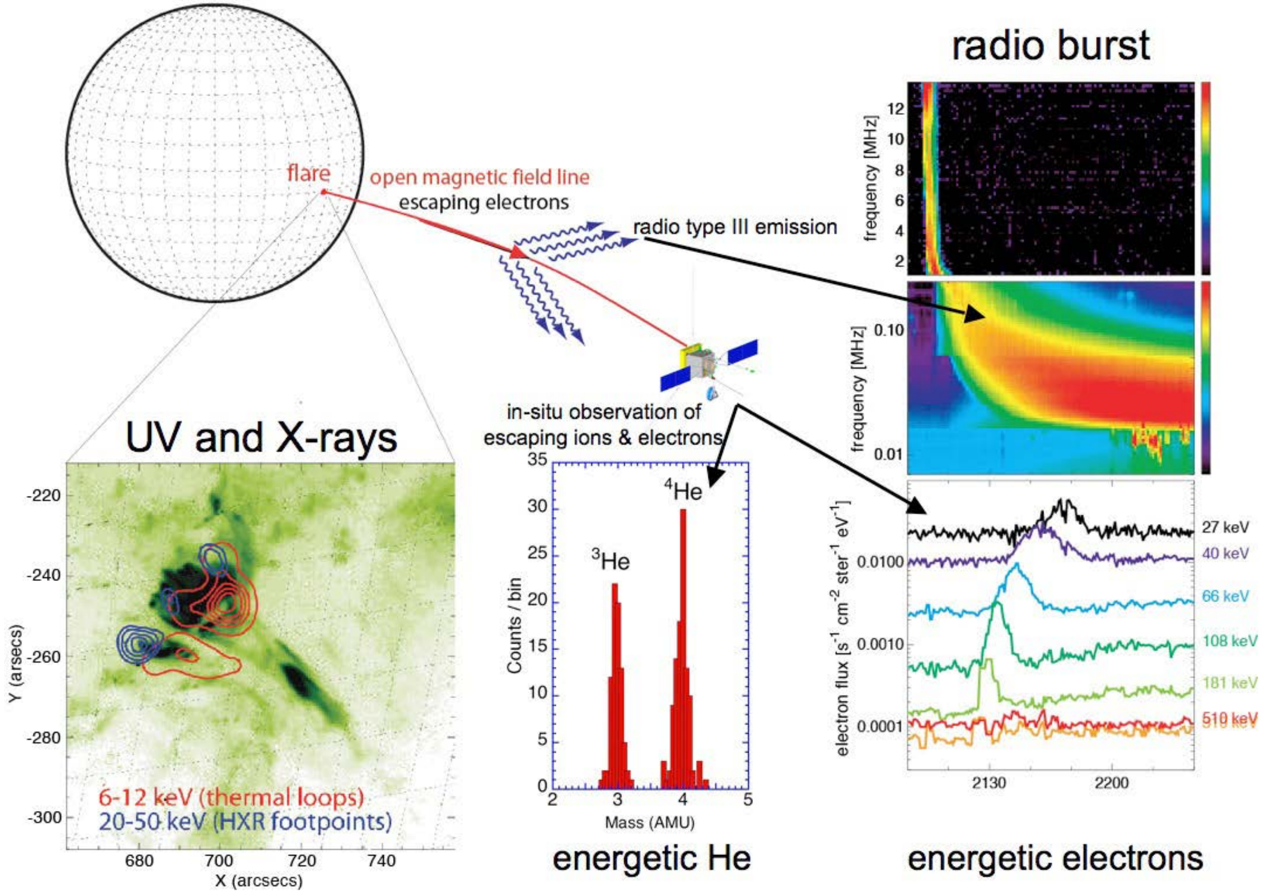
Science FITS files

Scientific community

Instrument know-how

Synergies with Probe+ & Solar Orbiter

- Aimed at understanding the link between the Solar wind and its source regions



- Solar Orbiter measures only the photospheric field
- MASC can provide the critical coronal magnetic field measurements necessary to establish the correct connectivity between the solar surface end the Spacecraft

Conclusions

- A mission dedicated to the understanding and quantification of solar coronal magnetism is bound to emerge
  - The proposed measurements are clearly identified by the community as key elements that can lead to major breakthroughs in heliophysics and space weather
  - Will provide key measurements in support to other missions like Solar Probe & Solar Orbiter
  - A stream of proposals:
    - SMESE (France/China microsat, 2006-2008), COMPASS (ESA M-class, 2007), SolMeX (ESA M-class 2010), SIGMA (ESA S-class 2012), WAMIS …
- Next opportunity: MASC
  - ESA / CAS small mission call expected in January 2015
  - Join us !