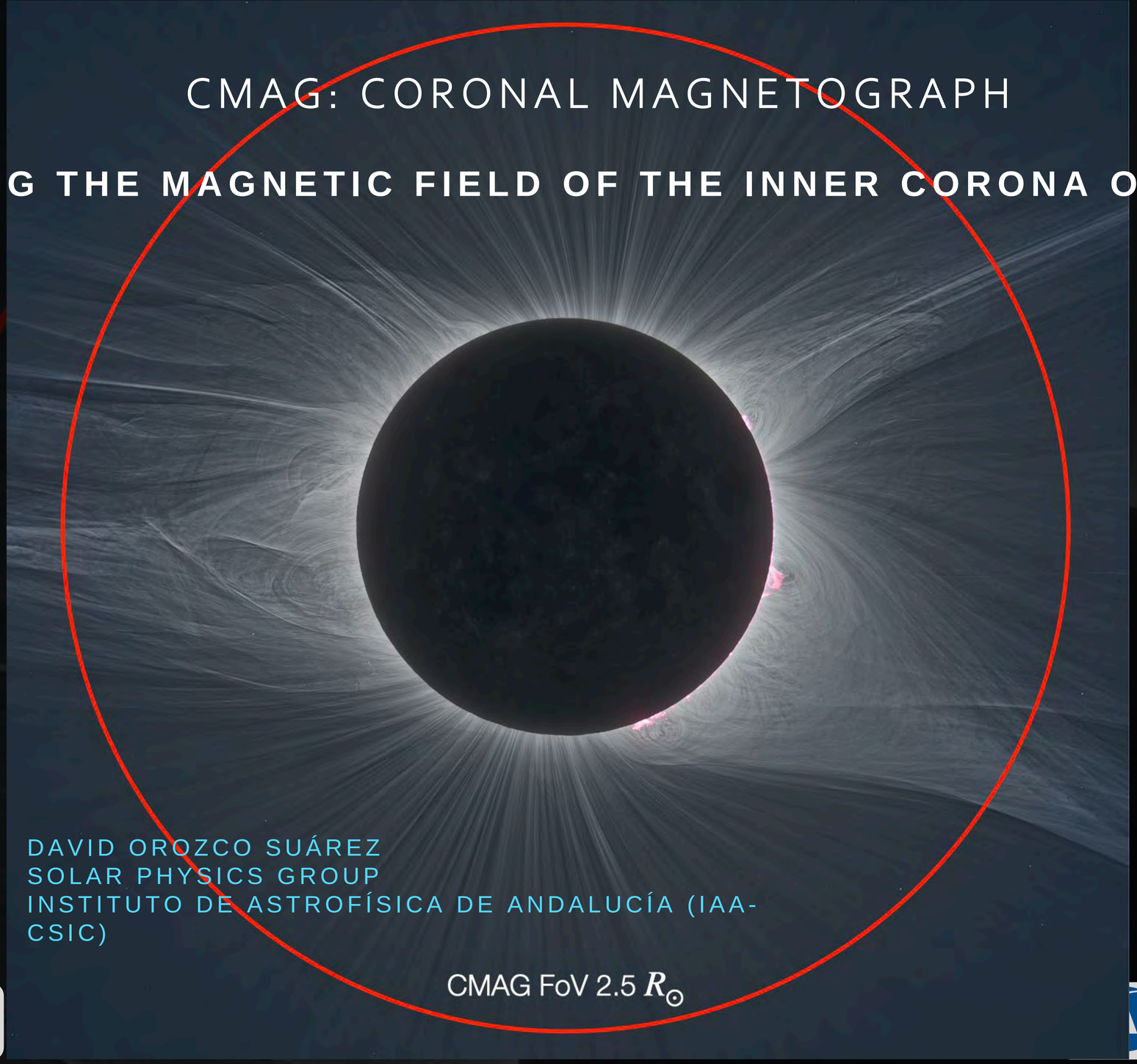
CMAG: CORONAL MAGNETOGRAPH

— MAPPING THE MAGNETIC FIELD OF THE INNER CORONA OF THE SUN—



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CMAG: CORONAL MAGNETOGRAPH

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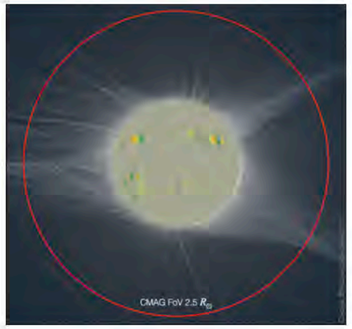
A mission to study and monitor the inner corona magnetic fields

Phase-1 proposal in response to the ESA's call for "Fast" mission opportunity



David Orozco Suárez

On behalf of the CMAG Consortium

Instituto de Astrofísica de Andalucía (IAA-CSIC) - Solar Physics Group

Deputy Lead Proposer: Jose Carlos del Toro Iniesta (IAA-CSIC, ES)

Team members: María Balaguer Jiménez and Luis R. Bellot Rubio (**IAA-CSIC & S³PC, ES**); Isabel Pérez Grande and Ignacio Torralbo Gimeno (**IDR-UPM & S³PC, ES**); Estaban Sanchis Kilders and José Luis Gasent Blesa (**UV & S³PC, ES**); Basilio Ruiz Cobo and David Hernández Expósito (**IAC & S³PC, ES**); Javier Trujillo Bueno (**IAC, ES**); Andrei Zhukov and David Berghmans (**ROB, BE**); Christian Kintziger (**UL, BE**); Marco Romoli (**UF, IT**); Silvano Fineschi (**INAF-OATo, IT**); Mihalis Mathioudakis (**QUB, UK**); Robertus Erdélyi (**UoS, UK** & **ELTE, HU**); Jackie Davies and Aristea Seitis (**RAL, UK**); Sarah Mathews (**MSSL, UK**); Lucie Green and David Long (**UCL, UK**); Eamon Scullion (**NU, UK**); Frédéric Auchère (**IAS, FR**); Jorrit Leenaarts (**SU, SE**); Louise Harra (**PMOD-WRC, CH**).

CMAG FoV 2.5 $R_\odot$

CMAG: CORONAL MAGNETOGRAPH
— SCIENTIFIC RELEVANCE —

THE SOLAR INNER CORONA IS KEY FOR CORONAL PHYSICS SCIENCE AND SPACE WEATHER MODELING AND FORECASTING

- Many relevant physical phenomena to space weather takes place in the inner corona: coronal loops, streamers, flares and CMEs (magnetic reconnection), the solar wind, etc. in which magnetic fields play a fundamental role.

- The solar inner corona is probably one of the most elusive layers to observations of the solar atmosphere since light emitted by the coronal material is tenuous and intermingled with background signals originated by scattered light from the solar disk.

- Necessary to pursue a space-borne, externally occulted coronal magnetographs.

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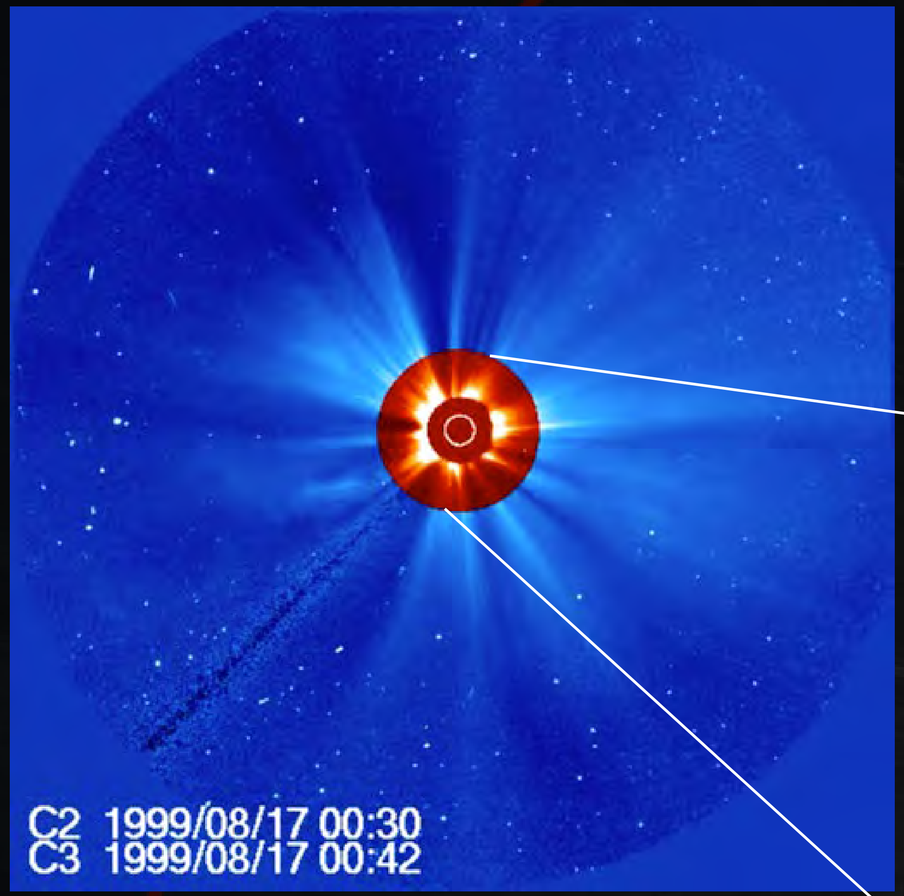
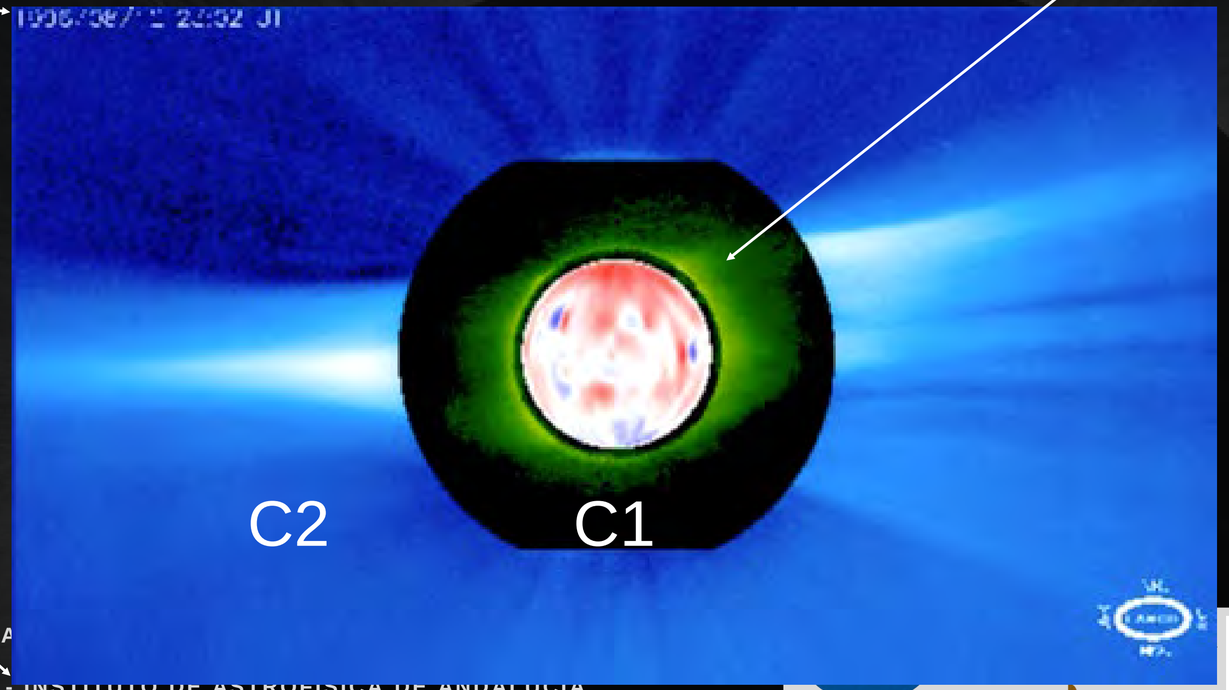
CMAG: CORONAL MAGNETOGRAPH
— PAST MISSIONS —



- LASCO C1,C2 and C3 instruments aboard SOHO at the Largange point L1 [Brueckner+ 1995]
- C1 1.1 to 3 solar radii (spectroscopy in Fe X 637 nm and Fe XIV 530 nm)
- C2 1.5 to 6 solar radii (still operative) - white light
- C3 3.7 to 30 solar radii (still operative) - white light



CMAG: CORONAL MAGNETOGRAPH
— PRESENT MISSIONS —

Degraded by diffraction straylight on disk

- LASCO (white light from 1.5 to 6 solar radii) aboard SOHO [Brueckner+ 1995]
- UVCS (slit spectrometer from 1.4 to 10 solar radii) aboard SoHO [Kohl+ 1995]
- METIS (linear polarimetry - monochromatic) aboard Solar Orbiter [Antonucci+ 2020]
  - From 1.7 to 3.1 solar radii at 0.28 AU and from 3.0 to 5.5 solar radii at 0.5 AU
- SoloHI (white light, from 5.2 to 42 solar radii) aboard Solar Orbiter [Howard+ 2020]

- ASPIICS (narrow band - Fe XIV line, from 1.1 to 3 solar radii) aboard Proba-3 [Galano+ 2022]
  - Observes almost the full inner corona of the Sun. Externally occulted !!!

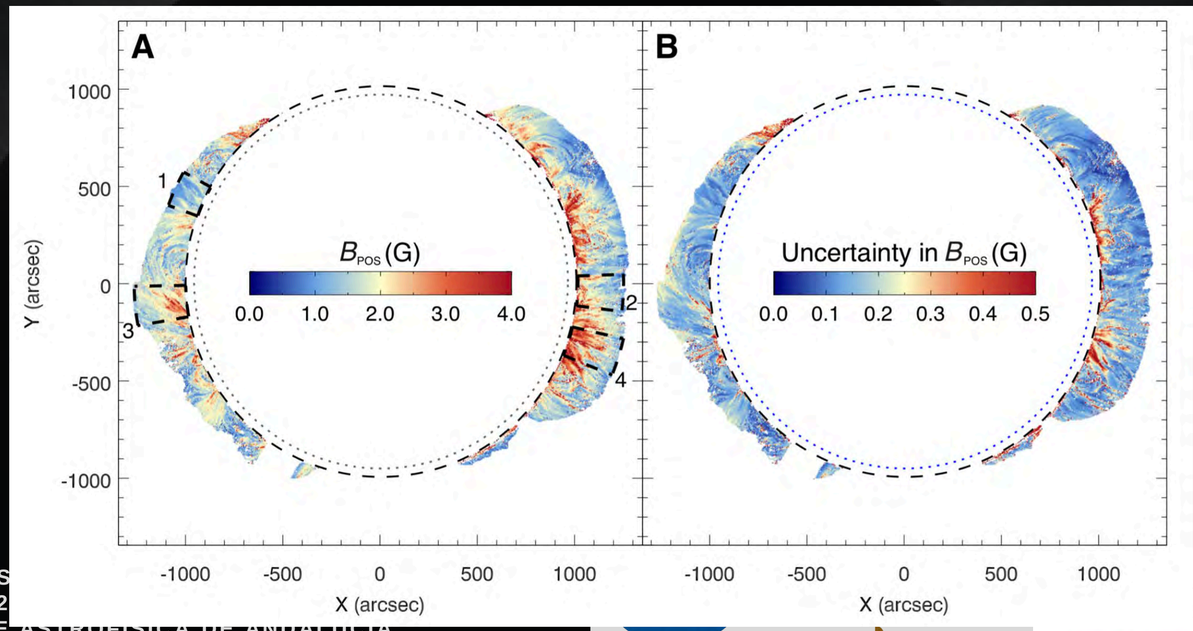
- These instruments provide critical information about the dynamical phenomena taking place in the solar corona. However, the dynamics is driven by the transformation of magnetic energy into radiative (flares) and kinetic energy (CMEs).
- Fine polarimetric measurements of the inner corona are paramount but harder to accomplish with similar spatial and temporal resolutions!

CMAG: CORONAL MAGNETOGRAPH
— GROUND BASED OBSERVATORIES —

- The coronal multi-cannel polarimeter (CoMP; HAO) [Tomczyk & Landi 2019]
  - Field-of-view (FoV): 1.05 to 3 solar radii and 20 cm aperture
  - Internal occulter ~Noise Level (pB) about 10^{-10}
  - Spatial Sampling: 4.5 arcsec = 9 arcsec resolution at Fe XIII lines at 1074.7 nm and 1079.8 nm
  - Image cadence with full polarimetry: 30 minutes (averaging many observations)
- CRYO-NIRSP on DKIST [Fehlmann+ 2016, Rimmele+ 2020]

- Very narrow FoV
- Degraded by stray light through Earth's atmosphere
- Rare and very low cadence

- Yang+ Science 369, 694 (2020) (indirect measurement of the plane-of-sky component of the inner coronal magnetic field).



CMAG: CORONAL MAGNETOGRAPH

- CMAG is an externally occulted coronal magnetograph: reduce diffraction straylight
- Two spacecrafts flying in formation pointing to the Sun (Proba-3 technology)
  - Orbit at the Lagrange L5 point (optimal for formation flight)
  - First spacecraft: occulter (4 meters diameter)
  - Second spacecraft: hosts the payload (transported as a piggy-back)
    - Occulter at 430 meters reduce background intensity to the required levels: minimize diffraction
- Would be an exceptional opportunity for the solar physics community
- No existing or planned mission is able to tackle these challenging measurements

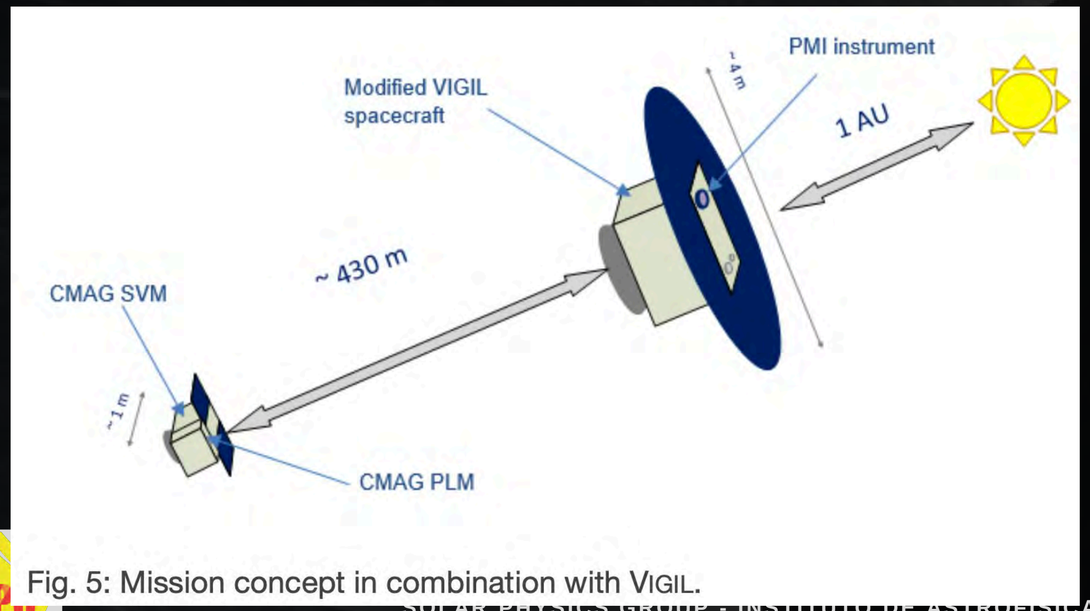
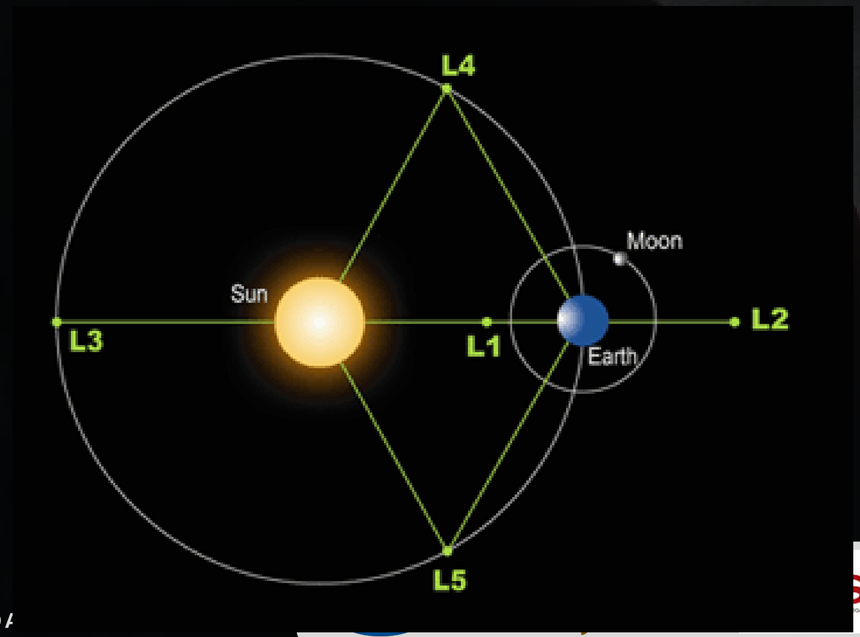


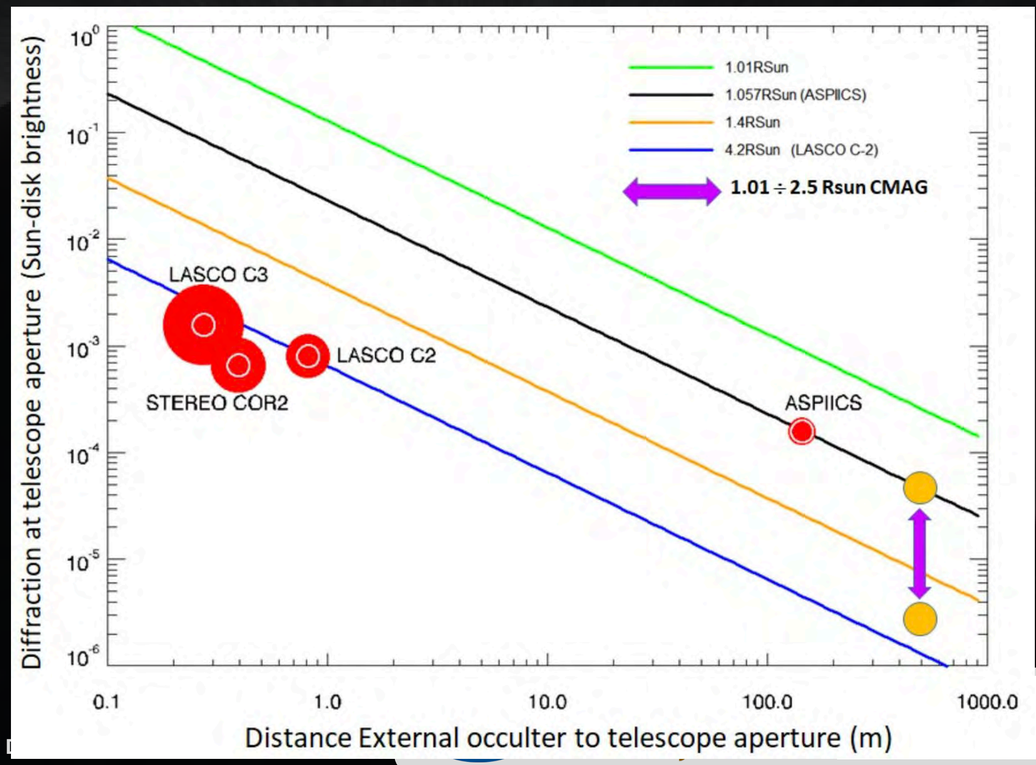
Fig. 5: Mission concept in combination with VIGIL.



CMAG: CORONAL MAGNETOGRAPH

- CMAG aims to be the first ever mission to:
  - Provide full vector spectropolarimetry in Fe XIV @ 530, Fe XI @ 789 nm, or Fe XIII @ 1074 nm of the whole inner corona between 1.02 to 2.5 $R_\odot$.
  - Provide better spatial resolution (2.5”) than former instruments/missions at a constant image quality (resolution) and cadence (1 min) which is essential for evolutionary studies and space weather prediction
  - Map the line-of-sight and plane-of-the-sky velocities of the inner corona.
  - Provide continuous vector magnetic field maps of the inner corona
- Cover most missing fundamental coronal science

- Unique combination with the ESA Space Safety Vigil mission: fills the gap between PMI (the Vigil photospheric magnetigraph) and the coronal instruments that observe the k-corona in visible light from 2.2 to 25 solar radii



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CMAG: CORONAL MAGNETOGRAPH
— THE CORONAGRAPH —

CORONAGRAPH
LYOT + EXTERNAL
OCCULTER + LYOT STOP

SPECTROGRAPH
FABRY-PEROT ($LiNbO_3$)

POLARIMETER
LCVRS

- Scientific payload:
  - ~ 10 cm aperture telescope (2.5" @ 750 nm) - Hybrid Lyot coronagraph -
  - Imaging spectropolarimeter (magnetograph and tachograph)
  - Heritage from IMaX (Sunrise I & II), SO/PHI (Solar Orbiter), and TuMag (Sunrise III)
  - Heritage from METIS (Solar Orbiter) and ASPIICS (Proba-3)

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CORONAGRAPH
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FABRY-PEROT ($LiNbO_3$)

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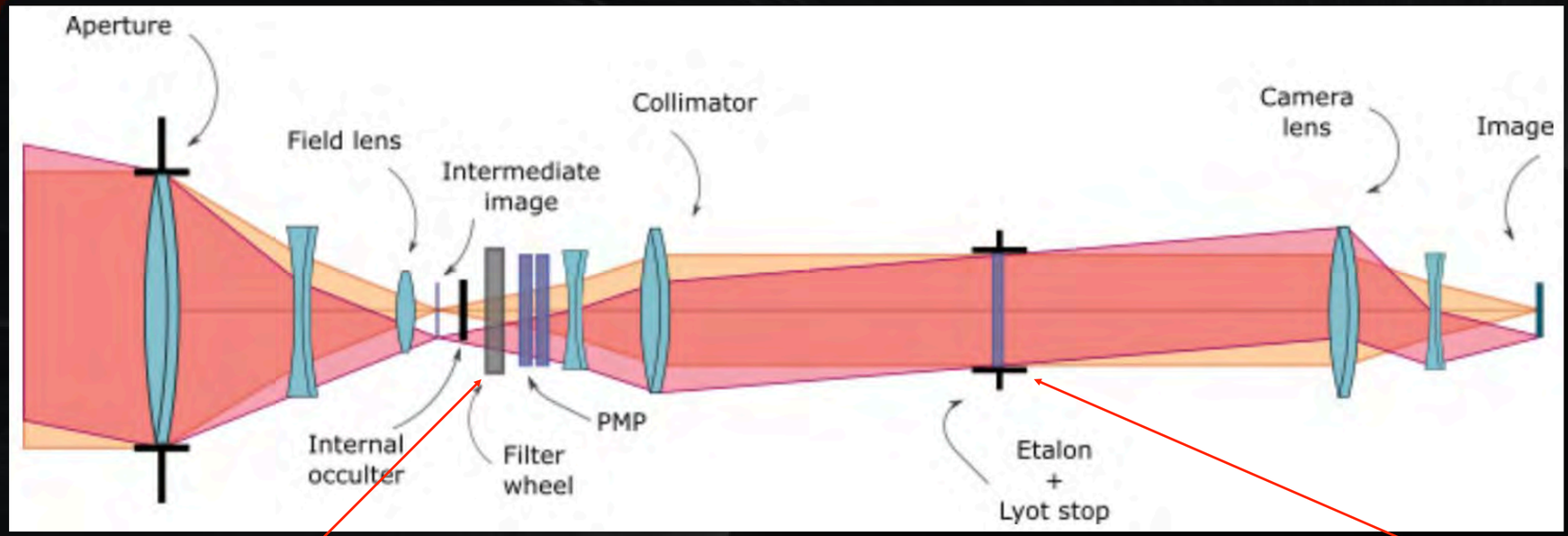

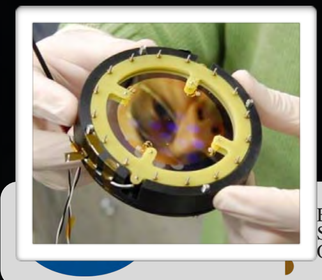

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EXCELENCIA SEVERO OCHOA
CSIC

CMAG: CORONAL MAGNETOGRAPH
— SUMMARY —

- Conceived to map the vector magnetic field and velocities of the inner corona at unprecedented spatial (2.5”) and temporal (1 min) resolutions.
- Placed at L5 for efficient formation flight technology
- Unique, low-risk, cost-effective and interdisciplinary scientific return fully relying on proven European technologies
- A leap in the current solar corona understanding, aiding coronal modeling and hence facilitating better space weather predictions.

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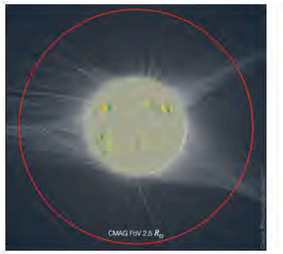

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