Space and Ground Missions and Facilities for Solar and Heliospheric Physics

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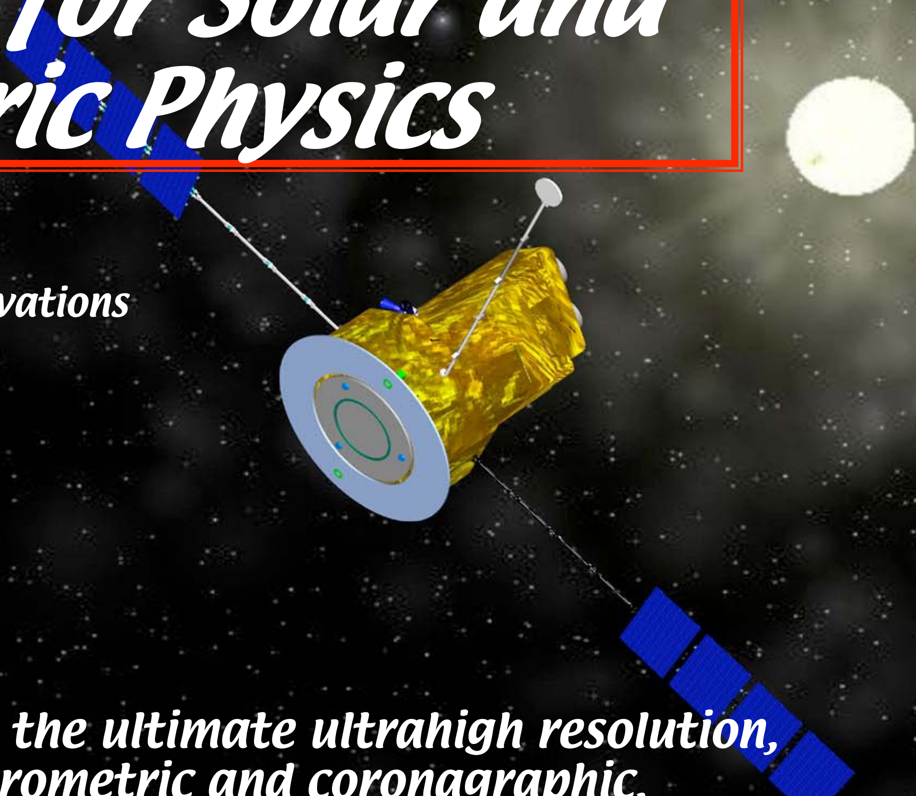
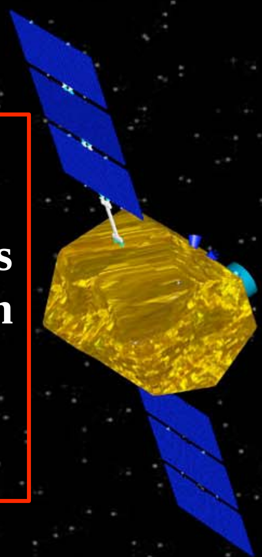
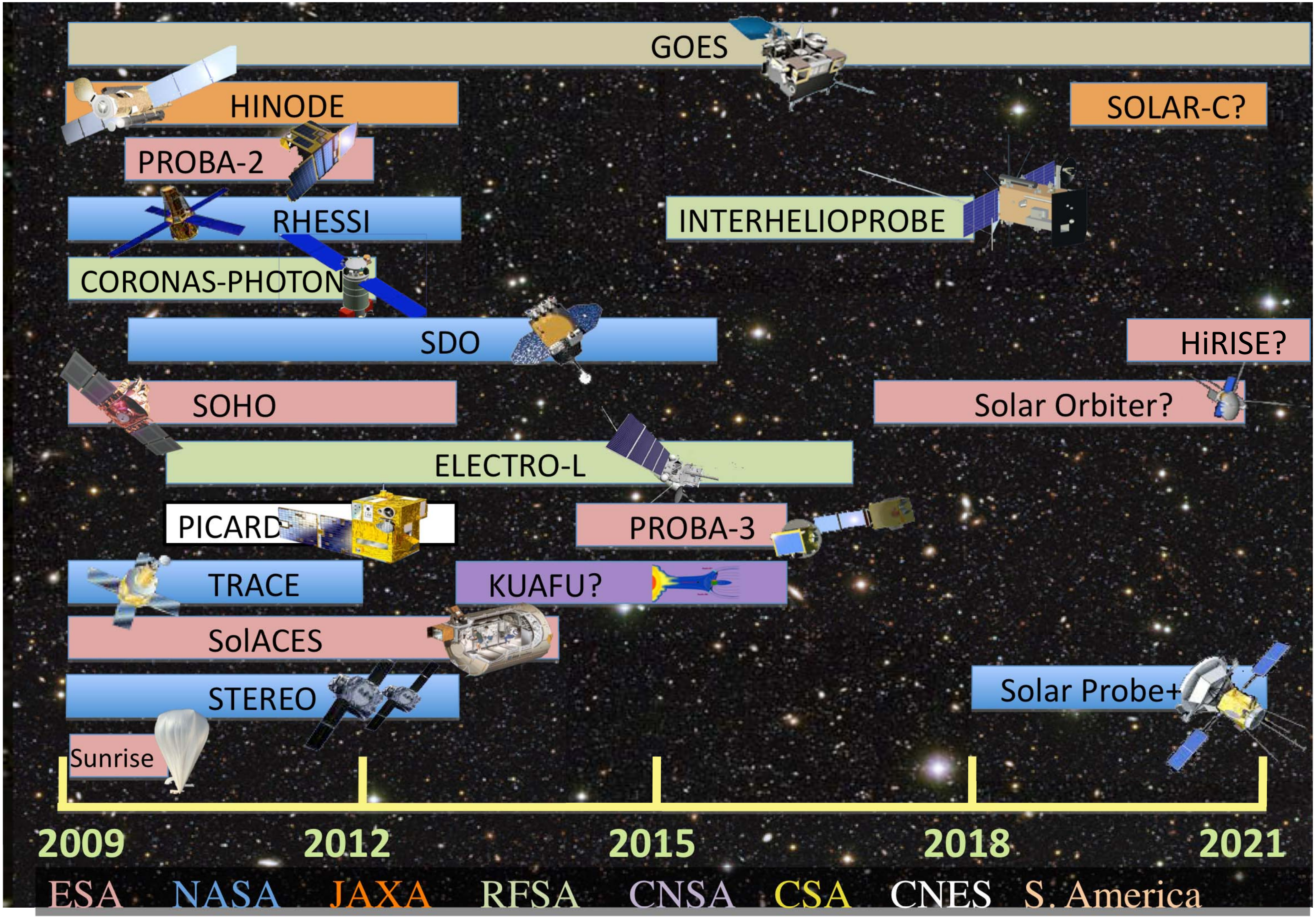


ESA Cosmic Vision: Only M Class Solar Mission pre-selected by SSWG in 2007



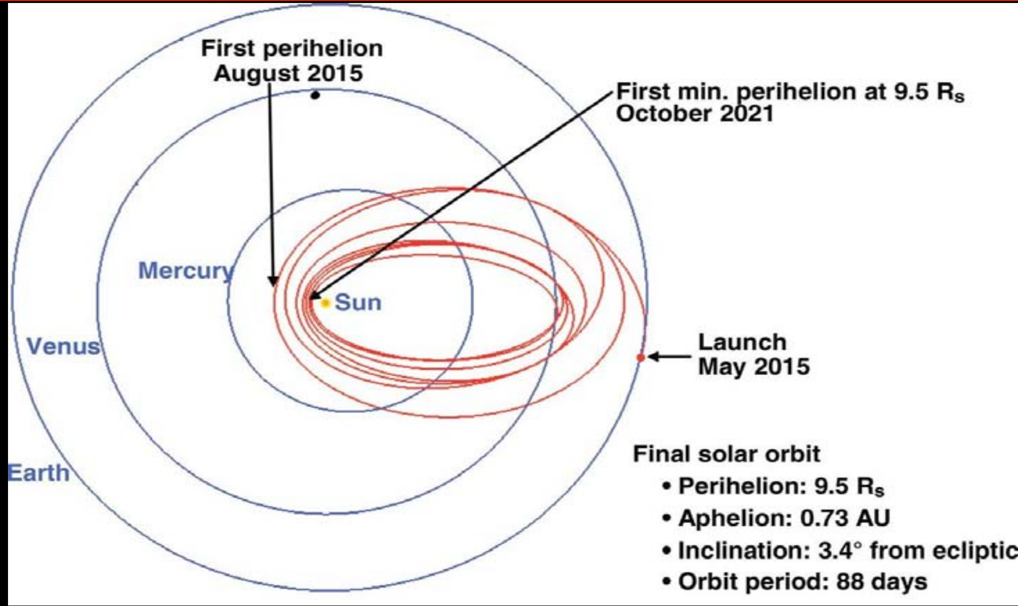
HiRISE: the ultimate ultrahigh resolution, interferometric and coronagraphic, Solar Physics Mission implementing 2 satellites in Formation Flying at L1 Lagrange point

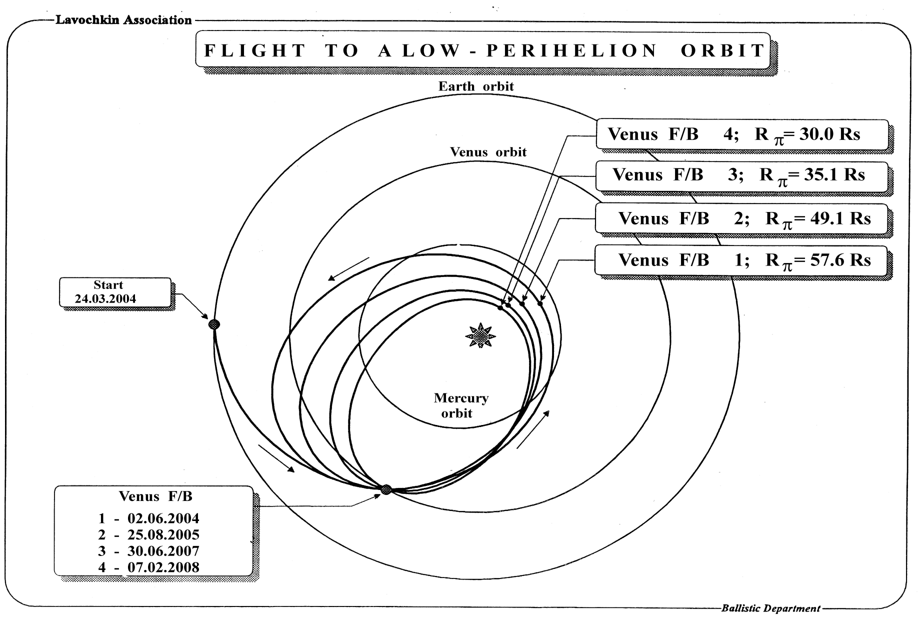
International Space Weather Initiative (ISWI)
Cairo, Egypt, November 6, 2010

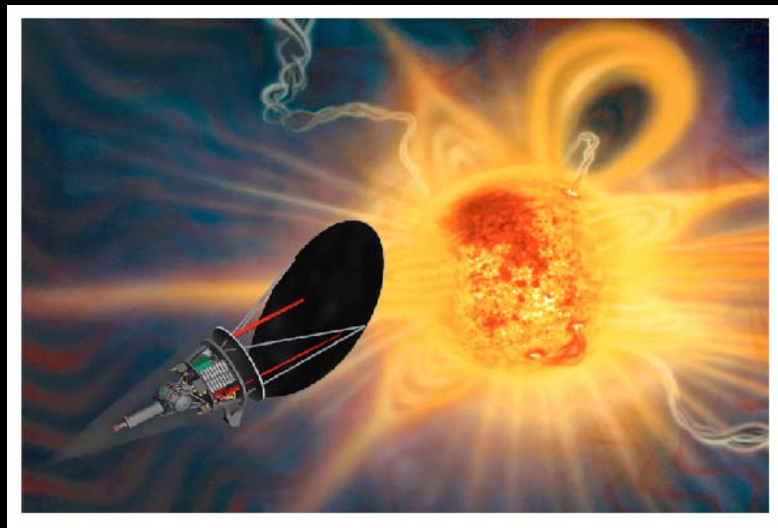

GOES
HINODE
SOLAR-C?
PROBA-2
RHESSI
INTERHELIOPROBE
CORONAS-PHOTON
SDO
HiRISE?
SOHO
Solar Orbiter?
ELECTRO-L
PICARD
PROBA-3
TRACE
KUAFU?
SolACES
STEREO
Solar Probe+
Sunrise
2009
2012
2015
2018
2021
ESA
NASA
JAXA
RFSA
CNSA
CSA
CNES
S. America

Interhelioprobe & Solar Probe+

RSA & NASA

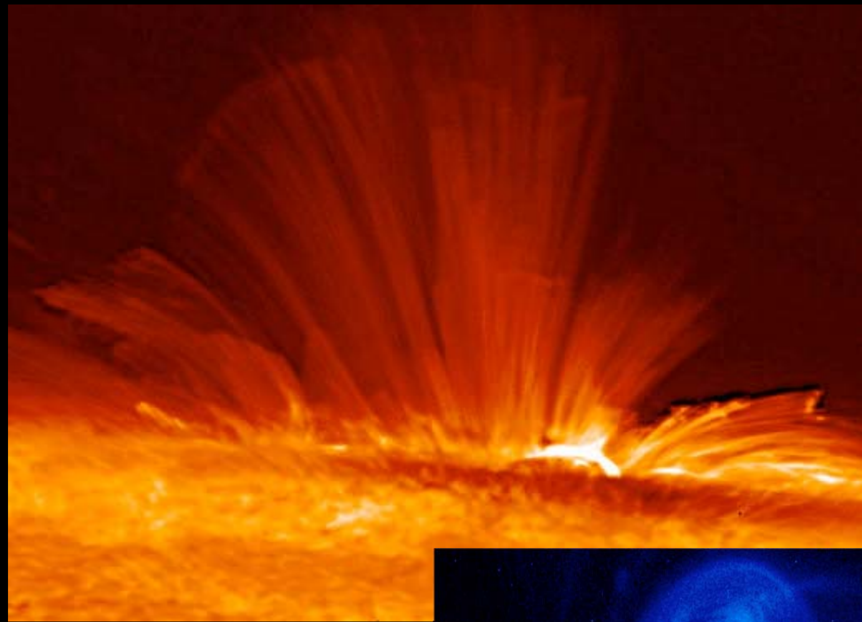


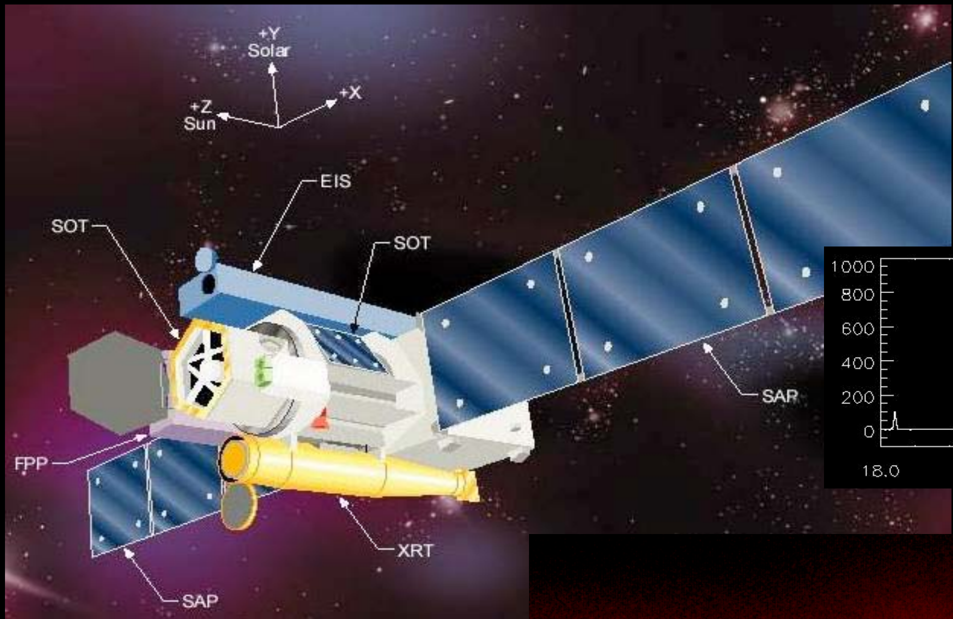


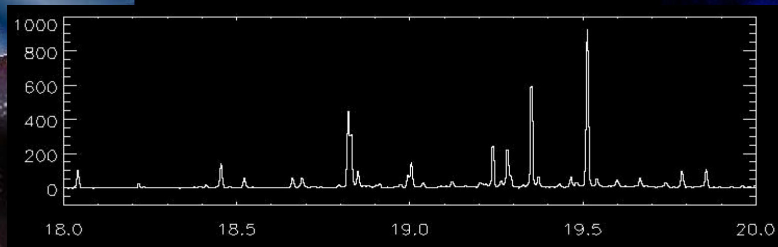


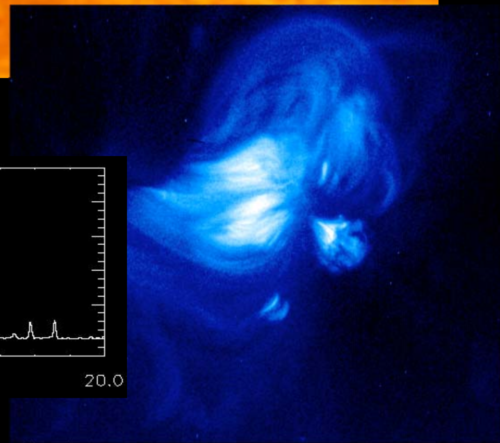
HINODE:

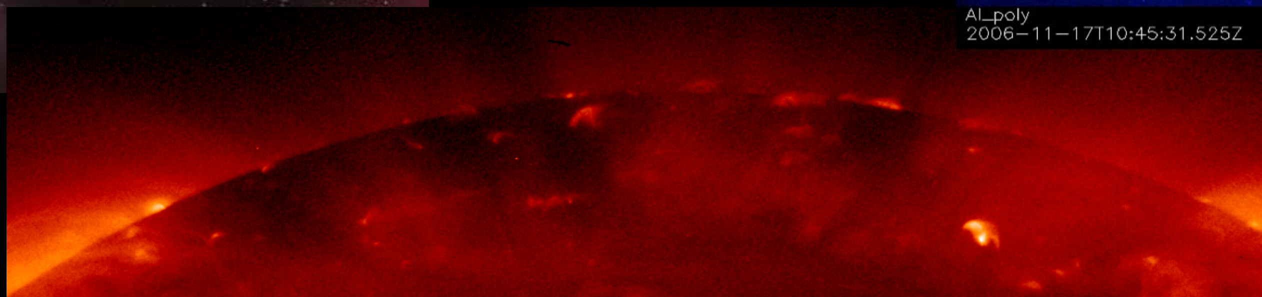
SOT (largest solar telescope flown)
XRT (best resolution SXR telescope)
EIS (EUV slit spectra & scan)



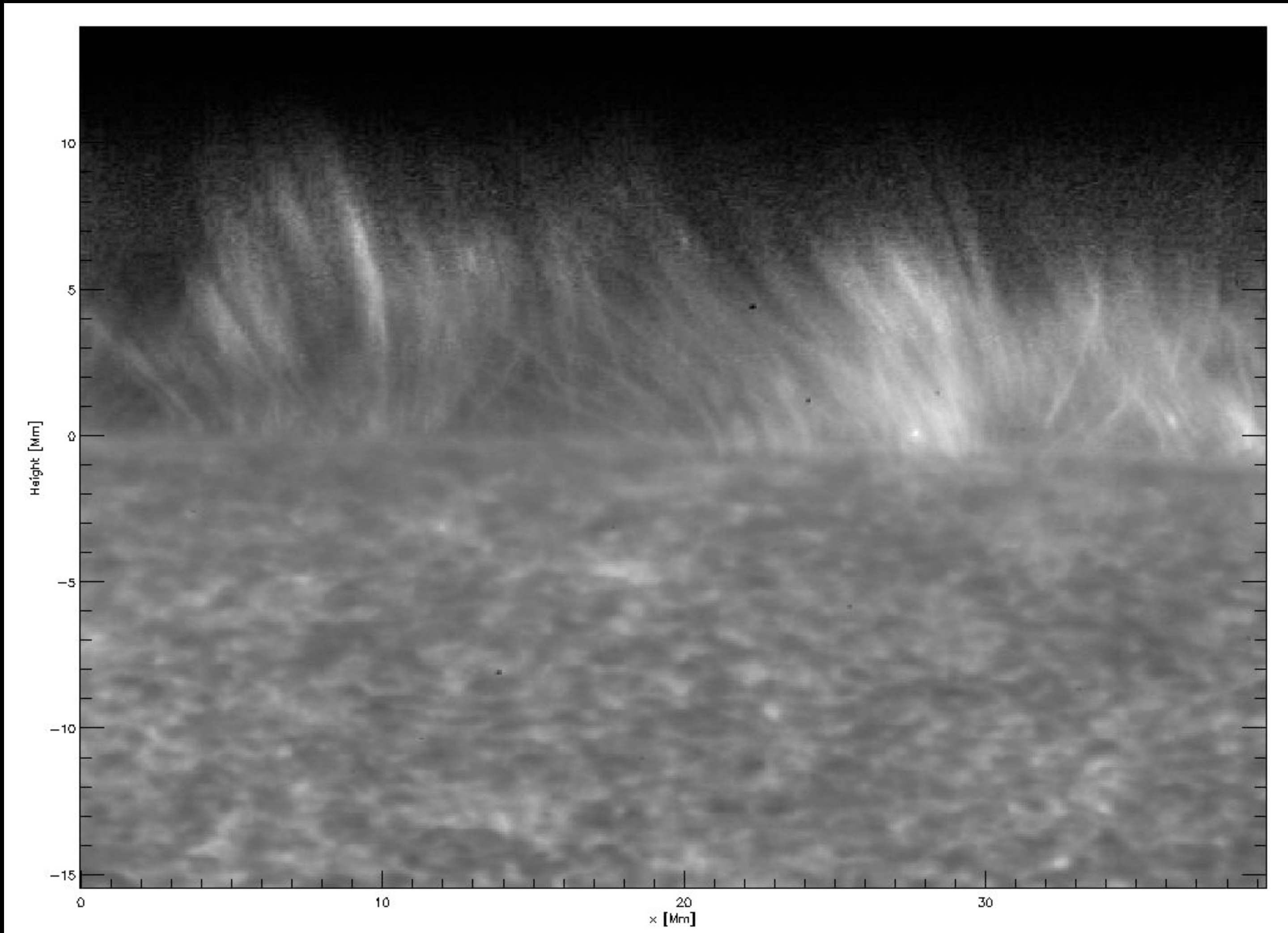








Spicules and Waves?

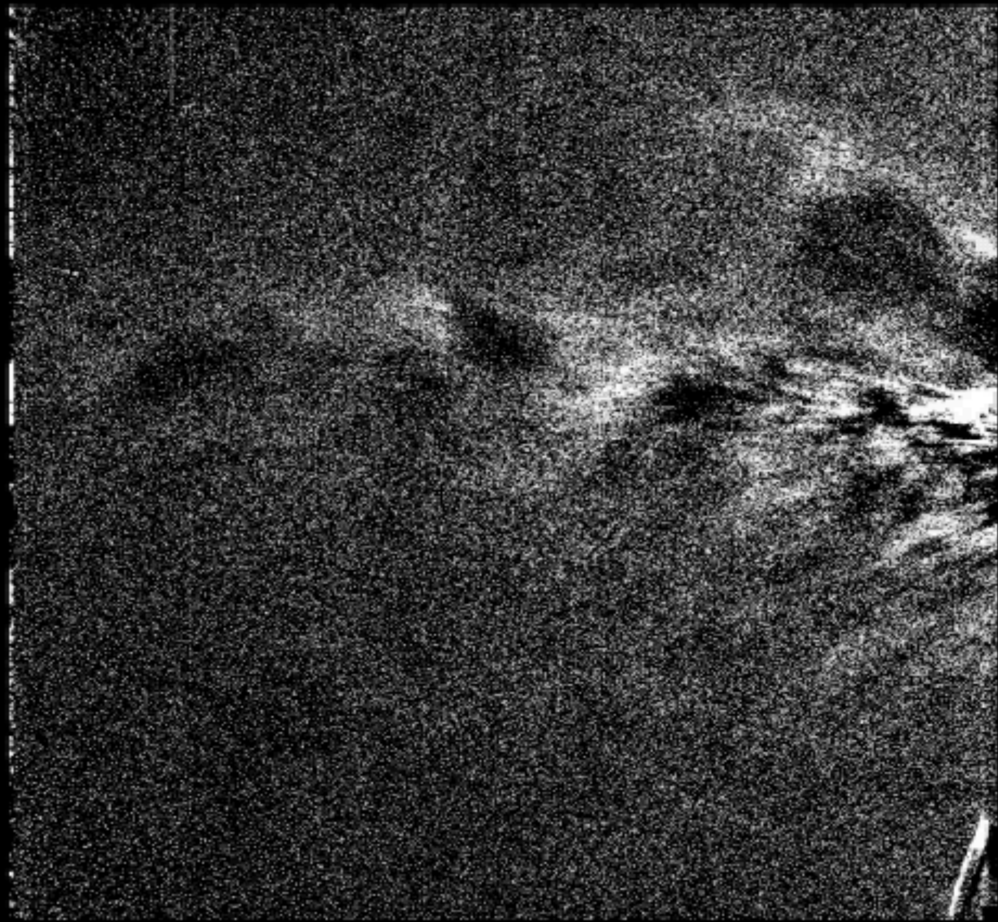


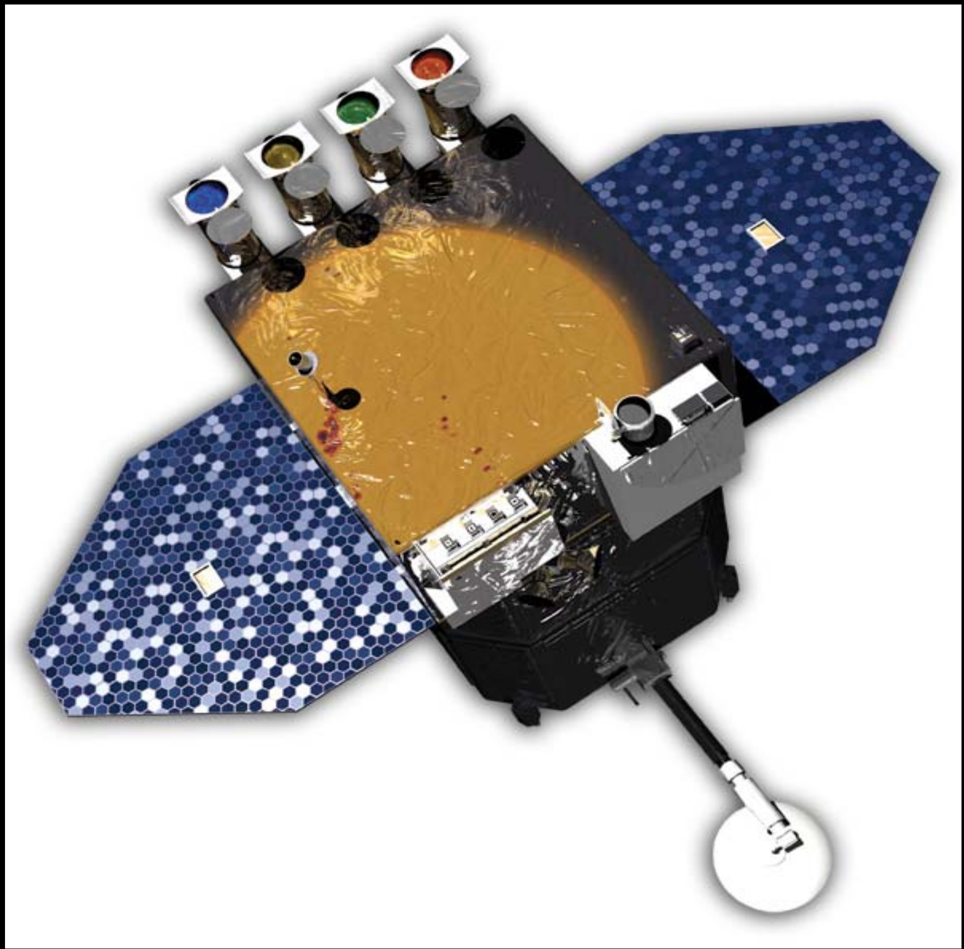
HiNODE Ca II H 3968 filter: spicules at the limb of the Sun are seen to form rapidly propelling matter upward, while moving transversely to their own long axis during their short lifetimes. Transverse motions may be caused by waves (Alfvén? MHD?) and would have enough power to drive the solar wind.

STEREO mission

1-month (Apr 2007) movie from HI-1

FOV 15 to 80 R; running difference W-L images (background subtracted): slow solar wind; comets; iCME; magnetic clouds etc.





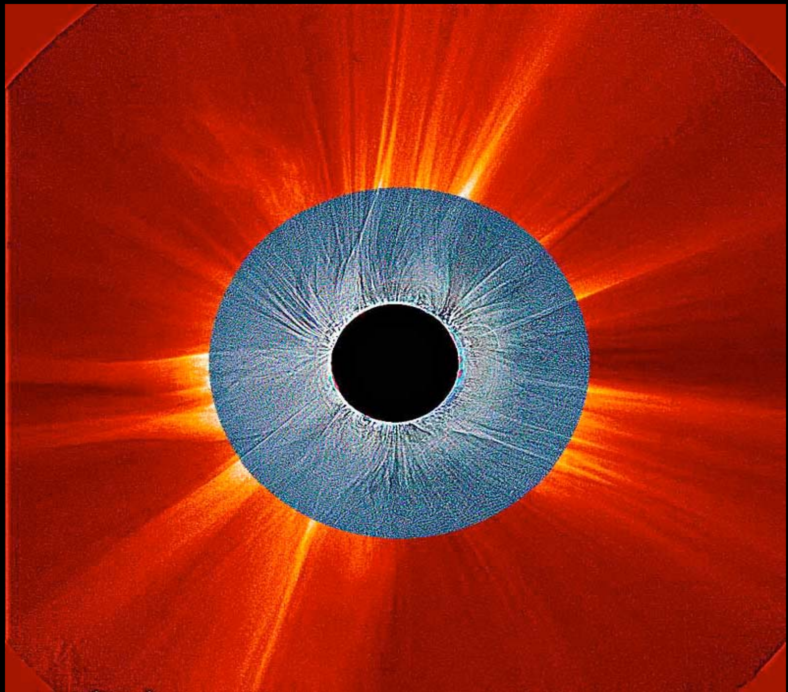
SDO, three scientific experiments:

Atmospheric Imaging Assembly (AIA)
EUV Variability Experiment (EVE)
Helioseismic and Magnetic Imager (HMI)

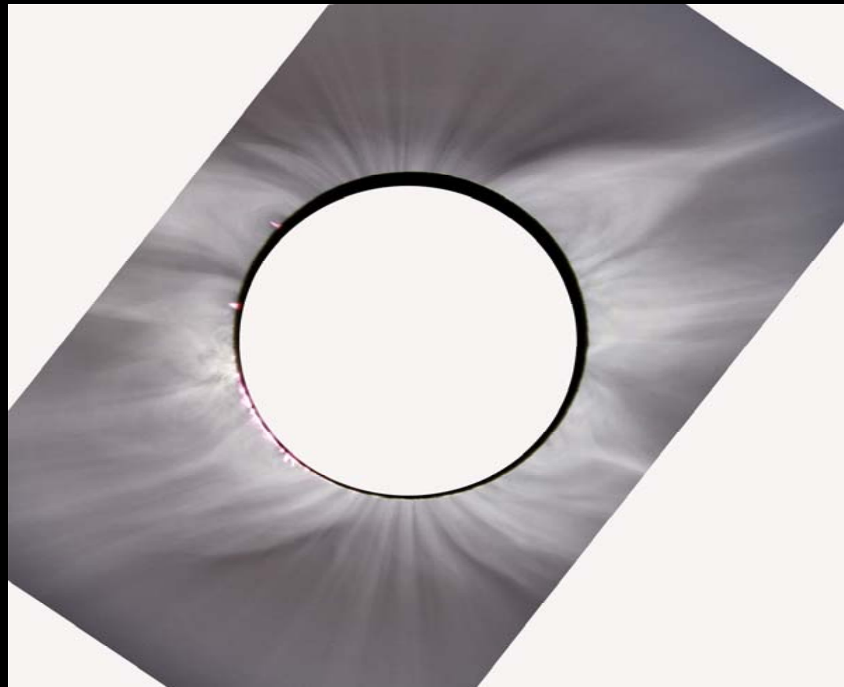
SDO is a sun-pointing semi-autonomous spacecraft that will allow nearly continuous observations of the Sun with a continuous science data downlink rate of **130 Megabits per second (Mbps)**

The spacecraft is 4.5 meters high and over 2 meters on each side, weighing a total of 3100 kg (fuel included)
SDO's inclined geosynchronous orbit was chosen to allow continuous observations of the Sun and enable its exceptionally high data rate

SOHO - Coronagraphs - Eclipses: the Inner Corona Paradigm



Composite image of the corona of the August 11th, 1999 eclipse in Iran. Inside: White Light image obtained with a radial gradient neutral filter; outside: Lasco-C2 (SoHO) image. Note the perfect correspondence of the radial fine structures (from Koutchmy et al., 2004)



Inner and middle corona through a radial filter observed during the March 29th, 2006 eclipse in Egypt (from Koutchmy et al., 2006).

Solar Astrophysics Roadmap for Ground & Space Future Facilities & Missions

- What are the current outstanding Solar Physics objectives?
- What strategy of observations between ground (including eclipses and best possible sites: Antarctica Dome C / Concordia) and Space?
- What instruments to achieve the scientific objectives and benefit the remarkable conditions offered on ground (noticeably Dome C / Concordia) and Space?

What are the Current Outstanding Solar Physics Objectives?

- Chromosphere, Transition zone & Corona:
  - Require spectroscopy and imaging at very high spatial and temporal resolution of the Chromosphere-Corona interface in order to reveal the true nature of the waves (MHD, Alfvén) barely detected by HiNODE limited spectroscopy (no line width) and resolution (200 km) - although current path for problem solving
  - No current mission (SDO included) is addressing this issue (nor coronagraphy)
- Chromosphere–Corona: the change of regime
  - Dramatic change in the spatial distribution of both the line emission and the velocity pattern is observed between the Transition Region and the low corona: rapid variation with mn of time to slow variations of hours to a day
  - Comparison of intensity and velocity maps suggest that plasma at TR temperatures occurs in loops at separated coronal temperatures

Interlinked Science Themes

4 Interlinked & Complementary Themes to trace the magnetic field from the solar core to the corona and interplanetary medium (at the L1 Lagrange point… HiRISE case):

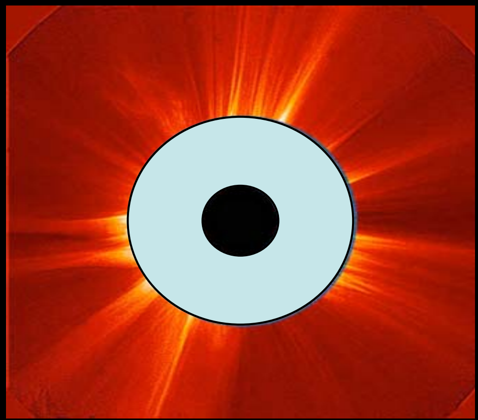
T1: Fine structure and (magnetic - waves) coupling of the Chromosphere –TR – Corona interface

T2: Heating, dynamics & magnetic field of the corona

T3: Local and global magnetohelioseismology

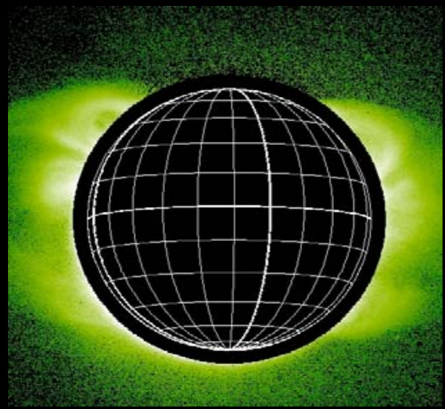
T4: Solar Variability & Space Weather

Current Observational Status of the Inner Corona



SOHO/LASCO-C2

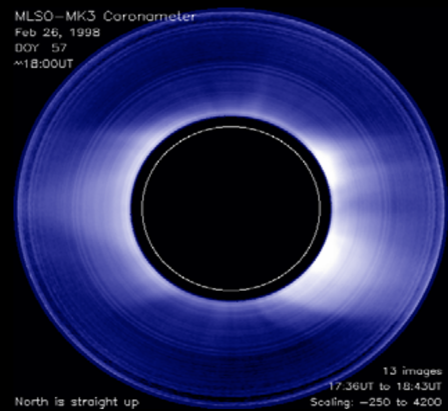
R > 2.5 R_{sun}



SOHO/LASCO-C1

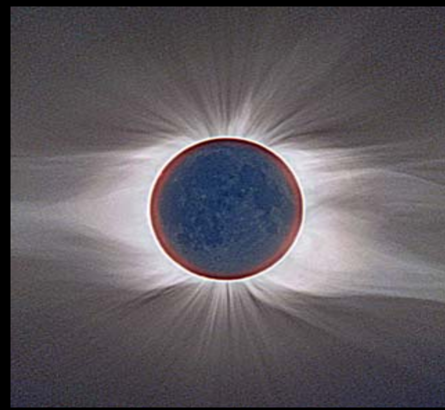
high level of straylight

and operated at solar minimum only



Ground-based coronagraph:

low spatial resolution and atmospheric noise



Total solar eclipses:

ideal but very rare, meteo dependent, and only a snapshot!

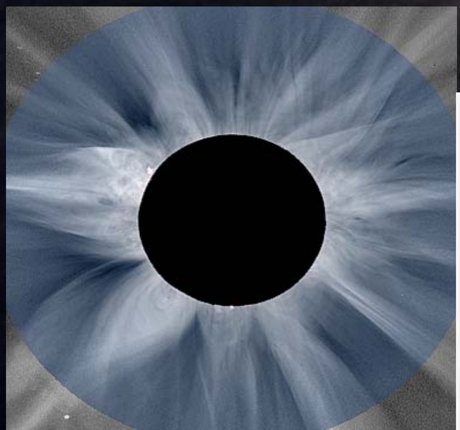
- After 40 years of space coronagraphy the lower corona (< 2.5 Rsun) remains practically unobserved
- Recent mission STEREO/COR-1 is also affected by large amounts of stray light and needs an elaborated data reduction process to reveal bright structures from 1.4 R_{sun}

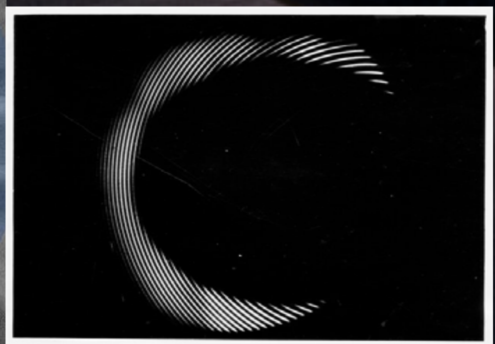
ASPIICS/PROBA-3 Formation Flying Externally-Occulted Giant Coronagraph Mission

Philippe Lamy[1], Luc Damé[2], Sébastien Vivès[1], Andrei Zhukov[3]
and the ASPIICS Team

[1]Laboratoire d'Astrophysique de Marseille (LAM), France
[2]LATMOS/IPSL/CNRS/UVSQ, Guyancourt, France
[3]Royal Observatory of Belgium, Uccle, Belgium

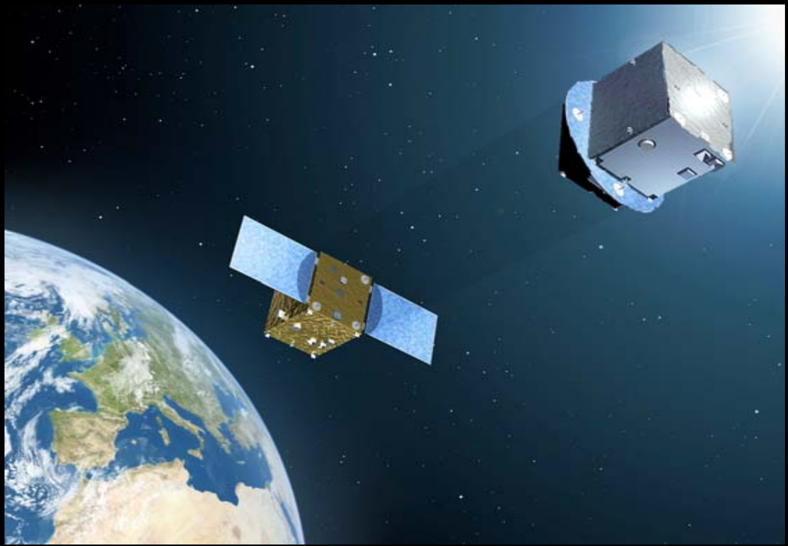
A precursor Formation Flying coronagraph for imaging and 2D spectroscopy of the inner solar corona

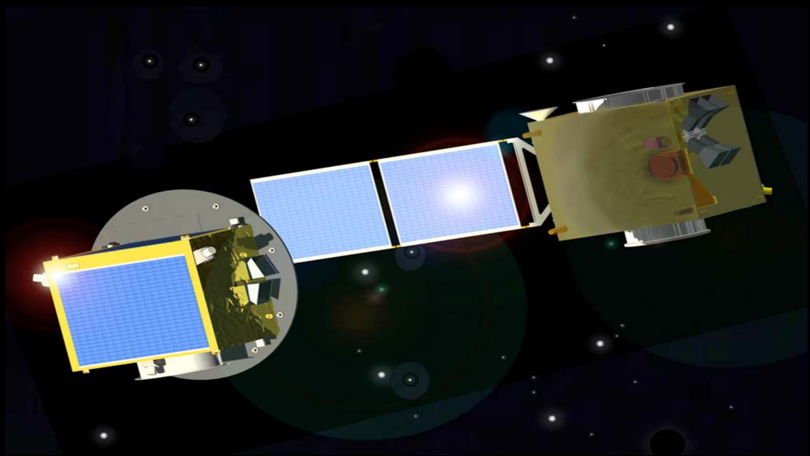




D23-E33 Multi-Spacecraft Observations
and Modelling of CMEs
and Stream Interaction Regions
COSPAR, Bremen, July 24, 2010

ESA/PROBA-3 Mission Concept





A coronagraph with the external occulter on one spacecraft and the optical instrument on the other spacecraft, ~150 meters from the first one

Objectives

- Formation Flying Demonstration: performance of high precision FF pointing and maneuvers of relevance for future FF missions
- Development, qualification and in-orbit validation of FF technologies (sensors, actuators, etc.)
- Design, development and validation methods for FF systems
- Science guest payload: ASPIICS Solar Coronagraph performing inner corona unique observations

Science addressed: heating and dynamics of the very inner Corona

- A giant externally occulted coronagraph like ASPIICS offers a unique perspective to study processes occurring very near above the solar limb, from 1.02 R_{sun} (20 arcsec) to 3 R_{sun}
- ASPIICS will allow characterizing the main magnetic, dynamical and thermo-dynamical processes in the very inner corona (almost down to transition region)
- High resolution 2D coronagraphy and polarimetry in the Fe XIV coronal Green Line (530.3 nm) address the following questions:
  - How is the corona heated? What is the role of waves?
  - How are the different components of the solar wind, slow and fast, accelerated?
  - To what degree do coronal inhomogeneities affect the heating and acceleration processes?
  - How are CMEs accelerated?
  - What is the nature of the interaction between the CME plasma and the magnetic field that drives the eruption?
  - What is the value and configuration of the magnetic field in the corona?

Imaging and Spectroscopy are Complementary THROUGHOUT the Solar Atmosphere

This is high resolution spectroscopy (HRTS 1978) that first showed the need for **Very High Spatial Resolution (<< 0.1”)**

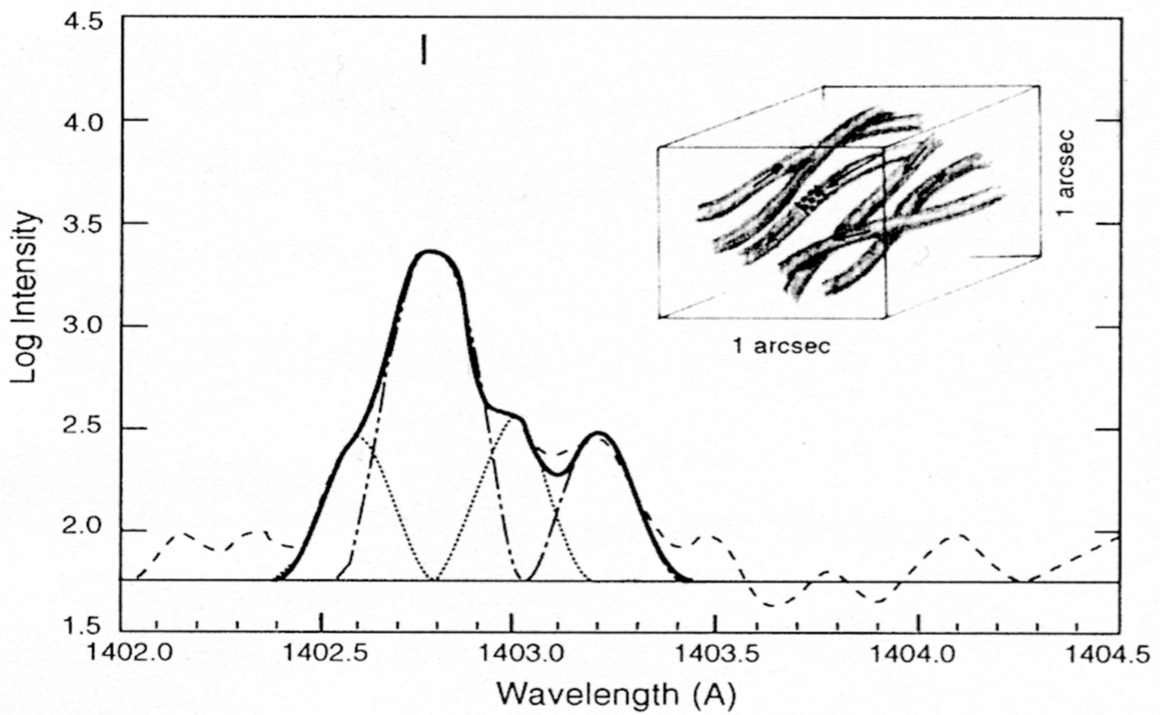


Figure 6. A complex 1402 Å profile observed with HRTS on 13 February 1978 (the 1393 Å line shows similar features). The profiles represents the emission from a 1 × 1 arc sec area on the Sun and have been fitted with Gaussian line components (solid line) and each line component is indicated. The raw data is the dashed line. Inserted is a cartoon of a possible explanation of the observed profiles.

Fine Structure: strands sub- & supersonic

(Brekke, 1999)

Filling Factor

1%: 0.1"

0.1%: 30 mas

UV & FUV

LATMOS

Institut Pierre Simon Laplace

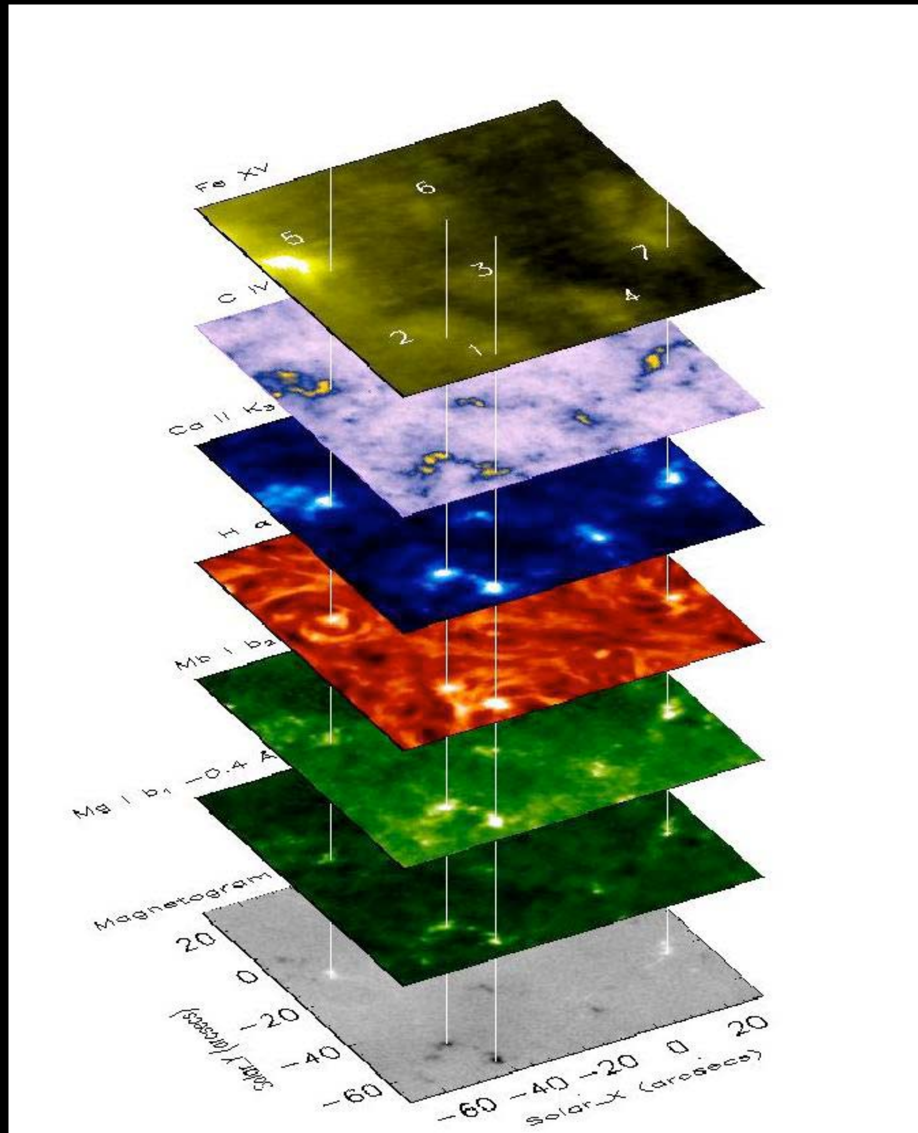
Future Missions Needs

- Doppler information
- Temperature coverage, Discrimination
- Resolution, resolution

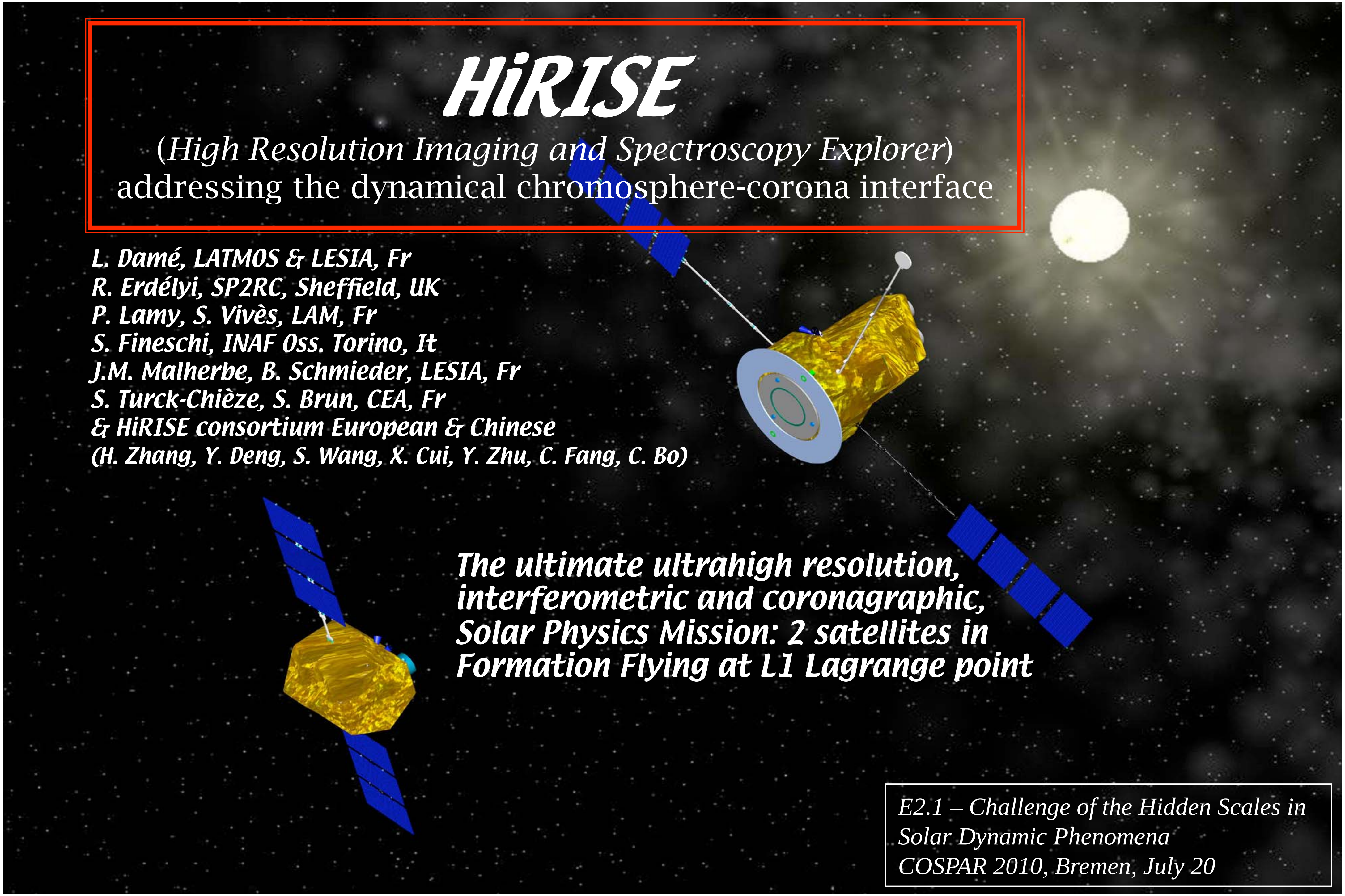
↓

- 3D view
- Fast spectral imaging: 2D spectroscopy
- Very high spatial, spectral & temporal resolutions

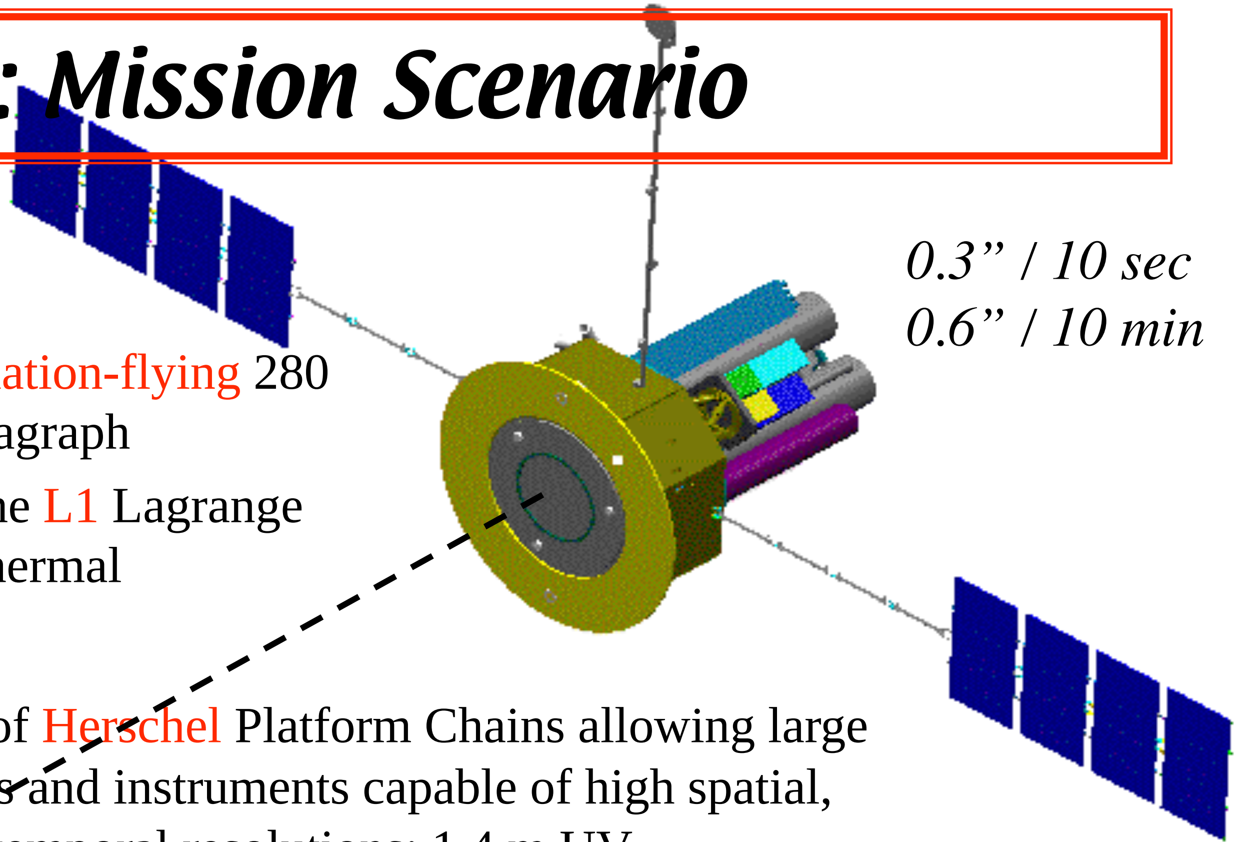
+ Inner Corona and B Field



(McAteer et al., 2003)

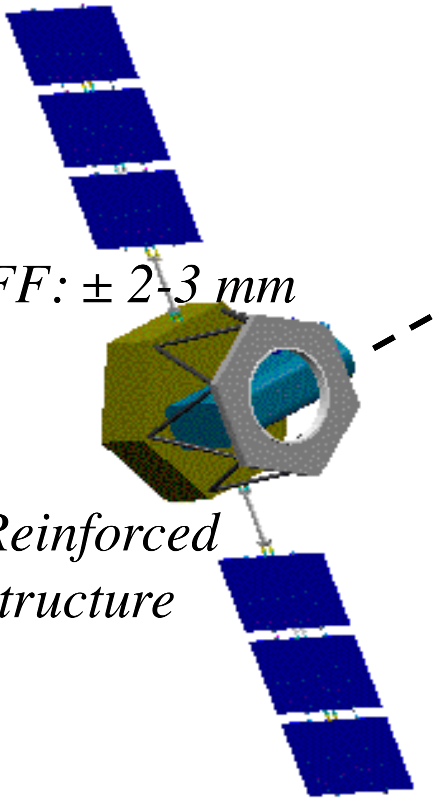

HiRISE
(High Resolution Imaging and Spectroscopy Explorer)
addressing the dynamical chromosphere-corona interface
L. Damé, LATMOS & LESIA, Fr
R. Erdélyi, SP2RC, Sheffield, UK
P. Lamy, S. Vivès, LAM, Fr
S. Fineschi, INAF Oss. Torino, It
J.M. Malherbe, B. Schmieder, LESIA, Fr
S. Turck-Chièze, S. Brun, CEA, Fr
& HiRISE consortium European & Chinese
(H. Zhang, Y. Deng, S. Wang, X. Cui, Y. Zhu, C. Fang, C. Bo)
The ultimate ultrahigh resolution, interferometric and coronagraphic, Solar Physics Mission: 2 satellites in Formation Flying at L1 Lagrange point
E2.1 – Challenge of the Hidden Scales in Solar Dynamic Phenomena
COSPAR 2010, Bremen, July 20

HiRISE: Mission Scenario



HiRISE:

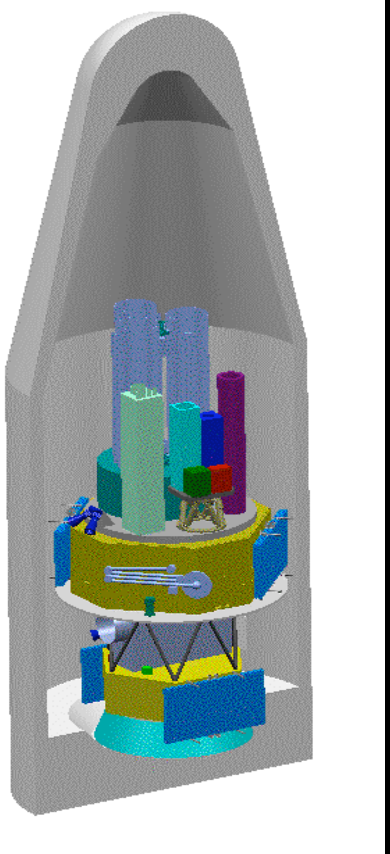
- Two satellites in "simple" formation-flying 280 m apart, forming a giant coronagraph
- Injected together (stacked) at the L1 Lagrange point 1.5 millions km: stable thermal environment



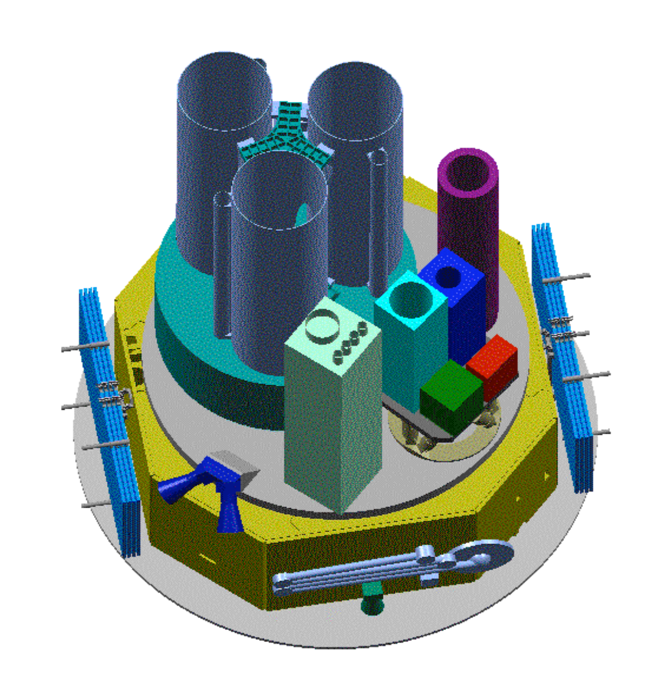
- Heritage of Herschel Platform Chains allowing large telescopes and instruments capable of high spatial, spectral, temporal resolutions: 1.4 m UV interferometer (3 x 500 mm telescopes) and 3D imaging spectro-polarimetry
- TTC: 40 cm Ka-band antenna @ 75% (30 Mbit/s) - Storage 100 GB /day (8 cards)
- Ergols for 15 years since L1 5 m/s / year (2 kg / year) with 30 to 60 kg available
- Chaser satellite: reinforced structure (carbon bars) & Cold Gaz Module (lifetime > 15 years)

A Major Payload (640 kg) Thanks to a Careful Mission Scenario

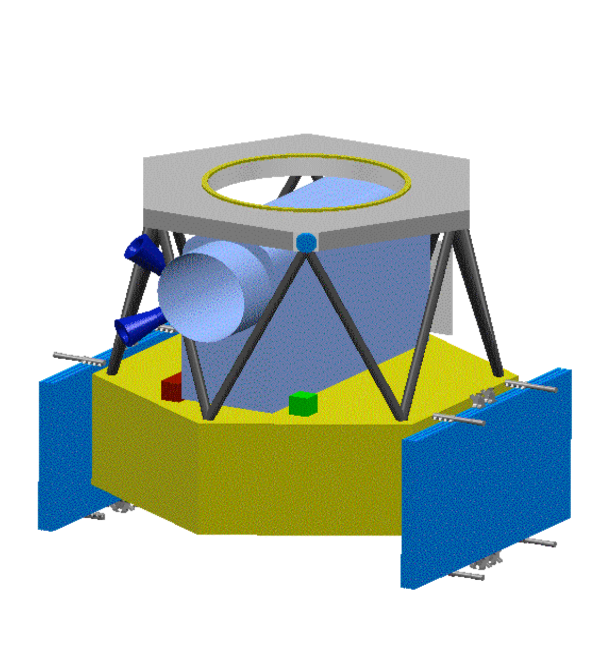
- Stacked Composite (NO SYLDO) for the two satellites
  (reinforced chaser platform: carbon tubes' structure 96 kg)
- Soyuz-Fregat launched from Kourou (ideal injection point)
  2040 kg available for L1 - 24% compliant margin (373 kg)



Soyuz with Stacked Composite



Main Satellite

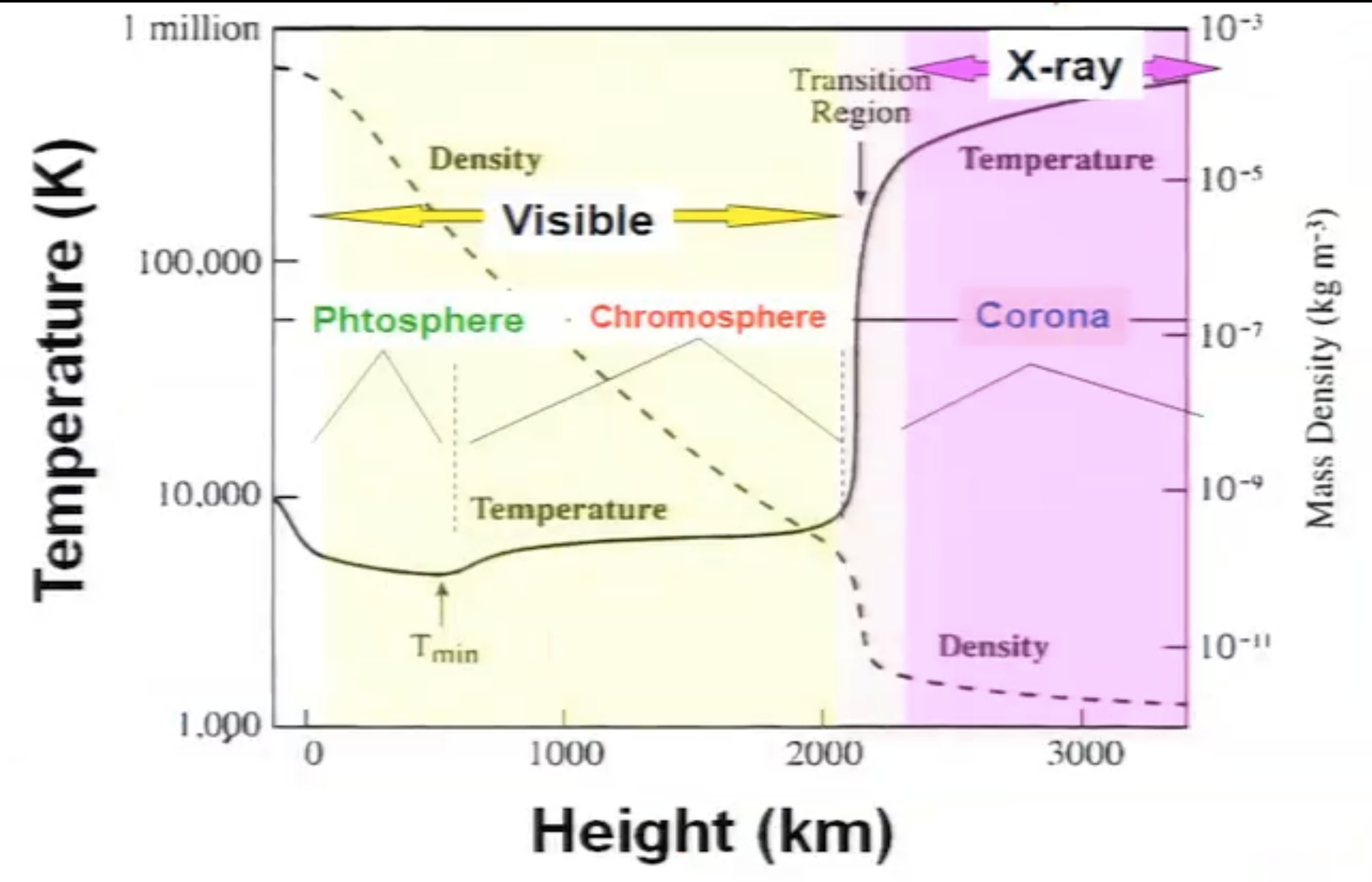


Chaser Satellite

High Resolution Roadmap for Future Space Missions and Observatories

- Following HiNODE, the accent is on the chromosphere-corona interface at high resolution: 3 proposals at Cosmic Vision 2007 (including HiRISE) and, now, Solar C version B (JAXA)
- HR & Coronal Mission perfectly justified after/complementing in-situ missions, Solar Probe+ & Interhelios Probe
- Cosmic Vision 2 is BEFORE Solar Orbiter selection <u>or</u> non-selection and, so, if the third mission is not Solar Orbiter, it could/should be HiRISE for very high resolution & coronagraphy of the inner corona
- HiRISE is also Chinese (NAOC, NIAOT, Nanjing, PMO, Changchun) rather than US. Possible in 12 years (2022) before the US plan next mission in 2026 (Europe/China before US?)

HiRISE: very strong Solar Science Case for High Resolution ZT/inner corona



HiRISE: very strong Solar Science Case for High Resolution ZT/inner corona

4 major, interlinked & complementary themes to trace the magnetic field from the solar core to the corona and to the interplanetary medium (L1 Lagrange point)

T1: Fine structure and (magnetic - waves) coupling of the Chromosphere –TR – Corona interface (dynamics of the small scale structure of active and quiet magnetic fields and its relation to coronal heating)

T2: Heating, dynamics & magnetic field of the corona (with direct coronal magnetic fields measurements IR and UV)

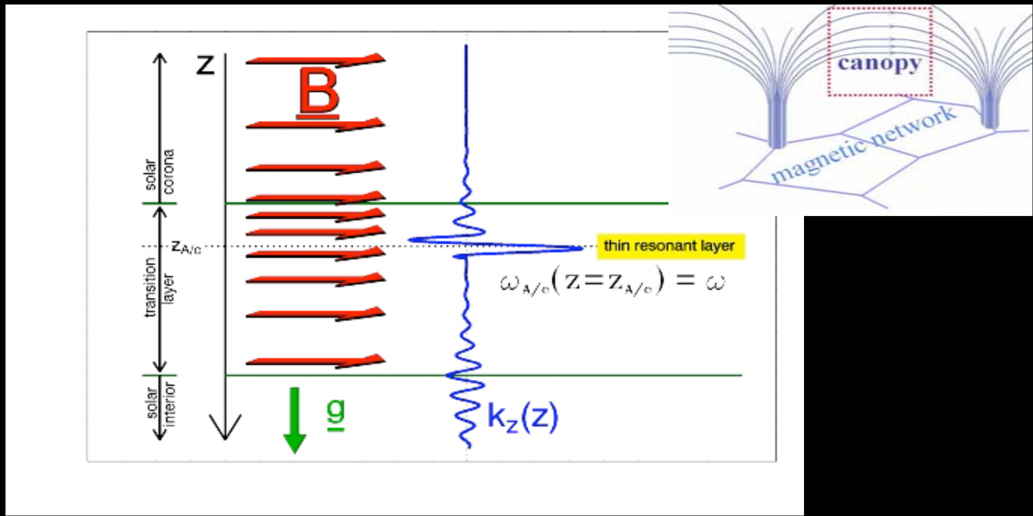
T3: Local and global magnetohelioseismology; oscillations and energetics of the chromospheric small scale structure, noticeably spicules (mass); magneto-hydrodynamics of sunspots

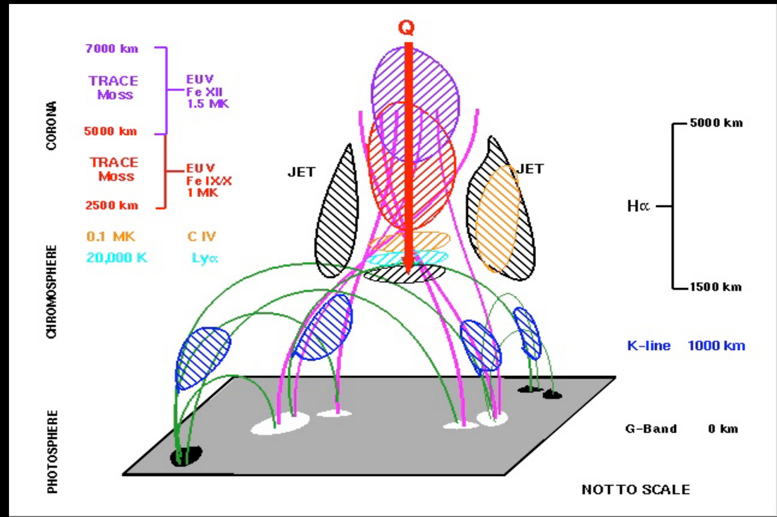
T4: Solar Variability, Space Weather and Space Climate

LATMOS

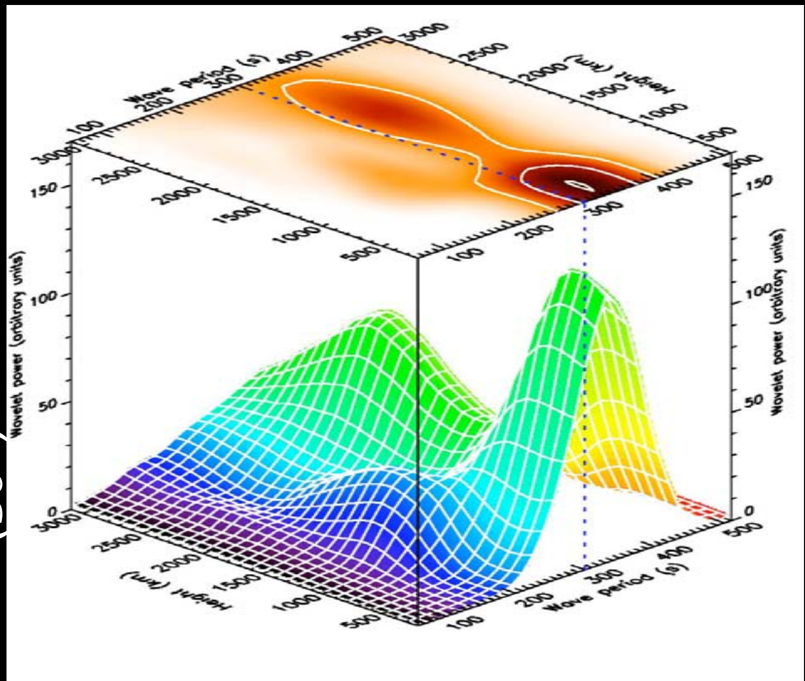
Sciences de l'environnement Institut Pierre Simon Laplace

Dynamical Coupling Convection-Chromosphere-TR





Inclined flux tube (50°)



Chromospheric dynamics in inclined flux tubes is dominated by five minute periods because of significantly increased leakage of photospheric *p* modes ➡ fine dissipating extended structures (**spicules**)

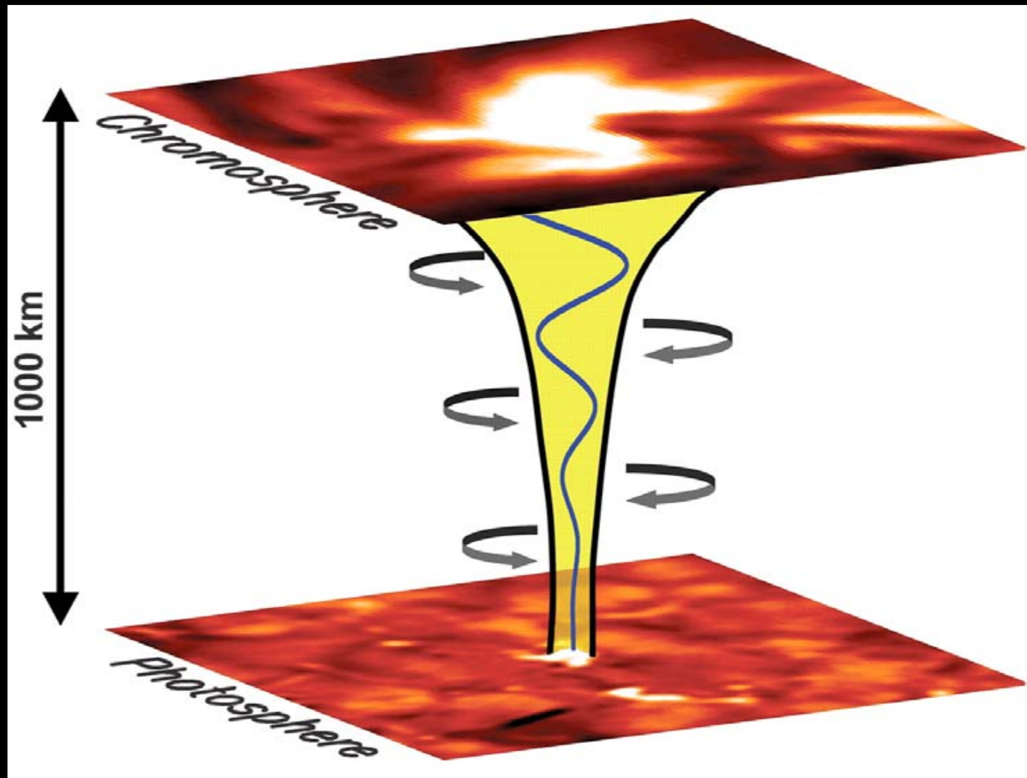
Erdélyi (2003)

Erdélyi <u>et al.</u> (2007)

Chromospheric Torsional Alfvenic Perturbations

Expanding magnetic flux tube sandwiched between photospheric and chromospheric intensity images, undergoing a torsional Alfvenic perturbation and generating a wave that propagates longitudinally in the vertical direction

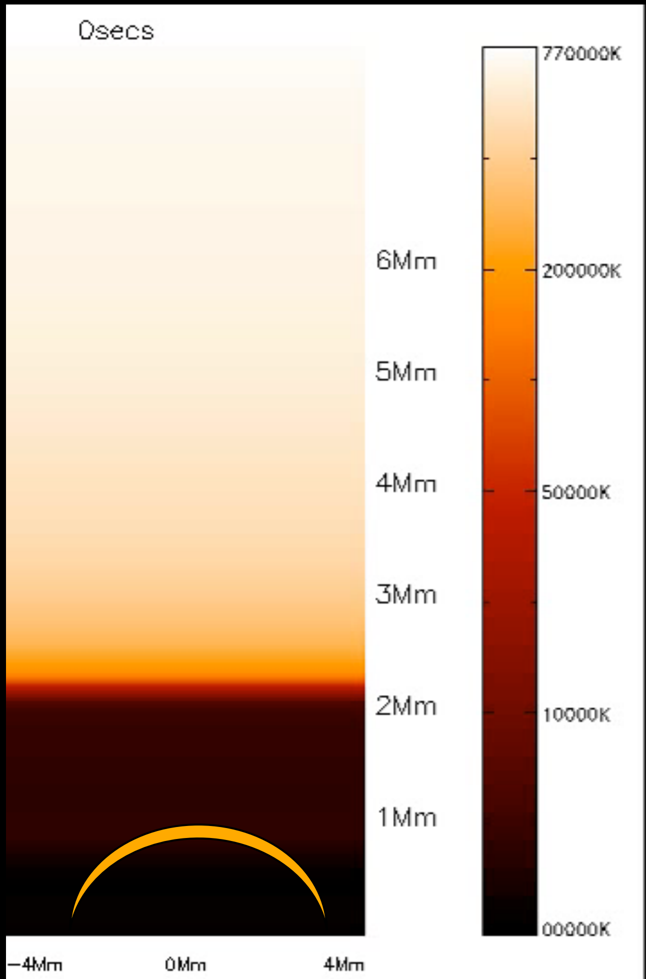
- Disk observations have been performed in an active region at the SST in H-alpha
- Alfvén waves in flux tubes could manifest as torsional oscillations that create simultaneous blue and red shifts, leading to the nonthermal broadening of any isolated line profile, and should thus be observed as full-width half-maximum (FWHM) oscillations



(Jess et al., Science 323, 1582–1585, 2009)

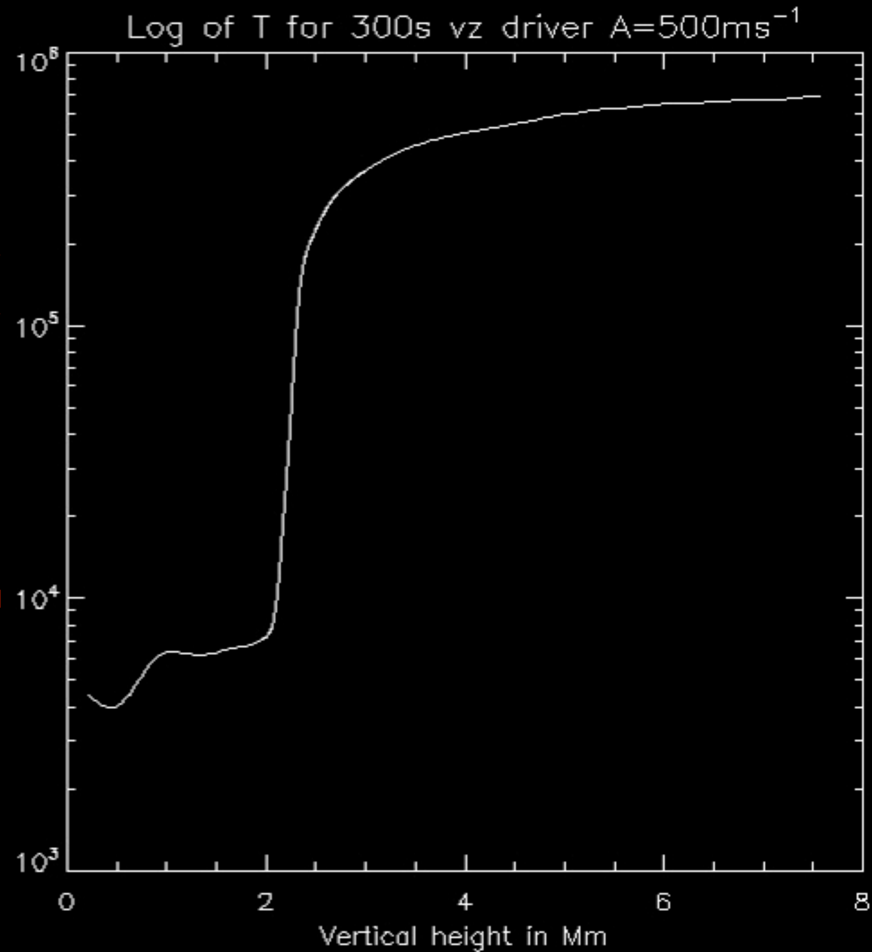
Wave Coupling into Transition Region

Height (measured from VAL z=0)



Driver

Temperature (K)



HiRISE Model Payload

Scientific Payload Concept **–** The HIRISE payload is distributed on two satellites 280 m apart with respective payloads (instruments) of 480 and 160 kg. The major payload includes 8 instruments (2 in the I2P, the Interferometer Instrument Package), in a volume of Ø2.6 m by 3 meters high:

- SOLARNET Interferometer (3x500 mm telescopes, 1.4 m baseline, actively cophased) .. 120 kg
- *I2P-1*: UV Imaging Spectrometer (UVIS) — subtractive double monochromator & IFTS.. 80 kg
- *I2P-2*: high resolution Vector Magnetograph (VM).. 80 kg
- EUV Imaging Spectrometer.. 50 kg
- EUV/XUV Imaging Telescope (full and resolved Sun)... 50 kg
- MOF (Magneto Optical Filter) for full Sun magnetograph and oscillations .... 40 kg
- NSSOT, solar shape & solar limb oscillations (full Sun 220 and 160 nm imaging)............. 35 kg
- PREMOS (TSI and Photometers with EUV, FUV, NUV, VIS & NIR channels)................ 11 kg
- STIP (Spectral and Total Irradiance Package) .... 14 kg

On the second satellite, in formation flying at 280 m (on a smaller platform):

- SuperASPIICS Green, IR (1074.7 nm) and UV giant externally occulted coronagraph .... 160 kg

To this set, 2 additions are considered:

- *in-situ* solar wind monitoring on the chaser satellite (particles and magnetic field)..........< 15 kg
- GOLFNG multi-points velocity oscillations on the Hexapod on the main satellite ....< 35 kg

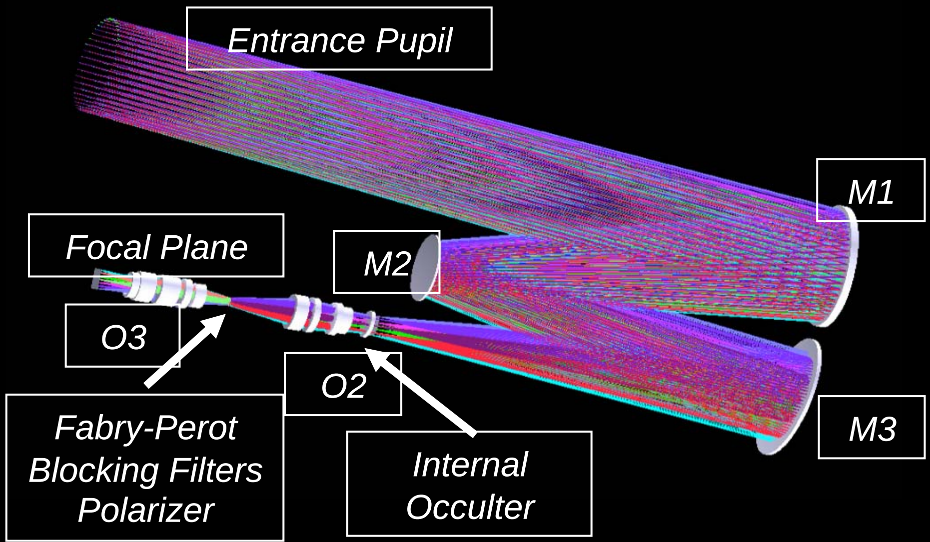
HiRISE Main Satellite:
Instruments' Resources Summary

Name	Measurement	Specifications	Mass kg	Volume (mm^3) L x W x H*	Power Watt	Telemetry Mbits/s
SOLARNET	3 telescopes interferometer	3 x 500 mm SiC mirrors cophased	120	Ø1500 x 2000	120	<0.1
I2P: Ultraviolet Imaging System (UVIS)	Very high resolution disk and limb imaging and spectroscopy	UV and FUV spectroheliograms between CIII 117.5 nm and the MgII lines 280 nm	80	Ø1500 x 800	120	3
I2P: Vector Magnetograph (VM)	2D Stokes profiles in the range 390 to 660 nm	8 channels simultaneously at $0, \pm \Delta\lambda, \pm 2\Delta\lambda, \pm 3\Delta\lambda, -4\,\Delta\lambda$	80		80	2
EUV Imager and Spectrometer	Imaging and diagnostics of TR and corona	EUV emission lines	50	Ø350 x 2000 (Telescope Ø250)	50	0.8
X-ray / EUV Imager	Coronal imaging	UV continua, Lyman-alpha, He and Fe Ion lines	50	400 x 400 X 2000 (Telescope Ø200 + 4 AIA type smaller telescopes)	50	1
Cacciani Magneto Optical Filter (MOF) °	High-resolution disk oscillations, imaging and magnetographs	Na D1 Na D2	40	300 x 300 x 1200 (Telescope Ø250)	50	1
SLIM °	Limb oscillations and full Sun UV and visible imaging	215 nm cont. 160 nm cont. Ly α, 538 nm	35	300 x 300 x 1000 (Telescope Ø150)	45	1
PREMOS °	Radiometers for Solar constant and Intensity Oscillations	UV, visible Visible and IR light	11	270 x 160 x350	30	<0.05
STIP °	Spectral and Total Irradiance Package		14	270 x 250 x 350	15	<0.05
TOTAL			**480**	**Ø2500 x 3000**	**600**	**9**

HiRISE Chaser Satellite:
Instruments' Resources Summary

Name	Measurement	Specifications	Mass kg	Volume (mm^3) L x W x H*	Power Watt	Telemetry Mbits/s
SuperASPIICS VisIR	Vis & IR	Fe XIV Fe XIII HE I 1083 nm	100	800 x 500 x 1500 (Telescope Ø300)	120	0.6
SuperASPIICS LCI	UV	Lyman series O VI	60			0.4
TOTAL			**160**	**800 x 500 x 1500**	**120**	**1**

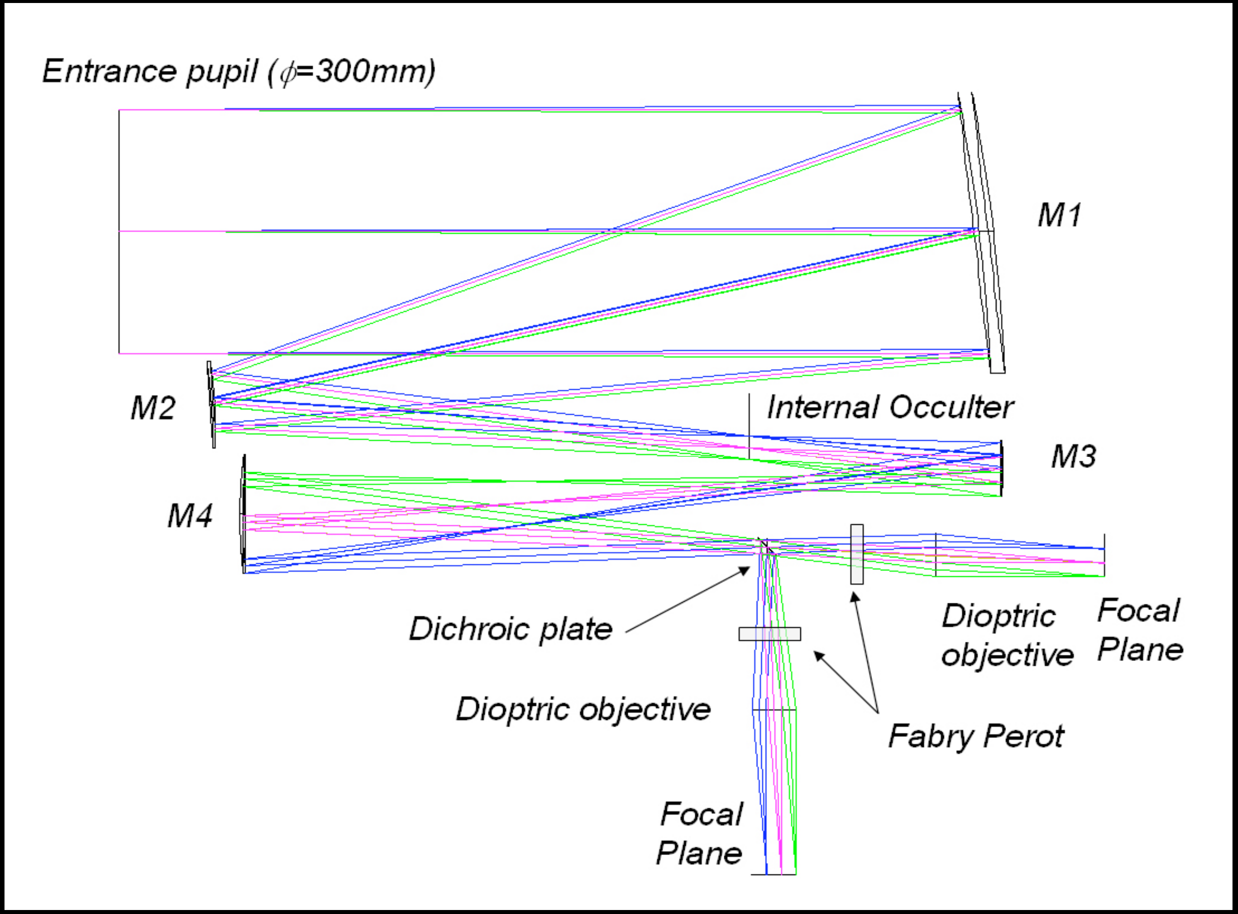
Extreme Coronagraphy & 2D Spectroscopy



HiRISE/SuperASPIICS	
Mass	160 kg
Volume	800 x 500 x 1500 mm^3
Average Power	120 W
Wavelengths	VISIR: Fe XIV 530.3 nm, Fe XIII 1074.7, 1079.8 nm, He I 1083 nm LCI: Lyman series, O VI
Nominal Telemetry	800 kbit/s (Science and Housekeeping)

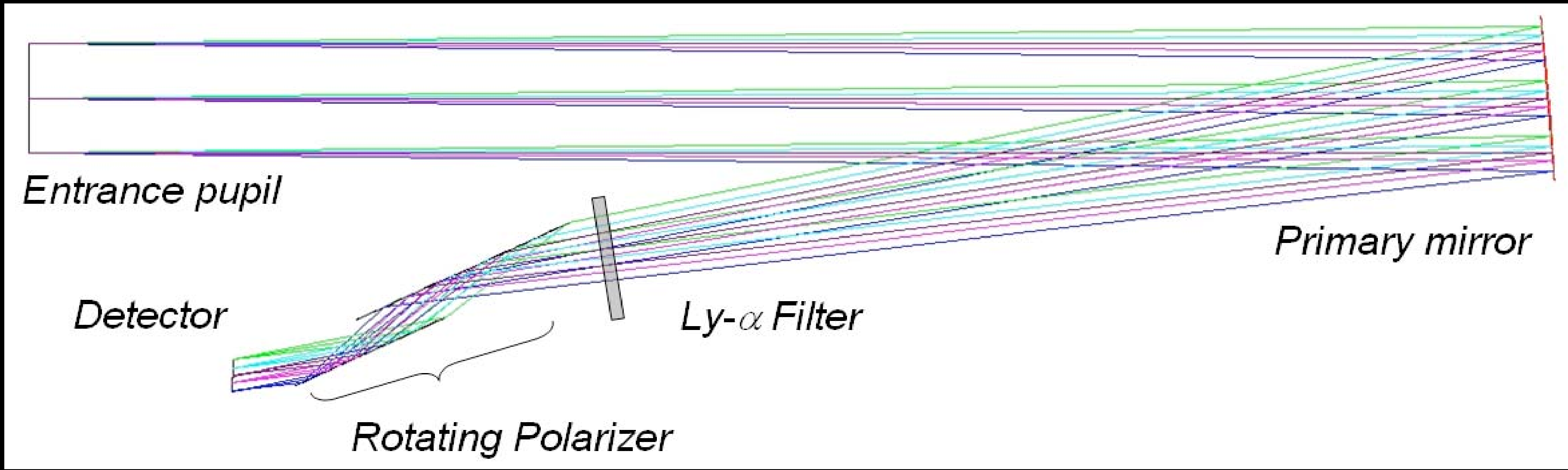
- Access to inner corona, possibly TR (1.01 Rs – 10”), with eclipse condition (scattered light / 1000-10000) and unprecedented spatial resolution (1” – 2”)
- Capable of measuring directly (Hanlé effect, UV, or forbidden lines, NIR) the coronal magnetic field
- Capable of plasma diagnostic measurements (density, temperature, velocity, turbulence (FP -> full field velocities, i.e. dynamics - flows along field lines)
- A truly new generation of instrument 2D spectro-imaging possible since flux & low scattered light (d=280 m vs. 75 cm & p=30 cm vs. 2 cm for LASCO/C2)

VISIR – Visible & IR coronagraph



The Visible-IR coronagraph optical layout (enhanced version of ASPIICS PROBA-3)

LCI - Lyman-alpha Coronal Imager



The Lyman Alpha and O VI Coronal Imager schematic set-up. Note that the filters are in a five positions filter wheel to access H I 121.6, 102.5 and 97.2 nm and O VI 103.2 and 103.7 nm.

UV implemented as a *channel* of VISIR (using a relay mirror after the M2 and before the internal occulter), to send the beam to the 5 positions filter wheel. The flip-in relay mirror position is not critical since there is no internal occulter in the UV channel: a compact and reliable solution.

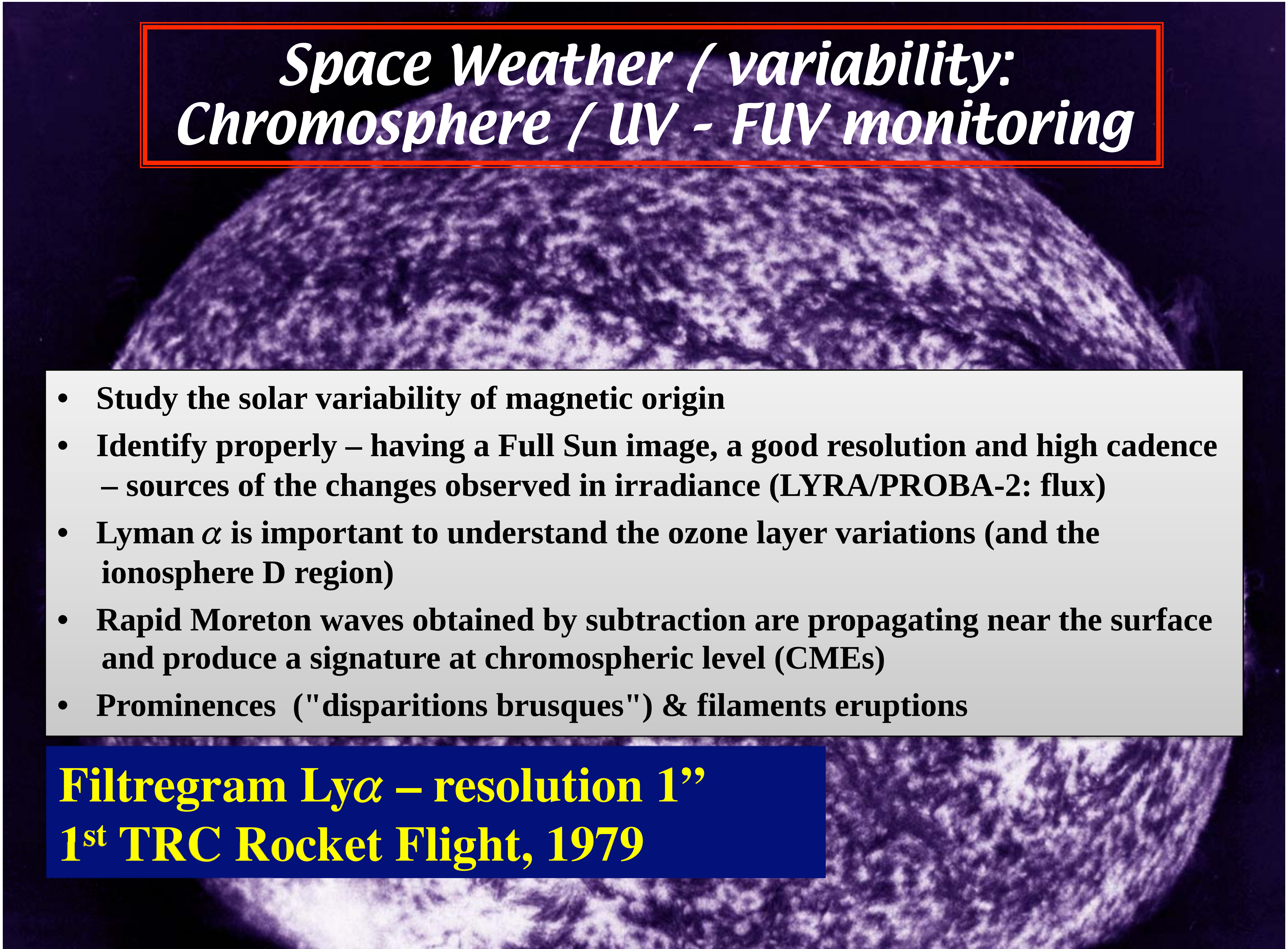
الصام المصري الفرنسي
للعلوم والتكنولوجيا
Année Franco Egyptienne de la Science et de la Technologie

STDF -IRD Microsatellite Project

- Joint initiative France – Egypt (Euro-med, FEST):
  Joint Innovative Projects Fund for Joint Research Projects
  1.8 M€ per year for 4 years (half-half Fr-Eg)
- Proposed Design Study of Microsatellite Project for Space Weather Monitoring (Space Environment) at Equatorial Orbit (NARSS, SWMC, LATMOS: co-PIs Amal Zaki, Luc Damé)
- Proposed applied payload with three (4?) instruments:
  - Plasma Flux Meter
  - Magnetometer
  - UV Lyman α Telescope (+ integrated Lyman flux?)

Space Weather / variability: Chromosphere / UV - FUV monitoring

- **Study the solar variability of magnetic origin**
- **Identify properly – having a Full Sun image, a good resolution and high cadence – sources of the changes observed in irradiance (LYRA/PROBA-2: flux)**
- **Lyman α is important to understand the ozone layer variations (and the ionosphere D region)**
- **Rapid Moreton waves obtained by subtraction are propagating near the surface and produce a signature at chromospheric level (CMEs)**
- **Prominences ("disparitions brusques") & filaments eruptions**



Filtregram Lyα – resolution 1”
1st TRC Rocket Flight, 1979

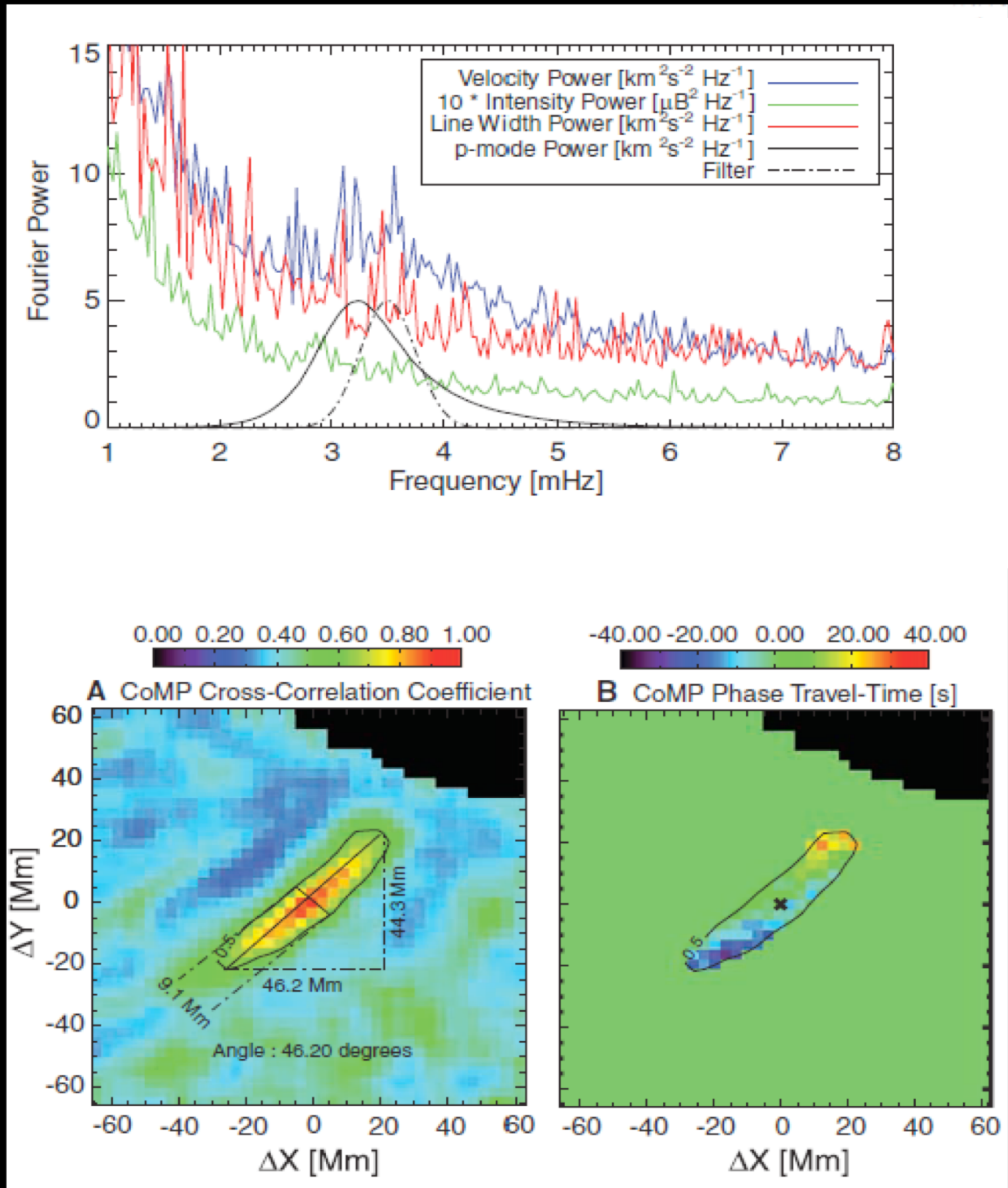
What can be done on ground?

- New generation solar coronagraphy
  - COMP
  - CLIMSO
  - AFSIIC
- Solar Activity Monitoring
  - FMT-CHAIN (H-Alpha Network)
- Very high resolution
  - GREGOR (ATST)
  - AFSIIC

Coronal Seismology

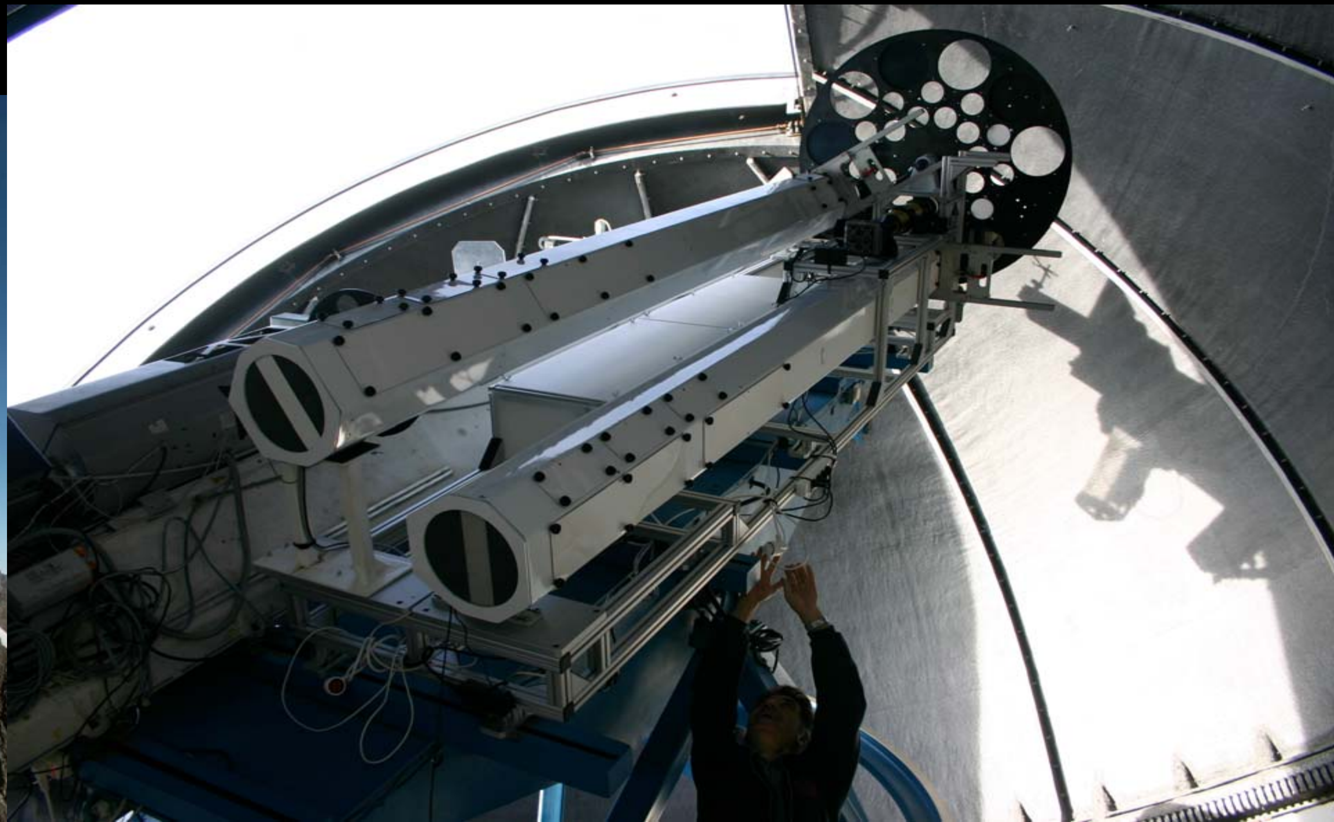
What processes contribute to the heating of the corona and what is the role of waves?

Alfvén Waves in the Solar Corona
S. Tomczyk, *et al.*
Science **317**, 1192 (2007)



CLIMSO - Pic du Midi

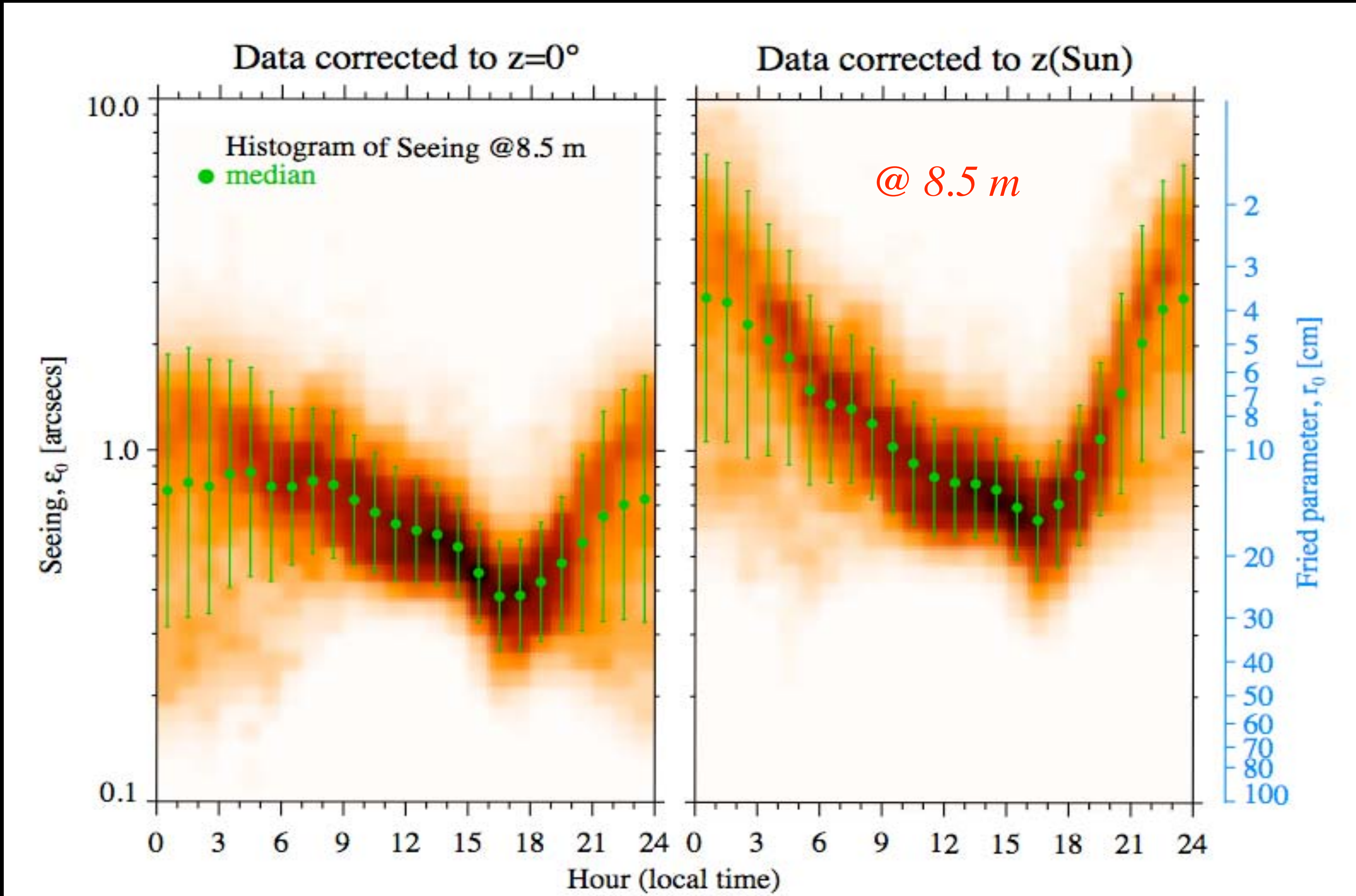
Survey of the disk activity and inner corona as developed at Pic du Midi Observatory by Jacques-Clair Noëns team




Pic du Midi / Observatoire Midi-Pyrénées / CNRS
Les Observateurs Associés / FIDUCIAL
CLIMSO L2 - KCaII solar telescope
Raw image 3933.682 Å
www.climso.fr
CLIMSO C1 - Halpha Coronagraph
Raw image 6562.82 Å
2007/11/17 16:01:50
CLIMSO

Dome C / Concordia Advantages

- Free Atmosphere Seeing is exceptional: 0.29 arcsec and, as well, τ_0 and isoplanatic patch
  - *high resolution observations potential for 2D spectral imaging and 3D spectro-polarimetry @ diffraction limit (1.4 m: 0.06"; 4 m: 0.025")*
- Low sky brightness and low water vapour
  - *coronal and IR observations*
  - *coronal magnetic field* DIRECT *measurements of forbidden lines at 1, 3 & 4 µm (Fe XIII, MgVIII, SiIX)*
  - *chromospheric dynamics, CO @ 4.5 µm (Tmin), min opacity @ 1.6 µm, chromosphere–TR B field @ 12 µm*
- High duty cycle (85%) & 4 Summer months with possibility of 2-3 weeks continuity
  - *local magnetoseismology of active regions, waves*
  - *flux emergence and evolution of magnetic field in active regions*


Data corrected to z=0°
Data corrected to z(Sun)
Histogram of Seeing @8.5 m
median
@ 8.5 m
10.0
1.0
0.1
Seeing, ε_0 [arcsecs]
Fried parameter, r_0 [cm]
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80
100
0 3 6 9 12 15 18 21 24
0 3 6 9 12 15 18 21 24
Hour (local time)

Conclusion

- Rich period but gap before next generation of missions (Probes)
- Importance of interface between chromosphere and corona recognized following Hinode (-> Solar C, HiRISE)
- Coronagraphs importance for inner corona (Hanlé direct coronal B field in FUV?) implemented with performances thanks to Formation Flying missions (ASPIICS/PROBA-3, SuperASPIICS/HiRISE)
- Chromosphere/Activity also addressed with more modest means: H-Alpha monitoring (ground); Lyman-Alpha (Space microsatellite possibility: France/Egypt Space Weather microsatellite project)
- Antarctica/Dome C complementary on ground (high resolution–coronagraphy–IR: coronal B field Fe XIII - SuperCOMP)


HiRISE
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Thank you!
Shokran!
ASPIICS