

# Fisica solare dallo spazio

Marco Romoli

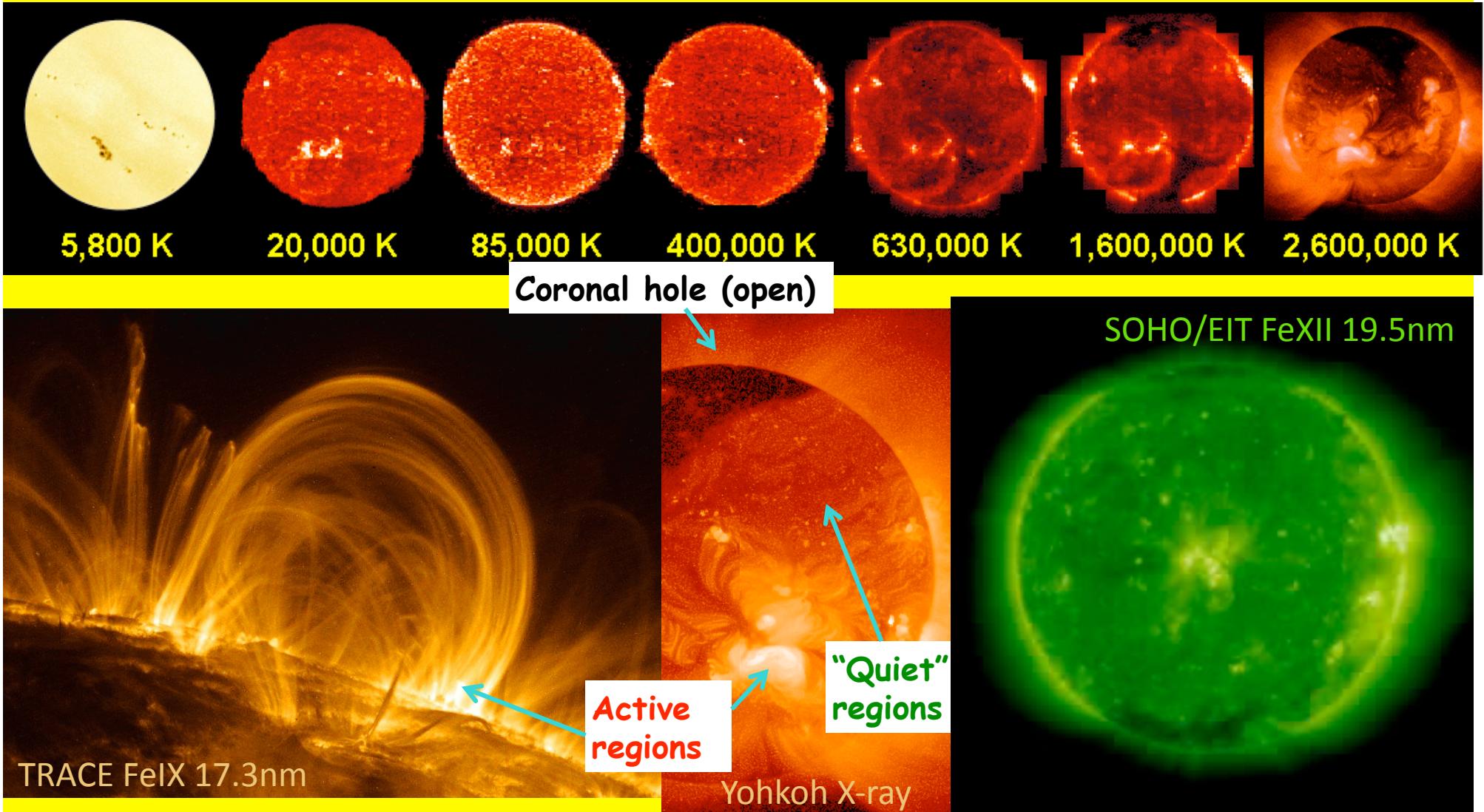
Dip. di Fisica e Astronomia

Sezione di Astronomia e Scienza dello  
Spazio

# Lo studio della corona solare

## Perché dallo spazio?

- Il plasma coronale a  $10^6$  K emette gran parte dello spettro in UV e X-ray.

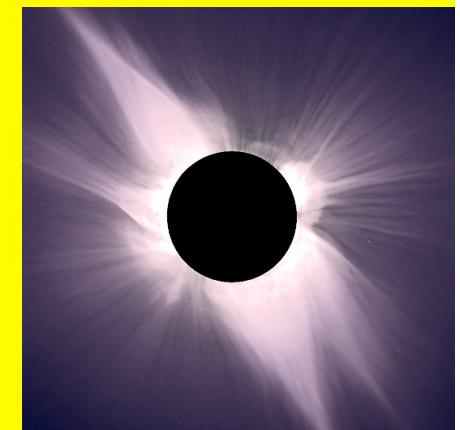
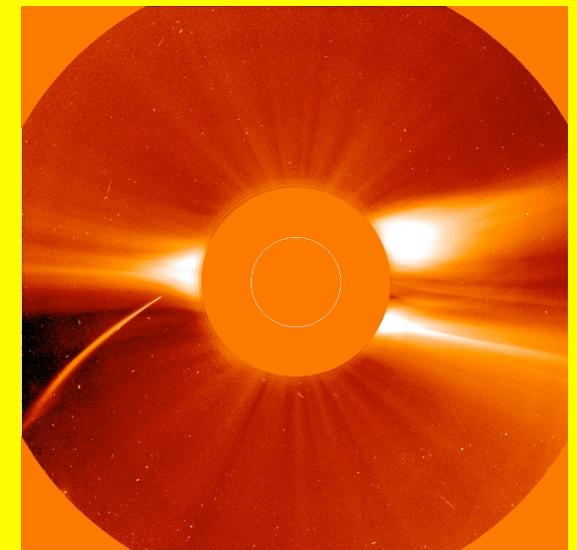
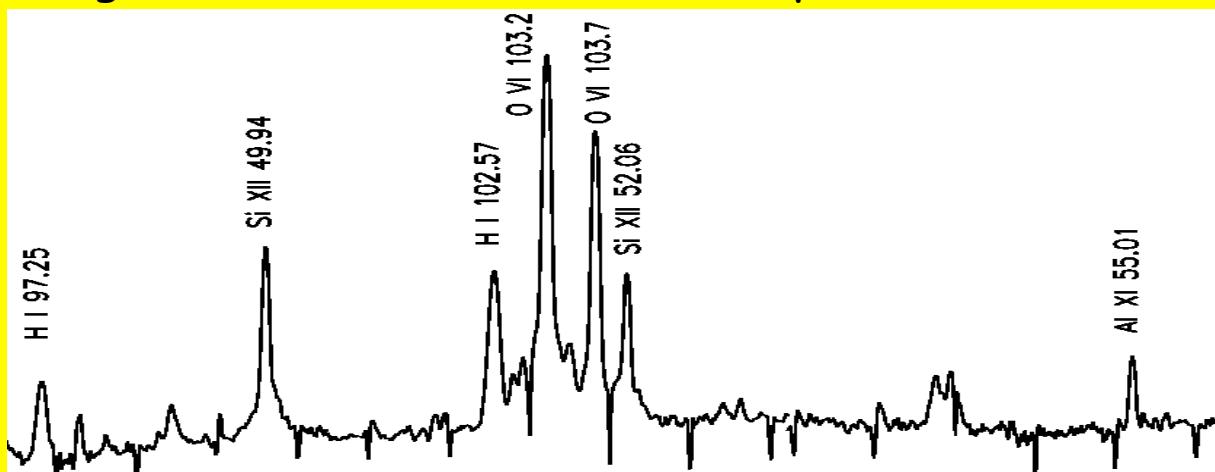


# Spettro-coronografia

- Le misure fuori lembo (nella regione di accelerazione del vento solare) consentono di seguire la dinamica degli stati di non equilibrio del plasma fino a che non si stabiliscono le condizioni asintotiche osservate a 1 UA.

**Occultamento** del disco è necessario perché la corona estesa è da 5 a 10 ordini di grandezza meno brillante del disco!

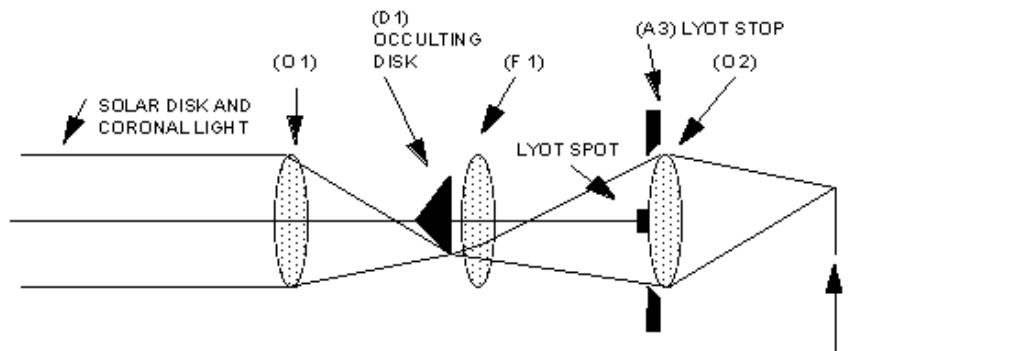
La **Spettroscopia** fornisce una dettagliata diagnostica dello stato fisico del plasma.



# Spettro-coronografia

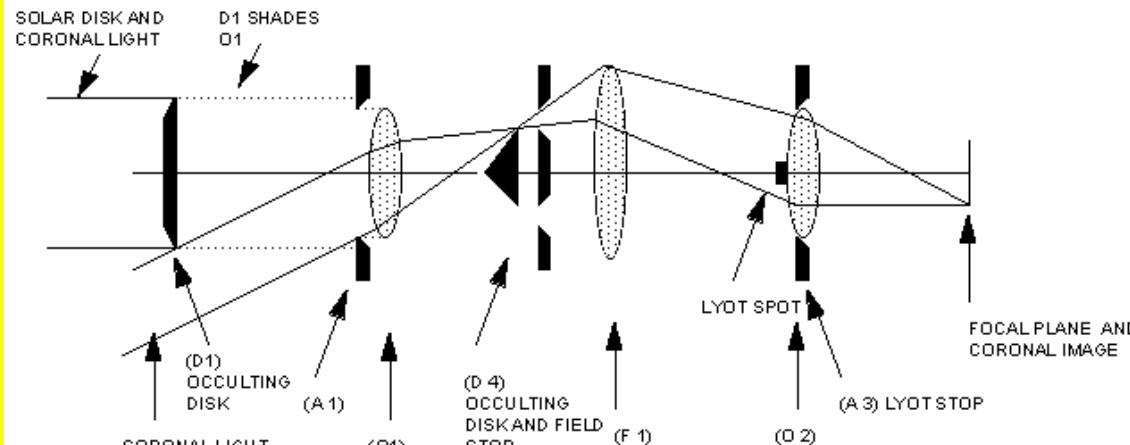
- Spettro-coronografi UV dallo spazio per determinare densità, abbondanze, temperature e velocità delle componenti del plasma.

INTERNAL OCCULTED REFRACTING CORONAGRAPH (LYOT)

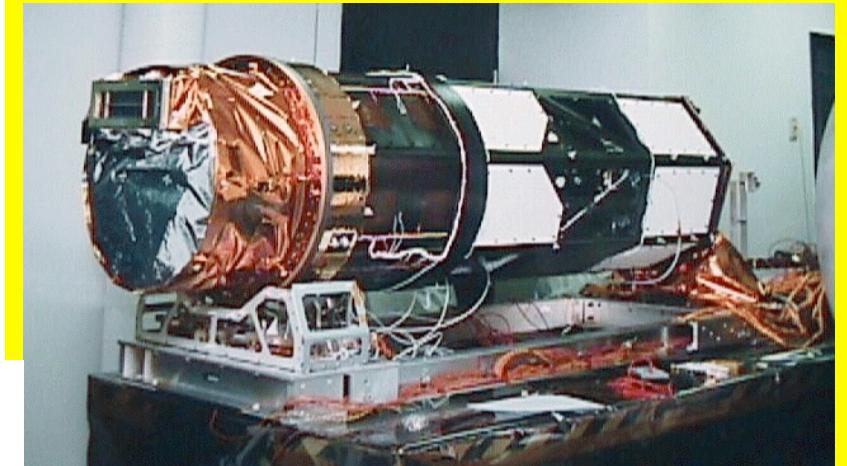


SOLAR DISK AND CORONAL LIGHT

D1 SHADES D1



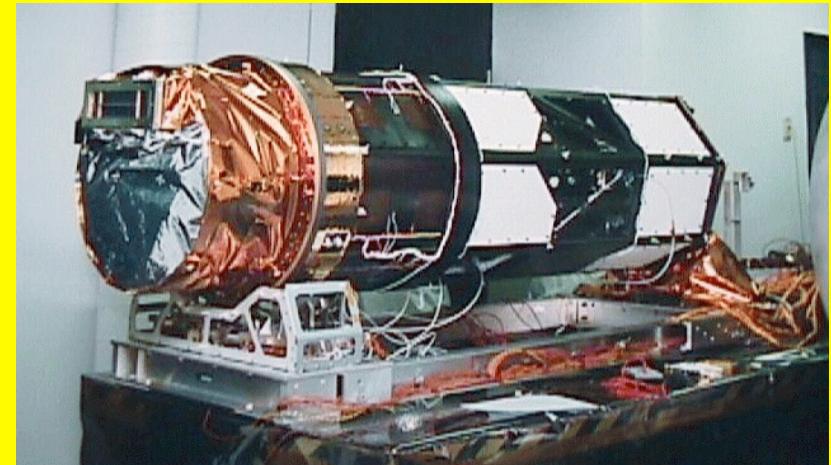
EXTERNALLY OCCULTED REFRACTING CORONAGRAPH (NEWKIRK)



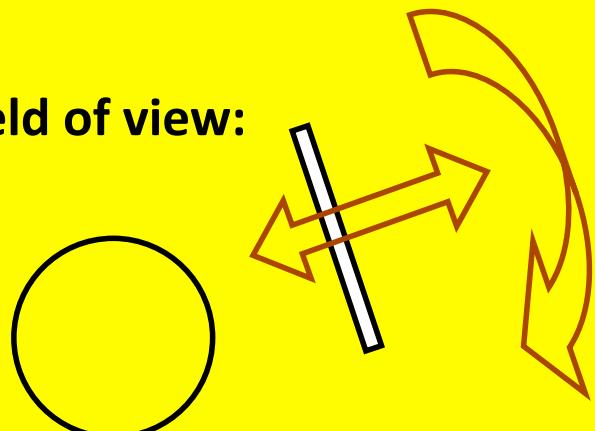
# The UVCS instrument on SOHO

PI: John Kohl (CfA) - CoPI: Giancarlo Noci (UniFI)

- **1979–1995:** Rocket flights and Shuttle-deployed Spartan 201 laid groundwork.
- **1996–present:** The Ultraviolet Coronagraph Spectrometer (UVCS) measures plasma properties of coronal protons, ions, and electrons between 1.5 and 10 solar radii.
- Combines “occultation” with spectroscopy to reveal the solar wind **acceleration region!**



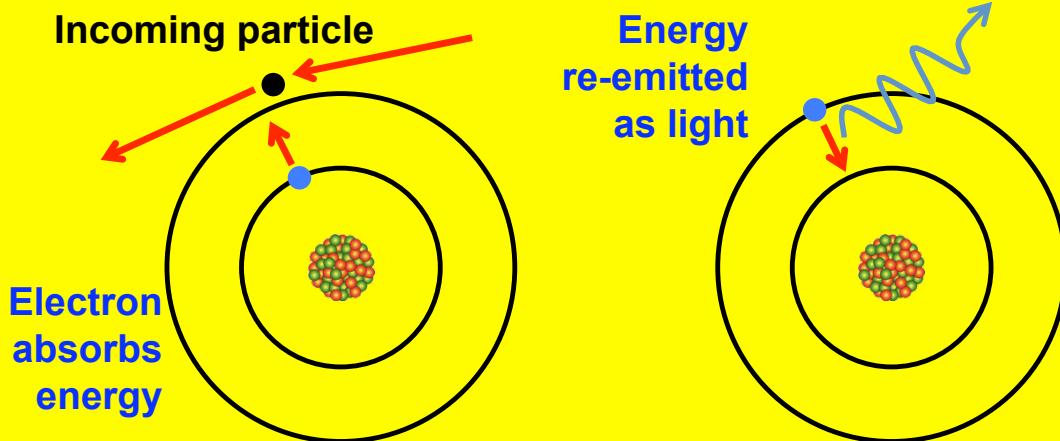
**slit field of view:**



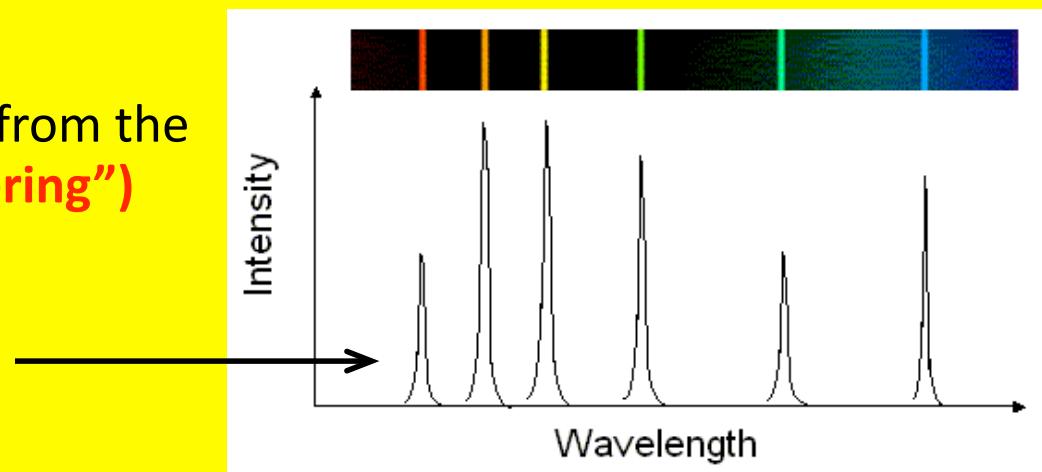
- Mirror motions select height
- UVCS “rolls” independently of spacecraft
- 2 UV channels: LYα (120–135 nm)  
OVI (95–120 nm + 2<sup>nd</sup> ord.)
- 1 white-light polarimetry channel

# What produces “emission lines” in a spectrum?

- There are 2 general ways of producing extra photons at a specific wavelength.
- Both mechanisms depend on the quantum nature of atoms: “bound” electrons have discrete energies . . .
- The incoming particle can be either:

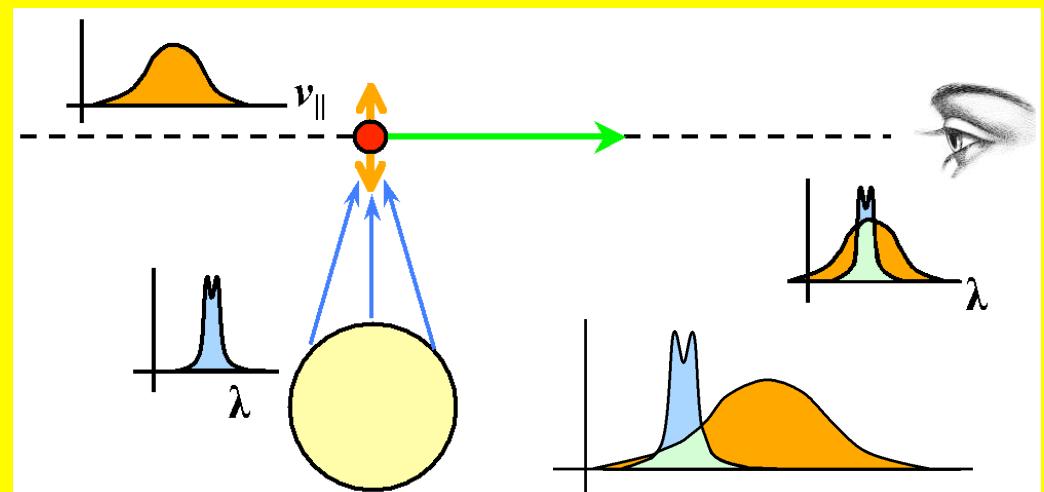
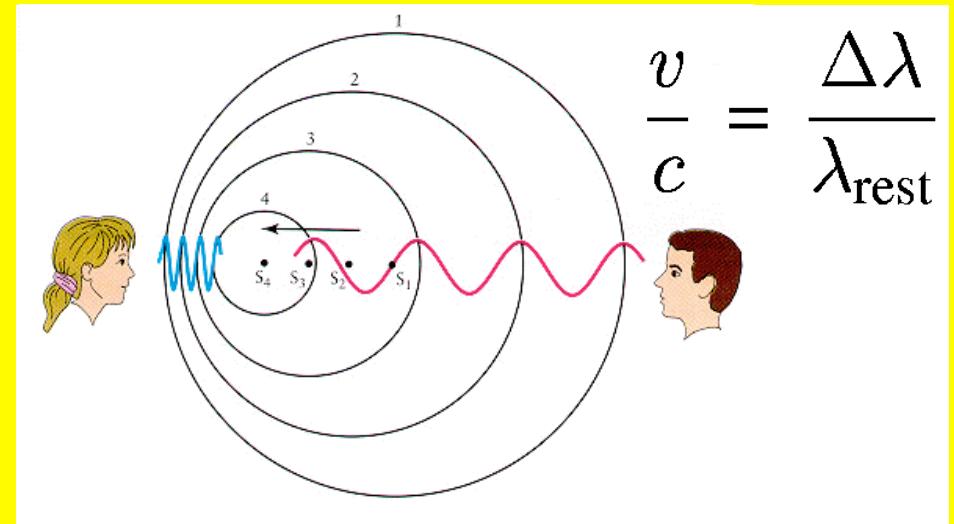


- A free electron from some other ionized atom (**“collisional excitation”**)
  - A photon at the right wavelength from the bright solar disk (**“resonant scattering”**)
- 
- There is some **spread** in wavelength



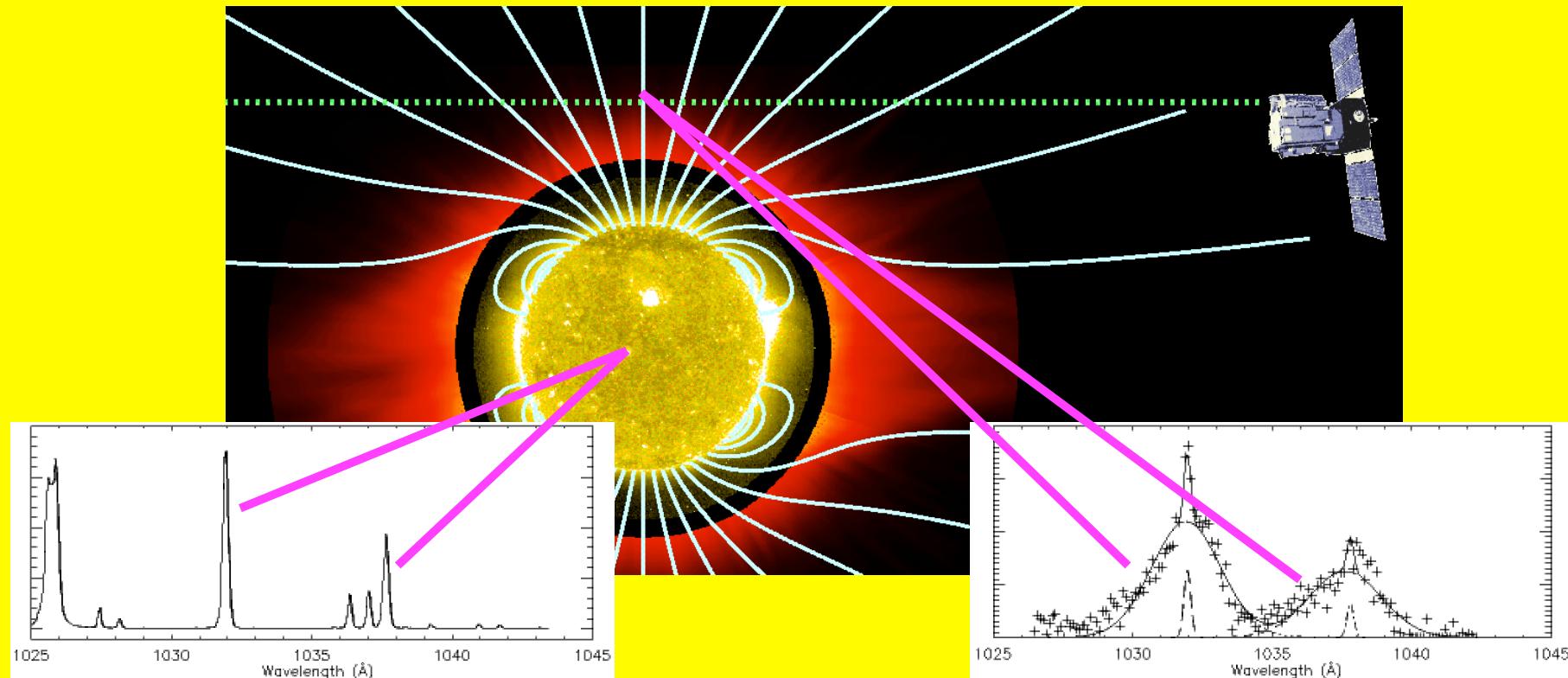
# Using lines as plasma diagnostics

- The **Doppler effect** shifts photon wavelengths depending on **motions** of atoms:
- If profiles are shifted up or down in wavelength (from the known “rest wavelength”), this indicates the **bulk flow speed** along the line-of-sight.
- The widths of the profiles tell us about random motions along the line-of-sight (i.e., **temperature!**)
- The total intensity (i.e., number of photons) tells us mainly about the **density** of atoms, but for resonant scattering there’s also another “hidden” Doppler effect that tells us about the **flow speeds** perpendicular to the line-of-sight.



# UVCS results: over the poles

- The fastest solar wind flow is expected to come from dim “coronal holes.”
- In June 1996, the first measurements of heavy ion (e.g.,  $O^{+5}$ ) line emission in the extended corona revealed **surprisingly wide** line profiles . . .



On-disk profiles:  $T = 1\text{--}3$  million K

Off-limb profiles:  $T > 200$  million K !

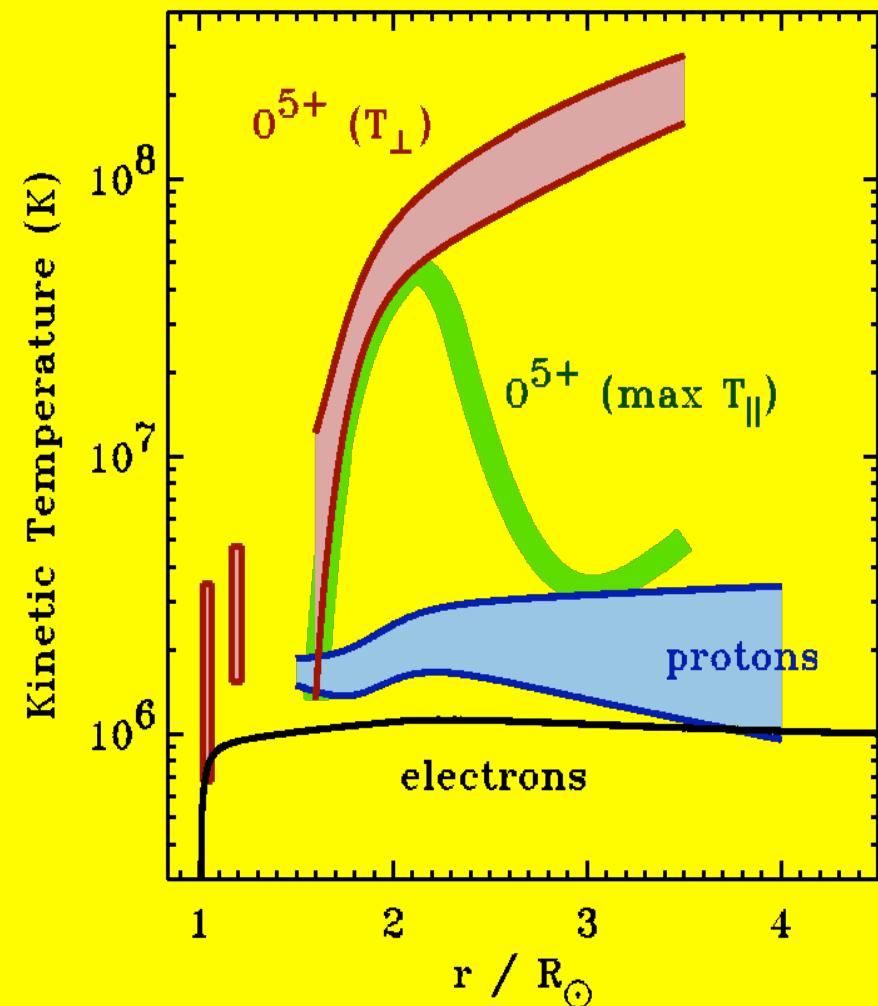
# Solar minimum UVCS results

UVCS has led to new views of the **collisionless** nature of solar wind acceleration.

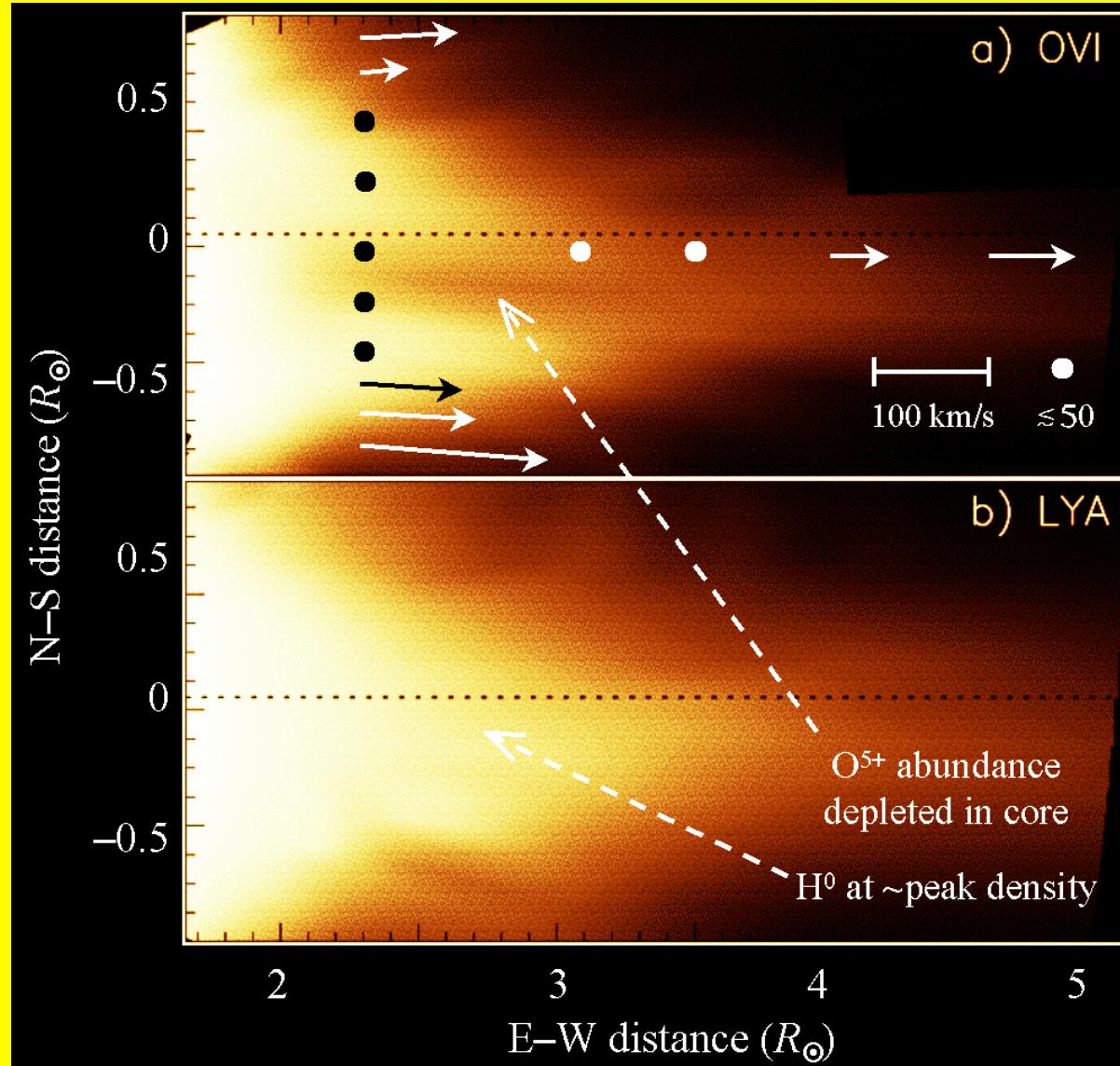
Key results include:

- The fast solar wind becomes **supersonic** much closer to the Sun ( $\sim 2 R_s$ ) than previously believed.
- In coronal holes, heavy ions (e.g.,  $O^{+5}$ ) flow **faster** and are **heated** hundreds of times more strongly than protons and electrons, and have **anisotropic temperatures**. (Kohl et al. 1997, 1998, 2006)

$$\left\{ \begin{array}{l} T_{\text{ion}} \gg T_p > T_e \\ (T_{\text{ion}}/T_p) > (m_{\text{ion}}/m_p) \\ T_{\perp} \gg T_{\parallel} \\ u_{\text{ion}} > u_p \end{array} \right\}$$



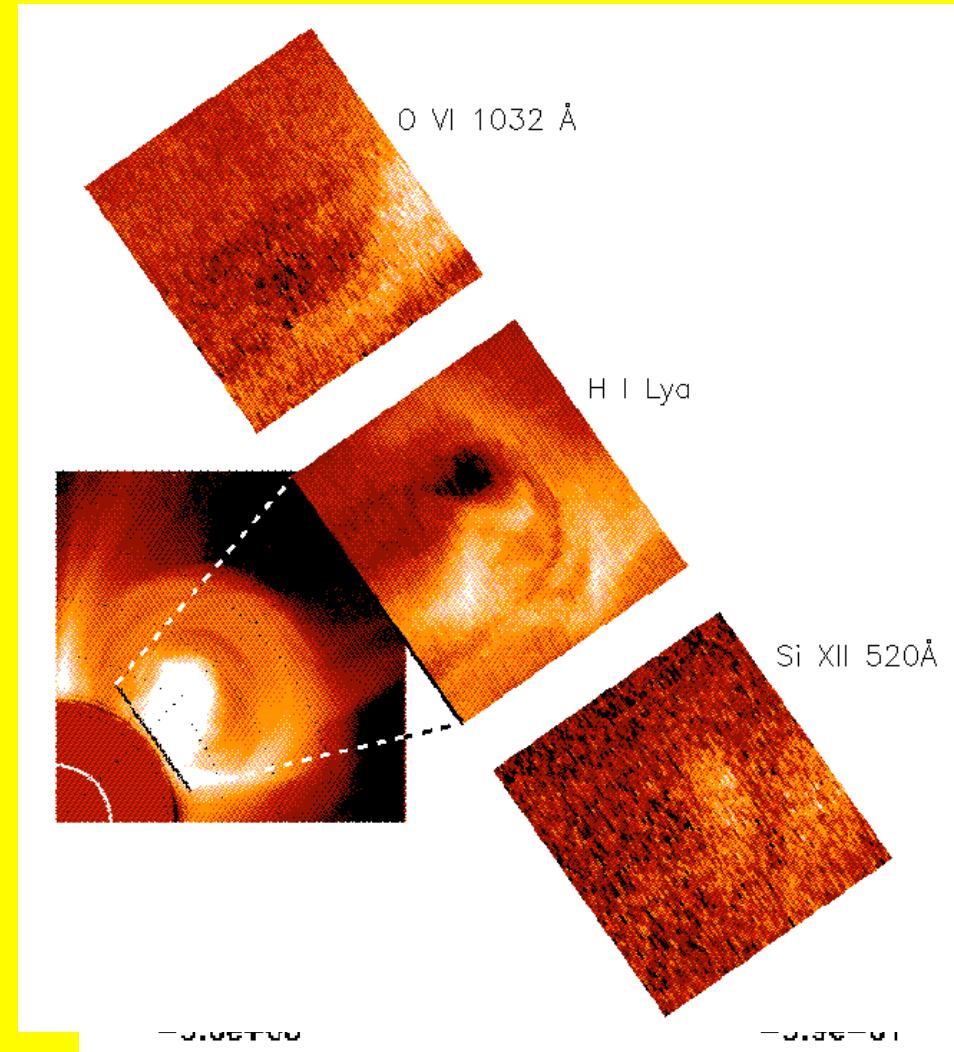
# Streamers with UVCS



- Streamers viewed “edge-on” look different in H<sup>0</sup> and O<sup>+5</sup>
- Ion abundance depletion in “**core**” due to grav. settling?
- Brightest “**legs**” show negligible outflow, but abundances consistent with in situ slow wind.
- Higher latitudes and upper “**stalk**” show definite flows (Strachan et al. 2002).
- Stalk also has **preferential ion heating & anisotropy**, like coronal holes! (Frazin et al. 2003)

# Helium coronal observations

- ✓ coronal He abundance
- ✓ increased contrast of coronal structures
- ✓ test abundance variation models  
(gravitational settling or Coulomb drag)
- ✓ differential outflow speed
- ✓ CME morphology

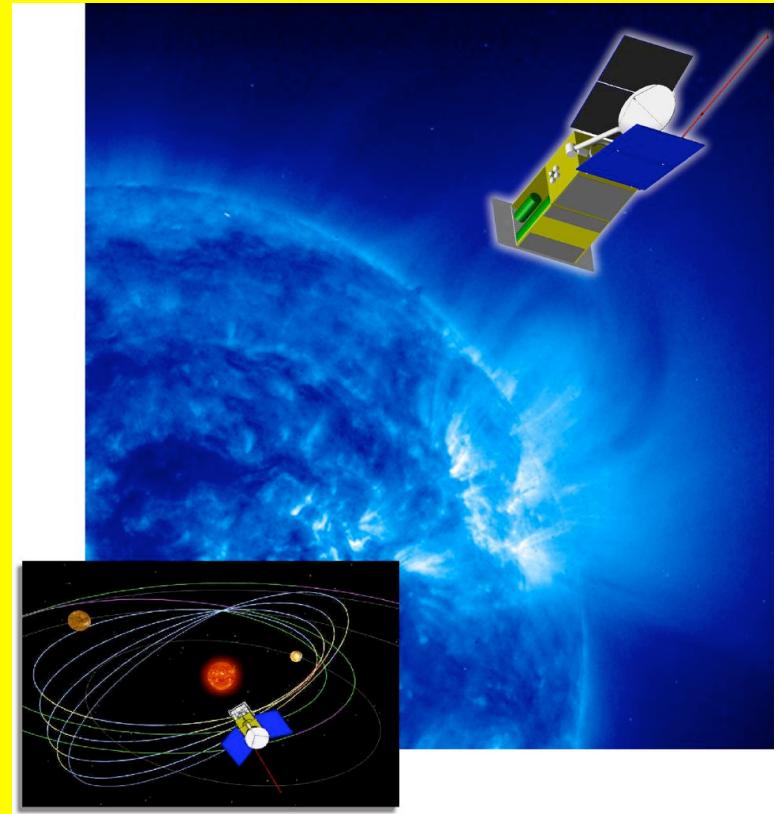


(Ofman, 2000, G.R.L., 27, 2885)

# Solar Orbiter: new perspectives

Mission ESA - Cosmic Vision 2015-25

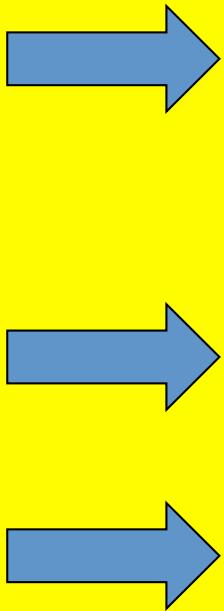
- exploring the inner regions of the Solar System
- study the Sun from a close-up point of view (upto 0.27 UA)
- quasi-corotation with the Sun
- provide images of the polar regions of the Sun from heliolatitudes upto 38°
- LAUNCH: 2017



# Why Solar Orbiter is a unique platform for METIS ?

## Solar Orbiter:

- Closer to the Sun
- Out of ecliptic
- Co-rotation



## METIS instrument:

- Good collecting area in 1-m class instrument externally occulted; lower heliocentric height of observation;
- Measurement of the longitudinal extent of streamers and CMEs;
- Investigation of evolution of coronal magnetic configuration by removing solar rotation.

# Solar Orbiter/METIS PI: E. Antonucci (OATo)

Externally occulted  
Coronagraph

On axis gregorian

HeII 30.4nm

HI 121.6nm

Broadband polarized VL

INAF/OATo

UniPd

UniFi

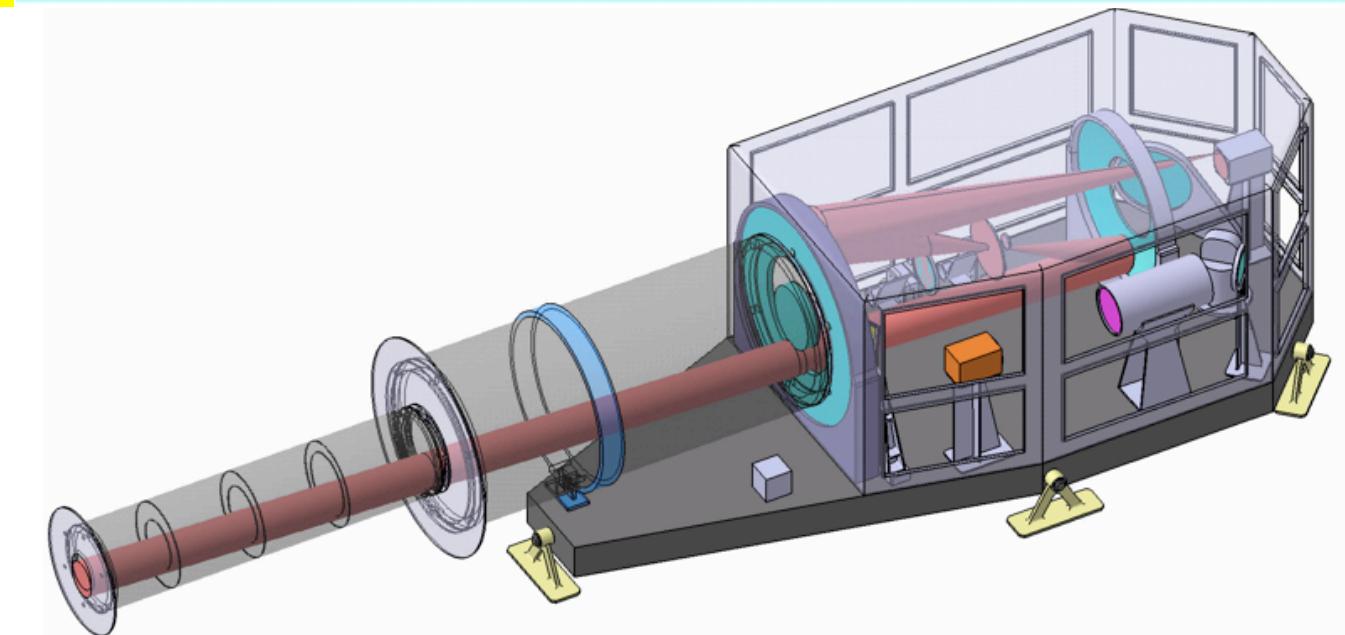
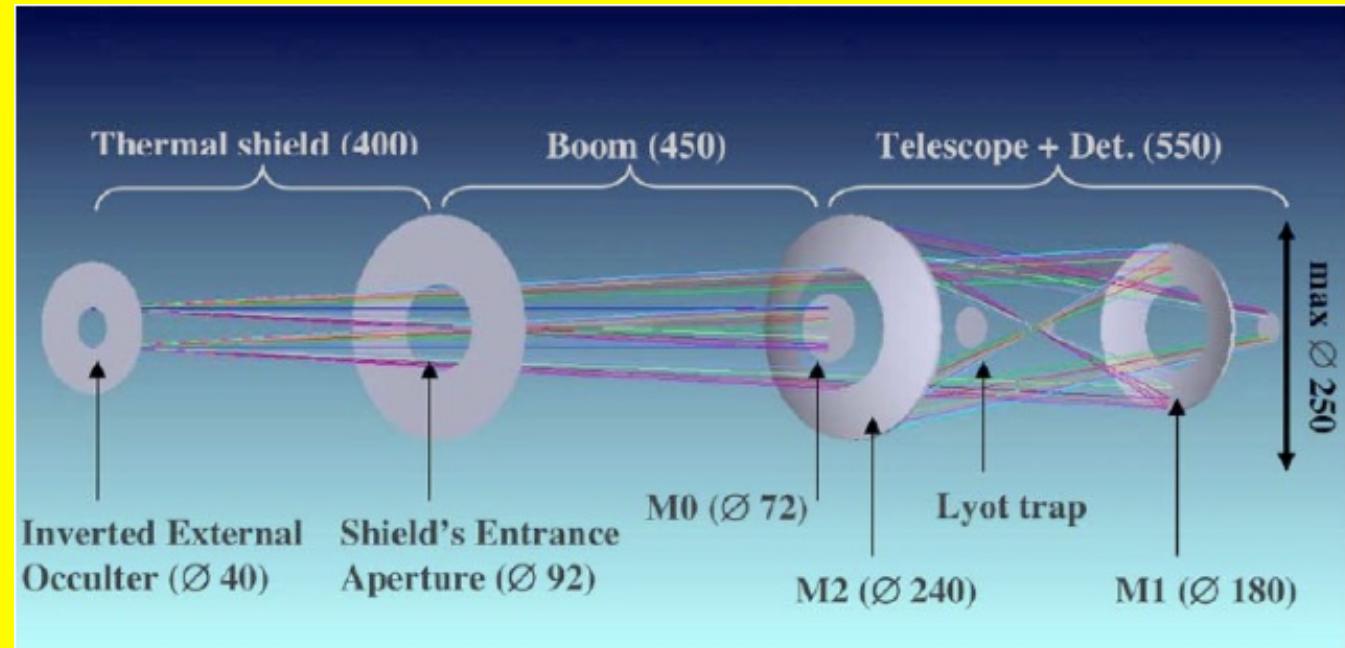
INAF/OACT

INAF/OACN

Max Planck Lindau, D

LAM, F

Rep. Ceca



# Solar Orbiter/METIS PI: E. Antonucci (OATo)

Externally occulted  
Coronagraph

On axis gregorian

HeII 30.4nm

HI 121.6nm

Broadband polarized VL

INAF/OATo

UniPd

UniFi

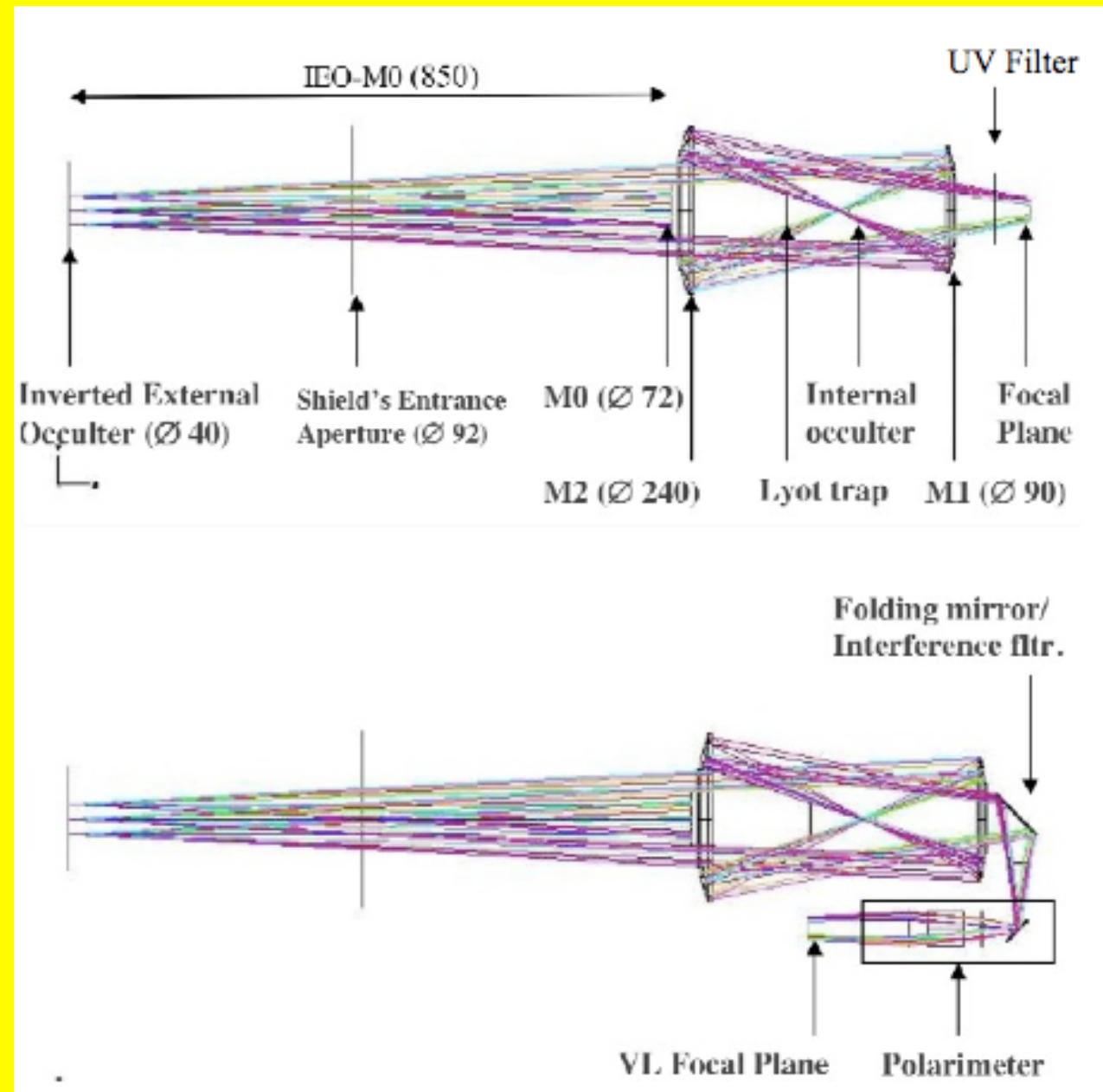
INAF/OACT

INAF/OACN

Max Planck Lindau, D

LAM, F

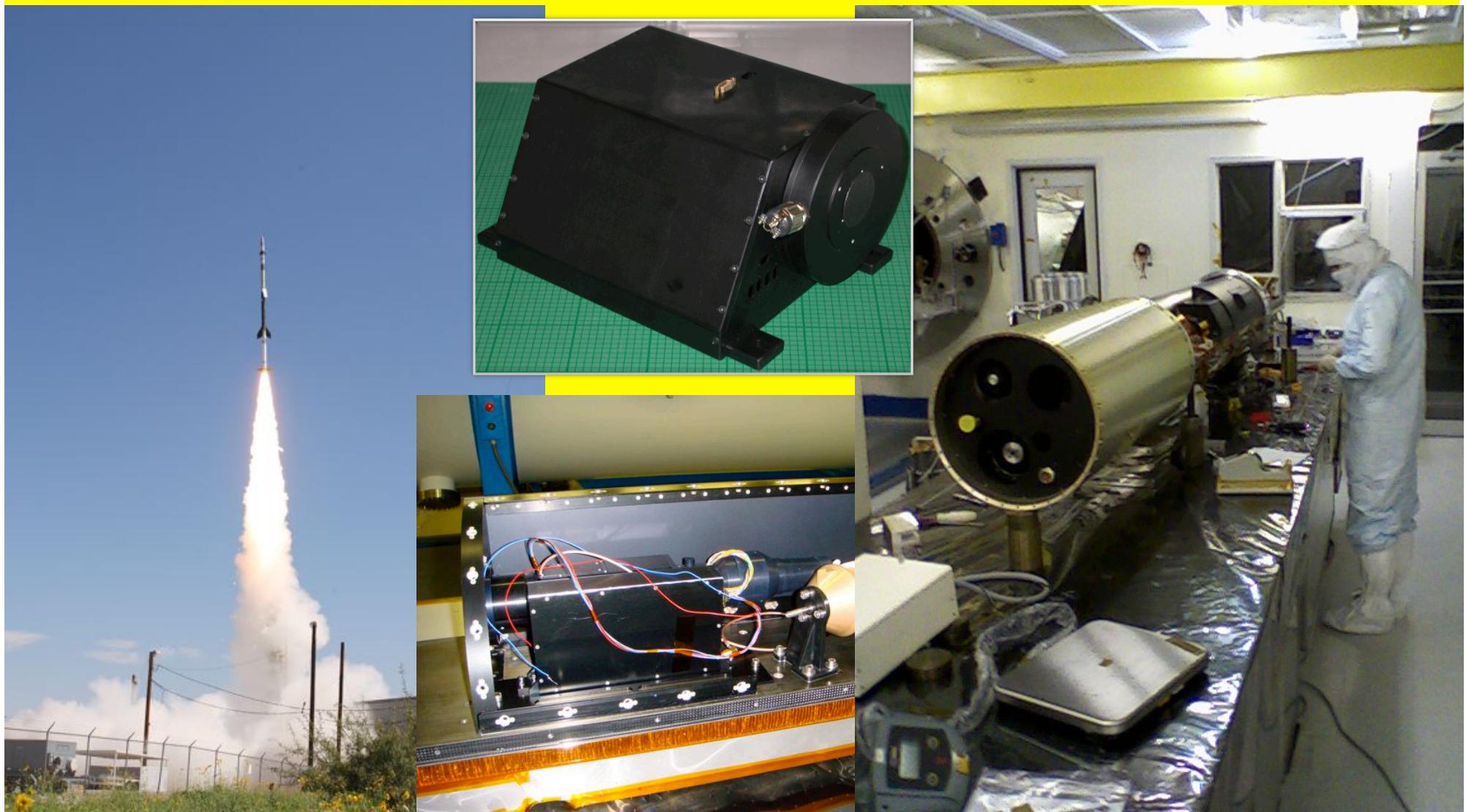
Rep. Ceca



# HERSCHEL-SCORE

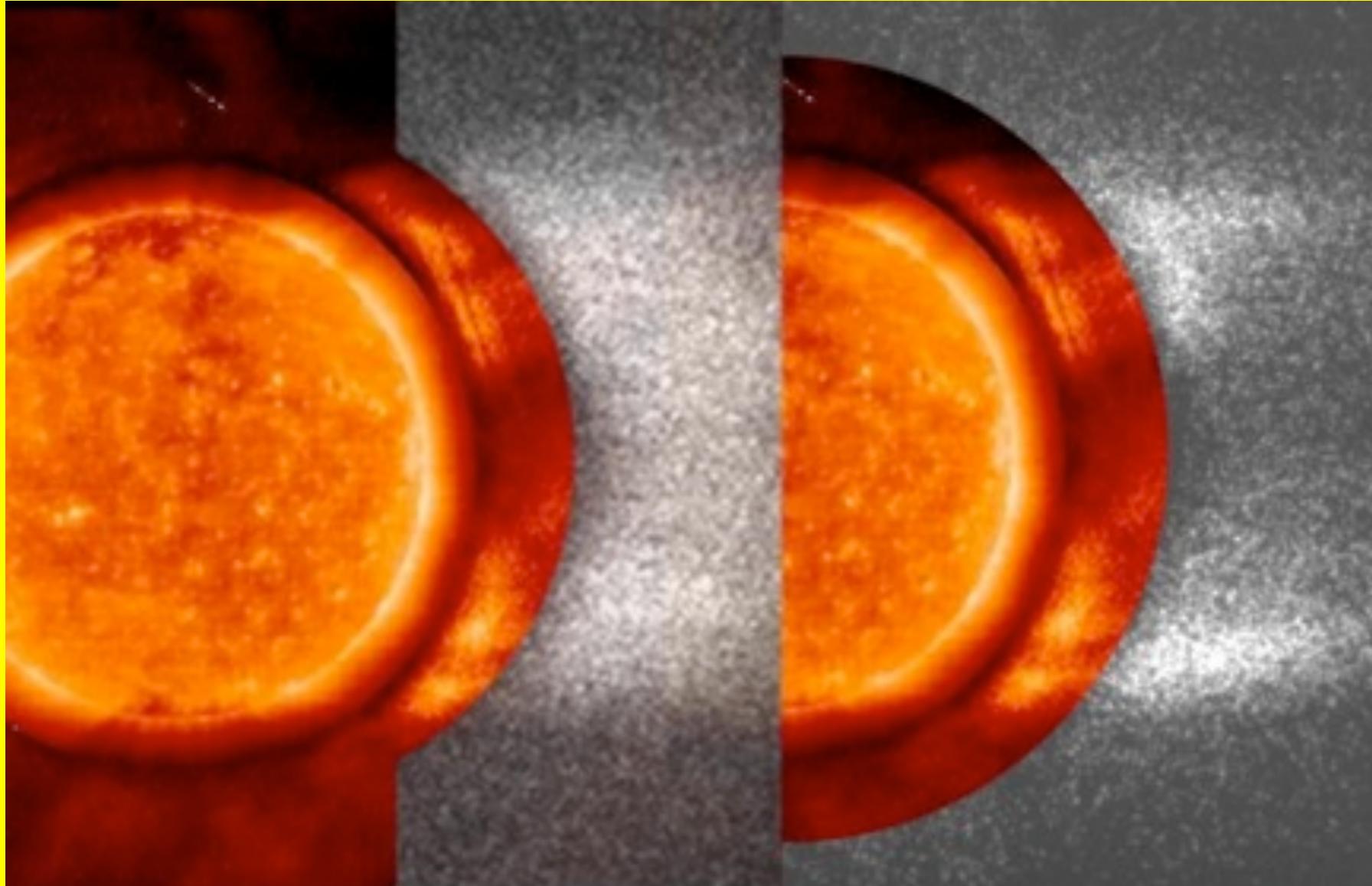
PI: Dan Moses (NRL)

- Missione sub-orbitale, banco di prova per Solar Orbiter



# HERSCHEL-SCORE

PI: Dan Moses (NRL)



# Proba 3

- ESA Formation Flying demonstrator.
- Simple Visible light coronagraph LAUNCH: 2014

- Consorzio:

- LAM, Francia

- INAF/OATo

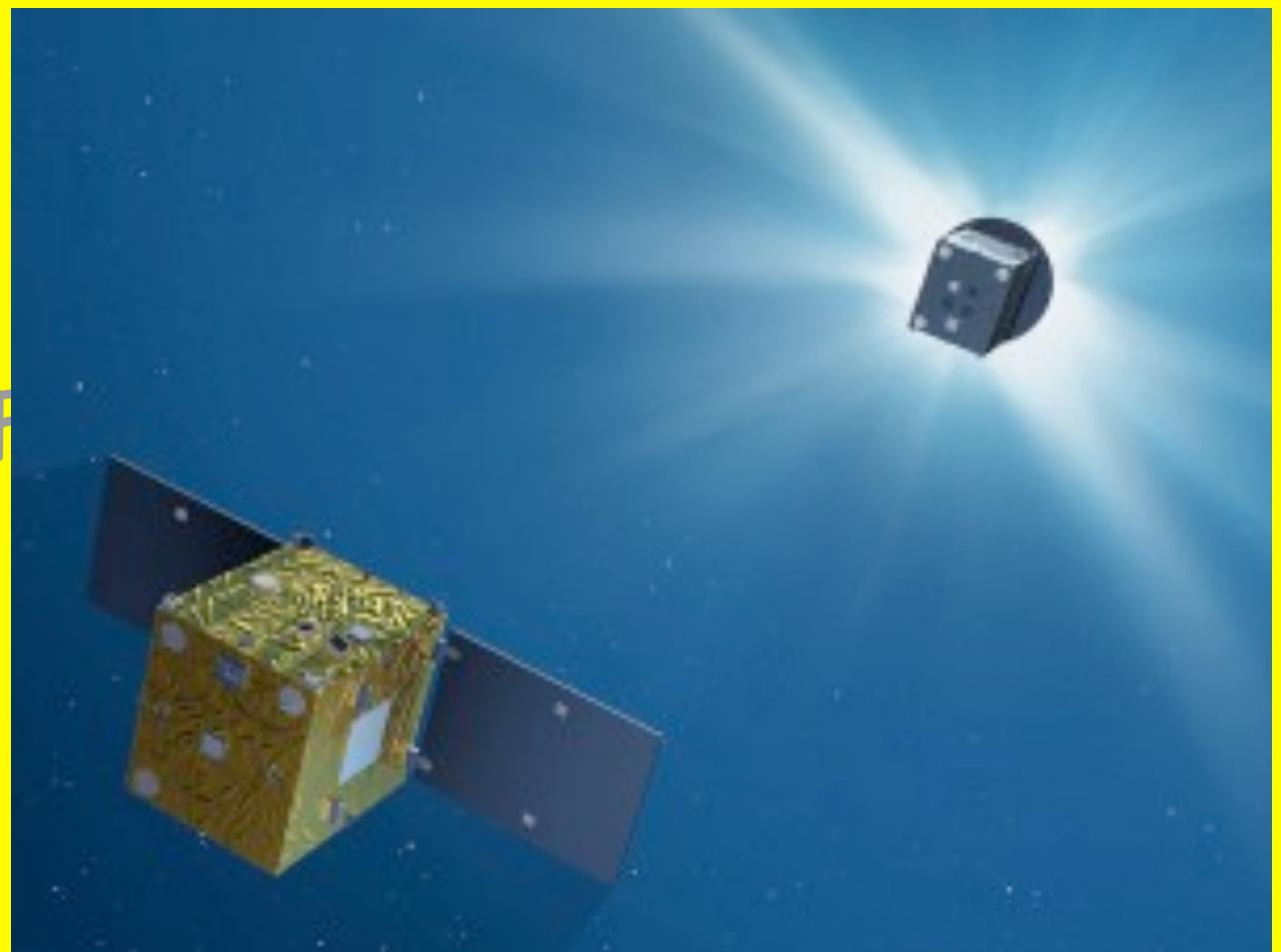
- UniPd

- UniFi

- Grecia

- CSL, Belgio

- Rep. Ceca



.

## Funded projects

### **ASI Esplorazione del Sistema solare 2008-2010**

Coronografia multibanda UV e visibile per l'osservazione della corona esterna

Partners: UniFI - INAF/OATo - UniPD - UniPV - INAF/IASF Mi

### **ASI Solar Orbiter (in fase di negoziazione)**

Partners: UniFI - INAF/OATo - UniPD - INAF/OACT - INAF/IASF Mi - INAF/OACN.

### **ASI Proba-3 (in fase di definizione)**

Partners: UniFI - INAF/OATo - UniPD

Personale del Dip. di Fisica e Astronomia coinvolto

Marco Romoli, ricercatore

Federico Landini, borsista post-doc

Maurizio Pancrazzi, borsista post-doc

Mauro Focardi, assegnista

Collaborano anche: Emanuele Pace, ricercatore

Egidio Landi Degl'Innocenti, PO

Giannina Poletto, retired

Giancarlo Noci, retired

Strutture di laboratorio per la spettroscopia UV

Laboratorio XUVlab (Sez. di Astronomia e Scienza dello Spazio)