



UV Spectro-polarimetry

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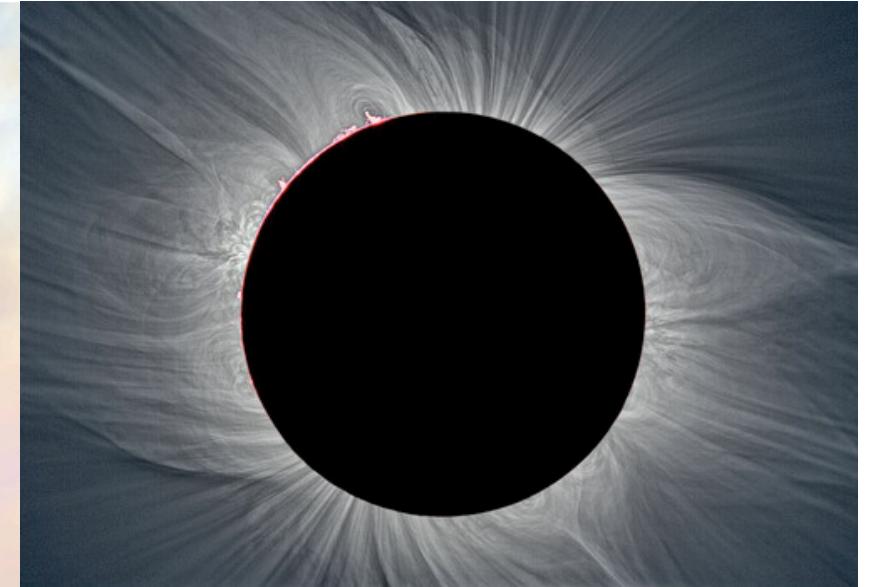
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Summary

Coronal magnetic field investigation - diagnostics techniques

Polarimetric techniques in the EUV

Past, present and future space missions



The magnetic field is the driver of the structure, dynamics and the energetics of the solar corona

BUT

the magnetic field is measured only at the solar surface and is poorly known in the corona itself.

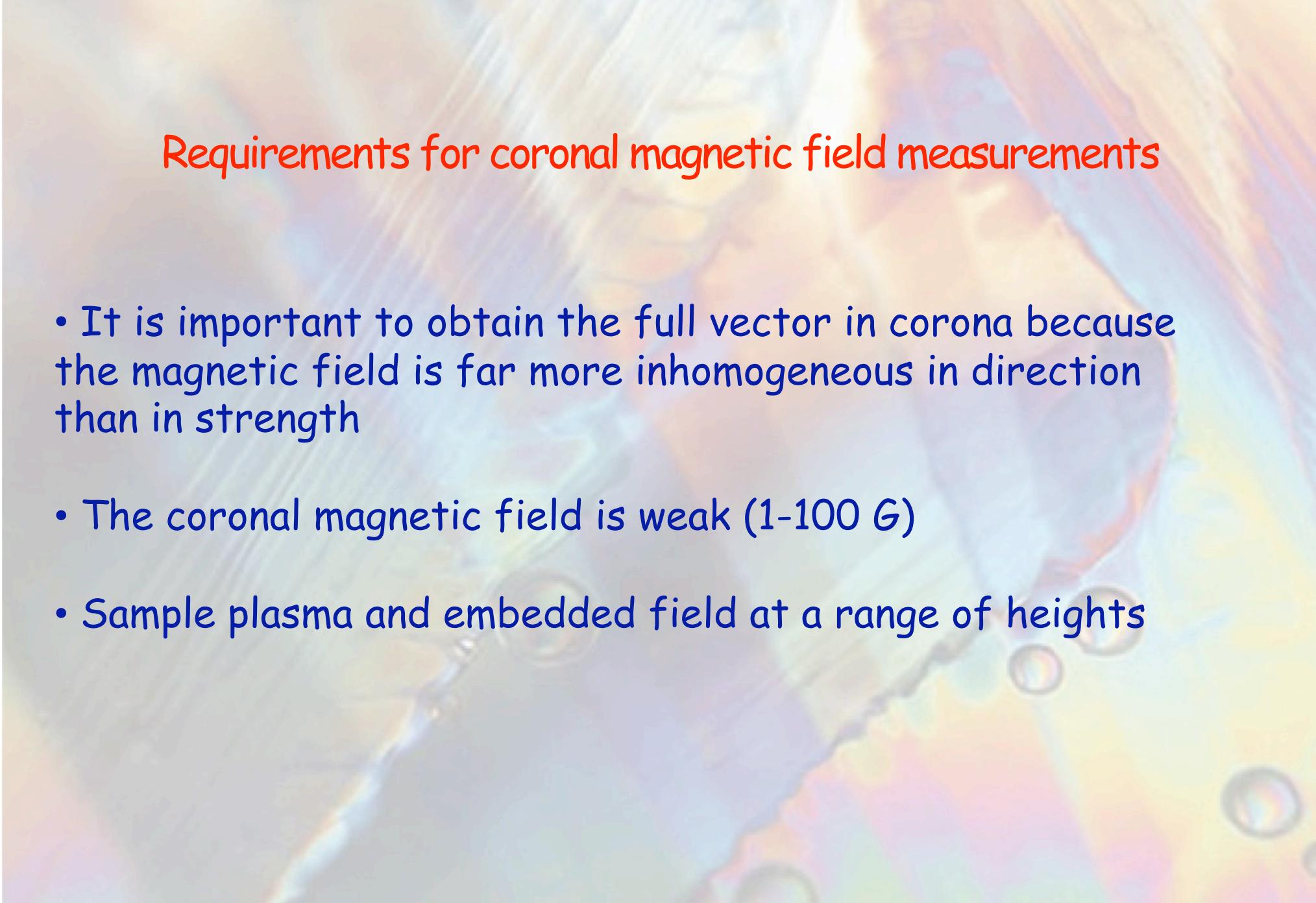
WHY?

BECAUSE it is not trivial to infer the magnetic field in corona.

It requires:

Different observing techniques

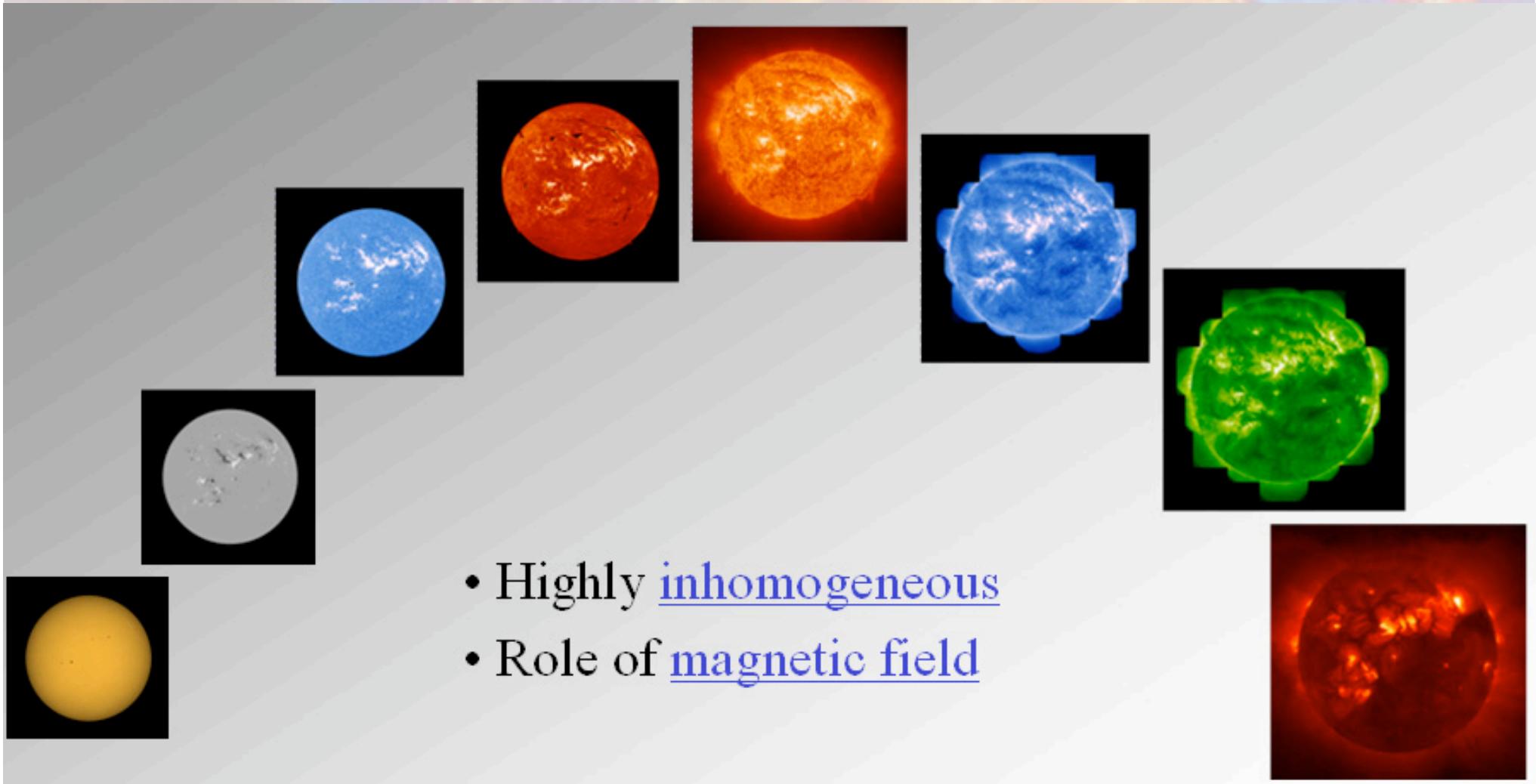
A lot of modeling to interpret results and remove LOS effects



Requirements for coronal magnetic field measurements

- It is important to obtain the full vector in corona because the magnetic field is far more inhomogeneous in direction than in strength
- The coronal magnetic field is weak (1-100 G)
- Sample plasma and embedded field at a range of heights

Requirements for coronal magnetic field measurements



Techniques

- Force-free extrapolation
- Coronal loop oscillations
- IR Zeeman effect
- Radio measurements
- Hanle effect on resonant lines

Technological issues on EUV polarization measurements

- Scarcity of polarization measurements is not only related to the need of space-borne instruments
- No transparent materials below the LiF cutoff ($\lambda < 105$ nm)
 - Reflection off mirror surface
 - Even at Brewster angles mirrors do not perform as ideal polarizers: metals have high reflectivities with low polarization ratio, "dielectrics" have low reflectivities with high polarization ratios.
- Above 105 nm the index of refraction of materials is highly variable. Optics perform well only within narrow wavelength bands

Technical solutions for EUV polarimetry

- Below LiF cutoff
 - Mirrors at pseudo-brewster angle
- Above 105 nm
 - Multilayer monochromatic Brewster angle mirror
 - Brewster angle transmission
 - Wire grid polarizer

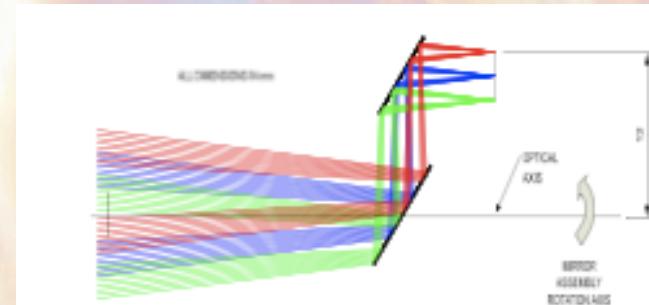


Figure 4-9 Close up view of the polarising mirror assembly showing the rotation axis of the polarising mirror assembly.

Pelletier et al.,
Appl.Phys.L 88 (2006)

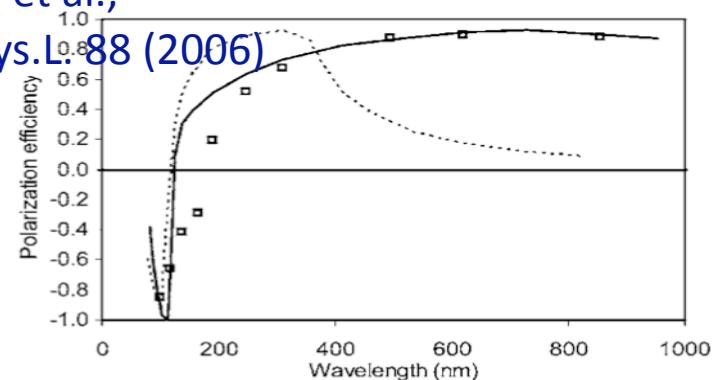


FIG. 2. Polarization efficiency as function of wavelength for aluminum (full line, in the infinite wavelength limit; symbols, numerical calculation) and silicon grids (dashed line, in the infinite wavelength limit) with volume fraction $r = \frac{1}{2}$ and thickness $h = 25$ nm.

Proposed spectro-polarimetric experiments

Several missions have been proposed to measure coronal magnetic fields by means of EUV spectro-polarimetric analysis:

- ASCE (Advanced Solar Coronagraphic Experiment) (NASA MIDEX, Kohl, 1999)
• HI Lyman series 121.6, 102.5, 97.2 nm + OVI 103.2/103.7 nm
- SMESE/LYOT (Small Explorer for Solar Eruptions/Ly α Coronagraph, CNES Francia, Vial, 2005) HI 121.6 nm Lyman- α
- COMO (Coronal Magnetism Observer, NASA ROSES 2008, Moses, 2009))
• HI 121.6 nm Lyman- α
- COMPASS (Coronal Magnetism, Plasma and Activity Studies from Space) (ESA Cosmic Vision 2015-2025, Solanki, Fineschi 2007)
• HI Lyman series 121.6, 102.5, 97.2 nm + OVI 103.2/103.7 nm

Funded projects

ASI Esplorazione del Sistema solare 2008-2010

Study and development of UV linear polarizers (Wire grid, reflection)

Partners: UniFI - INAF/OATo

PRIN-MIUR 2008 *Tecniche e Tecnologie Innovative per lo Studio del Magnetismo Solare*

Development of a complete UV linear polarizer prototype for HI Lyman- α

Partners: UniFI - INAF/OATo - UniPv

Progetto POR-FSE 2007-2010 Regione Toscana (fin Giovani ricercatori)

NANOPol: Costruzione di nanofili su aree estese per la realizzazione di polarizzatori a fili per lo studio di campi magnetici nella corona solare

Partners: UniFI - UniPi

Personale del Dip. di Fisica e Astronomia coinvolto

Marco Romoli, ricercatore

Federico Landini, borsista post-doc

Maurizio Pancrazzi, borsista post-doc

Collaborano anche: E. Landi Degl'Innocenti e E. Pace

Strutture di laboratorio per la spettropolarimetria UV

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

Linea SOURCE sincrotrone Frascati (resp. E. Pace) (in preparazione)

Bibliografia

- [1] Landi Degl'Innocenti, E., Landolfi, M.: 2004, "Polarization in Spectral Lines", Kluwer Academic Publishers, Dordrecht
- [2] Kohl J.L. et al.: 1995, "The Ultraviolet Coronagraph Spectrometer for the Solar and Heliospheric Observatory", *Sol. Phys.*, 162, 313.
- [3] Romoli M., Weiser H., Gardner L.D., Kohl J.L.: 1993, "Stray Light Suppression in a Reflecting White Light Coronagraph", *Appl. Opt.* 32, 3559.
- [4] Romoli M., Frazin R.A., Kohl J.L., Gardner L.D., Cranmer S.R., Reardon K., Fineschi S.: 2002, "In-flight calibration of the UVCS white light channel", in A. Paulhuhn, M.C.E. Huber, R. von Steiger (eds.) "The radiometric calibration of SOHO", SR-002, 181, ESA publication.
- [5] Gardner L.D. et al.: 1999, "The Advanced Solar Coronal Explorer Mission (ASCE)", in S. Fineschi, B.E. Woodgate, R.A. Kimble (eds.) "UV and X-Ray Detection, Spectroscopy, and Polarimetry III", Proc. SPIE 3764, 134.
- [6] Corti G., Romoli M.: 2003, "Characterization of materials for a vacuum UV polarization analyzer", *Appl.Opt.*, 49, 3950.
- [7] Romoli M., Landini F., Fineschi S., Gardiol D., Naletto G., Malvezzi M., Tondello G., Noci G.C., Antonucci E., 2001: "Stray light evaluation of the Ultraviolet and Visible-light Coronagraph Imager (UVCI) rocket prototype", in O.H. Siegmund, S. Fineschi, M. A. Gummin (eds.) "UV/EUV and Visible Space Instrumentation for Astronomy and Solar Physics", Proc. SPIE 4498, 27.
- [8] Fineschi, S., Solanki, S.K., Landi Degl'Innocenti, E., Trujillo Bueno, J., et al.: 2007, "COMPASS, Coronal Magnetism, Plasma and Acticity Studies from Space", a class-M mission submitted for the Cosmic Vision Programme of the European Space Agency, June 29, 2007

Polarizzatore a fili

Caratteristiche

- Lunghezza d'onda di lavoro ottimale 3-4 volte il periodo dei nanofili
- Si o Al su substrato trasparente
- Realizzati con ion etching

Vantaggi:

- Lavorano a banda larga
- Lavorano sull'asse ottico

Svantaggi:

- Supporto trasparente limita a $\lambda > 105 \text{ nm}$
- Piccole dimensioni $\sim 1\text{mm}$

Polarizzatore a fili

Caratteristiche

- Dalle teorie del campo d'onda può lavorare (ottimale) 3-4 volte il periodo

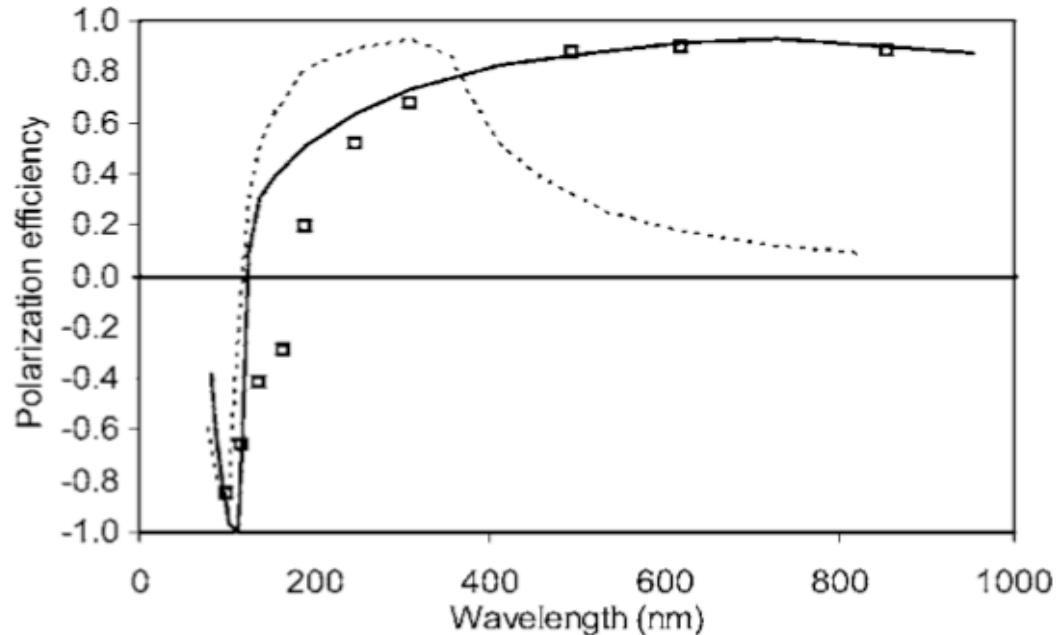
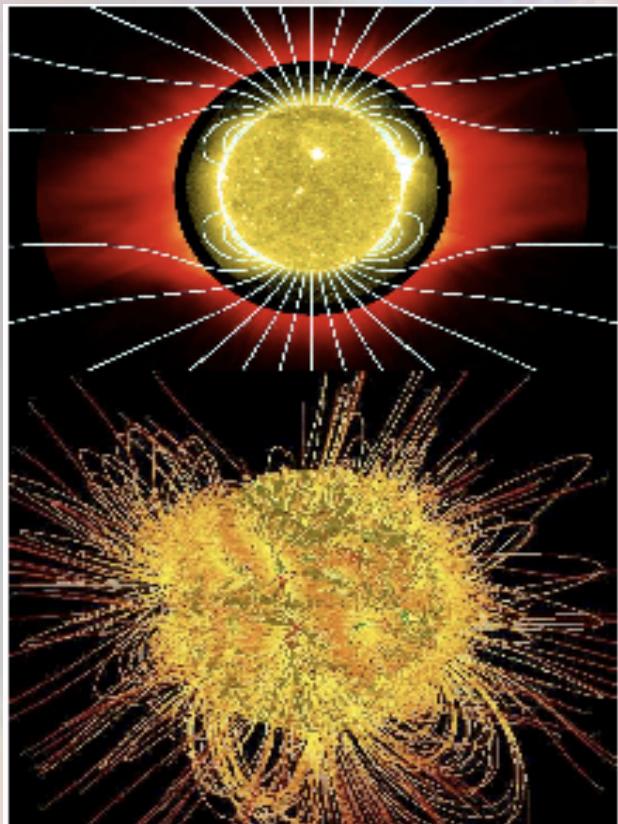


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Force-free extrapolation



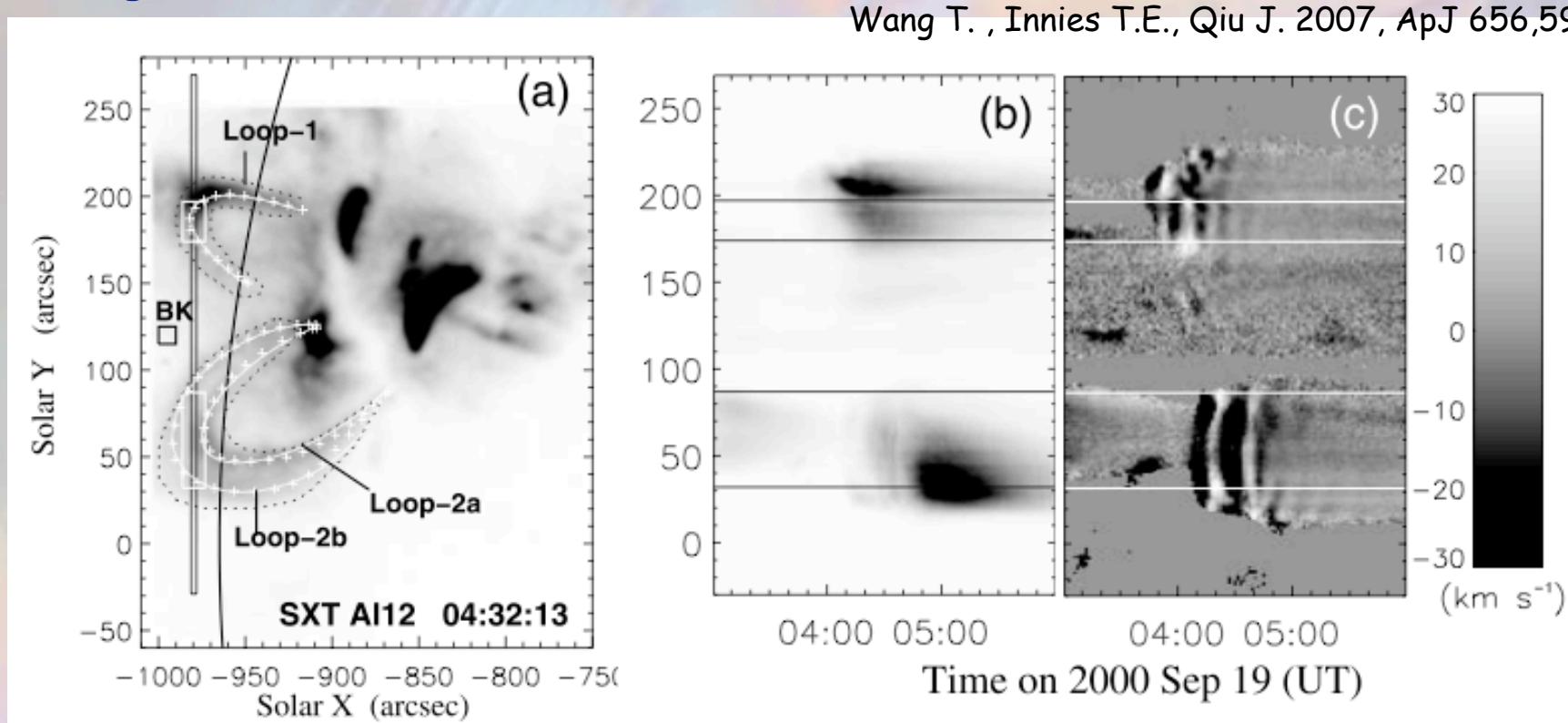
- Indirect technique
- Extrapolation of photospheric magnetic field
- Assume potential or force-free magnetic field throughout the corona
- Complimentary to direct coronal measurements.

Wiegmann T., Solanki S.K., 2004, ESA-SP-575, 3

Coronal loop oscillations

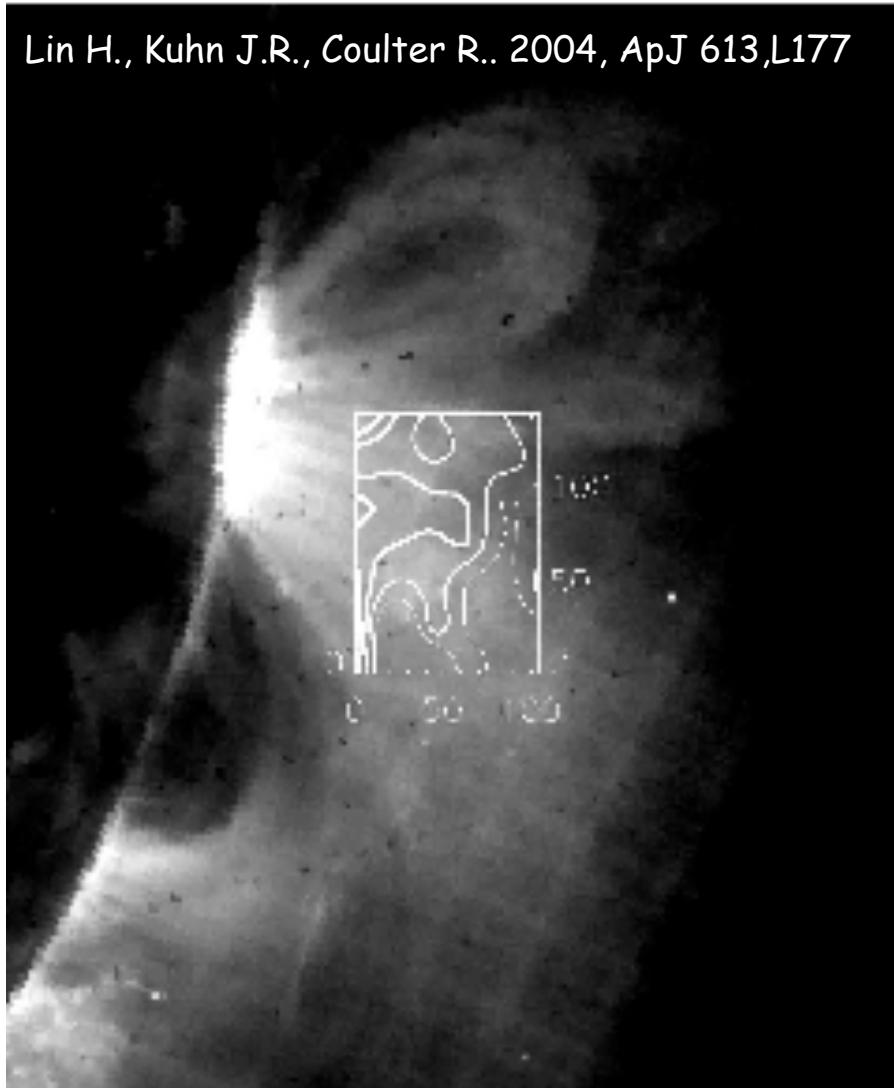
- Interpretation of flare-generated oscillations of coronal loops from Doppler shifts and plasma diagnostics (temp. and density)
- Local determination of magnetic field
- no magnetic field direction.

Wang T., Innies T.E., Qiu J. 2007, ApJ 656, 598



IR Zeeman effect

Lin H., Kuhn J.R., Coulter R.. 2004, ApJ 613,L177



- Zeeman effect is stronger in the IR (splitting $\Delta\lambda \approx \lambda^2 B$)
- Measured in FeXIII 1074.7 nm
- Only LOS magnetic field with circular polarization
- poor spatio-temporal resolution because of weak circular polarization

Radio measurements

- Several techniques are employed:
 - Rotation (Faraday rot.) of the plane of polarization of a linearly polarized radio signal occulted by the corona (Mancuso & Spangler, 2000, ApJ, 539, 480)
 - Type II Radio bursts (Mancuso et al., 2003, A&A, 400, 347)
 - Thermal gyroemission from active regions (Brosius & White, 2006, ApJ, 641,L69)
- Works at all coronal heights
- Needs additional observations
- Very local, no mapping.

Hanle Effect - resonant lines

Key parameter: $(\tau = 1/A_{ul}$, transition mean lifetime)

$$\Omega = \omega_L \cdot \tau \propto B$$

Regimes

$\Omega \gg 1$ strong field

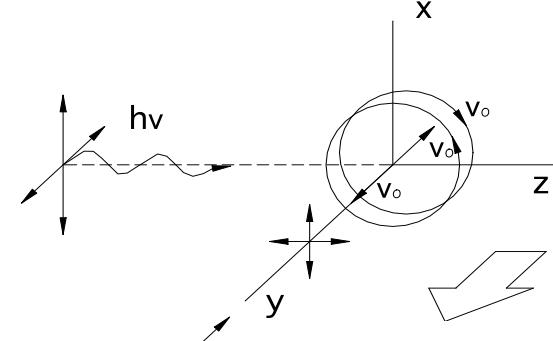
$\Omega \ll 1$ weak field

$\Omega \approx 1$ H.E. maximum sensitivity

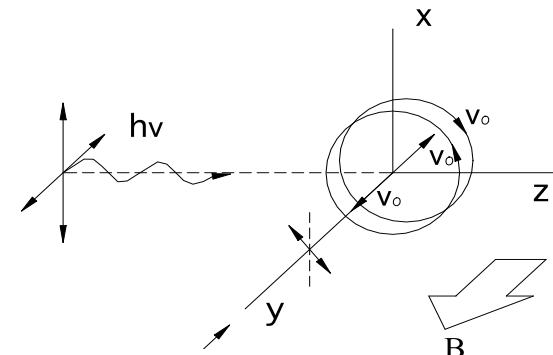
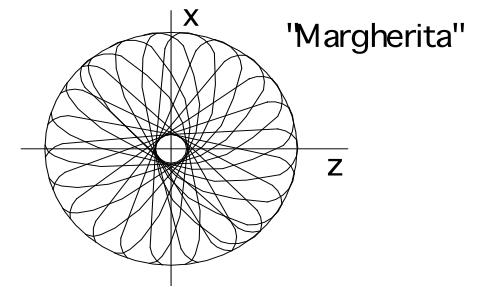
For B directed toward the observer and for 90° scattering (Breit, 1925):

$$\frac{p}{p_0} = \frac{1}{\sqrt{1 + 4\Omega^2}}$$

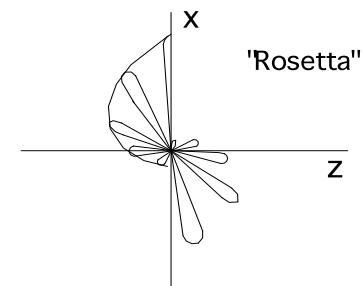
$$\phi = \frac{1}{2} \cdot \text{arctg}(2\Omega)$$



(a)



(b)



Hanle effect for magnetic field directed toward the observer. (a) Strong magnetic field ($\Omega \gg 1$) with the relative polarization pattern ("margherita") (b) Intermediate magnetic field ($\Omega \approx 1$) with the relative polarization pattern ("rosetta").

Hanle effect Sensitivity

$$A [10^7 \text{ s}^{-1}] \sim 0.88 \cdot g_J \cdot B [\text{G}]$$

Spectral line	λ (Å)	A_{12} (10^7 Hz)	B_{Hanle} (gauss)
H I Ly- γ	972	6.82	1 – 7
H I Ly- β	1025	16.7	2 – 20
H I Ly- α	1216	62.7	10 – 70
O VI	1032	41.6	6 – 50

Saturated Hanle effect: When the damping rate (inverse of A) is lower than the Larmor frequency the Hanle effect is saturated and the degree of linear polarization depends on the orientation of the magnetic field vector.