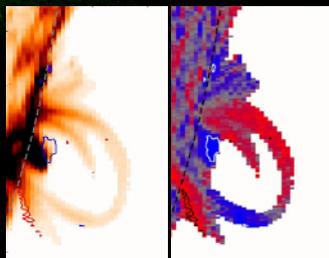
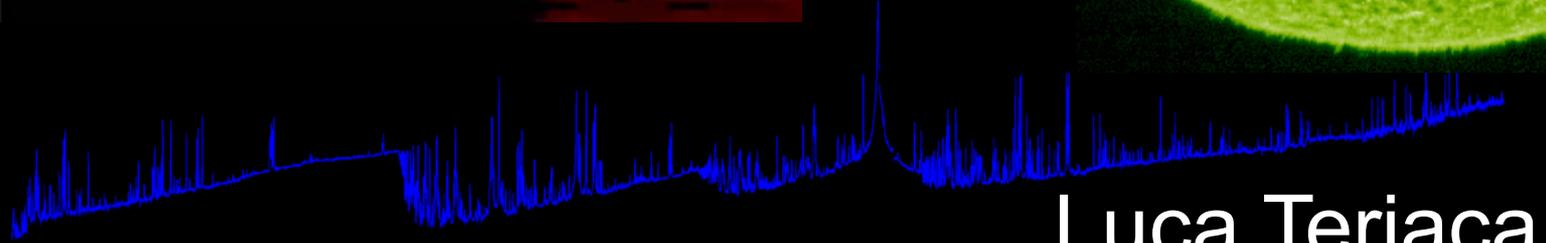
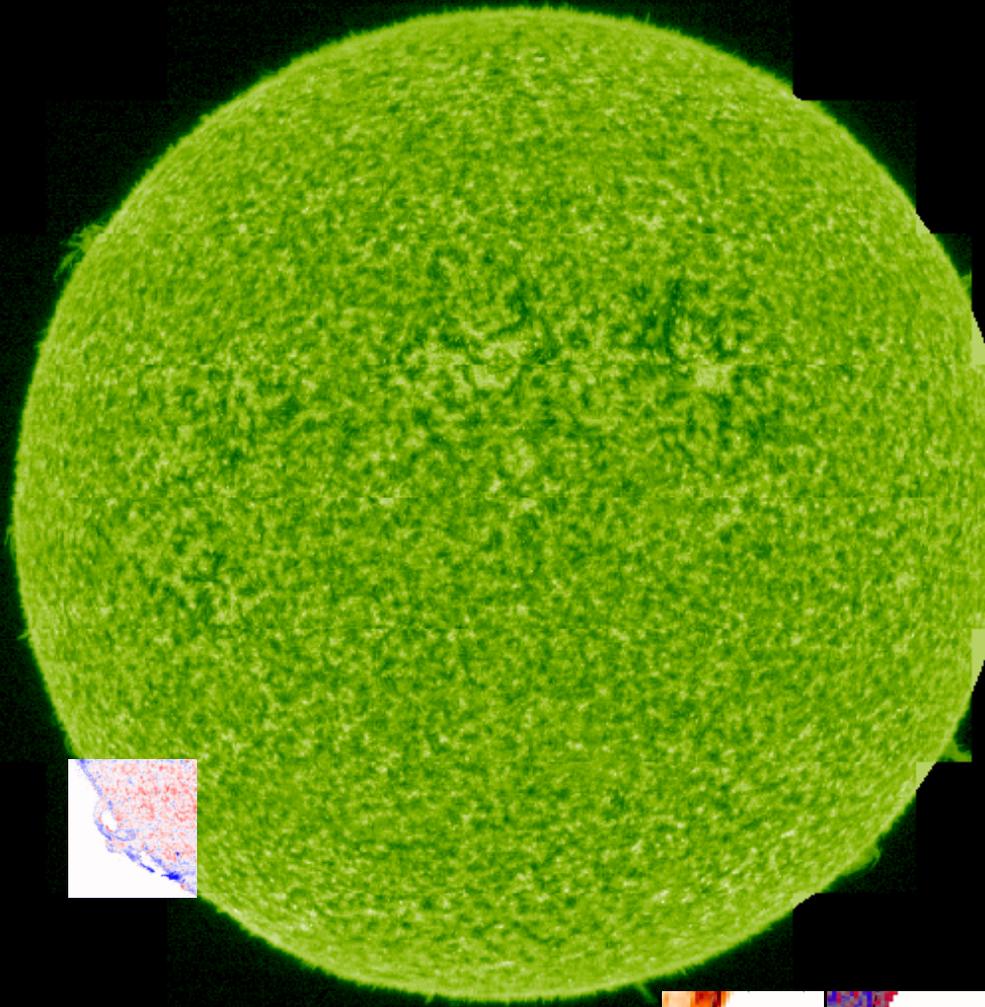


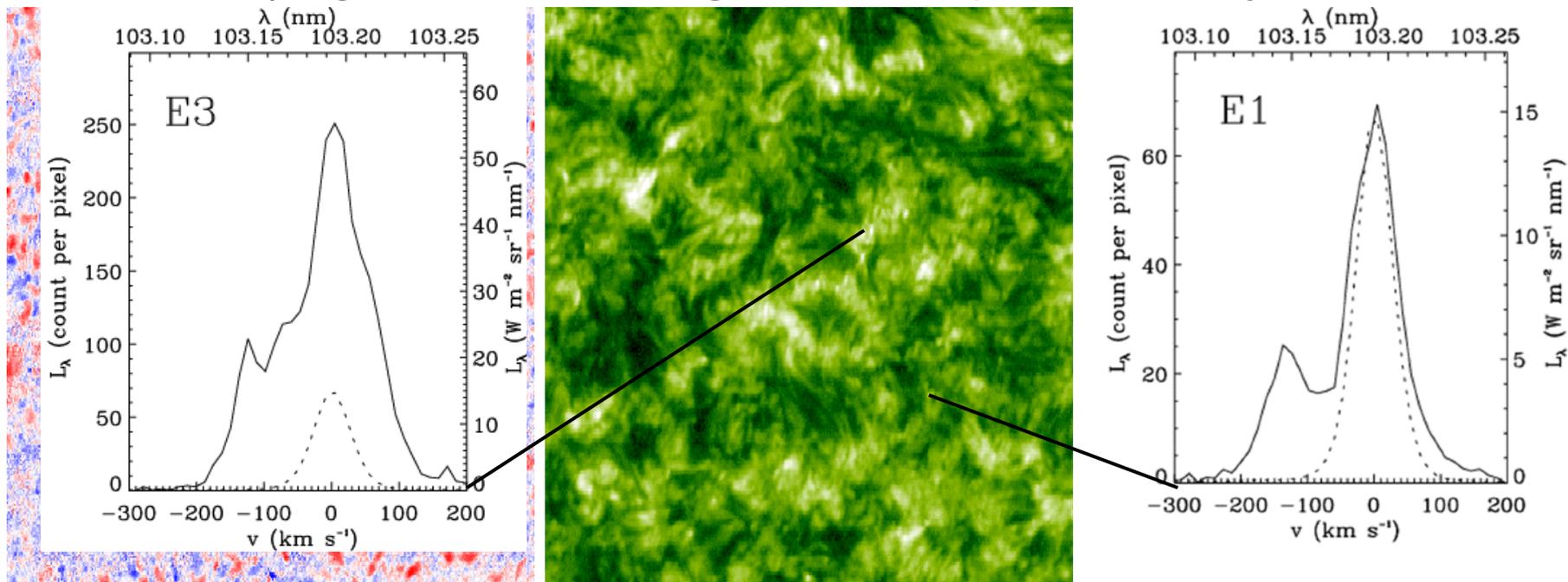
Highlights SOHO/Science: Spectroscopy



Luca Teriaca

Why spectroscopy?

- Detects **resolved** and **unresolved** (multiple flows, waves, turbulence) **dynamics** through line shapes and asymmetries.

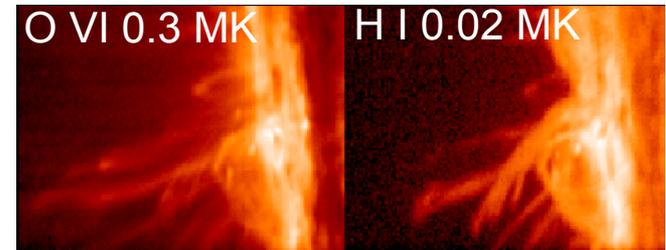


- Reveals **elemental abundances** and **ionization states** (chemical composition diagnostics).
- Avoids ambiguities from **broad, overlapping filter responses** in imaging.

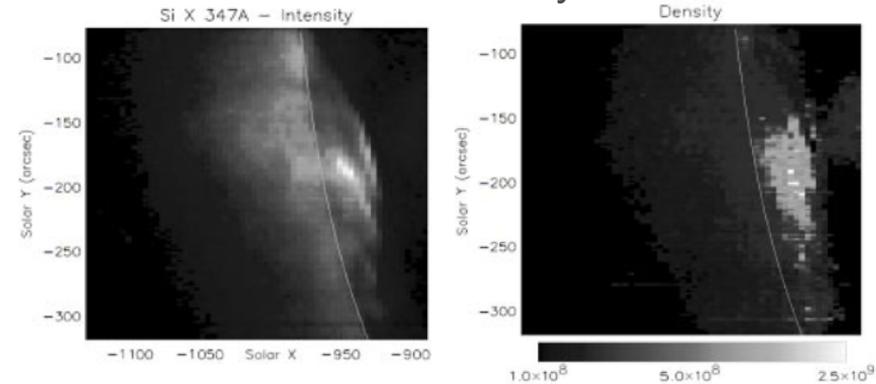
Why spectroscopy?

- Resolves the **temperature structure** of the solar atmosphere
- Determines electron **temperature** and **density** through line ratios
- Measures **line-of-sight velocities** via Doppler shifts and infer **turbulence** and/or **waves** via non-thermal broadening
- Measured/inferred quantities can constrain physical models
- Provides fundamental input to atomic physics

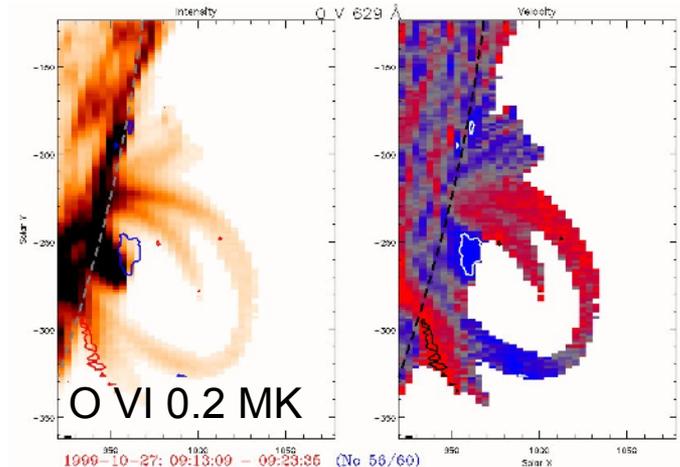
SOHO's spectroscopy improved dramatically all these fields



SUMER: May 1996



CDS: Mason et al. 1999

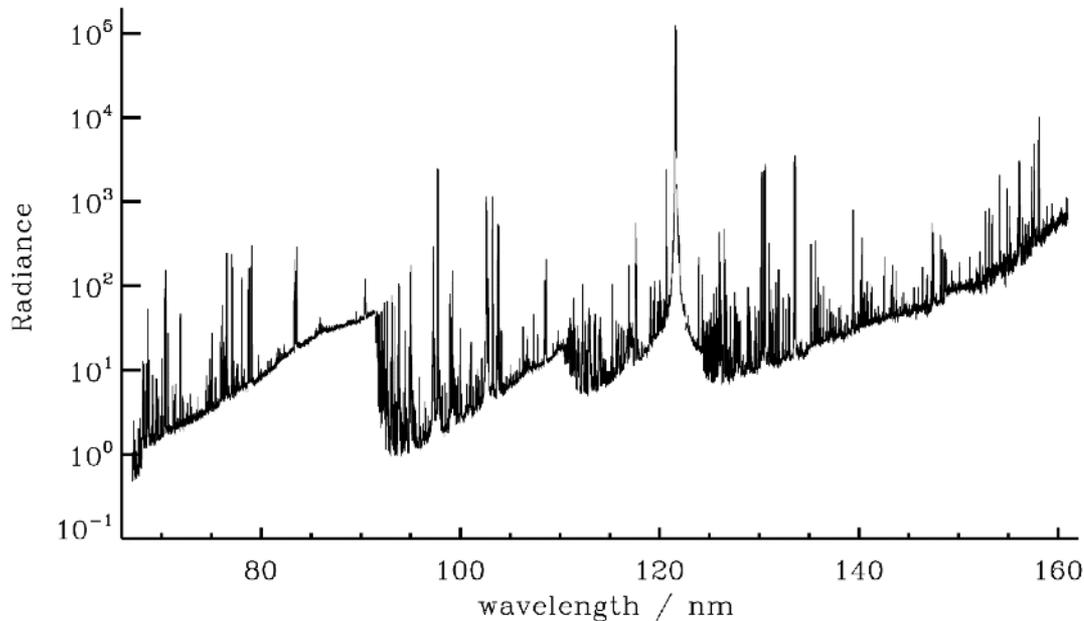


CDS: October 1999



SUMER: Solar Ultraviolet Measurement of Emitted Radiation

- *Since 1990 about 1500 publications (about 800 refereed)*
- *Wavelength range: $\approx 50 - 161$ nm (≈ 4 nm at a time)*
- *Spatial resolution ≈ 1000 km*
- *Velocity resolution ≈ 1 km/s*
- *Last observation 04.04.2017*



SUMER spectrum of the quiet Sun (Curdt et al. 2001)

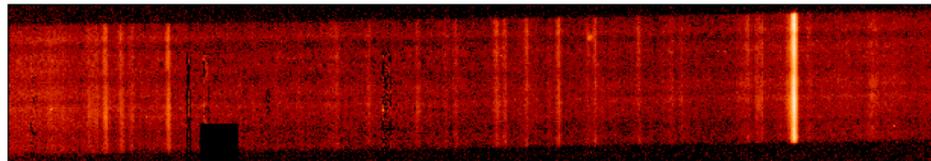


Courtesy U. Schühle

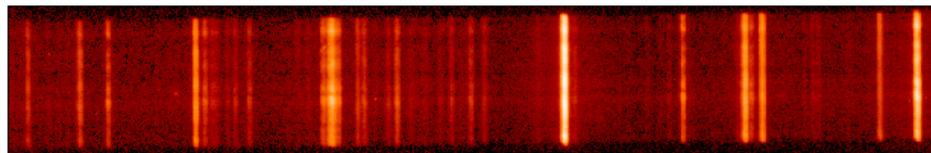


CDS: Coronal Diagnostic Spectrometer

- Since 1990 about 1000 publications (about 500 refereed)
- NIS wavelength range: 30.8 – 38.1, 51.3 – 63.3 nm
- GIS wavelength range: 15.1 – 22.1, 25.6 – 33.8, 39.3 – 49.3, 65.6 – 78.5 nm
- Spatial resolution ≈ 3000 km
- Velocity resolution ≈ 5 -10 km/s
- Last observation: 05.09.2014



320 340 360
NIS wavelength band 1



520 540 560 580 600 620
NIS wavelength band 2

Coronal Diagnostic Spectrometer
NIS spectra, 2 February 1996

Quiet sun spectra in the two NIS spectral bands

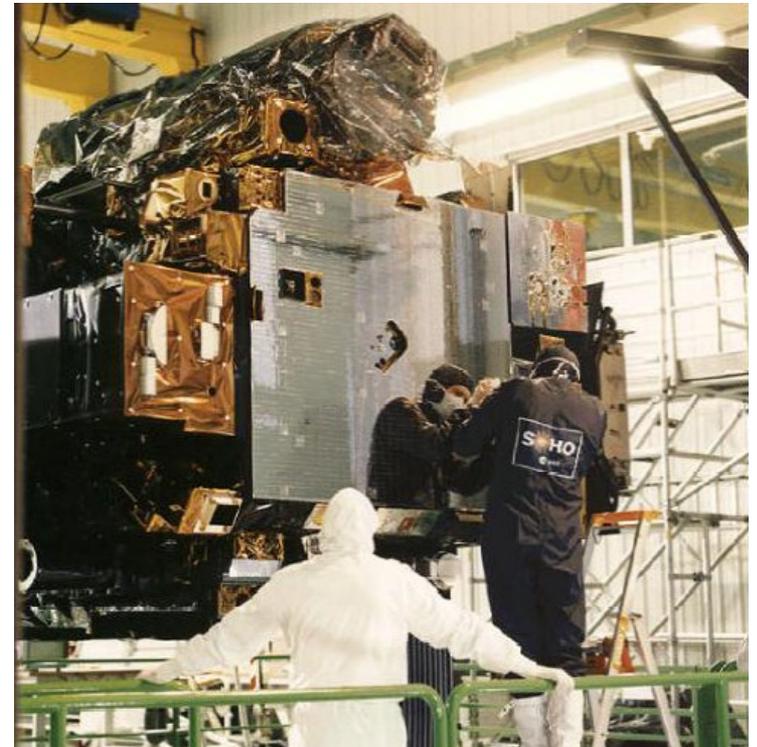
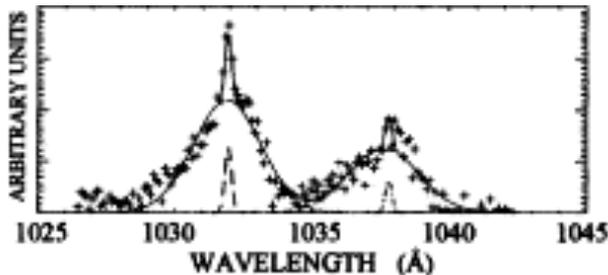


E. Sawyer installing CDS (from R. Harrison)



UVCS: UltraViolet Coronagraph Spectrometer

- Since 1990 about 800 publications (about 350 refereed)
- Ly α channel: 114.5 – 128.7 nm (110 – 136.1 nm by rotating the grating)
- O VI channel (1st order): 98.4 – 108 nm (93.7 – 112.6 nm extended)
- O VI channel (2nd order): 49.2 – 54 nm (46.9 – 56.3 nm extended)
- Spatial resolution \approx 10000 km
- Velocity resolution \approx 10-20 km/s
- Pointing: up to 10 solar radii from disk center
- Last data I could find: 19.01.2013



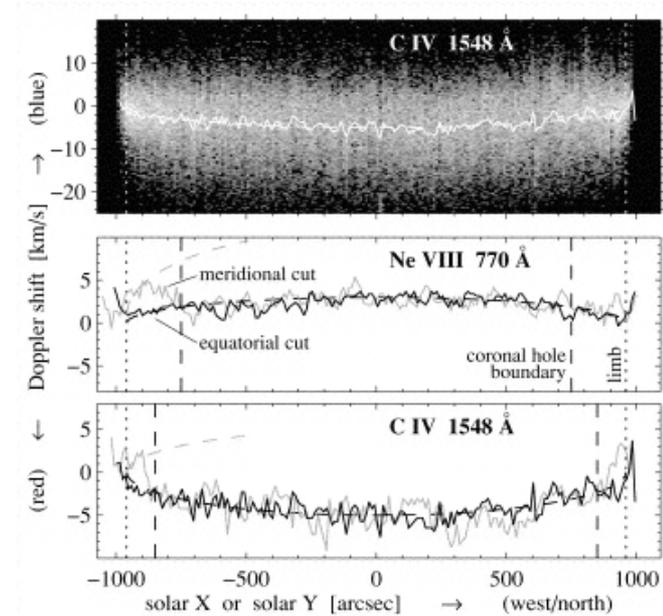
UVCS during integration (from E. Antonucci)

UVCS spectrum of a polar coronal hole at 2.1 solar radii above the limb. (Kohl et al. 1997. Extracted from Miralles et. Al 2004)

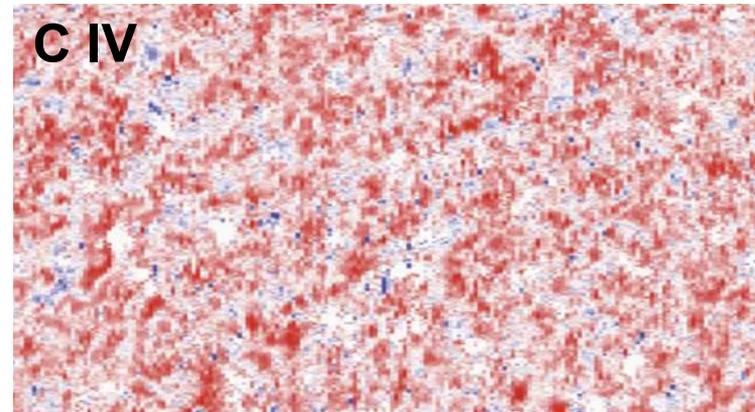
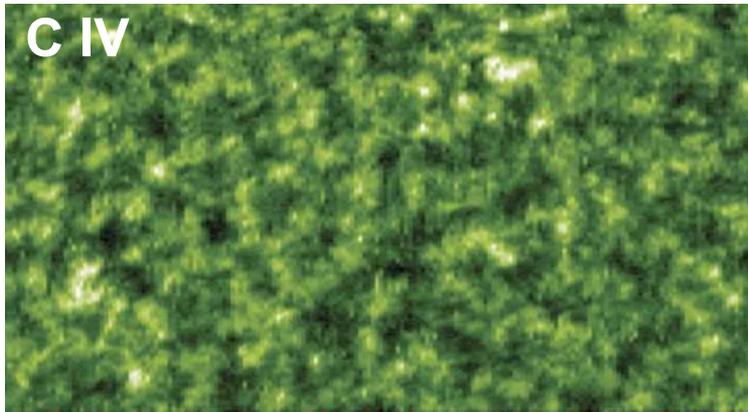
Science Highlights from Spectroscopy

Coronal circulation - QS

- Average redshift (downflow) in TR lines ($T < 0.5$ MK)
 - Concentrated in the network
- Average weak blueshift (upflow) in coronal lines ($T > 0.5$ MK)
- Clear center-to-limb variation



SUMER: Peter 1999

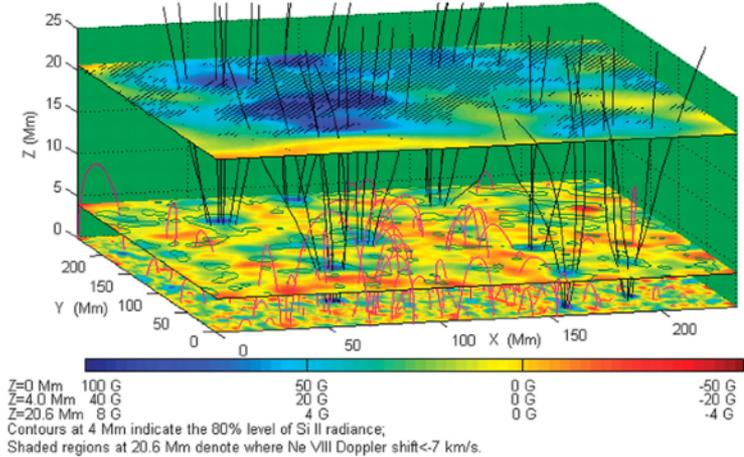


SUMER: From Tian et al. 2021 (but also Dammash et al. 1999, Hassler et al. 1999)

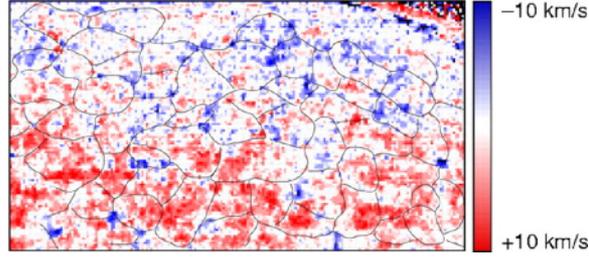
Science Highlights from Spectroscopy

Coronal circulation - CH

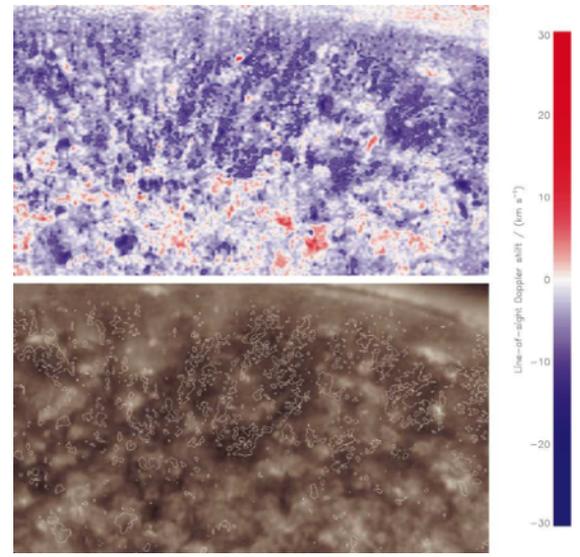
- Average redshift (downflow) in TR lines ($T < 0.5$ MK)
- Average (stronger) blueshift (upflow) in coronal lines ($T > 0.5$ MK)
- Outflows from coronal funnels



Tu et al 2005



SUMER: Hassler et

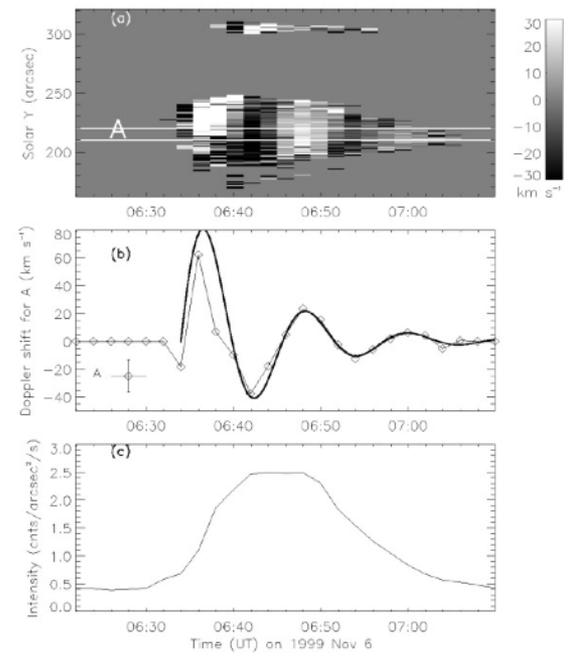


SUMER: Wilhelm et al 2000

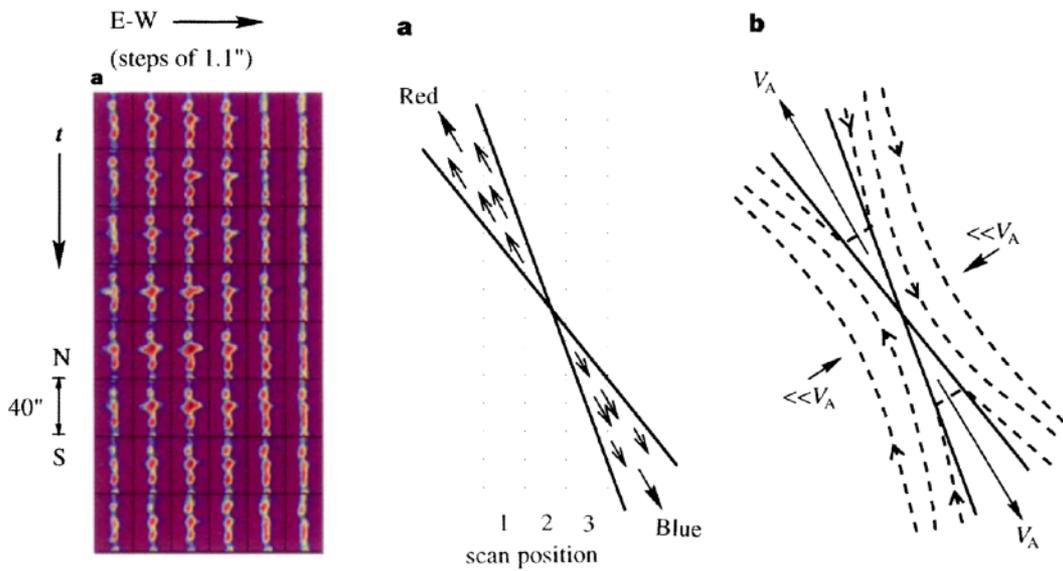
Science Highlights from Spectroscopy

Reconnection driven phenomena

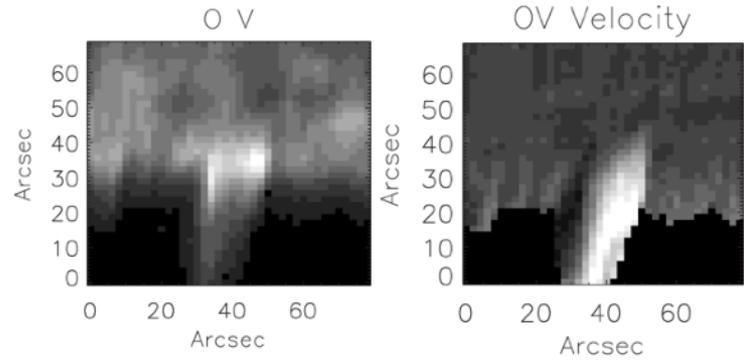
- Flare-driven damped Doppler oscillations (coronal seismology, see e.g., Wang 2011)
- Explosive events interpreted as bi-directional jets driven by reconnection
- Rotating macropicules could also be a signature of magnetic reconnection in jets



SUMER: Ofman & Wang 2002
(Wang et al. 2002)



Si IV - +
300 km s⁻¹
SUMER: Innes et al. 1997

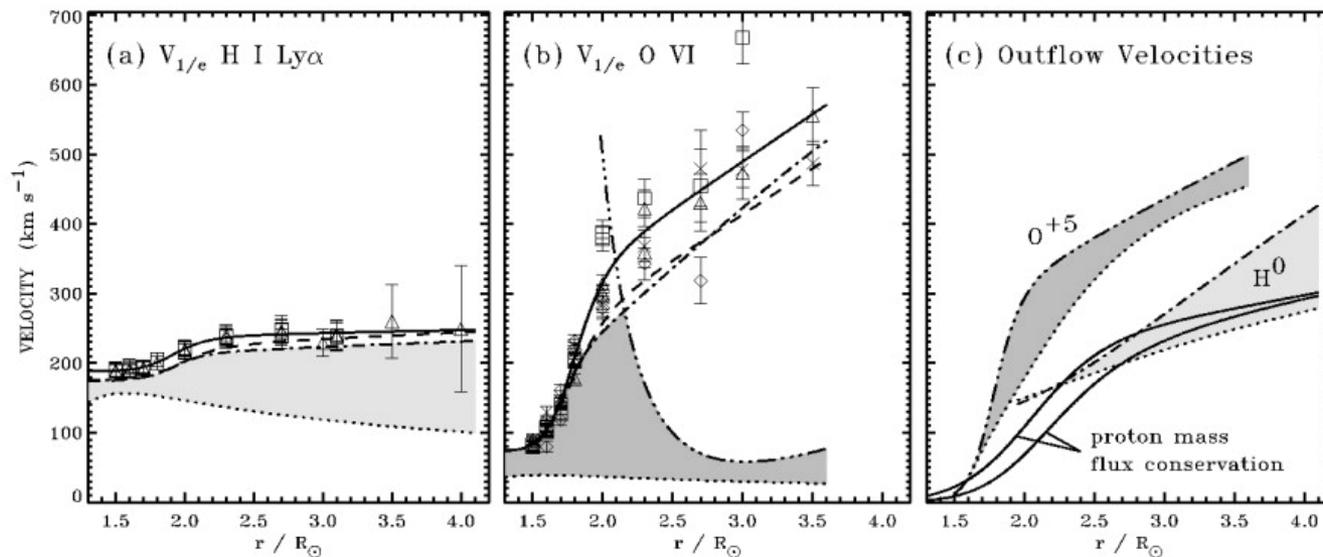


CDS: From Pike & Harrison, 1997

Science Highlights from Spectroscopy

Fast wind from Coronal Holes (off-limb)

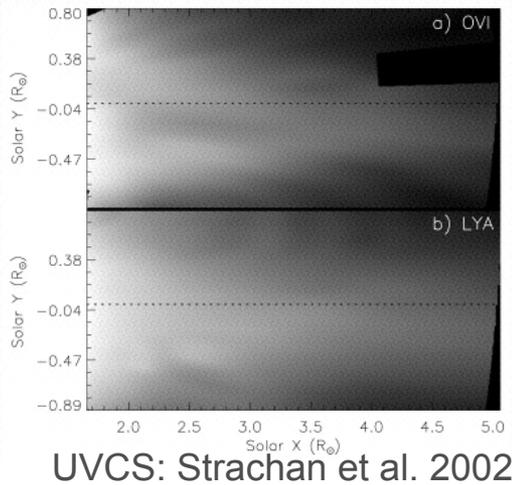
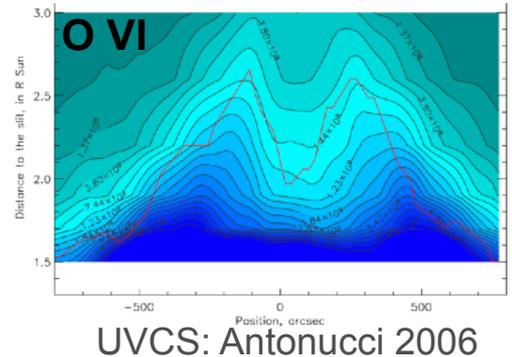
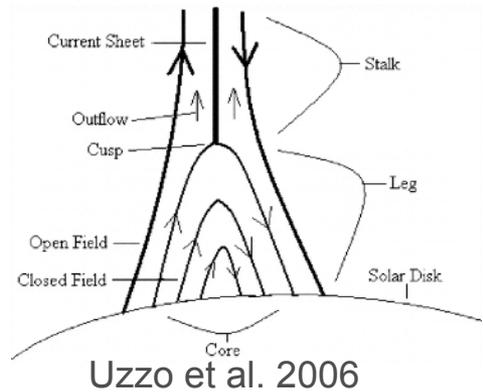
- Doppler Dimming (Kohl & Withbroe 1982, Noci et al. 1987) analysis determined that the fast solar wind is accelerated much closer to the Sun than originally believed, and that O^{5+} flows faster than protons
- O^{5+} ions are much more strongly heated than protons. Detailed analyses point to perpendicular temperatures of 2×10^8 K, roughly two orders of magnitude hotter than the protons, and T perpendicular to T parallel (with respect to the magnetic field) greater than 10.



Science Highlights from Spectroscopy

Slow wind from Streamers

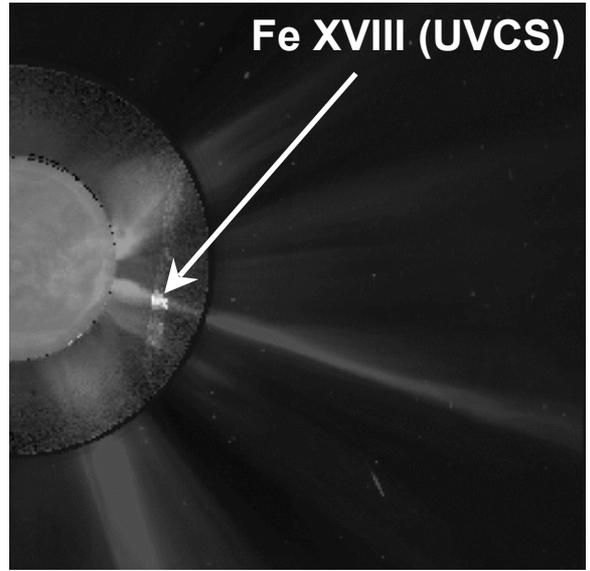
- A streamer consists of a central closed field region surrounded by an open field region called legs, which extend outward and above the closed field region
- Elemental abundances of heavy ions in streamer legs match those seen *in situ* in the slow solar wind. However, in the closed-field cores the abundances are depleted
- Doppler Dimming measurements at solar minimum revealed the legs of large equatorial streamers to be a primary site of slow-wind outflow, whereas their large central cores did not show signs of bulk acceleration



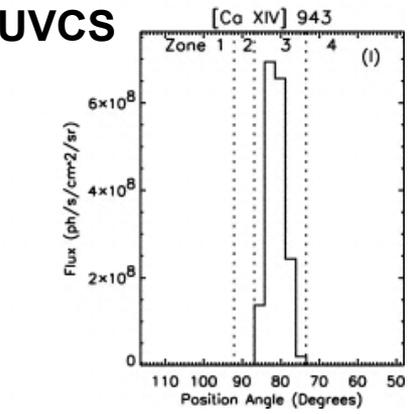
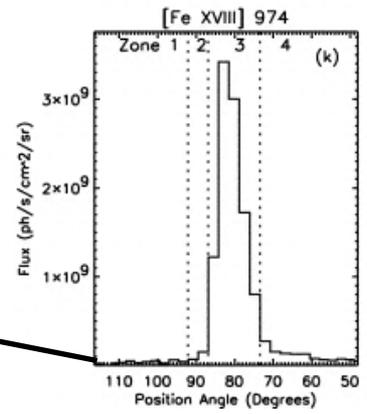
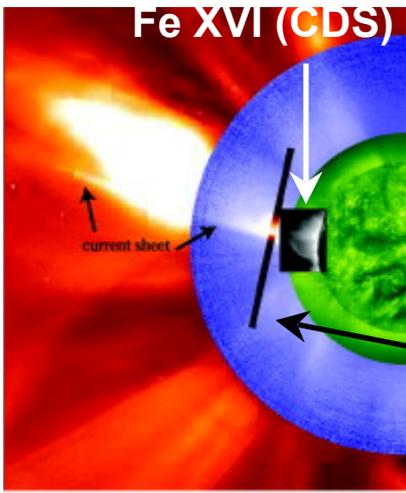
Science Highlights from Spectroscopy

Coronal Mass Ejections (CME)

- Spectroscopy provides real diagnostics of the physical conditions in CME plasmas as they accelerate through the corona. Measurements of CME energy budgets are key constraints to determining the dominate processes at work in these events.

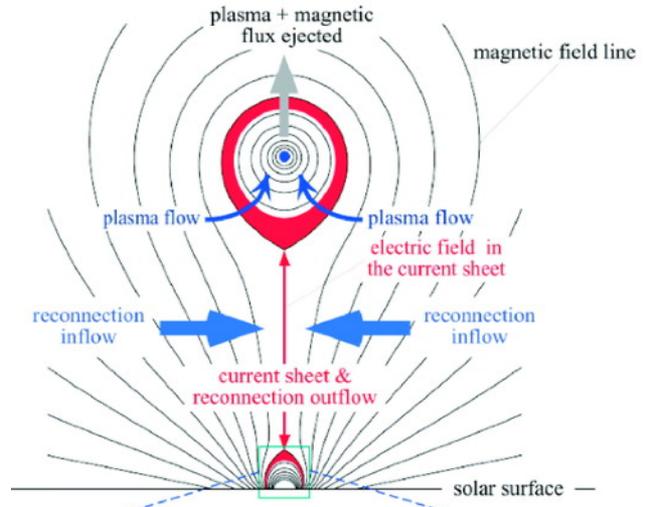


UVCS: Ciaravella & Raymond 2008



Fe XVI 2 MK, Ca XIV 3.5 MK, Fe XVIII 7 MK

Ko et al. 2003



Lin et al. 2005

Thank you!