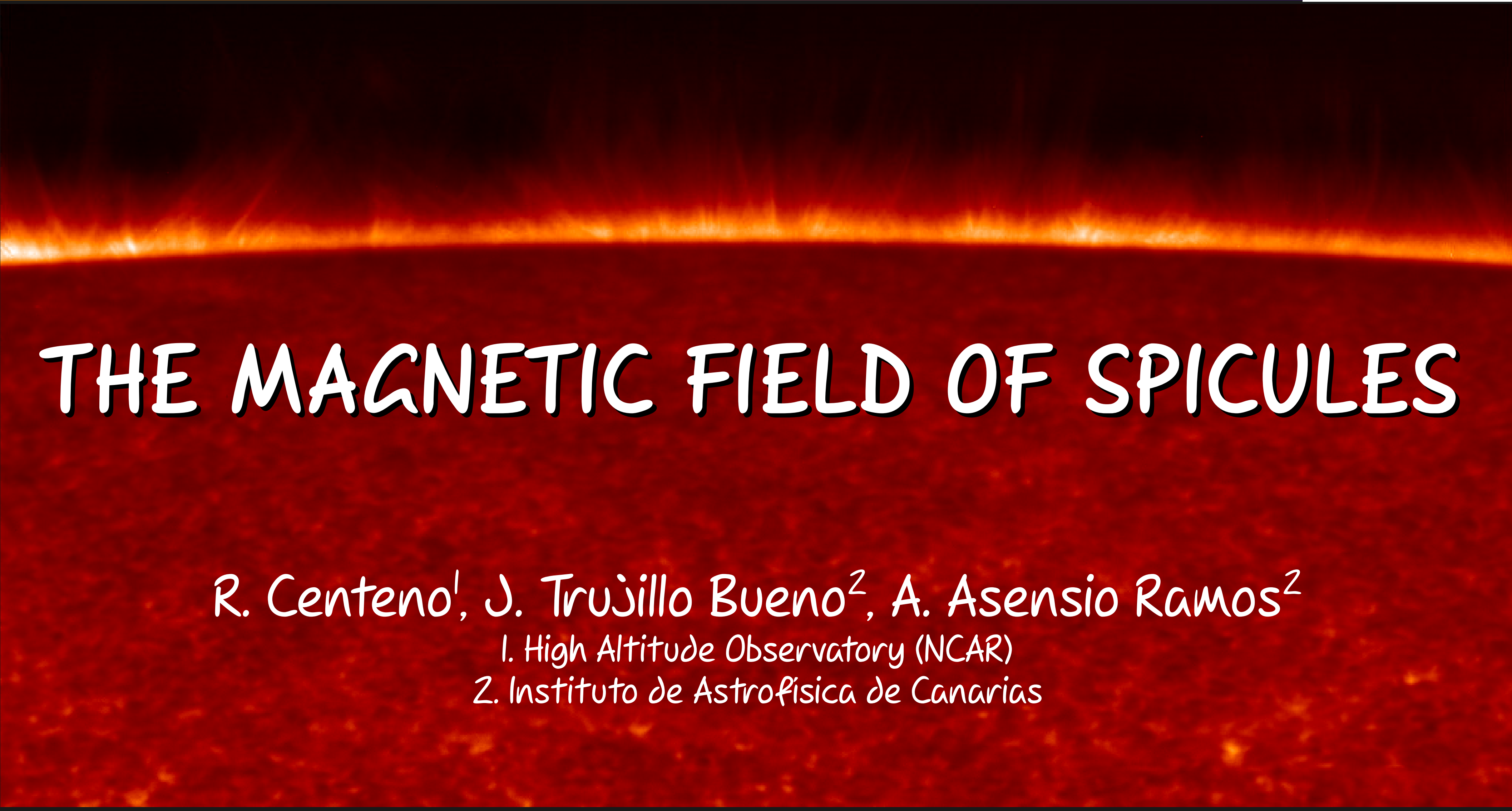

THE MAGNETIC FIELD OF SPICULES

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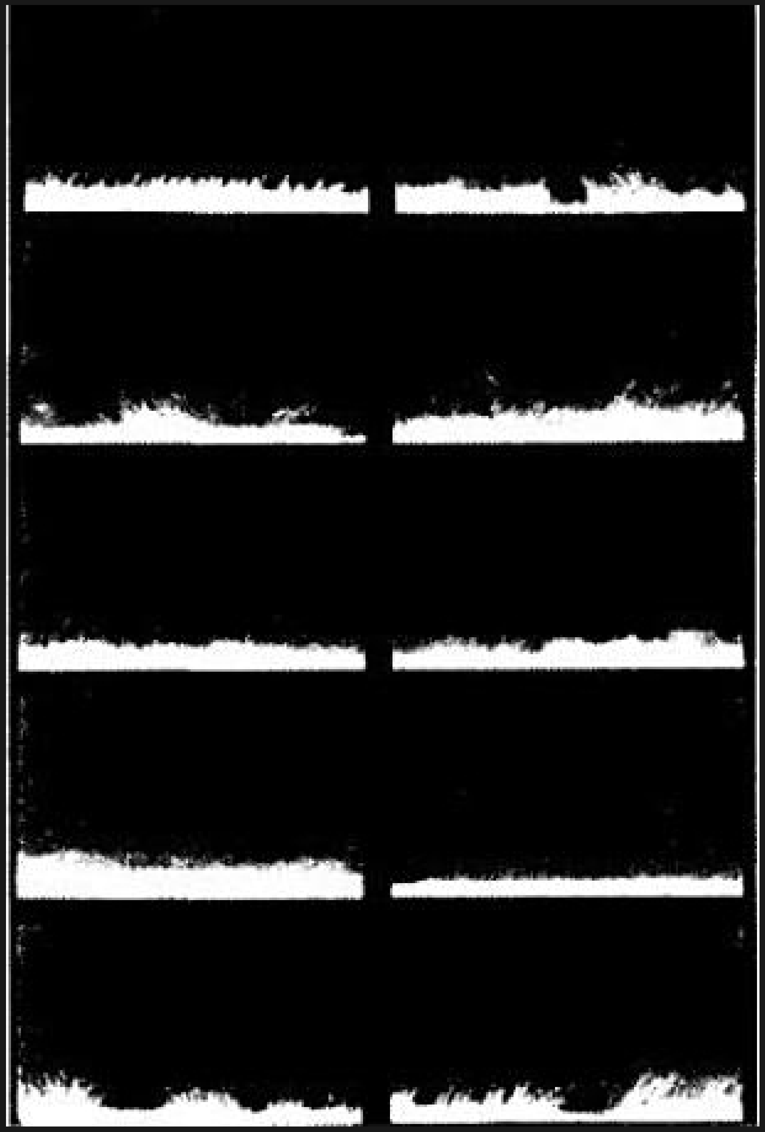
1. High Altitude Observatory (NCAR)
2. Instituto de Astrofísica de Canarias

Hinode – BFI (Ca II), courtesy of A. de Wijn

A brief history



A. Secchi in Le Soleil (1877)

Some properties of spicules:

Heights ~ 6500 – 9500 km
Widths ≤ 300 – 1500 km
Upward velocities ~ 25 km/s
T ~ 5000 – 15000 K
Densities ~ $3 \cdot 10^{-13}$ g/cm^3

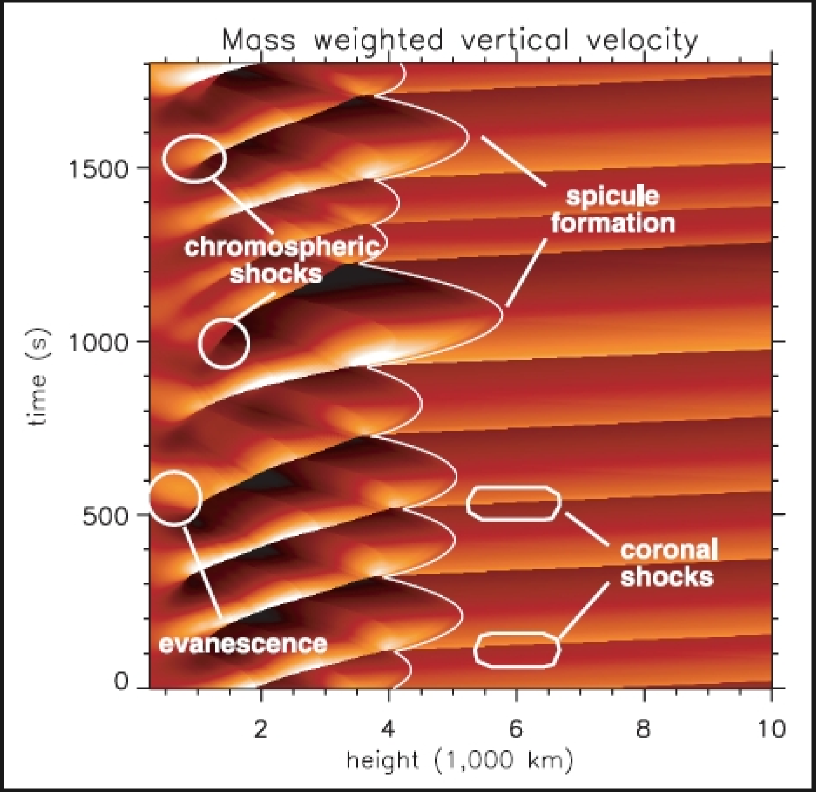
T and density constant with height

A brief history

Models have to explain properties of spicules:
- how can chromospheric material be raised to such heights without raising its temperature?

Main ingredients:
- Flux tube expanding from photosphere all the way up into the corona
- Large energy deposition at some point of the flux tube
- Non-linear regime

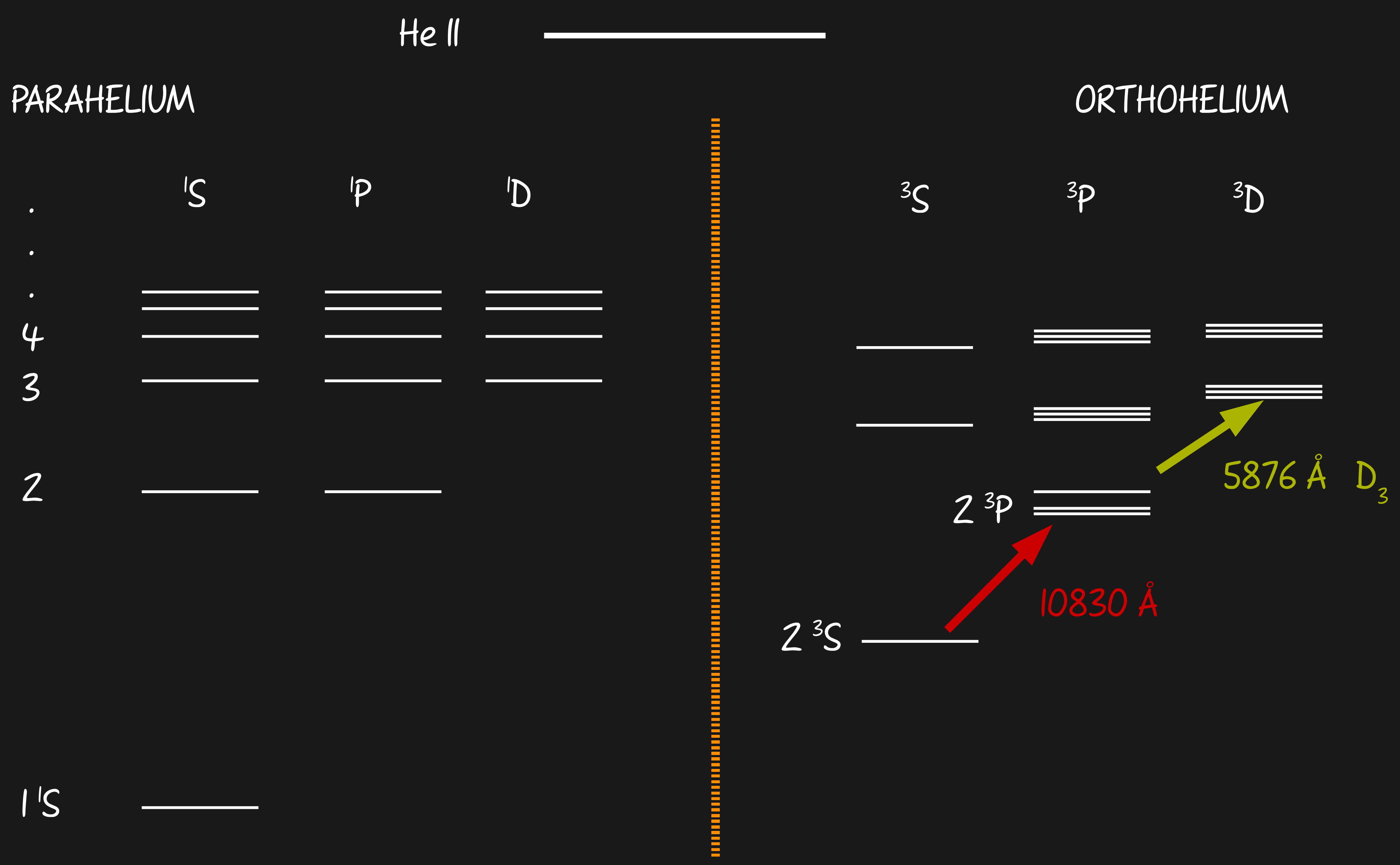
Models FAIL to reproduce some of the observational aspects of spicules partly due to our poor knowledge of spicule properties



See, e.g., De Pontieu et al. (2005)

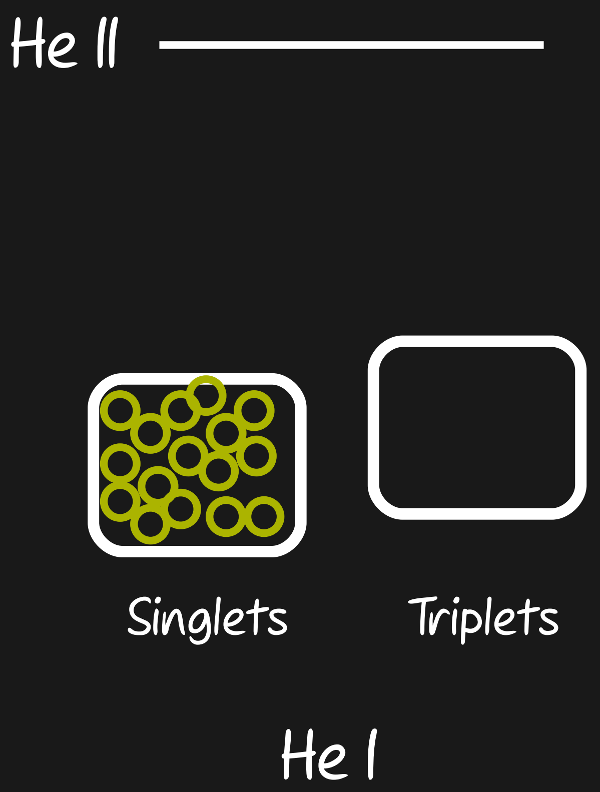
BOTTOMLINE: NEED FOR RELIABLE OBSERVATIONAL CONSTRAINTS OF SPICULAR PROPERTIES!!

He I 10830 Å


He II
PARAHELIUM
ORTHOHELIUM
¹S
¹P
¹D
³S
³P
³D
4
3
2
1 ¹S
2 ³P
2 ³S
5876 Å D3
10830 Å

Formation mechanism

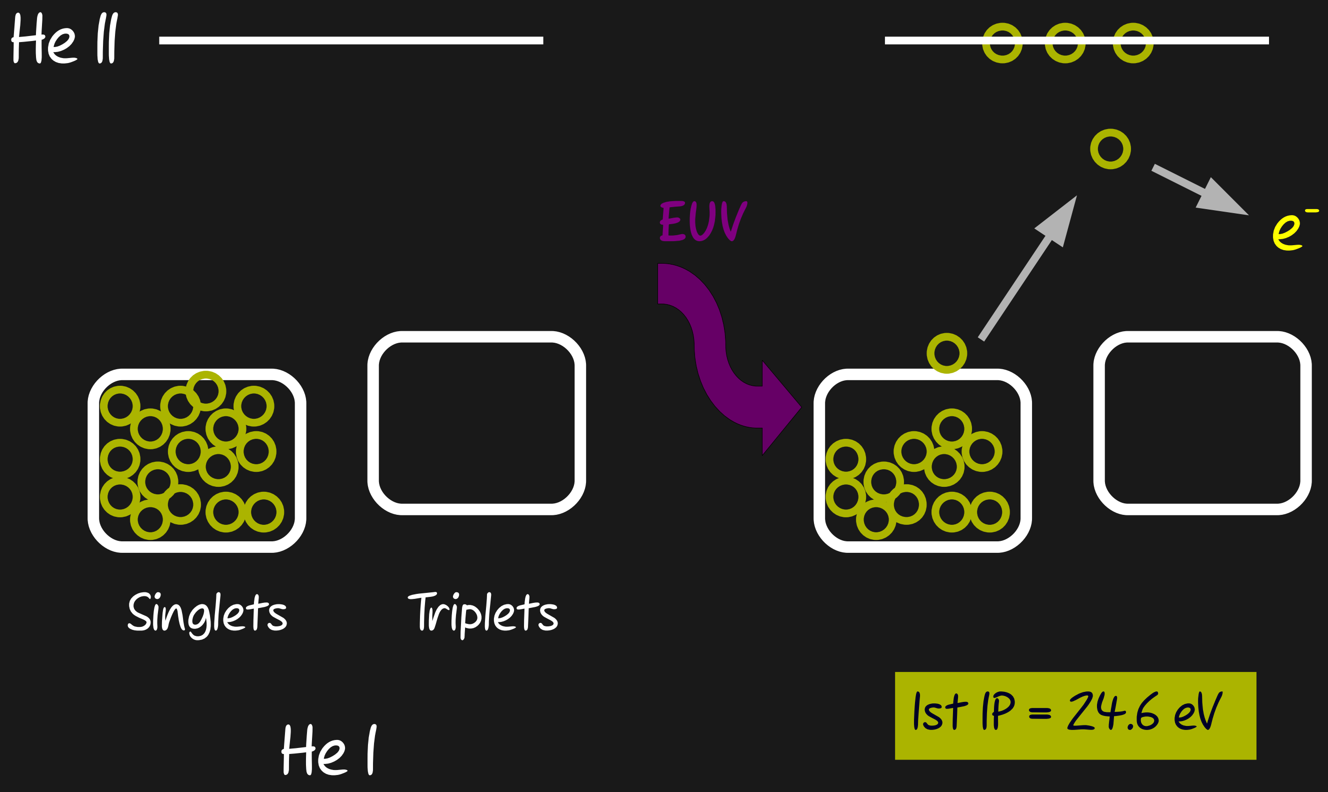
Under normal chromospheric temperature conditions triplet states are not sufficiently populated



Formation mechanism

Under normal chromospheric temperature conditions triplet states are not sufficiently populated

Coronal EUV light triggers the PR mechanism ...

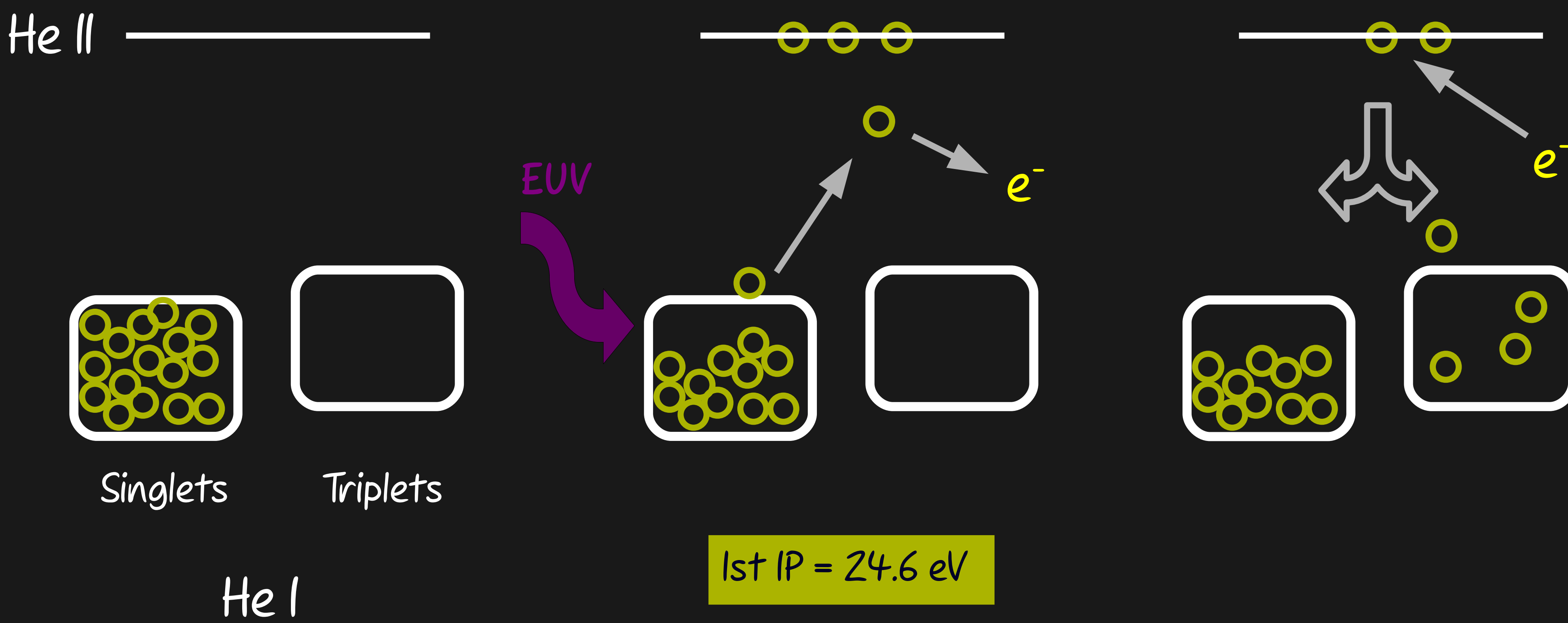


Formation mechanism

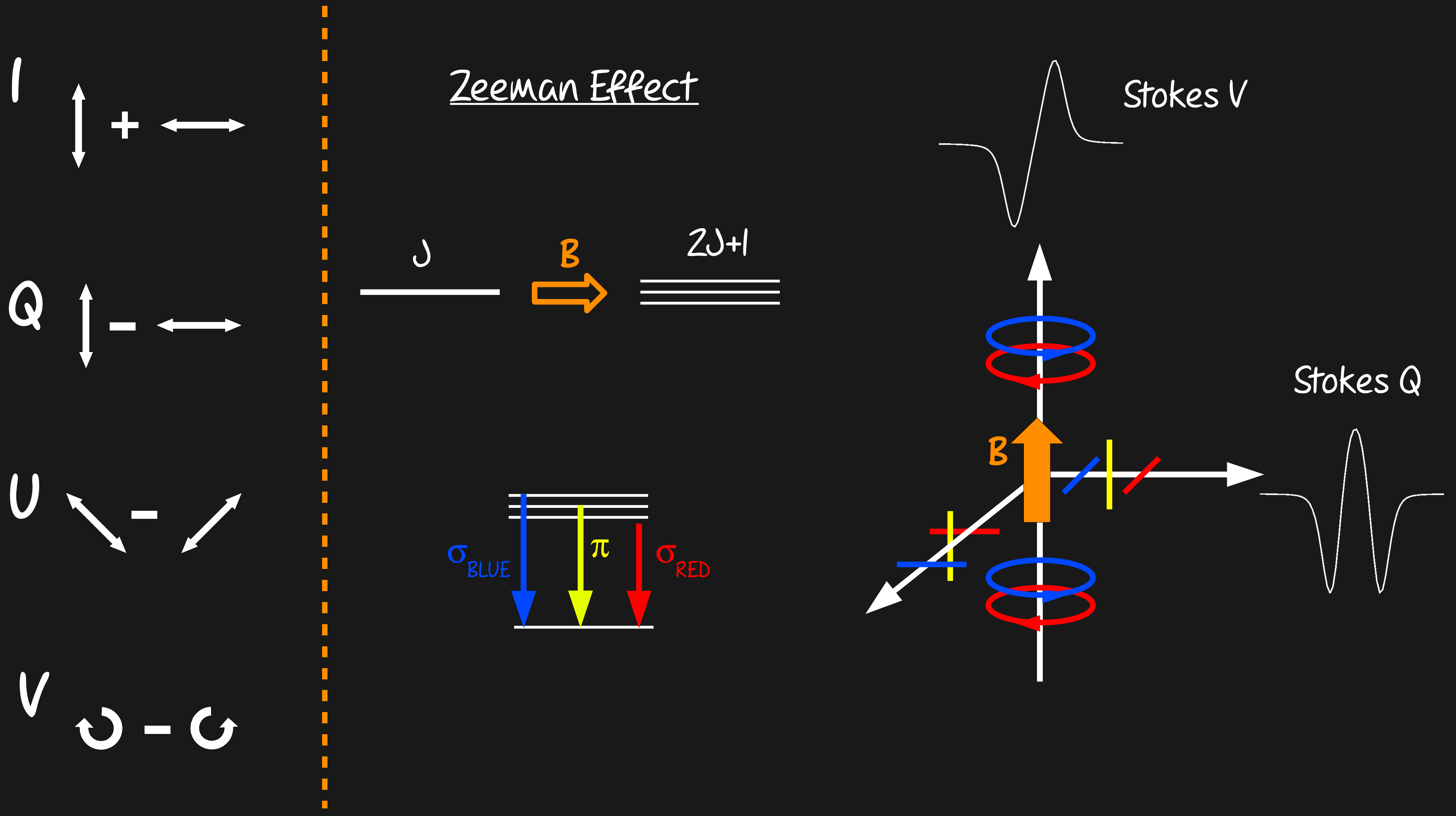
Under normal chromospheric temperature conditions triplet states are not sufficiently populated

Coronal EUV light triggers the PR mechanism ...

Which leads to an overpopulation of the triplet states

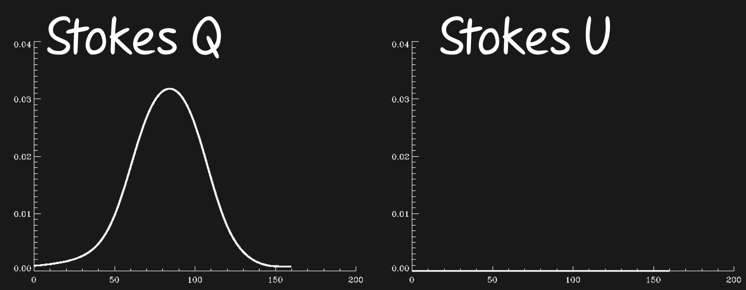


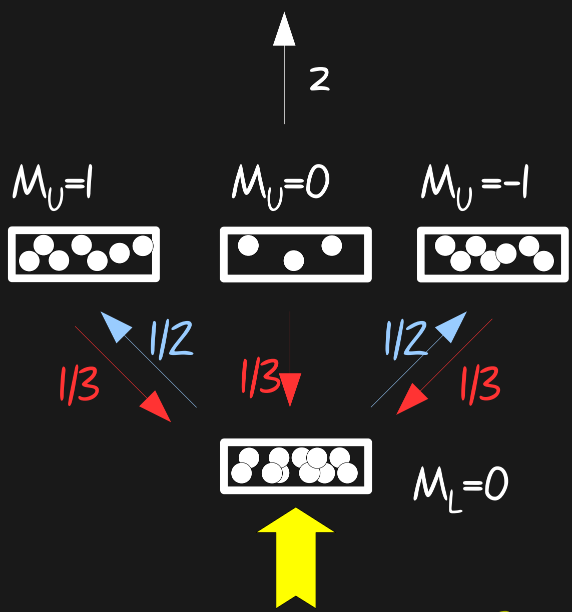
Zeeman, Hanle and scattering polarization



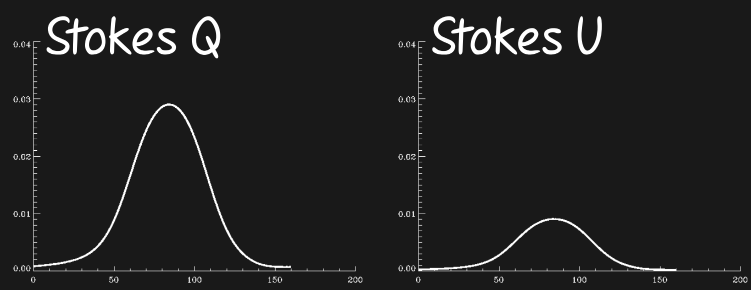
Zeeman, Hanle and scattering polarization

Scatt. Polarization (B = 0)





Hanle Effect (B ≠ 0)



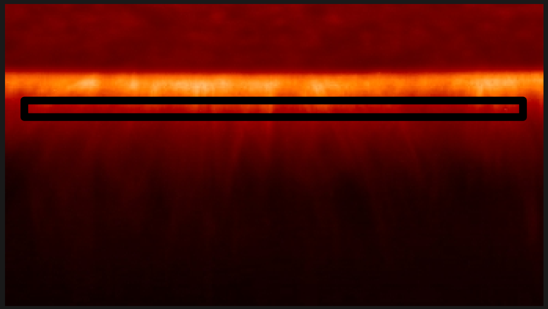
The presence of a magnetic field breaking the symmetry modifies the population imbalances and the quantum coherences between the magnetic sublevels, resulting in a net change and a rotation of the plane of polarization.

See review by Trujillo Bueno (2005)

Observations

VTT – Tenerife Infrared Polarimeter (TIP)
(Martínez Pillet et al. 1999;
Collados et al. 2007)

Full Stokes vector @ λ 10830 Å
Spectral sampling: 11 mÅ
Spatial sampling: 0.17"

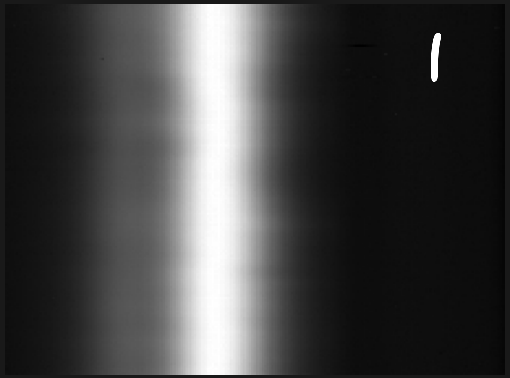


Slit fixed parallel to South limb, crossing QS spicules.
At 2" and 3" off-limb.

Time series of ~ 1 hr with 50 s cadence, averaged to achieve a high S/N
Spectral and spatial binning

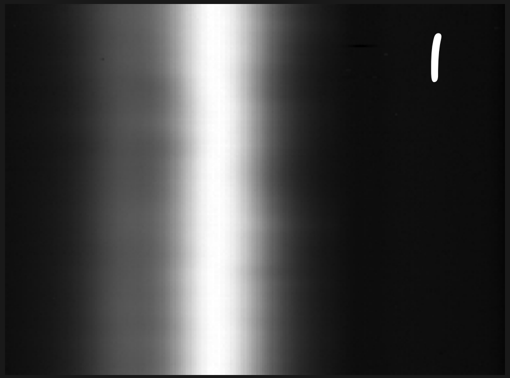
Date: August 2008
Conditions on the Sun: VERY quiet

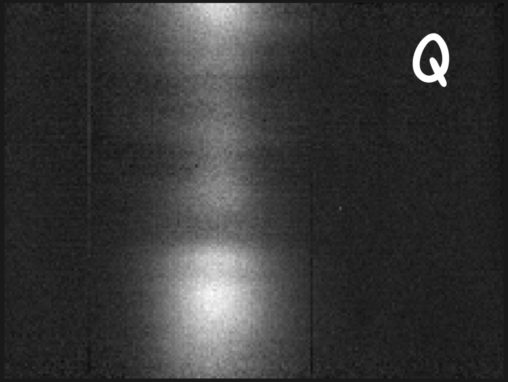
Stokes maps

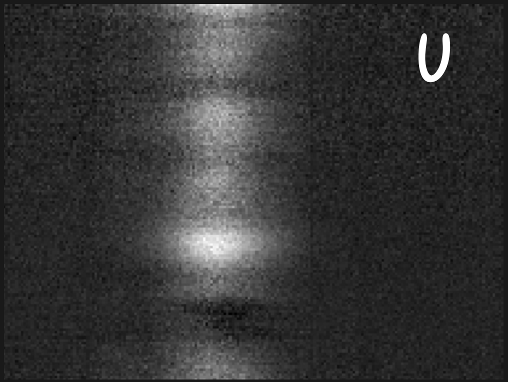


Stokes I provides **thermodynamical** information: τ, Doppler, damping

Stokes maps

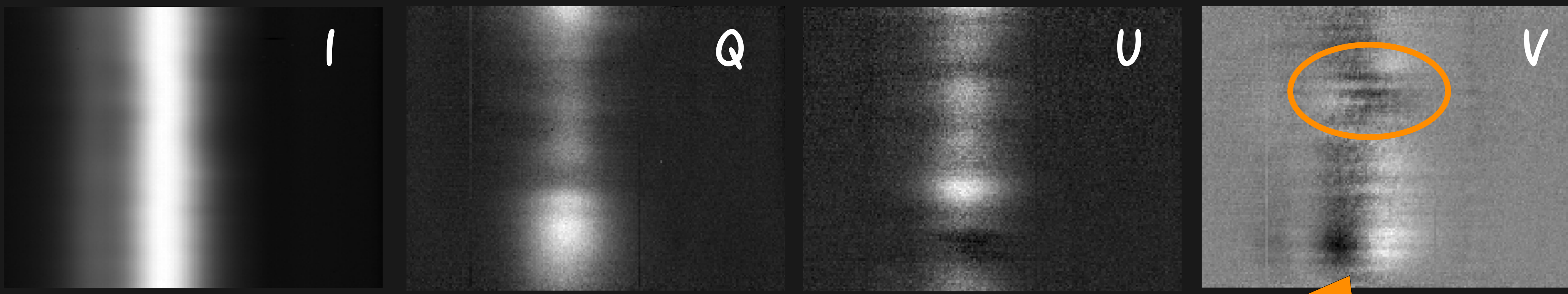


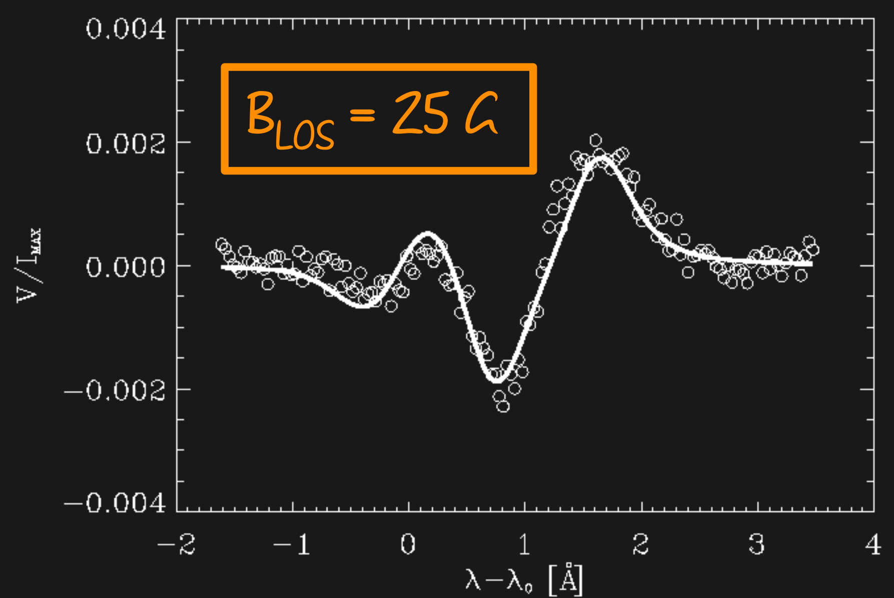




Stokes Q and U determine the magnetic **field orientation**. However, in the Hanle saturation regime, they only provide a **lower threshold for the field strength**

Stokes maps





Detection of a Stokes V Zeeman-induced signal that varies along the slit and even reverses polarity!!

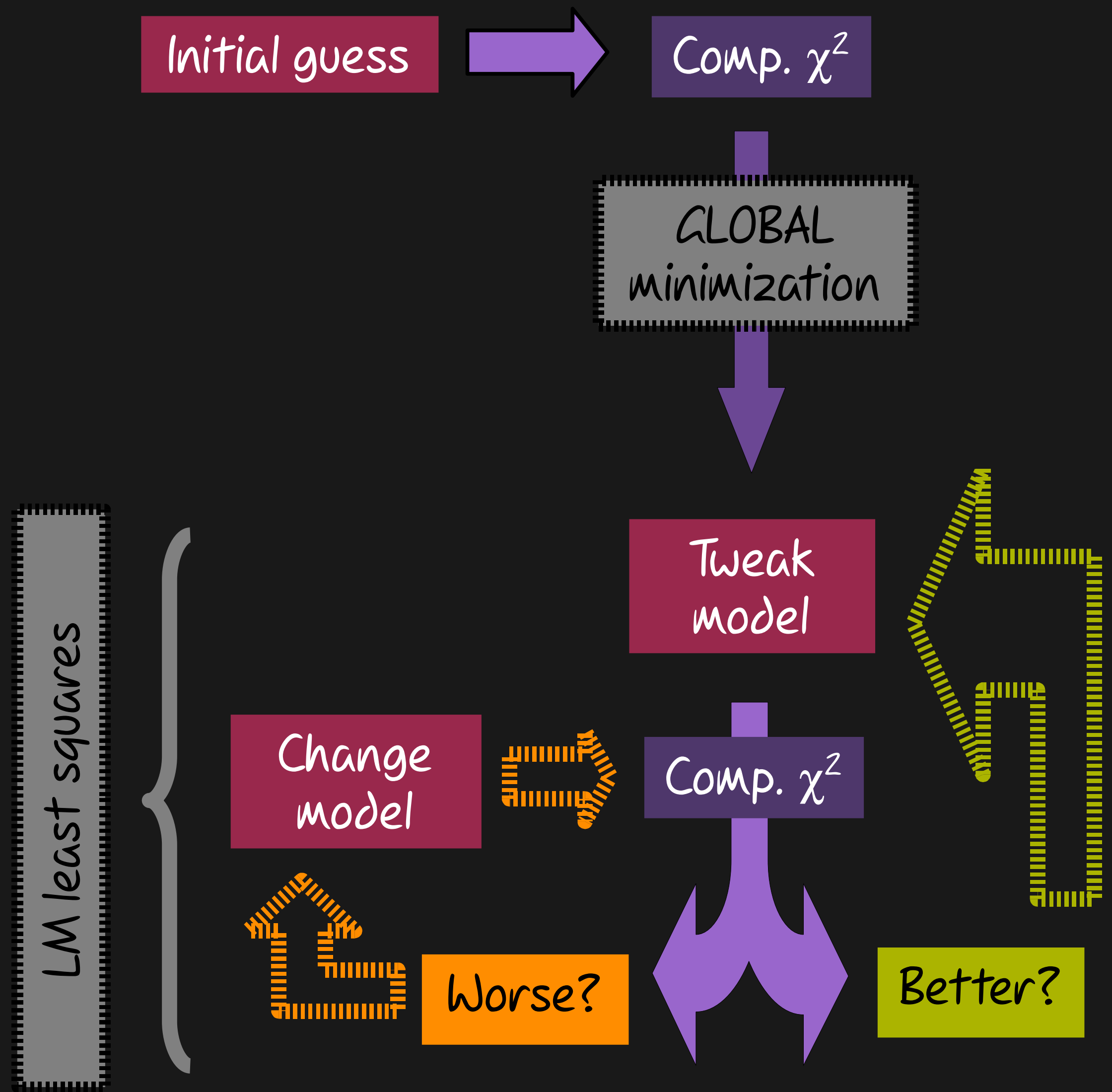
Inversion code

HAZEL inversion of Stokes profiles.
Asensio Ramos , Trujillo Bueno & Landi Degl'Innocenti(2008)

Physical ingredients:
- optical pumping
- atomic level polarization
- level crossings and repulsions
- Zeeman, Hanle, Paschen-Back

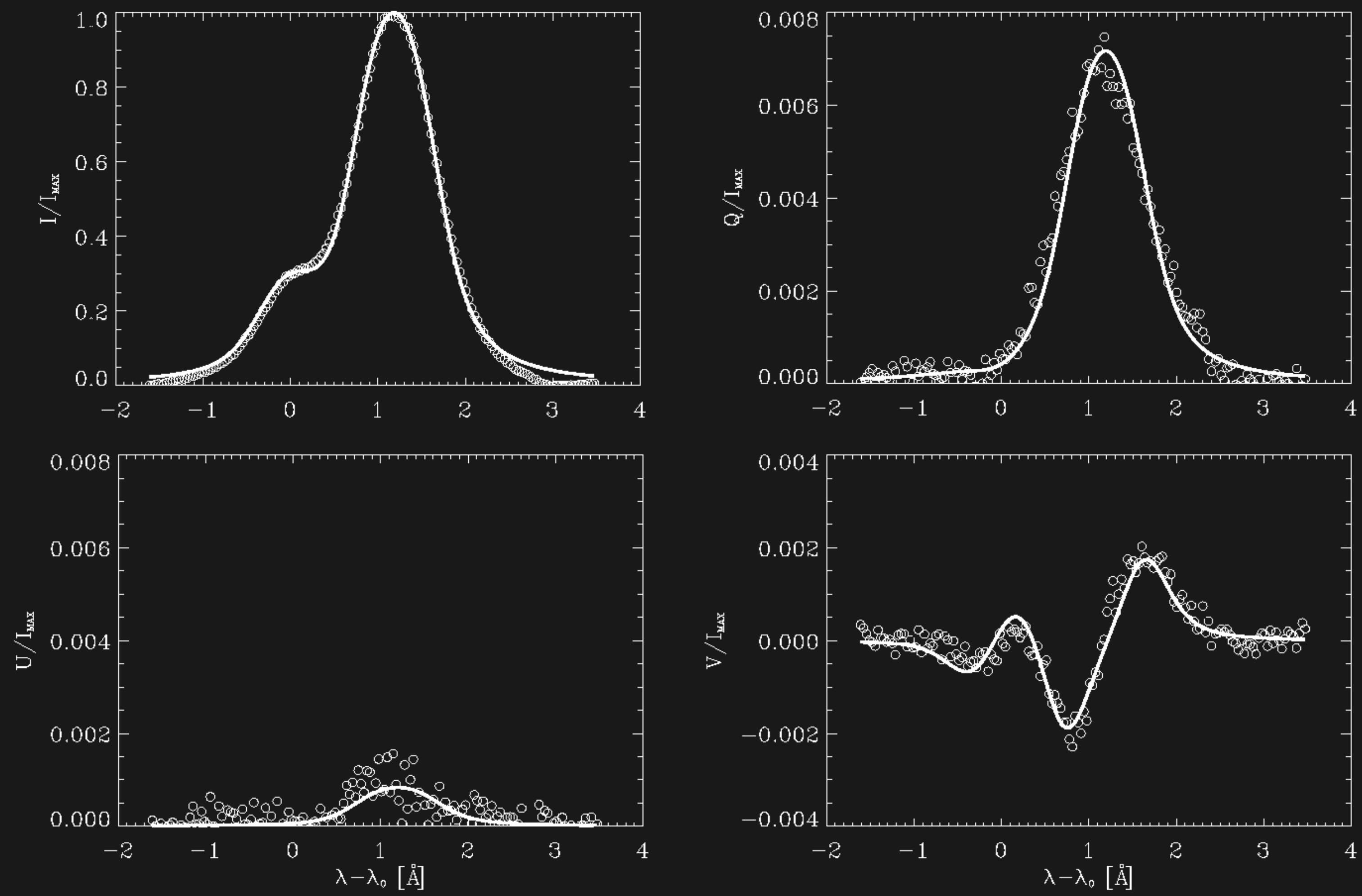
Radiative transfer in slab model:
- constant properties
- optical depth τ
- height h
- deterministic B
- illuminated by photospheric CLV

Free parameters:
B, θ, χ, Dopp, damp, τ , h, v

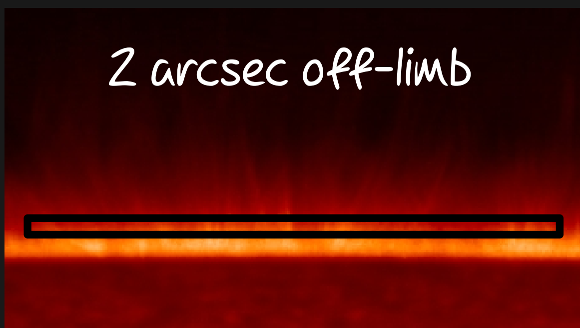


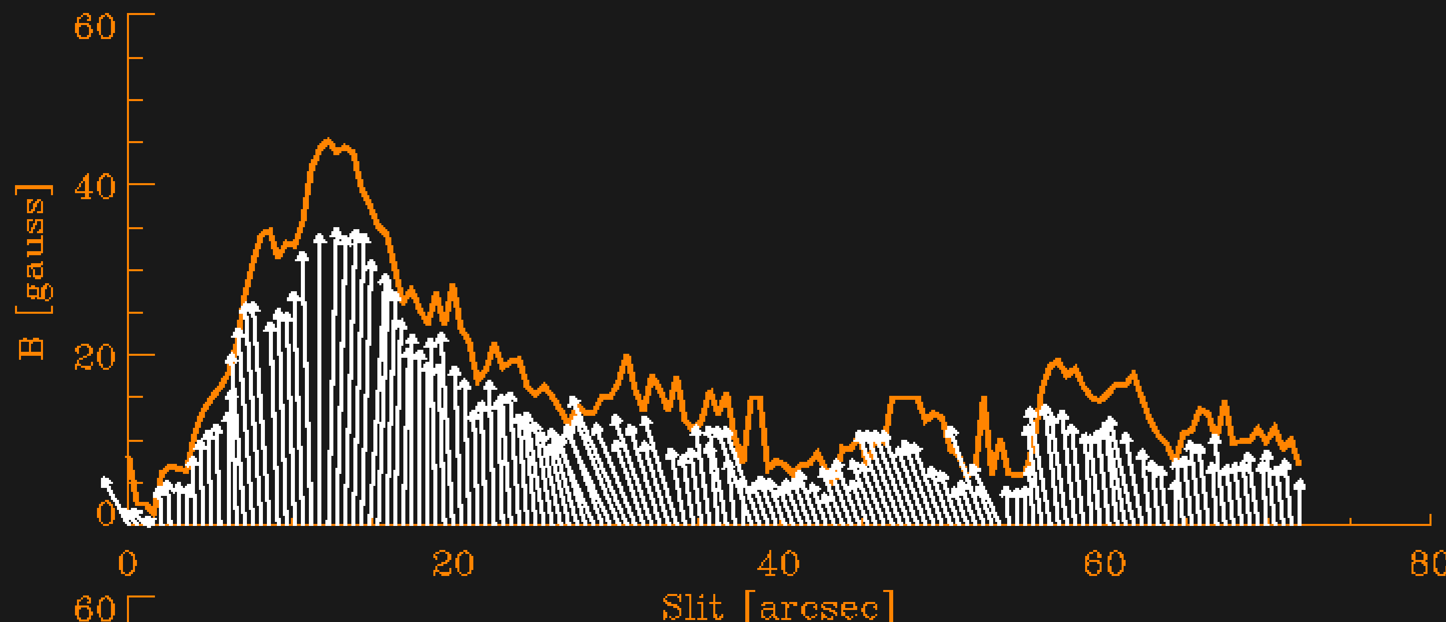
Inversion examples

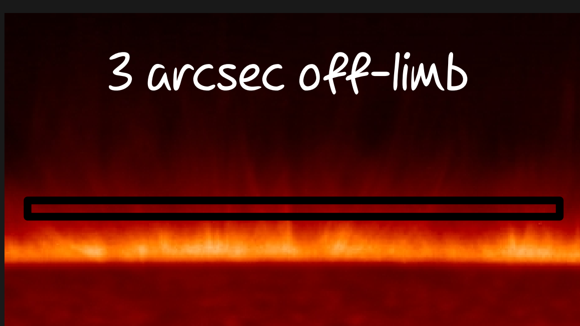
B = 36 gauss
θ = 38.6º
χ = -2.2º

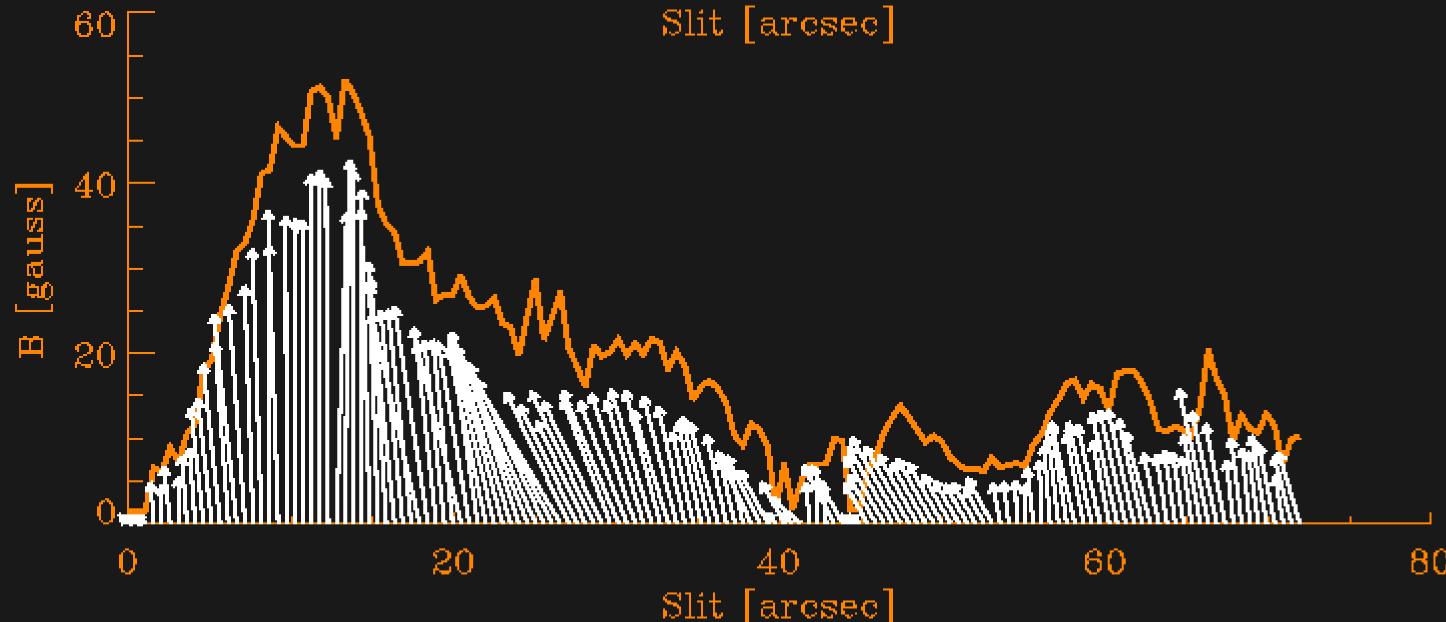


Derived magnetic field









Conclusions and remarks

High S/N spectro-polarimetric measurements of off-limb spicules in He I 10830 Å multiplet at different distances to the limb

* Detection of Stokes V -- crucial for determining magnetic field strength
  -- longitudinal Zeeman effect doesn't cancel out

* We measured the magnetic field vector along slit and at 2 heights above the limb
  -- spatial variations
  -- twist in magnetic field vector

* Aims for the future
  -- simultaneous Hα images and He D_3 measurements
  -- more detailed analysis as a function of height
  -- statistical properties at equator, poles, active and non-active regions

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