Magnetic flux emergence in the Sun & future solar telescopes.

Ada Ortiz

Fagdag - November 26, 2019

Outline

- Me in a nutshell
- The context (or what is that I did research on?)
- Some results (the real meat)
- Future solar telescopes

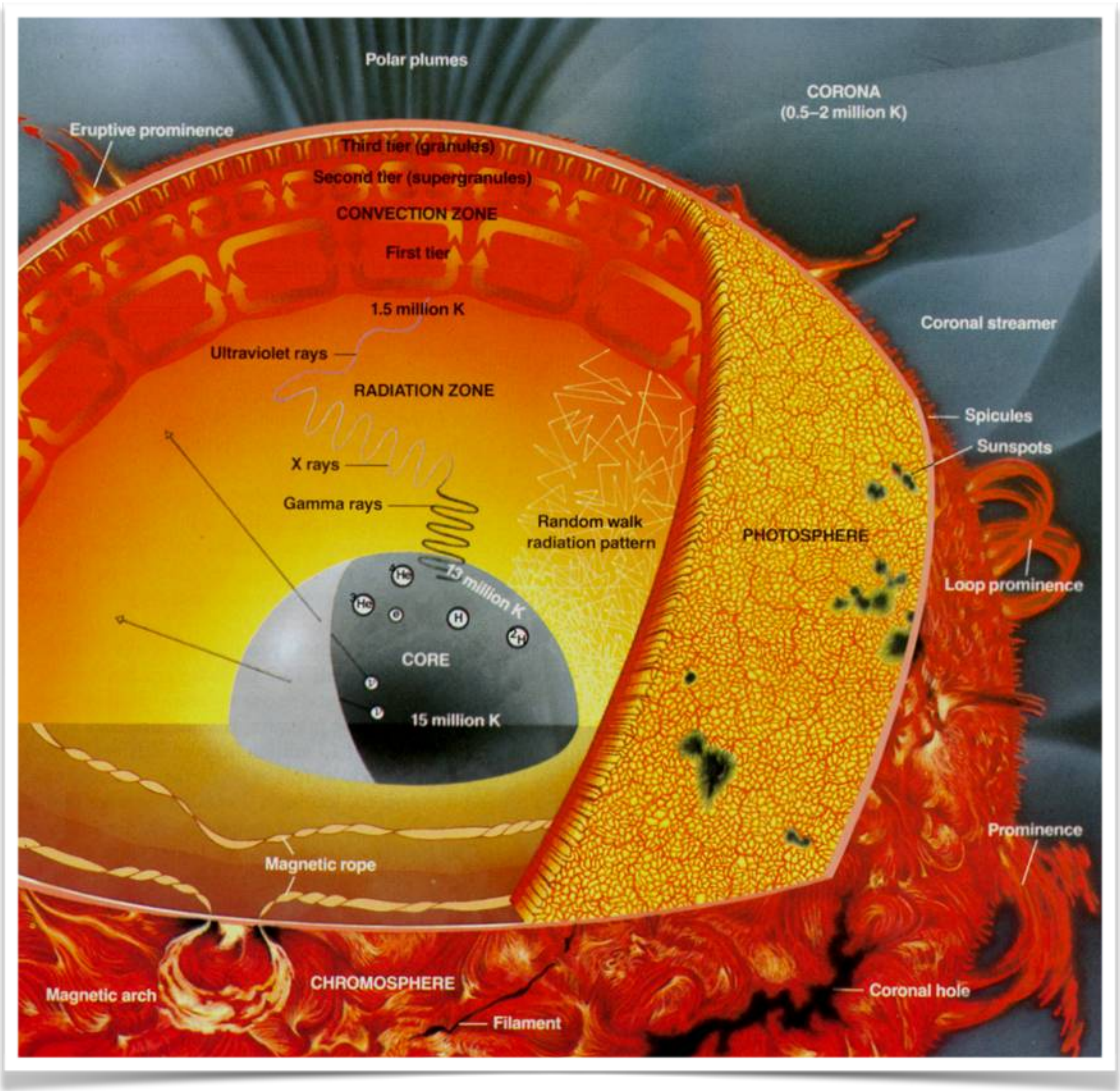
Me in a nutshell

- 2003: PhD in Physics (University of Barcelona)
- Doctoral thesis about solar irradiance variations due to magnetic activity present on the surface of the Sun
- 2004 - 2006: 1st postdoc at High Altitude Observatory (NCAR), Boulder (USA)
- 2007 - 2011: 2nd postdoc at Institute of Theoretical Astrophysics (UiO), Oslo
- 2011 - 2019: Researcher (forsker) at Institute of Theoretical Astrophysics (UiO), Oslo
- 2013 - 2014: Lecturer at Institute of Theoretical Astrophysics (UiO), Oslo
- 2015 - 2017: Guest researcher at Instituto de Astrofisica de Andalucia (IAA-CSIC), Granada (Spain)

- I am an Astrophysicist specialised in Solar Physics (the study of the Sun).
- I study the Sun from an **observational** point of view - as opposed to a numerical/theoretical perspective - with a very high component of **data analysis**.

- I analyse very high resolution remote observations of the Sun, both from ground-based telescopes and from satellites.
- To **extract physical information** about the conditions of the plasma in the atmosphere of the star.

- <u>The context (or what is that I did research on?)</u>



<u>Structure of the Sun</u>

<u>Solar Interior</u>

- Core
- Radiative zone
- Convection zone

<u>Solar Atmosphere</u>

- Photosphere
- Chromosphere
- Transition region
- Corona

How is the solar magnetic field created?

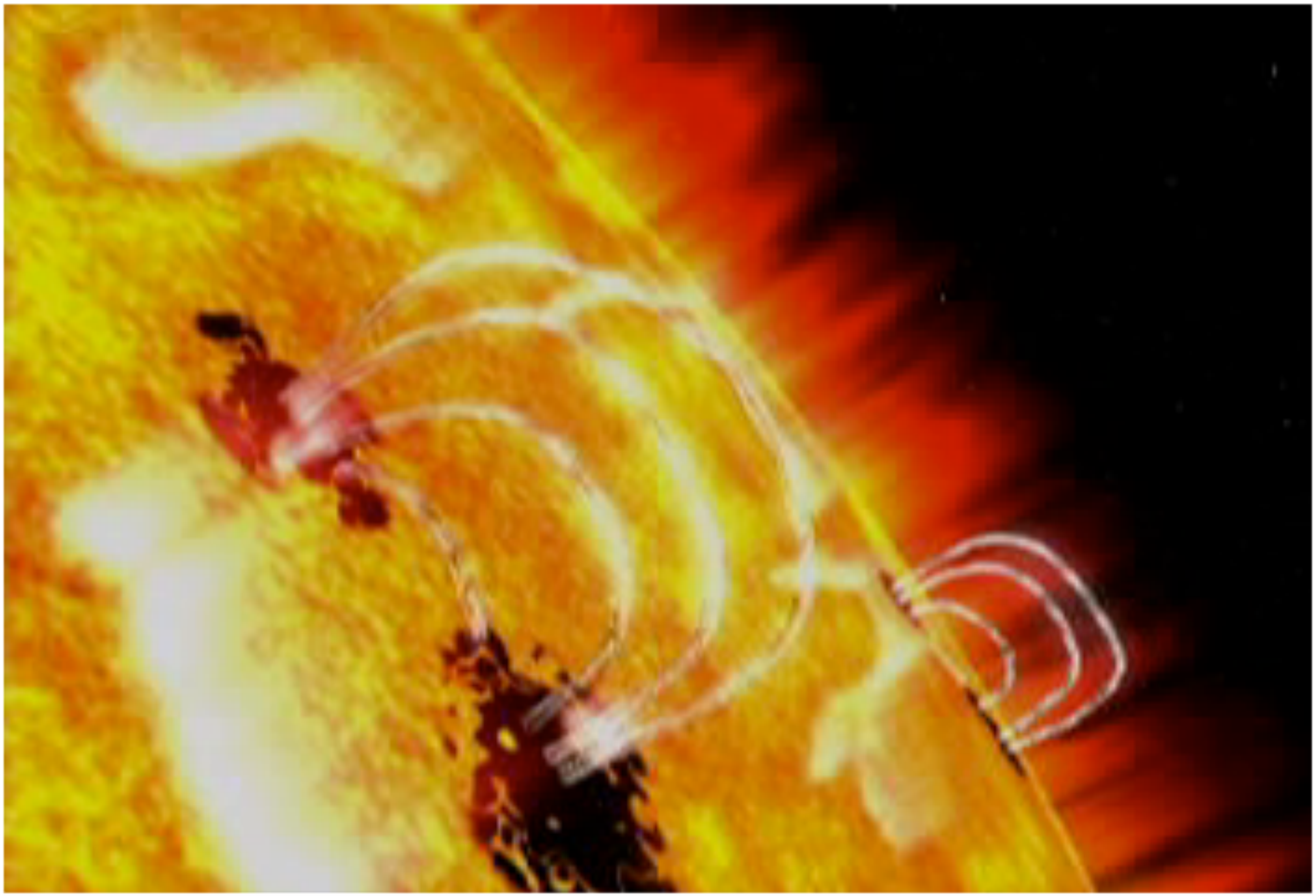
Poloidal field

because of differential rotation becomes toroidal field

preassure inside magnetic flux tube < pressure outside

buoyancy!
Alpha-omega effect

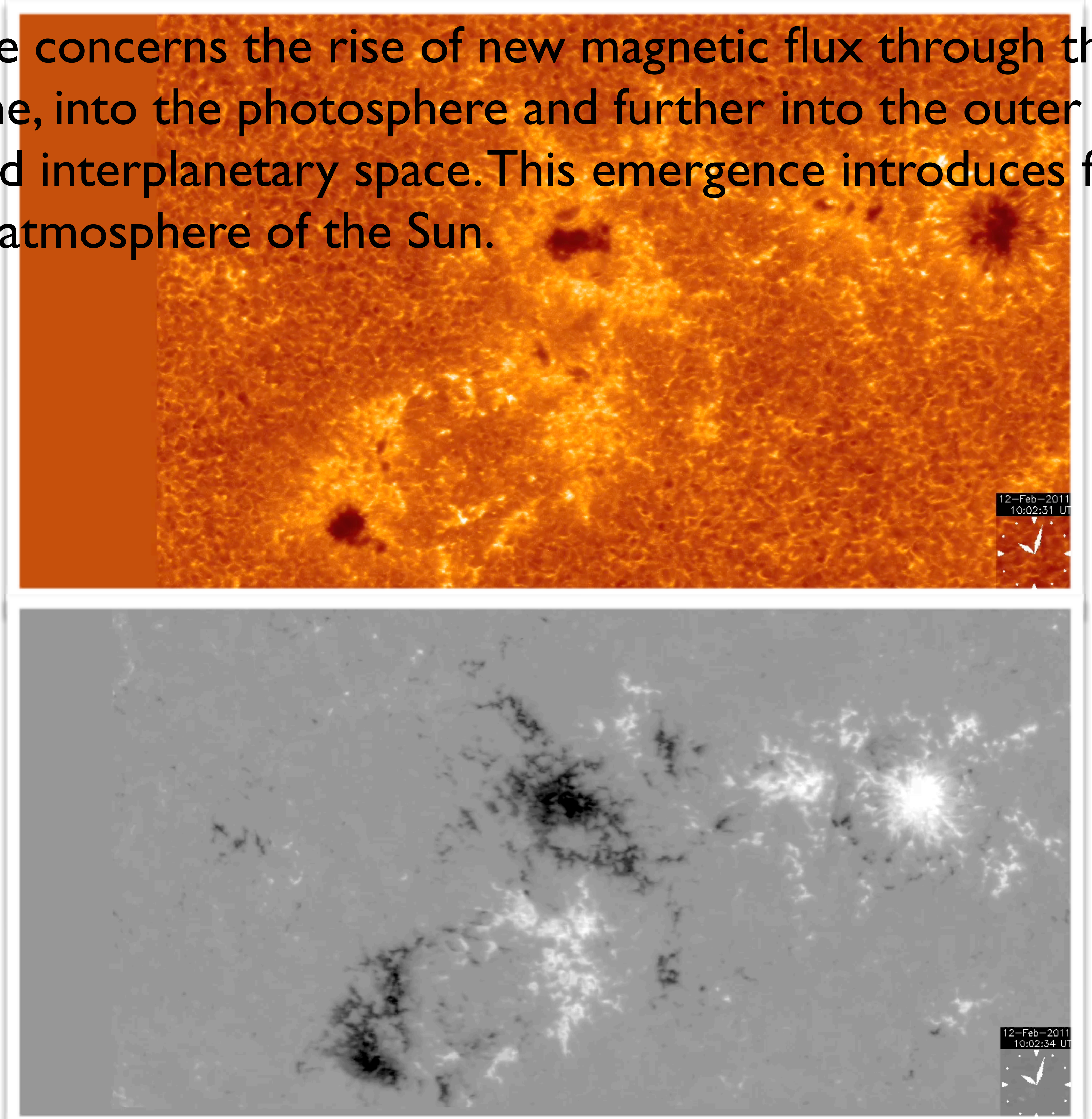
How do magnetic fields appear in the surface of the Sun?



And what is magnetic flux emergence anyway?

- Flux emergence concerns the rise of new magnetic flux through the convection zone, into the photosphere and further into the outer solar atmosphere and interplanetary space. This emergence introduces fields into the outer atmosphere of the Sun.

And looks like this



12-16 February 2011 (Hinode/SOT Ca II H and SP; credit: Joten Okamoto)

Motivation … or why do we care about flux emergence at all

- The magnetic field **dominates** and **shapes** the Sun's outer atmosphere. It is the **driver** of all observed solar activity. If we want to understand solar activity and the structure of the solar atmosphere we need to know:
    1. how the field protrudes and rises
    2. where does it go, where & how does it deposit magnetic energy
    3. how it dissipates

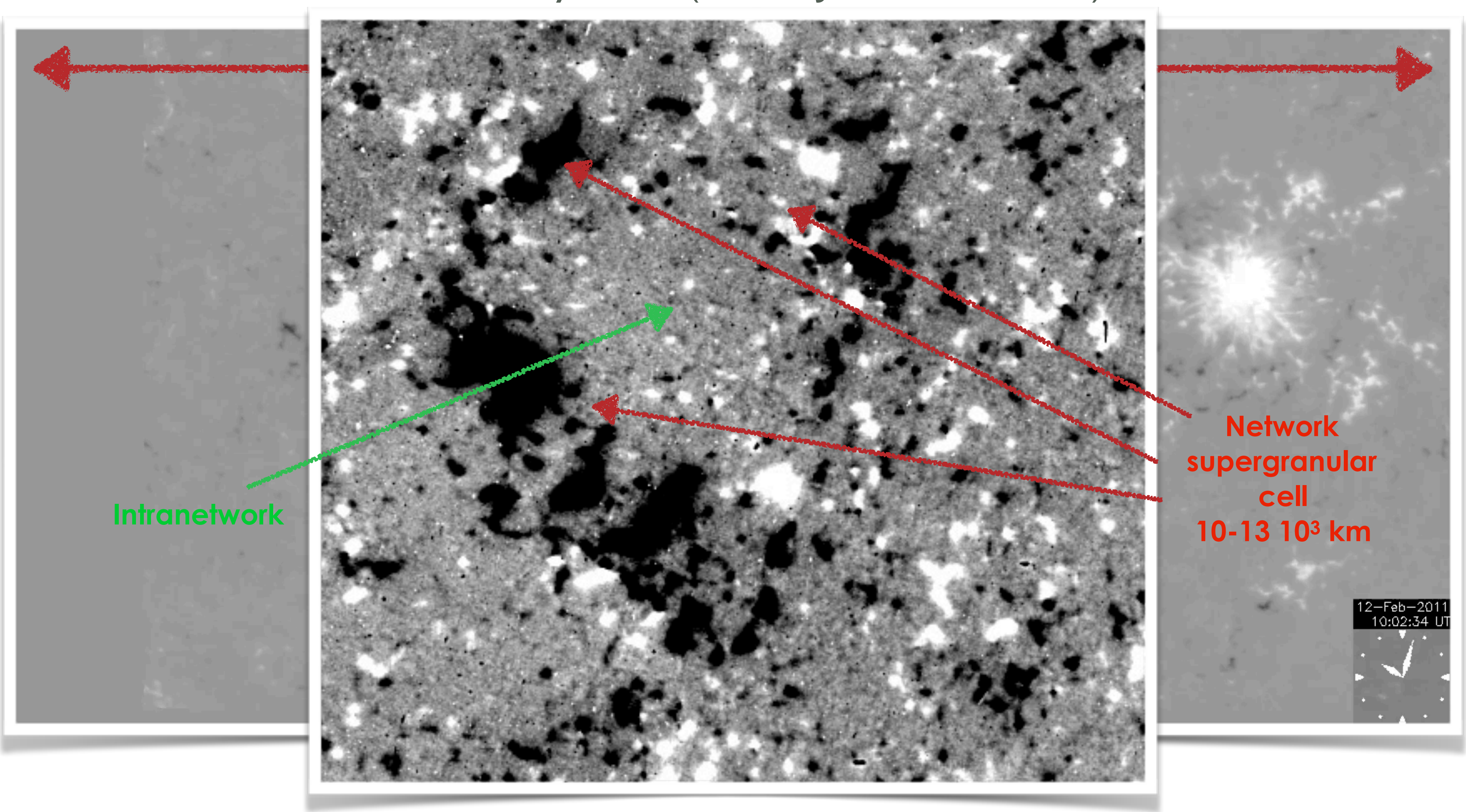
- Flux emergence - at all scales - implies the **lifting** of **magnetic energy** and **flux** to the upper layers of the solar atmosphere and into interplanetary space. Also **mass**! This energy converts into thermal and kinetic energy. It is therefore worth studying **its contribution to chromospheric, transition region and coronal heating and energizing.**

The ubiquitous flux emergence process

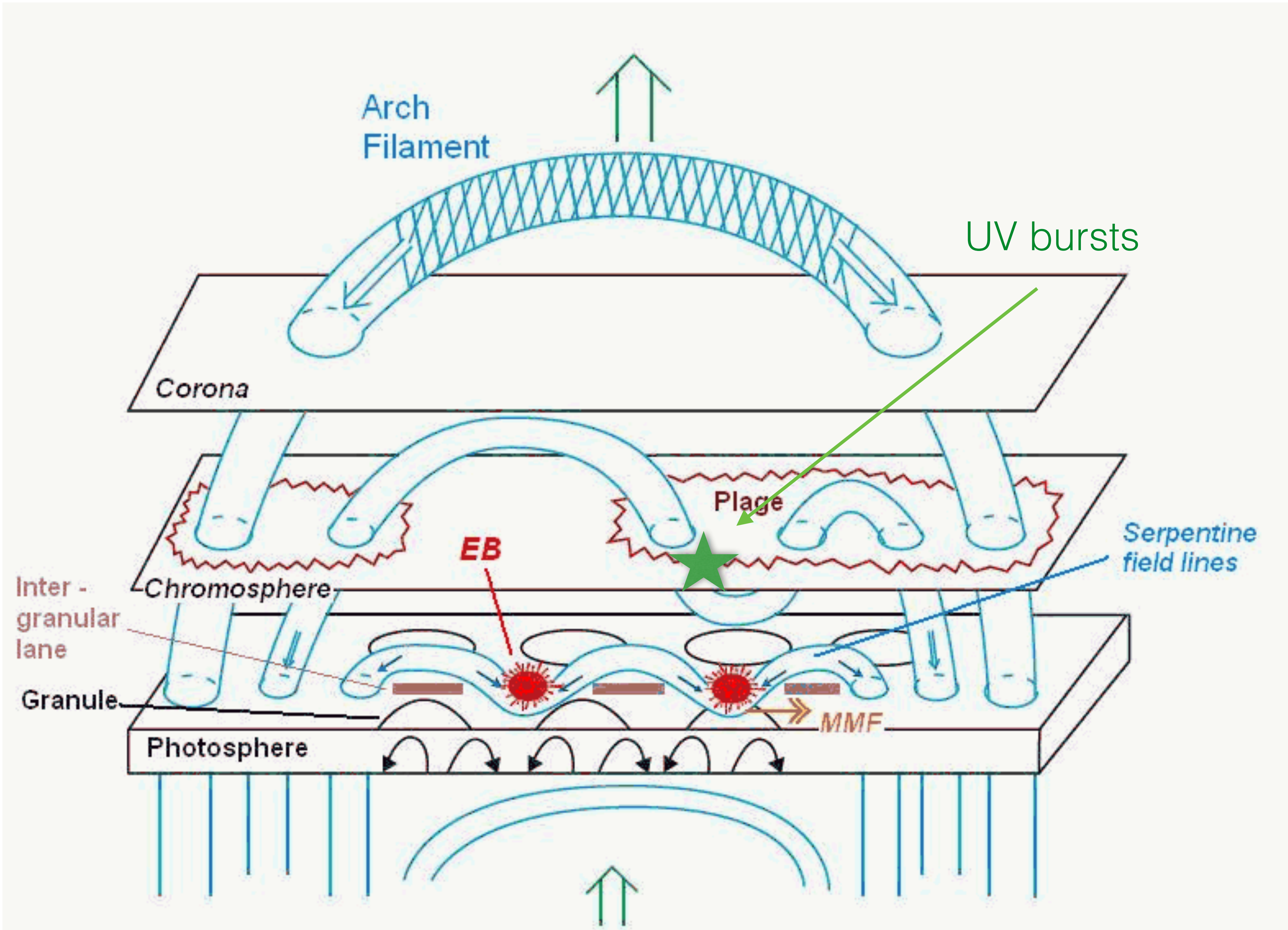
- Flux emergence occurs **at all possible scales:**
  - from the quietest Sun internetwork to the most active AR's

2-3 Nov 2010 @ 08:30 (Hinode/NFI magnetogram Na I D1 5896 A
credit: D. Orozco, L. Bellot, M. Gosic)

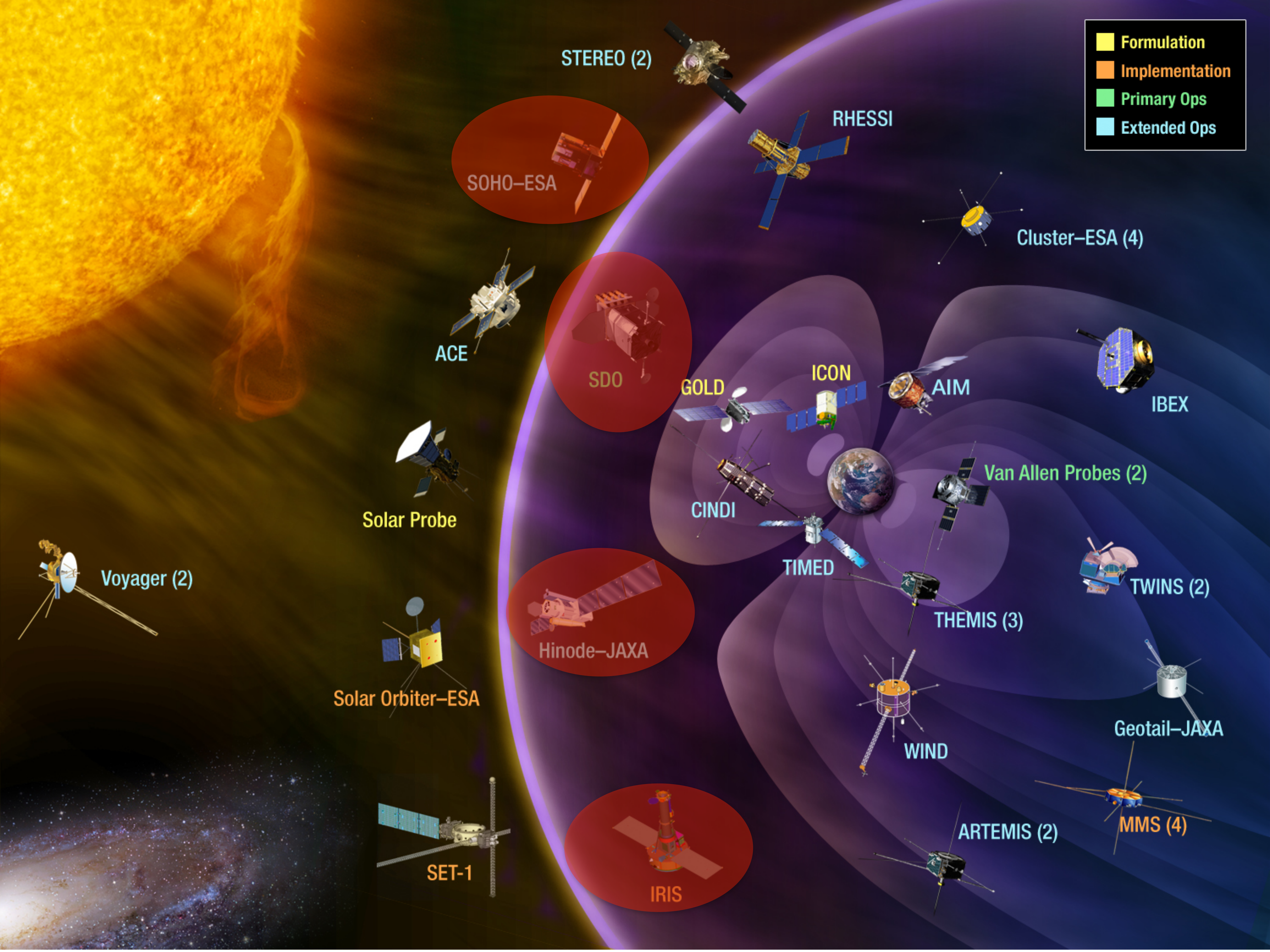
12-16 February 2011 (credit: Joten Okamoto)



A schematic picture of flux emergence



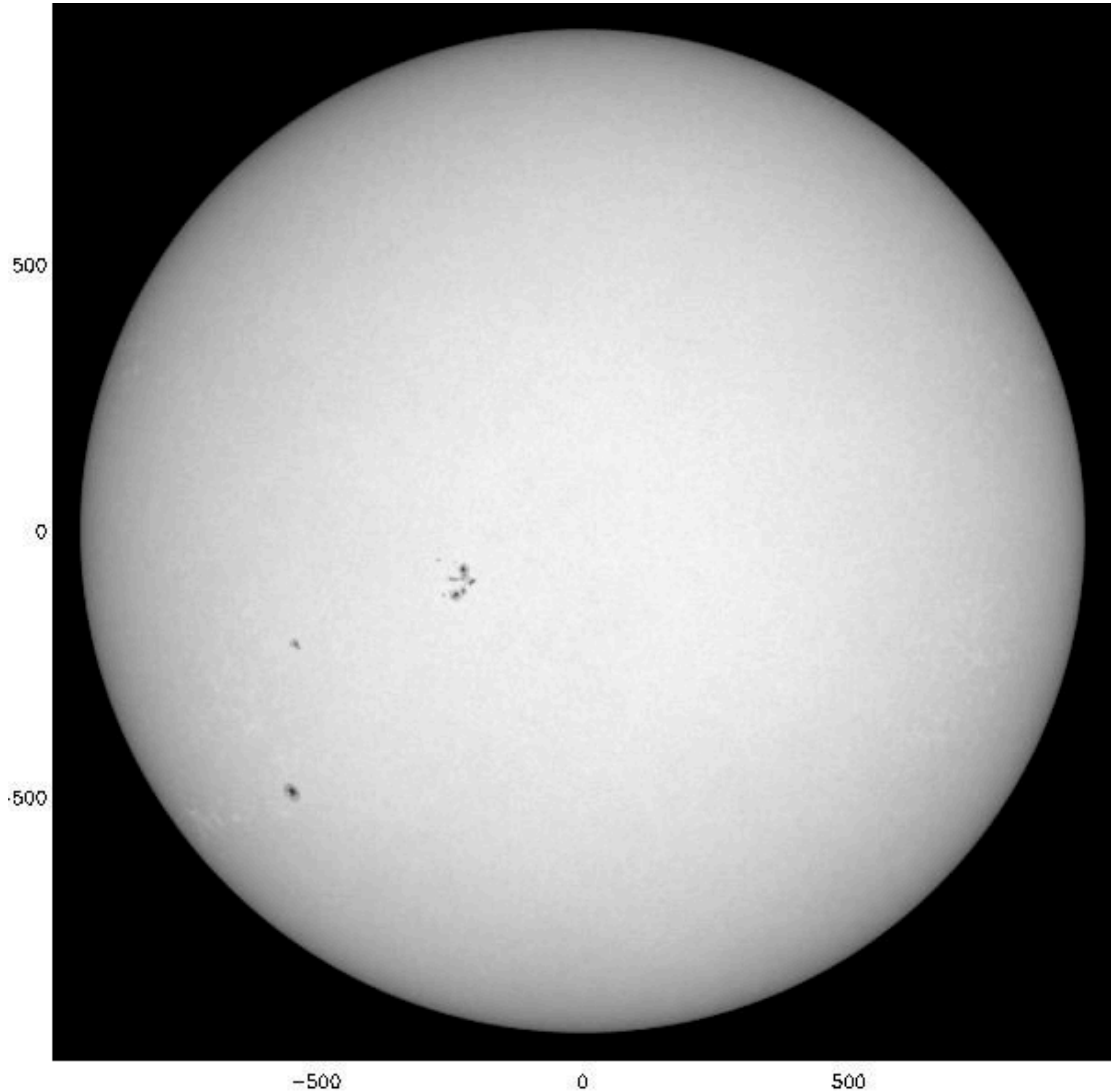
Schmieder & Pariat 2007 Scholarpedia 2(12):4335



Formulation
Implementation
Primary Ops
Extended Ops
STEREO (2)
RHESSI
SOHO–ESA
Cluster–ESA (4)
ACE
SDO
GOLD
ICON
AIM
IBEX
Van Allen Probes (2)
CINDI
Solar Probe
TIMED
Voyager (2)
TWINS (2)
THEMIS (3)
Hinode–JAXA
Solar Orbiter–ESA
WIND
Geotail–JAXA
ARTEMIS (2)
MMS (4)
SET-1
IRIS

Swedish 1-m Solar Telescope (SST) on La Palma

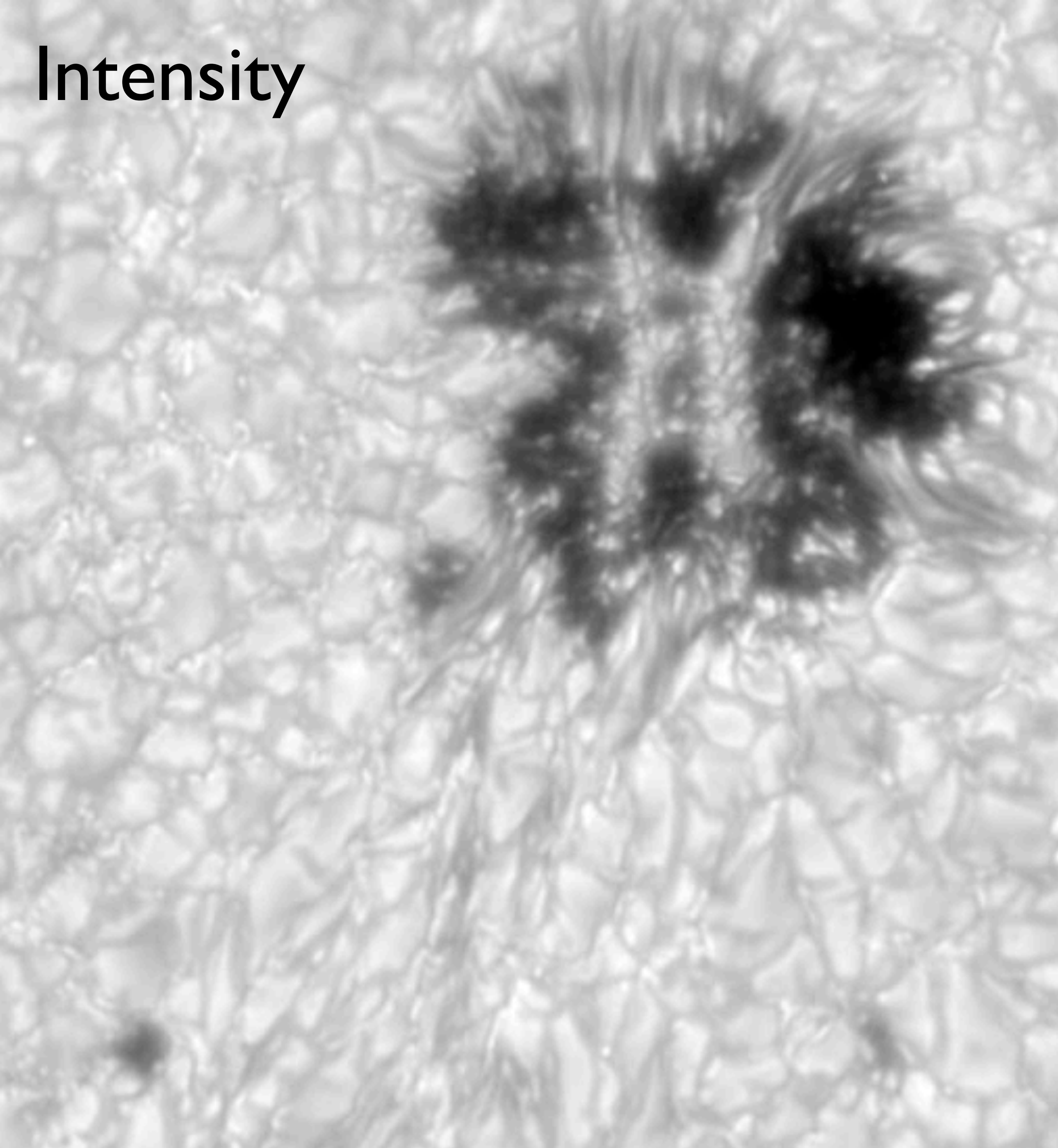
25 May 2003, 11:22:32 UT



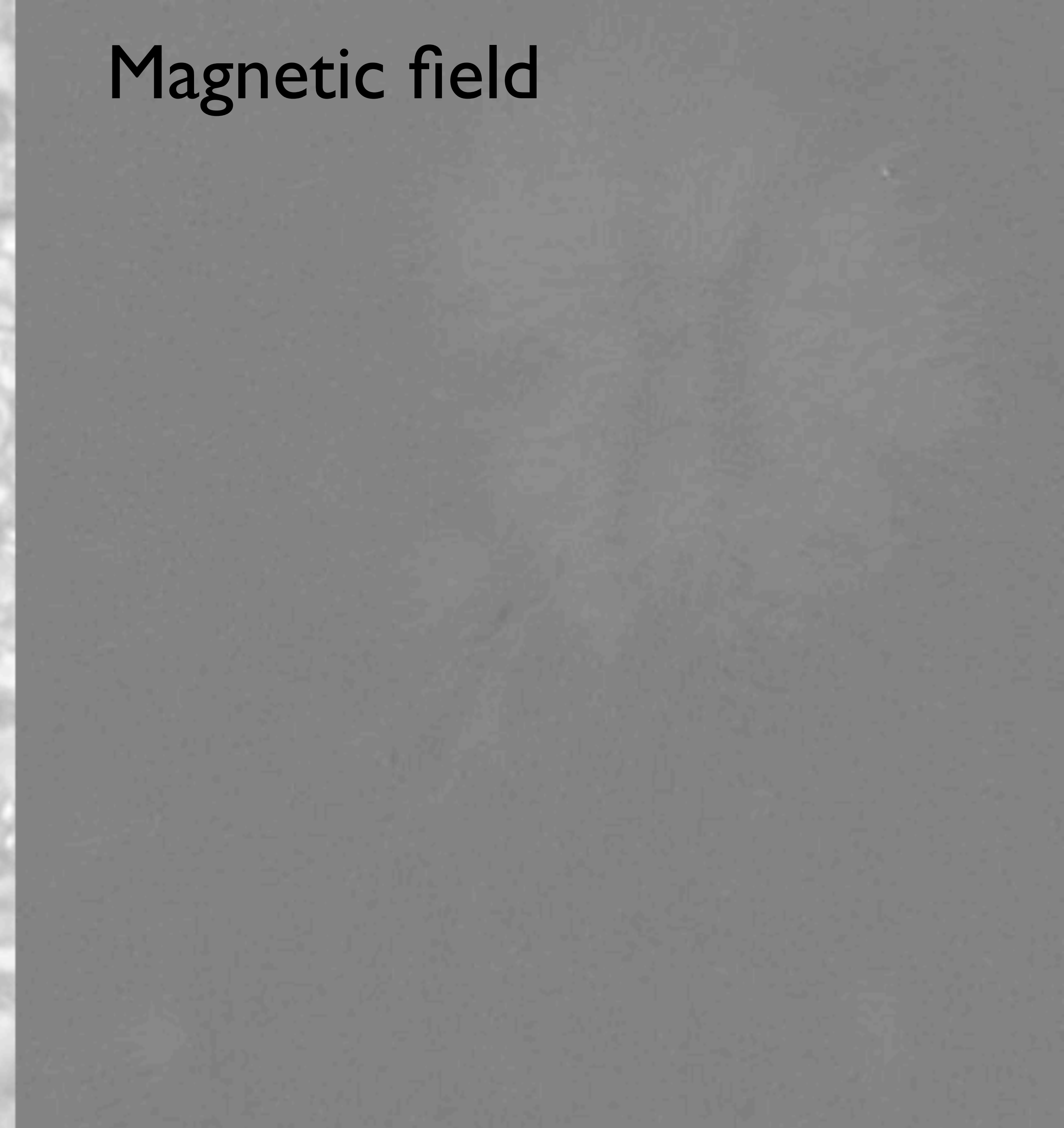
1 pixel = 100 km

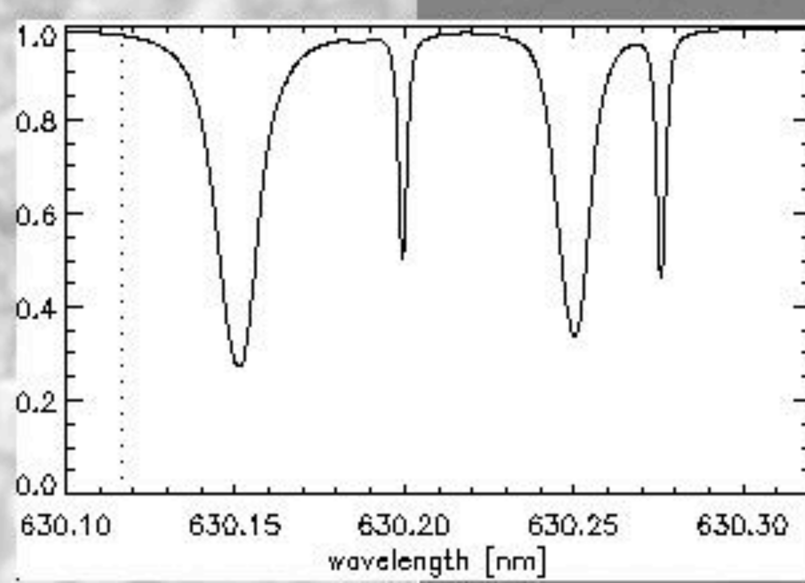
- 5 dimensional datasets: 2D in space, wavelength, time and Stoke parameters (x, y, λ, t, S)

Intensity



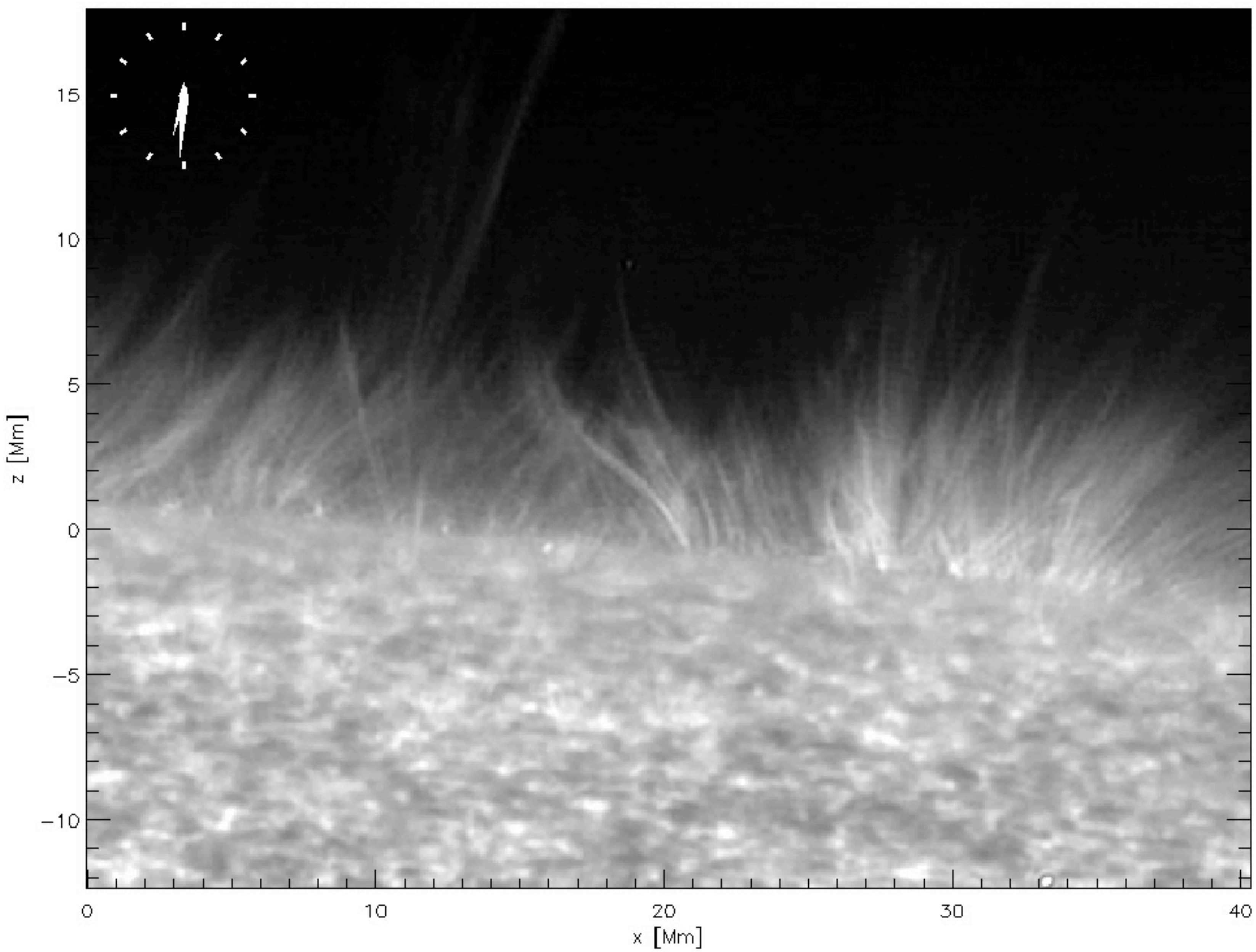
Magnetic field

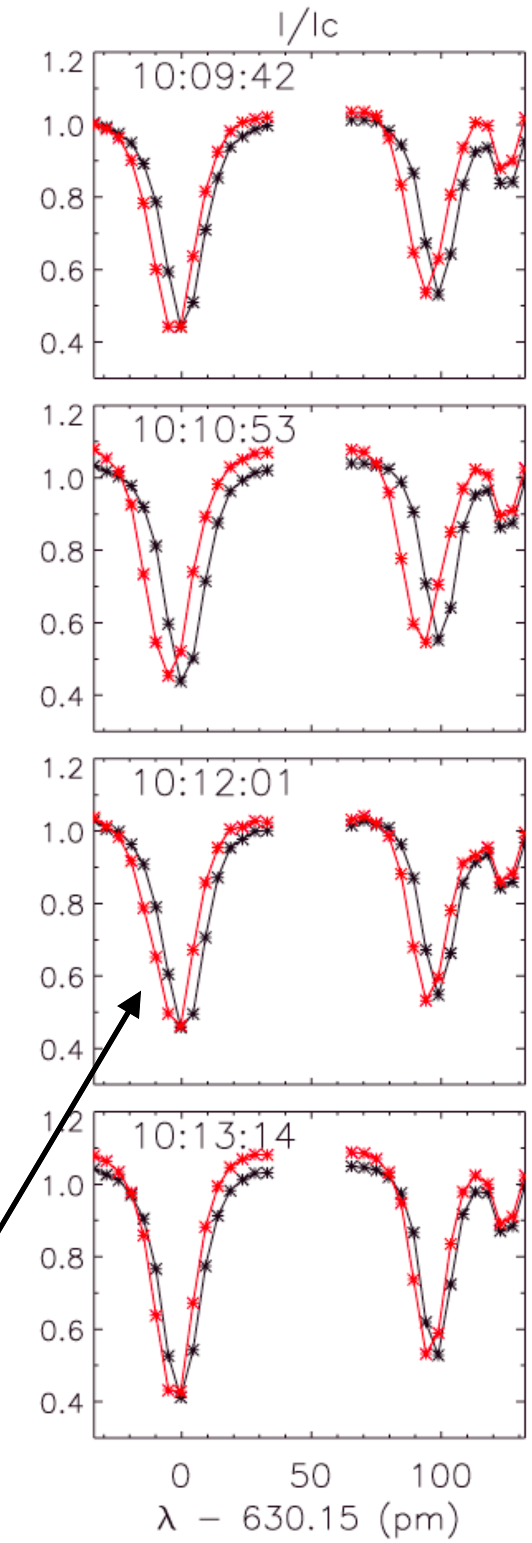




Spectra

Temporal series





Shift respect to rest wavelength = velocity of plasma

Some results (the real meat)

- The magnetic field, as it rises up through the solar atmosphere, **knits together all atmospheric layers: magnetic coupling**

No. 4, 1981 QUIET SUN EUV BRIGHTNESS COMPONENTS 637

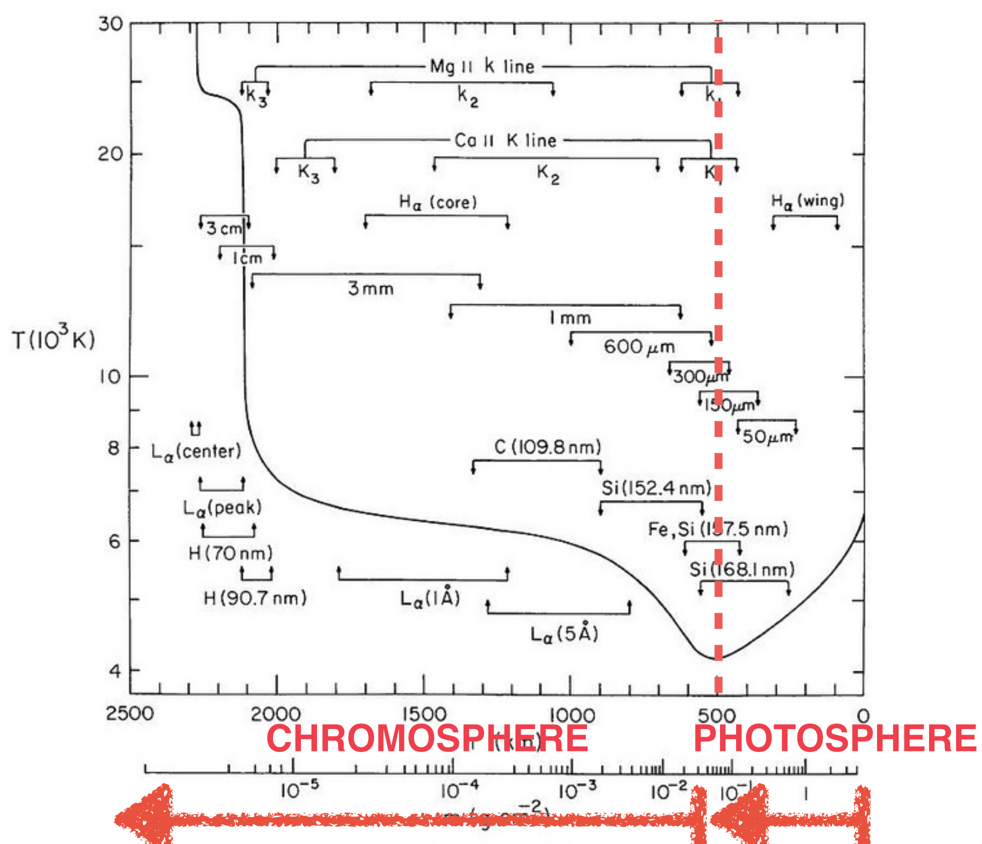
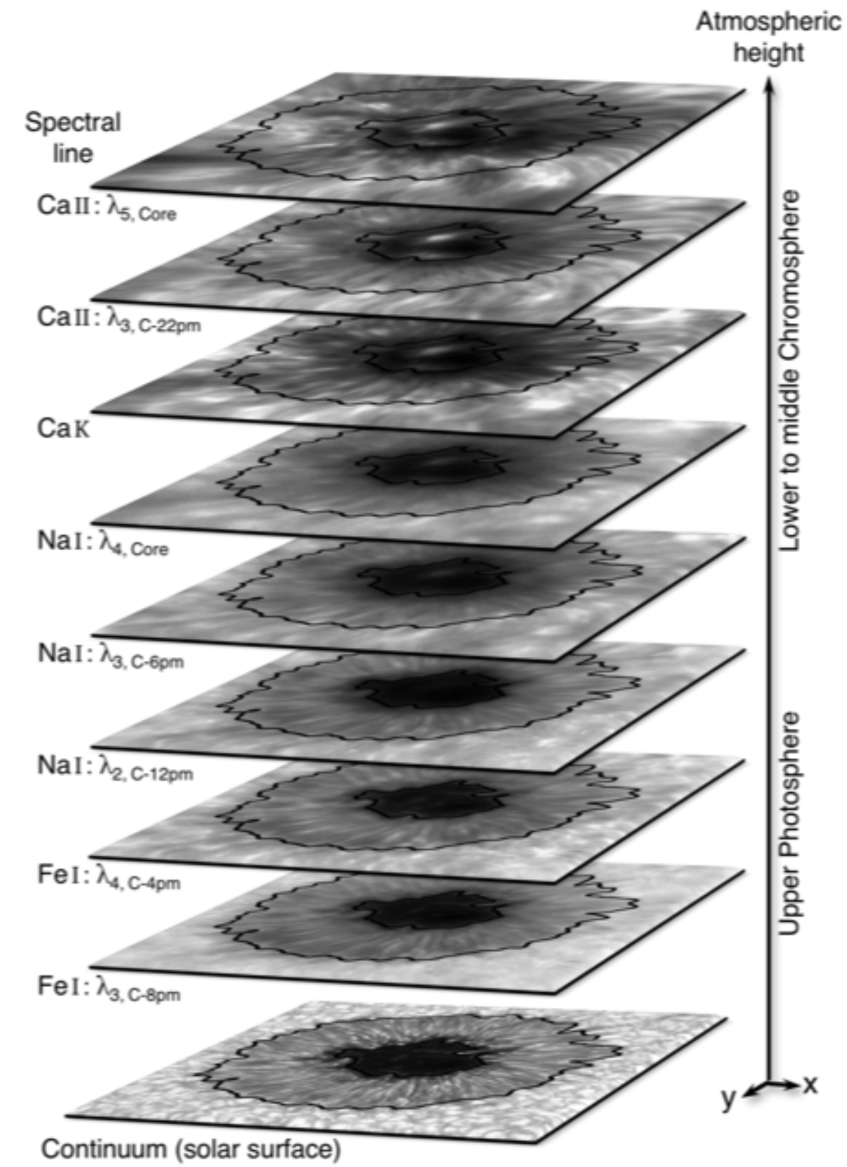
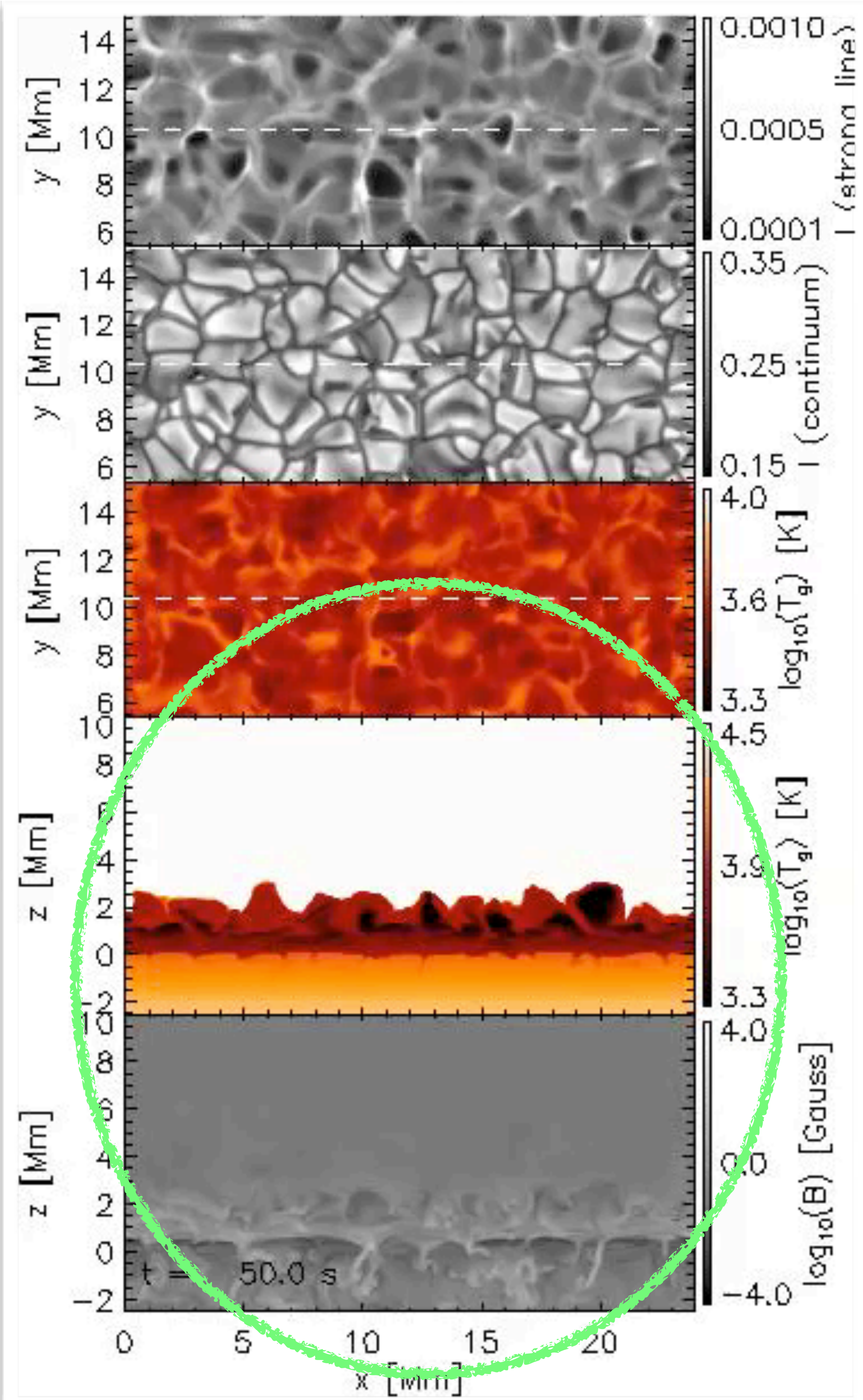


FIG. 1.—The average quiet-Sun temperature distribution derived from the EUV continuum, the Lα line, and other observations. The approximate depths where the various continua and lines originate are indicated.

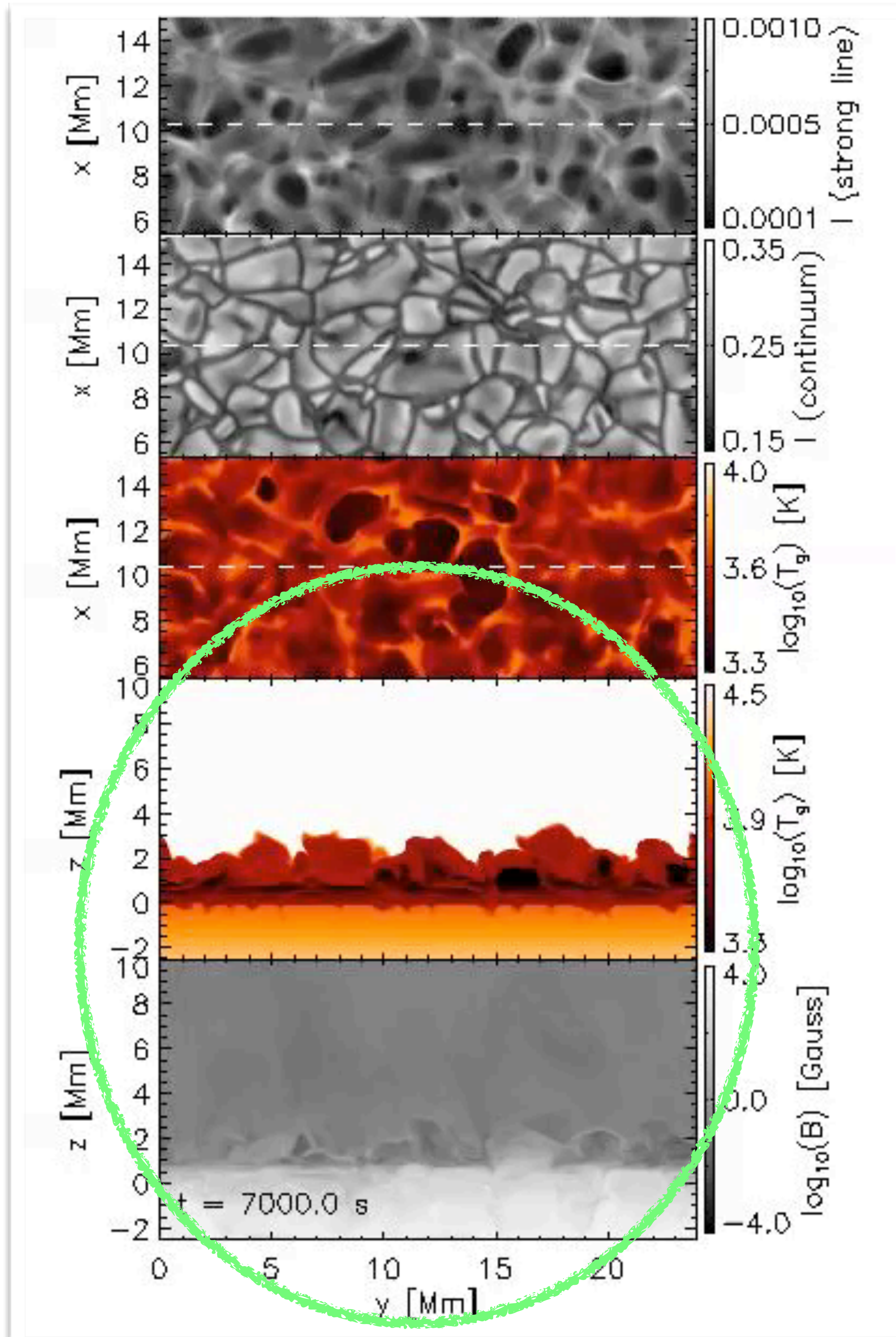
Vernazza J.E., Avrett E.H., and Loeser R. The Solar Chromosphere. III. Models of the EUV Brightness Components of the Quiet Sun. The Astrophysical Journal Supplement Series, 45:635-725, 1981 April.



By sampling different spectral lines we can get a **stereoscopic view** of the Sun's atmosphere.



y [Mm]
z [Mm]
x [Mm]
I (strong line)
I (continuum)
$\log_{10}(T_g)$ [K]
$\log_{10}(B)$ [Gauss]
0.0010
0.0005
0.0001
0.35
0.25
0.15
4.0
3.6
3.3
4.5
3.9
3.3
4.0
0.0
−4.0
t = 50.0 s



x [Mm]
z [Mm]
y [Mm]
I (strong line)
I (continuum)
$\log_{10}(T_g)$ [K]
$\log_{10}(B)$ [Gauss]
0.0010
0.0005
0.0001
0.35
0.25
0.15
4.0
3.6
3.3
4.5
3.9
3.3
4.0
0.0
−4.0
t = 7000.0 s

Flux emergence from the photosphere to the transition region:

Dark bubbles

“The trilogy” (observations & simulations)

Wavelength

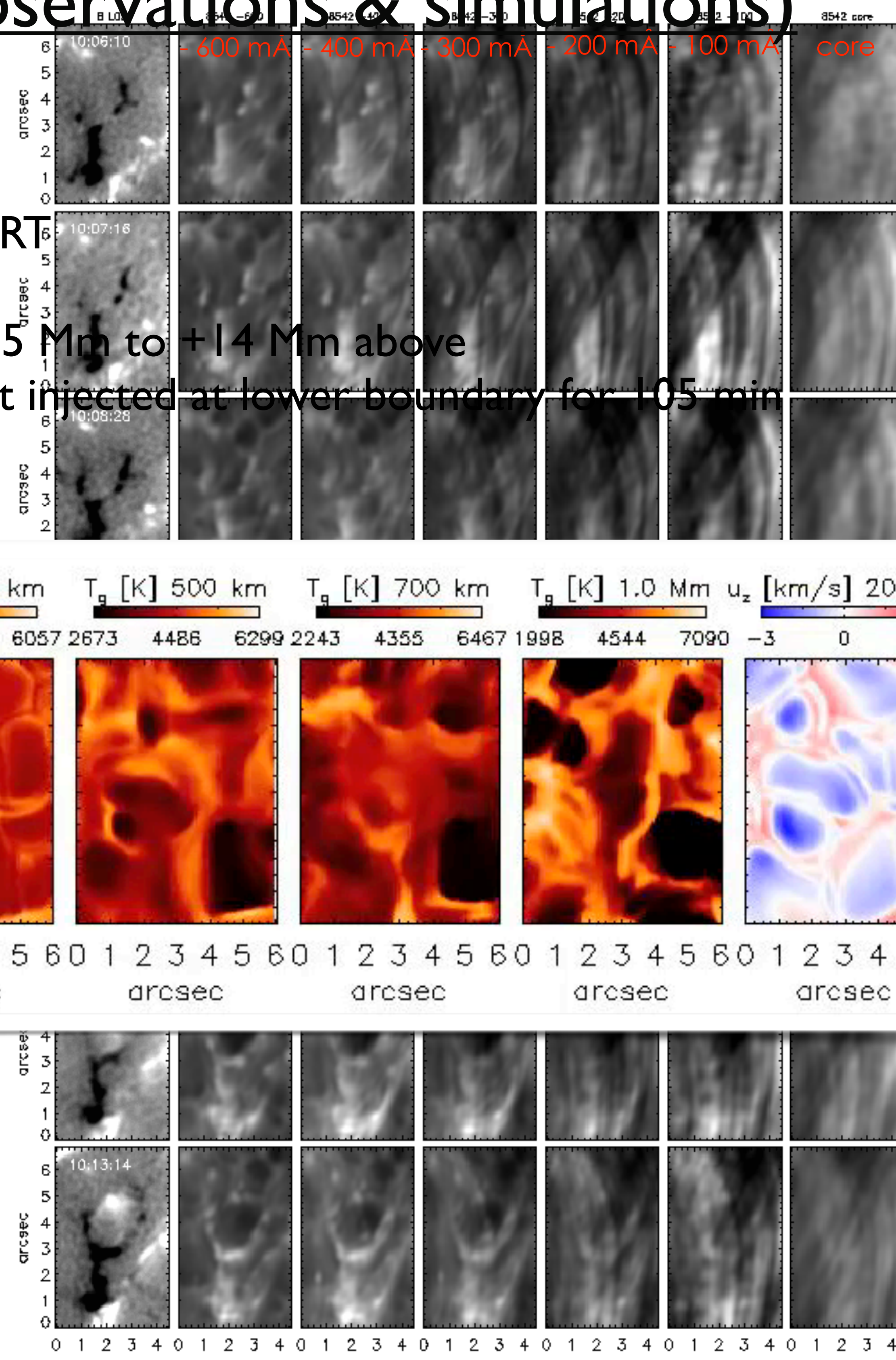
Photosphere → Chromosphere

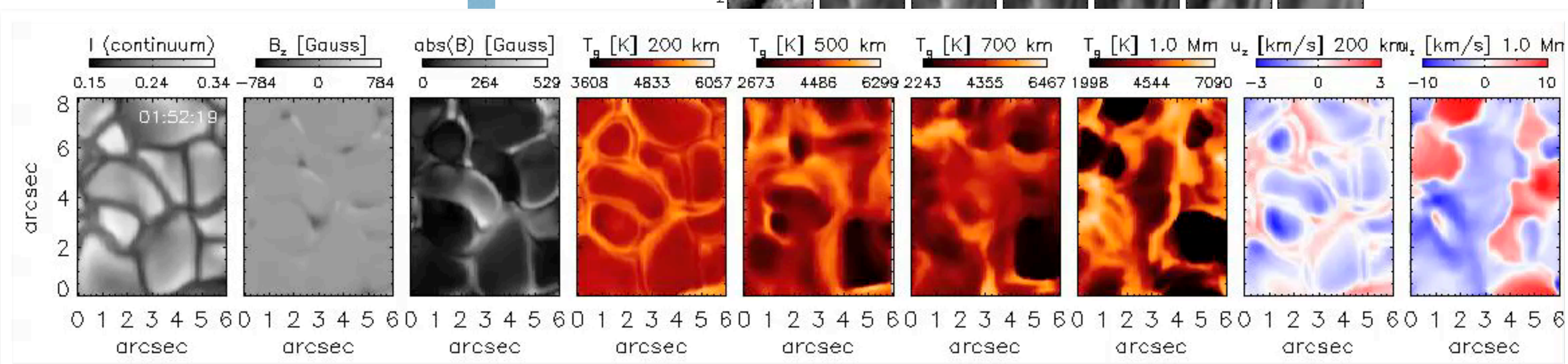
Time: 7 minutes

1 min. / time step

- SST simultaneous photospheric (Fe I 6302) and chromospheric (Ca II 8542) lines. Very high resolution (100 km for Fe I)
- Upflows in photosphere: 2 - 2.5 km/s

•BIFROST: MHD+RT
•24x24 Mm box
•Vertical range: -2.5 Mm to +14 Mm above
•3360 G flux sheet injected at lower boundary for 105 min

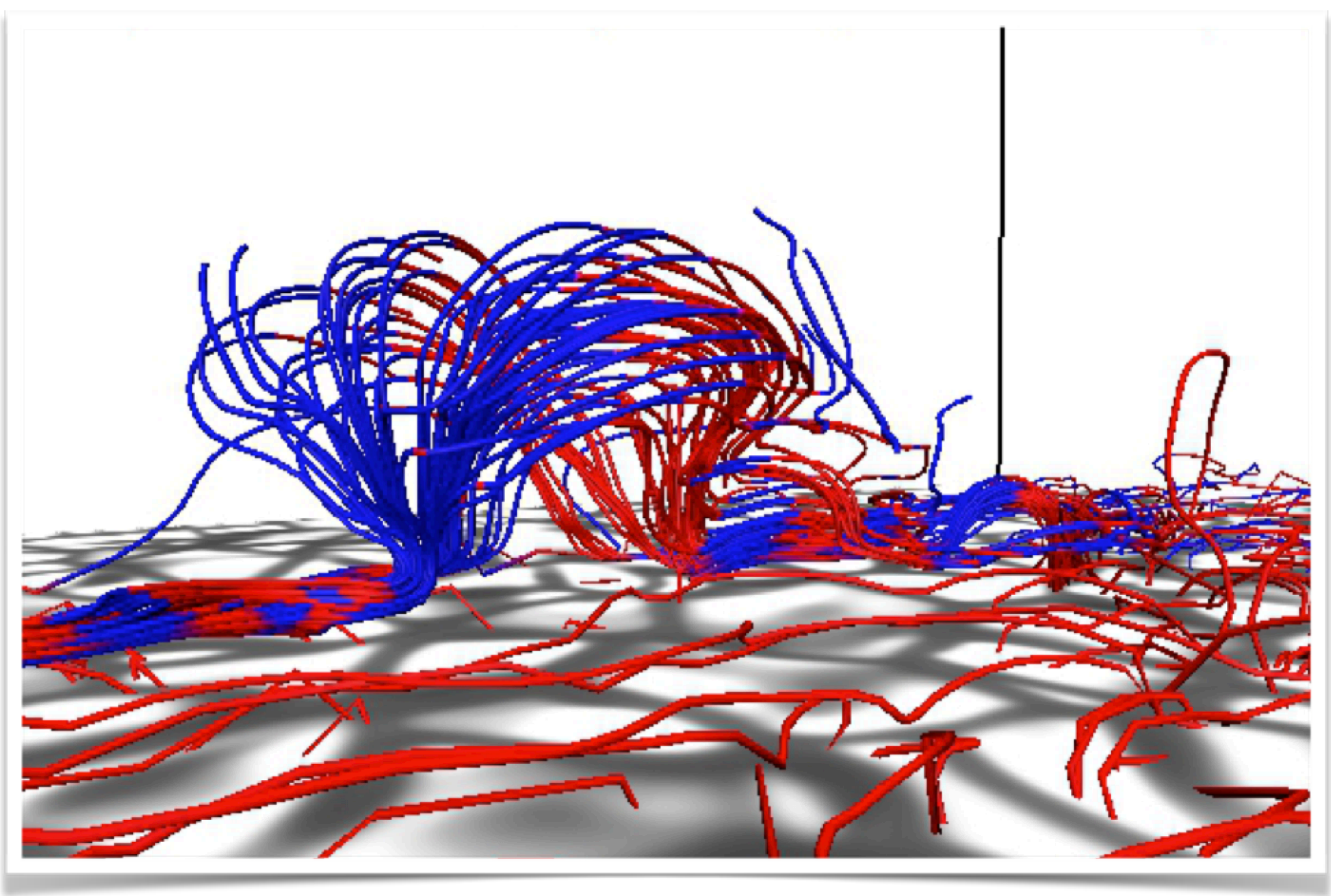




chromosphere

Ortiz et al. 2014, ApJ 781, 126

- **Novelty**: appearance of a **cold magnetized dark bubble** that rises through the atmosphere. Observed **from the wings to the core** of Ca II 8542.
- Realistic numerical simulations of flux emergence events **can reproduce** the dark bubble properties: diameter, time of formation, velocities and magnetic fields.

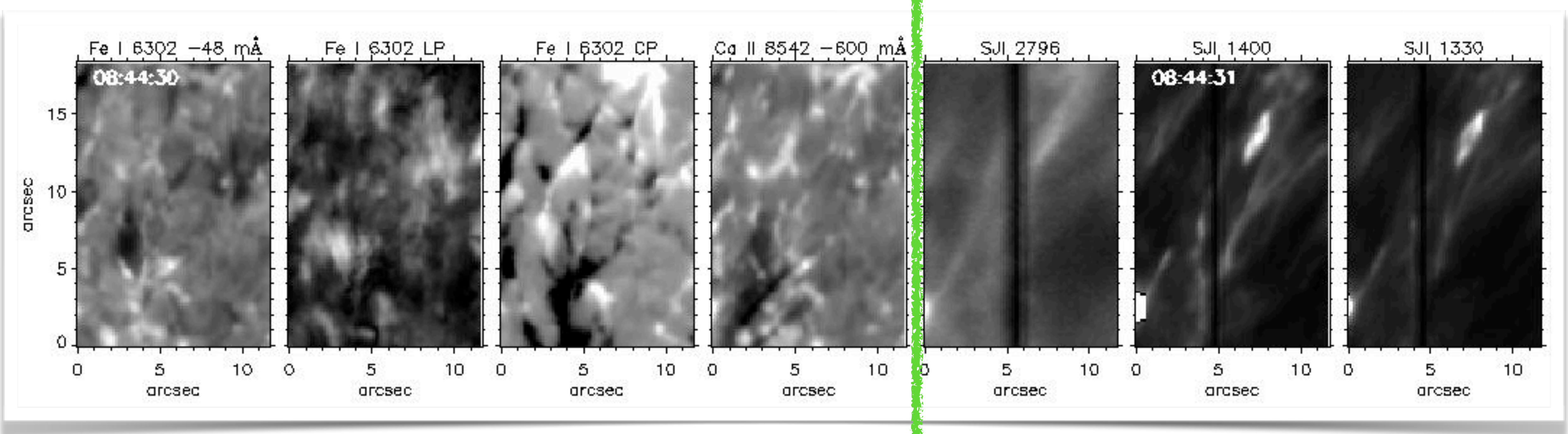


Ortiz et al. (2016), ApJ 825, 93

- SST/CRISP + IRIS + SDO/AIA simultaneous observations
- We extend our previous studies (Ortiz et al. 2014, de la Cruz Rodriguez et al. (2015) further up in the atmosphere using lines sensitive to upper chromosphere and TR.
- Goal: to follow a **single event** of magnetic flux emergence **from the photosphere to the corona** with unprecedented spatial, spectral and temporal resolution, presenting thus an **integral multi-wavelength study of the solar atmosphere** in a case of flux emergence.

Observations from ground-based telescope

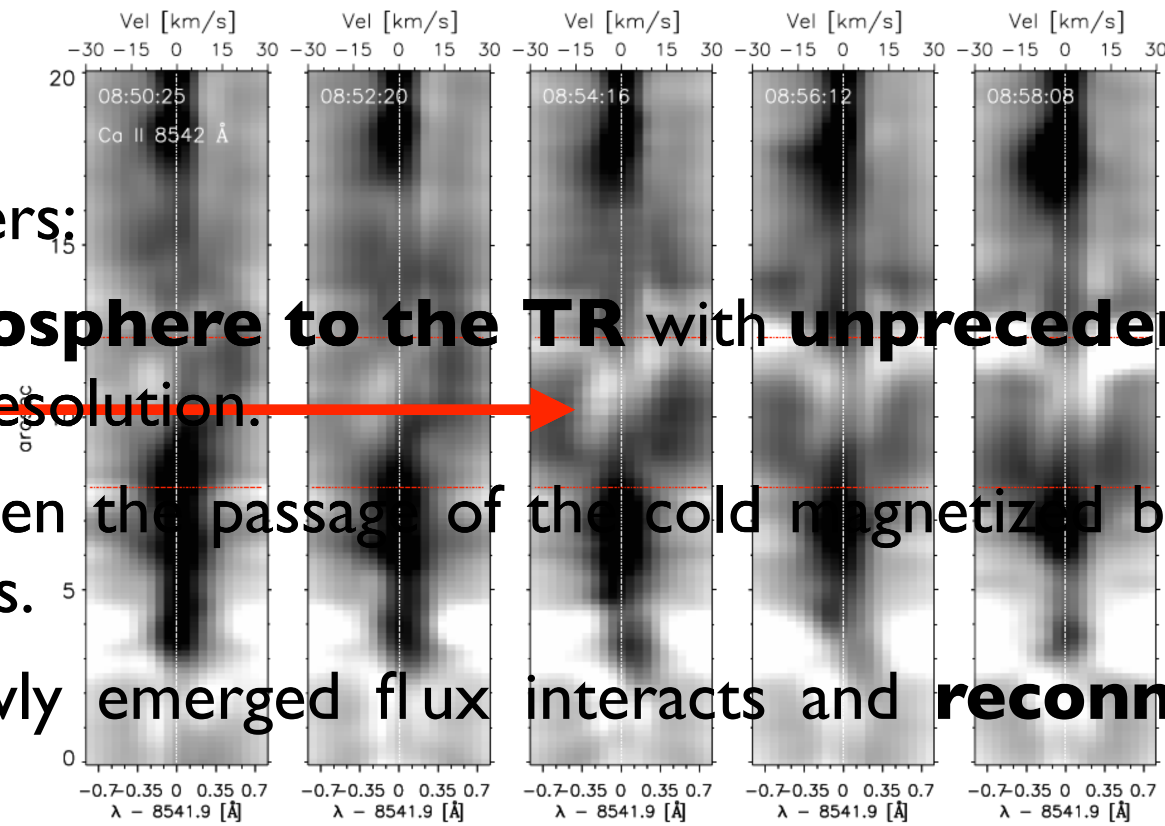
Observations from space



Transient **blueshifts within** the dark bubble region

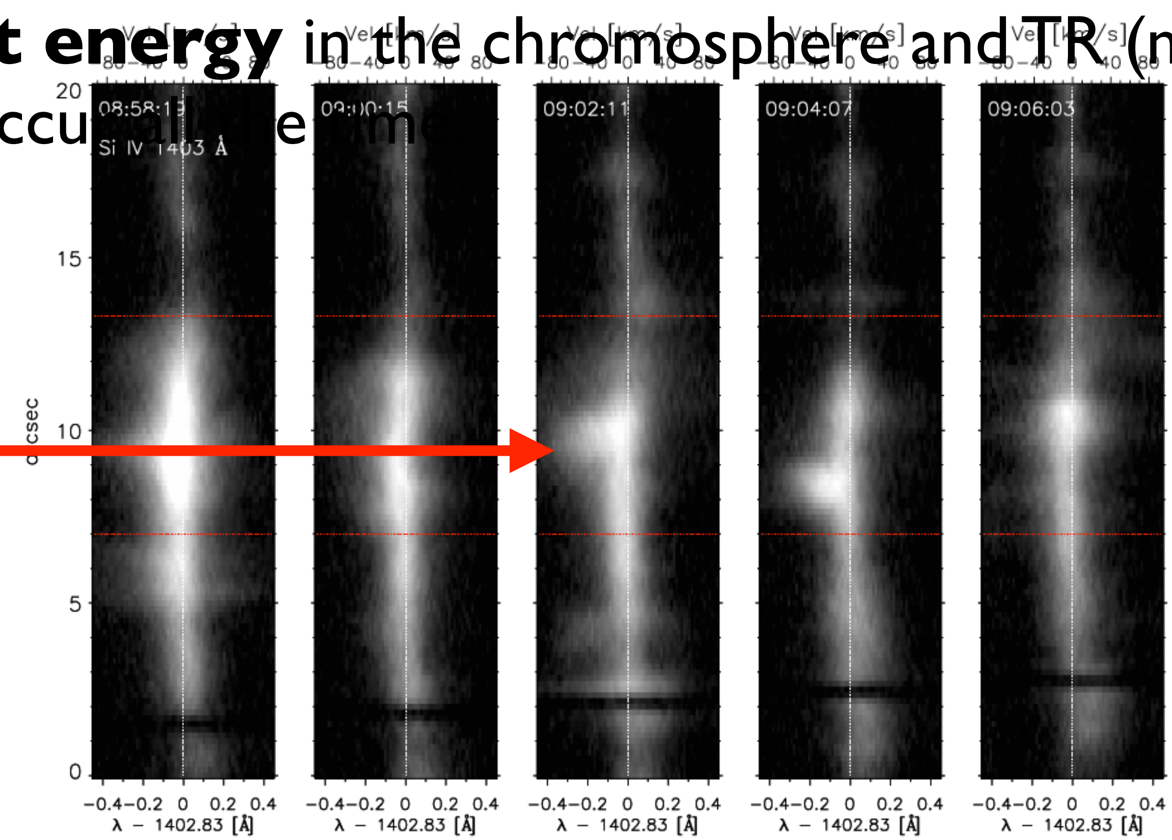
- By sampling lines sensitive to upper layers;
- We follow FE events **from the photosphere to the TR** with **unprecedented spatial, spectral and temporal** resolution.
- We have measured the **delays** between the passage of the cold magnetized bubble through the different atmospheric layers.
- **Significant activity** occurs as newly emerged flux interacts and **reconnects** with pre-existing flux.
- Flux emergence events clearly **deposit energy** in the chromosphere and TR (maybe in the corona?). Important, since they occu

Ca II 8542 blueshift at
08:54:16 UT



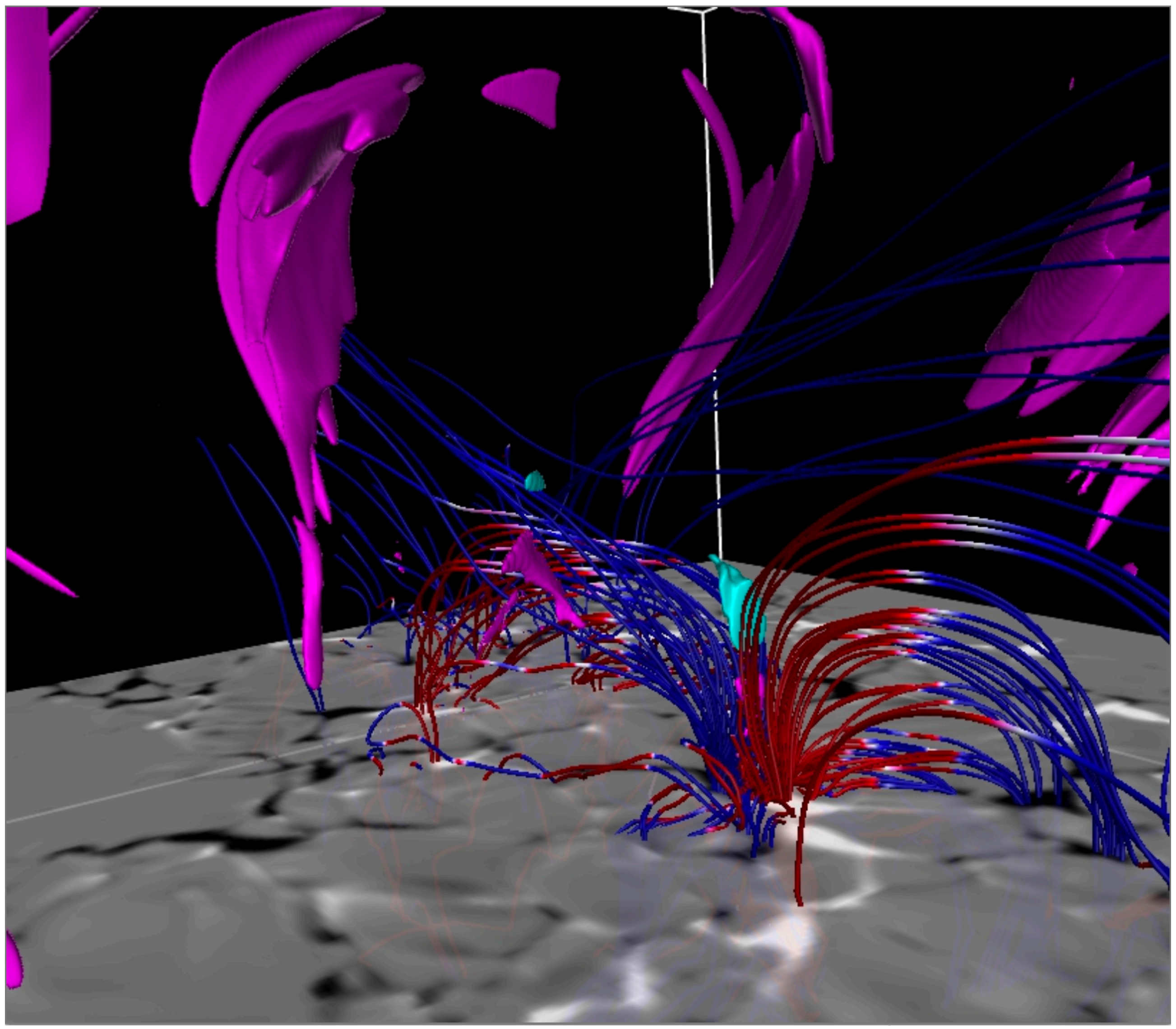
… and 8 minutes later,
higher up …

Si IV blueshift at
09:02:11 UT

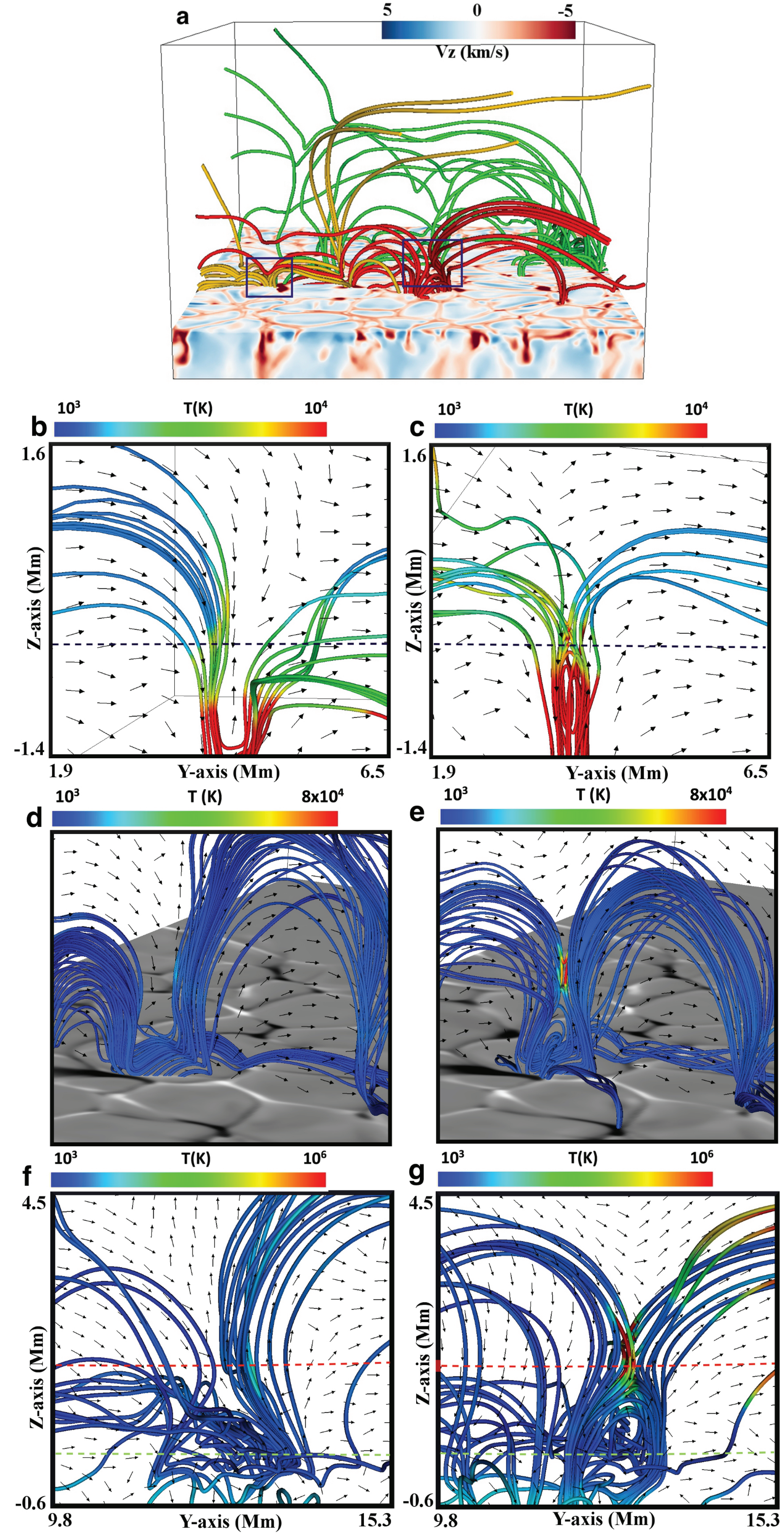


Ortiz et al. (2016), ApJ 825, 93

Reconnection at multiple heights:



chromosphere
at z=1.8 Mm



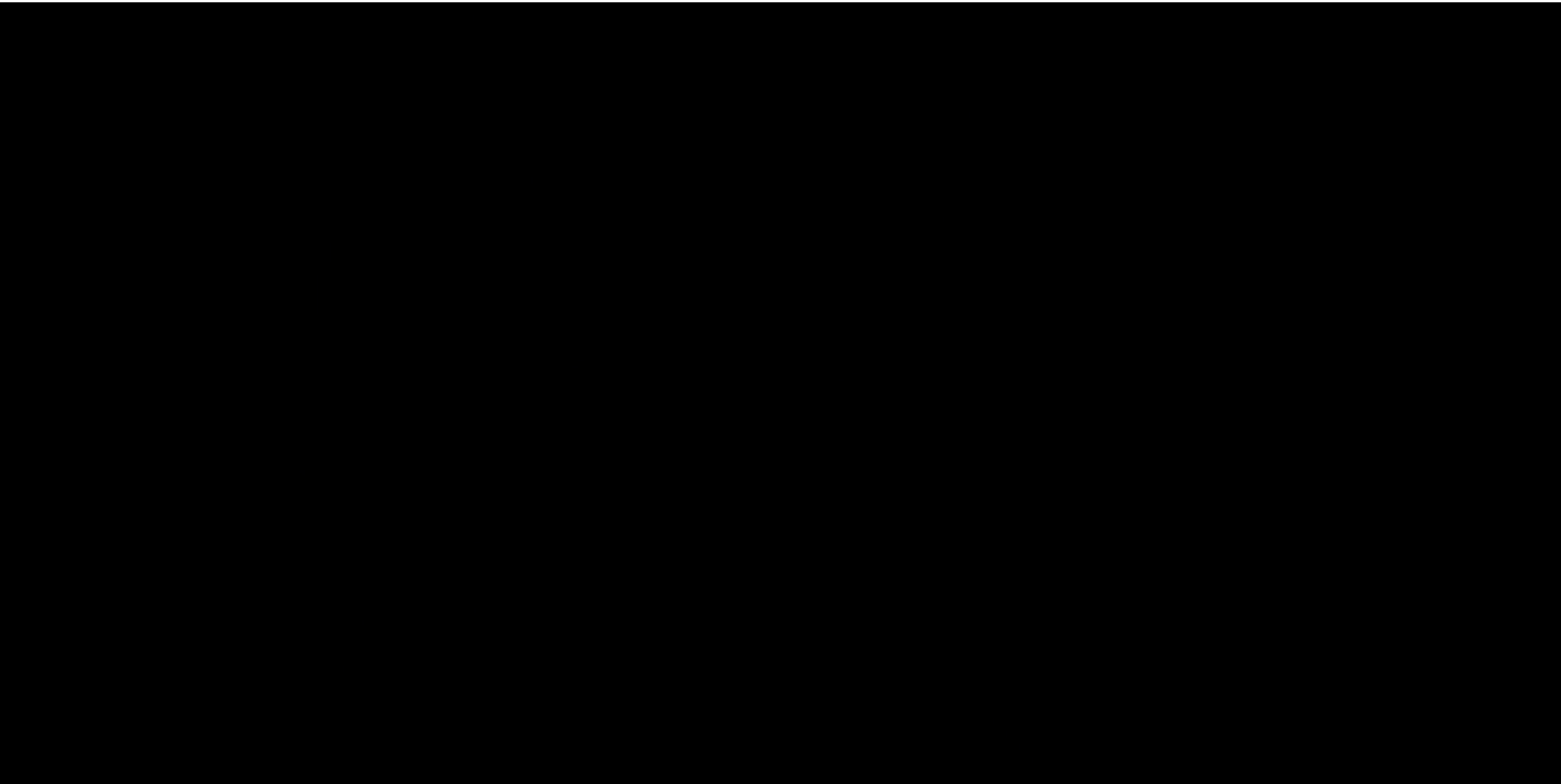
What did we learn here?

It is difficult to study flux emergence because it involves:

- Observations at **many wavelengths**
- Observations from **different observatories**, both on the ground and from space, with different instruments, resolutions, cadences, etc.
- Drastic changes in temperature, ionisation state, pressure along the solar atmosphere … by several orders of magnitude.

Still, we wanted to try:

- To follow a particular flux emergence event through the whole solar atmosphere **from the photosphere to the transition region** with **unprecedented spatial, spectral and temporal** resolution.
- **Integral multi-wavelength study of the solar atmosphere** in a case of flux emergence.
- Show how all layers in the solar atmosphere are coupled by the rising magnetic field



Thank you for your attention!