UNIQUE SCIENCE WITH TOTAL SOLAR ECLIPSES

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Photo: Pavel Starha, Kenya 2013

Brief historical overview of scientific discoveries from eclipses

The Solar Corona

Maraldi:

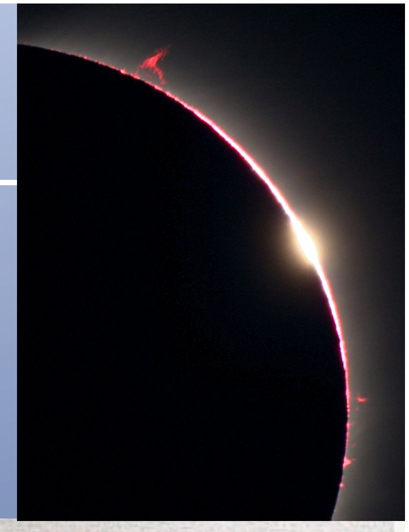
Corona is part of Sun because Moon traverses it during an eclipse

22 May 1724

Jose Joaquin de Ferrer gives name corona to what appears during an eclipse = part of Sun not Moon, because of its great size

16 Jun 1806

Prominences



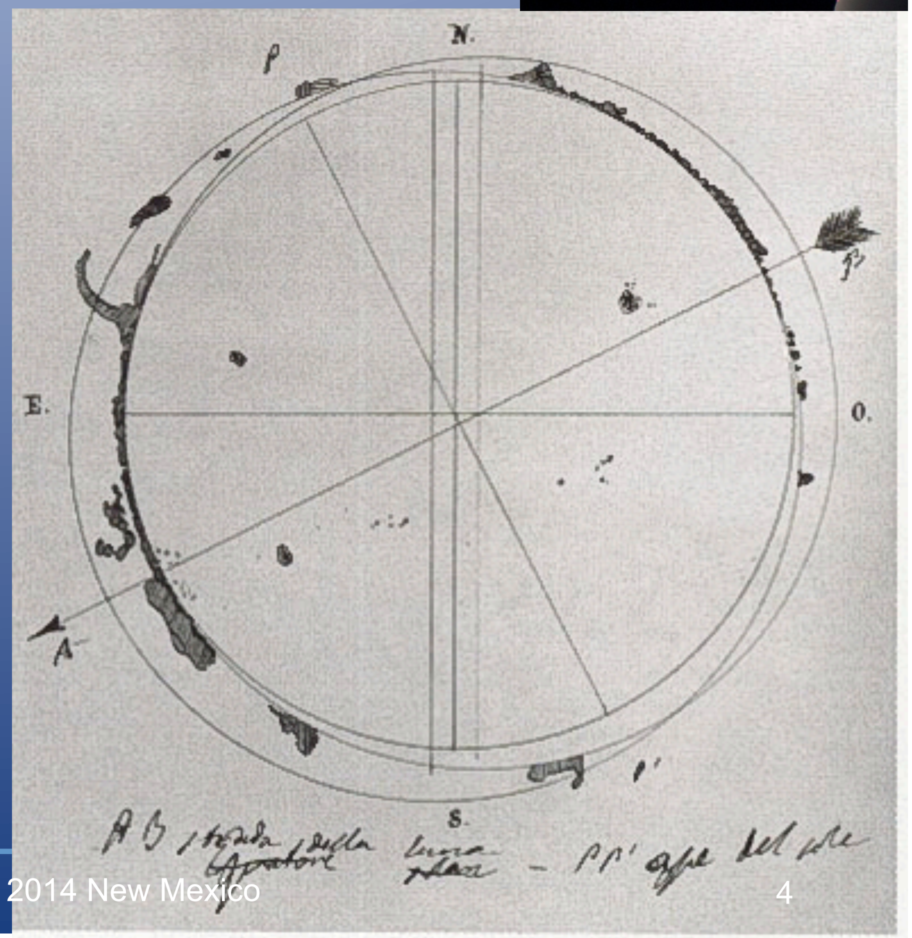
Grant, Swan and von Littrow:

Prominences are part of the Sun because Moon is seen to cover and uncover them as it moves in front of Sun

28 July 1851

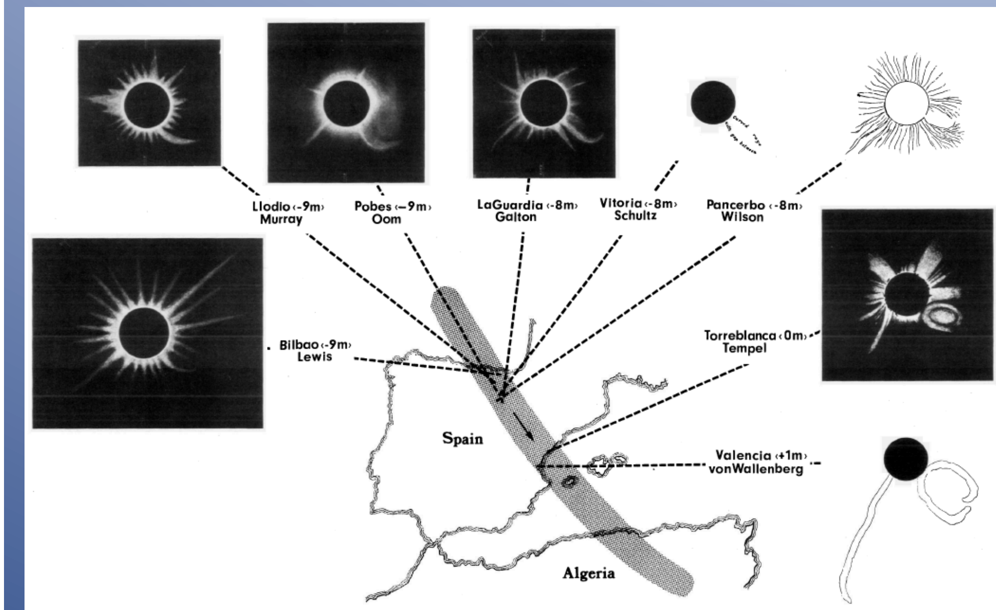
De La Rue and Secchi **use photography, with sites 250 miles apart to demonstrate that prominences are part of Sun (since they look the same)**

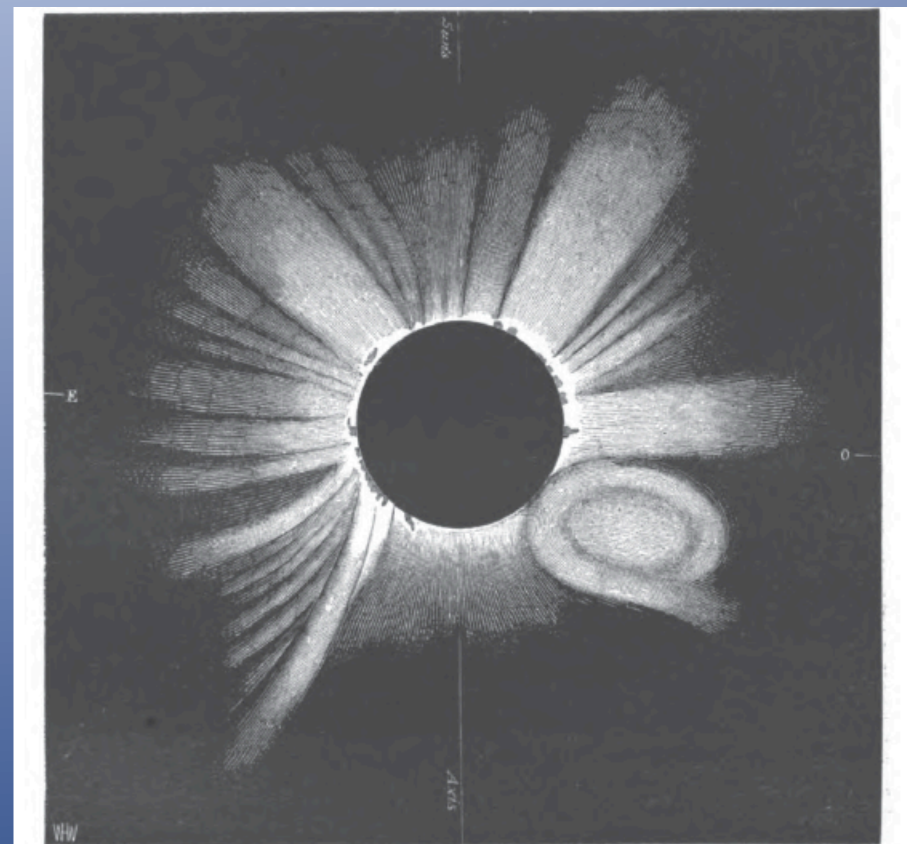
18 July 1860



ANGELO SECCHI ALSO MADE DRAWINGS AND TOOK

First eye-witness record of a coronal mass ejection





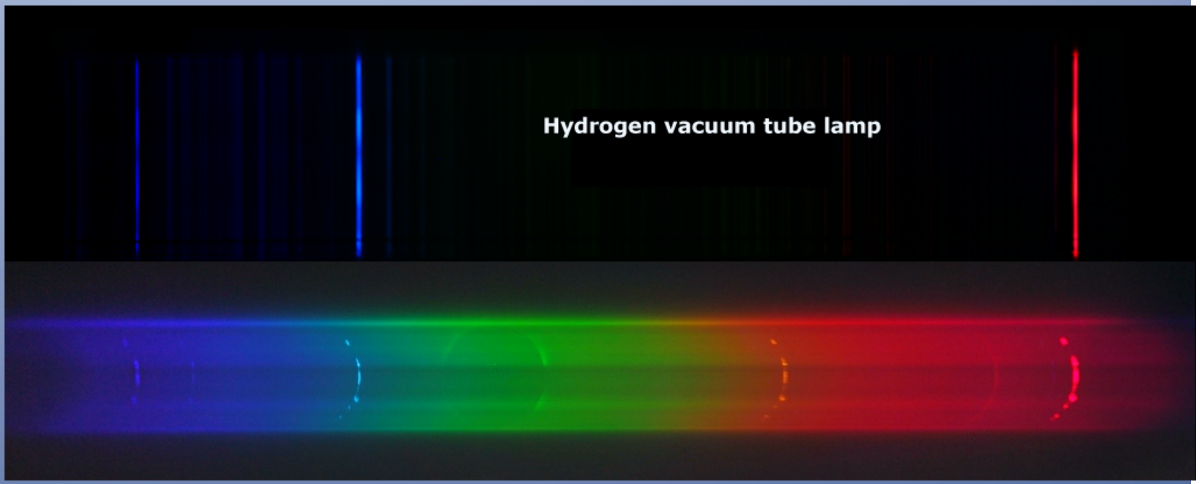
1860

TEMPEL: drawing of the corona during the 18 July 1860 eclipse, Torreblanco, Spain

Spectroscopy and Chemical Composition of the Corona

Tennant, Herschel, Janssen, Rayet and Pogson:

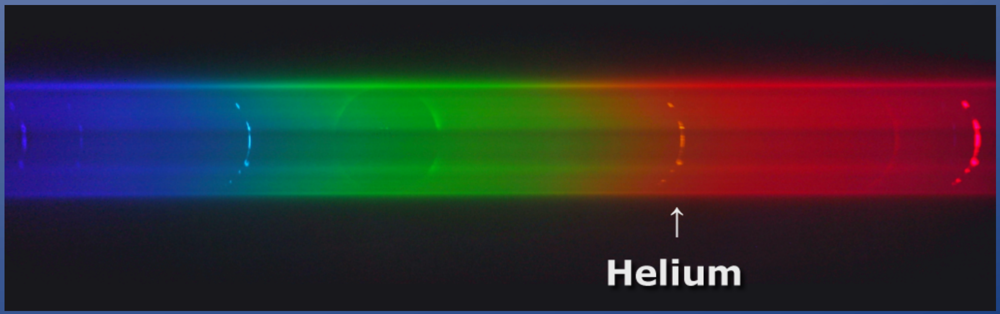
Spectroscopy shows that prominences are composed primarily of Hydrogen



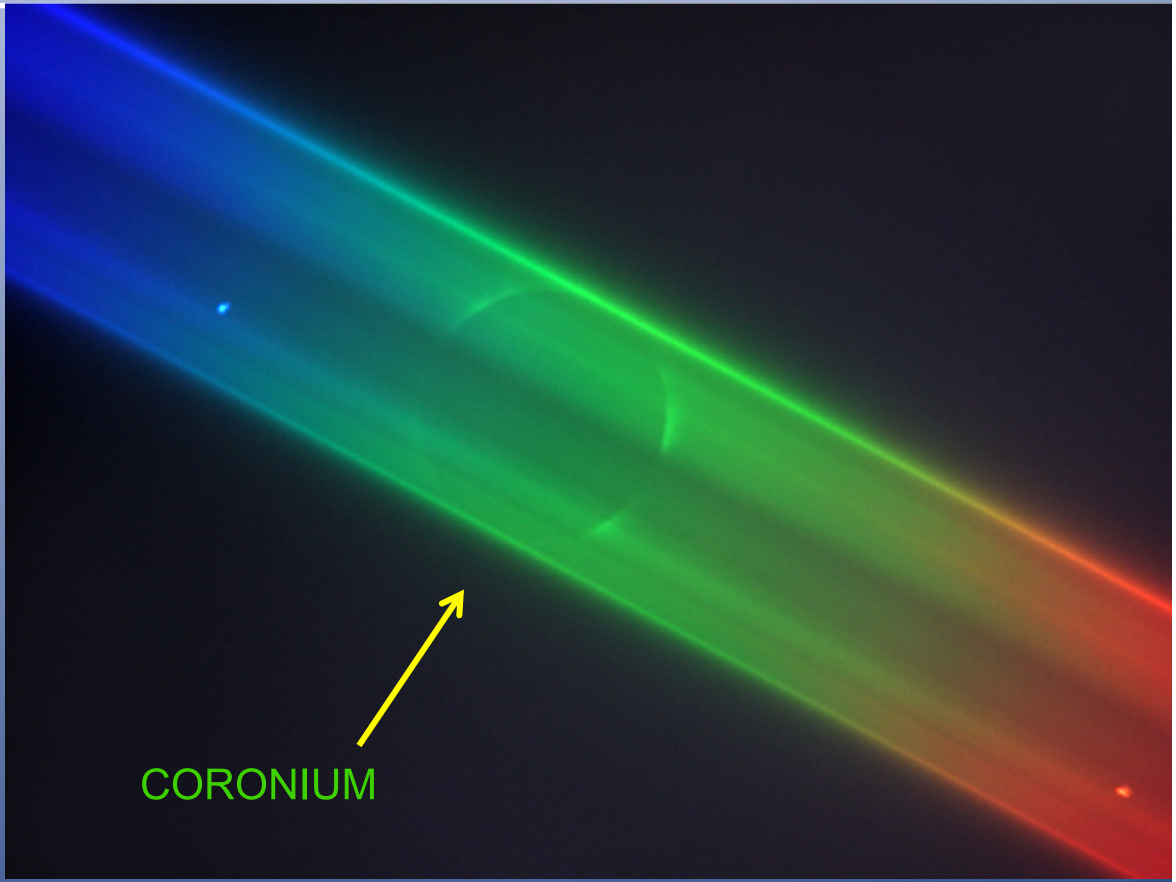
18 August 1868

Lockyer identifies a yellow spectral line in corona as signature of chemical element unknown on Earth. He calls it Helium.

Helium is first identified in the lab by *Ramsay* in 1895.



Spectroscopy and Chemical Composition of the Corona



7 August 1869

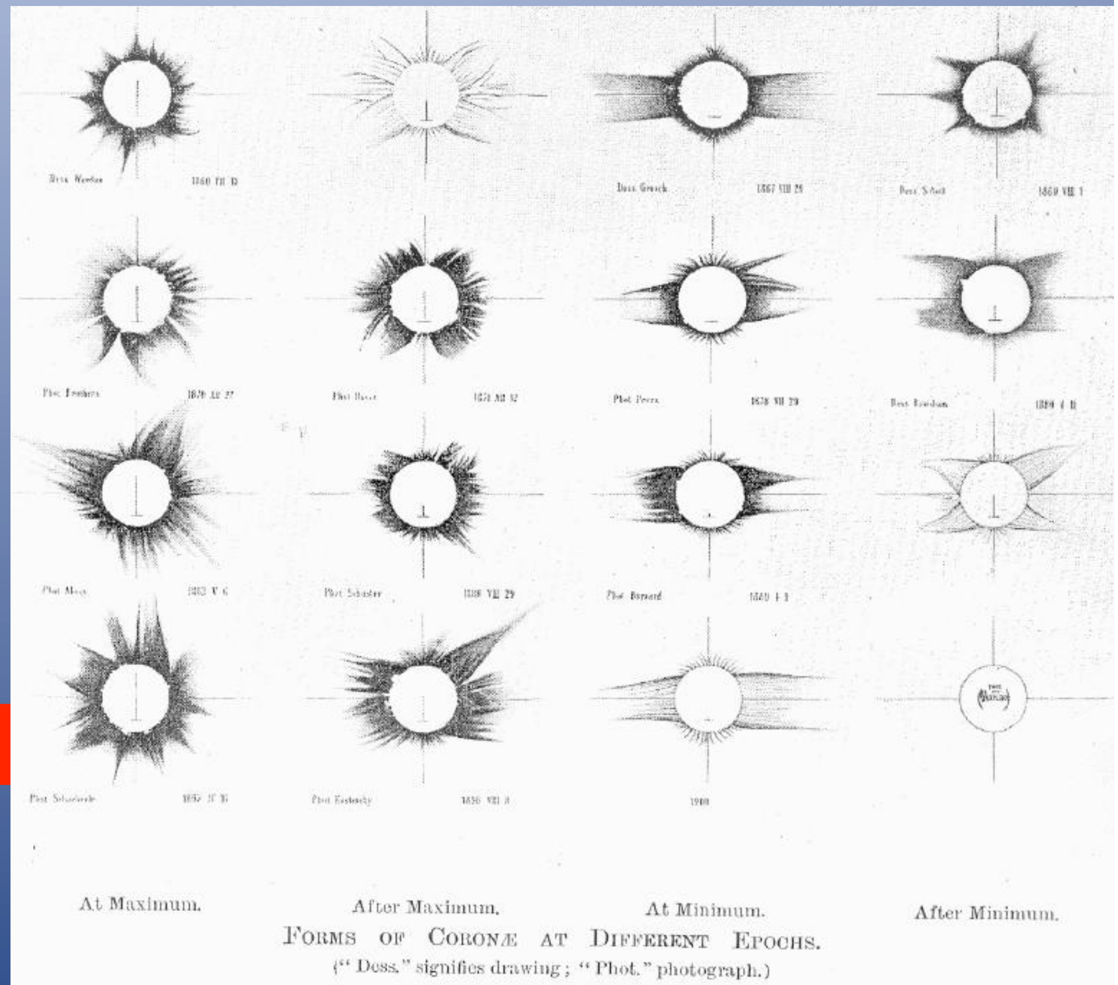
Young and Harkness independently discover a new bright line in the corona not seen on Earth, they name it coronium.

The solar cycle and the shape of the corona

Janssen Notices that the shape of the corona changes with sunspot cycle:

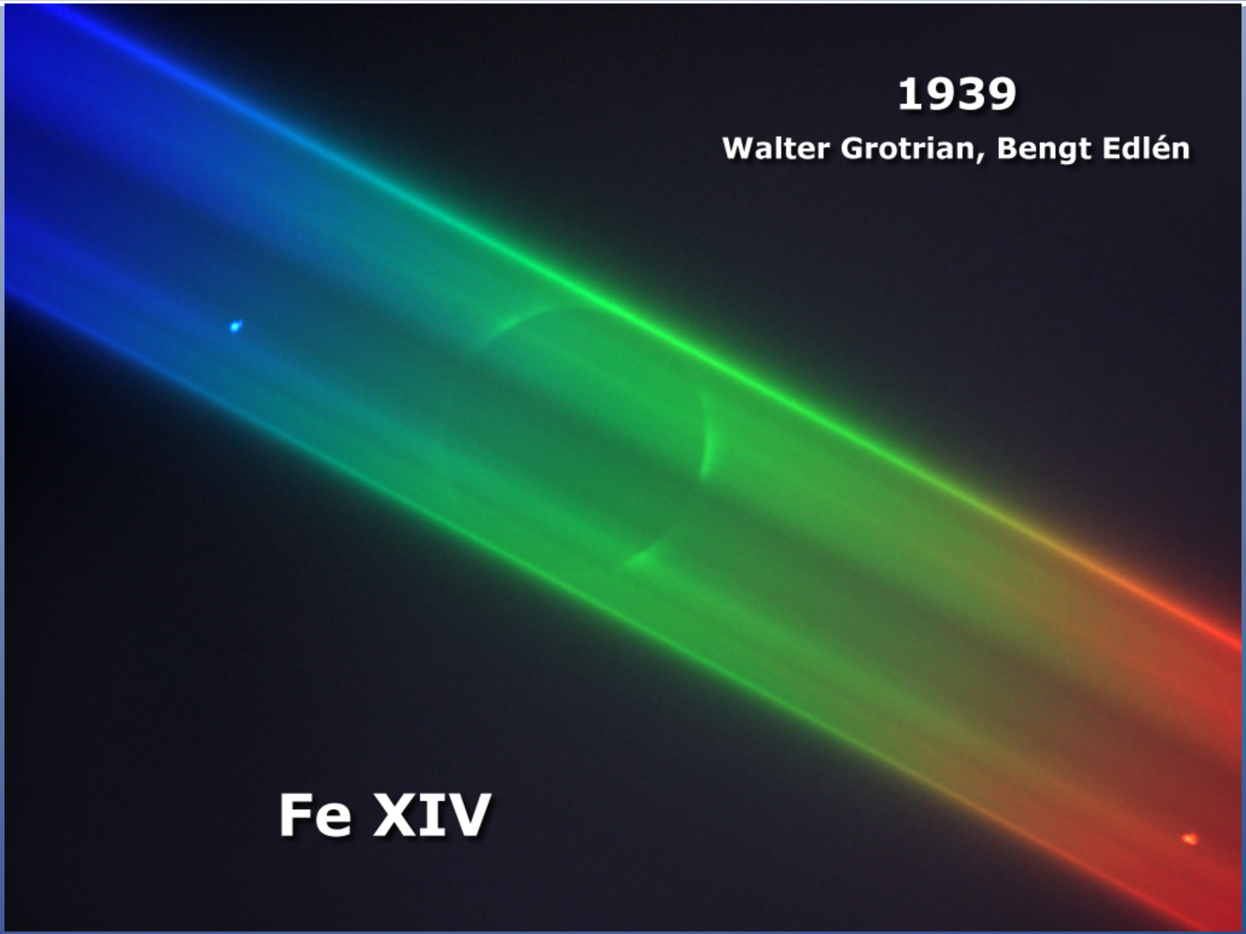
corona is rounder (1871) at maximum than at minimum (1878). It's the most convincing evidence that the corona is part of the Sun

12 December 1871 **29 July 1878**



From "The Indian Eclipse", 1898, British Astronomical Association, Ed. E. Maunder

The Hot Corona

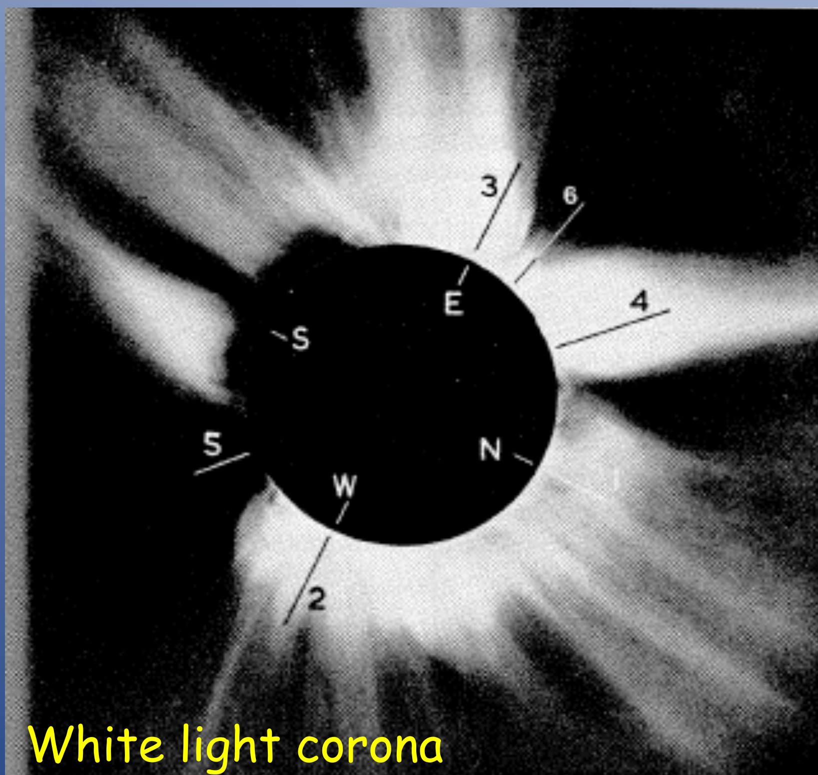


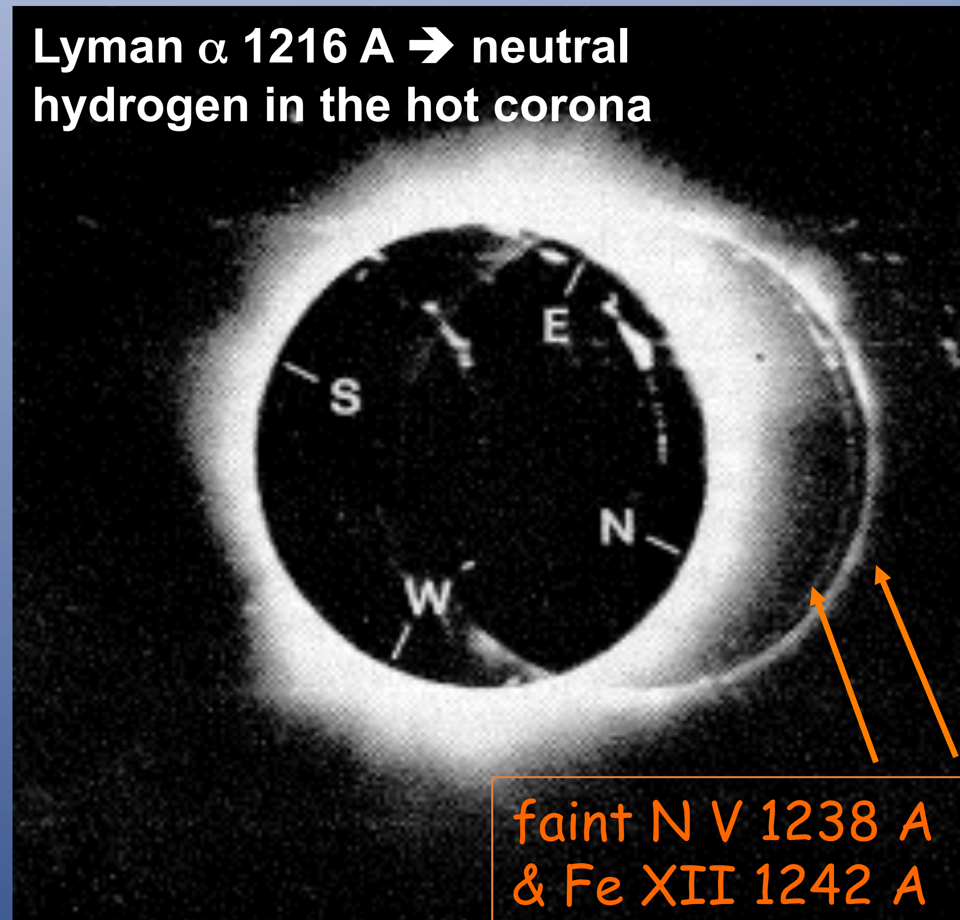
1939-41

Edlén and Grotrian identify coronium as **Fe^{13+}**

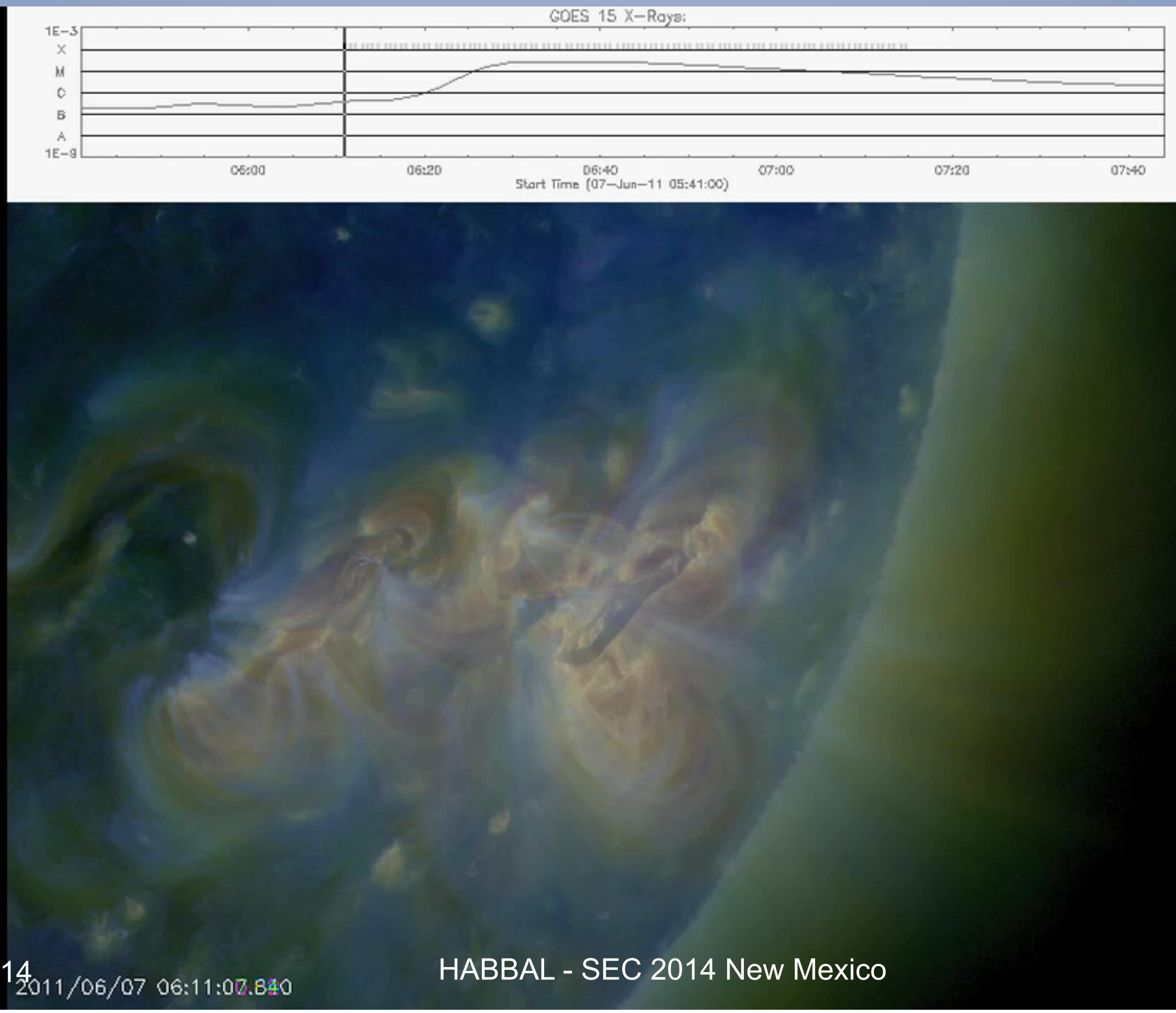
→ HOT CORONA **at T > 10^6 K**

Discovery of neutral H in the corona during the 30 June 1973 eclipse from rocket flight

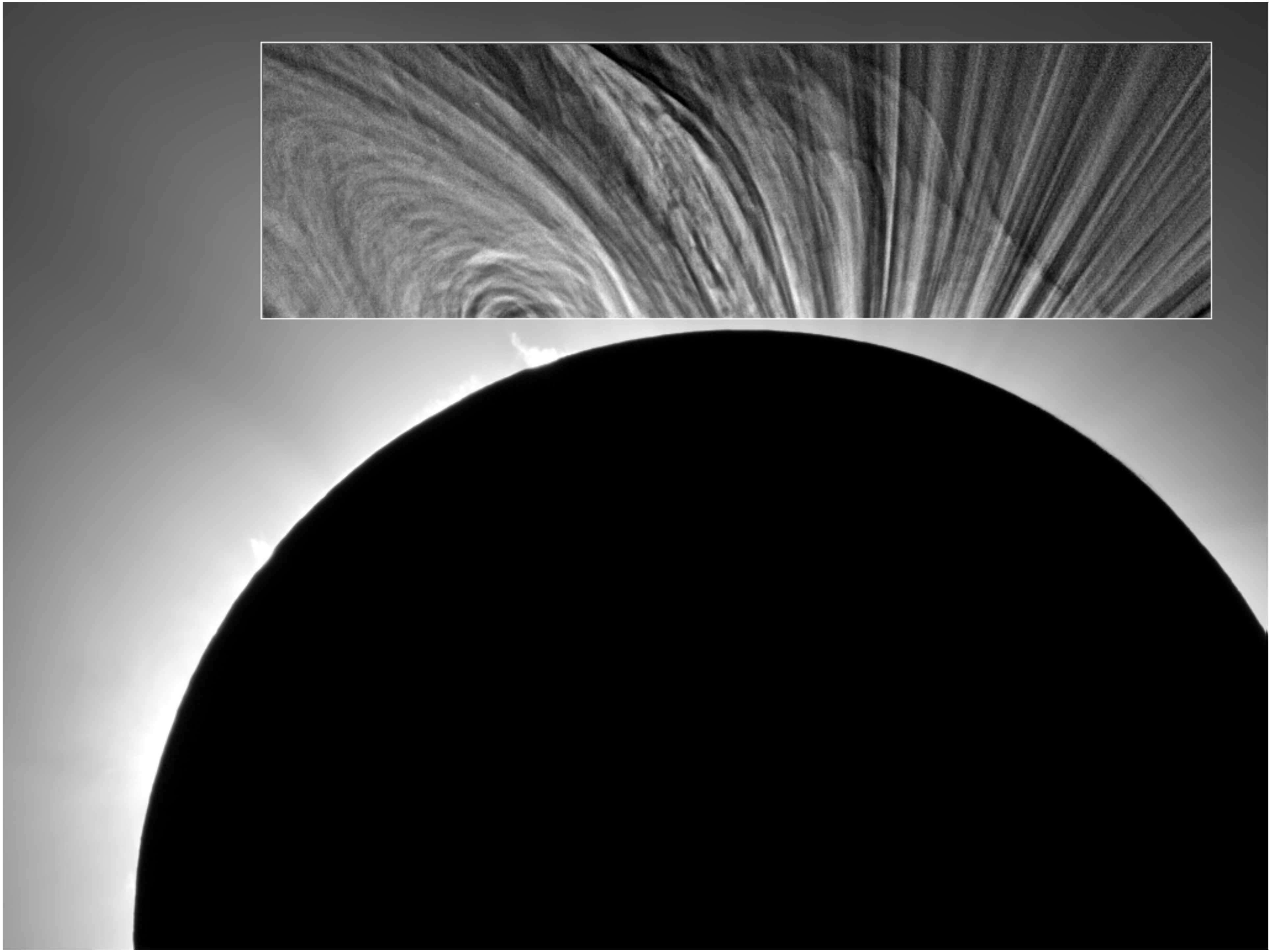




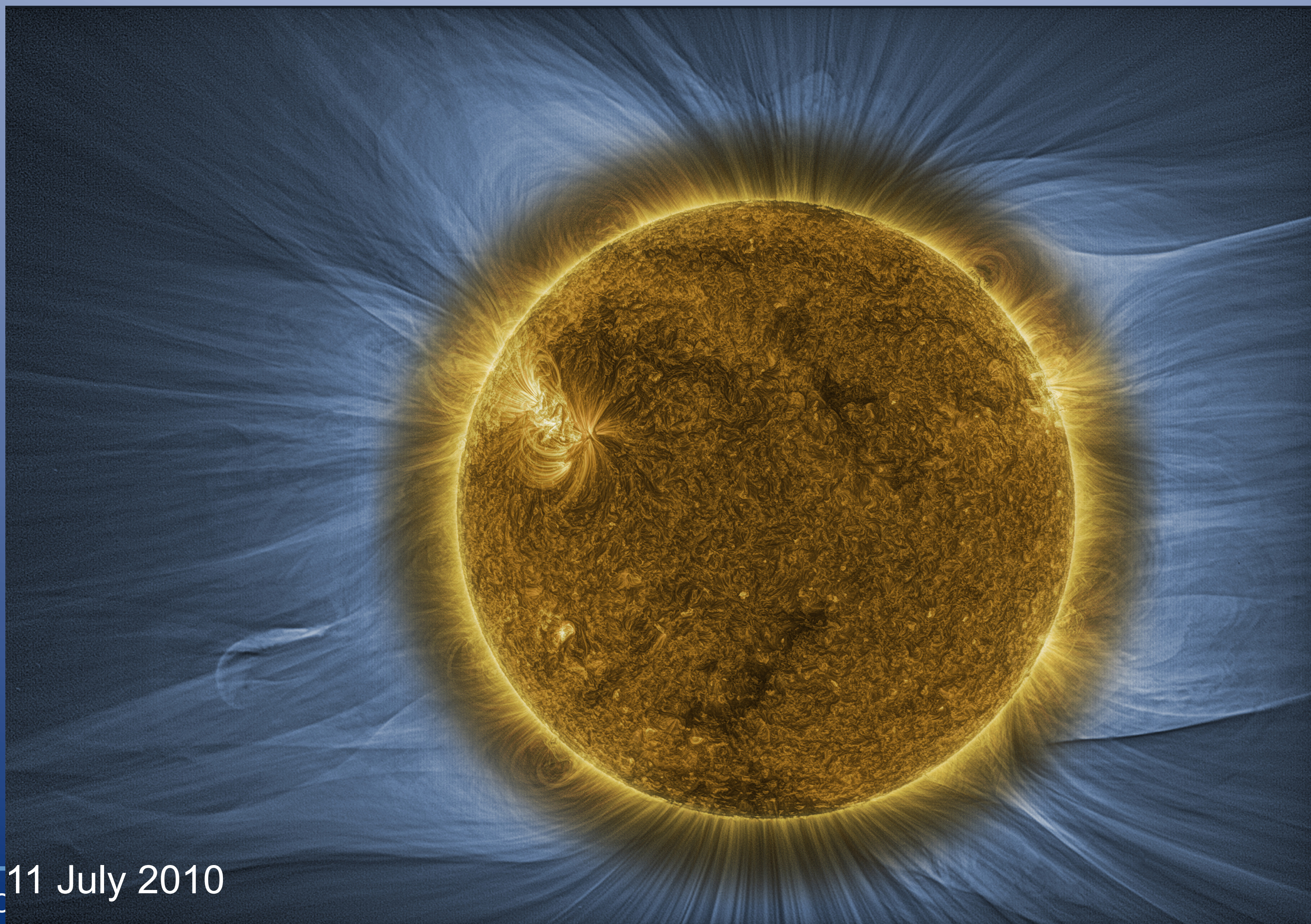
which led to the exploration of the Sun in the EUV



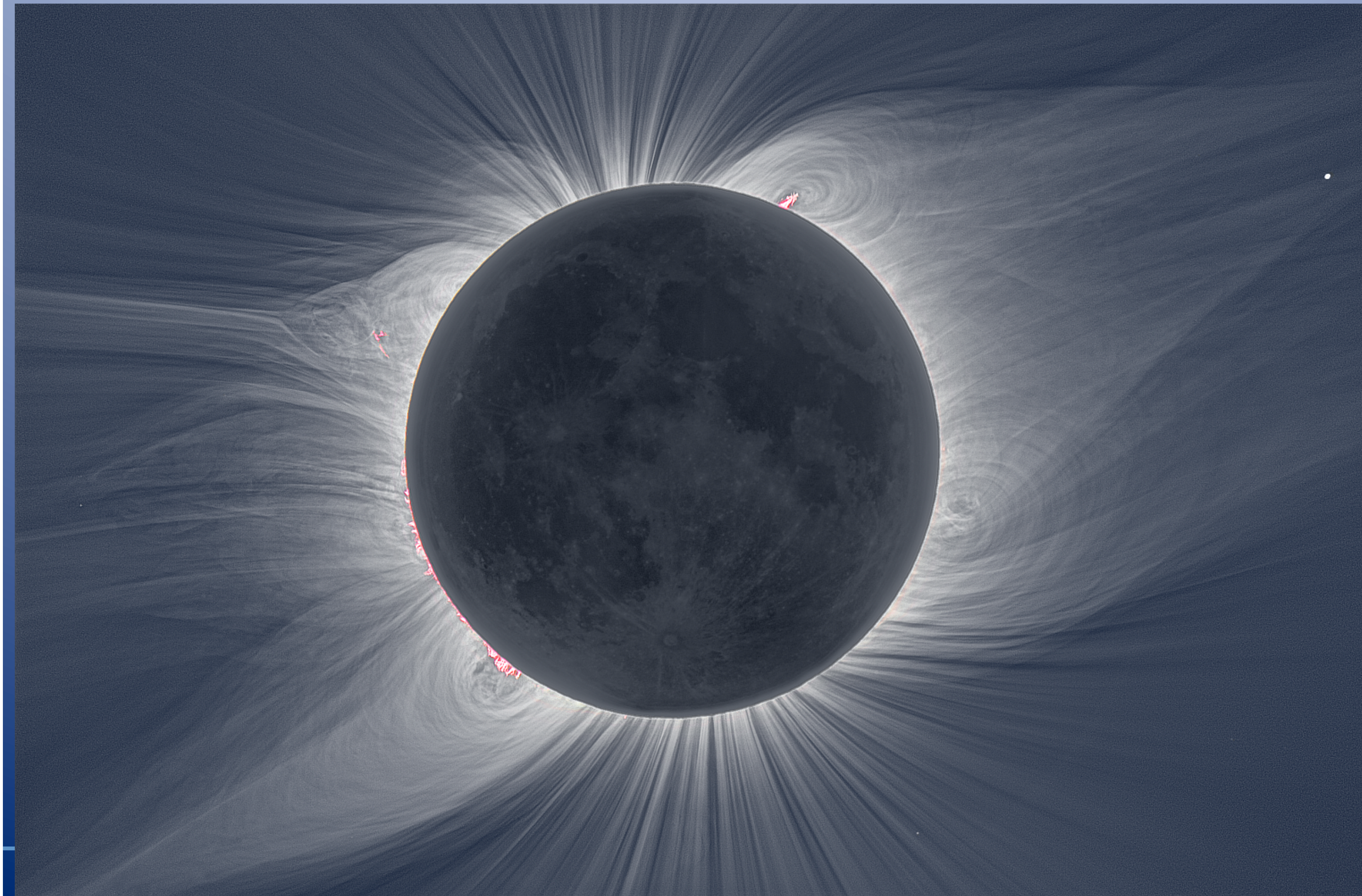
Role of image processing in revealing unsurpassed details of coronal structures



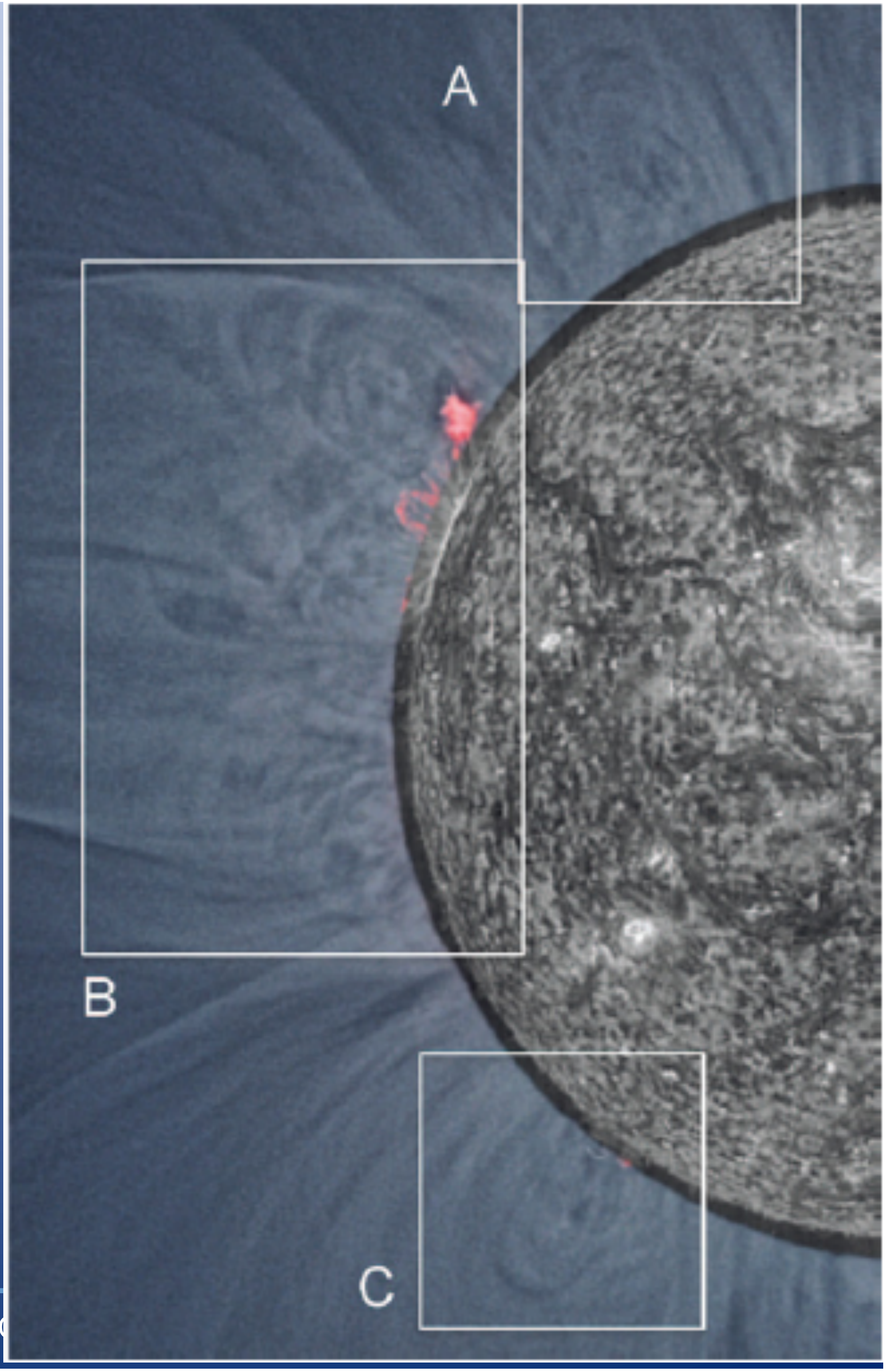
Connecting eclipse observations to high resolution space-based observations: validating the reliability of image processing



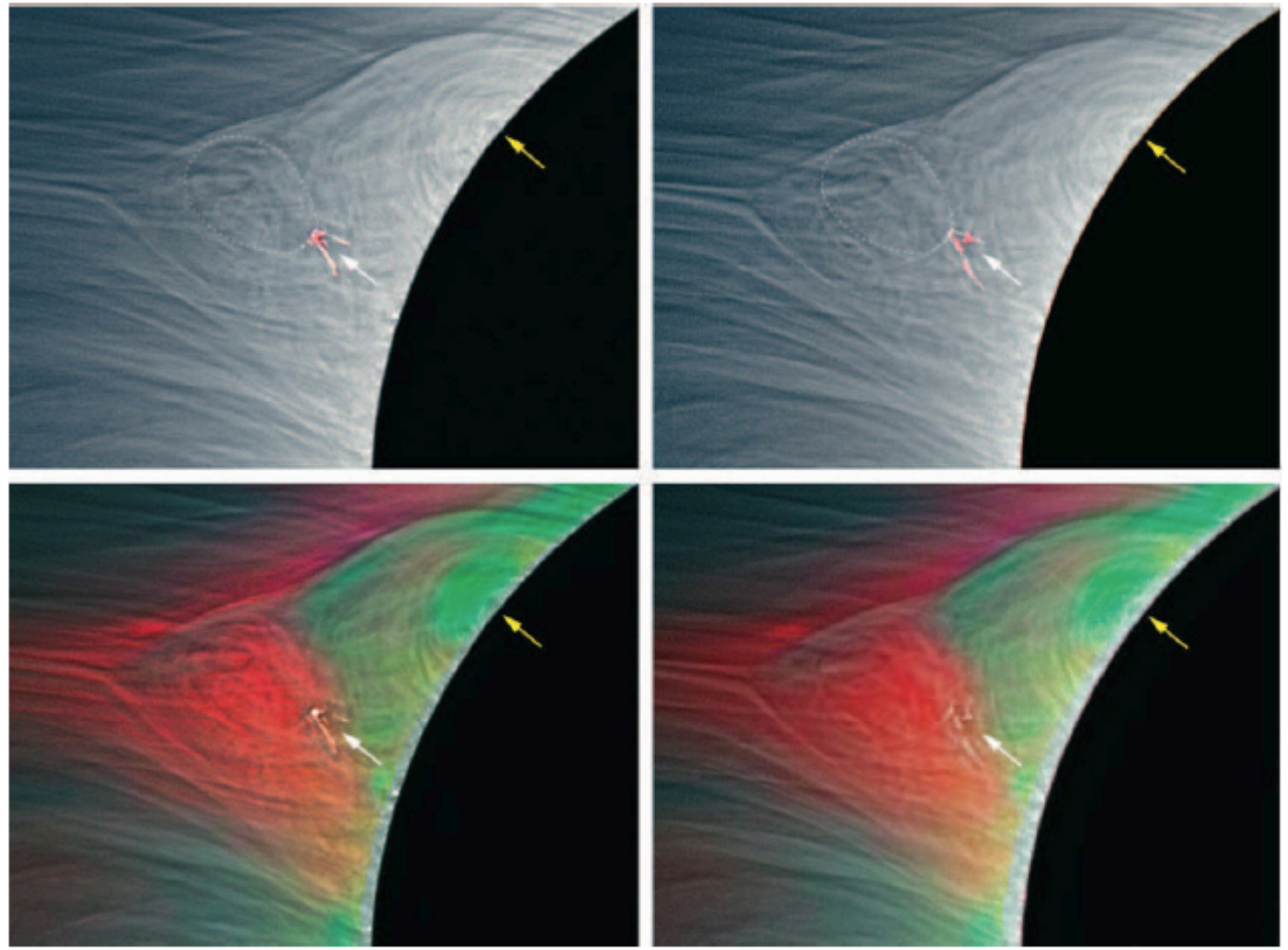
2008 August 1: All types of prominences



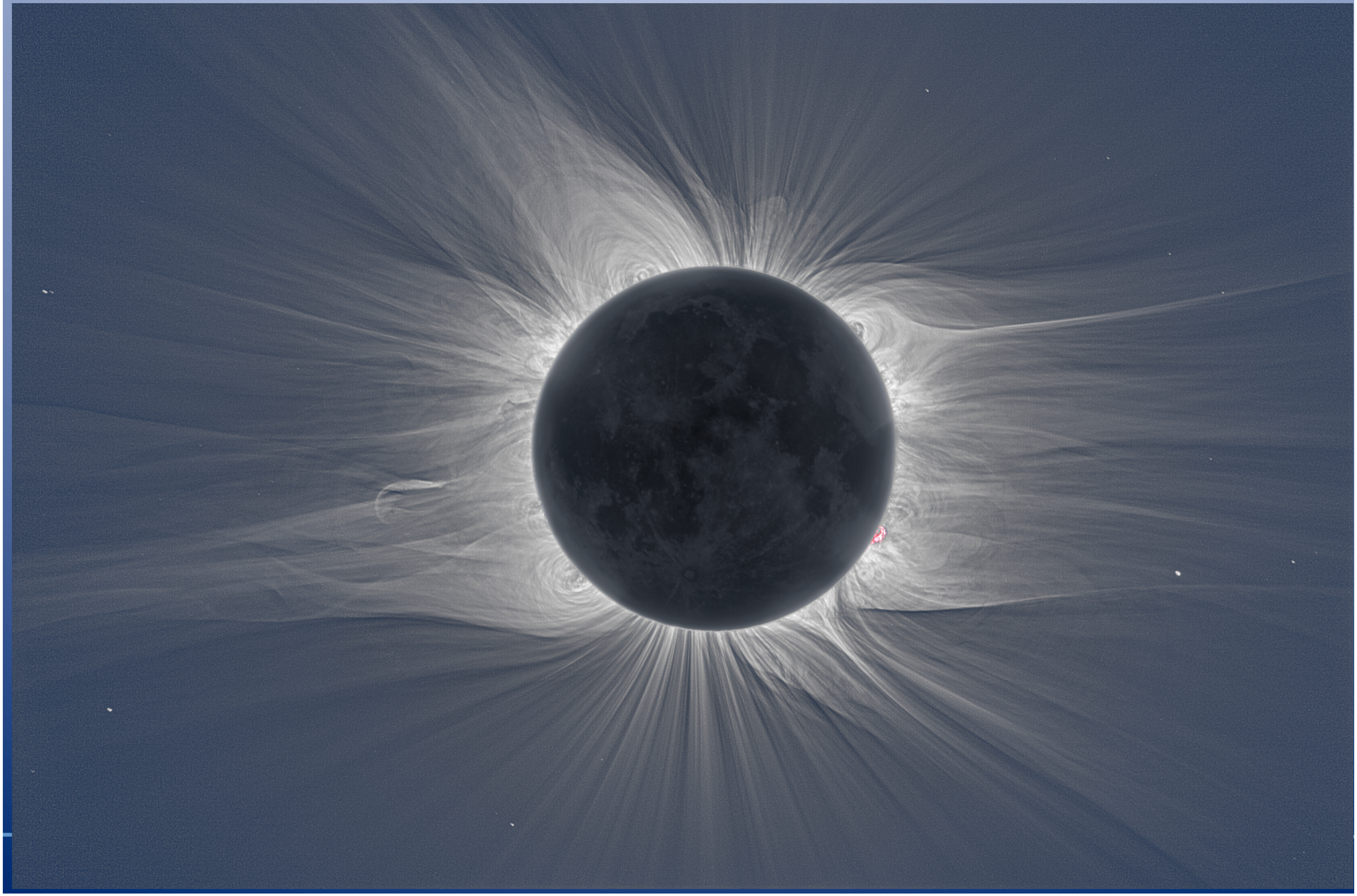
Prominence-corona interface



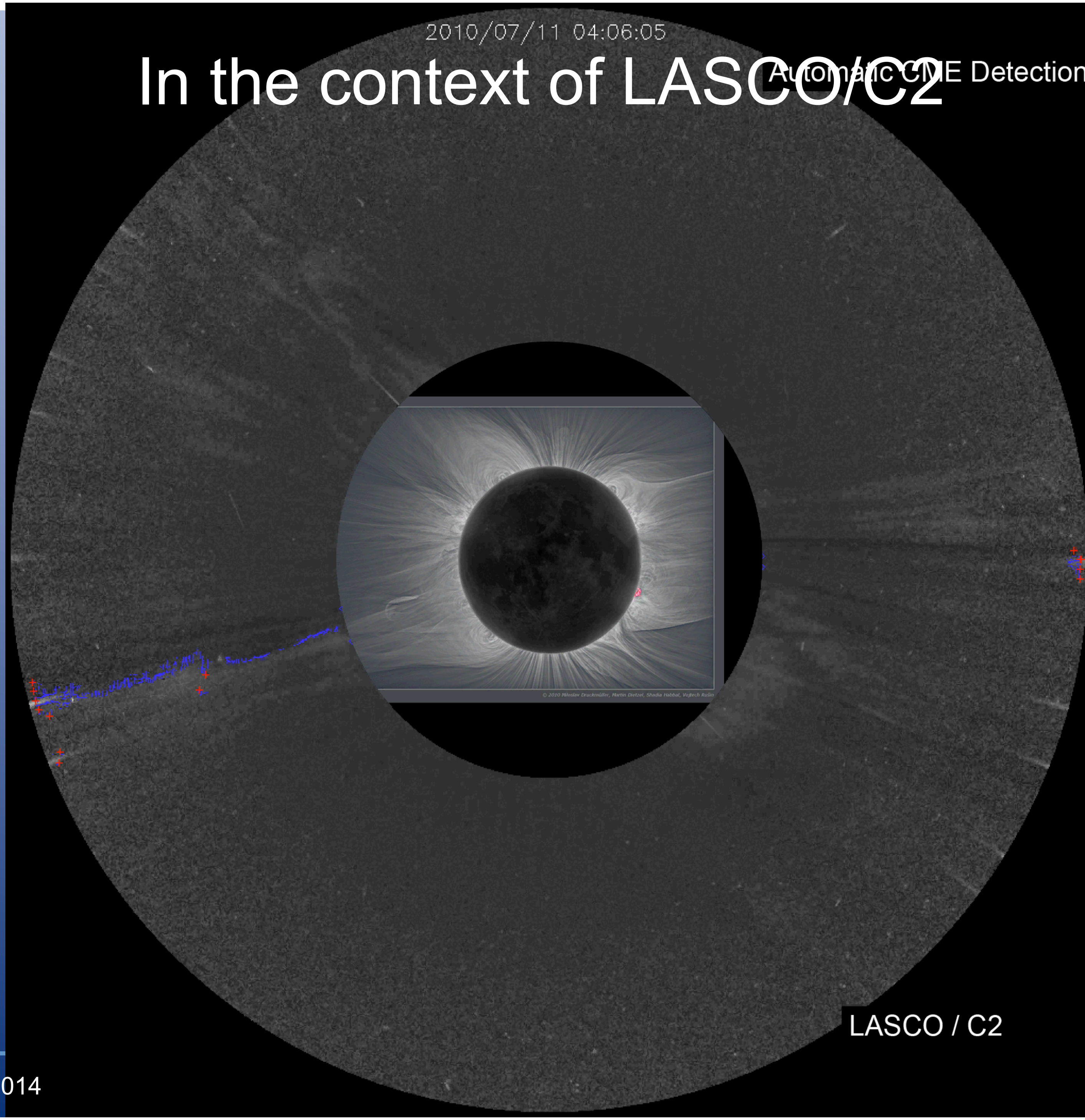
Prominences are directly linked to coronal structures



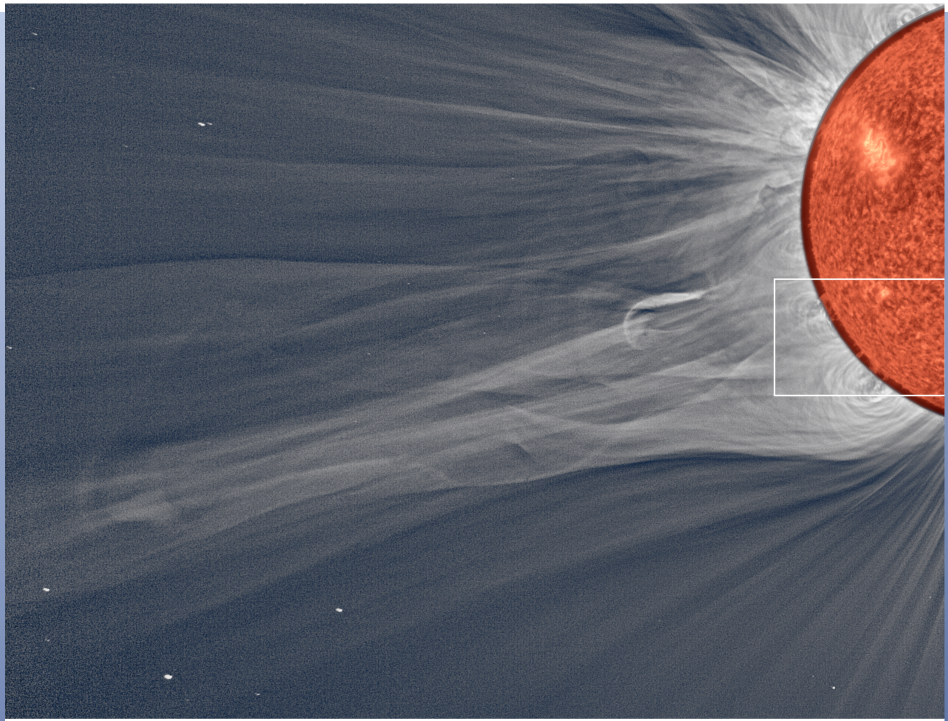
2010 July 11: The Hook and the Wedge

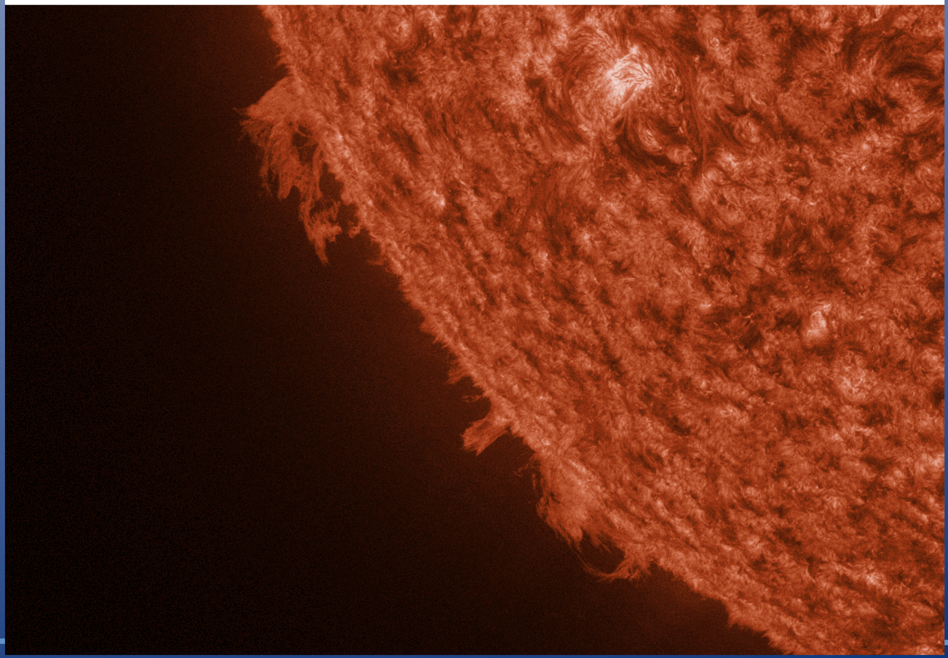


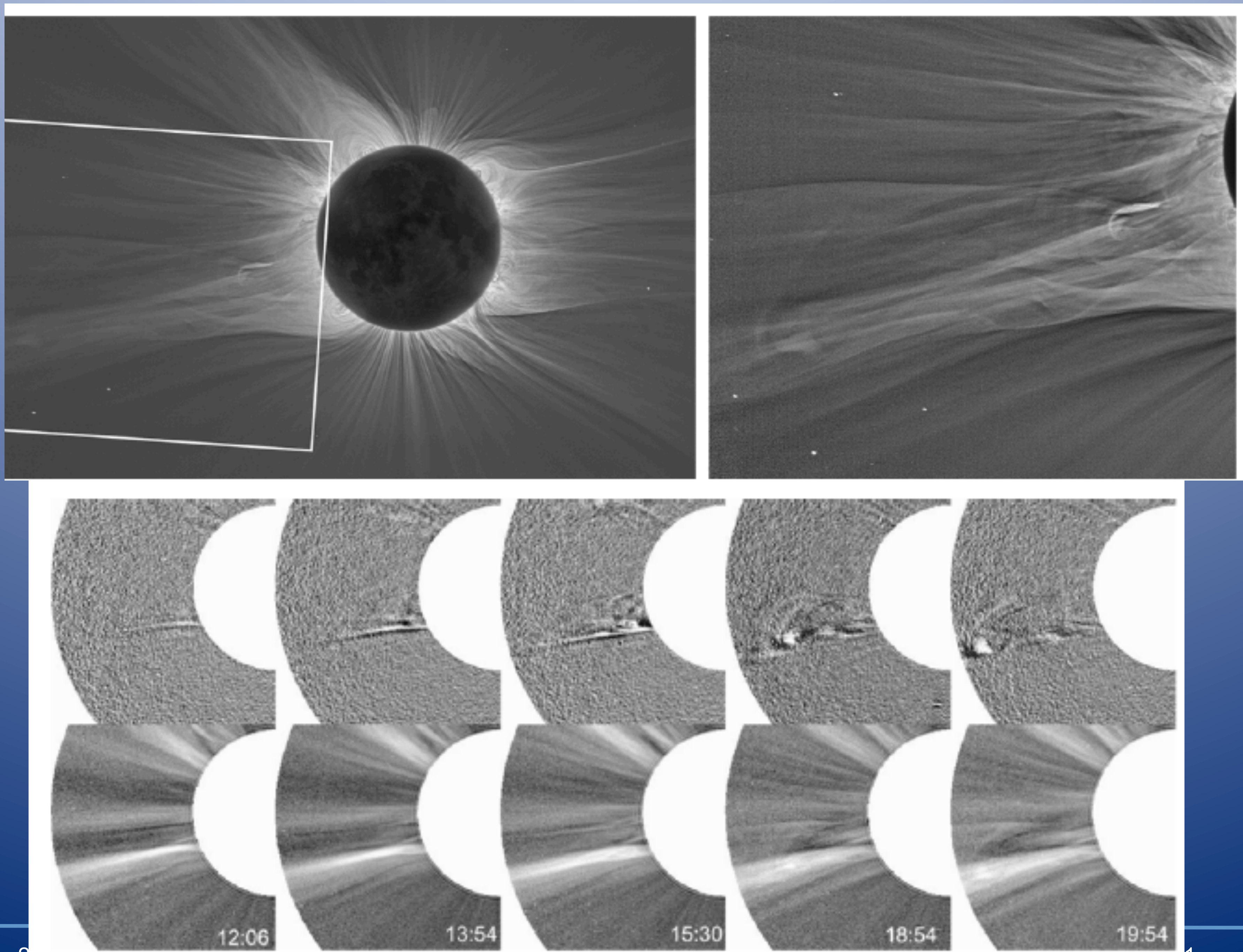
In the context of LASCO/C2

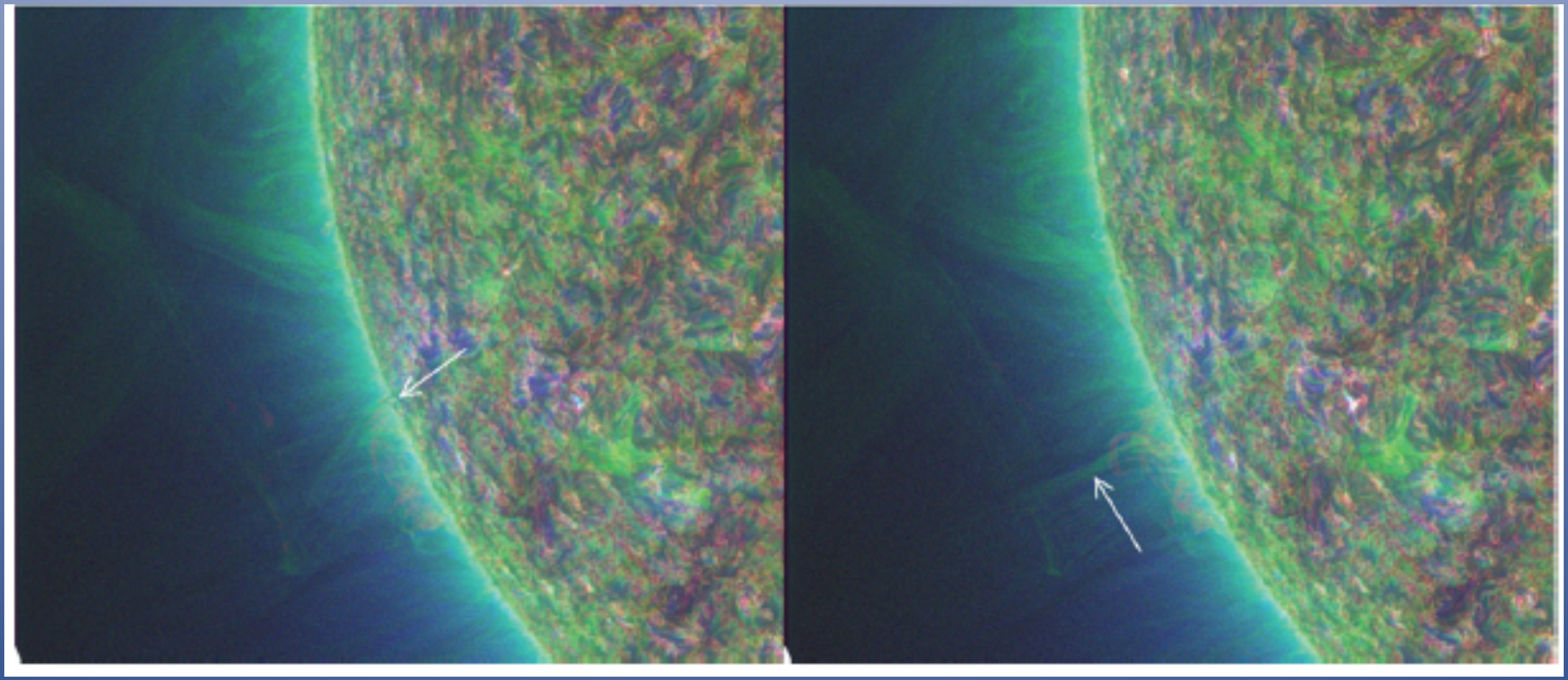


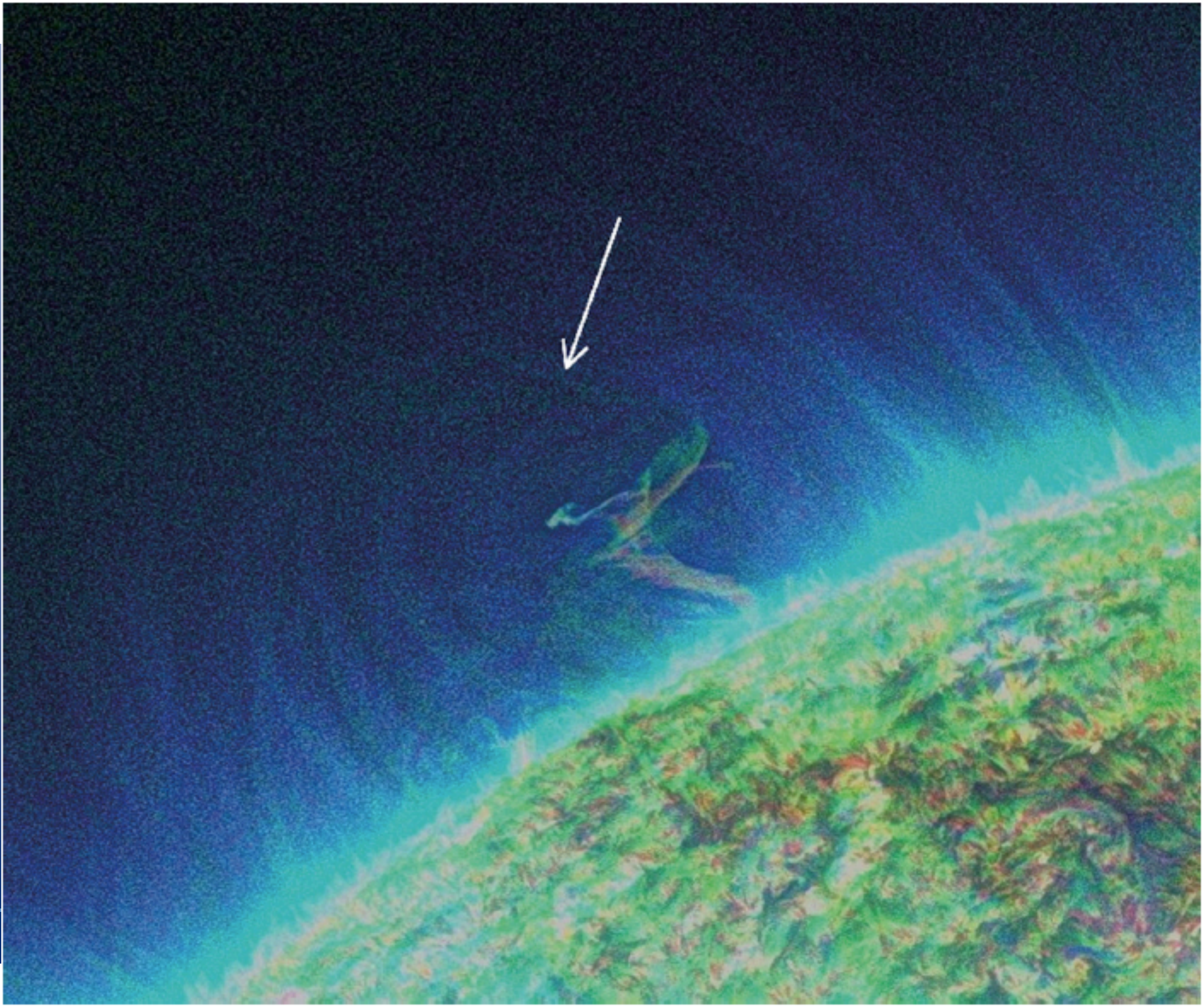
Twisted helical structure following a prominence eruption and suspended `hook'



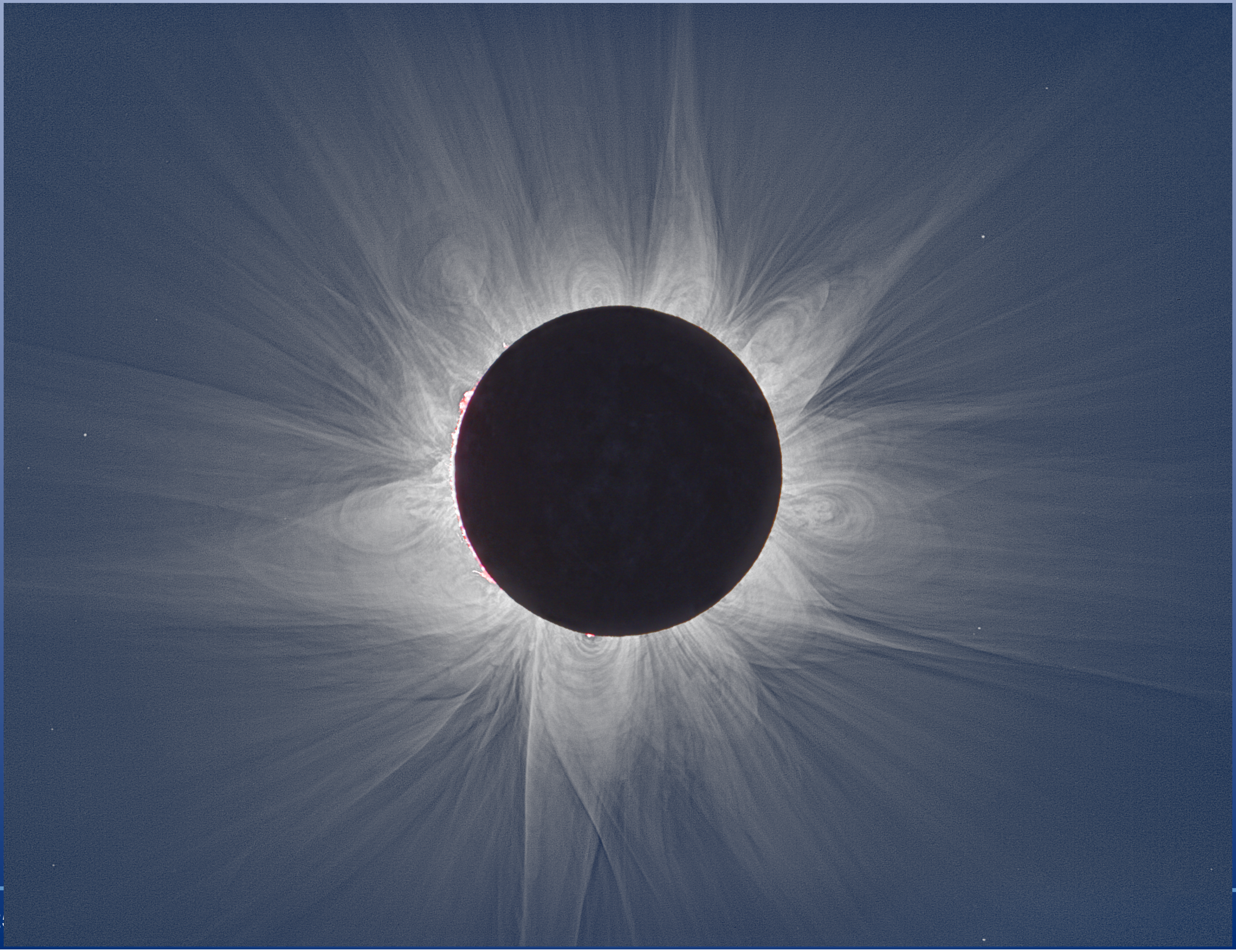



12:06
13:54
15:30
18:54
19:54





2012 November 3: A classic solar maximum Corona

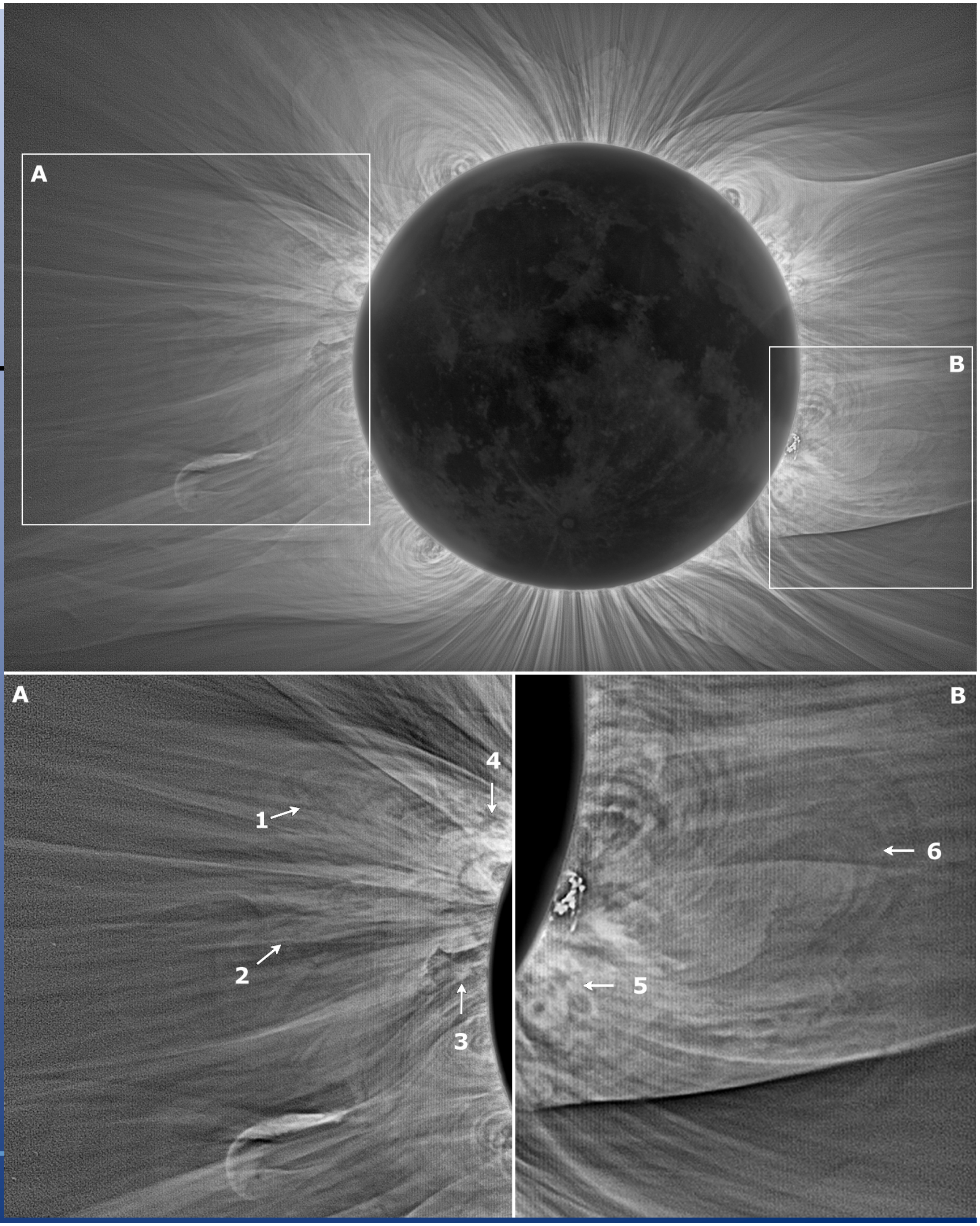


2013 November 12:
Prominence Eruptions and Plasmoids

Eclipse images: Snapshots of manifestations of plasma instabilities and dynamics associated with prominences

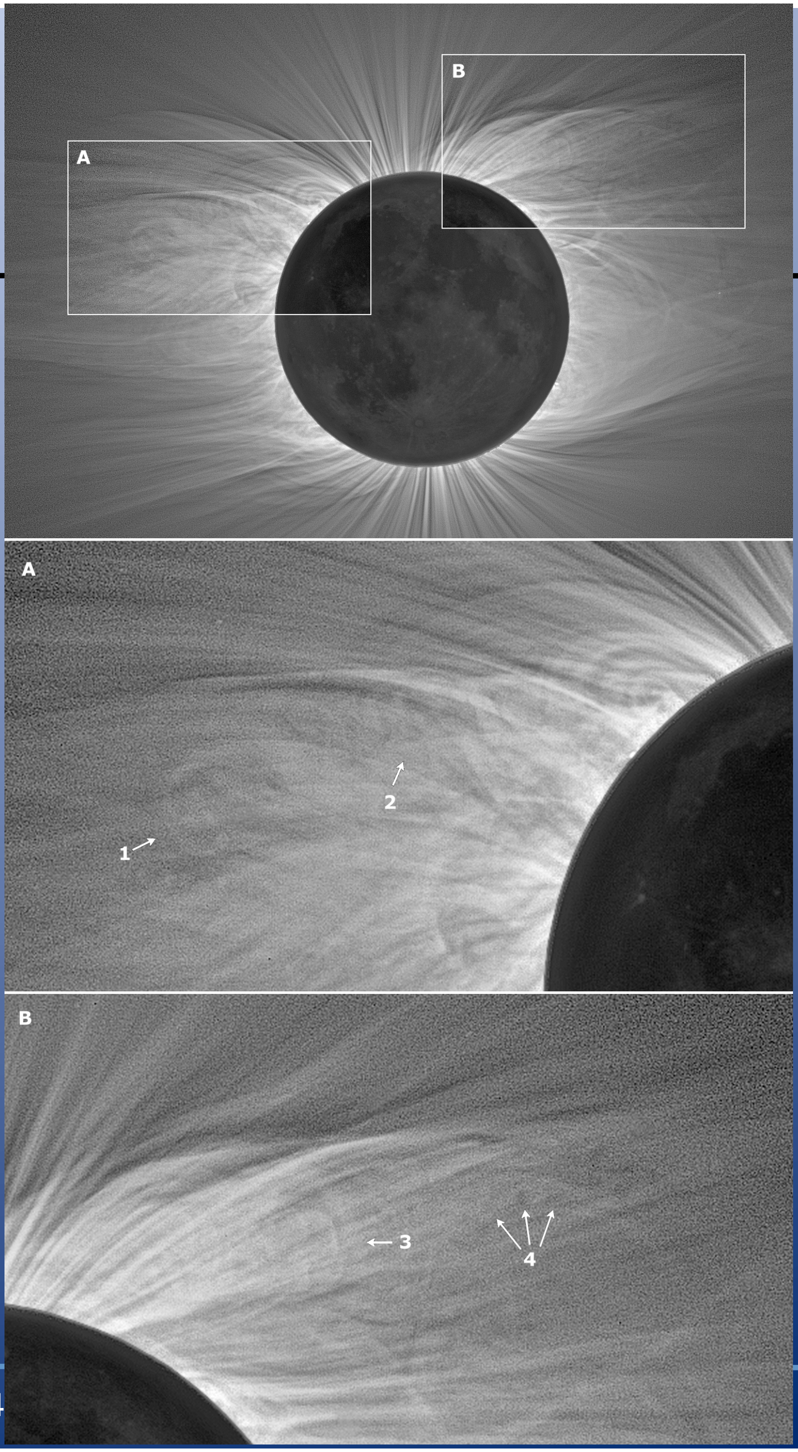
Vortices, plumes, expanding loops and helical structures

- Expanding nested loops
  → 1, 6
- Expanding helical structures (KH & RT instabilities)
  → 2
- Mushroom-shaped plumes (RT instability
  → 3
- Vortex rings
  → 4, 5

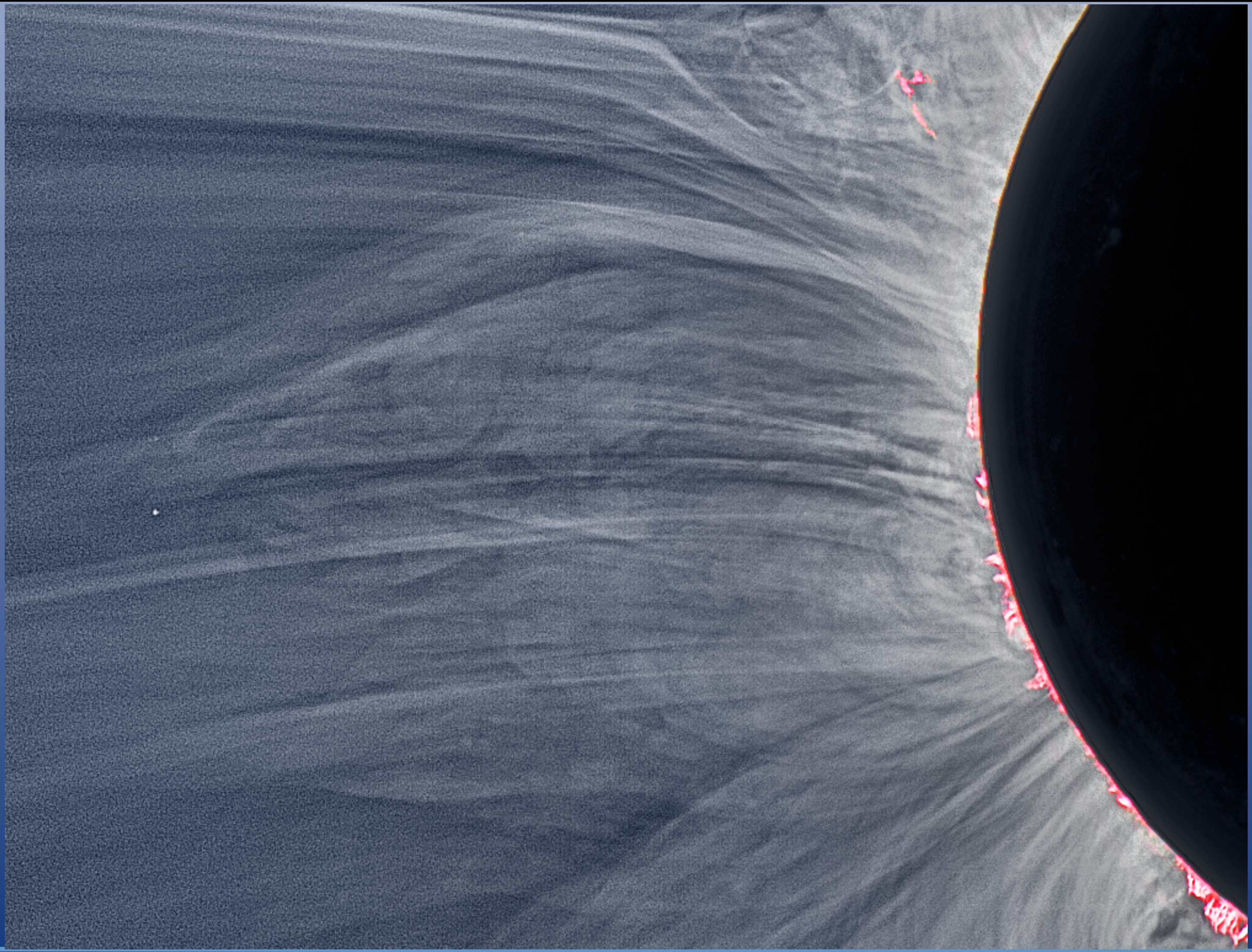


Expanding bubbles

- Expanding bubbles everywhere (evolution of vortex rings?)
  → 1, 2, 3
- Faint twisted helical structures with vortices
  → 4

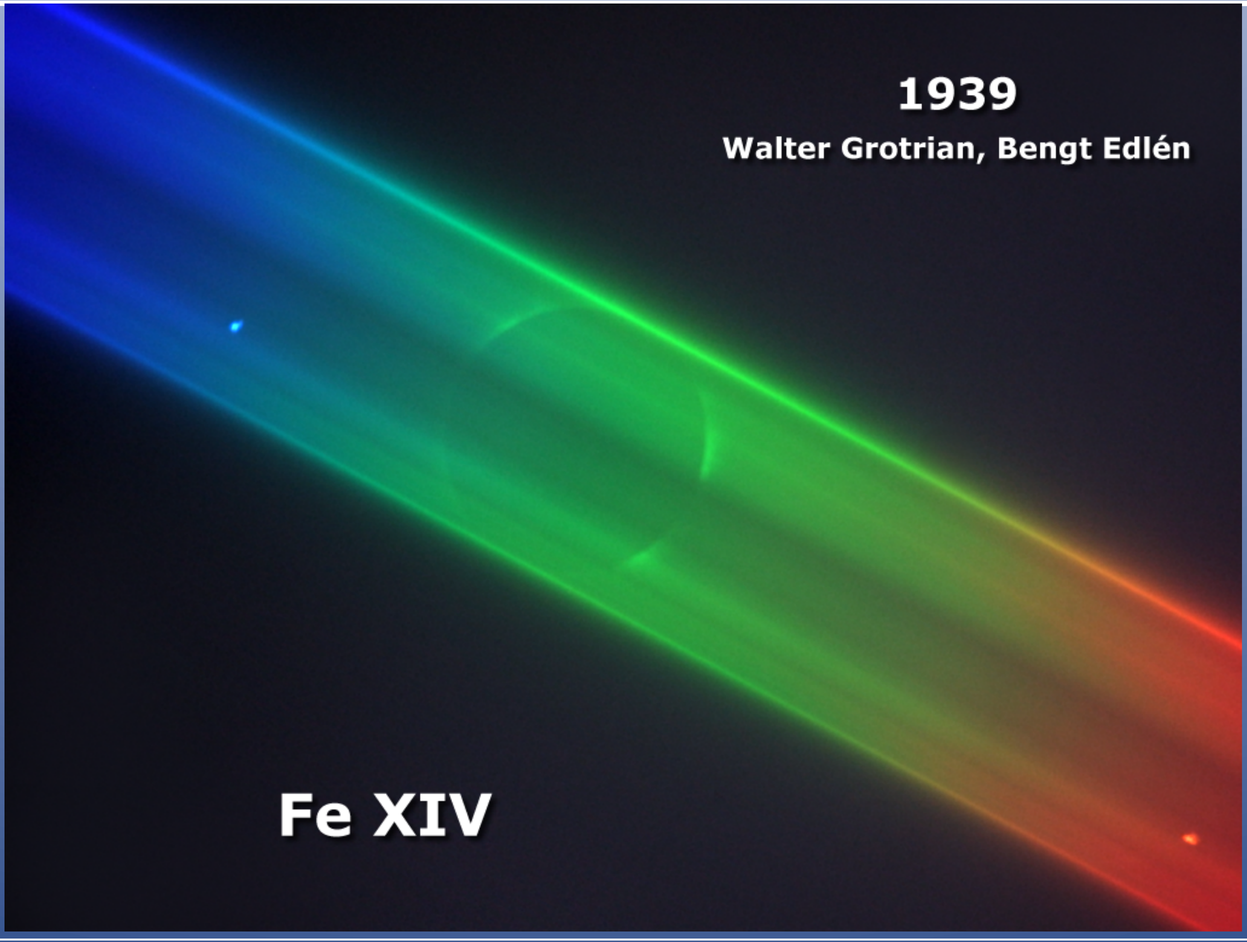


Discovery of faint structures: Nested loops and expanding bubbles



Imaging in coronal forbidden lines: Unique probes of the physics of the corona

Reminder: The Hot Corona

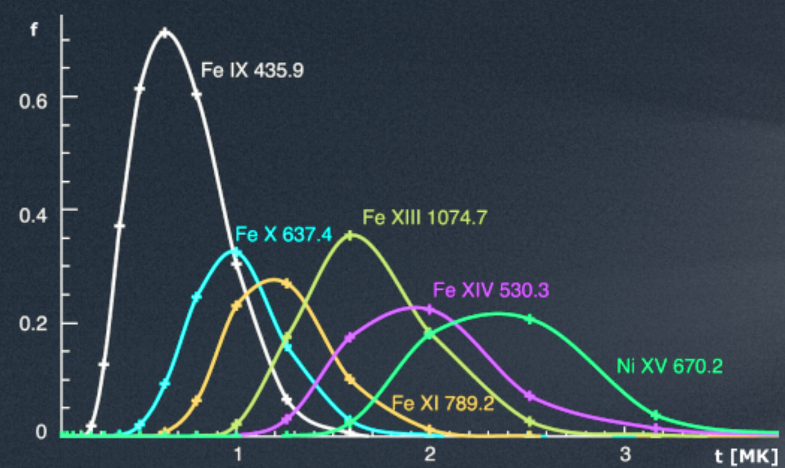


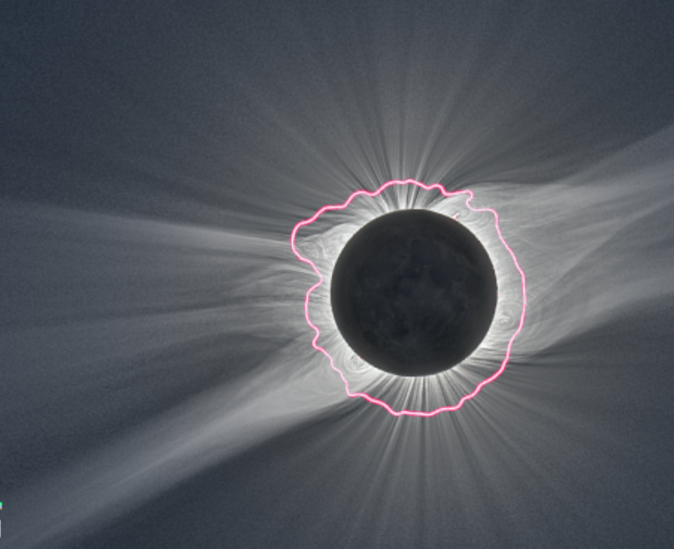
EDLÉN AND GROTRIAN identify coronium as **$Fe13^{+}$**

➔ **Corona is at $T > 10^6$ K**

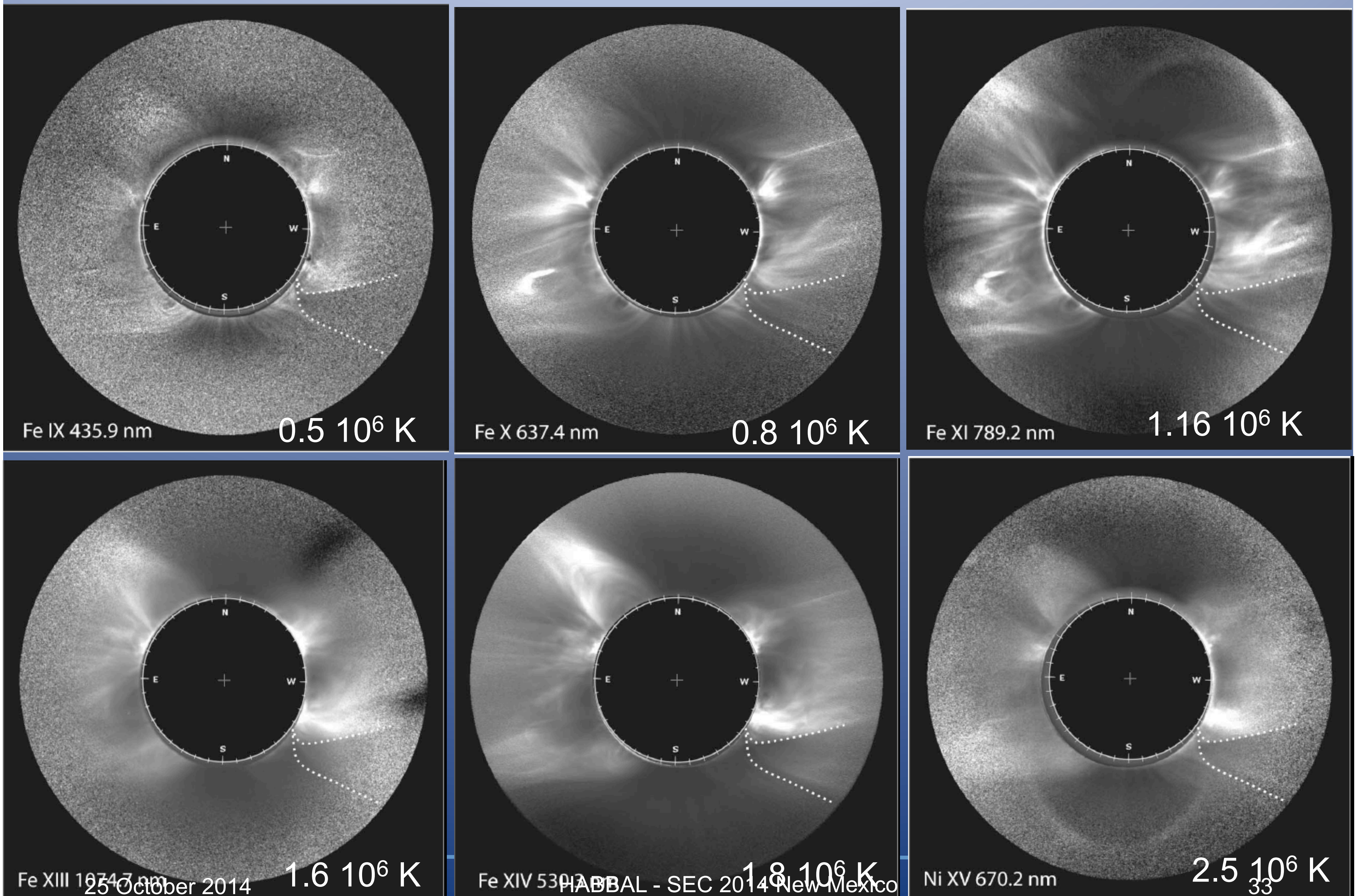
Coronal forbidden lines

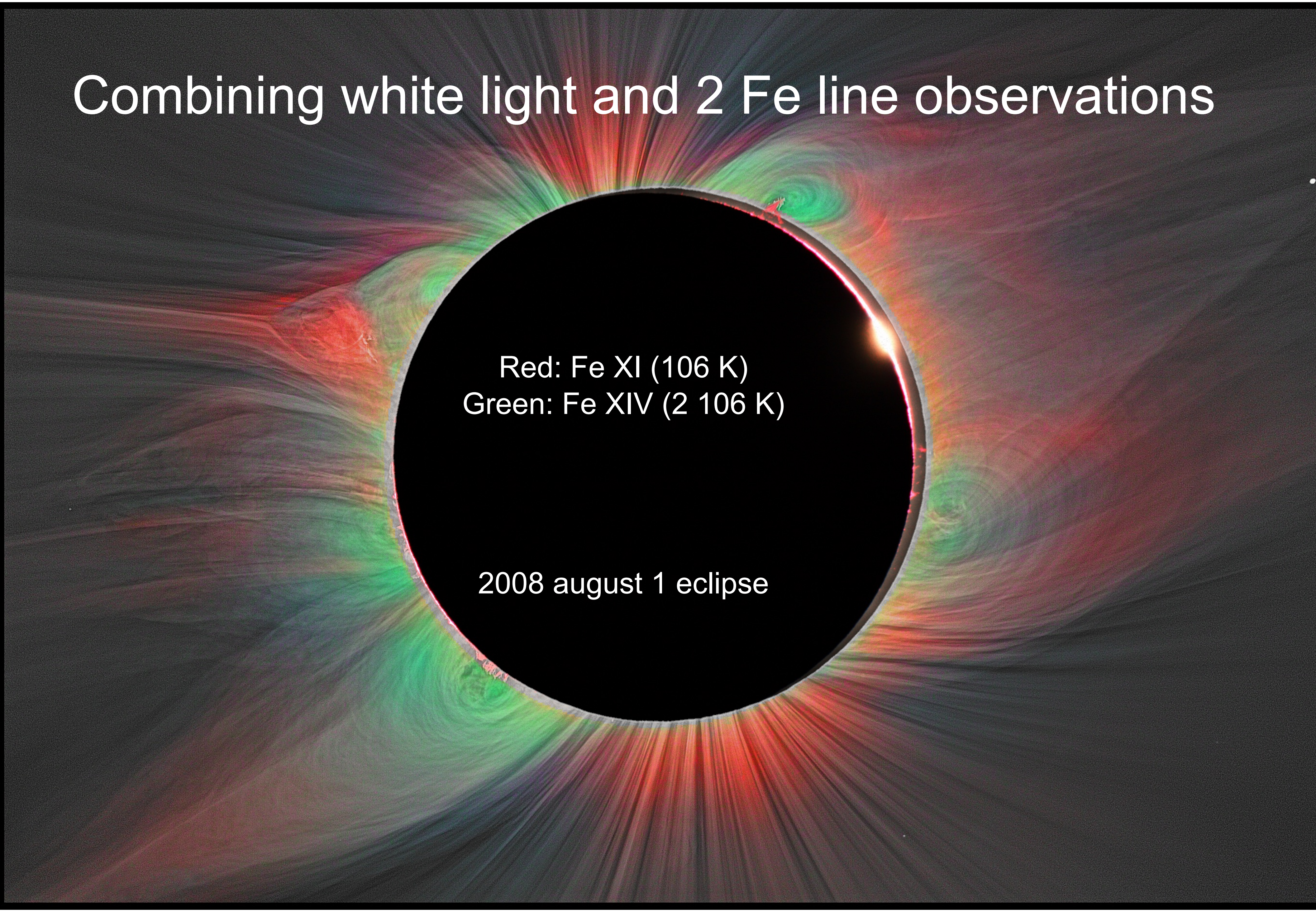
ion	wavelength	average living time of excited state	forbidden	excitation	observable from ground
Fe IX	435.9 nm	$6.9 \cdot 10^{-3}$ s	yes	resonance	yes
Fe X	637.4 nm	$1.44 \cdot 10^{-2}$ s	yes	resonance	yes
Fe XI	789.2 nm	$2.23 \cdot 10^{-2}$ s	yes	resonance	yes
Fe XIII	1074.7 nm	$7.0 \cdot 10^{-2}$ s	yes	resonance	yes
Fe XIV	530.3 nm	$1.7 \cdot 10^{-2}$ s	yes	resonance	yes
Ni XIV	670.2 nm	$1.8 \cdot 10^{-2}$ s	yes	resonance	yes
Fe ions	10 – 30 nm	$\sim 10^{-12}$ s	no	collisions	no





Example: Multi-λ Imaging of the corona on 11 July 2010




Combining white light and 2 Fe line observations
Red: Fe XI (106 K)
Green: Fe XIV (2 106 K)
2008 august 1 eclipse

A brief and simple introduction to the line intensities

$$I \approx I_C + I_R \propto \int N_e N_i \, d\ell \, ds + \int N_i \, d\ell \, ds$$

COLLISIONAL EXCITATION RESONANT EXCITATION

- Collisional excitation is dominant for EUV lines

- Resonant excitation is dominant for coronal forbidden lines

➔ If emission is dominated by resonance excitation then it extends to large radial distances

A really neat diagnostic tool of coronal thermodynamics

$$I \approx I_C + I_R \propto \int N_e N_i \, d\ell \, ds + \int N_i \, d\ell \, ds$$

collision-dominated   resonance-dominated

For white light:

$$I_{WL} \propto \int N_e \, d\ell \, ds$$

Ratio of the two (to first approximation) :

$$I / I_{WL} \propto N_i + N_i / N_e$$

N_i → collision-dominated → should decrease sharply with distance

N_i / N_e → resonance-dominated → should be flat if both have same gradient

A new diagnostic tool?

Proof of concept

For white light:

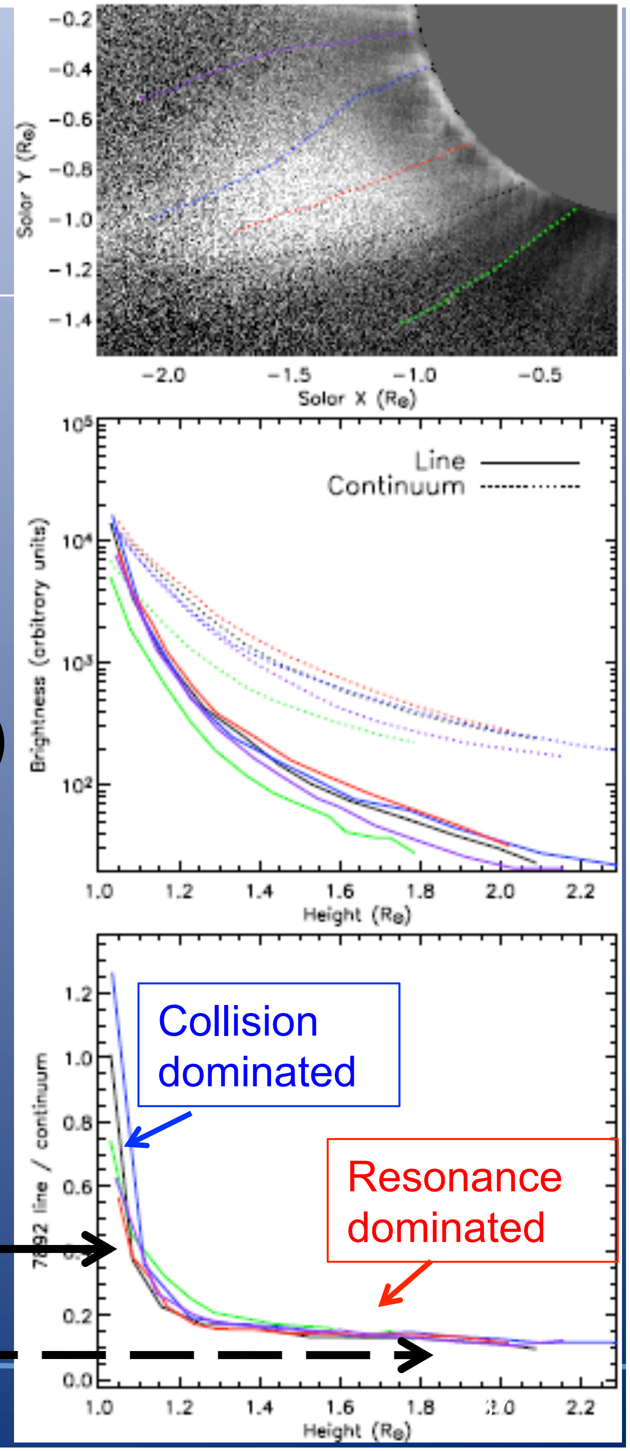
$$I_{WL} \propto \int N_e \, d\ell \, ds$$

Ratio of the two (to first approximation)

$$I / I_{WL} \propto N_i + N_i / N_e$$

collision-dominated → should decrease sharply with distance

resonance-dominated → should be flat if both have same gradient



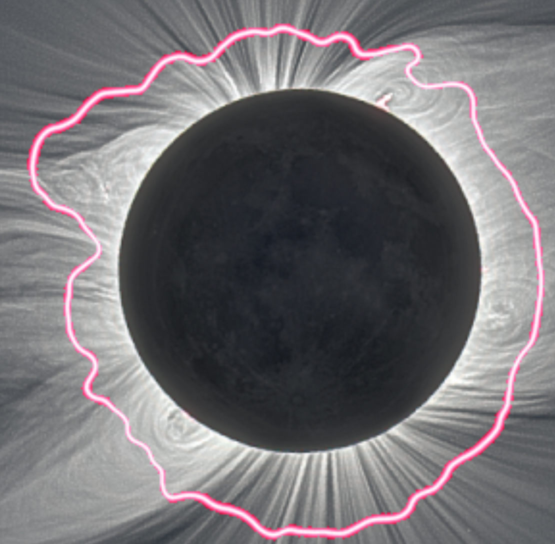
Once the 2 components are empirically separated:

➔ define a distance R_t for the transition collision-dominated → collisionless state

➔ Find $R_t \cong 1.1 – 2\ R_s$

$R < R_t$ → Multi λ observations

→ T_e map of the corona

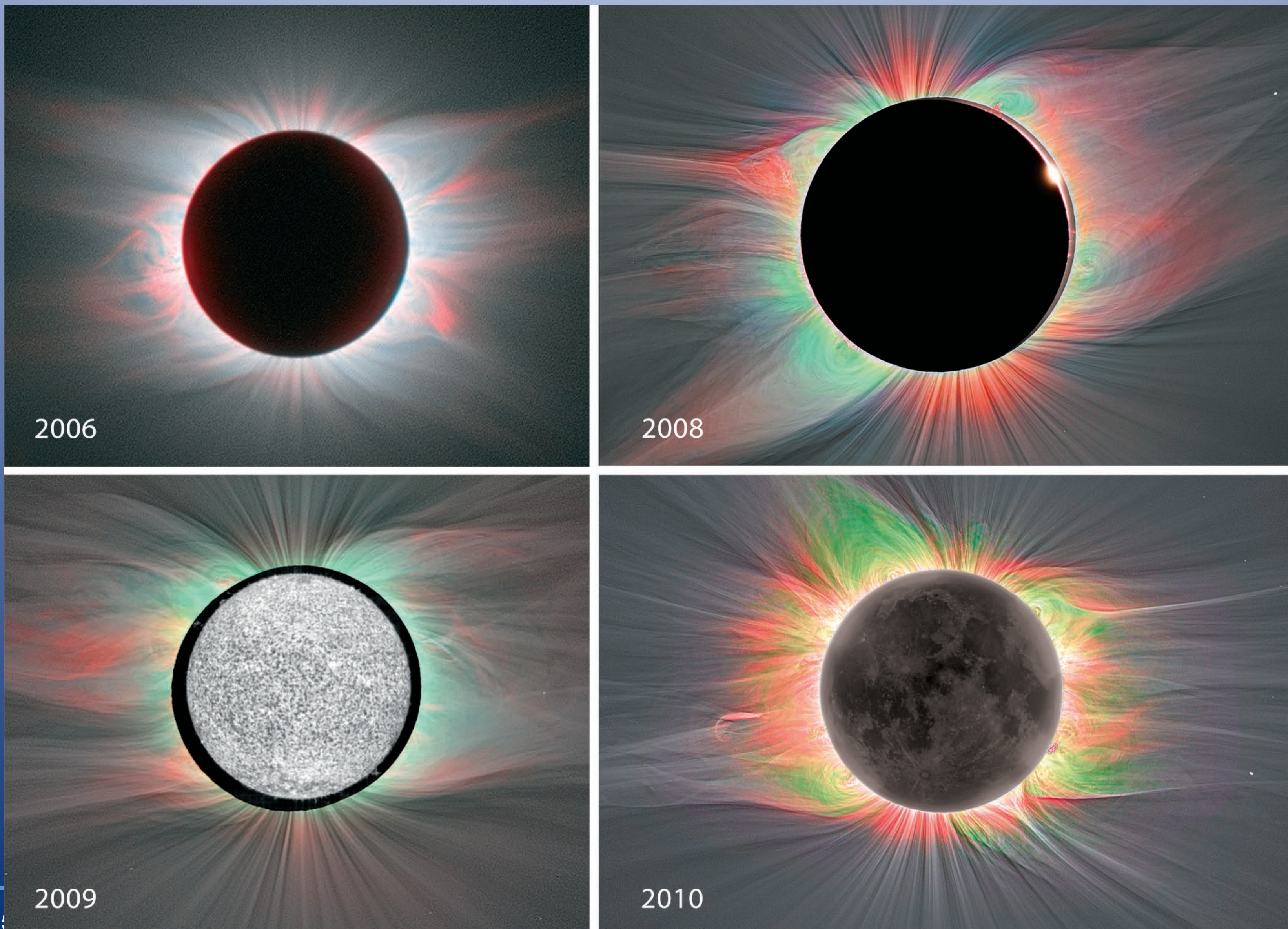


$R > R_t$ → Ions no longer interact with electrons through collisions, their charge state is fixed (frozen-in)
Multi λ observations

→ Charge state distribution in the corona

$R < R_t$: Electron Temperature Maps of the Corona

Fe XI (10^6 K), Fe XIV ($2\ 10^6$ K) and White Light



Quantitative inference of localized enhancement

For white light:

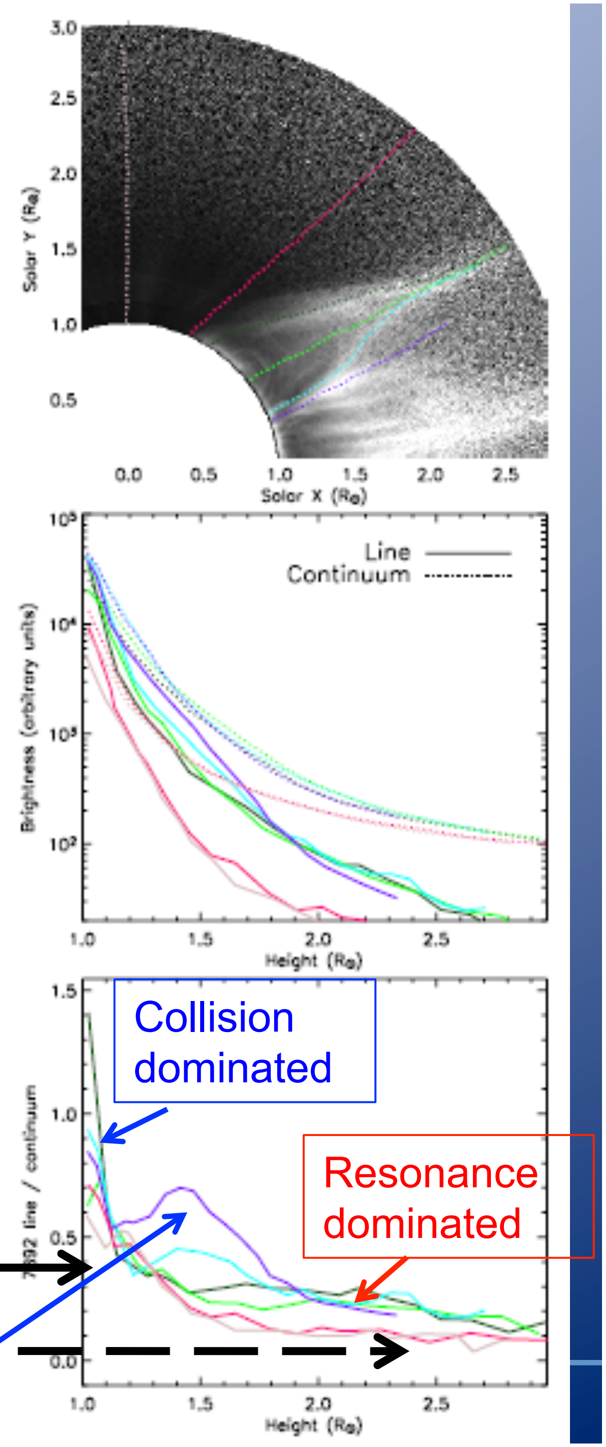
$$I_{WL} \propto \int N_e \, d\ell \, ds$$

Ratio of the two (to first approximation)

$$I / I_{WL} \propto N_i + N_i / N_e$$

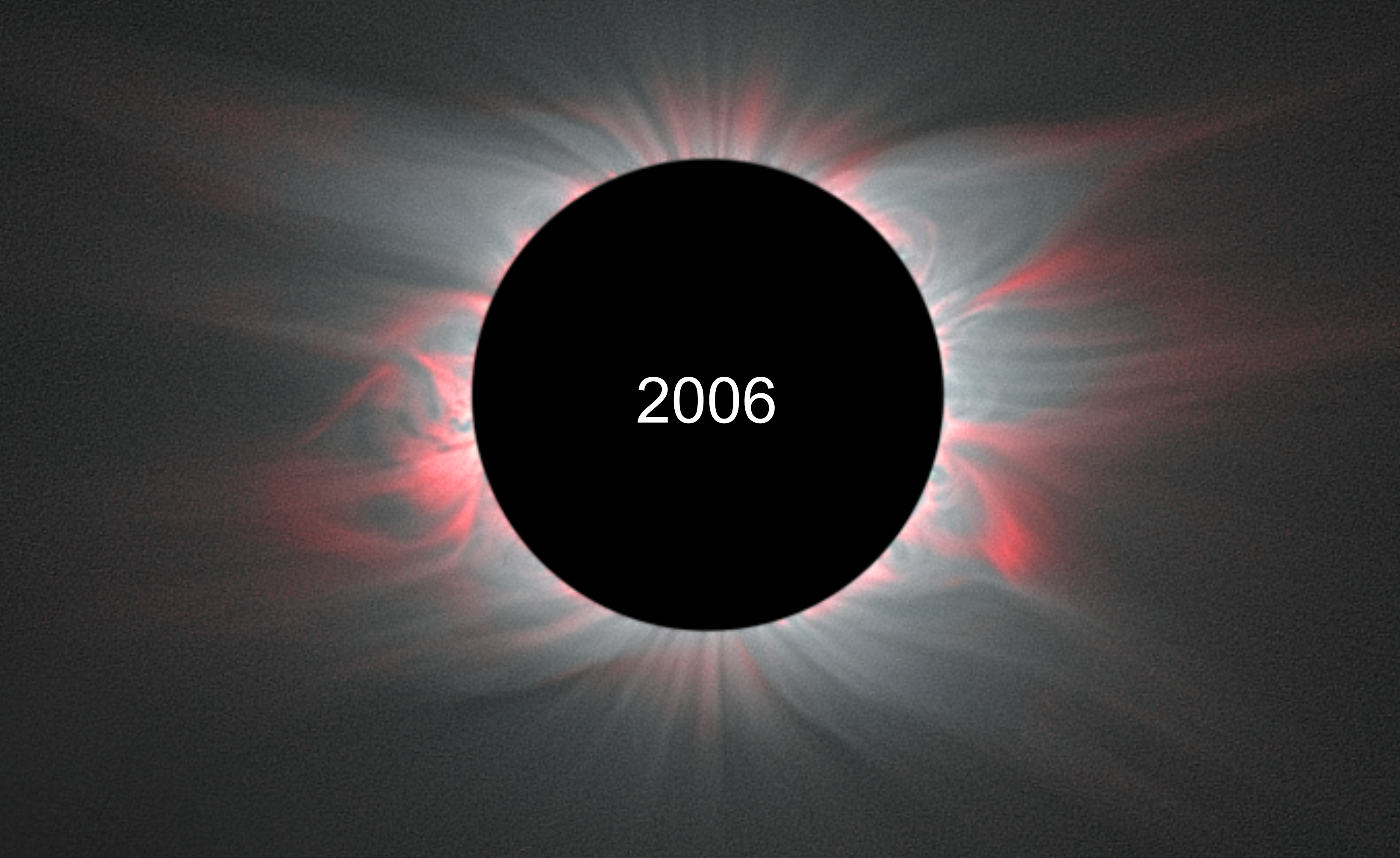
collision-dominated → should decrease sharply with distance

resonance-dominated → should be flat if both have same gradient



Enhanced Fe XI emission corresponds to magnetic regions with localized enhanced ion/electron density

Visualization of the localized Fe^{+10} enhancements in comparison to white light



Uniqueness of eclipse observations in the age of space exploration and large ground-based telescopes:

Field of view currently not covered by other instruments

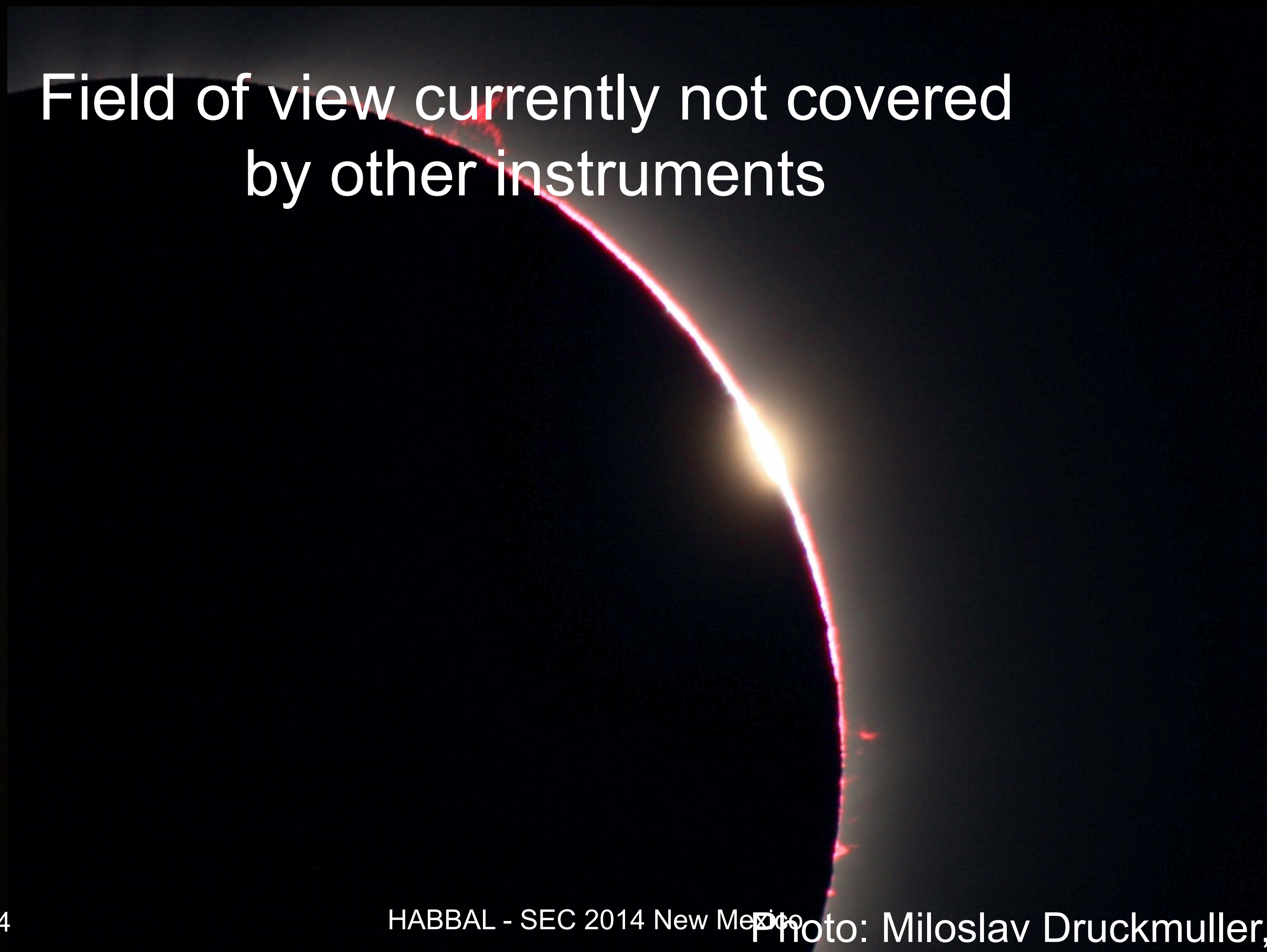
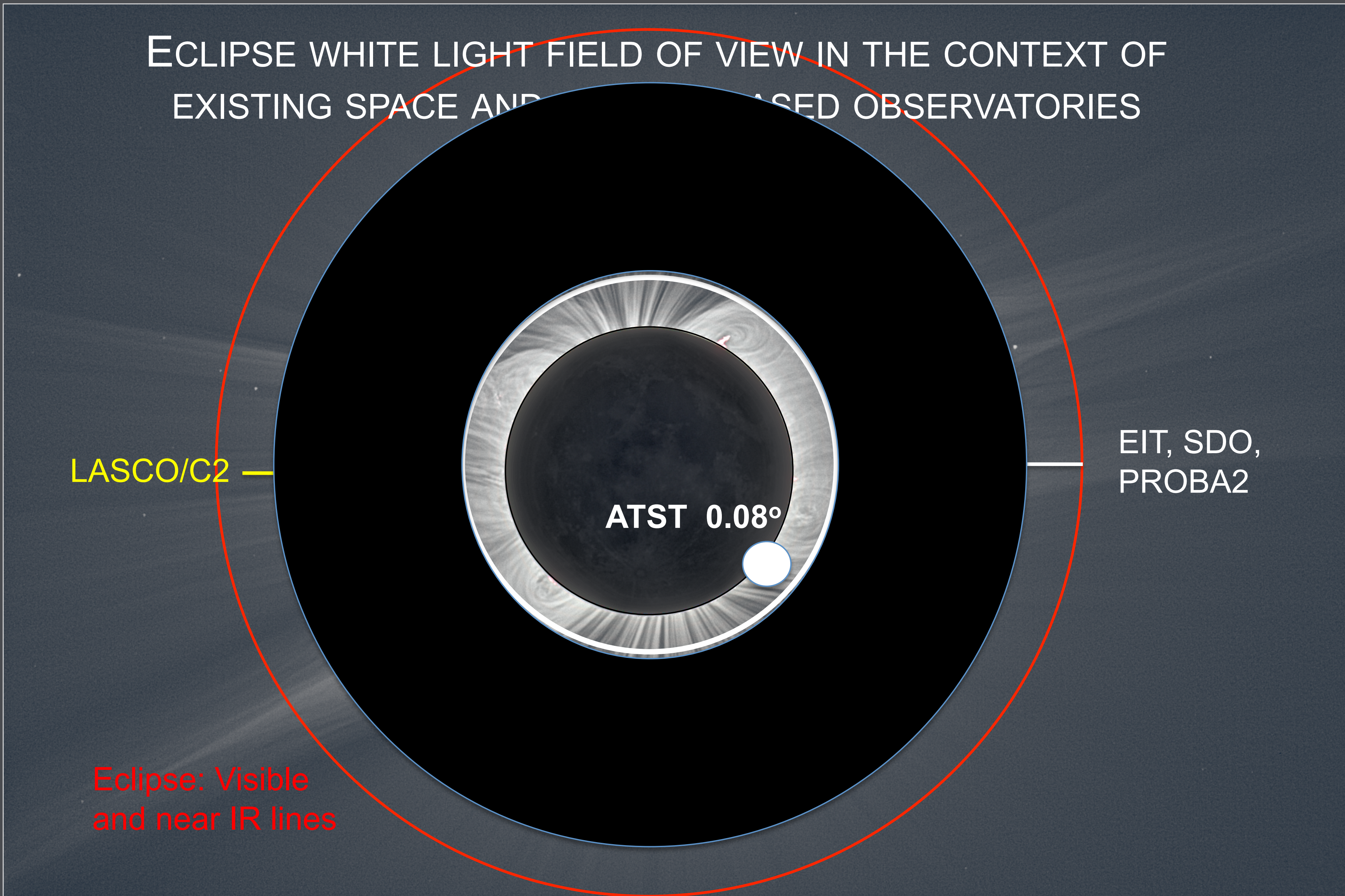


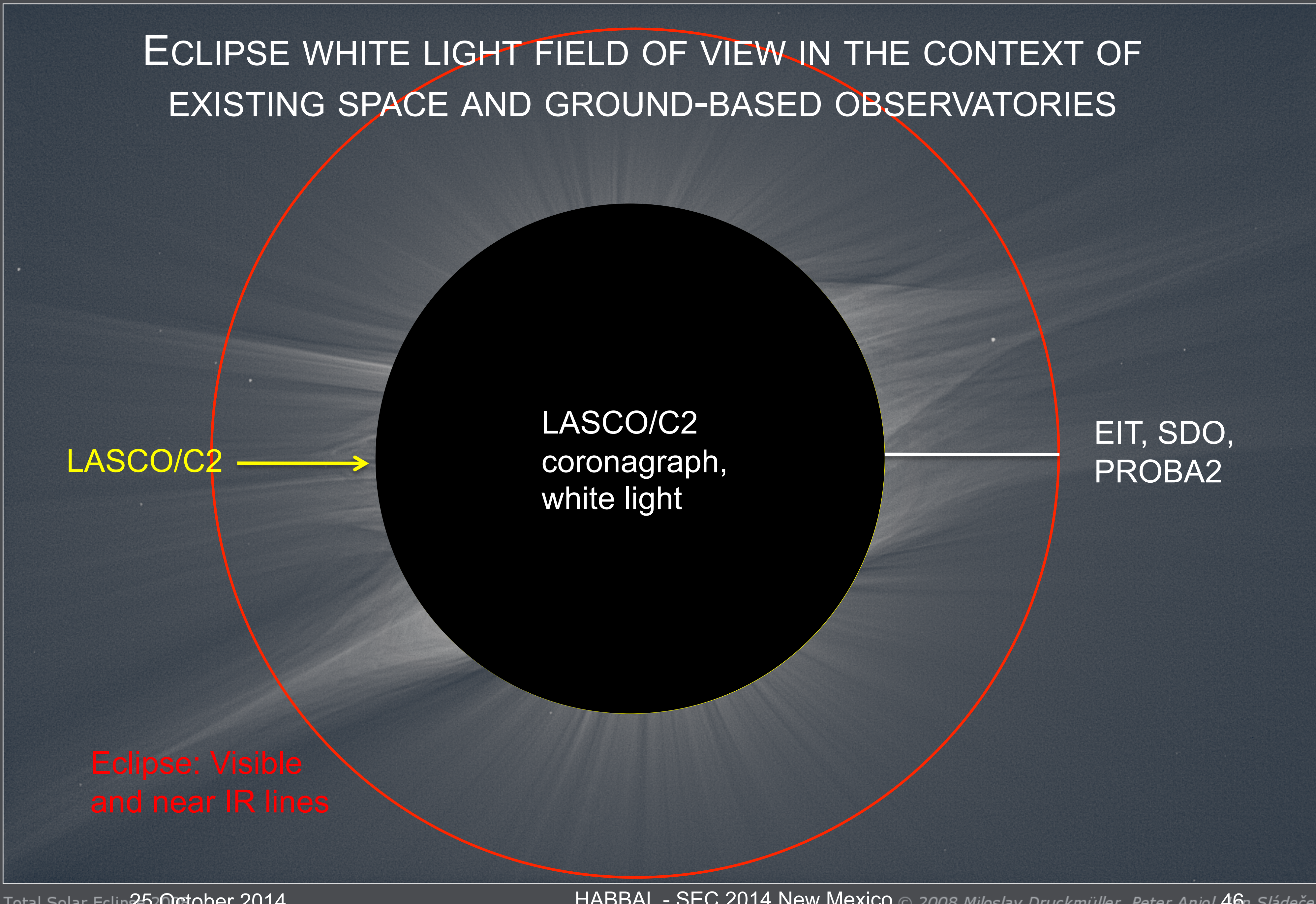
Photo: Miloslav Druckmuller, 2008

DKIST:
4 meter telescope with adaptive optics
Largest solar telescope in the world

ECLIPSE WHITE LIGHT FIELD OF VIEW IN THE CONTEXT OF EXISTING SPACE AN… …SED OBSERVATORIES



ECLIPSE WHITE LIGHT FIELD OF VIEW IN THE CONTEXT OF EXISTING SPACE AND GROUND-BASED OBSERVATORIES



Ideal and unique opportunities for 2017: Temporal changes in the corona in white light and multi-wavelengths coronal emission lines

CONCLUDING REMARKS

Eclipse observations remain unique and essential for exploring the solar corona

Currently, there are no other instruments that cover that region of space

High resolution white light images are revealing and capturing novel coronal structures, in particular the evolution of plasma instabilities and the expansion of twisted magnetic field lines as a consequence of dynamic events in the inner corona

Coronal emission lines provide unique diagnostics for probing the chemical and physical characteristics of the coronal plasma (e.g. composition and temperature)