

The Anglo-Swiss Club of Locarno  
Locarno, Hotel Belvedere, November 22, 2018

## **The Sun, our star**

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*Oskar Steiner*

Istituto Ricerche Solari Locarno (IRSOL), Locarno-Monti (CH) and  
Kiepenheuer-Institut für Sonnenphysik (KIS), Freiburg i.Br. (D)

Night sky above Locarno: this evening at 22:00



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# 1. The color of stars

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*Blue is cool and red is hot.* Right?



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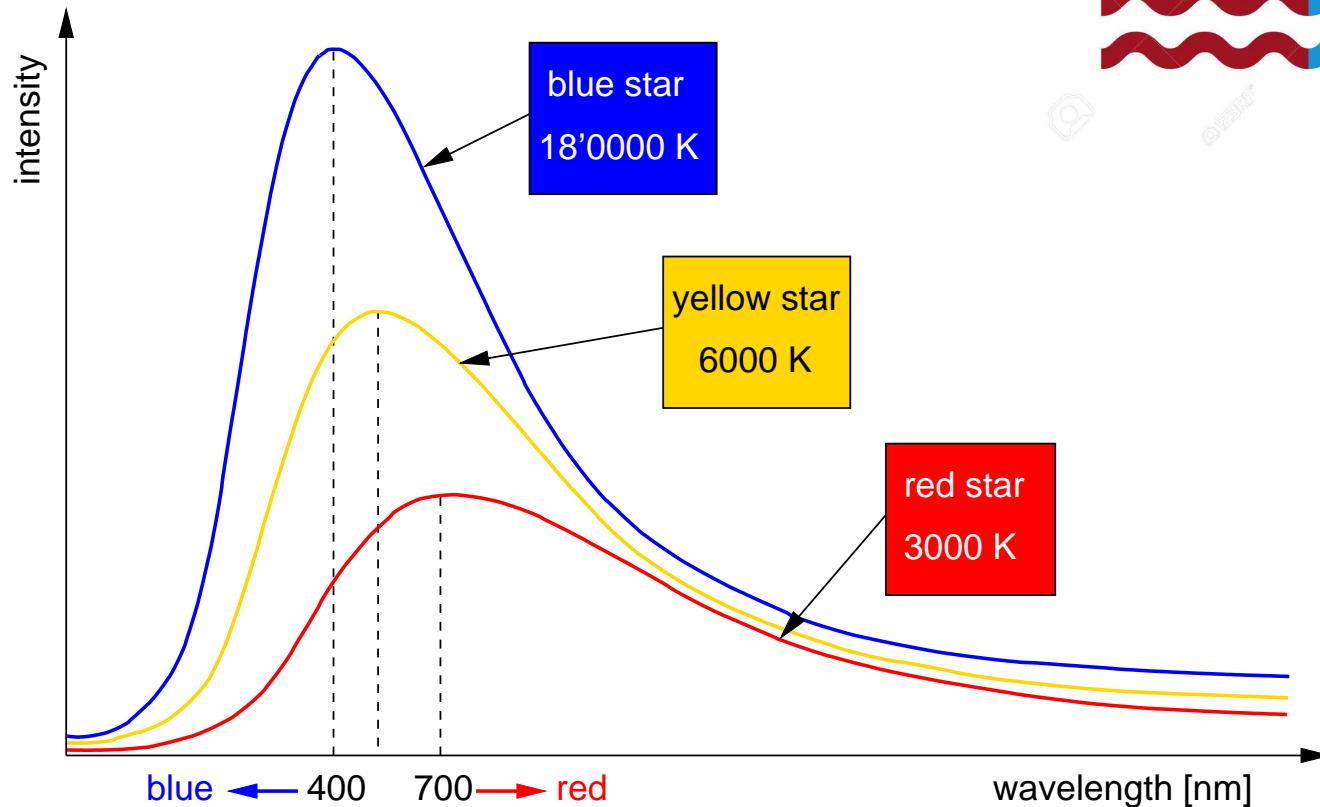
Not true for physicists!



# 1. The color of stars

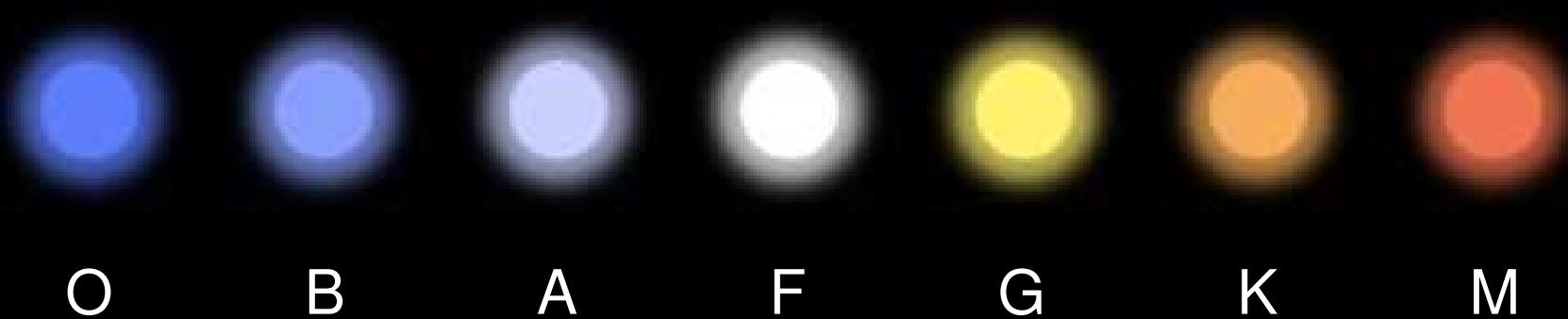
*Blue is cool and red is hot.* Right?

Not true for physicists!



*Blue stars are hot  
red stars are cool.*

## Spectral Classification of Stars



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O

B

A

F

G

K

M

Rigel (B8)

12 100 K

Sun (G2)

5772 K

Betelgeuse (M1-M2)

3590 K

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Oh

Be

A

Fine

Girl/Guy,

Kiss

Me

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Our Sun is a G2 dwarf star  
with effective temperature 5770 K.



glass prism dispersing  
light into colors.

From *Pink Floyd*: “The  
dark side of the moon”.



glass prism dispersing  
light into colors.

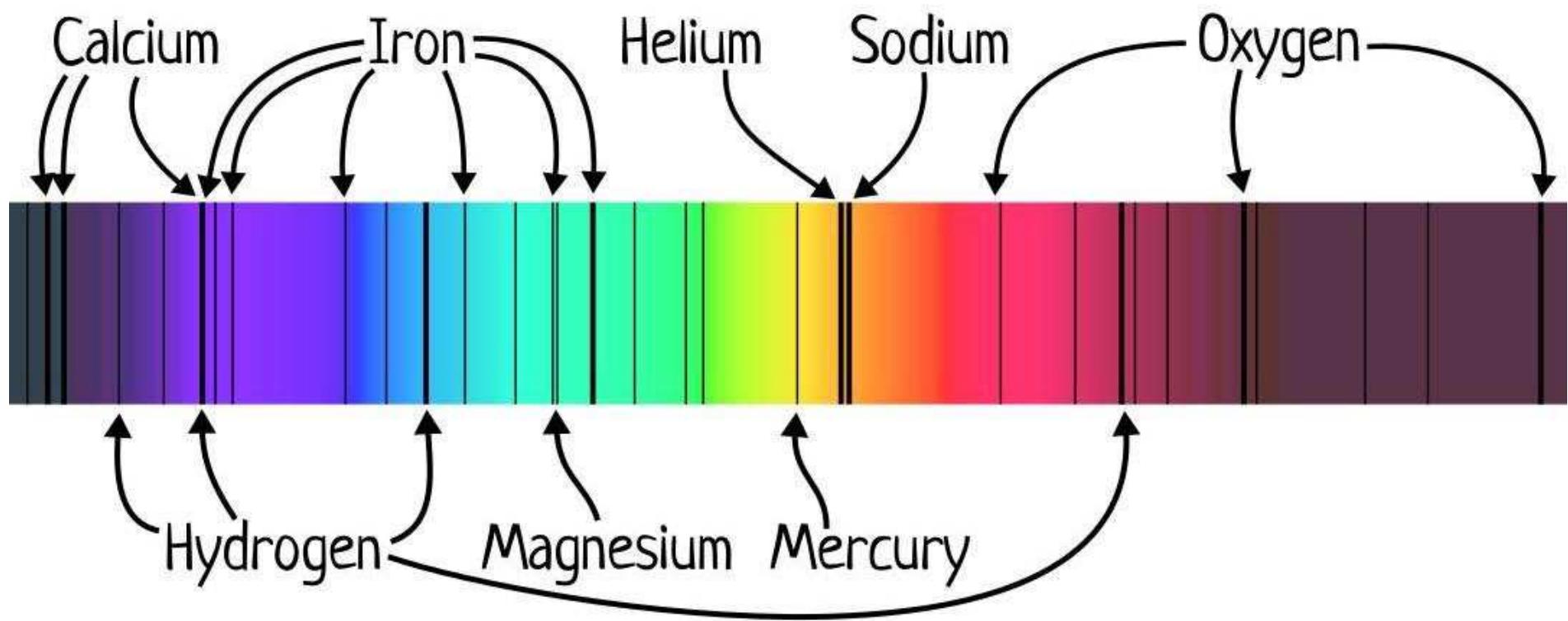
From *Pink Floyd*: “The  
dark side of the moon”.



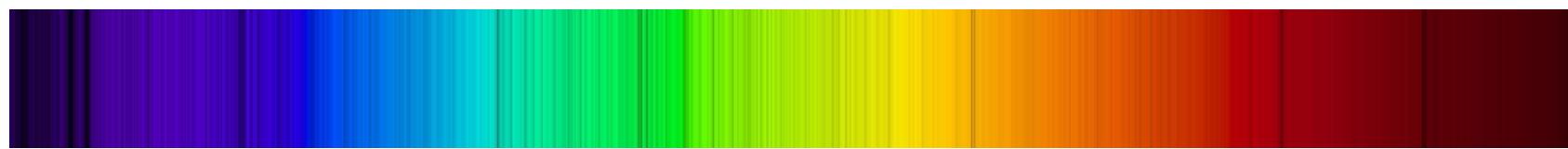
Spectrum of solar light published by Joseph Fraunhofer from Munich in 1817

*Deutsches Museum, München*

## 1. The color of stars (cont.)



The Balmer Series of Hydrogen

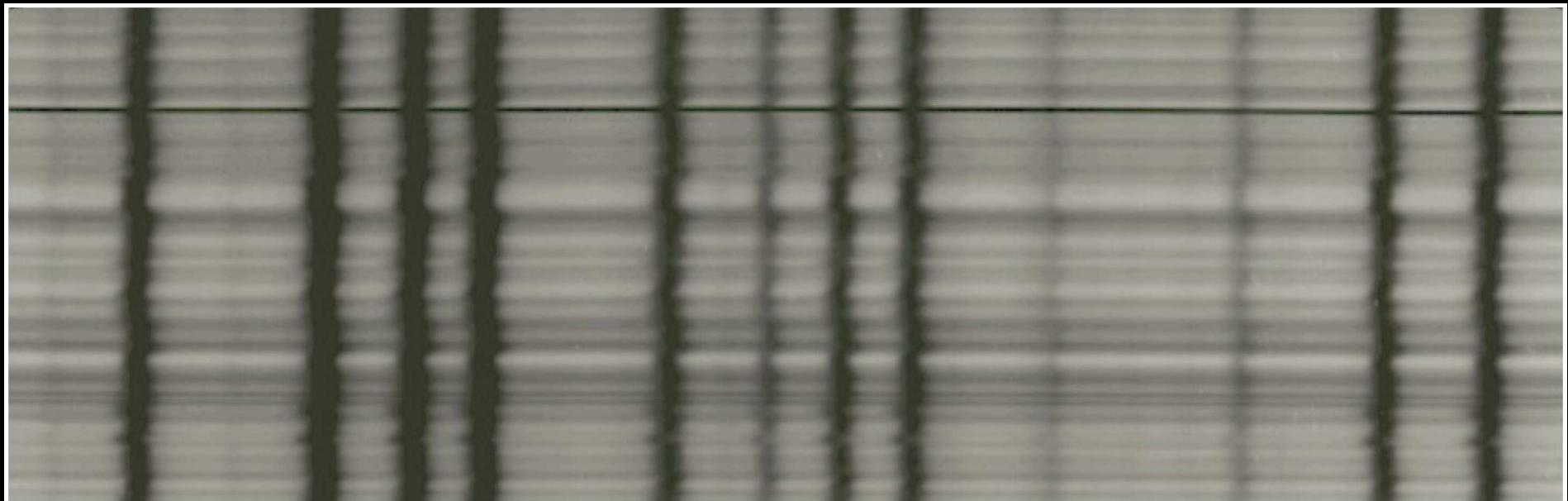


H $\delta$  H $\gamma$

H $\beta$

H $\alpha$

## High resolution spectrum: The Doppler effect

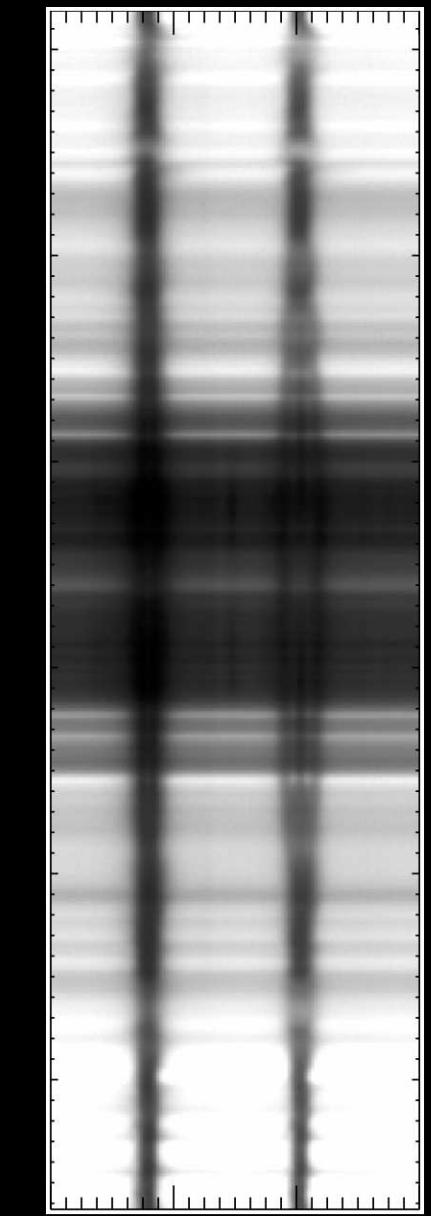


blue ←

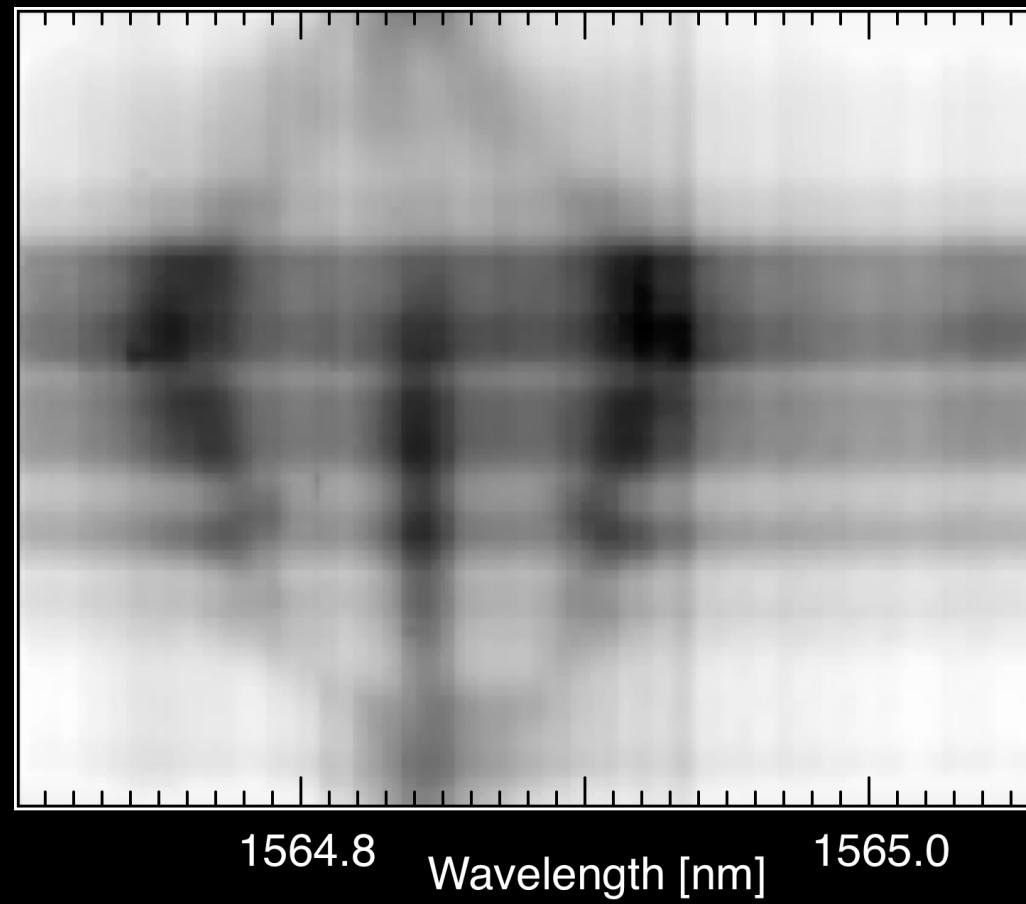
Wavelength  $\lambda$

→ red

Courtesy, *Tassos Nesis*, KIS



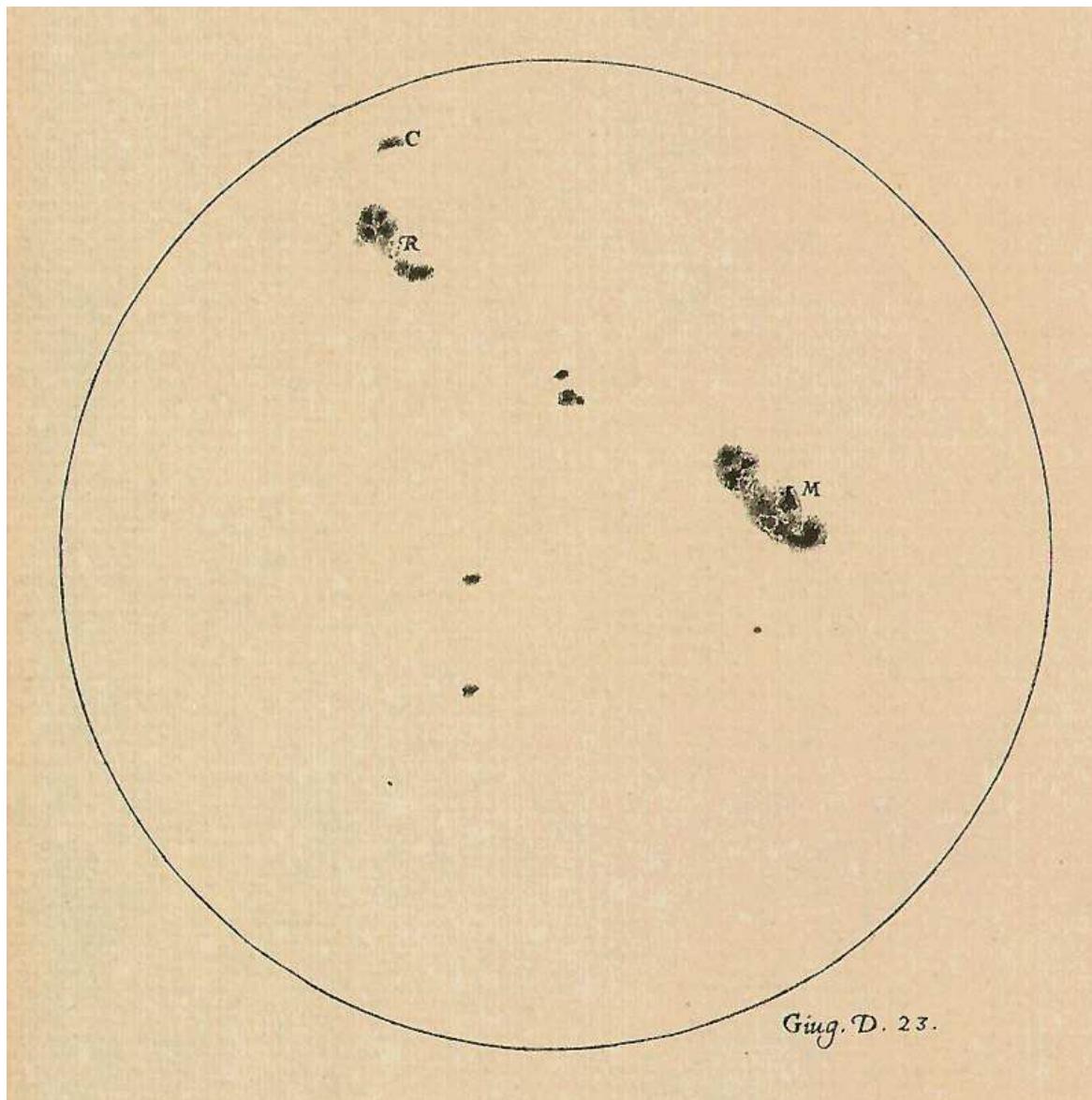
Splitted spectral lines: The Zeeman effect



630.09 630.17 630.25 630.33  
Wavelength [nm]

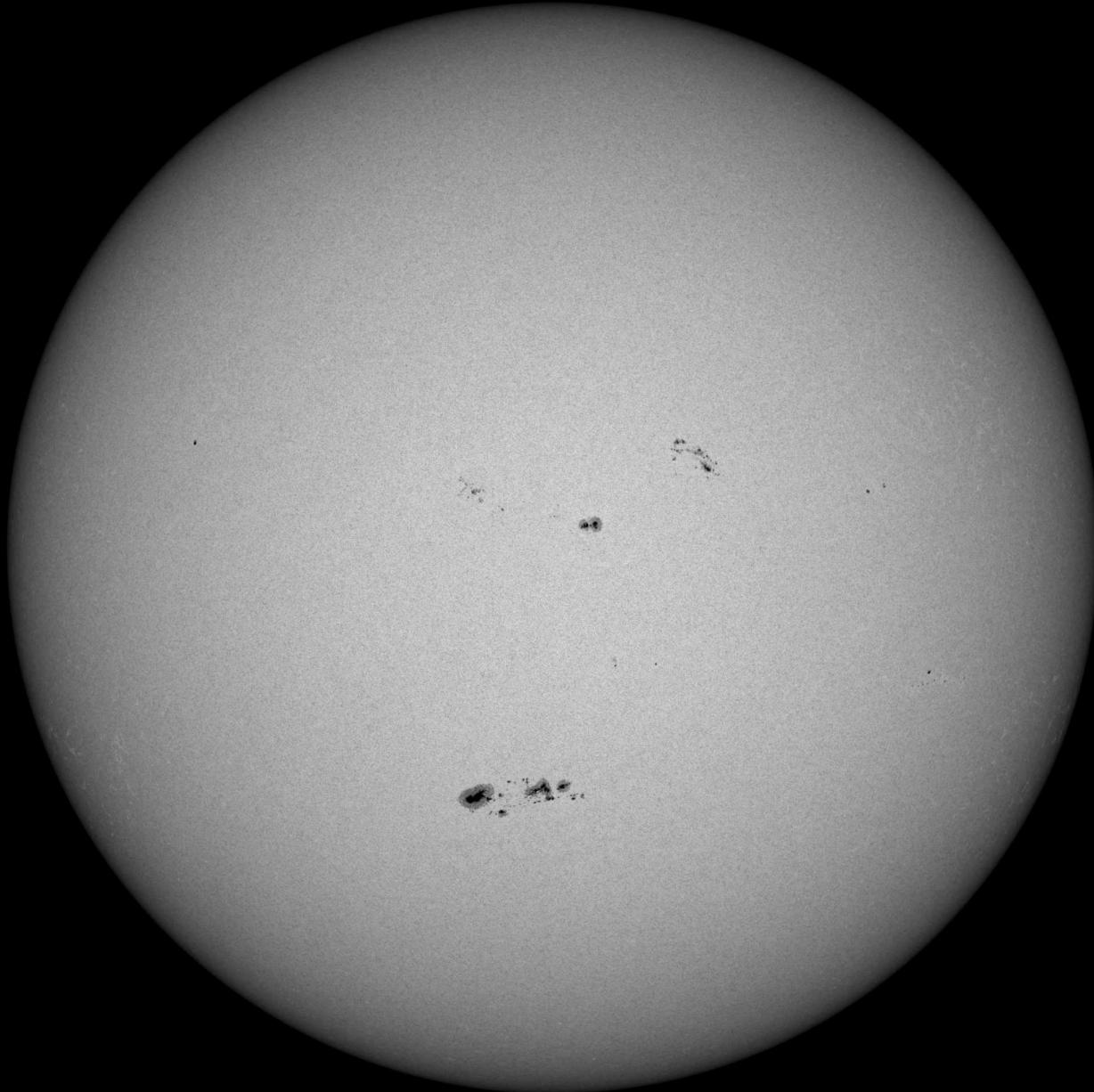
## 2. Sunspots

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Sunspot drawing by  
*Galileo Galilei* of  
*June 23, 1613*  
From the Galileo project  
<http://galileo.rice.edu/>

The Sun of September 26, 2015

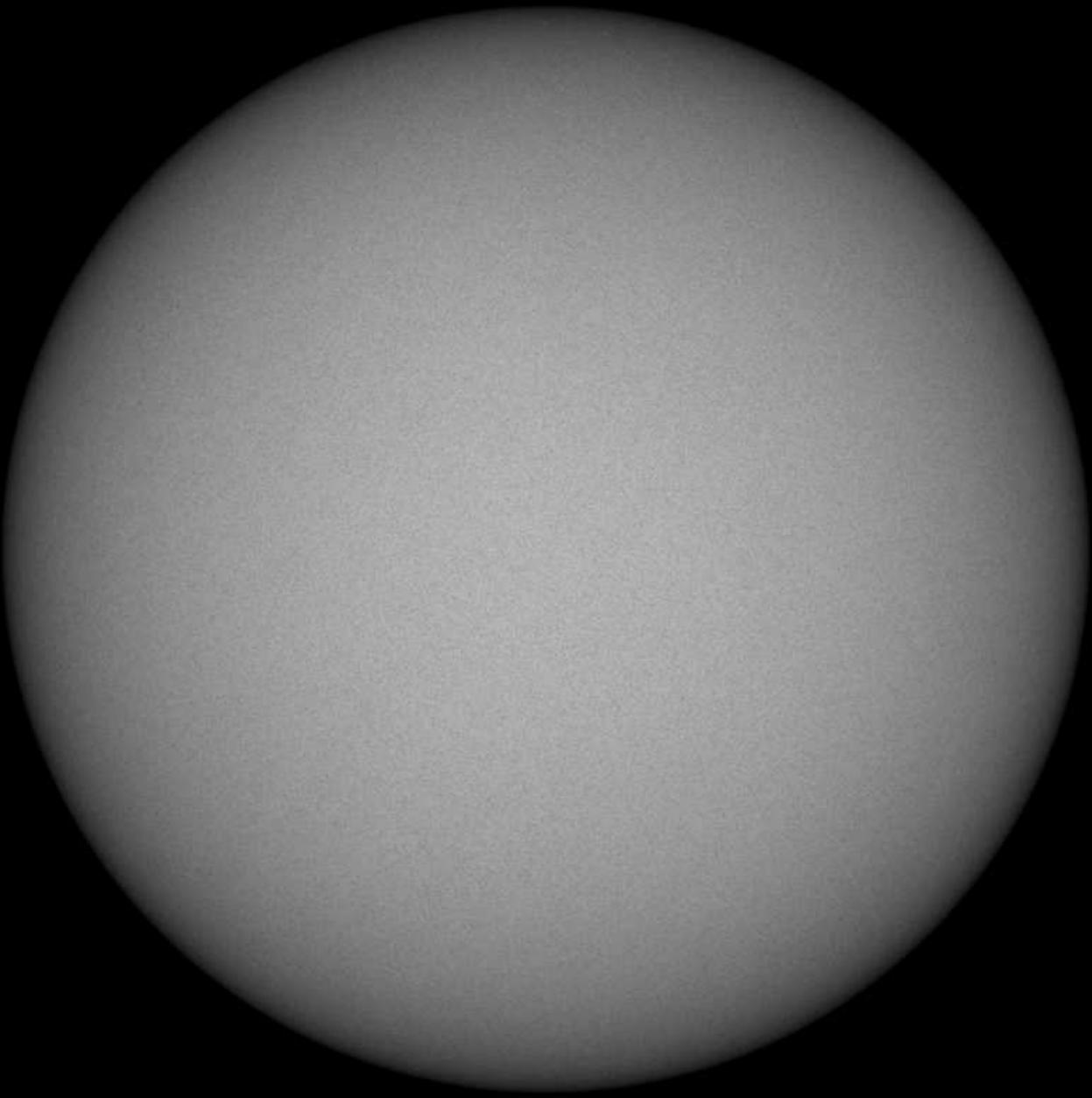


SDO/HMI Quick-Look Continuum: 2015.09.26\_13:55:30\_TAI

Sun in white light. From <http://sdo.gsfc.nasa.gov/data/>

Sun in EUV

The Sun today, November 22, 2018

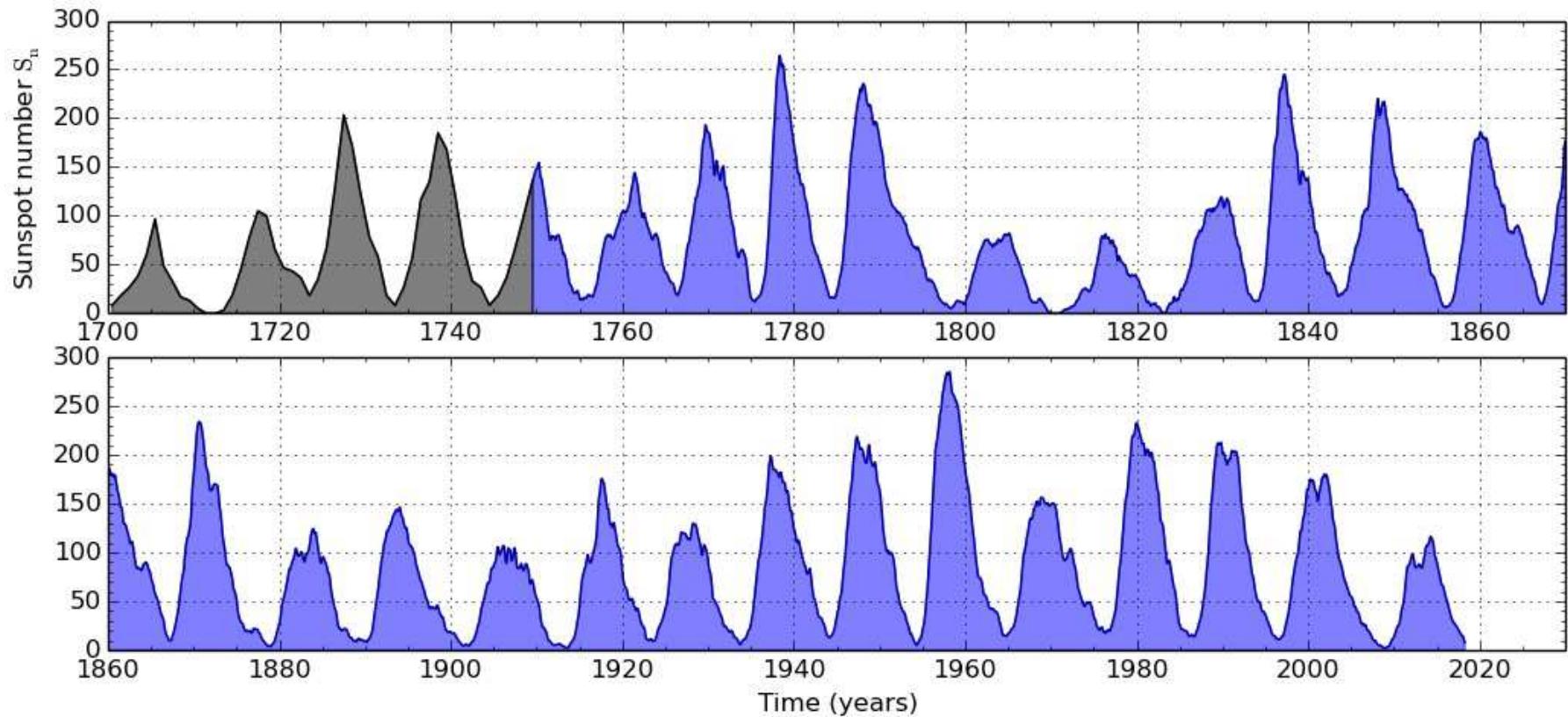


SDO/HMI Quick-Look Continuum: 2018.11.22\_09:23:15\_TAI

Sun in white light. From <http://sdo.gsfc.nasa.gov/data/>

Sun in EUV

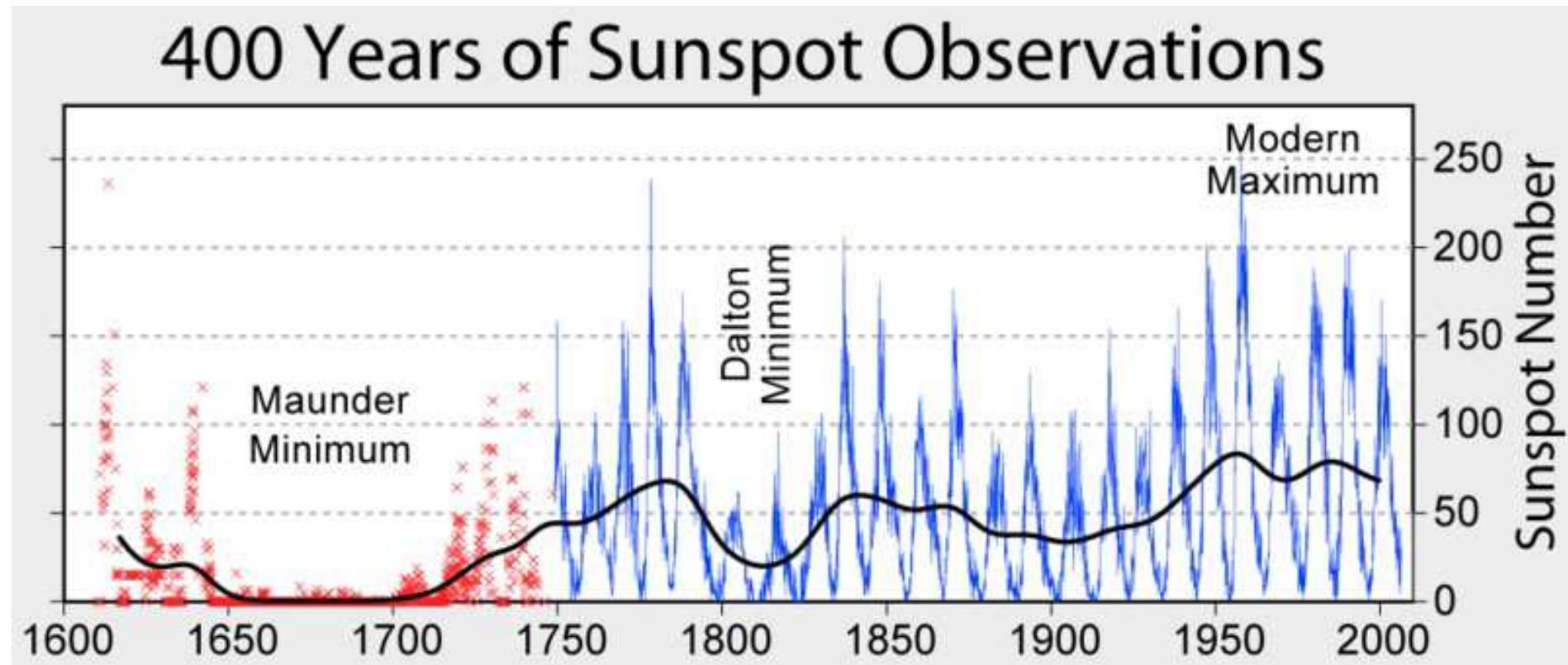
## 2. Sunspots (cont.)



International sunspot number  $S_n$ . Yearly mean number (grey) and monthly 13-month smoothed number (blue).

From <http://sidc.be/silso/> *Royal Observatory of Belgium, 2018, Nov. 1.*

## 2. Sunspots (cont.)



From [https://en.wikipedia.org/wiki/Solar\\_cycle](https://en.wikipedia.org/wiki/Solar_cycle)

## Maunder minimum and the “little ice age” from early 15th century to about 1850



Abraham Hondius, The Frozen Thames, 1677  
Museum of London



Pieter Bruegel the Elder, The Hunters in  
the Snow, 1556; Kunsthistorisches Museum Wien

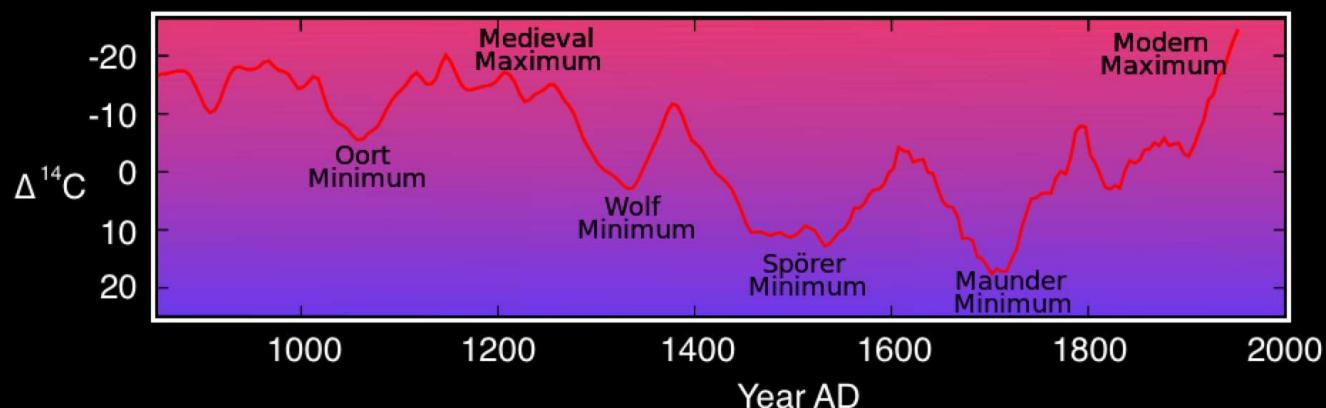
# Maunder minimum and the “little ice age” from early 15th century to about 1850



Abraham Hondius, The Frozen Thames, 1677  
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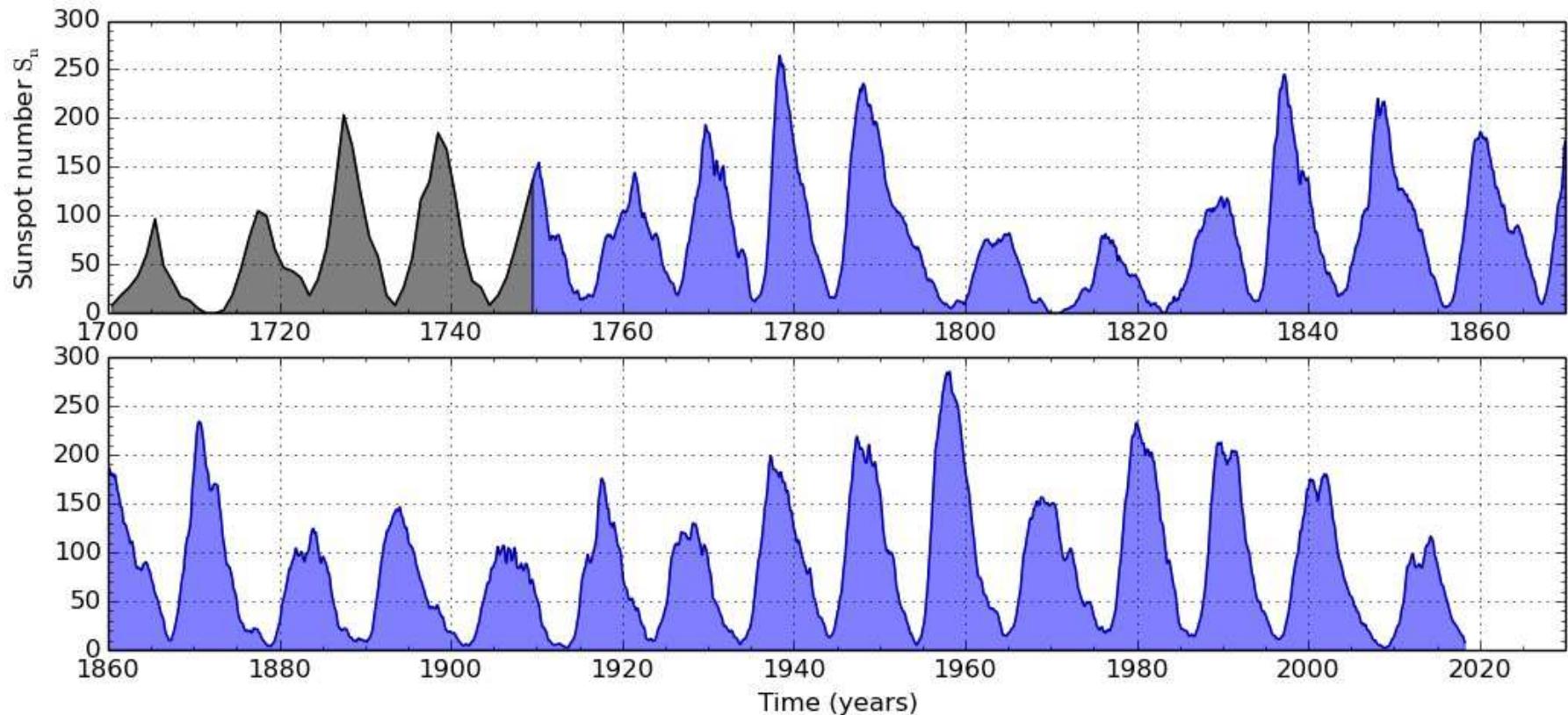


Pieter Bruegel the Elder, The Hunters in  
the Snow, 1556; Kunsthistorisches Museum Wien



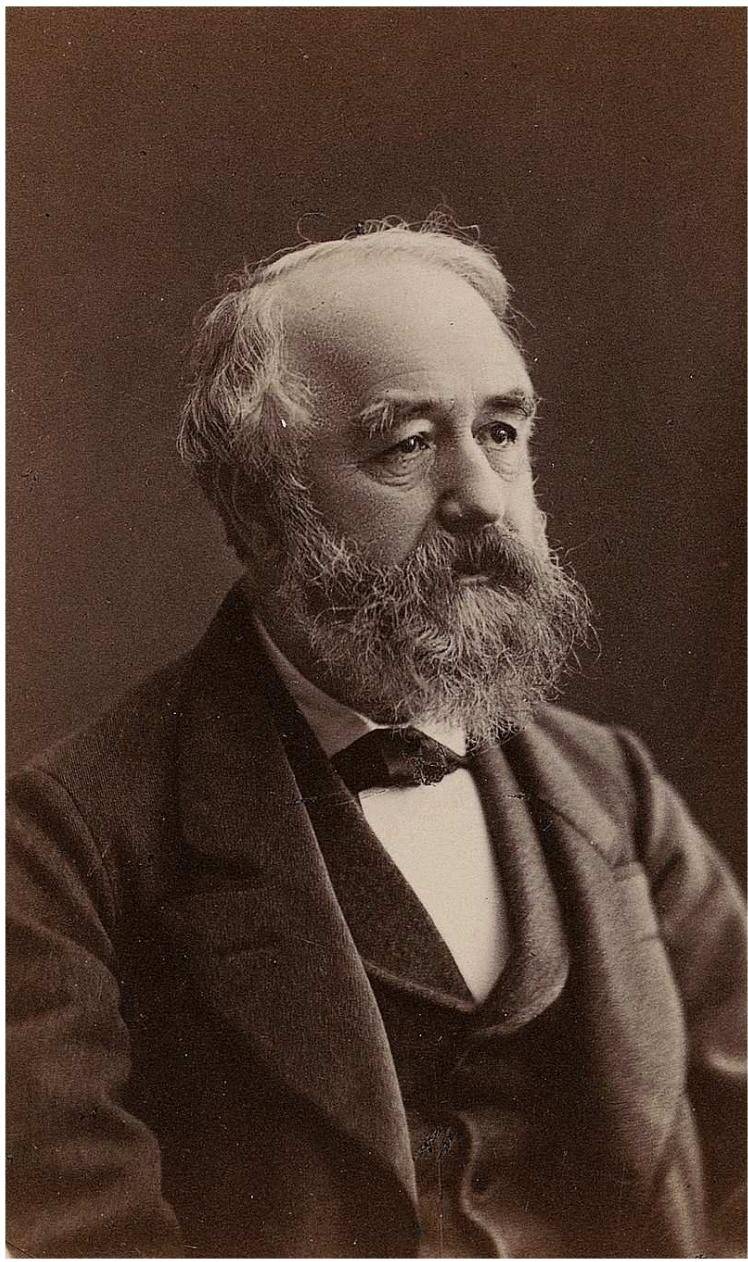
Solar activity from  $^{14}\text{C}$   
tree ring analysis

## 2. Sunspots (cont.)



International sunspot number  $S_n$ . Yearly mean number (grey) and monthly 13-month smoothed number (blue).

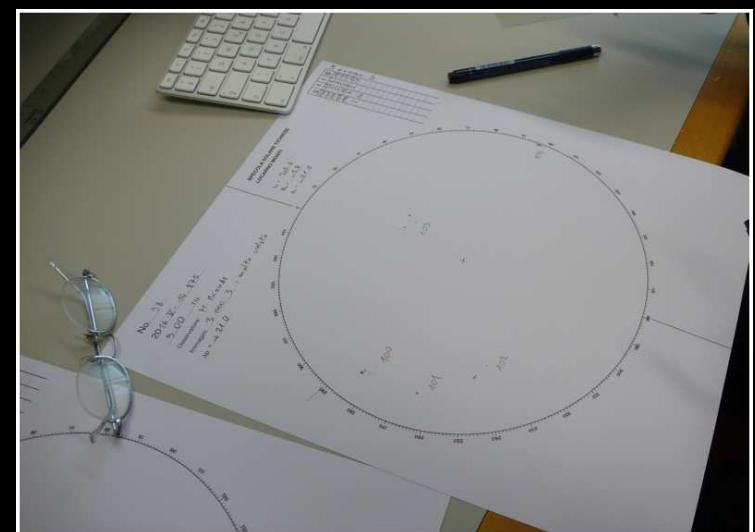
From <http://sidc.be/silso/> *Royal Observatory of Belgium, 2018, Nov. 1.*



Rudolph Wolf  
(1816–1893)  
and the Federal  
Observatory in  
Zürich



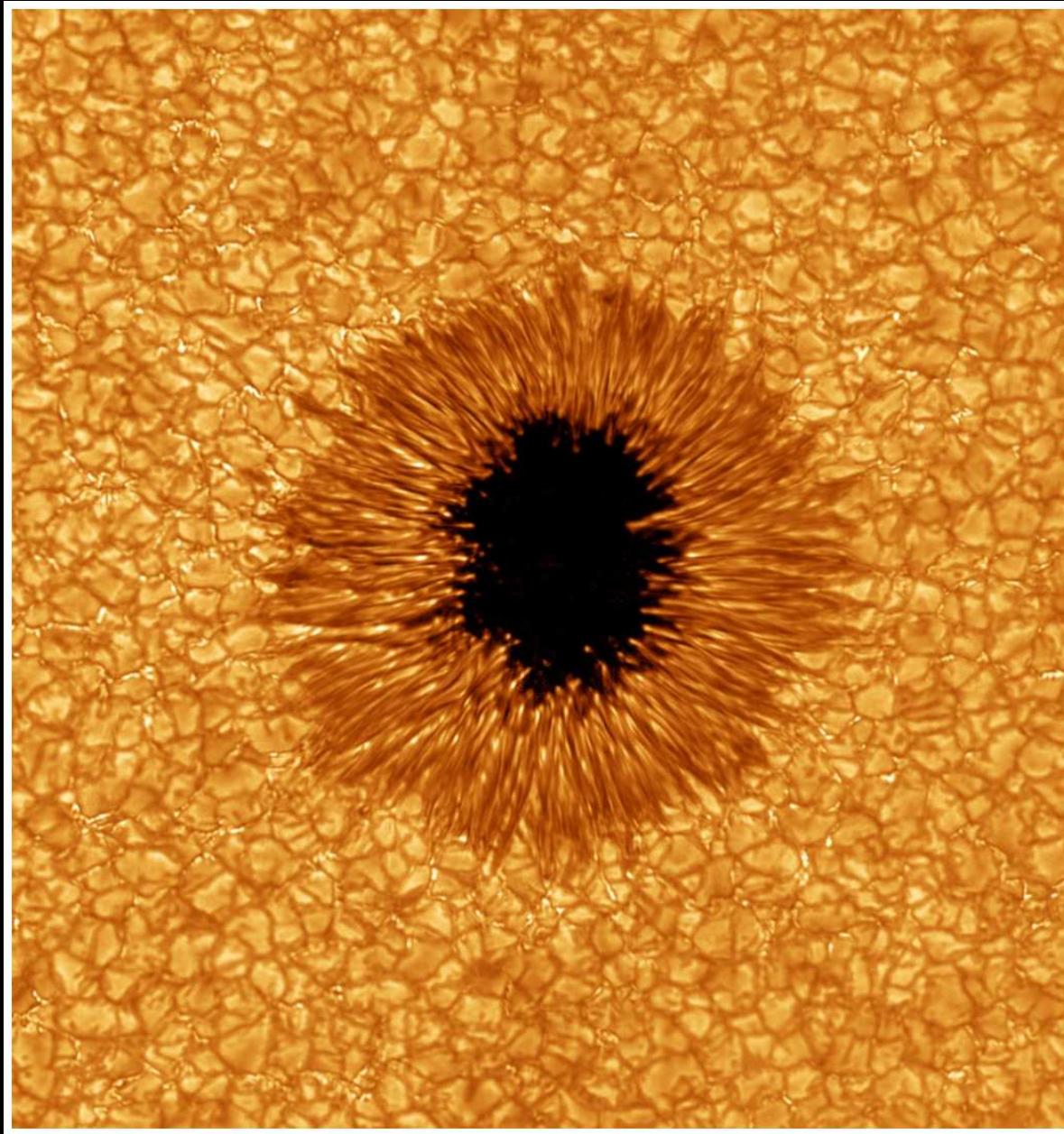
# Determination of the relative sunspot number



Specola Solare Ticinese <http://www.specola.ch>

Supported by the “Associazione Specola Solare Ticinese”

Reference (pilot) station for the determination of the International sunspot number by the Solar Influence Data Analysis Center of the Royal Observatory of Belgium.



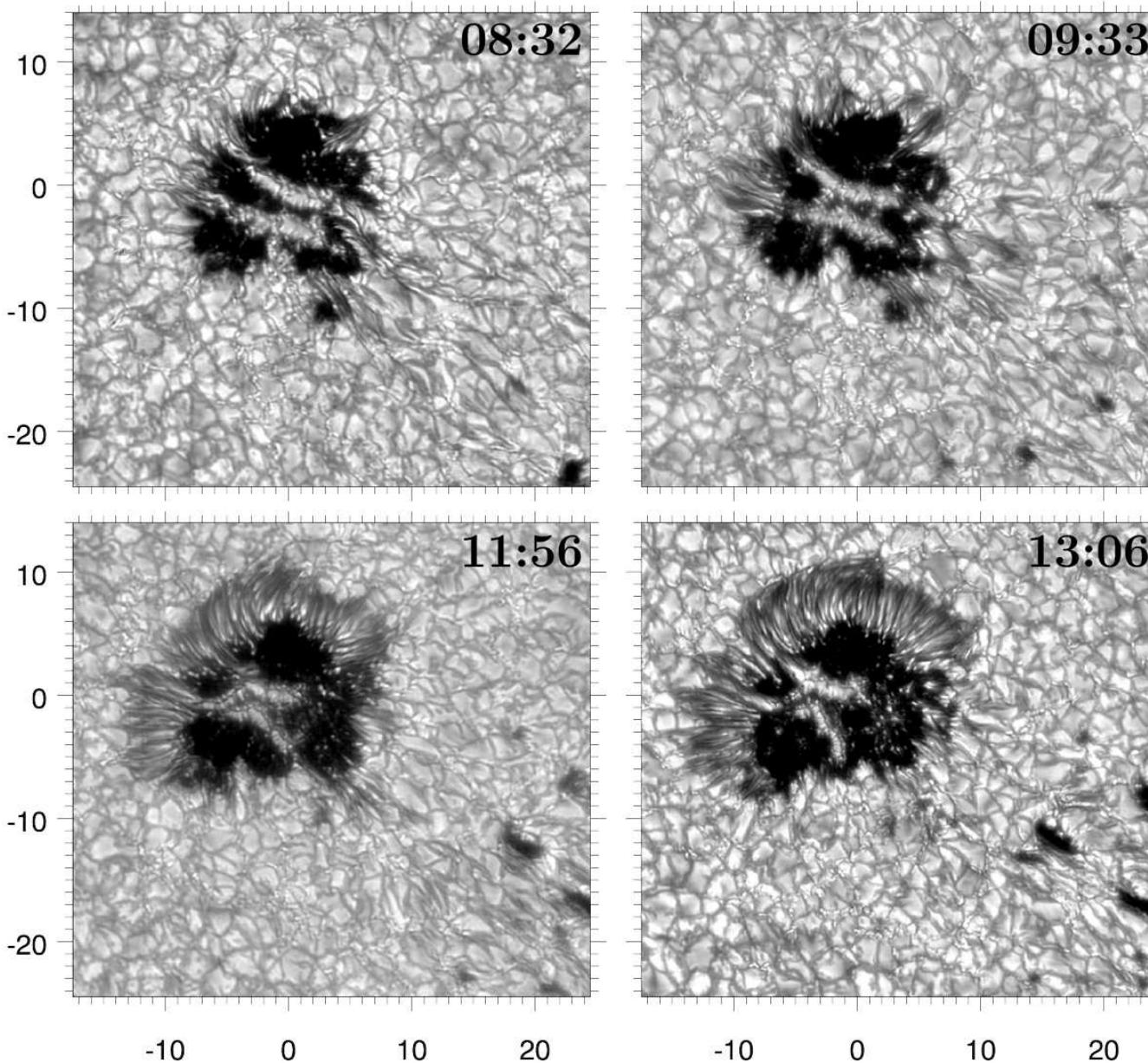
Sunspot of July 2, 2010

*Big Bear Solar Observatory*

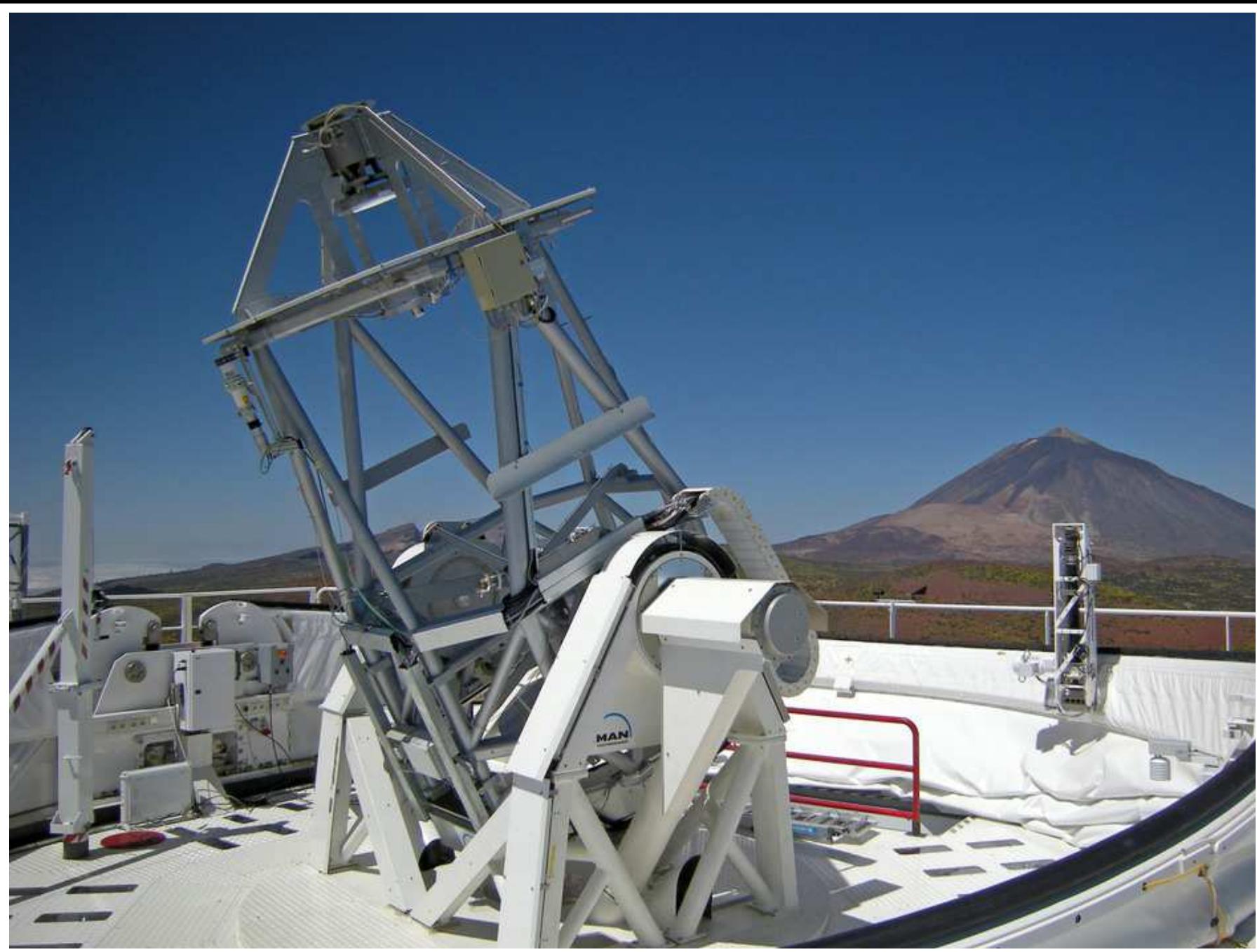
Observatorio del Teide, Izaña, 2390 m a.s.l.

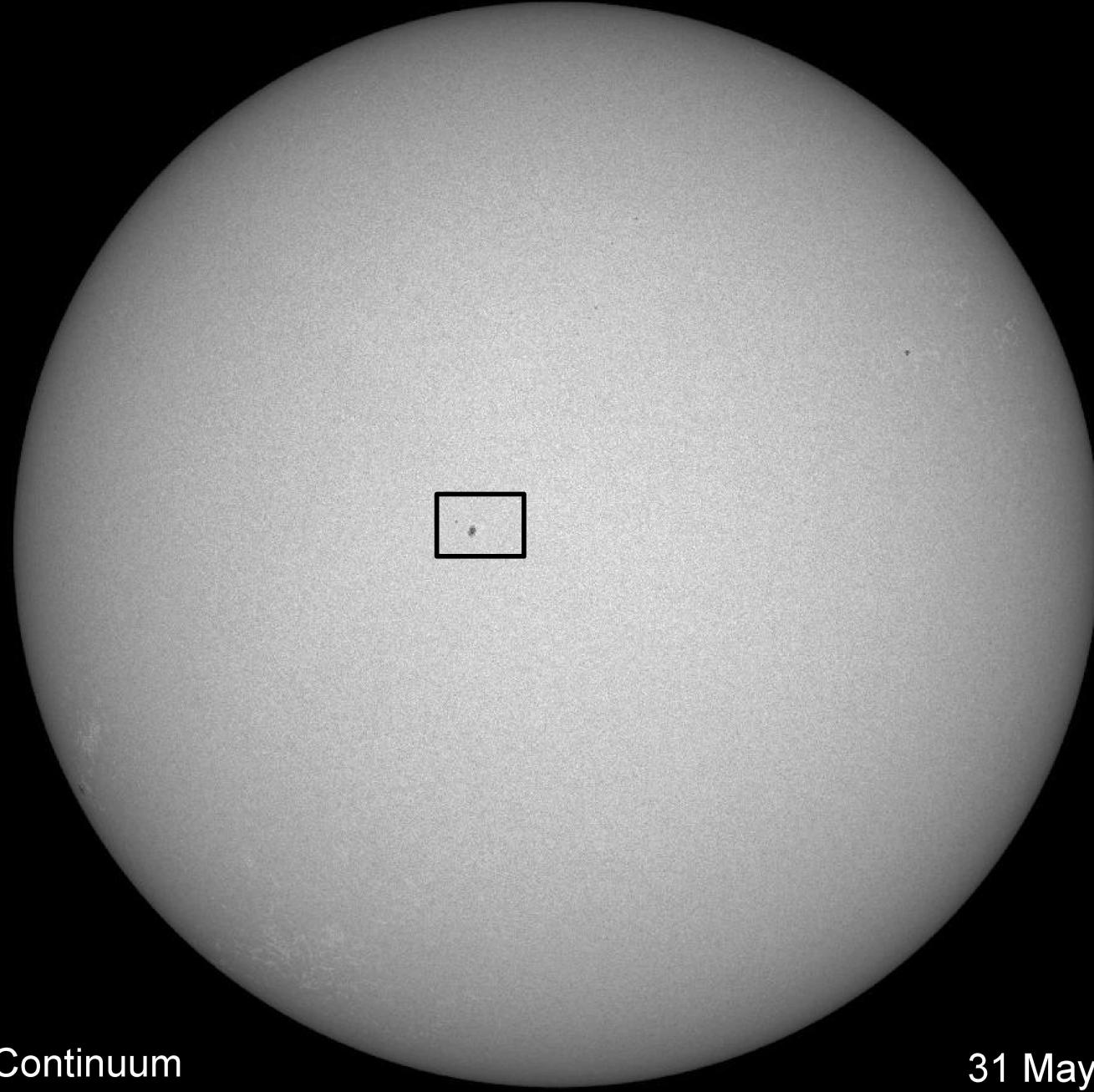


## 2. Sunspots (cont.)



Development of the penumbra of a sunspot over a time period of 4h 34 min. Recordings using a G-band filter at the VTT telescope in Tenerife. From *Schlichenmaier et al. 2010, A&A 512, L1*.

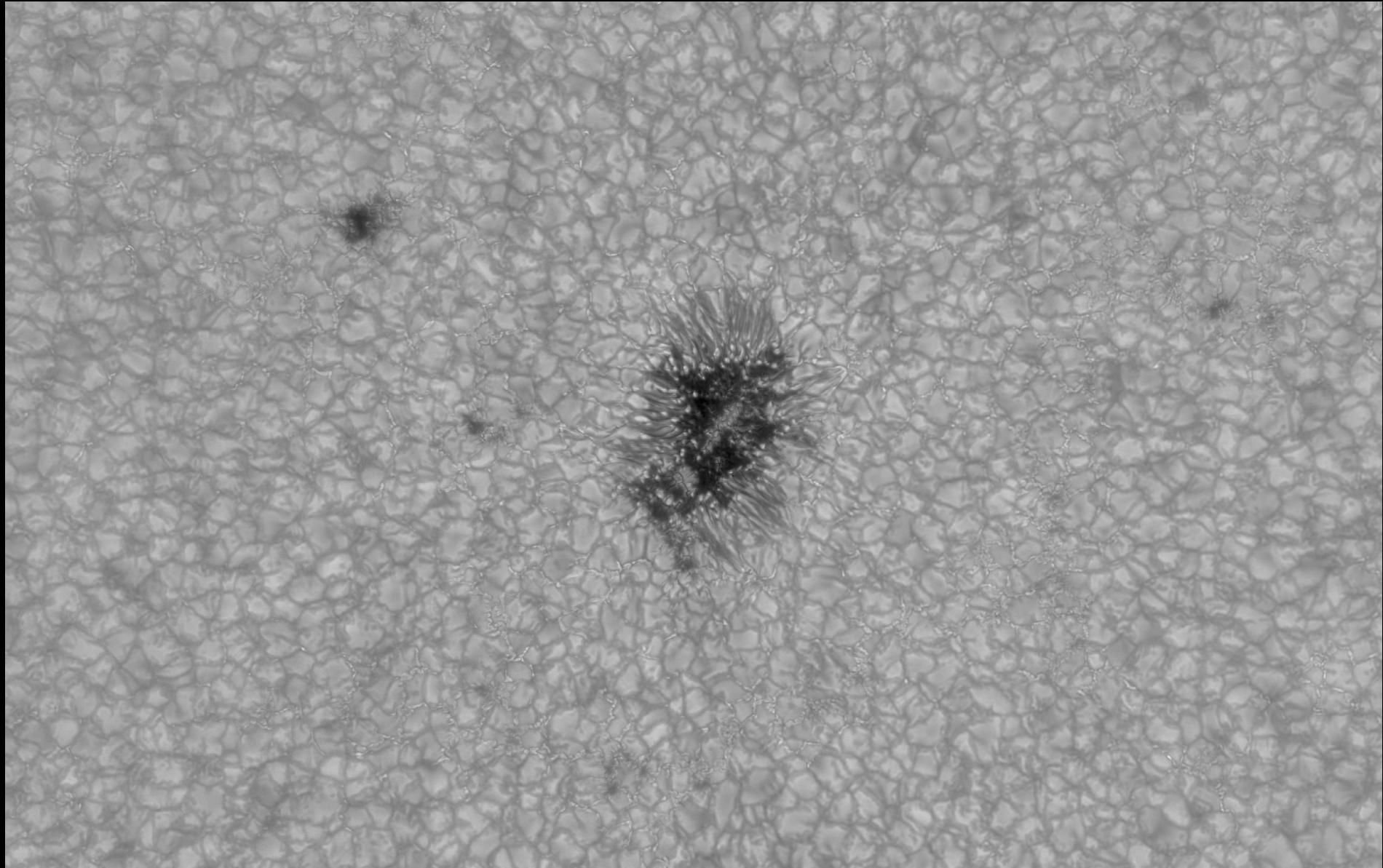




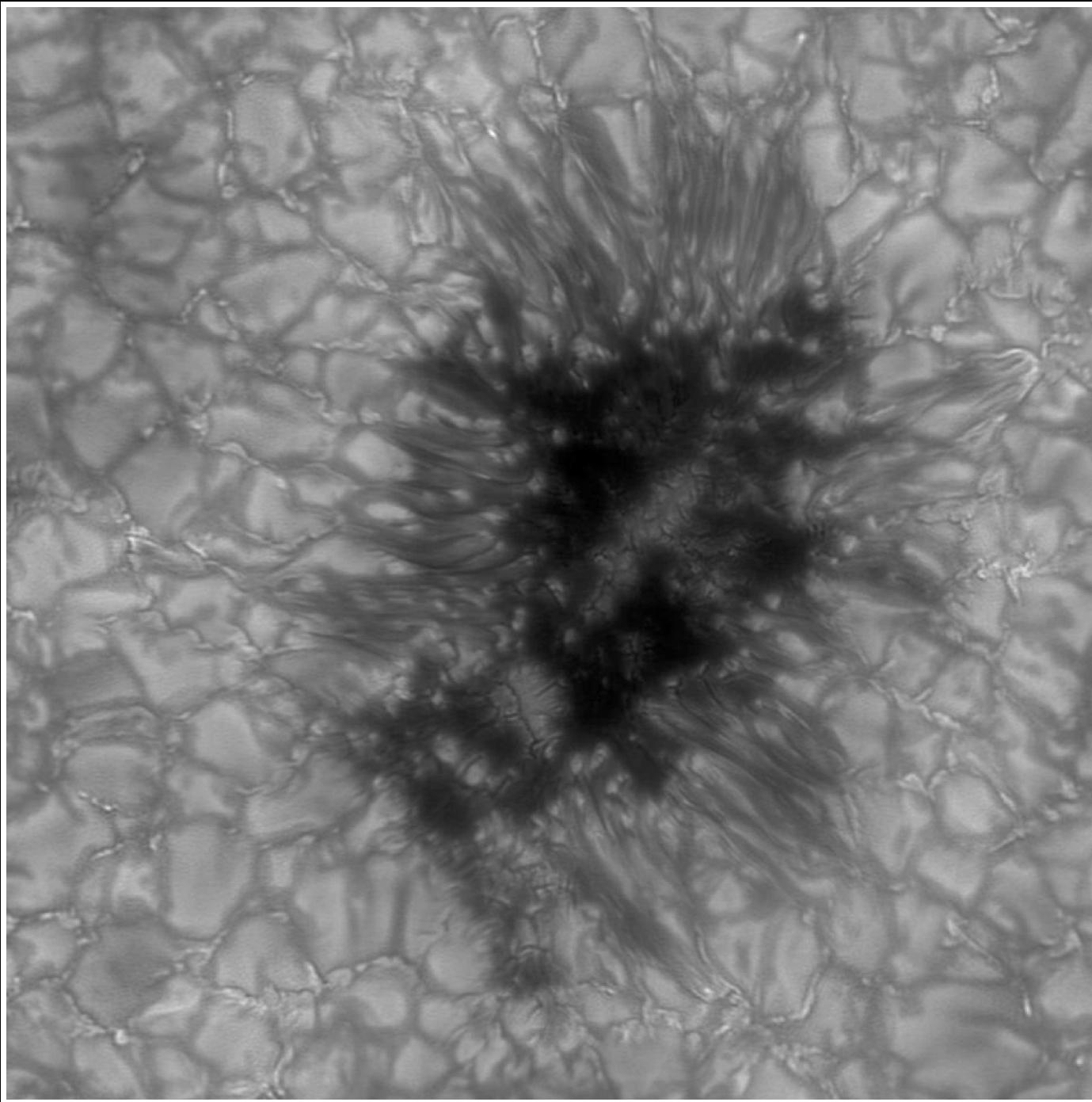
SDO HMI Continuum

31 May 2013 12:35

Recording with the GREGOR telescope at a wavelength of  $\lambda = 589$  nm.

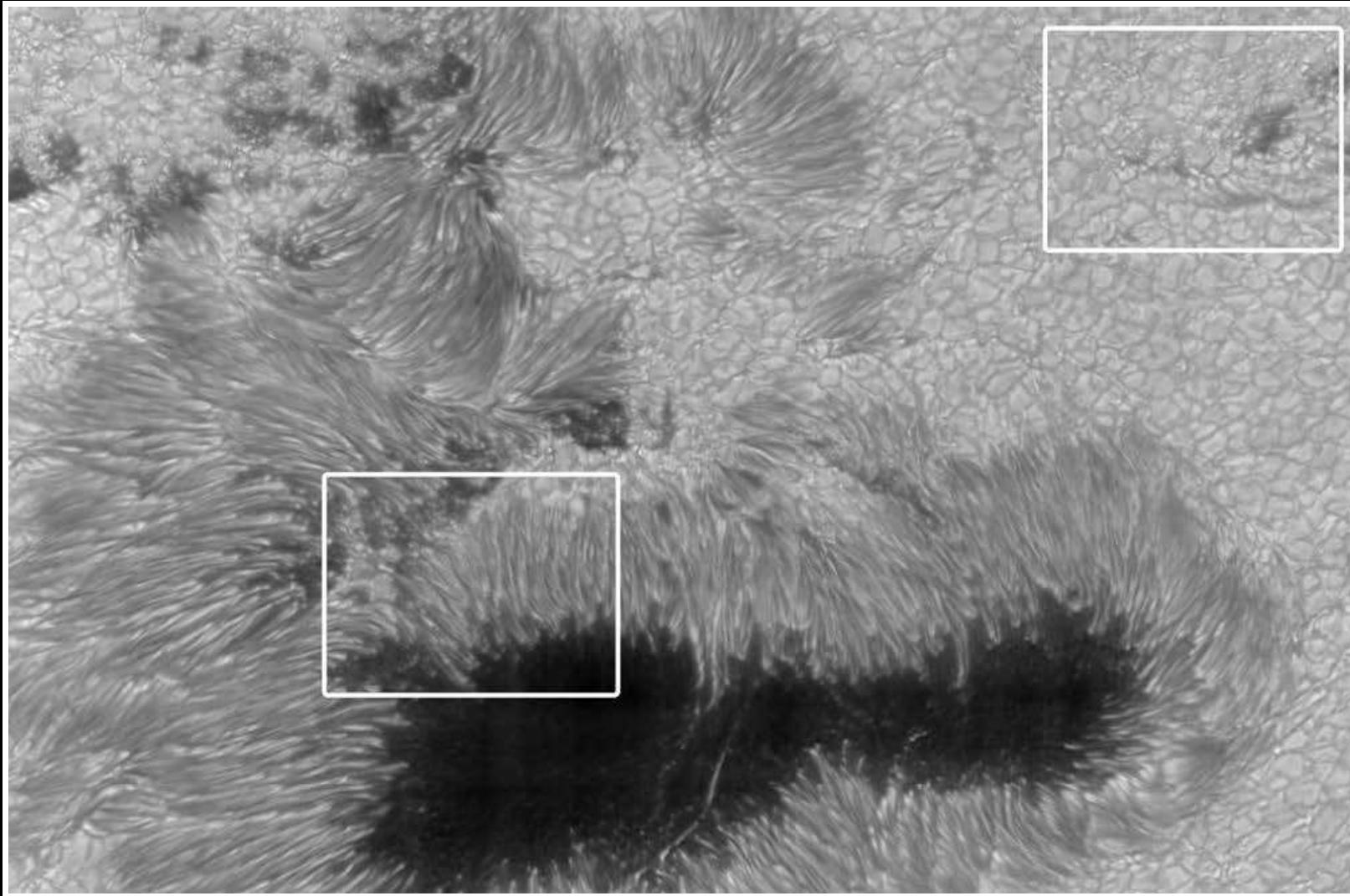


Sunspot in a field of view of  $114'' \times 72''$ .



Courtesy, R. Schlichenmaier

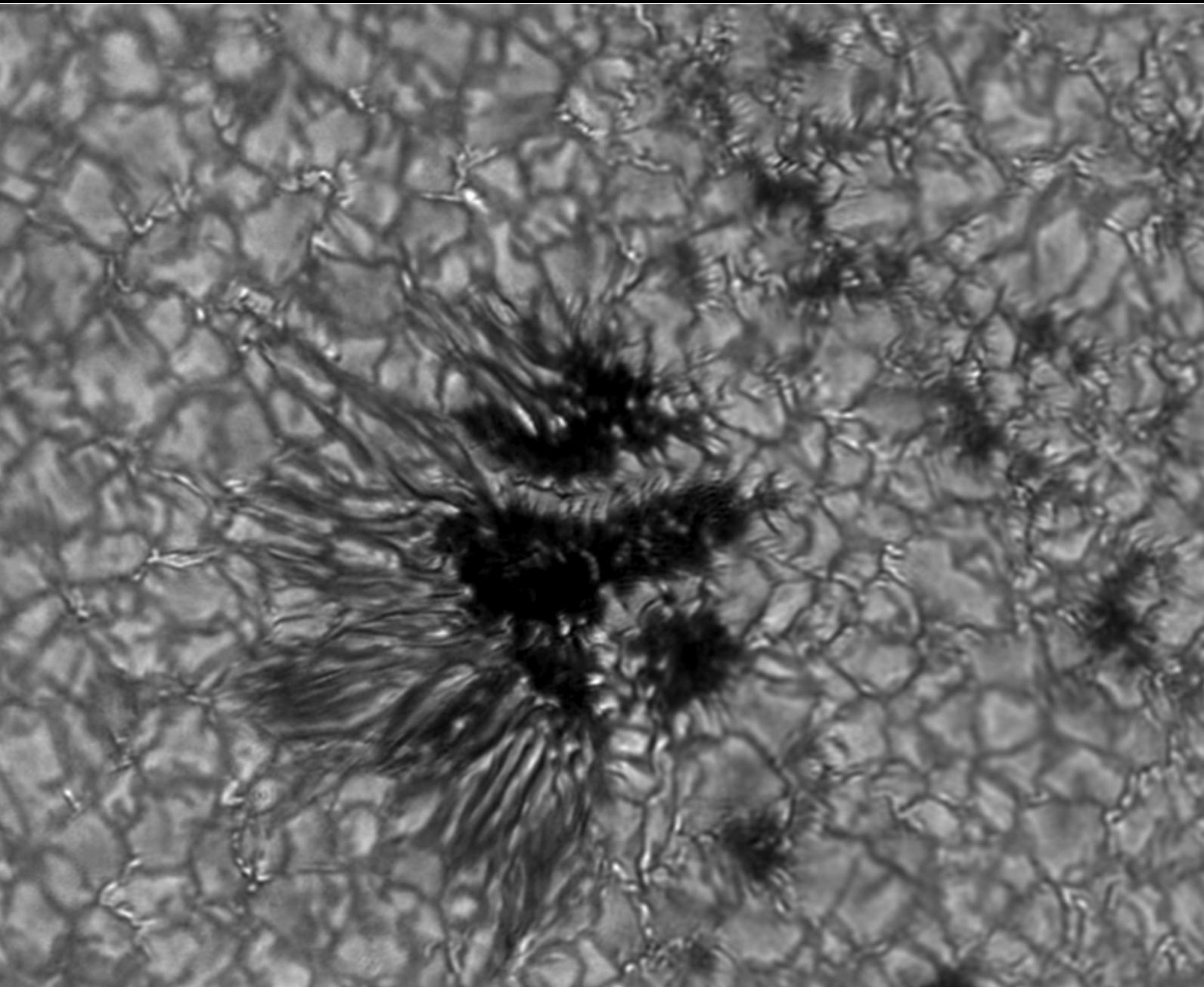
## Sunspot with the GREGOR telescope



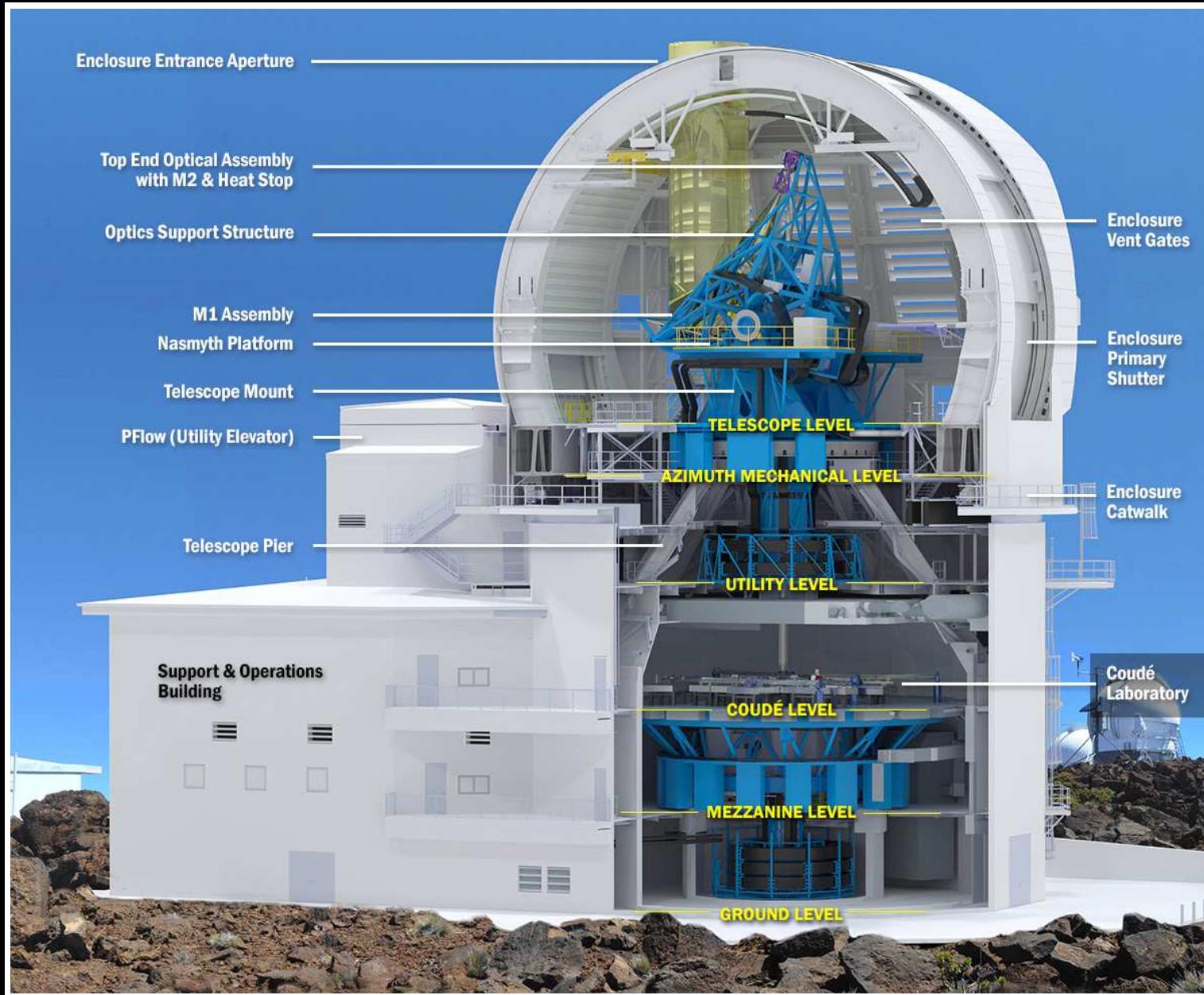
Sunspot in a field of view of  $110'' \times 67''$ . From 100 frames with speckle imaging at a wavelength of  $\lambda = 656$  nm.

Courtesy, *O. von der Lühe & R. Schlichenmaier (KIS)*

## Sunspot with the GREGOR telescope



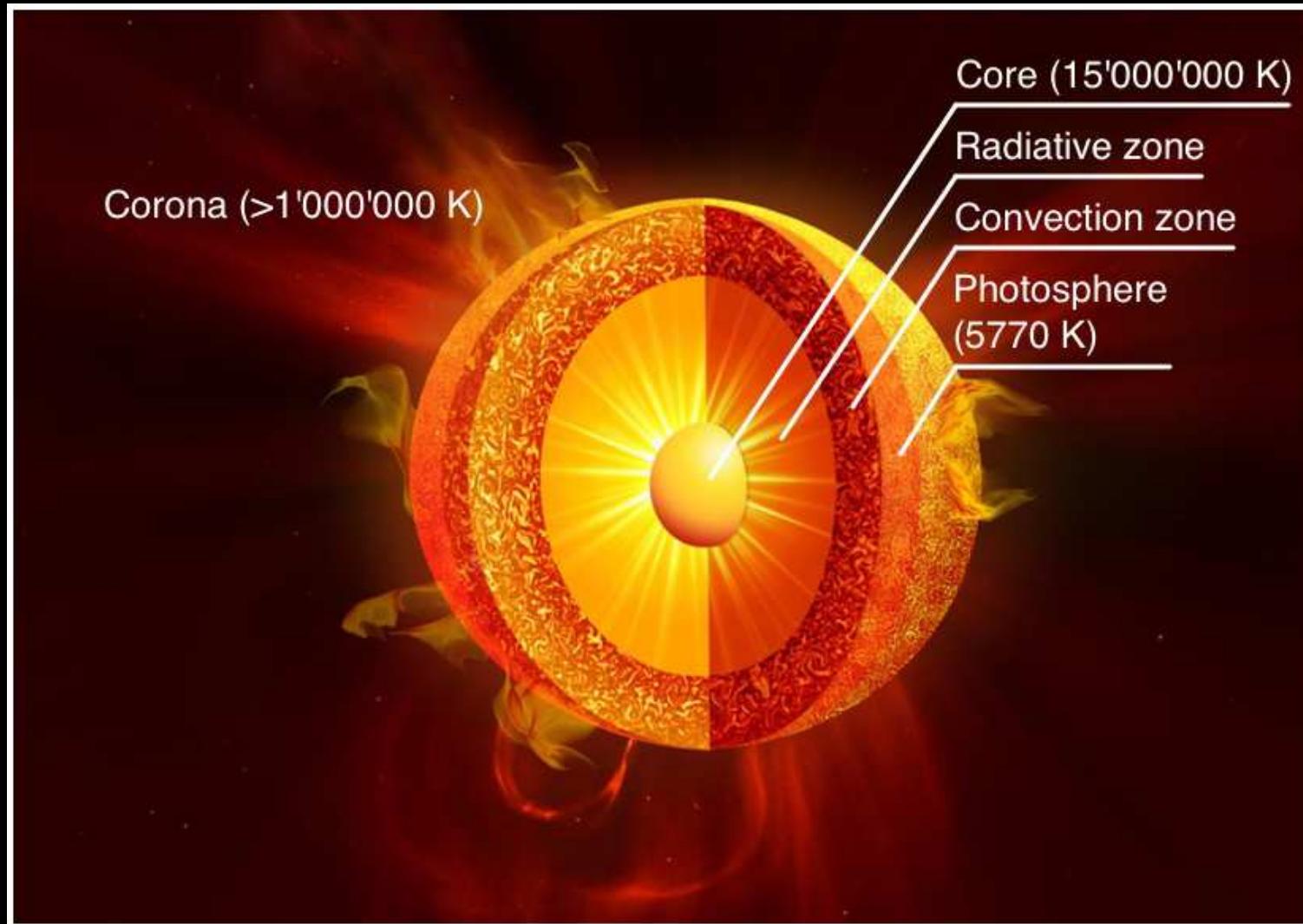
Courtesy, *R. Schlichenmaier (KIS)*



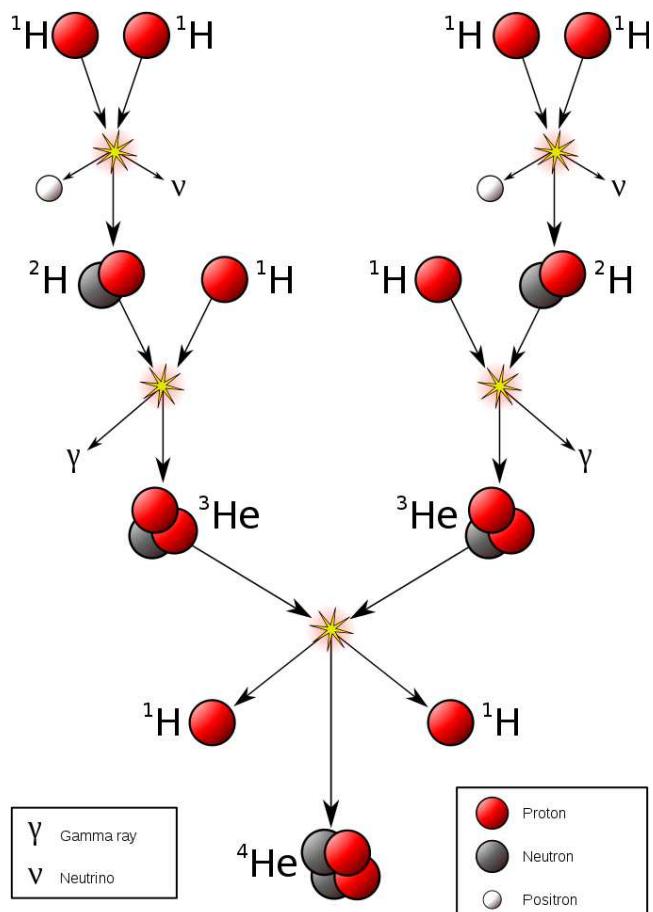
Daniel K. Inouye  
4 m solar telescope.  
Under construction  
at Haleakala  
Observatory on the  
Hawaiian island of  
Maui.

### 3. The structure of the Sun

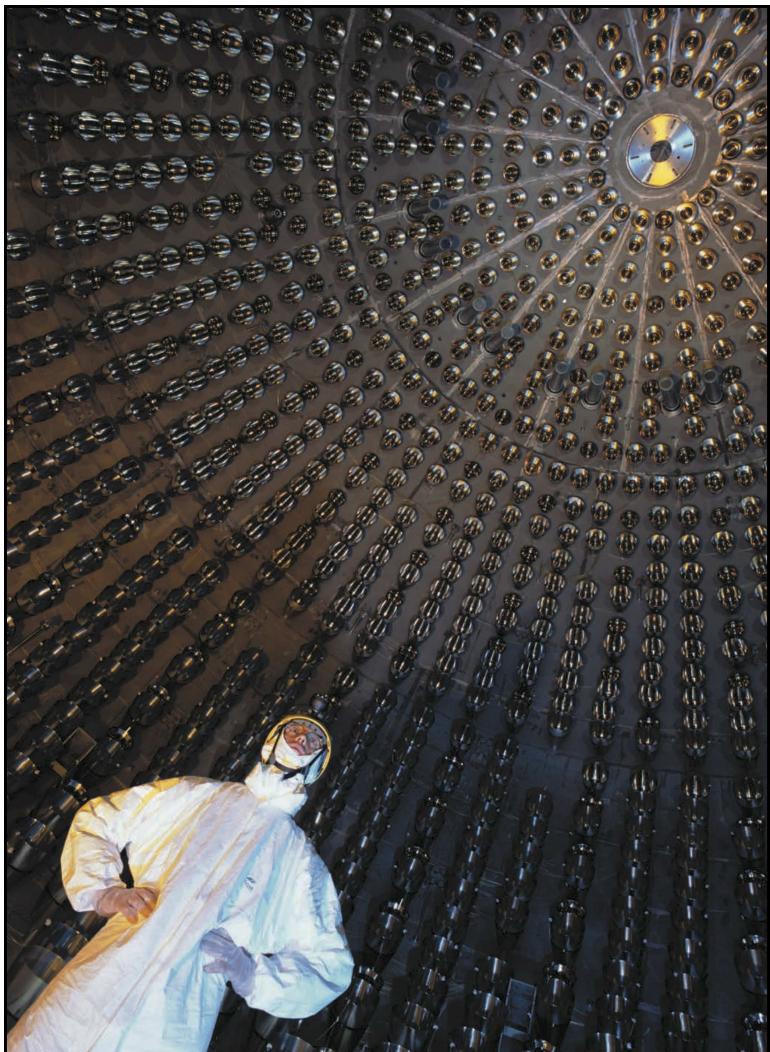
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### 3. The structure of the Sun (cont.)



Nuclear fusion in the core of the Sun:  
The p-p reaction chain turns four Hydrogen nuclei into a Helium nucleus plus radiation and neutrinos.



Borexino detector for solar neutrinos in the Italian National Laboratory of Gran Sasso (Abruzzo mountains) consisting of 280 tons of scintillator liquid.

### 3. The structure of the Sun (cont.)

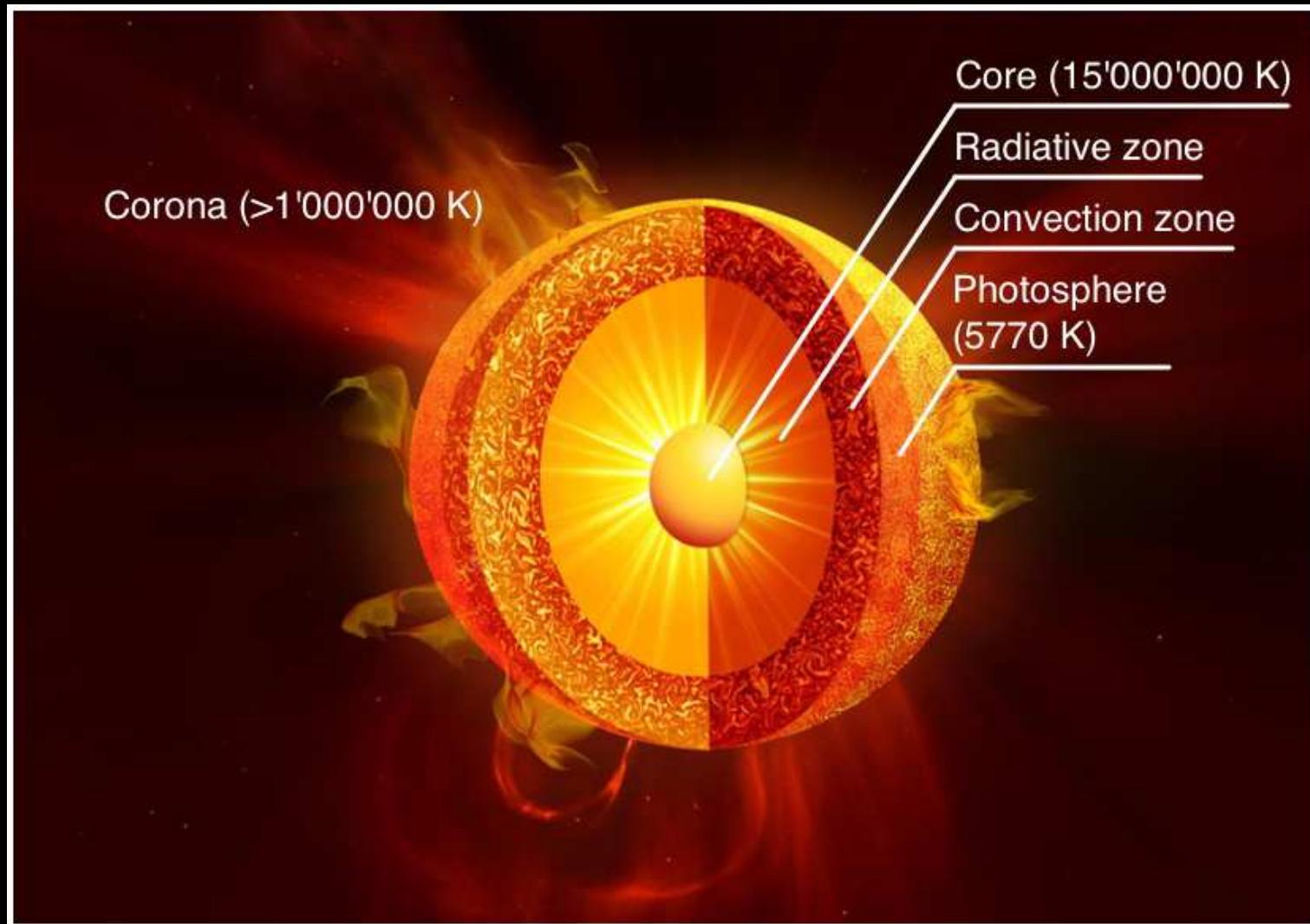
#### International Thermonuclear Experimental Reactor, ITER



Aerial view of the ITER site in Cadarache, near Aix-en-Provence

## 4. The violent Sun

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## The “Great American Eclipse” of August 21, 2017

From *Milosav Druckmüller*

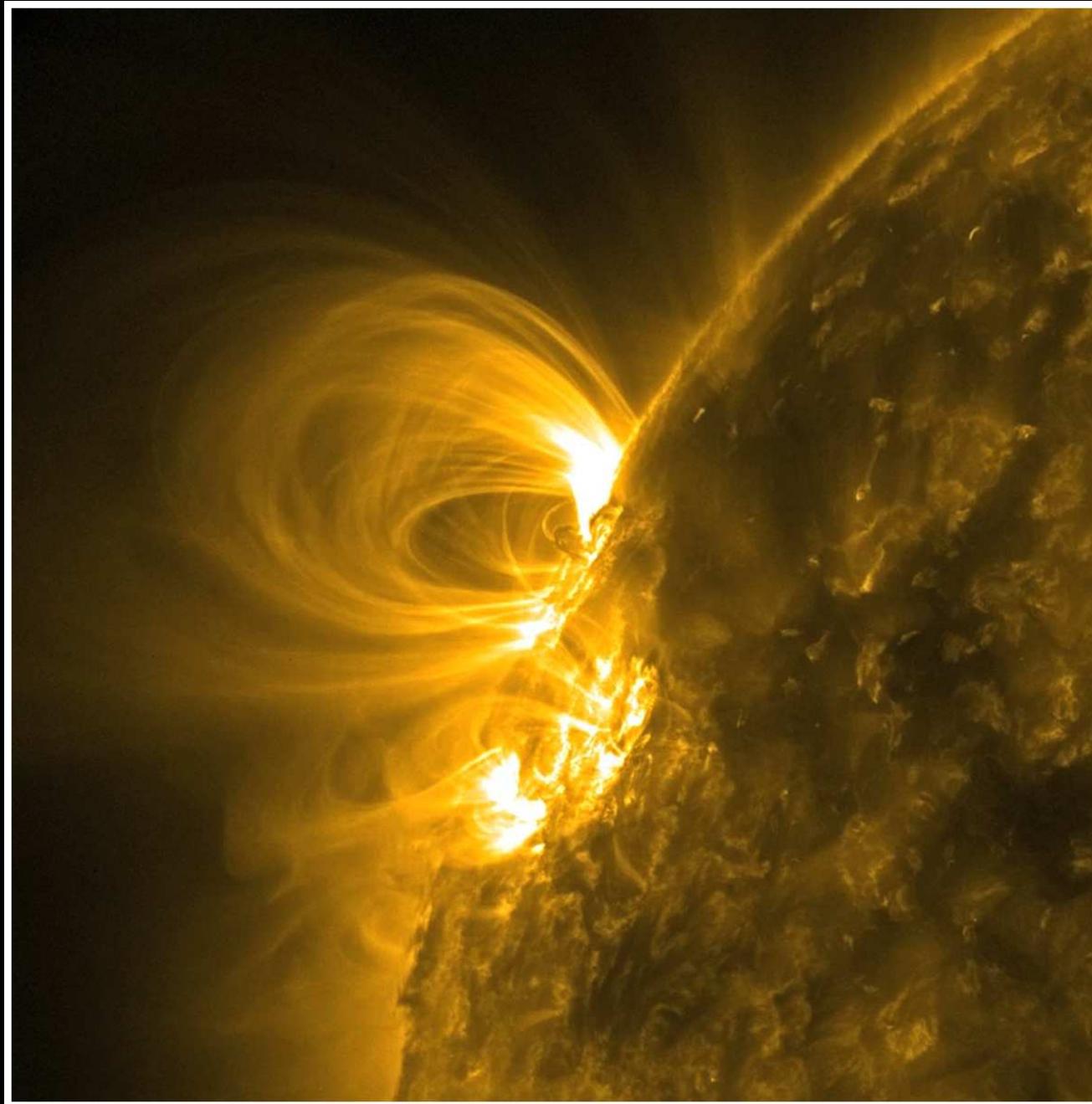


The “Great American Eclipse” of August 21, 2017

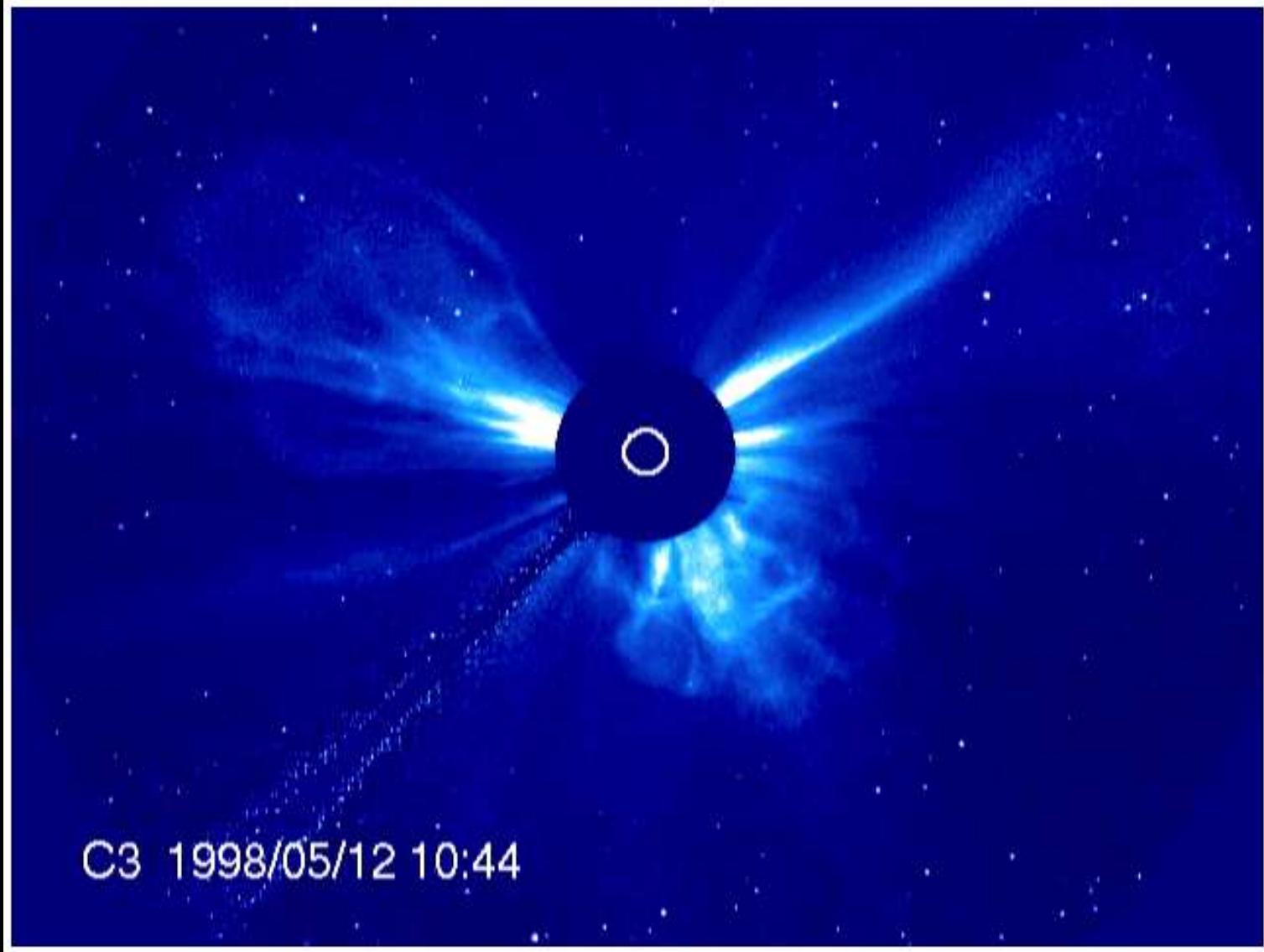


... with a pocket camera (from Casper, Wyoming)

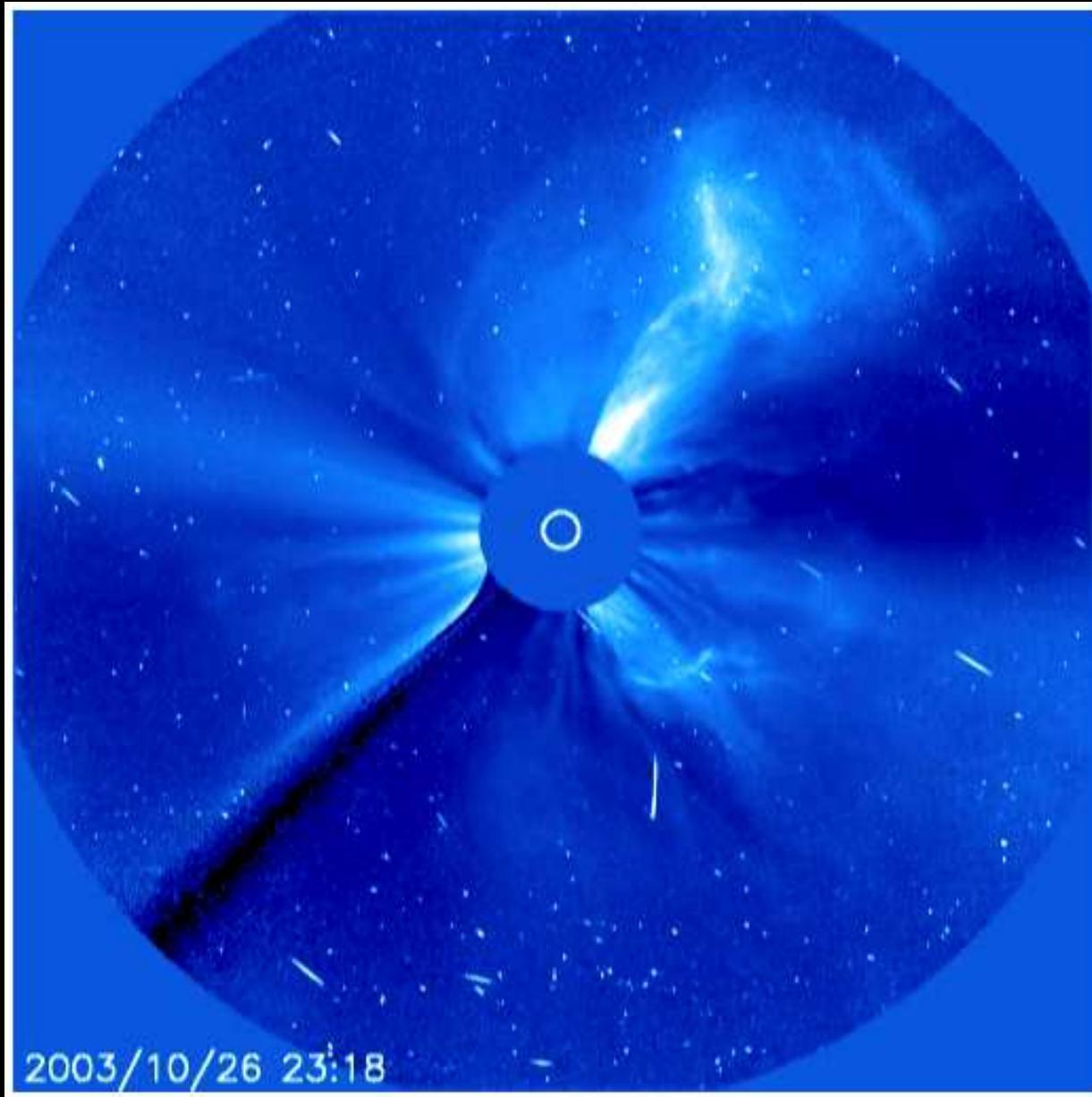
Coronal loops in continuous motion. Feb. 23–27, 2011



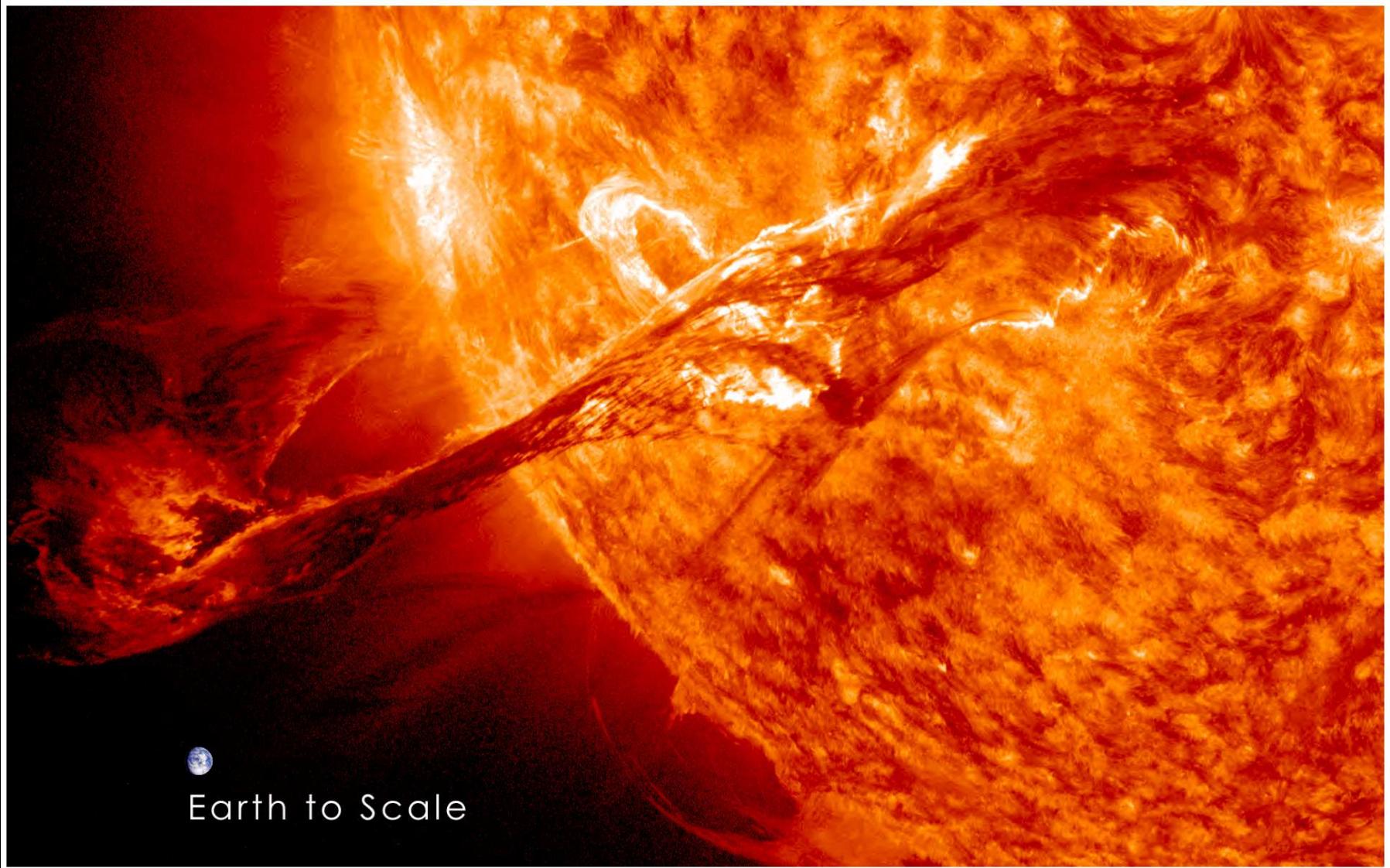
Picture taken in the  
extreme ultraviolet  
light at 17.1 nm with  
the *Solar Dynamics  
Observatory (SDO) of  
NASA*



Coronal mass ejection on May 12, 1998 seen in white light from space with the LASCO coronograph on board of the *SOHO satellite of ESA and NASA*



“Halloween storms” of Oct. 18–Nov. 7, 2003. White light with the LASCO coronograph on board of the *SOHO satellite of ESA and NASA*



Filament eruption of August 31, 2012 in the extreme ultraviolet light at 13.1 nm  
with the *Solar Dynamics Observatory (SDO) of NASA*



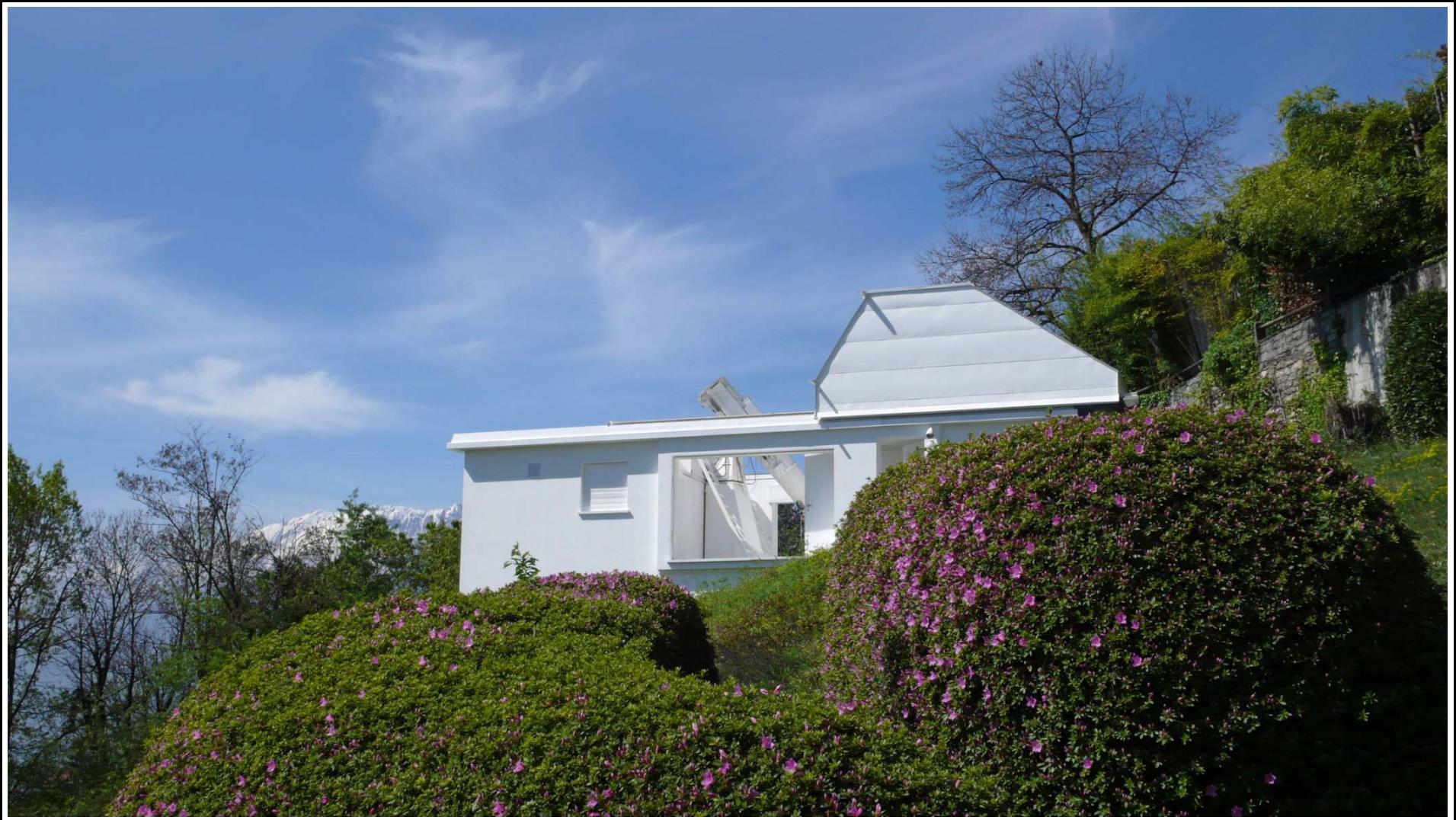
Aurora on September 3 following the coronal mass ejection of August 31.

*David Cartier, Sr.* from Whitehorse, Yukon, Canada

## 5. The Istituto Ricerche Solari Locarno, IRSOL

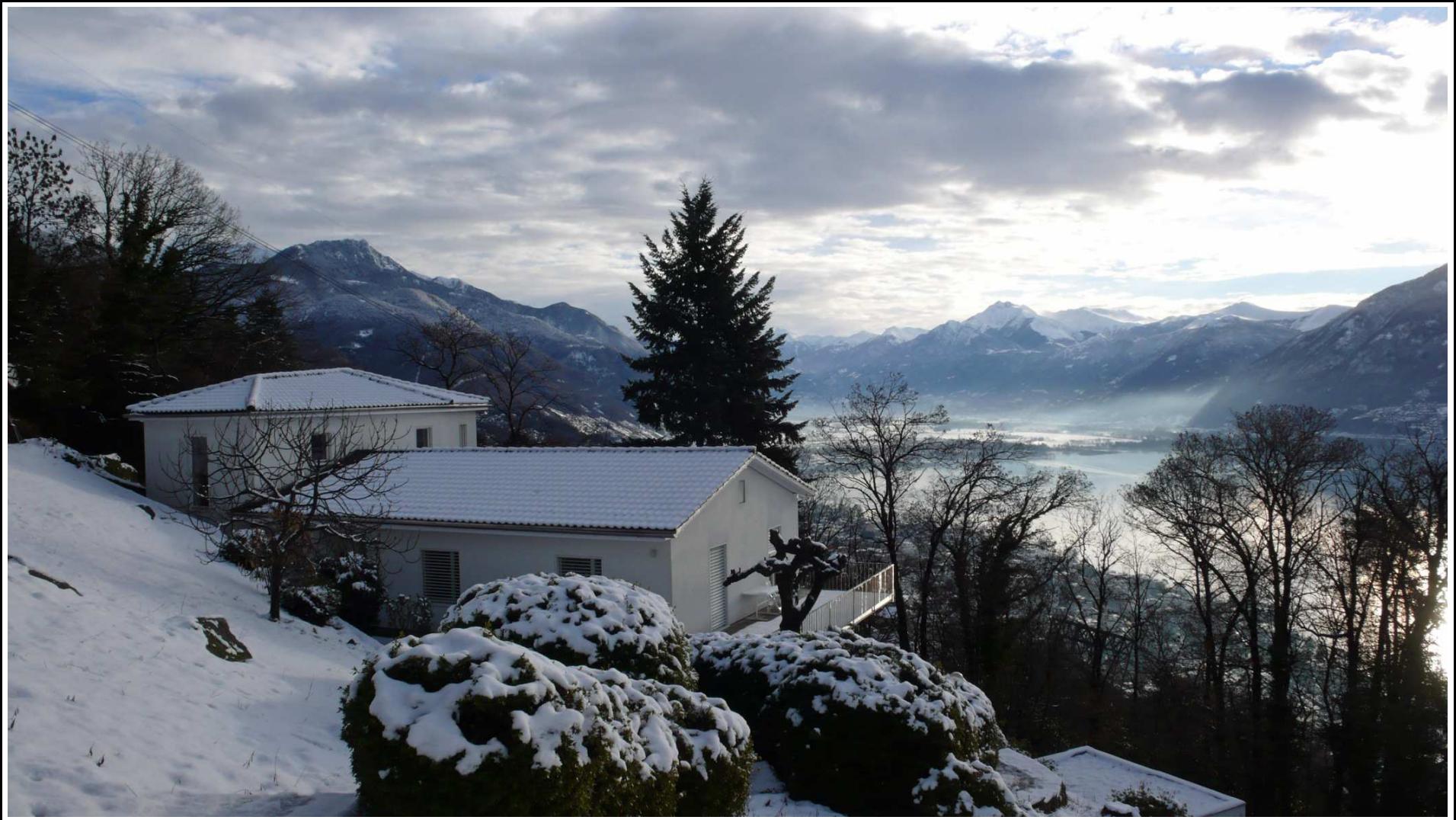


## Istituto Ricerche Solari Locarno (IRSOL)



Gregory-Coudé telescope (45 cm), equipped with Zimpol cameras for polarimetry.

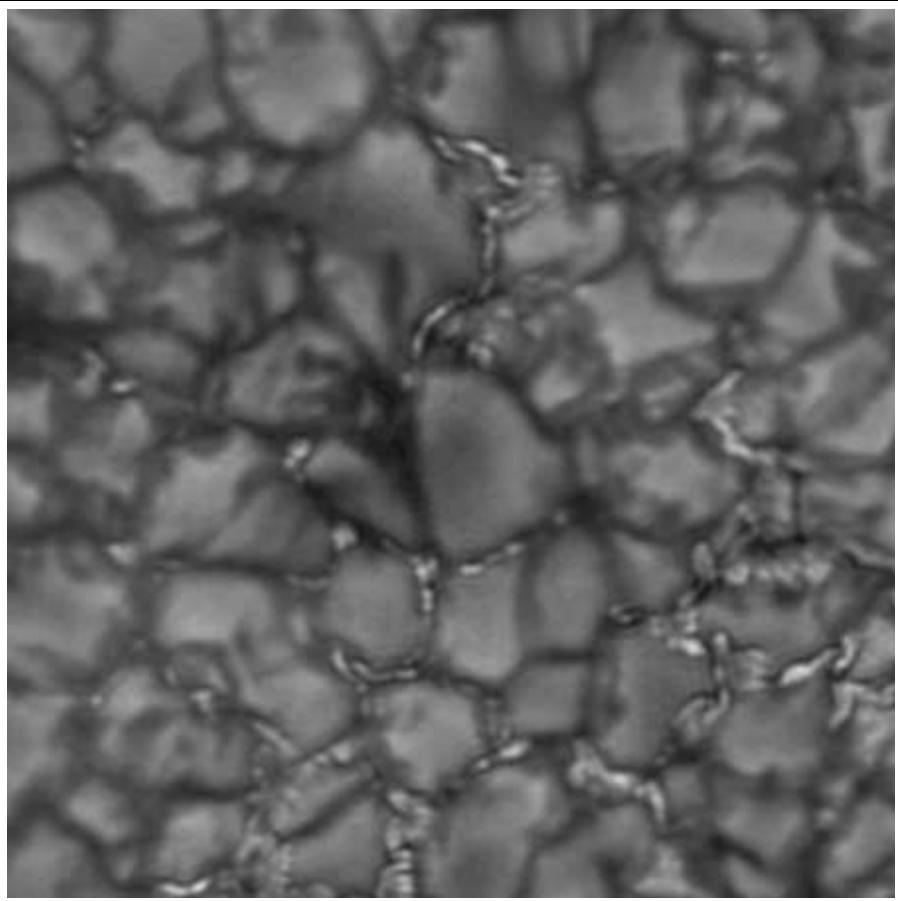
## Istituto Ricerche Solari Locarno (IRSOL)



IRSOL offices, workshop, and laboratory

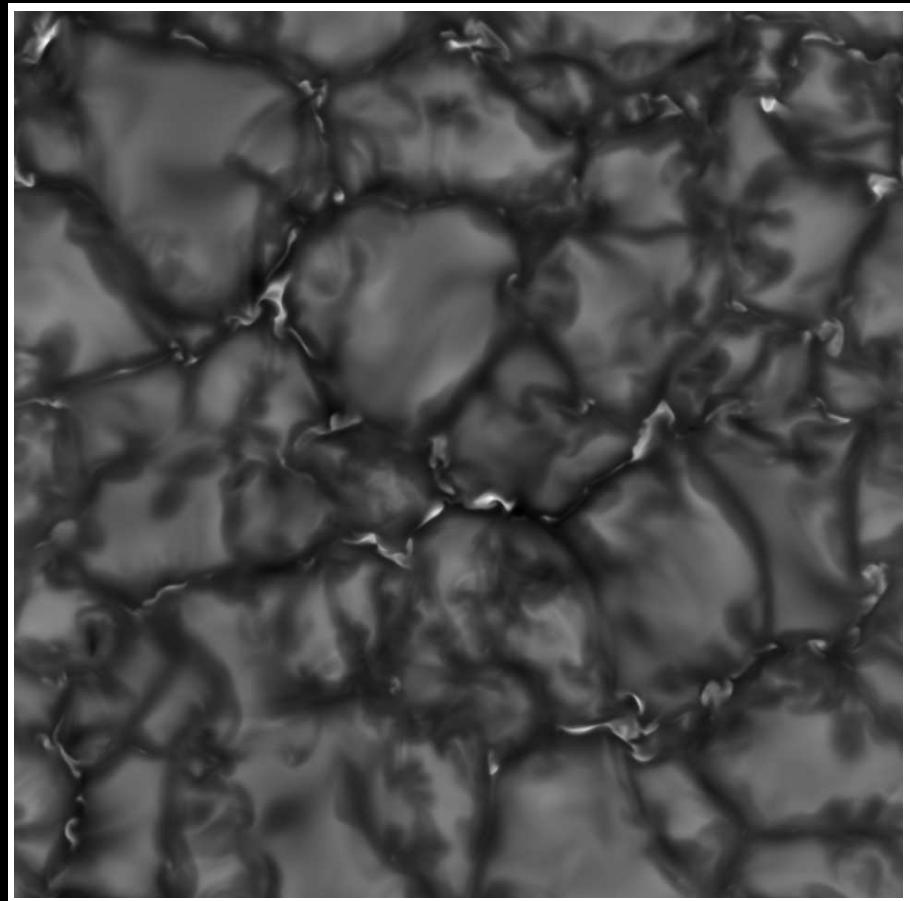
## 5. The Istituto Ricerche Solari Locarno, IRSOL (cont.)

Solar granulation *observed* with the  
1.48 m GREGOR solar telescope.  
Narrow band filter at  $\lambda = 4860 \text{ \AA}$ .



Solar granulation *simulated* with  
 $\text{CO}^5\text{BOLD}$ . Synthesized bolometric  
intensity.

Courtesy, *F. Calvo*



Computations: *Centro Svizzero di Calcolo Scientifico*

## 5. The Istituto Ricerche Solari Locarno, IRSOL (cont.)

Starting point are the *equations of magnetohydrodynamics*:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 ,$$

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot \left( \rho \mathbf{v} \mathbf{v} + \left( P + \frac{\mathbf{B} \cdot \mathbf{B}}{2} \right) \mathbf{I} - \mathbf{B} \mathbf{B} \right) = \rho \mathbf{g} ,$$

$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \cdot (\mathbf{v} \mathbf{B} - \mathbf{B} \mathbf{v}) = 0 ,$$

$$\frac{\partial \rho e_{\text{tot}}}{\partial t} + \nabla \cdot \left( \left( \rho e_{\text{tot}} + P + \frac{\mathbf{B} \cdot \mathbf{B}}{2} \right) \mathbf{v} - (\mathbf{v} \cdot \mathbf{B}) \mathbf{B} + \mathbf{F}_{\text{rad}} \right) = 0 .$$

$\rho$ : mass density;  $\mathbf{v}$ : velocity;  $P$ : gas pressure;  $\mathbf{B}$ : magnetic field;  $\mathbf{g}$  gravitational acceleration;  $e_{\text{tot}}$ : total energy density;  $\mathbf{F}_{\text{rad}}$ : radiative flux;  $t$ : time

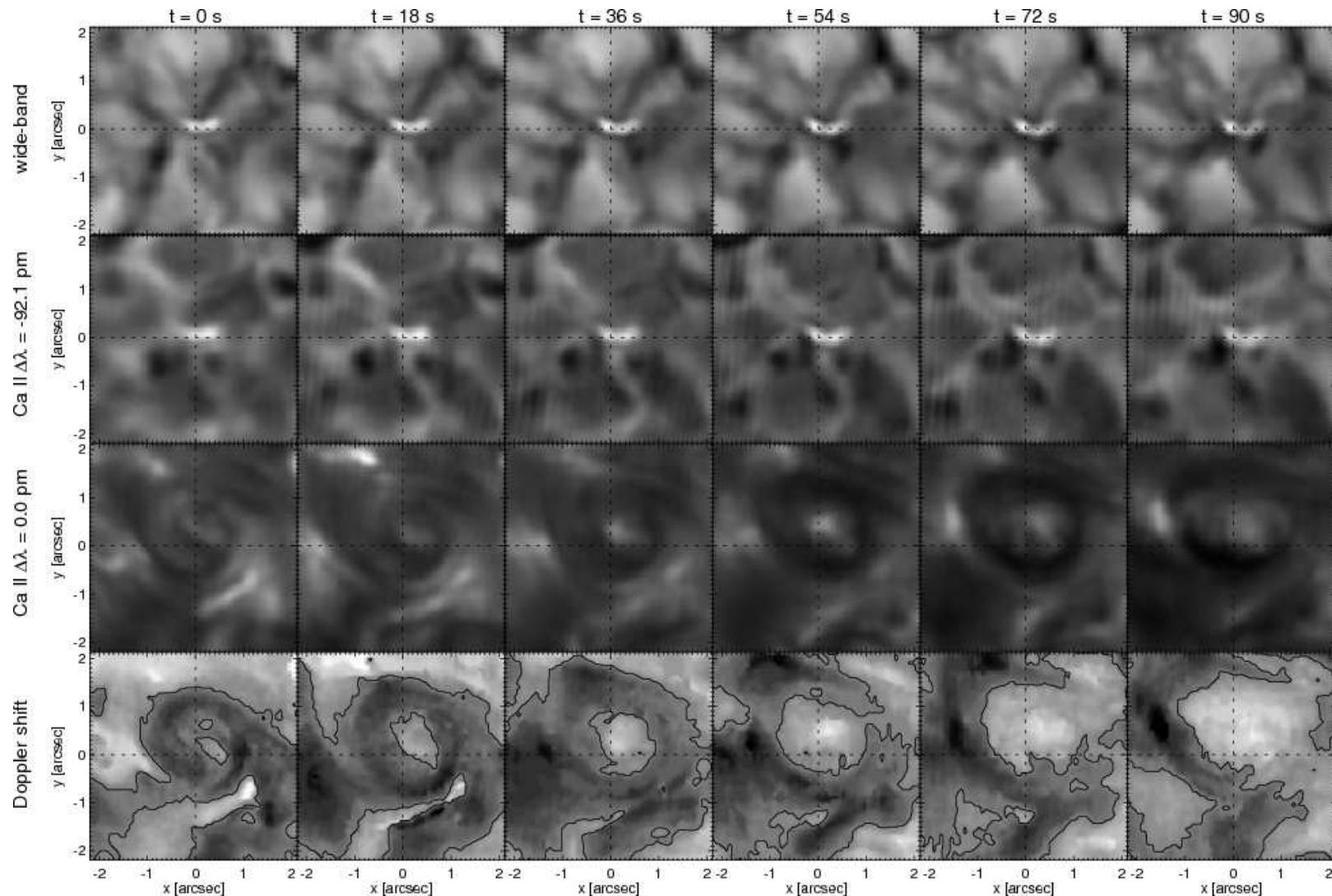
$$\rho e_{\text{tot}} = \rho e_{\text{int}} + e_{\text{kin}} + e_{\text{mag}} + e_{\text{pot}} = \rho e_{\text{int}} + \rho \frac{\mathbf{v} \cdot \mathbf{v}}{2} + \frac{\mathbf{B} \cdot \mathbf{B}}{2} + \rho \Phi$$

# Piz Daint @ CSCS in Lugano



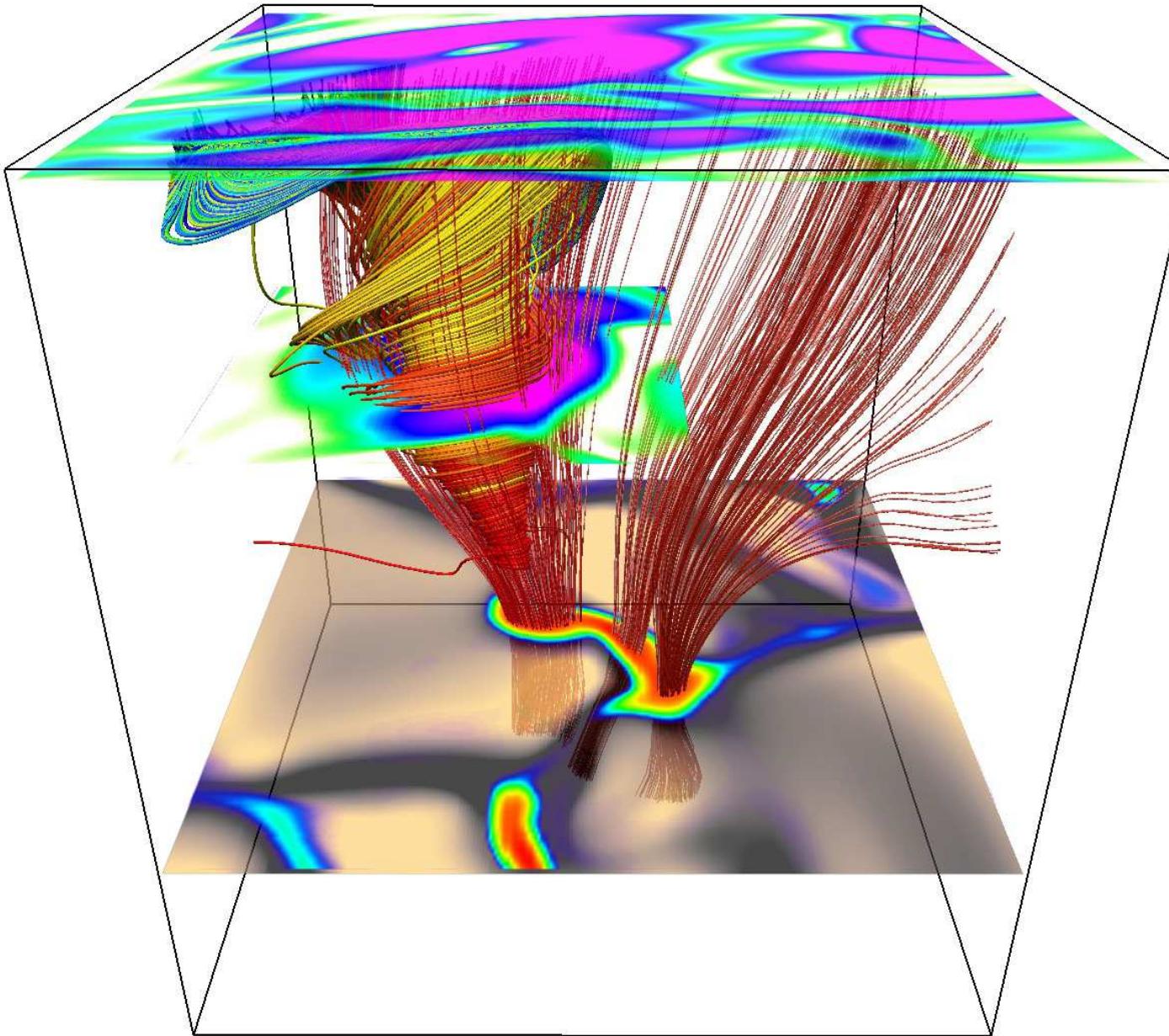
Piz Daint is a Cray XC50/XC40 with nodes of 12 cores with 64GB RAM and nodes with 18 cores and 128GB RAM, both Intel® Xeon® E5.

## 5. The Istituto Ricerche Solari Locarno, IRSOL (cont.)



From *Wedemeyer-Böhm & Rouppe van der Voort (2009)*

## 5. The Istituto Ricerche Solari Locarno, IRSOL (cont.)

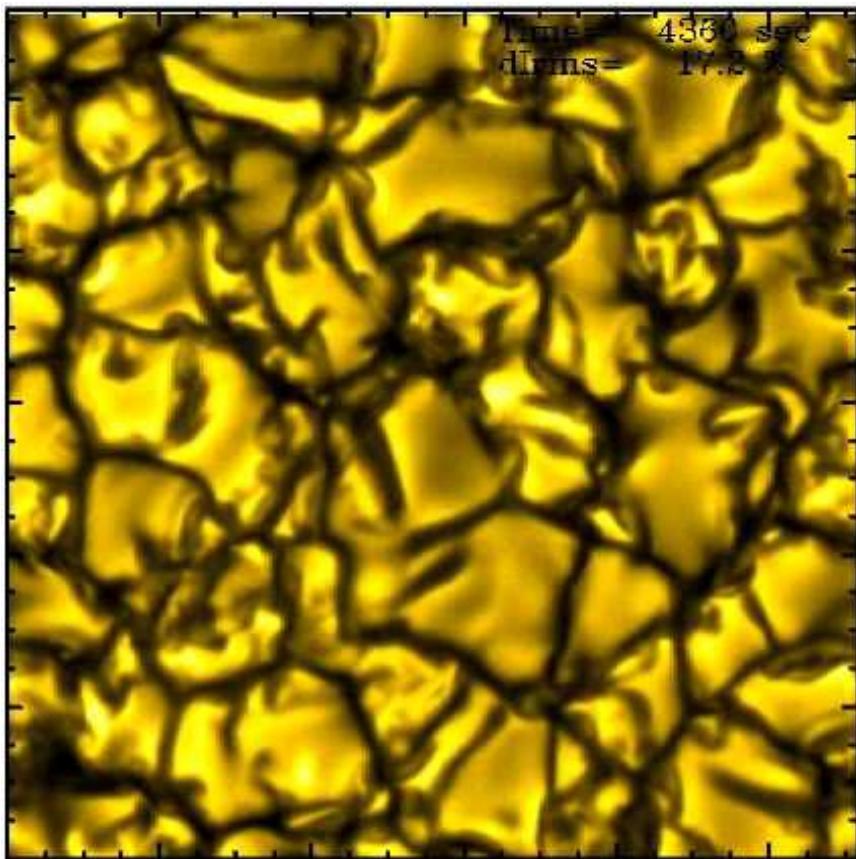


Close-up of a swirl event.  
The plasma flows along  
and co-rotates with the  
magnetic field (spiral  
streamlines). From  
[www.solartornado.info](http://www.solartornado.info).



## 5. The Istituto Ricerche Solari Locarno, IRSOL (cont.)

*Box in a star*



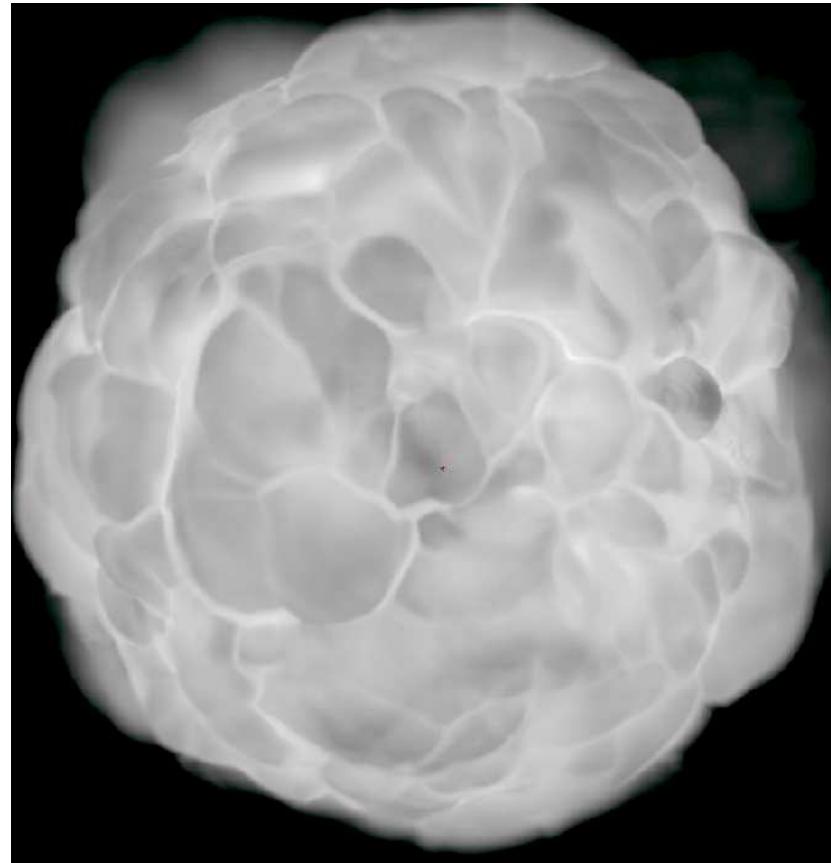
Simulation of *solar granulation with CO<sup>5</sup>BOLD*.

$400 \times 400 \times 165$  grid cells,  $11.2 \times 11.2$  Mm,

Contrast at  $\lambda \approx 620$  nm is 16.65%.

Courtesy *M. Steffen*, AIP Potsdam

*Star in a box*



Simulation of a *Betelgeusew with CO<sup>5</sup>BOLD*.

$235^3$  grid cells,  $m_{\text{star}} = 12m_{\odot}$ ,

$T_{\text{eff}} = 3436$  K,  $R_{\text{star}} = 875R_{\odot}$

Courtesy *Bernd Freytag*, Uppsala

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