Variations of the Solar Diameter and Spectral Irradiance: Measurements at total eclipses

by:

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with the collaboration of
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During the last decades, considerable efforts
have been devoted to the analysis of possible effects of
the **irregular activity cycles** of the Sun
through **solar forcing effects**

Topic connected to the
question of the **anthropogenic origin of global warming**
and to the influence of **volcanic activity**,
with consequences for
the **climate** and economic **life**.

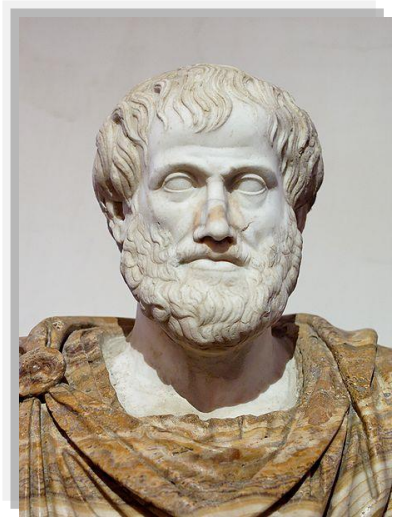
Intriguing background (premises?):

In ancient Egypt, the Sun was «excessively» proposed as a single divinity (pre-monotheism) leading to a catastrophic end of the reign of this famous Pharaoh …

The “inhuman” Sun!

Akhénaton (Aménophis IV)
v. 1350 B.C. (Cairo Museum) Aton

Following the teaching of famous ancient philosophers
like Plato, Aristotle and their followers,
the **Man** and not the **Sun** has been put at the center of the World as reflected in modern religions (Judaism, Christianism, Islamisme etc.)



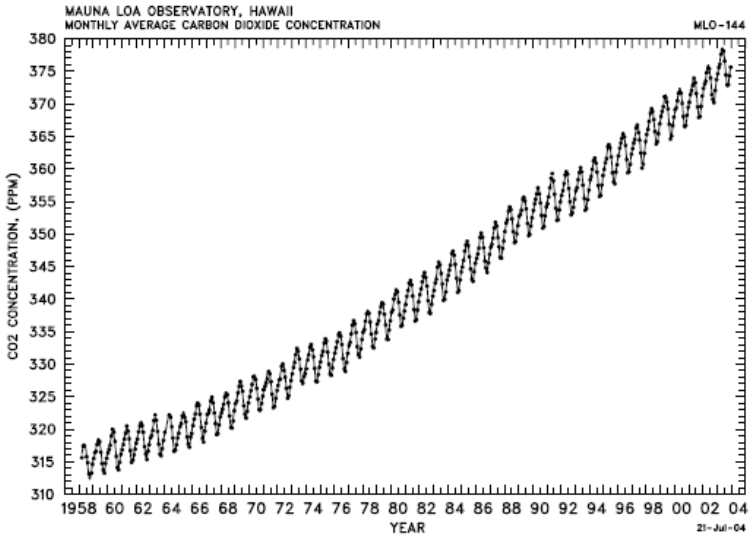
Aristotle (384 BC – 322 BC)
(Greek: Ἀριστοτέλης, *Aristotélēs*)

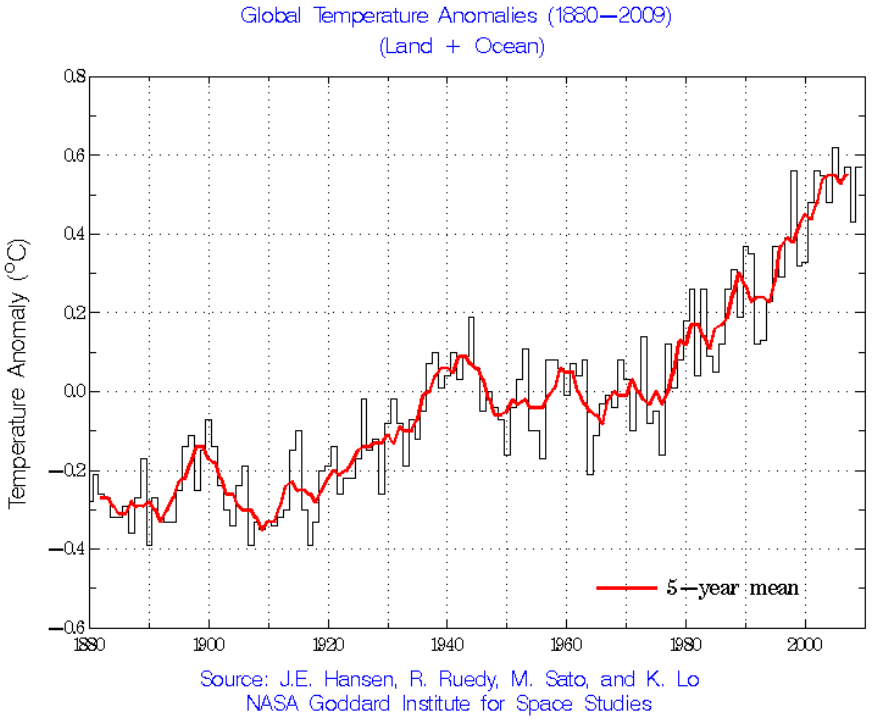
Phenomena
influencing
our life
could find
their origin
as a result of
the **human activity**

H. Schedel; Nuremberg (1493)

Unfortunately, the excessive belief
in geo-centrism and creationism
(model of the World in the middle age)
leads to wrong conclusions about
the real World.
Today:
***Philosophy** and **Science** became disconnected*

As regards **global warming**: It is now widely accepted
(but not unanimously so)
that a (dramatic?) global effect will “soon” result
as a consequence of the well confirmed rising amount of CO2
(and other components NO+, CH4..) in the Earth atmosphere,
producing an increased **greenhouse effect**





Reasonable but limited opinion
(climato-sceptics exist)
are however expressed

Conversely, there are data suggesting a possible solar effect:

Dendrochronological data- tree rings C14/ from J-M Malherbe, 2010 Lettre Acad Sc.

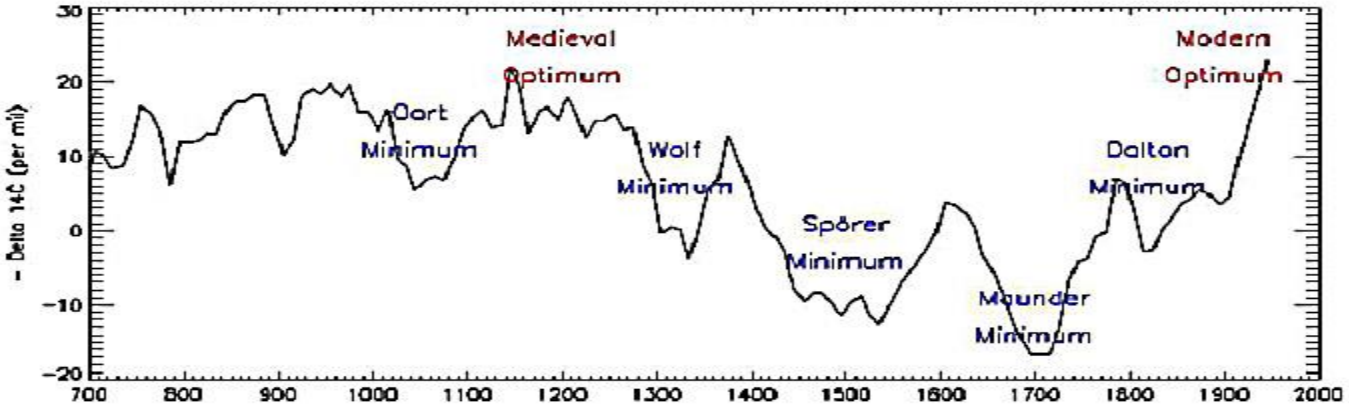


Fig. 3 : la concentration atmosphérique décennale en isotope ^{14}C mesurée dans les anneaux de croissance des arbres (selon les données Intcal98, Quaternary Isotope Laboratory) donne une indication sur l'activité solaire ancienne

Historical records of extended periods of **global cooling**
sometimes also called the "Little Ice Age",
(especially at the time of the **Maunder minimum**)
and **warming episodes** like during the 11- 12th centuries
⇒Vikings in **Greenland** and **Iceland** in 800- 1200 (farming developed!),
⇒wine produced in England and competing with France (!), etc.,
suggest
"solar activity could be responsible for important effects affecting our life"

but: ice- core ^{14}C and ^{10}Be data suggest volcanic activity dominates

The variations of the Total Solar Irradiance **S** can be analyzed assuming a simple model :

$$S = \sigma R_{\odot}^{2} T_{eff}^{4} / A^{2}$$

A is the distance Sun-Earth (***an average over 1 Year is considered to remove the orbital modulation***) equal to the astronomical unit (A=constant) while variations over the solar disk are neglected.

Variations can then be due to the changes of the solar radius $R_{\odot}$ or/and of the effective temperature T_{eff} of the photosphere (possibly a consequence of global processes occurring deep inside the Sun):

$$\Delta S_{\odot} / S_{\odot} = 2 \Delta R_{\odot} / R_{\odot} + 4 \Delta T_{eff} / T_{eff}$$

Because the relative variations of the TSI **S** during a solar cycle is < 0.1 %, the relative variation of the solar radius cannot be > 0”4 and indeed, it is considerably smaller (possibly near 10 msec) due to the variations of the effective temperature T_{eff} of the quiet photosphere, *which, however, seems not correlated with the solar cycle and magnetic activity (Kitt Peak 35 Years long measurements using solar spectra (Livingston et al.).*

Total Solar Irradiance

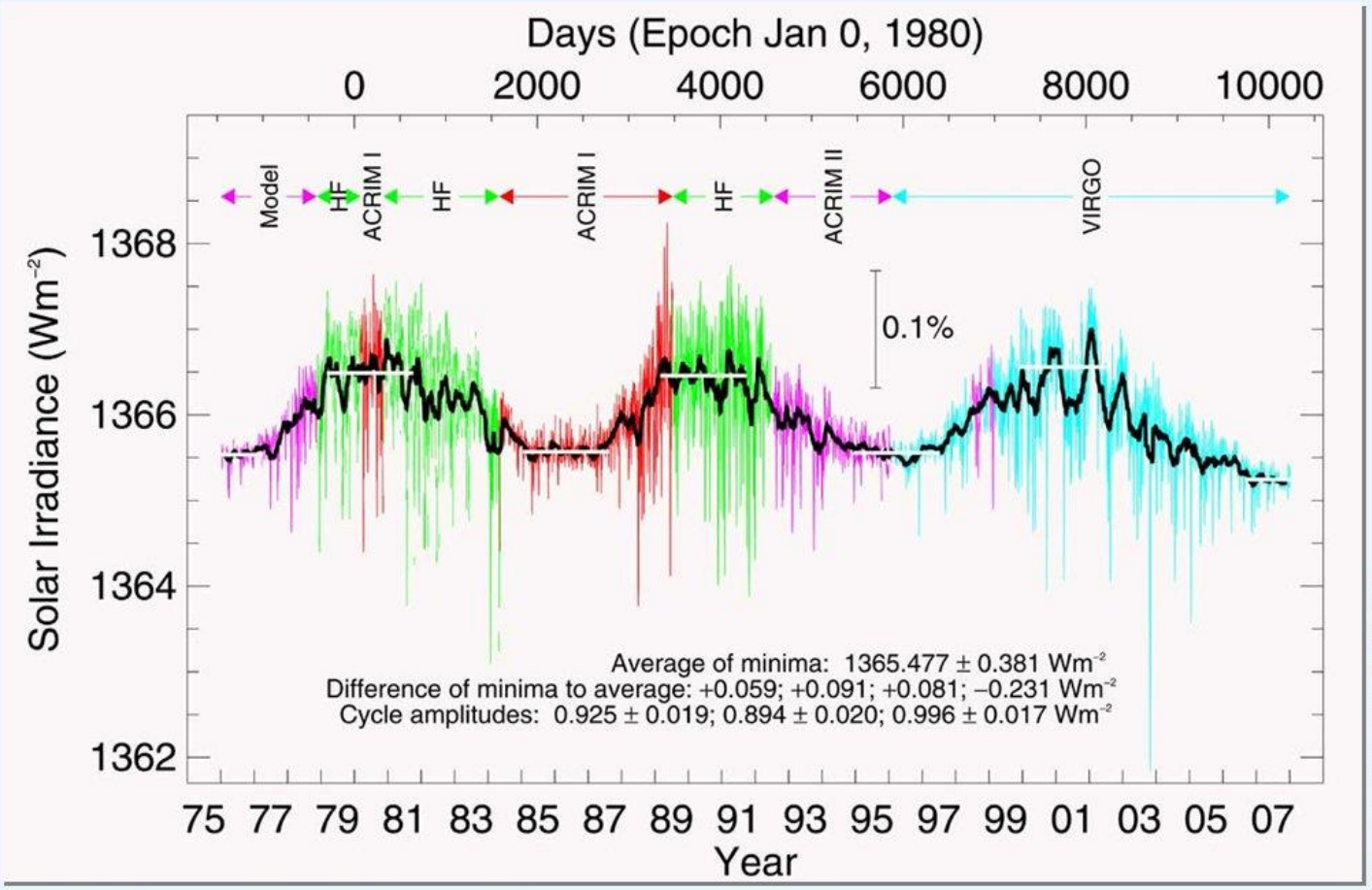


Figure from C. Fröhlich

- TSI is lower this minimum than the previous two
- Unexpected change after a greatly disputed increase in the previous minimum
- Few mechanisms exist for magnetic changes in the basal solar luminosity

To quantitatively translate solar magnetic modulation into irradiance variations, a clear mechanism-understanding is needed, or, better, evidence from solar "global" data are needed, including the solar radius variations

Measurements of the solar diameter variations have been performed for a long time (ex: A. Secchi book, 1872).

Several methods have been and/or are still used to measure the solar diameter:

- Specially designed **Heliometers**
more than 100 Years old=> visual but still the best “canonic” value (R=959”63) !?;
a large (1”57) correction for “irradiation” effect is introduced;

- Analysis of **planetary transits** (Mercury; Venus);

- **Solar Astrolabes** working at almucantarat
(long series; no correction for refraction; small aperture=> seeing);

- **Solar transit measurements** made with stationary G-B telescopes measuring at the same almucantarat;

- Analysis of **solar disk images made in Space**
MDI of SoHO; HMI of SDO? and Rhessi guiding device signal
dedicated **Picard mission**.

- Solar **Total Eclipse timing** of “contacts”.

A dedicated space mission was designed to avoid Earth Atmospheric effects (seeing)

THE PICARD mission

Gérard Thuillier[1], Werner Schmutz[2], Steven Dewitte[3], M. van Rumbeke and the PICARD team[4]

1 LATMOS-CNRS, France
2 PMOD-WRC, Switzerland
3 RMI, Belgium
4 ORB, PMOD, RMIB,CEA, CSA/EC, IAS, Obs. Meudon, OCA, Yale

Jean PICARD (1620 - 1682)

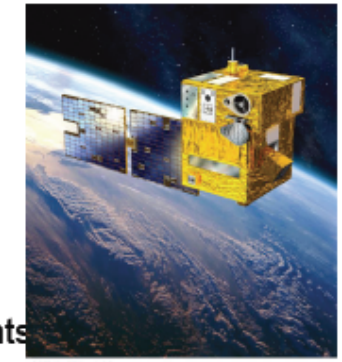
Outline

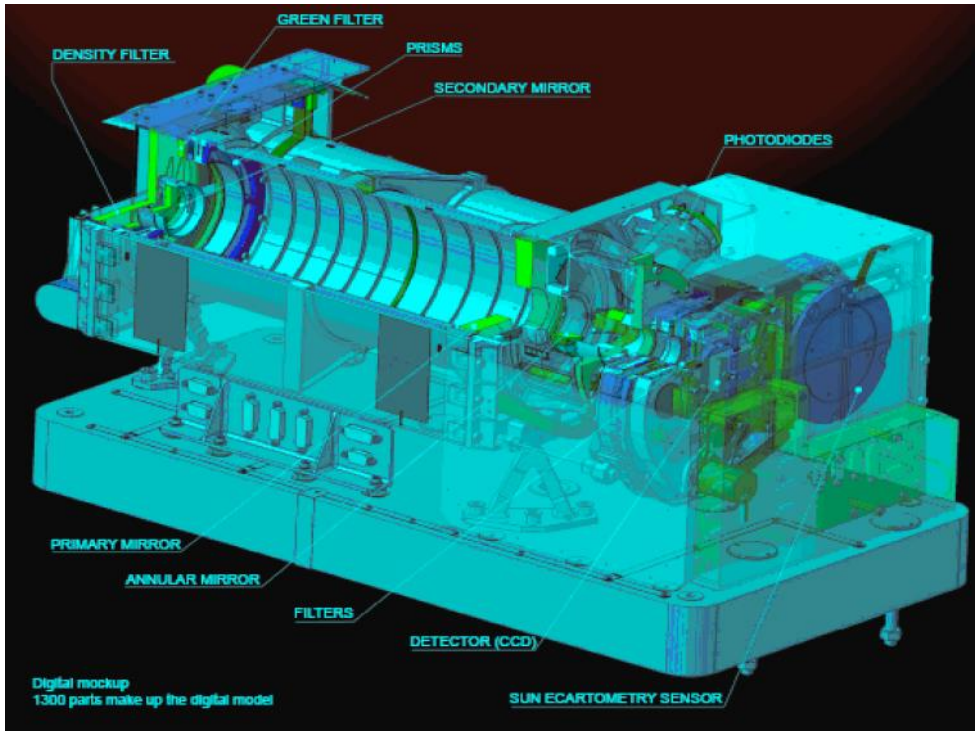
PICARD launch and solar activity predictions

PICARD scientific objectives

PICARD measurements

PICARD Mission with its associated measurements

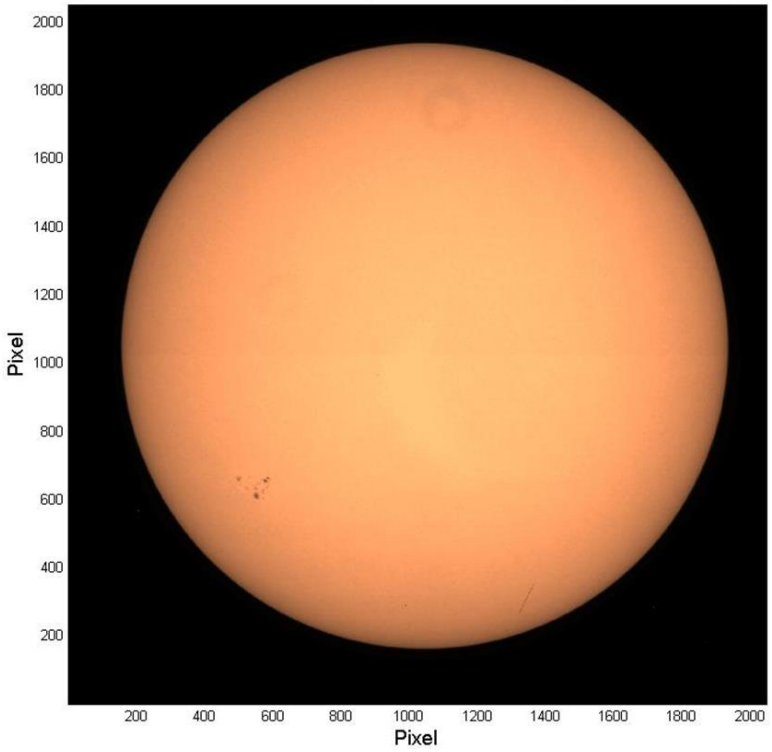




The SODISM instrument to measure the Solar Diameter using different filters (includes UV and KCaII filters)

1st light image on July 22, 2010.
After the commissioning phase (2010- 2011) orbital effects appeared, giving poor absolute values of the Solar diameter. Mission stopped in Apr.2013-
1 million images recorded.

"Picard mission" launched on June 15, 2010

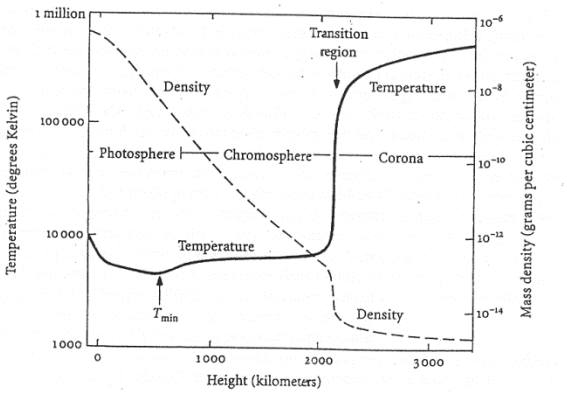


Failed to produce "direct" values due to orbital effects (Meftah et al, 2014) !!!!

The Solar Limb observed in the “pseudo-continuum” (broad band)

More than 120 Years old visual <R_{sun}> measurements of Auwers (1894) are still the best “canonic” value (959”63) used in Litterature!?; But, a large (1”55) correction for “irradiation” effect was introduced.
<u>Irridiation effect is absent at time of Solar Total Eclipses.</u>

Moreover, the true edge of the Sun Is not sharp and its spectrum could show variations



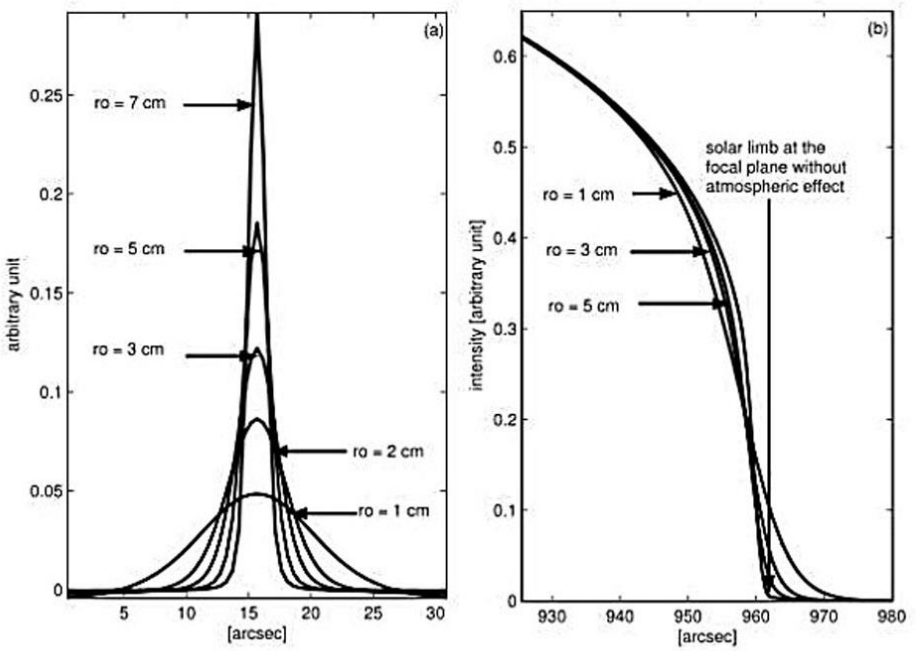


Figure 6: (a) PSF for several values of Fried’s parameter r_0 according to the Kolmogorov turbulence model, through a telescope having the instrumental characteristics of the DORaySol instrument; (b) effect of atmospheric turbulence on the solar limb. From Djafer, et al. [5].

2008 ApJ

Suggestions were made in 1980 that Solar Total Eclipses can produce critical measurements of the solar diameter

Early statements:

From ***Science*** 12 December 1980: Vol. **210**. no. **4475**, pp. 1243 - 1245

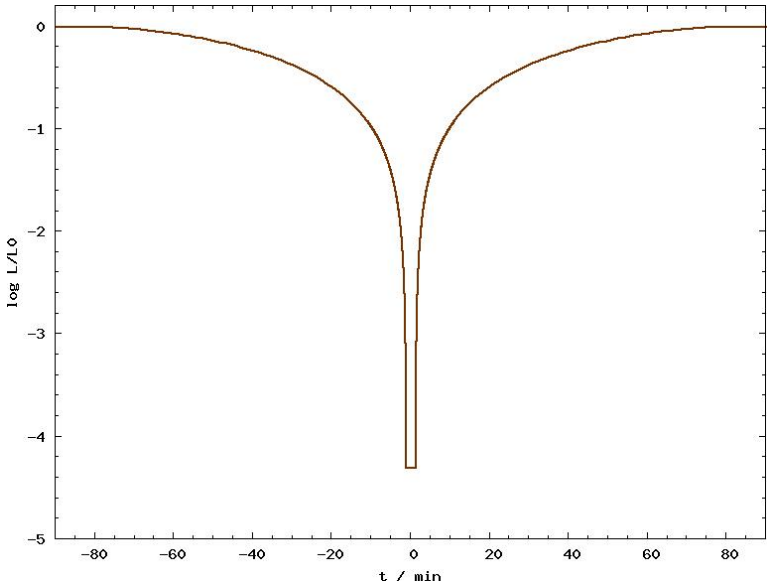
- **Observations of a Probable Change in the Solar Radius Between 1715 and 1979**

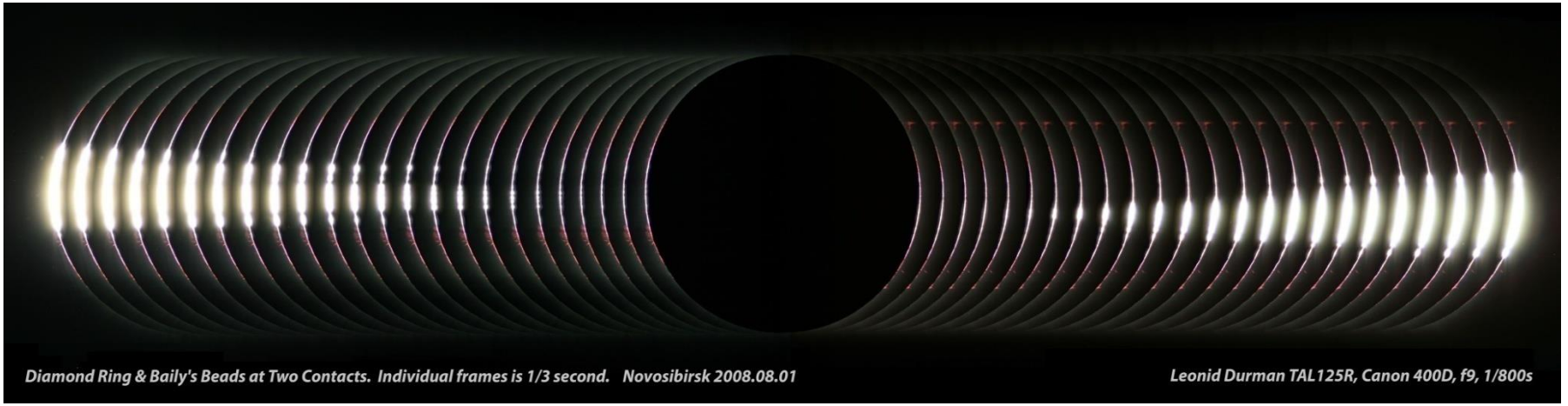
- **DAVID W. DUNHAM 1, SABATINO SOFIA 2, ALAN D. FIALA 3, DAVID HERALD 4, and PAUL M. MULLER 5**

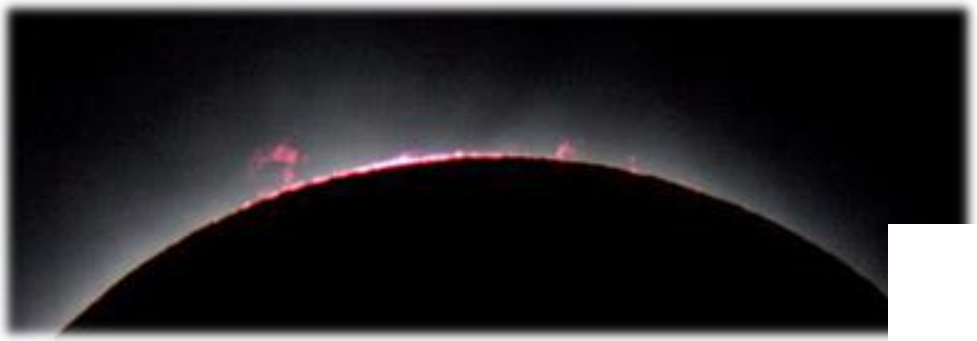
- 1 International Occultation Timing Association, Post Office Box 488, Silver Spring, Maryland 20907
  2 Laboratory for Planetary Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771
  3 U.S. Naval Observatory, Washington, D.C. 20390
  4 Post Office Box 254, Woden, ACT 2606 Australia
  5 Anglo-American Computers Ltd., Newcastle-on-Tyne, NE1 1LE England

- ***Solar eclipses were observed from locations near both edges of the paths of totality in England in 1715, in Australia in 1976, and in North America in 1979. Analysis of these observations shows that the solar radius has contracted by 0.34 ± 0.2 arc second in 264 years*.**

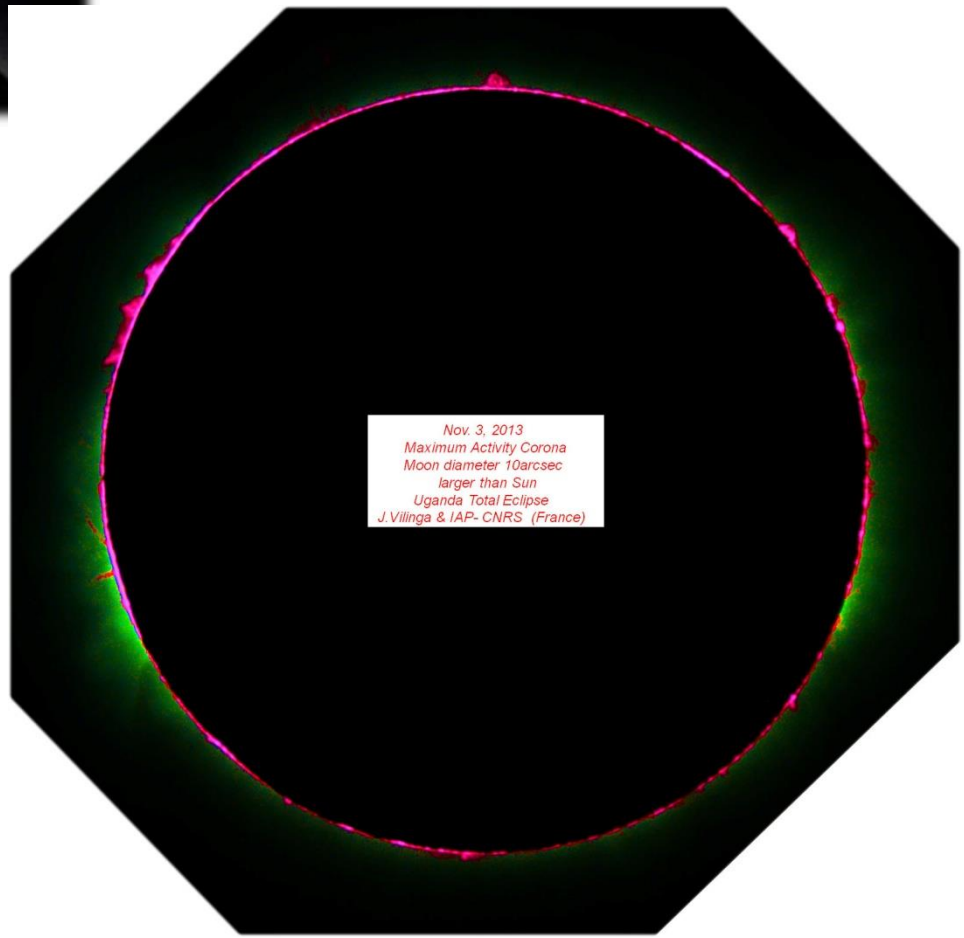
Illustration of the method







A magnified image from Jean Mouette to show the 3d contact during the last July 11, 2010 solar Total Eclipse (F660 mm; Canon 5D). :
In white, the lowest layers;
In pink, the chromosphere and prominences



Advantages of Eclipse Observations:

-Performed at ground => **economic**; small portable equipment;
- Free of seeing effects because occultation occurs in Space;
- It is a differential method: **the lunar disk is used as a "cosmic" reference**
(differential apparent motion of Sun and Moon
magnified by >1/30 compared to the diurnal motion)

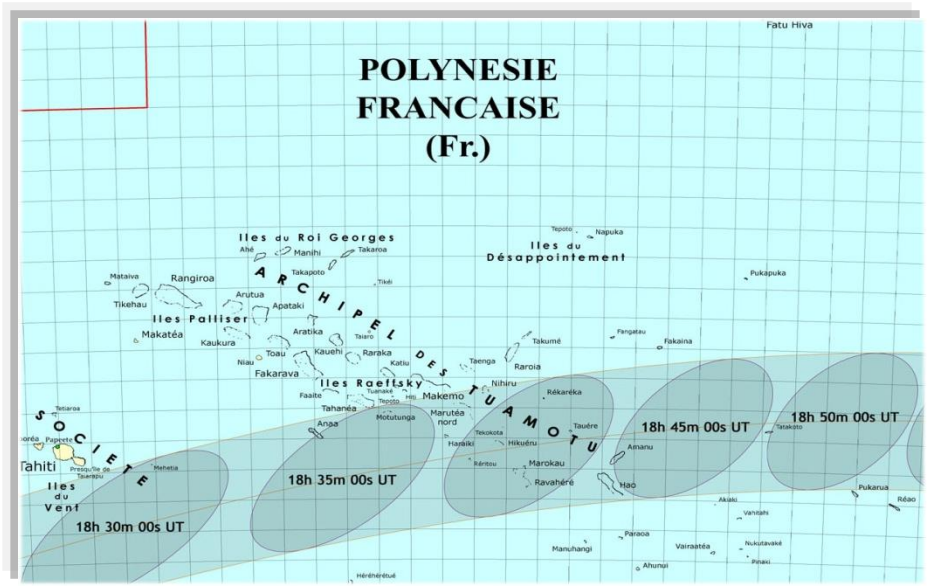
- **Free of** spurious effects due to the **scattered (parasitic) light**
from the disk like it is outside of total eclipses
unique method to correctly see the edge of the Sun!

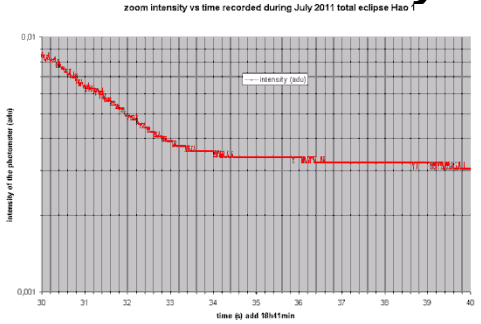
Additional advantages coming from the use of recent technologies:

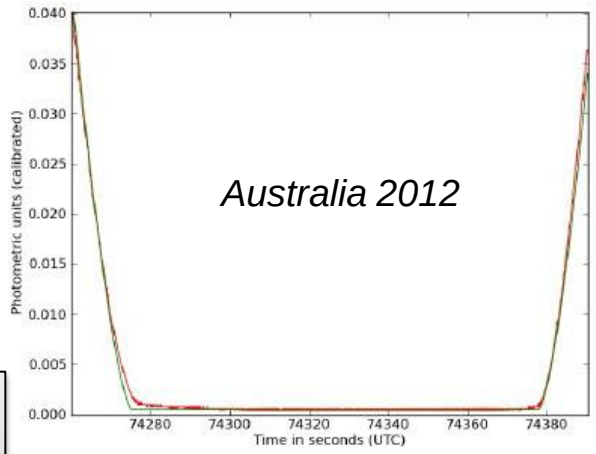
- Precise timing and positioning using GPS devices;
- Fast CCD imaging and **spectrally resolved time ser**ies;
- Finally: more precise lunar profiles are available
from stellar occultations and from the Kaguya space mission.

First results from single pixel photomatric observations were obtained at the solar total eclipse of July 11, 2010 (and after, at the 2012 eclipse in Australia)

Selected results were presented by J-P. Barriot Yesterday





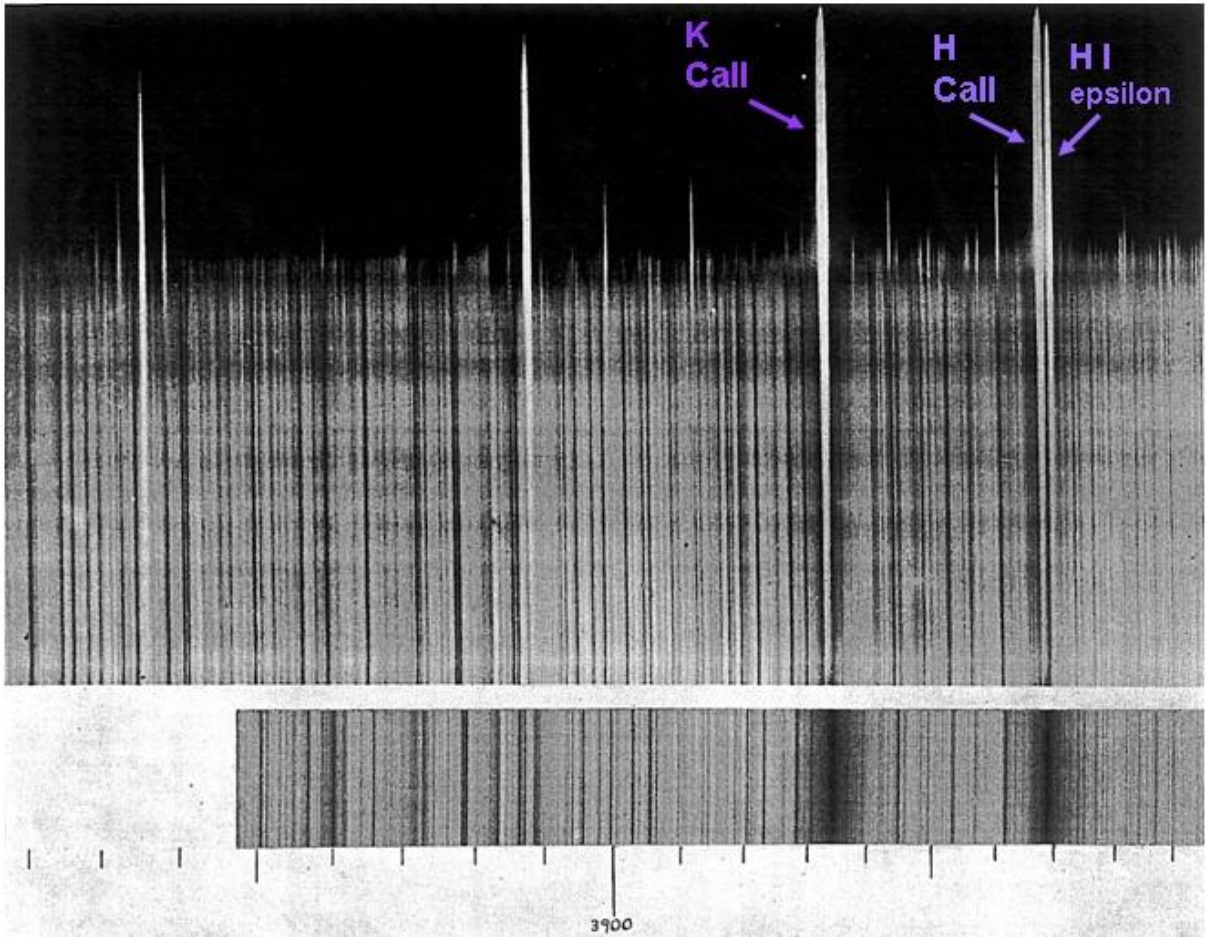


Several specially designed by CNES Photometers and Sync-systems driven by GPS Several sites for performing the measurements at each total eclipse

Designed for studying the long term solar diameter variations!

See also a Movie (extract) by Jean Mouette

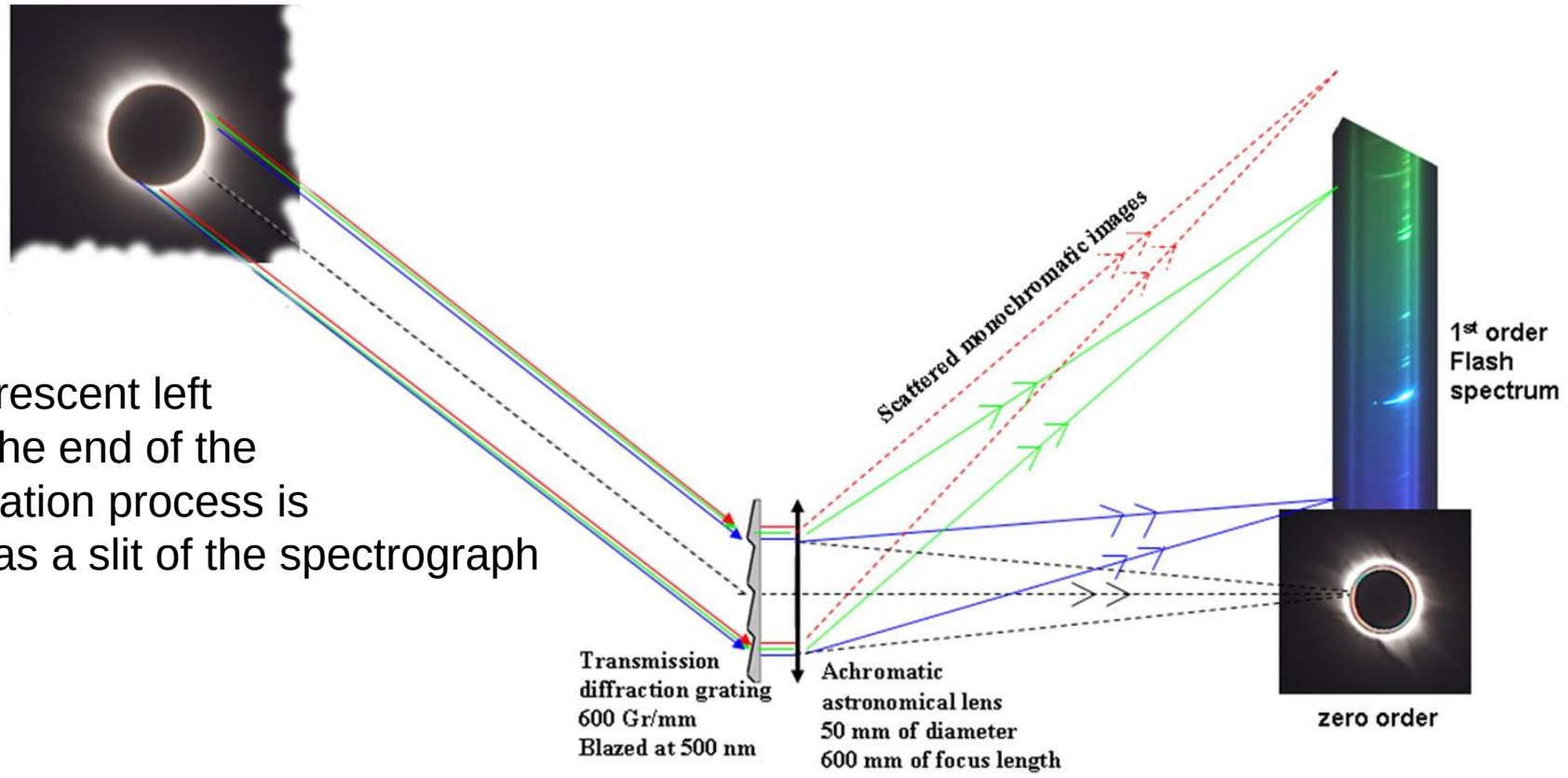
What about the **definition of the solar limb/edge** that is used?



Campbel W.W.(1904) Eclipse spectrum obtained using a ***moving plate and a radial slit***

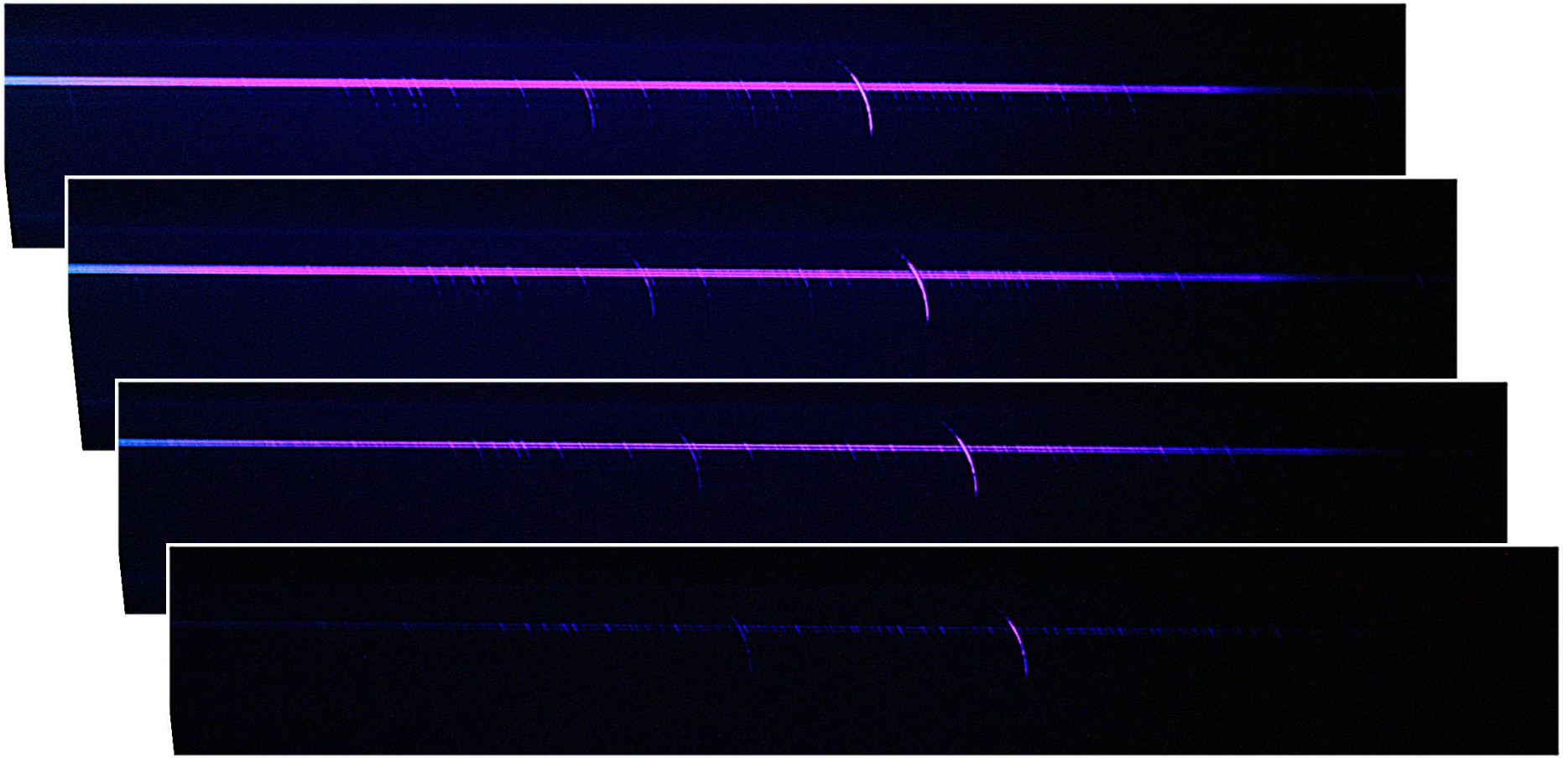
Observations with good spectral resolution free of atmospheric effects are needed: slitless (flash) eclipse spectra

The crescent left near the end of the occultation process is used as a slit of the spectrograph



Bazin et al 2006- 2013

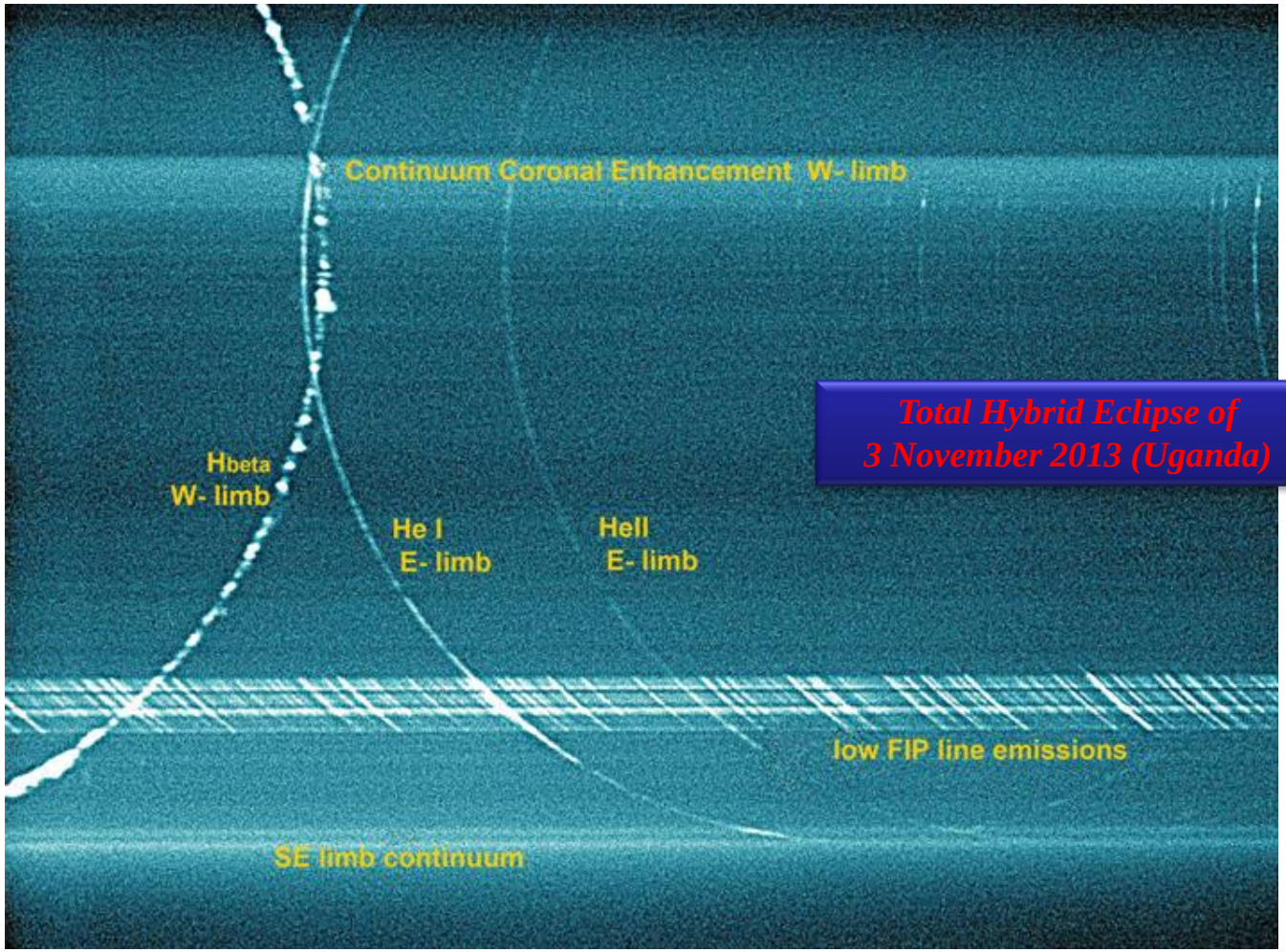
Flash spectra/SK/1200 l/mm F300mm Canon 40D; cadence 2 spectra/s; 2d contact

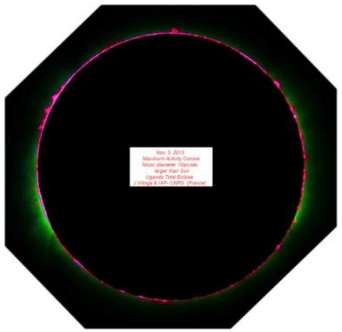


At a slow rate, 2010 eclipse in Hao- French Polynesia

High Resolution CCD Eclipse Flash Spectrum near the 2d contact and the 460 to 490 nm region *to show* ***low excitation lines*** *in* ***emission,*** ***in addition to the faint chromospheric Hβ HeI and HeII lines.***.

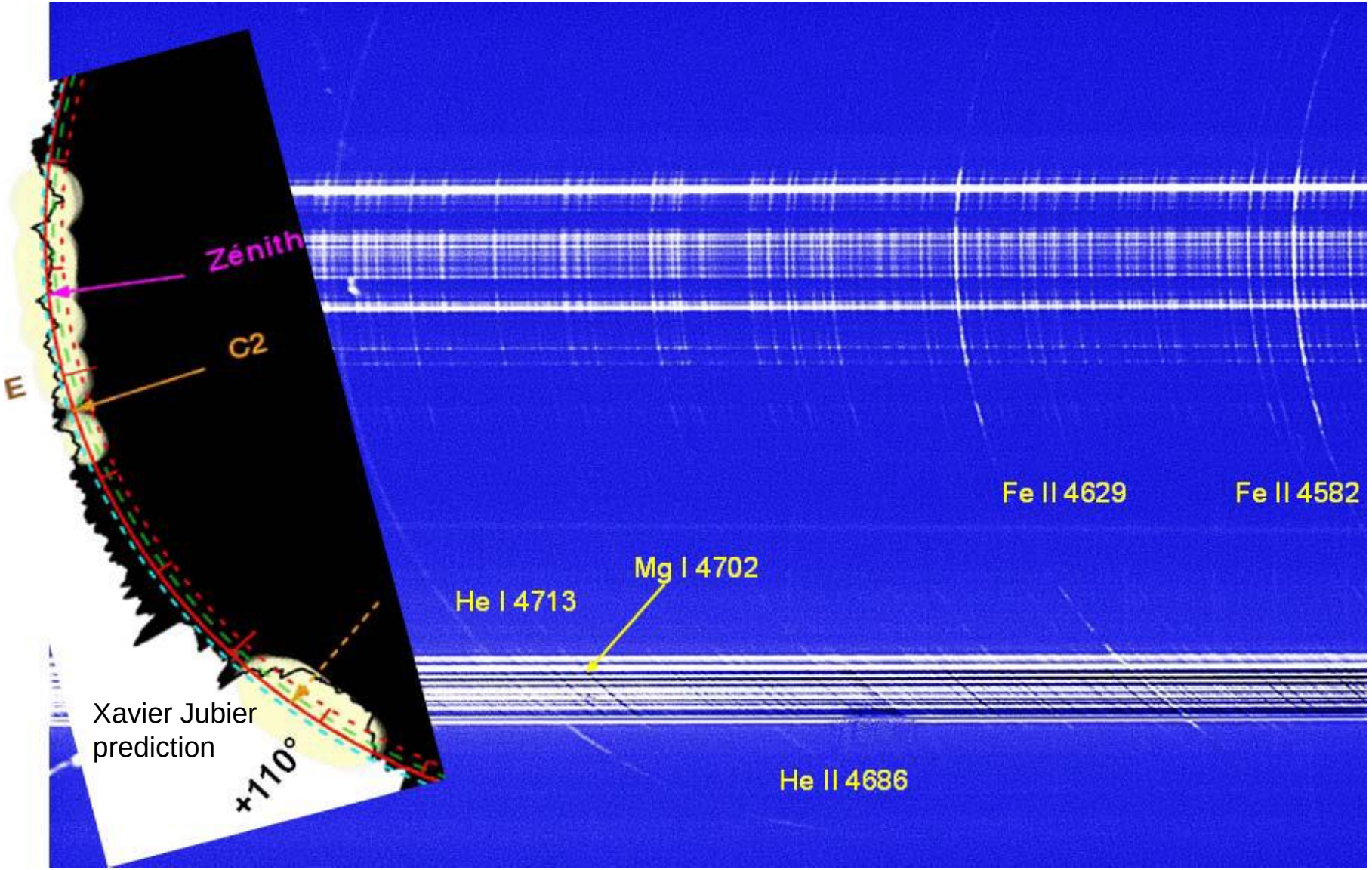
Cadence is now 15 sp/sec corresponding to # 30 km on the sun provided the details of the lunar profile are taken into account





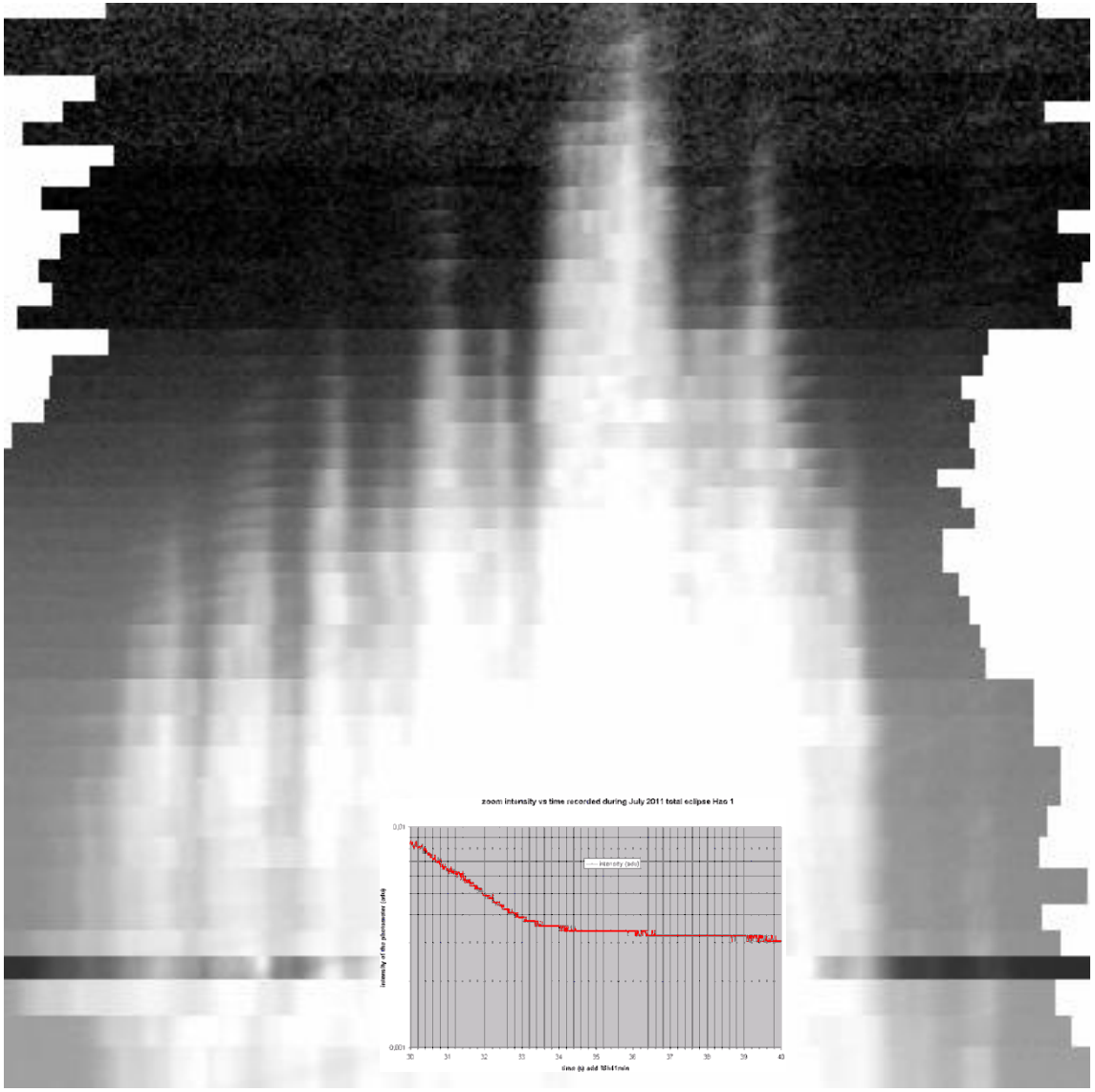
Bazin et 2014 (see poster)

Spectra from the last 2013 eclipse observed in Uganda, just before



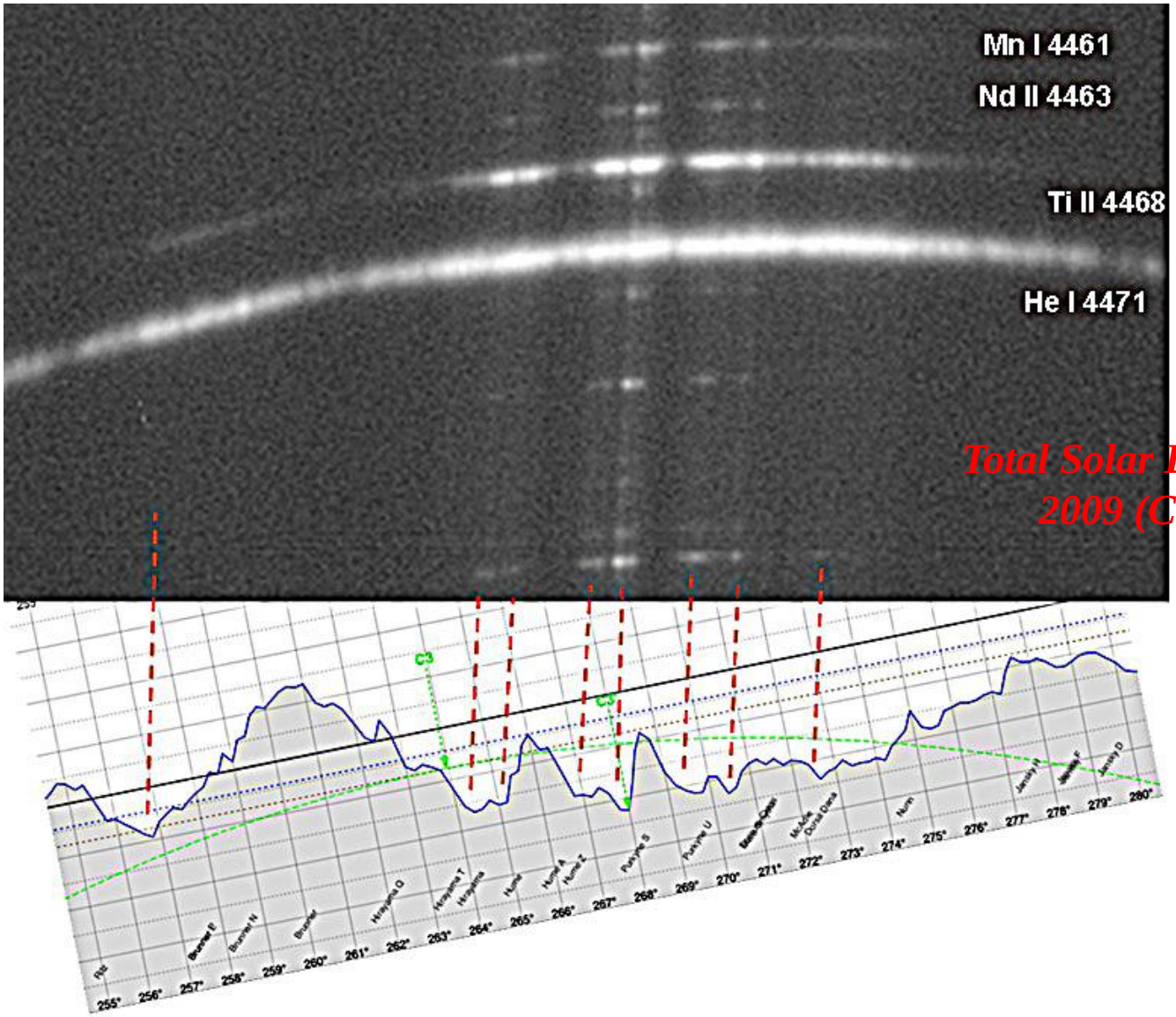
from C. Bazin et al. 2014

Superposed partial-frames in the pseudo-continuum, from a set of C3 flash spectra: ”Time-slice” analysis



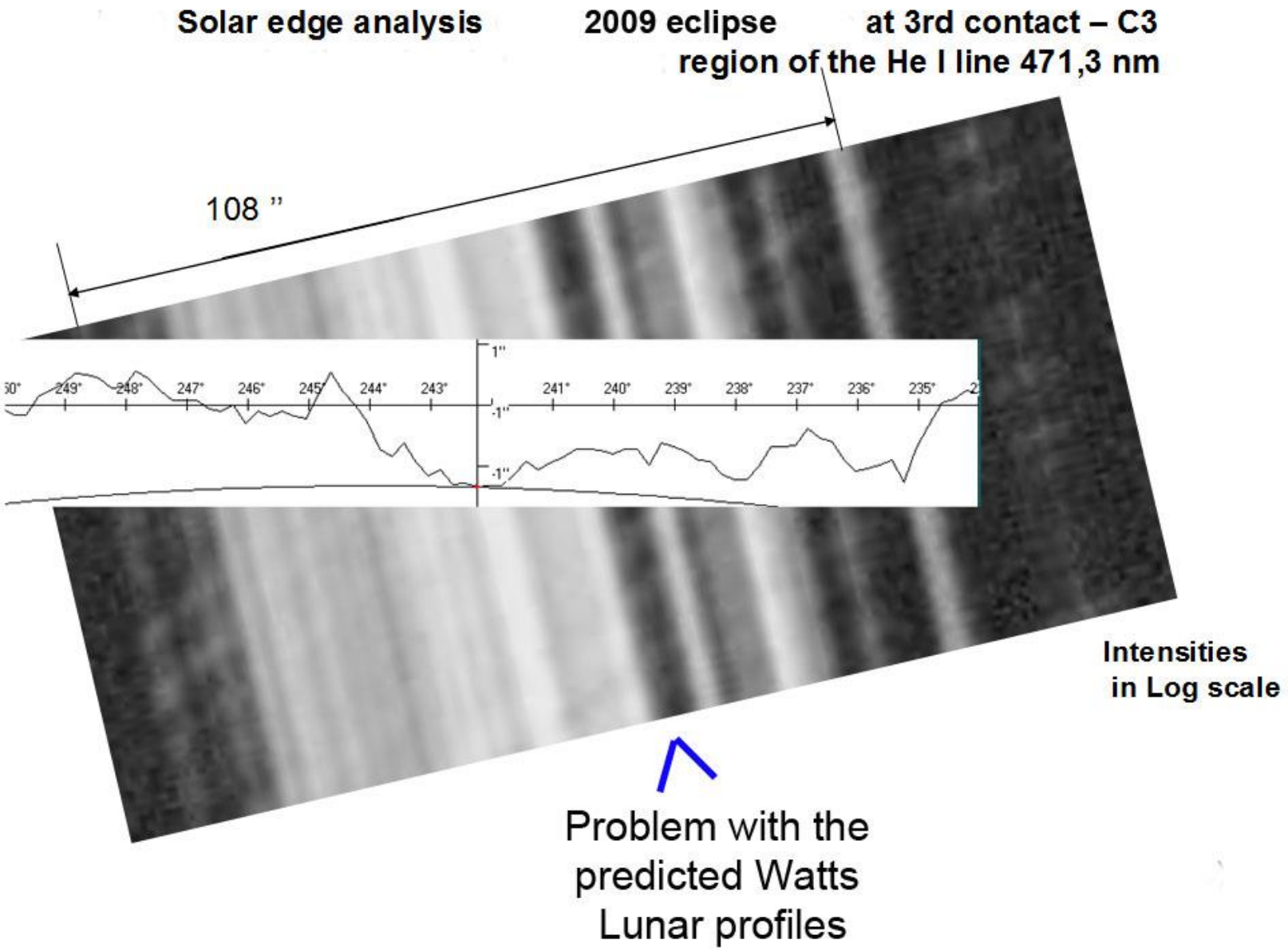
	Arc seconds
N° 5117 : 3,474 s	-0,989
N° 5120 : 3,672 s	-0,791
N° 5123 : 3,869 s	-0,594
N° 5126 : 4,067 s	-0,396
N° 5129 : 4,267 s	-0,196
N° 5132 : 4,463 s	0
N° 5134 : 4,727 s	0,264
N° 5137 : 4,925 s	0,462
N° 5140 : 5,122 s	0,659
N° 5142 : 5,254 s	0,791
N° 5143 : 5,320 s	0,857
N° 5146 : 5,518 s	1,055
N° 5149 : 5,716 s	1,253
N° 5155 : 6,112 s	1,649
N° 5158 : 7,035 s	2,572
N° 5161 : 7,233 s	2,77
N° 5162 : 7,562 s	3,099
N° 5165 : 7,760 s	3,297
N° 5167 : 8,090 s	3,627
N° 5170 : 8,288 s	3,825
N° 5173 : 8,486 s	4,023
N° 5174 : 8,816 s	4,353
N° 5177 : 9,014 s	4,551
N° 5180 : 9,211 s	4,748
N° 5183 : 9,409 s	4,946
N° 5186 : 9,607 s	5,144
N° 5189 : 9,805 s	5,342
N° 5192 : 10,003 s	5,537
N° 5195 : 10,201 s	5,737
N° 5198 : 10,728 s	6,257
N° 5201 : 10,926 s	6,457
N° 5204 : 11,124 s	6,657
N° 5207 : 11,322 s	6,857
N° 5210 : 11,520 s	7,057
N° 5213 : 11,718 s	7,247
N° 5216 : 11,915 s	7,447
N° 5219 : 12,113 s	7,647
N° 5222 : 12,443 s	7,977
N° 5225 : 12,641 s	8,177
N° 5226 : 13,037 s	8,567
N° 5229 : 13,235 s	8,767
N° 5232 : 13,432 s	8,967

Comparing with the limb profile from the classical Watts Lunar Atlas



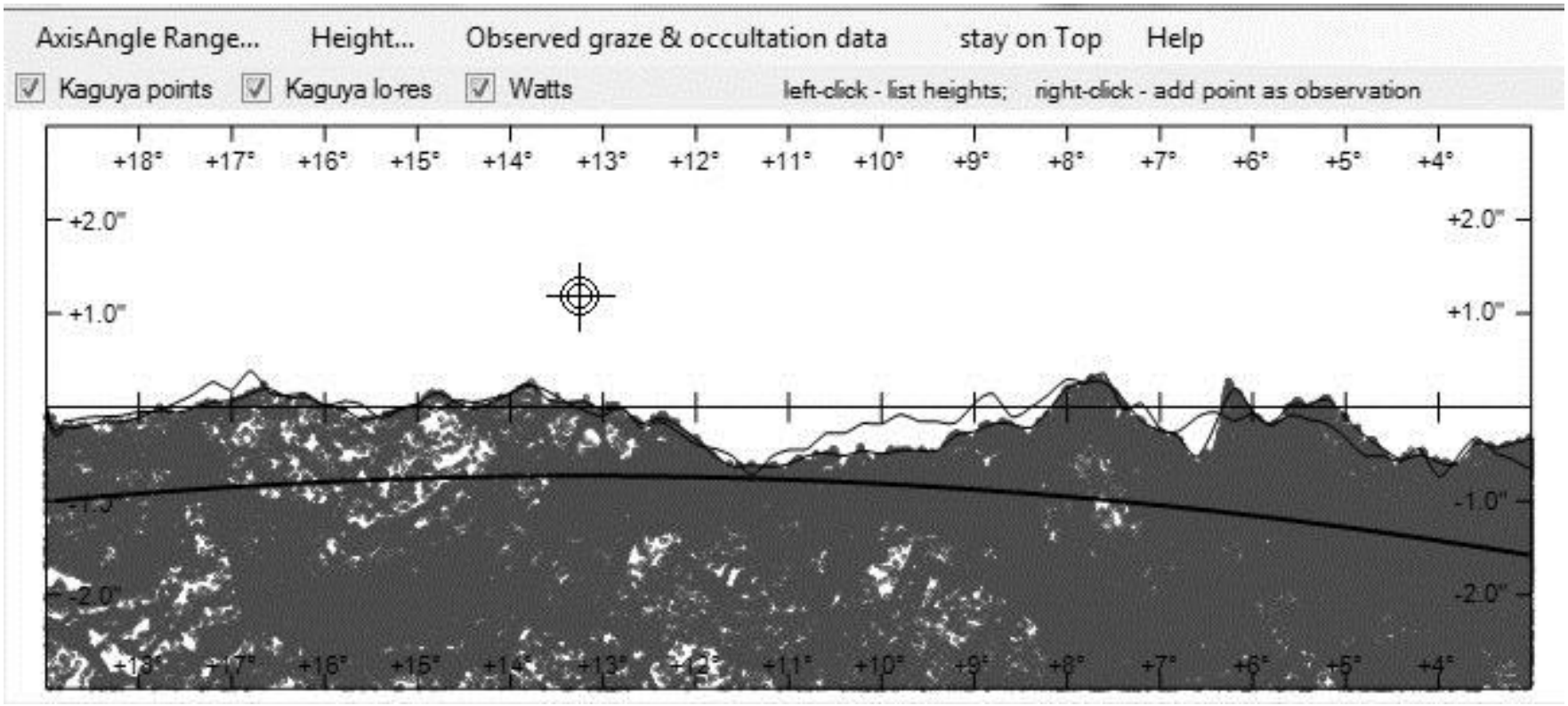
Total Solar Eclipse of 2009 (China)

At higher resolution:



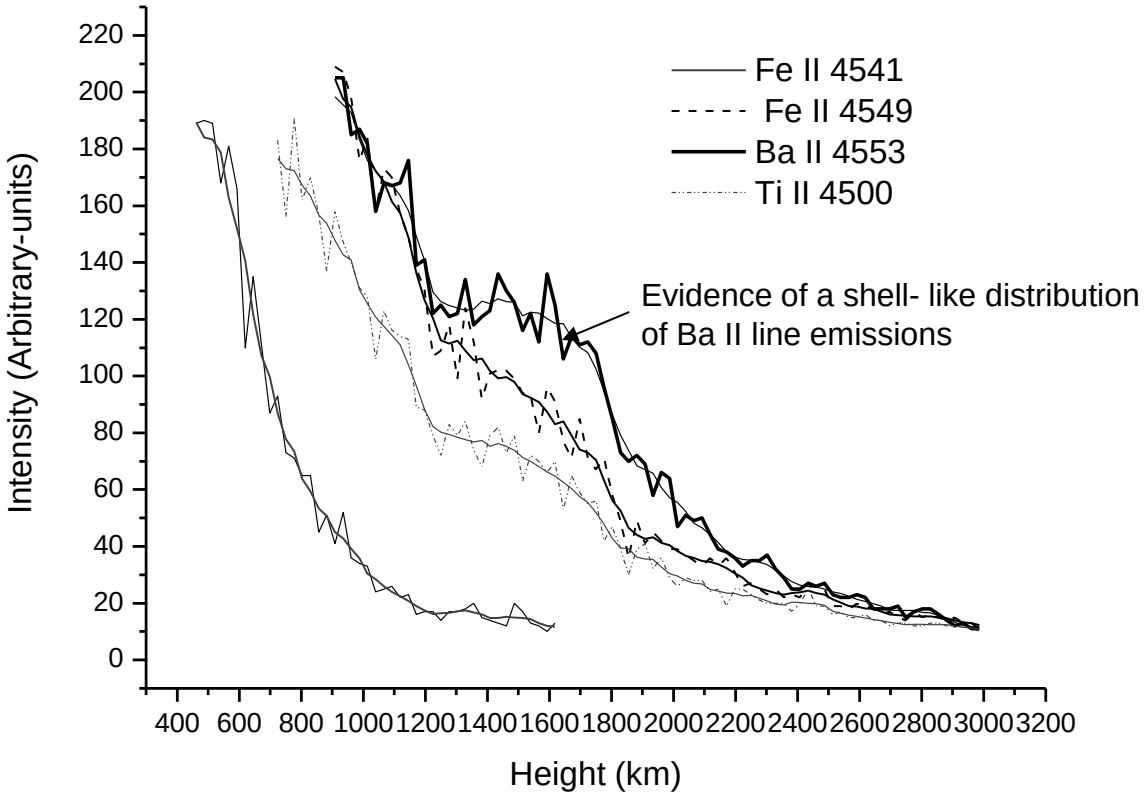
Improved lunar (3D) profiles should be used:…

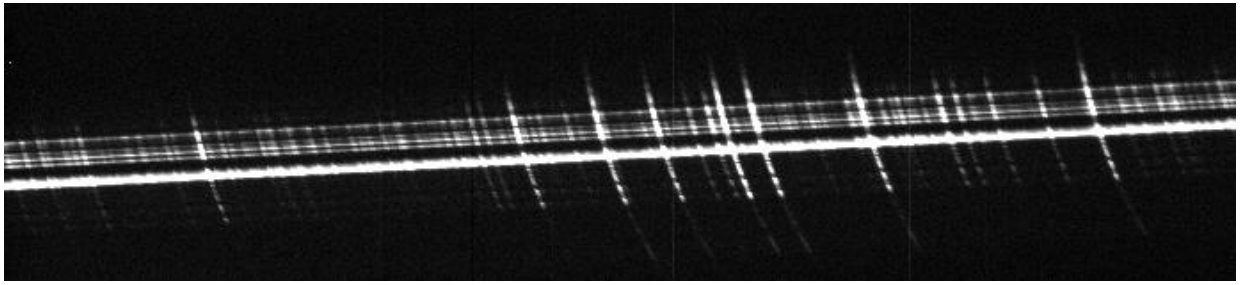
Profiles from the Kaguya satellite altimetry (JAXA-preliminary), near C2



Spectral lines at 2nd contact of July 22nd 2009 total solar eclipse in China

Intensity variations of the lines with height at 2d contact of the 22nd July 2009 solar eclipse.



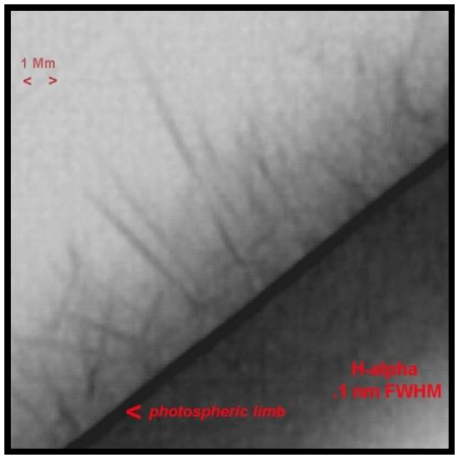


5 stacked flash spectra
at the 2nd contact
Frame rate of 15 images/s
with a CCD Lumenera camera.
Spectral lines arround 454.1 nm

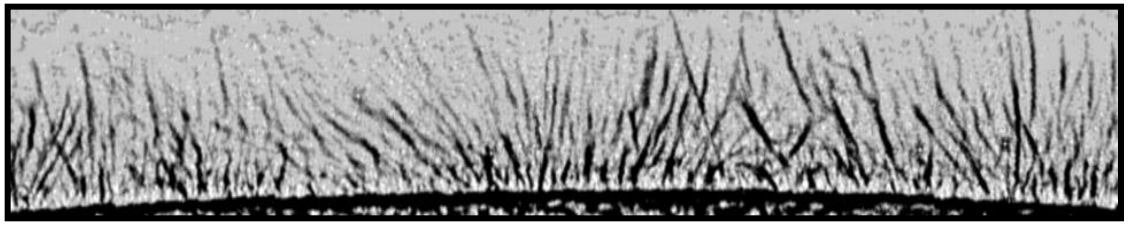
Prospects:

- **Solar diameter measurements using improved lunar profiles (Kagoya) and after averaging all the data from each eclipse, would permit a long terme survey;**

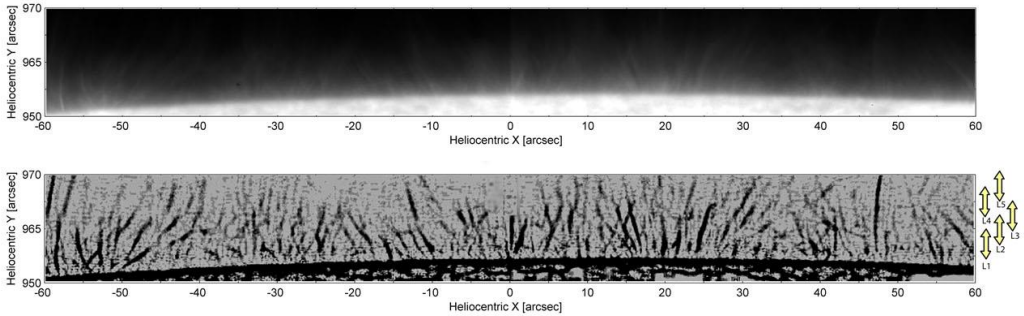
- New models of the upper layers of the solar atmosphere, immediately above the photosphere, should include magnetic effects !



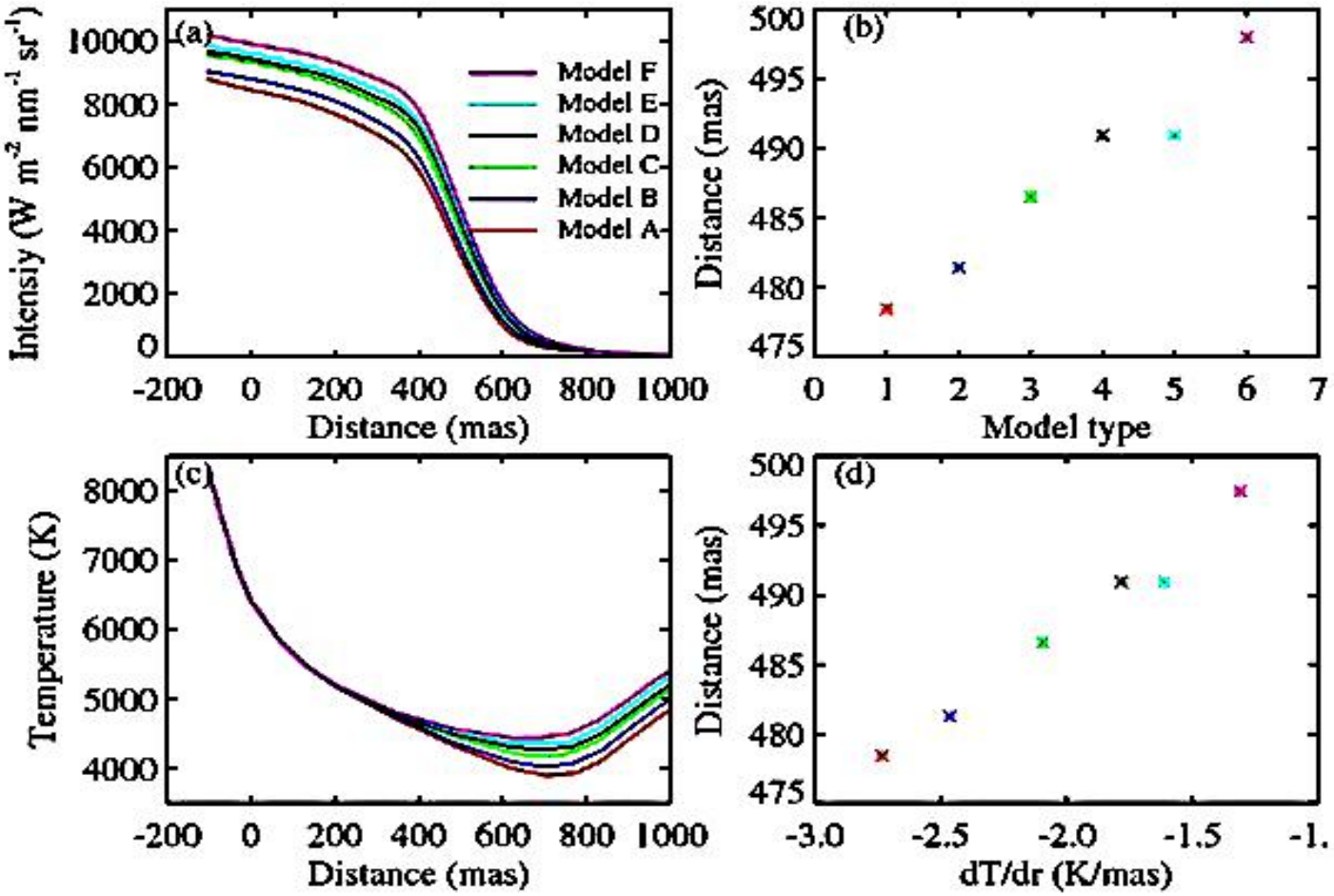
G-B Sac Peak Hα image in negative



S-B SOT Hinode processed image in HCaII



The position of the limb depends of the parameters of the Solar Atmosphere



From Thuillier et al. 2010 in SP

In conclusion

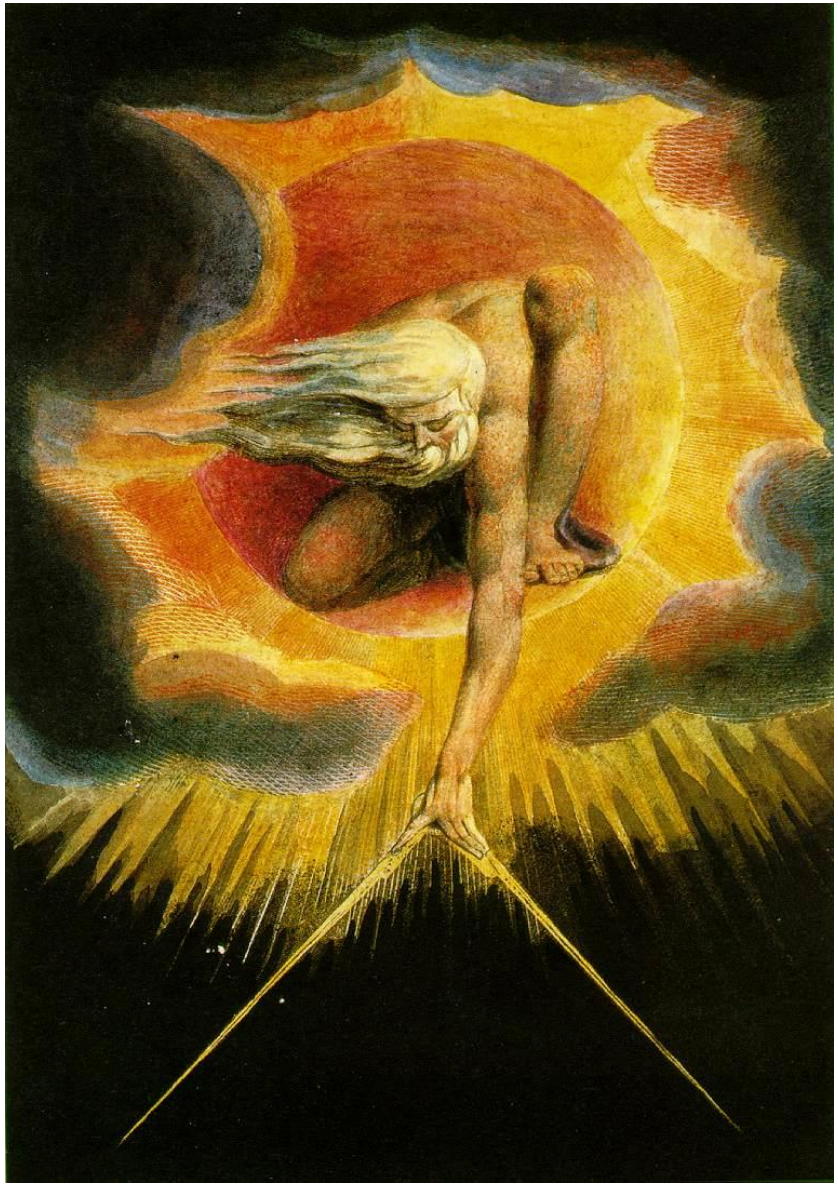
- Eclipse contact evaluations using quantitative measurements (photometers + GPS) give excellent results but total eclipses are rare events: Good for analyzing **long term solar diameter variations**!

- Besides the **emission lines** of the solar edge, true weak continuum is difficult to measure and flash spectra are needed;

- **Intensity variations of faint emission lines superposed on the true continuum, during the last and the first Baily's beads (near the 0.5 to 1 Mm heights) must be discussed to interpret historical (visual) and broad band contempory results;**

- A new **Solar edge** definition is needed: role of the faint singly ionized emission lines seen at the limb ? Interpretation in term of SSI is better.

- The **solar global magnetism** clearly influence the details of the layers at the limb.

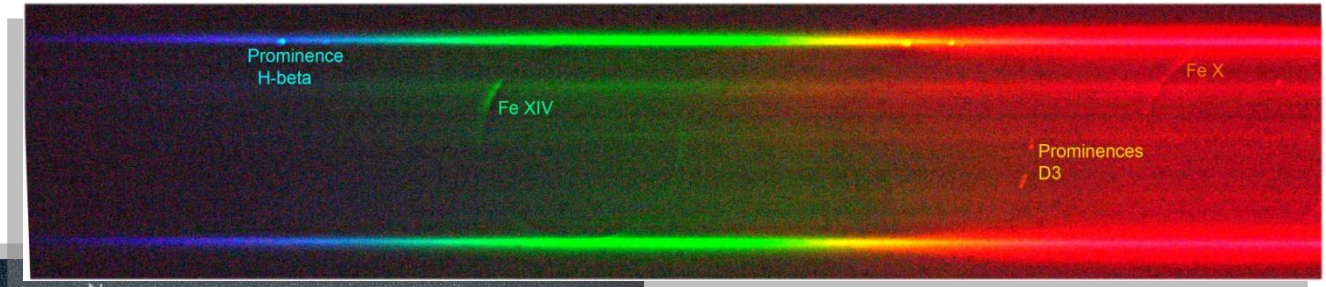


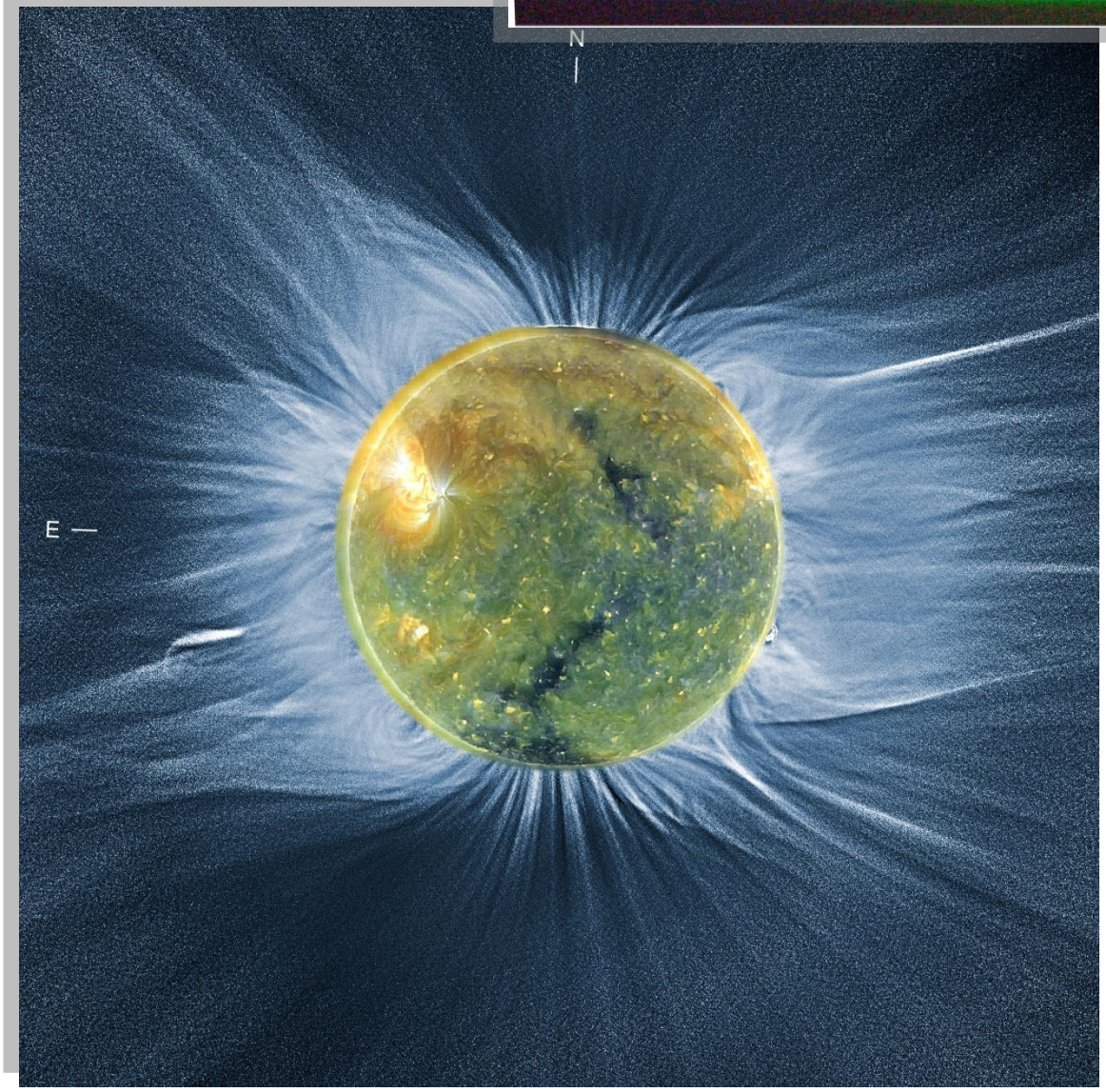
The Ancient of Days, frontispiece to *Europe a Prophecy*.
by William Blake (1794)

Thanks for your attention!

Merci de votre attention!

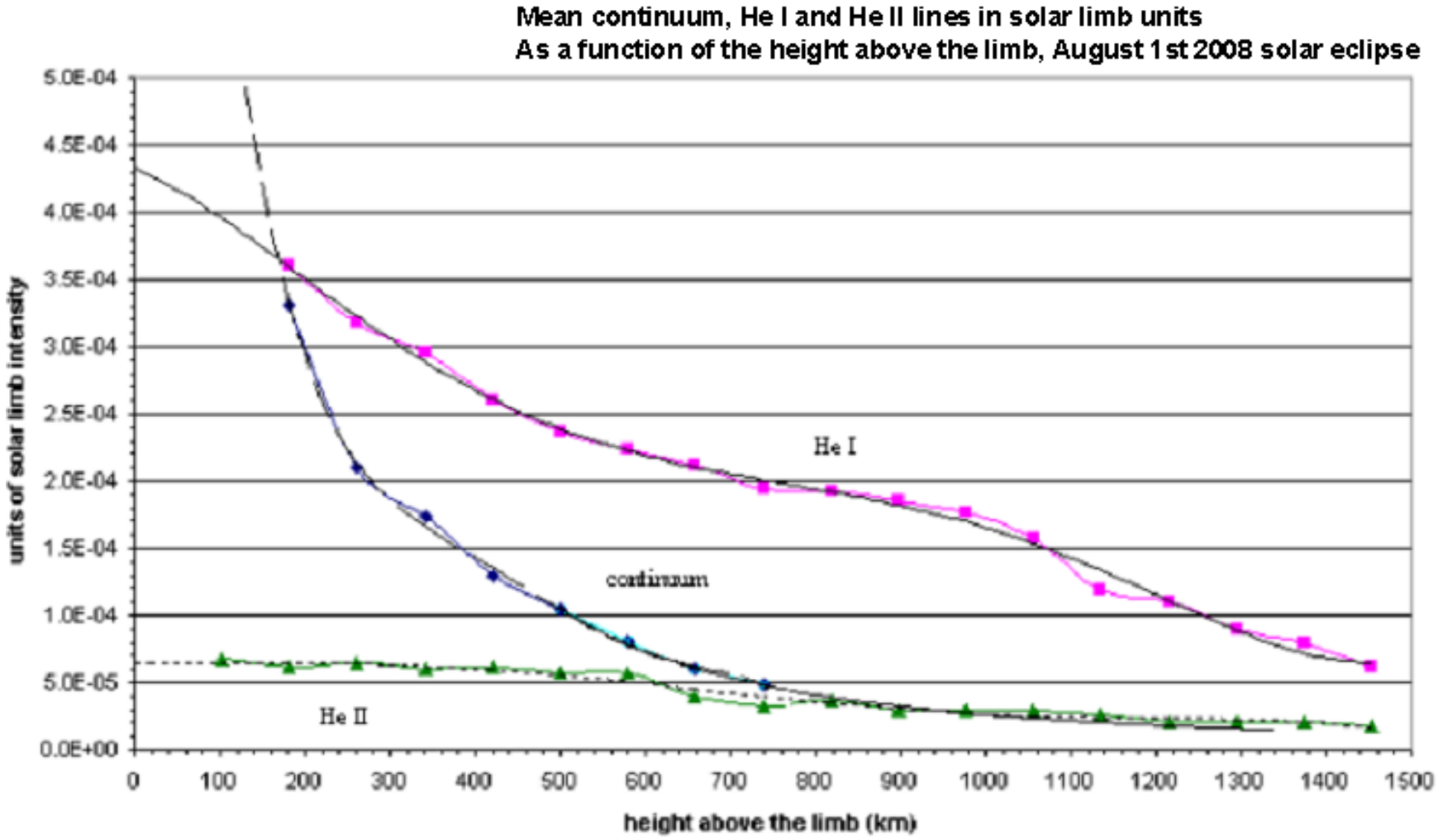
Coronal slitless spectrum (from S. Kuzin)





Reconstructed coronal Image (from J. Mouette) with AIA image inserted A magnetically dominated corona

Continuum flux variations obtained during the 2nd contact at the 1st August 2008 solar eclipse in Siberie



25 frames/s correspond to a 15,9 km spatial sampling. Watec camera 8 bit CCD-video