Total Solar Eclipses to Measure the Solar Diameter and its variation

by:

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- The solar diameter(s): Oldest Unresolved Problem of Solar Physics!

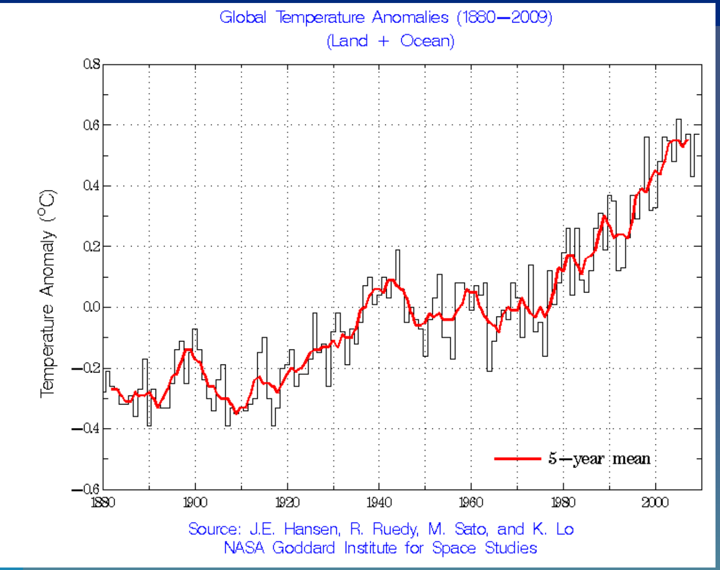
- Its variation in time has been suggested: Periods? Amplitudes? Phases?
- Additional aspects: shape of the limb (edge); oblateness

Considerable progress done lately

During the last decades, analysis of possible effects of the irregular activity cycles of the Sun through **solar forcing effects on irradiance variations**

/connected to the question of the **anthropogenic origin of global warming**, with many consequences for the **climate** and economic **life/**

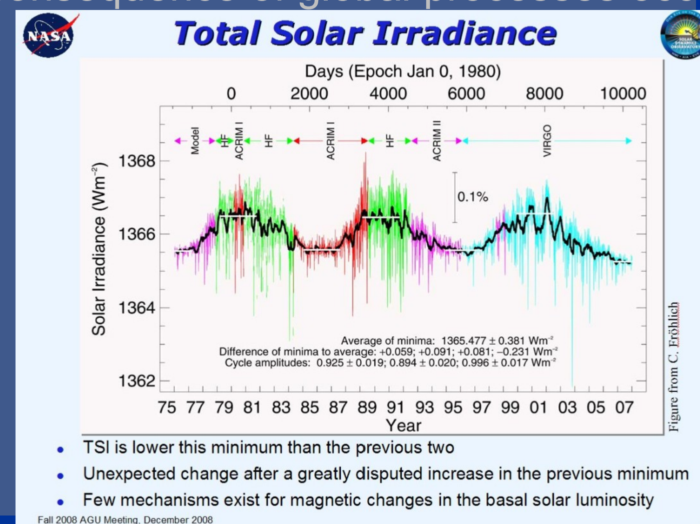
But, **what is the origin of the irradiance variations?**
One possibility is the variation of the Solar Diameter.



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 equal to the astronomical unit (constant) while variations over the solar disk are neglected and the orbital modulation are removed.
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):



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

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; then the variations of the effective temperature of the photosphere should be responsible but seem not correlated with the solar cycle and magnetic activity from 35 Years long series measurements at Kitt Peak using solar spectra (Livingston et al.).

Methods used to measure the solar diameter:

- Specially designed **Heliometers:** more than 150 Years old=> irridiation; seeing

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

- **Solar Astrolabes:** long series; small aperture=> seeing; big dispersion of data;

- **Solar transit measurements** made with G-B telescopes: irridiation; seeing; visual; but after 125 Years, still the best “canonic” value !?

- Analysis of **solar disk images made in Space:** MDI of SoHO; dedicated **Picard mission**; HMI of SDO; HXRT guiding device signal of Rhessi; planetary transits.

- Solar **Total Eclipse timing** of “contacts” at G-B: no seeing effect; long range measurements possible; Moon limb profiles with improved precision; epherides.

At time of solar total eclipses: precise timing of the 2d and the 3d "contacts"

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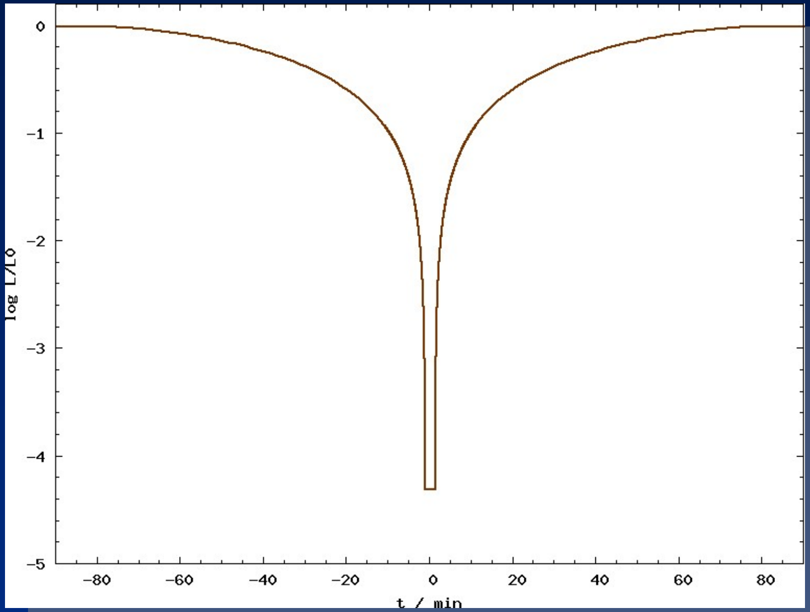

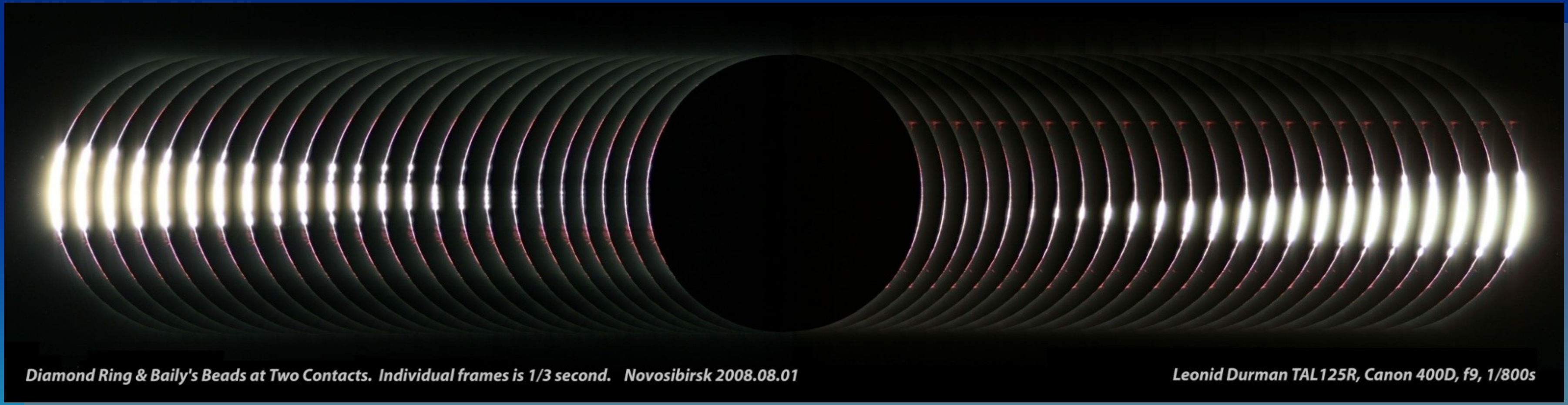

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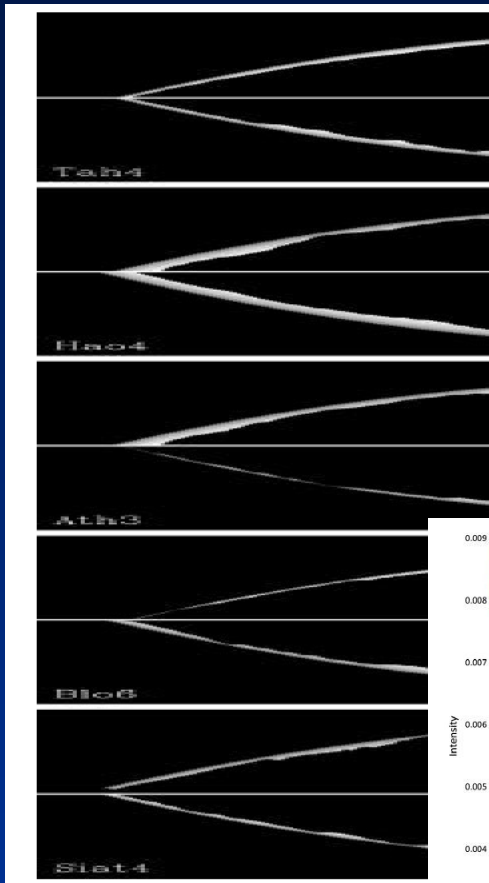
Advantages of Eclipse Observations:

- **Economic ground-based measurement with small portable equipment;**
- **Free of seeing effects: occultation occurs in Space and fluxes recorded;**
- **It is a differential method: the lunar disk is used as a reference**
(differential apparent motion of Sun and Moon magnified by >1/30)
- **Free of spurious effects due to the scattered (parasitic) light from the bright disk which is fully covered by the Moon**
(the only method giving this fundamental advantage, even in Space)

Additional advantages coming from the use of present technologies:

- **Precise timing and positioning using GPS devices;**
- **Fast CCD imaging and spectrally resolved time series;**
- **Finally: new lunar profiles available from the Kaguya space mission with improved precision.**

Eclipse contacts



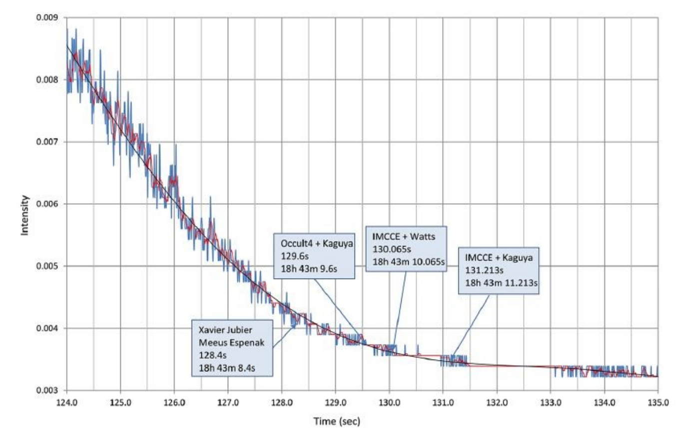
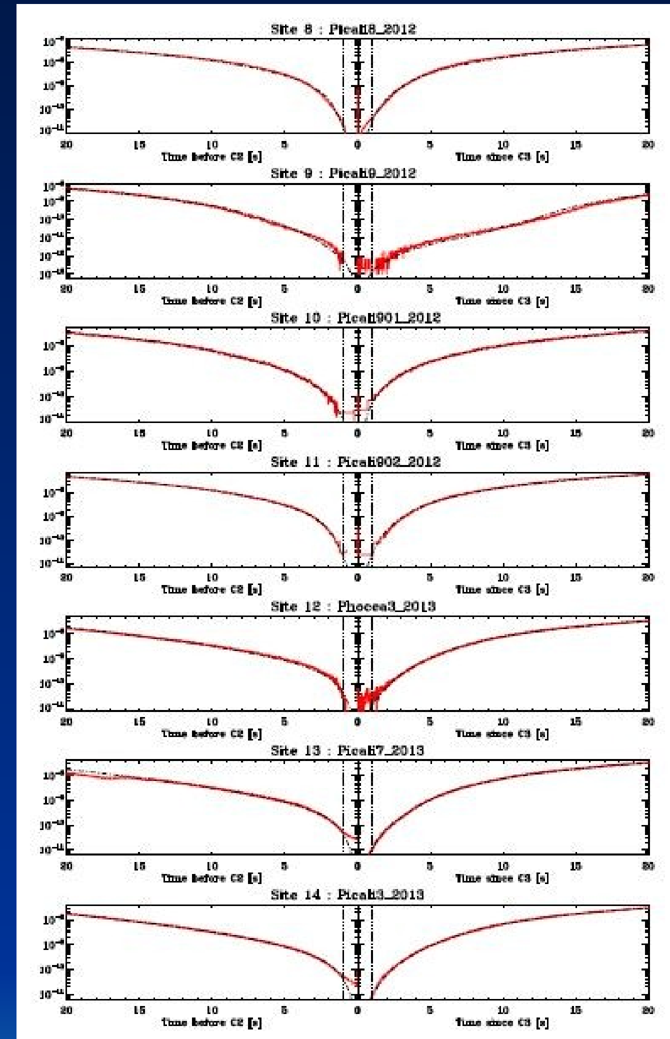
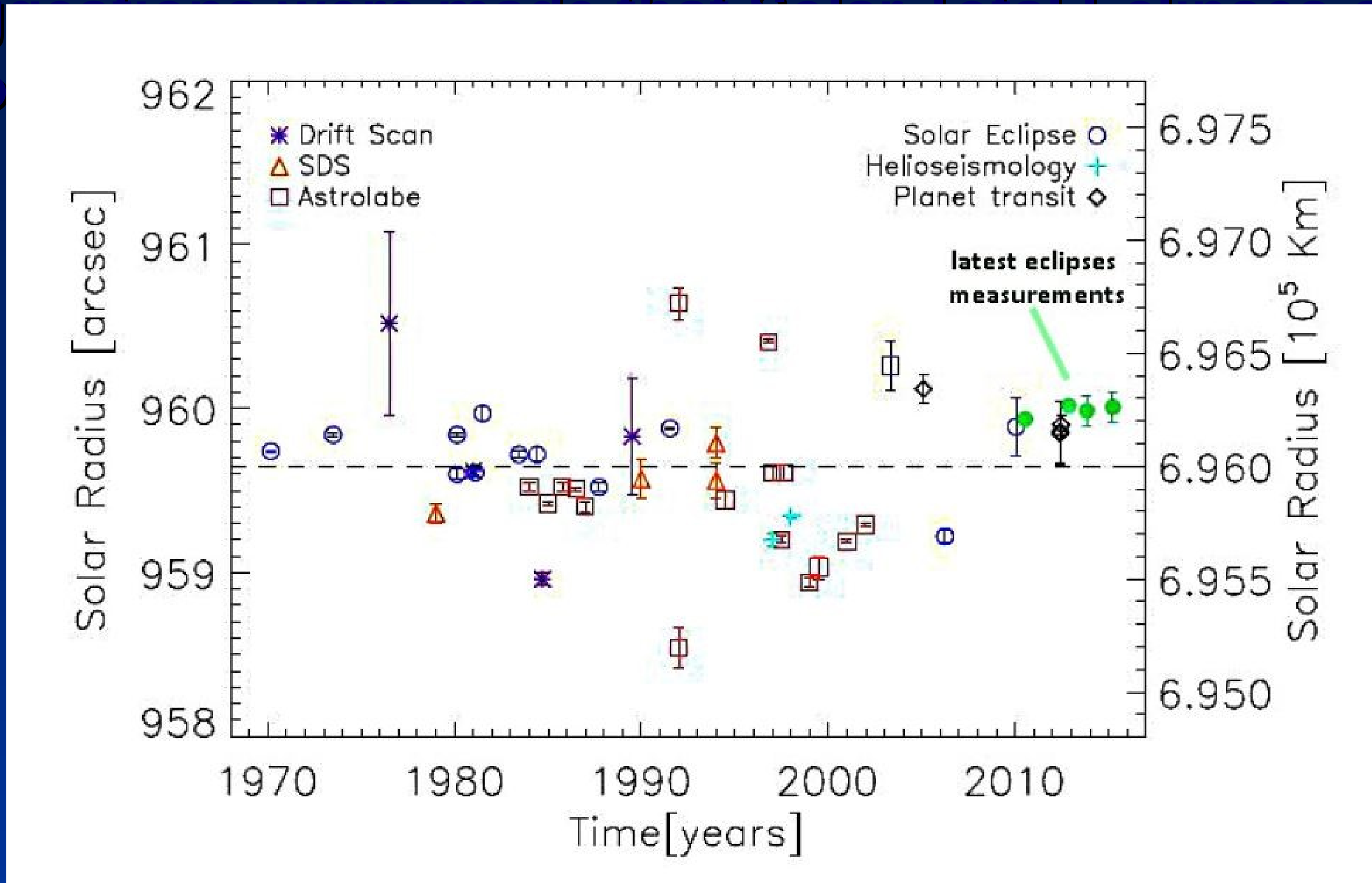


Figure 2 Illustration of the differences between various determinations of the time of second contact for the eclipse on 11 July 2010 at one of the observation sites on the Hao atoll. IMCCE corresponds to the method described in Section 2.2 with two different lunar limb profiles, "Watts" and "Kaguya". References for the two other sources are provided in the text. The original light curve (blue line) is also displayed after applying two different smoothings (red and black curves).



From Lamy et al 2015 in SP



Latest results from different methods (*from Lamy et al 2015*)

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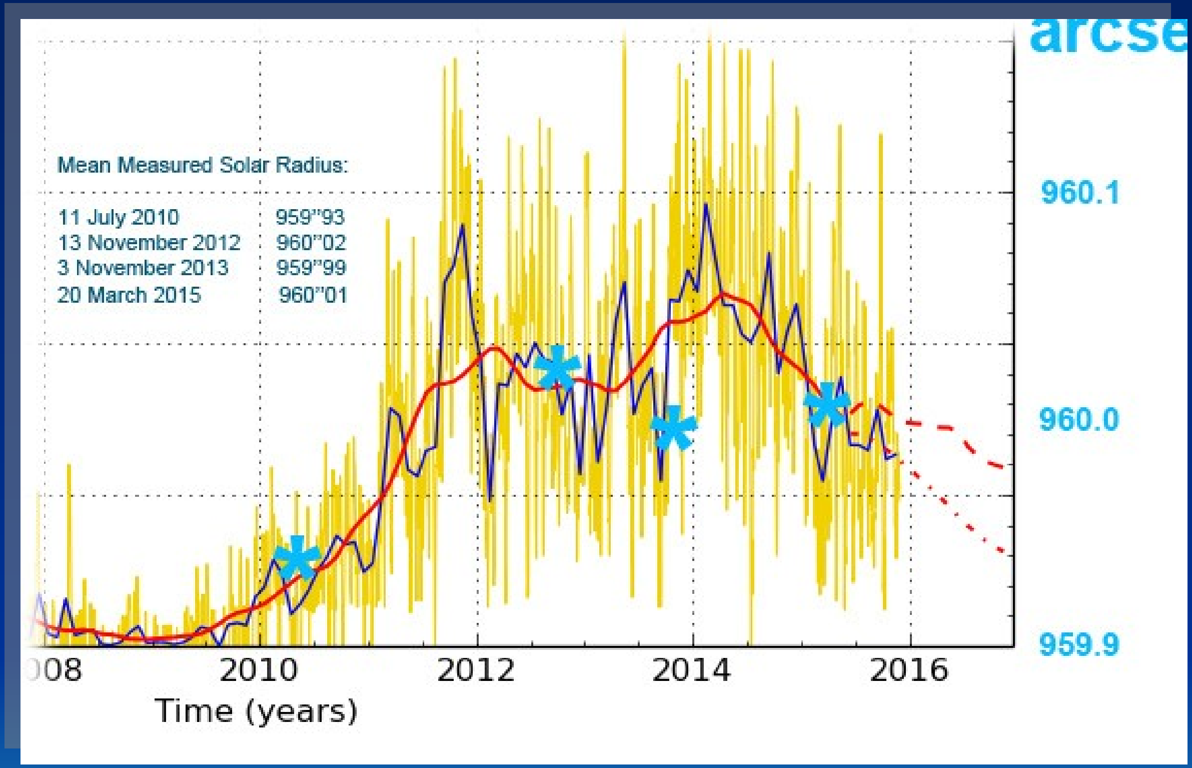
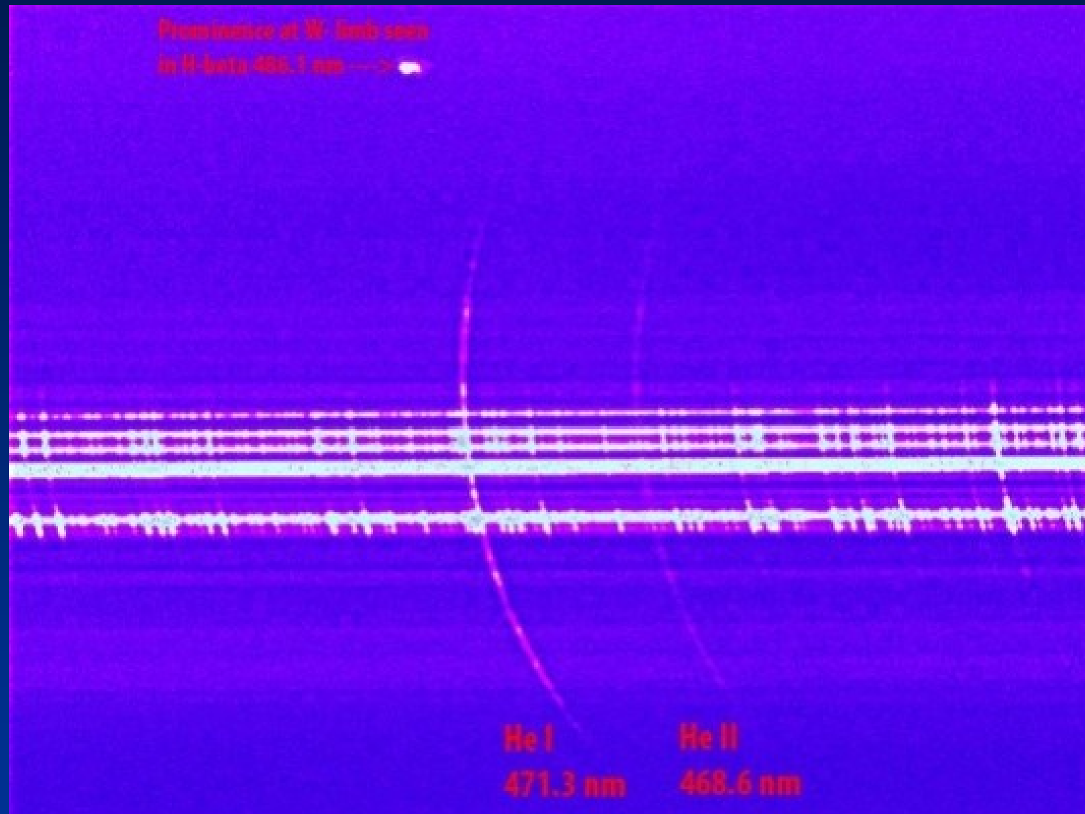
Overall, our latest eclipse results suggest a possible relationship
Solar Radius / Magnetic Activity (approx. in phase)
with a total amplitude of approximately 100 msec :
the influence on the Irradiance Variation is small (25 %)



- What could be the origin of the ***tiny variations*** of the solar radius measured from ***free of stray light*** study of the edge of the Sun at total eclipses?
- The deep ***spectroscopic*** analysis of the edge of the Sun provides an explanation



Part of the spectral sequence obtained in the vicinity of the 2nd contact, to show ***low excitation lines*** *seen in* ***emission, in addition to the faint chromospheric HeI and HeII lines.****. Average of 10 spectra taken in* ***2008.***

Bazin et al, 2010

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

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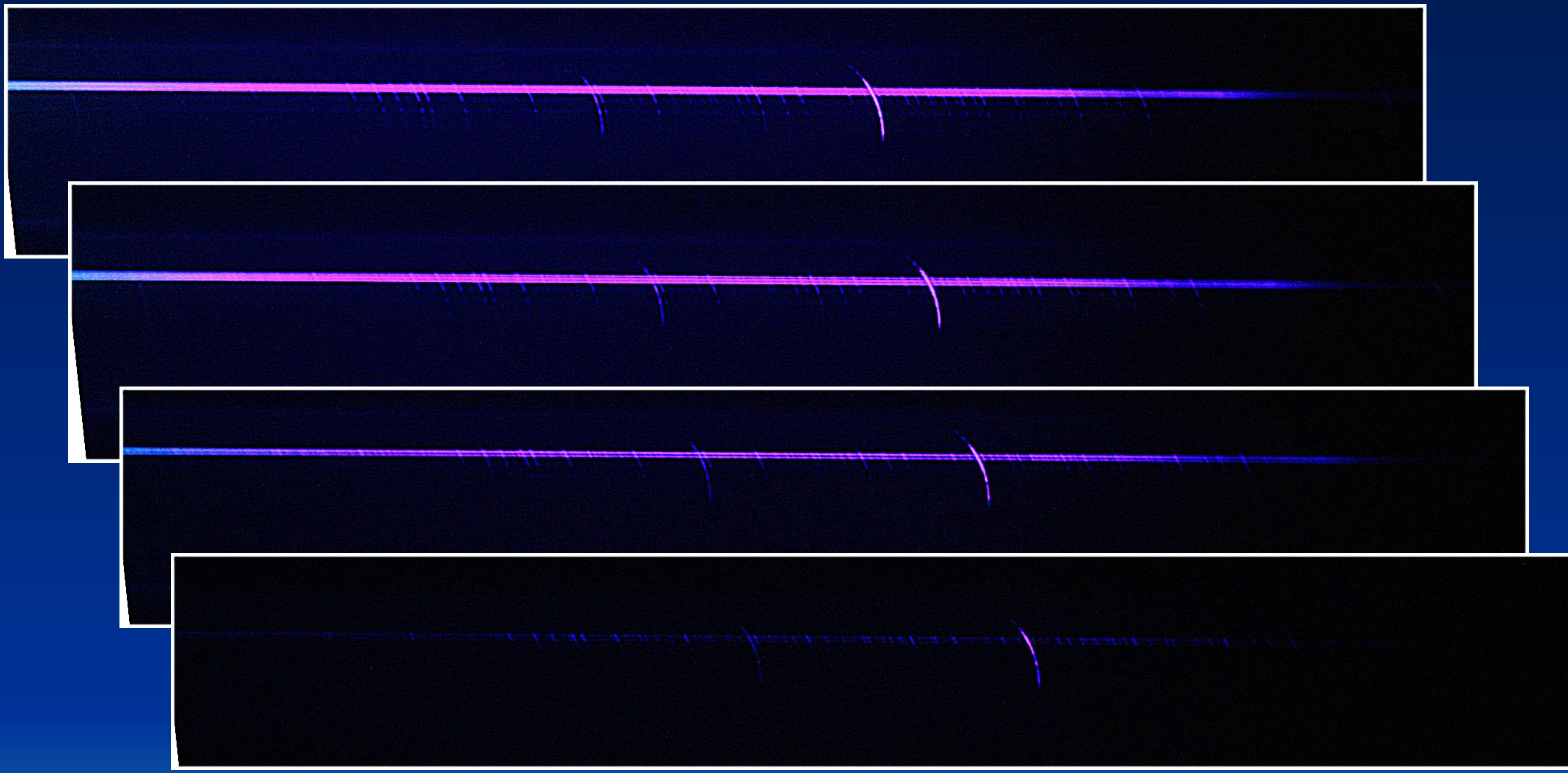

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During each eclipse contact, the edge of the Sun is seen, from the photospheric to the coronal heights (here a 0.3 s integrated spectrum)

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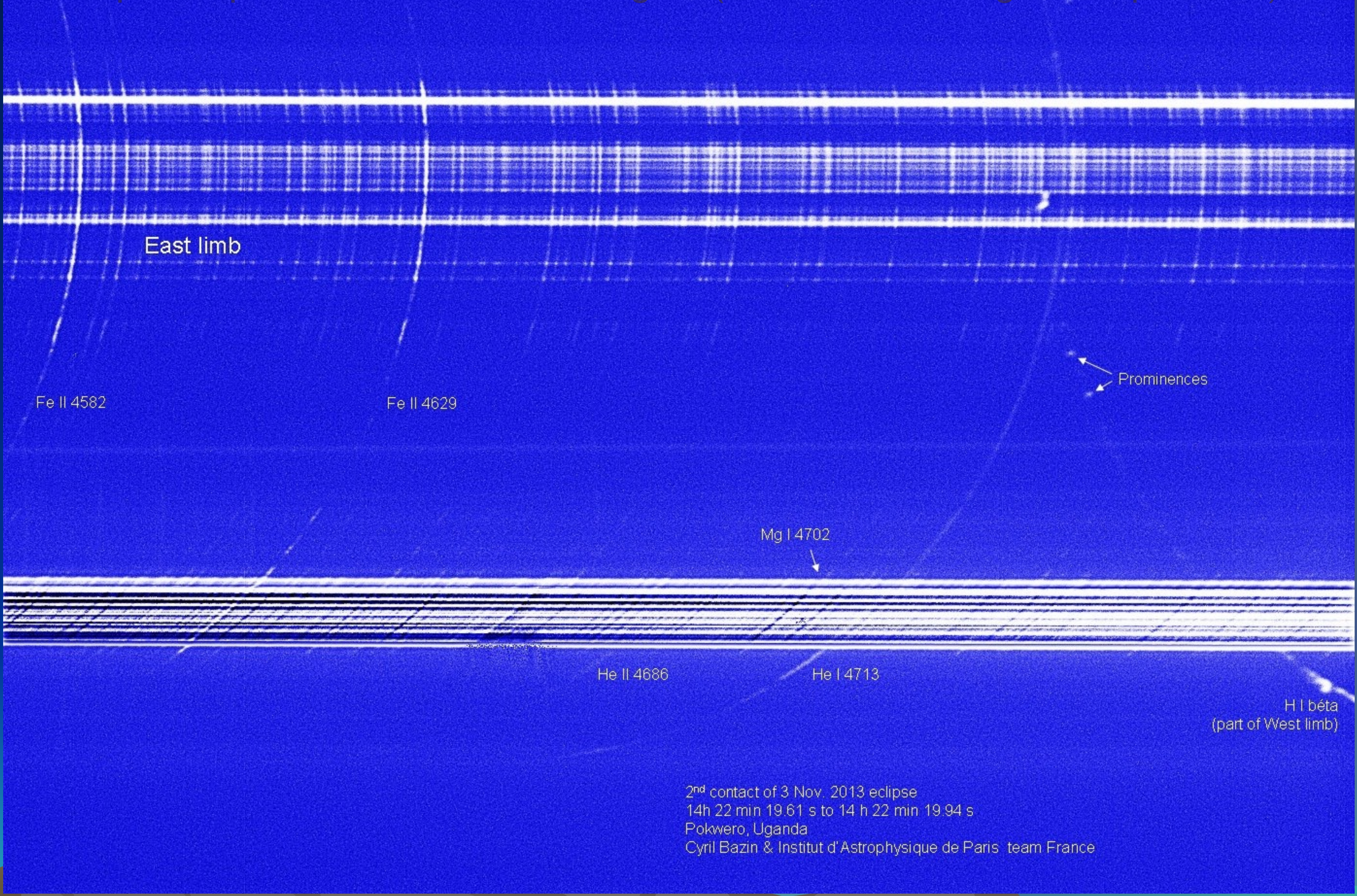

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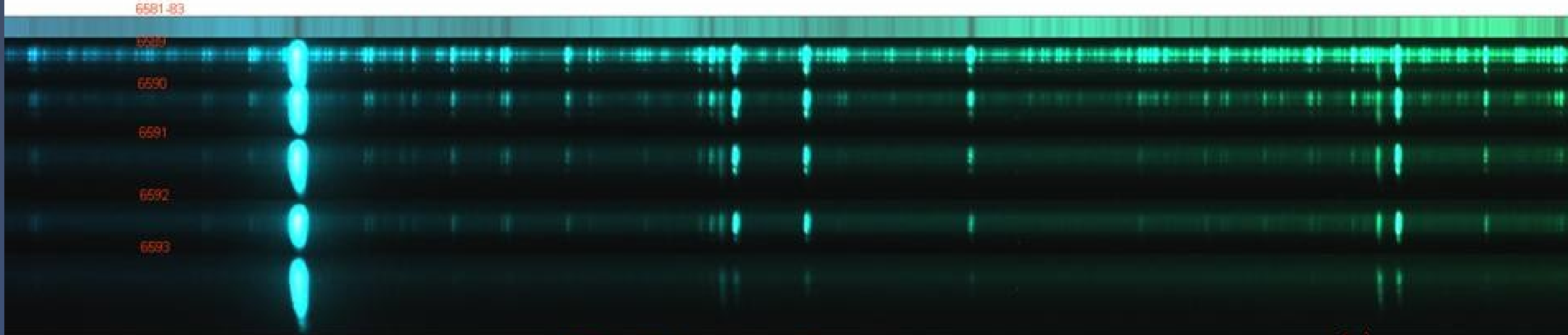
- At the last eclipses we developed 2 spectroscopic experiments using 2 different methods:
- the classical slit- less (flash spectra) method
- a new specially designed Littrow system using a large holographic grating

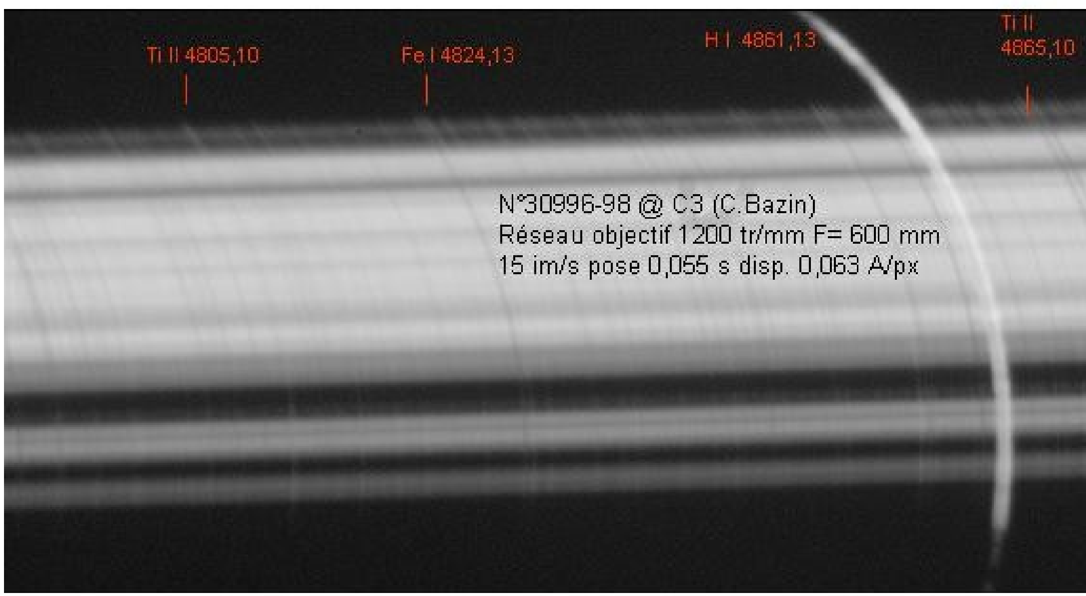
Contribution à l'étude de la basse atmosphère solaire au moyen de spectres éclairs obtenus lors de l'éclipse du 9 Mars 2016 (C. Bazin S. Koutchmy, S - IAP)

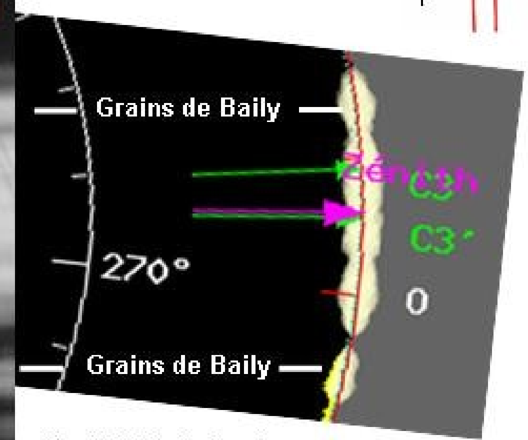


Somme de 3 spectres: 6581-82-83 0h41min45 -47s
6589 : 0h51min40s temps de pose: 0,0964s
6590 : 0h51min41s temps de pose: 0,0964s
6591 : 0h51min42s temps de pose: 0,0964s
6592 : 0h51min42s temps de pose: 0,0964s
6593 : 0h51min45s temps de pose: 0,0964s

Extrait du spectre à fente N° 6589 au 2 nd contact à 0h 51min 40s
dispersion 0,144A/px, réseau 2400 tr/mm, F=600 mm
(Koutchmy, S Kuzin, S. expérience. IAP) Ternate - Indonésie

Fente 300µm

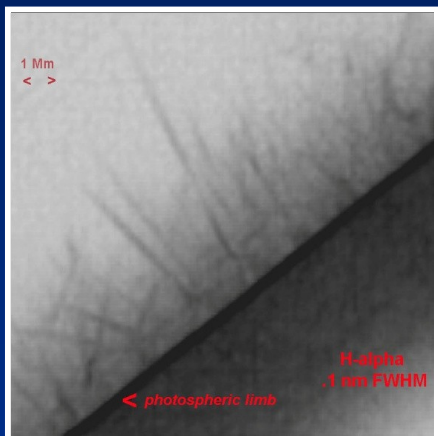




Profil du limbe lunaire
Au 3ième contact
(Xavier Jubier)

Prospects:

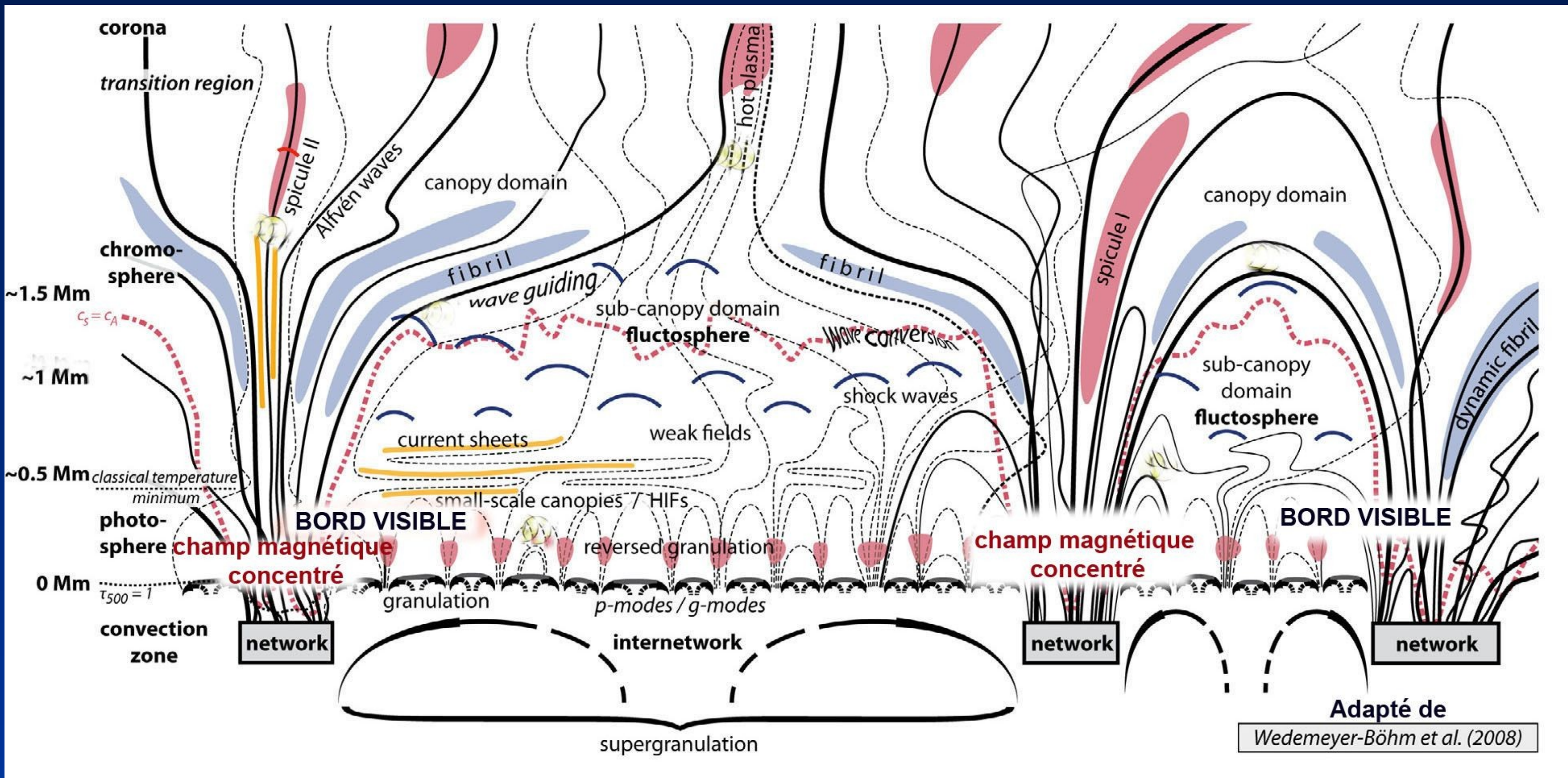
. **Solar diameter measurements using improved lunar profiles (Kagoya) and after averaging all the data from each eclipse, would permit a long term survey;**



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

G-B Sac Peak Hα image

S-B SOT Hinode processed image in HCaII



The layers determining the edge of the Sun are partly dominated by the emerging magnetic fields

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In conclusion

- **Eclipse contact analysis using precised fast measurements (CNES photometers) gives excellent results and total eclipses are events to follow far in the future;**
- **Intensity variations of faint emission lines superposed on the true continuum, during the last and the first Baily's beads (near the .5 to 1 Mm heights) must be discussed to interpret historical (visual) and broad band present results;**
- A new Solar edge definition is needed: role of the faint singly ionized emission lines seen at the limb ?
- The solar global magnetism influences the layers at the limb and could explain the minute variations of the solar radius at long term.

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

Merci de votre attention!

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Improved lunar (3D) profiles should be used

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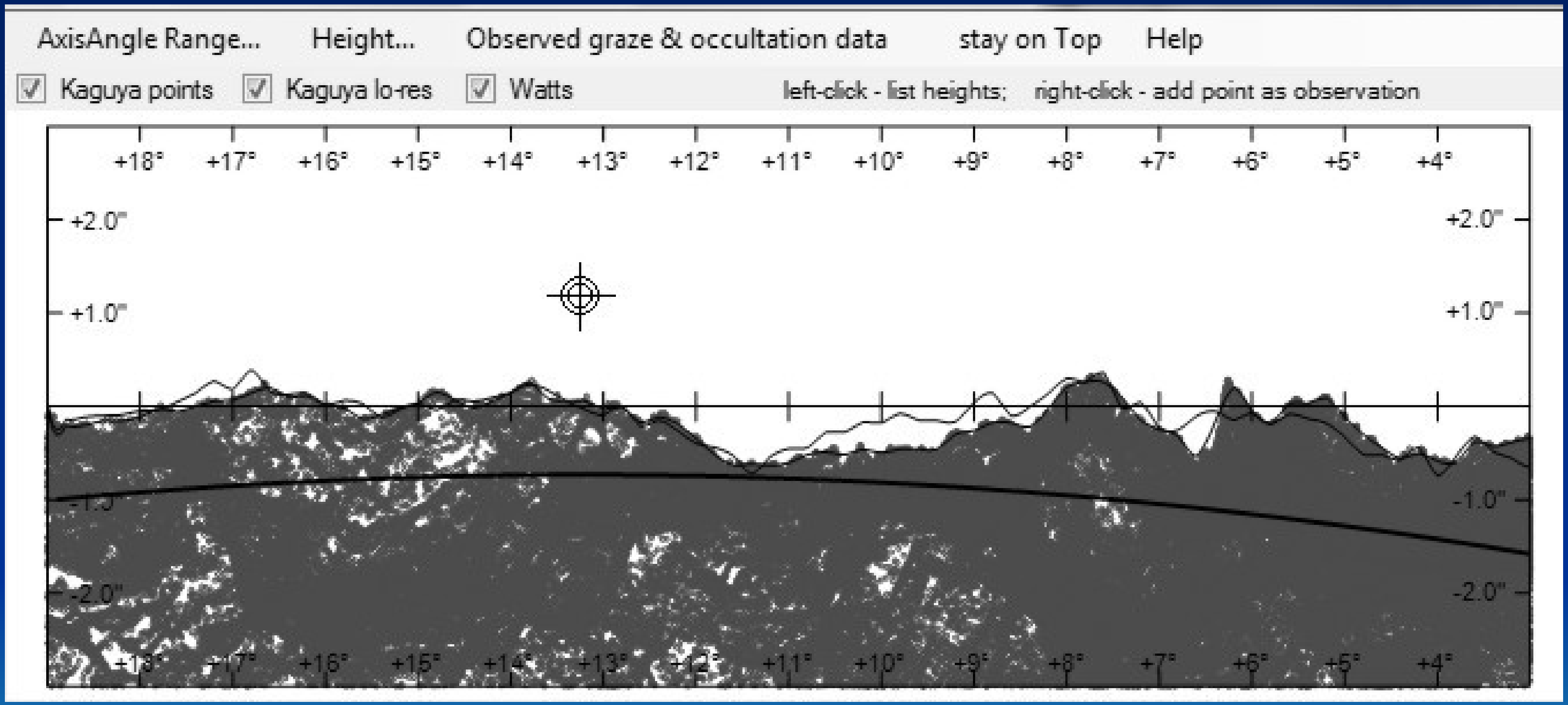
Profiles from the Kaguya satellite altimetry (JAXA-preliminary), near C2



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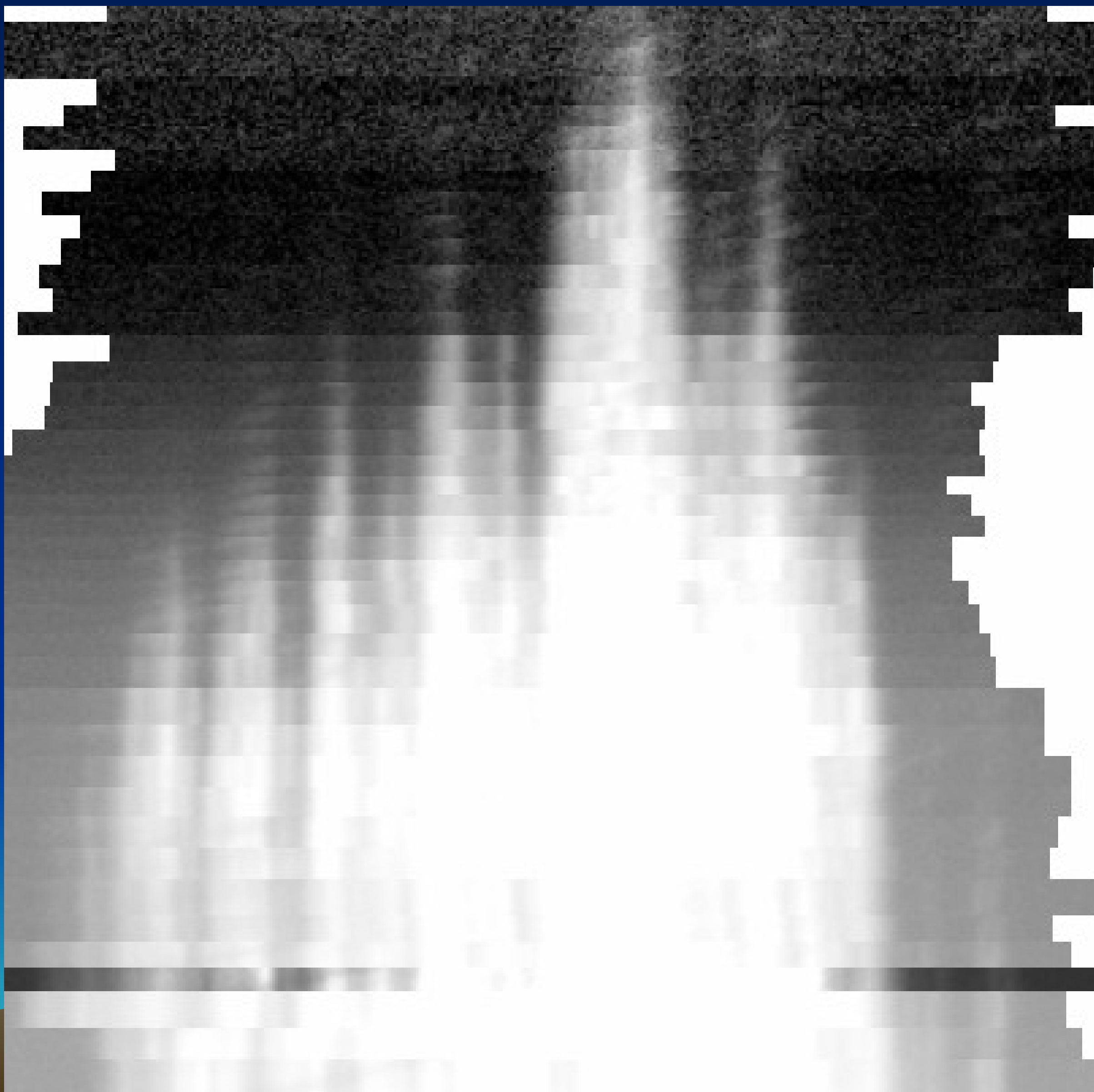
Superposed partial-frames near the continuum, from a set of C3 flash spectra:Time-slice analysis



	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