Where is the base of the Transition Region?

SDO, TRACE, IRIS and ALMA observations

(a compilation of recent works)

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Outline

- Introduction
- Observational issues
- Direct measurements using TRACE & SDO data
- Position of the limb from IRIS and ALMA data
- Formation height of the chromospheric network
- Summary and conclusions

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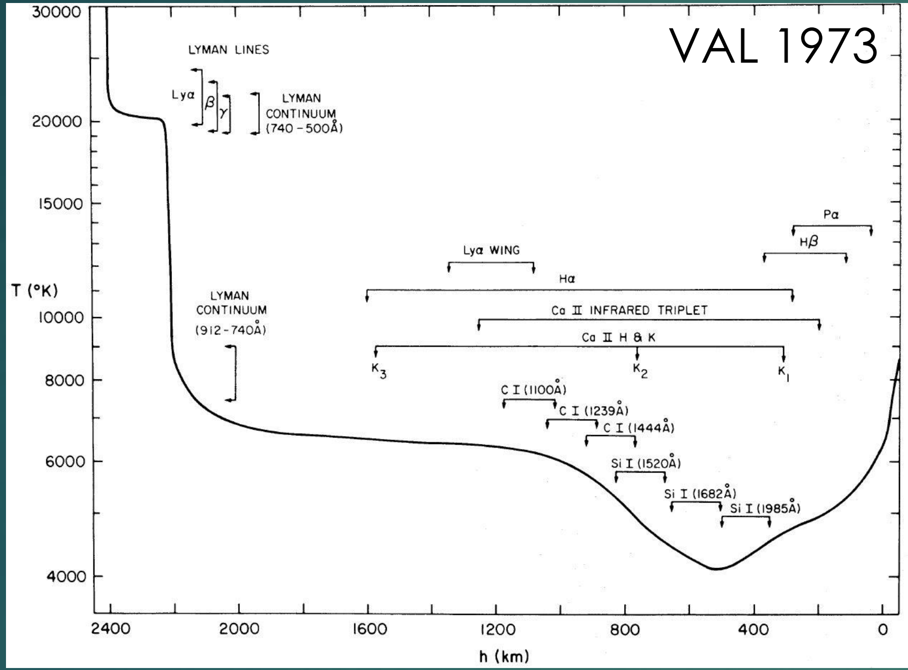
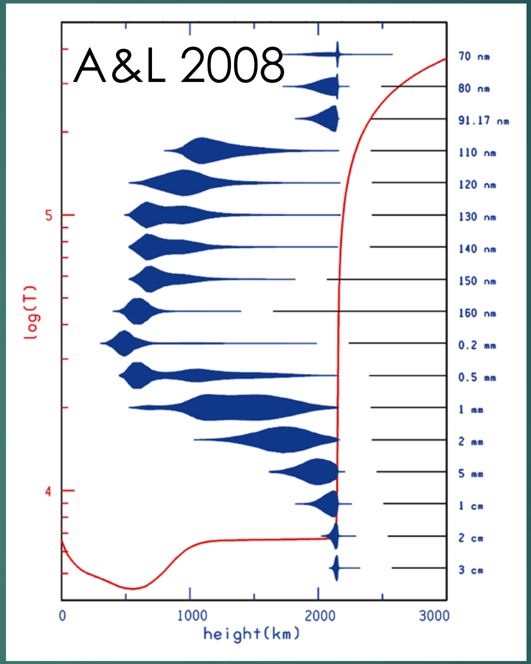
Introduction

Theoretical 1D models (hydrostatic) place the beginning of the chromosphere-corona transition region (TR) at a height of around 2000 km, measured from the τ=1 level at 5000 Å.





What is the observational basis?

- Eclipse data
- Maximum intensity of the 10833-Å He I and the 5875-Å D3 lines (Avrett and Loeser 2008)

With the high-resolution (1" or better) of present-day EUV images a better estimate may be expected

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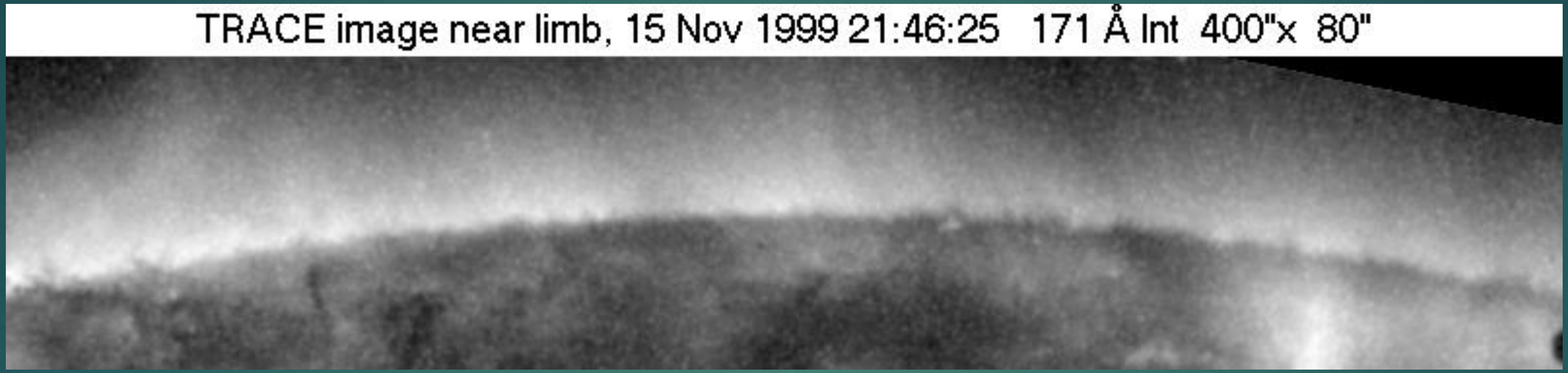
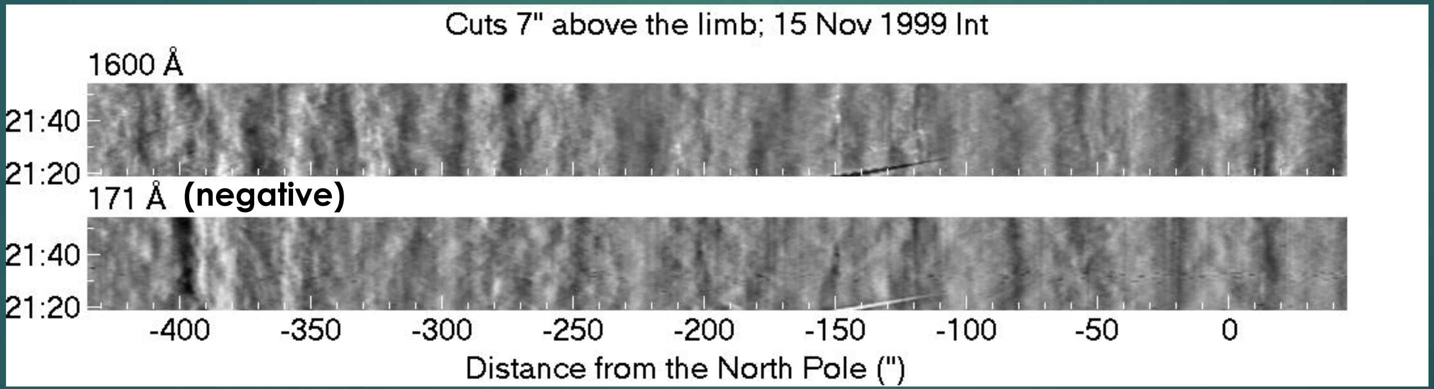
Observational issues

- Spicules absorb EUV emission low above the limb, thus obscuring the basis of the TR.



Are the absorbing structures spicules?



- Pointing accuracy, in order to place the EUV emission with respect to the white light (WL) limb.
- Height of the WL limb with respect to τ=1 level.

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A word about the height of the WL limb

- In order to compare with models, we need to know the height of the WL limb with from the $\tau_{5000} = 1$ level
- In these computations we used a value of 340 km (Table I-1 in Athay, 1976).
- This is consistent with Thuillier et al. (2011 Sol Phys 268, 125) who computed heights between 345-360 km for the VAL81 models at 5500 Å. They also found a small increase (~ 30 km) with wavelength from 4000 to 8000.

Correct pointing using transits

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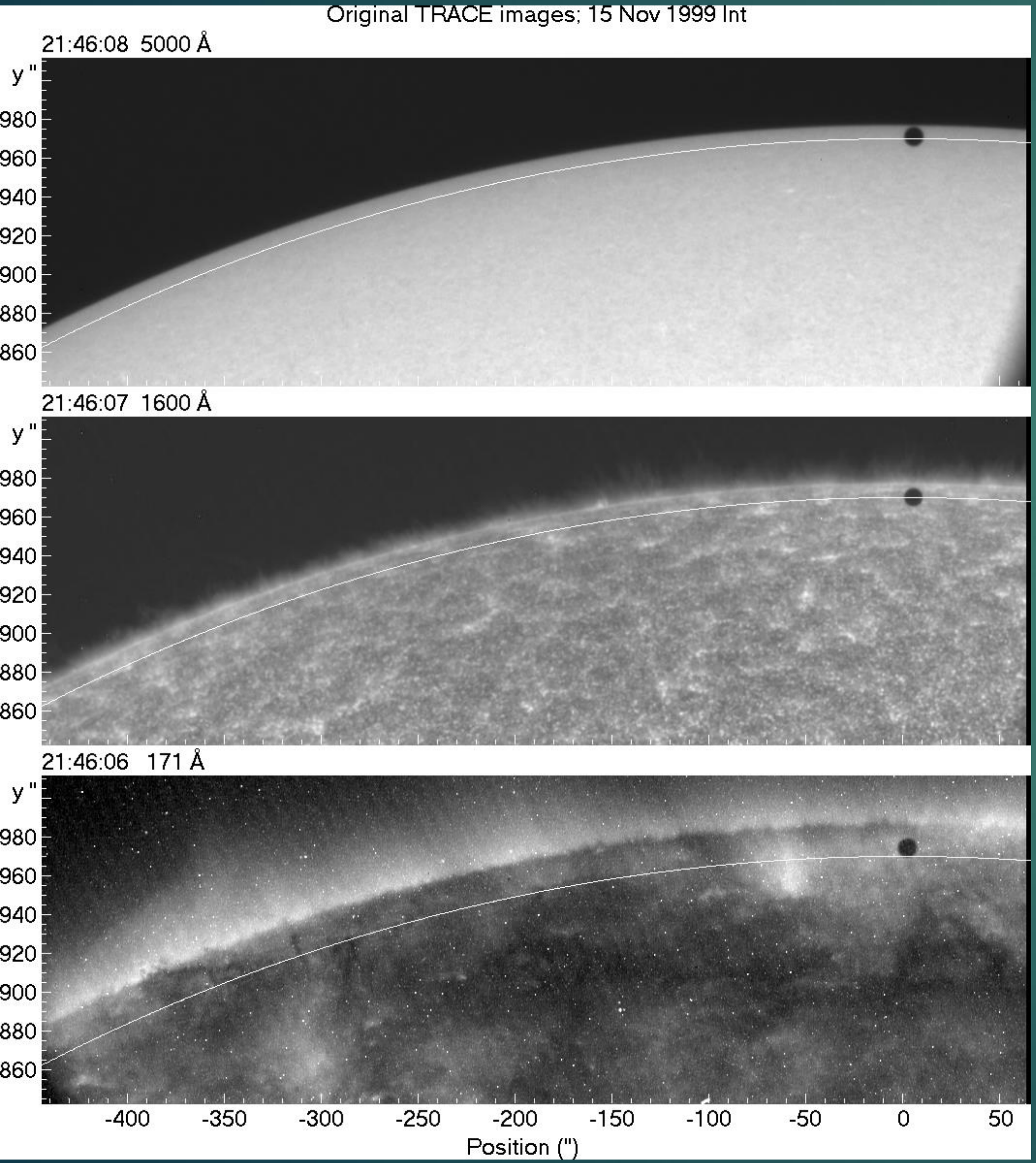
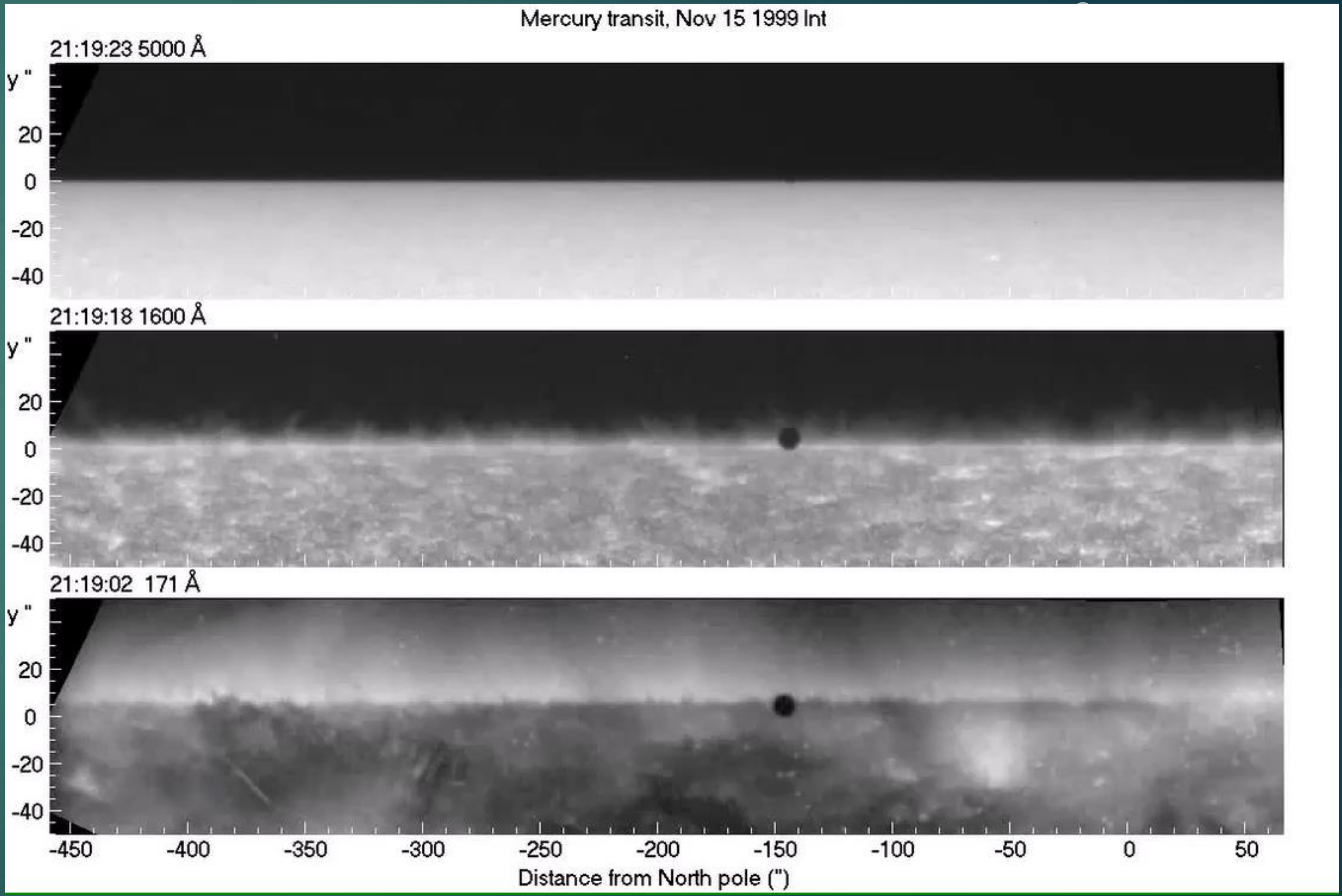
- Mercury transit Nov 15, 1999 (TRACE)
- Venus transit June 5, 2012 (SDO)

Work with A. Valentino (Solar Phys, 2019, 294:96; Erratum: Solar Phys, 2019, 294:146)

Mercury transit, Nov 15, 1999, TRACE

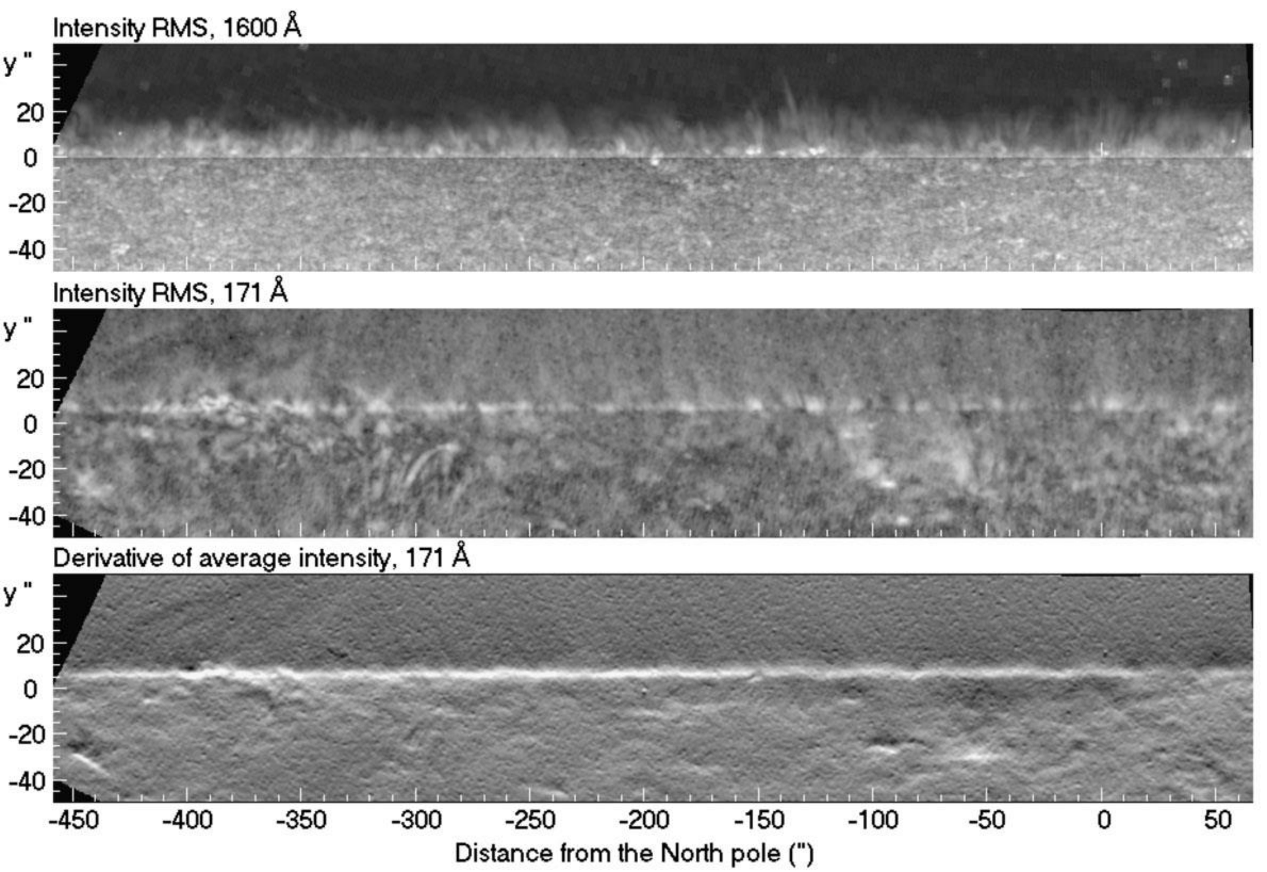


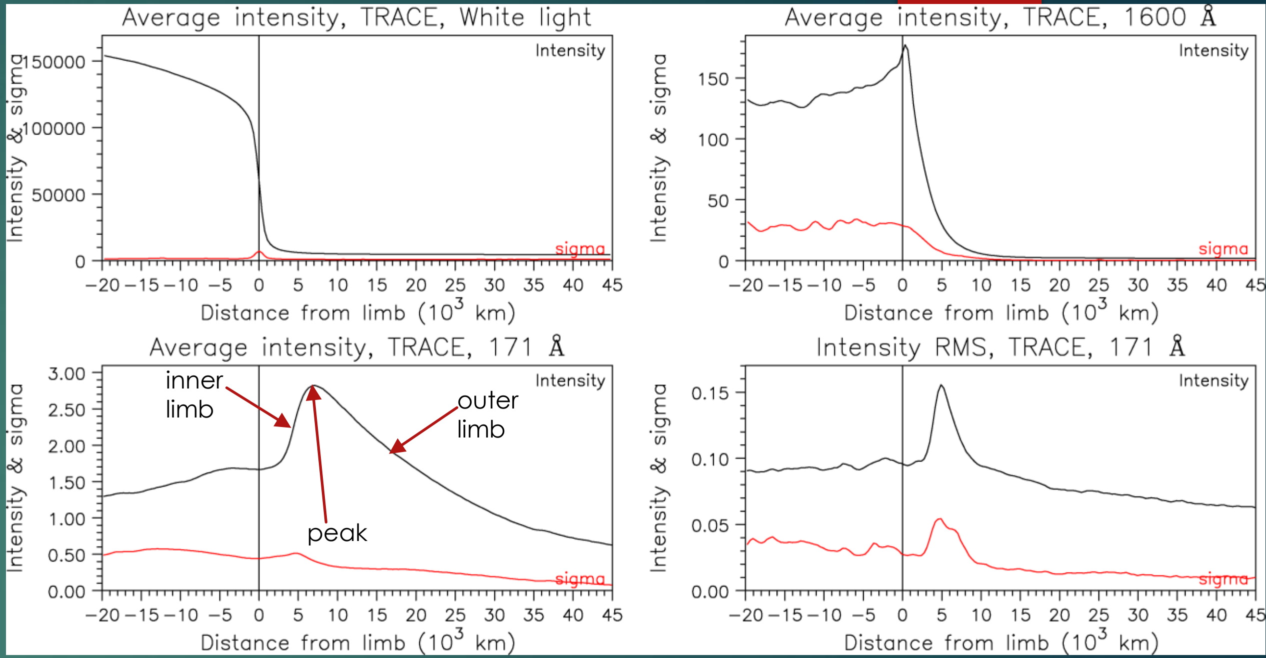
Significant pointing corrections



What can we measure ?

Time variations



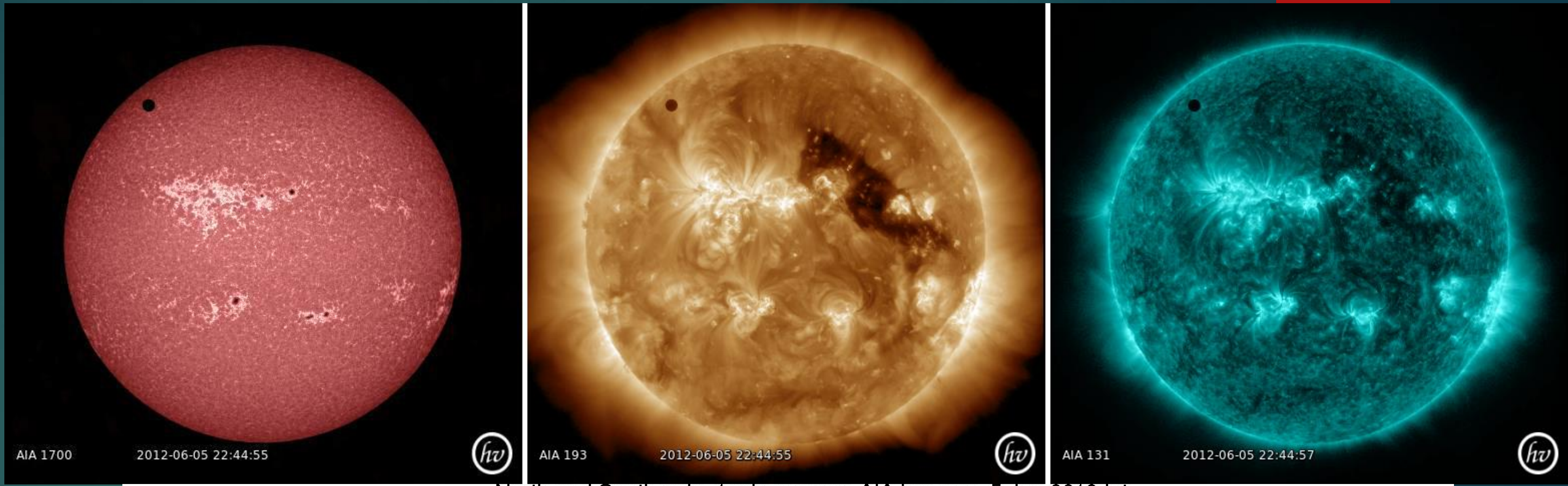


The average intensity profile in WL provides an accurate measurement of the position of the WL limb (inflection point, minimum of its derivative).
Intensity profiles with limb brightening give the positions of:
(a) The inner limb (max of derivative), (b) Peak intensity, and (c) The outer limb (min of derivative)

The inner limb is near the peak of the intensity RMS
For TR & coronal images it gives the height where the spicule forest becomes transparent.

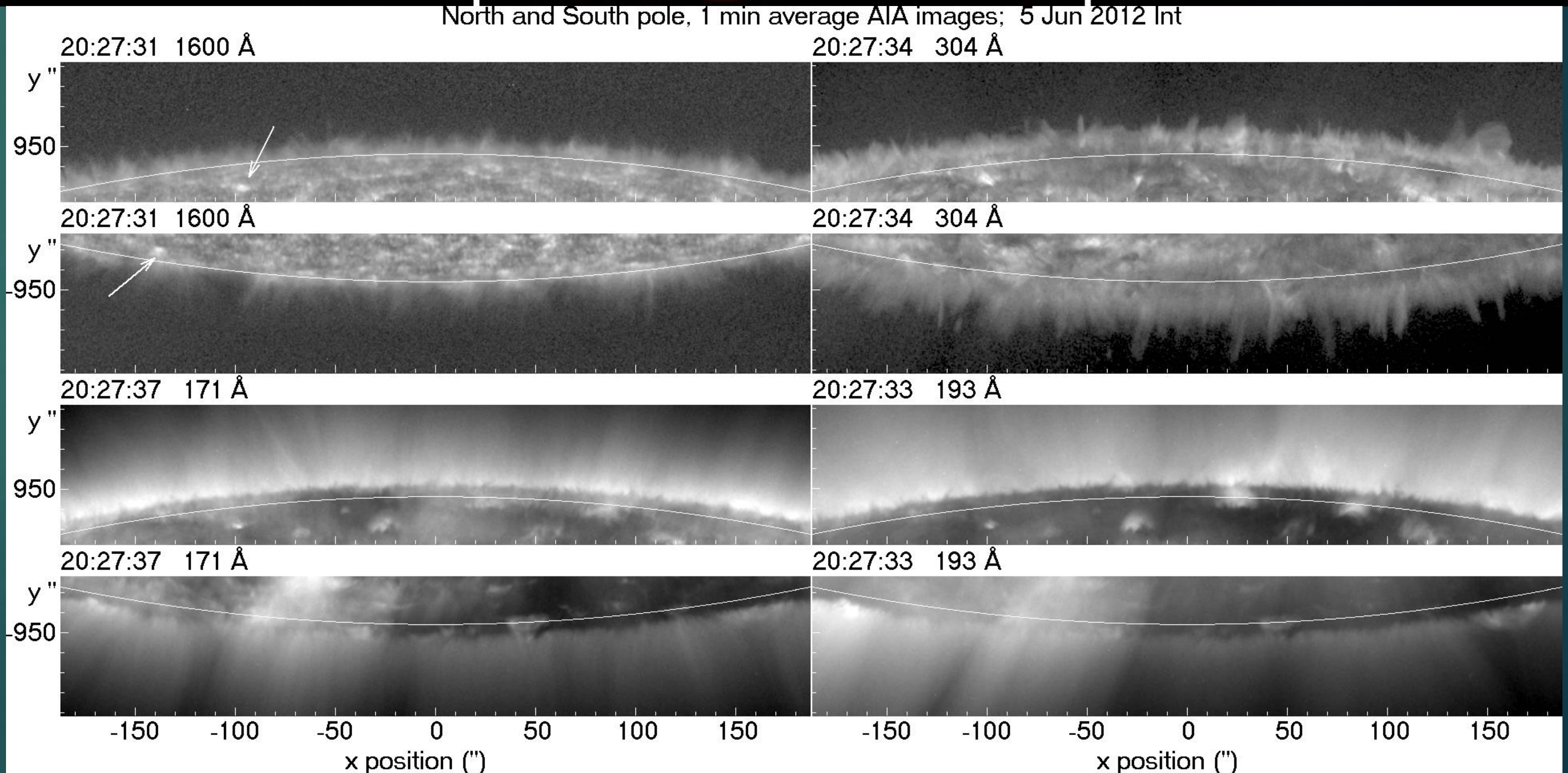
Venus, June 5, 2012 SDO

- Very small, but not negligible pointing corrections

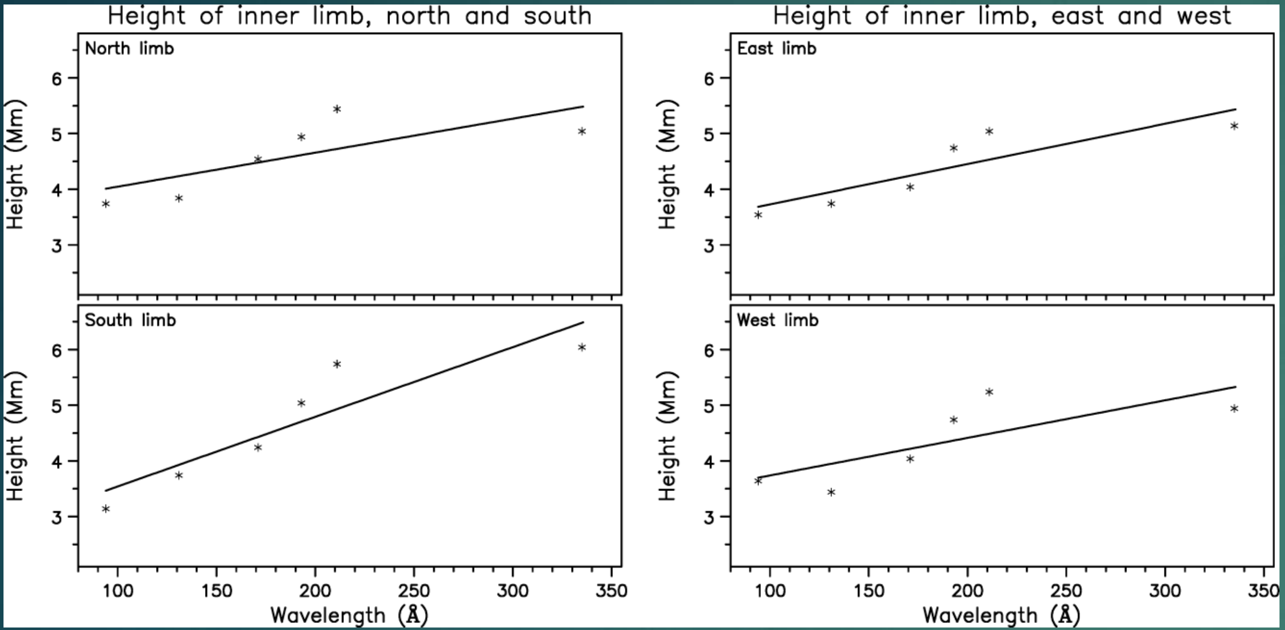


A look at the N and S limbs

Arrows point to network structures that appear closer to the limb at 304 Å than at 1600 Å (to be discussed later)



Position of the inner limb and height of the TR base



Measured from AIA intensity profiles

Spicule absorption is due to photoionization, principally of H I, but also from He I and He II. The absorption coefficient increases with wavelength, consistent with the fact that the height of the inner limb also increases with wavelength.

An upper limit of the height of the base of the TR can be deduced from the minimum height of the inner limb at 94 Å, which is about **3700 km** above the $\tau_{5000} = 1$ level.

A better estimate can be obtained from the extrapolation of the regression line of the average inner limb height versus wavelength plot to $\lambda = 0$, where there is no chromospheric absorption. This gives a height of

(3000 ± 500) km

which is above the value of 2140 km used by Avrett and Loeser (2008).

Another word or two about limb positions

- In photospheric and low chromospheric images, the limb is identified as the inflection point of the intensity profile
- In chromospheric lines that show enhanced emission above the optical limb the situation is more complicated. As the region of formation of the radiation has a certain vertical extent, the outer limb position represents the upper bound of this region rather than the average; moreover, chromospheric spicules will further increase the measured height.
- In such cases I used the position of the peak intensity.

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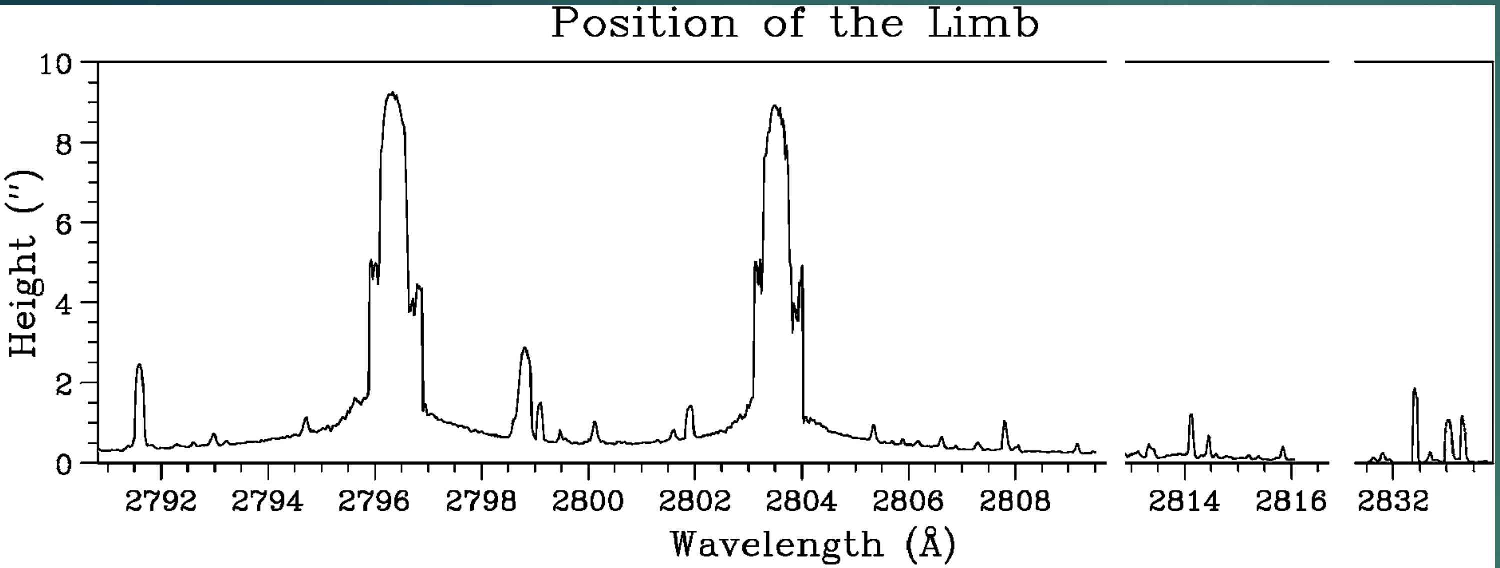
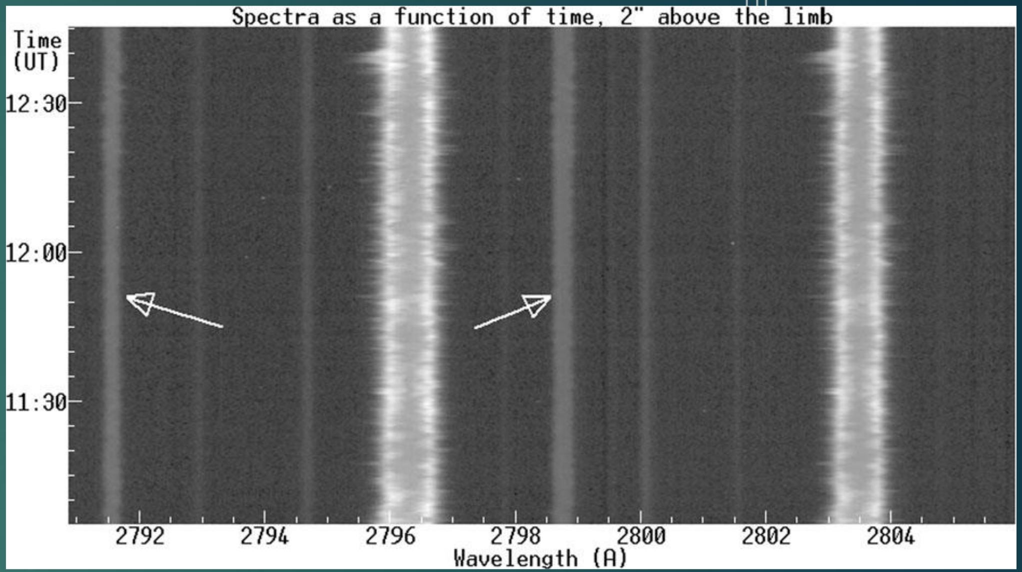
Limb positions from IRIS

- Limb height wrt 2832 Å limb in the near UV band of IRIS (left) and image cuts (right)





- No spicules visible in the Mg II triplet lines!
- Measured limb height in selected lines

Line	Inner limb (“)	Peak (“)	Outer limb (“)
2791.59 Mg II triplet	-	-	2.35
2798.79 Mg II triplet	-	-	2.91
1399.81 Si IV	1.17	2.92	4.93
1402.80 Si IV	1.16	2.59	5.26
1393.79 Si IV	1.51	2.37	5.81

Work with J-C Vial and others

(Alissandrakis et al. 2018, Solar Phys 293:20)

Limb position from ALMA full-disk images

- Pointing issues in high resolution images
- Full disk image resolution is low:

  60” in Band 3 (3mm) and 30” in band 6 (1.3mm)
- Averaging several data sets we obtained:

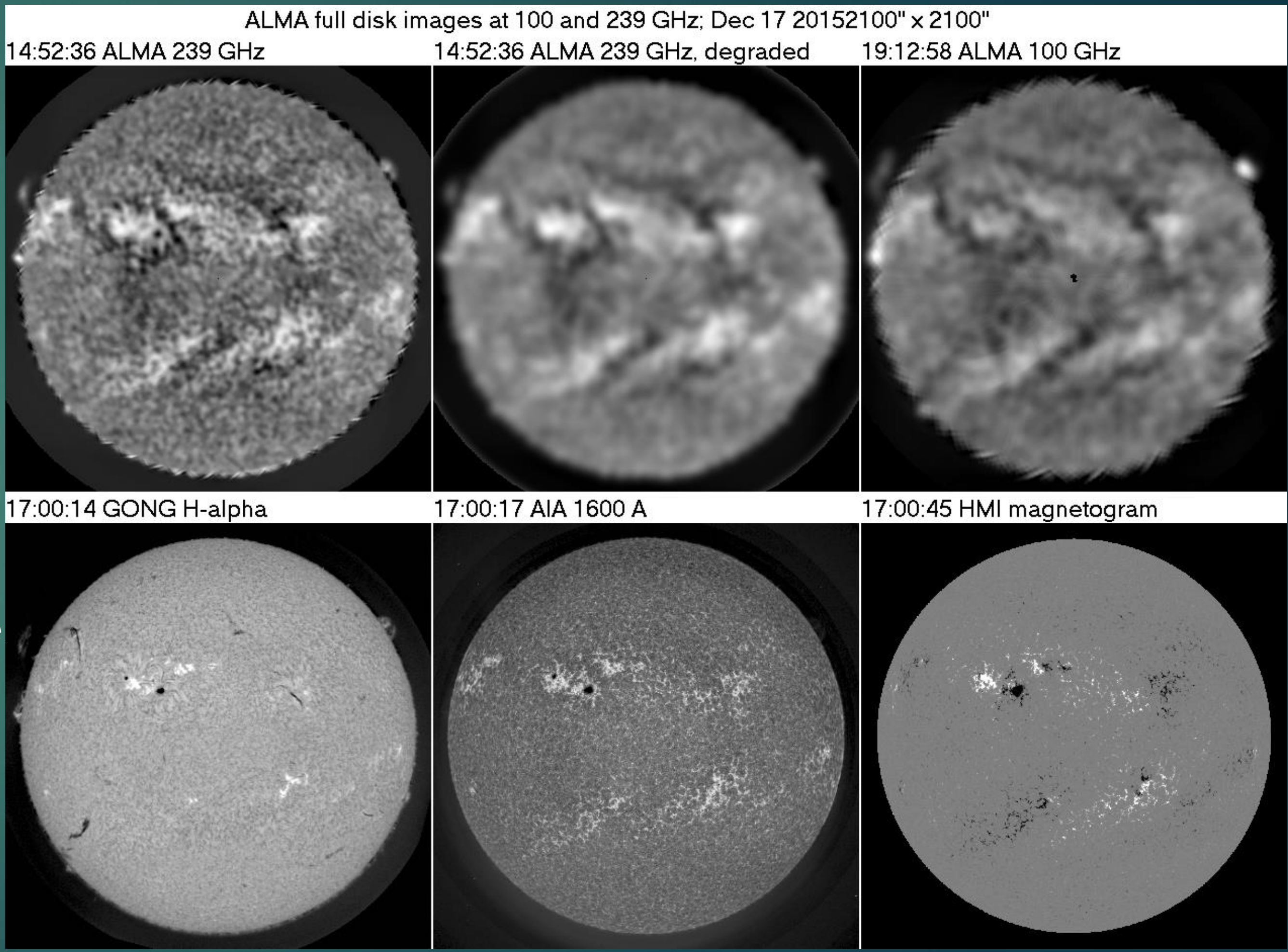
  2.4 ± 1.7 Mm at 1.3 mm, and

  4.2 ± 2.5 Mm at 3 mm

- Older eclipse observations give higher value

Work with A. Nindos, S. Patsourkos and T. Bastion

(Alissandrakis etal. 2020 A&A 640, A57)



(from Alissandrakis etal. 2017 A&A 605, A57)

Height of the chromospheric network

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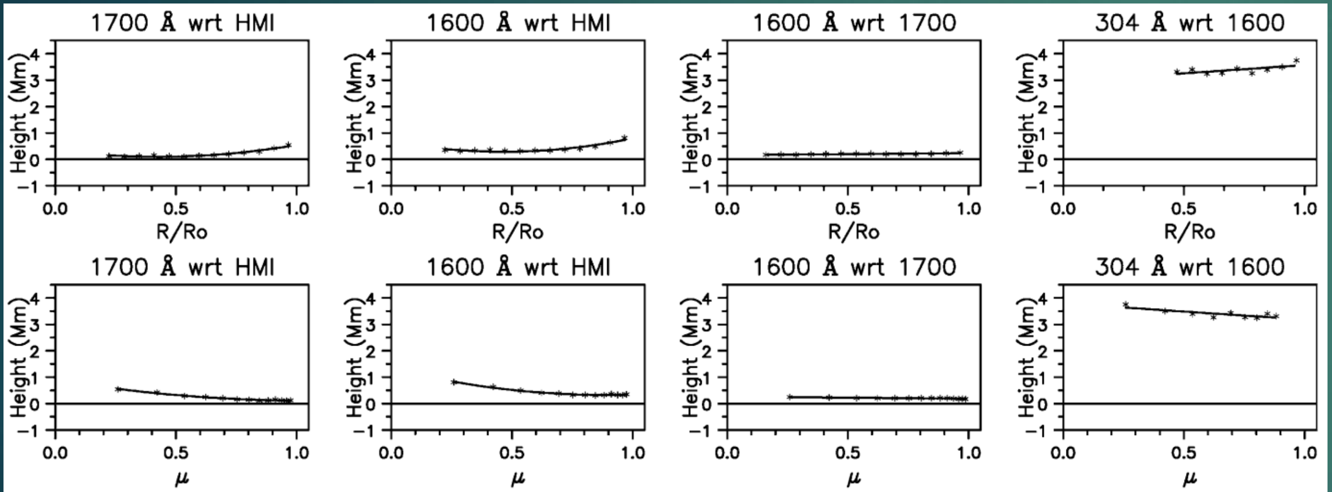
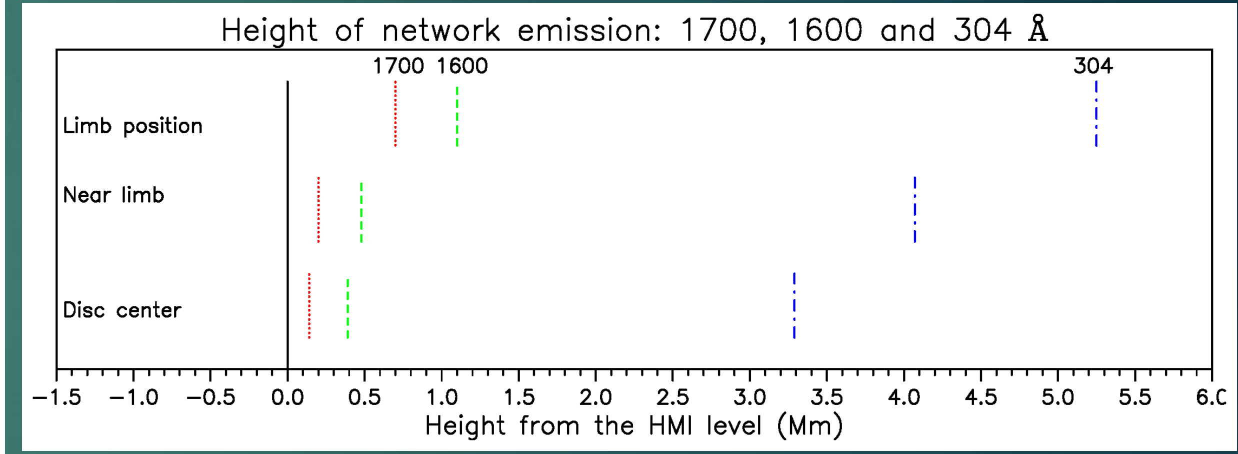
- Measured from the displacement of network structures in 1700, 1600 & 304 Å AIA images with respect to HMI images (Alissandrakis 2019, Solar Phys 294:161)

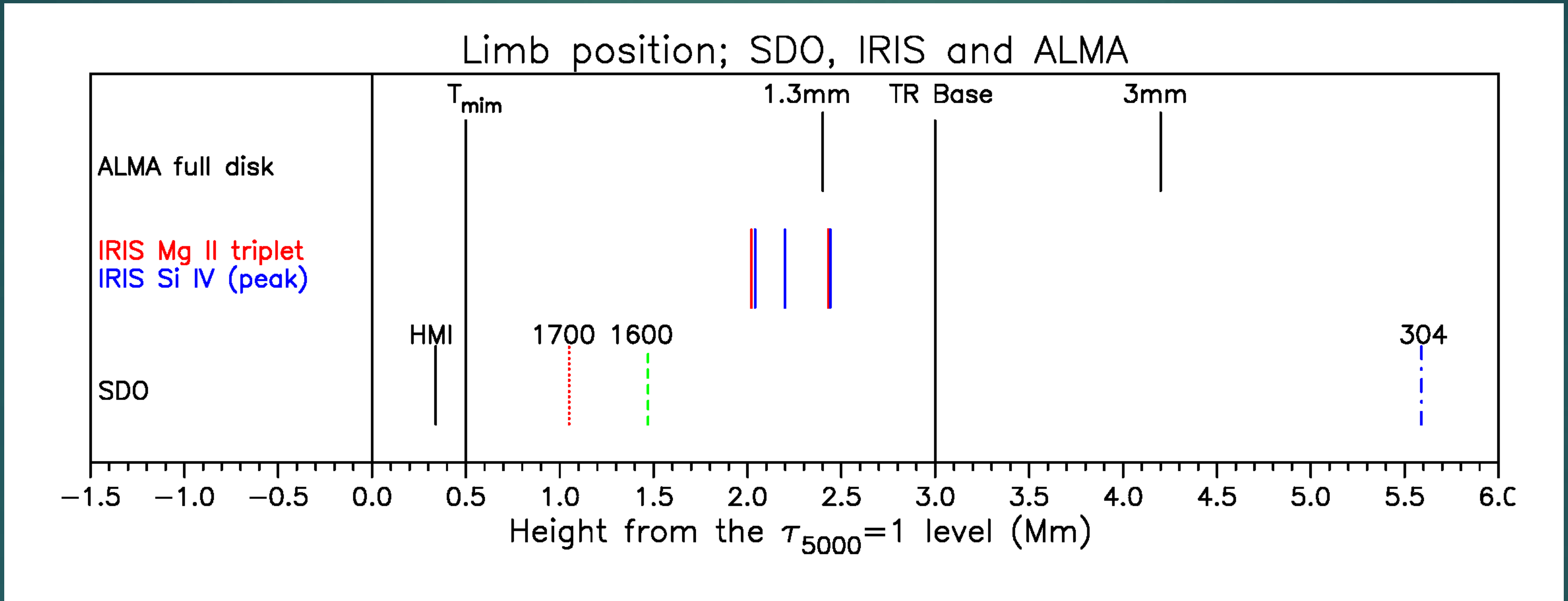




- Similar results were obtained by Rutten (2020, arXiv:2009.00376)

Summary & conclusions

- Putting everything together:



- The average chromosphere extends higher than 1D models predict.
- Several lines and continua formed below the base of the TR can be used to exploit this issue further

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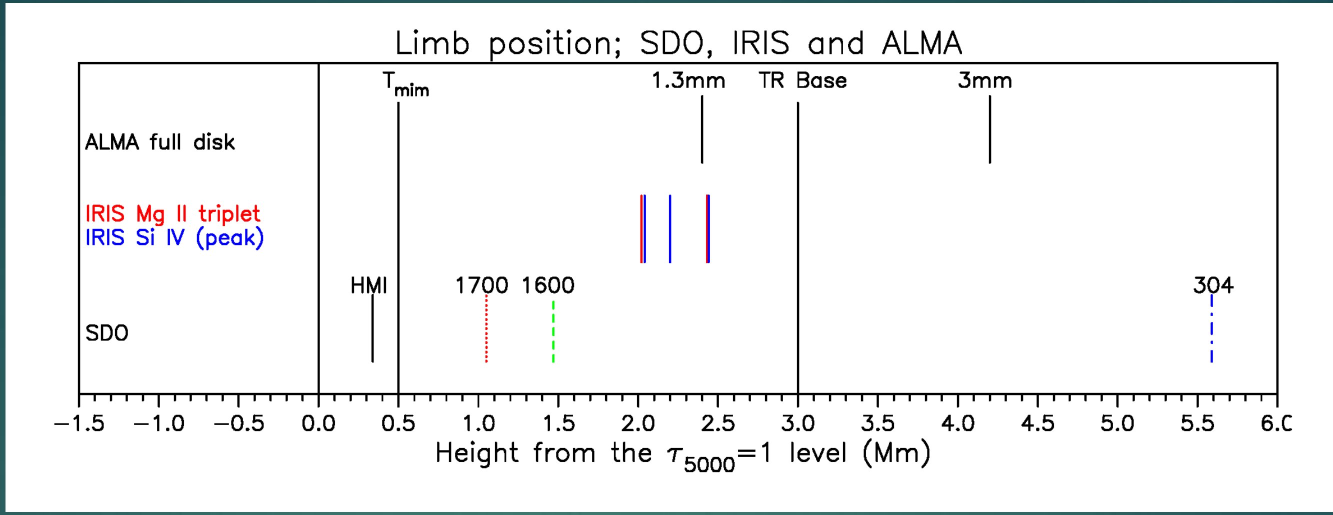

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That's all folks!
Thanks for your attention

I would like to draw your attention and ask for contributions to an article collection on "The Sun Seen with the Atacama Large mm and sub-mm Array (ALMA) – First Results", to be published in *Frontiers in Astronomy and Space Sciences* as a Research Topic.

The goal is to make an assessment of what we have learned from ALMA, putting in perspective ALMA's contribution to our understanding of the solar atmosphere. At the same time, it will serve as a guide to future work.

Editors: Costas Alissandrakis, Tim Bastian, Masumi Shimojo and Alexander Nindos.

For more information and submission details see https://www.frontiersin.org/research-topics/24755/