The Solar Wind Abundance Mystery

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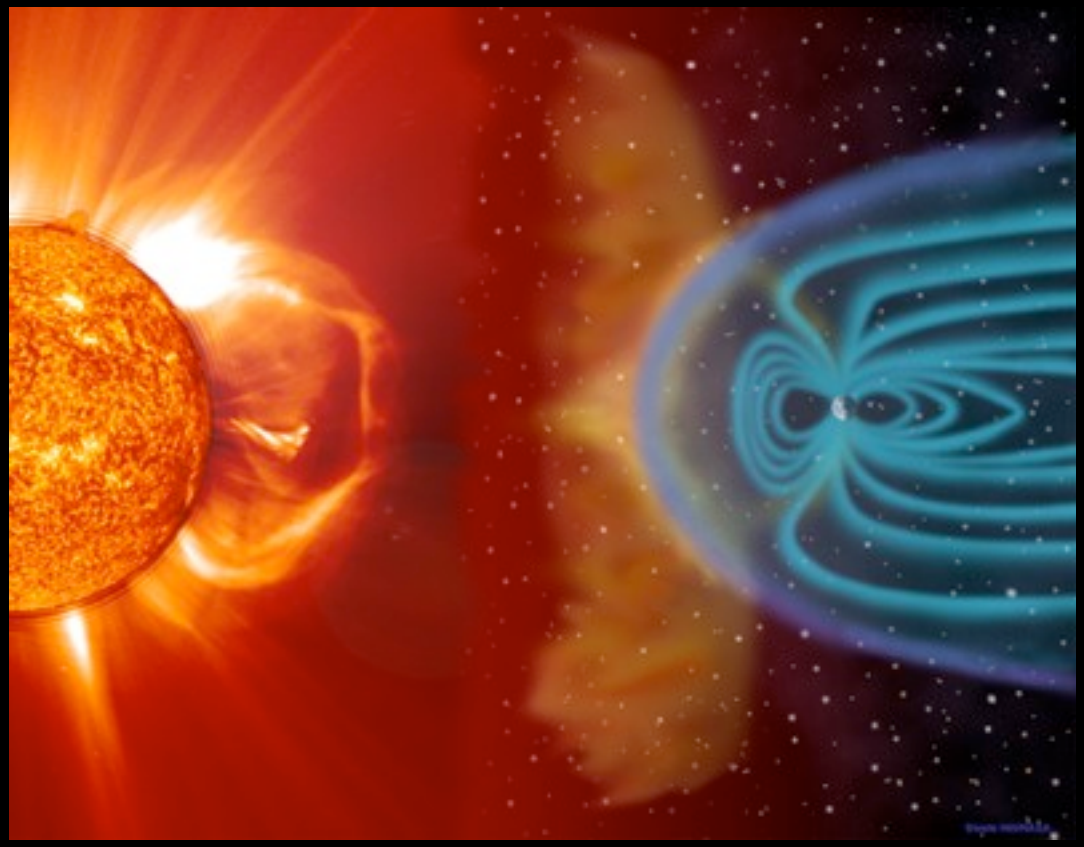
Purdue University

Working with my always helpful and incredibly genius mentor:
Dr. Scott McIntosh

The Solar Wind



"The stream of charged particles thrown most recklessly at our scared, lonely Earth by the big, bad Sun, who in a furious rage seeks our most utter ruin…."

- A random quote, anonymous source :)

Outline

I. Intro – What is Solar Wind?

II. The Spacecraft & The Instruments
- ACE, Wind & Ulysses
- Faraday Cup, SWICS, SWIMS & SWOOPS

III. The Project
- Investigate how the heating process at the bottom of the corona may have changed during the most recent solar minimum by analyzing the composition of the solar wind

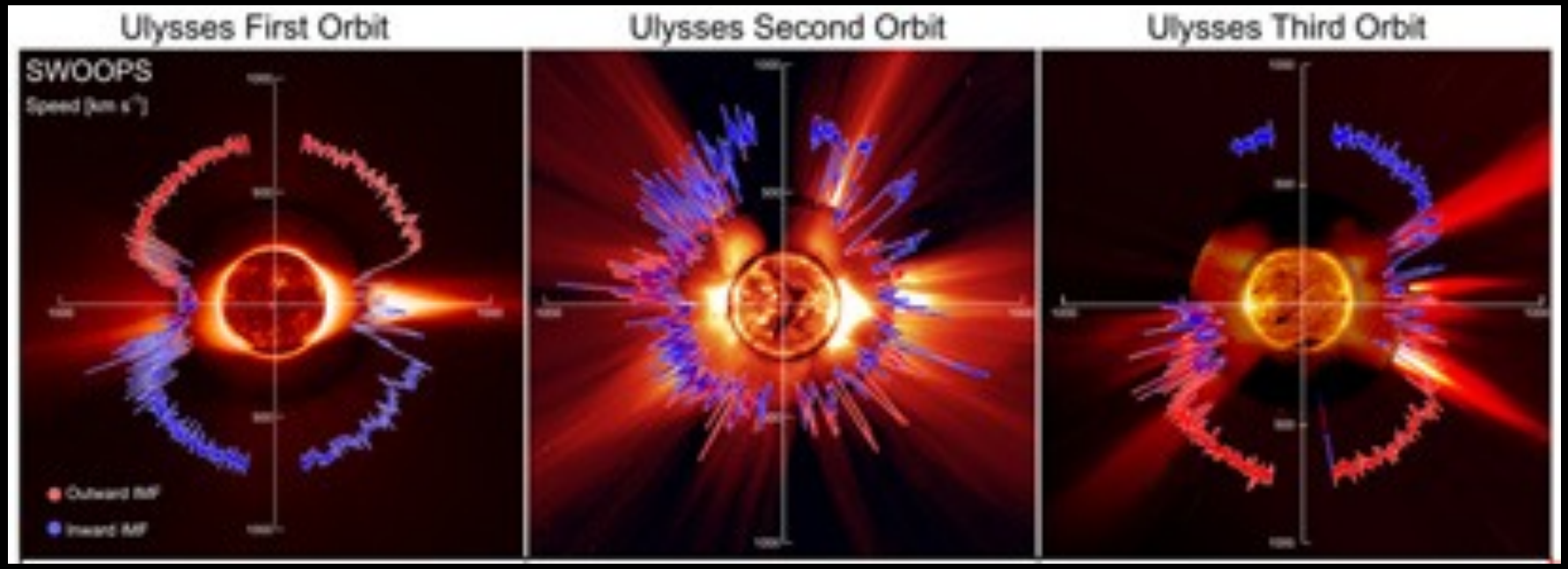
IV. Results

V. Summary & Conclusions

What is the Solar Wind?

- Continual supersonic release of charged particles radially outward from the Sun → results in loss of 10^{-14} M_{sun} each year
- Consists mostly of electrons and protons, along with a few heavier ions
- Carries magnetic fields and appears to be shaped in part by the magnetic field at the surface of the Sun

The Solar Wind & The Solar Cycle



Solar Minimum (22-23) | Cycle 23 Maximum | Solar Minimum (23-24)

During solar minimum, the Sun acts as a dipole with coronal holes dominating the poles → fast solar wind.

McComas et al., Geophys. Res. Lett., 2008.

The Spacecraft

Ulysses

- ⋆ mission dates: 1990 - 2008
- ⋆ entered into a polar orbit about the Sun
- ⋆ reveals information about the 3D heliosphere by reaching high solar latitudes

Wind

- ⋆ launched in 1994
- ⋆ located at L1
- ⋆ explores plasma processes in the near-Earth environment

ACE

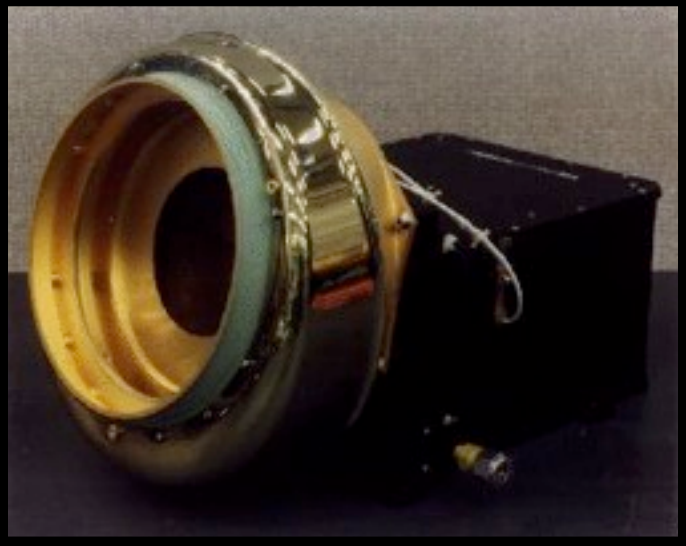
- ⋆ launched in 1997
- ⋆ located at L1 (with the Wind spacecraft)
- ⋆ studies the composition of the near-Earth environment in a wide range of energies

The Instruments

On *Wind*

- Measures velocity, density, and temperature
-

The Solar Wind Experiment (SWE)
Faraday Cup (FC)



Faraday Cup

The Instruments

On ACE

- Measures the charge state of minor ions like carbon and oxygen
-

The Solar Wind Ion Composition Spectrometer (SWICS)
The Solar Wind Ion Mass Spectrometer (SWIMS)

SWIMS

SWICS

The general idea....

The Sun is constantly "pitching" material our way. By catching and analyzing the composition of that material, we can discover something about processes taking place back on the Sun.

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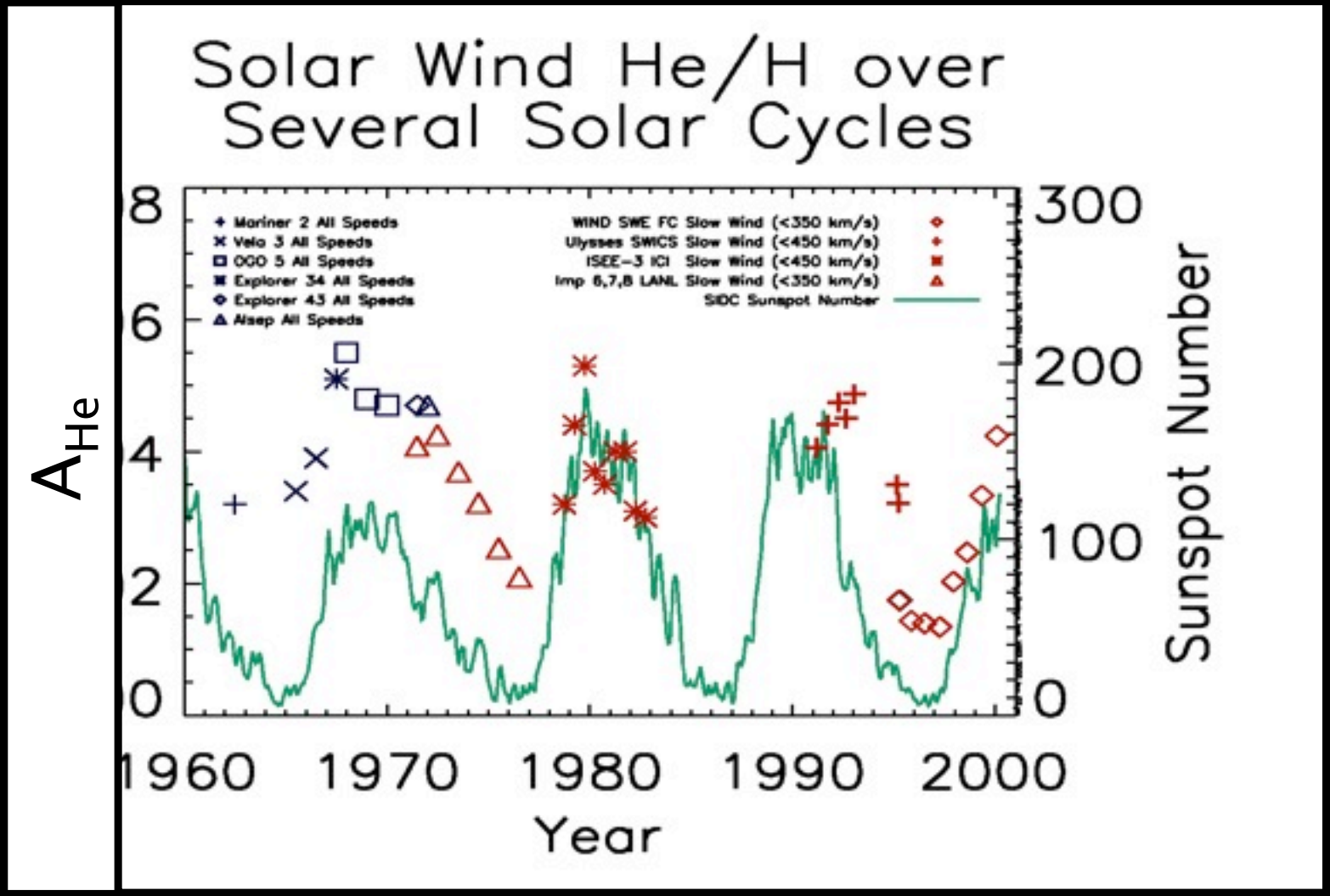
Solar wind helium abundance over time

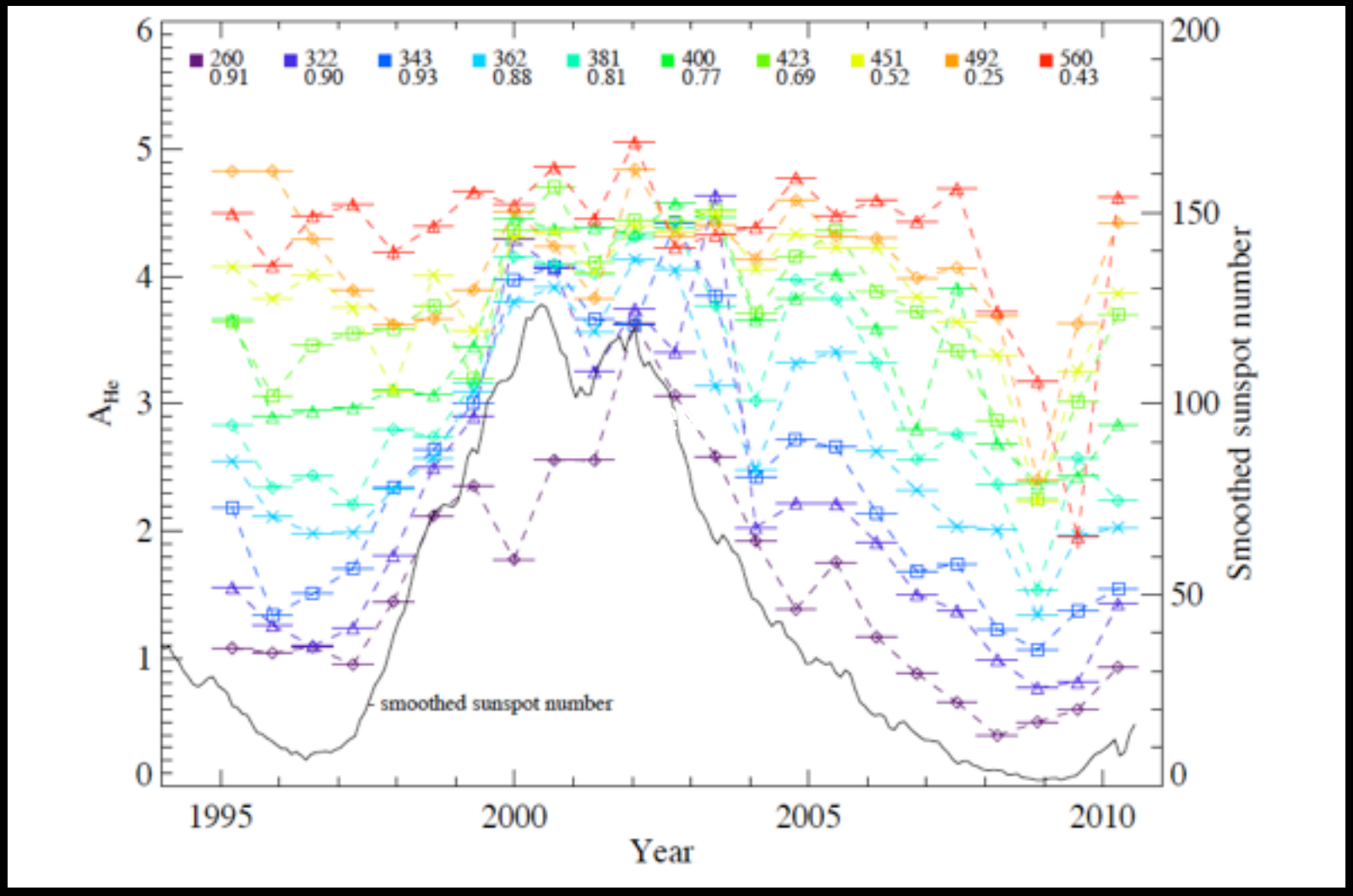
A_{He} from 1960-2000 increases with solar activity



Aellig, et. al., 2001, Ogilvie and Hirshberg (1974); Feldman et al (1978)

Solar wind helium abundance over time

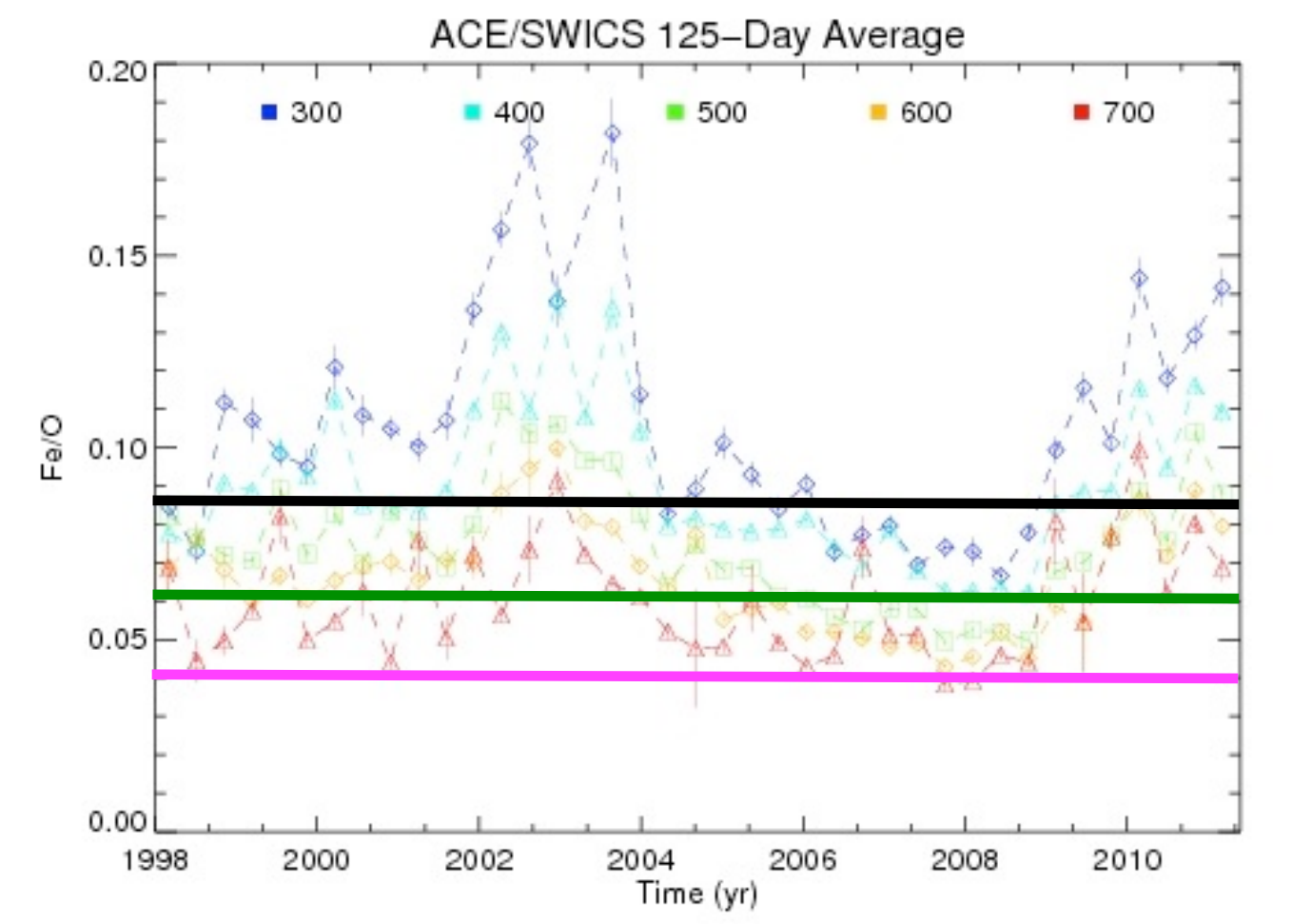
A_{He} from 1995-2009 from Wind



Was something pumping less He into the fast solar wind??

Solar wind iron fractionation over time

Fe/O from 1998-present from ACE/SWICS



Photosphere

Typical FW [x2]

Typical SW [>x2]

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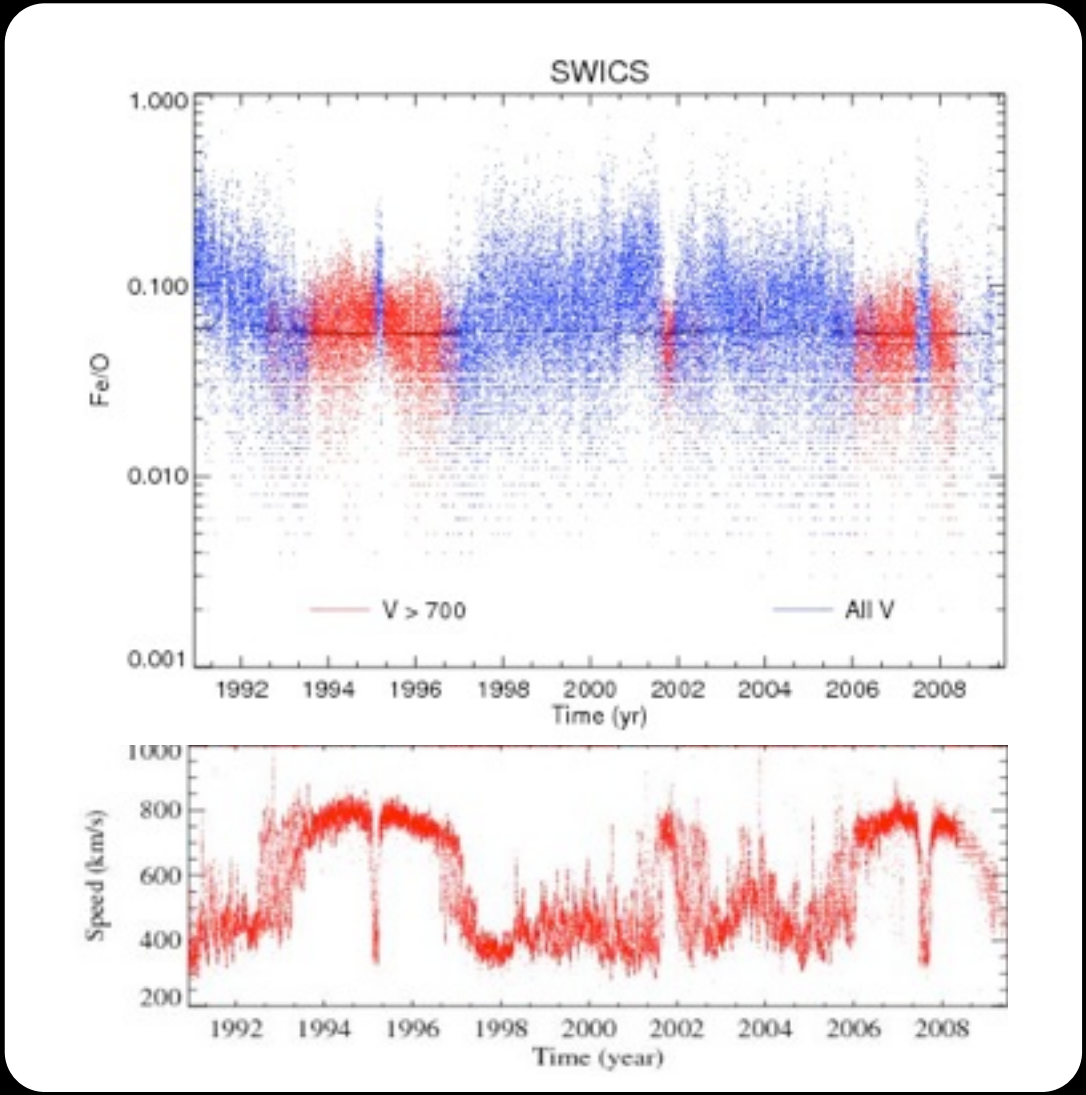
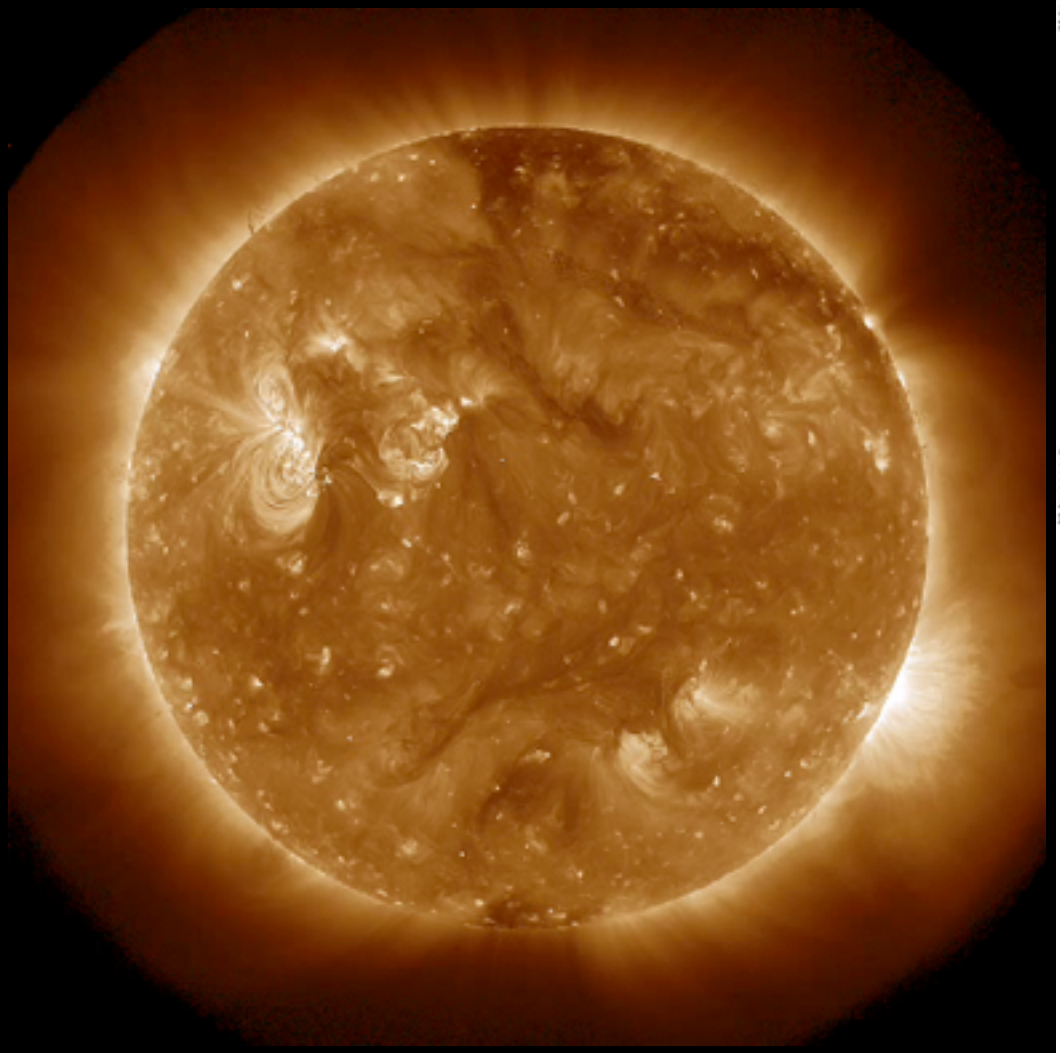
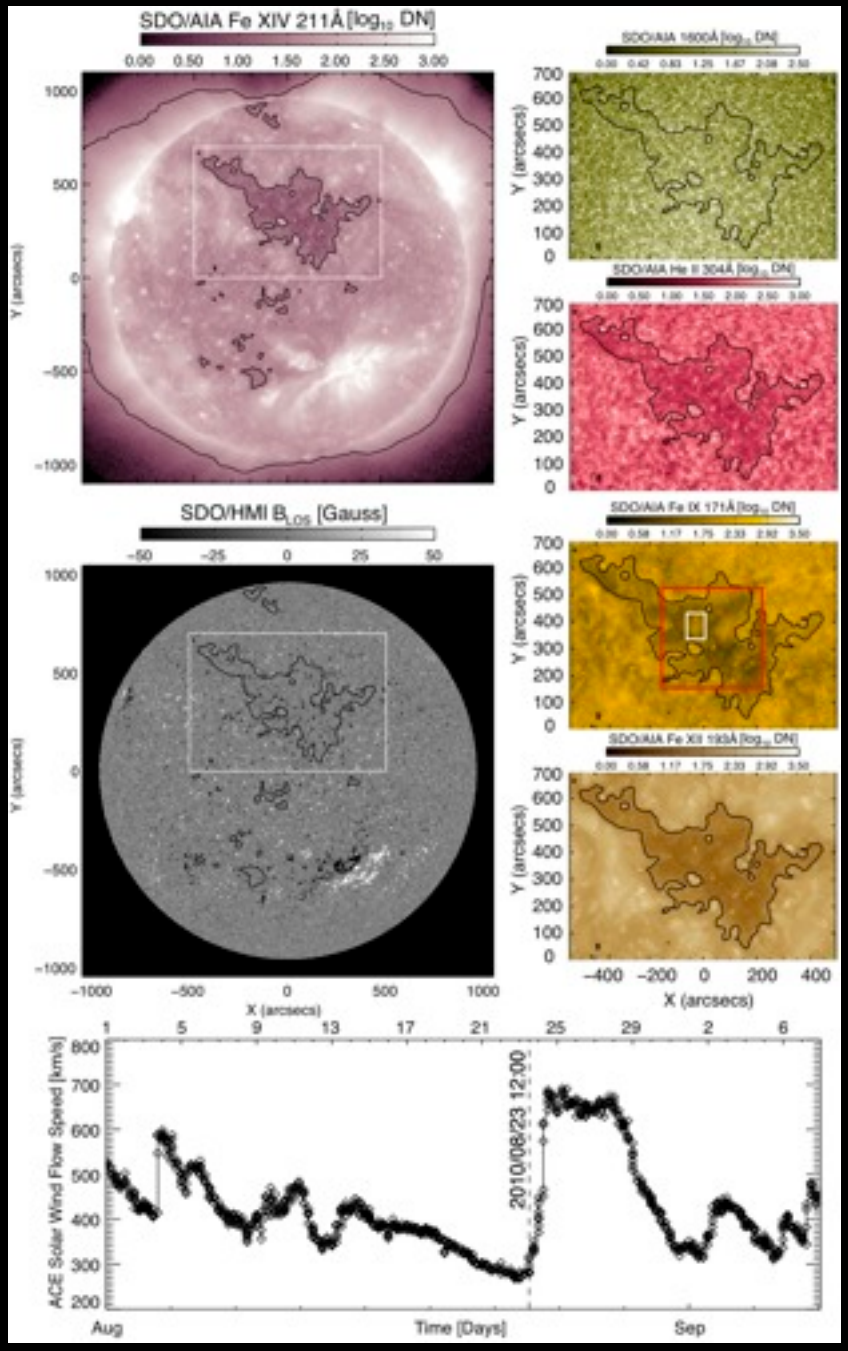
- We know that the fast wind comes from coronal holes.
- Question: Is the composition constant in one coronal hole?
- Let's take a break and look at one coronal hole in some detail!

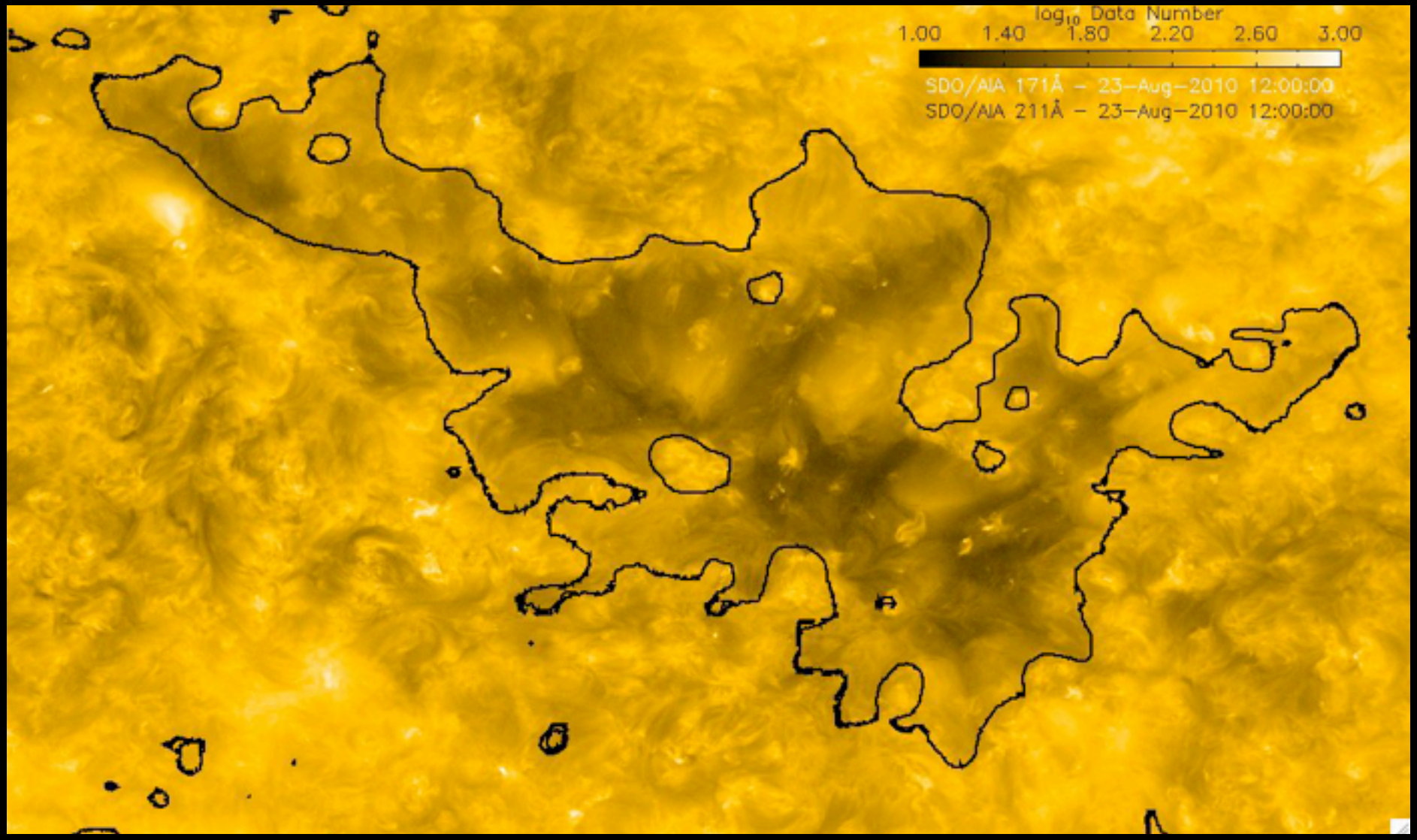
- ★ Are all coronal holes the same?
- ★ Looking for a relationship between the magnetic field strength and composition ratios
- ★ In the fast wind, Fe/O is almost always between 1 and 2 times the photospheric abundance



A Coronal Hole Example....






log10 Data Number
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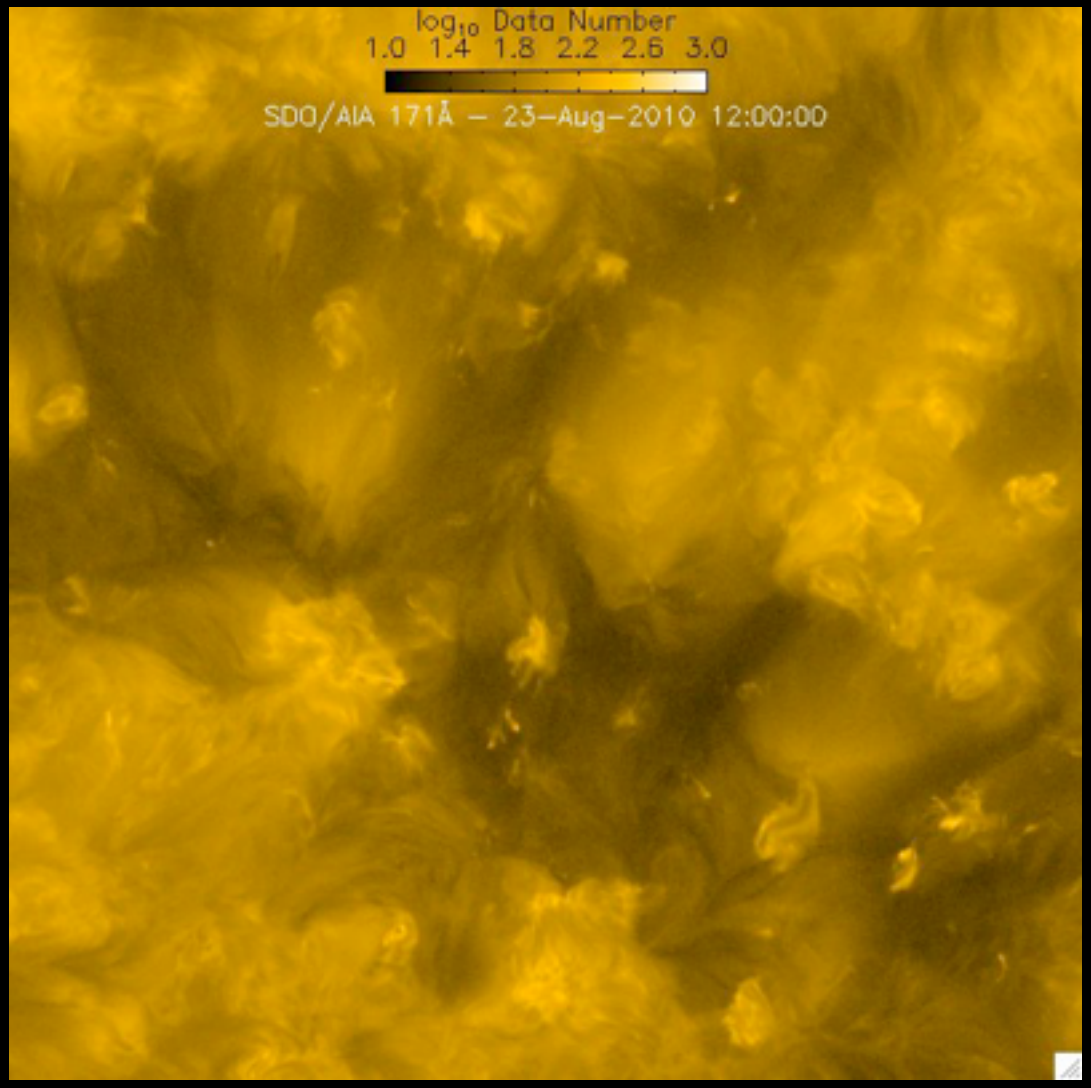
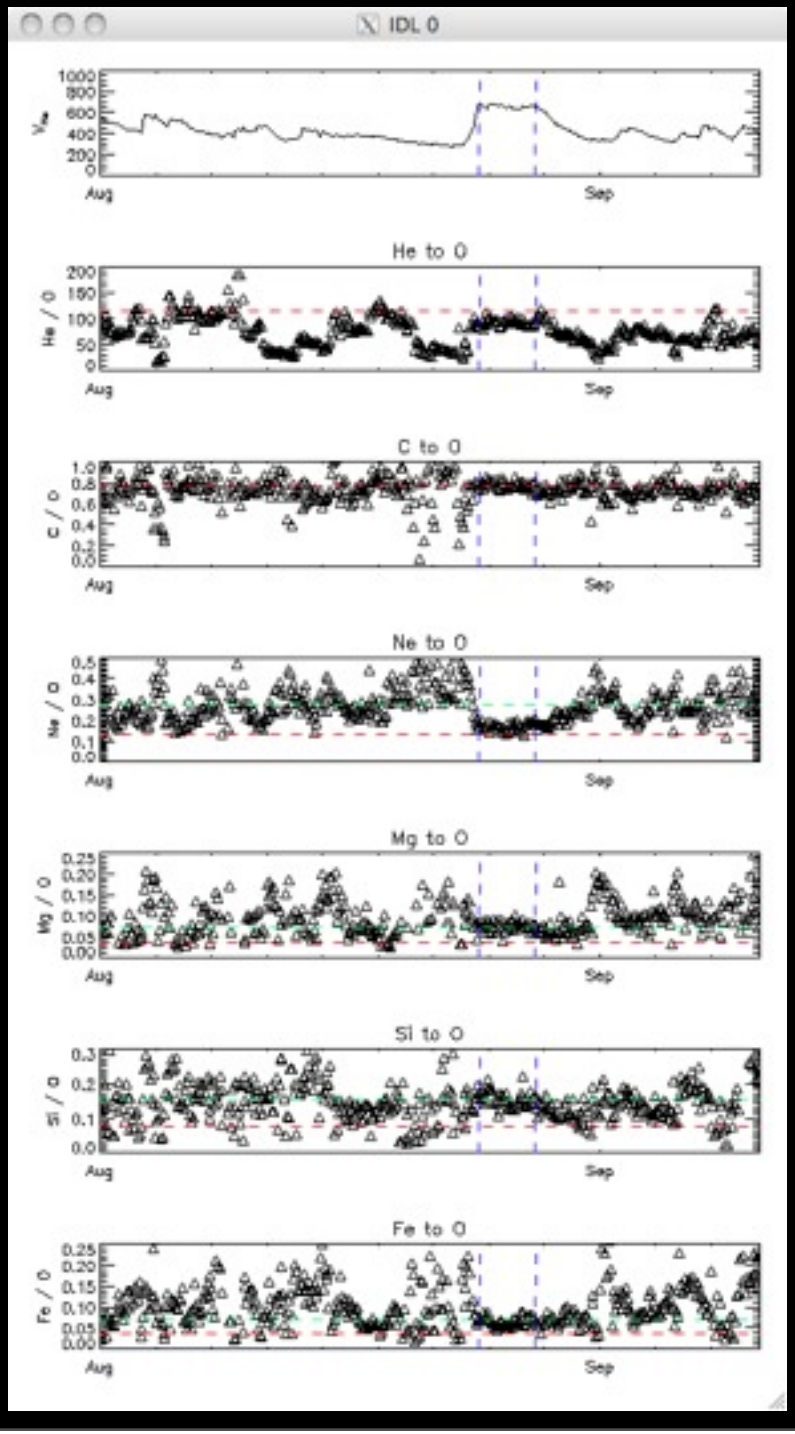
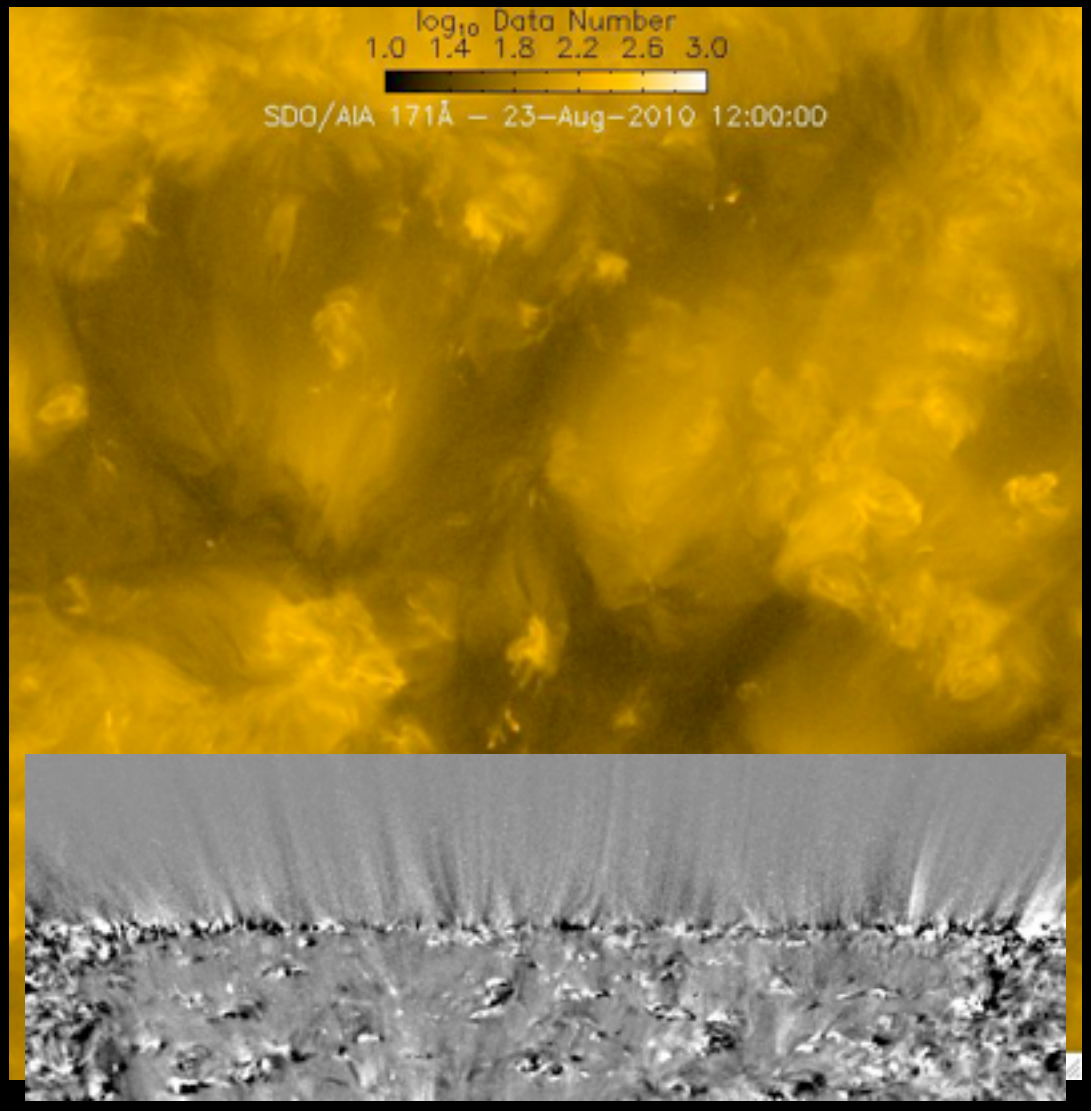
SDO/AIA 171Å – 23-Aug-2010 12:00:00
SDO/AIA 211Å – 23-Aug-2010 12:00:00


log10 Data Number
1.0 1.4 1.8 2.2 2.6 3.0
SDO/AIA 171Å – 23-Aug-2010 12:00:00


IDL 0
He to O
C to O
Ne to O
Mg to O
Si to O
Fe to O
Aug
Sep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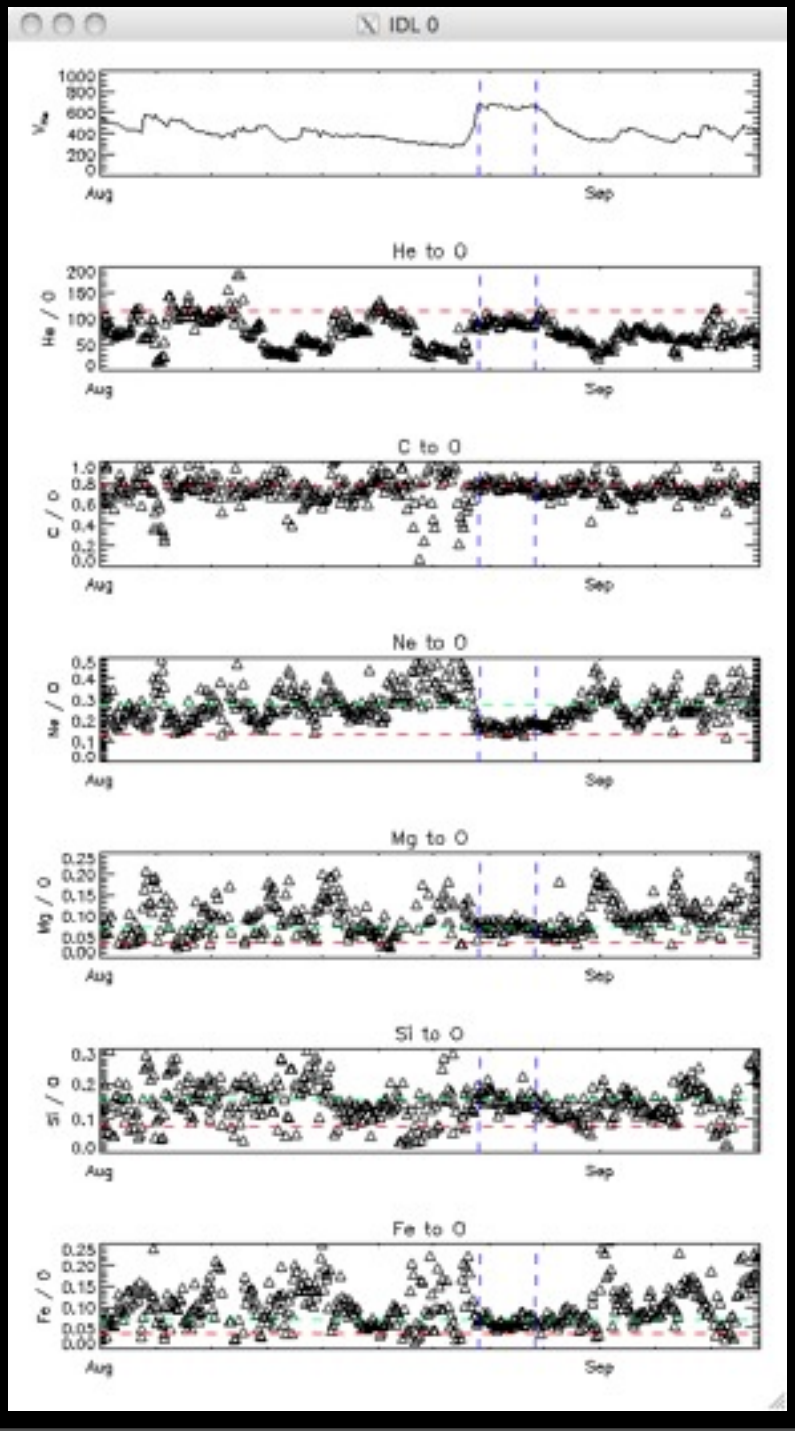
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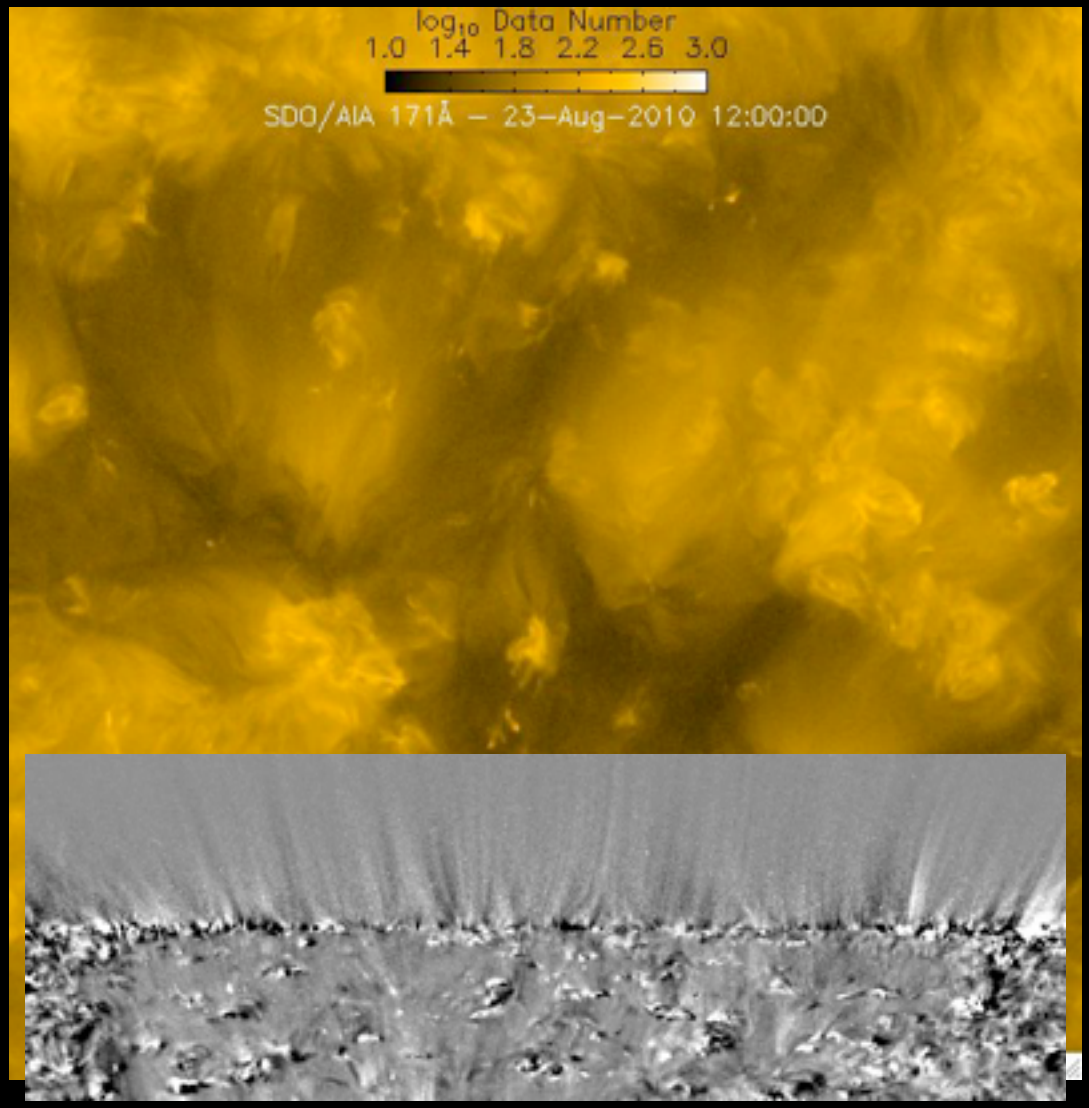
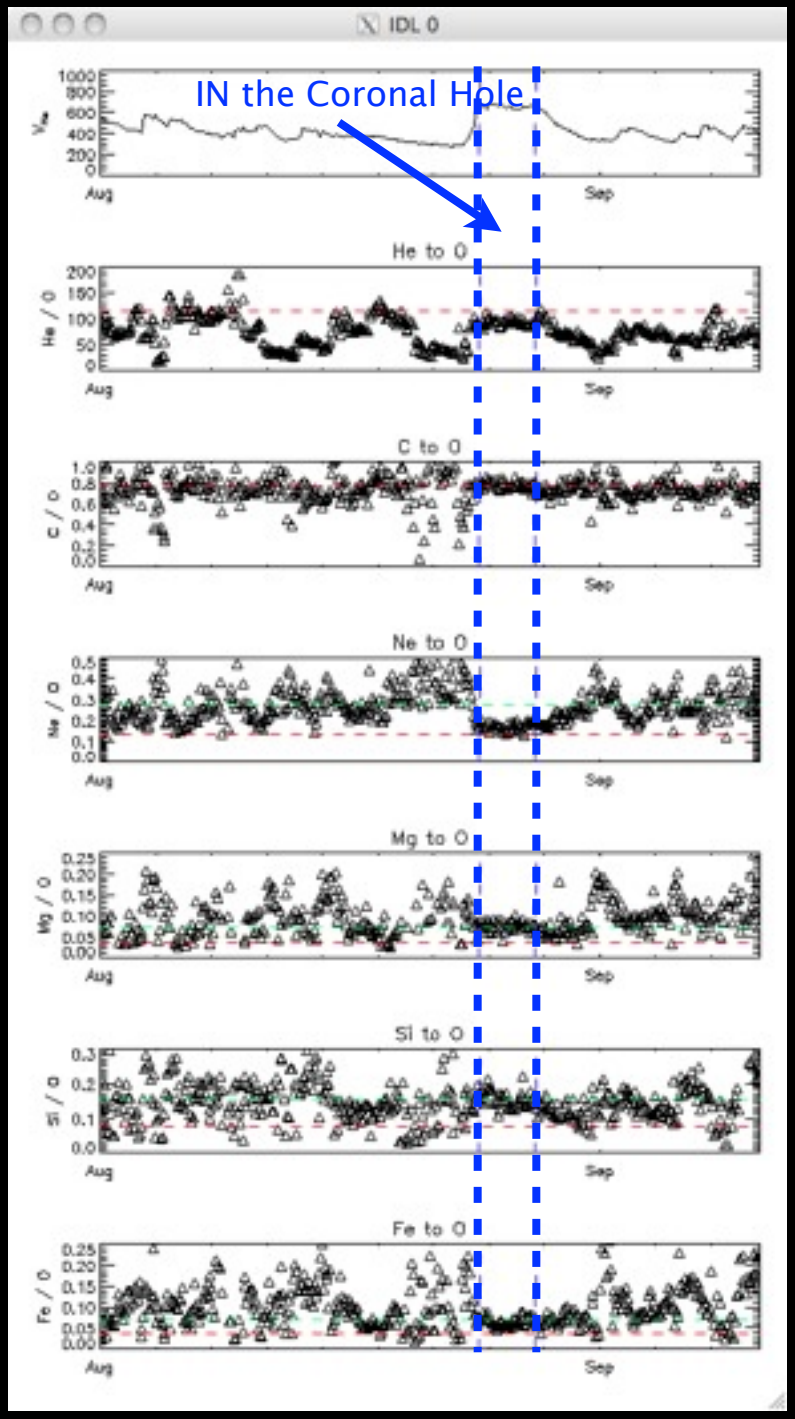
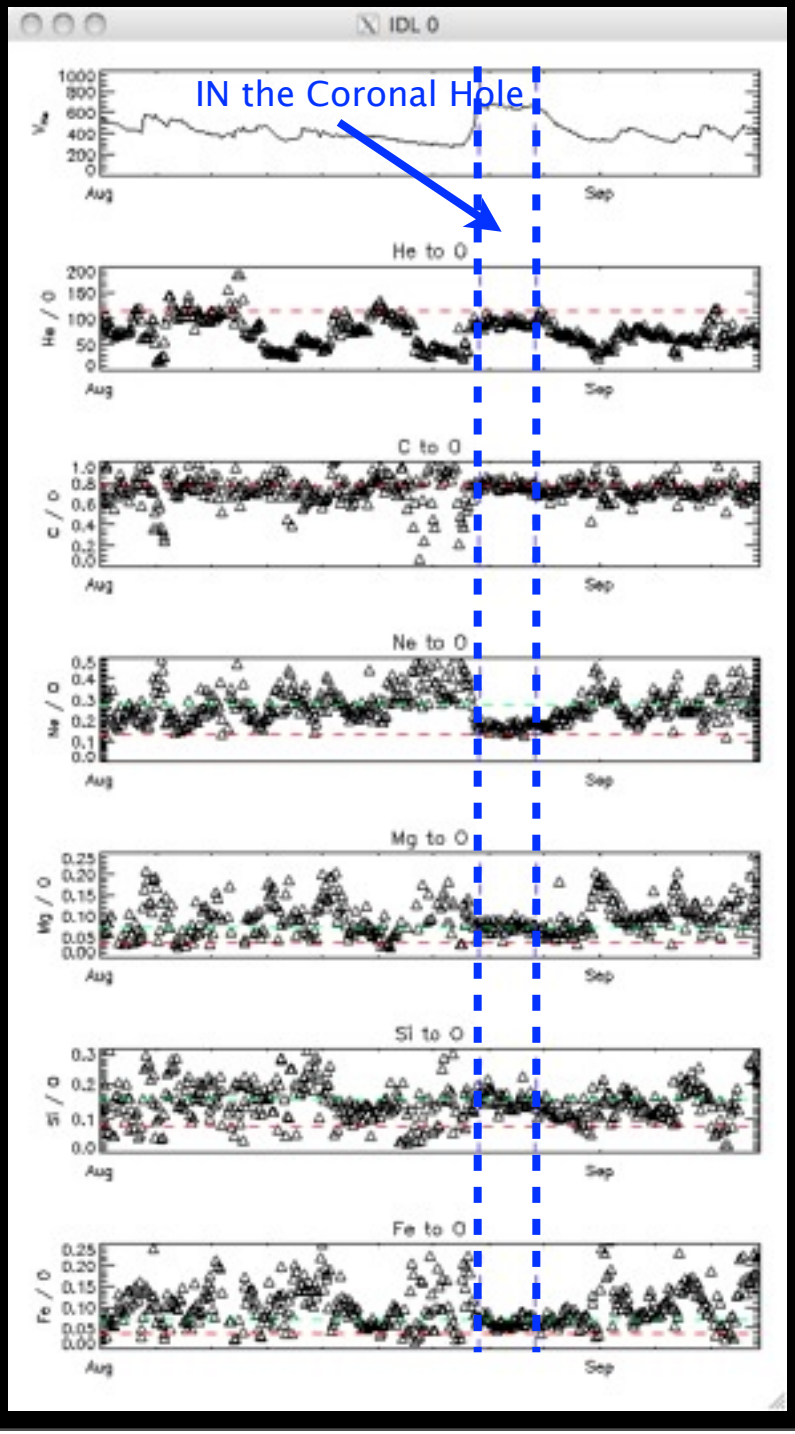
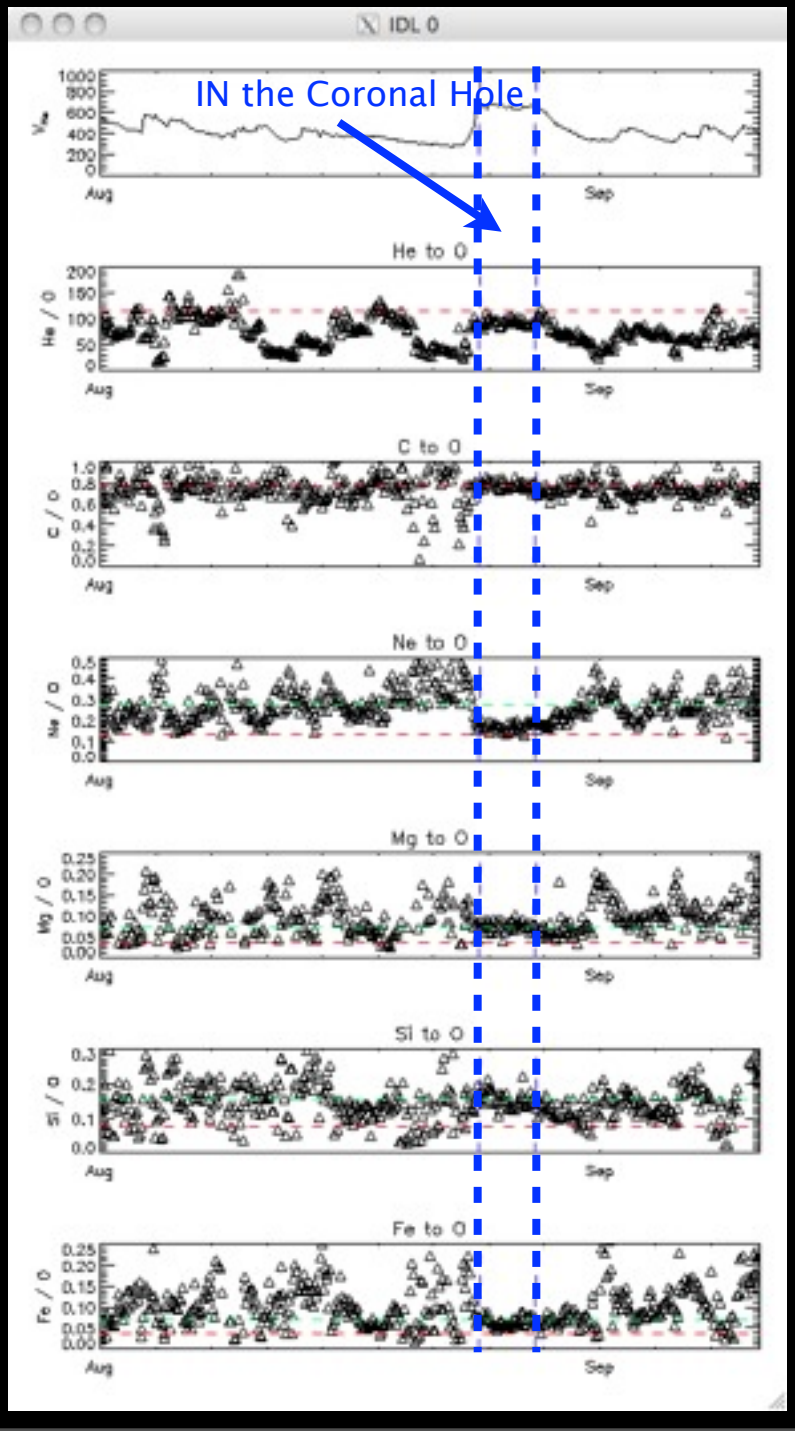




Compositional components constant with time in the fast wind flow


IDL 0
IN the Coronal Hole
He to O
C to O
Ne to O
Mg to O
Si to O
Fe to O
Aug
Sep

★ The mixture of atoms is relatively constant in the coronal hole.



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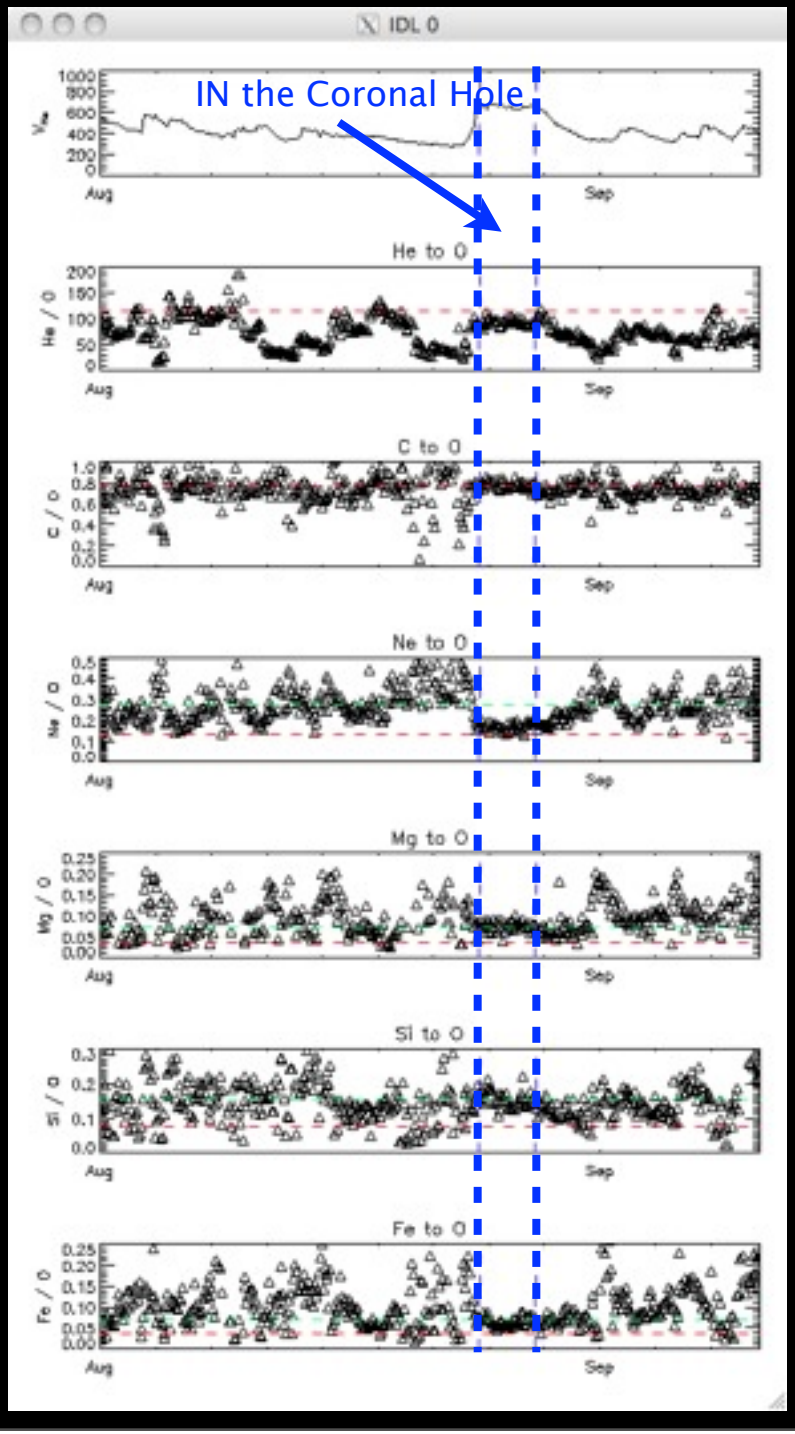
For example:
- The abundance of Mg, Si and Fe (all relative to O) = ~ two times the photospheric abundance



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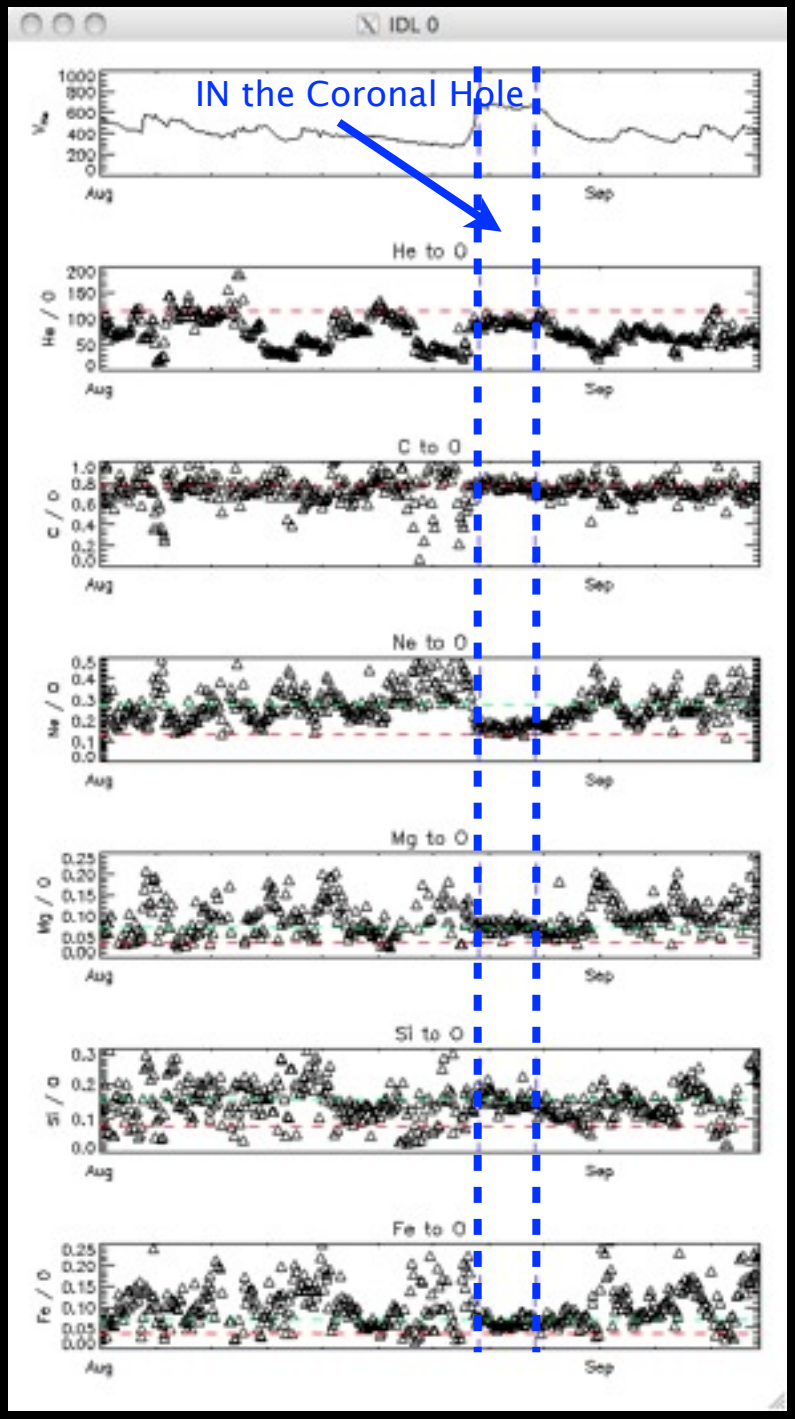
★ However, the reason behind this specific set of ratios is not well understood.



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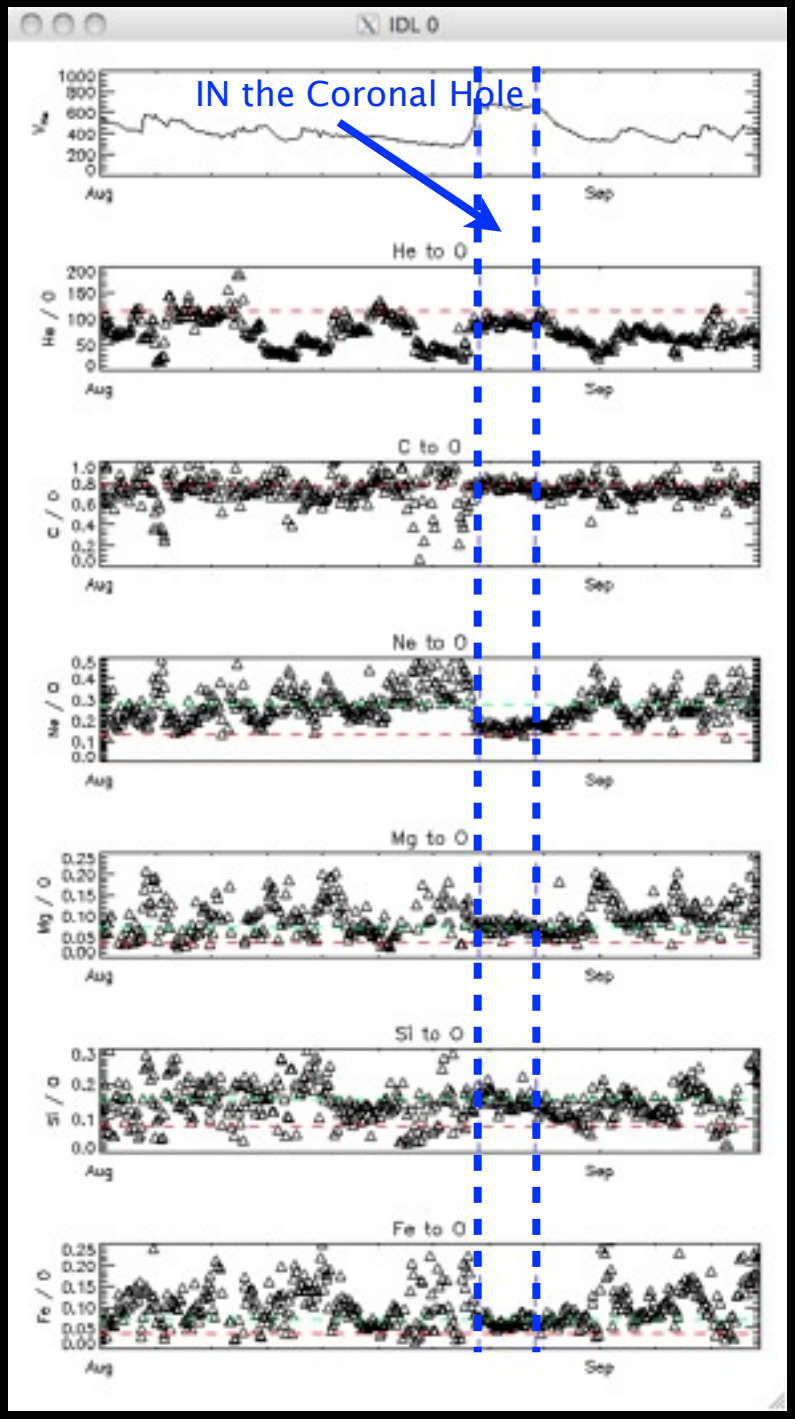
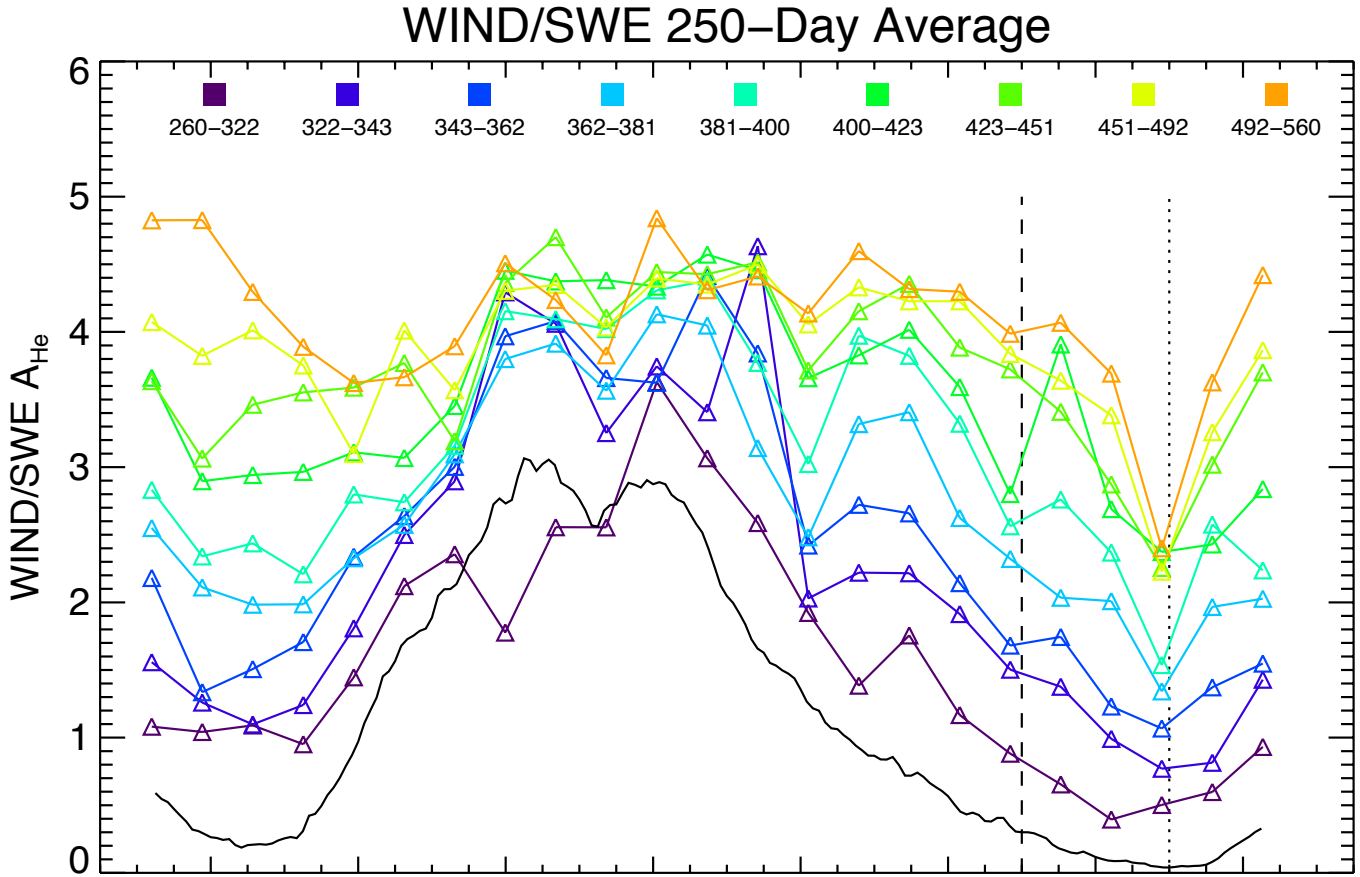
For example:
- The abundance of Mg, Si and Fe (all relative to O) = ~ two times the photospheric abundance

★ However, the reason behind this specific set of ratios is not well understood.

★ Understanding this pattern may provide information regarding what is happening physically (==> the heating process) before the plasma becomes collisionless.
Future work?

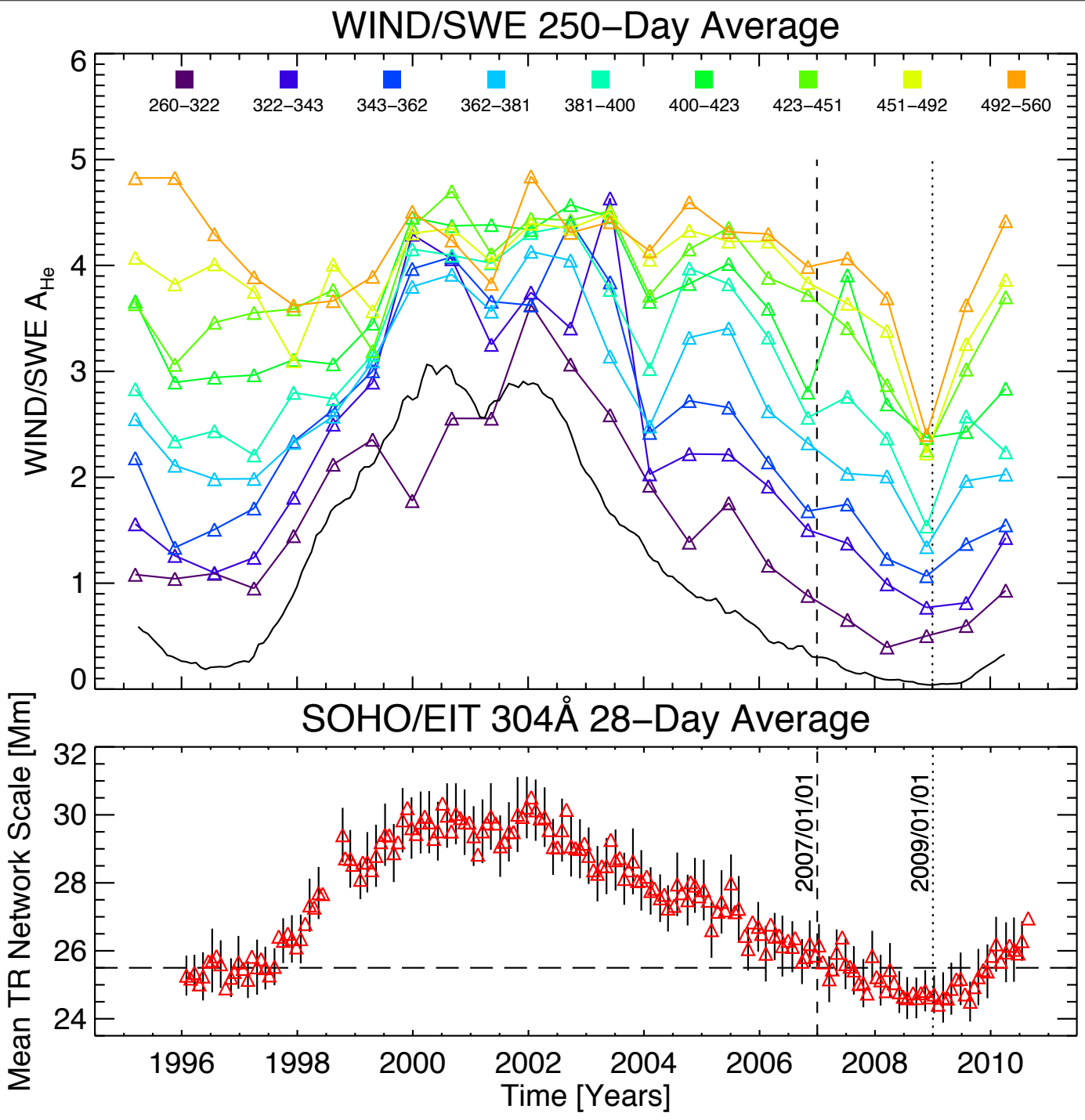


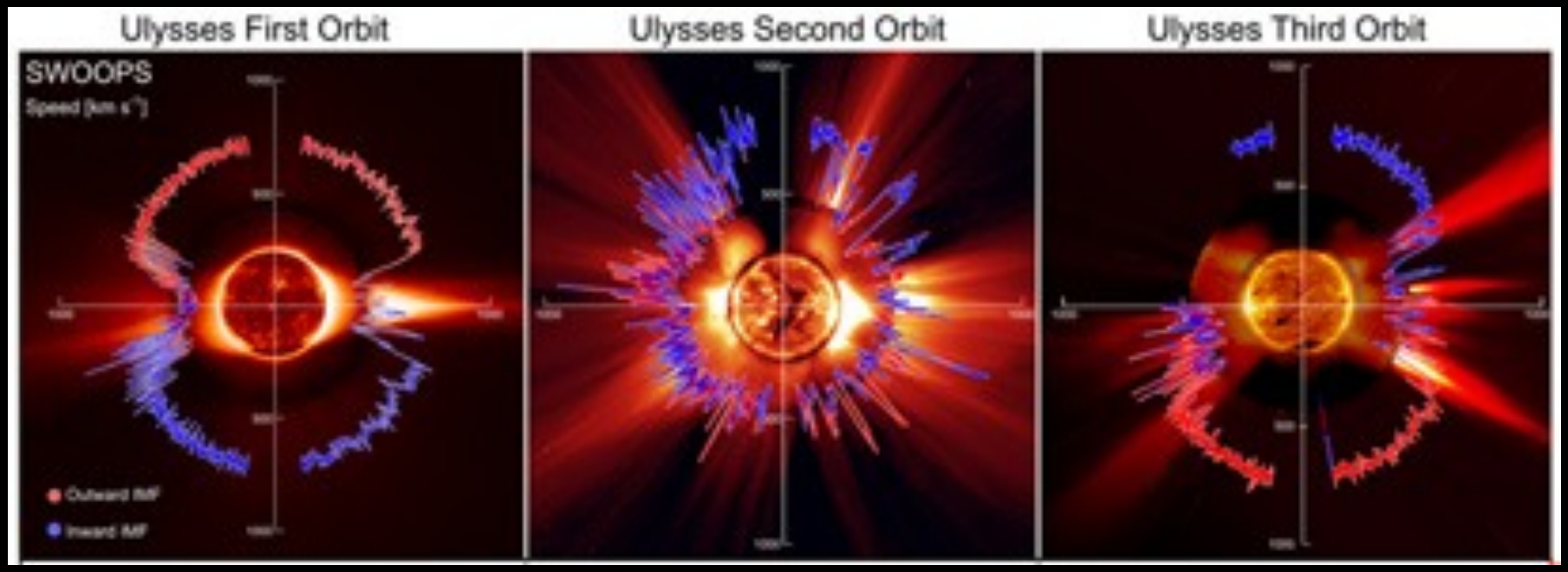


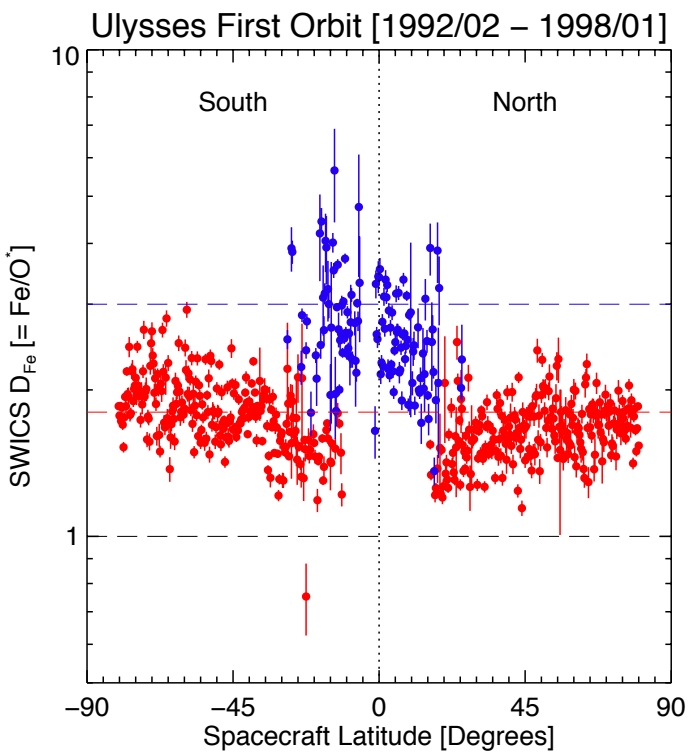
Looking again at Helium over time...

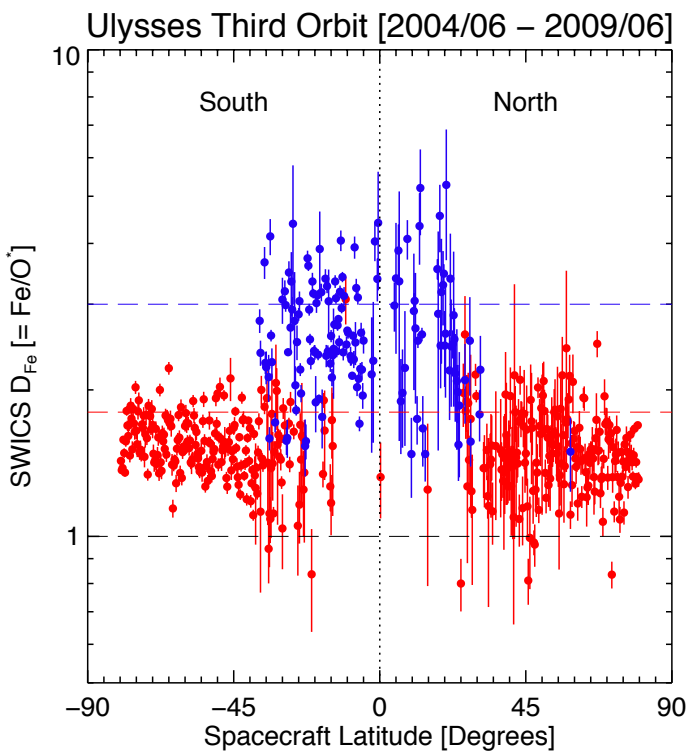
Notice the significant drop during the recent solar minimum

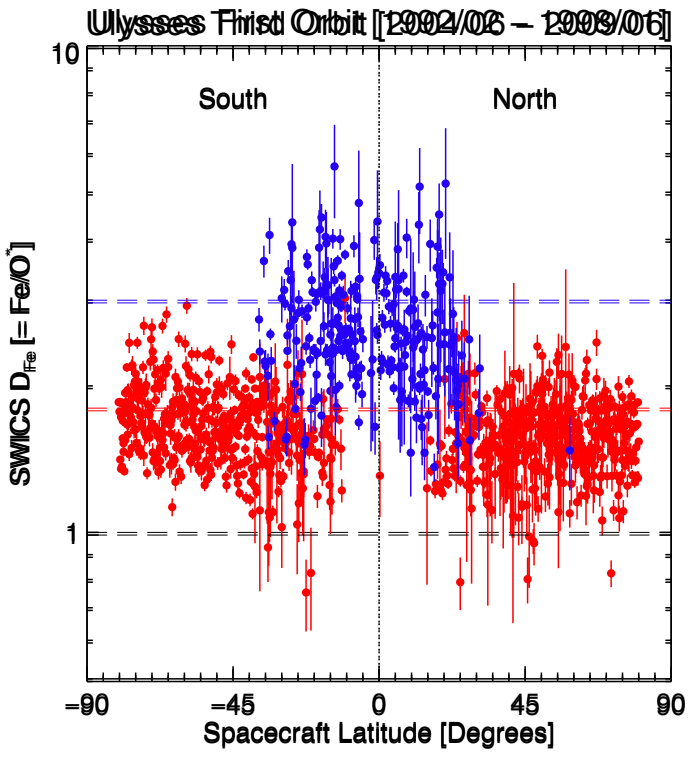
What might have caused this?


WIND/SWE 250−Day Average
260−322
322−343
343−362
362−381
381−400
400−423
423−451
451−492
492−560
WIND/SWE A_{He}
0
1
2
3
4
5
6
SOHO/EIT 304Å 28−Day Average
Mean TR Network Scale [Mm]
24
26
28
30
32
2007/01/01
2009/01/01
1996
1998
2000
2002
2004
2006
2008
2010
Time [Years]


Ulysses First Orbit
Ulysses Second Orbit
Ulysses Third Orbit
SWOOPS
Speed [km s⁻¹]
Outward IMF
Inward IMF


Ulysses First Orbit [1992/02 – 1998/01]
South
North
10
1
SWICS D_{Fe} [= Fe/O*]
–90
–45
0
45
90
Spacecraft Latitude [Degrees]


Ulysses Third Orbit [2004/06 – 2009/06]
South
North
10
1
SWICS D_{Fe} [= Fe/O*]
–90
–45
0
45
90
Spacecraft Latitude [Degrees]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90
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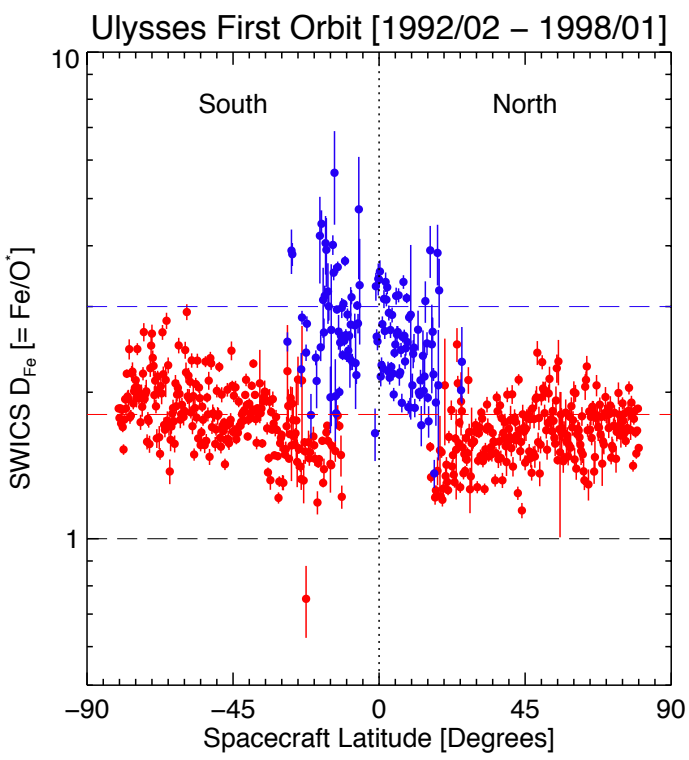
Ulysses First Orbit [1992/02 – 1998/01]
South
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10
1
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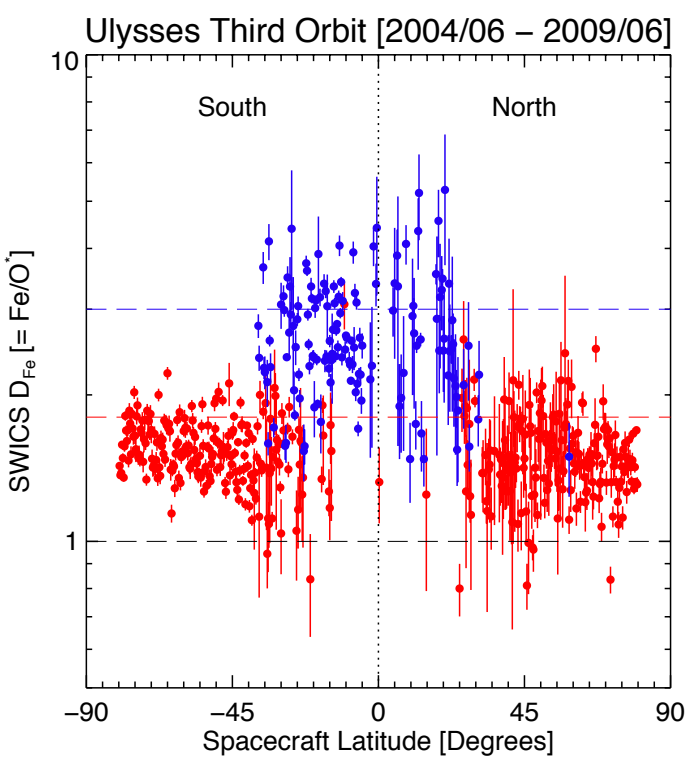
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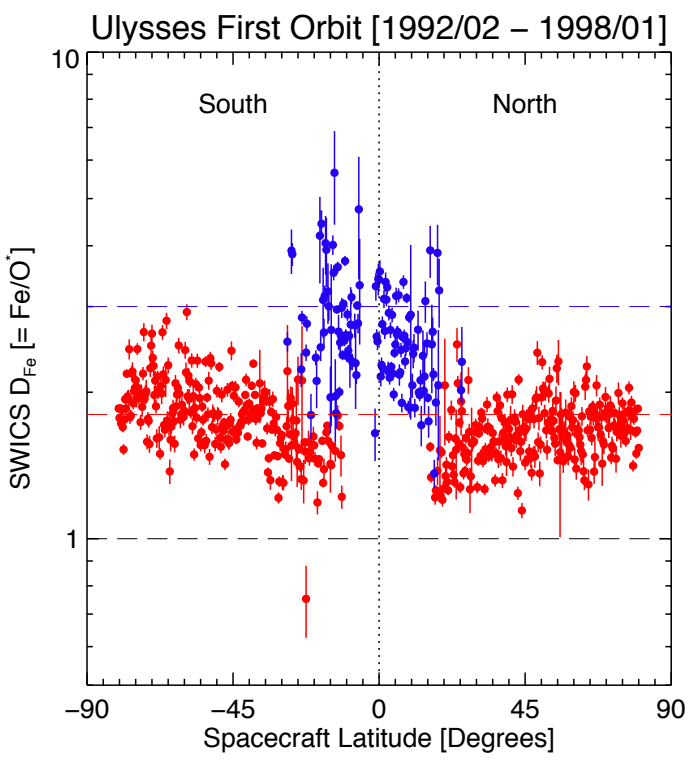
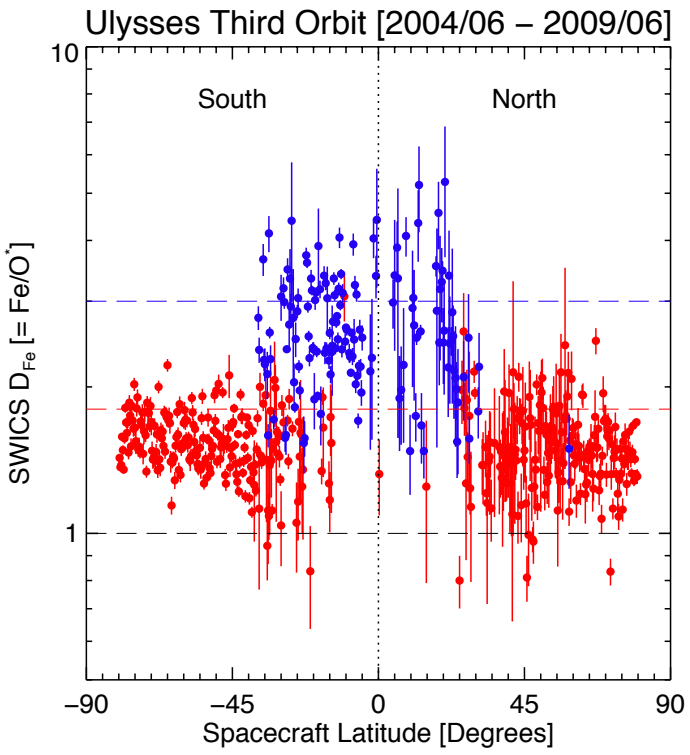
South
North
10
1
SWICS D_{Fe} [= Fe/O*]
–90
–45
0
45
90
Spacecraft Latitude [Degrees]

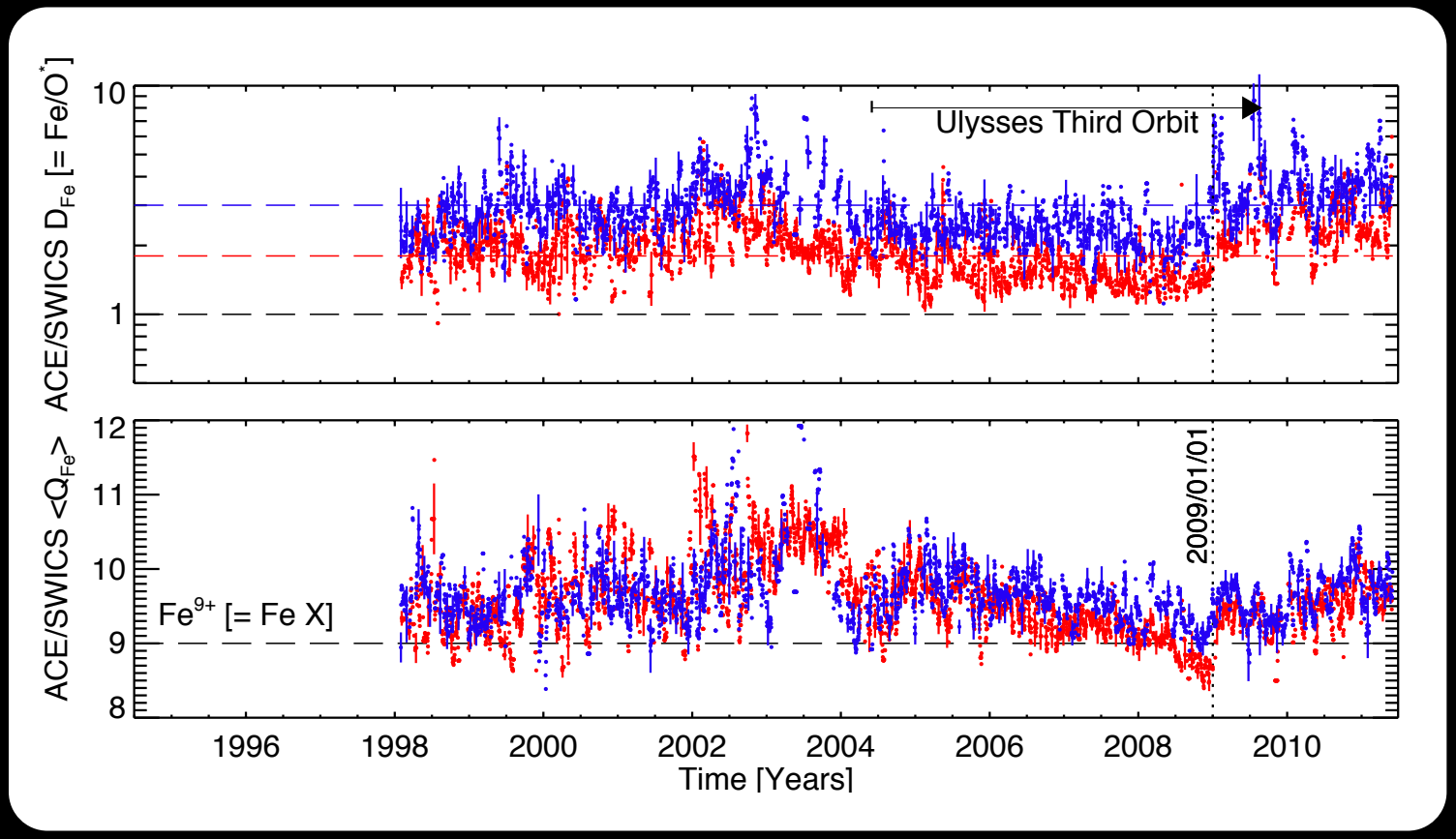
Fe/O in the fast wind was lower during the recent minimum compared with the last minimum





Solar wind Fe fractionation & charge state over time

Degree of Iron Fractionation & Charge State from 1998-present from ACE



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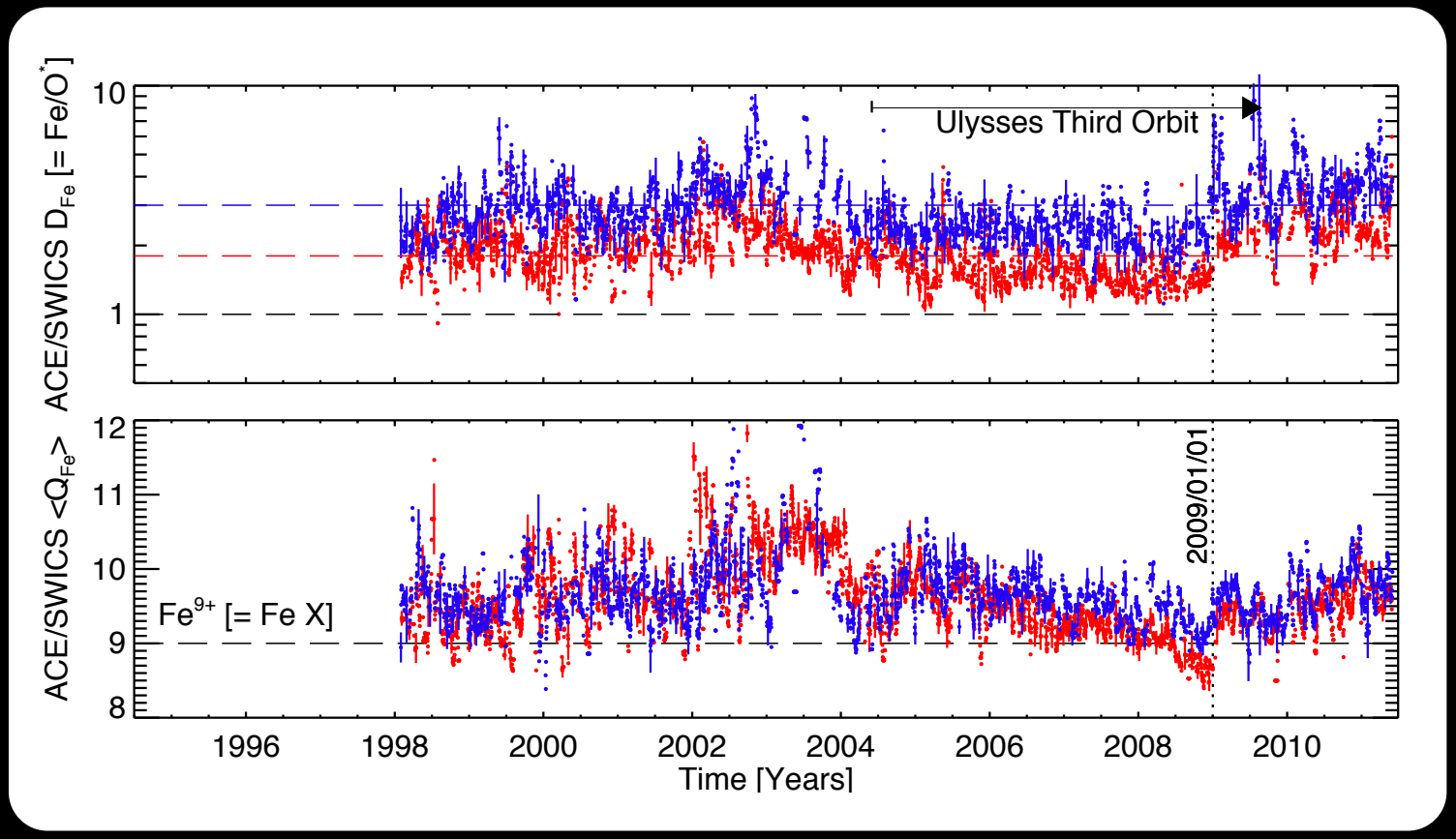
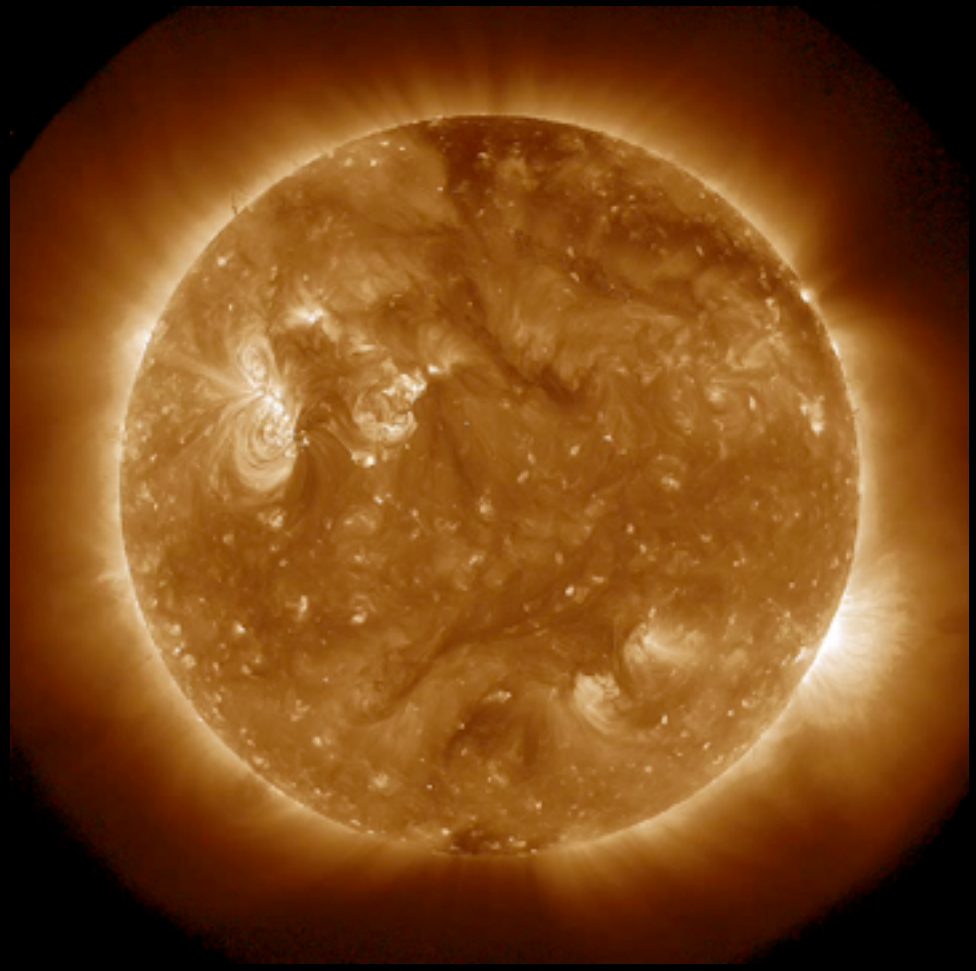
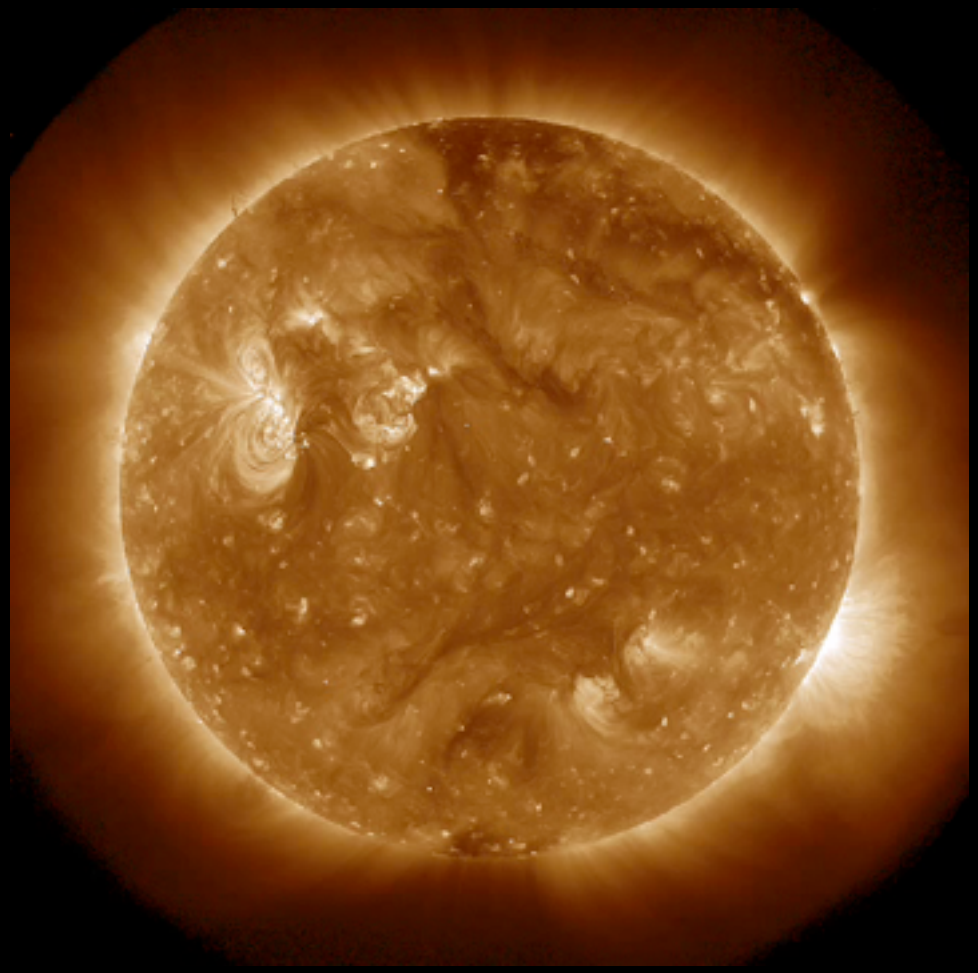


Both reach a low in 2009 and recover quickly

Summary

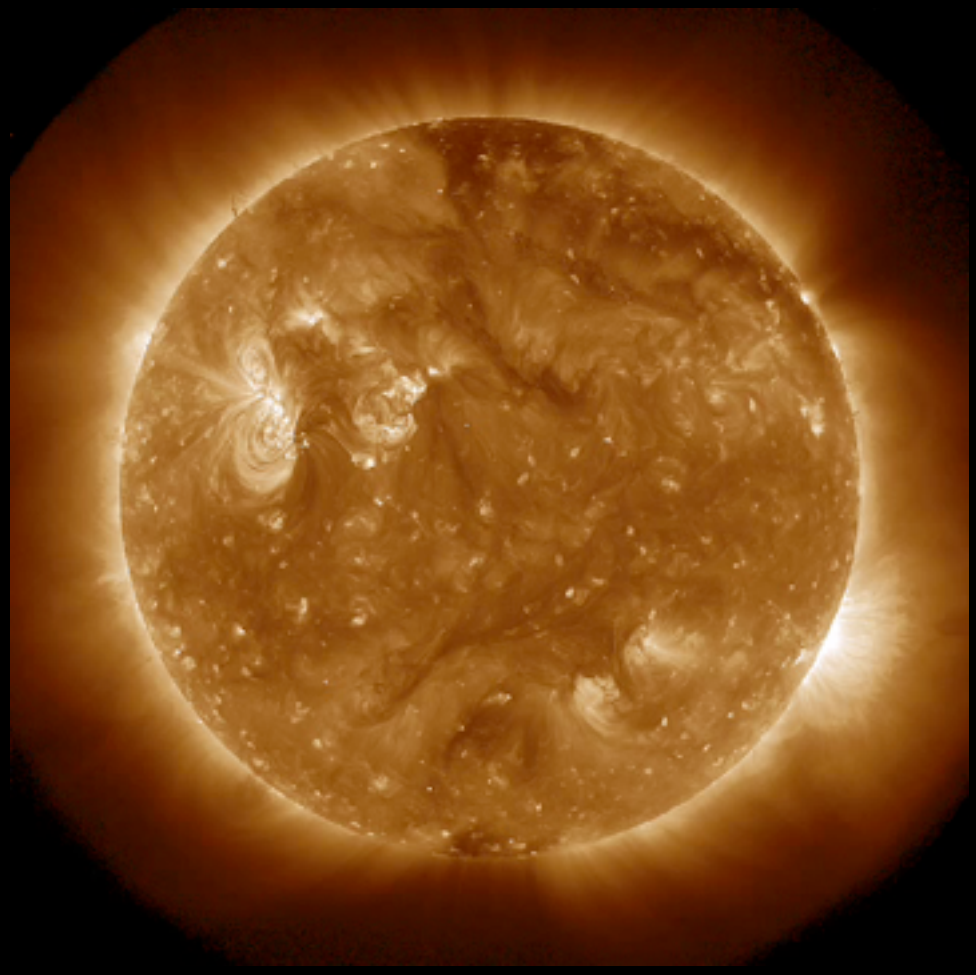


Summary



★ Reduction in A_{He} (even in the fast wind) coinciding with the reduction in the supergranular length scale during recent minimum

Summary



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★ Reduction in the fractionation of Fe in the fast wind during the recent minimum

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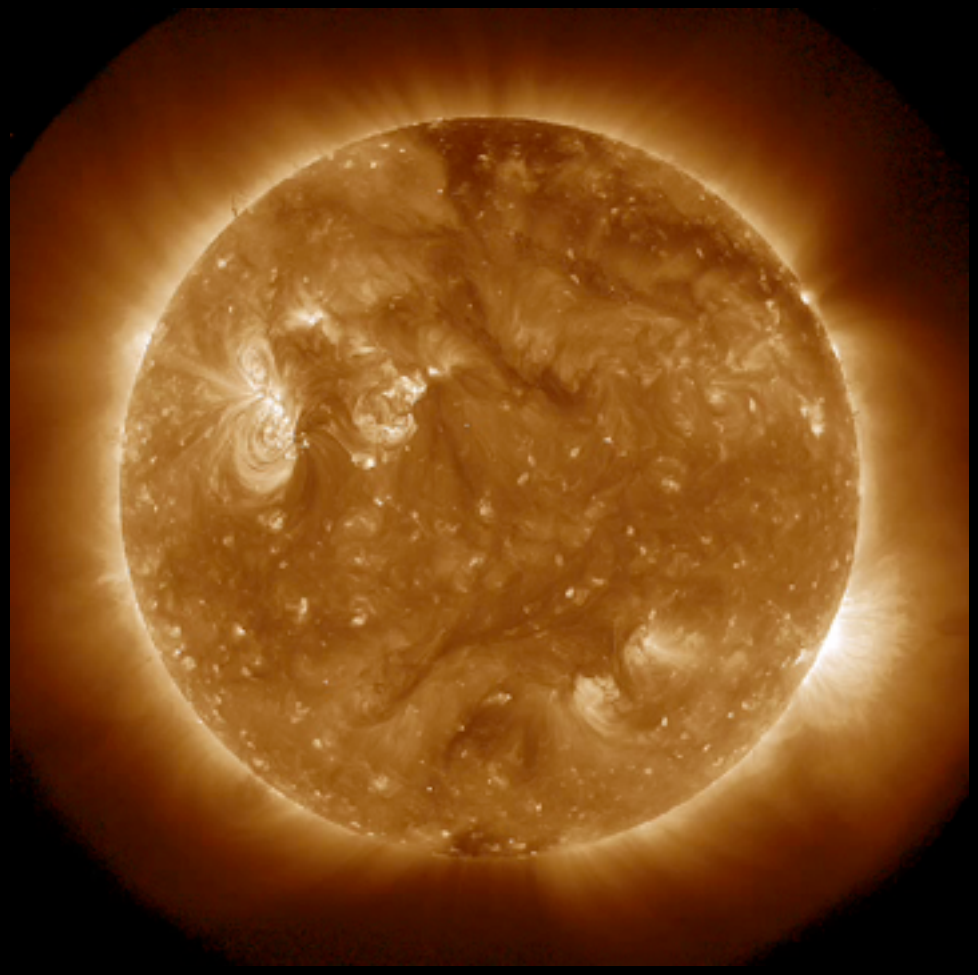
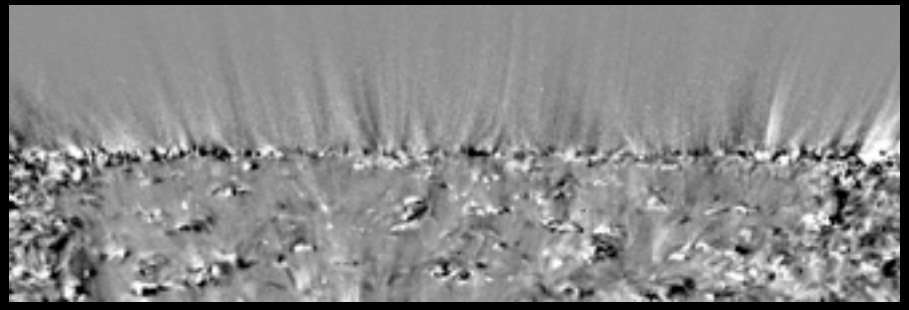


★ Reduction in A_{He} (even in the fast wind) coinciding with the reduction in the supergranular length scale during recent minimum

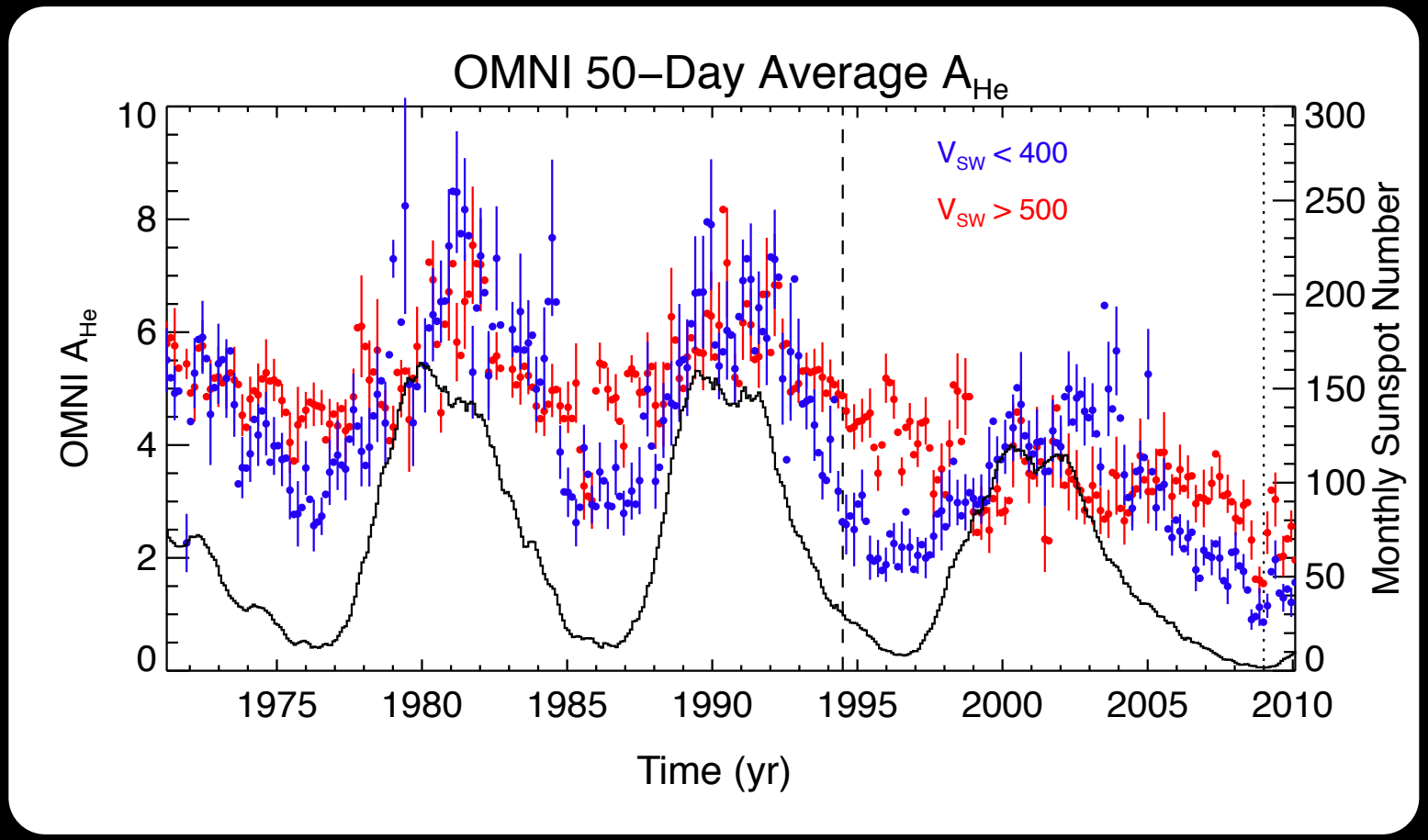
★ Reduction in the fractionation of Fe in the fast wind during the recent minimum

★ Consistent with a change in the heating at the roots?



What about the Helium abundance over multiple solar cycles?

A_{He} from 1971-2010 from OMNI data set



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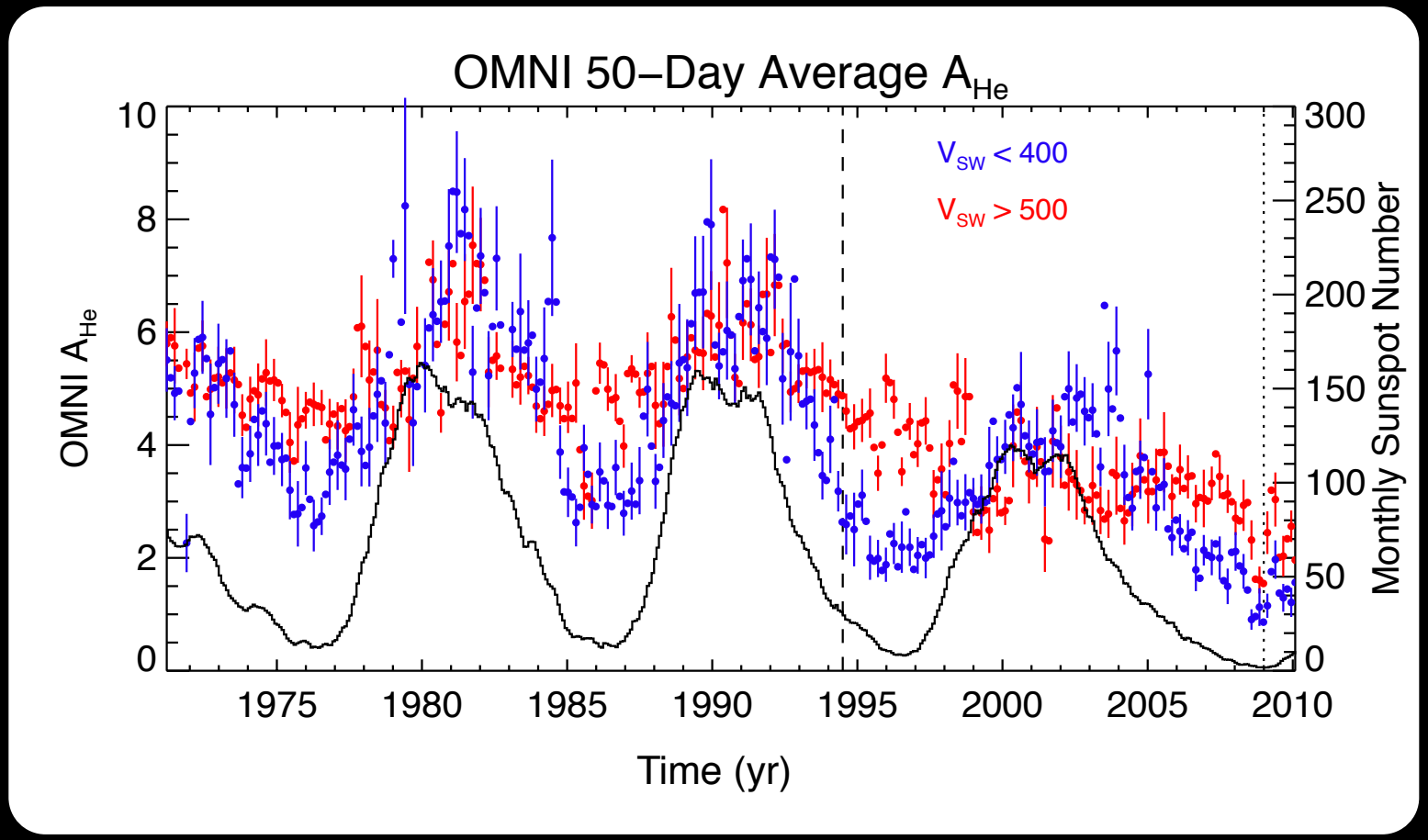
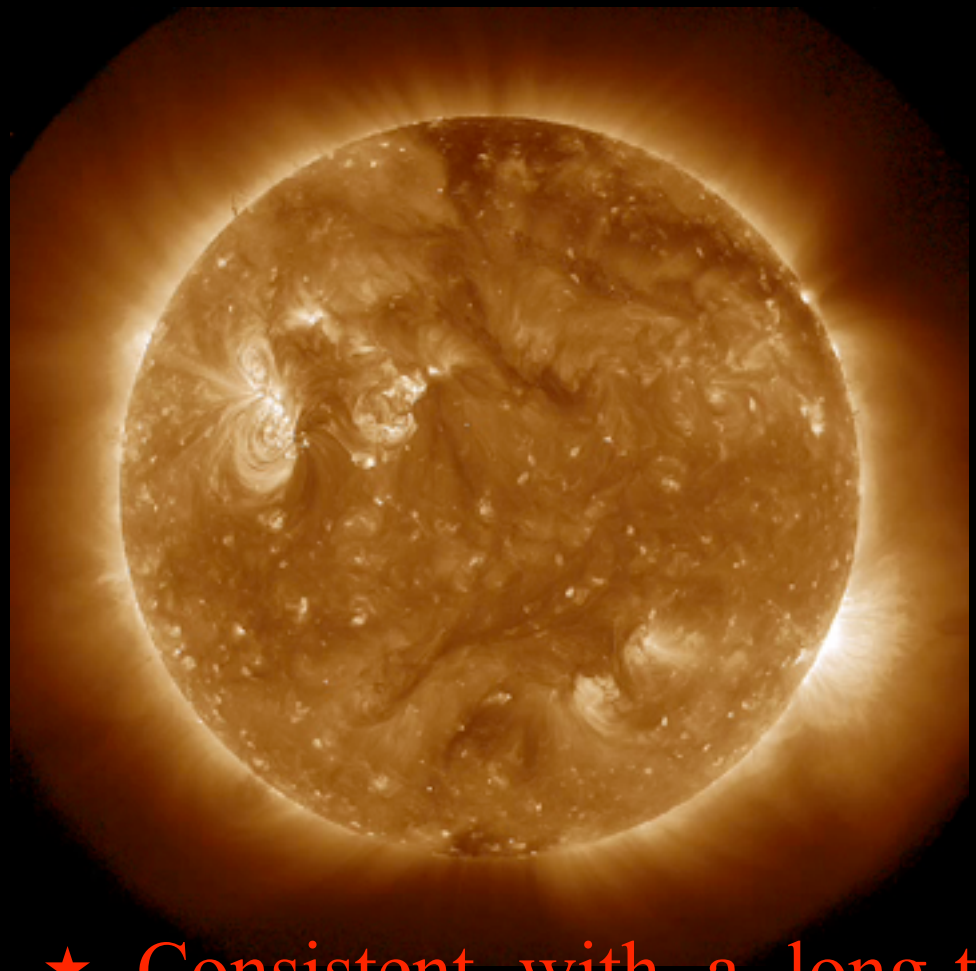


There appears to be a long-term reduction in the Helium abundance. Less energy release in the solar wind? Reduction in B?

Summary

★ Consistent with a long-term change in the basic heating process of the fast solar wind driven likely by changes in the field strength and distribution.

Summary



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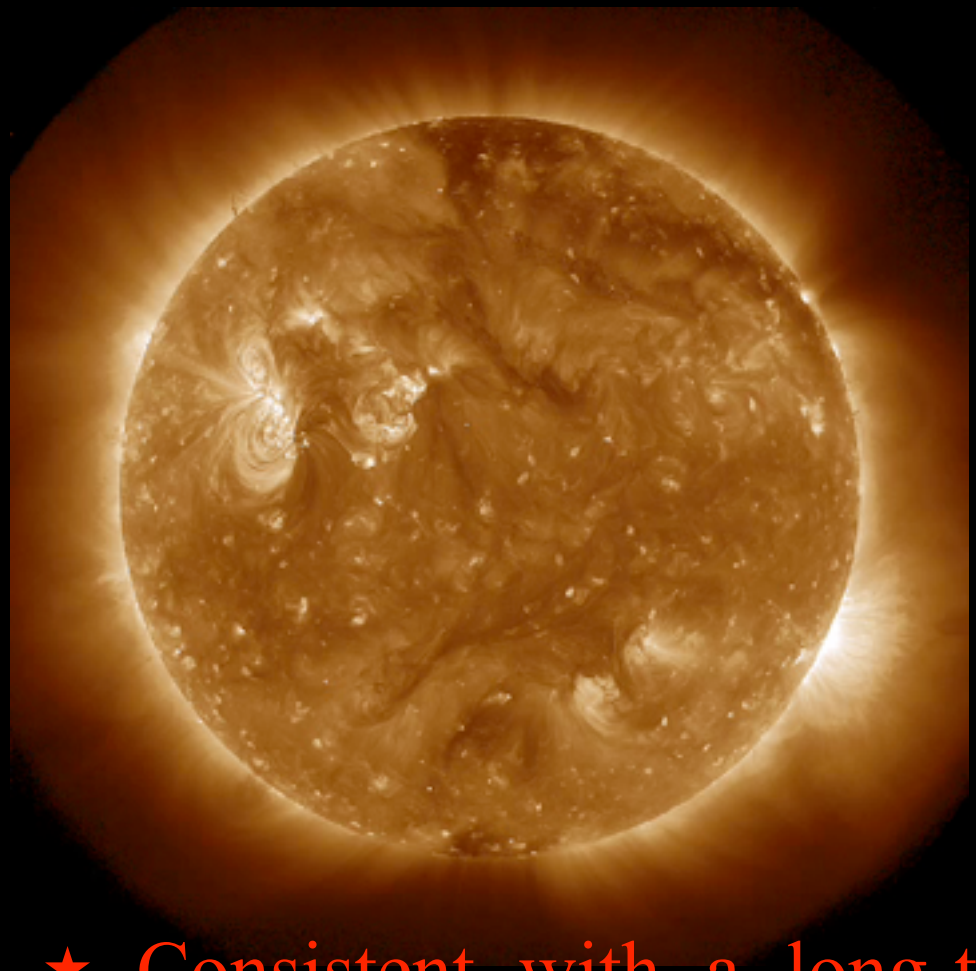
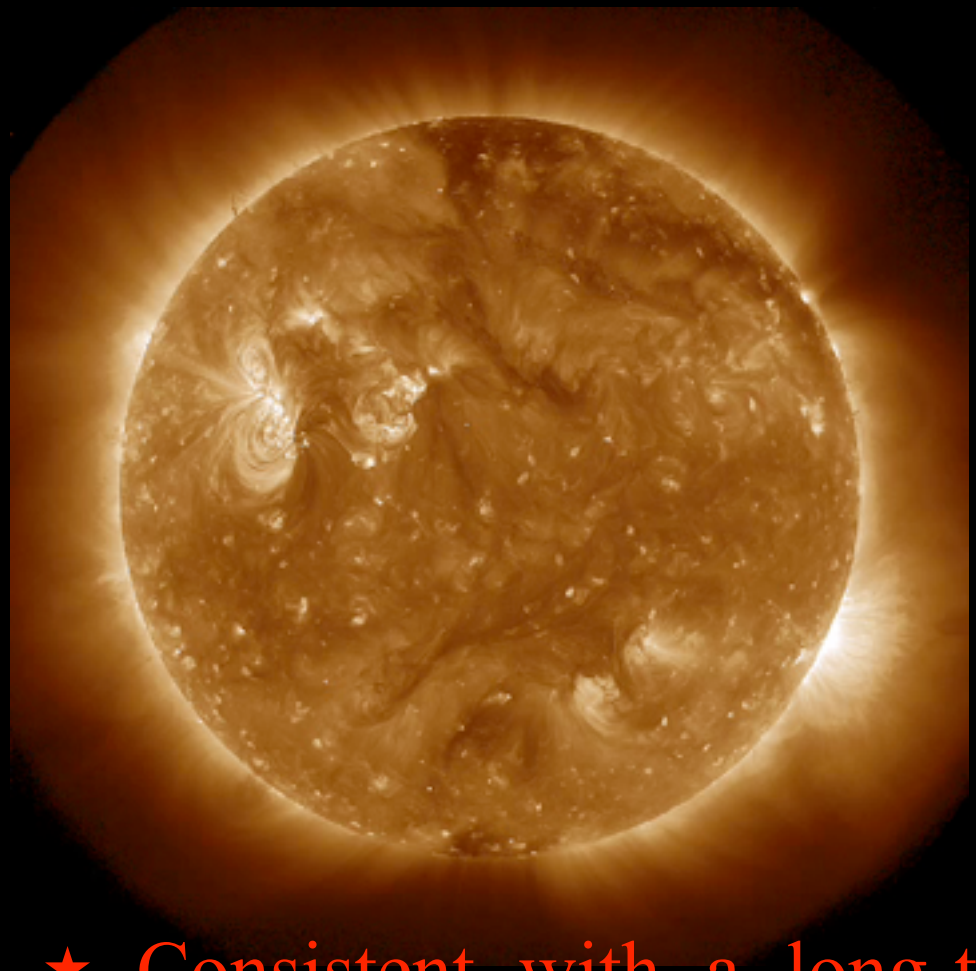


★ Reduction in A_{He} coinciding with the reduction in the supergranular length scale during recent minimum

★ Reduction in the fractionation of Fe in the fast wind during the recent minimum.

★ Consistent with a long-term change in the basic heating process of the fast solar wind driven likely by changes in the field strength and distribution.

Summary



★ Reduction in A_{He} coinciding with the reduction in the supergranular length scale during recent minimum

★ Reduction in the fractionation of Fe in the fast wind during the recent minimum.

★ Long-term decay of A_{He} indicating a possible reduction in the background magnetic field and the energy input in to the solar wind over multiple solar cycles

★ Consistent with a long-term change in the basic heating process of the fast solar wind driven likely by changes in the field strength and distribution.

A Special Thank You!

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