He/H variation in the solar wind over the solar cycle

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NESSC (CfA)
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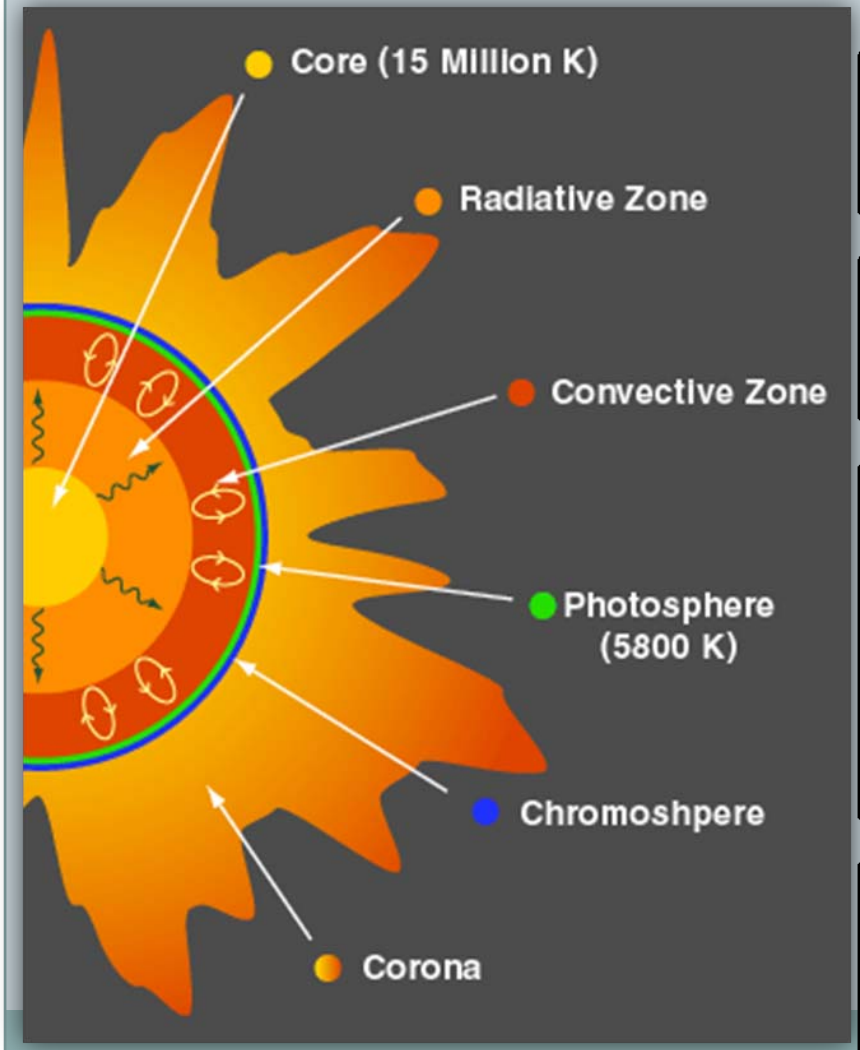
Who is involved

- Kasper (SAO)
- Bennett Maruca (Harvard University), new analysis of Wind Faraday Cup data
- Alan Lazarus, Mike Stevens (MIT), He/H variation over Carrington rotation and solar cycle
- Harlan Spence, Nicholeen Viall (BU): short period He/H variation in the solar wind
- Sarah McGregor (BU): Mapping solar wind He/H to solar sources

Relative abundance of helium



He/H (ratio by number density) within the solar core is 10%

- Matching observed radius and luminosity (Guzik & Cox, 1993)

Solar Interior ~ 8% within convection zone

- Helium becomes singly ionized then neutral within ~ 0.02 Rs (Basu & Antia 1995).

Solar corona ~ 4.5%

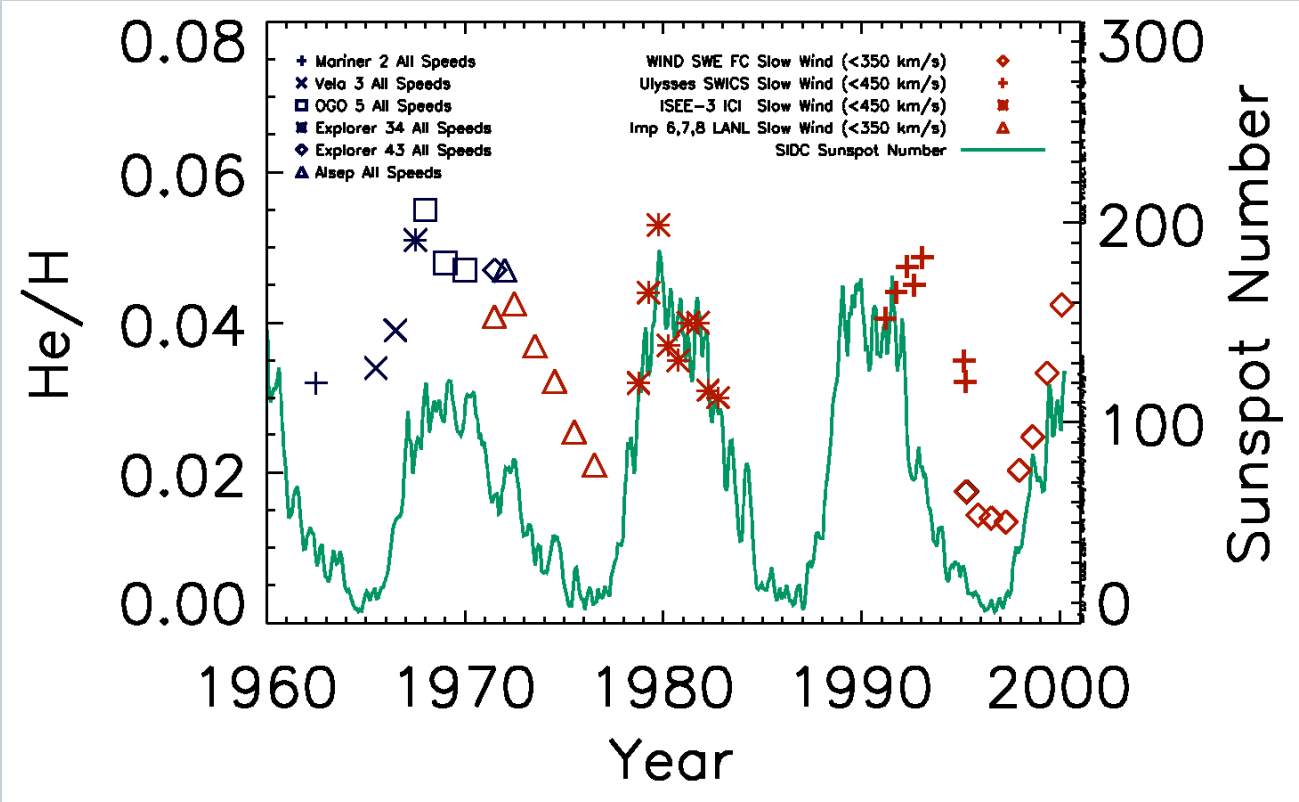
- Few direct measurements, but He/H ~ 4.5% (Lamming, 2004)
- Transport of He from convection zone through transition region to corona is poorly understood
- model H, H+, He, He+ and He+2 consistently (Hansteen et al 1994))
- simulations must boost drag x10 to produce coronal He/H

Solar Wind 0-30%

- He/H is the most variable quantity in the solar windHe/H is no more than 4.5% of quiet solar wind
- He/H can rise to 30% in ejecta (50% of mass flux!)

The solar wind helium abundance

He/H from 1960-2000 increases with solar activity

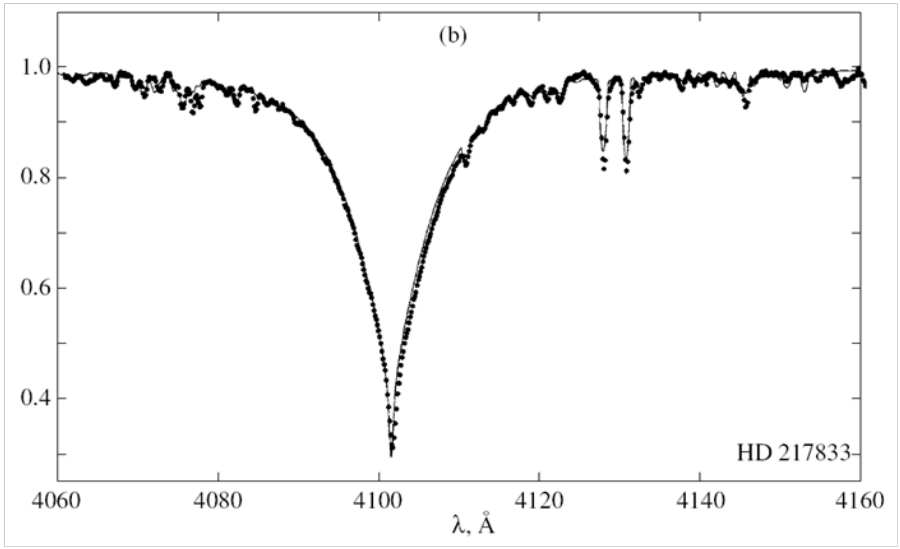


Aellig et al 2001

- Ogilvie and Hirshberg (1974); Feldman et al (1978)
- Why does He/H vary over the solar cycle?

Helium and magnetic fields

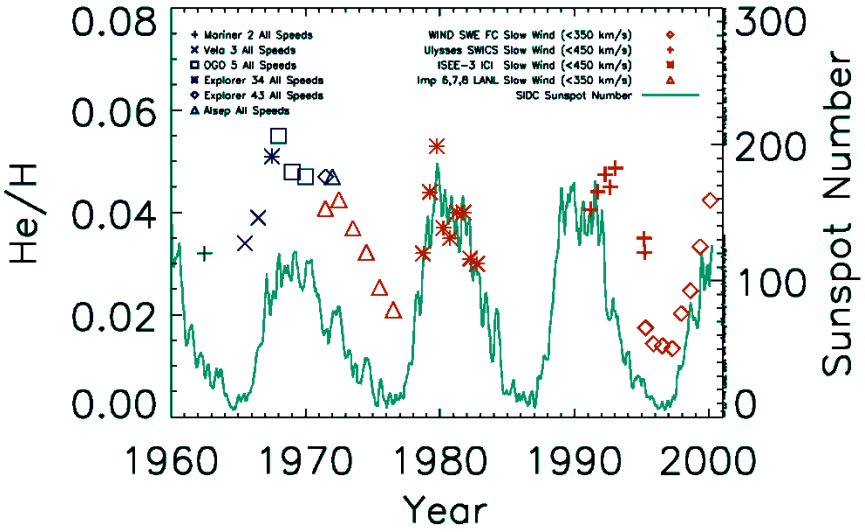
Helium spectral lines in stellar atmosphere



Glagolevskij et al (2006)

- Bp Stars ("p" for Peculiar)
- ~ 10x solar mass
- Young Bp stars poor in helium
- Strong magnetic fields 10kG

Helium in solar wind (1960-2000)

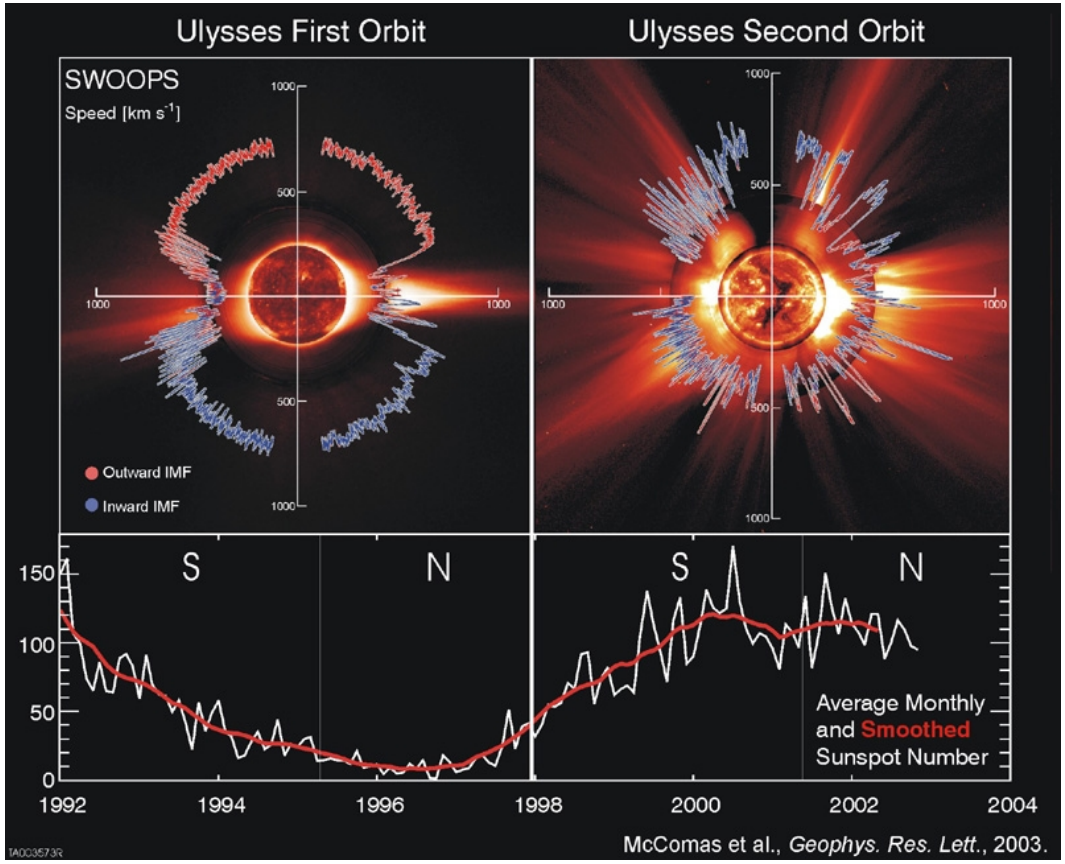


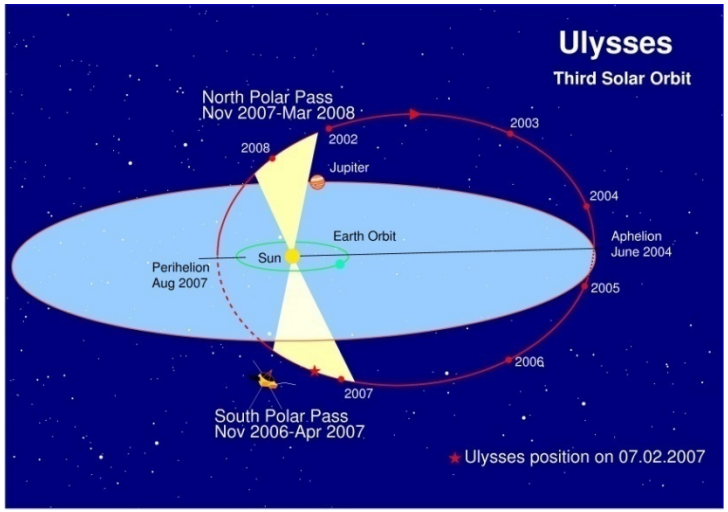
Aellig et al (2001)

- Ogilvie and Hirshberg (1974); Feldman et al (1978)
- He/H in solar wind correlated with solar cycle

Variation of solar wind speed

Latitude structure over the solar cycle

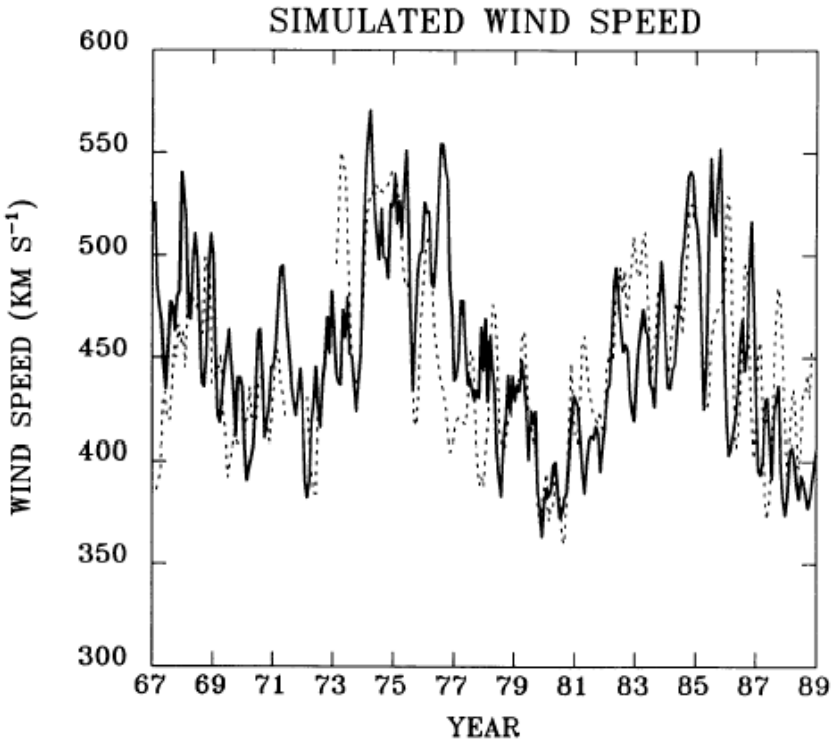




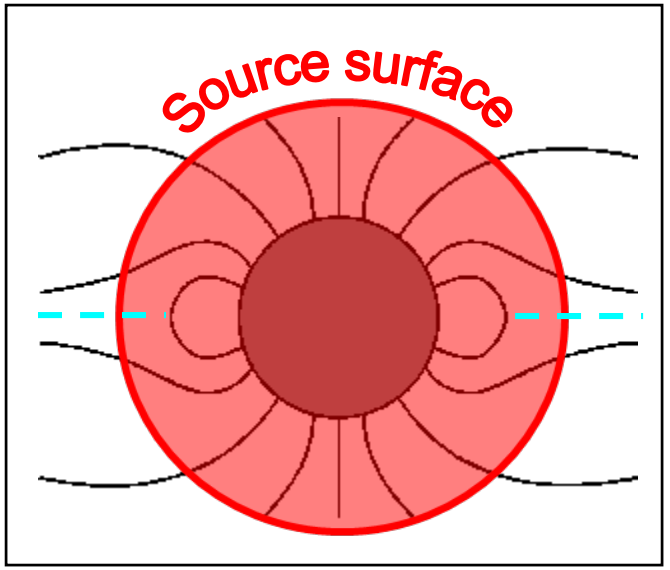
Variation of solar wind speed

Speed related to magnetic expansion

Parker (1958) model of solar wind: supersonic acceleration in DeLaval nozzle
Modification: field expansion controls the nozzle



(Wang, 1993)



The link between speed and He/H

Regulation of Coulomb drag

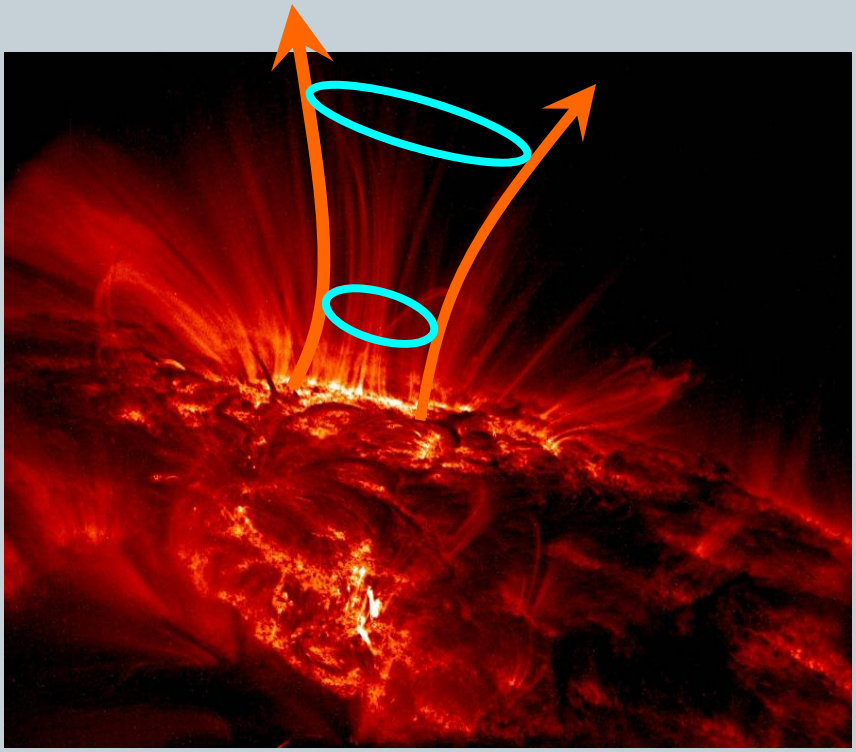
Helium does not experience the Parker mechanism directly
Instead Coulomb coupling to accelerated hydrogen is needed

$$f_s \equiv \left(\frac{R_o}{R_s}\right)^2 \frac{B(R_o)}{B(R_s)}$$

$$V \propto f_s^{-1}$$

$$\frac{He}{H} \propto \text{proton flux} \propto f_s^{-1}$$

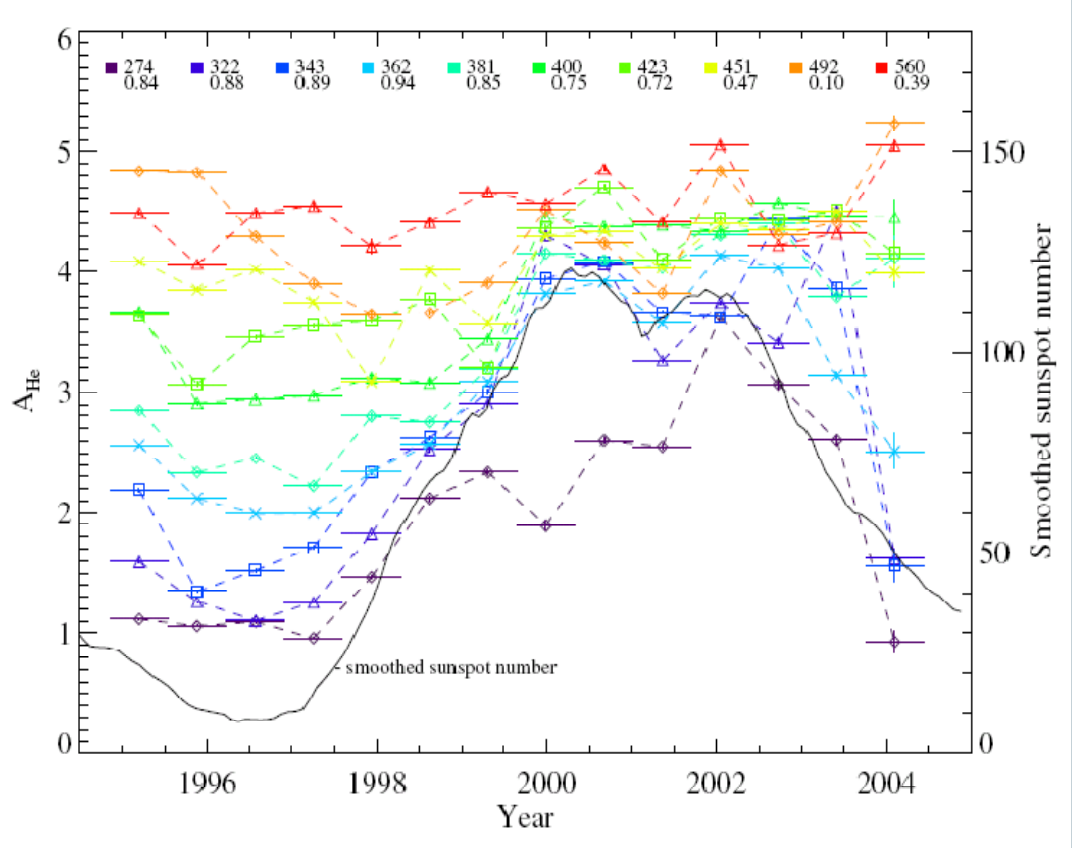
$$\frac{He}{H} \propto V$$



- Early explanation for dependence on level of solar activity:
  - Observation: Solar wind near magnetic reversal, the heliospheric current sheet (HCS), has low He/H
  - Slow solar wind near HCS, and HCS more often in equatorial plane during solar minimum
  - Fast wind and CMEs, seen more at maximum, have high He/H
- So is dependence just due to wind speed changing?

Wind Faraday Cup Observations

He/H over solar cycle

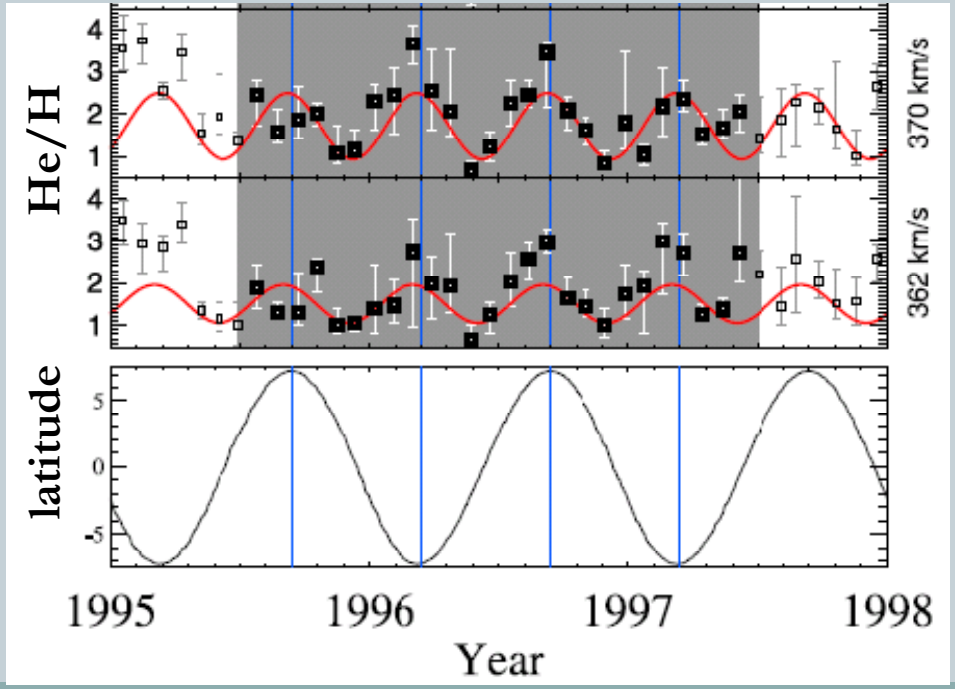


Updated version of *Aellig et al* [2001] Figure 2

- Wind/SWE
  - *Aellig et al* study [2001]
  - Kasper et al. [2007]
- He/H linear with speed during solar minimum
  - In agreement with expansion – drag argument
- Signal vanishes during solar maximum!
- Modulation returned in 2004-2005 for lowest speeds
- Why does speed dependence vanish?
- Higher resolution analysis

Six-Month Periodicity

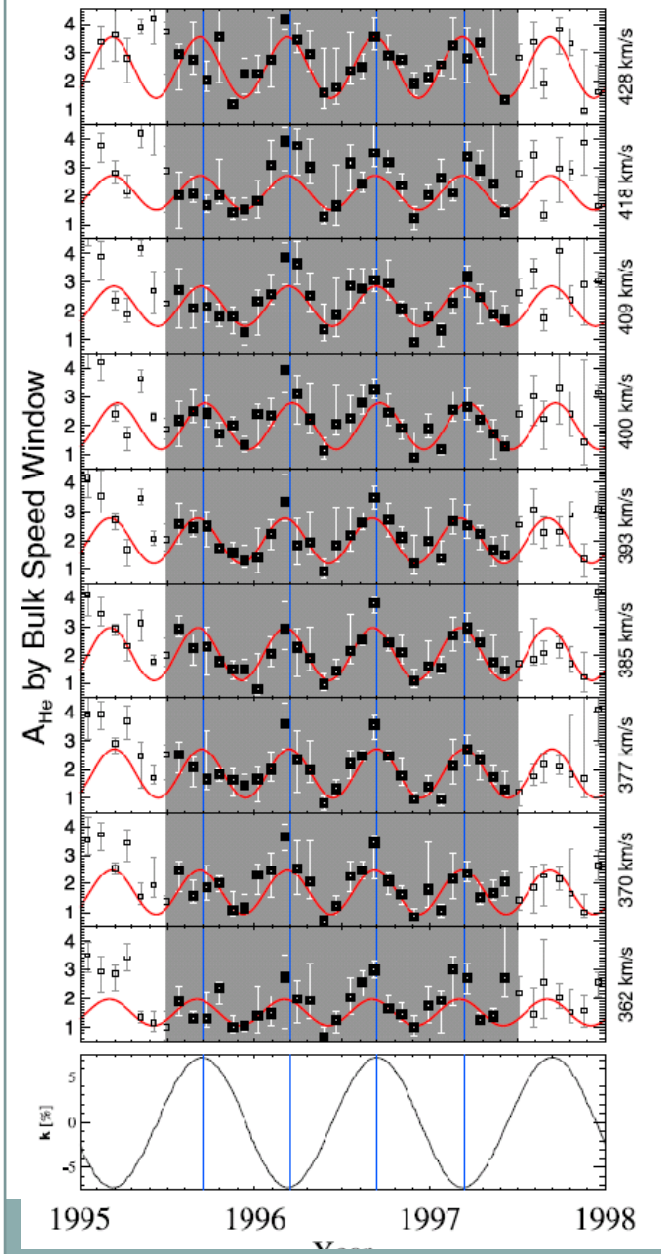
Carrington rotation averages of He/H in two narrow speed windows during solar minimum



$$\frac{He}{H} = A_0 + A_1 \sin(\omega t + \phi)$$

- Fit Carrington averages with sinusoid
- Six month periodicity
- Maxima in He/H as Earth leaves heliographic equatorial plane
- Consider:
  - Significance
  - Offset A_0
  - Amplitude A_1

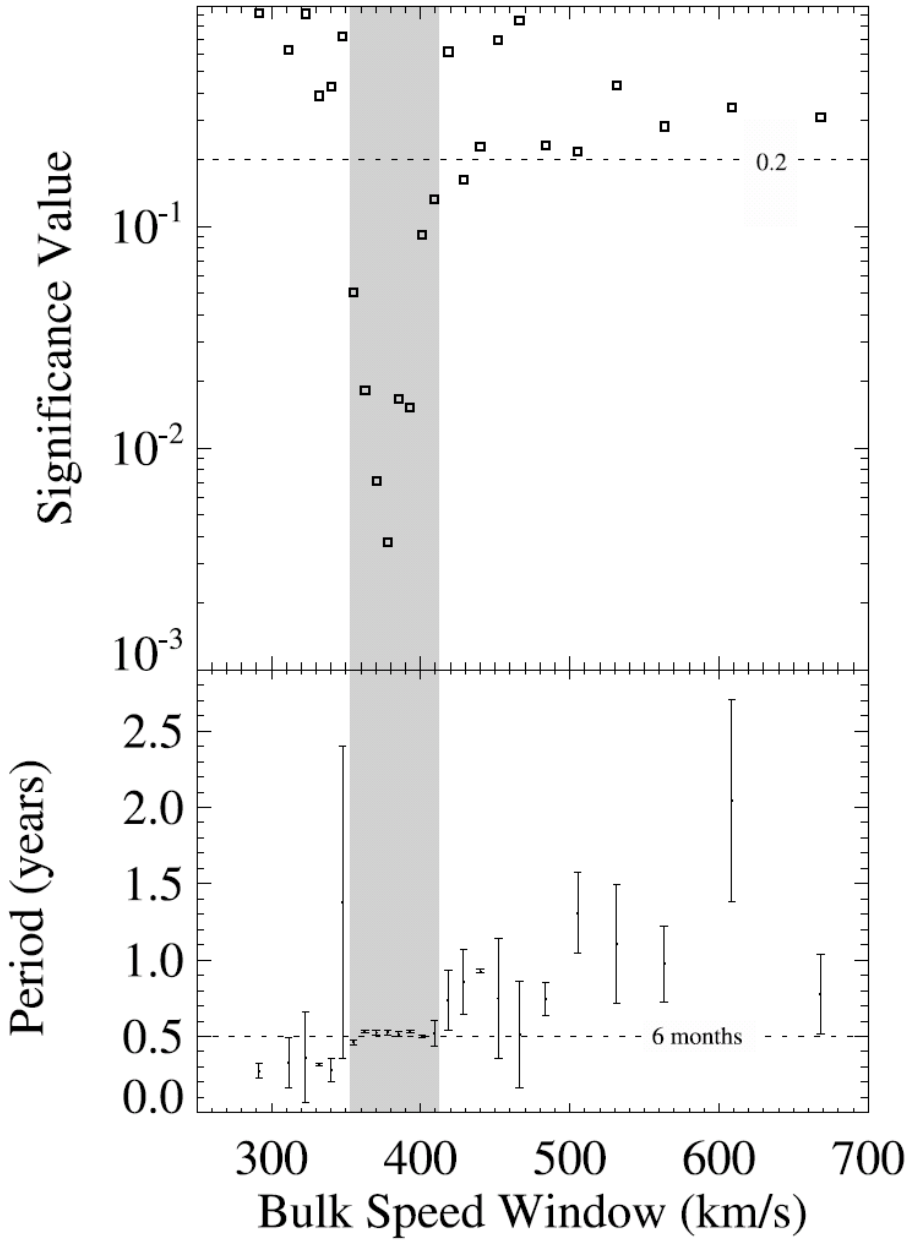
Carrington rotation He/H averages



428 km/s

362 km/s

Lomb-Scargle spectral analysis



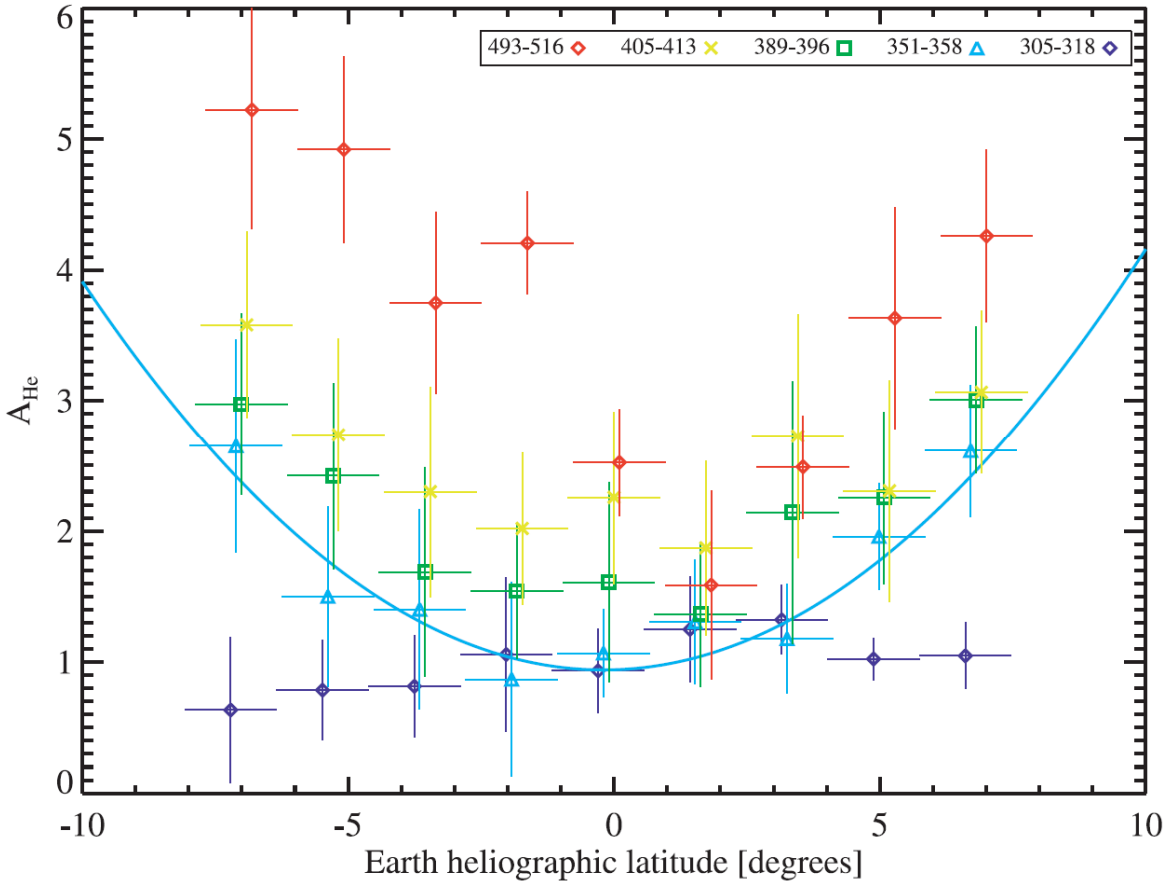
Possible explanation for latitudinal gradient

Long lived magnetic loops

TRACE

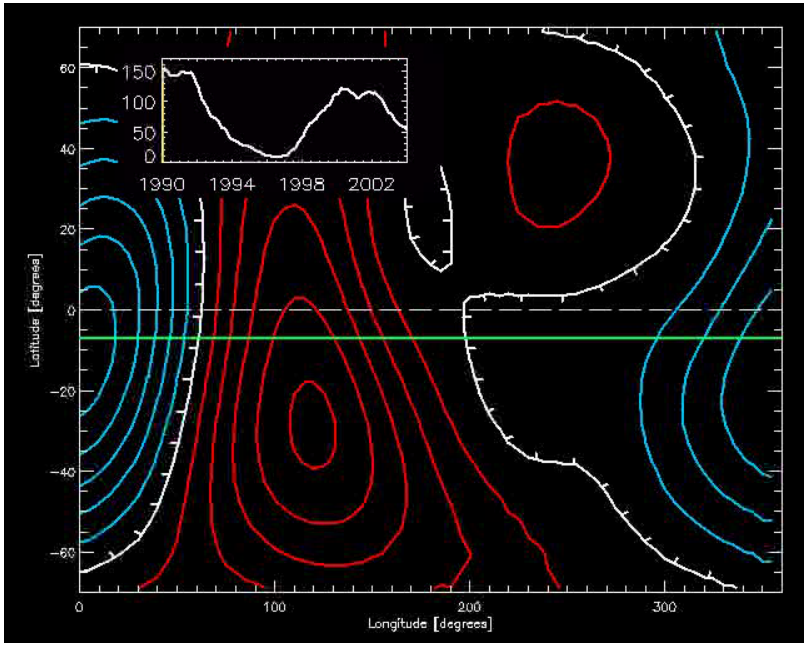
- Previous models have two flaws
  - Magnetic topology is simple – expanding field
  - Structures are stationary in time
- New time dependent models introduce gravitational settling
  - Endev et al. (2005)
  - Helium settles to bottom of loops
  - Decreased He/H at loop top
- Another option: washed out differential flow

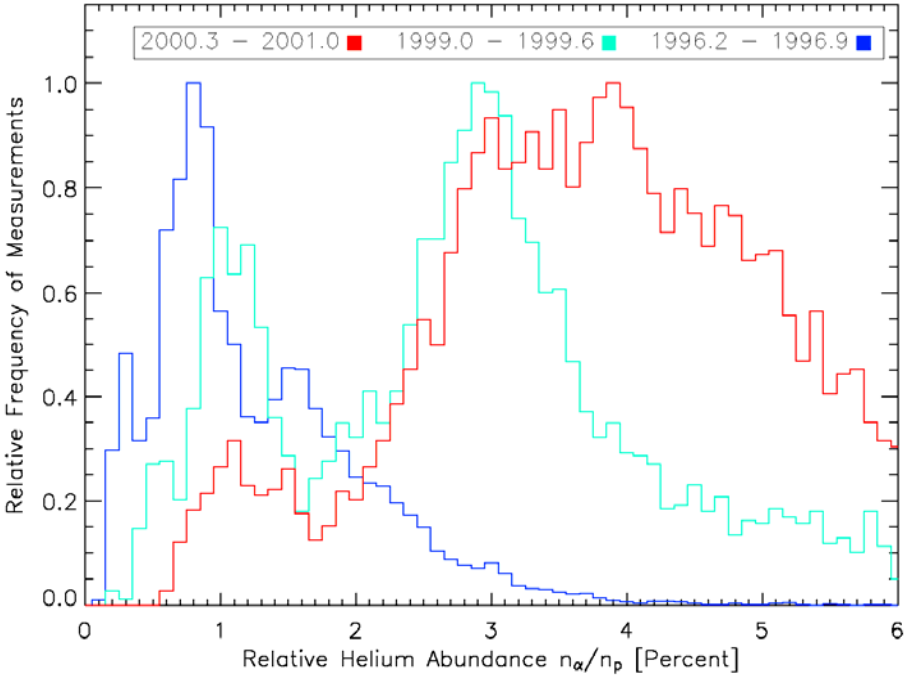
Observations sorted by latitude



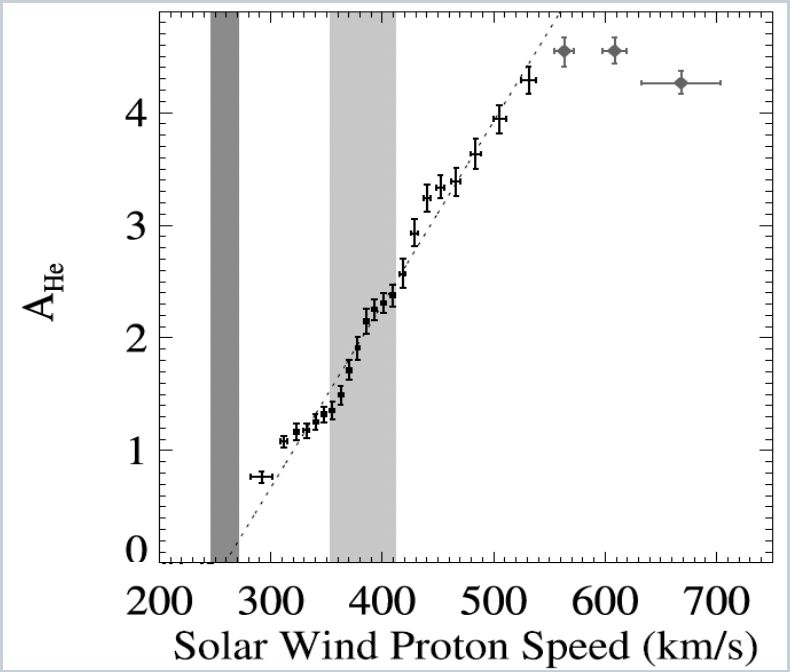
Two sources of slow solar wind?

300-320 km/s solar wind





Dependence of A_0 on speed



$$\frac{He}{H} = A_0 + A_1 \sin(\omega t + \phi)$$

- A_0 is an extremely linear function of V for speeds between 275-500 km/s
- This is not predicted analytically or numerically
- Extrapolates to a "vanishing speed" of 265 km/s

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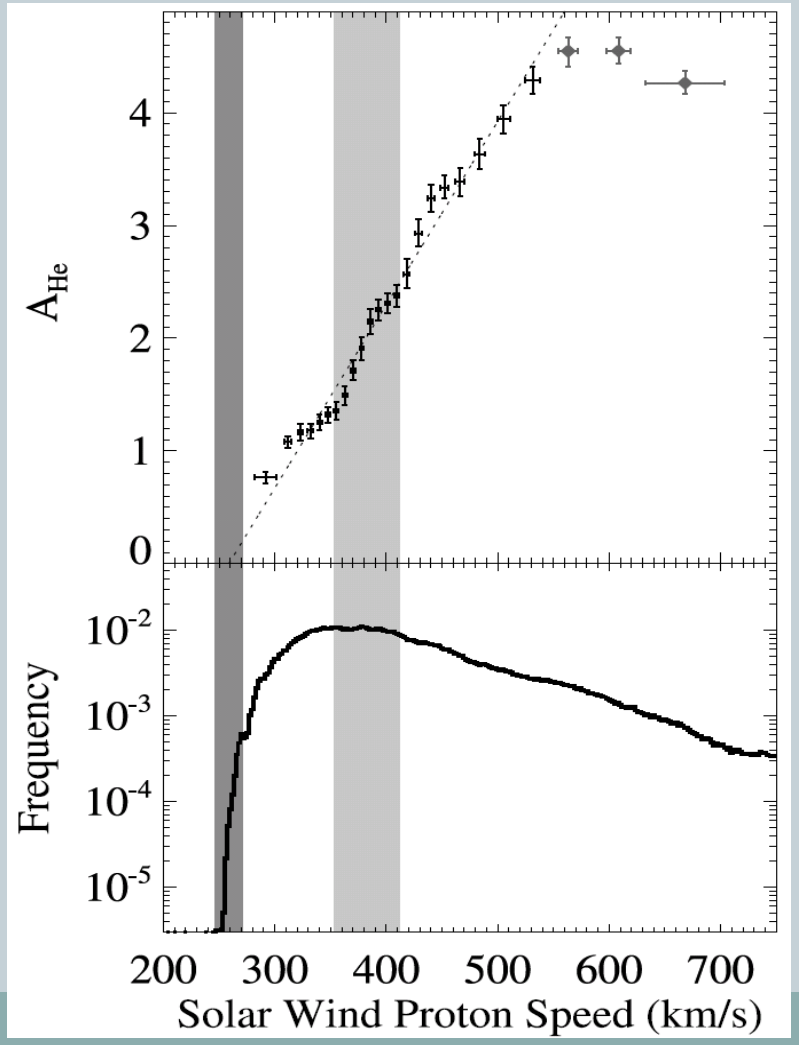
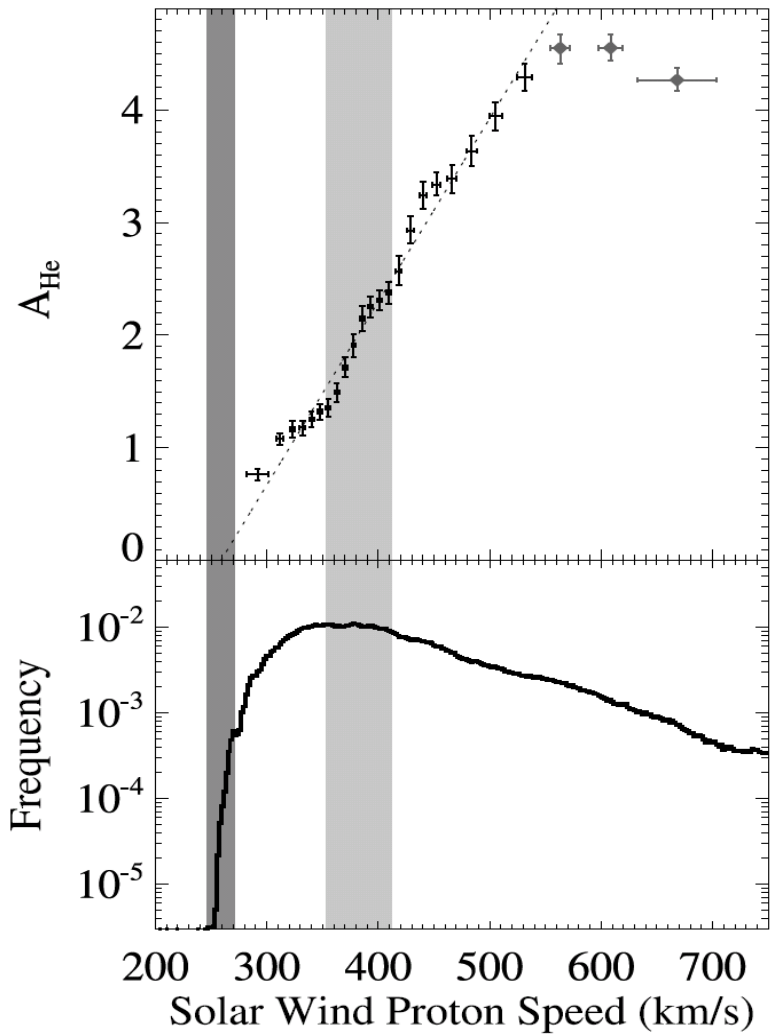


$$\frac{He}{H} = A_0 + A_1 \sin(\omega t + \phi)$$

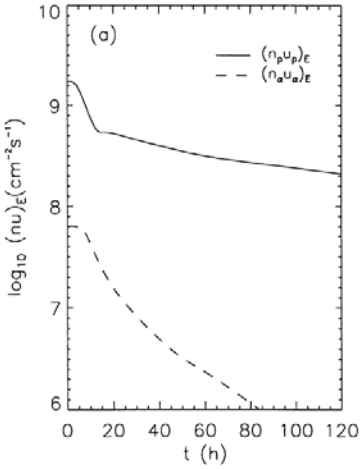
- A_0 is an extremely linear function of V for speeds between 275-500 km/s
- This is not predicted analytically or numerically
- Extrapolates to a "vanishing speed" of 265 km/s
- Histogram of distribution of solar wind speed at 1 AU over mission
- Why does this correspond to lowest observed solar wind speeds?

Hypothesis: Helium in corona impedes solar wind escape and acceleration

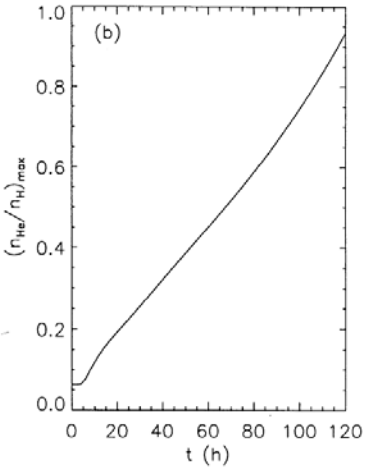


$$n_\alpha u_\alpha \approx \frac{n_\alpha}{n_p}\left[n_p u_p - \frac{m_{He} G M_S T^{3/2}}{1.2\times10^{-23} r^2} \right]$$

Escaping hydrogen and helium fluxes

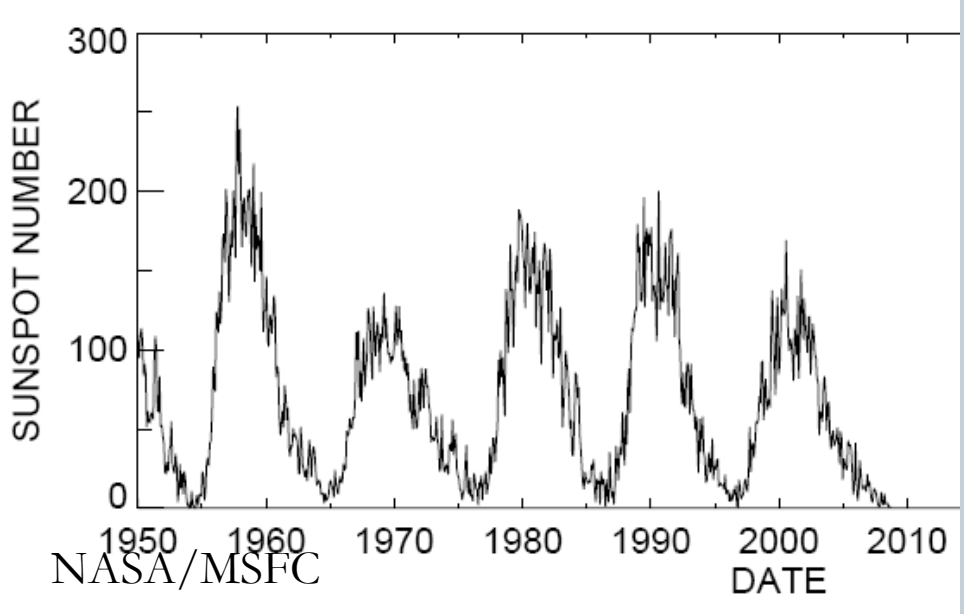


Fraction of helium in corona



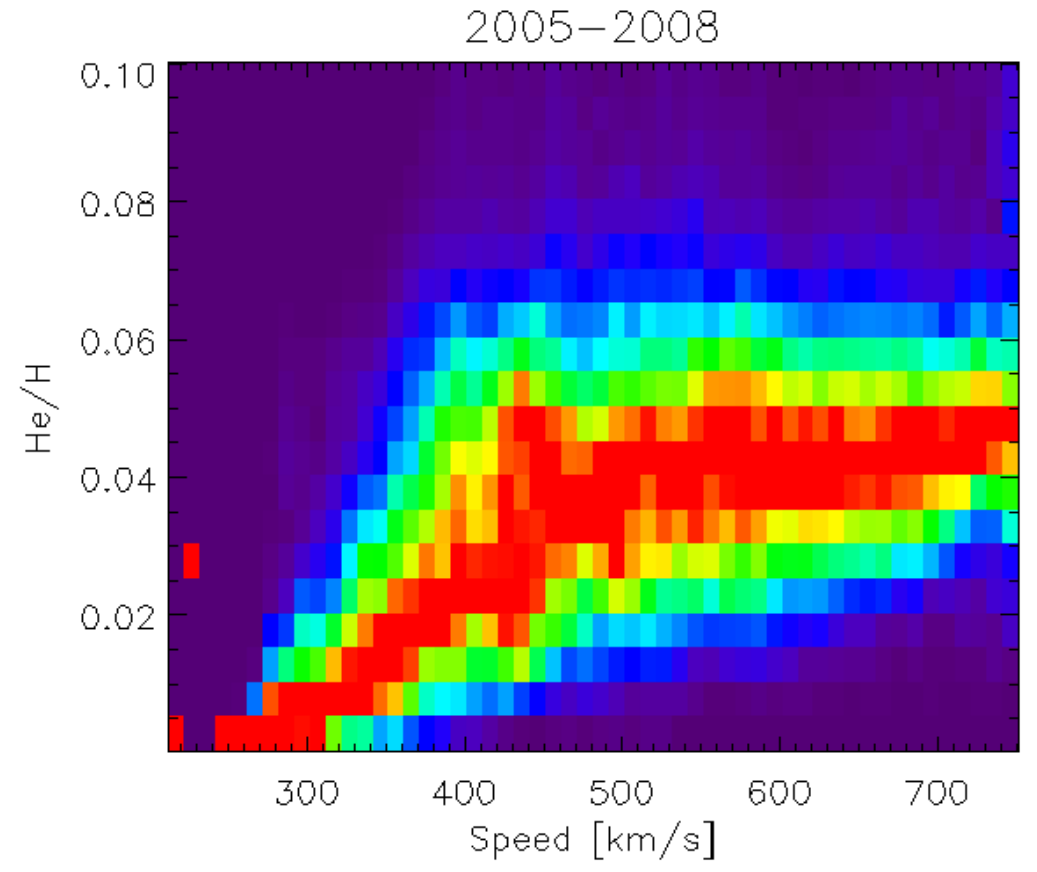
Hansteen et al., ApJ, 1994

Current solar minimum



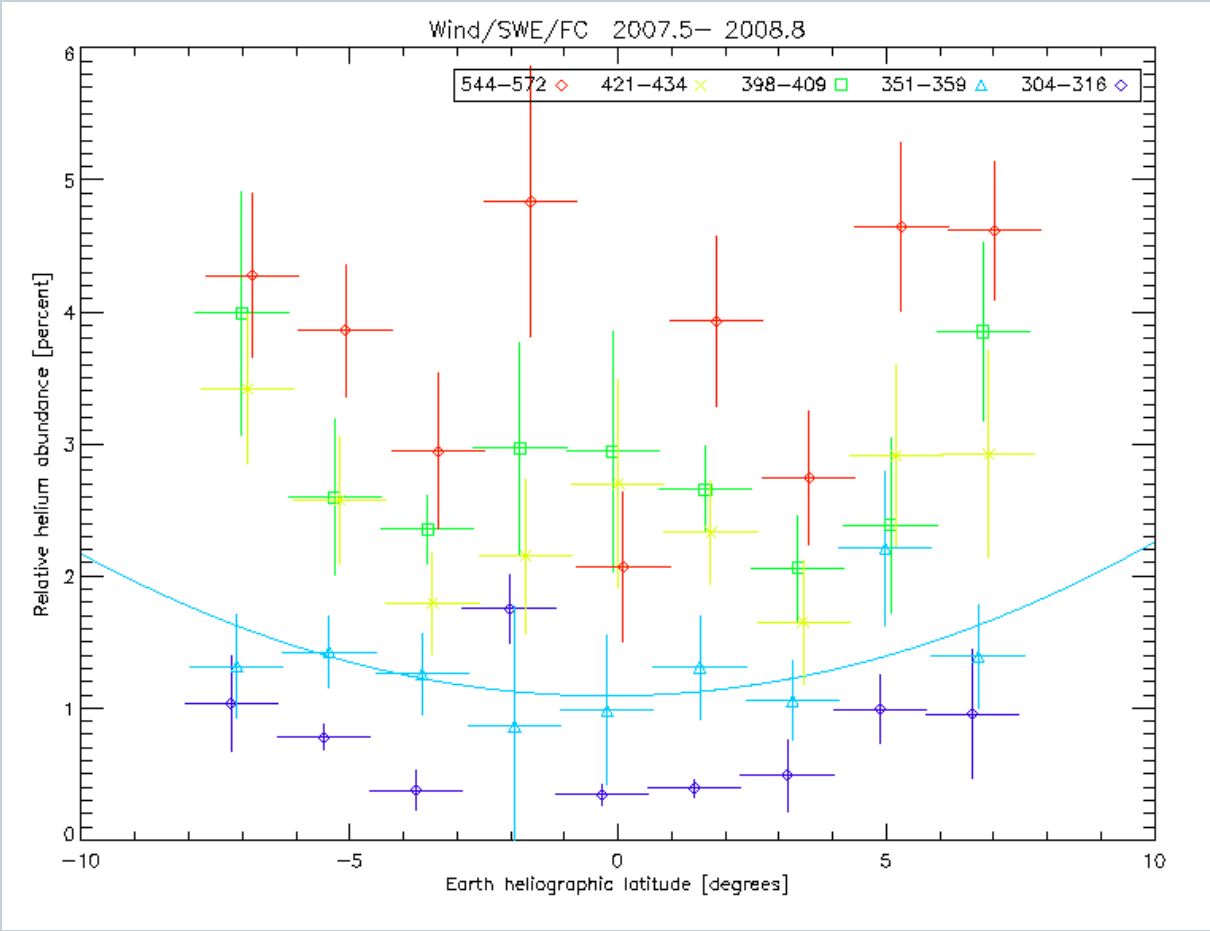
- Processed Wind data up through this August
- Examine He/H in the current solar minimum

Linear dependence with speed is back



- Observations from last three years show solid relationship between He/H and speed
- Cleaner than last solar minimum by eye

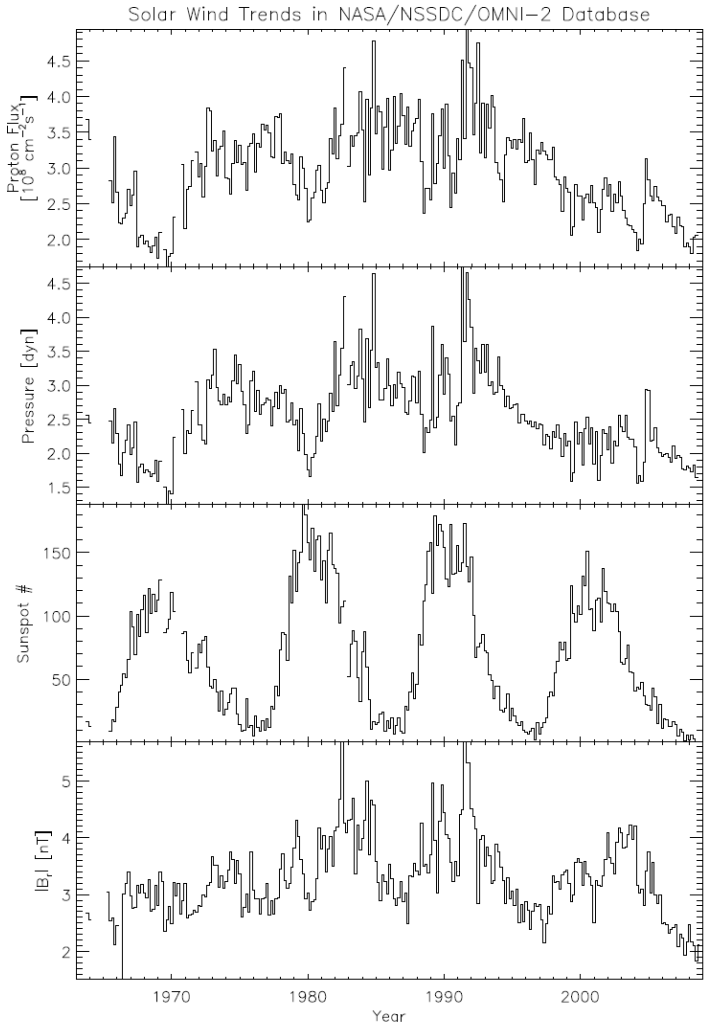
Possible return of latitude dependence

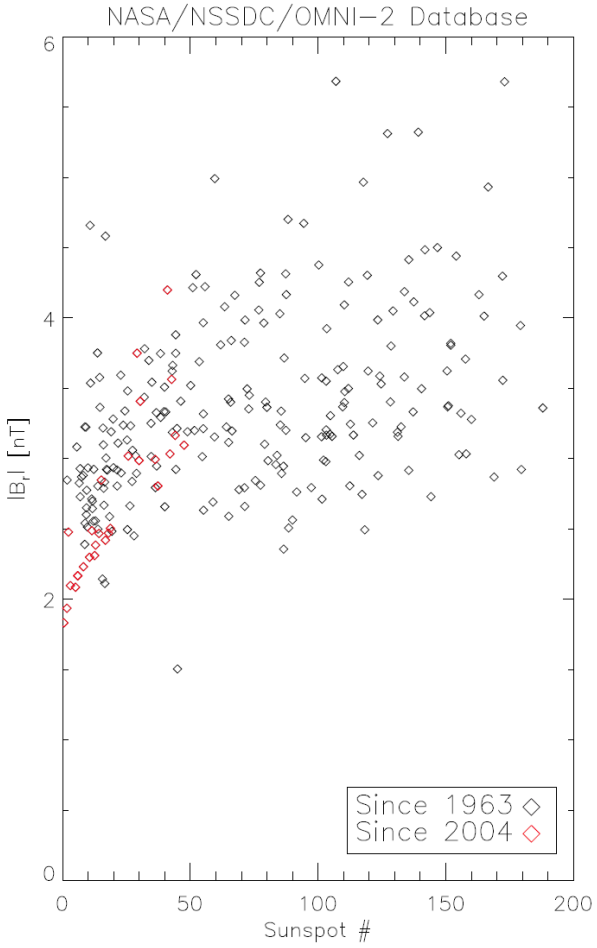


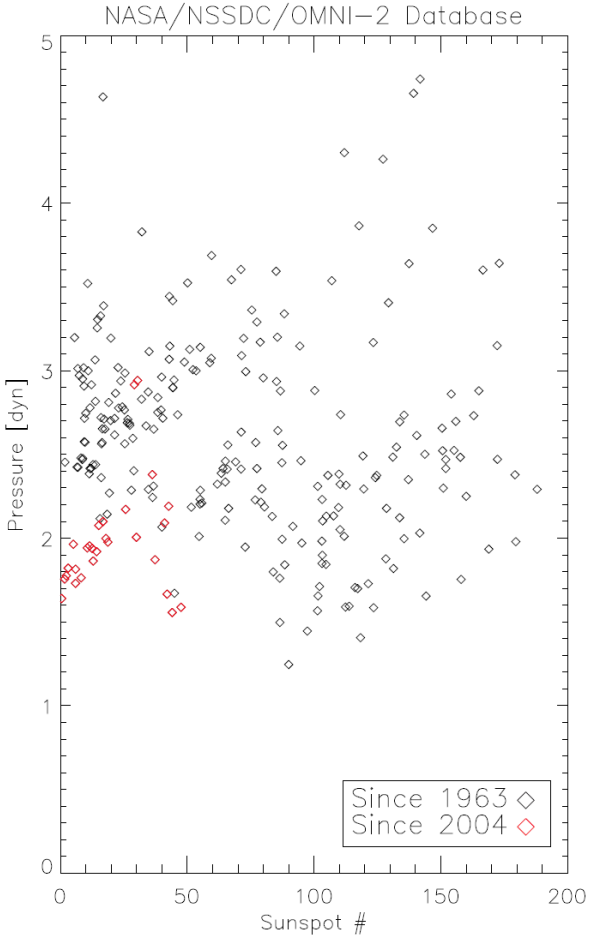
- Last 1.3 years of data begin to see slight latitude dependence
- More like a “W” shape than a “V” shape with latitude
- HCS not yet aligned with equator this minimum
- Need to wait or use a mapping model

Conclusions

- Solar minimum He/H dependence on speed (and implied vanishing speed) have returned
  - Should get more precise value for minimum speed
- Latitude gradient not seen yet
  - Wait for HCS to align with equator
  - Employ mapping methods to relate to coronal structure
- Additional work
  - Composition and charge state data with ACE – are there freeze-in temperature or minor ion abundance gradients?
  - Relate He/H variation on small timescales to non-steady solar wind sources


Solar Wind Trends in NASA/NSSDC/OMNI-2 Database
Proton Flux [10^8 cm^-2 s^-1]
Pressure [dyn]
Sunspot #
|B_r| [nT]
Year
1970
1980
1990
2000


NASA/NSSDC/OMNI-2 Database
|B_t| [nT]
Sunspot #
Since 1963
Since 2004
0
2
4
6
0
50
100
150
200


NASA/NSSDC/OMNI-2 Database
Pressure [dyn]
Sunspot #
Since 1963
Since 2004
0
1
2
3
4
5
0
50
100
150
200