Coronal Regulation of Solar Wind Helium over the Solar Cycle

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Overview

- **Understand variation of interplanetary He/H (number densities) as a function of time and solar wind speed**
  - Ambient He/H conditions over solar cycle
  - Connections between interplanetary He/H and wind formation
  - He/H~4.5% is 15% of dynamic pressure at Earth
- **Findings**
  - Slow solar wind He/H is a strong function of solar cycle
  - 6-month period variation of He/H -> latitude and neutral line
  - De-trended He/H is an *extremely* linear function of speed
- **Implications**
  - Magnetic field strength moderates proton flux and He/H
  - Two sources of slow wind (near neutral line and elsewhere)
  - Helium in the corona places a "stranglehold" on solar wind

Solar, Coronal, and Interplanetary He

- Solar Interior
  - He/H is 10% in the convection zone (helioseismology)
- Transport of He from convection zone through transition region to corona is poorly understood
  - model neutral, He^+ and He^{+2} consistantly
  - simulations must boost drag x10
- Helium absorbs energy from another source
  - indirectly from the accelerated hydrogen through Coulomb drag [Bodmer and Bochsler, 2000]
  - coupling to waves [Isenberg and Hollweg, 1983]
- Solar Wind
  - He/H is no more than 4.5% of quiet solar wind
  - More variable in slow wind
  - He/H can rise to 30% in ejecta (more than 50% of mass flux!)
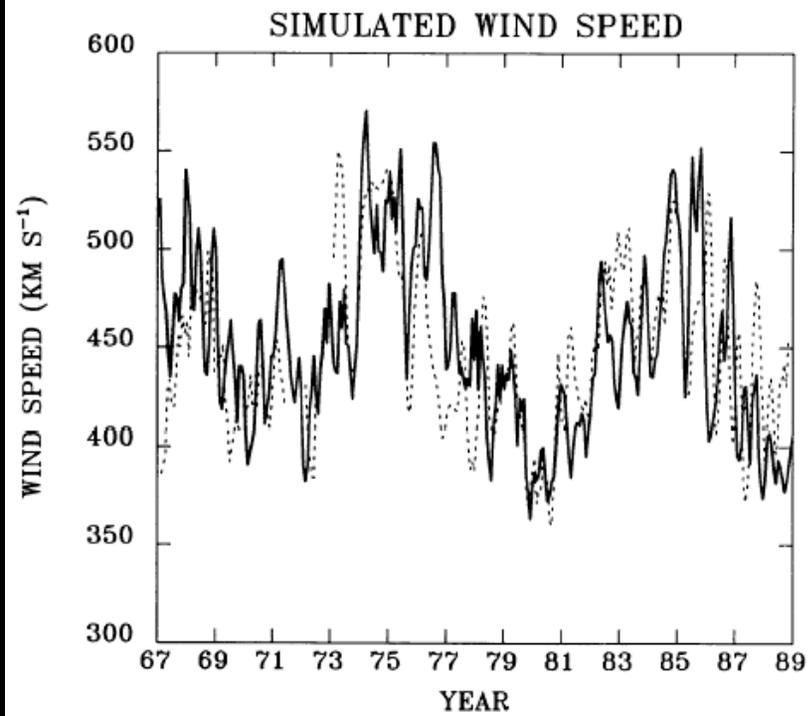
He/H from 1960-2000
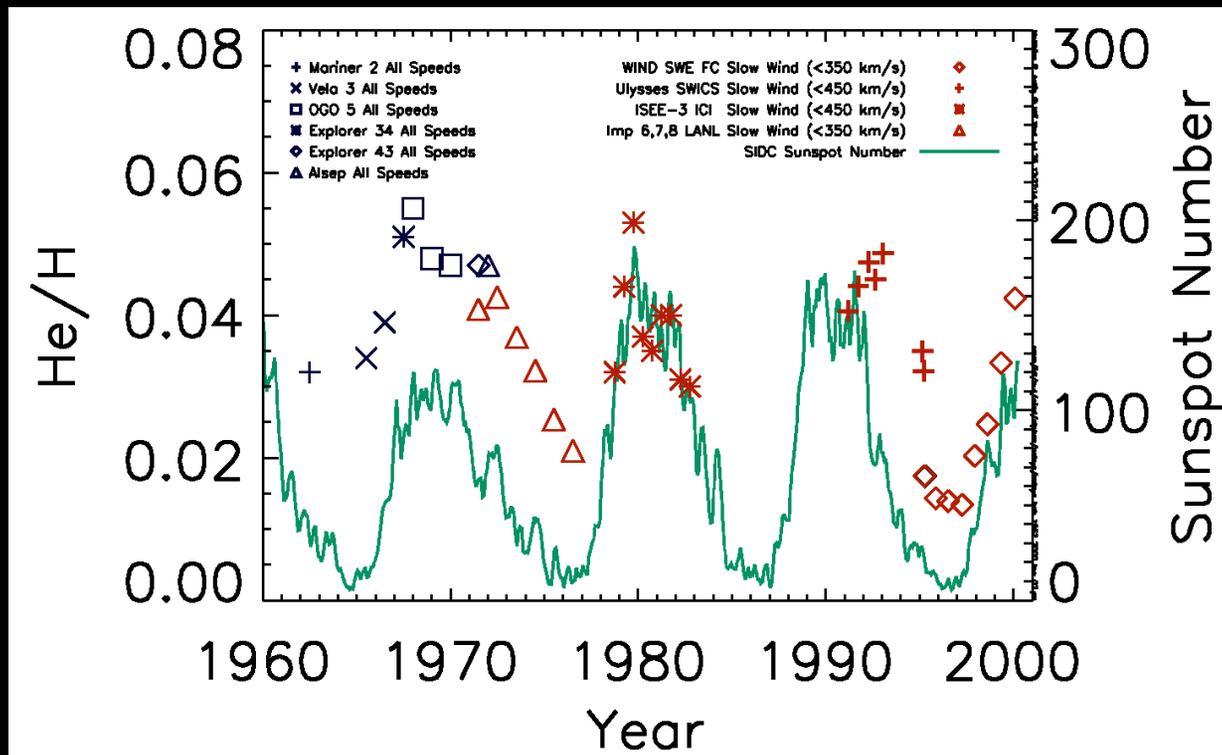
Wind Faraday Cup Observations

Updated version of *Aellig et al* [2001] Figure 2
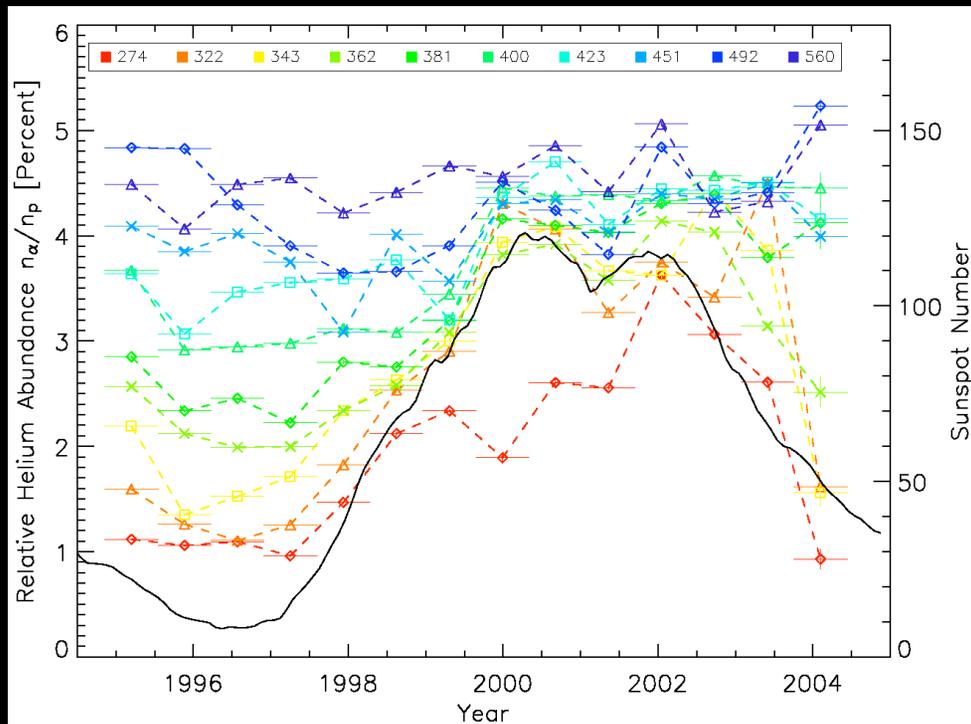
- 1995-2004
- 250-day averages based on *Aellig et al* study [2001]
- He/H linear with speed during solar minimum
- Signal vanishes during solar maximum
- Signal has returned in last year for lowest speeds

Why He/H proportional to V?

SIMULATED WIND SPEED

(Wang, 1993)
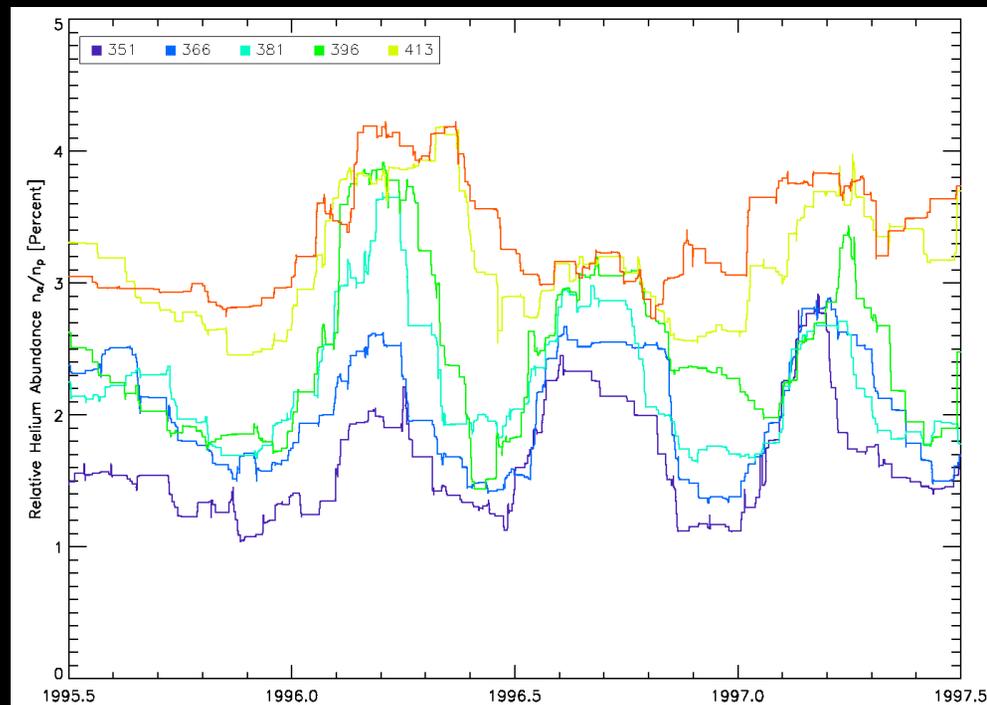
$$f_s \equiv \left(\frac{R_o}{R_s}\right)^2 \frac{B(R_o)}{B(R_s)}$$

# Why does He/H modulation vanish?
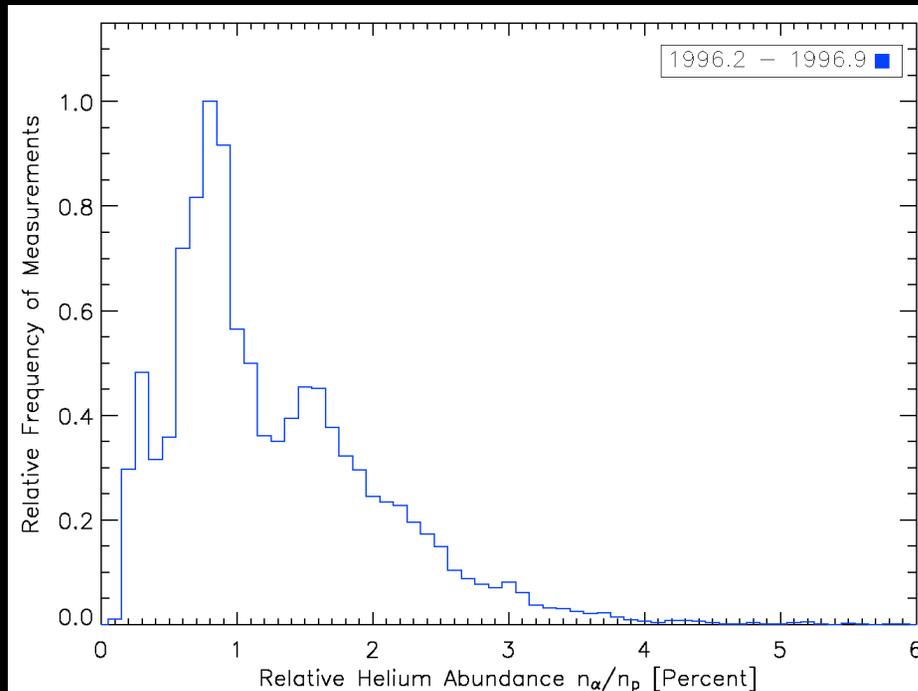
- Why does He/H modulation vanish?
- What accounts for the width of the He/H distribution?
  - Finer speed windows (25)
  - Remove all periods with shocks and ejecta
  - Higher time resolution than 250-day

Variation with higher time resolution

- 1000-point (2-weeks) running median filter
- 6-month periodic variation of He/H
- Seen with SWOOPS on Ulysses during rapid scan and by LANL instrument on IMP-7 in previous solar cycle
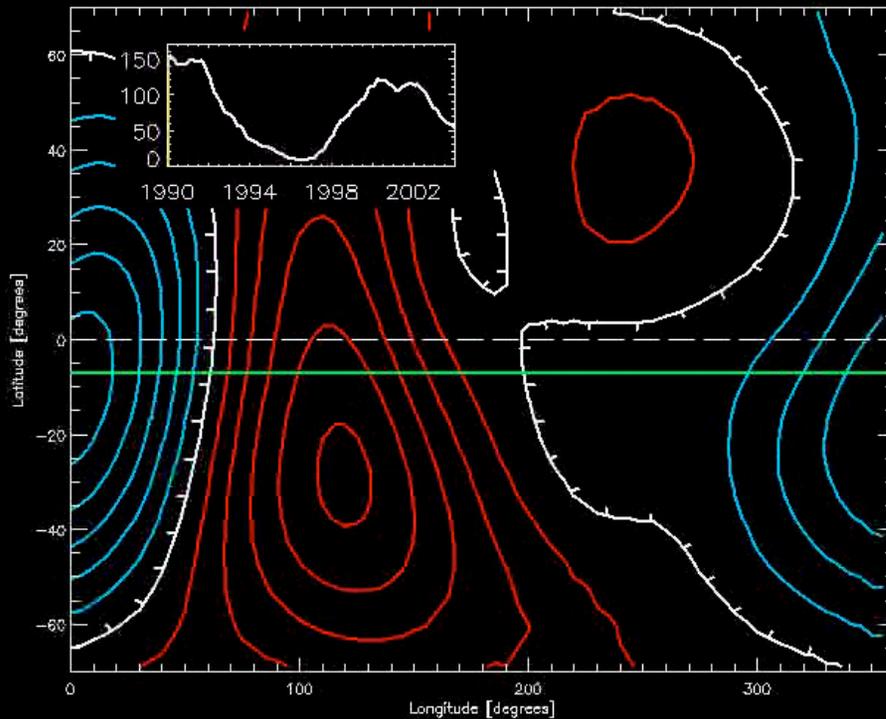- Calculate averages within Carrington rotations
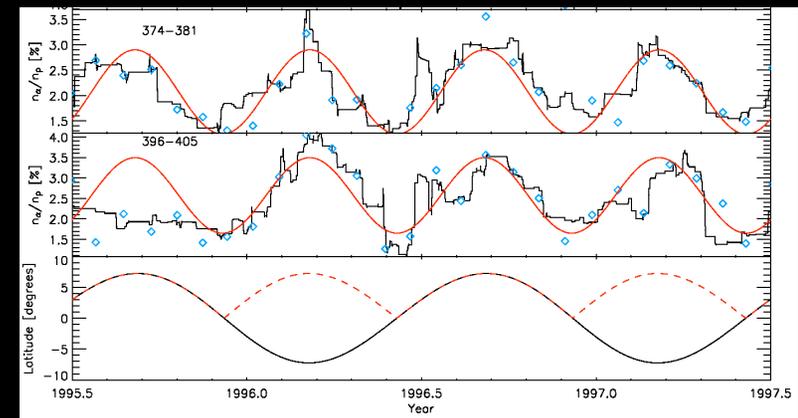
Characterizing the 6-month variation
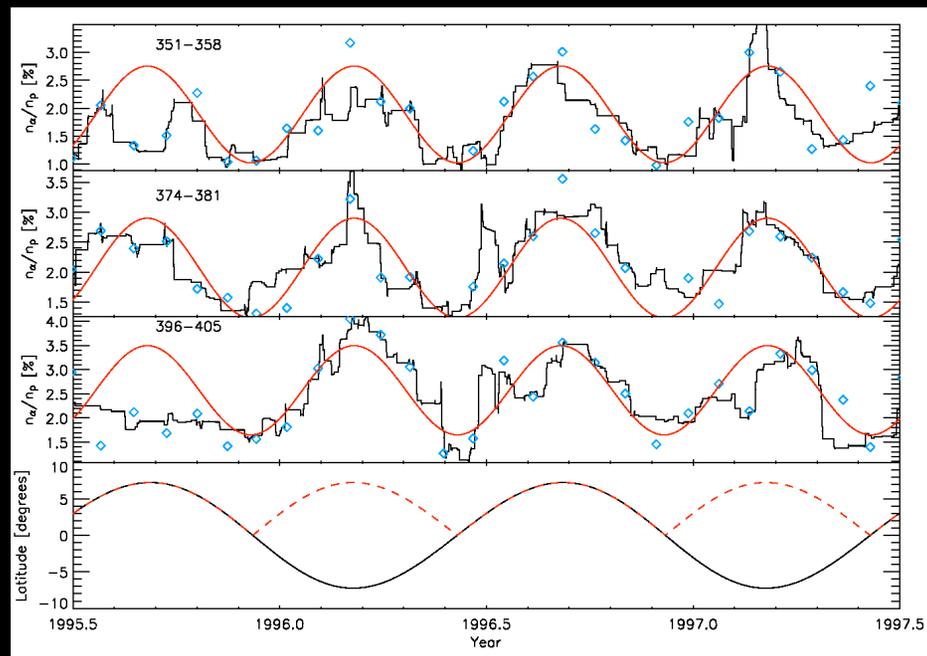
- **Fit Carrington averages with sinusoid**
- **Not as clear above 450 km/s**
- **Consider:**
  - Sinusoid
  - Offset A_0
  - Amplitude A_1

Six month periodicity is due to Earth's motion relative to the neutral line
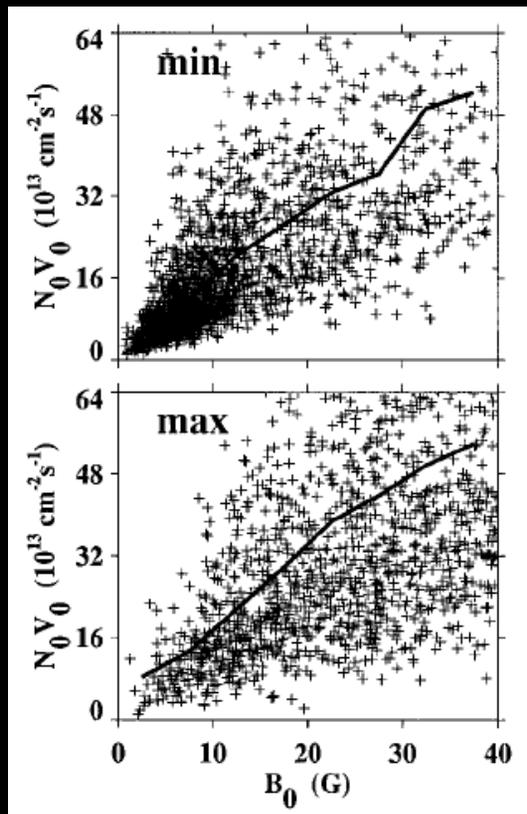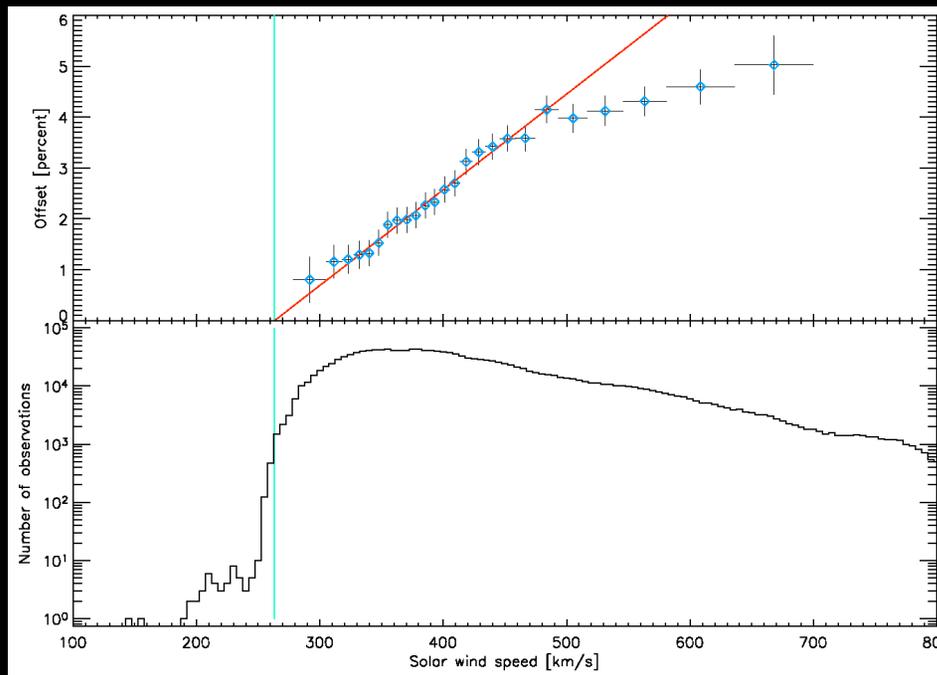
Field strength at 2.5 R_{sun} surface

WSO

Hypothesis: Field strength at source surface plays a role


(Wang, ApJ, 1995).

- Proton flux at 1 AU is correlated to magnetic field strength at source surface

- Perhaps enhanced He/H with heliographic latitude is a reflection of this
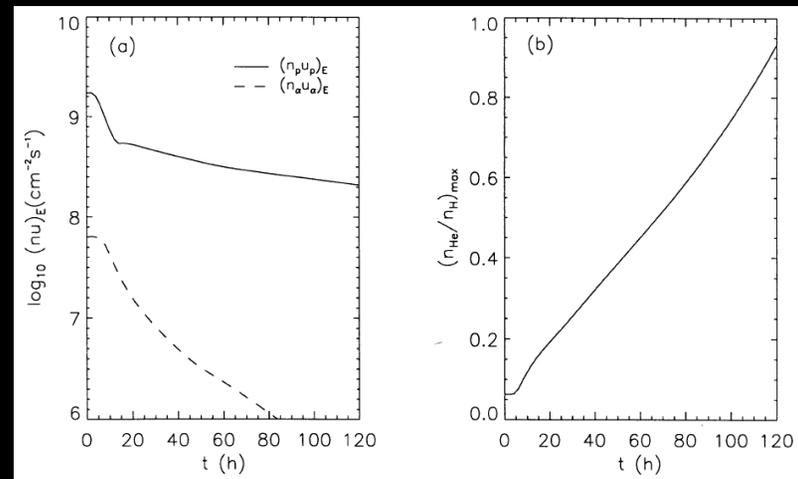
Dependence of A_0 on speed

- 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
- Why does this correspond to lowest observed solar wind speeds?

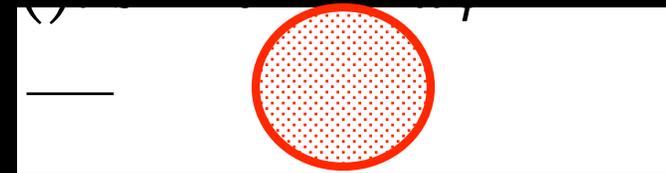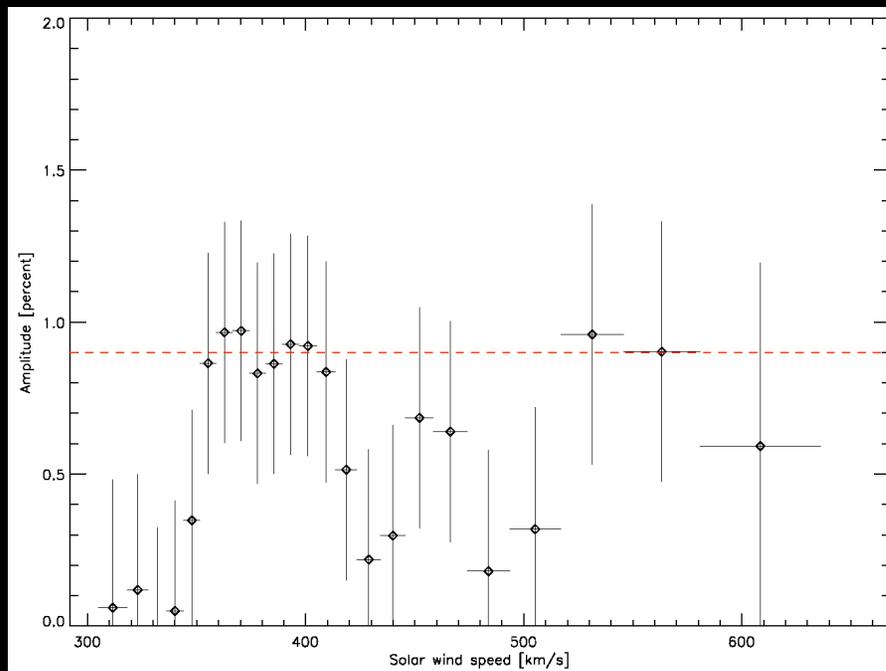# Hypothesis: Pooling helium in corona impedes solar wind formation
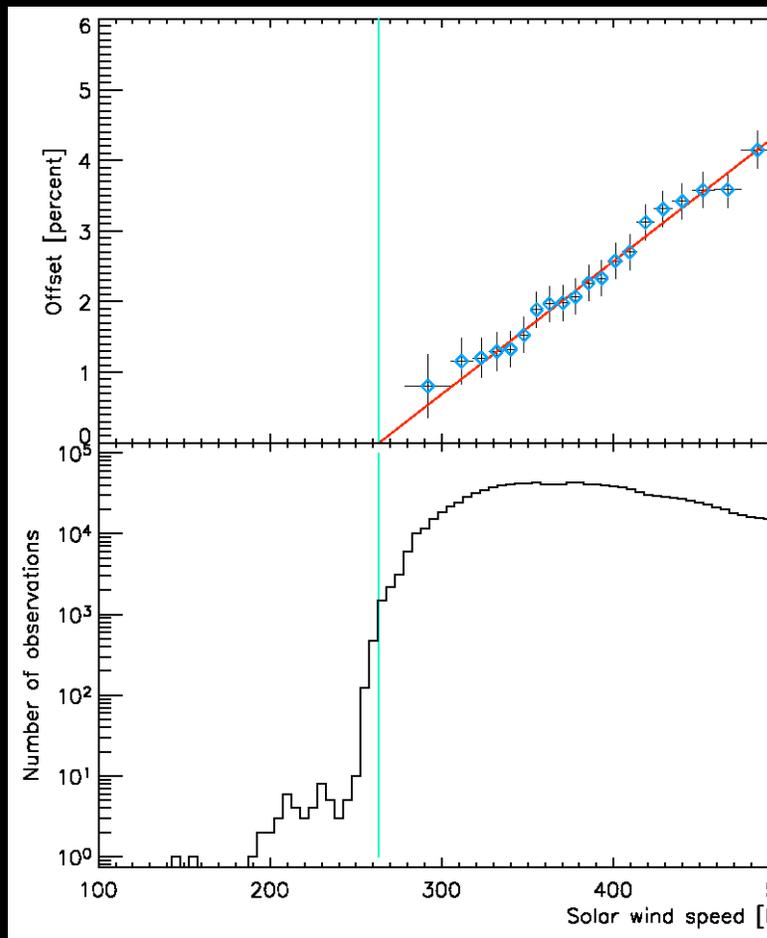
$$n_\alpha u_\alpha \approx \frac{n_\alpha}{n_p} \left[n_p u_p - \frac{m_{He} G M_S T^{3/2}}{1.2 \times 10^{-23} r^2} \right]$$
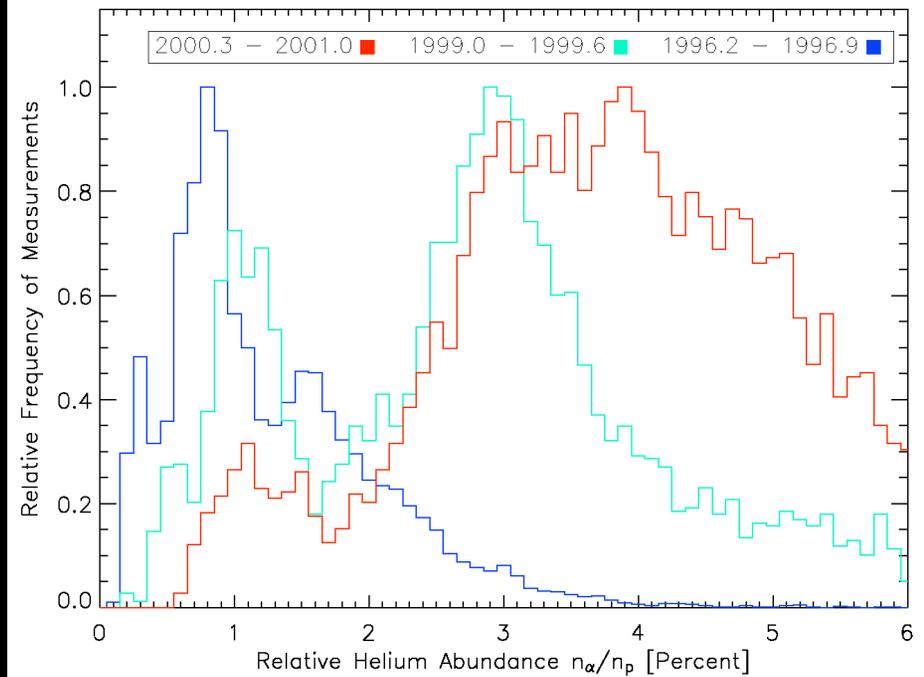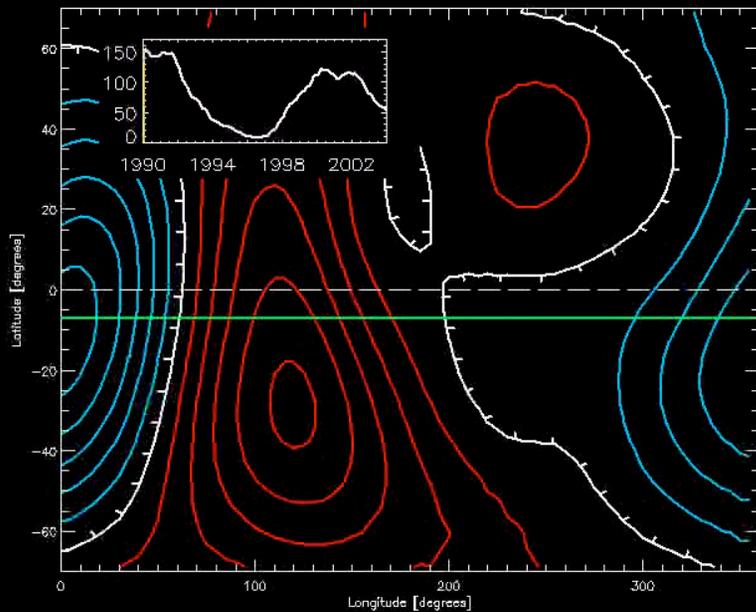

Hansteen et al., ApJ, 1994

Dependence of A_1 on speed

- Modulation is seen in speeds from 350-420 km/s
- Amplitude is constant at 0.9%

Two sources of slow solar wind?

Conclusions

- Better understanding of He/H variation, but also physical connection between coronal and interplanetary abundances
- Findings
  - Slow solar wind He/H is a strong function of solar cycle
  - 6-month period variation of He/H -> latitude and neutral line
  - De-trended He/H is an *extremely* linear function of speed
- Implications
  - Magnetic field strength moderates proton flux and He/H
  - Two sources of slow wind (near neutral line and elsewhere)
  - Helium in the corona places a "stranglehold" on solar wind
- Entering new period of modulation
- Thanks! NFS SHINE Grant ATM-0327723