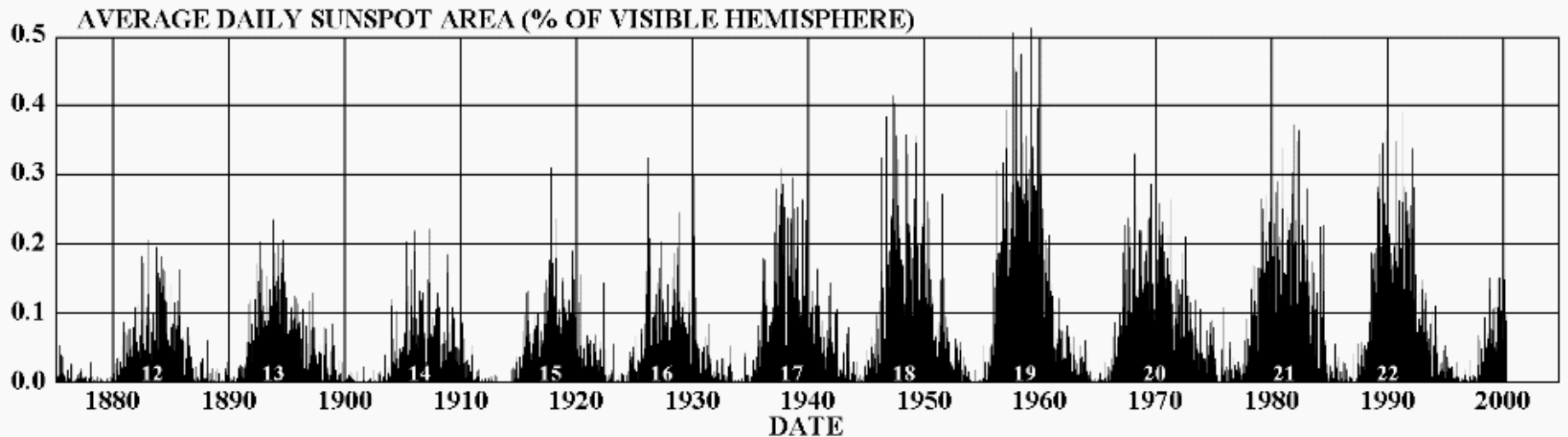
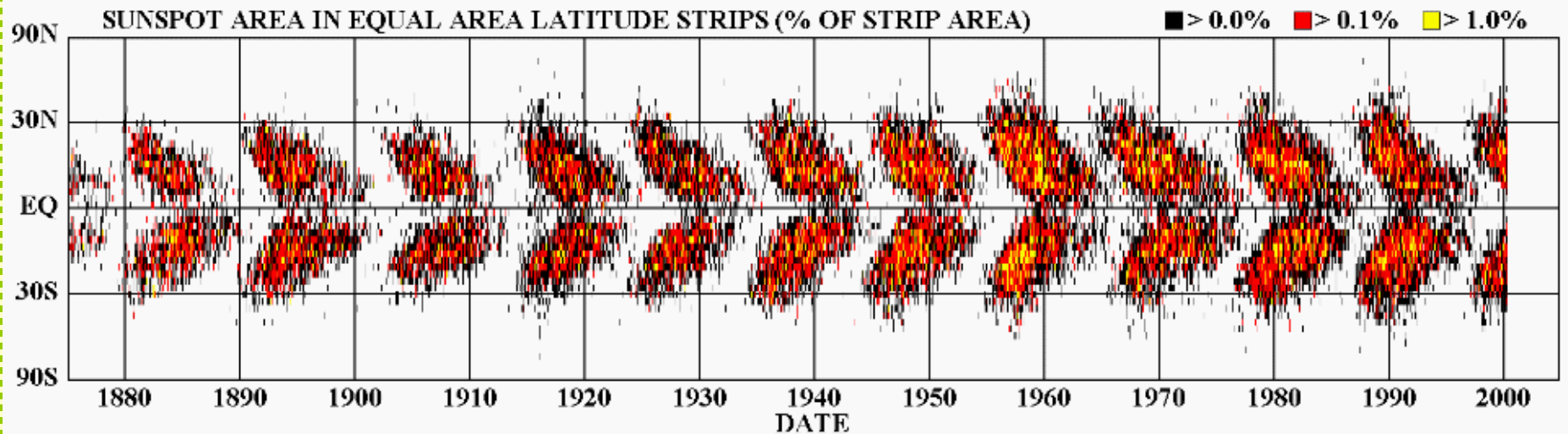


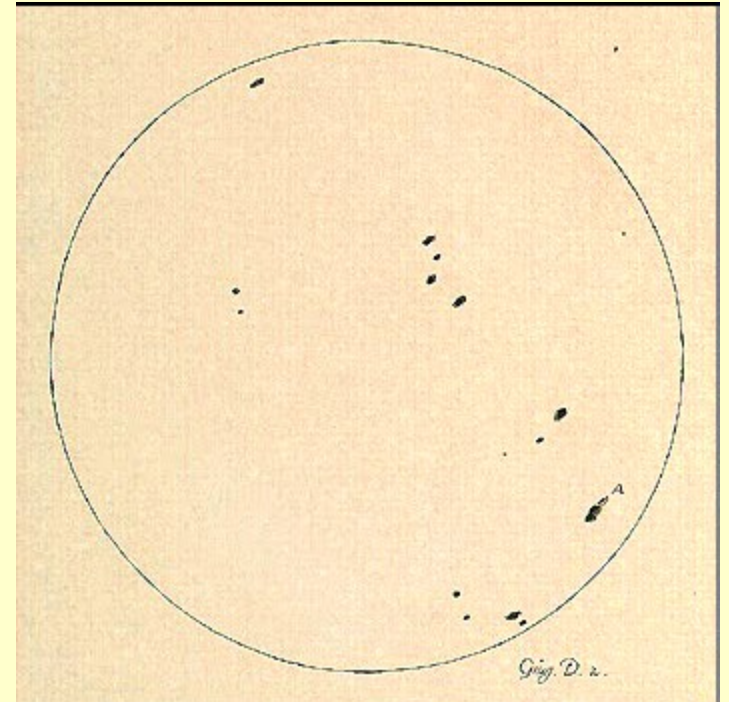
# 11-year Solar Cycles

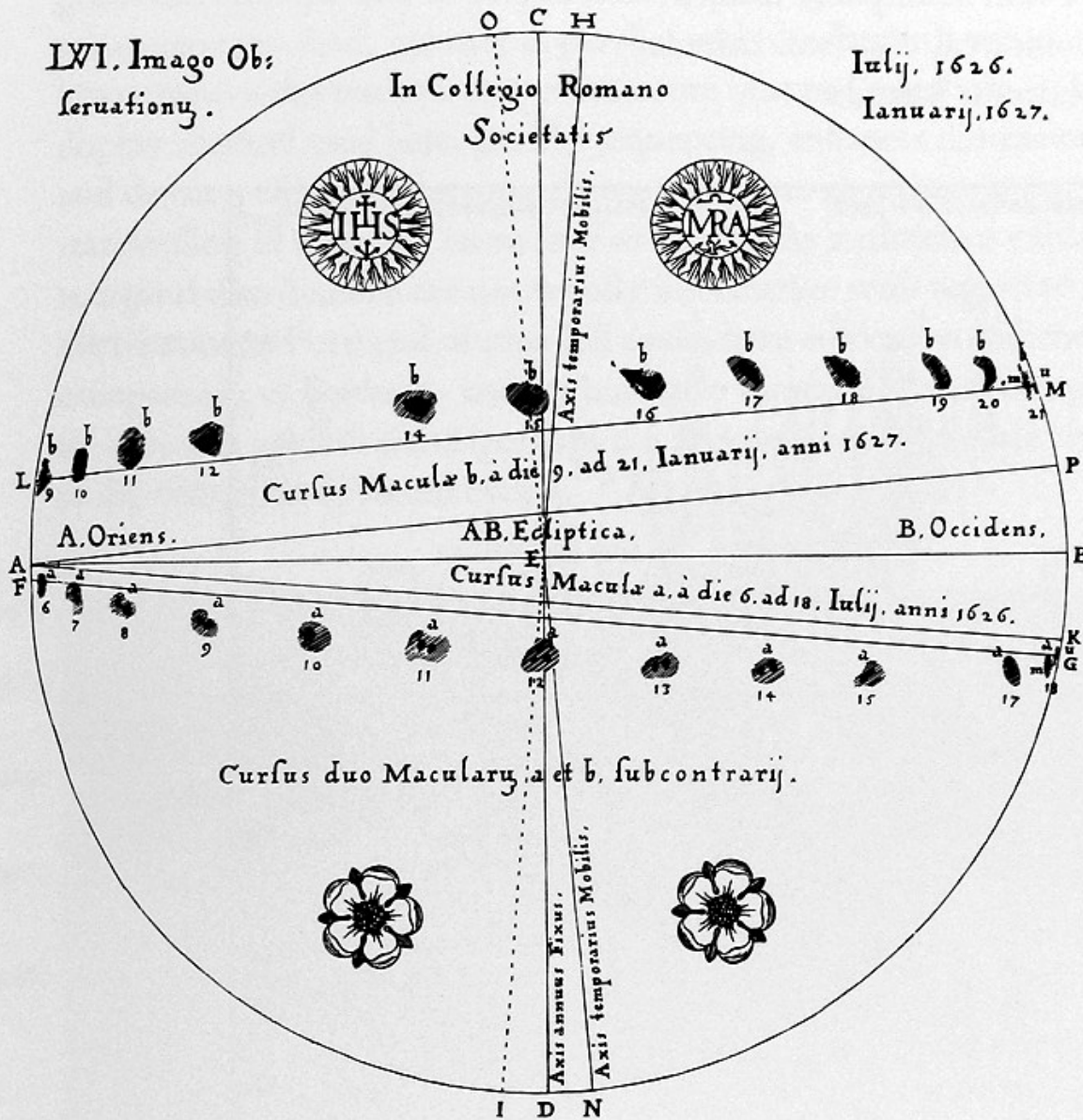
familiar butterflies... yet profound



# Early attempts

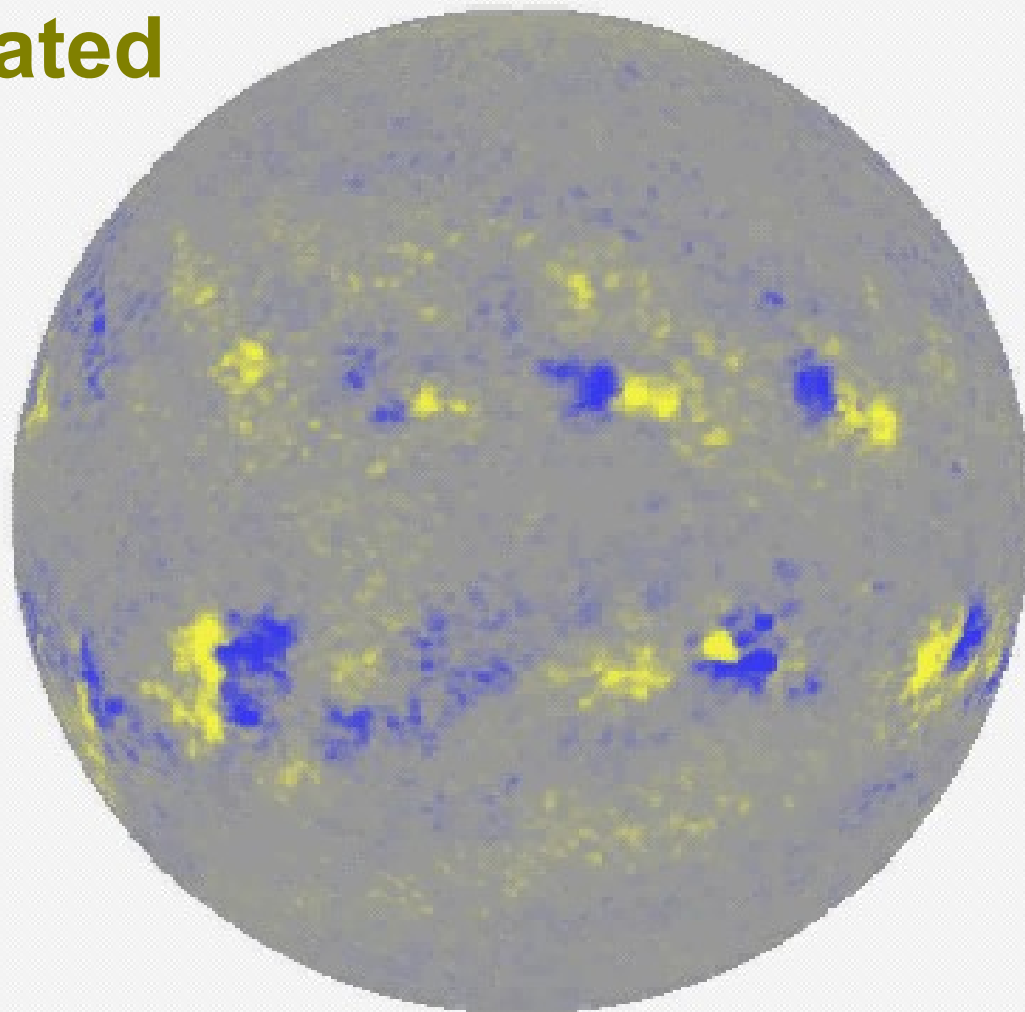
Galileo Galilei  
b. 15 February 1564  
d. 8 January 1642





**Christoph Scheiner**  
 25 July 1573 (or 1575)  
 in Markt Wald  
 near Mindelheim in Swabia  
 18 July 1650  
 in Neisse in Silesia

# Solar Cycle Animated



*MDI - Hathaway*

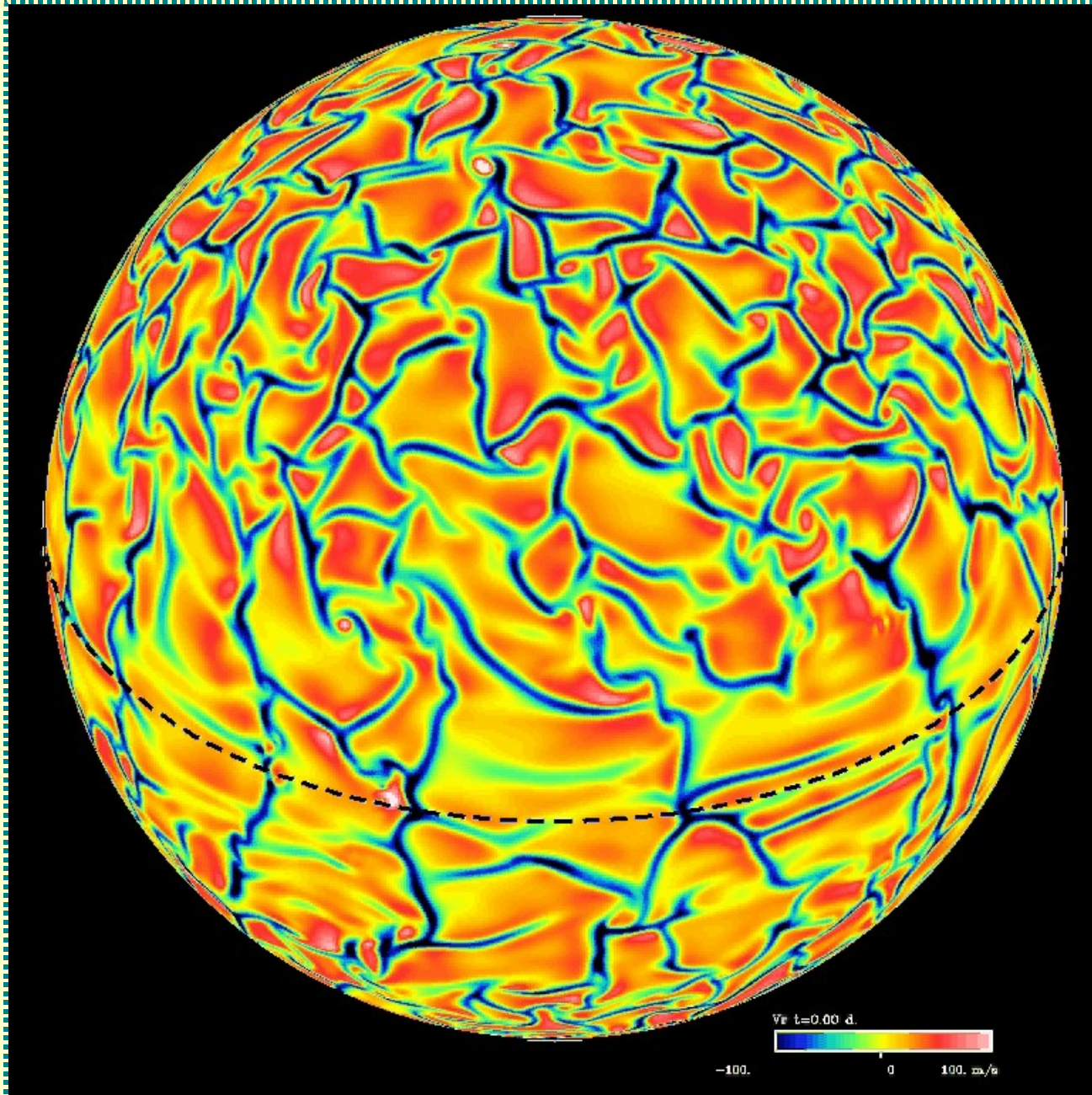
# UV view of solar magnetism

*SOHO EIT*  
195 A



1999/12/13 19:48:10

# Evolution in Radial Velocity (0.96 R)

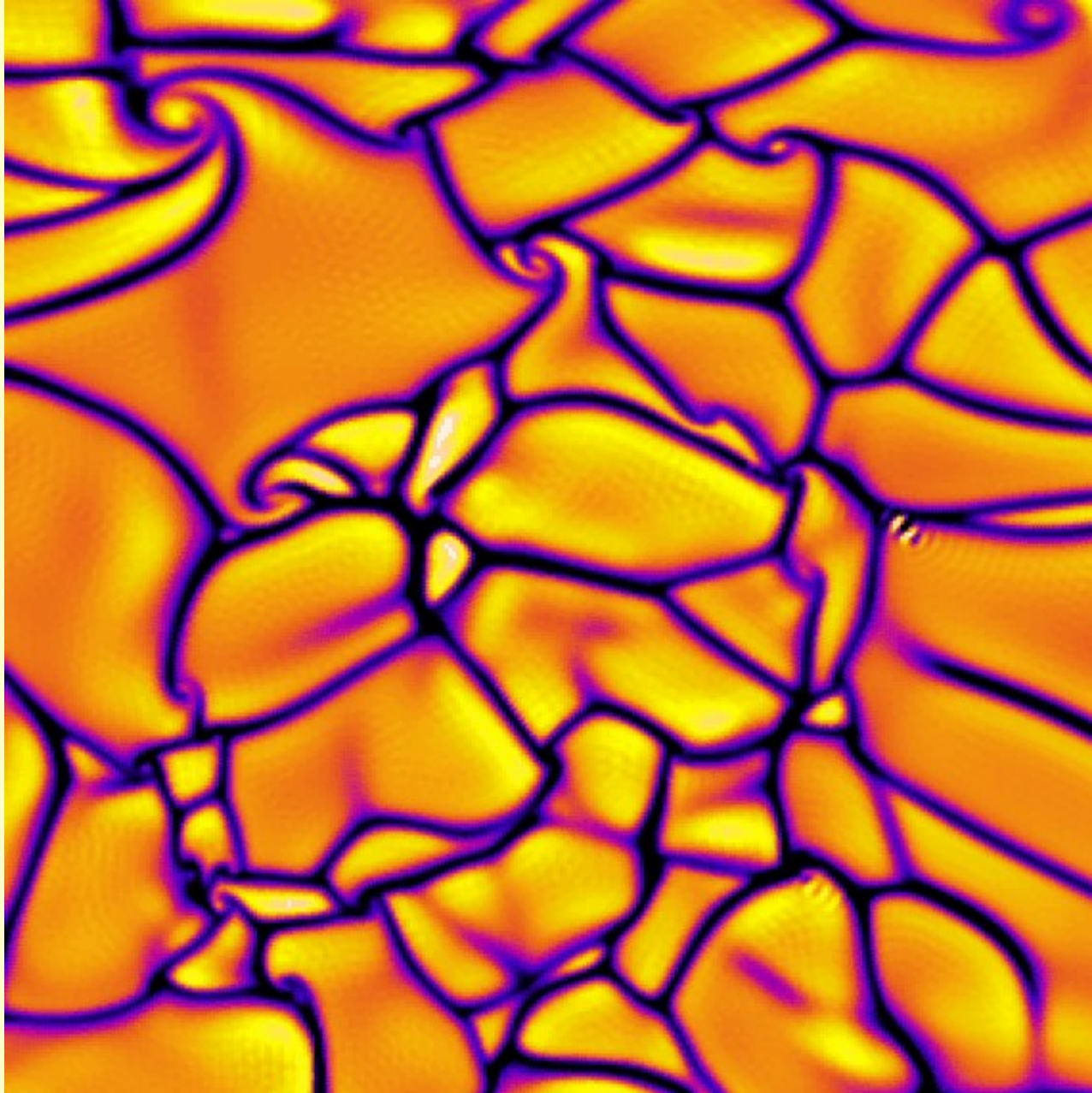


*NEAR TOP  
OF LAYER*

*VIEWED IN  
'CARRINGTON'  
FRAME*

*Case E  
Brun, Miesch  
& Toomre*

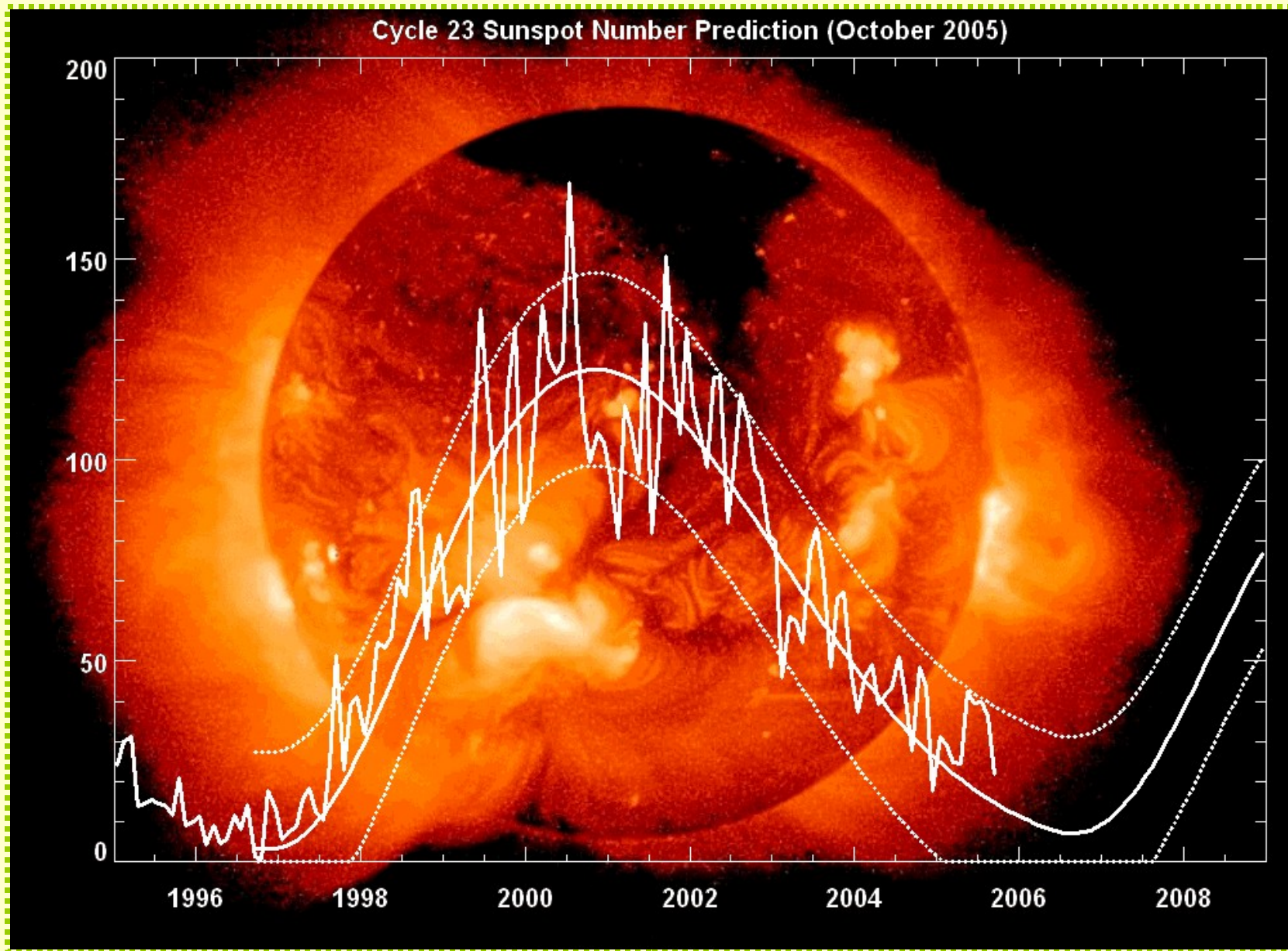
# Zoom-in detail on radial velocity



*50° N*

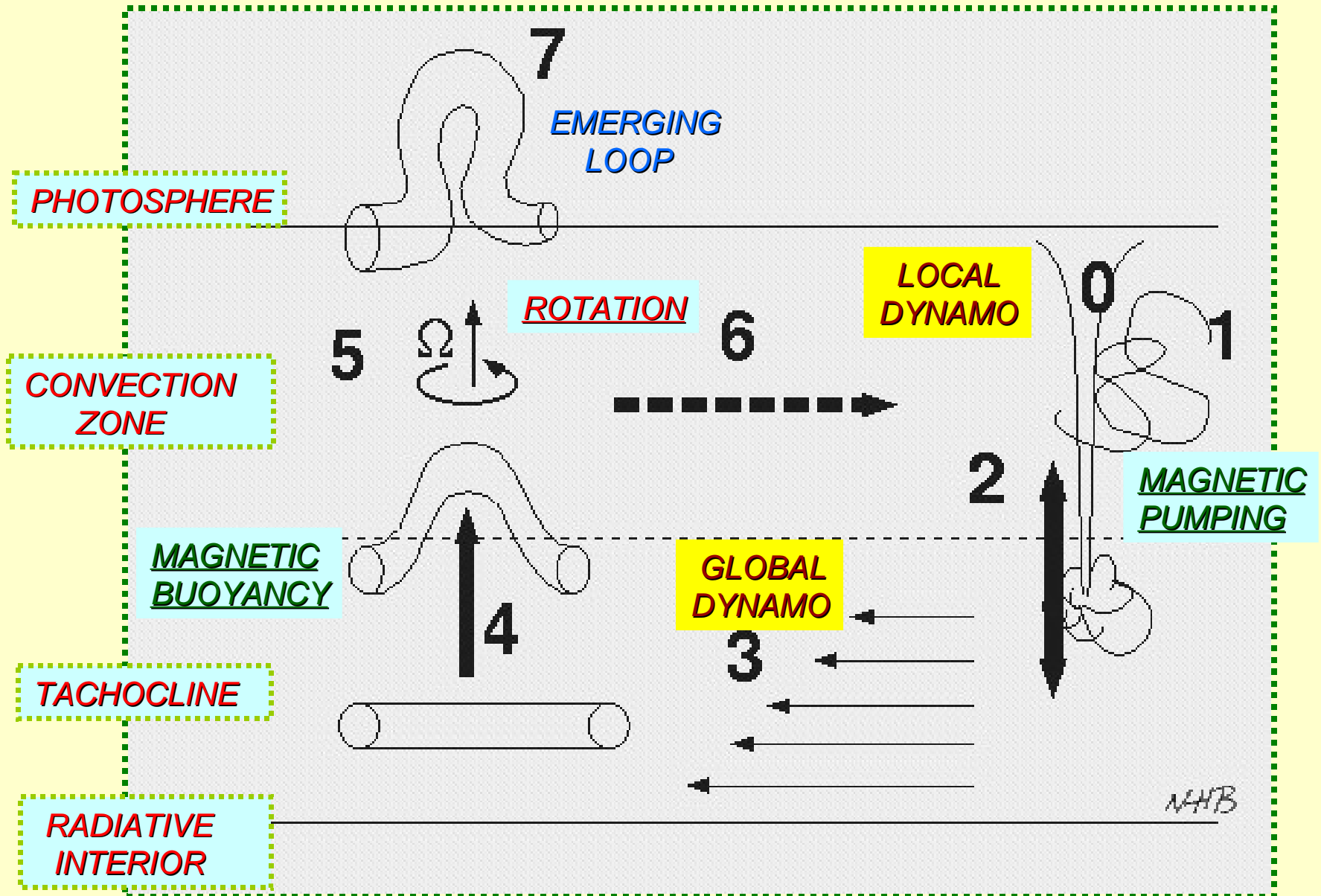
*EQ*

# Evolving Solar Activity in Current Cycle



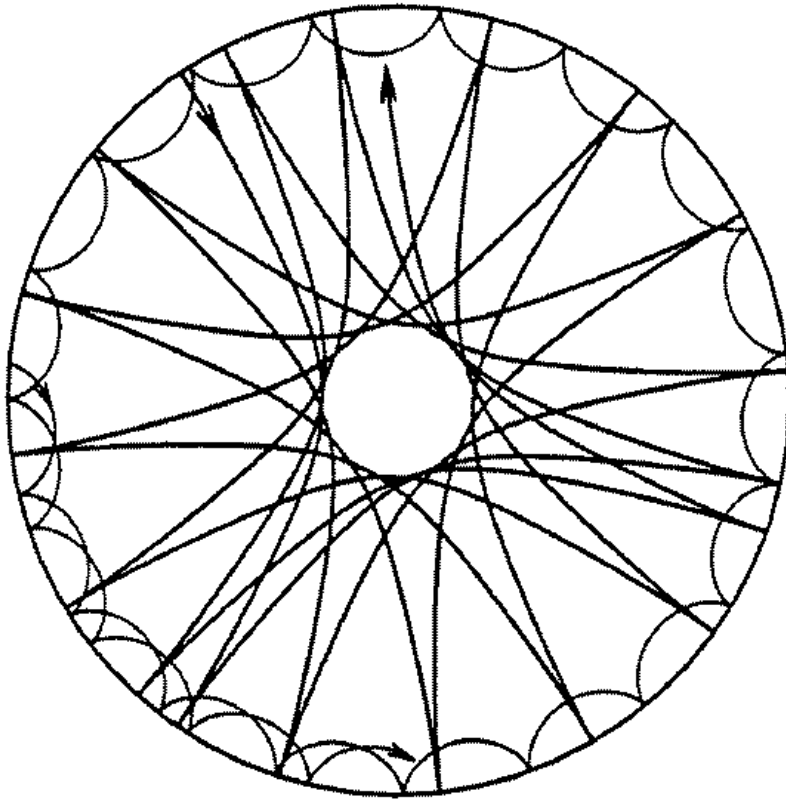
*Hathaway*

# Theoretical Solar Cycle (and it's many elements)



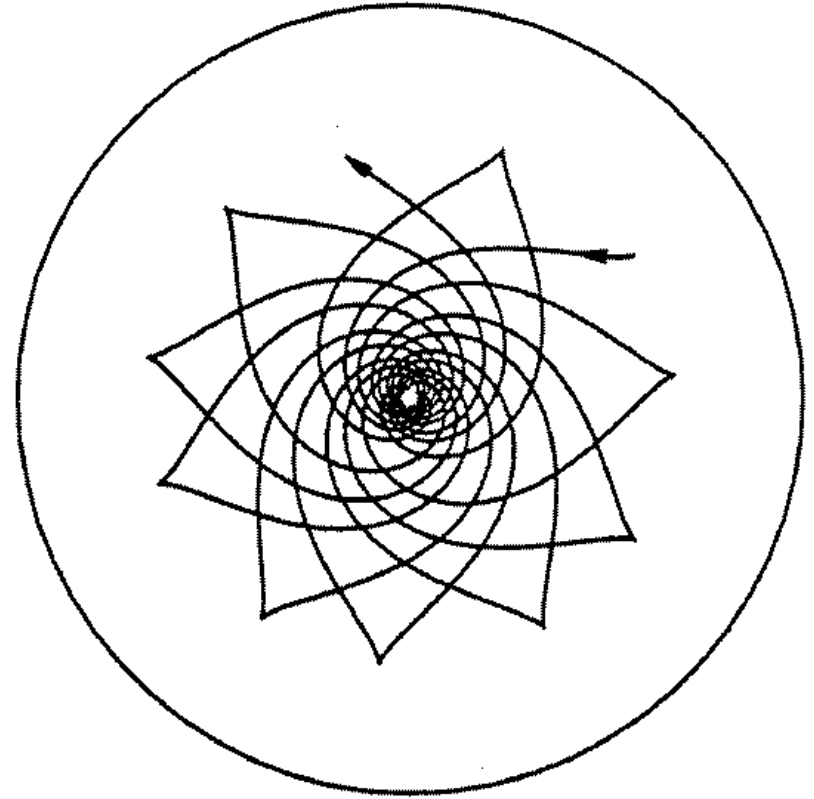
# Probing the interior with helioseismology

... *helping to sort out some of the dynamics*



GLOBAL ACOUSTIC WAVES

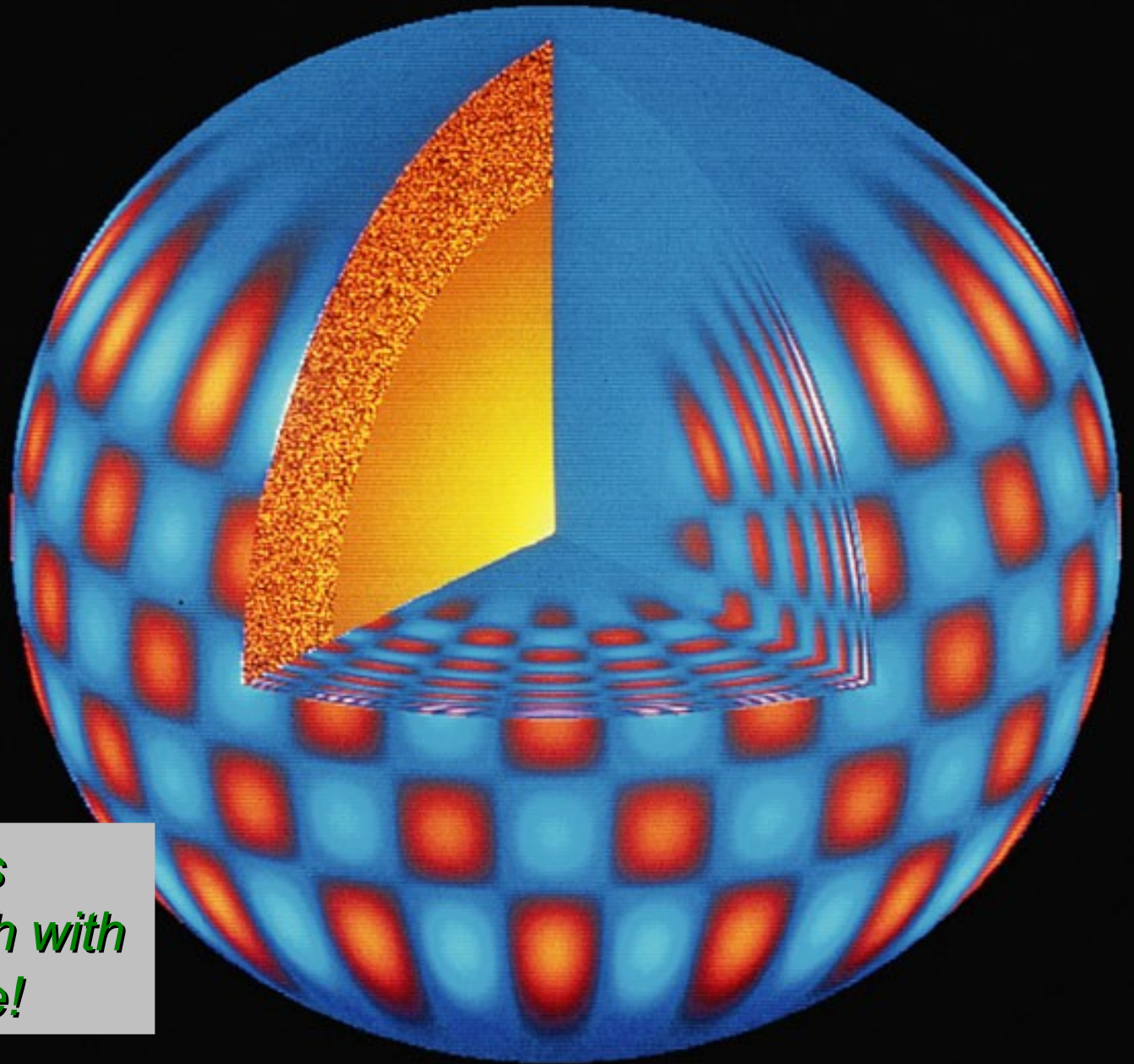
$$p_8(\ell = 2, 100)$$



INTERNAL GRAVITY WAVE

$$g_{10}(\ell = 5)$$

# Solar Oscillation Mode



*One of millions  
of modes, each with  
a different tone!*

# Linearized Perturbations Make Life Easier

Radial Velocity (linear modes):  $(n, \ell, m)$

$$\Psi(r, \theta, \phi, t) = V_n(r) Y_\ell^m(\theta, \phi) e^{-2\pi i \nu t}$$

$$Y_\ell^m = P_\ell^m(\cos \theta) e^{im\phi}$$

spherical harmonic degree  $\ell$

radial order  $n$

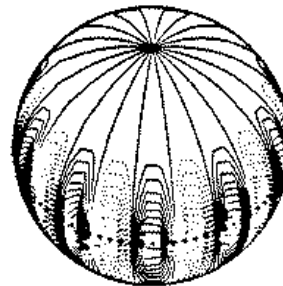
azimuthal order  $m$

frequency  $\nu$

**THREE  
QUANTUM  
NUMBERS**

$Y_\ell^m(\theta, \phi)$

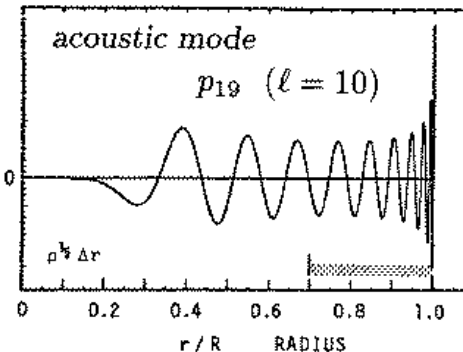
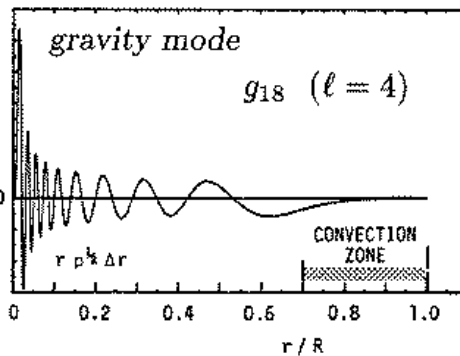
$\ell = 10$   
 $m = 5$



$\ell = 10$   
 $m = 10$

**--> FREQUENCY**

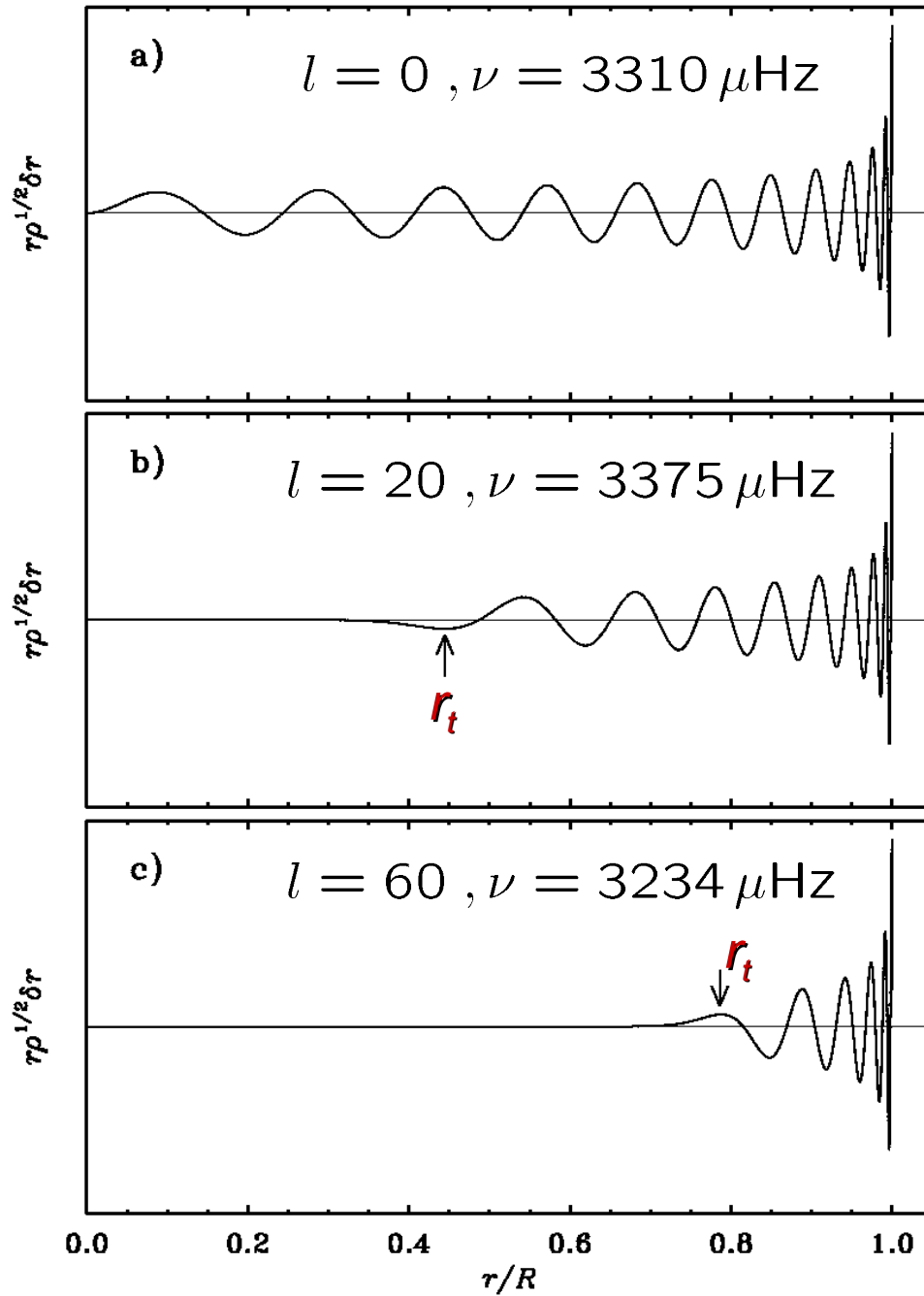
$V_n(r)$

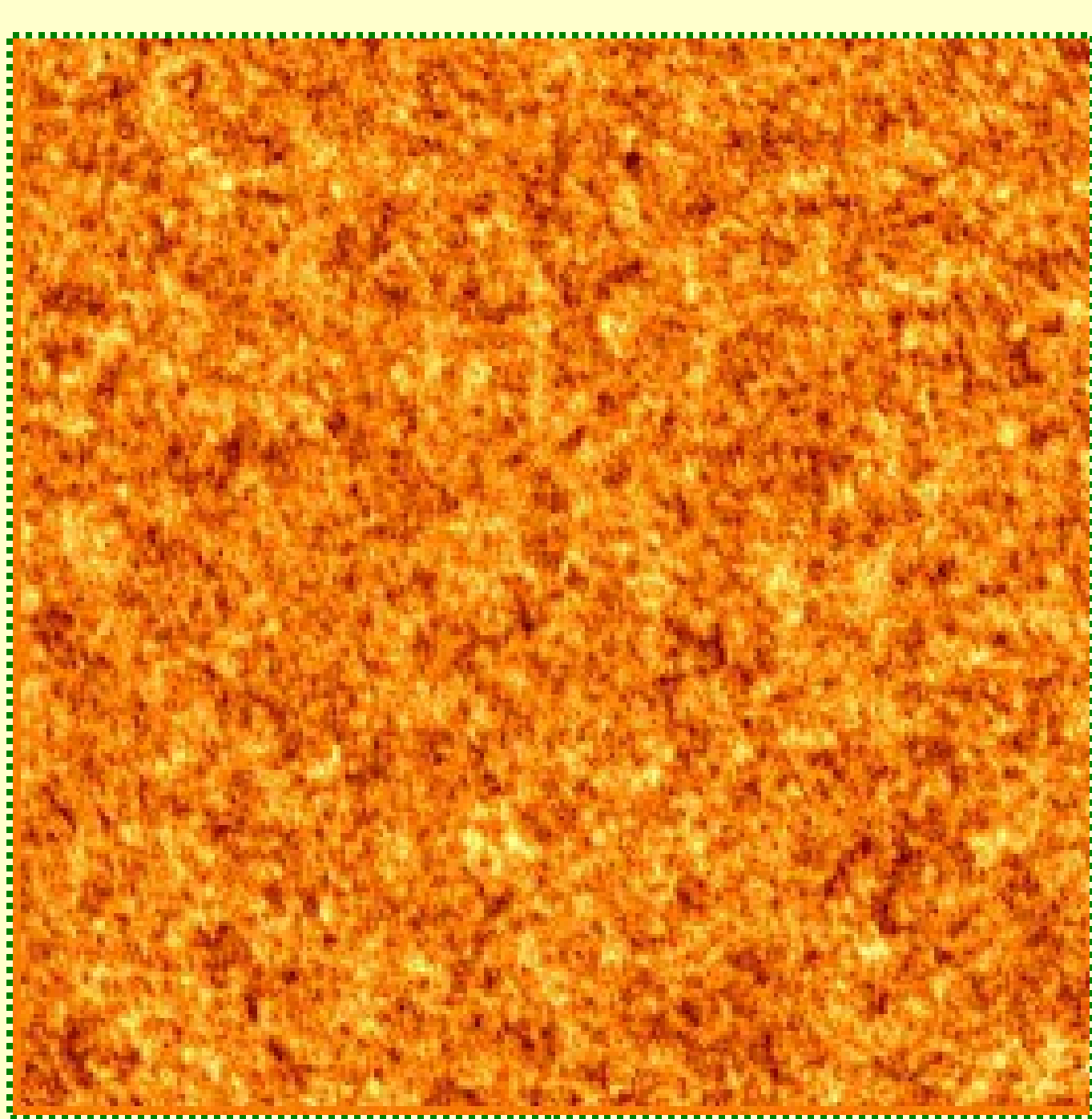


**GRAVITY  
MODE**

**ACOUSTIC  
MODE**

*p-mode  
radial  
eigenfunctions*



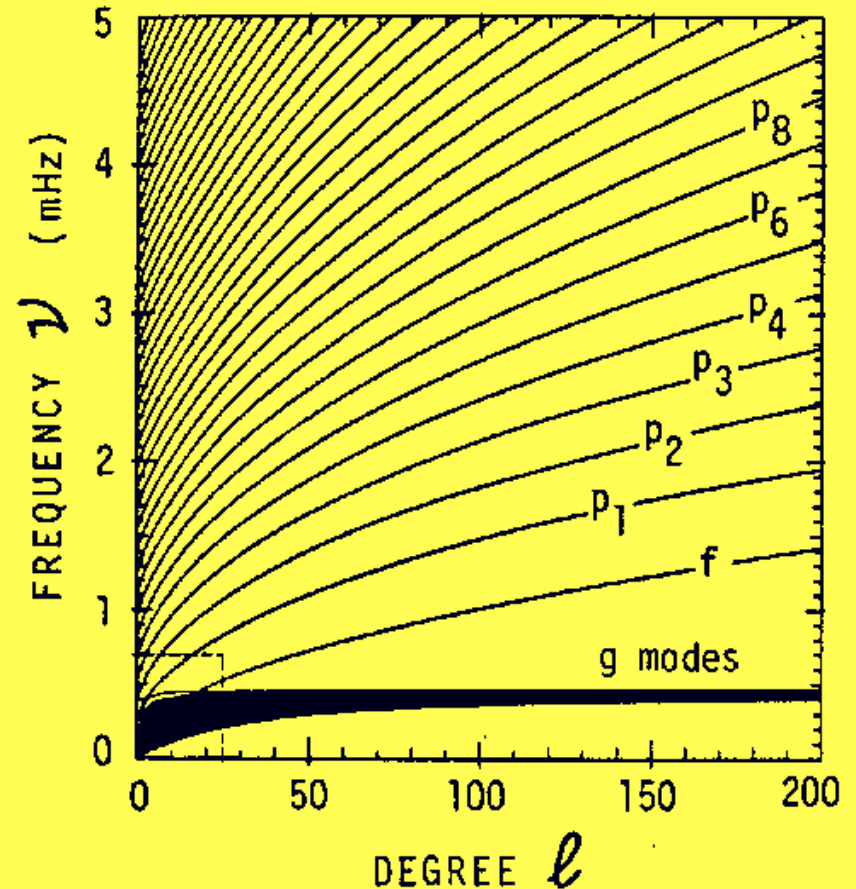
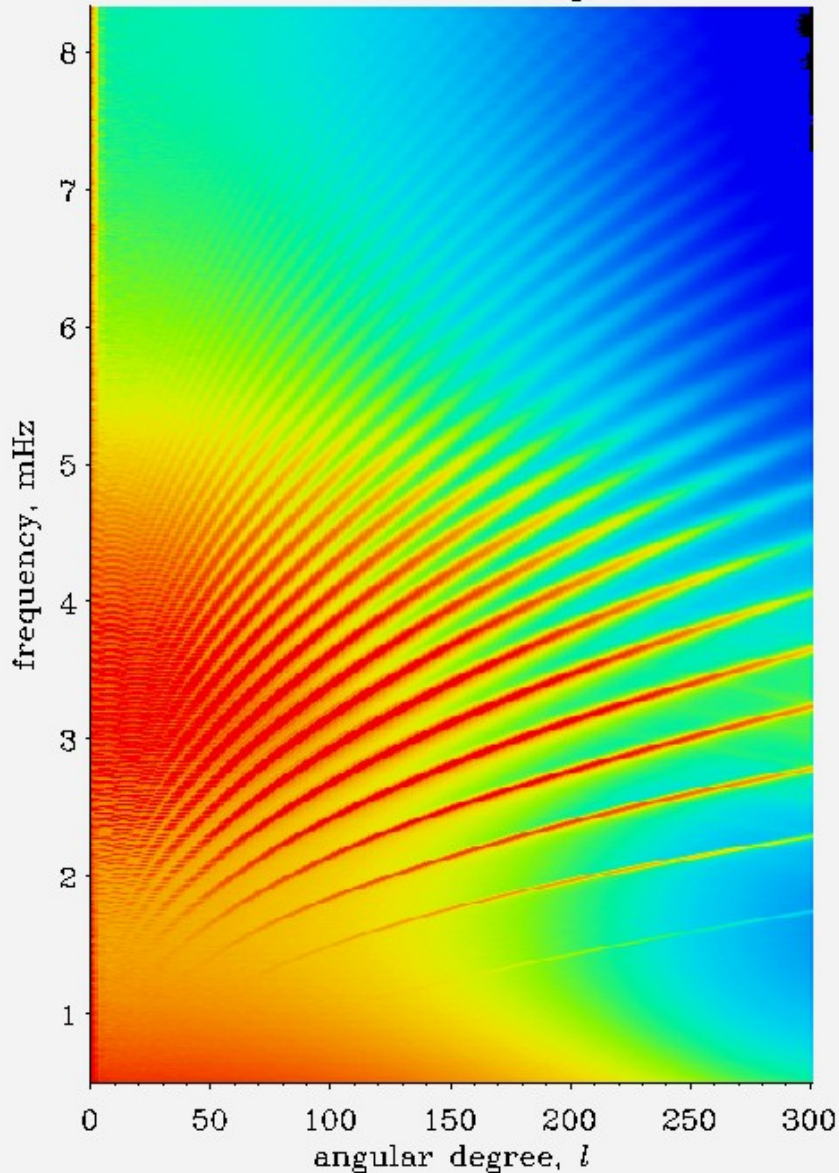


*Radial Velocity*  
*from Michelson*  
*Doppler Imager*

*~ 20° across*

# Power Spectrum of Global Modes

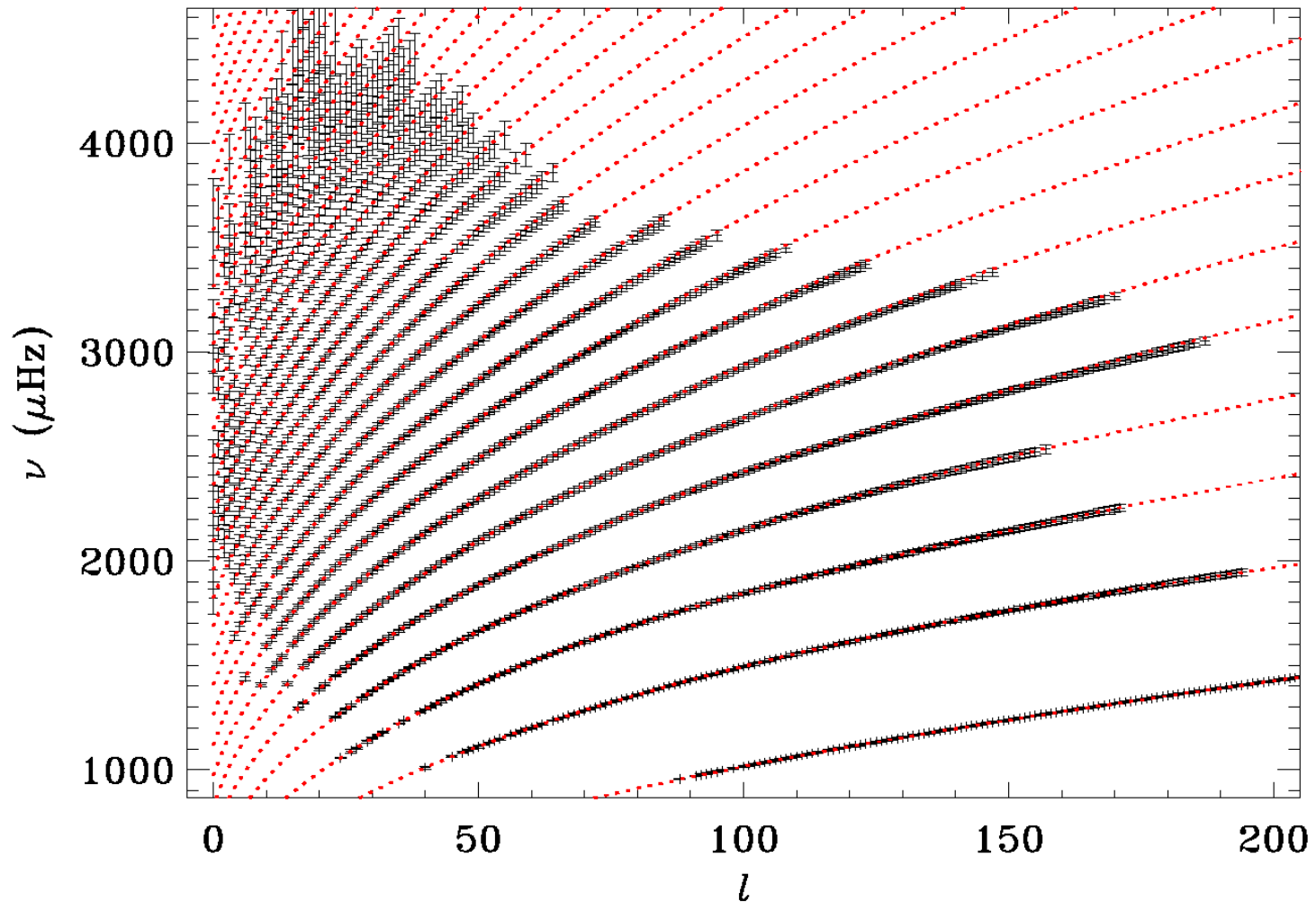
MDI Medium- $l$  Power Spectrum



**THEORY**

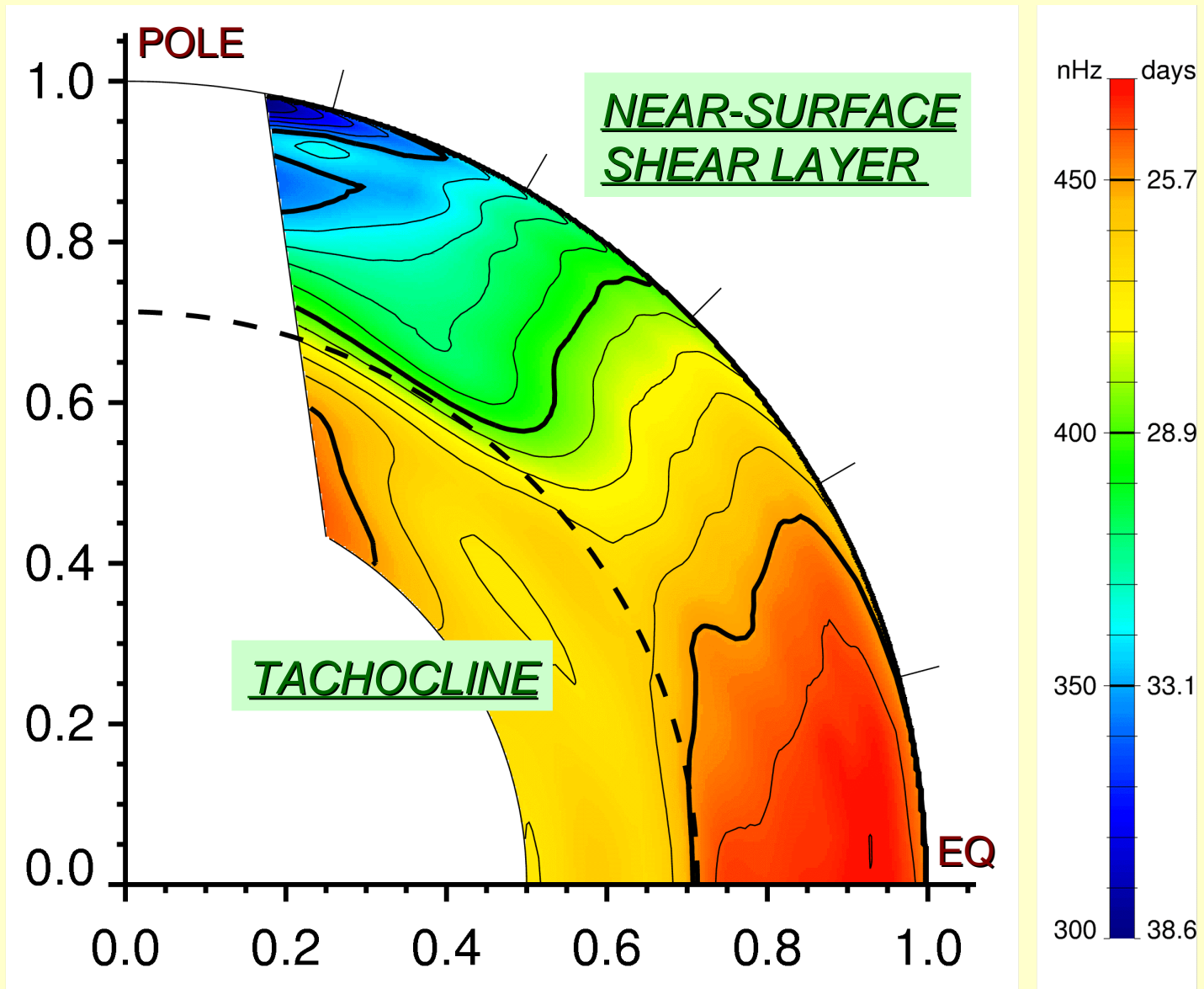
**MDI on SOHO**

# Observed p-mode frequencies



*m-averaged frequencies from MDI on SOHO 1000x error bars*

# Interior Angular Velocity



# Mean Angular Velocity Profiles

