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Flares, Oscillations and Cycles in the Sun and other Stars

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Flares and Oscillations in the Sun

- In 1972 Charles Wolff suggested that solar flares could excite free oscillations in the Sun
- The general idea by Wolff was that the flares would cause a thermal expansion that would act as a mechanical impulse by causing a wave of compression to move subsonically into the solar interior.
- The lifetimes of such oscillations would be around a day

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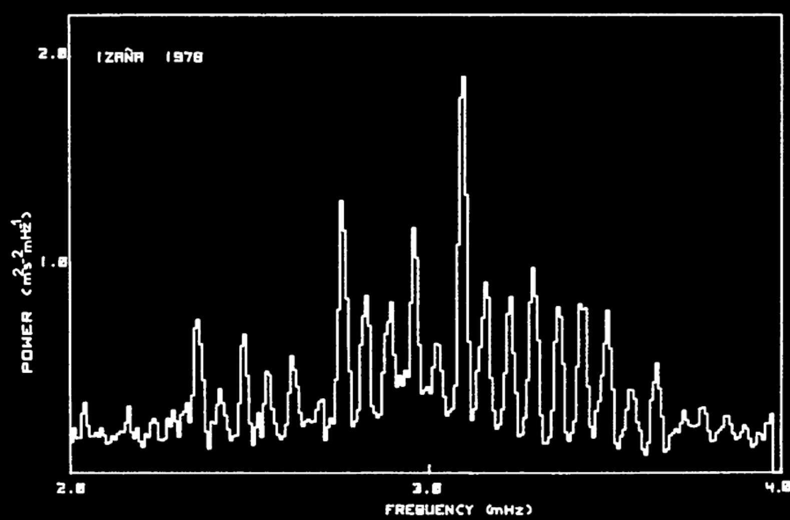
Free Oscillations of the Sun



Claverie et al., 1980, A&A, 91, L9

- In seventies the observations of 5-minutes global oscillations were confirmed.
- With global I here mean oscillation that can be seen in disk-integrated data.
- This means that we can observe the same kind of oscillations in other solar-like stars.

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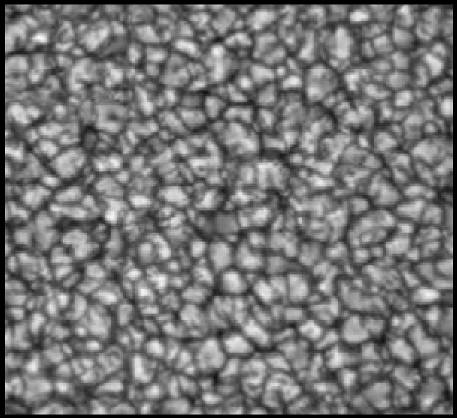
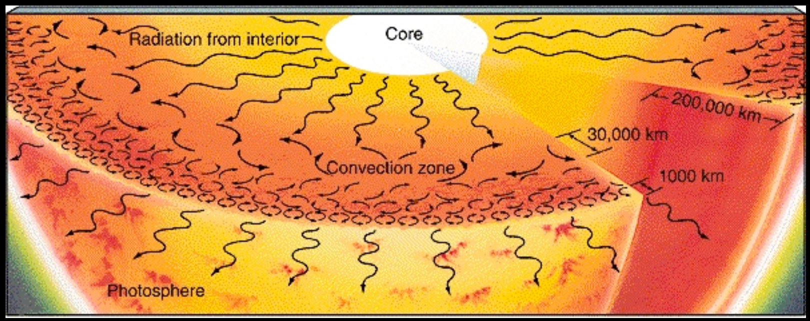
What Drive the Oscillations in the Sun





The solar p-modes are excitated by turbulent motion in the near surface convection zone.

As:

- This excitation mechanism gives the right amplitudes and mode lifetimes.
- This can excite f-modes

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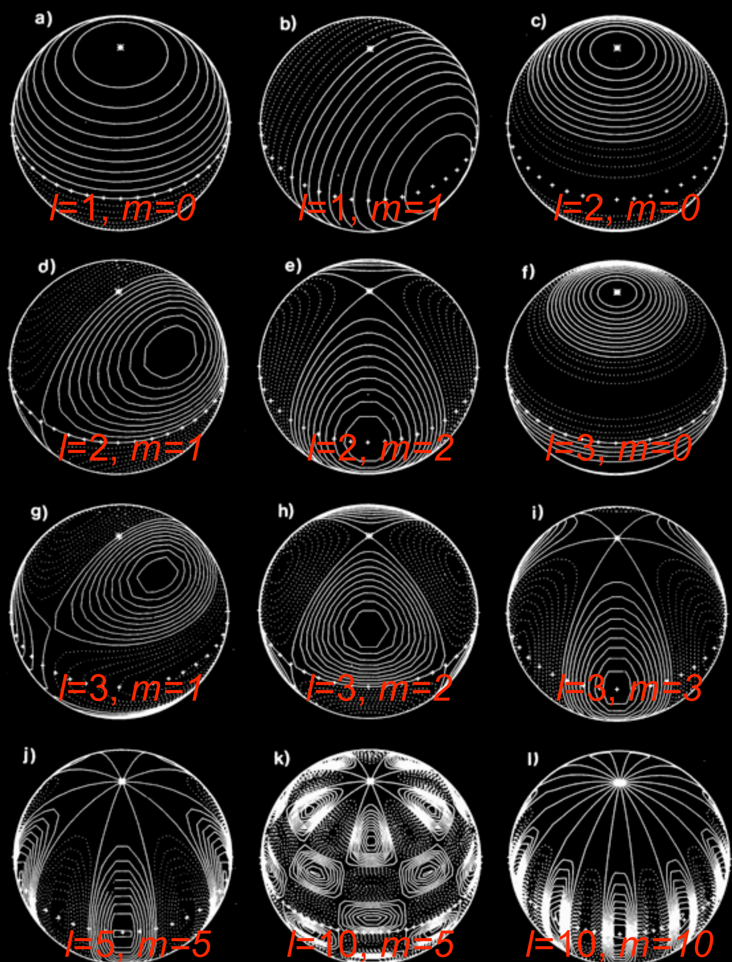
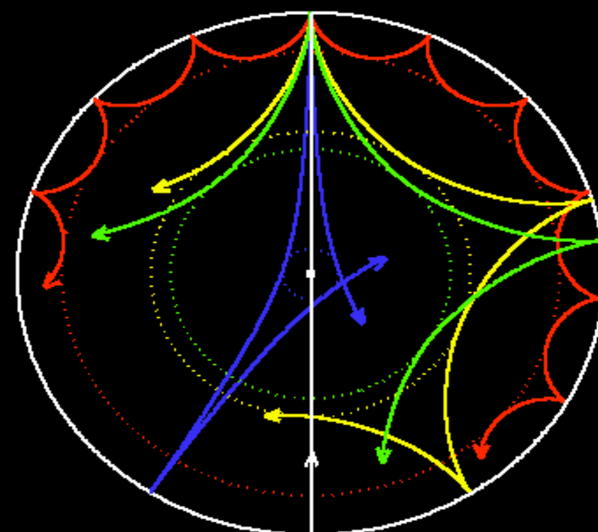
Goldreich & Kumar, 1988, ApJ, 326, 462

Solar Oscillation Modes





$\nu(n,l,m)$

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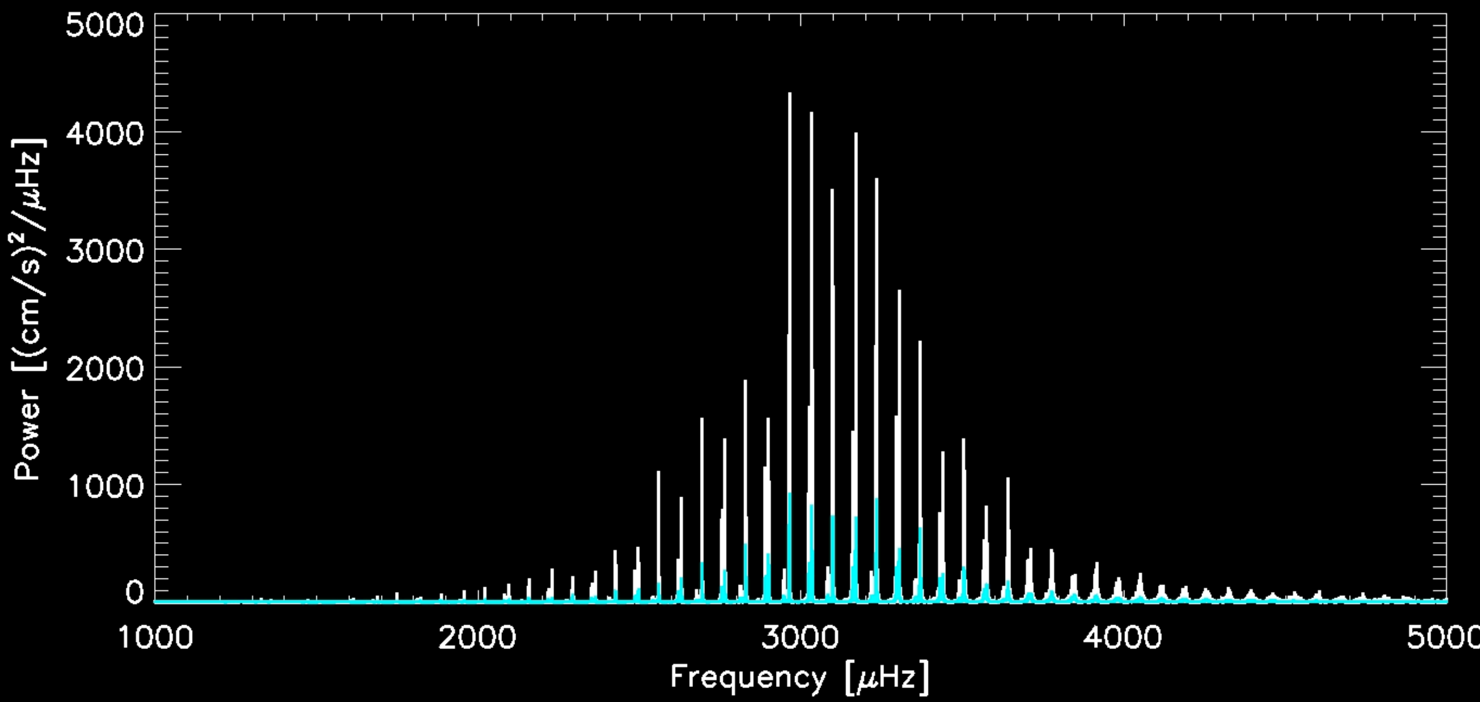
Solar Oscillation Modes



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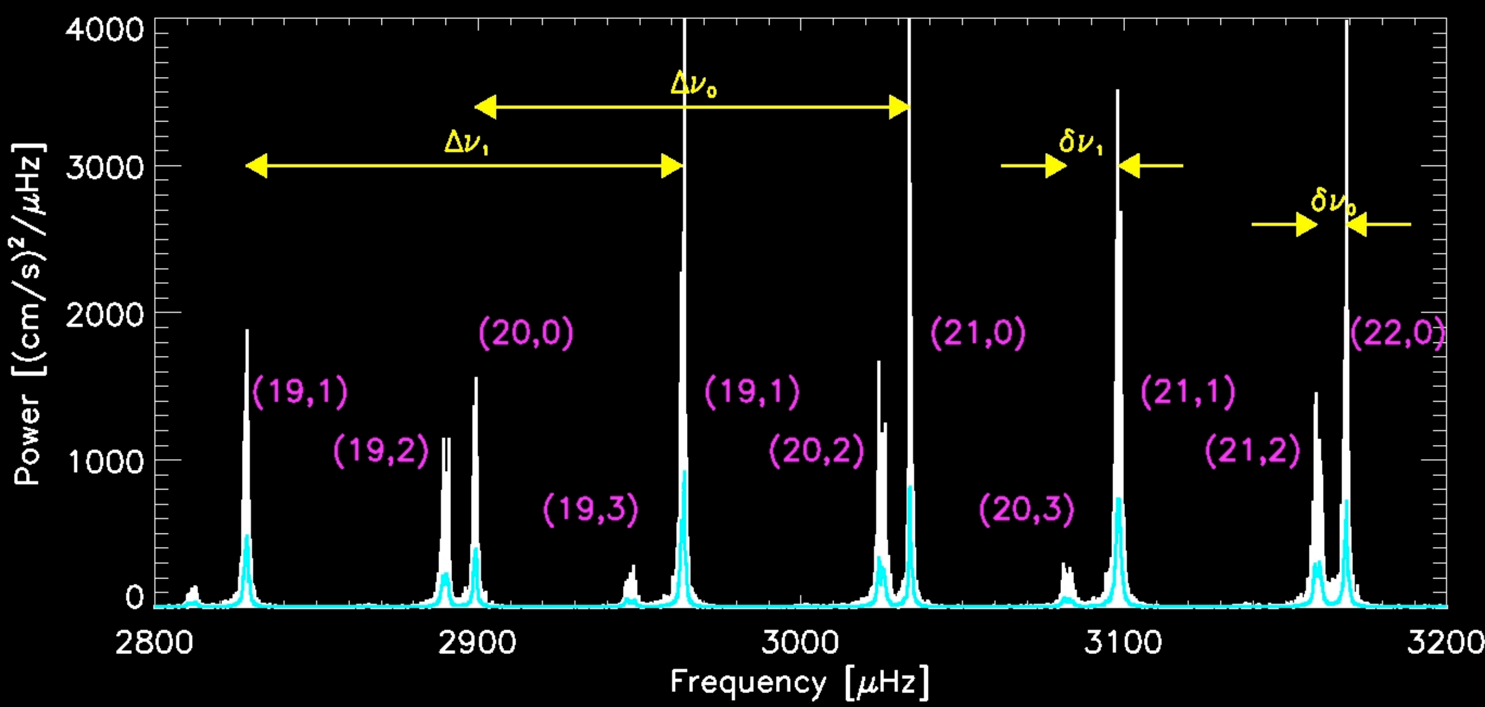
Solar Oscillation Modes



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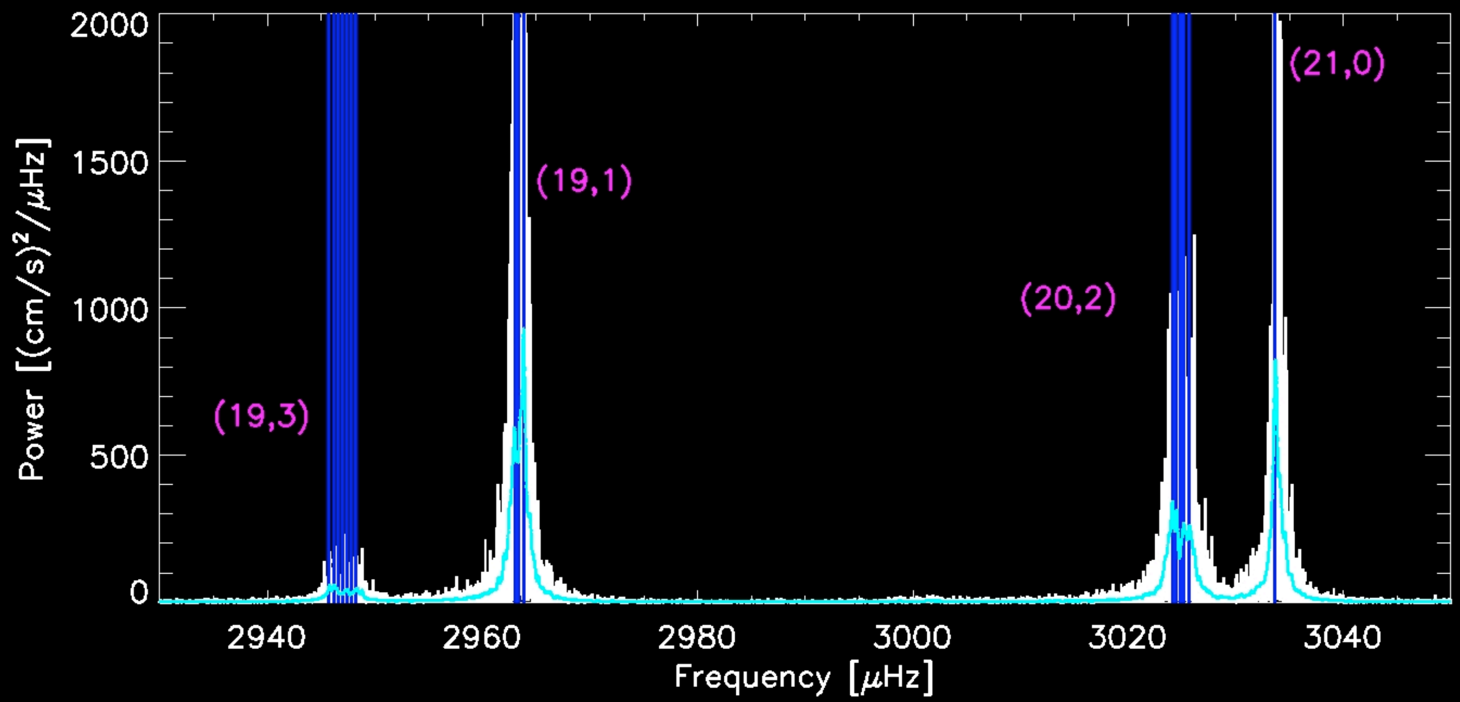
Solar Oscillation Modes



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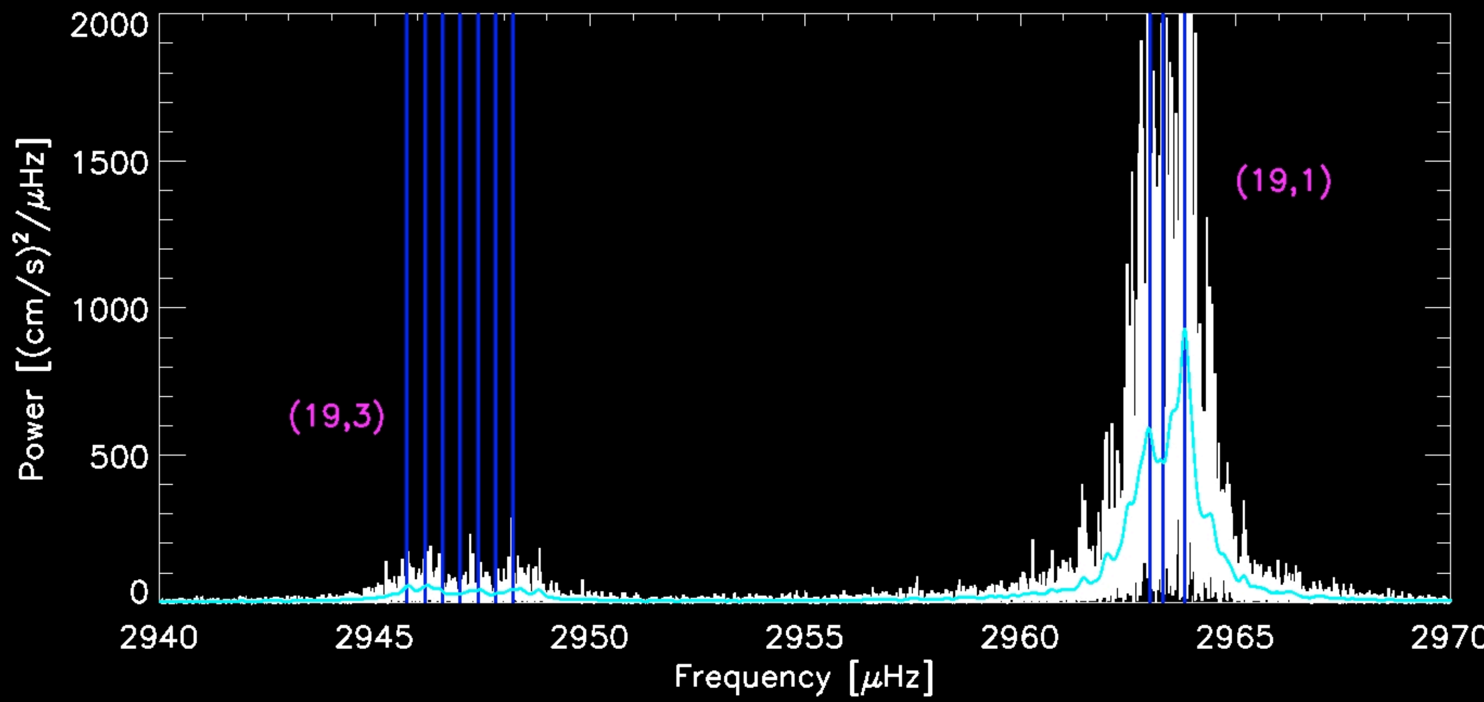
Solar Oscillation Modes



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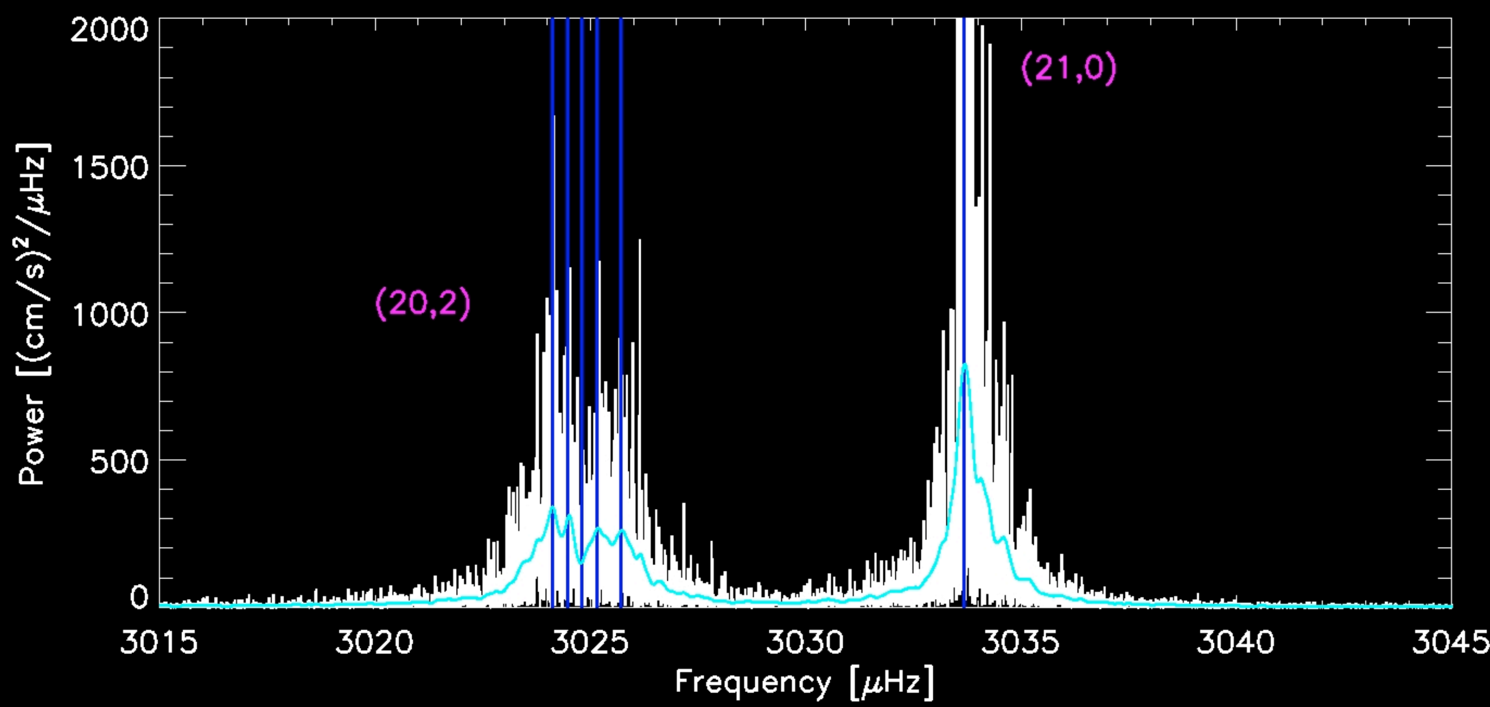
Solar Oscillation Modes



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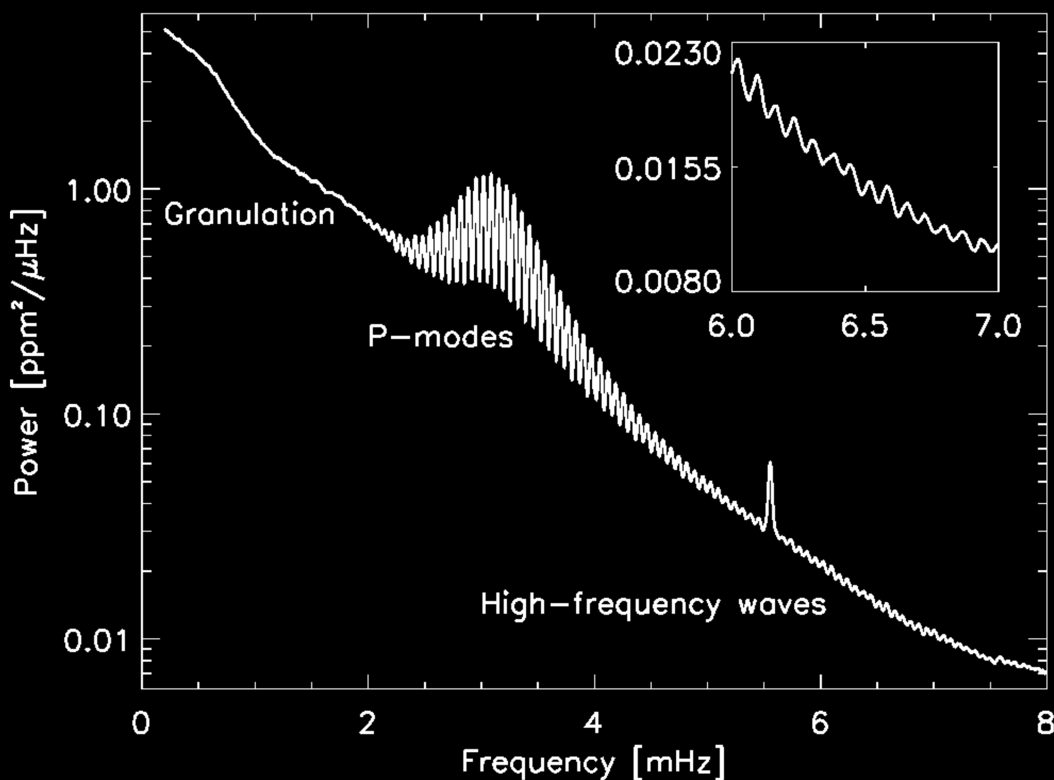
Solar Oscillations



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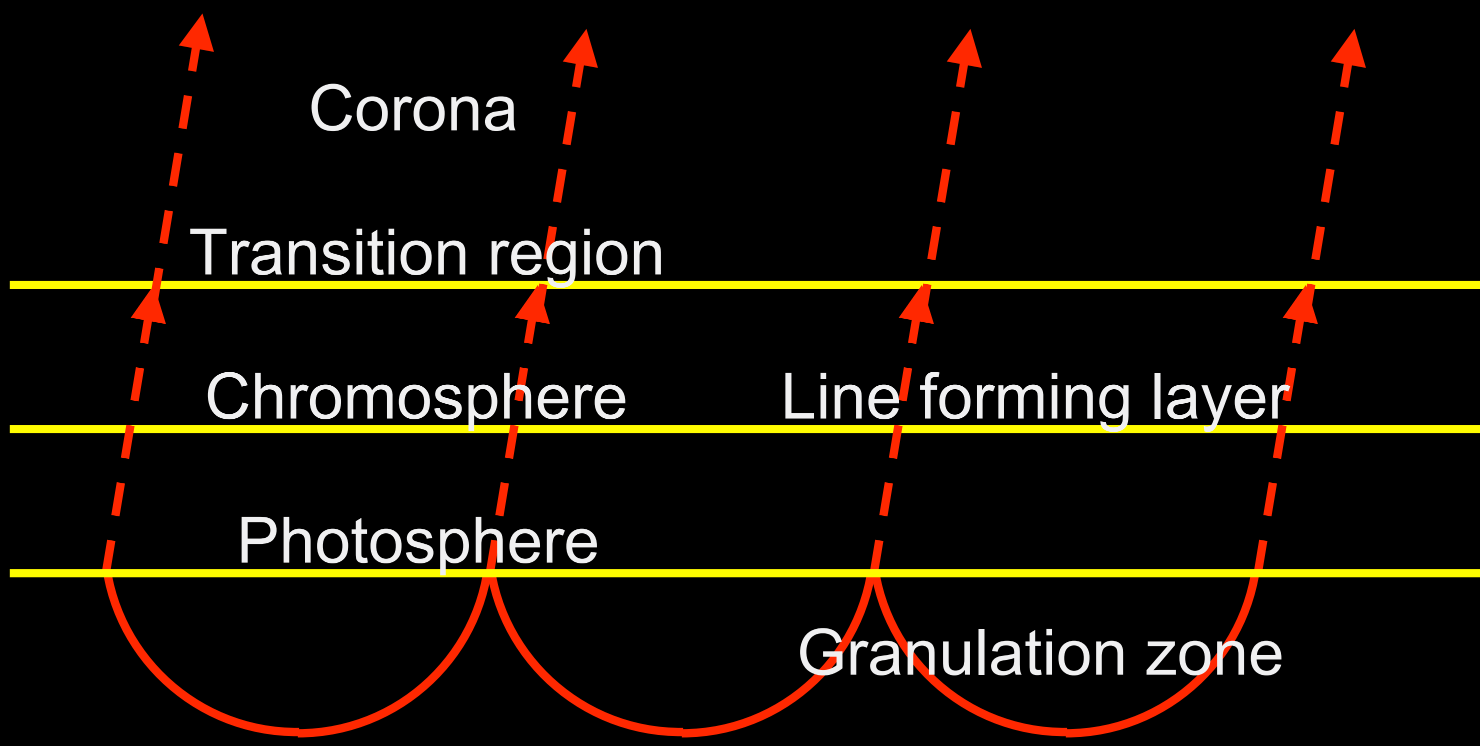
Models of High-frequency Waves

- High-frequency interference peaks (HIPS).
  (Kumar & Lu, 1991, ApJ, 375, L35)
- P modes reflected at the transition region.
  (Balmforth & Gough, 1990, ApJ, 362, 256)
- Chromospheric oscillations.
  (Deubner, 1995, APS, 76, 303)

High-frequency Interference Peaks



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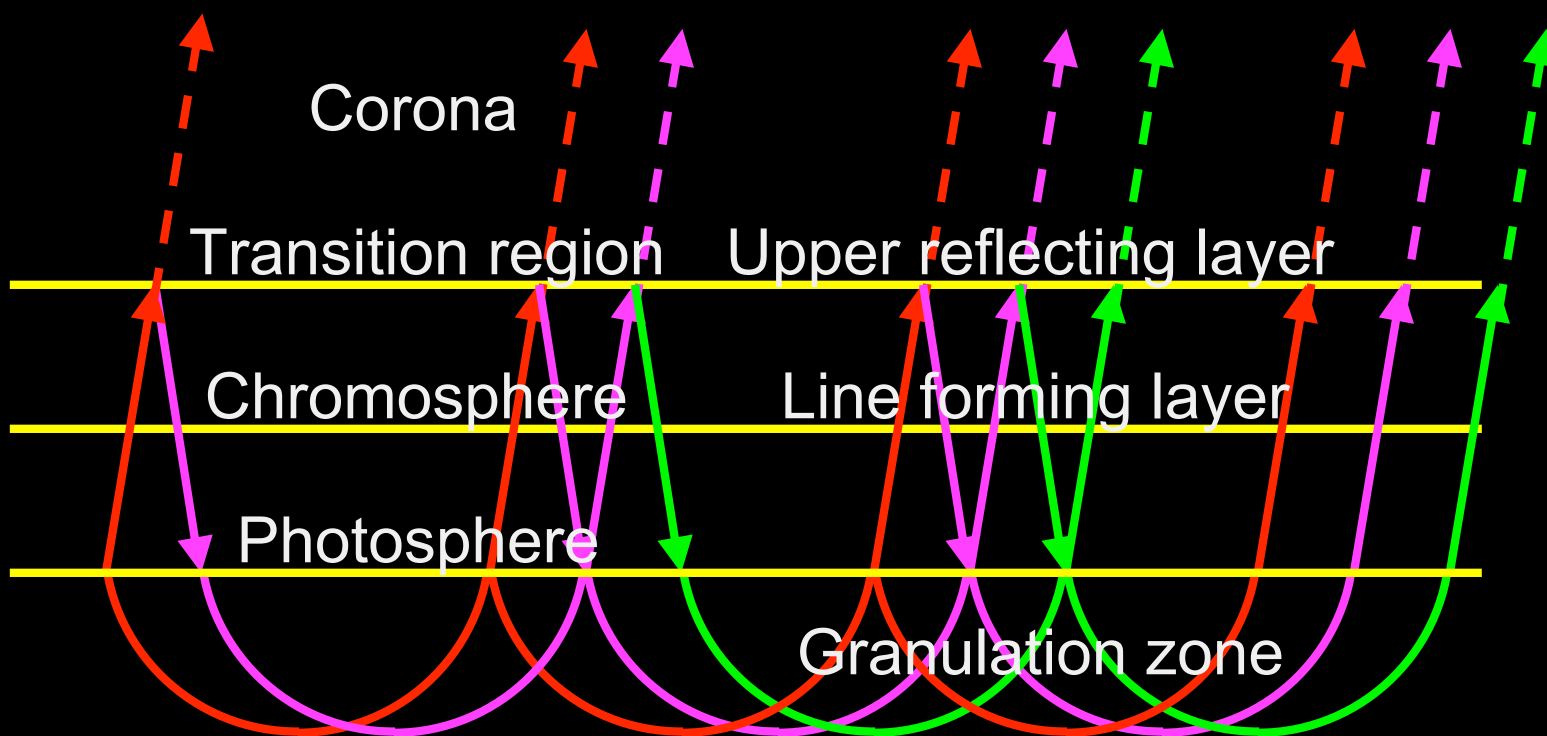
P modes Reflected
at the Transition Region



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Idea from Jefferies et al., 1997, ApJ, 485, L49

Chromospheric Waves

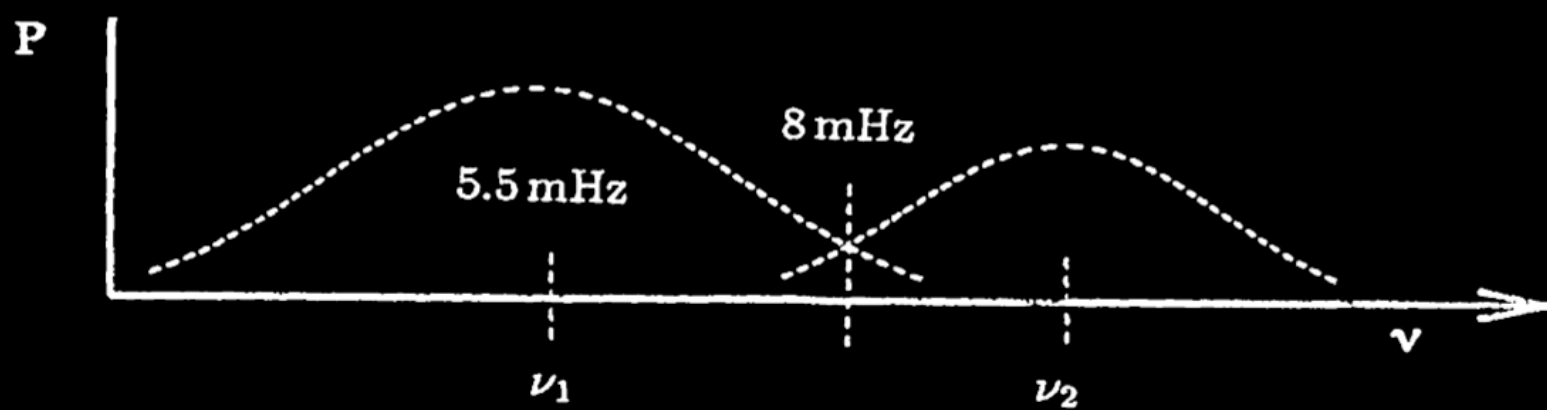

Figure 2 Sketch of the properties of a chromospheric cavity.

Deubner, 1995, ASP, 76, 303

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Localized Excitation

PLATE L6

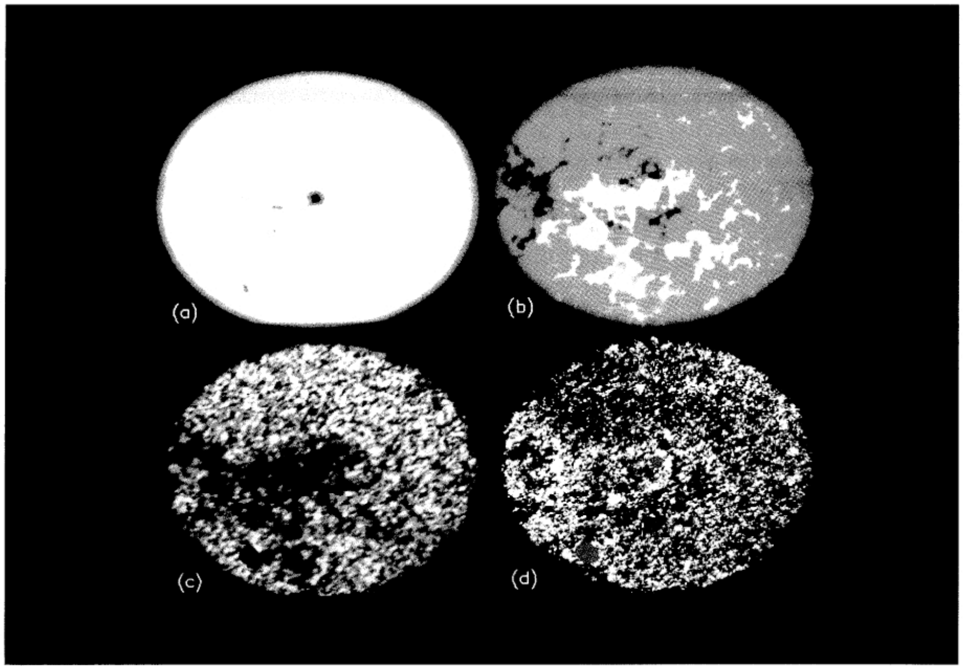

FIG. 1.—(*a*) Continuum intensity image of the active region. The elliptical outline is a result of apodization of the original rectangular image. The dark oblong region near the SW boundary of the image is an artifact introduced by an optical defect. (*b*) KPNO magnetogram of the same region, taken 135 m before the start of our observing interval and resampled at the same spatial scale as our CCD images. This image has been rescaled so that saturation occurs at $B = 500$ G. (*c*) Power integrated over the *p*-mode band. The range of power values P displayed is $1500 \leq P \leq 15{,}000$ m^2 s^{-2}. (*d*) Power integrated over the high-ν band. The range of power values P displayed is $150 \leq P \leq 400$ m^2 s^{-2}.

BROWN et al. (see 394, L66)

Brown et al., 1992, ApJ, 394, L65

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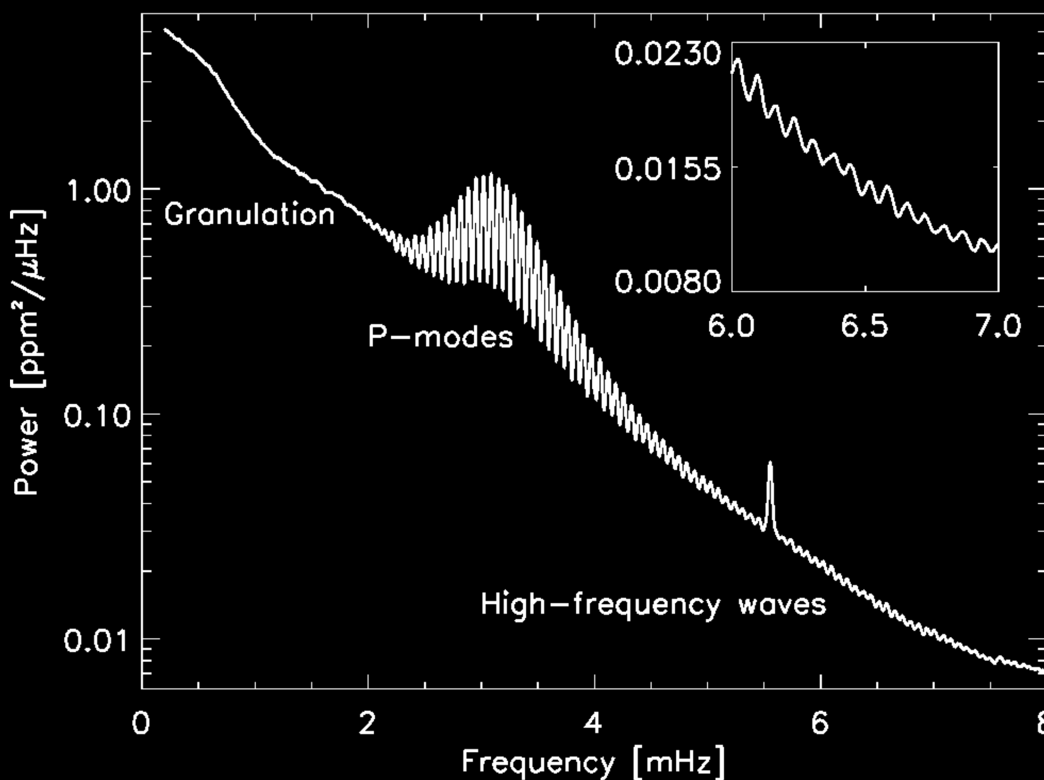
High-frequency Waves in the Sun



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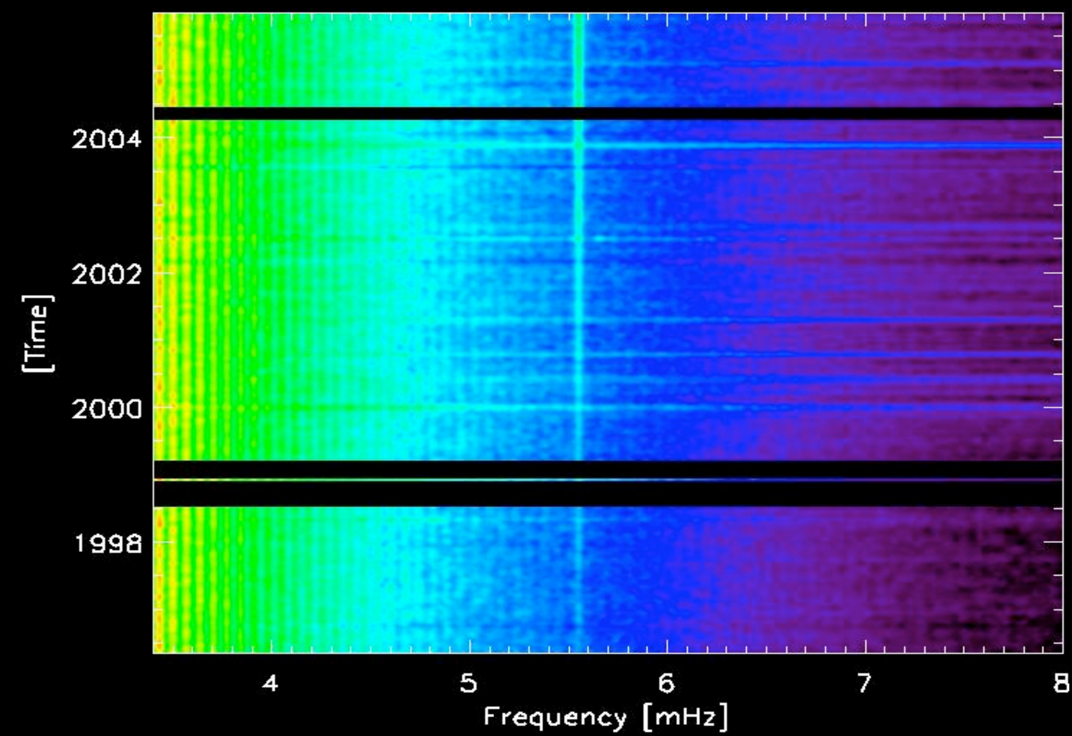
Karoff & Kjeldsen, 2008, ApJ, 678, L73

Frequency-time Diagram



Karoff & Kjeldsen, 2008, ApJ, 678, L73

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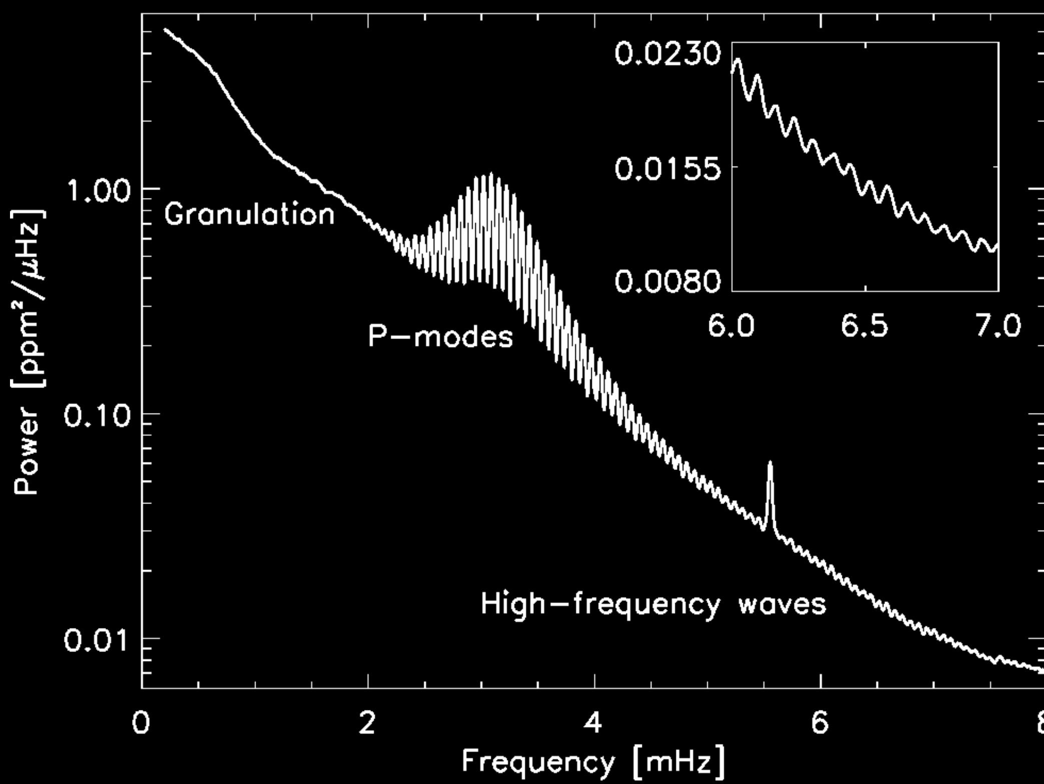
High-frequency Waves in the Sun



Karoff & Kjeldsen, 2008, ApJ, 678, L73

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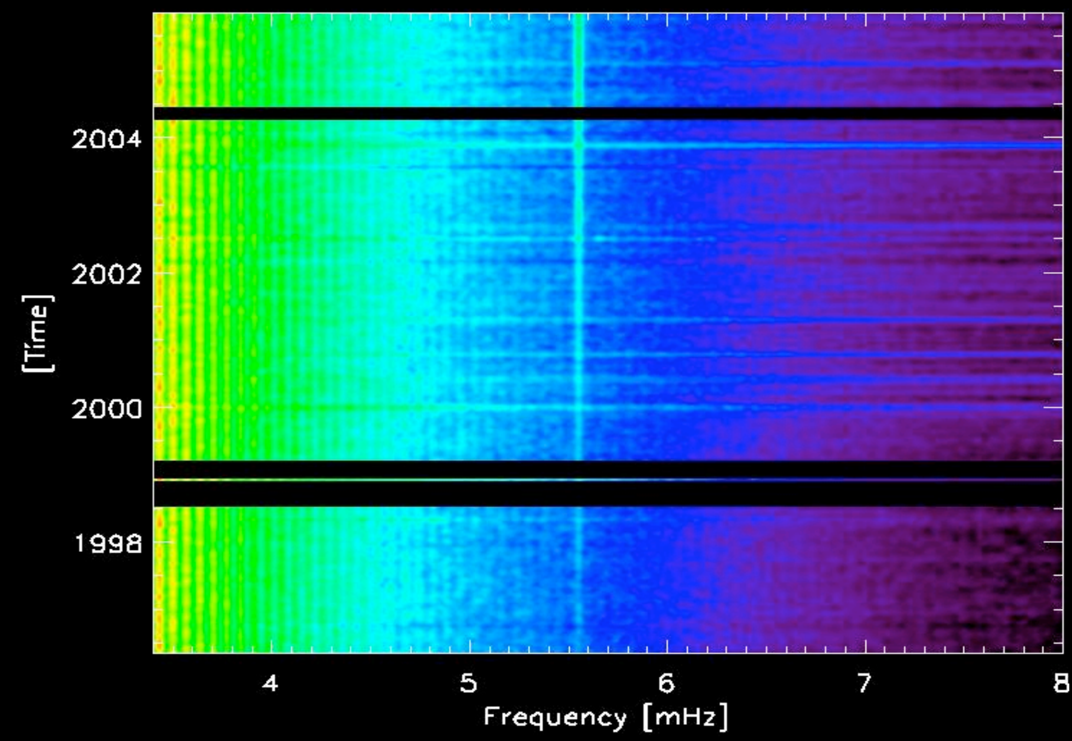

Karoff & Kjeldsen, 2008, ApJ, 678, L73

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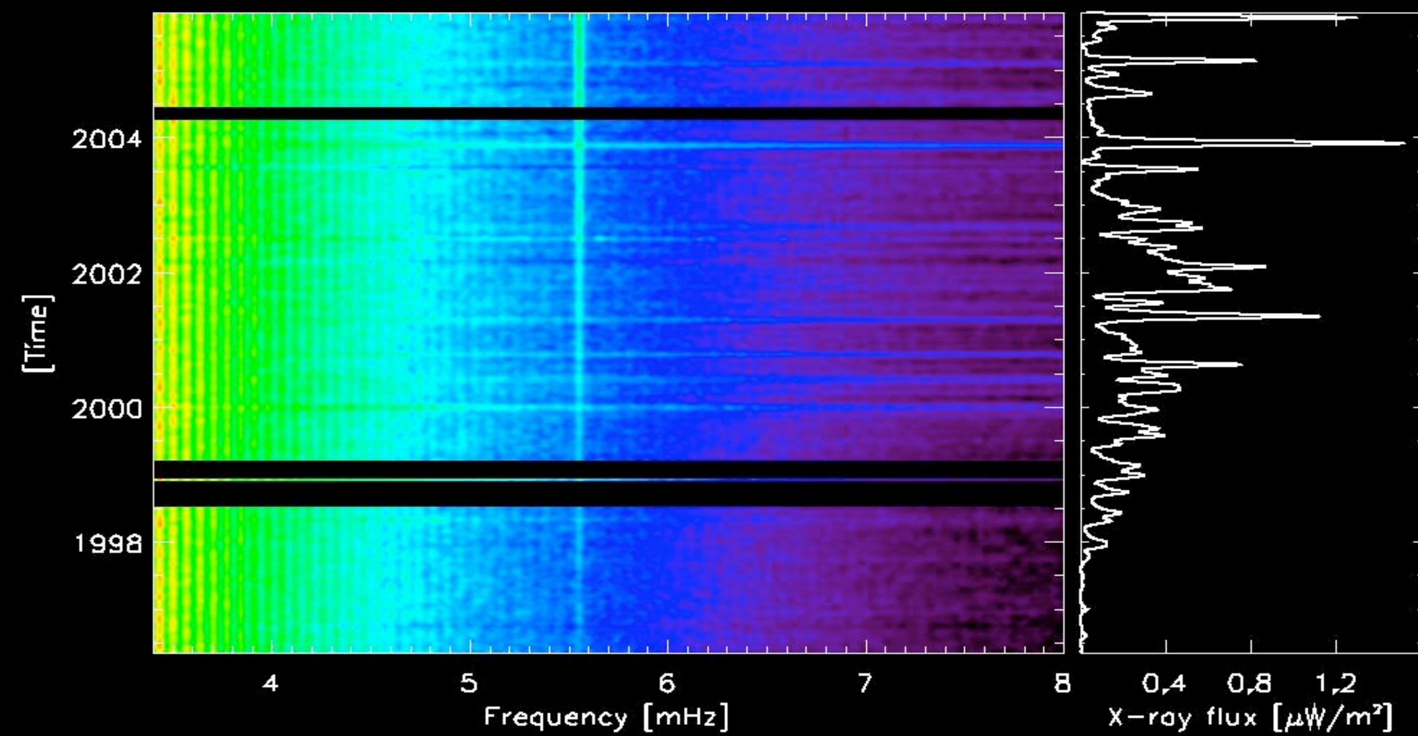
Correlation with X-ray Flux



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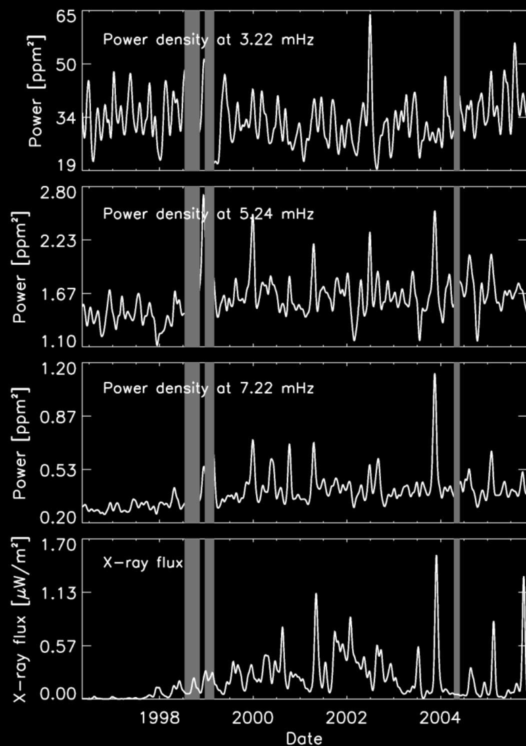
Karoff & Kjeldsen, 2008, ApJ, 678, L73

Correlation of Different Modes



Karoff & Kjeldsen, 2008, ApJ, 678, L73

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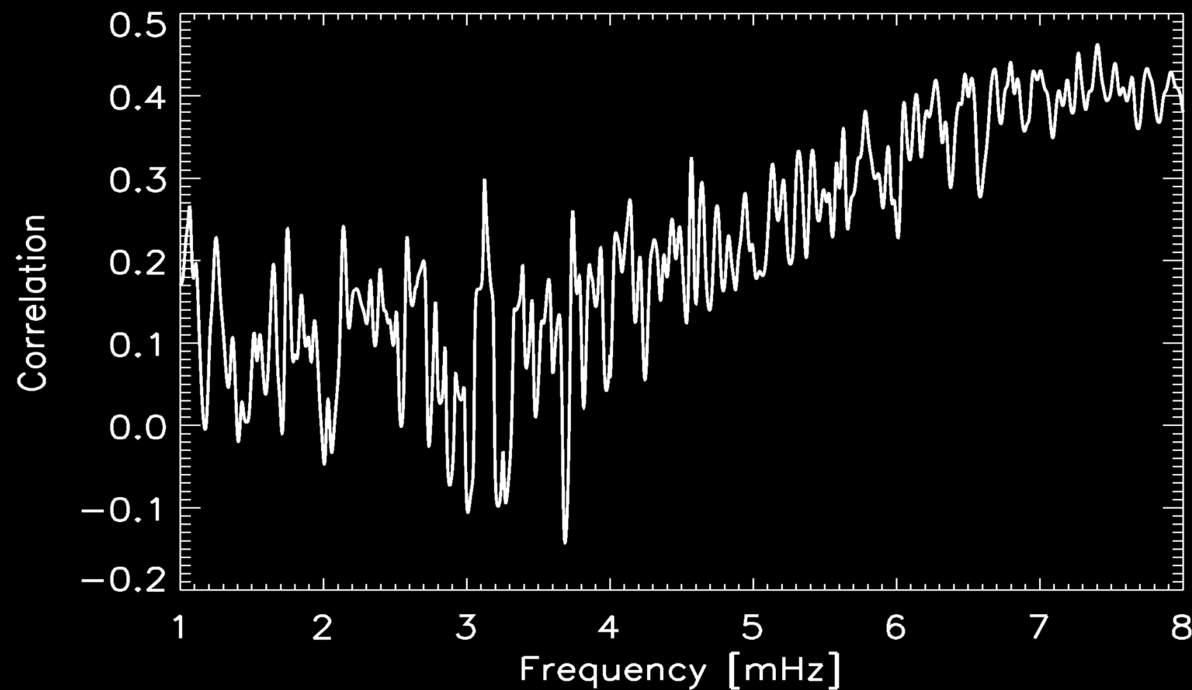
Oscillations at High Frequency are more Correlated



Karoff & Kjeldsen, 2008, ApJ, 678, L73

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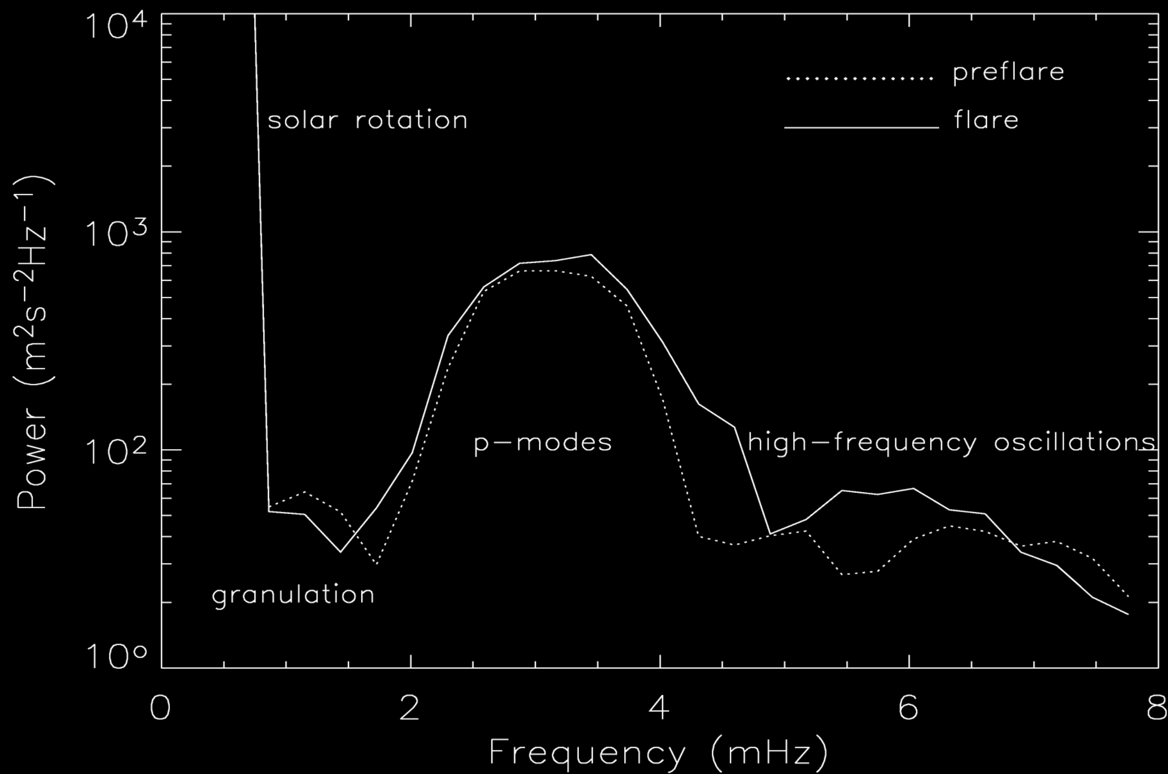
MDI Data



Work by Brajesh Kumar

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The Three Suggestions

- High-frequency interference peaks (HIPS).
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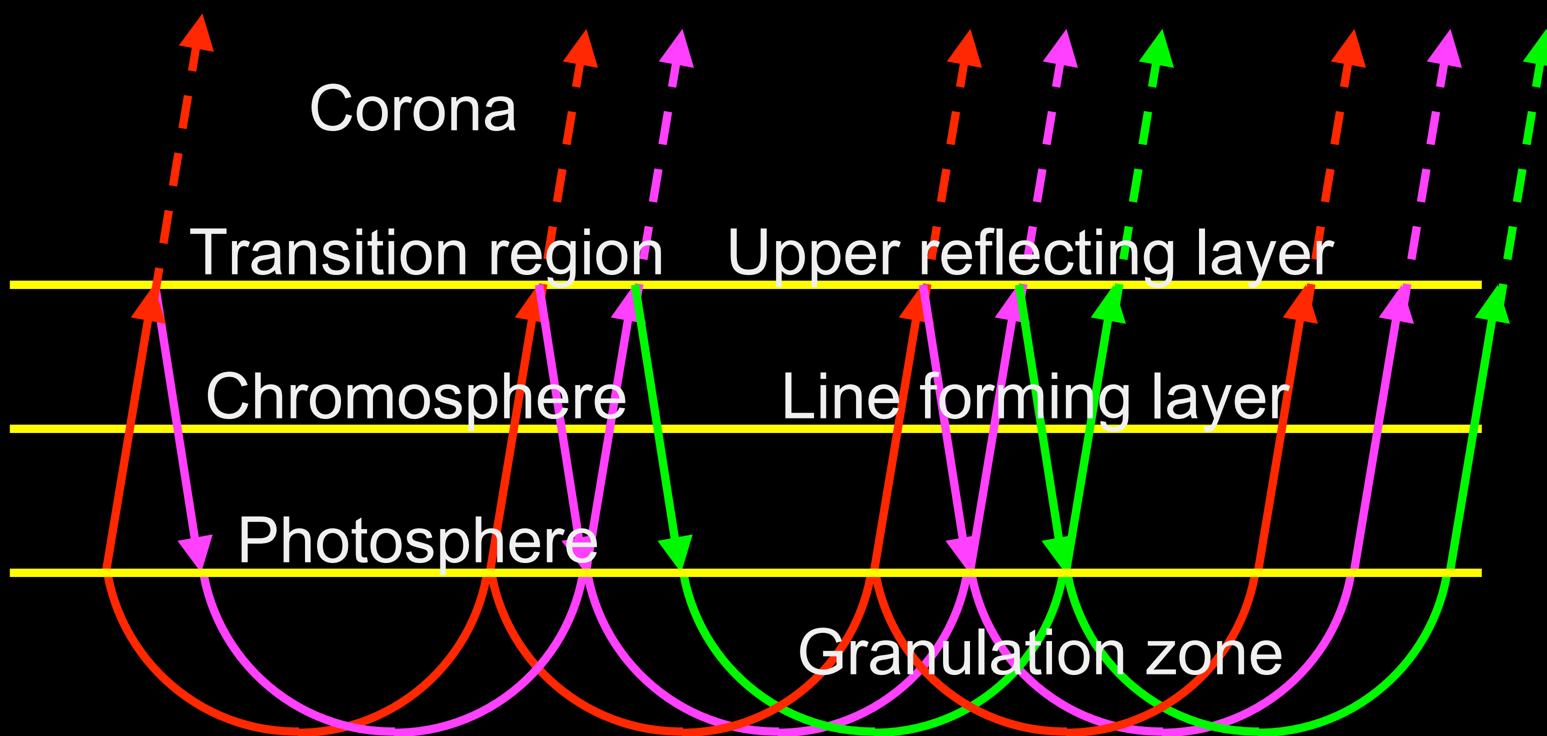
P modes Reflected at the Transition Region



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Idea from Jefferies et al., 1997, ApJ, 485, L49

Two Possibilities

- Improving space-weather predictions

- Observations of flare driven waves
  in solar-like stars - implications the understanding of the solar cycle

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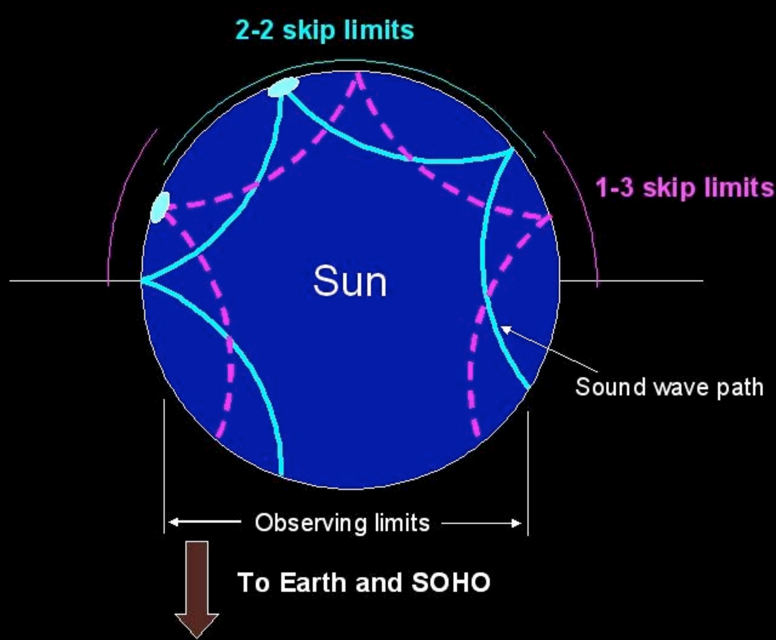
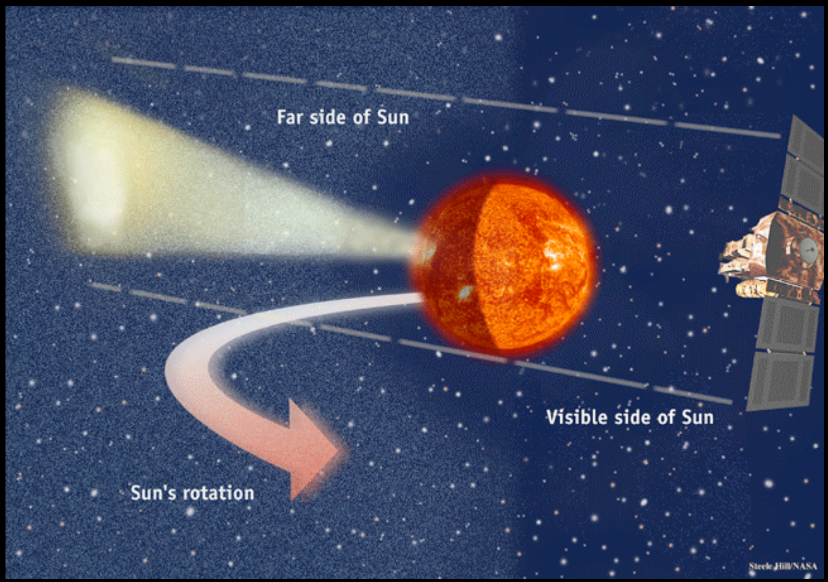
Predicting Space Weather

Helioseismic holography



Lindsey & Braun, 2000, Science, 287, 1799

Secondary sources of Lyman α radiation



Bertaux et al., 2000, GRL, 27, 1331

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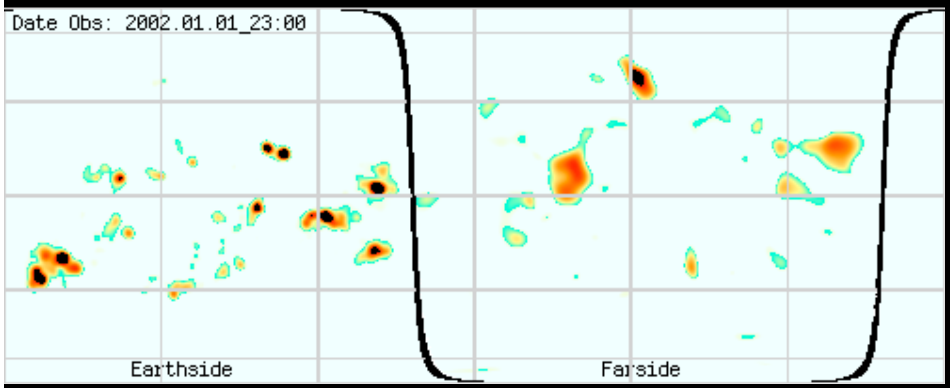
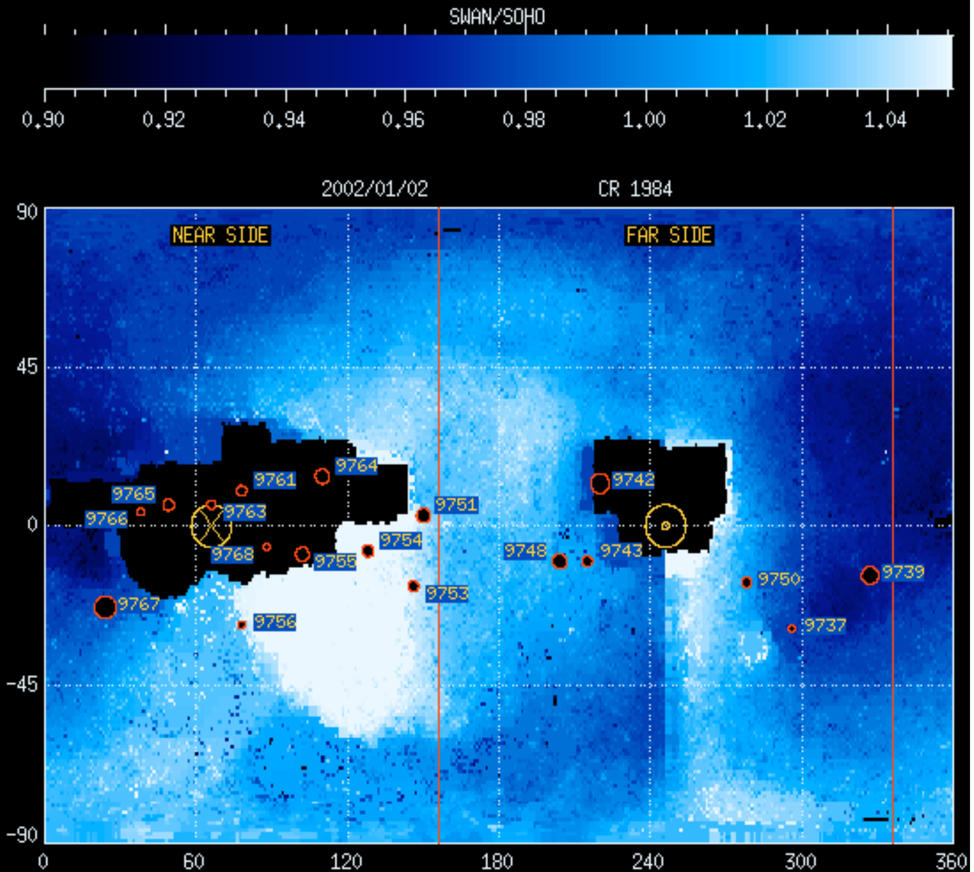
Predicting Space Weather





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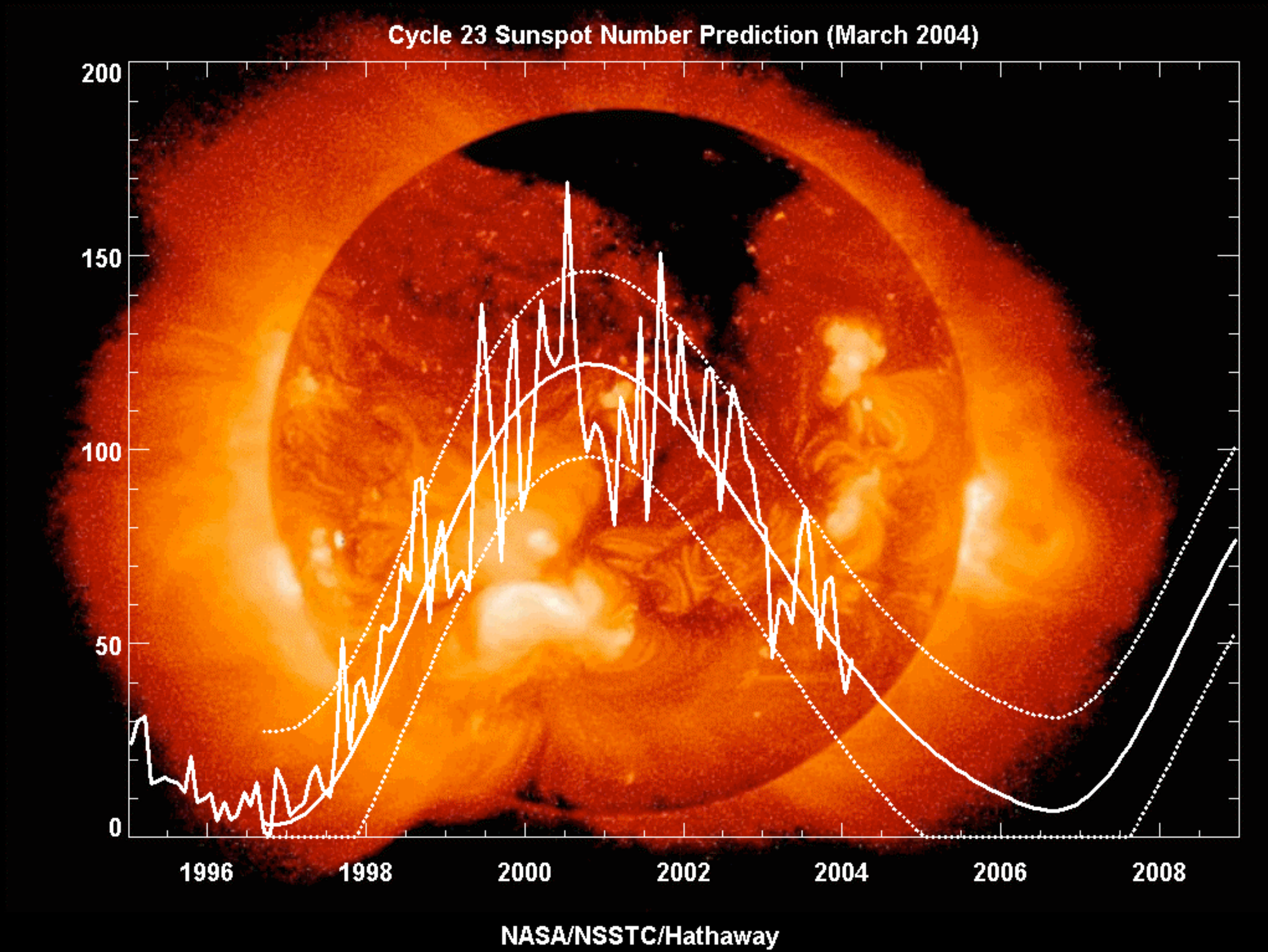

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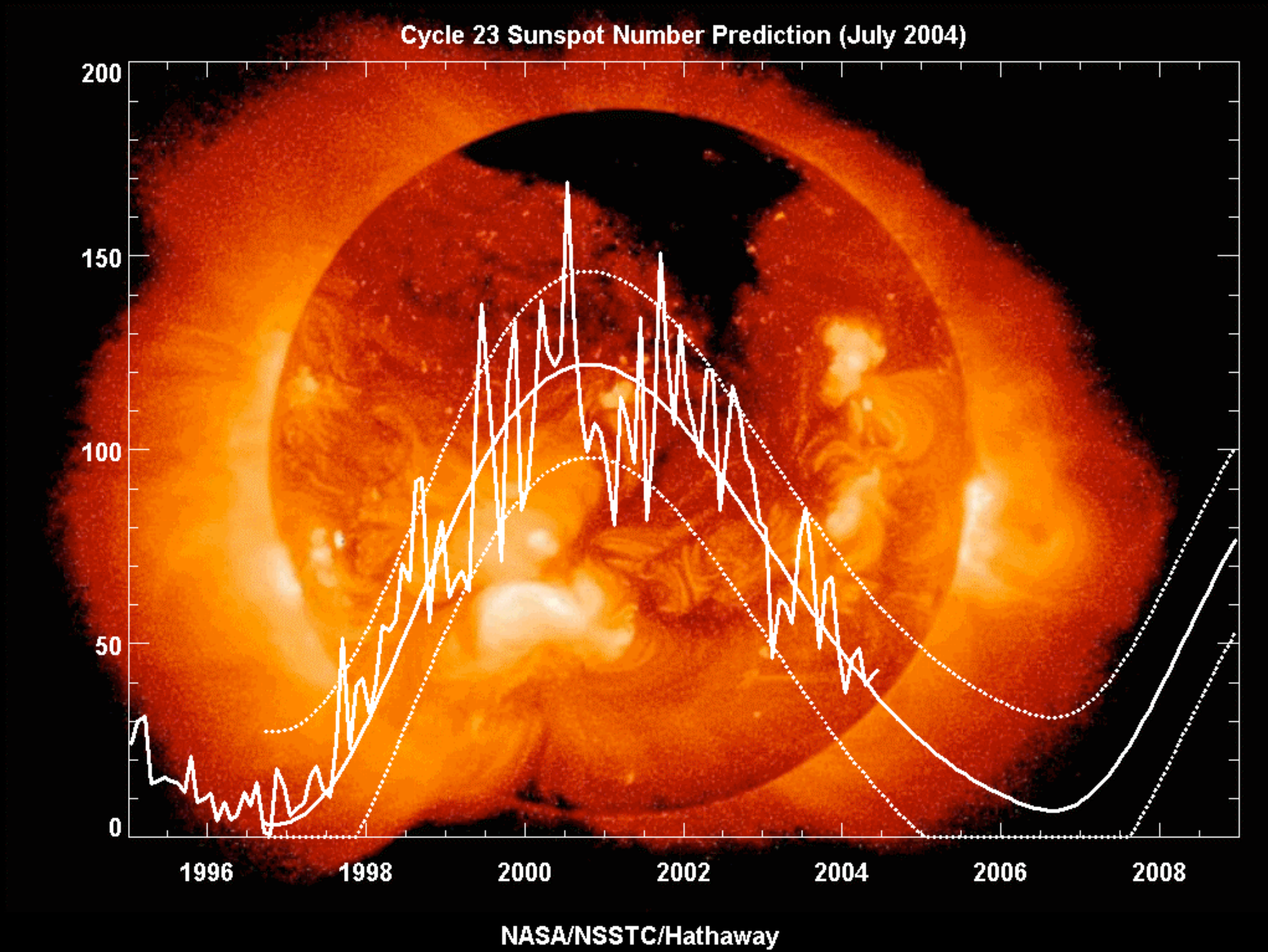

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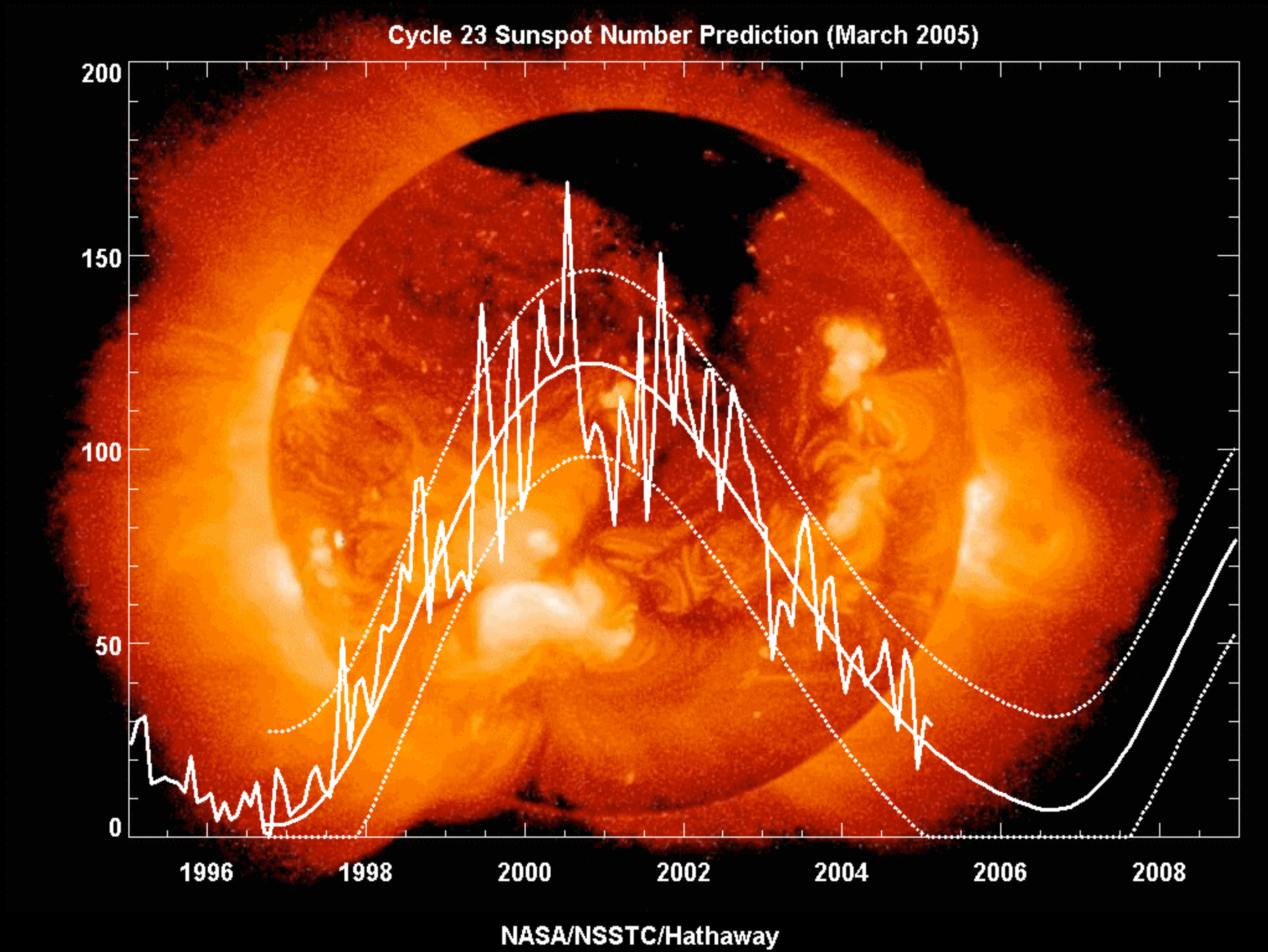

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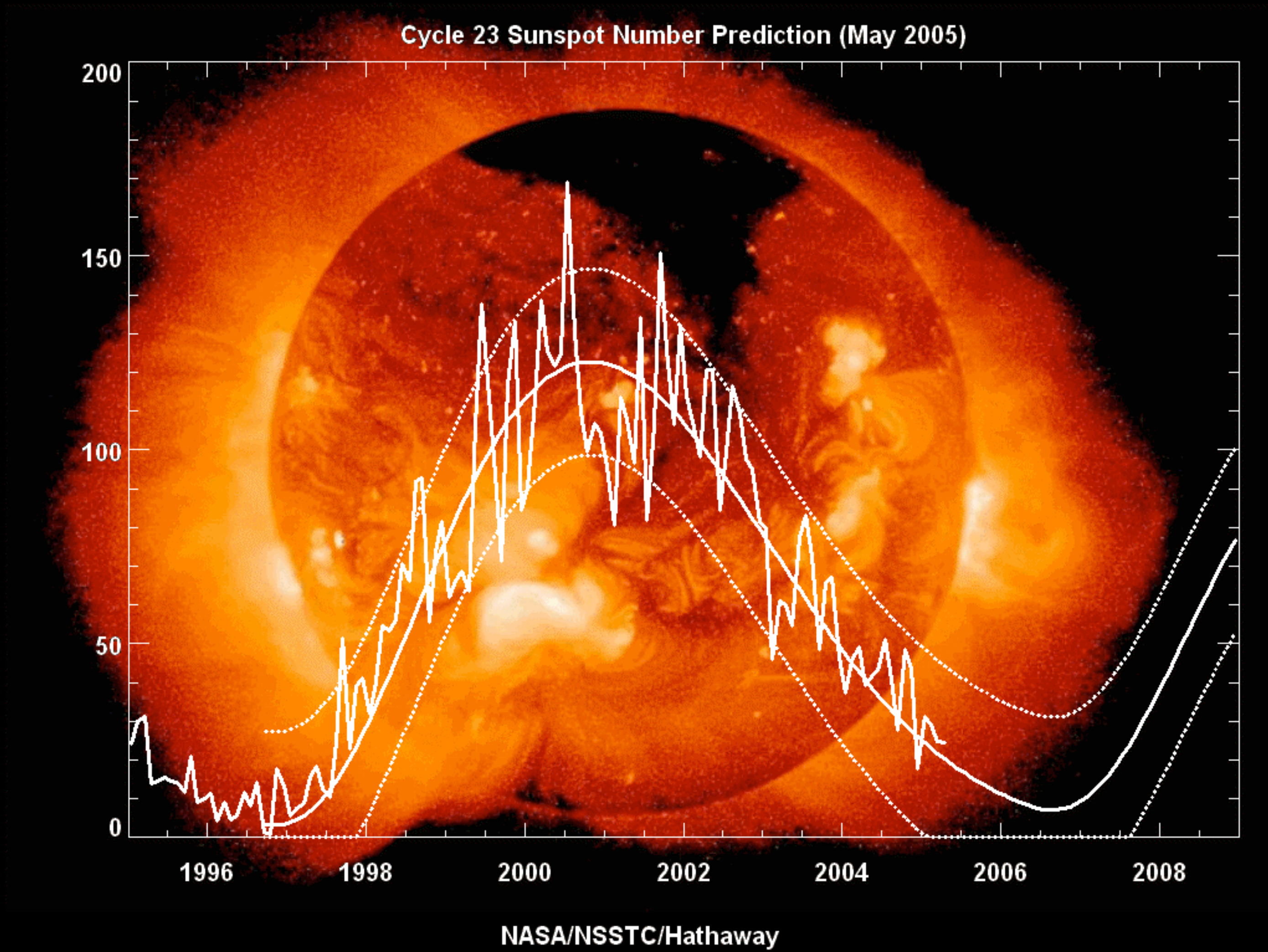

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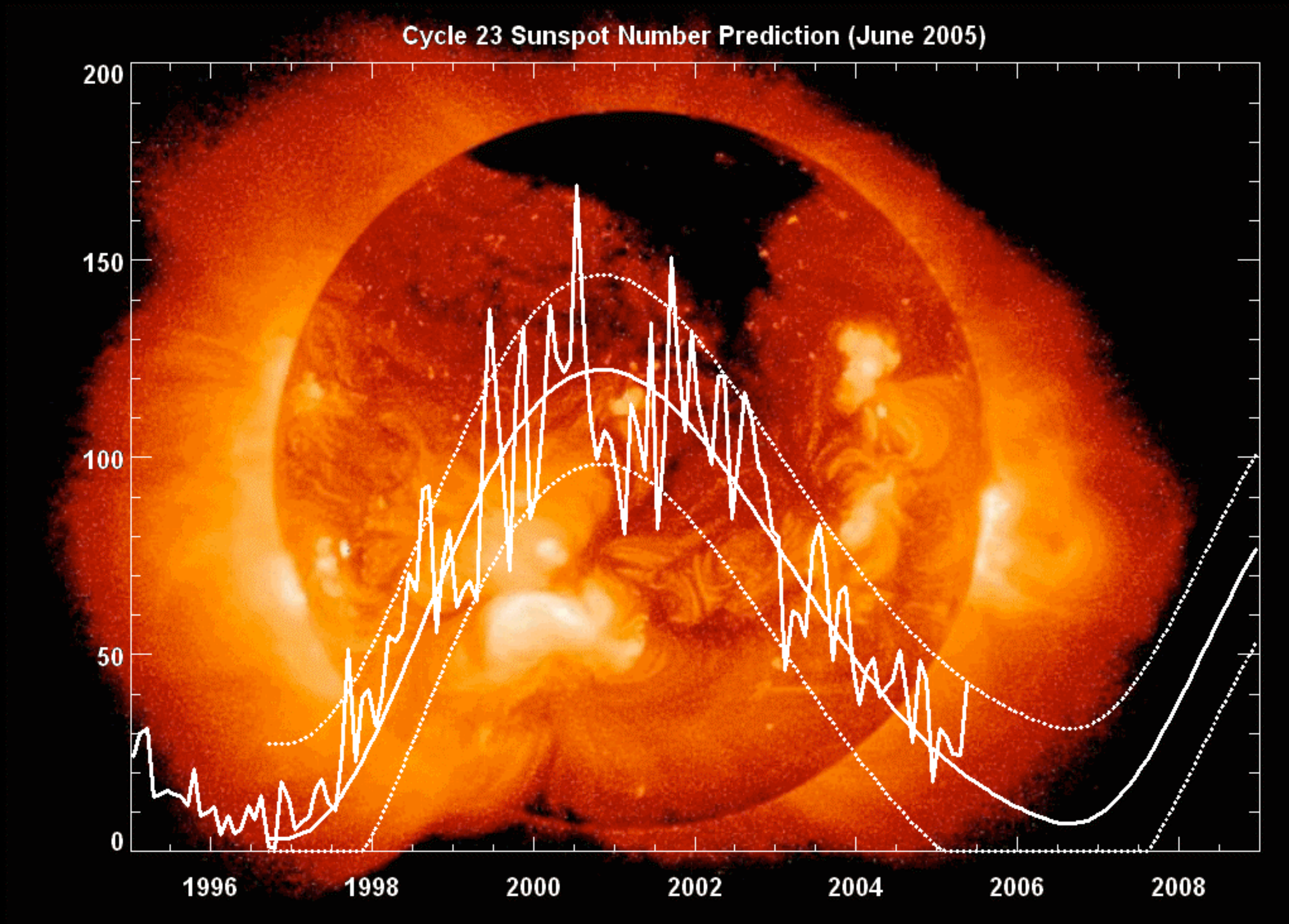

NASA/NSSTC/Hathaway

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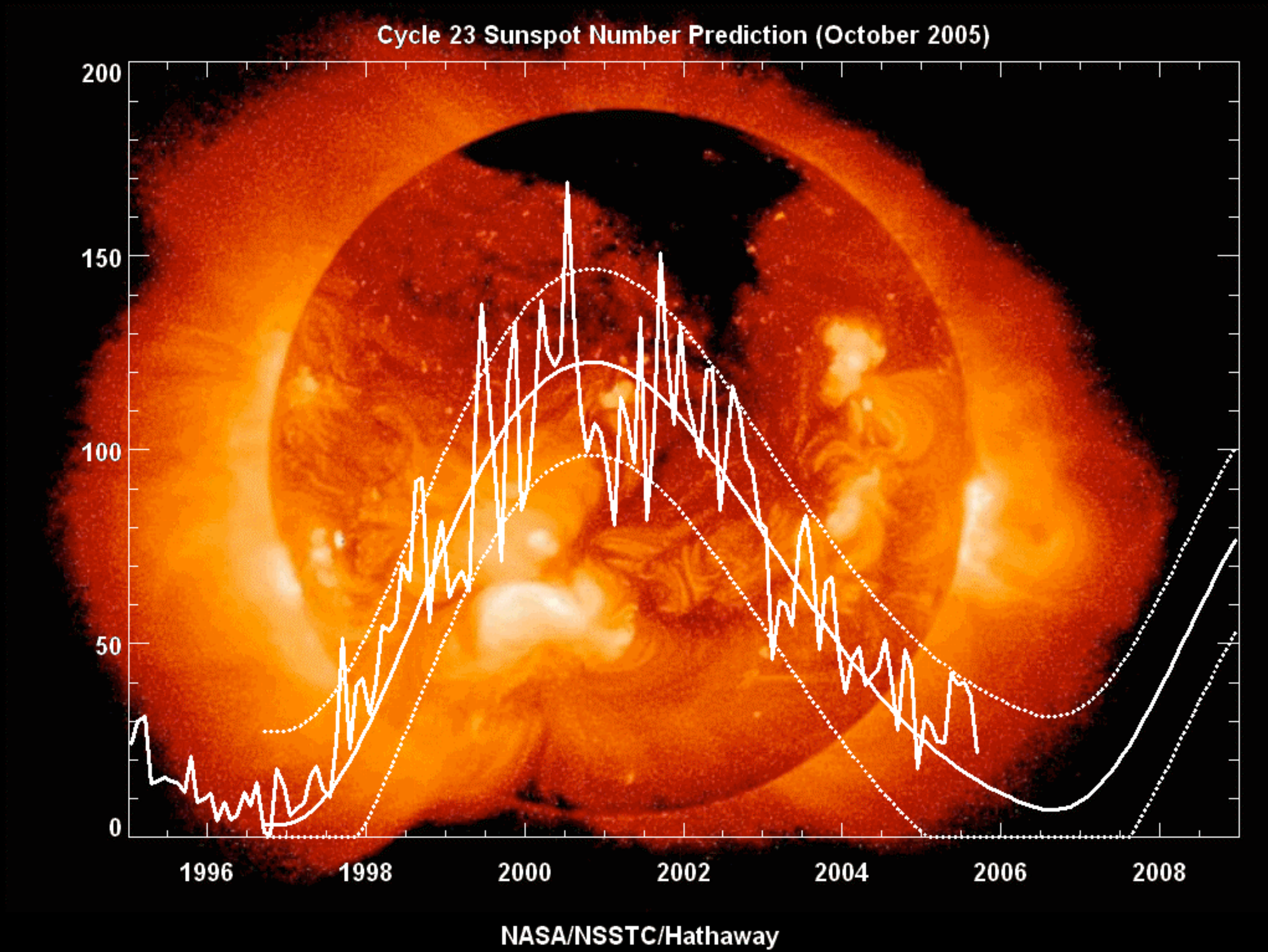

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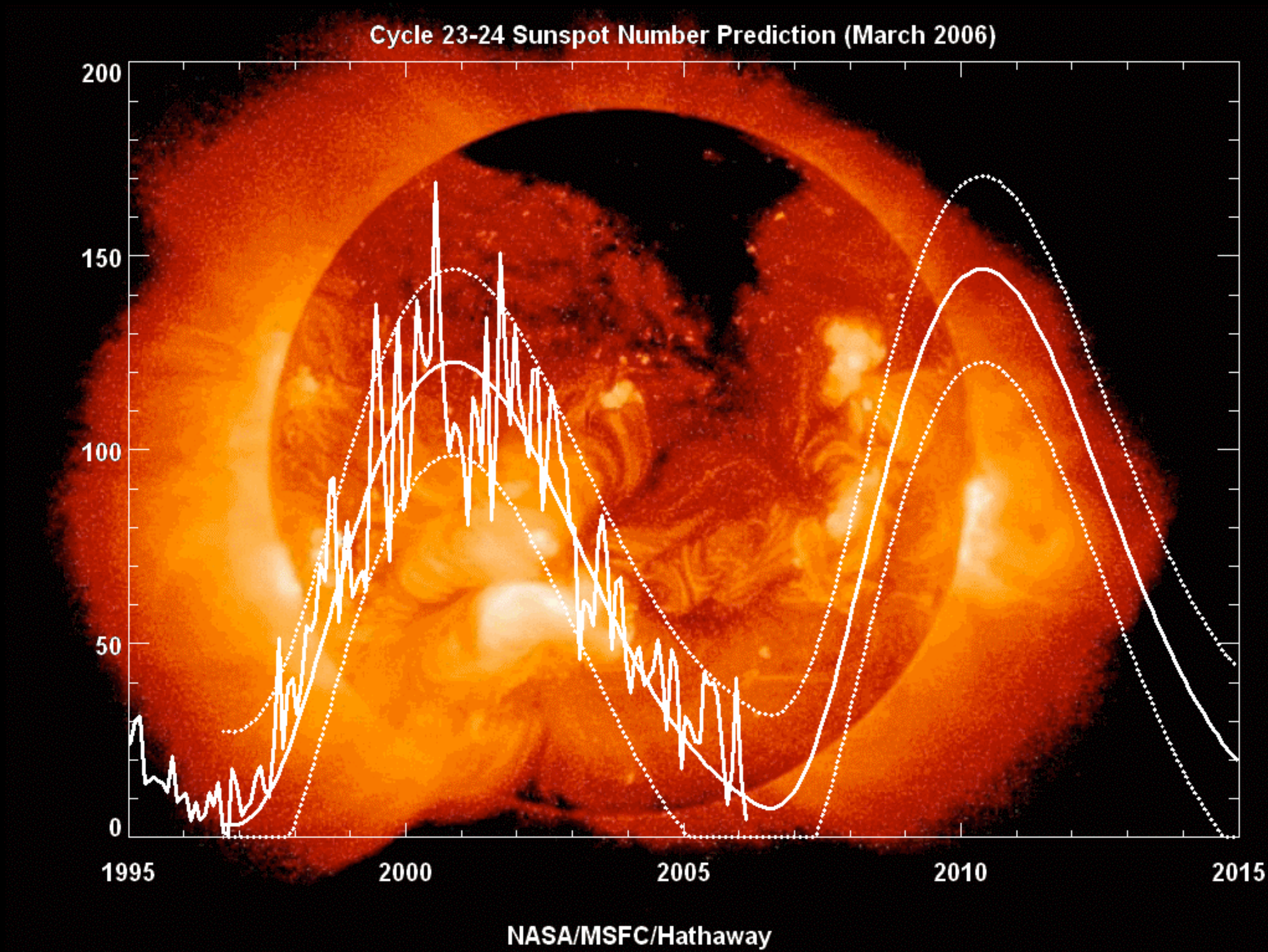

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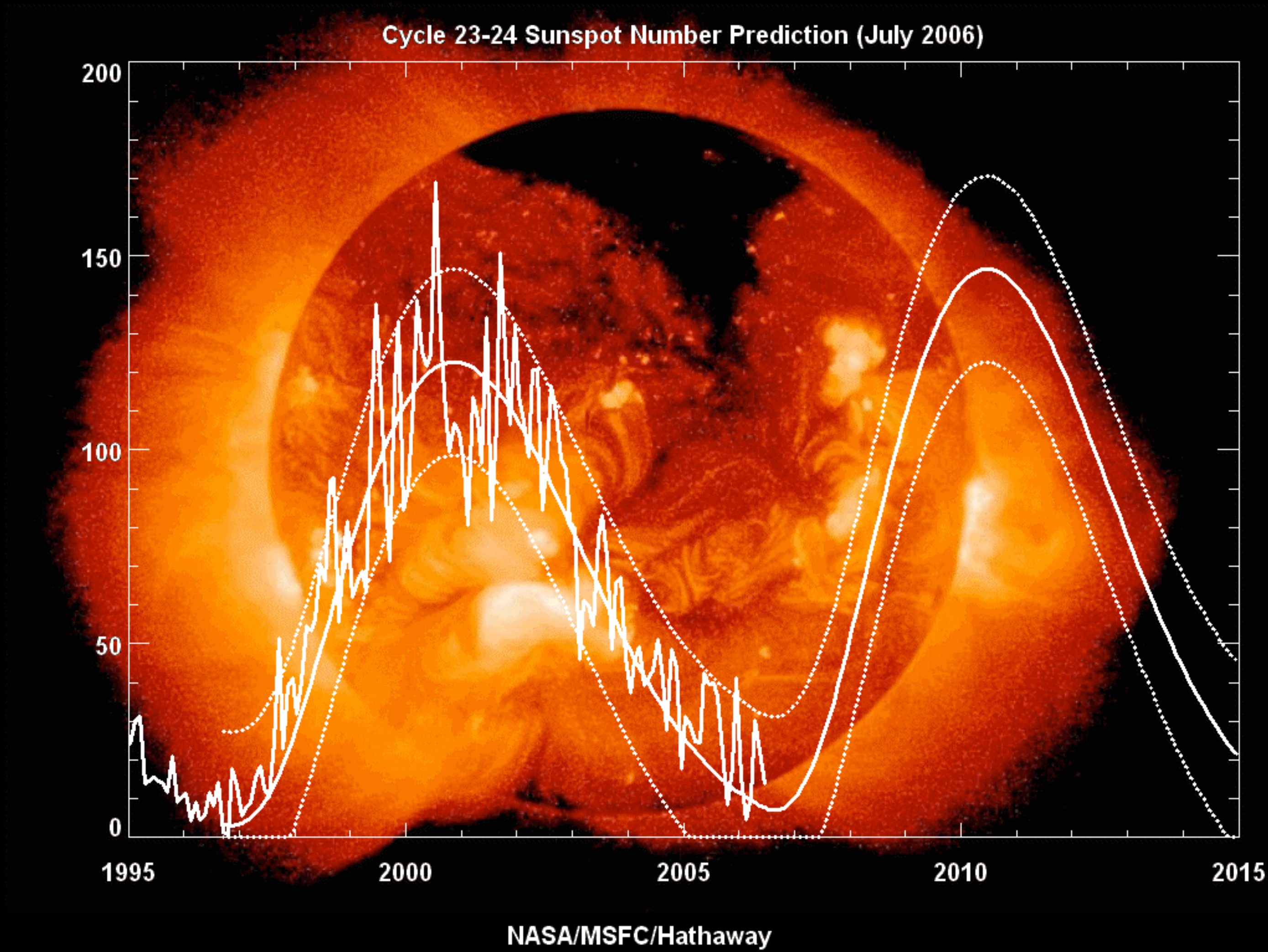

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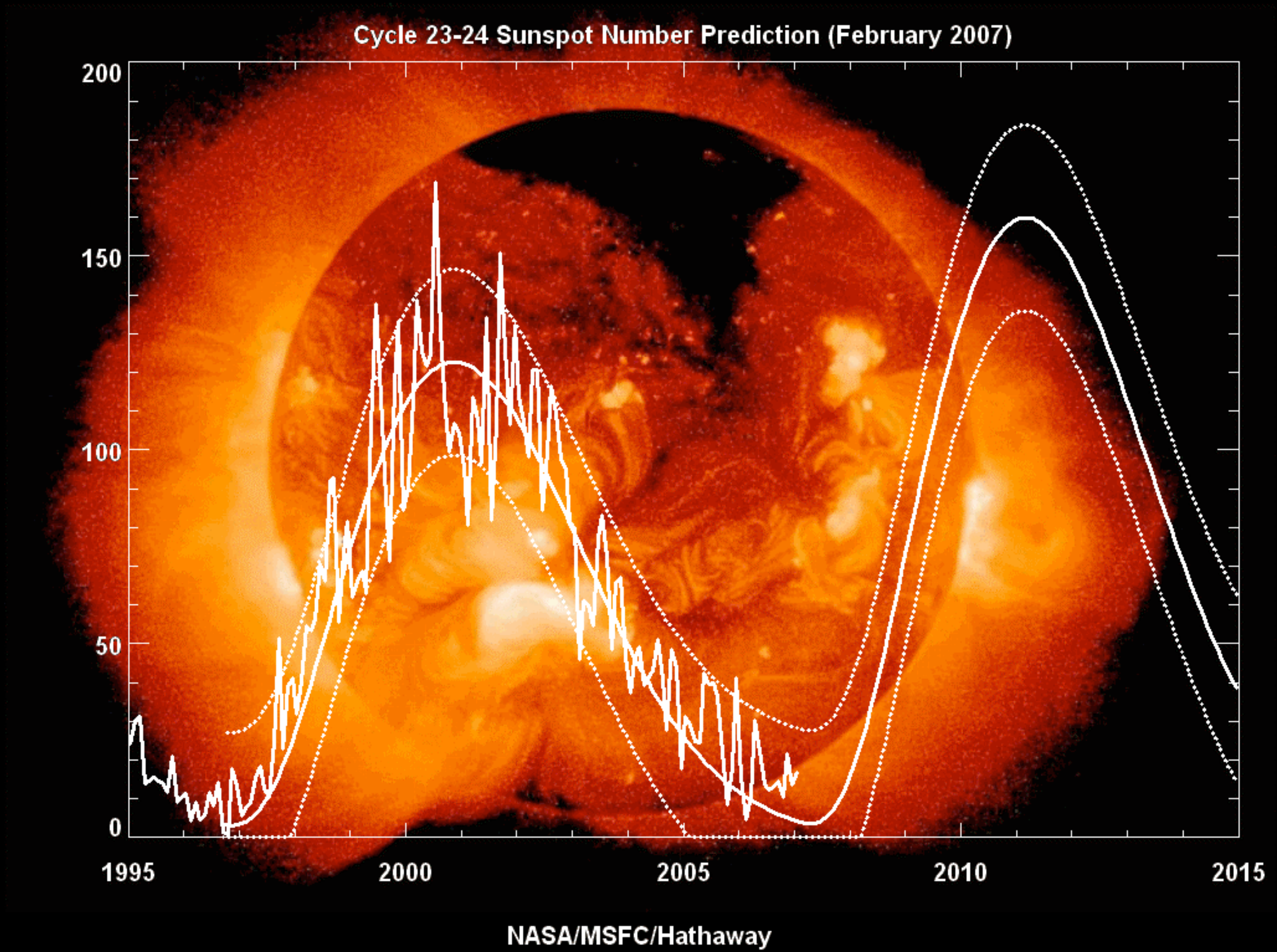

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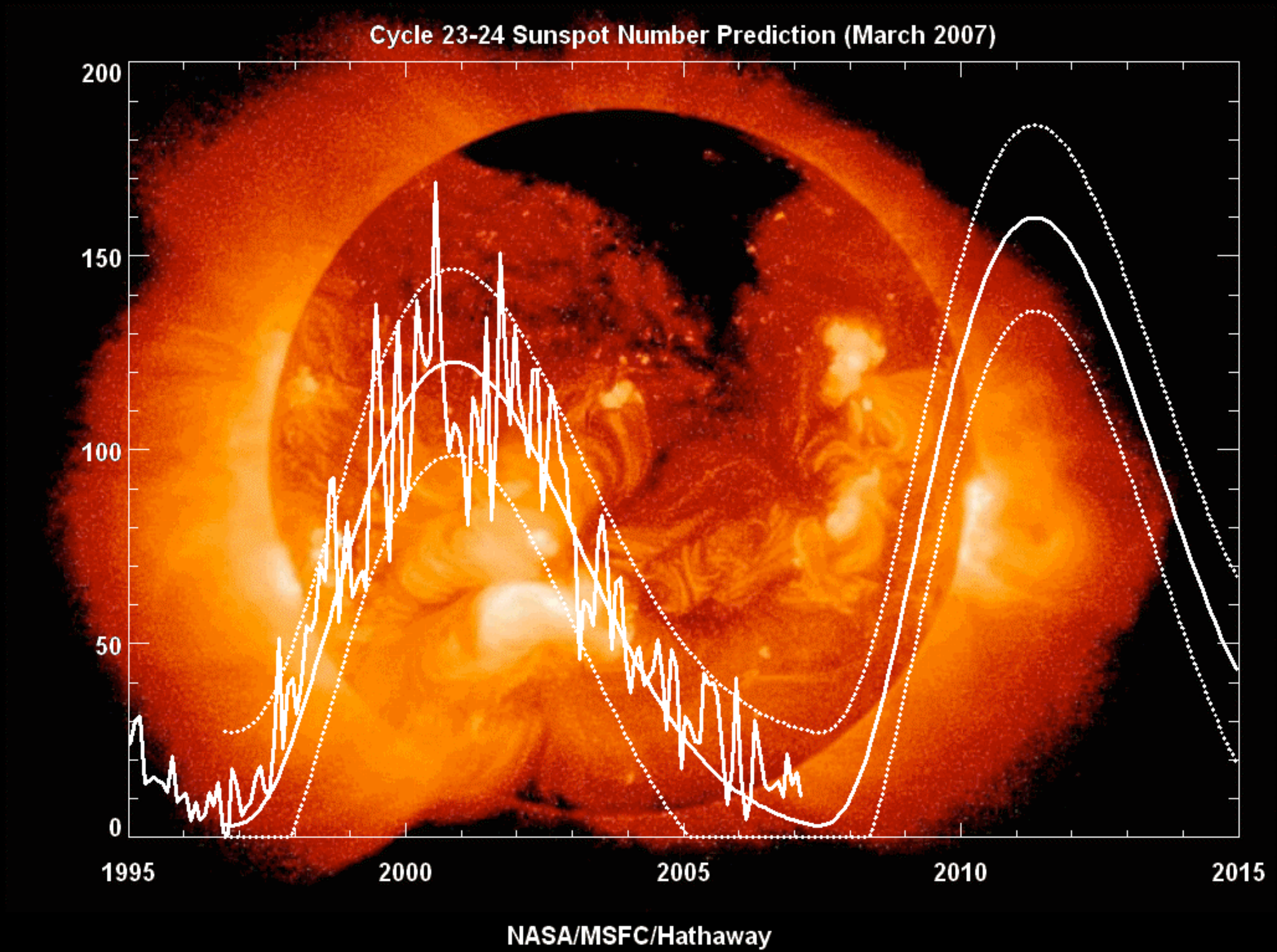

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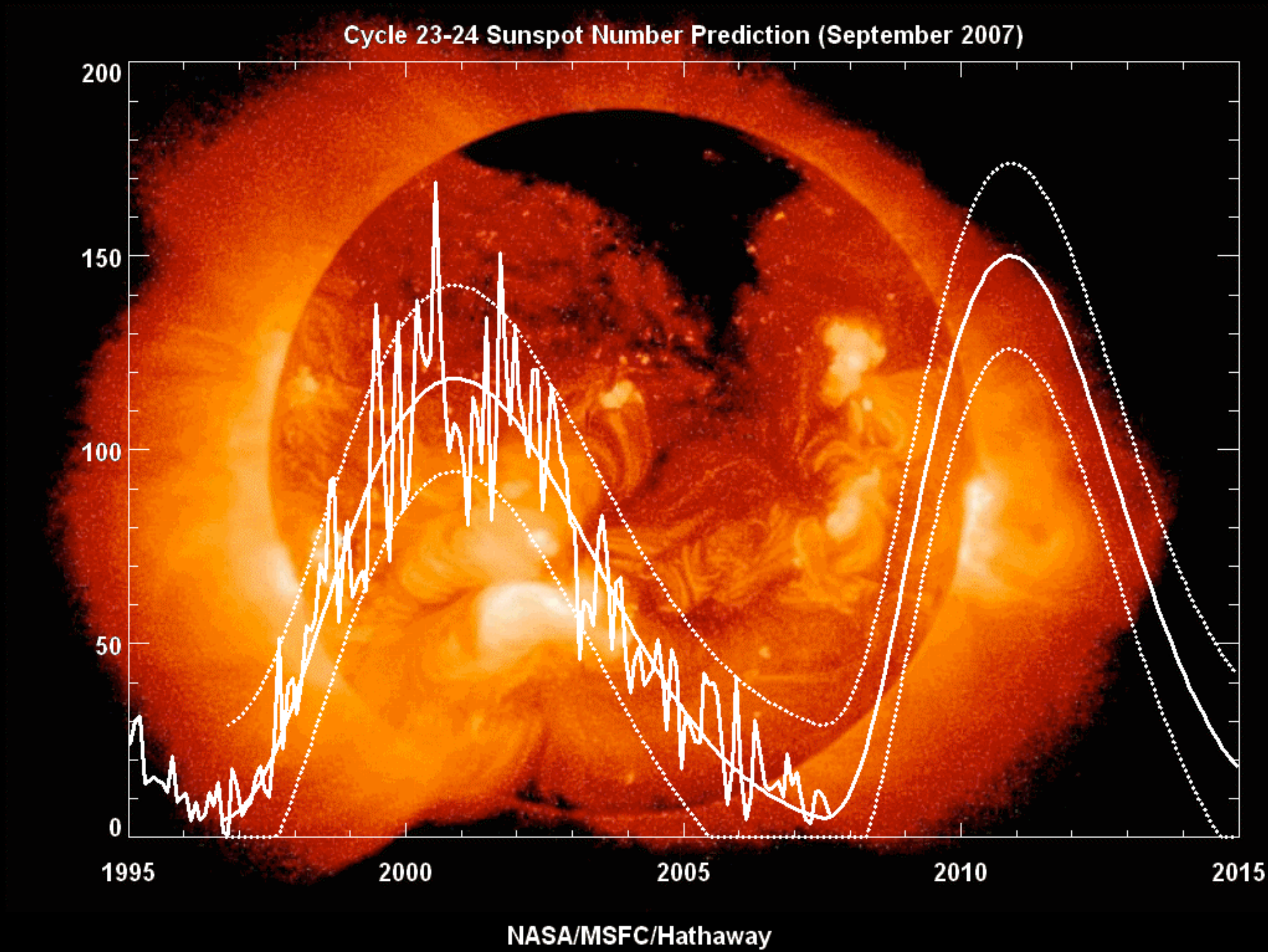

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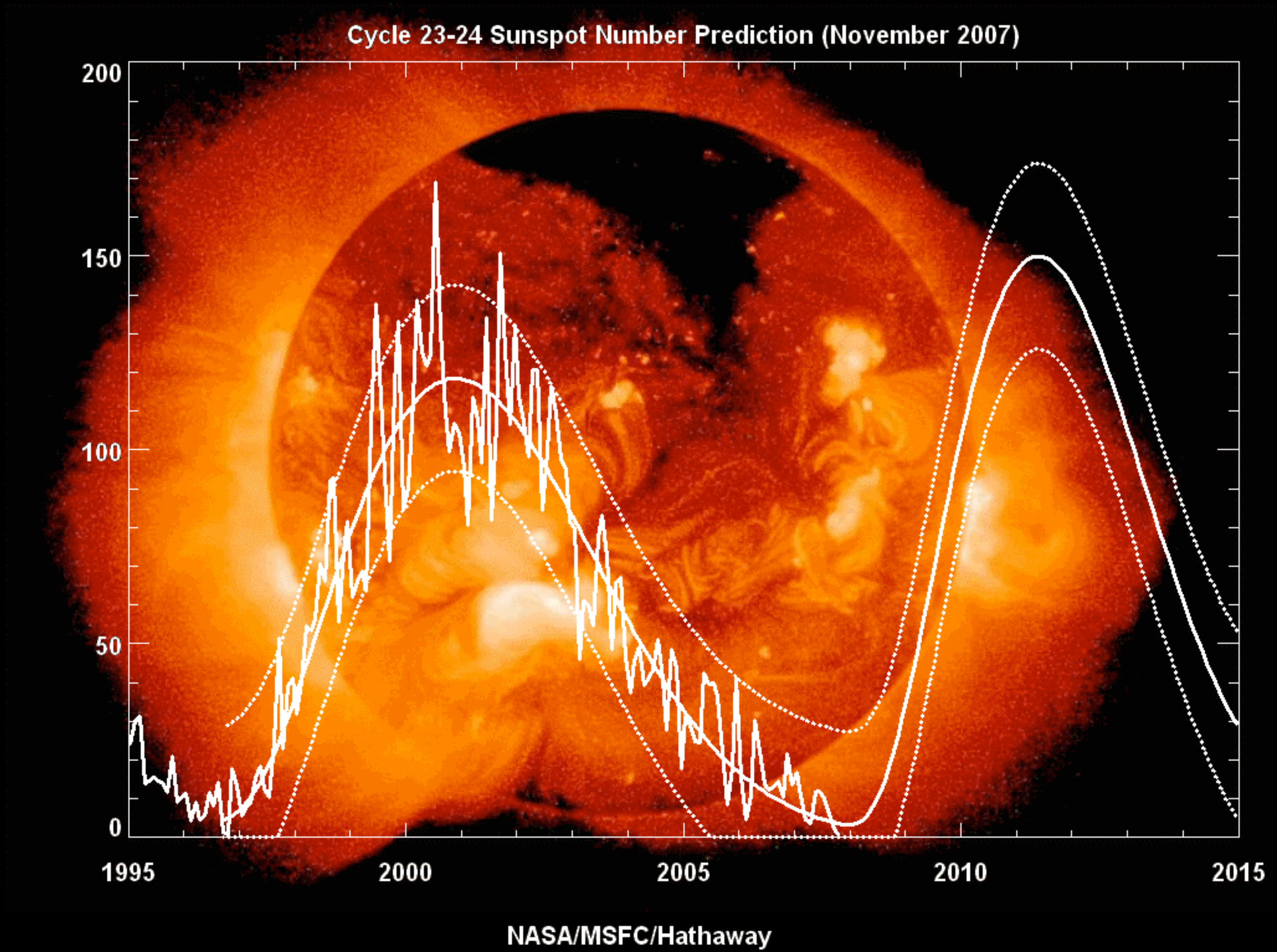
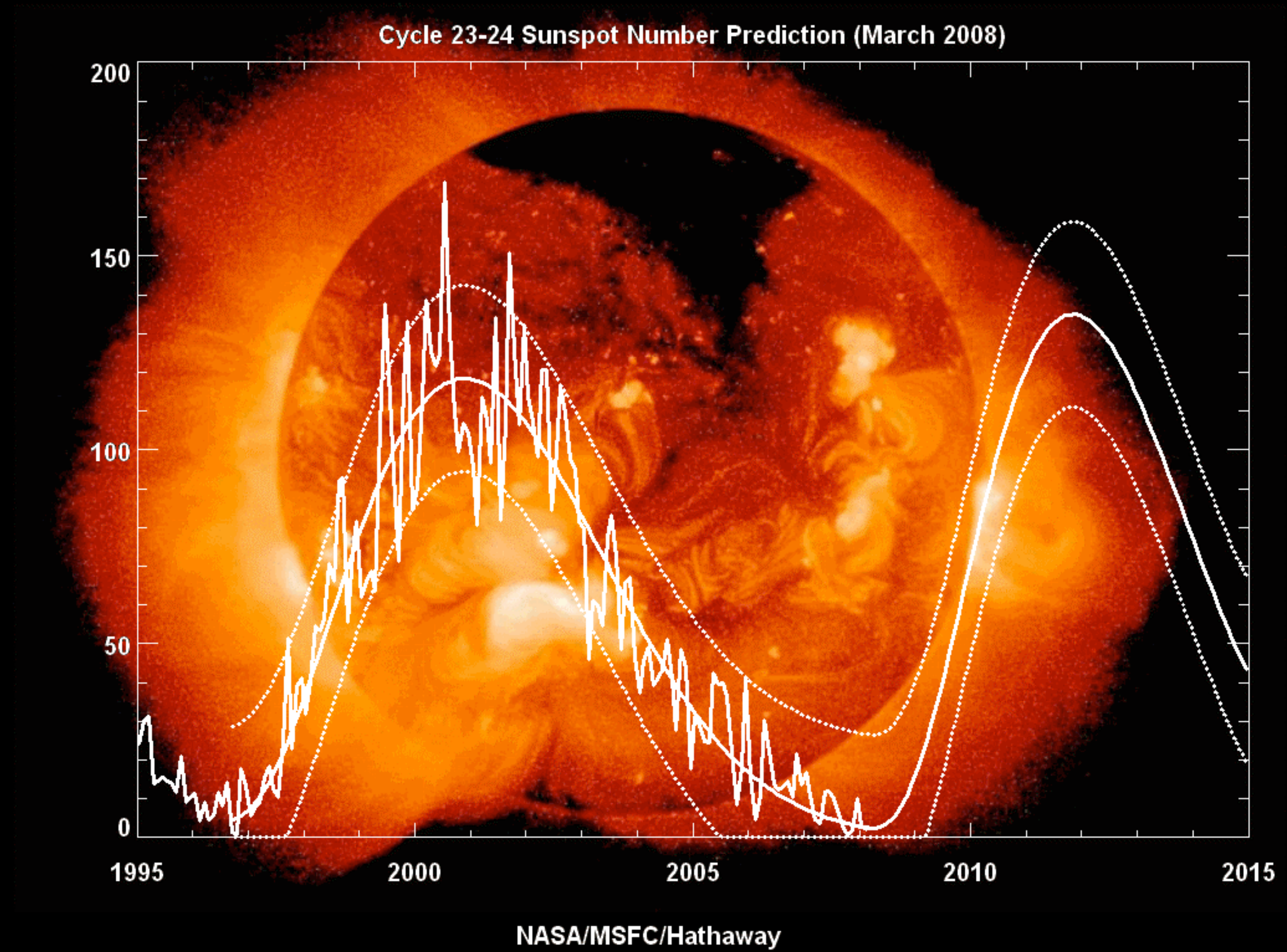

Cycle 23-24 Sunspot Number Prediction (November 2007)
200
150
100
50
0
1995
2000
2005
2010
2015
NASA/MSFC/Hathaway



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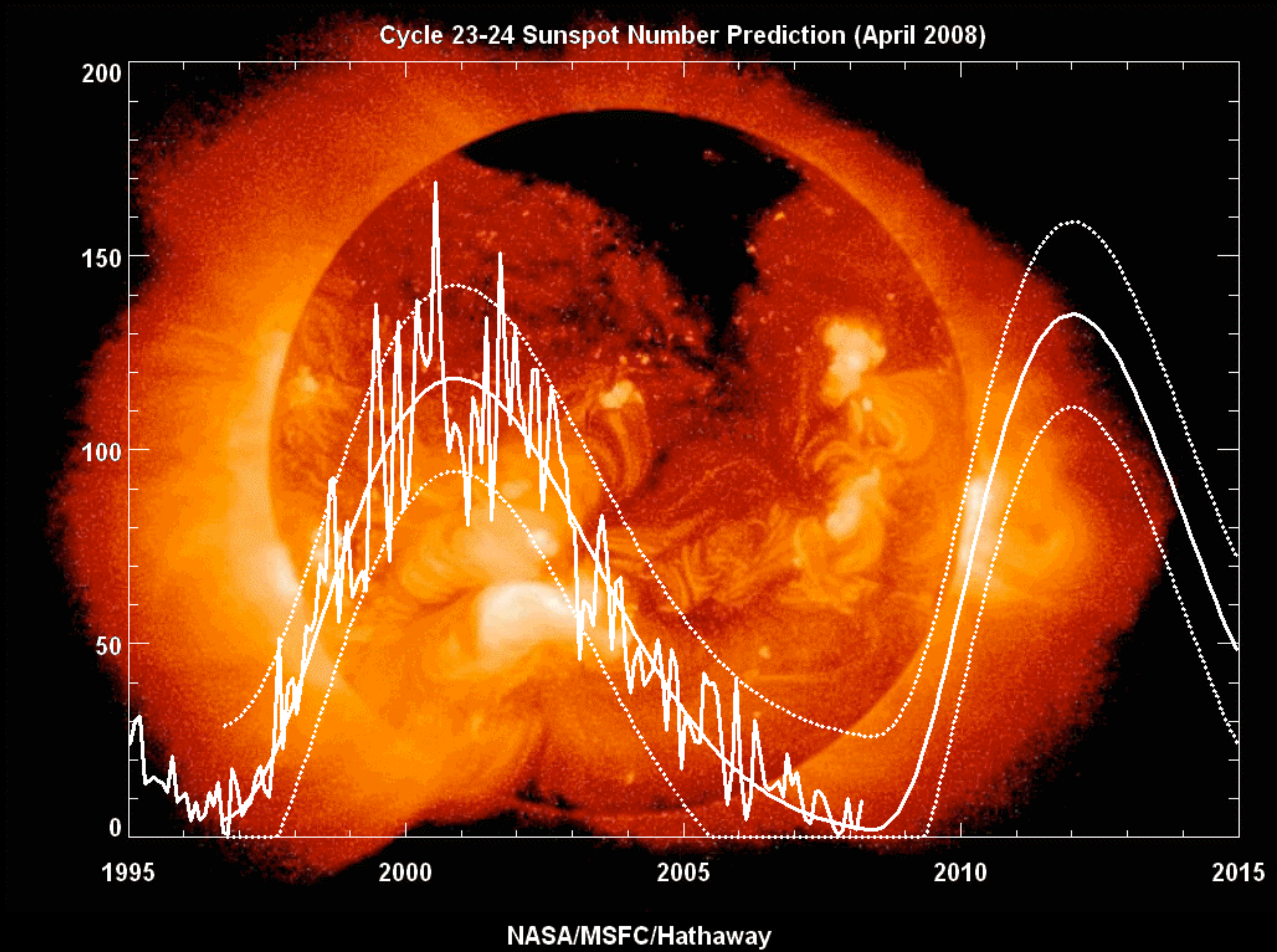

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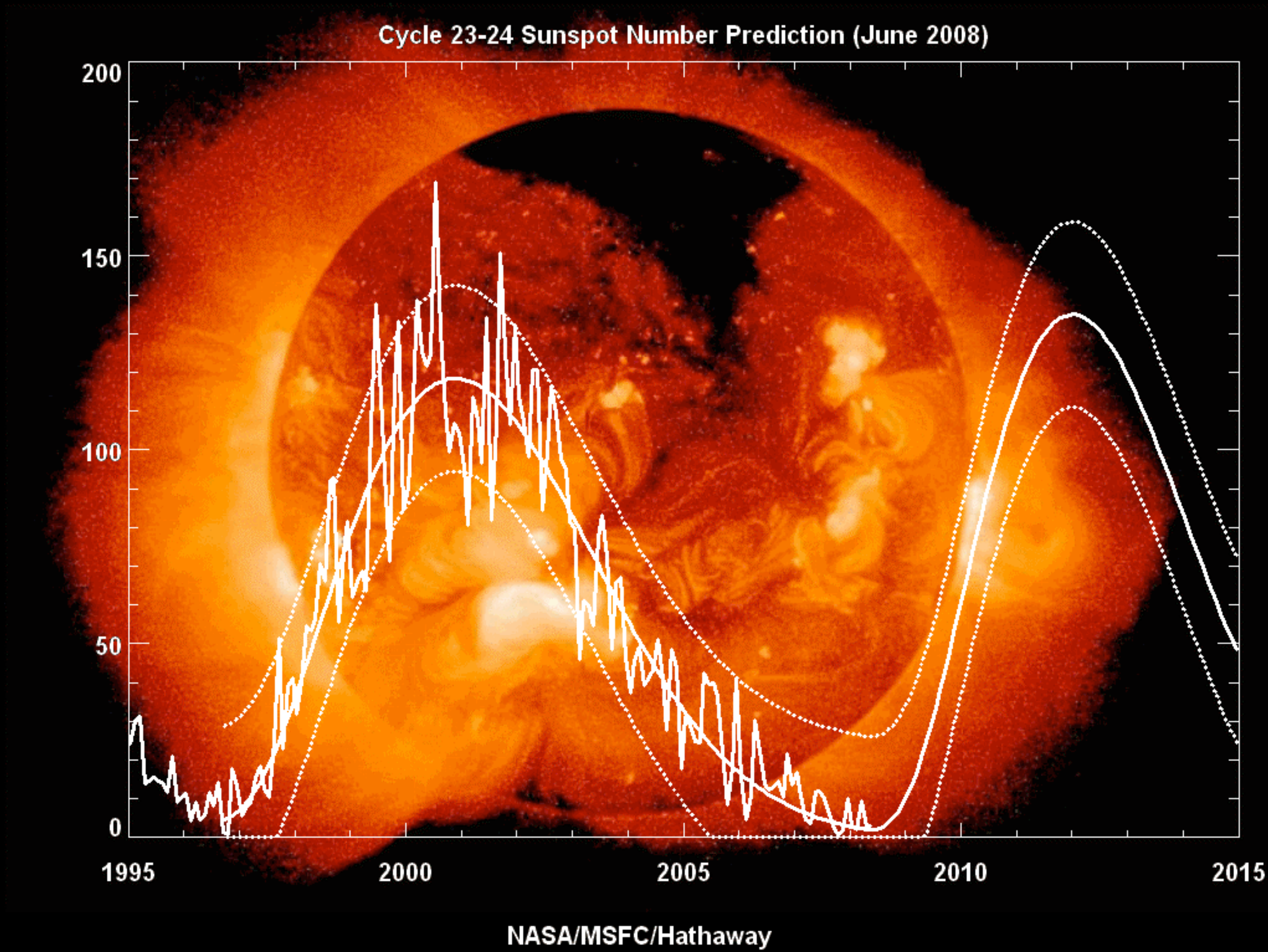

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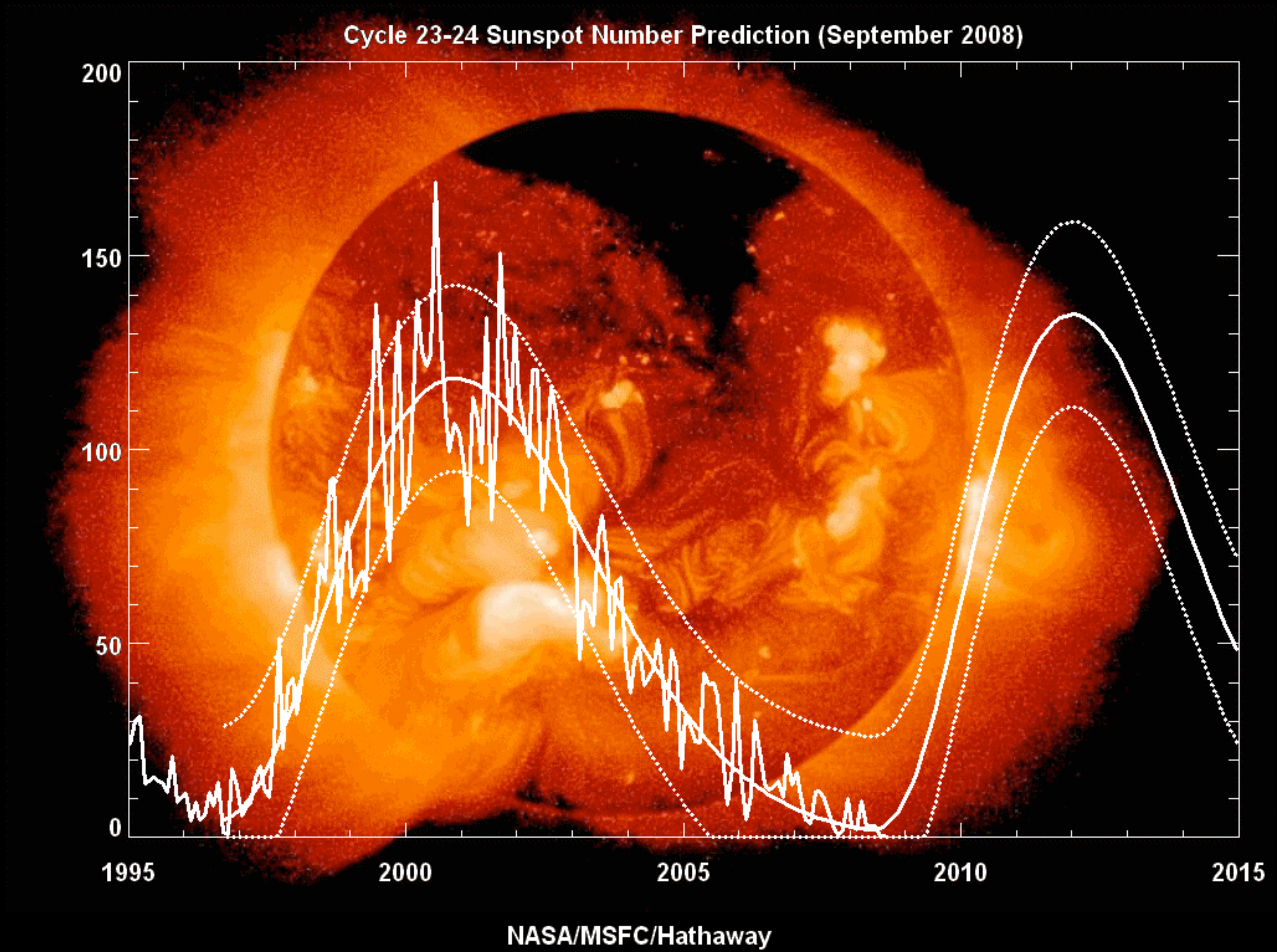

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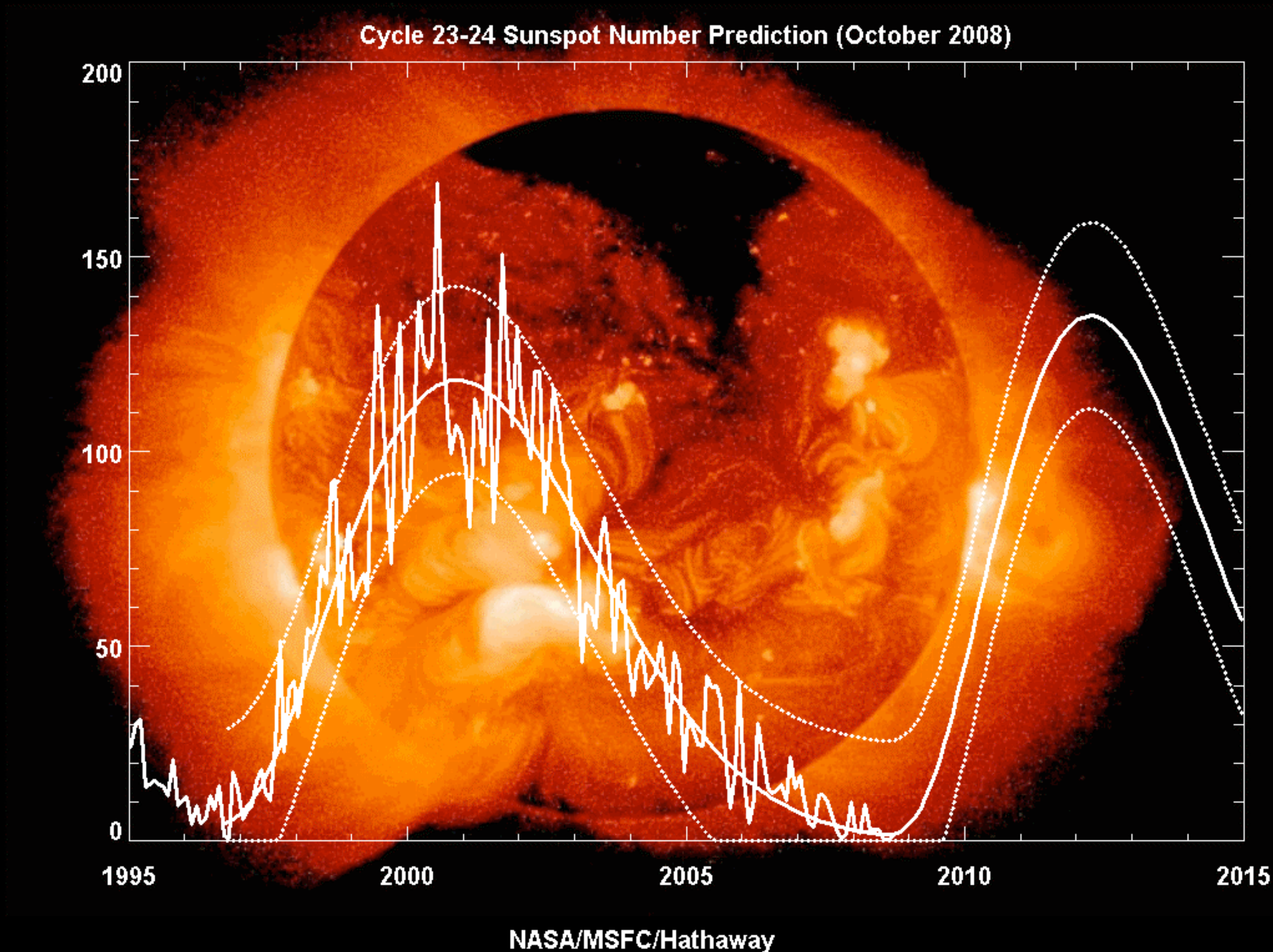

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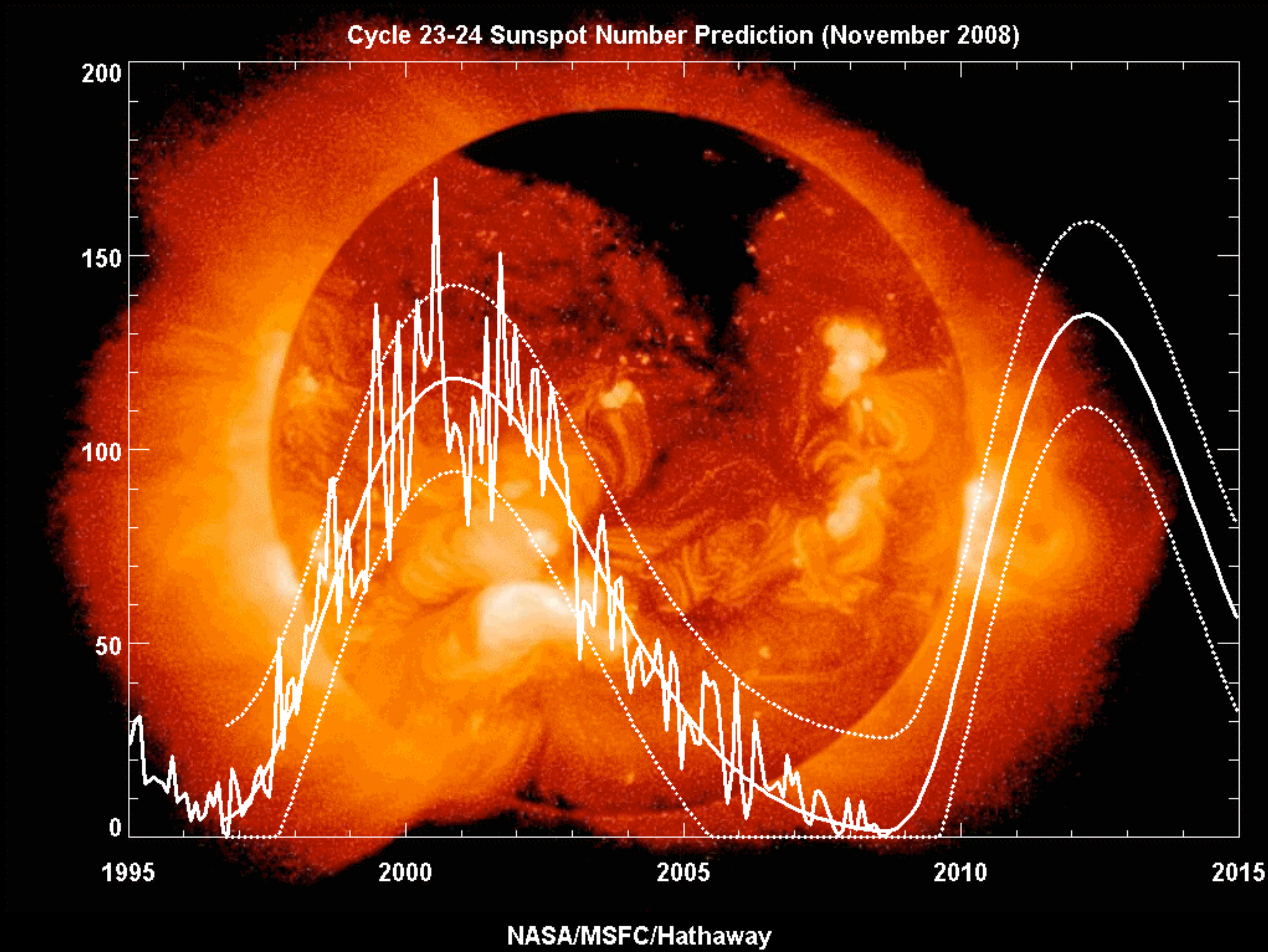

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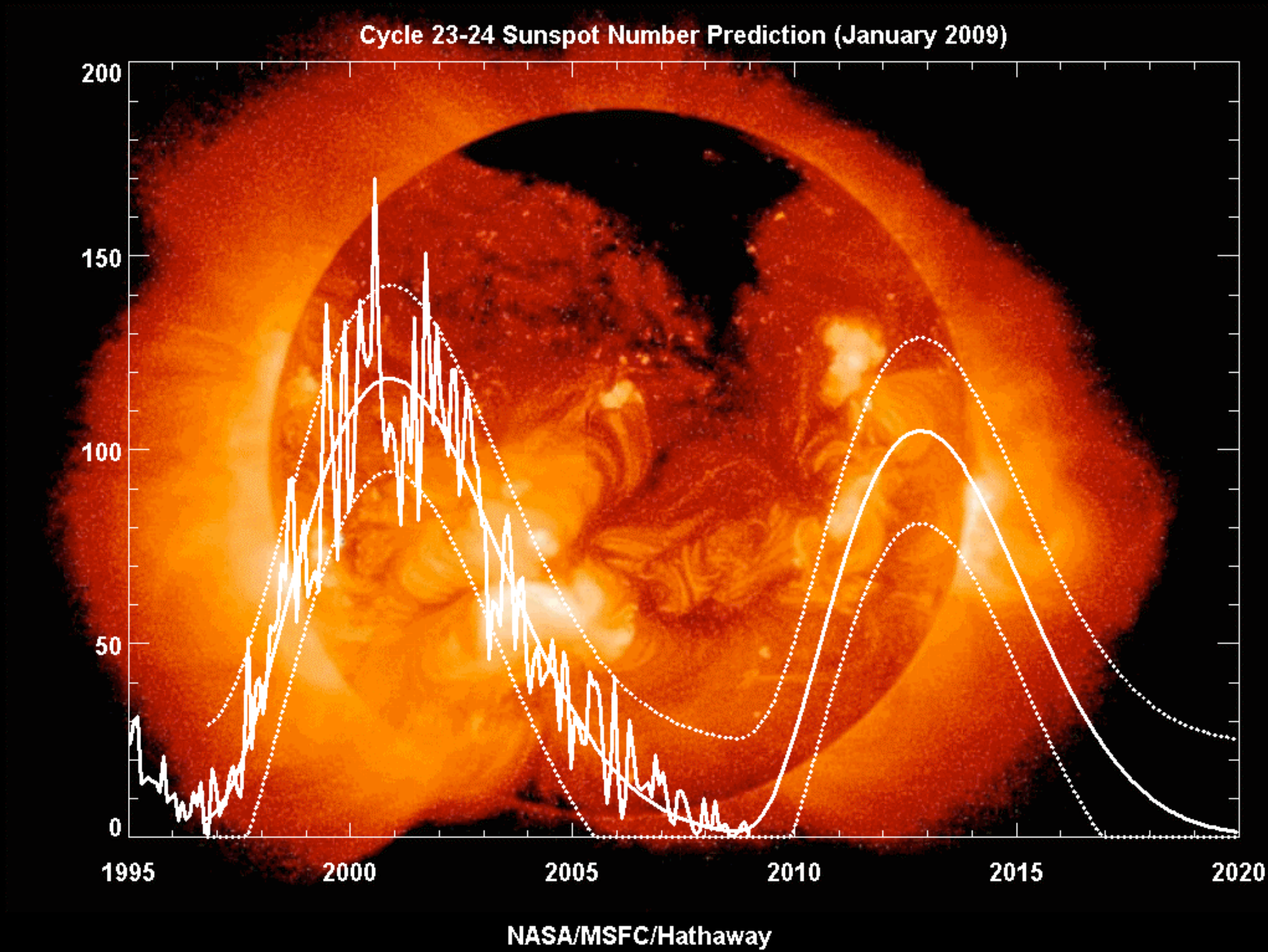

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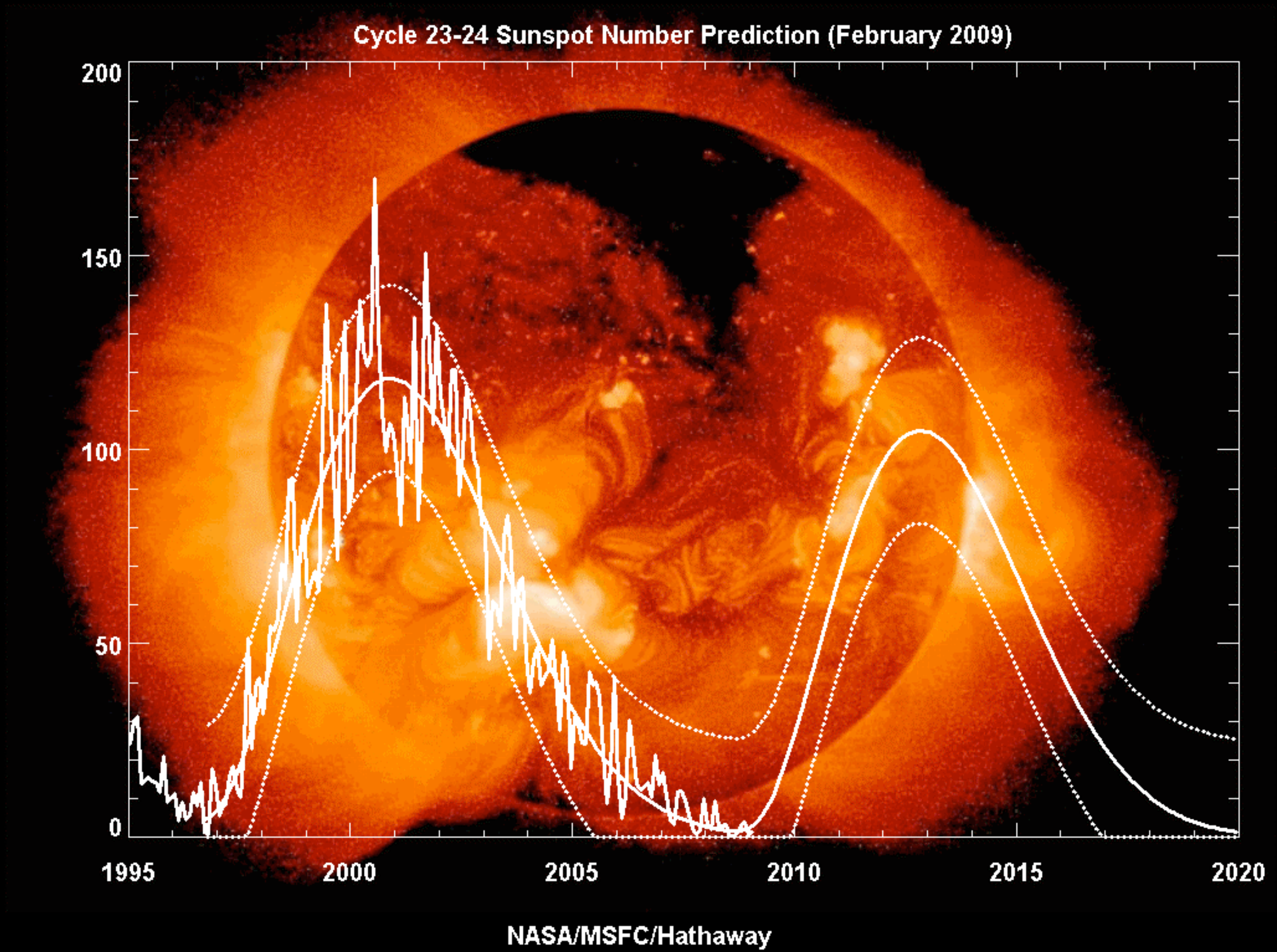

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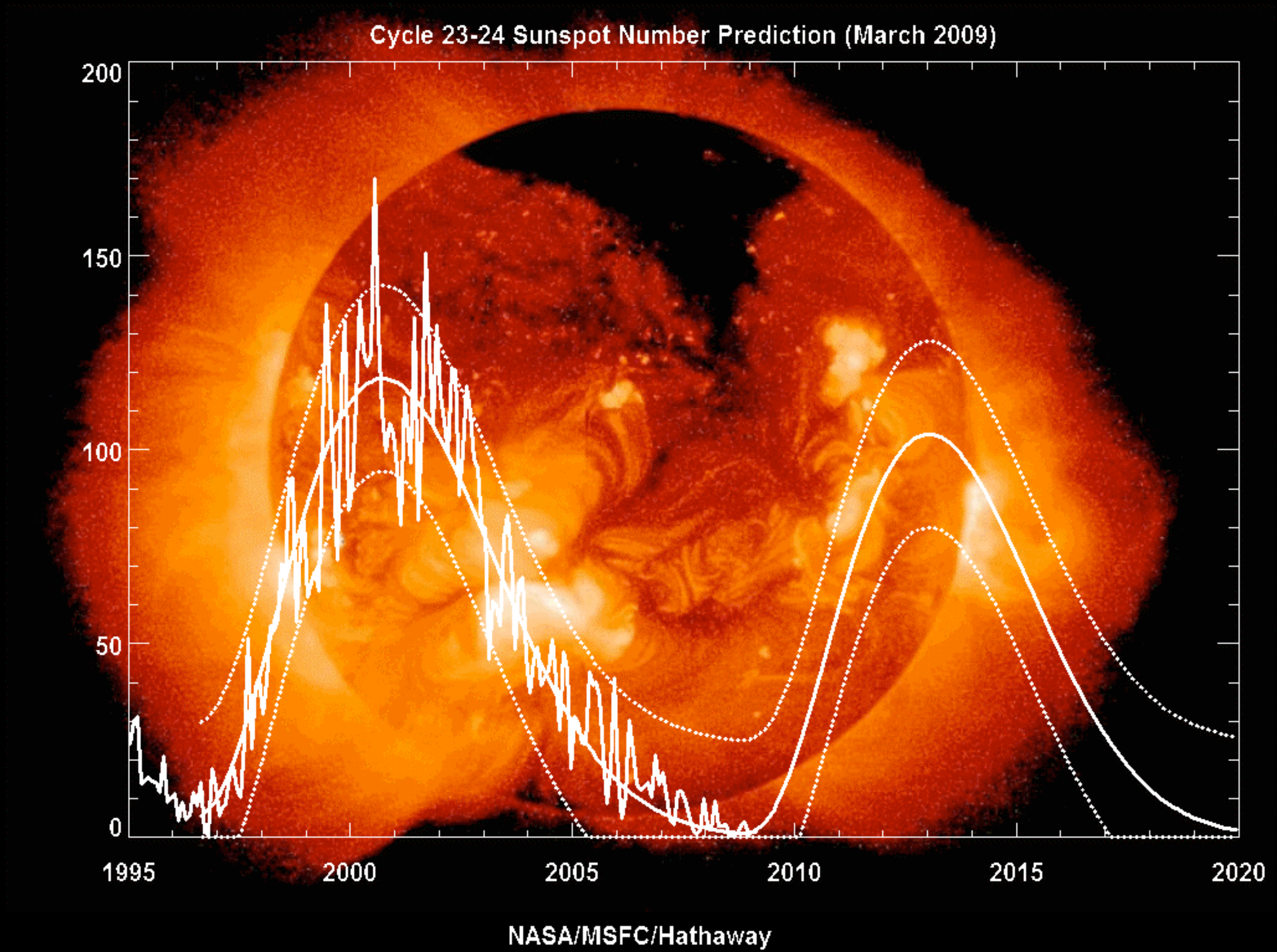

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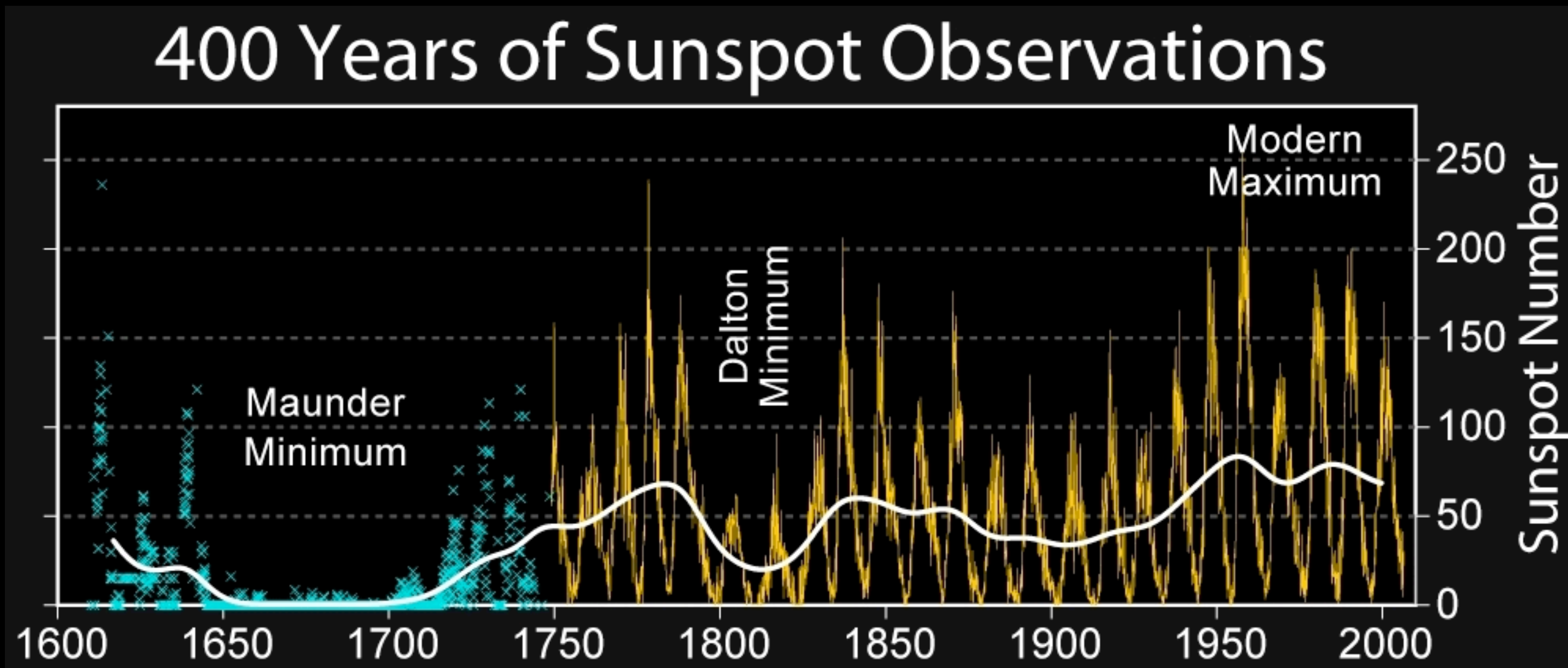

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The Mount Wilson Survey

- "K-type stars with low <*S*> values almost all have pronounced cycles"
- "F-type stars, especially those with low <*S*>, generally have nearly constant records (*flat*) or slow, secular variations (*long*)."
- "Among the G-type stars, very low amplitudes of chromospheric variations and levels of activity [Maunder minimum] occur only in stars with low <*S*>."
- "A few stars of all spectral types have two significant cycles. Those stars are located at intermediate values of <*S*>, and are close to the Vaughan-Preston gap."

Baliunas et al. 1995, ApJ, 438, 269

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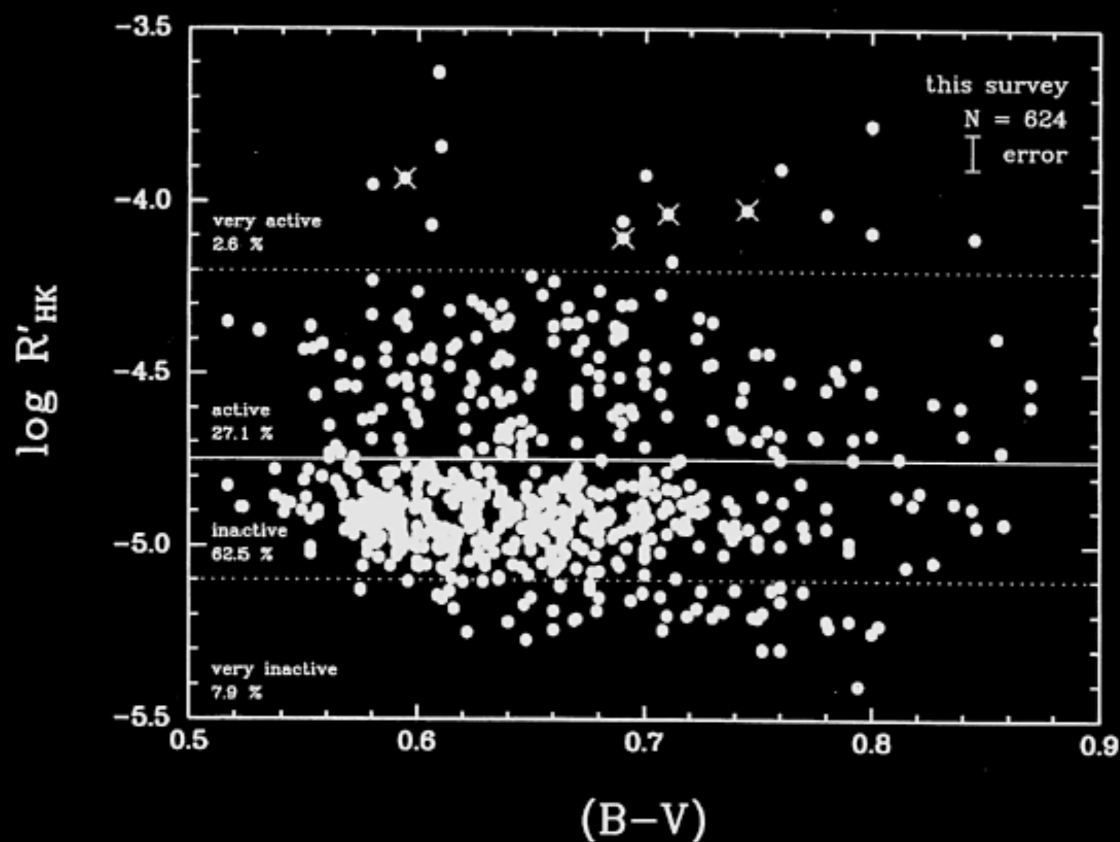
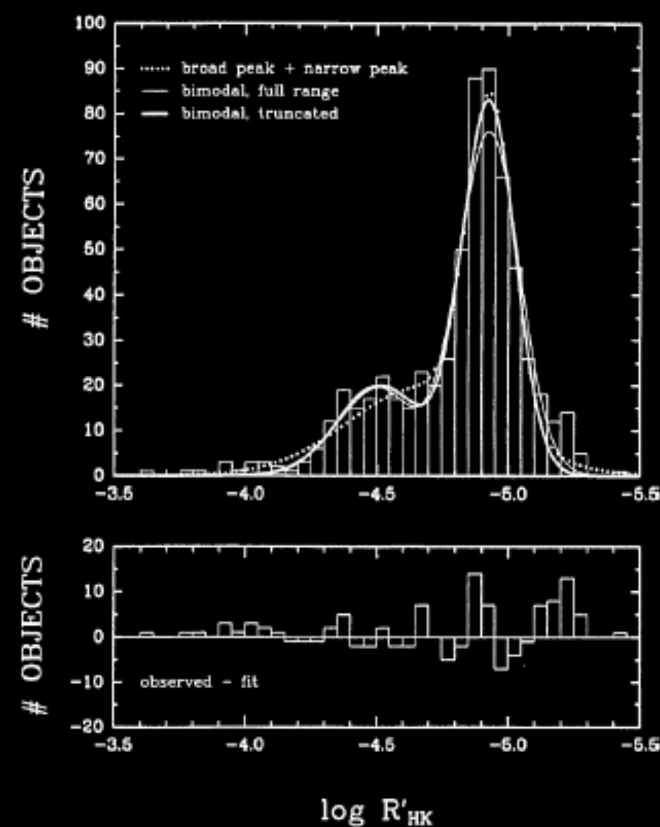
The Vaughan-Preston Gap





Henry et al. 1996, ApJ, 111, 439

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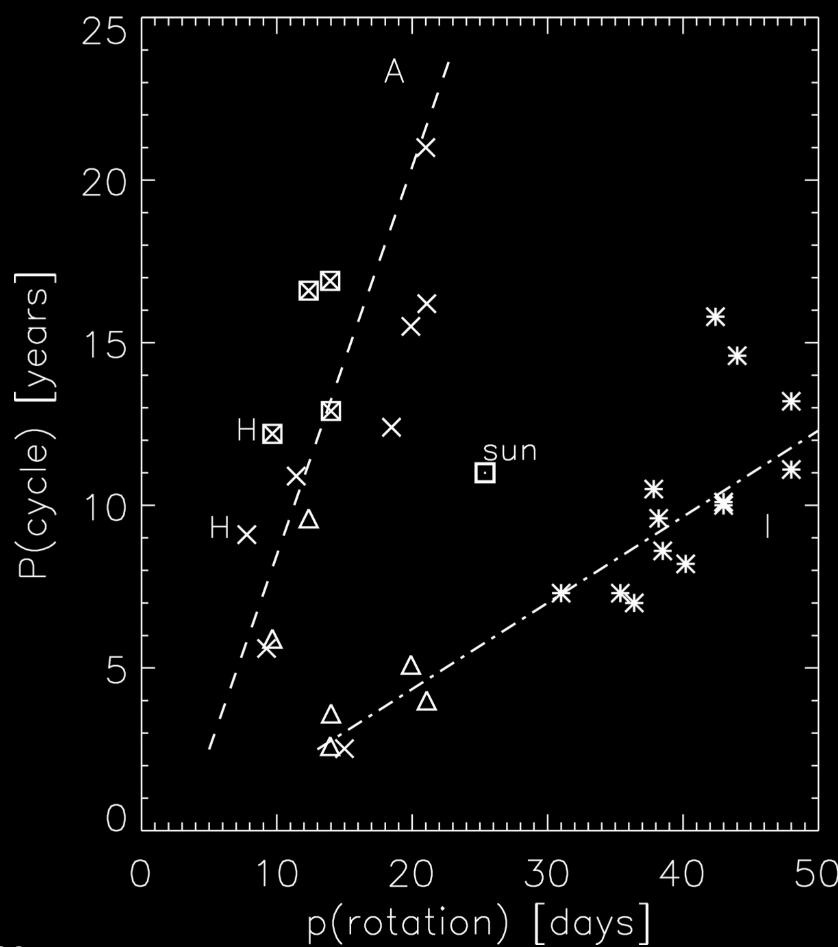
Cycle Period v Rotation Period



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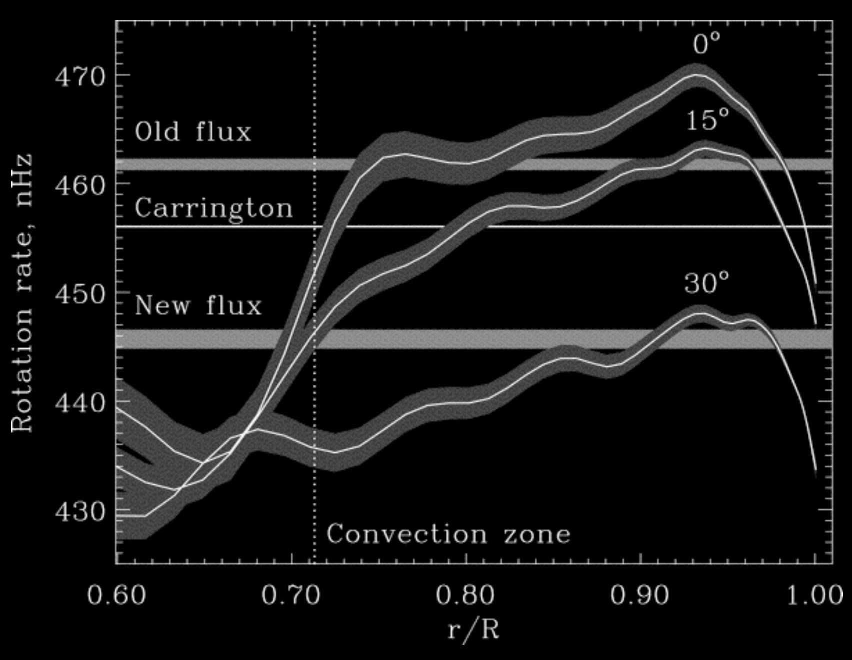
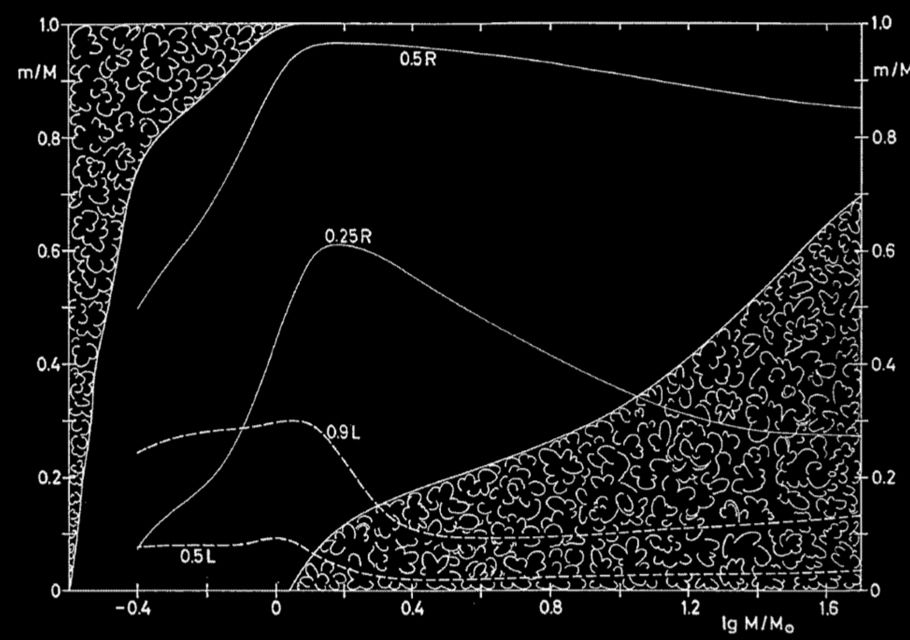
Böhm-Vitense 2007, ApJ, 657, 486

Dynamo Theory





Brandenburg 2005, ApJ, 625, 539
Kippenhahn & Weigert 1994, Springer

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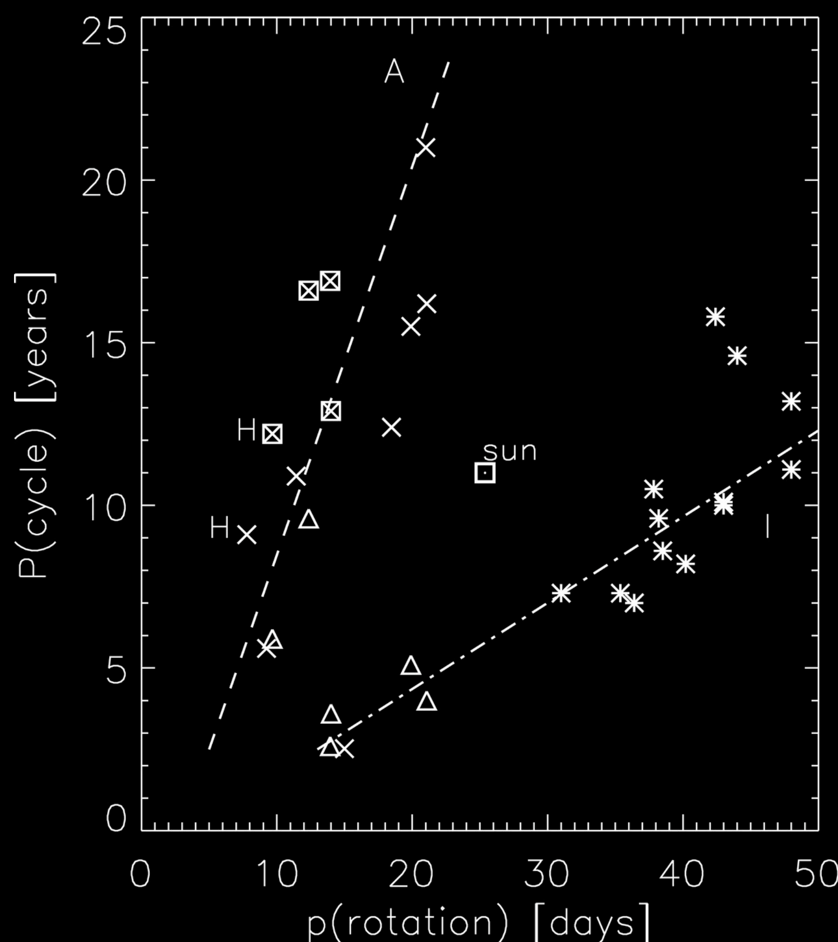

Böhm-Vitense 2007, ApJ, 657, 486

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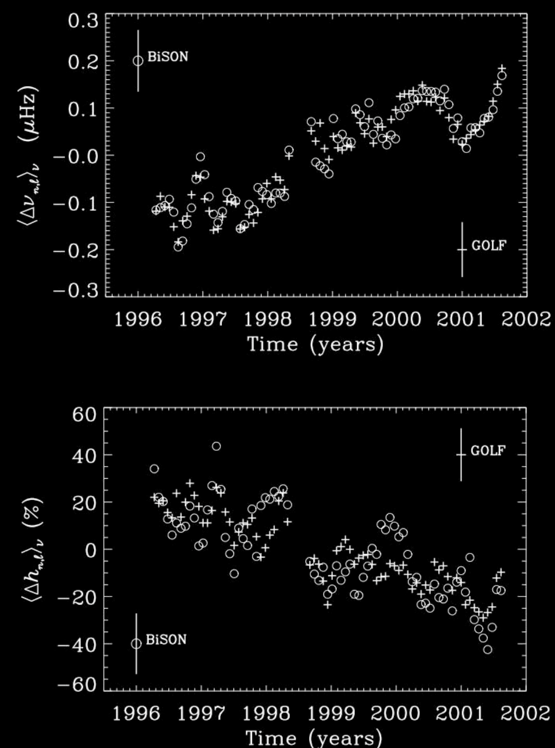
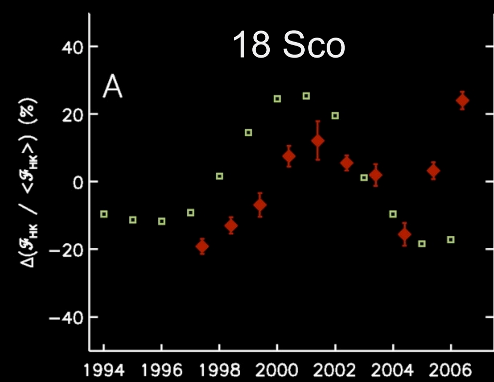
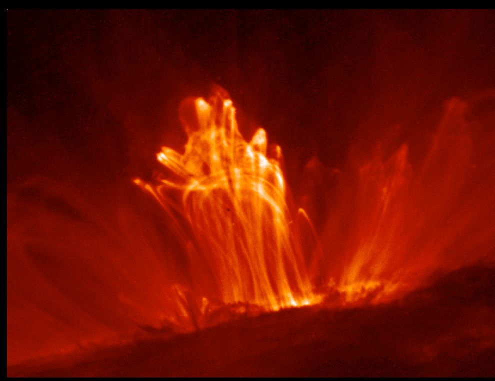
Revealing the Roots of Stellar Cycles

Jiménez-Reyes, 2004, ApJ, 604, 969







Hall et al., 2007, ApJ, 133, 2206

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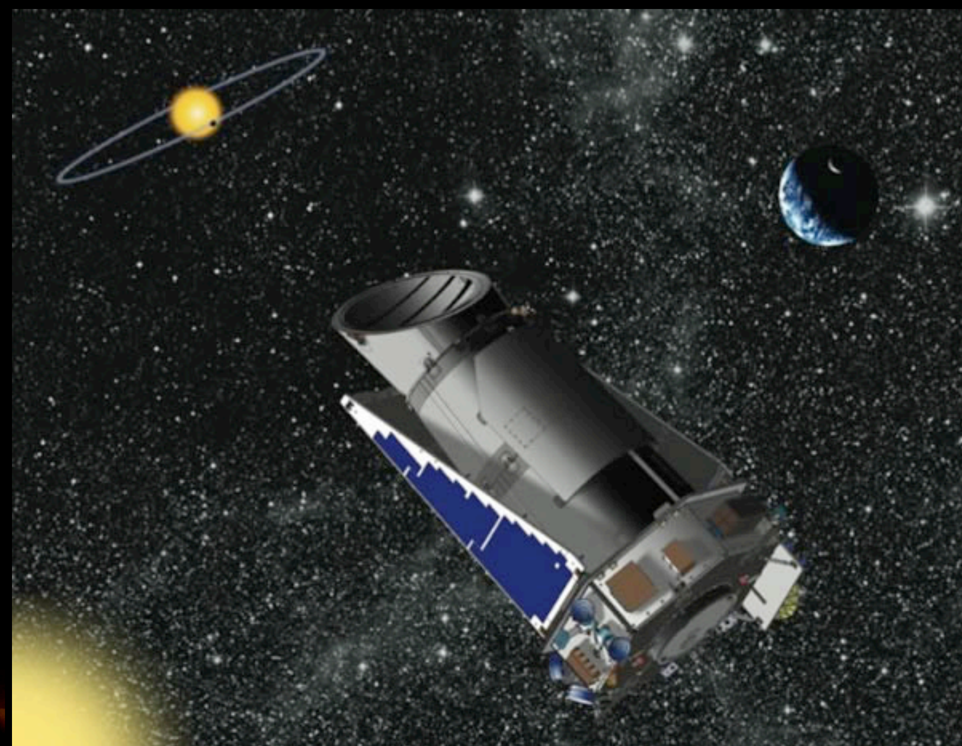
Kepler



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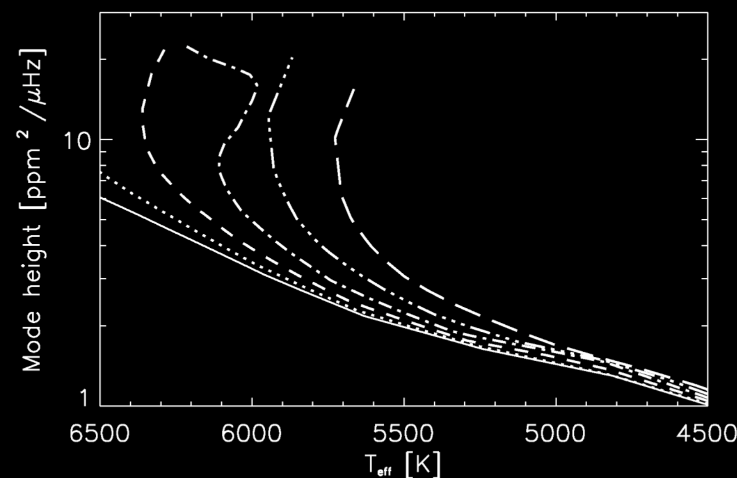
Mode Height v Temperature



$$A \propto \frac{L}{T_{\rm eff}^2 M} \propto \frac{T_{\rm eff}^2}{g}$$

$$H \propto \frac{A^2}{\tau} \propto g^{-2}$$

$$\tau \propto T_{\rm eff}^{-4}$$

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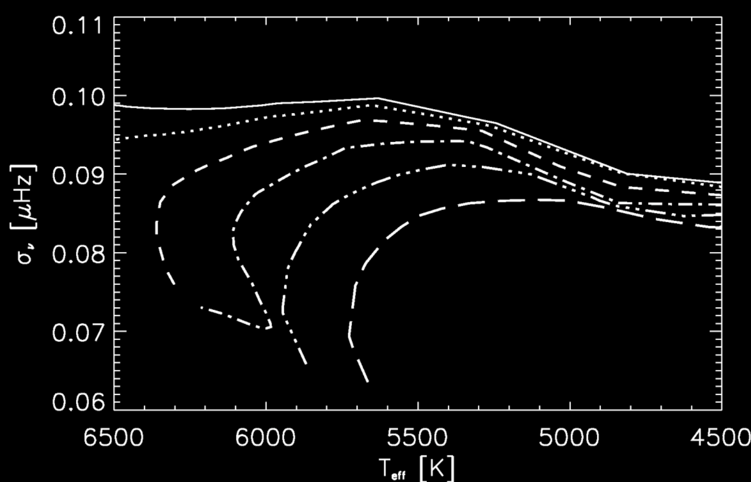
Chaplin et al. 2009, A&A, submitted

Frequency Precision v Temperature for a ~9th Magnitude Star Observed for 1 Year



$$\sigma_\nu = \sqrt{\frac{F(\mathrm{N/S})\Delta}{4\pi T}}$$

$$F(\mathrm{N/S}) = \sqrt{1+\mathrm{N/S}}\left(\sqrt{1+\mathrm{N/S}} + \sqrt{\mathrm{N/S}}\right)^3$$

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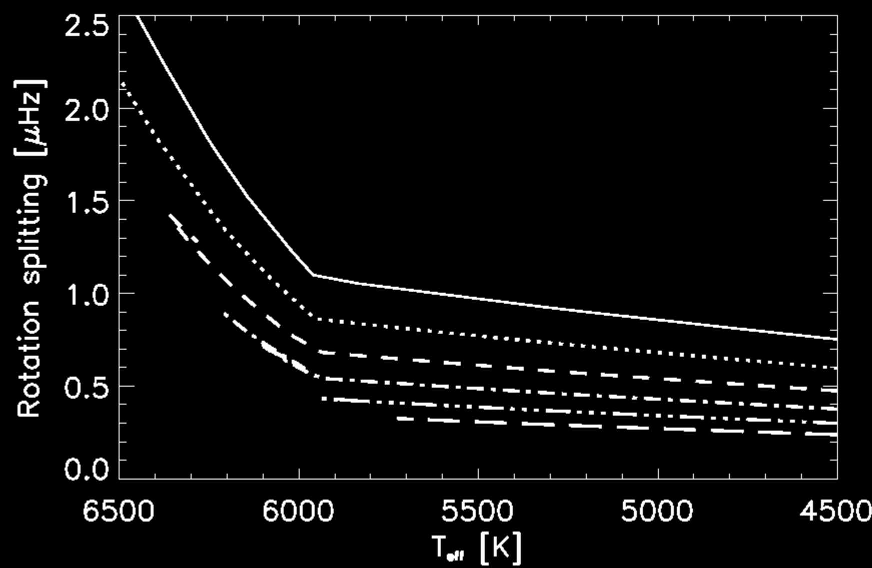
Libbrecht 1992, Sol. Phys., 387, 712

Rotation Splitting v Temperature



$$\log(P_{\rm rot}) - 0.5\log(T/0.625) =$$
$$\begin{cases} -0.669 + 2.580(B-V) & \text{for} \quad 0.45 \leq B-V \leq 0.62 \\ +0.725 + 0.326(B-V) & \text{for} \quad 0.62 < B-V \leq 1.30 \end{cases}$$

Aigrain, Favata & Gilmore 2004, A&A, 414, 1139

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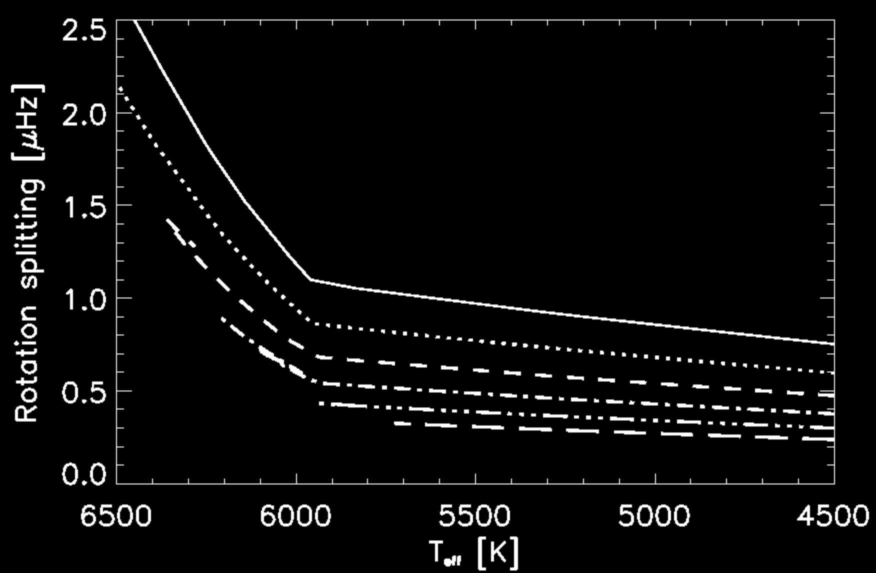
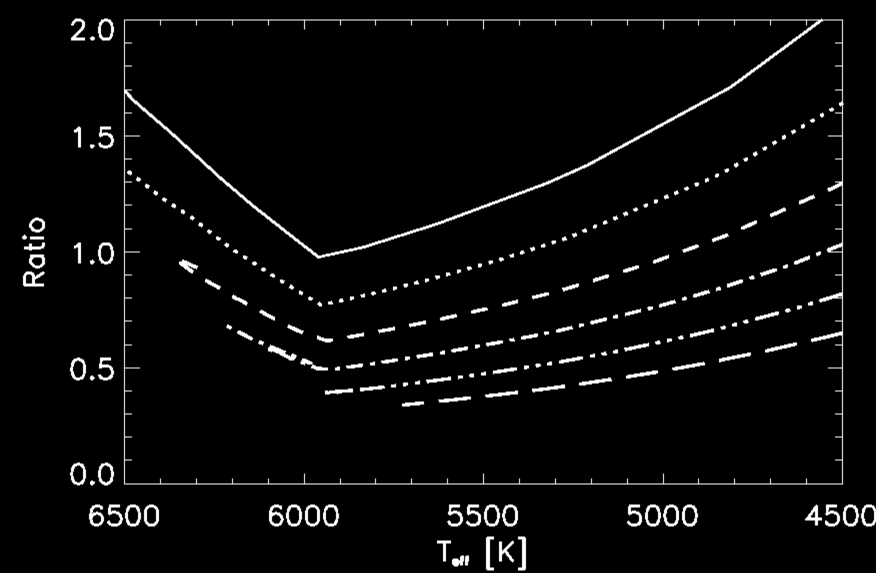
Rotation Splitting v Temperature





$$\log(P_{\rm rot}) - 0.5\log(T/0.625) =$$

$$\begin{cases} -0.669 + 2.580(B-V) & \text{for} \quad 0.45 \leq B-V \leq 0.62 \\ +0.725 + 0.326(B-V) & \text{for} \quad 0.62 < B-V \leq 1.30 \end{cases}$$

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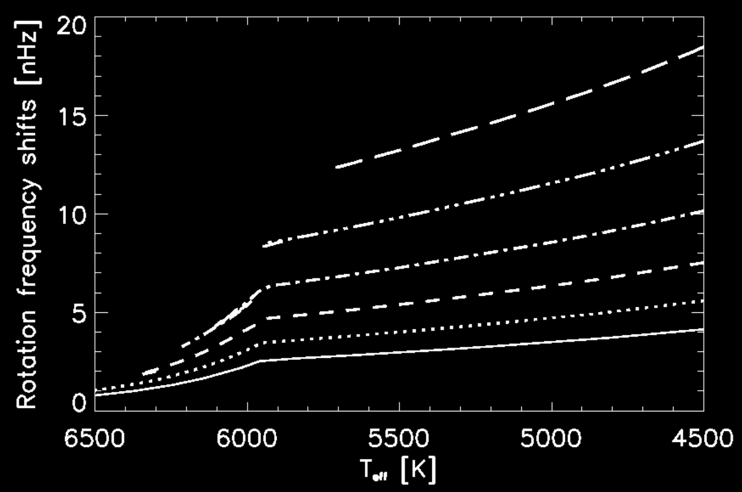
Aigrain, Favata & Gilmore 2004, A&A, 414, 1139

Rotation Shifts from Differential Rotation v Temperature



$$\delta\nu_{\rm diff.rot} \propto P_{\rm rot}^{1.3}$$

Donahue, Saar & Baliunas 1996, ApJ, 466, 384

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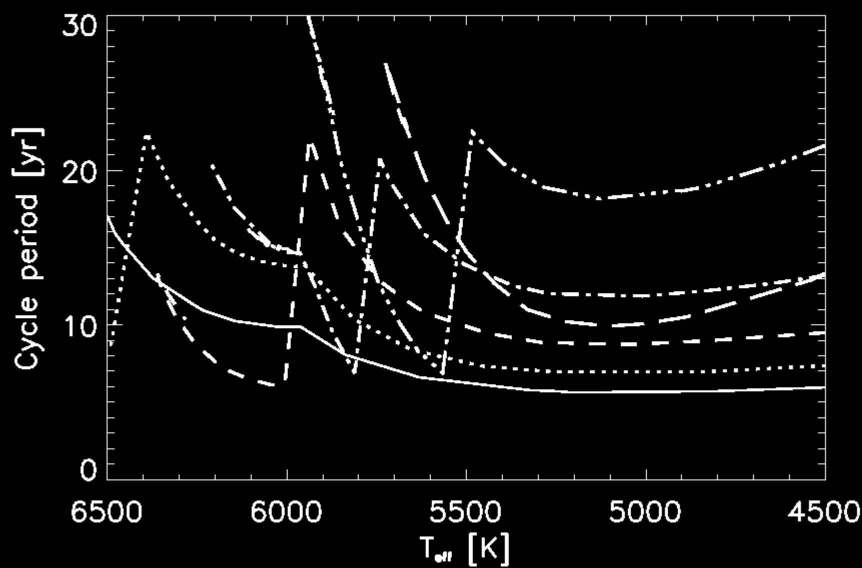
Cycle Length v Temperature



$$\log(\tau_c/P_{\rm rot}) = -(0.324 - 0.400y + 0.283y^2 - 1.325y^3), \quad (7)$$

where $y = \log(R'_{\rm HK} \times 10^5)$ and τ_c the convective turnover time. The convective turnover may then be calculated from a second scaling relation (which gives an answer in days):

$$\log(\tau_c) = \begin{cases} 1.361 + 0.166x + 0.025x^2 - 5.323x^3 & \text{for } x \geqslant 0 \\ 1.361 - 0.140x & \text{for } x < 0 \end{cases} \quad (8)$$

where $x = 1-(B-V)$. To calculate the $R'_{\rm HK}$ index, we solve the cubic Eq. 7 for the known input parameters: $B-V$ and $P_{\rm rot}$.

Noyes et al. 1984, ApJ, 279, 763

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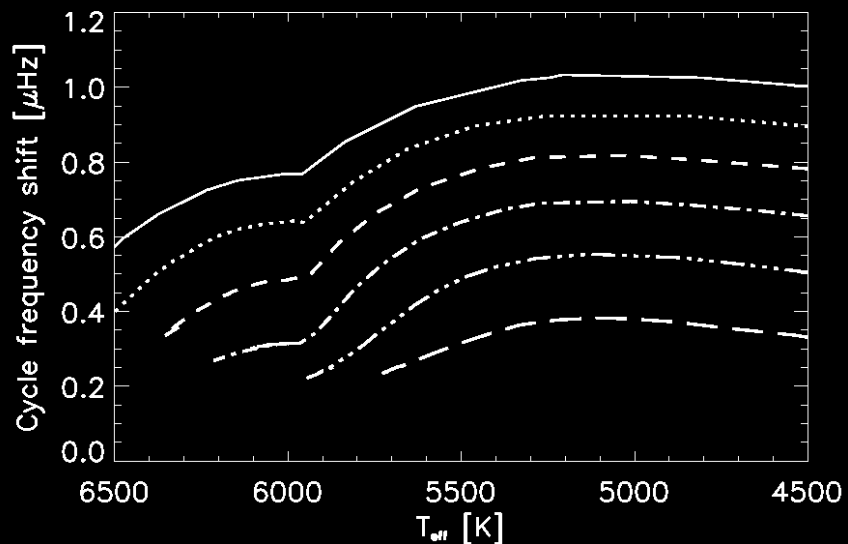
Cycle Acoustic Amplitude v Temperature



The amplitudes of the activity cycles $\Delta R'_{\rm HK}$ can be obtained from the relation given by Saar & Brandenburg (2002):

$$\Delta R'_{\rm HK} \propto (R'_{\rm HK})^{0.77}, \quad (9)$$

$$\delta\nu_{\rm cyc} \propto \Delta R'_{\rm HK}$$

Chaplin et al. 2007, MNRAS, 377, 17

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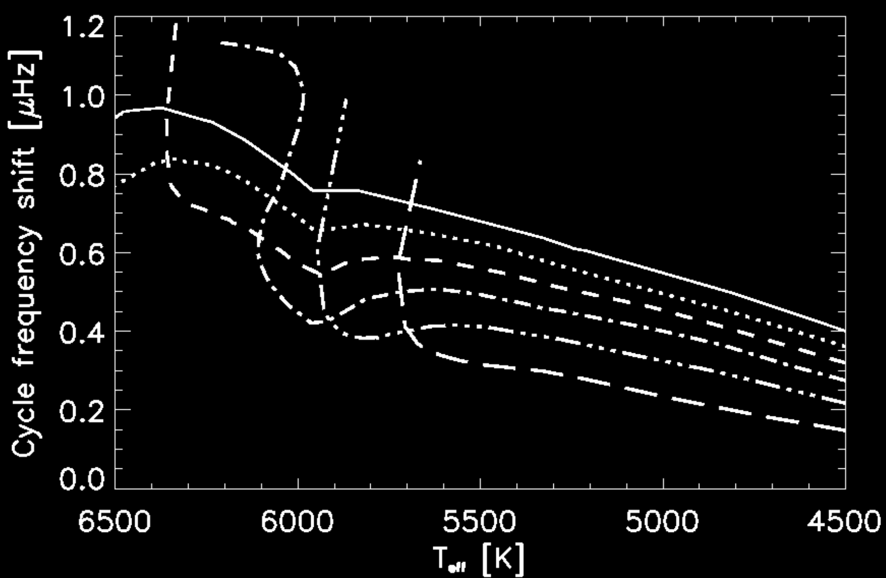
Cycle Acoustic Amplitude v Temperature



The amplitudes of the activity cycles $\Delta R'_{\mathrm{HK}}$ can be obtained from the relation given by Saar & Brandenburg (2002):

$$\Delta R'_{\mathrm{HK}} \propto (R'_{\mathrm{HK}})^{0.77}, \quad (9)$$

$$\delta\nu_{\mathrm{cyc}} \propto \frac{R^{2.5} L^{0.25}}{M^2} \Delta R'_{\mathrm{HK}}$$

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Metcalfe et al 2007, MNRAS, 379, L16

How to Measure the Depth of the Convection Zone

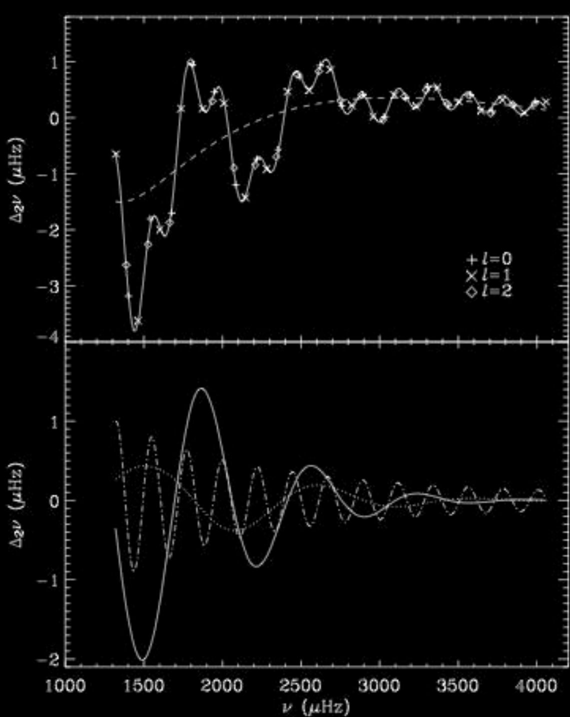

Figure 11. Top: the symbols are second differences $\Delta_2\nu$, defined by equation (2), of low-degree ($l = 0, 1, 2$) eigenfrequencies obtained from adiabatic pulsation calculations of the central model 0, and have the same relation to l as in Fig. 1. The solid curve is the diagnostic D_2 determined by equations (21), (30) and (37), whose 11 parameters α_k have been adjusted to fit the data by least squares. The measure χ^2 (mean squared differences) of the overall misfit is $(53\,\mathrm{nHz})^2$. The dashed curve represents the smooth contribution (last term in equation 21). Bottom: individual contributions of the oscillatory seismic diagnostic. The solid curve displays the He II contribution, the dotted curve is the He I contribution and the dot–dashed curve is the contribution from the base of the convection zone.

Houdek & Gough, 2007, MNRAS, 375, 861

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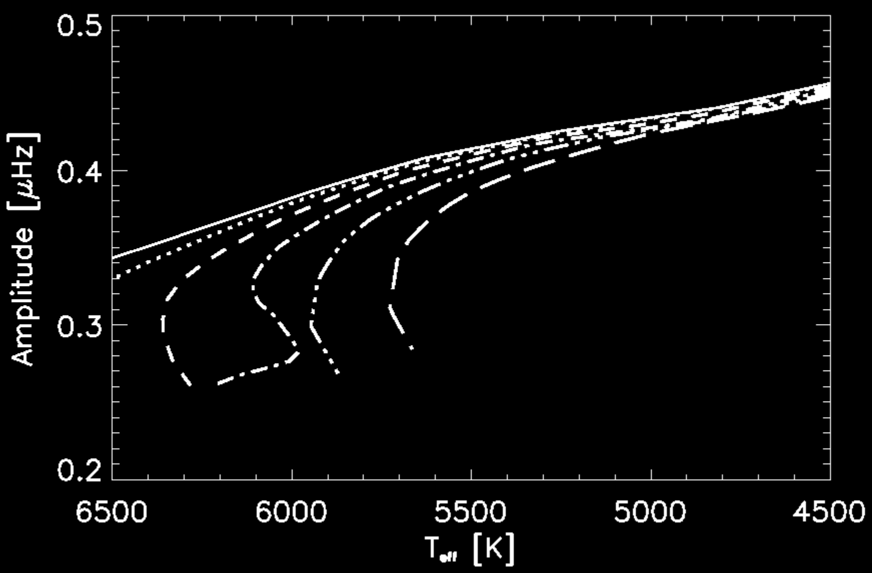
Acoustic Amplitude of the Depth of the Convection Zone v Temperature



$$A_{\rm cz} \propto 0.29 \cdot \log(g)$$

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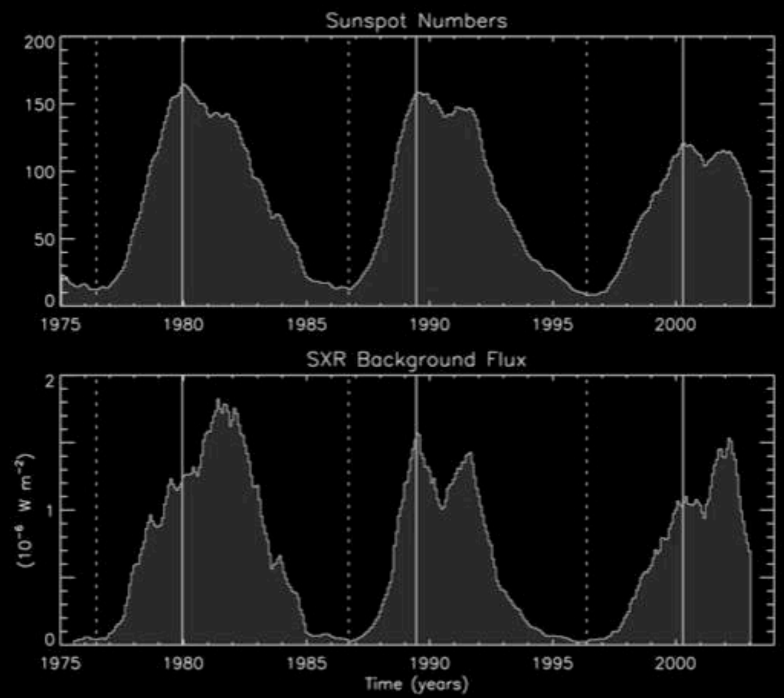
Relationship between Flares and Stellar Cycles?

- The soft X-ray background flux shows a delay of ~2 years to the Sunspot number in odd cycles (21 & 23).
- This might be related to the empirical Gnevyshev-Ohl rule which says that the sum of sunspot numbers over an odd cycle exceeds that of the preceding even cycle.
- Is this the case for other stars to?



Veronig, 2003, Solar Physics, 219, 125

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