12/6/00

Lecture 42 Helioseismology

Take home final Due 12/15
Review 12/8

Last time

$$\vec{\nabla} \cdot c^2(r)\, \vec{\nabla}\, \Phi(\vec{r},t) = \frac{\partial^2}{\partial t^2} \Phi$$

$$\vec{v} = -\vec{\nabla}\, \Phi$$

$$c = \left(\frac{\partial p}{\partial \rho}\right)_s^{1/2} = \gamma^{1/2} \left(\frac{RT}{M_0}\right)^{1/2} \qquad \gamma = \frac{c_p}{c_v} = \frac{5}{3}$$

M_0 = mean molecular wt

<u>Solar Model</u>

(A) Guess central ρ, T

(B) Integrate $\frac{d\rho}{dr}$ and $\frac{\partial T}{\partial r}$ from L_r till $\rho = 0$ ⟹ gives $M(R)$ and R

(C) adjust central ρ and T till model agrees with solar values

$\rho_c \sim 150\ g/cm^3$ $\qquad T_c \sim 1.3$ keV

Note $\vec{\nabla} \cdot c^2 \vec{\nabla}\, \Phi = \frac{\partial^2}{\partial t^2}\Phi$ is to simple because we neglected gravity. However qualitatively ok.

Seperation of variables $\Phi(\vec{r},t) = \sum_{lm} R_{lm}(r,t)\, Y_{lm}(\theta,\phi)$

Y_{lm} = spherical harmonic

Observe velocity at surface

$$v_r(\theta,\phi,t) = -\frac{\partial \Phi}{\partial r}\bigg|_{r=R} = -\sum_{lm} R'_{lm}(R,t)\, Y_{lm}(\theta,\phi)$$

Project out $R'_{lm}(R,t)$ by making a spherical harmonic transform of $v_r(\theta,\phi)$

$$\int_0^{\pi} \sin\theta\, d\theta \int_0^{2\pi} d\phi\; Y^*_{l'm'}\, Y_{lm} = \delta_{ll'}\,\delta_{mm'}$$

$$R'_{lm}(R,t) = -\int_0^{\pi} \sin\theta\, d\theta \int_0^{2\pi} d\phi\; v_r(\theta,\phi,t)\, Y^*_{lm}(\theta,\phi)$$

Example velocity observations slides 49,51
gmc3 pcV 5c.mov

F. Transform $R'_{lm}(R,t)$ in time to find normal mode frequencies

$$R'_{lm}(R,t) = \sum_n c_{nlm}\, e^{i\omega_{nl} t}\, \rho'_{nl}(R)$$

Note frequencies ω_{nl} are independent of m because Sun is spherically symmetric (to a good approx.). Just like energies of H atom in QM are independent of m.

Normal modes

$$\Phi_{nlm}(\vec{r},t) = \rho_{nl}(r)\, Y_{lm}(\theta,\phi)\, e^{i\omega_{nl} t}$$

See Model 14.ps $l=20$ $m=16$
pmode.mpg

mrc.mov
F. Transform → power spectrum partial wave amplitudes slide 53

Normal modes excited by complicated convective motion ⇒ not well understood [54]

Frequincies ω_{nl} carry info about $c^2(r)$ sound speed profile ⇒ $T(r)$ in Sun {slide 52}

Compare this to profile expected in standard solar model [slide 58]

Base of convective region slightly hotter and core slightly cooler than expected in standard solar model. However difference is small.

The Solar and Heliospheric Observatory

Spacecraft launched to study Sun. Many instruments. We are interested in one called

MDI/SOI (Michelson Dopple Image / Solar Oscillations Investigation)

Measures dopple shift of one sodium line at 1 million pixels!

Also GOLF (Global Oscillations at low frequencies) Measures dopple shift of light from full solar disk ⟶ information about low l modes.

Slide Show

1,2	Spacecraft
5	MDI
6	Orbit
7	Recovery
9	Parts of Sun
10	Erupting prominence
14	Magnetic loops
17	Large erupting prom.
34	Kinds of observations
40	Large coronal mass
41	ejection
46	Aurora

SOHO has discovered ~ 200 comets
Examples of crashes 255.mov
april29_comet1,2.gif