Helioseismology and the Helium Abundance

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Recent Reviews by Douglas Gough

http://arxiv.org/abs/1210.0820

http://arxiv.org/abs/1210.1114

- What have we learned from Helioseismology
- What have we really learned
- What do we aspire to learn
- Heliophysics gleaned from seismology

What have we learned

- How the sound speed and matter density vary through almost all the solar interior [except close to the center]
- Precise location of the base of the convection zone
- How the Sun rotates as a function of radial distance
- Thermal properties of and flows around and below a sunspot
- That the solution to the solar neutrino problem had to be sought in particle physics and in not the Sun
- Estimate of the Helium abundance ~25%
- Better estimate of the opacity and the equation of state
- Determination of the gravitational quadrupole moment J_2
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- What else?

What have we really learned

It takes only a brief scrutiny of the equations describing the structure and dynamical evolution of the Sun (it is not quite so brief to derive them) and the equations governing the low-amplitude seismic modes of oscillation to appreciate what broadly can, at least in principle, be reliably inferred. Anything further must depend on other criteria, such as general physical argument beyond seismology, traditional astronomical observation, or even prejudice. It is obligatory to be explicit about how such additional constraints are applied. The subject has advanced to a new level of sophistication; we are now trying to probe seismically (and otherwise) almost inaccessible aspects of the physics of the Sun, and the techniques for unravelling them are becoming more and more intricate, ***beyond the point at which most scientists wish to tread***. There must necessarily be an increased trust in our findings, and it is our responsibility not to betray it. Many of the broader scientific community want to use our results in their research; for that they need to know not only the limitations of our inferences, and the caveats upon which they are based, but also which aspects of what we seismologists tell them can really be trusted.

What do we aspire to learn

- Internal macroscopic dynamics of the Sun:
- Angular momentum transport
- Meridional Flows
- Amplification, distortion, and decay of the magnetic field and how it reacts back on the flow
- Formation, evolution, and decay of sunspots and solar activity
- How all this conspire to drive and control the solar cycle

Deep Meridional Flows

- What is the structure of the tachocline and meridional flows there and in the convection zone and do they vary with the solar cycle?
- Is there downwelling near the Equator and the Poles and upwelling at midlatitudes?
- Does this upwelling dredge up a primordial magnetic field from the radiative interior?
- Is there such an interior field and is it perhaps inclined and responsible for the ‘active longitudes’ and the sector structure?

Polytropic Depression

- A polytrope is a gas where the pressure p depends on the density ρ as $p \sim \rho^{\gamma}$ where the adiabatic index γ is between 4/3 and 5/3 for a stable star
- The adiabatic index γ depends on the number β of degrees of freedom for the gas $\gamma = 1 + 2/\beta$
- We can determine p and ρ from helioseismology and hence γ and β
- Ionization of Helium increases the number of electrons and hence β, which makes γ smaller
- From this ‘depression’ of γ the Helium abundance can be estimated
- Ionization of the heavier elements also provides electrons and lowers γ so the chemical composition of the Sun can in principle also be determined by helioseismology