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5. Conclusions
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Solar oscillations were discovered by Robert Leighton, a professor of physics at the California Institute of Technology. He announced his discovery at a meeting in Varenna, Italy, in 1960. Leighton making an observation of solar disc noticed a Doppler shift in frequencies of sunlight from different points of solar disc. This allowed him to observe that the Sun’s surface periodically oscillates.
Final explanation of solar oscillations was given independently by Roger Ulrich, John Leibacher and Robert Stein in 1970.
Final explanation of solar oscillations was given independently by Roger Ulrich, John Leibacher and Robert Stein in 1970. Oscillations of Sun’s atmosphere are caused by standing waves created in the interior of the Sun.
In the Sun can propagate three kinds of waves

- sound waves
- internal gravity waves
- surface gravity waves
Creation of standing waves in the interior of the Sun

Some waves with certain characteristics can be trapped between two horizontal reflecting boundaries.
Creation of standing waves in the interior of the Sun

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Creation of standing waves in the interior of the Sun

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The upper boundary for these waves lies just below the top of the convection zone. Above this boundary, the gas temperature drops off rapidly and so waves with enough low frequency are partially reflected, back into the convection zone.

The lower boundary lies few tens of thousands of kilometers beneath the surface and it depends on frequency and horizontal wavelength of an incident wave. At this boundary the increasing temperature and speed of sound act to bend a low frequency wave back toward the direction from which it came.
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Three dimensional standing waves can be described by using three numbers

- $N$ (the radial order) - number of nodes along a radius
- $M$ (the azimuthal order) - number of longitudinal node lines at the surface of the Sun, which is the number of planes slicing through the Sun longitudinally
- $L$ (the angular degree) - number of node lines at the surface of the Sun, which is the total number of planes slicing through the Sun
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Sound wave modes are called p-modes, internal gravity wave modes are called g-modes, and surface gravity wave modes are called f-modes.
From observations of solar oscillations we can examine the interior structure of the Sun: temperature distribution, chemical composition, internal rotation, etc.
Internal rotation of the Sun

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The depth into which standing wave can reach depends on the frequency and horizontal wavelength of a wave, that is on the $L$ number of wave modes. Waves with lower $L$ can penetrate deeper parts of the Sun. This allow us to make velocity map the interior of the Sun.
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Solar Oscillations
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Improvement of solar models

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Improving a solar model can be done by preparing a set of models differing slightly one from each other and choosing this model which in the best way reconstruct observed frequencies of oscillation modes.
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Improving a solar model can be done by preparing a set of models differing slightly one from each other and choosing this model which in the best way reconstruct observed frequencies of oscillation modes. Similar technique can be used to calculate the chemical composition of the Sun.
Improving Observations Of Solar Oscillations
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- Move to South Pole.
Move to South Pole.
Create a network of observatories.
Improving Observations Of Solar Oscillations

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- Create a network of observatories.
- Observe the Sun from space.
GONG (the Global Oscillation Network Group)

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SOHO (the Solar and Heliospheric Observatory)

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SOHO is an international project led and built by the European Space Agency. NASA launched it on December 2, 1995. SOHO carries twelve instruments. Of these, nine carry out coordinated studies of the corona and solar wind. The remaining three instruments were built to study solar oscillations.
SOHO instruments for measuring solar oscillations

- **GOLF (Global Oscillations at Low Frequencies).** Its main purpose is to probe the solar core with long-period sound waves and, hopefully, gravity waves. GOLF was designed to record low-degree oscillations with periods as short as two minutes and as long as one hundred days.

- **VIRGO (Variability of Solar Irradiance and Gravity Oscillations).** Its scientific objectives are similar to GOLF's, namely to record long-period, low-degree oscillations in order to probe the solar core. It covers the range of periods from two minutes to a day, with the aim of detecting solar gravity modes.

- **SOI/MDI (Solar Oscillations Investigation/Michelson Doppler Imager).** It records the usual five-minute p-modes, with good spatial resolution across the solar disk. It is most useful in probing the solar convection zone with oscillations of intermediate degree, say $L = 10$ to 200.
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- http://soi.stanford.edu/results/heliowhat.html