Precision Asteroseismology
Proceedings IAU Symposium No. 301, 2013
J. A. Guzik, W. J. Chaplin, G. Handler & A. Pigulski, eds.

doi:10.1017/S1743921313014671

Helio- and asteroseismology shedding light on "new physics"

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Abstract. Linkages between astronomy and physics have always been intimately close and mutually stimulating. Most often it was physics that served astronomy with its explanatory power. Today, however, we are increasingly witnessing the reverse: astrophysical considerations are being used to constrain new physics and moreover they are more efficient than laboratory experiments. This contribution reviews the ways helio- and white dwarf asteroseismology – branches in which Wojtek Dziembowski played a prominent role – are used for this purpose.

1. Introduction

There are two major problems in modern physics: Dark Matter (DM) and Dark Energy (DE), i.e. the accelerated expansion of the Universe. DM evidence is very strong (e.g., dynamical, gravitational lensing, cosmic microwave background radiation (CMBR) fluctuations, matter budget in the Universe). We expect DM composed of non-baryonic, neutral, stable and massive particles. Some hints come from particle physics, e.g. heavy particles, so called WIMPs, predicted by supersymmetry and axions, or light Nambu-Goldstone bosons invoked as a resolution of strong CP problem in QCD. Apart from solving the DM and DE problems other "exotic" possibilities may be contemplated, e.g. multidimensional worlds (Kaluza-Klein gravitons), primordial black holes, or varying fundamental constants. Exotic particles can serve as additional coolants (or heaters) in stellar interiors: in particular an additional coolant would heat up the star while it is ideal gas pressure supported (main sequence, horizontal branch), and cool it down while it is degenerate gas pressure supported (red giant branch, white dwarf, neutron star).

Helioseismology constrains the temperature profile inside the Sun, so it is sensitive to new channels of cooling/heating. Asteroseismology of pulsating white dwarfs (WD) is able to derive secular changes of period hence tracing the cooling rate. Comparison between evolutionary cooling and observations sheds light on possible new channels of cooling/heating.

2. Pulsating white dwarfs as a tool for astroparticle physics

G117-B15A belongs to the class of DAV WDs exhibiting non-radial pulsations in g-modes. DAV instability starts when the star is cool enough to develop a partial hydrogen ionisation zone sufficiently deep to excite pulsations. As the star cools further, the partial H-ionisation zone moves deeper, the thermal time-scale increases and so does the pulsation period. In 2005 after a total of 31 years of observations Kepler *et al.* (2005) obtained a measurement of the rate of period change with time for the largest amplitude periodicity at 215 s. Corrected for the proper motion, this rate can be compared with theoretical predictions setting limits to non-standard sources of energy or cooling.

Isern *et al.* (1992) raised for the first time the possibility of employing the measured rate of period change in G117-B15A to derive a constraint on the mass of axions. They considered the evolution of DAV WD models with and without axion emissivity, and compared the theoretical values of secular period rate for increasing masses of the axion with the observed rate of period change of G117-B15A at that time. The most recent estimate of axion mass from G117-B15A comes from Córsico *et al.* (2012) (see this paper for more details).

The interest in physical theories with extra spatial dimensions has recently experienced considerable revival in the context of DE. One can construct an effective theory of Kaluza-Klein (K-K) gravitons interacting with the standard model fields, calculate specific emissivity for gravi-bremsstrahlung of electrons and estimate the additional luminosity in K-K gravitons. Along these lines, using G117-B15A, Biesiada & Malec (2002) have obtained the bound on the energy scale for which extra dimensions might manifest themselves. This bound turned out to be one order of magnitude more stringent than the result obtained from LEP accelerator experiment. For the updated bound see Malec & Biesiada (2013).

There is also a debate in the literature over the issue of whether the quantities known as the constants of nature (such like G or fine structure constant) can vary with time. One of the reasons for this debate is connected with the string theory and associated ideas that the world we live in may have more than four dimensions. Because buoyancy is the restoring force for g-modes, the Brunt-Väisälä frequency is the most important quantity setting the scale in the pulsation spectrum. Using G117-B15A Biesiada & Malec (2004) obtained a bound on the rate of change of G. The most recent asteroseismological estimates are given by Córsico *et al.* (2013).

3. Helioseismology and primordial black holes

Primordial black holes (PBH) are expected to be formed in the early Universe - with a scale invariant power spectrum some overdensities will collapse into black holes. PBH production is enhanced during e.g. QCD phase transition when the pressure is suddenly reduced. The PBH mass range suggested by this mechanism ($10^{17} - 10^{26}$ g) cannot be probed by standard techniques like microlensing or gamma-rays. An interesting possibility to detect such a PBH was suggested by Kesden & Hanasoge (2011) who showed that passing through the Sun such PBH would excite distinctive oscillation patterns. It is very likely that PBHs can also leave unique transient imprints on echelle diagrams of pulsating stars.

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https://doi.org/10.1017/S1743921313014671 Published online by Cambridge University Press