

Proceedings of the  
11th “Patras” Workshop on Axions, WIMPs  
and WISPs PATRAS2015

June 22–26, 2015  
Zaragoza, Spain

Editors: Igor G. Irastorza, Javier Redondo, José Manuel Carmona, Susana Cebrián,  
Theopisti Dafní, Francisco J. Iguaz, Gloria Luzón.

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## **Impressum**

### **Proceedings of the 11th ‘Patras’ Workshop on Axions, WIMPs and WISPs (Patras2015)**

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## Preface

The 11th Patras Workshop on Axions, WIMPs and WISPs took place in Zaragoza, on June 22nd to 26th, 2015. After the successful 10th-anniversary edition of the conference last year at CERN, this edition broke again the record with 125 attendants, proof of the good health of the field and the increasing interest that axion physics is attracting. The participants enjoyed an intense program of science, comprising both theory and experiments, many interesting discussions, but also good gastronomy and sightseeing in Zaragoza. The presentations took place in the Aula Magna of the Paraninfo building of the Universidad de Zaragoza, famous for having hosted the lessons of Nobel-prize-winner Santiago Ramón y Cajal about a century ago, as well as one of the few lectures of Albert Einstein in Spain. For the 24th, the conference moved to Canfranc in the Spanish Pyrenees, where the attendants visited the Laboratorio Subterráneo de Canfranc (LSC), a singular facility in Spain, of which the local organizers are associated researchers.

As it is customary in the series, the workshop reviewed the latest advances in the physics case of WIMPs, axions and WISPs, including the latest theoretical developments as well as their link to astrophysics and cosmology, e.g. their potential role in our understanding of dark matter and dark energy. The current experimental efforts, as well as new proposals to detect these particles were also presented and discussed. The vitality of the field was patent in the scientific program of the workshop, including more than 80 oral presentations, as well as a poster session on the first afternoon of the week, in which 15 posters were presented and discussed. As a novelty this year, a prize for the best poster was organized, mostly addressed to the younger colleagues of the community. A prize committee was constituted (chaired by José Manuel Carmona and including also Axel Lindner, Babette Doebrich and Theopisti Dafni). The committee evaluated both the formal and scientific contents of the posters, as well as their presentation during the session. The decision was difficult due to the good quality of the posters, but the prize was finally awarded jointly to Doyu Lee (50%), Patricia Villar (25%) and Adrián Ayala (25%). We want to congratulate them all again.

We want to express our gratitude to all the participants of the workshop for their contribution to its success, and most especially to those colleagues who accepted our invitation to give one of the review talks of the conference.

Given the rapid evolution of our field, with new ideas and projects emerging constantly, the issuing of proceedings (for a meeting that is organized yearly!) is always a delicate issue. The question was exposed during the last day of the conference, and the community answered overwhelmingly in favour of the preparation of proceedings. In order to keep the novelty and freshness of the talks of the conference, we tried to arrange a publication process as fast as possible. Despite the strict deadline set, encompassing only the two summer months, 50 written contributions made it through to the present volume of proceedings, which we believe is another record for the series. We sincerely think that the present volume is a very good witness of the excitement and good quality of the research being done in our field. We hope you enjoy it!

## **Acknowledgements**

The local organising committee would like to thank the University of Zaragoza for supporting the workshop and for providing the magnificent premises of the Paraninfo building; in particular, we would like to thank Luis Miguel García Vinuesa, Vice-president of Research of the University, and Luis Oriol Langa, Dean of the Science Faculty, for their warm welcome of the workshop on the first day, as well as the LSC management and staff for their help with the visit on the 24th of June. The organisers wish also to acknowledge economical support from the following institutions: CERN, DESY, University of Bern, University of Zurich and University of Patras, that greatly helped the organisation of the workshop. In addition, support from the Spanish Ministry of Economy and Competitiveness, as well as from the European Research Council is acknowledged, through the research grants to the local groups. Special thanks also to the students of the local group and the secretariat of the Theoretical Physics Department for the help with the logistics of the organisation.

The local organising committee











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# Recent Progress with the KWISP Force Sensor

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The KWISP opto-mechanical force sensor has been built and calibrated in the INFN Trieste optics laboratory and is now under off-beam commissioning at CAST. It is designed to detect the pressure exerted by a flux of solar Chameleons on a thin (100 nm) Si<sub>3</sub>N<sub>4</sub> micromembrane thanks to their direct coupling to matter. A thermally-limited force sensitivity of  $1.5 \cdot 10^{-14}$  N/ $\sqrt{\text{Hz}}$ , corresponding to  $7.5 \cdot 10^{-16}$  m/ $\sqrt{\text{Hz}}$  in terms of displacement, has been obtained. An originally developed prototype chameleon chopper has been used in combination with the KWISP force sensor to conduct preliminary searches for solar chameleons.

## 1 Introduction

The KWISP (Kinetic WISP detection) force-sensor consists of a thin (100 nm) dielectric membrane suspended inside a resonant optical Fabry-Perot cavity [1, 2, 3]. The collective force exerted by solar Chameleons bouncing off the membrane surface [4, 5] will cause a displacement from its equilibrium position which can be sensed by monitoring the cavity resonant frequency. Since, in addition, the membrane is a mechanical resonator, the displacement sensitivity is enhanced by the mechanical quality factor of the membrane. For a detailed description of the KWISP force sensor see [6]. An absolute calibration of the KWISP sensor in terms of force has been obtained in the INFN Trieste optics laboratory by applying a known external force supplied by the radiation pressure of a laser beam (*pump beam technique*). This external force is modulated at a given frequency allowing one to explore the frequency region near the mechanical resonance of the membrane. Here we obtain a force sensitivity already at the 300 K thermal limit [7]. In order to effectively use the KWISP sensor for chameleon detection it is necessary to find a means of modulating the amplitude of the expected chameleon beam. By exploiting the ability of chameleons to reflect off any material surface when impinging at grazing incidence, and to correspondingly traverse it when at normal incidence [4], we have originally devised and built a *chameleon chopper* prototype. The chopper allows one to shift the expected chameleon signal away from the noisy region near zero frequency, eventually reaching, with a suitable high frequency chopper, frequencies near resonance. We have used the prototype

chopper, working at frequencies below 200 Hz, for preliminary solar chameleon search runs, also taking advantage of the fact that the KWISP membrane orientation in space is such, that a hypothetical chameleon beam from the sun will reflect off it at grazing angles between 0 and 20 degrees for about 1.5 hours each day. In the following we will briefly describe the sensor setup, the results from absolute calibration measurements, the chameleon chopper prototype and its use in preliminary solar runs.

## 2 The KWISP force sensor

The main element of the KWISP force sensor is a vacuum chamber containing an 85 mm-long Fabry-Perot cavity made with two 1-inch diameter, 100 cm curvature radius, high-reflectivity, multilayer dielectric mirrors. A  $\text{Si}_3\text{N}_4$ ,  $5 \times 5 \text{ mm}^2$ , 100 nm thick membrane is inserted inside the cavity and it is initially placed approximately midway between the two cavity mirrors (*membrane-in-the-middle* configuration). The Fabry-Perot cavity is excited using a CW 1064 nm laser beam emitted by a Nd:YAG laser. A second, frequency-doubled, CW beam at 532 nm emitted by the same laser is used as an auxiliary beam (*pump beam*) for alignment and for exerting a known external force on the membrane. When the sensor is in detection mode the Fabry-Perot cavity is frequency-locked to the laser using an electro-optic feedback loop [1]. The error signal generated by this loop is proportional to the instantaneous frequency difference between laser and cavity and its power spectrum contains the information on membrane displacements. The pump beam, amplitude-modulated at a given frequency, is then injected into the cavity and it exerts a known force on the membrane by reflecting off it. The intensity of the pump beam corresponds in our case to a net force of  $7.9 \cdot 10^{-14}$  N. The presence of this force is detected as a peak in the measured spectrum of the error signal. The membrane behaves as a mechanical oscillator and its fundamental resonant frequency and quality factor can be directly measured with the pump beam technique. Figure 1 shows a plot of several power spectra of the feedback loop error signal. The peaks indicate the presence of the calibration force, while different peaks correspond to different excitation frequencies. The peak with the largest amplitude occurs when the pump beam modulation frequency matches the membrane mechanical resonance frequency. The background level in Figure 1 gives a force sensitivity of  $1.5 \cdot 10^{-14}$  N/ $\sqrt{\text{Hz}}$ , corresponding to  $7.5 \cdot 10^{-16}$  m/ $\sqrt{\text{Hz}}$  in terms of displacement. These values correspond to the thermal limit at 300 K [7].

## 3 Preliminary solar runs with the chameleon chopper

To investigate the possible presence of a signal from a beam of chameleons emitted by the sun, it is necessary to impress a time modulation on it. This can be done by exploiting the general chameleon property of traversing any material when impinging on it at right angles, and of reflecting off it when arriving at grazing incidence (see [4] for details). We have designed and built a prototype chameleon chopper (see Figure 2) exploiting this property.

The chopper was placed in the proper position in order to intercept a hypothetical solar chameleon beam hitting the membrane at grazing incidence angles between 0 and 20 degrees, depending on the time of day. Data were then acquired by recording 40 s-long power spectra of the feedback loop error signal. A partial preliminary analysis of the solar data was conducted by computing for each spectrum the Signal-to-Noise Ratio (SNR) and by plotting the SNR as a function of time. A sample plot of this type is shown in Figure 3.



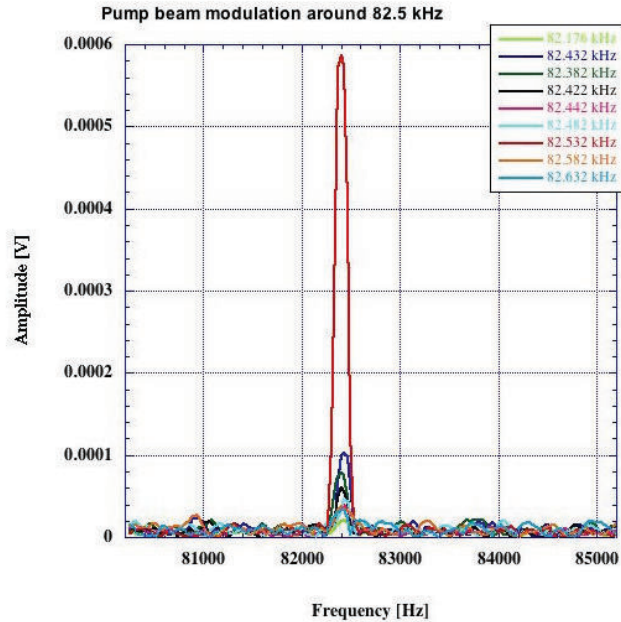


Figure 1: Plot of several power spectra of the error signal from the Fabry-Perot frequency-locking feedback loop. Each spectrum (identified by a unique color) has been taken with the pump beam exciting the membrane at a given frequency near the 82.5 kHz membrane resonance frequency (see legend in the figure). Note how the signal amplitude increases when approaching the resonance frequency. From these data one can estimate a mechanical quality factor of  $\approx 3000$ .

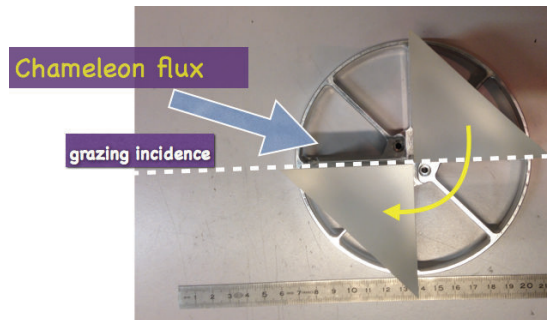


Figure 2: Prototype chameleon chopper and its working principle. The photograph shows a top view of the chameleon chopper prototype consisting of two optical prisms glued to a holding tray capable of rotating along its cylindrical symmetry axis. As the chopper rotates, it presents to the chameleon beam grazing-incidence and normal-incidence surfaces alternatively. The latter transmit chameleons, while the former reflect them, causing the required amplitude modulation. The prototype shown here can rotate at up to  $\approx 50$  Hz, corresponding to a chopping frequency of  $\approx 200$  Hz, as a grazing incidence surface is presented to the incoming beam 4 times each turn.

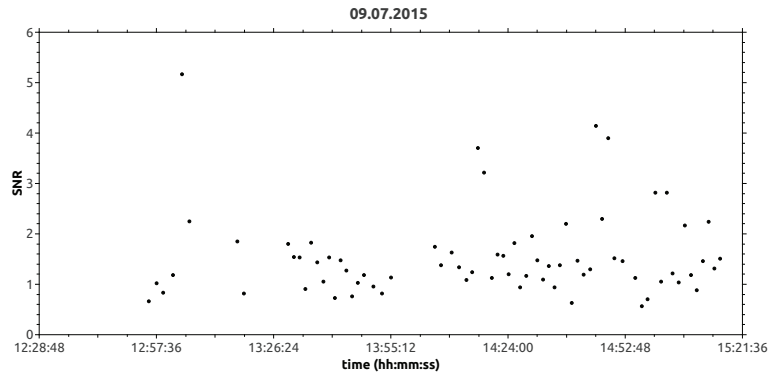


Figure 3: Data from a sample solar run. The graph shows a plot of the Signal-to-Noise ratio (SNR) near the chopper frequency (17 Hz in this case), measured in the power spectrum of the feedback error signal, as a function of time. Data were taken while the sun scanned through grazing incidence angles between 0 and 20 degrees. Notice that the dispersion of the data points indicates the absence of a clear signal.

## 4 Conclusions

The KWISP force sensor now running in the INFN Trieste optics laboratory has been calibrated in absolute terms using a known force exerted by an auxiliary pump beam. The measured sensitivity of  $1.5 \cdot 10^{-14}$  N/ $\sqrt{\text{Hz}}$ , corresponding to  $7.5 \cdot 10^{-16}$  m/ $\sqrt{\text{Hz}}$  in terms of displacement, is already at the 300 K thermal limit. The *chameleon chopper* concept has been implemented in a working prototype [8]. This was used in combination with the force-sensor to conduct preliminary runs for the detection of a hypothetical chameleon beam emitted from the sun. Analysis of the data from these runs is in progress [9]. The KWISP force sensor, once coupled to the X-Ray Telescope at CAST, has the potential to access unexplored regions in the Chameleon parameter space, possibly allowing a first glimpse at the nature of Dark Energy [5].

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