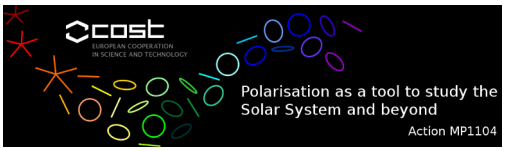
POLARIMETRY OF PLANETARY SYSTEMS

Villa Il Gioiello – Arcetri

23-26 September 2013



SOC

S. Bagnulo (chair) I. Belskaya (co-chair), A. Cellino (co-chair)
A-C. Levasseur-Regourd, H. Lamy, K. Muinonen, H. M. Schmid,
F. Snik, D. Stam, M. Sterzik, G.P. Tozzi.

LOC

S. Bagnulo, E. Masini, G.P. Tozzi (chair).

MONDAY 23
I - OBSERVATIONS AND MODELLING OF THE SMALL BODIES OF THE SOLAR SYSTEM

Chair: A. Cellino

09:00-10:10 **REGISTRATION**

10:10-10:30 **S. Bagnulo & G.P. Tozzi:** Welcome speech and practical information

10:30-11:00 **A. Cellino:** Asteroid Polarimetry: State of the art and a roadmap for future developments

11:00-11:30 **COFFEE BREAK**

11:30-12:00 **P. Tanga, A. Cellino & S. Bagnulo:** Portraits of Barbarians

12:00-12:30 **S. Fornasier & I. Belskaya** (presented by I. Belskaya)**:** Polarimetric observations of 2867 Steins and 21 Lutetia, targets of the Rosetta mission: groundtruth from the Rosetta fly-bys

12:30-13:00 **K. Muinonen, E. Zubko, A. Pentiilä, & G. Videen:** Polarimetric modeling of atmosphereless solar system bodies

13:00-14:30 **LUNCH BREAK**

14:30-15:00 **S. Bianchi:** History of Villa Il Gioiello (including a tour)

15:00-15:30 **I. Belskaya & S. Bagnulo:** Polarimetry of Transneptunian Objects and Centaurs

15:30-16:00 **A.-C. Levasseur-Regourd:** Polarimetry of comets, with emphasis on comet 67P/C-G

16:00-16:30 **COFFEE BREAK**

16:30-16:45 **S. Bagnulo, H. Boehnhardt, L. Kolokolova & G.P. Tozzi:** Polarimetry of comets 9P and 73P

16:45-17:00 **G.P. Tozzi, S. Bagnulo, H. Boehnhardt, & S. Fornasier:** Polarimetric observations of the nucleus of comet 67P/Churyumov-Gerasimenko, the target of the mission Rosetta.

17:00-17:30 **D. Boneva, L. Filipov, & K. Yankova:** On the study of small bodies and Zodiacal light

17:30-18:00 **DISCUSSION**

TUESDAY 24
II - THE PLANETS OF OUR SOLAR SYSTEM AND THEIR ATMOSPHERES

Chair: S. Bagnulo

09:30-10:00 **M. Sterzik, S. Bagnulo, D. Stam, C. Emde, R. Buras:** Spectropolarimetry of Earthshine

10:00-10:30 **E. Pallé, P. Miles-Paéz, & M.R. Zapaterio Osorio:** Spectropolarimetry of the Earthshine from visible to near-infrared wavelengths

10:30-11:00 **A. Bazzon, H.-M. Schmid, & D. Gisler:** The polarization of Earth

11:00-11:30 **COFFEE BREAK**

11:30-12:00 **A. López Ariste, F. Leblanc, C. Le Men, & B. Gelly:** Spectropolarimetry of the exosphere of Mercury

12:00-12:30 **M. Rodenhuis, F. Snik, L.J. Einarsen, et al.:** Narrow-band imaging polarimetry of the atmospheres of Venus and Saturn at multiple visible wavelegnths

12:30-13:00 **E. Buenzli, A. Bazzon, & H.M. Schmid:** Limb polarisation as a probe of haze in outer planet atmospheres

13:00-14:30 **LUNCH BREAK**

14:30-15:00 **A. García Munõz:** A Backward Monte Carlo model for polarization in planetary atmospheres

15:00-15:30 **D. Stam & T. Karalidi:** Spectropolarimetric signatures of Earth-like extrasolar planets

15:30-16:00 **DISCUSSION**

16:00-16:30 **COFFEE BREAK**

16:30-17:30 **DISCUSSION / MEETINGS OF WORKING GROUPS**

WEDNESDAY 25
III - INSTRUMENTS

Chair: F. Snik

10:00-10:30 **G. Borisov & T. Bonev:** FoRoRo2 at NAO Rozhen for polarimetric and spectropolarimetric observations

10:30-11:00 **H.M. Schmid & A. Bazzon** (presented by A. Bazzon)**:** SPHERE-ZIMPOL polarimetry of planetary systems

11:00-11:30 **M. Focardi, M. Pancrazzi, F. Landini, M. Romoli, E. Pace:** A proposal for a novel integrated nano Wire Grid Polarisers-based VNIR polarimeter for planetary studies from space

11:30-12:00 **COFFEE BREAK**

12:00-12:30 **D. Stam:** Observing the Earth as an exoplanet with LOUPE, the lunar observatory for unresolved polarimetry of Earth

12:30-13:00 **F. Snik and the iSPEX team:** iSPEX: measurements of atmospheric aerosols by a citizen science network using smartphone spectropolarimeters

13:00-14:30 **LUNCH BREAK**

14:30-15:00 **L. Abe et al.** (presented by P. Bendoya) **:** CAPS@C2PU

15:00-15:30 **O. Suarez, P. Bendyoya, & J.-P. Rivet** (presented by P. Bendoya)**:** EduCosmos: Participative science for high school students with 1 m telescopes

15:30-16:00 **DISCUSSION**

16:00-16:30 **COFFEE BREAK**

16:30-17:00 **DISCUSSION / MEETINGS OF WORKING GROUPS**

17:00-18:00 **Visit to the Osservatorio Astrofisico di Arcetri**

20:00-??:?? **CONFERENCE DINNER**

THURSDAY 26
IV - EXO-SOLAR PLANETS

Chair: M. Sterzik

09:30-10:00 **N.M. Kostogryz & S. Berduygina:** Polarimetry of transiting exoplanets

10:00-10:30 **N. Shchukina & J. Trujillo Bueno:** The continuum polarization of stars with transiting exoplanetary systems

10:30-11:00 **F. Snik et al.:** Infrared polarimetry of the HR 8799 planets near-infrared wavelengths

11:00-11:30 **COFFEE BREAK**

11:30-12:00 **P.A. Miles-Páez, M.R. Zapatero Osorio, E. Pallé, & K. Peña Ramírez:** Linear polarization of rapidly rotating ultracool dwarfs

12:00-12:30 **S. Berdyugina, A. Berdyugin, & V. Piirola:** Polarimetry of Hot Inflated Jupiters Reveals Their Blue Colors

12:30-13:00 **DISCUSSION**

13:00-14:30 **LUNCH BREAK**

14:30-17:30 **MEETINGS OF WORKING GROUPS**

LIST OF PARTICIPANTS

1	Stefano Bagnulo	Armagh Observatory, UK
2	Andreas Bazzon	ETH, Switzerland
3	Irina Belskaya	Kharkiv Karazin National University, Ukraine
4	Philippe Bendjoya	Observatorie de la Côte d'Azur, France
5	Svetlana Berdyugina	KIS, Germany
6	Daniela Boneva	Space Research and Technology Institute, Bulgaria
7	Galin Borisov	National Astronomical Observatory, Bulgaria
8	Esther Buenzli	MPIA Heildelberg, Germany
9	Alberto Cellino	INAF, Osservatorio Astrofisico di Torino, Italy
10	Maxime Devogèle	Observatoire de la Côte d'Azur, France
11	Mauro Focardi	INAF, Osservatorio Astrofisico di Arcetri, Italy
12	Antonio Garcia Munoz	ESA, The Netherlands
13	Maria Gritsevich	University of Helsinki, Finland
14	Nadiia Kostogryz	KIS, Germany
15	Egidio Landi Degl'Innocenti	Università di Firenze, Italy
16	Federico Landini	INAF, Osservatorio Astrofisico di Arcetri, Italy
17	Anny-Chantal Levasseur-Regourd	Univ. P. & M. Curie, Paris, France
18	Arturo Lopez Ariste	THEMIS CNRS, France
19	Paulo Miles-Páez	IAC, Spain
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21	Karri Muinonen	Finnish Geodetic Institute, Finland
22	Enric Pallé	IAC, Spain
23	Patrizio Patriarchi	INAF, Osservatorio Astrofisico di Arcetri, Italy
24	Jean-Pierre Rivet	Observatoire de la Côte d'Azur, France
25	Michiel Rodenhuis	Universiteit Leiden, The Netherlands
26	Rafael Manso Sainz	IAC, Spain
27	Nataliia Shchukina	Main Astronomical Observatory, Kiev, Ukraine
28	Frans Snik	Universiteit Leiden, The Netherlands
29	Daphne Stam	Delf University of Technology, The Netherlands
30	Michael Sterzik	ESO, Germany
31	Paolo Tanga	Observatoire de la Côte d'Azur, France
32	Gian Paolo Tozzi	INAF, Osservatorio Astrofisico di Arcetri, Italy
33	Padma Yanamandra-Fisher	Space Science Institute Research, Cajon Creek, USA

1.1 - Asteroid Polarimetry: State of the art and a roadmap for future developments

A. Cellino

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The state of partial linear polarization of the sunlight scattered by asteroid surfaces in different illumination conditions is diagnostic of a number of important physical properties of the objects. Historically, the most important applications of polarimetry to asteroid studies have been focused on the derivation of the geometric albedo and of the typical sizes of the particles forming the regolith layer covering the surface. This means that, making use of large telescopes, polarimetry can be of crucial importance to achieve a reasonable physical characterization of interesting objects, including members of dynamical families as well as near-Earth objects, particularly those which are potentially hazardous for the terrestrial biosphere. In addition, in more recent years it has been realized also that polarimetric properties are useful to identify objects belonging to different taxonomic classes, including some which may be extremely primitive. In this respect, the discovery of unexpected classes of objects exhibiting peculiar polarization properties (in particular, the so-called Barbarians) has been very important. There are therefore good reasons to expect that asteroid polarimetry will be very important in the years to come. In addition to existing observing facilities, new ones are going to begin operations in the near future.Some much needed developments of future investigations include a better calibration of the relation between polarimetric properties and albedo, a better understanding of the physics of light scattering phenomena, and some applications to hot topics in asteroid science, including asteroid families, the effects of space weathering, asteroid-comet relations, and techniques of alarm and mitigation of the danger posed by potential Earth impactors.

1.2 - Portraits of Barbarians: linking anomalous polarimetry to physical properties

P. Tanga (1), A. Cellino (2), S. Bagnulo (3)

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A few years ago, the asteroid (234) Barbara, belonging to the Ld class in the Bus-de Meo taxonomy, was shown to exhibit peculiar polarimetric properties, namely an unusually wide negative polarization branch and an inversion angle

around 30 degrees. Other objects exhibiting similar spectral reflectance properties (mostly corresponding to the L, and Ld taxonomic classes) were later found to exhibit the same polarimetric behaviour and were collectively nicknamed Barbarians. However, the Barbarian polarimetric properties are not found among all known L-class asteroids. Therefore, we cannot be sure that composition is the only and one responsible of the wide negative polarization branch. On the other hand, there is the possibility that a peculiar distribution of incidence/diffusion angles, resulting from the presence of large concavities on the object surface, could play a role in the polarimetric behaviour. We thus started an extensive study of (234) Barbara and other Barbarians, in order to obtain shape constraints sufficient to confirm or rule out the presence of concave regions. We studied extensively (234) Barbara, using both photometry and stellar occultations. The results show that large concavities are nearly ubiquitous on its surface. Preliminary light curves of other Barbarians seem also to suggest similar conclusions. We also note that a statistically significant excess of long rotation periods seems to be present among known Barbarians. These results suggest that the polarization properties might be at least partly due to the presence of large impact craters. The anomalous polarization of Barbarians, however, has also been interpreted in terms of high-albedo, spinel-rich Calcium-Aluminum inclusions (CAI) which could be abundant on the surfaces of some of these asteroids, according to their spectral reflectance properties and to analogies with CO3/CV3 meteorites. Such CAIs are thought to be among the oldest mineral assemblages ever found in the Solar System. Barbarians surfaces could be therefore rich in this very ancient material, possibly as a result of a long-term collisional evolution exposing such spinel-rich inclusions. Recently, it has been found that two Barbarians exhibiting the above-mentioned CAI spectral features are members of a dynamical family whose lowest-numbered member is (729) Watsonia. We have therefore made a successful proposal to make polarimetric observations of other members of the Watsonia family using the ESO VLT. The observations are still in progress, but we have already found that five out of seven of our Watsonia target objects observed so far do exhibit the polarimetric properties of typical Barbarians. The Watsonia family is therefore a previously unrecognized source of Barbarians, and the problem now will be to understand why these spectro-polarimetric properties seem to be so rare and whether there is any relation between the Barbarian phenomenon, the presence of CAI signatures and other physical properties including intense surface craterisation. Based on their properties, in any case, it seems that Barbarians are extremely interesting objects, and could be among the most ancient accreted bodies in the asteroid belt.

1.3 - Polarimetric observations of 2867 Steins and 21 Lutetia, targets of the Rosetta mission: groundtruth from the Rosetta fly-bys

Fornasier S. (1), Belskaya I. (2)

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Measurements of polarization phase curves in a wide range of phase angles provide unique way to assess the physical properties of the topmost surface layer from remote observations. In many cases the polarimetric method represents essentially the only means of obtaining meaningful estimates of the albedo of an asteroid by the well known experimental relationship between the albedo and the slope of the polarimetric curve at the inversion angle. We present the results of the groundbased polarimetric investigations devoted to the two asteroids 2867 Steins and 21 Lutetia, targets of the Rosetta mission, and we will compare the polarimetric results with the asteroids' surface properties derived from the Rosetta fly-bys. Polarimetric observations of 2867 Steins were carried out for the phase angles between 10 and 28 degrees. Its polarization phase curve is characterized by a shallow negative polarization, a small polarimetric slope of 0.037 ± 0.003 %/deg and an inversion angle of 17.3° in the V filter. All these features are typical of the high albedo E-type asteroids. On the basis of the polarimetric slope value, we have derived an albedo of 0.45 ± 0.1 (Fornasier et al. 2006), fully consistent with the albedo value of 0.40 derived by the OSIRIS instrument onboard the Rosetta mission during the September 2008 fly-by. Asteroid 21 Lutetia shows peculiar polarimetric properties. The most interesting polarimetric characteristic of Lutetia is its wide branch of negative polarization caracterised by a polarisation minimum of 1.30 ± 0.07 % and by a large inversion angle of 25.0 ± 0.4 deg which is not usual for a moderate albedo surface. Only asteroid 234 Barbara and few other asteroids called Barbarians exhibited a polarization branch wider than that of Lutetia. The closest meteorite analogues of Lutetia polarimetric properties are CV3 and CO3 carbonaceous chondrites. From the polarimetric properties it was suggested that Lutetia has heterogeneous surface properties, probably due to variations in the texture and/or mineralogy related to the surface morphology, and covered at least partly by fine-grained regolith (Belskaya et al. 2010). All these hypothesis were further confirmed by the Rosetta fly-by with Lutetia on 10 July 2010.

1.4 - Polarimetric Modeling of Atmosphereless Solar System Bodies

Karri Muinonen (1,2), Evgenij Zubko (1,3), Antti Penttilä (1), Gorden Videen (4,5)

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Polarimetric observations of atmosphereless Solar System objects are interpreted using a radiative-transfer coherent-backscattering model (RT-CB) that makes use of a so-called phenomenological fundamental single scatterer (Muinonen & Videen, JQSRT 113, 2385, 2012). Extensive computations with the discrete-dipole approximation (DDA) are then utilized to extract, from the phenomenological single-scattering solutions, physical solutions in terms of the size, shape, and complex refractive index of the scatterers (Zubko, Light Scattering Rev. 6, 39, 2012). For the validity of RT-CB, see Muinonen et al. (Astrophys. J. 760, 118, 2012). The new RT-CB-DDA modeling allows us to constrain the single-scattering albedo, phase function, and polarization characteristics as well as the mean free path length between successive scatterings. It further allows us to put constraints on the size, shape, and refractive index of the fundamental scatterers. We illustrate the application of RT-CB-DDA by interpreting the polarimetric observations of the C, M, S, and E-class asteroids.

1.5 - Polarimetry of Transneptunian Objects and Centaurs

Belskaya I.N. (1), Bagnulo S. (2)

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Discovery of vast population of small bodies in the outer part of the Solar system beyond Neptune have caused a great interest to investigate their physical properties. Applicability of traditional remote techniques to study trans-Neptunian objects (TNOs) are limited first of all by faintness of these distant bodies which requires using very large telescopes. One more restriction is geometry of the Earth-based observations limited to small phase angles due to remoteness of these objects from the Earth. The maximal possible phase angle for an object

orbiting at 40 AU reaches only 1.5° in case of the Earth-based observations. It means that polarization of TNOs surfaces can be measured only in very small phase angle range and it is unlikely to expect noticeable changes of polarization with the phase angle. However, the pioneering polarimetric observations of a trans-Neptunian object by Boehnhardt et al. (2004) revealed pronounced polarization phase angle dependence. These first polarimetric observations have stimulated further application of polarimetric technique to study surface properties of TNOs. At present, the observational data on polarization properties are available for 14 TNOs and Centaurs, and some general trends become evident. We review the available polarimetric observations and discuss their possible relationships with orbital characteristics and surface composition.

References

Boehnhardt H., Bagnulo S., Muinonen K., Barucci M.A., Kolokolova L., Dotto E., Tozzi G.P. Surface characterization of 28978 Ixion (2001 KX76). Astron. Astrophys. 415, L21L25, 2004.

1.6 - Polarimetry of comets, with emphasis on comet 67P/C-G

A.Chantal Levasseur-Regourd

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Solar light scattered on irregular dust particles that, in a comet, are found on the dark nucleus surface, in the wide coma surrounding it, and in the dust tail and trail, is partially linearly polarized. This talk is actually intended to summarize our present understanding the linear polarization (Q/I) of cometary comae. Polarimetric observations of cometary dust, either unique from in situ space probes or numerous from remote observatories, may be challenging, with polarized intensities measured through narrow-band filters, in order to avoid contamination from less polarized gaseous emissions. They are nevertheless of major interest. They enable comparisons between different regions within a coma, e.g., more polarized jet-like features and less polarized innermost coma, which point out the presence of different dust particles. They also allow the drawing of polarization phase curves that present a shallow negative branch in the backscattering region and a wide positive branch with a maximum in the $80° - 110°$ region. Such phase curves may point out, from observations above 30°, comets with a low polarization, comets with a high polarization, and exceptionally fragmenting comets with a very high polarization. The variation of the polarization with the wavelength, for a fixed phase angle, may also be monitored; the polarization of cometary dust mostly reveals a positive spectral gradient (polarization higher with increasing wavelength, in the visual domain), but in the innermost coma, where the gradient may be negative. Recent results will be summarized, with emphasis on changes likely to be triggered by the gradual evolution of dust particles. Tentative interpretation of the observed

polarimetric properties, in terms of dust particles size (and size distribution), shape and morphology (including porosity), complex refractive index (related to the composition) and geometric albedo (depending upon the above-mentioned physical properties) will be tentatively be analyzed. Recent progresses related to such approaches, which stem from elaborate light-scattering numerical and experimental simulations, and of comparisons between their results, will be presented. Finally, it is proposed to discuss the properties of the dust (see the three references below) within comet 67P/Churyumov-Gerasimenko (67P/C-G), the target of the European Rosetta mission that is expected to rendezvous 67P/C-G from May 2014 to December 2015. The spacecraft will have to hover above the nucleus, in the relatively unknown innermost coma to deliver the Philae lander. Also, after perihelion passage in August 2015, it will probably encounter jets triggered by seasonal effects on the nucleus.

References:

Fulle, M., et al. (2010) Comet 67P Churyumov-Gerasimenko: the GIADA dust environment model of Rosetta mission target, Astron. Astrophys., 522, A63

Hadamcik, E., et al., (2010) Polarimetric observations of comet 67P/Churyumov-Gerasimenko during its 2008- 2009 apparition, Astron. Astrophys, 517, A86

Tozzi, G.P., et al. (2011) Evolution of the dust coma in comet 67P/Churyumov-Gerasimenko before the 2009 perihelion, Astron. Astrophys , 531, A54

1.7 Polarimetry of comets 9P and 73P

S. Bagnulo (1), H. Boehnhardt (2), L. Kolokolova (3), G.P. Tozzi (4)

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3: Planetary Data System Group, Department of Astronomy, University of Maryland, USA
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Extended moving objects are probably the most difficult targets for high accuracy polarimetry. Pointing issues (particularly critical if differential tracking varies during the time of the observation), field distorsion, instrumental polarisation that may vary across the instrument field of view, are all effects that have to be addressed both while preparing the observations and at the time of data reduction. Comets are moving and extended objects. With the FORS instrument of the ESO VLT we have collected a dataset of imaging polarimetry and spectro-polarimetric data of comets 9P and 73P. In this talk we will critically present some results of our data analysis, disentangling established results from potential instrumental artifacts.

1.8 - Polarimetric Observations of the nucleus of comet 67P/Churyumov-Gerasimenko, the target of the mission Rosetta.

G.P. Tozzi (1), S. Bagnulo (2), H. Boehnhardt (3), S. Fornasier (4)

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The comet 67P/C-G was observed in photometry and polarimetry at eight epochs during Febraury and March 2010. The observations were performed with the FORS instrument of the ESO Very Large Telescope, using the broad-band special Bessel R filter. Each series of polarimetric observations consisted of one or more aquisition images obtained without polarimetric optics, and a series of images obtained with the half waveplate set at eight positions, in steps of 22.5°.

At that time the comet was after perihelion at an heliocentric distance of 3.4-3.7 AU. Its phase-angle varied from 15.4° to 3.72°.

By analizing the acquisition images we discovered that a long tail and a faint coma was present. The contribution of the coma/tail to the nucleus signal could contribute up to about 50 %. Without taking this into account we would introduce severe systematic errors.

In this talk we will present the method used to disentangle the polarisation due to the tail and coma from the polarisation of the nucleus. We conclude that coma and tail have polarisation characteristics similar to that of the nucleus.

1.9 - On the study of small bodies and Zodiacal light in the near-Earth and interplanetary space by the polarimetry methods

Daniela Boneva (1), Lachezar Filipov (2), Krasimira Yankova (3)

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We present our investigation on the small body properties and dynamics by applying the methods of polarimetry. A study of the zodiacal light as the indicator of interplanetary matter could provide an important information about an estimation of the magnetic surfaces in the Solar system. On the base of polarimetry methods we suggest a model for analysis of the Zodiacal lights stability and nature. Further, this method could be applied on the nano-satellite instruments data receiving and processing.

2.1 - Spectropolarimetry of Earthshine

M. Sterzik(1), S. Bagnulo(2), D. Stam(3), C. Emde(4), R. Buras(4)

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The quest for planets located in habitable zones, and, ultimately, life on extrasolar planets has already started. The origin of life in most extreme environments and the conditions for its evolution on Earth may be useful guides for our search of extraterrestrial Life. The emergence of photosynthesis early in Earths history marked the beginning of fundamental changes in climate and furnishes significant amounts of molecules far from chemical equilibrium into the atmosphere.

Our group has pioneered the astrophysical application of precision spectropolarimetry towards the characterisation of the atmosphere of planet Earth using Earthshine. Our measurements demonstrate that polarimetric spectra of the Earth allow to infer and characterise biosignatures.

We have obtained new spectropolarimetric observations of Earthshine (with low and high spectral resolution, and at various phase angles) at the VLT with the FORS instrument. The inclusion of realistic surface and scattering properties in enhanced radiative vector transfer models will allow to constrain the most robust signatures for the characterisation of Earth-like atmospheres. The application of (spectro)polarimetry may become key for the imminent search for life on exoplanets with the next generation of giant, ground-based, telescopes.

2.2 Spectropolarimetry of the Earthshine from visible to near-infrared wavelengths

E. Palle (1), P. A. Miles-Páez (1), M.R. Zapatero-Osorio (2)

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More than 900 extrasolar planets are known to date with masses spanning from a few Jupiter masses down to mass of Mars, and many more exoplanet candidates are awaiting to be confirmed. Furthermore, new instrumentation is being developed with capabilities to detect Earth-mass planets around nearby stars. This scenario suggests that the discovery of exo-Earths may lie in the near future. Thus, it becomes necessary to characterize our world as a exoplanet" to properly understand the soon-to come findings. Spectropolarimetry of the Earthshine is sensitive to the atmospheric patterns and surface features of the Earth (Sterzik et al, 2012). Here, we present our spectro-polarimetric earthshine observations obtained in the optical and near-infrared using ALFOSC on

the 2.5-m NOT telescope and LIRIS on the 4-m WHT telescope, respectively. We derived the linear polarization degree, induced by the Earth as a function of wavelength. We find that while the overall polarization of the Earths reflected light is weaker in the near-infrared, the polarization signature of atmospheric molecular features in this regime makes it ideal for the future characterization of rocky exoplanets.

2.3 - The polarization of Earth. Earthshine polarimetry in the B, V, R, and I band as function of phase

Andreas Bazzon (1), Hans Martin Schmid (2), Daniel Gisler (3)

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The characterization of the polarimetric properties of the planet Earth is important for the interpretation of expected observations and the planning of future instruments. I will describe our measurements of the polarization of Earth in the B, V, R, and I filter derived from observations of the earthshine back-scattered from the Moon's dark side for Earth phase angles between 30° and 110°. For the observations we used a specifically designed wide field polarimeter. Depending on wavelength λ and lunar surface albedo a the polarization of the back-scattered earthshine is strongly reduced. To determine the polarization of Earth, we correct our earthshine measurements by a polarization efficiency function $\epsilon(\lambda, a)$ for the lunar surface derived from measurements of Apollo lunar soil samples from the literature. The fractional polarization for Earth is decreasing with wavelength and at quadrature we find values 24.6 % for the B band, 19.1 % for the V band, 13.5 % for the R band, and 8.3 % for the I band. Together with literature values for the spectral reflectivity we obtain a contrast between the polarized flux of the Earth and the (total) flux of the Sun with an uncertainty of less than 20 % and we find that the best phase to detect an Earth twin is around $\alpha = 65°$. Our results are in qualitative agreement with polarimetric models of Earth-like planets and they can now be used to guide more detailed computations.

2.4 - Spectropolarimetry of the exosphere of Mercury

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Using the solar telescope THEMIS we have observed the Na D lines emitted by the exosphere of Mercury and measured its linear polarisation along the orbit of this planet. The polarization is due to resonance scattering in Na atoms polarized by the highly anisotropic illumination for the Sun. The presence of Na in the exosphere of this planet is highly related with the interaction of the Interplanetary Magnetic Field and the dipolar magnetic field of Mercury. There is therefore an opportunity to measure those fields in interaction through the Hanle effect. At present we have not reached those levels of sensitivity, but we have observed both the variation of polarisation along the orbit and the depolarization due to multiple scattering in the exosphere.

2.5 - Narrow-band imaging polarimetry of the atmospheres of Venus and Saturn at multiple visible wavelengths

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Imaging polarimetry of exoplanets is expected to become available from several instruments (e.g. SPHERE, GPI) in the near future. As a benchmark, imaging polarimetry observations of atmospheres of solar system planets are very useful. Venus in particular is interesting as it is the only planet with an atmosphere that we can observe at a wide range of phase angles. We present multi-wavelength imaging polarimetry of Venus and Saturn obtained with the Extreme Polarimeter, ExPo. The observations have been obtained using narrow-band filters in the range 364 - 648 nm, and, in the case of Venus, at a phase angle of 49 degrees. The Venus observations have been followed up using the ZIMPOL polarimeter at the IRSOL telescope at phase angles from 11 to 31 degrees. The upper atmosphere of Venus is known to contain sulphuric acid droplets of 1μm in diameter (Hansen & Hovenier, 1974), a result that was obtained using earlier polarimetric studies. From our new observations, that offer both higher spatial resolution and polarimetric sensitivity, we find that the degree of polarization varies strongly with wavelength and phase angle, as generally predicted by the

model by Hansen & Hovenier. However, the polarization behaviour near the equator differs considerably from that at the poles, hinting at different atmospheric compositions and/or stratifications. In the intensity images we detect a significant shift of the location of maximum intensity with wavelength. In both the observations of Venus and Saturn we also observe intriguing polarized features at smaller spatial scales, implying more complex scattering behavior or atmospheric structure. Attempts to model these features are ongoing and we present the preliminary results of this effort.

2.6 - Limb polarization as a probe of haze in outer planet atmospheres

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The polarization of light reflected from a planet provides unique information on the atmosphere structure and scattering properties of particles in the upper atmosphere. For the outer planets, observations from Earth measure mainly backscattered light that is generally unpolarized. However, a second order scattering effect produces a measurable limb polarization for resolved planetary disks.

We have obtained imaging- and spectropolarimetric observations of the limb polarization of the Jovian planets and analyzed archival HST imaging polarimetry of Titan. We interpret our observations with a Monte Carlo scattering code that calculates the intensity and radial polarization depending on the scattering and absorption properties of gas and haze particles.

For Uranus, we are able to reproduce the spectropolarimetric signal from 530 to 930 nm with a combination of Rayleigh scattering and an extended haze layer. The limb polarization is enhanced within methane absorption bands due to an heterogeneous vertical distribution of absorbers. From the model, we predict the polarimetric signal at large phase angles which is of interest for extrasolar planet searches.

Jupiter shows pronounced limb polarization of up to 10 % at the poles, which we can reproduce with aggregate haze particles. Similar haze is found in Titan's atmosphere. Our data of Saturn reveal a transient polarization feature near the equator. Neptune's limb polarization signal is similar to Uranus. We discuss the diagnostic potential of our limb polarization observations and models.

2.7 - Backward Monte Carlo model for polarization in planetary atmospheres

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The stellar light scattered from a planet's atmosphere is polarized. Despite the well-known potential in the technique of polarimetry, the characterization of the polarization spectrum of the Solar System planets remains incomplete, even in those cases where measurements are available. This is partly due to the complexity of the polarization phenomenon in scattering media and the difficulty for its accurate modelling. The interest in polarimetry has increased over the last years because the technique presents clear advantages for the detection and characterization of exoplanets and their atmospheres through the analysis of the planet's disk-integrated signal. Phenomena such as the rainbow, glint and Rayleigh/Mie scattering, which have associated polarized signatures, have been postulated as indicators of various atmospheric properties.
In this communication, we present an ongoing effort whose ultimate goal is to build a tool capable of predicting both the spatially-resolved and disk-integrated polarization signature of planets. For that purpose, we explore the capacities of the Monte Carlo sampling method in its application to solving the vector radiative equation. Monte Carlo sampling is particularly efficient when the required SNR is not particularly high and/or when the spectral resolution is moderate. We will present the current status of the project, including validation exercises and ongoing applications to planets of the Solar System and beyond.

2.8 - Spectropolarimetric signatures of Earth-like extrasolar planets

D. Stam & T. Karalidi

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Polarimetry appears to be a strong tool for detecting exoplanets and also for characterizing them. By lack of disk-integrated polarisation signals of the Earth, numerical models can be used to estimate the expected signals that are needed for the development of polarimeters for exoplanet research and for investigating the information content of the data. I will show results of numerical simulations for Earth-like exoplanets, and discuss the features in the polarimetric spectra. I will also briefly describe a database with calculated reflected total and polarized fluxes that can be used for modeling signals of various types of planets.

3.1 - Possibilities of FoReRo2 at NAO Rozhen for polarimetric and spectro-polarimetric observations. Comet C/2011 L4 (PanSTARRS) preliminary results

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We present the possibilities of the 2-Channel Focal Reducer (FoReRo2) at the 2 m Ritchey-Chrétien-Coudé (RCC) telescope at National Astronomical Observatory (NAO) Rozhen for polarimetric and spectro-polarimetric observations. The features of this apparatus for Solar System polarimetric investigations will be discussed as well as some problems with calibrations and instrumental polarization determination. As an example we will present preliminary results from the last observing campaign of our team for observations of the new bright comet C/2011 L4 (PanSTARRS) discovered on June 6, 2011 with Pan-STARRS 1 telescope (Haleakala). The comet was observed in the imaging polarimetry mode of the FoReRo2 through blue and red continuum filters centred at 443 and 684 nm respectively. The variation of linear polarization with wavelength is investigated using new spectro-polarimety mode of FoReRo2.

3.2 - SPHERE-ZIMPOL polarimetry of planetary systems

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SPHERE-ZIMPOL is be a high-resolution, high-contrast imaging polarimeter which is expected to become operational in 2014 at the VLT. This talk gives an overview of the instrument capabilities and describes possible science programs for SPHERE-ZIMPOL including spatially resolved polarimetry of Titan and Asteroids, circumstellar disks and the search of polarized light from extra-solar planets. First observations of this kind could be proposed by a COST team for the science verification program of this instrument.

3.3 - A proposal for a novel integrated nano Wire Grid Polarisers-based VNIR polarimeter for planetary studies from space

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We present a proposal for a novel full-Stokes integrated polarimeter based on nano Wire Grid Polarisers (nano-WGP) and a Liquid Crystal Variable Retarder (LCVR) operating by filtering the polarised radiation in a narrow band of the VNIR and placed in front of the detector. The device (Figure 1) has the potentiality to perform the overall measurement of the Stokes vector components (I, Q, U, V), exploiting the random addressing of a hybrid or CMOS detector with a customised readout scheme and an embedded digital data pre-processing hosted by the camera assembly.

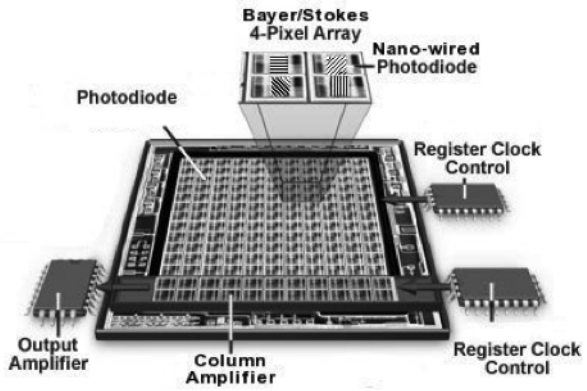

Figure 1: The nano-WGP integrated polarimeter shown without the retardance plate.

LCVRs acts as a tunable retardance plate (e.g. a quarter wave plate), while sub-matrix WGPs matching the pixels surfaces and oriented in at least three different directions (e.g. 0°, 45°, 90° and 135° for a 2x2, 4 px sub-array) act as linear analysers for the incoming photons. Such an integrated device permits to perform the full Stokes vector measurement during the integration time (split in 2 runs in order to measure the circular polarisation V component too) and to operate a cross-calibration along the pixels sub-arrays improving the measure reliability and the overall detector efficiency. The polarised radiation is measured by a detector performing non-destructive readouts to improve the S/N ratio over the exposure time required to capture the planetary faint signal,

when operating the device in readout noise (RON) limited conditions. A preliminary on-board (i.e. by means a FPGA and an on-board memory) pre-processing on the digital data is performed. The on-board logic also manages the overall digital signals generation and timing for the detector and LCVR control (to set the retardance value and for the thermal stabilisation control). The proposed device is optimised for space use due to low power consumption (of the order of 1-3 Watts), low mass and volume, no moving parts, low complexity and a potential embedded pre-processing to alleviate the processing capabilities and computing resources of the data handling unit. It would represent an important investigating tool for planets and exo-planets studies (e.g. linear polarised light characterising the planet surface, magnetic interactions between stellar coronae and planets by means of circular polarisation measurements) and for solar atmosphere studies in order to measure the electron densities to perform plasma diagnostic on the K-corona.

3.4 - Observing the Earth as an exoplanet with LOUPE, the lunar observatory for unresolved polarimetry of Earth

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By lack of disk-integrated polarimetry of the Earth, numerical models are being used to predict expected signals of Earth-like exoplanets. Despite the sophistication of these models, the true variation of the Earth's signal is hard to predict and to model. We will present plans for LOUPE, a small, robust spectropolarimeter that could be placed on the moon to observe the Earth as if it were an exoplanet, and first results for a laboratory set-up.

3.5 - iSPEX: measurements of atmospheric aerosols by a citizen science network using smartphone spectropolarimeters

F. Snik & iSPEX team

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iSPEX is a spectropolarimetric add-on for the iPhone camera, which, together with a dedicated app, turns that smartphone into a scientific measurement device for atmospheric aerosol measurements. In July 2013, thousands of participants spread across the Netherlands carried out iSPEX measurements of the blue sky; one of the largest citizen science experiments ever. We present some preliminary results from this measurement day, and an outlook for the future of this and similar projects.

3.6 - CAPS @ C2PU

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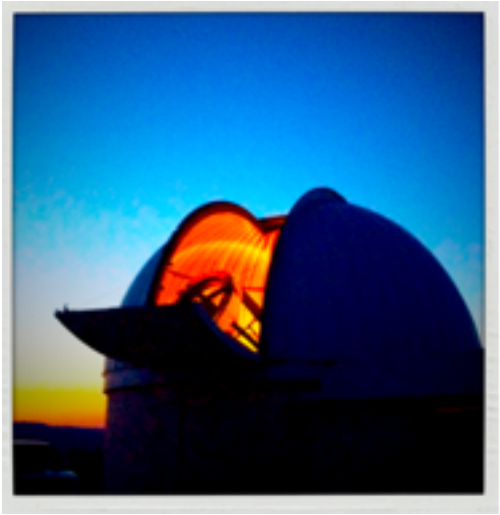

Figure 1: West Dome of the C2PU : Centre for Pedagogy in Planet and Universe at Observatoire de la Cte dAzur France

CAPS stands for "Calern Asteroid Polarimetric Survey". It is a program of observation that will start at the end of 2013 in the south part of France : Plateau de Calern. The instrument is a a new "single-shot" CCD polarimeter based on a "double-Wollaston" configuration. This configuration allows simultaneous acquisition of the three Stokes parameters I, Q, U without any moving parts. The linear polarisation degree can thus be measured accurately, even for targets with fast polarisation and/or airmass variations. This configuration is well suited configuration for the polarimetric observation of asteroids. The polarimeter is installed at the Cassegrain focus f/12.5 of a 104 cm telescope that has been fully refurbished by Observatoire de la Côte d'Azur (OCA) and Universitde Nice Sophia Antipolis (UNS) for both pedagogy and research purposes in the framework of the Centre for Pedagogy in Planet and Universe (C2PU). The full project C2PU consist in twin telescopes in different configurations. The West-Telescope, on which CAPS is installed, is completely operational and is remotely reachable.

3.7 - EduCosmos: Participative science for high school students with 1m telescopes

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EduCosmos is a project that will allow high- and medium-school students to participate in scientific research. Researchers from the Observatoire de la Cote d'Azur (Nice, France) propose scientific projects that need observations with the two 1-meter telescopes belonging to the Observatoire, located at the Plateau de Calern (alt. 1280 m), 70 km away from Nice, that are part of the C2PU project (see presentation CAPS @ C2PU). The students, guided by their teachers and by the EduCosmos team, will perform the observations remotely. Teachers are formed in agreement with the local education authorities to be able to understand the scientific project, perform the observations and reduce the data. Students will be formed by their teachers and will have the support of the EduCosmos scientific team to be able to conduct successfully the observations and to understand their participation in the scientific program. The telescope is equipped with a polarimeter that will be available for the students observations. A special effort has to be done to bring polarimetric notions to a high-school public and their teachers.

4.1 - Polarimetry of transiting exoplanets

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Since the discovery of the first extrasolar planet methods of their detection and characterization are rapidly developing. The best characterized planets are so far those which were detected by different methods. Thanks to the recent high accuracy polarimetric instruments, polarimetry has become an independent technique for characterizing exoplanetary systems as it yields information inaccessible to other methods. As was shown observed polarization variability due to scattering in the planetary atmosphere reveals the orbital period of the planet, inclination, eccentricity, orientation of the orbit as well as the nature of scattering particles in the planetary atmosphere. We present and discuss another polarimetric effect caused by a planet transiting the stellar disk and, therefore, breaking its symmetry and resulting in linear polarization of a partially eclipsed star. Such an effect was predicted in 1950 for binary stars, and it was first detected in the eclipsing binary Algol. Estimates of this effect for transiting planets were made only recently. In particular, we demonstrated that the maximum polarization for one of the brightest transiting planets HD 189733b strongly depends on the centre-to-limb variation of linear polarization for the host star. However, observational and theoretical studies of the limb polarization have been largely concentrated on the Sun. As was shown in our previous study, we expect to observe a larger centre-to-limb linear polarization for cooler stars. Here we solve the radiative transfer problem for polarized light and simulate the centre-to-limb polarization for stars of different spectral classes taking into account various opacities. Employing our simulations for all transiting exoplanets we select most promising targets for future polarimetric observations.

4.2 - The continuum polarization of stars with transiting exoplanetary systems

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Zero linear polarization is expected for a spherically symmetric star. Any asymmetry causes incomplete cancellation of the stellar limb polarization and, as a result, non-zero polarization. It is important to investigate the linear continuum polarization of exoplanetary systems as a result of the occultation of the star by

a transiting planet. In order to estimate this effect it is necessary to know the center-to-limb variation of the stellar continuum intensity (the limb-darkering law) and the center-to-limb variation of the continuum polarization in the stars under consideration. Up to now observational and theoretical studies of the continuum polarization have largely concentrated on the Sun (e.g. Trujillo Bueno & Shchukina 2009, and references therein). The results of such studies are usually adopted to calculate the continuum polarization resulting from occultation effects in given atmospheric models of late-type stars (e.g. Carciofi, Magalhães 2005; Kostogryz et al. 2011). Here we present results on the linear continuum polarization produced in the atmospheres of late-type stars of F, G, K types. We use a grid of Kurucz ATLAS9 one-dimensional atmosphere models with overshooting. The computations are presented for metallicities ranging from 0.5 up to +0.5 solar abundances, with gravity varying between 3.0 and 4.8 and effective temperatures between 4600 K6400 K. We account for the physics of Rayleigh scattering from the ground level of neutral hydrogen and of Thomson scattering at free electrons to describe polarization for these stars. The numerical method of solution is based on the iterative methods developed by Trujillo Bueno & Manso Sainz (1999). Since the atmosphere is one-dimensional, the radiation field has rotational symmetry with respect to the vertical to the stellar atmosphere and the only non-vanishing Stokes parameters are I and Q. We calculate the center-to limb continuum polarization $P(\mu) = Q(\mu)/I(\mu)$. Results for the wavelength range between 300 nm800 nm and for the Johnson-Cousins UX, B, V, R, I filters are discussed. We also present new results on the efective polarizability and on the anisotropy of the continuum radiation. We discuss the variation of these quantities with the effective temperature, gravity and metallicity of the star. We approximate the center-to-limb variation of the stellar continuum intensity and the center-to-limb variation of the continuum polarization by polynomials of 4th and 6th order, respectively. The continuum polarization for several representarive stars with extrasolar planetary systems are discussed in detail. Among them are HD189733, CoRoT-2, TrES-3, WASP-4. The results of our radiative transfer modeling can be applied to predict polarization curves produced during planetary transits.

4.3 - Infrared polarimetry of the HR8799 planets

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2: SRON, the Netherlands
3: API Amsterdam, the Netherlands
4: ESO, Chile

We present the first results from our VLT/NaCo polarimetric observations of the HR 8799 exoplanetary system. The planets are expected to be polarized in the near-IR, as their thermal emission gets scattered in their hazy atmospheres.

Asymmetries due to spots, band or flattening may give rise to a few percent of linear polarization. For these observations, we introduce a new observing mode at NaCo: pupil-stabilized polarimetry. This allows for both angular differential imaging and high-accuracy polarimetry, as the instrumental polarization is minimized and stabilized. We present the performance of speckle suppression due to PSF subtraction with a PCA approach, and due to the dual-beam polarimetry. Preliminary estimates on the (upper limit upon) the polarization of planets b and c will be presented.

4.4 Linear polarization of rapidly rotating ultracool dwarfs

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We present imaging linear polarimetry data of a sample of 18 late-M, L-, and early-T type dwarfs taken with the Z- and J-band filters and the LIRIS instrument of the 4.2-m William Herschel Telescope (Figure 1). All of our targets have projected rotational velocities 30 km s-1 and ultracool atmospheres ($T_{\rm eff} \leq 2800\,{\rm K}$), which may harbor clouds of condensate particles in oblate-shaped objects. Our polarimetric measurements have typical error bars of $\pm 0.13\,\%$, i.e., at the 3 level linear polarization larger than $0.4\,\%$ can be positively detected. Seven dwarfs appear to be polarized in the J-band with indices of$P = 0.4 - 0.7\,\%$, suggesting the presence of atmospheric dusty structures. There is a hint that the dwarfs with the largest rotations (vsini 60 km s-1) show higher incidence of positive J-band linear polarization than the dwarfs with smaller projected rotational velocities. Also, we find variability in the linear polarization of a few dwarfs indicative of 'weather' changes. This work has been recently accepted for publication in A&A.

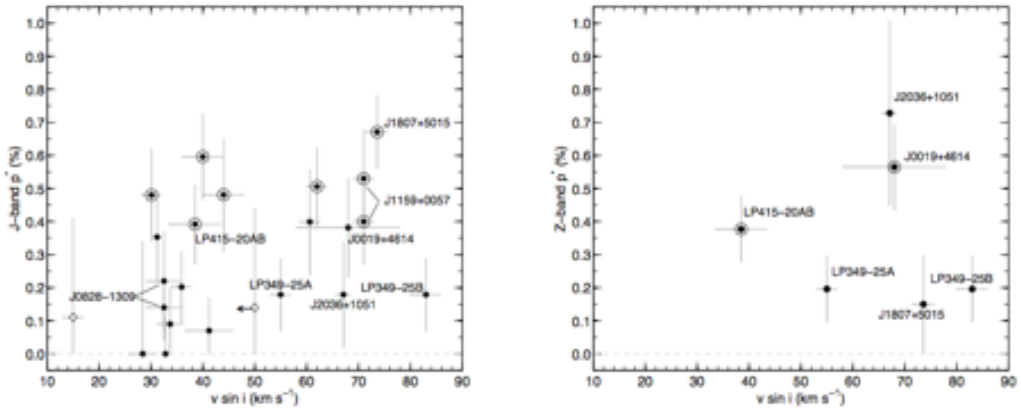

Figure 1: Debiased J-(left) and Z-band (right) linear polarization degree as a function of projected rotational velocity. Our data are plotted as black dots and data from the literature as open diamonds (the arrow stands for an upper limit on vsini). Positive detection of linear polarization ($P/ \geq 3$) is indicated by open circles surrounding the black dots. Some objects are labeled. Velocity measurements and their associated error bars are taken from the literature as explained in Miles-Páez et al.

4.5 Polarimetry of Hot Inflated Jupiters Reveals Their Blue Colors

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2 : Finnish Centre for Astronomy with ESO, University of Turku, Finland

Polarimetry is a powerful technique for detecting directly exoplanetary atmospheres and probing their geometry, chemistry, and thermodynamics. Recently, we have started a polarimetric survey of nearby planetary systems with hot Jupiters closely orbiting their host stars. Here we will discuss our previous results in the context of recent albedo estimates using the secondary eclipses, and we will present new polarimetric observations of other exoplanets.

From Hotel Classic to Villa il Gioiello on foot: http://goo.gl/maps/NoLHU
From Villa Agape to Villa il Gioiello: http://goo.gl/maps/kExbC
From Railway station to Hotel Classic on foot: http://goo.gl/maps/oRuZF
From Railway station to Villa Agape by bus then on foot http://goo.gl/maps/ZbCqd
From Porta Romana to conference dinner: http://goo.gl/maps/LlYZi