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Imaging at High Angular Resolution of Stellar Surfaces and Close Environment

Evry Schatzman School 2017

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Figure 1. Some of the organisers of the school (from left to right: Yveline Lebreton, Nicolas Nardetto, Eric Lagadec and Guillaume Mella)

Figure 2. Yveline Lebreton et Nicolas Nardetto, enjoying the welcoming reception.

Figure 3. The EES17 participants.

List of participants

1. Beldi Samir, GEPI, Observatoire de Paris, France
2. Bollen Dylan, Institute of astronomy, KU Leuven, Belgium
3. Borgniet Simon, CNRS UMI 3386 - Laboratoire Franco-Chilien d'Astronomie, Chile
4. Bouchaud Kevin, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
5. Ceau Alban, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
6. Crida Aurélien, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
7. Falla Romain, STAR Institute, Liège, Belgium
8. Fontanive Clémence, Institute for Astronomy, University of Edinburgh, Scotland
9. Hocdé Vincent, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
10. Jonak Juraj, Charles University, Faculty of Mathemathics and Physics, Czech Republic
11. Kervella Pierre, LESIA, Observatoire de Paris, France
12. Koumpia Evgenia, University of Leeds, UK
13. Kravchenko Kateryna, ULB Bruxelles, Belgium
14. Labdon Aaron, University of Exeter, Astrophysics Group, UK
15. Lagadec Eric, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
16. Lagrange Anne-Marie, Institut de Planétologie et d'Astrophysique de Grenoble, France
17. Lanthermann Cyprien, Institut de Planétologie et d'Astrophysique de Grenoble, France
18. Lebreton Yveline, LESIA, Observatoire de Paris et IPR, Université de Rennes 1, France
19. Lehmann Lucien, XLIM, Limoges, France
20. Ligi Roxanne, Laboratoire d'Astrophysique de Marseille, France
21. Martinache Frantz, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
22. Martinod Marc-Antoine, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
23. Maury Anaëlle, Département d'Astrophysique, CEA, Université Paris Saclay, France
24. Mella Guillaume, JMMC, Institut de Planétologie et d'Astrophysique de Grenoble, France
25. Ménard Francois, Institut de Planétologie et d'Astrophysique de Grenoble, France
26. Millour Florentin, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
27. Mourard Denis, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
28. Nardetto Nicolas, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France

29. Postnikova Marina, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
30. Potier Axel, LESIA, Observatoire de Paris, France
31. Rainot Alan, KU Leuven, Belgique
32. Royer Frédéric, GEPI, Observatoire de Paris, France
33. Saldanha da Gama de Almeida Elisson, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
34. Soulain Anthony, Laboratoire Lagrange, Observatoire de la Côte d'Azur, France
35. Surdej Jean, Université de Liège, Belgium
36. Trahin Boris, CNRS UMI 3386 - Laboratoire Franco-Chilien d'Astronomie, Chile
37. van der Plas Gerrit, Institut de Planétologie et d'Astrophysique de Grenoble, France
38. Villenave Marion, Institut de Planétologie et d'Astrophysique de Grenoble, France

Contents

Preface

The 2017 edition of the Evry Schatzman school (EES 2017) of the French National Program for Stellar Physics (PNPS) was held in Roscoff (France) from the 24th to the 29th of September[1]. This school focused on high angular resolution imaging. High angular resolution is a thriving theme with many operating instruments such as SPHERE (VLT) and ALMA, but also long-term projects, like the forthcoming JWST and ELT. It concerns monolithic telescopes, but also interferometric instruments with for instance, PIONIER (VLTI), MIRC (CHARA), VEGA (CHARA), GRAVITY (VLTI), MATISSE (VLTI) . . . , or at longer wavelengths ALMA and NOEMA. All these instruments, with their specific angular resolution, their wavelength coverage and spectral resolution, are essential for studying star forming regions, protoplanetary discs, as well as the surface and environment of stars. High angular resolution imaging is a priority theme for the National Program for Stellar Physics (PNPS) and is also essential for the study of extrasolar systems, a unifying theme of the French National Program for Planetology (PNP).

The research theme of "High Angular Resolution" is today structured in France by the ASHRA (Action Spécifique pour la Haute Résolution Angulaire) specific action. Research in the High Angular Resolution domain aims at a single objective: the control of the wave front to reach the limit of resolution. Around this objective, the discipline has been regularly diversified by the successive apparition of several research themes during its history: optical interferometry, adaptive optics, very high dynamics, signal processing, not to forget the study of atmospheric turbulence, and the development of innovative optical concepts.

The impact of optical interferometry on stellar physics (but not only) is extremely diverse. We can mention the determination of fundamental stellar and exoplanetary parameters, asteroseismology, the distance to Cepheids, the study of protoplanetary disks, fast rotators, the convective structure of (super)giant stars and their circumstellar environments. Interferometry has produced images since about 2009. At the same time, thanks to the development of adaptive optics, it is now possible to directly image the very close environment of giants and red supergiants (like Betelgeuse or L2 Puppis) with monolithic telescopes (such as NACO at the VLT, for example). These revealed the presence of asymmetric nebula due to non-isotropic, transient mass loss. SPHERE (VLT)is currently producing similar results. In the longer term, direct imaging of stellar surfaces will be possible with the ELT, leading to a better understanding of stellar convection, the environment of massive or evolved stars together with their mass loss, etc...

High angular resolution requires state-of-the-art instrumental expertise, which must take into account a whole range of technical and scientific constraints. The rapid evolution of this theme in the world of stellar and planetary physics raises the need of a good communication between several communities: high angular resolution instrument designers on the one hand and their users on the other, i.e. stellar-physicists and/or exo-planetologists, for instance. This school thus aimed first and foremost to bring these two communities close together. There are also strong emerging synergies between the different imaging techniques: monolithic telescopes versus interferometry, optical versus radio observations, and we can also mention, for instance, the fruitful complementarity of interferometry and asteroseismology, in order to determine the fundamental parameters of stars. The school aimed at clarifying these synergies. It was also a matter of "democratizing" the high angular resolution techniques in order to make this theme more accessible to the entire "stellar" and "planetary" community.

The EES 2017 school gathered 38 participants, including 1 master student, 20 doctoral students, 3 post-docs, 1 computer engineer, and 13 researchers, including 10 speakers/organizers. The proportion of students and post-docs was therefore significant (around

[1] https://hraetoile2017.sciencesconf.org/program

63%). Seven participants were coming from European, non-French, laboratories. The school was organized around five three-hour courses, three four-hour sessions, and two thematic seminars.

The **first lecture**, by Frantz Martinache, was dedicated to the principles of imaging together with a practical session on atmospheric disturbances and image processing techniques. The **second course**, by Anne-Marie-Lagrange,[2] gave an overview of current imaging instruments with the latest applications both in terms of planetology (protoplanetary disks, detections of exoplanets) and in terms of stellar physics (environment of evolved stars ...). The corresponding practical session was devoted to SPHERE/VLT data processing. The first part of the school on imaging (mostly related to monolithic instruments) finally ended with perspectives, and a seminar on the ELT. The **third course**, by Jean Surdej, introduced the complex principles of interferometry based on the imaging principles enunciated in the first lecture. The **fourth lecture**, by Denis Mourard, continued with an overview of current optical interferometric instruments and the latest spectacular astrophysical results, including in particular the determination of fundamental stellar and planetary parameters. The associated practical session was based on the tools of the JMMC (Center Jean-Marie Mariotti, French structure offering user support for all the interferometric instruments of the world), with also an example of data processing and image reconstruction in interferometry. The session on optical interferometry ended with a seminar on the most recent instrument, Gravity on the VLTI. The school finished with a **fifth lecture** on radio interferometry, by Anaëlle Maury, which was an important complement to previous lectures[2].

The school thus made it possible to understand that interferometry is ultimately an imaging technique, and that radio interferometry, which is 30 years older than optical interferometry, has benefited from the fact that it is easier to determine the fringe position (phase) in this wavelength range, compared to the optical domain. This also allows for a more direct image reconstruction. The overview of the astrophysical applications associated with these different techniques was very complete, with a good balance (and interesting links) between proto-planetary disks, exo-planets and stellar environments. In addition, the three practical sessions, highly appreciated, have really made it possible to give practical tools to the students for this sometimes very complex knowledge on imaging techniques. These sessions also allowed a lot of exchanges among the participants in a rather relaxed atmosphere. In addition to classes, lectures and seminars, a discussion session around a few posters was organized to stimulate communication and questions.

We hope that this book will be useful for the students but also engineers and researchers who attended the school, and to anyone who wants to learn about the fundamental principles of imaging and interferometry, as well as the latest astrophysical applications. The field of Imaging and High Angular Resolution in stellar physics is a very active field of research, which gives spectacular results, in the sense that they can be of interest also to the public. Let us mention to finish the famous star peanut which had, in its time, opened the astro-appetite of the public, especially in the French Riviera ! This result was obtained by our colleague Olivier Chesneau who passed away the 17th of May 2014, specialist of interferometry. We dedicate this school and this book to him and his memory.

We warmly thank our colleagues of the Scientific and Local Organizing Committees, Anthony Meilland for the design of the website of the school and the poster, Guillaume Mella for his very careful and expert handling of the practical sessions, and Isabelle Lapassat for managing the administrative aspects. We warmly thank Anna Surdej who made a careful video-recording of the talks and took many photos. We are also grateful to everyone from the staff of the Station Biologique de Roscoff for their warm welcome and help during the

[2]Unfortunately, this lecture has not been reproduced in the book

school. Last but not least, we warmly thank the lecturers Frantz Martinache, Jean Surdej, Denis Mourard, Anne-Marie Lagrange, Annaëlle Maury, and Pierre Kervella for their comprehensive lectures and enthusiasm, which made the school a success.

Nicolas Nardetto, Yveline Lebreton & Eric Lagadec

- EES 2017 co-chairs

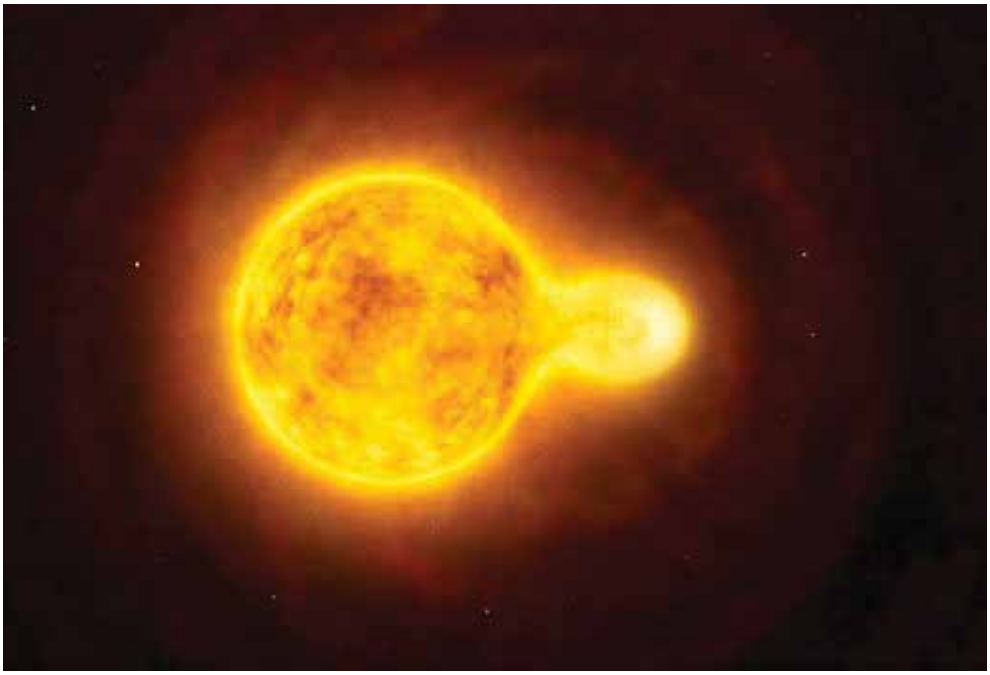

Figure 4. Artist's impression of the yellow hypergiant HR5171, a.k.a. the peanut Nebula, as mapped by our late colleague Olivier Chesneau. Olivier was a very active member of the high angular resolution community and the observations he obtained of this object are a perfect example of what high angular resolution can teach us about stellar physics.

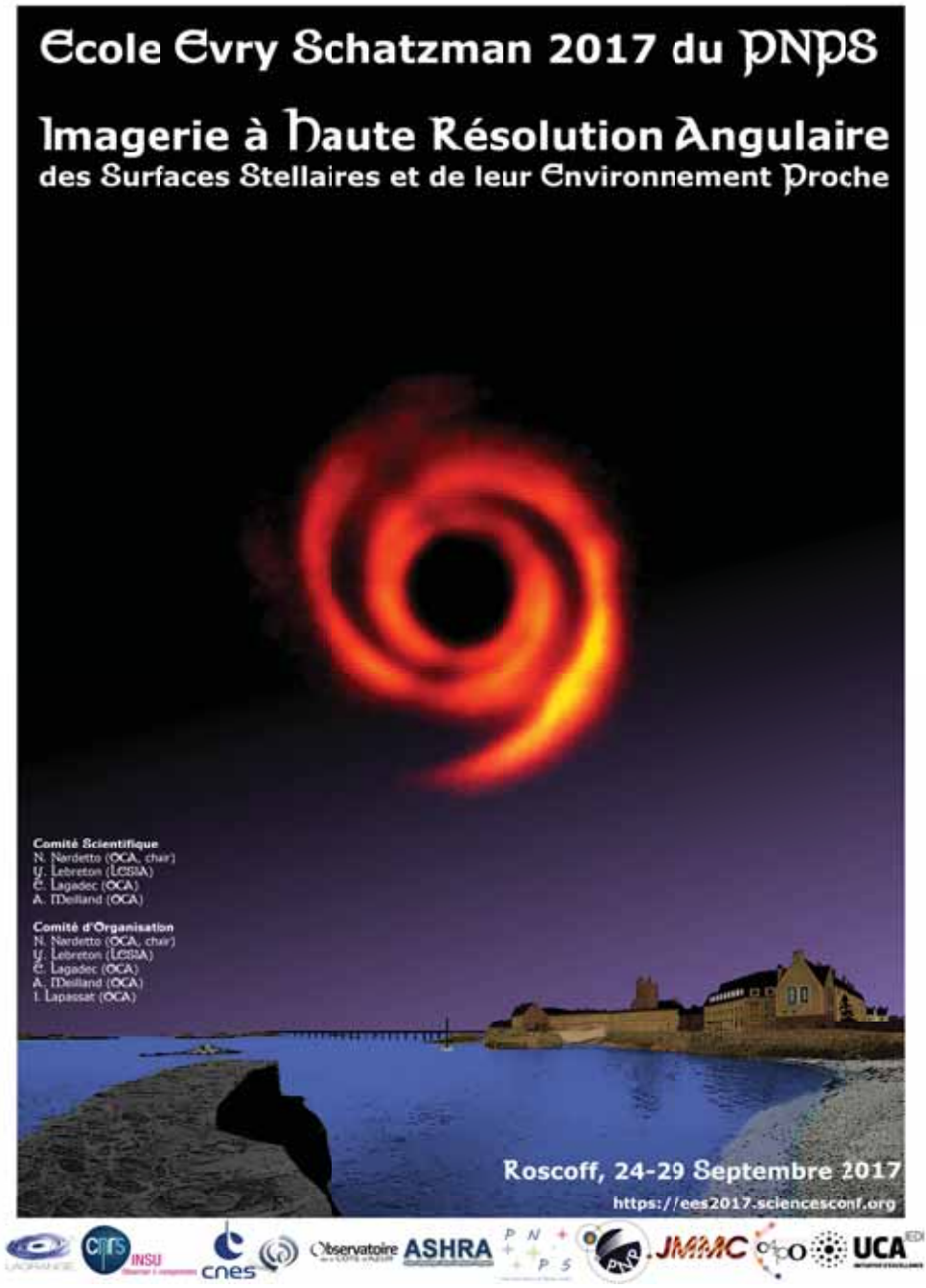

Figure 5. Poster of the 2017 Evry Schatzman School (credit: Anthony Meilland, OCA).