Report on the Workshop

400 Years of Stellar Rotation

held at Natal, Brazil, 21–26 November 2013

José Renan de Medeiros[1]
Claudio Melo[2]
Luca Pasquini[2]

[1] Departamento de Fisica, Universidad Federal do Rio Grande do Norte, Natal, Brazil
[2] ESO

The workshop marked the 400th anniversary of the observation of sunspots by Galileo and his deduction of the rotation of the Sun. The topics covered extensively both the theoretical and observational aspects of stellar rotation for stars of all types, from pre-main sequence to evolved stages, and including binary stars and stars hosting planets. A summary of the selected themes is presented.

Figure 1. The participants at the workshop "400 years of Stellar Rotation" by the beach at Tabatinga.

Motivation

Stellar rotation is both a very old topic, going back to the time of Galileo, and a very topical one, at the forefront of current research in stellar physics. As described on the webpage of the conference[1], Galileo Galilei reported in 1613 in his book the *"l'Istoria e dimostrazioni intorno alle macchie solari e loro accidenti"* evidence for sunspots and the interpretation of their motion as due to Solar rotation. A few centuries separated this first reported evidence of the rotation of the Sun from the first studies at the beginning of the 20th century, by Eddington, Milne, von Zeipel and others, addressing the impact of rotation on stars from a theoretical point of view. Thus, 400 years after the discovery of Galileo, the subject of the rotation of the Sun and of other stars is still a very active area of research, as testified by the 144 scientists from 21 countries who attended the conference held in the beautiful city of Natal, Brazil. The conference was co-sponsored by ESO, the University Federal of Rio Grande do Norte and the International Institute of Physics of Natal.

Conference themes

The conference occupied five full days, with more than 60 invited reviews, contributed talks and almost 50 posters. The topics were organised into nine sessions, including: pre-main sequence and low-mass stars; massive stars; evolved stars; modelling evolution with rotation; rotation, magnetic fields and binaries. A session on the Sun was followed by: rotation and chemical abundances; rotation, activity and planets; and the conference ended with sessions devoted to the legacy of space missions and to our understanding of stellar rotation.

The conference also featured two enlightening talks about Galileo and his cultural environment. In his opening review "Galileo, the man and the scientist", Alberto Righini summarised the entire scientific life of Galileo with emphasis on his discovery of sunspots and rotation. He was of the opinion that Galileo Galilei was close to a sort of Florentine Protestant movement and this motivated the strong reaction of the Catholic Church. He has described this thesis in full in his book on Galileo (Righini, 2008). In his talk "Galileo, the artist and the scientist", given on the final day of the conference (not at the conference venue, but in the exotic surroundings of Tabatinga Beach), Paolo Molaro emphasised that Galileo was not only the father of modern science, but also an innovative and inspirational mind in many fields, a real man of the *rinascimento*, dominating philosophy, music and painting. Paolo Molaro also presented the fascinating story of a mysterious portrait that might be of Galileo himself (Molaro, 2012).

To summarise the results of such a broad-ranging conference and select scientific highlights is a difficult task, which may lead to unfair omissions. Accepting this risk, we present a short summary of some, subjectively selected, scientific highlights covering many aspects of observations and theory, including rotational periods, magnetic fields, activity and abundances, dynamo theory and its relationship with stellar structure and differential rotation.

The many different talks presented recent results both from theoretical and observational standpoints. Experiments like SOHO have provided a detailed view of the internal and surface rotation of the Sun. The precise photometry obtained with the Kepler and CoRoT satellites has made rotation periods for thousands of stars available. In addition, projected rotational velocities (*V*sin*i*) are provided for thousands of stars, thanks to ground-based high-resolution spectroscopy. These data offer the unique possibility of detailed studies of the behaviour of the rotation of the Sun in time, as well as the evolutionary behaviour of stellar rotation all along the Hertzsprung–Russell (HR) diagram. Techniques like interferometry allow the shape of fast-rotating stars to be explored directly and spectropolarimetry provides information about the external magnetic field and, together with measures of rotation, gives indications on how these two properties interact. Asteroseismology also provides invaluable information on the internal rotation of stars and poses new challenges to stellar modellers.

Theory and models

From a theoretical point of view, rotation does appear to be an essential ingredient for understanding the evolution of single and close binary stars. Rotation has an impact not only in the area of stellar physics, but also on the evolutionary scenarios and lifetimes of different types of stars, leading to the modification of stellar populations, and thus the photometric evolution of galaxies. It may change the yields of some elements, especially at very low metallicity, providing new insights into the early chemical evolution of galaxies. Rotation has an impact on the nature of progenitors of core-collapse events and of long soft gamma ray bursts. The range of initial masses that give birth to white dwarfs, neutron stars and black holes will probably also depend to some extent on rotation. How the rotation of a star depends on the presence of planets, a question already addressed by Struve, was discussed during the conference, as well as what may happen when a planet is engulfed by its host star. As demonstrated by these few points, rotation is at the crossroads of many topical subjects in modern astrophysics, from planet and star formation to the evolution of galaxies passing through the first stellar generations in the Universe.

Stellar rotation studies discriminate between Solar-type stars and those, hotter than the Sun, without an external convective zone. It is no exaggeration to state that “the Universe without rotation would have been much less interesting”. Thus Georges Meynet concluded his vibrant review in which he explained that, for massive stars, rotation explains a number of observed phenomena, from unexpected surface chemical composition, to the interferometric measurements of flattening (presented by Antoine Merand and John Monnier) and departures from the Von Zeipel darkening law. A positive conclusion is that evolutionary models of massive stars incorporating stellar rotation seem to be able to reproduce many of the observations. Models are therefore an essential tool to predict the production of key elements produced by massive, very metal-poor stars, that are barely observable at present. The impact of satellite missions has also dramatically changed what we know about white dwarfs, revealing large discrepancies between observed rotation periods and spectroscopically determined $V \sin i$ values. In an equally energetic talk, Andre Maeder walked us through a number of the present puzzles (such as the abundance of nitrogen at low metallicity and the *s*-elements), where rotation of massive stars could play a role, concluding that the early Universe was controlled by stellar rotation.

Observations

Currently there are a striking number of stars for which the ages and stellar masses are quite well known. This favourable situation arises mostly from the results of the CoRoT and Kepler satellites, which were reviewed by Annie Baglin and Soeren Meibom respectively. However ground-based photometric surveys of thousands of stars with measured rotational periods all over the HR diagram, including stars in many open clusters, also contribute strongly. Jerome Bouvier reviewed how this wealth of data has allowed the modelling of the early angular momentum evolution taking place in stars from the pre-main sequence (PMS) up to Solar age. Although the main ingredients of early angular momentum evolution have been known for quite some time, the amount, and mainly the quality, of the data have now allowed a much more refined modelling of the physics involved. Luiza Rebull reviewed the legacy of the Spitzer Space Telescope for our understanding of stellar discs; more detailed studies of the young stellar disc–rotation interaction in the infrared have been enabled for a wider range of ages and masses than ever before.

As usual more information does not necessarily mean more answers, but rather more questions! For many of the stars studied with other techniques, the physical characteristics can also be derived by using asteroseismology. In contrast to main sequence stars, these data show that in evolved stars, the nucleus rotates about 13 times faster than the external atmosphere. This finding indicates that the cores rotate slower than expected if the star were a solid body, but faster than if a shellular rotation model (i.e., one where the rotation in the interior of the star mainly depends on the radius, so that each incremental shell rotates with the same angular velocity, but different from the nearby shells) is assumed. The presence of a certain amount of coupling between the core and the surface is deduced. This coupling is of course fundamental to understanding the internal mixing of the chemical elements, and may therefore help to explain some of the peculiar abundances observed in giants. What, however, is the missing angular momentum transport process: internal gravity waves or a magnetic field?

The same kind of data allows the study of gyrochronology, i.e., how stars slow down during their lifetime on account of the presence of winds, mass loss and magnetic fields. Sydney Barnes reviewed the prospects for and limitations of this technique. Interestingly enough, while a regular rotational period–age pattern is observed in open cluster stars, the results are not so clear for field stars with ages derived from asteroseismology. In general, the debate on whether gyrochronology is a viable way of measuring stellar ages appears to be quite lively. An associated question is whether the rotation of the Sun is anomalous for its mass and age. The answer appears to be: probably not.

For some stars even differential stellar rotation can be obtained, showing that, although the Solar case is not common, differential rotation behaviour generally agrees with models. Indeed, in his didactic review, Nuccio Lanza presented spectroscopic and photometric methods to measure surface differential rotation, also considering recent contributions from high-precision photometric time series from the MOST, CoRoT and Kepler space missions. New, large, spectroscopic surveys are complementing the satellite data, producing precise stellar parameters and measured *V*sin*i*. Steve Kawaler and Kepler Oliveira reviewed the present status of methods for determining the rotation velocities of white dwarf stars via asteroseismology and spectroscopy, which will open up the study of rotation in the final stages of stellar evolution.

Stellar rotation and angular momentum evolution are also intimately coupled to proto-planetary discs and to the presence of planetary systems. The interaction between planets and stars is, however, not limited to the dynamics in the early stages, but continues all through the stellar lifetime. On the one hand, evidence is being sought for the presence of chemical abundance peculiarities in planet-hosting stars. R. Similjanic and A. Recio-Blanco reinforced the evidence for a link between rotation history and light-element abundances. This connection is not new, but in spite of the amount of data available, its nature is not yet fully understood.

On the other hand, rotation-induced magnetic activity of stars plays a key role in determining whether planets can retain a magnetosphere, which is essential for life as we know it. As Edward Guinan emphasised, "the Sun is still a dangerous star". In the same vein, Nuno Santos remarked on the analysis of rotation from the point of view of the research on exoplanets; he noted that "astronomers working on exoplanets don't like the fact that stars rotate", since the rotation–activity connection is the main source of stellar noise in planet searches.

Several talks (e.g., Reiners, Gouveia dal Pino, Vishniac and Lazarian) reminded us that while magnetic activity and magnetic fields can now be measured well in many stars and qualitatively understood, detailed modelling of the (Solar) dynamo still encounters several challenges in reproducing the observations. For binary stars in particular, as stressed by Klaus Strassmeier in his review, the situation is significantly more complex.

Acknowledgements

Galileo would likely have been delighted to discover the long trail that has been explored in Solar and stellar rotation since his time! The conference was superbly organised, and the attendees could enjoy the beautiful beach of Tabatinga, close to Natal, on the social trip (see Figure). The Local Organising Committee, and in particular Bruno Canto Martins, Sanzia Alves and Bia Pessoa, had a hard time making everything run smoothly, or perhaps more appropriately, "rotate swiftly", but succeeded admirably.

References

Molaro, P. 2012, AN, 333, 186
Righini, A. 2008, *Galileo. Tra scienza fede e politica*, (Bologna: Editrice Compositori)

Links

[1] Conference web page: http://www.dfte.ufrn.br/400rotation/index.htm

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Report on the

ALMA Community Days: Preparing for Cycle 2

held at ESO Headquarters, Garching, Germany, 19–20 November 2013

Suzanna Randall[1]
Andy Biggs[1]
Tim Davis[1]
Claudia Lagos[1]
Thomas Stanke[1]
Leonardo Testi[1]
Martin Zwaan[1]

[1] ESO

ALMA has now been obtaining scientific observations for the astronomical community for over two years. While commissioning is still continuing, the upcoming Cycle 2 should allow for nearly 2000 hours of science observations. The Cycle 2 ALMA Community Days, summarised here, were designed to optimally prepare the European ALMA Community for proposal submission and were held just a couple of weeks before the Cycle 2 deadline.

The Atacama Large Millimeter/submillimeter Array (ALMA), is the world's leading observatory at millimetre and submillimetre wavelengths. It is the result of a global cooperation involving Europe (through the ESO Member States), North America and East Asia, as well as the host country Chile. Located at the unique site on the Chajnantor Plateau in northern Chile at over 5000 metres above sea level, the final array will comprise at least 66 high precision antennas equipped to observe in the 30 GHz to 1 THz frequency range. The antennas are grouped into the main array, comprising 50 12-metre dishes, and the Atacama Compact Array (ACA, also known as the Morita Array), containing 12 closely placed 7-metre antennas together with four total-power 12-metre antennas used to recover large-scale structures on the sky. By combining data obtained with different configurations of the main array and the ACA, complex and extended sources can be accurately imaged.

ALMA has been used, at least part of the time, for observations proposed by the