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The Earth as a Distant Planet

A Rosetta Stone for the Search of Earth-Like Worlds

Springer

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ISSN 0941-7834
ISBN 978-1-4419-1683-9 e-ISBN 978-1-4419-1684-6
DOI 10.1007/978-1-4419-1684-6
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2010922052

Cover illustration: G. Pérez (IAC)

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Since the discovery of the first planet outside the Solar System (or exoplanet) in 1992, detection of the number of planets is increasing exponentially. This planet search is generating one of the most active and exciting fields in astrophysics for the next decades. Although we are not capable of detecting and exploring planets like our own yet, ambitious ground and space-based projects are already being planned for the next decades, and the discovery of Earth-like planets is only a matter of time.

The theory of stellar evolution has been tested and developed by observations of several stellar types at different times of their evolution. In the 1980s, the observations of 'The Sun as a Star' provided the role of our star as the Rosetta stone in interpreting the observations of sun-like stars with different mass, age and level of magnetic activity. This solar–stellar connection had a double avenue, because the stellar observations also contributed to a better understanding of the solar magnetism.

Although we are probably set for some surprises, the example of the Earth and the rest of the rocky planets of the solar system will be our guidance to classifying and understanding the multiplicity of planetary systems that might exist in our galaxy. In a similar way to that of the Sun as a star, it is reasonable to expect that the future observed population of planets in the galaxy will exhibit a wide range of planet types and evolutionary stages. Observations of 'The Earth as a Planet' will provide the key to understanding future observational spectra of such bodies. However, the *Earth-Exoplanets connection* will also work in both directions. When a substantial database of exoplanets becomes available, statistics of planetary formation and evolution will become possible. This will provide vital information in solving some of the questions about the formation and evolution of our own planet and the solar system, for which we still have no answers.

The current view on stellar evolution is very deterministic. The future and evolution of a star depend on two basic properties: its mass and its metallicity. If these two quantities are known, we can establish whether the star will explode as a supernova in a few million years or if it will end its days as a red giant. For planets, the picture is a little more complicated. At first instance, the mass of the planet, its composition and its distance from the parent star will determine its habitability and evolution. But other factors, such as the presence of gas giant planets, can also play a major role in its evolution. The parent star will also influence the evolution of the planet.

To establish the solar–stellar connection, we needed only to compare the stars; similarly, to establish the Earth–exoplanets parallelism, we need to compare not only the planets but also the physical properties and evolution of their planetary systems as a whole. For example, we may be able to determine how many of the ‘rocky’ planets that we detect have experienced a runaway greenhouse effect, such as Venus, or how many have lost their atmosphere as Mars has. By observing planets of different ages, we also learn about the state of our own planet in different epochs.

Undoubtedly, one of the main concerns for astrophysics in the coming years will be the search for life. If a planet has all the suitable original conditions to develop and sustain life, does life necessarily occur? And if it does, what are the average time scales for the development of bacteria, plants or intelligence? Are we alone? ... During its evolution, some of the most dramatic changes suffered by our planet affected the composition of the atmosphere. Extraterrestrial observers would obtain two different spectra of our planet depending on the epoch of the observation. Early on the Earth’s history, the major atmospheric signatures were those of CO_2 and water vapour, but in recent times (in terms of millions of years), together with such spectral features, the bands of molecular oxygen (O_2) and ozone (O_3) are also present. This dramatic change, the rise of oxygen content, was triggered by the appearance of life. In the future, we may be able to infer whether life is common or not in the universe by observing the evolutionary stages of millions of planets. From the tiny bacteria to technological civilizations we can expect to see life signatures in the atmosphere of exoplanets.

In summary, this book will focus on observations of the Earth as a model for the search of exoplanets and on the information that we will be able to extract from their observation. We put ourselves in the position of an external observer looking at the solar system from an astronomical distance, and we try to answer how we could conclude that this particular planet, the third in distance to the central star, is essentially different from the others and capable of sustaining life. Then, we apply what we learn from this change of perspective to the search for exoplanets similar to Earth.

The first chapter of the book provides first a historical briefing on the progressive knowledge of our planet. Then, we start with a sort of space travel. Starting with first observations from the altitude, using balloons and rockets, we continue with the views of our blue planet from the Moon and the different planets of our solar System. One of the most important achievements of space research was the capability to observe the Earth from outside, floating in space.

This concept will be complemented with the second chapter, where we describe the main properties of our planet. A description of the present Earth from its interior to the atmosphere is given, followed by a review of the different periods of the Earth history.

The third chapter shows how the Earth should be observed from space as Sagans’s blue dot. The photometric, spectroscopic and polarimetric properties of the globally integrated light reflected/emitted by Earth are discussed. Special emphasis is given to the Earthshine observations, the sunlight reflected by Earth toward the dark side of the Moon, as a proxy for such global observations.

The outer layers of the Earth are discussed in Chap. 4. Many interesting processes resulting from the interaction of the atmosphere with the high energy solar radiation, solar wind and cosmic rays occur at high altitude. Observed from space the Earth glows in discrete spectral lines (airglow), enhanced during transitory events such as the auroras. The UV and X-rays are excellent diagnostic tools for investigating these regions of the atmosphere.

The existence of life is one of the most relevant properties of our planet, and the Earth would look completely different without it. However, detecting it unambiguously from vast distances is no trivial matter and ingenious techniques should be used for this purpose. This matter will be handled in Chap. 5. Toward the end of the chapter, the main features of our technological society, as reflected in the Earth's electromagnetic spectrum, are described, providing a hint as to how to detect other extraterrestrial civilizations.

Detection of other Earths is the essential requirement to apply the Earth–Exoplanets connection. Chapter 6 is dedicated to a review of the current and future projects, explaining in detail the current limitations in detecting the less massive planets. A research field with a brief history, starting in the 1990s, but which has undergone rapid development and is becoming one of the most important fields in current Astrophysics.

The mass of an astronomical body, together with the chemical composition of the environment where it was formed, determines its future. Stars are massive enough to reach temperatures that permit thermonuclear reactions in their interiors. Less massive brown dwarfs can make this process only by burning deuterium. Planets were recently defined by an international committee and come mainly in two classes: Giants and terrestrial. For the latter, the Earth, Mercury, Mars and Venus are our references; however, the possibilities are larger. Lacking observations of terrestrial exoplanets, we can figure out theoretically how these exo-earths could be, changing some of the basic parameters. From Super-Earths and Super-Mercuries to Carbon planets, an ample diversity of possible worlds is presented in Chap. 7. Some selected exoplanets discovered already are studied in detail.

However, planets are not isolated bodies. They experience the influence from the parent star and the rest of planetary companions in the planetary system. The broad destiny of a planet is determined by its initial mass and chemistry, but the ultimate fate depends on how the planet is affected by the interactions with its companions. To be in the right place is a good recipe. In Chap. 8 we discuss these collective processes, along with the different theories on the formation of planetary systems. As usual we start with our own solar system, which can be confronted with the first observations of proto-planetary disks and multiple planetary systems.

The last chapter is a necessarily failed attempt to answer some fundamental questions regarding the position of our planet in the Universe: Is our Sun special? Is our Solar System common? and finally: Is our Earth unique? The complete answers can only be provided by observations, and search for bio-markers, of terrestrial exoplanets to be discovered in the future. In the meantime, we can, however, remark that we have a unique process of formation and an ample diversity of planetary systems. Birth and environmental factors determine together the structure and evolution of a planetary system and its components.

Many people have been involved at the Instituto de Astrofísica de Canarias (IAC), in different ways, in the preparation of this book. R. Castro elaborated and retouched a substantial number of the figures and the Library staff (M. Gómez, and L. Abellán) provided an excellent service in tracing old publications. The computer services maintained our informatics tools in operation, helping when a problem appeared.

We thank I. Gómez Leal and J.A. Belmonte for the task of reading critically the whole book. F. Anguita, V. Bejar, C. Esteban, A. García Muñoz, I. Ribas, J.A. Robles, J. Schneider and R.M. Zapatero-Osorio also have critically read different drafts of the book chapters and made valuable comments, advices and suggestions. Figures and data have also been kindly supplied by T. Bastian, C. Benn, E. Böhm-Vitense, C. Bounama, R. Buser, V. Courtillot, C. Esteban, M. Harris, P. Hoffman, B.W. Jones, L. Kaltenegger, E. Kokubo, M. Kuchner, G. Laughlin, M. Livio, N. Loeb, D. López, J.J. López Moreno, K. Menou, R. Neumeyer, A. Oscoz, M. Perryman, E. Pilat-Lohinger, I. Ribas, J. Robles, K. Shingareva, M. Sterzik and D. Valencia. We thank the NASA ADS service, which provides a wonderfully efficient service to the scientific community. Archives of NASA and ESA have also been used.

Anna Fagan helped to make this book readable in English. We alone, however, bear the responsibility for its contents. We thank the Springer staff, especially Dr. Harry Blom, for his confidence in our work. We also acknowledge the excellent work done by Ms A. Sridevi and her team (SPi) during the production of this book.

Finally, our families showed great patience and gave us their full support during the lengthy process of writing this book, which we dedicate to them.

La Laguna
July 2009

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Acronyms

AIM	Aeronomy of ice in the mesosphere
AU	Astronomical unit
BCE	Before common era
COROT	Convection rotation and planetary transits
ELT	Extremely large telescope
E-ELT	European extremely large telescope
ESA	European Space Agency
ESO	European Southern Observatory
EUV	Extreme ultraviolet
GOES	Geostationary Operational Environmental Satellite
HST	Hubble Space Telescope
IAU	International Astronomical Union
IMF	Initial mass function
INGRID	Isaac Newton Group red imaging device
IPMO	Isolated planetary-mass objects
LHB	Late heavy bombardment
MAHRSI	Middle High Resolution Spectrograph Investigation
NAOS	Nasmyth adaptive optics system
NASA	National Aeronautics and Space Agency
NEAR	Near earth asteroid rendezvous
OWL	Overwhelmingly large telescope
PAL	Present atmospheric level
SeaWiFS	Sea-viewing wide field-of-view sensor
SOHO	Solar and Heliospheric Observatory
TIMED	Thermosphere ionosphere mesosphere energetics and dynamics
TIROS	Television infra-red observation Satellite
TP	Terrestrial planet
TPF	Terrestrial planet finder
UV	Ultraviolet
VIRTIS	Visible and InfraRed Thermal Imaging Spectrometer
VLT	Very large telescope, ESO
WHT	William Herschel telescope

Units

1 μm = 1,000 nm = 10,000 Å

1 Astronomical unit (AU) = Mean Sun–Earth distance = 149.60×10^6 km
1 Light Year (ly) = $9,461 \times 10^{12}$ km = 63,241 km
1 Parsec (pc) = 3,2616 ly

Ga (Gigayears) = 10^9 years
Ma (Million of years) = 10^6 years
Earth Mass (M_E) = 5.9736×10^{24} kg
Jupiter Mass (M_J) = $1,8996 \times 10^{27}$ kg
Solar Mass (M_S) = $1,989 \times 10^{30}$ kg

1 Joule = 10^7 ergs

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