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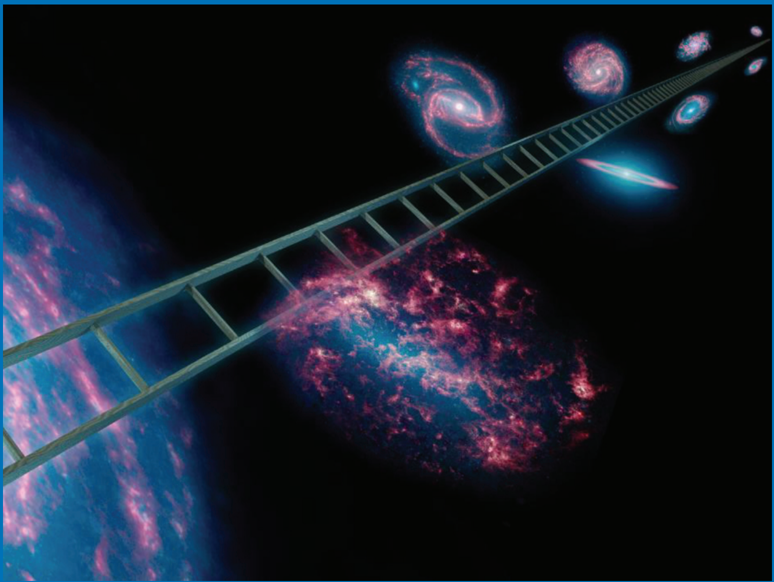
Advancing the Physics of Cosmic Distances

Edited by

Richard de Grijs



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ADVANCING THE PHYSICS OF COSMIC DISTANCES

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COVER ILLUSTRATION: THE COSMIC DISTANCE LADDER

Astronomers using NASA's *Spitzer Space Telescope* have greatly improved the cosmic distance ladder used to measure the expansion rate of the Universe, as well as its size and age. The cosmic distance ladder, symbolically shown here in this artist's concept, is a series of stars and other objects within galaxies that have known distances. *Spitzer* researchers took advantage of infrared light for the latest Hubble constant measurement of 74.3 ± 2.1 km s^{-1} Mpc^{-1} (systematic uncertainty), published in October 2012 (Freedman et al., 2012, *ApJ*, 758, 24). This finding agrees with an independent supernovae study from 2011 and improves by a factor of three on Freedman et al.'s seminal 2001 study based on observations obtained as part of the *Hubble Space Telescope* Key Project on the Extragalactic Distance Scale.

(*Image credit*: NASA/Jet Propulsion Laboratory, California Institute of Technology; *text* paraphrased based on *Spitzer Space Telescope* press release ssc2012-13: http://www.spitzer.caltech.edu/news/1461-ssc2012-13-NASA-s-Infrared-Observatory-Measures-Expansion-Of-Universe)

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ADVANCING THE PHYSICS OF COSMIC DISTANCES

PROCEEDINGS OF THE 289th SYMPOSIUM OF THE INTERNATIONAL ASTRONOMICAL UNION HELD IN BEIJING, CHINA AUGUST 27–31, 2012

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Preface: Advancing the Physics of Cosmic Distances

Knowing the distance of an astrophysical object is key to understanding it: without an accurate distance we do not know how bright it is, how large it is, or even (for long distances) when it existed. But astronomical distance measurement is a challenging task. Distances to stars were first measured in 1838 by Bessel, von Struve, and Henderson, and accurate distances to other galaxies—even the nearest—date only from the 1950s. This is not really surprising, since the only information we have about any object beyond our Solar System is its position (perhaps as a function of time) and its brightness (as a function of wavelength and time). Yet, from this unpromising starting point, modern astronomers have developed methods of measuring distances which can take us from the nearest star to the most distant galaxy, using techniques that vary from the mundane (the astronomical equivalent of the surveyor's theodolite) to the exotic (the bending of light in general relativity, wiggles in the spectrum of the cosmic microwave background). Nevertheless, the most accurate optical and near-infrared methods of distance determination, from the solar neighbourhood to the highest redshifts, in use today rely heavily on having access to accurate spectroscopy, supplemented by astrometric measurements in the Milky Way (and slightly beyond).

In 1997, the *Hipparcos* space mission provided (for the first time) a significant number of absolute trigonometric parallaxes at milliarcsec-level precision across the whole sky, which had a major impact on all fields of astrophysics. In addition, during the past ten years, the use of ground-based 8–10 m-class optical and near-infrared telescopes (the twin *Keck* telescopes, the *Very Large Telescope*, *Gemini*, *Subaru*) and space observatories (the *Hubble* and *Spitzer Space Telescopes*, the *Chandra X-ray Observatory*, *XMM-Newton*) have provided an unprecedented wealth of accurate photometric and spectroscopic data for stars and galaxies in the local Universe. Radio observations, particularly with the Very Long Baseline Array and the Japanese *VERA* array, have achieved 10 micro-arsecond astrometric accuracy. Moreover, stellar models and numerical simulations are now providing accurate predictions of a broad range of physical phenomena, which can now in principle be tested using accurate spectroscopic and astrometric observations (including measurements of, e.g. line ratios and shapes, spectral slopes, radial velocities and velocity dispersions). However, at present, comparisons of theory and observations are mainly hampered by precision (or lack thereof) in distance measurements or estimates.

As far as we are aware, there has never been an IAU Symposium on the physics of cosmic distance determination as broad as that held at the XXVIII$^{\rm th}$ IAU General Assembly in Beijing. While a number of past IAU Symposia addressed individual aspects of the methods and physics underlying the fundamentals of distance determination, we felt the need for a new, interdisciplinary Symposium encompassing the broad range of techniques and theories. Rather than focusing on historical perspectives, we wanted to truly highlight the tremendous amount of recent and continuing research into a myriad of exciting and promising aspects of accurately pinning down the cosmic distance scale. Putting the many recent results and new developments in the relevant subareas into the broader context of the physics driving cosmic distance determination is the next logical step, which will benefit from the combined efforts of theorists, observers and modellers working on a large variety of spatial scales, and spanning a wide range of expertise. Given the very significant range of sizes, scales, and physical processes bearing on the validity and usefulness of many current methods of distance determination throughout the Universe, an IAU General Assembly was considered the most suitable, ideal (possibly

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the only viable) venue to bring together experts with backgrounds in such a broad range of astrophysics.

We believe this to be a very exciting time in the context of this Symposium. Very Long Baseline Interferometry sensitivity is being expanded allowing, for example, direct measurement of distances throughout the Milky Way and even to Local Group galaxies. The field will benefit from expert input to move forward into the era of *Gaia*, optical-interferometer, and *Extremely Large Telescope*-driven science, which (for example) will allow us to determine Coma-cluster distances without having to rely on secondary distance indicators, thus finally making the leap to accurate distance measurements well beyond the Local Group of galaxies. With the launch of *Gaia* imminent, this is a really opportune time to be looking forward to the first *Gaia* catalogues, and understand how the science areas touched upon in this Symposium will be fundamentally changed by the *Gaia* results, what the big open questions are that *Gaia* can address in the Symposium's context, and what the future of complementary techniques and observational approaches will be once the *Gaia* catalogues become available.

In this Symposium, we aimed to bring together experts on various aspects of distance determinations and (most importantly) the underlying physics enabling this (without being restrictive in areas where statistical and observational approaches are more relevant), from the solar neighbourhood to the edge of the Universe, exploring on the way the various methods employed to define the milestones along the road. We will emphasise, where possible, the physical bases of the methods and recent advances made to further our physical insights. We aimed to provide a snapshot of the field of distance measurement, offering not only up-to-date results and a cutting-edge account of recent progress, but also full discussion of the pitfalls encountered and the uncertainties that remain. We wanted to provide a roadmap for future efforts in this field, both theoretically and observationally, and in particular considered the key question as to whether the field is best served by having access to the next-generation of extremely large telescopes and the *Square Kilometre Array* (as well as the *James Webb Space Telescope*, slated for launch towards the end of the current decade) and/or if significant progress can still be made with dedicated 2–4 m-class optical telescopes as well as upgraded radio interferometers.

Although our focus was techniques of distance determination, this is intimately linked to many other aspects of astrophysics and cosmology. On our journey from the solar neighbourhood to the edge of the Universe, we encounter stars of all types, alone, in pairs and in clusters, their life cycles, and their explosive ends: binary stars, in particular, play an important role in this context, e.g. in pinning down accurate distances to the Pleiades open cluster and Local Group galaxies, as well as in future ground- and space-based surveys (including *Gaia*, RAVE, and others); the stellar content, dynamics, and evolution of galaxies and groups of galaxies; the gravitational bending of starlight; and the expansion, geometry and history of the Universe. As a result, the Symposium offered not only a comprehensive study of distance measurement, but a tour of many recent and exciting advances in astrophysics.

Looking back at a very successful meeting, we are strengthened in our resolve to make this meeting happen and would like to thank all participants for a hugely rewarding and thought-provoking week in Beijing.

Richard de Grijs and Giuseppe Bono, co-chairs
(on behalf of the Scientific Organising Committee of IAU Symposium 289)

Beijing/Rome, November 2012

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Financial support was provided by the International Astronomical Union in the form of travel grants for 20 participants, selected from the invited and contributing speakers, PhD students, and scientists from less-favoured countries. The Local Organising Committee consisted of the Local Organising Committee of the IAU's XXVIIIth General Assembly, to whom we are grateful for structural and logistical support.