Introduction: Discoveries in Astronomy[1]

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MANY MILLENNIA AGO, the first humans gazed in awe at the multitude of stars in the dark night sky. Thus was the birth of astronomy. Human wonderment at the cosmos appears in every culture in history. Astronomy has been the source of our deepest discoveries about the nature of the Universe and our place within it.

More than 240 years ago the first paper[2] ever "read" at a meeting of the American Philosophical Society was about astronomy! David Rittenhouse, who built the first telescope in America, published his predictions for the transit of Venus. Only 160 years earlier, in 1609, Galileo Galilei had first turned one of his telescopes to the night sky and made remarkable discoveries that changed the world forever: mountains and craters on the Moon, a plethora of stars invisible to the naked eye, the phases of Venus, moons around Jupiter, and the rings of Saturn.[3]

To celebrate the four hundredth anniversary of these first astronomical observations through a telescope, the International Astronomical Union (IAU) proposed that 2009 be recognised as the International Year of Astronomy. UNESCO endorsed the proposal, and on 20 December 2007 the United Nations proclaimed the year 2009 as the International Year of Astronomy.

The United Nations 62nd General Assembly IYA2009 Resolution reads:

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[1] Read 12 November 2009.

[2] D. Rittenhouse, A. M., "Calculations of the Transit of Venus over the Sun as It Is to Happen June 3d 1769, in lat 40°. N. Long. 5h West from Greenwich. Communicated June 21st 1768," *Transactions of the American Philosophical Society* 1 (1769): 4.

[3] G. Galilei, Tommaso Baglioni, *A Sidereal Messenger* (Venice, 1610).

International Year of Astronomy, 2009

The General Assembly,

Recalling its resolution 61/185 of 20 December 2006 on the proclamation of international years,

Aware that astronomy is one of the oldest basic sciences and that it has contributed and still contributes fundamentally to the evolution of other sciences and applications in a wide range of fields,

Recognizing that astronomical observations have profound implications for the development of science, philosophy, culture and the general conception of the universe,

Noting that, although there is a general interest in astronomy, it is often difficult for the general public to gain access to information and knowledge on the subject,

Conscious that each society has developed legends, myths and traditions concerning the sky, the planets and the stars which form part of its cultural heritage,

Welcoming resolution 33 C/25 adopted by the General Conference of the United Nations Educational, Scientific and Cultural Organization [UNESCO] on 19 October 2005,[4] to express its support for the declaration of 2009 as the International Year of Astronomy, with a view to highlighting the importance of astronomical sciences and their contribution to knowledge and development,

Noting that the International Astronomical Union has been supporting the initiative since 2003 and that it will act to grant the project the widest impact,

Convinced that the Year could play a crucial role, inter alia, in raising public awareness of the importance of astronomy and basic sciences for sustainable development, promoting access to the universal knowledge of fundamental science through the excitement generated by the subject of astronomy, supporting formal and informal science education in schools as well as through science centres and museums and other relevant means, stimulating a long-term increase in student enrolment in the fields of science and technology, and supporting scientific literacy,

1. *Decides* to declare 2009 the International Year of Astronomy;

2. *Designates* the United Nations Educational, Scientific and Cultural Organization as the lead agency and focal point for the Year, and invites it to organize, in this capacity, activities to be realized during the Year, in collaboration with other relevant entities of the United Nations system, the International Astronomical Union, the European Southern Observatory and astronomical societies and groups throughout the world, and, in this regard, notes that the activities of the Year

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[4] United Nations Educational, Scientific and Cultural Organization, *Records of the General Conference, 33rd session, Paris, 3–21 October 2005* (Paris: United Nations Educational, Scientific and Cultural Organization), vol. 1, *Resolutions*, chap. 5.

> will be funded from voluntary contributions, including from the private sector;
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> 3. *Encourages* all Member States, the United Nations system and all other actors to take advantage of the Year to promote actions at all levels aimed at increasing awareness among the public of the importance of astronomical sciences and promoting widespread access to new knowledge and experiences of astronomical observation.

The IAU made the first approach to the United Nations in March 2006. All proposals to the UN must come from a member state; because of the link to Galileo, it was agreed that this was to come from Italy. The first initiative failed when continuity was impaired by a change of government in Italy. However, we received useful advice on the process, including words to use to minimise redrafting by the "second committee," which can cause delays and introduce unwanted changes. The second initiative in 2007 was successful, receiving strong support from many nations. International Year of Astronomy activities are now being conducted in 148 countries, which is the greatest penetration of any International Year.

In this International Year of Astronomy APS meeting, four hundred years after Galileo's discoveries, we look at more recent discoveries in astronomy and will hear first-hand accounts of how they were made.

The conventional view of the scientific method, in which a theory leads to a prediction, which is confirmed by an experimental result, is not the main path to new discoveries in any area of science. Many studies, for example those of Derek de Solla Price[5] and Martin Harwit,[6] have shown that discoveries normally follow technical innovation, not theoretical predictions. Derek de Solla Price was the first to apply scientific analysis to the discovery process. The idea occurred to him when he noticed the exponential growth in stacks of the *Philosophical Transactions of the Royal Society*, divided into equal time periods, between 1665 and 1850. He had the complete set in his home while Raffles College (University of Singapore) had its library built.[7] He concluded that the normal mode of growth in science is exponential, and that this growth is driven by the exponential development of technology. These new discoveries then lead to paradigm shifts and new theories. Examples of such exponential growth in science and technology are ubiquitous; Moore's Law[8] is a famous example.

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[5] Derek J. de Solla Price, *Little Science, Big Science* (Columbia University Press, 1963).

[6] Martin Harwit, *Cosmic Discovery* (MIT Press, 1984); *Physics Today* 56 (2003): 38.

[7] Jo Marchant, *Decoding the Heavens* (London: William Heinemann, 2008).

[8] Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics* magazine 38.8 (19 April 1965).

Many of these discoveries are made serendipitously,[9] but, as Pasteur famously remarked in an 1854 lecture, "In the field of observation, fortune favours only the prepared mind." Astronomy is an observational science. The stars and galaxies are millions and billions of light years away, so we astronomers cannot do any experiments. All we can do is observe. The history of astronomy has been defined by discoveries made with instruments of ever-increasing power (and cost). The exponential growth in capability of the telescopes has been crucial for maintaining the stream of discoveries in astronomy.

Four hundred years ago Galileo took the step from naked-eye instruments to the first telescope and made discoveries so astonishing that they triggered the beginning of the modern evidence-based scientific methodology. But for more than three hundred years following Galileo's discoveries, astronomical observations were confined to the narrow window of visible light. In 1933, however, that all changed. Karl Jansky was working for the Bell Telephone Laboratory, looking for the source of interference with transatlantic telephone communications, which were then carried by short wave radio. Jansky found that the noise-like interference appeared to be coming not from anywhere on Earth, but from the center of the Milky Way Galaxy.[10] This was a remarkable discovery, and it opened up an entirely new and very large window on the Universe. Follow-up studies with radio telescopes made over the past seventy-five years have resulted in the discovery of a wide range of unexpected phenomena and a number of previously unknown but very important constituents of the Universe.

More recently, the opening of the space age and the development of orbiting observatories above the Earth's atmosphere has resulted in even more new discoveries from observations at X-ray and gamma-ray wavelengths that do not penetrate the Earth's atmosphere. But what we now call radio astronomy was the first of the new astronomies, and it is not surprising that so many new phenomena were first found in radio observations.

These discoveries were often not the consequence of looking for anything special, or of testing ideas or theories, but were often the outcome of a) communications research such as Jansky's detection of cosmic radio emission; b) military activities such as the discovery of radio emission from the Sun using World War II British coastal radar

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[9] Robert K. Merton and Elinor Barber, *The Travels and Adventures of Serendipity: A Study in Sociological Semantics and the Sociology of Science* (Princeton University Press, 2004).

[10] K. Jansky, "Electrical Disturbances Apparently of Extraterrestrial Origin," *Proceedings of the Institute of Radio Engineers* 21 (1933): 387.

defense systems,[11] or the discovery of gamma-ray bursts, the most powerful events in the Universe, while looking for clandestine atmospheric nuclear tests;[12] c) studying something else, such as the discovery of pulsars;[13] or, d) just looking with a new kind of instrument.

As described by Owen Gingerich,[14] in the following paper, Galileo certainly didn't anticipate the astonishing discoveries made with the first telescope. In the following three papers some of the most important unanticipated discoveries in the last half century are described. Maarten Schmidt[15] describes his discovery of quasars, the detection of the cosmic microwave background is related by the co-discoverer, Robert Wilson,[16] and the discovery of pulsars by Jocelyn Bell is described by Malcolm Longair.[17] Interestingly, Penzias and Wilson were working for the same telephone company in New Jersey as Karl Jansky some thirty years earlier: Bell Labs. Like Jansky, they were using equipment that was originally built not to do astronomy but to enhance transatlantic telephone communications. The first pulsar was also discovered while looking for something else, the twinkling or scintillation of quasars.

There are a number of so-called next-generation telescopes now on the drawing boards—which will work at radio, optical, and X-ray wavelengths. If history is any guide, the excitement of these powerful new instruments will not be in the old questions that they will answer, but in the new questions that they will raise.

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[11] J. S. Hey, in *The Evolution of Radio Astronomy*, Science History Publications (1973), 14.

[12] R. W. Klebesadel, I. B. Strong, and R. A. Olson, "Observations of Gamma-Ray Bursts of Cosmic Origin," *Astrophysical Journal* 182 (1973): L85.

[13] A. Hewish et al., "Observation of a Rapidly Pulsating Radio Source," *Nature* 217 (1968): 709.

[14] "Galileo, the Impact of the Telescope, and the Birth of Modern Astronomy"; see p. 134 below.

[15] "The Discovery of Quasars"; see p. 142 below.

[16] Robert Wilson's paper is not included in this publication, but the interested reader is referred to his 1978 Nobel Prize Lecture, which can be found in *Nobel Lectures, Physics 1971–1980*, ed. Stig Lundqvist (Singapore: World Scientific Publishing Co., 1992), 463–83, or online at http://nobelprize.org/nobel_prizes/physics/laureates/1978/wilson-lecture.pdf.

[17] "The Discovery of Pulsars and the Aftermath"; see p. 147 below.