A New Era in Gamma-Ray Astronomy with the Cherenkov Telescope Array

"In the field of observation, chance only favours the prepared mind."
Louis Pasteur (1854).

It is a truism that major advances in astronomy have usually followed the introduction of a new tool. In 1610 Galileo's improved "spyglass" dramatically revealed the four moons of Jupiter, illustrating that not all celestial bodies orbit the Earth, contrary to the then prevailing view. In the report of this momentous discovery, Galileo wrote:

"I propose great things for inspection and contemplation, by every explorer of Nature. Great, I say, because of the excellence of the things themselves, because of their newness unheard of through the ages, and also because of the instrument with the benefit of which they make themselves manifest to our sight."

His advice has been followed with great success by subsequent researchers, leading e.g. to the serendipitous discovery of the cosmic microwave background in 1965 using a horn antenna designed to relay telephone calls via satellite, and of pulsars in 1967 using a radio telescope designed to study rapid time variations in the signal from quasars. The first X-ray detector carried aboard a sounding rocket in 1962 saw a powerful source in the sky that turned out to be a neutron star binary. Subsequent observations of X-ray sources led to the discovery of stellar black holes.

In his influential book "Cosmic Discovery" (1981), the astronomer Martin Harwit provided many such examples and noted in addition that the innovators are frequently not professional astronomers themselves, but rather physicists or engineers. (Harwit also argued against construction of major international facilities like the Hubble Space Telescope on the grounds that it would be unlikely to discover anything really new; however subsequent major discoveries, e.g. dark energy, exoplanets etc., have shown this fear to be quite unfounded... interestingly enough these discoveries too were unanticipated.)

Another window on the sky that opened up just over two decades ago is high-energy gamma-ray astronomy using ground-based Imaging Atmospheric Cherenkov Telescopes. Following pioneering attempts in the 1960s led by Chudakov and Zatsepin in the USSR and Jelley and Porter in the UK (for reviews see Weekes, Physics Reports 160 (1988) 1 and the article of Hillas in this volume), the field began effectively in 1989 with the first robust detection of the Crab Nebula in TeV gamma rays using the 10-m diameter IACT at the Whipple Observatory. This activity has grown rapidly to become one of the most productive sub-fields of astrophysics today, with modest investments leading to many exciting discoveries with experiments like H.E.S.S., MAGIC and VERITAS. Over 100 sources are now known (<http://tevcat.uchicago.edu>), many of them unanticipated and many more yet

unidentified. Among the identified sources, which have been subjected to morphological, spectroscopic and temporal studies are active galactic nuclei (BL Lac), starburst galaxies, pulsar wind nebulae, shell-type supernova remnants, Wolf-Rayet stars, giant molecular clouds, X-ray binaries and the Galactic Centre. IACTs have also provided sensitive probes of dark matter annihilation in the Galaxy and in the satellite dwarf spheroidal galaxies, and of possible high-energy Lorentz invariance violation due to quantum gravity effects. Another application has been as a probe of the extragalactic background light, which would attenuate TeV radiation from very distant sources, as well as measurement of high-energy cosmic-ray electrons and nuclei.

Overviews of this remarkable progress have been given in several excellent reviews (e.g. Cronin, Gibbs & Weekes, ARNPS 43 (1993) 883; Aharonian, Buckley, Kifune & Sinnis, Rep. Prog. Phys. 71 (2008) 096901; Hinton & Hofmann, ARNPS 47 (2009) 523).

The next logical step in this enterprise is the Cherenkov Telescope Array (CTA). This will provide increased sensitivity ($\sim$ milli- Crab fluxes with 5 sigma in 50 h at TeV energies), wider energy coverage ($\sim$ 30 GeV–300 TeV), better angular resolution ($\sim$ 20 at TeV energies), superior energy resolution (RMS < 10% at TeV energies), and a wider field of view (6-8 deg) than existing instruments. Over 1000 scientists and engineers in $\sim$ 170 institutions in 27 countries are engaged presently in the prototyping of the concepts formulated in a Design Study, which was conducted during 2008-11 (CTA Consortium, Experimental Astronomy 32 (2011) 193) and construction is scheduled to occur during 2014–18. There will be two sites, one in the Southern hemisphere which will focus on galactic sources, and one in the Northern hemisphere aimed mainly at extragalactic studies. For the first time in this astronomical field, CTA will be operated as an open observatory.

It is thus an opportune moment to take stock of what we have learnt from observations to date, as well as the theoretical models in which the data is interpreted, and look forward to what CTA will provide. Accordingly Part A of this Topical Issue is devoted to invited reviews from leading experts on the key science topics, while Part B presents detailed studies done by various CTA Working Groups using Monte Carlo simulations of possible array configurations.

Soon other windows too will open on the sky - in high-energy neutrinos and perhaps in gravitational waves. The era of multi-messenger astronomy will soon be upon us.

In summary, to inspire the reader to engage with this authoritative set of papers, we cannot do better than quote Marcel Proust (*À la recherche du temps perdu*, 1923):

"The only true voyage of discovery, the only fountain of Eternal Youth, would be not to visit strange lands but to possess other eyes, to behold the universe through the eyes of another, of a hundred others, to behold

the hundred universes that each of them be- holds, that each of them is."

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