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AUTHOR COMMENTARIES - From Special Topics

Gamma-ray Bursts - June 2009
Interview Date: June 2009

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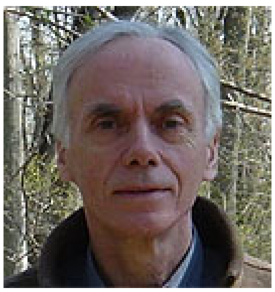


Peter Mészáros

From the Special Topic of Gamma-ray Bursts

According to our Special Topics analysis on Gamma-ray Burst research over the past decade, the work of Dr. Peter Mészáros ranks at #1 by total citations and by total number of papers, based on 147 papers cited a total of 5,074 times. In Essential Science IndicatorsSM *from Thomson Reuters, his record includes 153 papers, the majority of which are classified in Space Science, cited a total of 5,564 times between January 1, 1999 and February 28, 2009.*

Dr. Mészáros is the Eberly Chair of Astronomy & Astrophysics and Professor of Physics, as well as the Director of the Center for Particle Astrophysics, at the Pennsylvania State University in University Park, PA.

In the interview below, he talks with ScienceWatch.com *about his gamma-ray burst research.*

SW: Would you tell us a bit about your educational background and research experiences?

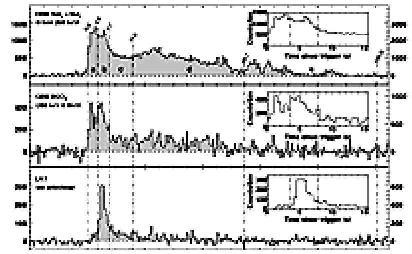
My parents were war refugees from Hungary who settled first in Belgium and later in Argentina, where as a boy on camping trips I slept under the stars and wondered what makes them shine. I got an MS degree in Physics at the University of Buenos Aires, and continued graduate studies at the University of California, Berkeley, where I got my Ph.D. in 1972, working on the astrophysics of the interstellar medium.

I became fascinated with high-energy astrophysics and cosmology during postdoctoral stints at Princeton and Cambridge (UK). I worked on early versions of cold dark matter cosmology and black hole accretion problems, and until 1990 I concentrated mainly on black holes and magnetized neutron stars in various forms. However, gamma-ray bursts (GRBs) were becoming an increasingly attractive puzzle, which somehow was connected to those interests of mine, but it was not clear exactly how.

SW: What influenced your focus on gamma-ray bursts?

The Compton Gamma Ray Observatory was launched by NASA in 1990, and demonstrated that GRBs were isotropically distributed, so they had to be either very nearby galactic objects, or very distant cosmological objects. If the latter, they would be the most energetic explosions in the Universe, and this definitely turned my attention towards GRBs, during a sabbatical spent at Cambridge, which led to a long and fruitful line of work on the subject.

Two mileposts of this were our fireball shock model, with Martin Rees, where we described the GRB radiation as originating in external and internal shocks in the relativistic outflow following the explosion, where electrons are accelerated and radiate via the synchrotron and inverse Compton mechanisms. Much new data and theory has been upcoming since then, and many new questions have arisen, but these models continue being the main workhorses used for fitting and interpreting the data.



This illustrates (partial image shown) nicely the point about the high energy pulse (last curve down) coming 4 seconds later than the low energy pulse (first curve), which is the basis of our argument for constraining the quantum gravity energy scale.

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SW: One of your most influential papers is the 1997 *Astrophysical Journal* article "Optical and long wavelength afterglow from cosmological gamma-ray bursts" (Mészáros P, Rees MJ, 476[1]: 232-7, 10 February 1997). Would you talk about this paper and how it set the groundwork for future work in this field?

In this paper we predicted, before the observations, that an afterglow from the external shock was inevitable, leading to emission at increasingly longer (and hence easier to observe) wavelengths, which would decay as a power-law in time sufficiently slowly to allow accurate localizations with X-ray and optical telescopes. This indeed was very soon afterwards achieved when the Italian-Dutch satellite Beppo-SAX started to detect afterglows, and optical redshifts proved that GRBs were at cosmological distance. Thus, they were indeed the mightiest powerhouses in the Universe: they burn up as much energy in a few seconds as the Sun does in ten billion years, or as an entire galaxy does in 100 years.

The study of afterglows is what has allowed us to map the distribution with redshift of gamma-ray bursts, i.e., how they fit in with the development of the universe. It also led to the identifications of the host galaxy and progenitor star types, as well as providing a closer and deeper look into the afterglow mechanism and its interaction with the host galaxy medium. These types of experimental data have provided the guidance and tests needed to develop the contemporary theoretical views.

SW: Your most-cited paper in our analysis is the 2004 *Astrophysical Journal* paper, "The Swift gamma-ray burst mission." Would you tell us about this paper, its goals and findings?

The Swift mission was designed to follow up burst afterglows in a prompt fashion, so that one could point an X-ray and optical instrument at it before the afterglow had time to fade much. This was made possible by building Swift so that as soon as a burst was detected by an omni-directional (but poorly focused) gamma-ray detector, the spacecraft would slew (repoint) in less than 100 seconds to acquire a high angular resolution x-ray and optical image, and communicate this to the ground in 5-10 seconds to alert large ground-based optical telescopes.

This is a key mission, with the principal investigator Neil Gehrels from NASA and teams from Penn State, NASA, Los Alamos, the UK, and Italy participating in the design, building, and operation, which is controlled from the Mission Control center at Penn State. My role in this was and is to serve as Lead of the theory team participating in the analysis of the GRB data it produces. Swift has resulted, as we hoped, in production-line generation of large numbers of identifications, redshift distances, and multi-wavelength studies of bursts. This has led to a much more detailed elucidation of the physics of bursts, showing that they are much more complex than they appeared from the much sketchier early observations. It has led to the secure identification of the progenitors of some bursts, which are massive stars whose explosion leads also to a supernova remnant, and leaves behind a black hole.

It has also led to the demonstration that a second class of shorter bursts is probably associated with the merger of compact binaries involving neutron stars, which must also result in forming a black hole. And it has led to the detection of the most distant object in the Universe, GRB 090429, whose extreme distance was first estimated by Derek Fox at Penn State, and which was soon spectroscopically confirmed at a record redshift of z=8.1. This distance corresponds to the burst having occurred only 630 million years after the Big Bang, when the Universe was just 1/22 of its present age.

SW: More recently, you were part of the team that published the March 2009 *Science* paper, "Fermi Observations of High-Energy Gamma-Ray Emission from GRB 080916C" (Abdo AA, *et al.,* 323

[5922]: 1688-93, 27 March 2009). Could you tell our readers something about this paper?

This burst was detected by the recently launched Fermi satellite, and it was the first burst for which Fermi's LAT high-energy pair-conversion counters detected with high confidence a large number of photons above GeV energies. Fermi is a large international collaboration, led by principal investigator Peter Michelson from Stanford, with contributions from many universities and labs. Detecting a source with a high density of photons at this energy is extremely interesting, since in order for photons of this energy to avoid annihilating each other and converting into electron positron pairs, the plasma jet where they originate must be moving at extremely relativistic speeds.

Previously we had rough estimates of how close this speed had to be to the speed of light, but with large numbers of photons and a good GeV spectrum it was possible to demonstrate that the jet had to be moving with Lorenzt factors Gamma of about 880, an extremely high value corresponding to a velocity which is roughly 0.999999 of the speed of light.

The most interesting result, however, was that the highest energy photon of 13 GeV arrived about four seconds later than the lower, MeV energy photons at the outset of the burst. Quantum gravity is a theory which is as yet non-existent but which is the Holy Grail of 21st century physics, uniting gravity and quantum mechanics in a Theory of Everything. One of its general predictions is that it induces foam-like fluctuations in space-time which cause a relative delay between the propagation of higher and lower energy photons. The magnitude of the delay depends on a fundamental quantity of physics, the Quantum Gravity energy scale, which is estimated to be around 1.3 x 1019 in GeV units.

+enlarge

From left to right: Nino Cucchiara (from Milano, grad student of Fox at PSU), Dr. Derek Fox (assistant prof. at PSU), Dr. Alessandra Corsi (from Rome, postdoc of PM), Peter Mészáros, Dr. Xuefeng Wu (from Nanjing, postdoc of PM), Dr. Kenji Toma (from Kyoto, postdoc of PM).

The delay observed in GRB 080916C allowed our team to set an experimental lower limit to this scale, the highest obtained so far by any group, of just one order of magnitude below the theoretical estimate, 1.5 x 1018 GeV. These unimaginably high energies are completely out of reach of even the highest energy particle accelerators such as the LHC at CERN, which aims to probe up to 14,000 GeV, but this burst allowed us to set a robust experimental lower limit on this much higher, fundamental energy scale.

SW: What are some of the key things we now know about gamma-ray bursts that we didn't know 10 years ago?

We confirmed 12 years ago that they had afterglows and they were at cosmological distances, and in the last 10 years we have learned a number of other new key facts. One is that within seconds after the gamma-ray trigger, sometimes a very intense optical flash is also detected, and it is still disputed whether it is due to a reverse external shock or it is associated with the prompt gamma-ray mechanism. We know that some bursts (those with gamma-ray durations above two seconds) are associated with the collapse of young massive stars, sometimes showing a supernova remnant, and we have detected what appears to be the breakout of the shock through the progenitor star.

We have learned that shorter-duration bursts appear to originate from older, lower mass progenitors, probably the merger of neutron star binaries. We have obtained evidence which indicates that the bursts signal the endpoint of the evolution of certain types of stars, and signal the formation of a black hole. This is a way in which galaxies seed themselves with stellar mass black holes.

We have learned that bursts occur already at the earliest dates being probed by telescopes, and are among the most distant objects in the Universe. We have learned that the jets producing the radiation through which burst are seen are more relativistic and have a more complex geometry than had been originally considered in the absence of the data we have now.

SW: In what directions do you see this field going in the next decade?

We need to better understand the prompt gamma-ray emission mechanism, and how it relates to the generation of magnetic fields and relativistic particles. Missions such as Fermi will allow us to probe into the higher energy range, which will help to understand the total energy budget, including how much energy is involved in protons and magnetic fields. We also need to know what the contribution of neutrinos and gravitational waves is. These sources provide natural laboratories where conditions and energies surpass anything that terrestrial laboratories can provide. Experiments such as IceCube, Auger, LIGO and VIRGO, and air Cherenkov telescopes will provide new information and constraints on questions posed by GRBs, which could have important implications in other areas of science.

We also expect to see a large increase in the use of GRBs as cosmological probes. They provide the most intense electromagnetic beacons at the largest distances; they act as lighthouses shining through the fog. They indicate where they are, what the burst's immediate environment consists of, and also what is the distribution and chemical composition of the material between them and the Earth. GRBs are basically time machines: we can travel back in time, and see how the universe looked at the earliest time when stars first started to form. This will allow probing how these first sources of radiation reionized and lit up the Universe. The proposed JANUS mission, which is in the last stages of review by NASA and in which Penn State is involved, is designed to provide many of the answers to such cosmological questions.

SW: What lessons would you like lay people to remember about your research?

Major questions of interest to all humanity, such as how the Universe looks at the earliest times and the largest distances we can probe, can be addressed with resources which require a minuscule fraction of the US budget. International collaborations are invaluable in achieving such goals. Universities, both public and private, coupled to the resources of national labs and agencies, are ideal hothouses for providing the talent and manpower which can lead to momentous scientific results.

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Peter Mészáros's current most-cited paper in *Essential Science Indicators*, with 438 cites:

Gehrels N, *et al.*, "The Swift gamma-ray burst mission," *Astrophys. J* 611(2): 1005-20, Part 1, 20 August 2004. Source: *Essential Science Indicators* from Thomson Reuters.

KEYWORDS: GAMMA-RAY BURSTS, SWIFT GAMMA-RAY BURST MISSION, X-RAY AFTERGLOW LIGHT CURVES, GAMMA-RAY BURST AFTERGLOWS, FIREBALL SHOCK MODEL, REDSHIFT, HOST GALAXY, PROGENITOR STAR TYPES, FERMI SATELLITE, PHOTONS, GEV SPECTRUM, OPTICAL FLASH, EMISSION MECHANISM, MAGNETIC FIELDS, RELATIVISTIC PARTICLES, JANUS MISSION, COSMOLOGY.

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