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Summary

Roger Blandford

KIPAC, PO Box 20450 MS29, Stanford, Palo Alto, CA 94309, USA.

Abstract: The first International GLAST Symposium was held at Stanford, with less than a year to launch. Recent advances in the TeV and MeV ranges augur well for GLAST making major discoveries in GeV astronomy. Expectations for observations of several source types and backgrounds are summarized, along with some remaining organizational challenges.

GLAST

Soon after GLAST is launched at the end of this year, the Large Area Telescope or LAT, will survey the sky every 3hr between 0.02 and 300 GeV with effective areas ~ 0.3, 0.9 m^2 for E_γ ~ 0.1,1-100 GeV, a field of view ~2.5 sr and an angular resolution decreasing from ~5^o at 0.1 GeV to ~5' at 100 GeV. GLAST should detect ~ 10^9 cosmic γ-rays above ~0.1 GeV during its expected ten year lifetime. [Ritz, Michelson]. The Gamma Ray Burst Monitor or GBM, will observe from 5 keV to 30 MeV band with an effective area ~100 cm^2, a 9 sr field of view, ~1^o angular resolution and ten percent energy resolution [Meegan].

SOURCES

Stars

The most important star, our own, will be observed from soon after solar minimum to solar maximum in 2017. The GBM and LAT will combine with a flotilla of solar satellites to make unprecedented observations of solar flares and coronal mass ejections superceding the capabilities of RHESSI. It will also provide frequent measurements and sobering reminders of the radiation hazard to which future astronauts will be exposed [Share].

One of the big surprises in TeV astronomy is the detection of the neutron star – Be binary, LSI +61 303 by MAGIC and INTEGRAL especially at phases well away from periastron. The emission most likely arises from the interaction of a pulsar outflow with the stellar “excretion disk”. Two other “HMGBs” have already been detected, promising much more from GLAST [Dubus, Cortina, Hermsen]. Other surprises include the identification of a source with the young star cluster, Westerlund 2, possibly associated with a WR binary and unidentified sources in the Cygnus region [Abdo].

Jets

Relativistic jets have been observed in AGN, GRB, PWN and XRB (for the acronymically challenged). It seems increasingly likely that there is a common mechanism at work, which we still do not understand. Gamma ray observations of these objects promise unique diagnostics over an enormous range in the ratio of the observation timescale to the dynamical timescale.

Almost all of the AGN sources are Blazars, which are identified with the small fraction, ~10^{-3}, that are directed towards us. It now appears that as we progress from the most luminous FSRQ = beamed FR2s to the less luminous BL Lac = beamed FR1 sources, the peaks of the synchrotron and inverse Compton spectra progress to higher frequency, the transition frequency moves through the X-ray band and the TeV spectrum hardens [Kataoka]. This may be an evolutionary sequence. A newly activated black hole has a high mass supply rate and its disk is a powerful UV source of soft photons for the Compton process. After

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time, the mass supply decreases, the radiative efficiency falls and the jet to disk power ratio increases so that the more energetic jet synchrotron photons dominate [Padovani, Celotti].

The official EGRET blazar sample comprised 60 objects, though subsequent analysis has more than doubled this number. The fluxes from these sources range from $\Phi^{(-1)}$ (integral or differential per ln E counts above 0.1 GeV in units of cm^{-2} s^{-1}) ~2 x 10^{-7} to ~ 2 x 10^{-5} when flaring. After 10 years, GLAST should make 5σ detections to $\Phi^{(-1)}$~ 2 x 10^{-9}, or fainter if known blazar locations are used as priors. Projections for the integral counts range from 10^3 to 10^4 [Dermer]. There are now nearly 20 TeV blazars including MKN 501, which varies in minutes, plus M87, (an FR1 = unbeamed BL Lac) [Wagner, Mazin].

Next turn to GRBs. EGRET detected one short and four long bursts including the delayed emission seen from GRB 940217, a finding that has been echoed in the Swift observations of short bursts which challenge the coalescing neutron star interpretation [Piran, Granot]. Swift and Suzaku observations have also transformed our view of long GRBs which are mostly believed to be associated with collapsars [Gehrels, Fukazawa]. Irregular “plateau” emission is seen between the main initial burst and the afterglow and the behavior of the afterglows themselves, which initially exhibited the achromatic breaks in their decays, characteristic of simple jet models, is now seen to be far more complex [Butler, Briggs]. Although it may not have been planned this way, it now seems likely that GBM, LAT and Swift will work splendidly together to study ~ 100 bursts per year. Swift will furnish the identifications, GBM, the broad keV-MeV spectra and LAT the GeV detections and limits. Careful re-pointing will allow Swift and LAT to have a common field of view for a quarter of the time and facilitate prompt follow up of GBM triggers.

The Crab Nebula remains the archetypical γ-ray source and provides a unit of flux ($\Phi^{(-1)}$ ~ 5 x 10^{-7}). Chandra observations show clear linear features directed along the pulsar spin axes varying with relativistic speed, as has been seen in several other examples. At least seven PWN are TeV sources so far.

Finally, we turn to the XRB jets or Galactic superluminals – “quasars for the impatient”. There are no confident detections to date but several are anticipated.

There are common observational and phenomenological themes in interpreting these sources. Layered or structured jets are almost inevitable in any explanation with a fast jet core surrounded by a sheath of more slowly moving material with speed decreasing with increasing angle. A step velocity profile with a thin boundary layer expanding over ten decades of radius would be remarkable. Relativistic beaming is such a powerful amplifier (the intensity is boosted by three powers of the Lorentz factor at the transformed frequency) that what is observed in a given source is probably dominated by those regions in the source where the proper velocity perpendicular to the line of sight is ~ c. This introduces two powerful selection effects. The first is that the flux may be dominated by relatively insignificant parts of the source and the observed variability could be unrepresentative of the source as a whole. The second is that our view of a characteristic jet speed could be dominated by the number of potential sources in our sample. Galactic superluminal typically have slower speeds than extragalactic jets and this may be because the sample is very limited and we simply do not have enough to be guaranteed a few pointed right at us. Conversely, we have studied more GRB than AGN jets and this might explain why the most prominent examples of the former may have ten times the Lorentz factor of the latter.

A related issue is the rapid gamma ray variability seen in blazars and GRBs. In both cases, the emission must originate from radii much greater than ct_{var} because the density of photons with energy in excess of the pair production threshold ~m^2c^4/ E_γ, is so high that environment is quite optically thick [Baring]. This is one reason why relativistic beaming was invoked in the first place. Generally, it is supposed that there is a bulk Lorentz factor Γ, then the actual emission radius will be $\Gamma^2 ct_{var}$. However, it could be much larger if the emitting elements are themselves moving with relativistic speeds in random directions in the jet center of momentum frame. This may be required by the observations in sources like MKN 501 and GRBs if they exhibit prompt GeV emission. This will, in turn, inform the debate on whether the variability is caused by processes around the central black hole creating internal shocks or is due to local instabilities in the outflow.

Yet another common issue is jet composition. In AGN jets the debate has been whether or not jets are hadronic (ions), leptonic (pairs) or electromagnetic (fields). Of course they must be all three and the question is which component carries most of the power. The argument against leptons is that radiation drag is catastrophic close to the black hole and some other carrier must be invoked. One argument in favor of electromagnetic transport is that the X-ray signature of bulk Compton emission is not generally seen. Two arguments against are that simple models of relativistic, magnetically confined jets have most of their power carried by the plasma anyway and that jets appear to slow down and are likely to do this by entraining ambient, hadronic gas. As most models of jet formation are essentially electromagnetic, and magnetic field is unavoidable in the vicinity of black hole, much the most natural scheme is electromagnetic to leptonic to hadronic. All of this is in striking contrast to what has been proposed to explain GRBs. Most models, including those for the magnetar explosions that account for soft gamma ray repeaters, posit that jets are initially radiation dominated like the early universe but with entropy per baryon in the million K rather than billion K range. These entropies are enormous and whereas they are natural in the context of a hot big bang, they are rather unnatural for GRBs. It seems more reasonable that, as with the AGN jets, the entropy is always low and that the initial energy transport is electromagnetic with the outflow again ending up in hadrons accelerated by an external shock advancing into the ambient interstellar medium.

Jet confinement has also attracted much attention in recent years. There have been heroic attempts using VLBI polarimetry of AGN jets to detect the Faraday rotation gradient across the jet that would be a telltale signature of a confining toroidal field pinching an outflowing jet. The results have been tantalizing but not convincing [Taylor]. Better progress is seen with protostellar jets. The confinement is certainly needed because the minimum pressures required inside compact jets exceed the maximum pressures allowed observationally in the surrounding interstellar medium. (It should be remarked that this inference is dependent upon the radio emission being due to the synchrotron process. Observations of intraday variability at cm wavelengths have called even this into question and stimulated the development of jet models that incorporate coherent emission.) In the case of long GRBs, the initial confinement is provided by the stellar envelope and provided that the jet can emerge from the star well-collimated and with an ultrarelativistic outflow speed, it will remain confined within a cone of opening angle ~ Γ^{-1}. What happens in short GRBs is very unclear. Indeed there is not very good evidence that they are well-collimated.

This is a wonderful opportunity for GLAST to make a big impact on our generic understanding of relativistic jets. The ideas and many of the observational facts are already in place and GLAST can provide the connection between them. However, I believe that our understanding of the physics is too poor to carry out this program by fitting data to models that are computed under a large number of untested assumptions. Instead, I think that it will be more useful to proceed inferentially one step at a time. The first such step is to verify that the gamma ray emission mechanism is, indeed, inverse Compton scattering. 0.1-1 GeV observations surely provide a discriminant against hadronic emission models. Conversely, if IceCube detects VHE neutrinos from blazars, then this would be a very strong argument for hadrons.

The next step in understanding AGN jets will be to locate the emission sites for the TeV, GeV and radio emission. The conventional view is that the high energy emission comes from a single zone, perhaps where there is a discontinuity in the ambient gas profile or an obstacle like a molecular cloud. The radio core is then thought to arise from a radio photosphere in the jet with size increasing roughly in proportion to the wavelength. In essence, the observer is looking to down to unit optical depth to synchrotron absorption. The moving features, that give rise to the superluminal expansion, are then optically thin regions of enhanced dissipation, particle acceleration and field amplification, perhaps associated with relativistic shock fronts, that move outward with the flow. Other possibilities have been proposed including that the gamma rays originate outside the radio core. After all, mm emission has been traced to within 1000 gravitational radii in M87. Alternatively the gamma rays may be emitted inside the radio core from a pair production "gammasphere" so that the TeV photons come from a larger radius than the GeV photons. All of this is testable using an aggressive and coordinated campaign of radio and TeV monitoring of a sample of highly variable sources and cross-correlating GeV and TeV gamma ray photon arrival times with radio fluxes.

After identifying the sites of emission, the challenge will be to make more accurate estimates of the powers, pressures etc associated with jets as a function of radius. Large VLBA mapping campaigns, already underway, will be very important for seeing if there are generic scaling relations that govern the behavior of relativistic jets. Finally, these estimates, in combination with recent, impressive 3D relativistic MHD simulations should advance our understanding of the origin of relativistic jets in the gas flows around massive black holes. This will also be important for understanding much better the role of AGN in galaxy formation.

Pulsar Physics

Pulsars were discovered in 1967 but we still cannot agree upon how they shine. The coherent radio emission is attributed either to giant charge density fluctuations that radiate curvature radiation, much like individual electrons and various maser processes where traveling radio waves grow by extracting energy from positrons and electrons streaming out along the open magnetic field lines. Six pulsars were detected by EGRET and at least three sites of gamma ray emission – polar caps, slot gaps and outer gaps - have been identified [Harding]. The first challenge to GLAST, which is projected to find ~ 100 pulsars, is to make unequivocal choices as to where the both the radio and the gamma ray emission is located. The hope is that GLAST will find enough examples of new pulsars, especially those where the observer and magnetic inclinations can be modeled, that it will be possible to carry out this program. (Note, though, that the polarization directions are orthogonal to those predicted by the "rotating vector" model, which may be a signature of maser emission or a propagation effect.) The task should be facilitated by the recent numerical solution of the force-free-structure of a rotating dipole magnetosphere, which is quite different from the structure of a spinning vacuum magnetosphere and ought to be fairly simple. More sophisticated models of the spectra will also help. Once the sites are identified, it will be possible to relate the powers to the local current density and potential distributions and use the gamma ray pulse profiles to understand the electromagnetic environment in the emission region.

GLAST also has the possibility of discovering many new types of pulsar including radio quiet pulsars like Geminga, millisecond pulsars and gamma ray counterparts of the recently discovered Rotating RAdio TransientS [Johnston, Ransom]. It will also be very prescriptive to determine if the new GLAST pulsars have TeV counterparts.

Supernova Remnants

H.E.S.S observations of young supernova remnants, notably RX J1713.7-3946 have led to the remarkable discovery that supernova remnants can almost certainly accelerate particles to energies in excess of 300 TeV, quite close to the "knee' in the cosmic ray spectrum [Drury]. Now supernova remnants have long been identified as the primary source of Galactic cosmic rays. However, the acceleration mechanism has been controversial. The association of nonthermal X-rays with portions of the shock fronts in remnants like SNR 1006 [Slane] points to diffusive shock acceleration which seems capable of explaining the necessary high efficiency and automatically transmits the correct source spectral slope. However alternative schemes that attribute the acceleration to second order Fermi acceleration in the post-shock flow have also been proposed. Whatever the acceleration mechanism, it seems necessary for the magnetic field strength to be amplified simultaneously with the particle acceleration to many times the nominal interstellar value of 3μG if only to reduce the Larmor radius of a 0.3 PeV proton or electron, ~ $E_{PeV}B_{\mu G}^{-1}$ pc, to a small enough value to confine the particles while they are undergoing their final energy-doubling.

If protons are responsible for the 100 TeV emission in remants like RX J1713.7-3946, then the required thermal plasma density, > 1 cm^{-3}, might be expected to produce more thermal X-rays. Conversely, if electrons inverse Compton scatter the microwave background then more synchrotron X-ray emission is predicted. GLAST is likely to detect ~ 100 SNR and make a big impact in understanding cosmic ray acceleration. It will fill in the large gap between X-ray and TeV observations and will be able to resolve the largest remants. (It is encouraging that RX J1713-3946 has probably already been seen as an EGRET source.) GLAST should also be capable of detecting spectral signatures of pions or synchrotron-Compton sources and settle the question of whether or not the TeV emission is hadronic or leptonic. Finally, it should also be able to discover observationally what conditions (external density, shock speed, size etc) are necessary to accelerate up to the knee in the spectrum and perhaps finally put the final pieces in the solution to the century old riddle of the origin of cosmic rays.

Backgrounds

GLAST will not only detect individual sources. Its wide field of view will enable the very difficult measurement of the many cosmic gamma ray backgrounds that it can see, while accurately rejecting the much larger local cosmic ray foregrounds. Moving outward, there is the interplanetary background which may be enhanced through the inverse Compton scattering of sunlight by cosmic ray electrons. Next will come the existing puzzle of the diffuse interstellar background which is expected to account for about three quarters of the photons that the LAT will detect and which exhibits a GeV excess of unknown origin [Digel], in contrast to the MeV and TeV backgrounds, which are mostly thought to comprise discrete sources, (except possibly in the inner Galaxy and Cygnus regions [Abdo, Knodelseder]). GLAST should be able to see if the GeV excess is due to sources like pulsars or variations in either the gas, as traced by CO surveys, or the cosmic rays. The constantly improving GALPROP program is proving invaluable in these studies.

Understanding the interstellar background is a pre-requisite to understanding the extragalactic gamma ray background of $d\Phi^{(-1)}/d\Omega{\sim}1.5 \times 10^{-5}$ sr^{-1}. The default presumption is that this background is just the sum of unresolved AGN, as is the case for the X-ray background. In round numbers, EGRET accounted for ten percent of the background with FSRQ whose counts only increase inversely with flux and are unlikely to contribute much more. However, BL Lacs are much closer and will have a Euclidean slope allowing them to make up the difference. Unfortunately, GLAST will have neither the sensitivity nor the angular resolution to account for all of the background, but should determine if we have to invoke diffuse contributions like emission from intergalactic shock fronts.

The observation of gamma rays with energy E_γ GeV provides an upper limit on the energy density of background stellar photons at redshift z with wavelength $\sim 0.5(1+z)^2 E_\gamma$ μ. The energy cut off is predicted to be $< 30\ z^{-1.5}$ GeV. Where the inequality takes into account intrinsic absorption. Observations, made at TeV energies have already proved to be constraining and GLAST will do much more. This may be particularly interesting for limiting the density of the first Population III stars [Hartmann].

It is likely that measurements using Auger will determine if UHE cosmic rays have a “GZK” cutoff, if there are astronomical sources and if they are not protons by the time GLAST is launched. On the assumption that the answer to each of these questions is negative, it will be possible to use GLAST GeV background observations to argue more rigorously, that the cosmic rays are accelerated “bottom up” rather than “top down”.

Finally there is the possibility of detecting neutralino annihilation, unambiguously. If we are very lucky and this is not forbidden by particle physics – there will be a line. More likely, though, there will be a hard spectral distortion. Demonstrating the reality of such a feature presents a great observational challenge. However, it will be worth the effort as this is surely the greatest discovery that GLAST can make [Wai, Kuhlen, Koushiappas].

CHALLENGES

The data challenges exercises reported here have been very successful recovering simulated sources and debugging pipelines. [Fosatti, Torres, Ubertini]. This activity is getting closer to the concerns of the various science working groups and it may be time to start mounting some science challenges that anticipate debates about what observations suffice to answer scientific questions like those outlined above. In addition, despite heroic efforts, the multi-wavelength campaigns that are being fostered by the various science working groups still need more attention if they are to be ready for the start of GLAST observing [Thompson, Thorsett, Carraminana].

Everything is coming together in γ-ray astronomy. H.E.S.S. has demonstrated, spectacularly, the existence of new source types and MAGIC [Torres], VERITAS [Kieda] and MILAGRO [Abdo] should soon be contributing detections at a similar rate. AGILE [Tavani] is about to be launched and, although it is less sensitive than GLAST it is more sensitive than EGRET and should provide more complete monitoring of the brighter sources, especially during the first year. The unplanned partnership with Swift will make the GBM a powerful contributor to our developing understanding of GRBs. The days immediately before and after launch will have their share of anxiety and uncertainty but there is guarded optimism that all the hard work and international collaboration that has brought GLAST so far will be rewarded with great discoveries.

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