Part 11

Summing Up

High Energy Processes and Phenomena in Astrophysics
IAU Symposium, Vol. 214, 2003
X. D. Li, V. Trimble, and Z. R. Wang, eds.

Conference Summary: What is High Energy Astrophyics?

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Abstract. The original intent of the conference was to focus, first, on the physical processes (accretion, collimation, and all the rest) shared by two or more of the kinds of sources generally thought of as belonging to high energy astrophysics and, second, on the full range of phenomena, at all wavelengths, exhibited by those sources. This summary therefore addresses some of these issues as well as some new results presented at the symposium and some of the still-unanswered questions that were raised.

1. Introduction

The phrase "high energy astrophysics" seems first to appear in print in the proceedings of a 1965 Varenna (Italy) summer school with that title. In the introduction, the editor (Gratton 1966) provided his definition in the form "rate of release of energy per second and per gram is very high" compared to normal stars and galaxies. He included gravitational collapse, supernovae, and QSRS (the acronym for quasi-stellar radio sources, which we eventually came to pronounce as quasars) as examples The early "Texas" symposia on gravitational collapse and other aspects of relativistic astrophysics added cosmology, gravitational radiation, solar neutrinos and other "not normal stars and galaxies" to the inventory.

About five years later, three organizations were founded to coordinate similar studies. These were (a) the Division of Cosmic Physics of the American Physical Society, now called the Division of Astrophysics, whose founders came largely from the cosmic ray community and, to a lesser extent, from the nascent X-ray and gamma-ray communities, (b) the High Energy Astrophysics Division of the American Astronomical Society, whose founders includes optical and radio astronomers and many theorists, and (c) Commission 48, High Energy Astrophysics, of the International Astronomical Union, again largely the creation of theorists, radio, and optical astronomers (with about 50% overlap with the initial membership of HEAD).

None of these entities has maintained quite as broad a focus as its initial vision. Indeed Comm. 48 has ceased to exist completely, having been merged about six years ago with Commission 44, Astronomy from Space (on the advice of its own president). HEAD is dominated; almost entirely by X- and gamma-ray astronomers and DAP only slightly less so.

Thus, somehow, "high energy astrophysics" has come to mean more nearly "high energy per photon or particle" rather than "high energy per event or source". It was one of the goals of Symposium 214 to try to restore some of the original balance, and this was clearly achieved, beginning with the first talk by Blandford, who asserted that HEAp is a completely multi-wavelength discipline, and continuing with a number of other speakers (e.g. Rudak) asserting that they were not wavelength chauvinists.

2. HEAp as a Set of Observed (more. or less) Objects and Events

Historically first in this set are the (galactic) cosmic rays, known from 1900 to carry large amounts of energy per particle, though the particles were generally thought to be gamma rays until the 1930s. In fact, about 99% of the energy is in positively charged particles, mostly protons, and, though the acceleration process is generally placed in or around supernovae and their remnants, no real SNR has anything like that ratio of ion energy to electron energy. McCray and Pun pointed out, however, that we will have an unprecedented opportunity to watch SN shock acceleration in progress over the next few decades as the ejecta from SN 1987A encounter circumstellar and interstellar material.

The very highest energy cosmic rays ($10^{18} - 10^{20}$ eV and beyond), were the focus of several conference presentations. (e.g. Fukushima, Tan, Gorham). The chief underlying issue is how they can get to us from any reasonable distance through the sea of cosmic microwave photons. Whether their arrival directions are clustered and whether they are truly protons enter into the possible answers, of which there do not seem to be very many. The chief possibilities would seem to be some unexpected class of nearby source (in which case clustering would be expected), new physics (that lowers the interaction cross section), some new sort of particle, like a decaying WIMP, lodged in the halo of the Milky Way, or an enormous flux of very high energy neutrinos impinging on a sea of low energy galactic neutrinos and making Z^0 particles which, in turn, decay to the UHECRs. The very highest energy gamma rays reaching us present a similar problem (their enemy is the intergalactic background of optical and infrared photons, whose energy density is somewhat uncertain). Takita and Cao considered them.

Second member of the set is the supernova phenomenon. In 1933, only Baade and Zwicky (1934) knew that these were powered by stellar core collapse to neutron stars. By 1966, just about everybody knew it (Wheeler 1966). Admittedly, the details of how energy is transferred from the collapse so as to expel the ejecta we see is still in dispute. Moiseenko favored a magneto-rotational mechanism, while Lai preferred the currently more popular neutrino-driven convection, and noted that most new-born neutron stars (including binaries and also black holes from supernovae) have been given a "kick velocity" by asymmetric explosions. These are the Type II (and also the stripped Type Ib,Ic) or core collapse supernovae. For the Type Ia's (nuclear explosions) the outstanding question for decades has been the nature of their progenitors. Han concluded that, unfortunately, any of the popular candidates (binary white dwarf mergers; mass transfer in symbiotic stars, recurrent novae, or other CVs) can provide the event rate we see, though they make somewhat different predictions for the evolution of that event rate with time (and probably for nucleosynthesis).

Third, still historically, we come to the QSRSs, QSOs, quasars, and other active galactic nuclei. Radio galaxies were actually first (and inspired the beginnings of gamma-ray astronomy because some theorists attributed them to collisions of galaxies with anti-galaxies), but the modern paradigm of accretion onto very massive black holes followed hard upon the 1963 discovery of quasars (Salpeter 1964; Zeldovich and Novikov 1964). No one at the symposium expressed serious doubts about the massive black hole engine, though there was much discussion of mechanisms for energy extraction and transformation to the forms we see (next section). In the "high energy per photon" regime, a number of QSOs (etc.) are EGRET sources (Hurley) and at least a few (prototypes Mkn 421, 501) extend into the TeV range addressed by Gao and Takita. These days, X-ray emission is practically part of the definition of a proper QSO, but it is also characteristic of the less powerful Seyfert 1 nuclei (McKernan, Padmanabhan, and a number of posters). A standard question is "where is the warm absorber?", but I think the most interesting answer to a related question was, "the narrow lines come from the broad line region" (Padmanhaban)

Fourth are neutron stars as real (rather than theoretical) entities, both single and binary. The story of the discovery of pulsars has been told too often to need repeating here, and places the recognition of the existence of single neutron stars firmly in.1968. The binaries actually came first, but less clearly. The prototype, Sco X-1, was recorded in a 1962 rocket flight, and credit for being first to think or say "accretion on a neutron star from a close companion" has been disputed. The first to write were, however, pretty clearly Zeldovich and Novikov (1966). At the present symposium, Manchester provided a masterful overview of the inventory of single (pulsar) neutron stars. The total now exceeds 1500, of which 27 (including all those with "slowing-down ages" less than 5000 years) have associated supernova remnants. X-ray emission, strong magnetic fields, or both also go with short apparent lifetimes, though not all such pulsars are bright. Globular clusters are endowed with far more than their fair share, with 23 known in 47 Tuc alone. Radio telescopes in China have not yet added to the inventory but are providing valuable long-term timing information (Na Wang). Inventories of neutron star X-ray binaries were addressed by Q.D. Wang, Griffiths, and Soria, and radiation processes etc. by a number of other speakers (next section). This is perhaps the place to mention two "existence" questions: Are there strange quark stars as well as neutron stars in the real world (yes, according to Xu), and are there remnants of hypernova events (yes, at least one, according to Asvarov, though the events themselves are no longer needed for gamma ray bursts, of which more shortly).

Stellar mass black holes enter our inventory in 1972 (Bolton 1972; Webster and Murdin 1972) with the first radial velocity curves providing estimates for the compact component in Cygnus X-l (6 solar masses or more, as it remains to this day). Single, stellar-mass black holes have been tentatively located among the lenses in the MACHO and related projects, but did not appear at this symposium.

Sixth and last of the entities mainstreamed at IAUS214 to be recognized were the gamma ray bursters. Known to a few members of the nuclear test monitoring community at Los Alamos and in Moscow from about 1970, by the time of the 1974 Texas symposium they had spawned so many models that one speaker thought it simplest to display a list of theorists who had not promulgated a model. The list contained one name, J.P. Ostriker (who undoubtedly formulated one soon after). The models then included the neutron star surface phenomena that were popular through the 1980s, neutron star binary mergers (popular in the 1990s), and many less likely stories, like white holes, comets (in the solar system or impacting the surfaces of neutron stars), and nuclear fission explosions. The proceedings of a GRB conference held just before the launch of CGRO (Ho, et al. 1992) makes wonderfully nostalgic reading. Blandford, Hurley, Kulkarni, and Piro reminded us of the happy tale of the detection of X-ray tails by BeppoSAX and the progress to optical and radio counterparts, leading to the universal recognition that (most) GRBs occur in normal, star forming galaxies, but so rarely the our supply of one a day or thereabouts is pulling in events out to redshifts of four and more.

Of course, these triumphs pertain only to the GRBs that last more than a couple of seconds. No counterparts have yet to be found for the comparably numerous category of short duration bursts. HETE-II has localized one (Ricker) but, by the time the rest of the wavelength world got there, there was nothing to be seen. Thus it remains somewhat an article of faith that there will be something for X-ray, optical, and radio astronomers soon. The association with starburst galaxies and supernovae thus also pertains only to the long-duration bursts. Even among the long duration bursts, while most have X-ray tails, only about half turn up as visible or radio sources. Visible (or, rather, invisible) excuses include dust and very large redshifts. In either case, this dictates infrared searches (Antonelli).

Additional astronomical entities that appeared at the meeting and are mentioned at least briefly below include normal galaxies, sources of neutrinos (especially the sun) and gravitational radiation, and X-ray emitting clusters of galaxies, which have been a rich source of information about mergers of galaxies and clusters, the amount and distribution of dark matter in clusters, early nucleosynthesis, and much else (Forman).

A good many other sorts of astronomical objects and events would seem to meet either the definition of high energy per event or high energy per photon or both but somehow never made it onto the program. These include the novae, supersoft X-ray binaries and other sorts of cataclysmic variables with and without strong magnetic fields tied to their white dwarfs (most of which are X-ray sources), colliding winds in binary stars (the RS CVn's and WR binaries, are characteristically sources of bremsstrahlung X-rays and sometimes synchrotron radio), and solar and stellar flares, which are known to (a) emit X-rays, (b) accelerate particles to the point of being able to produce at least a few nuclear reactions around the sun and perhaps in the solar proto-planetary nebula, (c) collimate supersonic jets in the case of young stellar objects with bipolar molecular flows, and (d) trigger coronal mass ejections, which are also at least somewhat collimated.

3. HEAp as a Set of Physical Processes Shared by Classes of Sources and Objects

The most obvious of these are the various radiation mechanisms, in which energy that has been present in some other form is transmogrified into photons.

Atomic line and edge emission and absorption. This is perhaps the least obvious if you start from a "high energy" vantage point. But, first, such features tell us that atoms are present, which was essential in ruling out inverse Compton radiation as the source of X-rays from clusters of galaxies long ago. More recently, line emission and absorption has told us that the cluster gas has nearly solar metallicity at the center, dropping outward (Forman), that gamma ray bursters happen where there is iron (and possibly other heavy elements) around, possibly in larger quantities than found in random stellar atmospheres or the ISM (Piro), that the accretors in some X-ray binaries have more properties of black holes than just compact large masses (Zhakarov, via the profiles of iron lines), and that most of the local baryons are in a diffuse medium (Sect. 5)

Thermal radiation is another sort of orphan. When optically thick, it is called black body (for instance the radiation from the surface of neutron stars that are not pulsars, though even then the spectrum and polarization are strongly modified by magnetic field effects, Lai). When optically thin, it is called bremsstrahlung or, better, free-free emission (since hardly anyone misspells "free"). X-ray clusters are now known to be doing this (Forman), as are a subset of the core-collapse supernovae when their ejecta encounter material previously shed by the progenitor star (Immler, Mccray). Reprocessing of photons by dust comes somewhere in between (e.g. poster by Komossa and Hasinger), with individual grains optically thick, but the ensemble partly transparent in some cases, though Hasinger rather casually remarked that he thinks 90% of all AGNs are essentially invisible in optical radiation.

Cerenkov radiation is normally thought of as a way of detecting very high energy particles (Samuelson, Barwick, Totsuka, and others), but the poster by W.W. Wang et al. proposed that the Fe line emission from a few gamma ray bursters might have Cerenkov origin rather than the fluorescence or recombination normally proposed (and please consider those mechanisms thereby to have been mentioned too!).

Masing by definition makes photons of low energy each, but can result in very large flux densities (that is, energy per second per Hz per steradian). The poster by Babkhovskaia and Poutanen mentioned a model for the water masers in NGC 4258 (a galaxy that one would otherwise call merely mildly active, though the maser velocities and positions provide strong evidence for a massive black hole at its center). Nobody mentioned stimulated Raman scattering (for which we were grateful, never having understood it), but it appears in the archival literature in the context of AGN and other line spectra.

Synchrotron radiation inverse Compton scattering, and their "cross product" synchrotron-self-Compton are the canonical processes for making high energy photons or (in the context of supernova remnants, radio galaxies, and all) high energy per source though the photons are radio ones. The thought that synchrotron radiation might be important in the Crab Nebula can be traced back to Shklovskii (1953) and has proved to be the case there from radio to X- and gamma-rays. A territory to which Chandra images and spectra have made significant recent contributions is the decision on whether most AGN jets radiate synchrotron or inverse Compton X-rays. This was not much addressed at the symposium. The archival literature now firmly says that there is some of each, one or the other predominating in a particular source, and the relevant talks (Fan on AGN beaming, Stawarz on emission from stratified jets) at least did not disagree. The traditional diagnostics for synchrotron and inverse Compton at radio and optical wavelengths are the spectral shape and polarization. In X-rays, we still have only spectral data. X-ray polarimetry is one of the last large, unopened windows in astrophysics, though questions to speakers from both Blandford and the present author did not arouse much enthusiasm for it. One X-ray polarimeter has been flown. It looked at one source, the Crab Nebula, and found it to be highly polarized. This was in the early 1970s.

"The" pulsar radiation mechanism is clearly the sum of many processes that can be calculated by various simplified formulae, including curvature radiation, photon splitting, synchrotron and Compton radiation, cascades initiated by photon-photon pair production and by photon-field pair production, and probably some others (Rudak, Qiao). An unusual variant attributes even the radio emission to Compton upscattering of photons that started out with still lower frequencies (Xue). We suppose (without much desiring to try it) that somehow all of these and the ones in the previous paragraph(s) could be described together with a sufficiently complete solution of Maxwell's equations, and that many or most of the mechanisms should be thought of as telling an electron what to do when it finds itself in an environment dominated by some one other entity (field, high frequency photons, low frequency photons, dense matter, dilute atomic gas, and so forth).

Other processes that were mentioned in connection with more than one sort of source (etc.) during the symposium included (a) the two basic energy sources: gravitational contraction, collapse, or accretion and nuclear explosions, (b) particle acceleration, especially in shocks, for supernovae and their remnants McCray, and also most definitely for GRBs (J. Wang, H.K. Lee, Chernenko), (c) collimation of jets and outflows for AGNs, GRBs, and the subset of black hole X-ray binaries called microquasars (Mirabel), and (d) not mentioned except in the summary talk the generation and amplification of magnetic fields on scales from sunspots to pulsars to spiral arms to the intracluster medium. The choices are dynamos and primordial fields, each of which has problems.

Deserving of a separate paragraph are the enormous range of instabilities that can arise in accretion disks and their interfaces with accreting objects, magnetospheres, and streams of gas from companions. Some involve sudden shifts in opacity (the traditional dwarf nova instability) or magnetic fields (the Balbus-Hawley instability, so called because it was recognized by several others earlier but popularized by them) or beats between two periodic processes (some versions of quasi-periodic oscillations) These collectively are presumably responsible for the richness of temporal phenomenology in XRBs, GRBs, AGNs, and all. Aspects of the range of problems were addressed by Gilfanov and Yu (on disk inner edge locations), Poutanen (on LMXRBs where we see the rotation periods of the neutron stars), Menna (on periodic and non-periodic variability in both LMXRB and HMXRB), Torkelsson (on spin ups and downs), X.-B. Wu (on disk oscillations rather than beats for certain QPOs), and J.-F. Lu (who focussed on the underlying, persistent disk in which an outer, Shakura-Sunyaev flow transitions to advection dominated accretion flow close to a black hole). Difficult to classify, but perhaps part of the "instability" picture, was the GRB model presented by H.K. Lee. involving a black hole and accretion disk more or less as usual, but within which, we think, repeaters would be possible. Producing variability when energy is derived from black holes by accretion seems to be straightforward if complex. No speaker particularly talked about rapid variability in Penrose or Blandford-Znajek processes, but we have infinite faith in the creativity of theorists and would not for a moment deny the possibility.

Energy transport from the central engine to the nebulae, lobes, shells, and all that we see is yet another generic sort of process, frequently (not always) accomplished by jets, beams, or other collimated structures. Through perhaps three-quarters of the 35 year history of high energy astrophysics, the carriers have been supposed to be material beams, whether ionized atoms or electron-positron plasmas. The jets of Stawarz and Mirabel, among other speakers, were of this sort. But we were interested to see some revival of interest in beams of Poynting flux or electromagnetic radiation for transport in pulsar wind nebulae (Gotthelf).

4. Whatever Roger Blandford Says It Is

Remarkably, the first speaker, without any coaching from the Scientific Organizing Committee, began by attributing two characteristics to high energy astrophysics. The first was that it is a multi-wavelength (indeed extending beyond mere photons) enterprise, and the second was that it has a commonality of physical processes that manifest themselves in a range of source types.

Classic examples of the need for a full range of wavelengths include the settling of the galactic/extragalactic issue for gamma ray bursters (gamma rays to call our attention to the phenomenon, X-rays to localize events on the sky; visible light for redshifts, and visible light and radio data for total energies), and the demonstration of the presence of black holes in both active galaxies and a subset of X-ray binaries (radio and X-rays to tell us something interesting was going on, but optical imaging and spectra to pin down compactness and masses of the accretors).

A number of examples of "physics in common" appear in Blandford's article. We caught some (but not by all means all) of the cases mentioned by other speakers, for instance the existence of high/low spectral and luminosity states (where high L = soft spectrum and conversely) in AGNs as well as X-ray binaries (Zdzarski, who however expressed surprise that the time scales for the transitions between states do not seem to scale with the mass of the central black hole), the similarity of the beaming in AGNs and GRBs (J. Wang), and a possible association between the time variability of GRBs and that of the QPOs in X-ray binaries (Chernenko).

5. Recent Progress

Here are the new (or newish) classes of objects and processes and the new (or newish, or more firmly established) answers to old questions that struck me as memorable as the week went by. Efforts to order them in any particular way have failed, so they are just numbered.

1. Microblazars. The microquasars presented by Mirabel all have their jets more or less in the plane of the sky. He pointed out that, by analogy with AGNs with various jet alignments, there should also be at least a few aimed more or less straight at us, which should show strong Doppler boosting, rapid variability, strong and variable polarization, and so forth.

2. X-ray flashers. The natural name for these would seem to be X-ray bursts, since a capsule description is "gamma-poor GRBs." Unfortunately the name is already taken. Ricker was fairly certain that they form a continuum in Lx/L_γ with the GRBs. Kulkarni was not quite so sure. They are anyhow observationally rather distinct in the sense that there are almost none in the BATSE data base, so that they constitute, more or less, a HETE discovery.

3. Tidally disrupted stars being accreted by otherwise silent central black holes in galaxies. These have been advertised and/or sought for many years. Komossa made the existence of at least one case, NGC 5904, sound very persuasive.

4. Optical flashes from Be XRBs. Again there is one best case, A0535+26 in 1995 (Dorokhova). This talk puzzled several participants; by appearing in the "future" session, but the point was that another of the important future "missions" is the International Virtual Observatory and that, with access to it, astronomers anywhere in the world will be able to address a range of astronomical questions that once required you to build your own instrument (as Hurley remarked for gamma rays) or at least to be at the right sort of institution (as Padmanabhan remarked in discussion). A second XRB talk that combined original observations from a less-than-famous observatory with archival data was also scheduled in that session, but the speaker was unable to participate at the last minute.

5. Multiplicity of GRB types. I am an agnostic on the divisions beyond long and short, but Preece noted that, however you define your categories, there are outliers in the n-dimensional space of temporal structure, spectrum, and fluence.

6. Ultraluminous X-ray sources and intermediate mass black holes. The key issue is whether the latter is the (or an) explanation for the former, whose existence in a number of nearby galaxies (mostly though not exclusively spirals) has been established (Soria). The alternatives are (a) transient super-Eddington (presumably because asymmetric) accretion and radiation, (b) beaming of the X-rays toward us, and (c) unresolved sources (not addressed by the speakers). Pakull has shown that, for one example, in the dwarf galaxy Holmberg II, beaming is probably not the right answer, because there is a surrounding nebula whose brightness is such that it seems to need to be illuminated by the entire derived X-ray luminosity of the central source.

7. The gamma-ray burst - supernova connection. All GRBs with redshifts less than 0.7 show a late-time contribution to their light curves consistent with a core-collapse SN (Kulkarni). The number is, of course, not very large. The GRBs are definitely beamed, reducing their total energy requirements to more like 10^{51} ergs than 10^{53}. Thus hypernovae are not "needed", though this does not require their non-existence.

8. Kick velocities are real, but go are connections (one anyhow) between supernovae and neutron stars where the remnant has expanded very asymmetrically, leaving the pulsar on its edge, without any large proper motion being implied (Gvaramadze). Manchester concurred, at least for the case of G54.1+0.3.

9. All pulsars with slowing-down ages less than 5000 years have associated supernova remnants, but not all (of either the pulsars or the remnants) are bright. Pulsars with slowing down ages longer than those implied by other considerations may simply have started with long rotation periods, while those whose ages seem too short have arguably rearranged their magnetospheres and field geometries so that the slowing down index n is very different from 3 (Manchester). Energy transport out from pulsars to their nearby nebulae may well be largely Poynting flux, so that no rapid transfer of energy to relativistic particles is required (Gotthelf). This is a mercy for those of us who have never understood the Kennel-Coroniti model.

10. Silicon and iron in Kepler's SNR are well mixed (poster by Cassam-Chenai et al.). This is, of course, not true for Cas A. In the case of SN 1987A, there was some early mixing by nickel bubbles, but how much layering exists over the total ejecta will be gradually revealed over the next decade or two (McCray).

11. The X-ray background has now largely been resolved into sources (an announcement that has been made several times before) according to Hasinger and Griffiths. The surprise is that the faintest sources contributing (whose counts have been extracted by a method known to radio astronomers as P(D) and to optical ones as surface brightness fluctuations) are about as numerous as normal galaxies (Griffiths).

12. The X-ray emission from the plane of the Milky Way and at least some other normal spirals is more than 50% diffuse, rather than being the sum of XRBs, SNRs, and such (Q.D. Wang).

13. The cooling flow scare has been greatly exaggerated (but has not, in my view, completely evaporated). The original scare arose as early as Einstein images of clusters, in which (though T(r) was not really measured) it seemed that if the central pressure were to be high enough to support the gas, the cooling time there must be considerably less than a Hubble time, and gas mass divided by cooling time could be as much as 1000 solar masses per year. But a range of optical and infrared and radio observations revealed little or no atomic or molecular gas or newly formed stars. The

choices seemed to be formation of exclusively low mass (non-blue, non-bright) stars or something wrong. Even the X-ray astronomers started to be scared when Chandra and XMM saw no central gas cooler than 1-2 keV, a range through which a cooling flow would have to pass to get to stars. The problem has now been solved, or anyhow reduced by an order of magnitude to 100 rather than 1000 solar masses per year in typical rich, relaxed clusters. Hasinger invoked reheating of the gas by the jets, bubbles, and all of active galaxies at their centers. Forman mentioned in addition conduction, mergers, shocks, cold fronts, and sloshing of gas as indicators and mechanisms.

14. Faint accreting black holes don't accrete much. That is, most of the gas gets blown back out (for which the acronym is ADIOS) rather than going down the tubes and taking its energy with it (for which the acronym is ADAF) according to Blandford. Other speakers would perhaps have disagreed.

15. The missing baryons found. Calculations of big bang nucleosynthesis and comparison of the results with abundances of deuterium, helium, and lithium in relatively unprocessed gas imply a cosmic baryon density of 4-5% of the closure density. At redshifts of 4 and larger, most of that gas is to be found in assorted absorption line clouds whose presence is revealed in the spectra of QSOs whose light passes through them. The location at z = zero has not been so obvious, with stars and gas in galaxies and clusters adding up to less than half the total. Well, it seems that about three-quarters of the z = 0 baryons are still in a fairly diffuse phase, consisting of warm-to-hot sheets and filaments, absorption (and emission) by which could only be pinned down with the good wavelength resolution at soft X-ray and hard UV wavelengths. There is warm/hot diffuse gas very close to the Local Group, and if the sightline is typical, it represents the missing material well.

16. Answer to the solar neutrino puzzle and the mixing angles of leptons and quarks. At 8 MeV, the neutrinos emitted by B8 would surely be high energy if they were photons or other particles, though of course the sun has a luminosity of only one solar luminosity (known quite precisely, at least in those units). The critical items are (Totsuka), first, that the missing neutrinos were always there (they have simply rotated from electron neutrinos to another flavor, probably muon neutrinos) and second, when you put the solar results from SuperKamiokande together with the atmospheric neutrino results from SuperK and the solar ones from SNO, you can calculate the mixing angles among the three flavors of leptons, for comparison with the quark mixing angles (which come from things like the decay of strange and charmed particles). The answers are:

Leptons	Quarks
$\sin^2 \theta_{12} = 0.6 - 0.9$	$\sin^2 \theta_{12} = 0.188$
$\sin^2 \theta_{23} = 0.92 - 1.0$	$\sin_2 \theta_{23} = 0.0664$

I was surprised to learn that they are so different (though perhaps I should not have been). The more likely of the two remaining possible combinations of neutrino masses has them all small and the cosmic neutrino density only about 0.1% of closure. The corresponding cosmic density of primordial gravitational radiation could be even smaller, or, just possibly, a good deal larger (Melek).

It is perhaps worth recalling that the first data set suggesting a deficit of solar neutrinos relative to the standard astrophysical model goes back to about 1970 (and that the physicists initially nearly all blamed the astronomers for not getting that model right). Other puzzles dating from the same period were (a) the Dicke (oblate) sun, which eventually proved to be a rediscovery of solar plages and the activity cycle by very difficult methods and (b) the coincidences between bar detectors for gravitational radiation located in Maryland and Chicago (Argonne National Lab) and, later, in Maryland and Rome. That data stream eventually included about 200,000 hours of data on strip chart recorders, magnetic tape, and so forth, collected by a single researcher. Even TAMA, of the modern detectors, with 1000 hours of data (Koruda) has a ways to go to match that record. Direct detection of either the cosmic neutrino or the cosmic gravitational radiation background is probably at least 100,000 hours of data collecting ahead of us.

6. Problems and Future Approaches

My own list of "further work required", many of which have already been mentioned, includes the ejection mechanism for core-collapse supernovae, the progenitors for nuclear deflagration supernovae, the correct assortment of pulsar radiation mechanisms, and the cause of slowing-down-indices different from n = 3. Another set is the nature of the underlying sources in supersoft X-ray binaries, short duration GRBs, ultraluminous X-ray sources, and the unidentified gamma ray (EGRET) sources, which still outnumber the identified ones about 170:100 (Hurley). "How do they get here?" seems to be the right question for the highest energy cosmic rays and photons.

"Do they exist?" applies to hypernovae (no longer needed for GREs) and quark stars (the most urgent need for which came from an incorrect distance to one source according to discussion after the talk by Xu).

Some things whose existence is fairly well established but for which "how they do it" is not included (a) the excess of QSOs in the sky around galaxies of much smaller redshift (this is not just an Arp/Burbidge phenomenon but also shows up in conventional surveys, and it is not clear that the answer provided by Yushchenko helps much), (b) where the high velocity clouds fit into the gas and energy budget of the Milky Way (infalling virgin gas vs. part of a recirculating system driven by supernovae), and I mention it here because the ambiguous infall/outflow of gas in Cen A, mentioned in one of the poster.

I suspect that "both please" (as Winnie the Pooh said about honey and condensed milk on his bread) or even "all of the above" is the right answer to the unresolved dichotomies of black hole energy extraction by Blandford-Znajek vs accretion processes, AGNs vs starbursts for the most luminous (typically infrared) galaxies, and the causes of QPOs in X-ray binaries, CVs, AGNs, and

GRBs, though the AGN ones have not really been seen (the time scale is only a few months if things scale with black hole mass from the kHz affairs in XRBs, but you need to follow 10^5 cycles to pick them up in Fourier transforms).

Finally, as we look ahead, cases can be made for an enormous number of missions and ground-based observatories, most of which are very expensive. A small subset of the ones we heard about includes XEUS, ASTROSAT (an Indian concept appearing in a poster), ASTROD and miniASTROD, INTEGRAL, SWIFT, AGILE, GLAST, REM, Constellation-X, Lobster, Rosati, LISA and LIGO II (gravitational radiation detectors, Mavalvala, Ni) Auger, K2K, Icecube, ARGO., and other neutrino and high energy particle detectors(Barwick, Totsuka). Paul discussed several of the gamma ray schemes and Hasinger some X-ray ones, while Rüdiger focussed on the future of gravitational radiation detectors. It is clear that we, even if "we" includes all the astrophysicists in the world, cannot afford all of these (though Li T-P's discussion of how to make better use of the photons we already have is something that we can all afford!). The present decision process includes both mutual agreement within wavelength bands and, sometimes, within countries, but warlike competition between wavelengths (do you want Constellation-X or CELT??) and, sometimes between countries (do we really need SIRTF so many years after ISO has flown?.). One has a natural prejudice in favor of urging more consultation and cooperation, though I would not swear that this is the right answer.

Of particular interest to foreign participants were Chinese plans for future missions and observatories. Construction is already under way on the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), and a good site has been identified for the Five Hundred Meter Aperture Spherical Telescope (FAST, a radio dish in a naturally hemispherical dip, like Arecibo). Under consideration for launch are the Solar Space Telescope (SST) and the High-energy X-ray Modulated Telescope (HXMT, Li T-P.)

Acknowledgments. It is the traditional prerogative of the last speaker to thank those who have made the gathering possible. First and foremost, my gratitude and that of all of us goes to Prof. Yang Ji of Purple Mountain Observatory , who chaired the Local Organizing Committee. He was, it seems, once the student of Prof. Wang Zhen-ru, of Nanjing University, who originally suggested that there should be an IAU symposium on some topic in high energy astrophysics in Suzhou, and to whom also our thanks. Others who helped above and beyond the call of duty, include Richard McCray, who maintained the SOC web site, and Li Xiangdong, also of Nanjing, who will be editing the proceedings. The IAU is, of course, thanked for provision of travel funds for about 20 of the participants, their Sfr 25,000 having been slightly augmented by a couple of members of the SOC with large American salaries. There is a tentative Chinese proposal to hold the 2009 general assembly of the IAU in Shanghai, and we who have spent this very pleasant week in Suzhou will surely all hope that this proves possible.

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