PROCEEDINGS OF SCIENCE

Concluding Remarks

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I present a summary of some of my concluding remarks from the conference *The Extreme and Variable High Energy Sky*. The meeting represented both a celebration of the 9th anniversary of the launch of INTEGRAL, and a broad discussion of high energy astrophysics in general – resulting in a nice scientific program which also exposed the key results of INTEGRAL to a broader community. While at the original meeting, I presented a one or two sentence summary for every talk, and closed with a few unifying thoughts, this paper will focus on the unifying thoughts, since the proceedings will be available for the rest of the meeting's talks. One of these themes is that gamma-ray missions often achieve key results only late in their mission lifetimes, with a few of the exciting recent results from INTEGRAL shown at the meeting representing good examples of this. Another is a rapid change coming in the high energy landscape (with RXTE coming down, and NuStar soon due to launch), which may change the role INTEGRAL plays in the high energy astrophysicist's toolkit. A final point is a discussion of the need for a new approach to calibration at high energies in the era of much higher sensitivity observatories, including the recognition that where rarely used modes exist at all, they often have the potential to represent the most major breakthroughs from a mission, and deserve a share of the ground calibration effort far in excess of the share of the observatory time they are expected to use.

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1. Introduction

The *The Extreme and Variable High Energy Sky* meeting, hosted in Chia Laguna, Sardinia, Italy represented an excellent opportunity to consider the high energy landscape at the present time, with more than 80 participants present, from Europe, North and South America, Asia and Australia. The program consisted of a series of nice review talks and as well as some exciting new results, with about 63 talks and 17 posters presented. At the workshop, I gave a one to two sentence description of each talk, and tried to tie everything together. For my contribution to this conference proceedings, I will focus on the synthesis part of my talk, mentioning other people's talks at the conference where they provide examples of key points I am trying to make. I hope that readers will be assured that there were many scientific talks I do not discuss here which I think were at least as interesting as the ones I do discuss.

2. *New results nine years in*

Some of the new results presented at the meeting, even nine years after the satellite's launch, demonstrate key capabilities that INTEGRAL has relatively to other satellites. These results cover both the obvious advantages of INTEGRAL, like its sensitivity to nuclear emission lines, but also cover some of the more subtle capabilities of INTEGRAL, like its capability of making long uninterrupted observations.

2.1 The discovery of ^{44}Ti from SN 1987A

Sergei Grebenev presented the results of deep observations of the Large Magellanic Cloud, which included the discovery of ^{44}Ti emission lines from Supernova 1987A. This discovery represents a key breakthrough for understanding the supernova, as previously there was a discrepancy between the total nickel mass produced in the supernova and the amount of energy seen to have been released in it. Interestingly, a substantial fraction of the LMC data were originally approved with the aim of looking for X-ray binaries in the LMC, rather than for looking at the properties of SN 1987A – highlighting the capabilities of INTEGRAL to achieve diverse science goals with a single observation.

2.2 Emission line transients

It was also noted, in Erik Kuulkers' talk, which was supposed to be about the Galactic Bulge scans, that the Bulge scan program has been preempted for observations of a supernova in the nearby galaxy M 101, in which there is some hope to detect nuclear emission lines. At the time of the writing of this article, no detections had been made, but the observations were ongoing. It is also worth noting, as I did in my talk, that there has not yet been a bright black hole X-ray transient which was observed by INTEGRAL around the state transition from hard to soft state – the time when a line thought to be a redshifted annihilation line was reported in Granat observations (Gilfanov et al. 1991). Proposals have been accepted in many cycles to make these observations, but not transient has cooperated by turning on at such a brightness level during the INTEGRAL visibility windows. Both the fact that it has taken so long to have a supernova bright enough for TOO observations, and that the right kind of black hole transient still has not occurred highlight the need for long missions to achieve certain types of science.

2.3 The value of long, uninterrupted observations

INTEGRAL has the longest orbital period of any high energy satellite in the sky right now. This provides it with two key advantages compared to all other satellites: its Earth occulation durations occupy a much smaller fraction of the total time than for most other missions (giving it a large observing efficiency), and perhaps more importantly, phenomena with variability on timescales of a few hours can be studied much more effectively with INTEGRAL than with other missions, and a significant number of cycles can be observed within a single INTEGRAL orbit. This was illustrated at the meeting by Dimitry Klochkov's presentation where he showed some quasi-periodic oscillations from a Be X-ray transient - gaining new insights about a phenomenon which had previously been studied only with EXOSAT (which also had a very long orbital period). In principle, a wide variety of other phenomena on long timescales can also be studied with INTEGRAL, of course; it should also be noted that the long observing windows make it much easier to obtain moderate duration segments of data which are strictly simultaneous with ground-based data.

3. *The role of INTEGRAL in the upcoming era of high energy missions*

INTEGRAL has some capabilities – most notably its high spectral resolution in the nuclear line emission region – that are vastly superior to those of any other mission. In most ways, though, its capabilities overlap with those of Swift, RXTE, MAXI, and Suzaku – the other instruments which currently work in the same energy range, and three new missions, NuStar, Astrosat, and ASTRO-H, are soon due to be launched, and also work in an energy range overlapping with that of INTEGRAL. It is important, then, to highlight the science that can be done either only with INTEGRAL, or much better with INTEGRAL than with these other missions. Having already addressed a few of its unique capabilities that were highlighted by talks during the meeting, I will discuss its unique capabilities for finding faint transients

3.1 High sensitivity monitoring

We are soon to enter an era where RXTE is taken out of commission, meaning that we will lose the RXTE All-Sky Monitor and its Bulge Scans taken with the pointed Proportional Counter Array. This will leave Swift, INTEGRAL, Fermi-GBM, and MAXI as wide-field survey missions. INTEGRAL's niche in this suite of instruments is that it provides better sensitivity and angular resolution than the other three missions can, albeit over a much smaller field of view. This is an especially important niche – in the regions richest in Galactic transients, the confusion limit is a serious problem in achieving maximum sensitivity for all of the other wide-field instruments. Additionally, the excellent sensitivity of both Fermi-GBM and especially MAXI are derived in part from having softer responses than the other existent wide field instruments (other than the RXTE All-Sky Monitor). What this means is that the faintest transients are most likely to be detected in pointed INTEGRAL observations, rather than by the truly all-sky instruments. An interesting point for future work is that the field of view of INTEGRAL is similar to or larger than the field of view of LOFAR, except at LOFAR's very lowest frequencies, and given that INTEGRAL has the best instantaneous sensitivity of any mission over such a field of view, it should be especially useful for coordinated searches for fast radio and hard X-ray transients.

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An illustrative example of this comes from the recent discoveries of accreting millisecond pulsars. Two of the past three millisecond X-ray pulsars discovered have been found by INTEGRAL, and both illustrate the unique capabilities of INTEGRAL. The most recent discovery, of IGR J17498-2921, was of a source in the Galactic Plane and within 8 degrees of the Galactic Center, at a flux of only about 15 mCrab (Gibaud et al. 2011). Both the low flux and the crowded region make it difficult for the other missions to detect such sources. The previous INTEGRAL discovery of a millisecond X-ray pulsar was that of IGR J00291+5934, which is located quite close to an Uhuru source and a DQ Her class cataclysmic variable (Eckert et al. 2004).

4. Extragalactic highlights

While most of the key results from INTEGRAL have been on Galactic science (in part due to a pointing strategy focused on the Galactic Plane), some key extragalactic results were discussed as well. For example, in his review talk, Gabriele Ghisellini highlighted both the importance of finding even small numbers of high redshift blazars, and the value of soft gamma-ray observatories for finding them; while blazar studies in the gamma-rays is normally thought to be the province of *Fermi*, Ghisellini pointed out that because of the blazar sequence, in which the peak of the Compton upscattered component of the blazar emission shifts to lower energies for the most powerful sources, the very most powerful blazars peak at tens to hundreds of keV, and hence are more easily discovered and studied in the soft gamma-rays than in other bands. Another exciting extragalactic discovery was the upper limit placed on the hard X-ray emission from two ultraluminous X-ray sources, presented by Sergey Sazonov. At the present time, there are competing models for explaining the spectra of ultraluminous X-ray sources which diverge rather strongly from one another just above the energy bands in which focusing instruments work. INTEGRAL's superior angular resolution to e.g. Suzaku and Swift BAT is actually crucial for such work, since these sources are located within groups of galaxies from which there can be other potential sources of hard X-ray emission.

5. *A new approach to calibration?*

A recurring theme during the meeting was that many high energy observatories are limited by their calibration, rather than by photon statistics. Two additional complications exist – the first is the use of the Crab as the primary calibration source. While only recently, as discussed, for example, in Marty Weisskopf's talk at this meeting, was the Crab shown to be variable on relatively short timescales, we should, in fact, *expect* that the Crab should have some long timescale variability as well, at the level of at least a few percent; the "canonical" Crab spectrum primarily from sounding rocket flights made in the late 1960's and early 1970's (Toor & Seward 1974). The Crab pulsar is only about 1000 years old, so the timespan over which a constant energy injection rate into the nebula has been assumed implicitly is about 4% of the lifetime of the pulsar. On the other hand, the advent of more sensitive high energy observatories than we have had in the past allows for a much larger number of pulsar wind nebulae to be observed in order to calibrate satellites, so problems related to short term variability of calibration sources might be reduced.

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The second complication that was raised in a couple of contexts at this meeting is that often, not enough time is devoted to ground calibrations to allow full calibration of non-standard data modes. I take no position on whether the primary investigators of missions have made the right decisions here – there are obvious substantial financial costs associated with keeping fully built satellites on the ground, and with using beam time to test them, and it may well be that the proper decision is not always to calibrate every mode that might be used by observers. At the same time, it is important to remember that the special modes are often where the biggest scientific discoveries will be made, since they usually involve taking the fullest advantage of the unique capabilities of the satellite. It is also not my intention to be critical, with the benefit of hindsight, of decisions already made by people with a much better understanding of the constraints of mission development and planning than I have. I simply aim to raise a few points to help contribute to a discussion about how future missions should be calibrated.

The first example of a special mode raised by Elise Egron when discussing spectral modelling of XMM-Newton data taken in timing mode. Timing mode with XMM is a classic example of the type of mode which is used infrequently, but for which a good calibration can be especially important. Occasionally the mode is used to make timing measurements of moderately bright sources, but most frequently, it is used to do spectroscopy on the brightest sources that XMM can observe (with some observers also doing timing analyses on these data). As a result, timing mode observations are among the very most likely to be limited by systematics, rather than statistical fluctuations, and hence among the sets of observations most likely to benefit from having excellent calibration. Pile-up effects are thus most likely to be important for such sources, even with the high time resolution of the timing modes. While classical pile-up effects (i.e. simple addition of the energies of the two incident photons, or grade migration) are well understood and can be simulated in a straightforward way, it has become clear that there are related charge transfer inefficiency effects that are still being studied, but which are not as easily modeled (e.g. Ng et al. 2010). As a result, in certain situations, one must decide between throwing away the core of the point spread function, which means the lose of a very large fraction of the source counts, and the loss of statistical significance, or including such data, and having the results heavily dominated by systematic errors, so that the real uncertainties are not well understood.

The second example of a special mode which was not fully calibrated is the Compton mode on IBIS on INTEGRAL. INTEGRAL has two modes which can be used to study polarization in the gamma-rays – Compton mode on IBIS, in which coincident events are detected in both ISGRI and PICSIT (e.g. Götz et al. 2009), and the search for coincidence events with SPI (Kalemci et al. 2007; Dean et al. 2008). In the meeting, the recent finding from Compton mode on IBIS, that Cygnus X-1 is polarized in the 400 keV - 2 MeV range, was presented (Laurent et al. 2011, presented by Diego Götz). At the same time, Elizabeth Jourdain presented an analysis of the SPI data for Cygnus X-1 showing that the spectral energy distribution for the Compton mode data was not the same as for the SPI data. There remains an open debate about whether the Compton mode polarization result may be robust, with the only required change a re-evaluation of the response matrix of the Compton mode that would fix the energy spectrum (and there are some additional concerns related to the fact that the SPI analysis and the Compton mode analysis are from heavily overlapping, but not strictly identical time intervals). These apparently small discrepancies between the two analyses have, in fact, profound implications for the accretion geometry in the system, since the hard tail found in the

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Compton mode observations actually dominates the high energy luminosity of Cygnus X-1 if the spectral model proposed by Laurent et al. (2011) is correct, while the emission at the same energies is a small fraction of the total power in the results of Jourdain et al. (2011) and in the older OSSE and COMPTEL data. Again, while the polarization modes can be used on only a small fraction of the INTEGRAL source catalog, the information extracted from the polarization measurements carries far more unique information than what can be learned in most other cases.

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