Title

WHEN ONE-PHOTON WAS A DISCOVERY, 2 WAS A SPECTRUM, AND 3 WAS THE ROSSI-PRIZE, DOCUMENTS FROM THE BEGINNINGS OF GAMMA-RAY ASTRONOMY

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"WHEN ONE PHOTON WAS A DISCOVERY, TWO WAS A SPECTRUM, AND THREE WAS THE ROSSI PRIZE", DOCUMENTS FROM THE BEGINNINGS OF GAMMA RAY ASTRONOMY

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ABSTRACT

Gamma ray astronomy was nearly 15 years old and had already been honored with a review in ARA&A when SAS-2 saw the first extra-solar-system photon above 100 keV (and also roughly the next 7999). This is in sharp contrast with the beginnings of radio and X-ray astronomy, whose first detected sources were essentially serendipitous, much brighter than expected, and eventually the inspiration for new radiation mechanisms and new classes of objects. The initial gamma ray sources (PSR 0833 in Vela, the Crab, and an unidentified γ195+5) were considerably fainter than early predictions from nuclear gamma ray lines alone. The field has been dogged throughout its history by a curious mismatch between expectation and reality. An extreme case is gamma ray bursts, of which two kinds were predicted (supernova shock break-outs and evaporating black holes) and two kinds were seen (classic and soft repeaters), but they are not the same two kinds. Examination of contemporary publications provides less insight into the reasons for this than had been expected.

INTRODUCTION

From 1900 to 1929, very high energy gamma rays were part of the astronomical inventory, because cosmic rays were so identified. Opinion changed rapidly in the wake of Bothe and Kohlhörster's (1929) demonstration of the enormous penetrating power of the primary particles, and while the first sentence of their short paper includes the word "Gammastralung," the last word but two is "Korpuskularstrahlen." Early rocket work (e.g. Rossi & Hulsizer 1949) showed that less than 1% of the GCR primaries were photons, and gamma rays took another 20 years or so to become an integral part of the astrophysical real world.

The original motivation for this mini-investigation was a subjective impression of an enormous difference between the early years of γ ray astronomy and those of radio and X-ray astronomy. Jansky's (1933) discovery of the galactic center and Reber's of Cyg A (1944) were accidental, initially widely ignored, but eventually productive of much puzzlement, especially after the Crab Nebula (Bolton et al. 1949) joined the parade. In the end, a new emission mechanism, synchrotron, had to be postulated to explain the data. The optical identification of Cyg A with a supposed pair of colliding galaxies (Smith 1951; Baade & Minkowski 1954) prompted Burbidge and Hoyle (1956) to suggest interaction of a galaxy and an antigalaxy as the underlying energy source, leading to the prediction of an enormous flux of annihilation gamma rays.

Giacconi et al's (1962) discovery of Sco X-1 was similarly unexpected (early rocketeers had to claim they were looking for X-ray fluorescence from the moon -- a phenomenon only just found by ROSAT -- to justify their flights). Along with the discovery of X-rays from the Crab Nebula (Bowyer et al. 1964), it led to the first serious consideration of neutron star physics by astronomers. In fact the NS cooling calculations prompted by the first Crab paper have outlived the discovery that the X-rays actually come from an extended region by about 30 years.

Incidentally, the title of this contribution is stolen directly from the January 1993 Rossi Prize Lecture by Gerald Share, but he reports that he, in turn, borrowed it from someone else.

THE PRE-DISCOVERY ERA

Americans tend to date the beginning of serious gamma ray astronomy to the publication of Morrisons's (1958) prediction that "there is likely to be a still undetected but entirely measurable flux of γ-rays bearing astronomical information of the highest interest." His four best-bet sources were the sun, the Crab (at $10^{-2}\,\gamma/cm^2$-s assuming the C^{254} model for SN light curves), Cygnus A (at 0.1 - 1 γ/cm^2-s for the annihilating galaxies model), and creation of matter and anti-matter. The extended discussion of origin of cosmic rays by Hayakawa et al. (1958) mentioned photons under the heading of contaminants, emphasizing lines from $e^{\pm}$ annihilation (called by them positon-negaton), n capture by p's, and neutral pion decays. Their predicted γ/p ratio was actually somewhat too low.

Braccesi et al. (1960) flew a nuclear emulsion stack on a balloon to look for Cygnus A, setting a limit of $5X10^{-3}\,\gamma/cm^2$-s. The same issue of Nuovo Cimento contains another Braccesi paper leading up to the studies of quasars with which he is much more closely associated today. The next few flights gradually lowered the limit on Cyg A. Cline (1961) pushed it to $1.2X10^{-3}$ with a balloon-borne detector incorporating a mercury converter, CsI pair detector, and plastic anticoincidence shields. Kraushaar & Clark (1962) reached $3.4X10^{-4}$ for Cyg A and limits between 10^{-2} and $3X10^{-3}$ for the Crab, the galactic center, Cas A, M31, and several other interesting parts of the sky. They were left with the conviction that "the remaining 22 events, which come from a variety of directions in space are gamma rays." Their instrument, carried by the Explorer XI satellite, had a considerable advantage in exposure time over its predecessors. These three papers all carried the title "Search for...," and we know what that means!

"Evidence for a Source..." in the direction of Cygnus at a level of $1.5\pm0.8X10^{-4}\,\gamma/cm^2$-s above about 100 MeV was announced by Duthie et al. (1966) after they flew a balloon-borne scintilation and Cerenkov telescope. Since we no longer suspect Cyg A of extensive annihilation, this must have been Cyg X-3 in outburst, or a false alarm.

Such was the experimental situation when Fazio (1967) wrote the first Annual Review of gamma ray astronomy. He admitted that "Up until now, no photons of energy greater than 100 keV originating from beyond the solar system have definitely been detected," and went on to describe a wide range of predictions, of varying degrees of optimism. His plot of the diffuse background shows Kraushaar's 22 photons converted to an upper limit, but also the first real detection by Arnold et al. (1962) flying on Ranger 3. This was truly a generation ago, for Jim Arnold was a mere broth of a boy when Ranger flew, and a symposium and dinner marking his retirement took place this summer.

THE YEARS OF DETECTIONS

1968 saw the first two positive reports still generally credited and cited. Clark et al. (1968) found that the photons detected by OSO-3 were concentrated toward the galactic plane in latitude and the galactic center in longitude. And Haymes et al. (1968) reported a balloon detection of 100-300 keV flux from the Crab Nebula, amounting to about $2X10^{-4}\gamma cm^{-2} s^{-1}$ and joining fairly smoothly on to early X-ray spectral data. These papers are past the point of naming the individual photons, and the error bars suggest a total of a few hundred each.

Following the announcement of a pulsar in the Crab Nebula, the Rice group re-examined the arrival times of their photons and found pulsation at the optical and radio period, corrected for spin-down (Fishman et al. 1969). Because the photons were collected on 4 June 1967, their period is the earliest one known (or ever to be known) for NP 0532. Some differences between the pulsed and unpulsed spectra were already evident.

SAS-2 went up on the author's 29th birthday and returned data until about June 1973. The paper confirming a Crab Nebula source (Kniffen et al. 1974) cites Fishman et al. but not Haymes et al. The discovery or confirmation paper for a Cygnus source (Lamb et al. 1977) does not cite Duthie et al.

SAS-2, COS B, and a number of balloon- and rocket-borne telescopes and detectors up to the launch of CGRO brought gamma ray astronomy to the stage where we could say that most of the predicted processes had been seen -- nuclear gamma ray lines (though not Cf^{254}!), $e^{\pm}$ annihilation, π^{o} decay, brehmsstralung, inverse Compton scattering, and (though you can argue about this one) synchrotron radiation.

BURSTS: PREDICTED AND SEEN

Cosmic rays re-enter the picture because Colgate (1968) realized that the shock break-out mechanism he had proposed for their acceleration should also produce an impressive brief spurt of gamma rays. He suggested $5 X 10^{47}$ ergs in $1.5X10^{-5}$ sec, with an average energy of 2 GeV. If a supernova anywhere within the Hubble radius had done this in the last few years, we would know about it!

Hawking's (1974) note on "Black Hole Explosions" does not explicitly mention bursters (like Einstein and the Michelson-Morley experiment, it is not clear whether he was aware of them). He gives formulae from which you can extimate that black holes of 10^{15} g, which just boil away in the age of the universe, will indeed be copious gamma ray sources in their last few seconds. If the universe were closed by these, we would also know about it.

Actual gamma ray bursts started showing up in Vela spacecraft data in 1969. By 1972, 16 had accumulated (Klebesadel et al. 1973), at least one of them also detected by the Cosmos-461 satellite (Mazets et al 1974). At the time, one did not imagine that this could possibly be the 461st Soviet satellite. These 16 were all classical gamma-ray bursters, of which BATSE has now recorded many hundreds. A second class of soft repeaters is generally also recognized to exist. Thus we can say that two kinds of gamma ray bursts were predicted and two kinds have been seen. But they are not the same two kinds.

A NOTE ON SOCIOLOGY

Early papers on radio astronomy were greeted with profound inattention by most of the (optical) astronomical community, to the point where the then-editor of the Astrophysical Journal found it necessary to say editorially (Chandrasekhar 1959) that ApJ did not automatically reject radio papers, encouraged their submission, and had in fact published no fewer than 10 in the past two years. A more recent ApJ editorial saying much the same thing about instrumental papers met with similar scepticism. One's first impression is that gamma ray astronomy was greeted with much more enthusiasm, being incorporated into the main-stream journals, featured at conferences, and recruiting astronomers to its ranks almost from the beginning.

I think this is only partly true. The two major early theory papers appeared in Nuovo Cimento and Prog. Theor. Phys., Colgate's supernova burst prediction in the Canadian Journal of Physics; and the early upper limits and detections in Nuovo Cimento and Phys. Rev. Letters and JRG. And the early authors have come largely from the cosmic ray and other physics communities. Not until 1968 do gamma rays blossom in ApJ, the traditional bastion of conservative astronomy. Neutrino and gravitational radiation astronomy have had comparable checkered beginnings in roughly the same time period. Astronomers still seem to prefer the photon they know to the photon they don't.

Why the mismatch between early predictions and actual flux levels? Spectacular radio fluxes coming from optically dull parts of the sky clearly played a major part. But it is perhaps also significant that the two largest overestimates, of annihilation in radio galaxies (Burbidge and Hoyle 1956) and of the amount of Cf^{254} in supernovae (Burbidge et al. 1957, B^2FH), both came out of the Steady State stable. Without these targets to shoot for or at, observing would have begun much more slowly. You don't always have to be right to make important contributions.

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