0.0.1. Galactic Annihilation Radiation

Current Status: 511 keV γ-rays characteristic of electron-positron annihilation were found over 30 years ago from the general direction of the Galactic Center. This line is by far the strongest astrophysical γ-ray line, and the long-standing model for the dominant source of these positrons is the β^+ decay of the radionuclei, ^{56}Ni, ^{44}Ti, and ^{26}Al in supernova ejecta and Wolf-Rayet winds (e.g., Colgate Astrophysics and Space Science 8, 457, 12970; Burger, Stephens, Swanenburg Astrophysics and Space Sciences 8, 20, 1970; Clayton Nature Physical Science, 244, 173 1973). SPI, the germanium spectrometer on *INTEGRAL*, is the pre-eminent current tool for studying the narrow 2-γ line emission from direct annihilation and singlet emission from positronium and measurement of the 3-γ continuum emission from the triplet state.

In two recent papers (Higdon, Lingenfelter, and Rothschild ApJ, 698, 350, 2009, and Lingenfelter, Higdon, and Rothschild Phys Rev Letters 103, 031301, 2009) the authors have reminded the astrophysics community that the positrons are emitted with relativistic velocities in the β^+ decay and that they must slow down before annihilating. Thus the propagation of the positrons in the various interstellar temperature and density media must be taken into account. The result is that production sites can be quite different than the annihilation sites. The authors compared their Monte Carlo results with the INTEGRAL/SPI results and the oft-quoted mystery of the bulge-to-disk ratio of the annihilation radiation as compared to the SNIa distribution is no mystery at all. One just needed to take propagation into account. It was also shown that the assymetry in the SPI bulge measurements could be easily ascribed to the asymmetry of the Galactic spiral arms as view from Earth.

The claim of a mystery with the bulge-to-disk ratio resulted in a flood of ~150 theoretical papers invoking e^+–e^- pair production in the annihilation of some new light scalar dark matter particles and antiparticles. Most analyses were based on the initial speculation of Boehm et al. (Phys. Rev. Lett. 92, 101301, 2004), where the assumption was made that the positrons could not propagate more than 1 pc before annihilation. Lingenfelter, Higdon, and Rothschild demonstrated that not only was the propagation number wrong, but the positronium fraction would be greatly at odds with the INTEGRAL/SPI measurements. Thus, there is no new signal in the SPI results for dark matter to explain.

The SPI instrument is helping to elucidate this puzzling situation. Upper limits on 511 keV emission from particular objects are becoming more and more constraining as data accumulate. Limits on the emission from SN1006 already imply that if its explosion was typical of SNIa, such events cannot be responsible (?) **But Gerry, the positrons do not annihilate there!**. In comparison to the flux from the bulge, 511 keV radiation from the disk is weak, perhaps implying that some of the positrons can escape from the disk during the $\sim 10^5$ yr they take to slow down to ~10 eV when annihilation can take place efficiently (?).

Fig. 1.— (top) The 511 keV radiation from the Galactic bulge and central part of the Galactic disk showing the asymmetry in the disk emission with higher significance than in the original report by Weidenspointer et al. now that more data have been included.

While imaging the 511 keV distribution provides clues to the source of the positrons, the line shape (a superposition of the 511 line and the redder positronium continuum wing) reveals crucial information about the sites and circumstances of their annihilation. In the warm ionized and HII phases, essentially all of the positronium is formed by radiative combination after the positrons are thermalized and its annihilation produces narrow (~1.2 keV FWHM) 2-γ 511 keV emission 25% of the time and 3-γ continuum emission the rest of the time. In the cold neutral phases essentially all of the positronium is formed by charge exchange in flight producing a broad (~5.8 keV) Doppler shifted 511 keV line. One can then use the observed "511-map" to provide a unique probe of the ISM.

Future Science: Two outstanding observations need to be made. The first is the measurement of the flux, positronium fraction, and line width for the Galactic halo annihilation radiation. The positronium fraction will be very dependent upon the amount of dust in the halo (Jean et al. 2006), and thus yield a measurement of the amount of refractory elements in dust in the halo. The second observation, albeit also necessitating long accumulation times, is the prediction that the 0.5-1.5 kpc bulge radiation will be coincident with the tilted disk (Ferrière, Gillard, and Jean A&A 467, 611, 2007) and thus confined to two diagonally opposed quadrants (Higdon, Lingenfelter, and Rothschild). Confirmation is crucial to validating that the outerr shells of molecular clouds are the annihilation sites of galactic positrons.

Long total integration times are needed to achieve the sensitivity necessary to make further progress with the study of the Galactic annihilation signal. Currently in AO-7, there are several accepted proposals related to investigating the 511 keV emission from the Galaxy. These include the continuation of carefully designed comparison of two regions in the Galactic plane on either side of the Galactic Center (at $l \pm 25^\circ$), optimized to confirm and further investigate the perhaps no so surprising results of ? showing a disk asymmetry. About half of the planned data has now been accumulated. The US (Skinner) is involved both in these observations (as Co-I) and in an associated program to combine these data with those obtained incidentally to other observations (as PI). Thus further exciting progress in the understanding of the distribution of positron production and annihilation in the Galaxy can be anticipated.

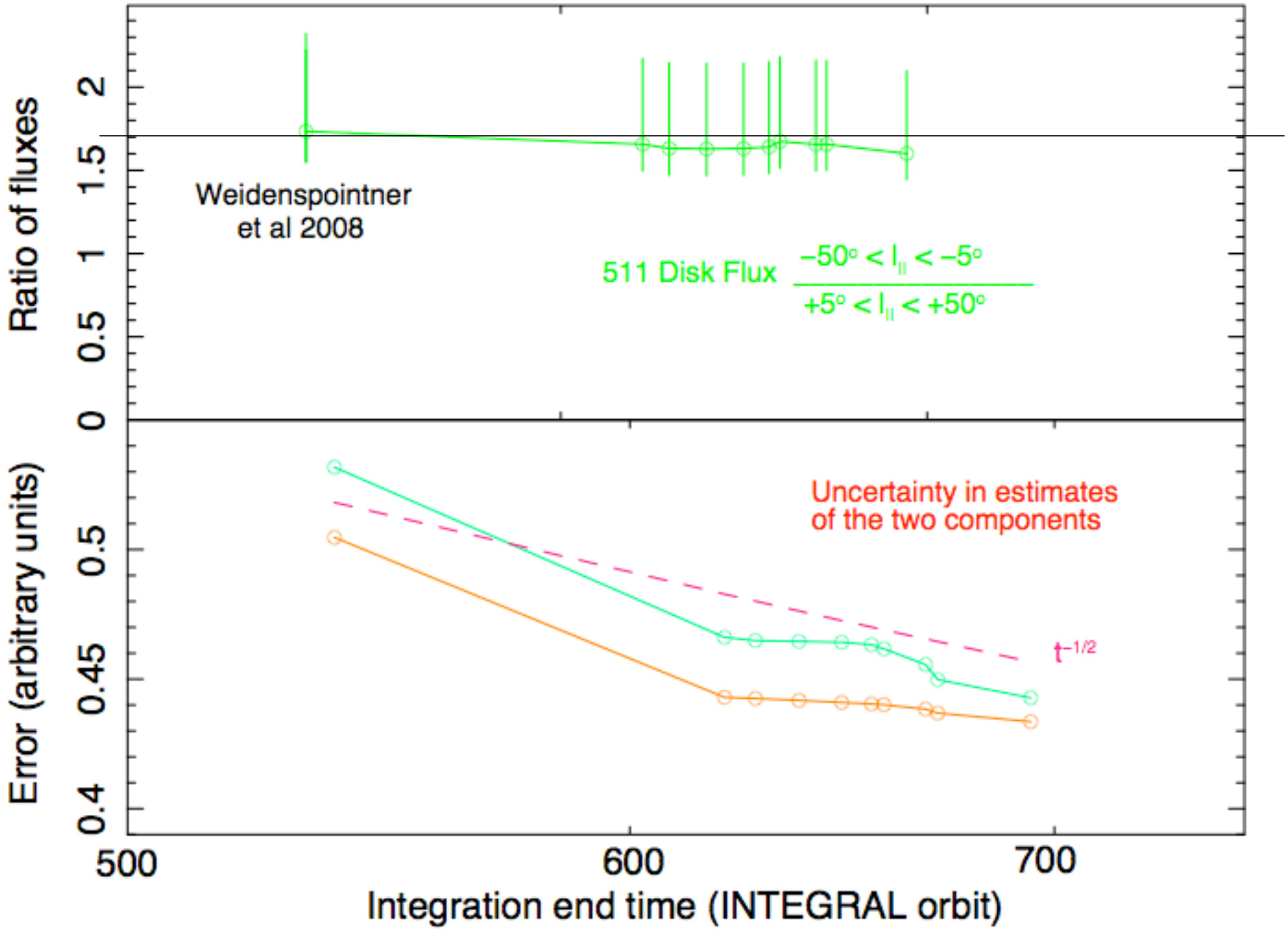
New since SR 2008 :-

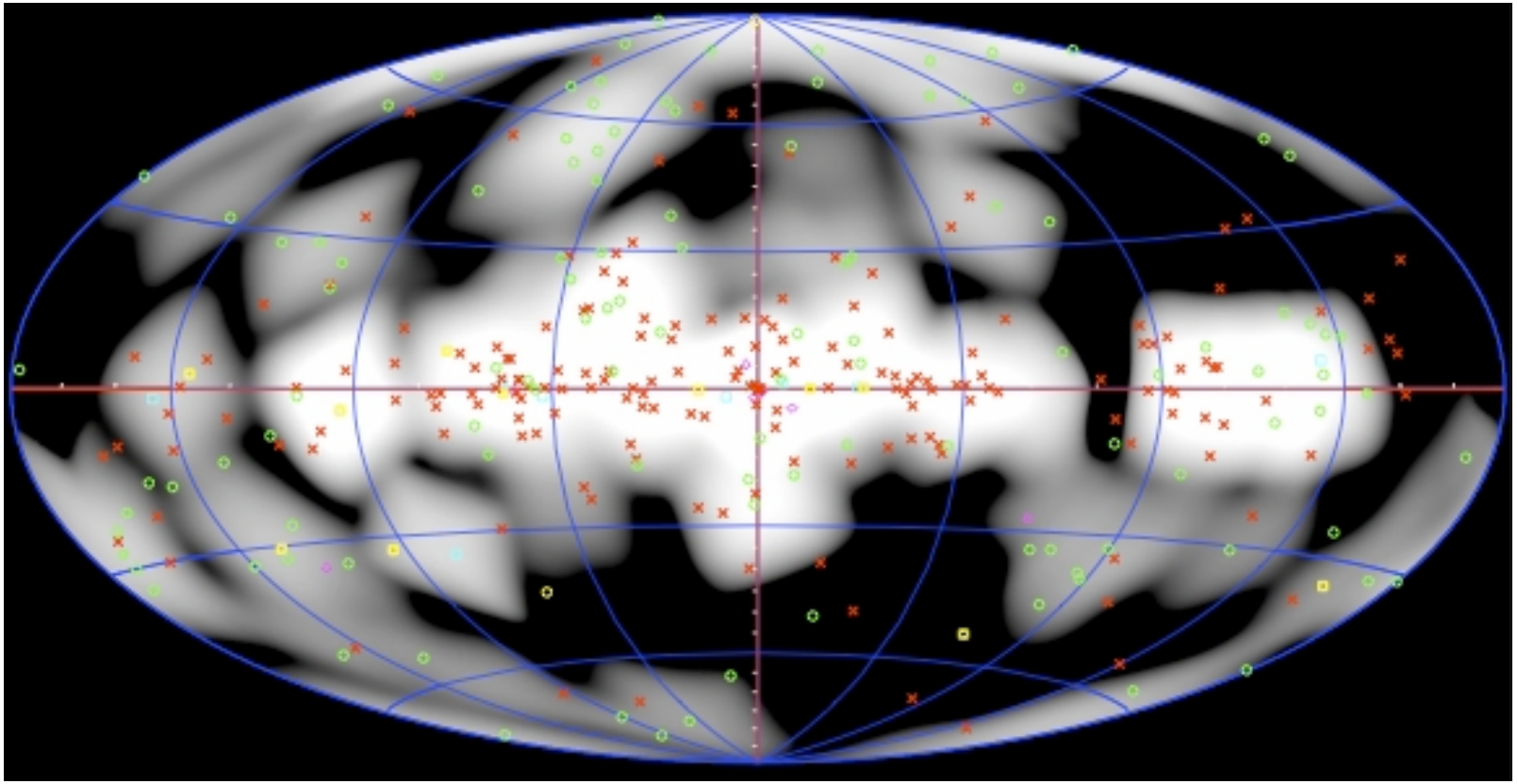
- Higdon et al work (also Jean et al)

- More data analysed (only Skinner et al Copenhagen conference paper)

- Ping-Pong measurements underway (Spring, Autumn 2009)

- More spectroscopy (and mapping) studies on the way (but no publications)


Ratio of fluxes
2
1.5
1
0.5
0
Weidenspointner
et al 2008
511 Disk Flux
−50° < l_II < −5°
+5° < l_II < +50°
Error (arbitrary units)
0.5
0.45
0.4
Uncertainty in estimates
of the two components
t^−1/2
500
600
700
Integration end time (INTEGRAL orbit)



SWIFT-BAT 22 MONTH HARD X-RAY SURVEY