
The First All-Sky Map of Electron-Positron Annihilation

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on behalf of the SPI team



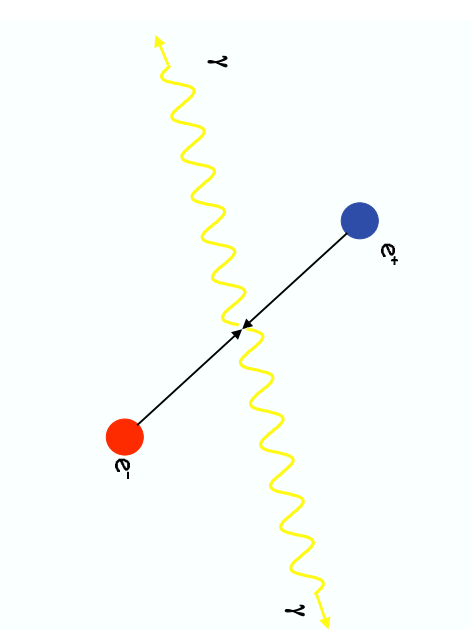
Antimatter

- For every particle there exists an antiparticle
- Particle and antiparticle share properties such as mass, but particle and antiparticle have opposite electrical charge
- Even antiatoms, consisting of antielectrons and antiprotons, can exist
- Antimatter and matter cannot coexist, when a particle meets its antiparticle they mutually annihilate
- The energy released in this annihilation can be calculated applying Einstein's most famous equation:

$$E = mc^2 + mc^2 = 2mc^2$$

Electron-Positron Annihilation

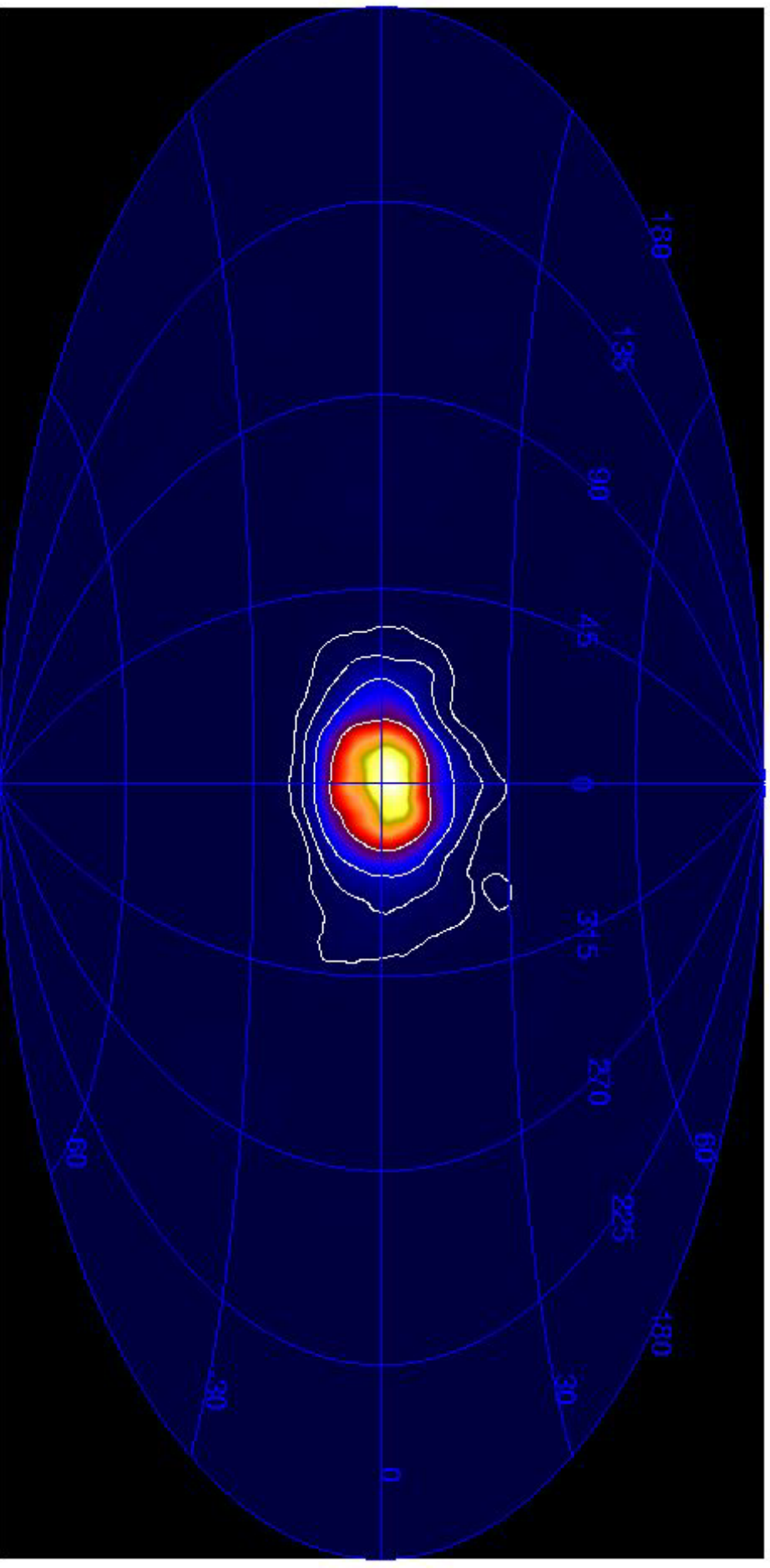
- The antiparticle of an electron is a positron
- When a positron meets an electron, they both annihilate into pure energy (here γ -radiation)
- The hallmark of the electron-positron annihilation is the production of photons with an energy of 511 keV (which corresponds to the rest mass energy of electrons/positrons): $e^+ + e^- \longrightarrow \gamma_{511} + \gamma_{511}$



The Positron Mystery

- Surprisingly, we do see 511 keV gamma rays, showing that positrons are being produced somewhere in the Galaxy, and are annihilating
- Although the line was discovered as early as the 1970s, **the origin of positrons, and their annihilation sites, have remained a longstanding mystery**
- Investigating this mystery is one of the prime scientific objectives of the spectrometer SPI onboard the European Space Agency's *INTEGRAL* observatory
- We do not yet have a final solution, but we have found a valuable clue!

The First All-Sky Map of 511 keV Line Emission



- The emission appears to be surprisingly concentrated around the center of the Galaxy, it is “bulge dominated”!
- The detailed origin of the emission is still unclear

What are the Implications of this Clue?

- The annihilation radiation from our Galaxy is bulge dominated, there is no significant emission outside the GC region
- The young stellar populations are concentrated along the Galactic disk (disk population)
- The old stellar populations of our Galaxy (bulge and halo) are concentrated around the GC
- Dark Matter is concentrated around the GC
 - ⇒ The origin of positrons appears to be connected with an old stellar population and/or dark matter
 - ⇒ The young stellar population appears to be ruled out

What are the Positron Sources in Our Galaxy?

- Young, massive stars cannot be the source of the positrons
- Candidate old population sources include
Low-Mass X-Ray Binaries,
Type Ia Supernovae,
or Novae
- (Light) Dark Matter is another intriguing possibility

Electron-Positron Annihilation Flux and Rate

Our results provide new constraints on the 511 keV line flux from, and the electron-positron annihilation rate in, our Galaxy.

We have been able to measure:

- Flux: $(1.3 - 3.4) \times 10^{-3} \text{ ph cm}^{-2} \text{ s}^{-1}$

This means that on average each square centimeter of our instrument sees one 511 keV γ -ray photon every 5–13 minutes

- Annihilation Rate: $(1.8 - 3.7) \times 10^{43} \text{ s}^{-1}$

Assuming steady state, this means that $(2 - 4) \times 10^{10}$ tons (the mass of a mountain) of positrons annihilate in the central region of our Galaxy every second

Summary and Conclusions

- Using observations during the first year of the INTEGRAL mission has allowed us to produce the first-ever all-sky map in the 511 keV line arising from electron-positron annihilation
- 511 keV line emission is bulge/halo dominated, no significant emission outside GC region
- The origin of positrons seems to be associated with an old stellar population (and not with the disk of the Milky Way)
 - Candidate origins: Low-Mass X-Ray Binaries, Novae, or Type Ia SNe
- (Light) Dark Matter is another possibility

**The origins of positrons are still shrouded in mystery,
but we are beginning to lift the veil!**

Prospects

This is just the start of the new science of positron astronomy

**Analysis methods are still improving;
we expect at least 6 times more data... .**

**We anticipate making significant progress
– and obtaining many more interesting results –
over the coming years!**