The 65^{th} Compton Lecture Series

The Quest for Gamma Rays: Exploring the Most Violent Places in the Universe

Lecture 8: Residues of a Violent Past

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Slides and additional information can be found at *http://kicp.uchicago.edu/∼ehays*

1 Diffuse Backgrounds

Diffuse backgrounds provide information about distant sources and undiscovered types of sources. Measurements of the diffuse gamma-ray background have been ongoing for almost as long as we have been studying celestial gamma rays.

Selected Measurements of the Gamma-Ray Background

- **SAS 2 1972-1973** - The second Small Astronomy Satellite had a short life due to a battery failure. However, it still generated the first detailed map of the gamma-ray sky. This confirmed a diffuse background from the dense regions of the Galactic plane. The gamma-ray background spectrum was extended to GeV energy, but couldn't confirm or deny a mysterious bump around 1 MeV found by earlier detectors in balloons and on several Apollo missions.

- **CGRO 1991-2000** - The Compton Gamma Ray Observatory carried four different gamma-ray detectors. Two of these, COMPTEL and EGRET, contributed measurements of the gamma-ray background. COMPTEL mapped the sky for low-medium energy gamma rays, while EGRET mapped the sky for high energy gamma rays. COMPTEL bridged the spectrum between X-ray measurements and the SAS 2 satellite measurements, and finally removed the troublesome MeV bump.

  EGRET extended the spectrum to energies around 10 GeV. The background was separated into a galactic and extragalactic component.s Not only did the Galaxy glow in gamma rays, the whole Universe did as well. The extragalactic background appeared uniform over the sky without bumps or features. However, EGRET discovered that there were more Galactic background photons at GeV energies than expected based on models.

- **Milagro 1999-present** - Milagro is a ground-based gamma-ray telescope that uses particle showers caused by very high energy gamma rays in the atmosphere to map large parts of the overhead sky simultaneously. Because Milagro is located in New Mexico, only the Northern Hemisphere has been observed using this technique. Milagro views regions of the galactic plane away from the Galactic Center that include several of the spiral arms. Although the Galactic plane as a whole does not show up in the Milagro sky map, one part of it, the Cygnus Arm is the brightest region. There are some bright spots that may be associated with supernova remnants. When these are removed, there are still gamma rays that track dense regions of gas in the spiral arm. Milagro detects the most energetic of very high energy gamma rays. The EGRET spectrum for the Cygnus Arm ends at around 10 GeV, but Milagro adds a measurement at 20 TeV. Like EGRET, Milagro finds more photons than predicted by models for the galactic background.

- **H.E.S.S. 2004-present** - The High Energy Stereoscopic System is a ground-based telescope that images the Cerenkov light from particle showers caused by gamma-rays in the atmosphere. H.E.S.S. is located in Namibia and has a great view of the Galactic center. H.E.S.S. views a square of sky about 5° wide and has mapped a narrow strip around the Galactic Plane extending from the Center of the Galaxy to 60° in either direction. Two bright gamma ray sources are the center of the Galaxy and a nearby supernova remnant. When those two sources are removed from a small section of the gamma-ray map around the Galactic Center, a faint glow remains along the galactic plane.

2 Decoding the Background

Understanding the gamma-ray backgrounds, galactic and extragalactic, is important both for interpreting results for individual sources and for probing faint or truly diffuse sources of gamma rays. In order to find out what is in the background, we first have to do some detective work.

Decoding the Background: Instrumental Backgrounds

Measuring background is a tricky business. This is because when you accept all the leftovers of your other measurements, you may find effects that are caused by your telescope! This is probably what caused the infamous MeV bump. This energy is interesting for reasons of cosmology, but it is also an energy where we can see radiation from certain isotopes. In other words, the material that the telescopes were made of, and in some cases the spacecraft that carried them, can radiate at this energy and cause what we call an instrumental background. Whenever we look at background measurements, we have to be very careful to understand the backgrounds that can be caused by the instrument or the technique we use to make the measurement.

Decoding the Background: Unresolved Sources

When we see diffuse emission, the key question is, is it really diffuse? What if there are many faint, distant, individual sources making up what we see as diffuse? For example, think of impressionist paintings that use many small points of color instead of brush strokes. When you stand back far enough from the painting, you can no longer tell that it is made of dots and it instead appears smooth. How do we know if this is happening?

In the case of X-rays, small sections of the extragalactic background can be examined by high resolution X-ray telescopes. What they see is that the X-ray diffuse background resolves into many distant galaxies, quasars. Blazar galazies are a primary gamma-ray source. Could the extragalactic gamma-ray background also be due to distant galaxies? Probably not enitrely, but the gamma-ray blazars must be a major component. We also have reasons to suspect that there could be other less dominant contributions from GRBs, radio emitting galaxies, and normal galaxies like our own.

In the past, the MeV bump caused speculation that we may be able to see a gamma-ray signature from particle events in the early universe or the possily the decay of early black holes. However, there is no evidence for these types of contributions in recent measurements.

What is in the extragalactic background?

1. Blazar Galaxies - $60\% - 100\%$
2. GRBs - 1% or less
3. Other Galaxies - $< 1\%$
4. Anything else?

We already know something about extragalactic gamma rays because of the objects that we do see. We have a good idea of how and where these objects are distributed using information at other wavelengths. For example, we can use optical, radio, and x-ray observations to figure out how many distant galaxies there may be. When we put this information together with how many gamma rays we expect from that type of galaxy, we can estimate how many gamma rays may come from the Universe at large.

What is in the galactic background?

1. Diffuse emission from cosmic rays
2. Gamma ray sources - Pulsars/Supernova Remnants/Pulsar Wind Nebulae
3. Star forming regions with strong stellar winds
4. Anything else?

Within our Galaxy, it becomes difficult to make accurate predictions because we do expect diffuse gamma rays from the cosmic rays that permeate Galactic space. Most cosmic rays probably come from Supernova explosions, where they are energized by strong shocks and magnetic fields. Once they have been accelerated, they spread throughout the Galaxy being deflected by magnetic fields. They don't travel in straight lines and when we see them here at the Earth, they have been jaunting around the galaxy for many thousands of years. This poses a problem for predicting how many gamma rays we should see from different parts of the Galaxy. What if the cosmic rays near the Earth are different from those in other parts of the Galaxy?

We can turn this around. Cosmic rays are interacting with regions of gas throughout the Galaxy and producing gamma rays. The gamma rays come directly to us, and therefore tell us about what the cosmic rays are like in other parts of the Galaxy. We can use measurements of diffuse gamma rays from all over the Galaxy to figure out how similar or different distributions of cosmic rays may be. To do this well we have to understand what the unresolved gamma-ray point sources are and the relative importance of several methods by which cosmic rays can generate gamma rays.

What is left?

Decoding backgrounds is hard work, but there is a big potential payoff. If we find we cannot explain all the gamma rays that we see, and we convince ourselves that we have exhausted the alternatives, then the excess may be a signal of something new. One intriguing possibilty for a GeV excess is a buried signal from dark matter. Dark matter is spread throughout our Galaxy and the Universe. [1]. Gamma rays might be able to provide another way to map dark matter.

Nothing is ever easy, but the good news is that we have a starting point for understanding some components of the backgrounds. Our current ground-based gamma-ray telescopes are now making several critical measurements of the diffuse gamma-ray distribution in space and energy at very high energies. Also, the upcoming GLAST mission will provide the best sky map yet of high energy gamma rays in our Galaxy and throughout the Universe.

A Few Interesting Web References

- For more information about diffuse high energy backgrounds search here - http://imagine.gsfc.nasa.gov
- Read about the early space missions here (and current ones, too) - http://heasarc.gsfc.nasa.gov/docs/observatories.html

References

Aharonian, F. A. 2004, Very high energy cosmic gamma radiation : a crucial window on the extreme Universe, River Edge, NJ: World Scientific Publishing, 2004

Weekes, T. C. 2003, Very high energy gamma-ray astronomy, IoP Series in astronomy and astrophysics, Bristol, UK: The Institute of Physics Publishing, 2003

[1] Just this week scientists reported finding a ring of dark matter resulting from a collision of two distant galaxy clusters. The Hubble telescope cannot see dark matter directly, but can study the effects of gravity on light passing through clusters to trace the distribution of dark matter. You can find articles with more details on many of the space and astronomy news websites, e.g. imagine.gsfc.nasa.gov or space.com.