The 65^{th} Compton Lecture Series

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

Lecture 4: Galactic Renegades

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

1 High Mass X-ray Binary Systems

X-ray telescopes detect periodic signals that are not from a simple pulsar, a rotating neutron star left in the wake of a supernova explosion. These periodic signals repeat in days as opposed to seconds. This time period is too long to be caused by the rotation of a neutron star, but the right timescale to be caused by two stars orbiting each other. Measurements reveal that these are binary systems and that some of them are a type called microquasars.

What is a microquasar?

Stellar binary systems are a common phenomenon. The formation of stars requires raw material, and the regions rich in star-forming material produce a large number of stars. It is not uncommon to find some of them gravitationally bound into a pair. A pairing composed of a compact object and a massive normal star is particularly interesting for the study of particle acceleration. Observations have found X-ray binary systems that include a compact object with particle jets. This kind of X-ray binary is called a microquasar to make an analogy to the large jets seen coming from the cores of distant quasar galaxies. A compact stellar remnant with jets is accelerating particles. A massive star companion can provide the target material and conditions required to produce high energy photons. For some of these binary systems conditions are right to produce a periodic gamma-ray signal.

High Mass Binary System Components

- High mass star - This is a normal star. This star may by 30 or more times the mass of the Sun in systems that are favored to produce high energy emission.
- Disk around high mass star - Massive stars blow off their outer layers and build up a disk of material around thier equator.
- Compact remnant - This could be either a pulsar or a black hole. Both of these objects produce particle jets.

- Particle jet - The compact remnant produces a particle jet that in a few cases is very extended and can be resolved by high resolution radio observations.
- Accretion disk - The gravitational pull of the compact remnant draws material from the massive star into a disk of gas and dust.
- Orbit - The shape of the orbit plays a key role in producing the periodic signal. The orbit is used to determine the relative masses, but it is difficult to determine the orbit precisely enough to make an absolute mass measurement.

Ultimately, one of the stars in a binary system will burn out and either explode or leave behind a white dwarf star. If the star is massive enough, it undergoes a supernova explosion and leaves behind a neutron star or possibly a black hole. In some cases, the now extremely compact remnant and the normal star companion remain bound together after the explosion. The violence of the explosion can be deduced from the shape of the orbit. The dead compact star and still burning companion continue to orbit each other and can produce some interesting effects.

The compact object present in many X-ray binaries could be either a pulsar or a black hole. In most cases, the measurements are not accurate enough to determine the difference. However, there are several binary systems that do strongly indicate the presence of a black hole because of the mass concentration of the compact object.

Black Hole Facts

- Mass - Black hole masses range from stellar size black holes in our galaxy to suppermassiveblack holes in the centers of galaxies that are millions or billions times more massive than the Sun. Observations of regions mass densities that exceed normal stars and even neutron stars provide evidence for black holes.
- Size - Black hole size is defined by the event horizon. You can think of this as a spherical surface around the black hole where the gravity becomes so strong that something travelling the speed of light can never escape the gravitiational field. This means we cannot see anything beyond this surface. The radius of the event horizon is proportional to the mass. This means that more massive black holes are also larger. A relatively small stellar mass black hole, a few times the mass of the Sun, has an event horizon radius of about 10 km. A large black hole with mass of a few million times that of the Sun has an event horizon radius of few million kilometers.
- Accretion disk - Outside of the event horizon, the black hole acts like any other object with mass. It has a gravitational field determined by its mass that attracts other matter. Gas and dust surrounding the black hole are attracted and will eventually fall into the black hole. The material collects into a disk surrounding the black hole. Material in the disk attains high velocites close to the event horizon and heats up. The hot gas emits X-rays. We can measure the temperature and velocity of this disk and figure out how strong the gravitational field is and how small the central, invisible object has to be.

By definition we cannot observe black holes directly. What we can observe is how objects that we can see are affected by gravity. X-ray binaries provide a way to find black hole candidates and measure their mass and size. Observations of the centers of some galaxies also provide strong evidence for black holes. The velocity and radius of the surrounding material and sometimes spectral lines detected in X-ray emission indicate an unseen central object with such a high density that it must be a black hole.

2 Very High Energy Binaries

Three Gamma-Ray Binaries

1. **PSR 1259-63** - This is a pulsar binary system. The orbit is large and very elongated. The pulsar reaches the closest point to the massive star, called periastron, once every 3.4 years. The High Energy Sterescope System (H.E.S.S) in Namibia, detected gamma rays coming from this object while the pulsar was passing near the massive star in 2004.

2. **LS 5039** - This object is a microquasar. with an orbit period of 3.9 days. The jets were found in ? by ?

3. **LS I +61 303** - This object was discovered in 2006 by the Major Atmospheric Gamma-ray Imaging Čerenkov (MAGIC) telescope located in the Canary Islands. The gamma-ray emission could be produced by jets from the compact object or by the strong stellar wind interacting with the pulsar. The type of compact object in this system is not yet determined.

Is it a gamma-ray microquasar?

The recent discoveries of gamma-ray emission from several binary systems have provoked discussion about whether the emission is from the microquasar, the jets, or from the strong steller wind producing a shocked region with wind from the orbiting pulsar. The systems are small and the objects are close together. This makes deducing the exact nature of the compact object and resolving the jet structure difficult. The power of the jets in the LS I +61 303 system are argued to be too weak to produce gamma rays and that another mechanism is at work.

A Normal Star Binary System with Big Winds

No matter what the mechanism is at work in these binary system, they provide a wonderful experimental opportunity. Rarely in astronomy do we get the chance to watch a process repeat at a known time in the same place and same way. The binaries act a little like a lab experiment where we use the compact object acts as a test probe of the environment around the massive star. As the compact object travels through the stellar disk we learn about the density of the stellar wind. Gamma rays depend stronly on the magnetic field and the motion of the compact object gives us measurements of how the magnetic fields changes at different points aroudn the star. Although these systems are quite unique, the are exposing processes that occur many places. Recently, non-periodic gamma rays have been detected coming from the vicinity of a massive star that is not in a binary system. Normal stars have not typically been suspected of being gamma-ray emitters and the general importance of wind systems in accelerating particles is not well known. The large magnetic fields of massive stars and the outflow of material in winds around them could even provide insight into short bursts and flares of x-rays and gamma-ray bursts.

WR 20a

WR 20a is a binary system made up of two massive Wolf-Rayet stars. Although these are normal stars, they are farily unique ones since they each exceed 70 times the mass of the Sun and have strong stellar winds and strong magnetic fields. The energy output is only somewhat less than the energy output of a supernova explosion.