

Monday, April 21, 2014

Exams returned, key posted, histogram

Fifth exam and sky watch, FRIDAY, May 2.

Reading for Exam 5: Chapter 9 – Sections 9.6.1, 9.6.2, 9.7, 9.8; Chapter 10 - Sections 10.1-10.4, 10.9; Chapter 11 - all except Section 11.6 (abbreviated, focus on lectures); Chapter 12 - all; SKIP Chapter 13; Chapter 14 – all

**Electronic class reviews now available.** Please respond. We find the feedback very valuable.

Astronomy in the news:

NASA's Lunar Atmosphere and Dust Environment Explorer has crashed into the moon as planned


Update on new “nearby” supernova SN 2014J in M82

Nothing to report

## One Minute Exam

According to Stephen Hawking:

 Black holes are totally black

 Combining a neutron star and an anti-neutron star will make a black hole

 A singularity is a point

 Black holes can explode

## Goal:

To understand how we search for real black holes and why binary systems with mass transfer and accretion disks are so important.

# Chapter 10 - Finding Black Holes for Real

Reading: Chapter 10, Sections 10.1-10.6, 10.9

We know that massive stars evolve to form iron cores that absorb energy and collapse. A compact object must be left behind.

Some explode and leave rotating, magnetic pulsars

Some explode and leave highly magnetic magnetars

Some explode but leave black holes or completely collapse to leave black holes

**We don't know which massive stars do which!** Tendency to think that more massive stars are more prone to making black holes, but the rotation of the star, the presence of a binary companion, and other factors may influence the outcome.

We do know that black holes exist, so some stars make them.

# Black Holes for Real

There may be 1 - 100 million black holes in the Galaxy made by collapsing stars over the history of the Galaxy.

That means that the nearest black hole may be only a few tens of light years away. How do we find them?

Black holes made from stars are really black! (Negligible Hawking radiation).

Those alone in space are not impossible to find, but very tough.

Event horizon of 10 solar mass black hole has a radius of 30 km ~ 20 miles, somewhat bigger than size of Austin, easily fit between Georgetown and San Marcos

Very black

None yet identified.

# Black Holes for Real

Look for binary systems, where mass accretion occurs.

Will not see the black hole, do not yet have the technology to “see” a black spot.

Can detect the *halo of X-rays* from orbiting matter, the accretion disk, near the event horizon that will reveal the presence and nature of the black hole.

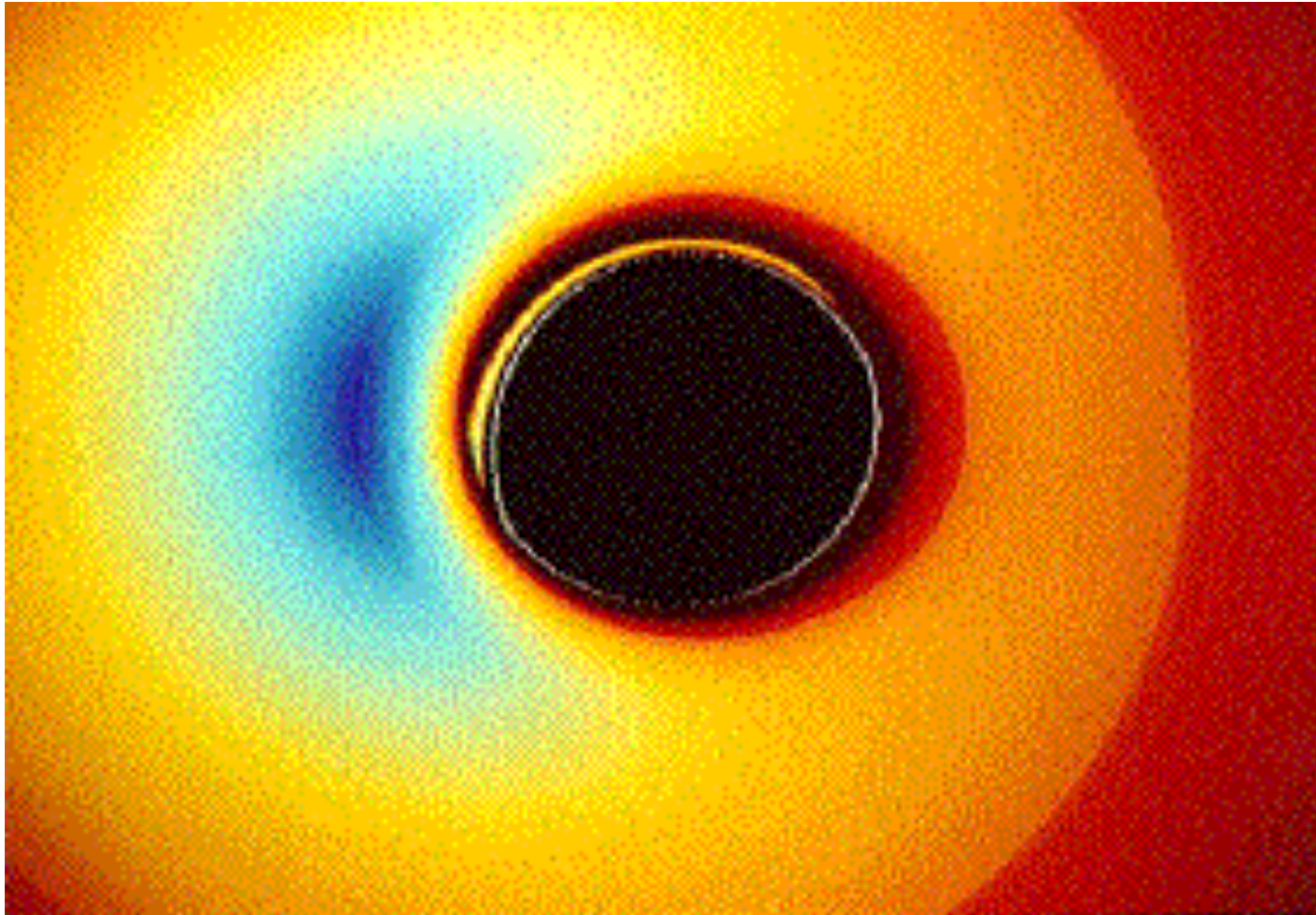
***Look in accreting binary systems!***





Goal is to get close-up study of strongly warped space:

*Event Horizon Telescope*, array of radio telescopes plans to examine the massive black hole in the center of the Milky Way



Perez and Wagoner, Stanford: computer simulation of radiation from inner black hole accretion disk

Black holes are so weird and so important that the standards of evidence have to be high!

*Current evidence is still primarily circumstantial, but very strong:*

*Stellar mass black holes* (several to  $\sim 10$  solar masses), in binary systems in our Galaxy or nearby galaxies

*Intermediate mass black holes* ( $\sim 1000 - 10,000$  solar masses)??, in binary systems or stellar clusters in our Galaxy or nearby galaxies

*Supermassive black holes* (million to a billion solar masses) in the middle of our Galaxy and in the middle of many, many others.

***Circumstantial arguments for presence of black hole in a binary system:***

Only neutron stars and black holes have the high gravity necessary for intense X-rays.

Use Kepler's laws to measure the total mass of the system, astronomy to determine the mass of the mass-losing star, subtract to get mass of "unseen" companion emitting X-rays.

Maximum mass of neutron star is  $\sim 2$  solar masses

***Intense X-ray source in binary star system with mass exceeding 2 solar masses is, by a process of elimination, a candidate black hole.***

There are about 20 binary star black hole candidates in our Galaxy and in the Large Magellanic Cloud (near enough to detect the X-rays) that have masses measured to be greater than 3 solar masses, and hence too massive to be a neutron star.

There are another 25 binary star black hole candidates with similar X-ray properties, but no measured mass.

## *Cygnus X-1*

First X-ray source discovered in the direction of the constellation Cygnus.

Discovered in 1970's by Uhuru Satellite (Swahili for Freedom).

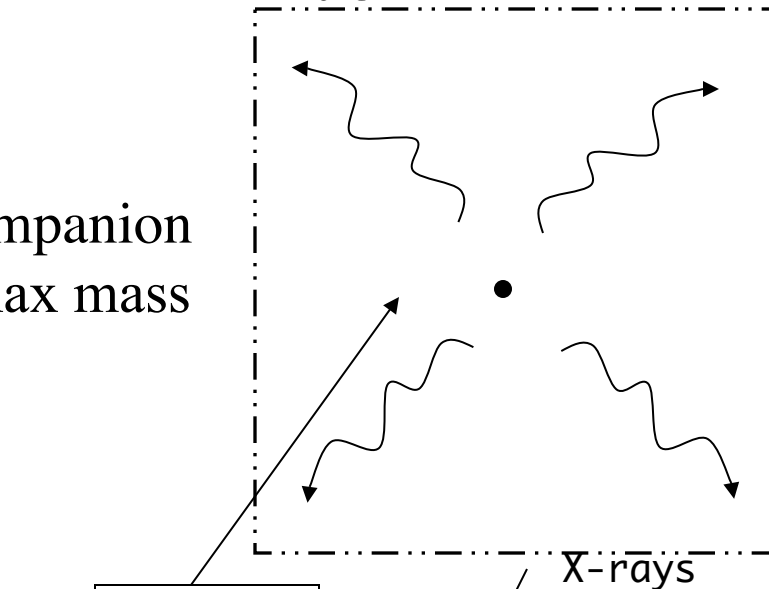
First and still most famous stellar-mass binary black hole candidate.

Can't see this system with the naked eye, but can find constellation Cygnus - look for it for sky watch!

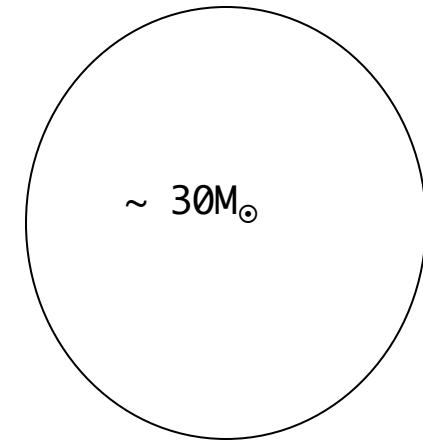
# Cygnus X-1

Optically dark  
X-ray emitting companion  
 $\geq 10M_{\odot} \gg$  NS max mass  
 $\Rightarrow$  BH

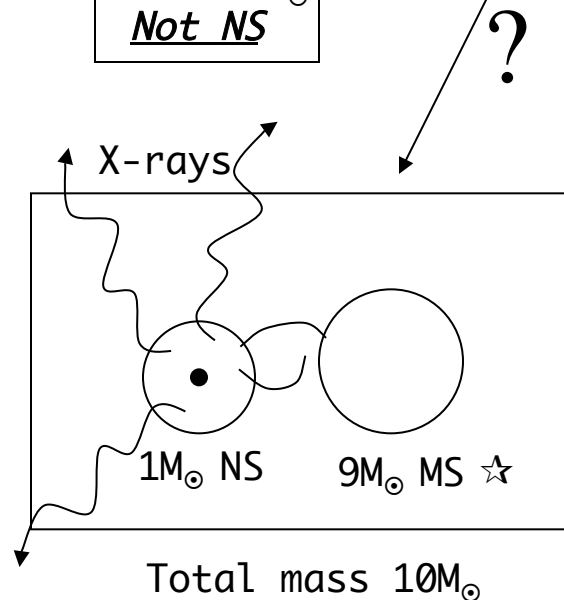
Could nature be  
tricking us? All  
we really know  
is that there is a  
 $10M_{\odot}$  “thing”  
emitting X-rays



$M \sim 10M_{\odot}$   
*Not NS*



Blue supergiant, mass  
losing star



One possibility:  
 $9M_{\odot}$  normal star  
“lost in glare” of  $30M_{\odot}$   
like flashlight next to  
searchlight. Took hard work,  
but by now virtually ruled out.

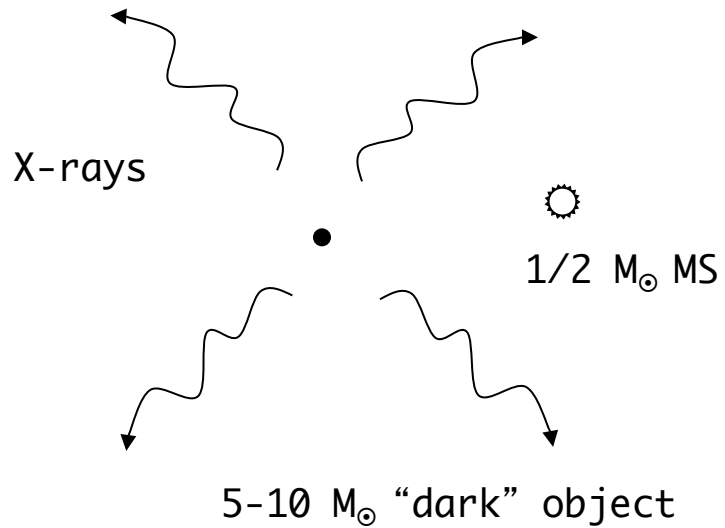
Expect only two or three systems like Cygnus X-1 in our Galaxy.

Bright, massive, short-lived companion

Maybe only one, and we found it!

Surprisingly, most binary black hole candidates have small mass main sequence companions, typically  $\sim 1/2$  solar mass.

Observe  $\sim 45$  such systems and guess there may be  $\sim 1000$  in the Galaxy



For systems with small mass companions cannot hide a 3rd star in the system

⇒ best black hole candidates.

Evidence still circumstantial but virtual proof of black hole



Not sure how these binary systems form.

Would have expected massive stars that can make black holes in core collapse to have massive companions, like Cygnus X-1.

Need to have black hole very close to small mass companion, current separation smaller than size of the star that made the black hole.

Possibilities:

Black hole progenitor swallows small mass companion while a red giant?

Companion forms from left-overs of collapse that formed the black hole?

# Proving Black Holes

Astronomers search for ways to directly determine that the dark object producing X-rays is a black hole, not a neutron star.


How would you identify a black hole of 1 solar mass?


Evidence that in some circumstances black holes, but not neutron stars, can produce very hot, rarified inner accretion regions, making gamma-rays, but few X-rays.

This is evidence that the object has **no surface**.

## One Minute Exam

The best candidate for a binary star system with black hole is:

 One with a 30 solar mass ordinary star

 One with a 1/2 solar mass ordinary star

 One with two black holes in orbit

 Cygnus X-1

Black hole candidates in the directions of Sagittarius, Ursa Majoris, Perseus, Scorpius, Ophiuchus, Vulpecula, Monoceros, Lupus, Cygnus (2) (Find and observe the constellations for sky watch)

Cygnus X-1

AO620-00 = Nova Mon 1975 = V616 Monocerotis - one of the first and best studied with a small mass companion, black hole about 5 solar masses.

V404 Cygni - somewhat evolved companion, but one of the best cases for a black hole with “dark” mass of about 12 solar masses.

Two candidates in the Large Magellanic Cloud:  
LMC X-1, LMC X-3

Total number of such systems known, about 45.

## Goal:

To understand how we have discovered supermassive black holes and how they affect galaxy formation and evolution.

# Supermassive Black Holes

Long suspected in quasars, active galactic nuclei: huge power from small volume, billion solar mass black hole could do it.

More recently, proof that many (even most! John Kormendy, UT) ordinary galaxies also have a supermassive black hole in their centers (dead quasar).

Again, do not yet see a “dark spot,” but use Kepler’s Laws, motion of many stars, gas  $\Rightarrow$  orbital period, separation

3.7 million  $M_{\odot}$  black hole in our Galaxy [UCLA link - movie]

Center of Milky Way Galaxy in direction of constellation Sagittarius – (find Sagittarius for sky watch)

Up to billion  $M_{\odot}$  black holes in quasars.

Jet from billion  $M_{\odot}$  black hole in center of M87, large elliptical galaxy in the Virgo cluster (find Virgo!)

