April 8, 2011

Exam 3, sky watch, Flatland back.

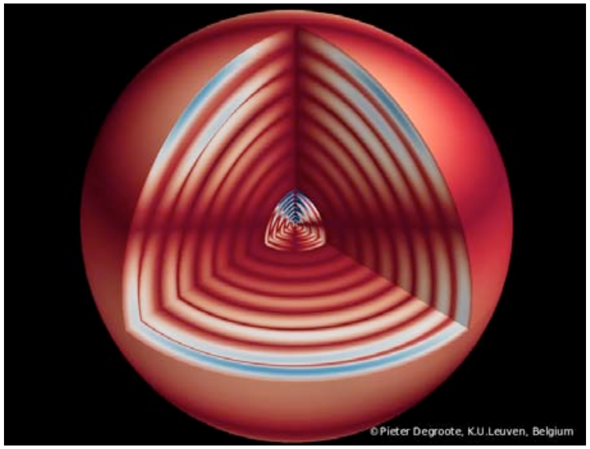
Exam 4, Friday, April 15. Review sheet, review session next week.

Reading: Chapter 9, Sections 9.5.2, 9.6.1, 9.6.2. 9.7, 9.8

Chapter 10, Sections 10.1-10.6, 10.9

Astronomy in the news:

Pic of the day: probing the insides of red giants with seismology by Kepler satellite, He burning or beyond? What about Betelgeuse?



Goal:

To understand the full space-time associated with rotating black holes.

One Minute Exam

In the mathematical solution for a rotating black hole:

➡ The surface of infinite redshift is identical to the event horizon.

⬅ You can escape the black hole back to the universe from which you entered.

⬆ There are exactly two universes.

⬇ The space entered through the ring singularity is different than the space surrounding the singularity.

Chapter 10 - Finding Black Holes for Real

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.

Goal:

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

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?

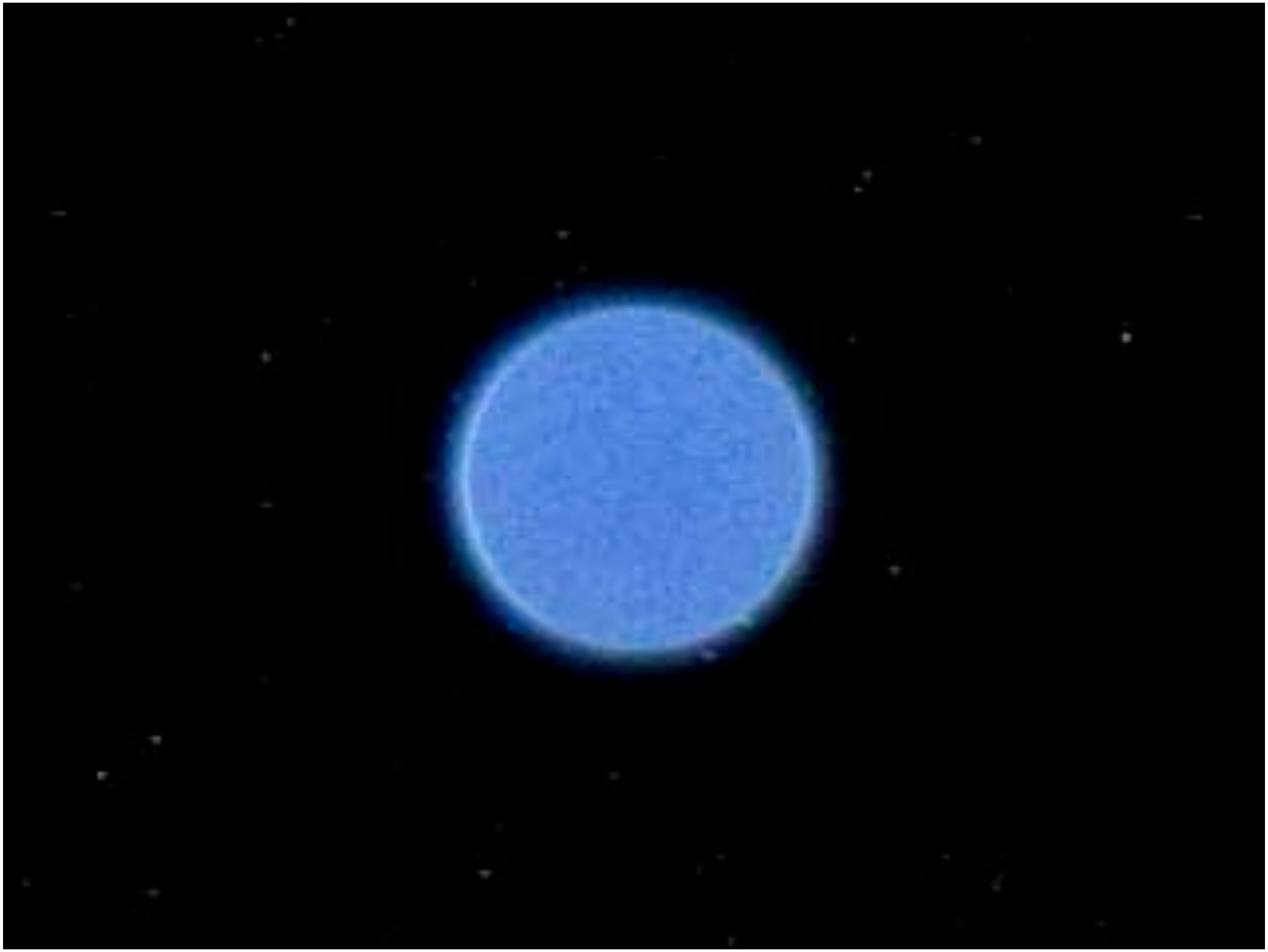
Black holes made from stars are really black! (Negligible Hawking radiation).

Those alone in space are not impossible to find, but very tough. None yet identified.

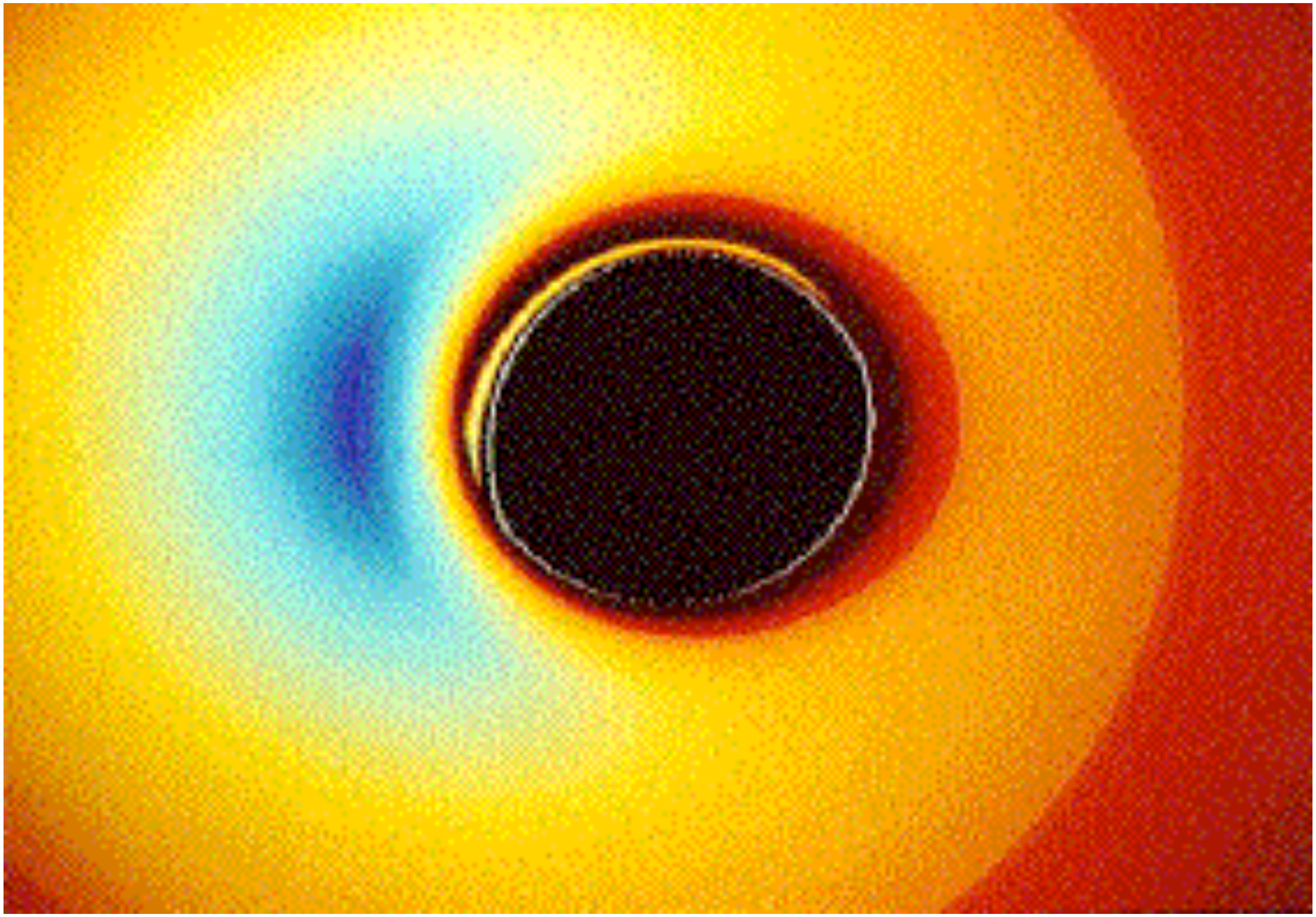
Look for binary systems, where mass accretion occurs.

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



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 ~ 10 solar masses), in binary systems in our Galaxy or nearby galaxies

Intermediate mass black holes (~ 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 ~ 2 solar masses

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

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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 simlar 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).

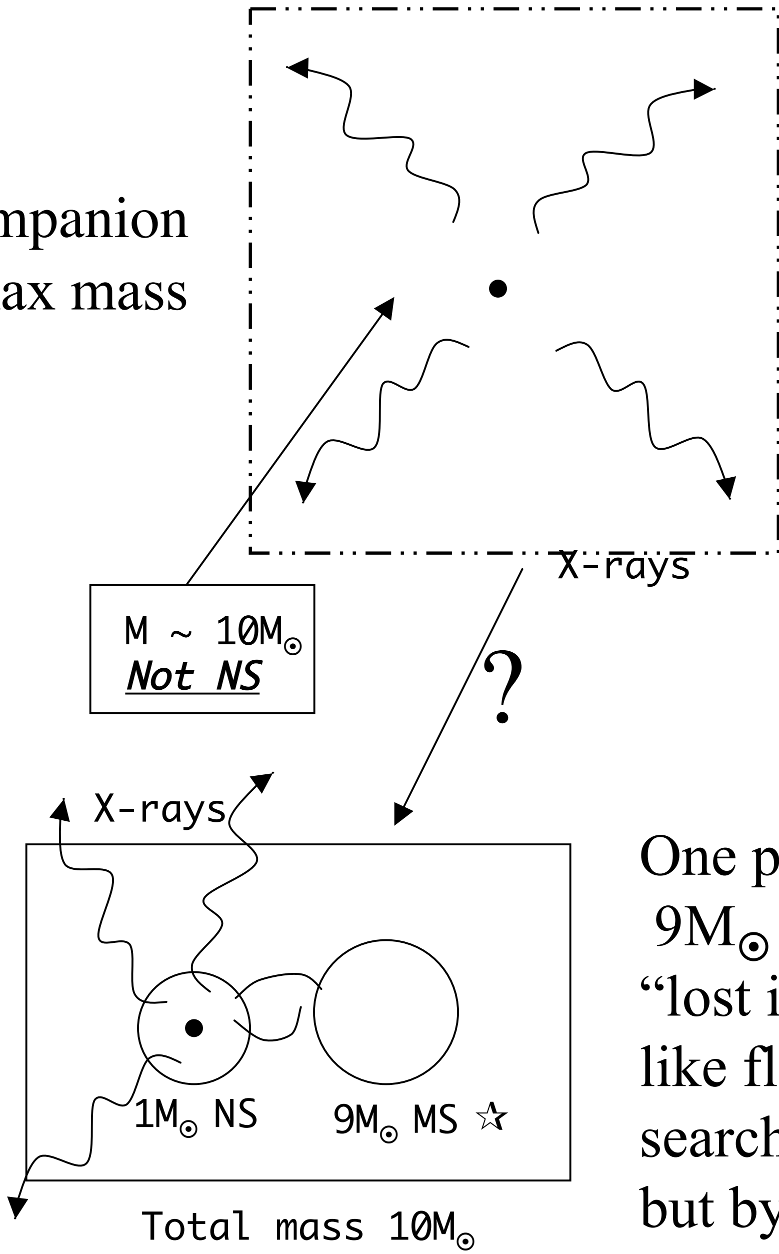
First and still most famous stellar-mass binary black hole candidate.

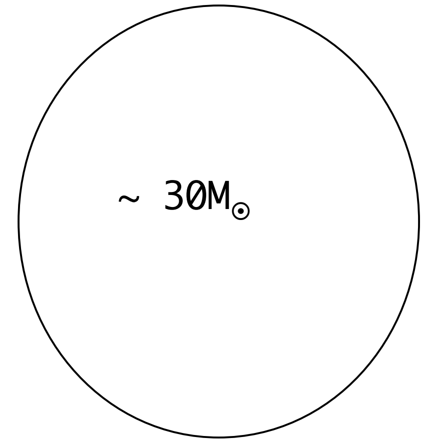
Can't see this system with the naked eye, but can find constellation Cygnus - look for it for sky watch!

Cygnus X-1

Optically dark
X-ray emitting companion
$\geq 10M_\odot$ >> 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





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.

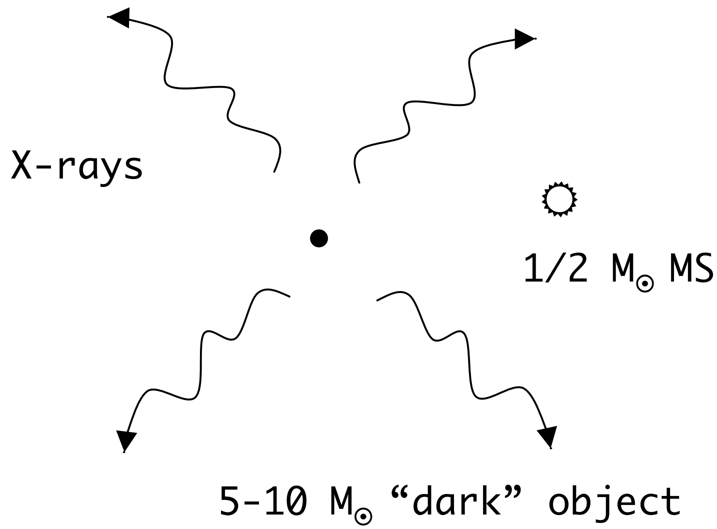
Expect only two or three systems like Cygnus X-1 in our Galaxy.

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 ~ 1/2 solar mass.

Observe ~45 such systems and guess there may be ~1000 in the Galaxy



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

$\Rightarrow$ best black hole candidates.

Evidence still circumstantial but virtual proof of black hole

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

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.

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

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 ⇒ 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!)

Surprising discovery:

It was long thought that supermassive black holes were somewhat incidental to galaxies,

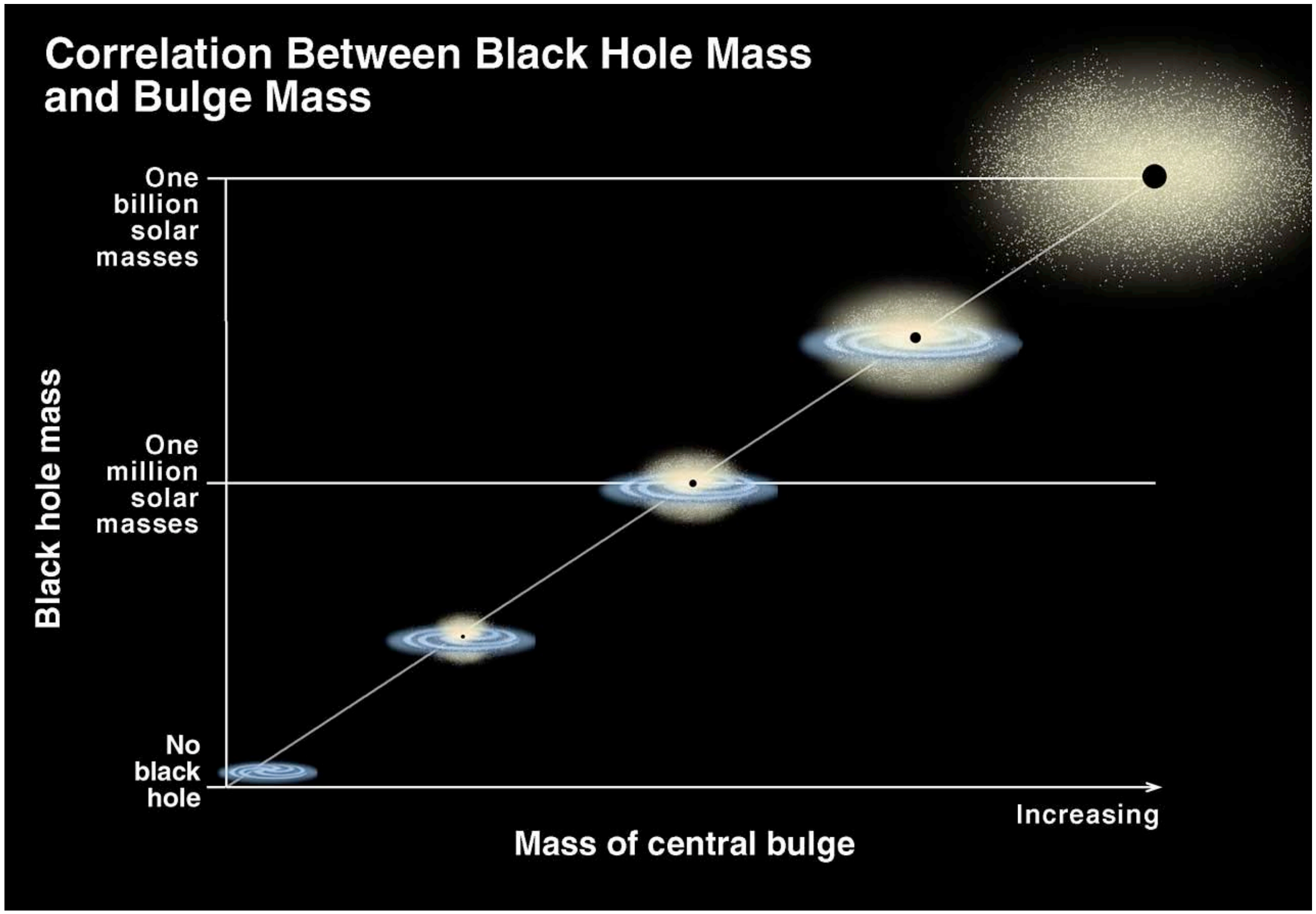
Formed of matter that somehow drained into the center of the galaxy, so galaxy could have large mass or small mass black hole depending on circumstances.

Recent work by Karl Gebhardt (UT) and others has shown that even stars so far from the center that they cannot possibly feel the gravity of the black hole *now* are moving in such a way that ***the larger the mass black hole, the higher the speed of the stars!***

Andromeda
M31

Correlation Between Black Hole Mass and Galaxy Bulge Mass

Mass of Black Hole



Mass of Central Bulge of Galaxy

The implication is that the mass of the galaxy (at least the inner portions, the Bulge) is always close to 800 times the mass of the black hole.

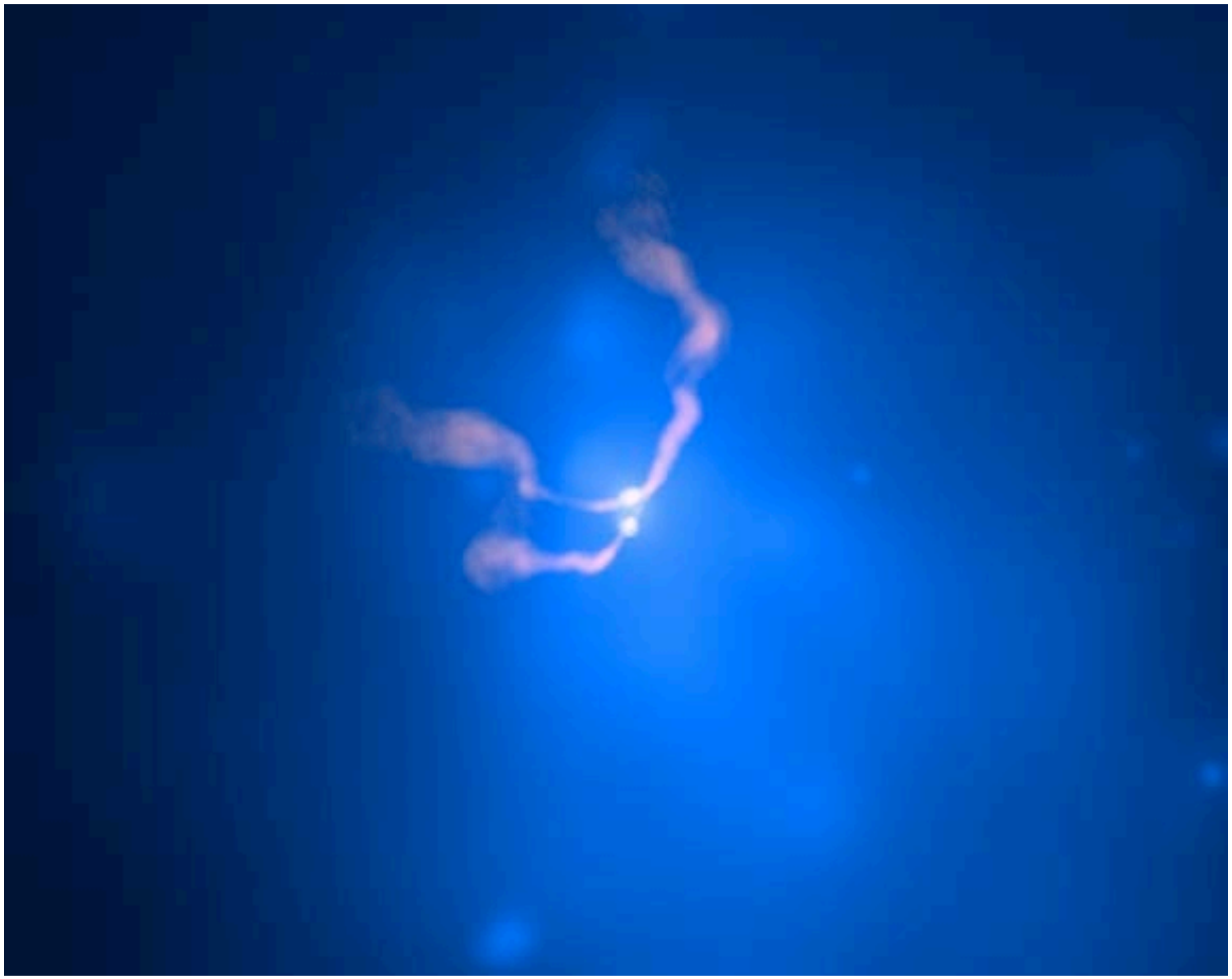
This means that ***the formation of the black hole is somehow intimately connected with the formation and structure of the whole galaxy.***

Galaxies "know" how big a black hole to make.

Mechanism uncertain: Does the galaxy control the black hole or the black hole somehow control the galaxy?

Most popular current idea: energy from accretion of matter into disk around black hole feeds back to the surrounding galaxy, blowing excess galaxy gas away when galaxies are young and growing.

Colliding black holes in 3C75, feed energy back into the stars and gas of the colliding galaxies.



One Minute Exam

How can we discover a stellar mass black hole that has no accretion disk around it?

➡ Look for X-rays

⬅ Look for gamma-rays

⬆ Look for jets

⬇ We can’t

One Minute Exam

What is the relation between the mass of a supermassive black hole and the galaxy in which it resides?

- ➡ There is none, the black hole can be big or small, depending on how it grew and for how long
- ⬅ The larger the mass of the galaxy, the smaller the mass of the black hole
- ⬆ The larger the mass of the galaxy, the larger the mass of the black hole
- ⬇ The larger the radius of the galaxy, the larger the mass of the black hole

Goal:

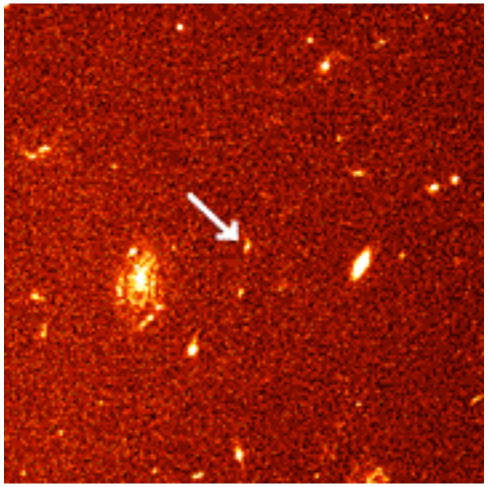
To understand the nature of cosmic gamma-ray bursts, how they may represent the birth of black holes or magnetars, and how they are connected with Type Ic supernovae.

Gamma-Ray Bursts (Chapter 11)

Swift satellite

Cosmic explosions, flashes of gamma-rays lasting about 30 seconds, detected by satellites.

Seen across the Universe.



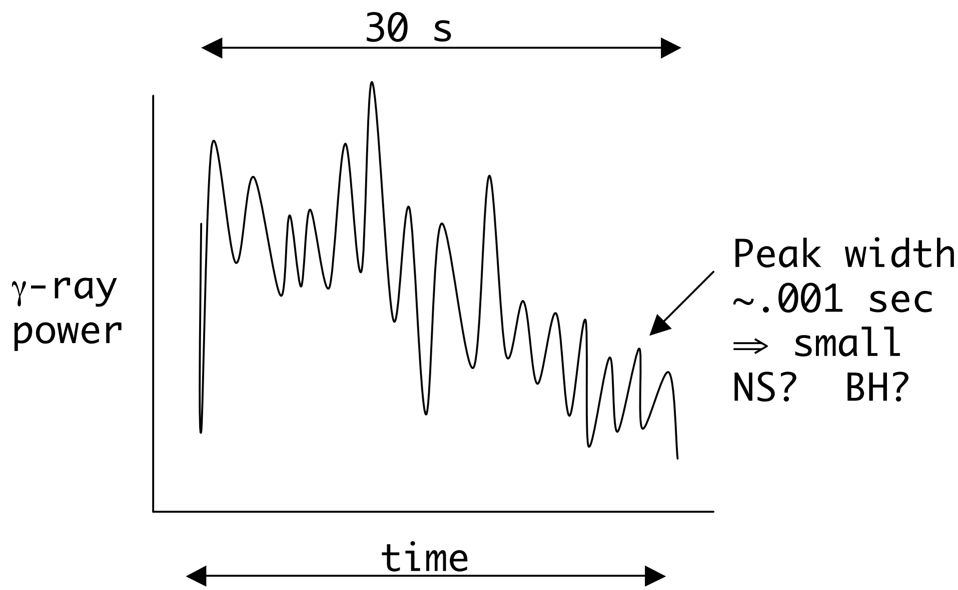
Energy is expelled in narrow jets.
Energy comparable to that of supernovae, but all in gamma-rays, with later ***afterglow*** in X-ray, radio and optical radiation.
Birth of a black hole?

Gamma-Ray Bursts unite ***stars*** and ***cosmology***

Mystery since late 60's - satellites to monitor space nuclear test ban treaty, avoid confusion between astronomical effects, and bombs

Flare of γ -rays lasts ~ 30 sec

Never Repeat - for 30 years, no optical counterpart,
C*an't focus gamma-rays*.
Did not know which of millions of stars to look at.

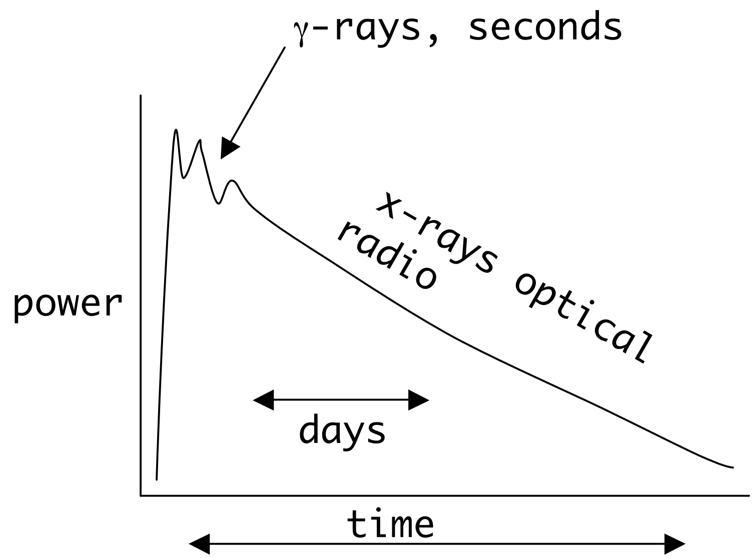


Did not know the distance: guesses ranged from within the Solar system to cosmologically distant

Goal:

To understand what a gamma-ray burst “afterglow” is and why it is so important.

Revolution in 1997: 1st detection of "afterglow" - optical, radio, X-ray, fading light



Position localized - could bring full armament of modern astronomy to bear on the fading radiation.

⇒Found bursts were in distant galaxies - all at huge, cosmological distances, billions of light years away.

⇒ Very bright to shine that far

January 23, 1999 optical flash associated with the gamma-ray burst itself (need to discover, swivel telescope, look in 30 seconds!)

9th magnitude - human limit 6th magnitude, could almost see with naked eye, could have seen with good binoculars, but half way across the Universe!

March 19, 2008, “naked-eye” GRB 080319B discovered by Swift satellite had a peak apparent magnitude of 5.8 and remained theoretically visible to human eyes for approximately 30 seconds.

September 16, 2008, GRB 080916C discovered by new Fermi Satellite, 12.2 billion light years way, was the intrinsically brightest optical event ever recorded, equivalent to brightness of 9000 supernovae.

April 23, 2009, GRB 090423 discovered by the Swift satellite, the most distant object ever observed in the Universe, about 13.1 billion years ago, when the Universe was only 630 million years old.

If gamma-ray bursts shine equally in all directions, the energy released in gamma rays would be 1000-10,000 × SN or 10-100 × core collapse neutrinos.

Comparable to total annihilation of entire star into pure energy!

Goal:

To understand the energy in gamma-ray bursts and why it is important that the energy is "beamed."

BUT

Light bulb versus laser pointer or flash light

Bursts do not radiate in all directions!

They are strongly focused into jets!

Bursts are focused into only about 1/100 of total sky

Typical gamma-ray burst energy ~ 1/3 supernova kinetic energy

But send matter at 99.997% of the speed of light

Supernova energy into a mass equivalent to Jupiter, not the mass of the Sun, as for supernovae

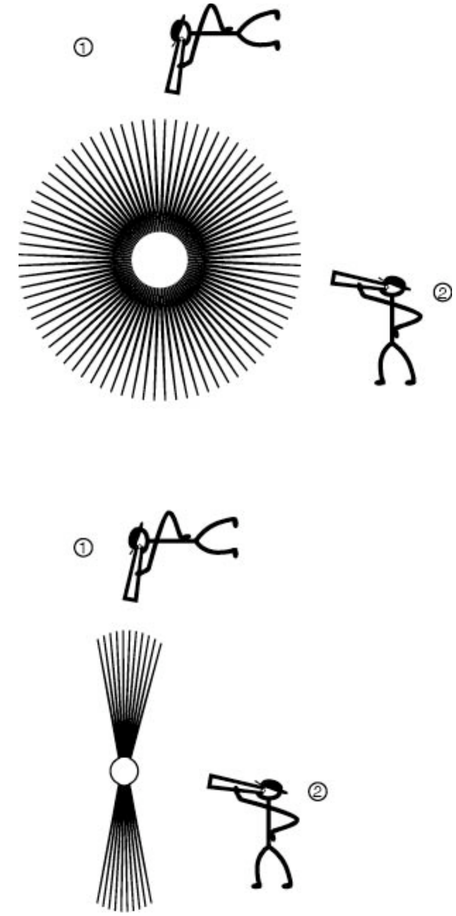


Figure 11.4

They explode ~100 times more often than observed (could observe about 2 per day if looked in all directions, all the time) because most have the jet aimed away from us.

Goal:

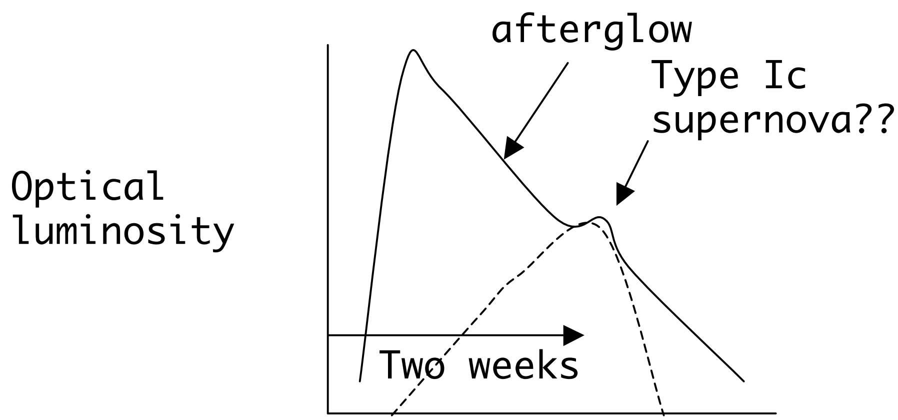
To understand how gamma-ray bursts are connected to supernovae.

Find all gamma-ray bursts in regions of massive young stars (spiral arms of spiral galaxies, irregular star-forming galaxies like the LMC) ***Something to do with death of massive stars***

Explode once every 10^4-10^5 years in a given galaxy versus about once per 10^2 years for ordinary supernovae, so relatively rare.

Most popular guess is that gamma-ray bursts represent the birth of a *black hole* in the collapse of a massive star. Alternative suggestion - might be a highly magnetized neutron star or *magnetar* (Chapter 8)

Early circumstantial evidence for several bursts associated with supernovae.



Are gamma-ray bursts produced in some form of core-collapse supernova?

Circumstantial evidence was followed by proof:

GRB 030329 was nearby, only 3 BILLION light years away! Relatively bright, an ideal target.

SN2003dh was discovered a week later! Spectrum of a Type Ic supernova

By now many associated supernovae have been found: **all are Type Ic supernovae**

But all Type Ic supernovae are not gamma-ray bursts

The current picture: Gamma-ray bursts result from the collapse of a massive star from which the hydrogen and most of the helium have been stripped, probably to produce a black hole (but maybe a magnetar), that emits a tightly focused, highly relativistic jet.

Every burst, twice a day somewhere in the Universe - the birth of a black hole aiming its jet at us?

~100 aimed elsewhere for every one aimed at us.

Have not yet proven that black holes are involved. Tough problem!

NASA Animation: Black Hole Forming in Star, producing jet and Gamma-Ray Burst

One Minute Exam

It is important to understand that gamma-ray bursts emit their energy in tightly collimated beams because otherwise

➡ Estimates of the distance will be wrong

⬅ Estimates of the mass of the black hole formed will be wrong

⬆ Estimates of the energy emitted will be wrong

⬇ Estimates of the type of supernova in which they explode will be wrong.

Goal:

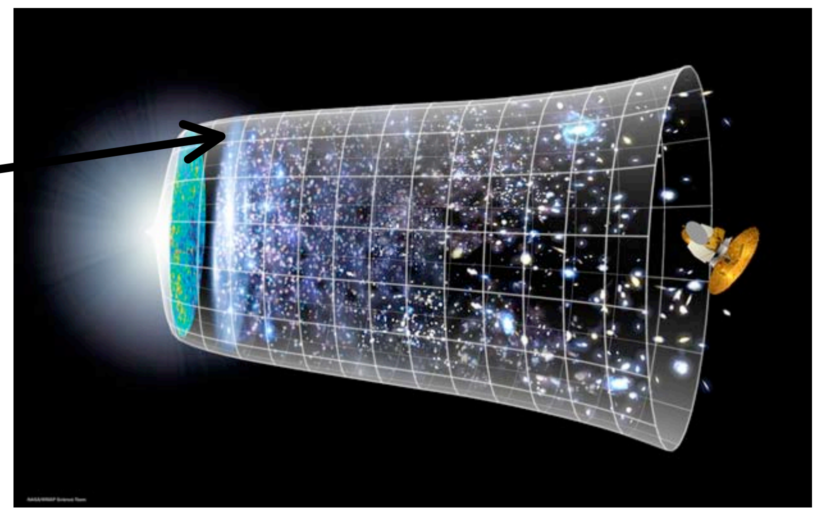
To understand what the "Dark Ages" of the Universe were, why they came to an end, and what gamma-ray bursts have to do with that.

Gamma-ray bursts are intensely bright lights

Can be seen at great distance

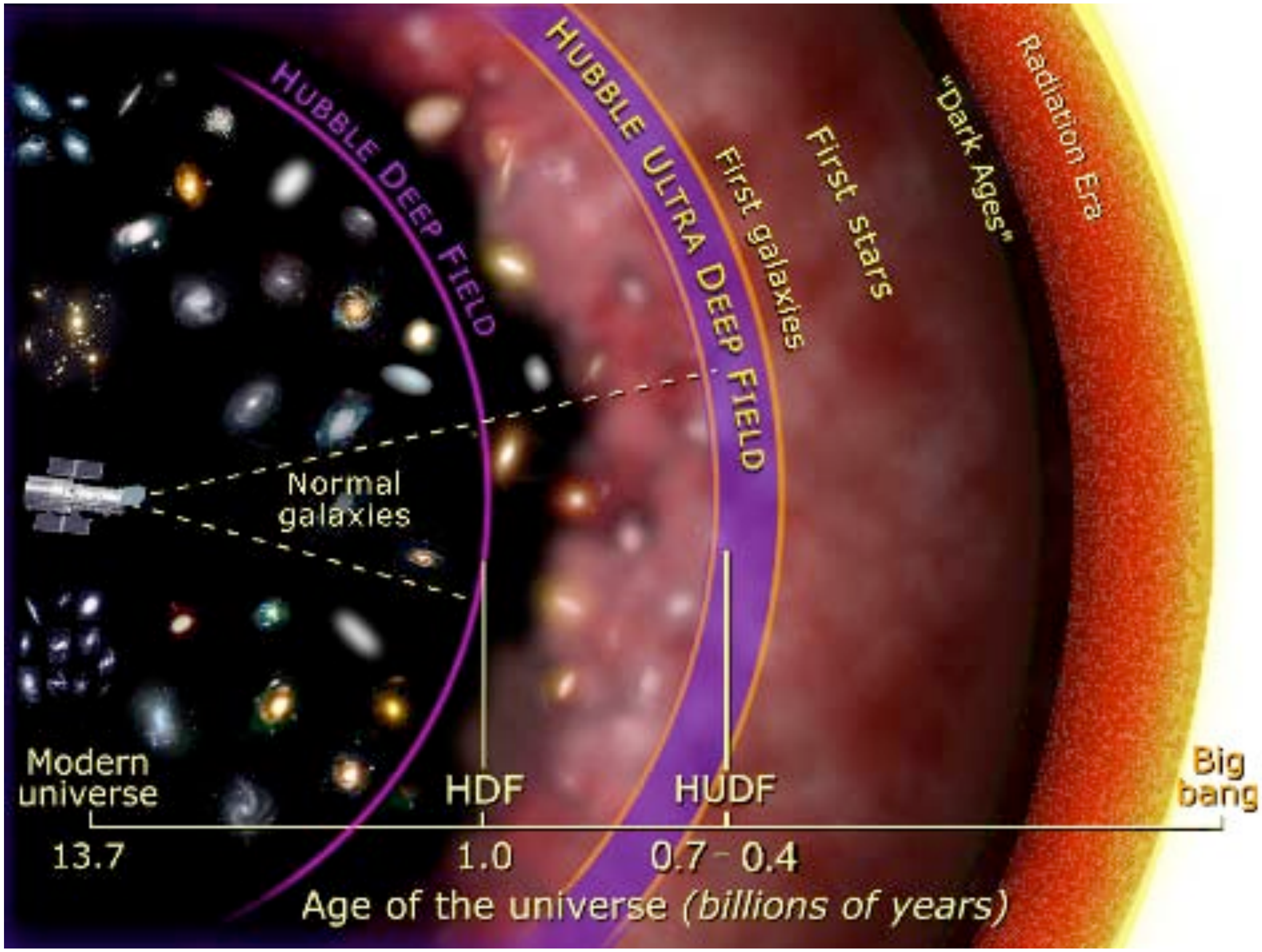
Probe cosmology, the early Universe

Dark Ages, after the Universe cooled off a million years after the Big Bang, before stars and Galaxies first formed half a billion years later



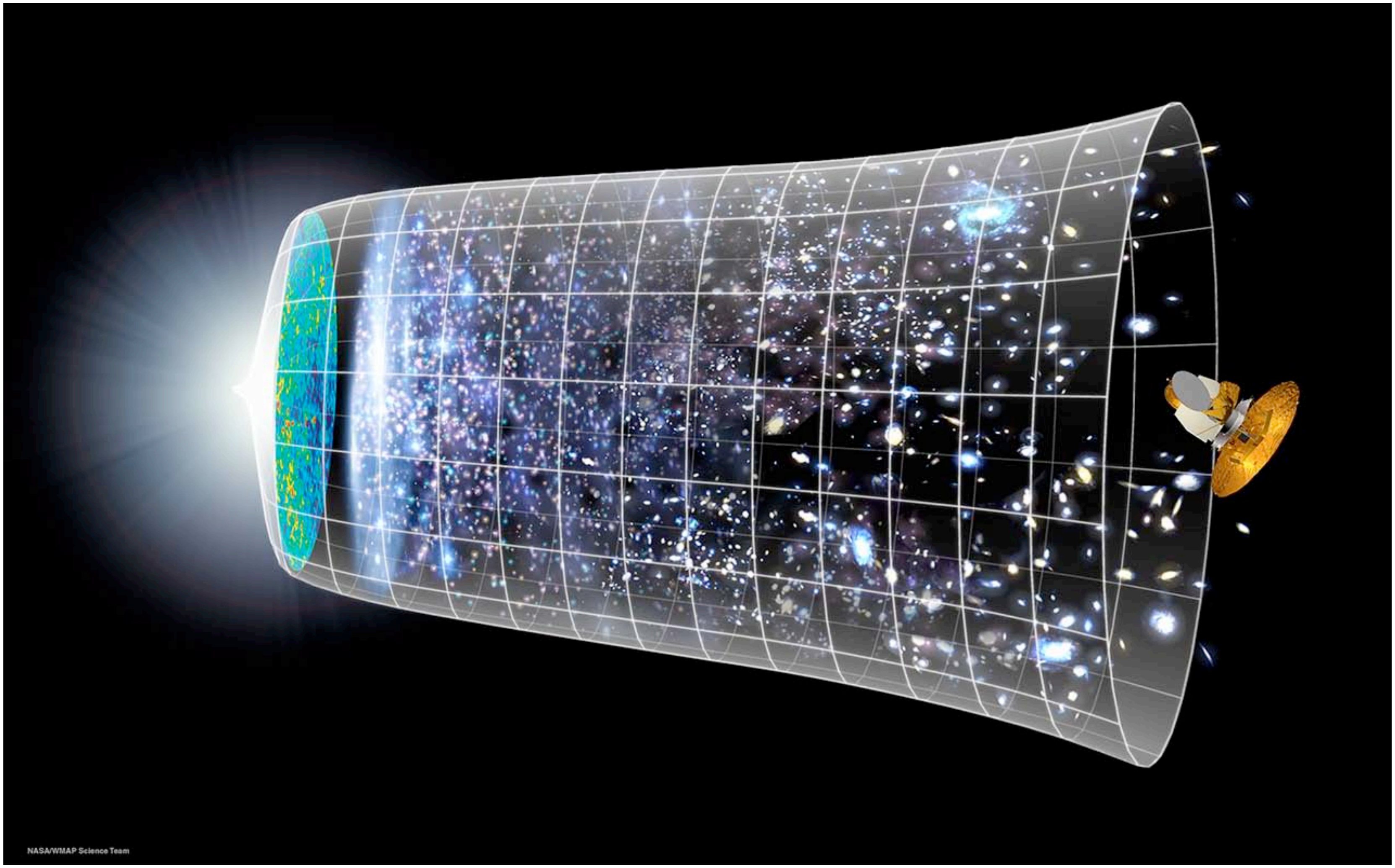
Point toward the Big Bang.

The past is all around us, in every direction, out in space, back in time.



Gamma-ray bursts could be among the first objects seen at the end of the Dark Ages as the first stars are born and die, over 13 billion years ago. GRB 090423 is the first example.

From the Big Bang to Now



END OF MATERIAL FOR EXAM 4