

Astronomy 102.  
September 13, 2005.



Galactic Supernova Remnant IC 443  
Credit & Copyright: Jean-Charles Cuillandre (CFHT), Hawaiian Starlight, CFHT

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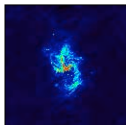
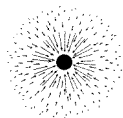
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Astronomy 102, September 13, 2005.  
Back to our Black Holes.

- Today we will continue our exploration of black holes.
- On Thursday we visited Hades, which is a black hole with a mass of 10 solar mass units.
- We also visited Sagittario, which is a black hole with a mass of  $10^6$  solar mass units.
- We found it difficult to get close to these black holes and we encountered several problems:
  - Large tidal forces
  - Break down of Newtonian mechanics.



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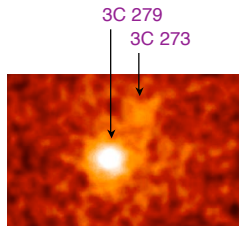
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Exploration of Black Holes:  
Let's travel to 3C 273.

- From our observations on Thursday we have concluded that the only way in which we can get close to the horizon of a black hole is by traveling to a super massive black hole.
- We decide to travel to Gargantua, which is a hypothetical black hole near the quasar 3C 273.



Gamma-Ray Quasar  
Credit: EGRET team  
Compton Observatory, NASA

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## Why go to a quasar? Compact dynamos of light.



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## A view of a Quasar.



Artist: Walt Feimer, STScI

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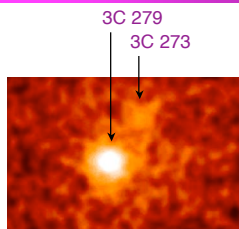
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## Why travel to 3C 273?

The bright object in the center of the false color image above is quasar 3C 279 viewed in  $\gamma$ -rays. 3C 279 is a nondescript, faint, star-like object in the visible sky. In June of 1991 a  $\gamma$ -ray telescope onboard NASA's orbiting Compton  $\gamma$ -Ray Observatory unexpectedly discovered that it was one of the brightest objects in the  $\gamma$ -ray sky. Shortly after this image was recorded the quasar faded from view at  $\gamma$ -ray energies.



Gamma-Ray Quasar  
Credit: EGRET team  
Compton Observatory, NASA

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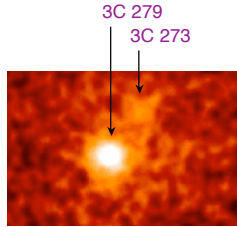
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## Properties of 3C 273.

- 3C 273 is a galaxy with a large black hole at its center.
- The black hole appears to have the following properties:
  - Mass =  $2 \times 10^9$  solar mass units
  - Circumference of the horizon = 0.3 ly.
  - The black hole is rotating fast.
  - A spinning accretion disk surrounds the black hole, and the material that is falling into the black hole gives this region a luminosity of 1,000,000,000,000 times the solar luminosity.
- However, this black hole is not heavy enough!



Gamma-Ray Quasar  
Credit: EGRET team  
Compton Observatory, NASA

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## Let's go and explore Gargantua.

- Gargantua is located  $2 \times 10^9$  light years from Earth.
- You operate your starship in the same mode as before: the acceleration of the space ship is +g during the first half of the trip, and -g during the second half of the trip.
- The trip takes 42 years, measured on the starship, but **2 billion years**, measured by an observer on Earth. (Extreme relativistic length contraction!)



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## After years we are approaching our destination!



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(Artist's) view of 3C 273 from "our" black hole Gargantua

Ejected material: "twin jets," speeds near  $c$

Accretion disk  
Black hole  
(at center of disk)

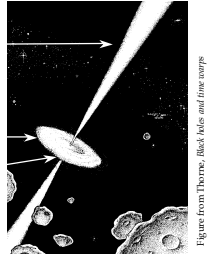


Figure from Thorne, Black Holes and Time warps

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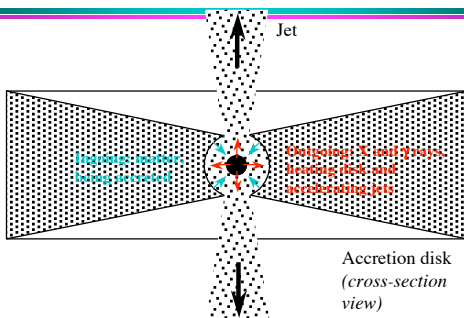
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Structure of an accretion disk



Accretion disk  
(cross-section view)

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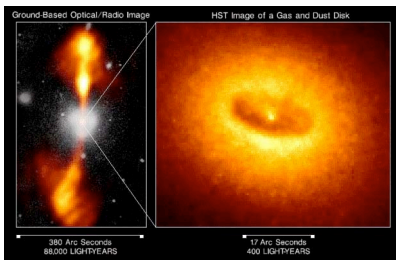
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Astronomer's view of NGC 4261 (Hubble Telescope, NRAO Very Large Array).



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## Properties of Gargantua

- After entering into orbit around Gargantua we determine its properties:
  - Mass =  $1.5 \times 10^{13}$  solar mass units
  - Circumference of the horizon = 29 ly.
  - The black hole is not rotating.
  - Little material is falling into it.

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We are tired from all this travel!  
Let's take a mid-lecture break.

- Homework set # 1 is due on Friday September 16 at 8.30 am.
- Homework set # 2 will be available via WeBWork on Friday morning September 16 at 8.30 am.
- Recitations will start today (September 13).



Gaseous Pillars - M16  
HST - WFPC2  
© 1995-1996 by ST ScI Corp. November 2, 1995  
A. Fowler and P. Roman (ST ScI Corp.), NASA

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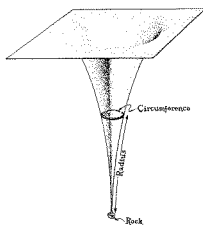
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Now that we are rested, let's explore  
Gargantua.

- Our goal is to descend to a location just above the horizon (such that your orbit would have a circumference 1.0001 times the horizon's).
- At this position, the acceleration due to gravity is 10g (we can deal with that).
- It takes 13 years to descend from a stable orbit (a few horizon circumferences) to our current position just above the horizon.
- Our measurements indicate that we experience an extreme warping of space!



(Figure from Thorne, *Black holes and time warps*)

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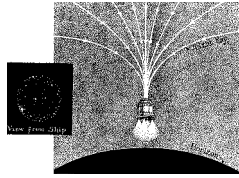
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### What do we see when we descent towards the horizon of Gargantua?

- The appearance of the sky changes dramatically as you descend.
- This is a result of the fact that light rays are deflected by the gravitational field generated by the black hole.
- Instead of being spread out in all directions, the stars and galaxies are compressed into an ever-shrinking circle directly overhead.
- The colors of stars and galaxies are shifting towards blue.



(Figure from Thorne, *Black holes and time warps*)

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### View of the sky from just above a planet's surface.



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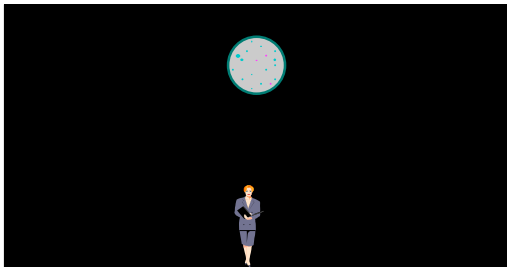
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### View of the sky from just above a black hole's horizon.



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## Why is there such a big difference between Gargantua and 3C 273?

- The material that is sucked up by a black hole can be obtained from stars that get close enough to the black hole to be ripped apart by the strong tidal forces.
- The guts of the stars will orbit the black hole and will be slowly sucked in; the guts of stars are the main components of the accretion disk around 3C 273.
- Around Gargantua, the tidal forces are too weak to rip a star apart and instead, the star is swallowed by the black hole as one piece.

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## Let's go home .....

- After all our travels, let's go home.
- Wait a moment ....., Is there still a home for us?
- Let's look at our calendars:

Trip	Our time	Earth time
Earth - Hades	6 years	26 years
Hades - Sagittario	20 years	30,102 years
Sagittario - Gargantua	42 years	2,000,000,000 years
Gargantua - earth	42 years	2,000,000,000 years
Total	110 years	4,000,030,128 years

- Will the earth still be there?
- Will the earthlings know who we are?

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## Let's not go home ....., but make a new home!

- We decide to return to a hypothetical pair of black holes in what used to be the Orion Nebula, 1,500 ly from Earth.
- The trip from Gargantua takes 42 years (2 billion years for an observer on Earth).
- You arrive just in time to watch the black holes coalesce into one single, spinning black hole.
- Just afterwards, your spaceship is rocked violently by the burst of **gravitational waves** released in the course of the coalescence.



The Colorful Orion Nebula. Credit: Gary Bernstein (U. Michigan); Copyright: U. Michigan, Laurent

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## Let's build a new home!

- The new black hole looks fascinating.
- You enter into orbit, and measure its mass to be 45 solar masses.
- Based on the known masses of the original holes, which added up to 48 solar masses, you conclude that 3 solar masses have been lost; they have been transformed into energy (e.g. in the form of gravitational waves).
- The new black hole spins with a rate of 270 revolutions per second.
- You determine that 20% of the mass of the black hole is stored in the form of energy associated with the tornado-like deformation of space.
- You decide to build an energy extractor to extract this energy.

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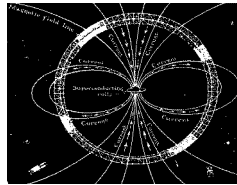
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## Our new home!

- The energy stored in the deformation of space is about  $10^4$  times as much energy as our Sun radiates in its entire lifetime.
- Our crew builds a giant girder works,  $5 \times 10^6$  km in circumference (2.2 times that of the Moon's orbit around the Earth), rotating once every half hour to provide 1g gravity on its inner and outer surfaces.
- The energy of the "swirl" is tapped to fuel the new city on the girder-works.



(Figure from Thorne, *Black holes and time warps*)

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## So what have we learned?

- Lengths appear to contract when traveling at speeds close to that of light.
- No speed can exceed the speed of light.
- Nothing can escape from within a black hole's horizon.
- Light is radiated by electric charges falling into a black hole.
- Gravity waves!
- Near the horizon of a black hole:
  - Space warps.
  - Time warps.
  - Gravitational red shift.
  - Very strong gravity and tidal forces.
  - Gravity and tidal forces very near horizon are *less* for a heavier black hole than for a lighter one.
  - Orbits smaller than 3 horizon circumferences: "reverse thrust" required to change, resulting in instability
  - No orbits smaller than 1.5 horizon circumferences
  - Sky compressed into a small circle overhead

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Done!  
Next: The Theories of Newton and Einstein.



IC 1396 in Cepheus Credit:  
Digitized Sky Survey,  
ESA/ESO/NASA FITS Liberator

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