Astro 210

Lecture 35

April 18, 2018

Announcements:

- **HW10 due Today 5:00 pm online**
- HW 11: The Final Frontier posted, due next Friday

Last Time: General Relativity

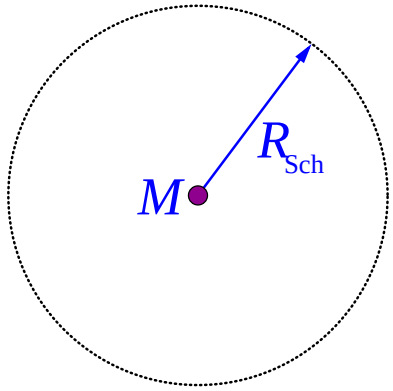
General Relativity: key idea is *Equivalence Principle*
Q: what's general about this relativity?
Q: what's the principle? what's equivalent? consequences?

example: masses released (1) from rest, or (2) with $\vec{L} \neq 0$
both theories agree on the kinds of motion that result
but Newton sez: gravity force results in acceleration
while Einstein sez:
• gravity intimately connected with space & time ("spacetime")
• massive objects distort spacetime "like a rubber sheet"
Demo: spandex black hole

Last Time: Black Holes–Theory

size: Schwarzschild radius

$$R_{\text{Sch}} = \frac{2GM}{c^2}$$



Q: what is a black hole? key features?

Q: how's it black? how's it a hole?

Q: what's life like near and far from a black hole?

iClicker Poll: Black Holes

From a safe distance, you drop an object (nuclear waste? Voldemort?) on an isolated black hole.

Will you see it fall in?

A yes, no matter your distance from the hole

B maybe, depends on how far you are from the hole

C no, because it never actually falls in

D no, although it does actually fall in

Falling Into a Black Hole

No barrier, bells, or whistles at horizon
infalling objects go right through

seen from afar, time dilation and redshift progressively severe
as object approaches horizon

progressively strong relativistic flux reduction

so as seen from afar:

- time elapse slows until appears "frozen"
- signal redshifts
- image fades until last photon emitted before horizon crossing and then object gone–and black hole mass higher

Life Inside a Black Hole

once inside $R_{\rm Sch}$, no getting out
all matter $\rightarrow$ center $\rightarrow$ point (?): "singularity"
i.e., finite mass M in volume $V = 0 \rightarrow$ density $\rho \rightarrow \infty$!
D'oh! known laws of physics break down

A few remarks:

- we know that all observers travel to center
- don't know what happens once there
- regardless, certain that you die if you go in
- in a way, it's not a relevant question, since can't get info out even if went in (no Nobel Prize!)
- once crushed to $< 10^{-33}$ cm, quantum mechanics important
  i.e., need quantum theory of relativistic gravity!
  ... but there isn't one...yet
- if you have quantum gravity theory, please tell instructor and we'll publish it (your name may even go first!)

iClicker Poll: You Thought the BP Spill Was Bad

Experiment:
Industrial accident causes Sun to be crushed to black hole
Spokesdroid from Interplanetary BP: "Mistakes were made."

Vote your conscience!

What happens to Earth's orbit?

A nothing: same orbit!

B spirals in: aaargh!

C stronger gravity, but does not fall in

Life Far From a Black Hole

No change in orbit!

Newtonian explanation: wrong in detail, but correct spirit:
when **outside** of Sun, gravity acceleration is
$a = GM_\odot/r^2$: only M matters
gravity same as if Sun were $1M_\odot$ BH

gravity outside star **not** increased by becoming BH
no more pull than before!
$\longrightarrow$ "black hole threat" not any more dangerous than
"nearby star gravity" threat

So sleep well tonight!

Black Holes: From Theory to Observations??

So far: discussed *predicted* black hole properties

that is: General Relativity says

black holes *can* exist in nature

but question remains: is there *evidence*

that black holes *do* exist in nature?

Q: how to "see" one to test theory? No light escapes!!

Evidence for Black Holes

recall: in death of some massive stars (perhaps $M > 30 M_\odot$?):
gravity wins, collapse unstoppable
black hole formed $\rightarrow$ should be inevitable part of star formation

how detect? no light emitted from BH, but:
can observe matter interacting with BH

X-ray binaries: stellar-mass black holes (few $M_\odot$)
massive star born in bound system with less massive star
larger star $\rightarrow$ SN $\rightarrow$ BH left behind
if supergiant companion, close orbit:
some gas falls onto BH $\rightarrow$ compressed, heated $\rightarrow$ X-rays

what you see: giant star orbiting unseen massive companion,
and emitting X-rays
`www: Cygnus X-1`

Our Own Galactic Center

central ~ 30 pc of Galaxy:
can't see optically (*Q: why?*), but can in other wavelengths:
extended (non-point) radio emission (Sagittarius A)
from high-energy electrons

radio source at center: Sgr A*
size 2.4 AU(!), variable emission in radio, X-ray
`www: X-ray Sgr A*`

in infrared wavelengths: can see stars near Sgr A*
and they move! `www: Sgr A* movie`
elliptical paths! closest: period $P = 15.2$ yr
semi-major axis: $a = 4.64 \times 10^{-3}$ pc
$\rightarrow$ enclosed mass $(3.7 \pm 1.5) \times 10^6 M_\odot$
Q: and so?