Astro 210
Lecture 35
April 20, 2011

Announcements

- HW 10 due next time: computer-based, pick one of two
  for the theory-inclined: simulate a star
  for the observation-inclined: cosmology data analysis
- also due Friday: OBAFGKM(LT) mnemonic contest
  win 10 bonus points, and maybe also glamourous prizes

Last time: massive stars–the James Dean of the cosmos

- *live fast*: high mass $\rightarrow$ strong gravity, high T
  rapidly pass through nuke burning stages until iron core
- *die young*: in spectacular supernova explosion
- *leave a beautiful corpse*: high-velocity, superheated,
  metal-rich gas ejected, plus compact object at center

Now that your astro-muscles are strong

You *fully qualify* for upper-level astrophysics **courses**

- ASTR 404: Stellar Astrophysics
- ASTR 405: Solar System and Interstellar Medium
- ASTR 406: Galaxies and the Universe
- ASTR 411: Astronomical Techniques

and you are welcome but *overqualified* for medium-level courses:

- ASTR 330: Extraterrestrial Life
- ASTR 350: Introduction to Cosmology

If you are a LAS Physics major
it's cheap to add **Astronomy Major**
$\rightarrow$ many requirements are the same
after ASTR 210: 18 advanced hours, of which ≥ 10 from ASTR

If you are in Engineering, it's cheap to add an **Astronomy Minor**
after ASTR 210: 15 ASTR hours, ≥ 9 of which are advanced

SN 1987A

most recent "nearby" supernova:
Jan. 1987: SN in nearby galaxy (LMC)
`www: discovery image`

a lucky "experiment" to test our ideas about supernovae

crown jewel:
$\star$ supernova neutrinos detected on Earth
`www: SuperK`
signal as about 20 νs, spread over about 10 sec
but came from exploding star 50 kpc = 150,000 lyr away!
`www: 2002 Nobel Prize: Masatoshi Koshiba and SuperK`

confirms:
- most ($> 99\%$!) of explosion energy carried by ν's
- visible energy only 1% of total!

Neutron Stars

In supernova core, when collapse begins

e degeneracy pressure overcome by removing electrons!

electrons and protons crushed together

to form forming neutrons and neutrinos: $p^+ + e^- \rightarrow n + \nu$

- neutrinos escape: star cools by ν emission!
- core reaches nuclear density: $\rho_{\rm nuc} \sim 10^{18}$ kg/m^3

neutron star

radius? set by density and mass

$\rho \sim \rho_{\rm nuc} \sim M/R^3$, typically, $M_{\rm NS} \simeq 1.5 M_\odot$

$\rightarrow R \sim (M/\rho_{\rm nuc})^{1/3} \sim 15 - 20$ km

tiny! size of Champaign-Urbana!

Q: but why doesn't the neutron star itself collapse?

neutrons, like electrons, are fermions
i.e., obey Pauli principle
$\rightarrow$ neutron star supported by degenerate neutrons!
$\rightarrow$ a "neutron solid"

...or so theorist imagined

neutron stars originally predicted in mid 1960's
but thought to be so compact that unobservably small

Pulsars

sources that emit periodic, pulsed radio signals

discovered accidentally: Jocelyn Bell

`www: Princeton pulsar group: audio pulsar`

`www: 1974 Nobel Prize: Anthony Hewish`

Pulsar signals

- periods very regular–better than atomic clocks!
- very fast! P range 1 s down to < 1 ms!

A Rotating Star?

Q: what would happen if Earth spun that fast?

Warning! If spin too fast
equator speed $> v_{\rm esc} \rightarrow$ unbound!
equatorial material flung away!

max possible rotation rate at equator:
when gravity balances centripetal acc.
$v_c = \sqrt{GM/R}$; but at equator $v_c = 2\pi R/P$
$\rightarrow 2\pi R/P = \sqrt{GM/R}$

$$\text{or } P = 2\pi\sqrt{\frac{R^3}{GM}} = \sqrt{\frac{3\pi}{G\rho}} = \frac{4\times 10^5 \text{ s}}{\sqrt{\rho}} \quad (\rho \text{ in kg/m}^3) \qquad (1)$$

shortest possible period!

density to explain $P = 1$ ms?
$\rho_{\rm min} \geq (4\times 10^5/P)^2 \sim 10^{17}$ kg/m^3
$\rightarrow$ must be NS!

Lighthouse Model for Pulsars:
spinning, magnetized NS $\rightarrow$ beam of radio waves
diagram: Pulsar spin and off-axis radio beam

`www: Chandra Crab`

Note: NS extremely dense $\rightarrow$ strong gravity
escape speed $v_{\rm esc} \sim 1/3\ c$!

Newtonian dynamics, gravity:
ok if $v \ll c$ won't do! need...

`www: Big Al`

∞

iClicker Polls: Gravitation Warmup Twofer

Recall your (Newtonian) gravitation

a test particle, mass m, launched from "infinity" with speed $v_0 > 0$
passes gravitating mass M
What is the path of the particle?

A no deflection: straight line

B deflected towards M

C deflected away from M

Same question, but for *massless* test particle, $m = 0$

Gravitation Revisited

Newton gravity force law

$$F_{\text{grav}} = \frac{GMm}{r^2} \tag{2}$$

implies that if M moves and so r changes:

$\rightarrow$ gravity force changes instantaneously over all space!

"signal" of motion instantaneously transmitted throughout the universe

Einstein sez: this is totally illegal! an unmitigated disaster!

no signal–including gravity–can move faster than c!

Einstein's Equivalence Principle:

in a closed room, no experiment can distinguish (non-gravitational) acceleration vs gravity

Q: explain ball drop–Earth's surface vs accelerating rocket?

Rocket Experiment: `www: illuminating animation`

⋆ light ray deflected

⋆ entire light path bent (in fact, a parabola!)

But by equivalence principle:
must find same result due to gravity, so:

⋆ gravity bends light rays

gravitational lensing

Q: what if shine light from basement to attic?

Gravitational Redshifting

Also: in accelerating spaceship:

⋆ shine light from basement to attic

spacecraft & attic speed increases during light travel

$\rightarrow$ attic observer seed light *redshifted*

similarly, basement observer sees attic light *blueshifted*

Gravitational Redshift

And there's more:

redshift $=$ decrease in light frequency f

but $f = 1/P$, light wave oscillation period

so redshift $\rightarrow P$ increases

but light oscillations are like clock ticking, so...

Gravitational Time Dilation

⋆ clocks in basement appear to run slow
when viewed from attic!
and attic clocks appear fast when viewed from basement!

in fact, attic clocks faster by $\Delta t = t_{\text{attic}} - t_{\text{basement}} = g\Delta h/c^2$

⋆ time "warping" due to gravity:
"**gravitational time dilation**"
⋆ gravity influences "flow" of time!

Q: how to test these effects in real world?