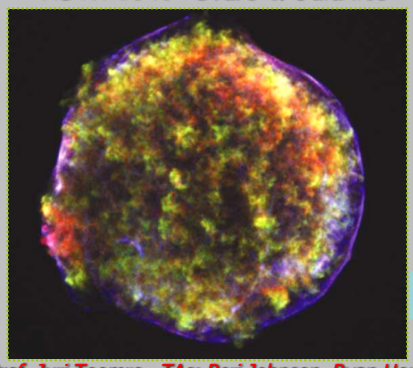
ASTR 1040: Stars & Galaxies



Tycho Brahe SNR (1572)

Prof. Juri Toomre TAs: Peri Johnson, Ryan Horton

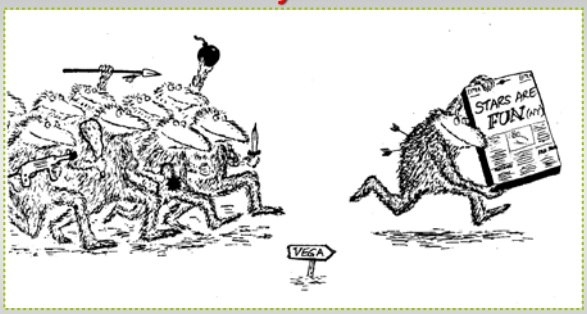
Lecture 19 Tues 20 Mar 2018

zeus.colorado.edu/astr1040-toomre

Joys of Black Holes

- Black holes, their general properties, and their "care and feeding" – and Mr. Einstein's work S.2 (special relativity), S.3 (general relativity)
- How to detect black holes (indirectly) in close binary systems (read 18.3)
- Best "stellar-mass" black hole candidates: Cygnus X-1, SS433
- Gamma-ray bursts (hypernova?)
- Our Milky Way Galaxy in overview, aspects of any spiral galaxy – and a fine SONG
- Overview read Chap 19 "Our Galaxy"

So did we really love this exam?



RESULTS FROM SECOND MID-TERM EXAM

SECOND MID-TERM EXAM

- Grade boundaries, based on 110 points (graded on a "curve"):

- If 98/110 (89%) or over, A's [35%]
- 87/110 (79%) or over, B's [44%]
- 77/110 (70%) or over, C's [16%]

Also +, plain, and – within these ranges

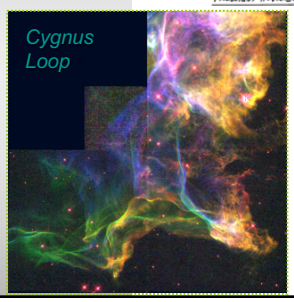
Go through answer sheet – and talk to us if do not understand our choices. Keep exam + answers for future review (comp final)

REVISIT

Listening to Pulsars

- PSR 0329+54 typical, normal pulsar: period 0.714 sec (~1.40 rotations/sec)
- PSR 0833-45 VELA pulsar: period 89 millisec (0.089 sec) (~11 rot/sec) in SNR ~10,000 yrs a
- PSR 0531+21 CRAB pulsar: ~30 rot/sec young neutron star known
- PSR J0437-4715 "millisec" pulsar, ~174 rot/s
- PSR 1937+21 fastest pulsar, ~642 rot/sec surface of star moving at 1/7 c!

SNR "numbers game"



SUPERNOVA REMNANTS (SNR)

... EXPANDING DEBRIS OF EXPLOSION

DO NOT LAST VERY LONG BEFORE DISPERSING

- FOR ABOUT 1000 YEARS, SEEN IN X-RAY, VISIBLE, RADIO
- AFTER ~ 10,000 YRS, SHOCK WAVE SNOWPLOWS MATERIAL AHEAD, BUT GAS HAS COOLED → RADIO EMISSION ALONE
- PROBABLY INVISIBLE AFTER ~ MILLION YEARS

BUT... SUPERSHELLS CAUSED BY SUCCESSIVE SN IN OB ASSOCIATIONS MAY LAST MUCH LONGER!

THE NUMBERS GAME:

~120 SNR DETECTED IN OUR GALAXY (MOSTLY IN RADIO)
5 HAVE IDENTIFIABLE PULSARS

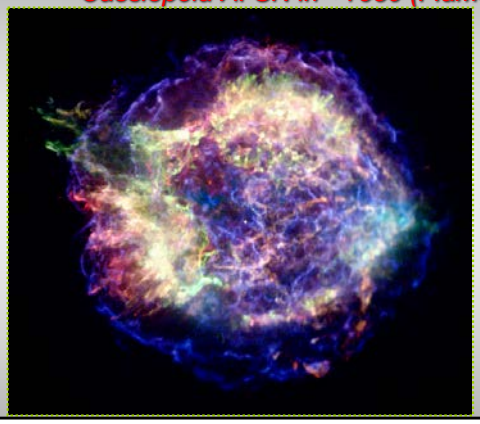
~ 50 SNR IN LMC

~ 10 SNR IN SMC

BUT ~ 400 PULSARS FOUND IN OUR GALAXY, 1 IN LMC

ANSWER: PULSARS VISIBLE LONGER (~ 4 MY), PROPER MOTION OF PULSAR MAY CARRY IT AWAY FROM SNR

Cassiopeia A: SN in ~1680 (Flamsteed)

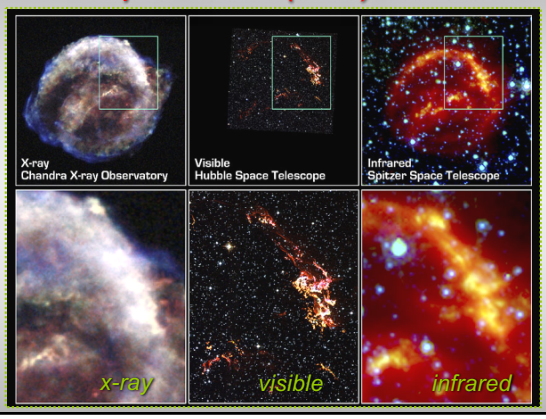


Youngest SNR in MW (Chandra X-ray image)
synchrotron emission

Neutron star at center

Cass A: Viewed with Spitzer IR

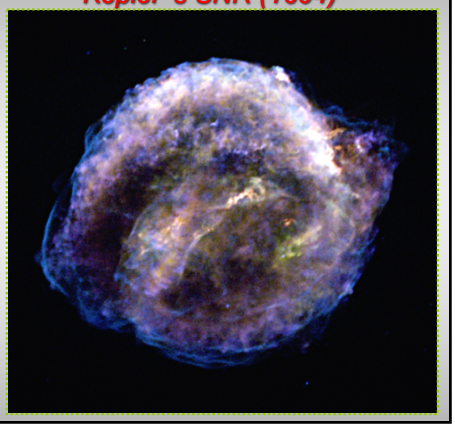
Kepler's SNR (1604) SN in MW



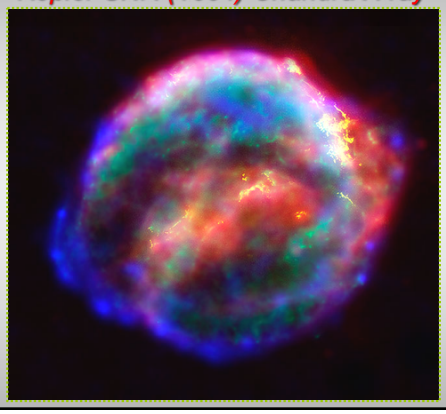
Kepler's SNR (1604)

Chandra X-ray image
red: oxygen
yellow: iron
blue: shock

"prompt" Type Ia SN



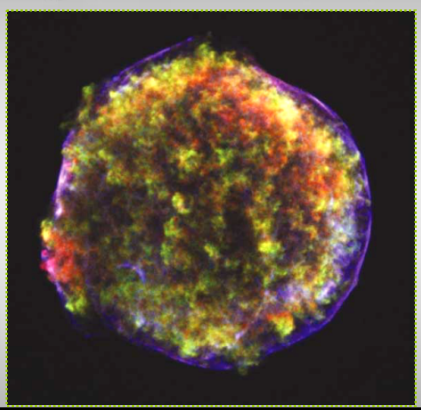
Kepler SNR (1604) Chandra X-ray



In Milky Way: Tycho Brahe SNR (1572)

Chandra X-ray

20 ly across



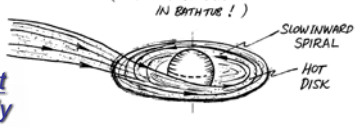
Mass transfer → accretion disk

ACCRETION DISKS

USUALLY MASS TRANSFERRED IN BINARY HAS TOO MUCH ANGULAR MOMENTUM (SIDEWAYS, ROTATIONAL MOTION) TO FALL STRAIGHT IN

⇒ FORMS DISK

(FLATTENED VERSION OF VORTEX IN BATHTUB!)



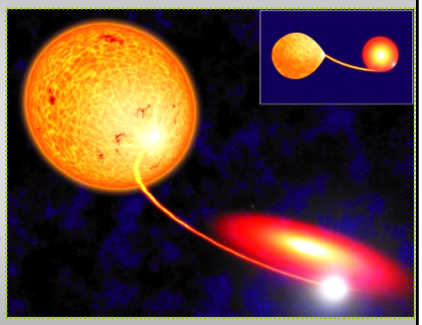
GAS HEATS UP AS IT SPIRALS IN ⇒ RADIATES VISIBLE, UV, X-RAY....

disk gets very hot -- radiates brightly

makes neutron stars and black holes visible!

"Compact Companions" in Binary Systems

- Again: mass transfer from red giant companion spirals onto accretion disk
- Inner parts become VERY hot -- glow in UV, X-rays

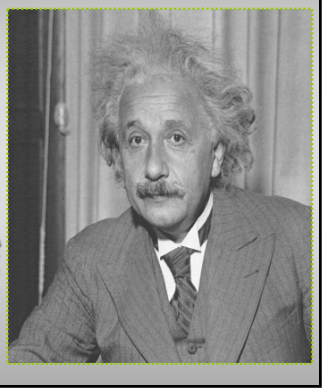


Reading ahead Clicker – Black Holes

- What do we mean by the event horizon of a black hole? **C.**
- **A.** The distance from black hole at which stable orbits are possible
- **B.** The very center of the black hole
- **C.** The sphere inward from which neither light nor anything else can escape
- **D.** The place where x-rays are emitted

GR and Spacetime

- Einstein's (1911) General Theory of Relativity: gravity is really the warping of spacetime around an object with much mass
- Light travels in "straight lines" – and its bending comes from spacetime being curved by gravity



Time slowed down .... by moving fast or strong gravity

Einstein's Special / General Theories of RELATIVITY

Our sense of time is relative ..

IF nothing can move faster than speed of light, space and time are linked → spacetime

TIME DILATION .... MEASUREMENTS OF TIME ARE RELATIVE

TIME RUNS SLOWER FOR:

1. FAST MOVING OBJECTS (EINSTEIN 1905 (SPECIAL THEORY OF RELATIVITY)) — "SR" 1905

ASTRONAUTS (16 Km/sec)

TIME SLOWS DOWN ~ $^1/_{10^9}$ ~ 10^{-3} sec/week

(AGES MORE SLOWLY AS VIEWED BY US)

RADIOACTIVE PARTICLE IN ACCELERATOR

MOVING ALMOST AT SPEED OF LIGHT c

LIVES 100 – 1000 TIMES LONGER AS VIEWED BY US

2. OBJECTS IN STRONG GRAVITY (EINSTEIN 1911 (GENERAL THEORY OF RELATIVITY)) — "GR" 1911

ON EARTH: TIME SLOWED DOWN BY 1 PART IN 10 BILLION

WHITE DWARF: 1 PART IN 1000

NEUTRON STAR: TIME IS 70% SLOWER

BLACK HOLE: TIME STOPS

⇒ TIME APPEARS TO SLOW DOWN IF YOU OBSERVE PROCESS DEEP IN A GRAVITATIONAL FIELD!

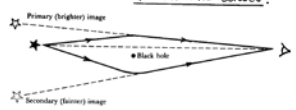
Effects of strong gravity on light

can act like lens

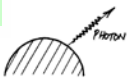
can redshift light

EFFECTS OF GRAVITY ON LIGHT ... COURTESY OF EINSTEIN

1. STRONG GRAVITY CAN BEND LIGHT: USUALLY SLIGHT DEFLECTION, BUT IF VERY STRONG GRAVITY ⇒ GRAVITATIONAL LENSES!



2. LIGHT ESCAPING STRONG GRAVITY FIELD IS REDSHIFTED: "GRAVITATIONAL REDSHIFT"

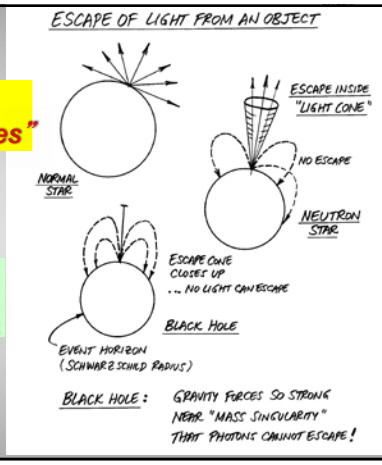


PHOTONS LOSE ENERGY FIGHTING GRAVITY

REDDER PHOTONS ≡ LOWER FREQUENCY

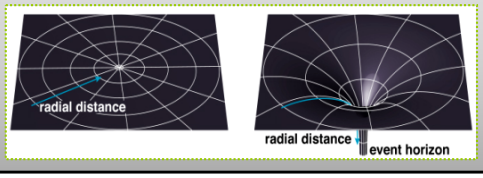
Light and "escape cones"

cone narrows as gravity forces get more intense



Black Holes

- Escape velocity $v_{esc}^2 = 2 \times G \times \text{mass} / R$ (sec 4.5)
- Mitchell & Laplace in 1700's (post Newton) speculated about objects so compact that v_{esc} exceeds speed of light
- Einstein showed space and time are not distinct (IF speed of light c is constant) → SPACETIME singularity in spacetime → black hole

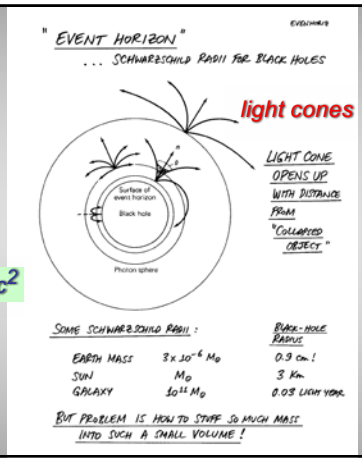


"Event horizon"

Schwarzschild radius: where escape velocity is speed of light

$R_s = 2G \text{ mass} / c^2$

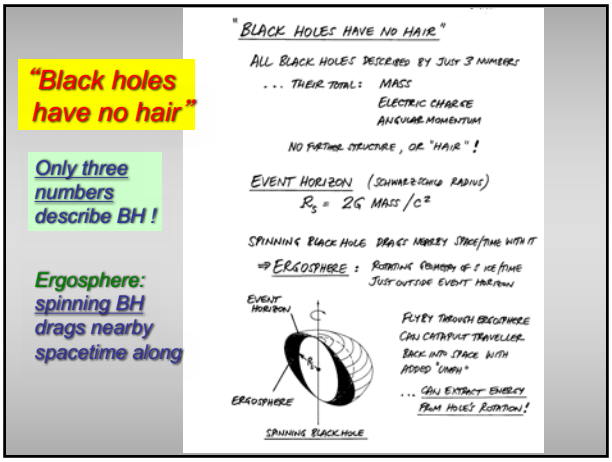
most simply: (R_s in km, $R_s = 3$ M, M in M_{sun})



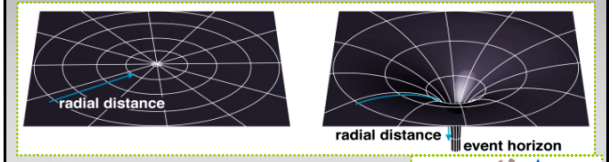
"Black holes have no hair"

Only three numbers describe BH!

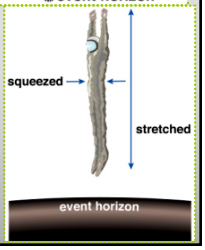
Ergosphere: spinning BH drags nearby spacetime along



Warping of Space by Gravity

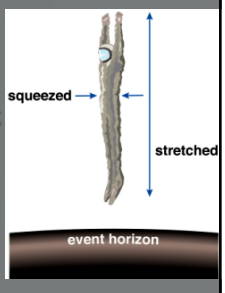


- Gravity imposes curvature on space
  - light's path through space will be "bent by gravity"
  - within the event horizon, it cannot climb out of the hole
- As matter approaches event horizon…
  - tidal forces are tremendous
  - object would be "spaghettified"



3 aspects of falling into a black hole:
1) Spaghettified

- As matter approaches the singularity…
  - tidal forces (difference between gravitational force at two points) are tremendous
  - Your feet would feel a much stronger pull of gravity than your head
  - object would be "spaghettified"



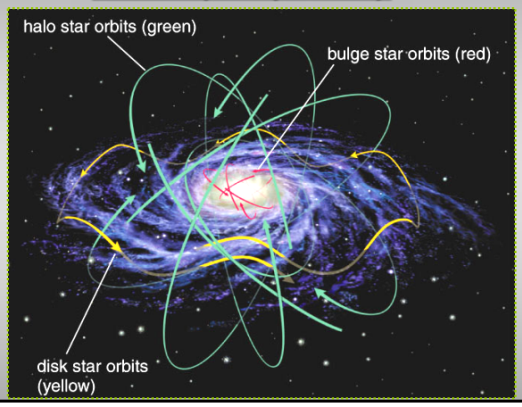
OVERVIEW

Our Milky Way Galaxy

- 100-400 billion stars
- 100,000 light years in diameter, or ~ 30,000 pc = 30 kpc (kilo-parsecs)
- Sun is located about 8.5 kpc from center, in the `Orion Arm'

Artist's sketch!

Our Milky Way Galaxy



Stars and gas are all moving!

THIS INSPIRES A SONG!

Sing our way to the Milky Way

THE GALAXY -- LIGHTEN UP

Whenever life gets you down, Mrs. Brown,
And things are hard and tough,
And people are stupid, obnoxious and down,
And you feel that you've had quite enough...

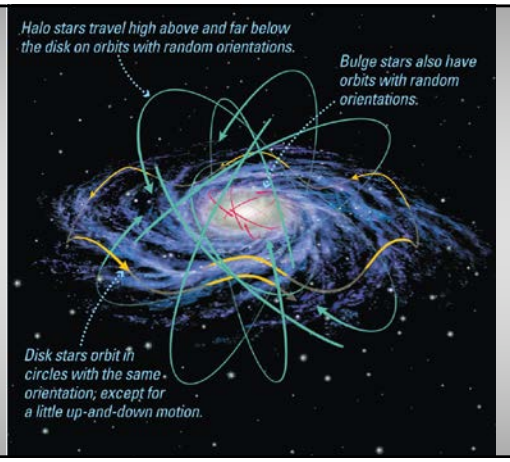
Just remember that you're standing on a planet that's evolving
And revolving at 900 miles an hour.
It's orbiting at 90 miles a second, so it's reckoned,
From the sun that is the source for all our power.
The sun and you and me and all the stars that we can see
Are moving at a million miles a day
In an outer spiral arm at 40 thousand miles an hour
In the Galaxy we call the Milky Way.

Now the Galaxy itself contains a hundred billion stars.
It's a hundred thousand light-years side from side.
It bulges in the middle 16 thousand light-years thick,
But out by us it's just 3 thousand light-years wide.
We're 30 thousand light-years from galactic central point.
It'll go round every 200 million years.
And our galaxy is only one of millions and billions
In this amazing and expanding Universe.

Now the Universe itself is still expanding and expanding
In every direction it could wish
As fast as it can go, the speed of light we know,
12 million miles a minute and that's the fastest speed there is.
So remember when you're feeling very small and insecure
How amazingly unlikely was your birth,
And pray that there is intelligent life somewhere up above,
For there isn't any down here on Earth.

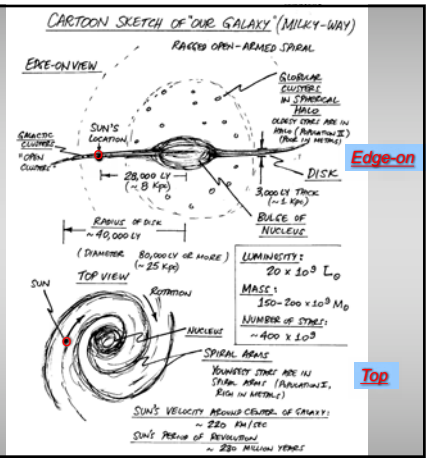
Lighten up, there are stars in the sky,
Lighten up, it's a good question why,
But you don't know the answer and neither do I,
So meanwhile let's just all lighten up.

And remember that you're standing on a planet that's evolving ...



One-pager: ALL about us!

Sketch of Milky Way



Edge-on

Top