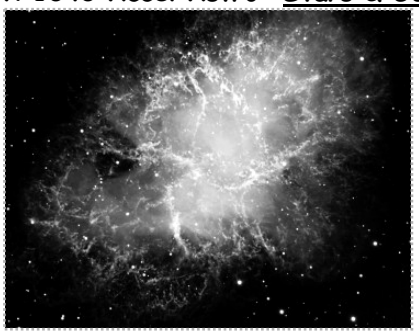
ASTR 1040 Accel Astro: Stars & Galaxies



M1 Crab supernova (optical)

Prof. Juri Toomre TA: Kyle Augustson

Lecture 18 Thur 13 Mar 08

zeus.colorado.edu/astr1040-toomre

Today in Bizarre-Land

- Massive stars end life with *supernova explosion*, leaving behind either *neutron star* or *black hole*
- *Pulsars* – fast spinning neutron stars with fierce magnetic fields; gradually slow down
- *Synchrotron radiation* makes the light seen as pulses – and thus Crab nebula + pulsar shines (and pulses) brightly in many wavelengths
- Joys of nearest supernova: *SN 1987A*
- How *mass transfer from binary companion* can *spin-up pulsar*

Things to do

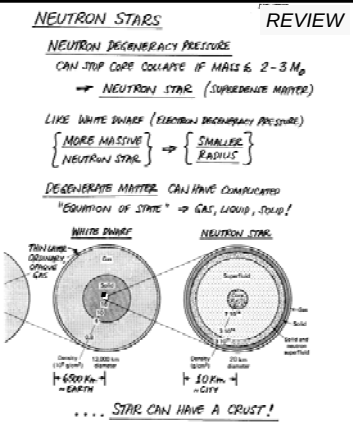
- Respond to discussion (next Thur) on *"we are made of star stuff, and how does it come about"*
- Read *18.4 Black Holes* carefully for Tues lecture, overview read Chap *19 `Our Galaxy'*
- Report on Observatory # 4 last night
- Progress with *Planet Finder*
- *Evening Review* tonight 7-9pm, prepare for *Second Mid-Term Exam* on Mon 17 Mar (crib sheet competition!)

Neutron stars

More massive, smaller in size!

Star with a crystal crust !

Idea of neutron stars first suggested in 1930s (Landau, Zwicki, Baade, Oppenheimer) … but seemed like wild dreaming

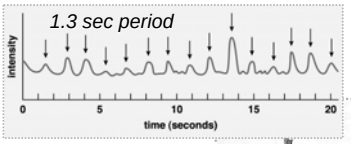


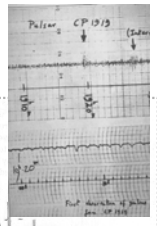
Favorite Postcard: Size of Neutron Stars

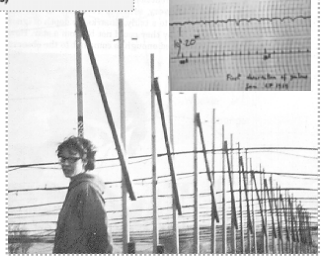
- *Structure determined by gravity vs. neutron degeneracy pressure*
- *Size ~ 10 km. More massive, smaller !!*
- *Crushing gravity at its surface, so not a nice neighbor …or place to visit …. as tourist – try Big Apple instead.*

Neutron star over NYC !

Observing the`First' Pulsar: BIG discovery





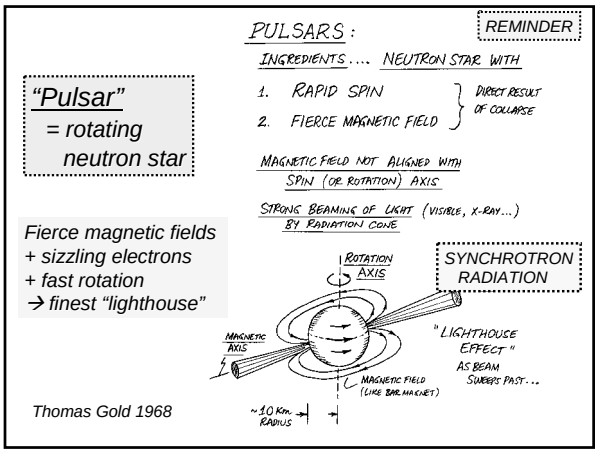


- *Jocelyn Bell : Cambridge (UK) graduate student in 1967 (+ Anthony Hewish) discovered pulsars by accident*
- *Little Green Men (LGM) ? Just WHAT could cause signal?*

"Pulsar"
= rotating neutron star

Fierce magnetic fields
+ sizzling electrons
+ fast rotation
→ finest "lighthouse"

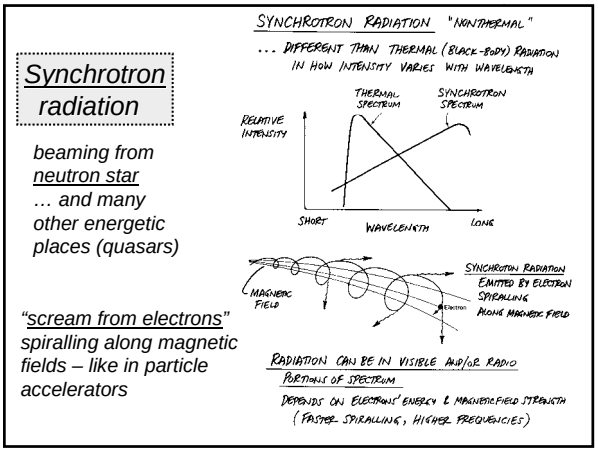
Thomas Gold 1968



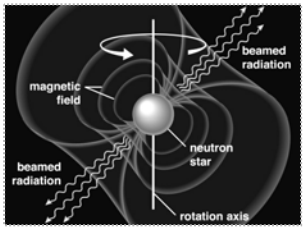
Synchrotron radiation

beaming from neutron star … and many other energetic places (quasars)

"scream from electrons" spiralling along magnetic fields – like in particle accelerators



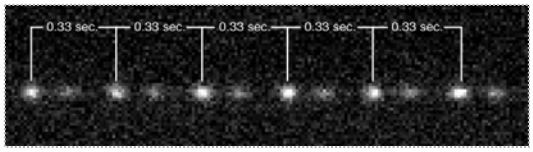
Pulsars and Neutron Stars



Pulsars are lighthouses in our Galaxy!

Mystery resolved when pulsar discovered in Crab Nebula (known to be supernova remnant) -- Messier 1 or M1 !

The Crab pulsar also pulses in visual light



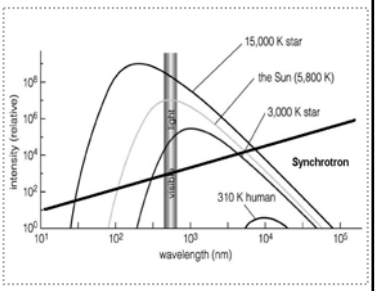
Spinning Bowling Ball Demo

Neutron Star in the Lab

+ Sound on the Web

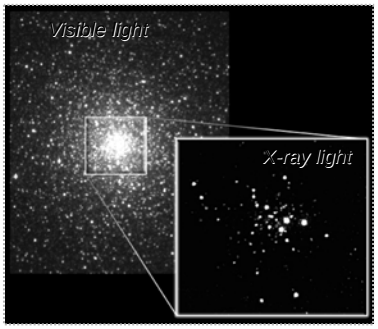
Synchrotron Radiation

- *Fast electrons in strong magnetic fields → neutron stars, black holes*
- *Different shape from thermal radiation: emits at all wavelengths, strongest in radio*



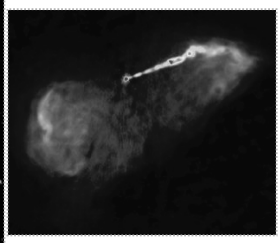
Visible vs. X-ray emission

- *Thermal light from stars → visible and IR*
- *Synchrotron light from neutron stars → X-ray and radio*



Visible Light vs. Radio
Thermal vs. Synchrotron

Elliptical galaxy -- visible



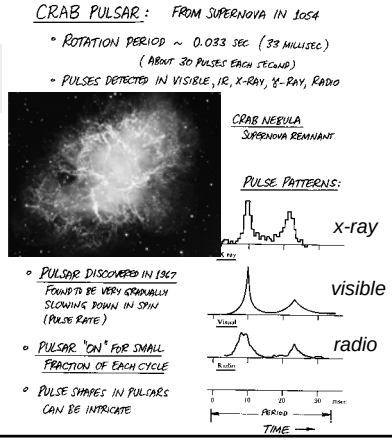
Same galaxy -- radio

Back to famous friend !

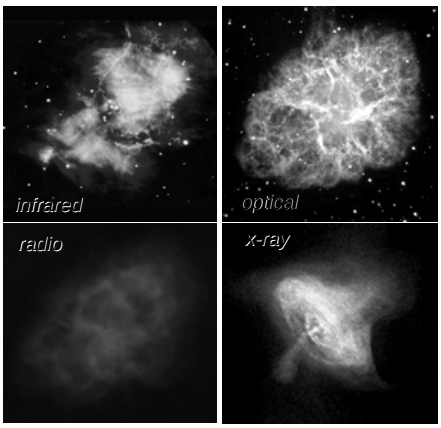
SN: Crab Nebula M1

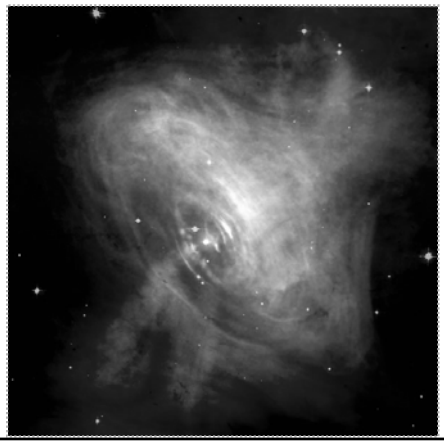
4 July 1054

Crab's pulse patterns



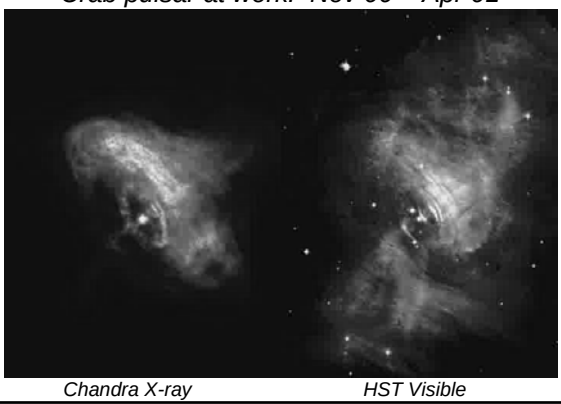
Crab Nebula SNR





Chandra X-ray view of Crab center

Crab pulsar at work: Nov 00 – Apr 01

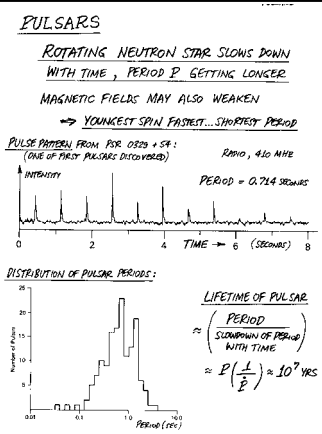


Chandra X-ray *HST Visible*

Gradual slowing down of pulsar rotation

Energy emitted in pulses comes from rotational kinetic energy

(Listen to pulsars from our website)

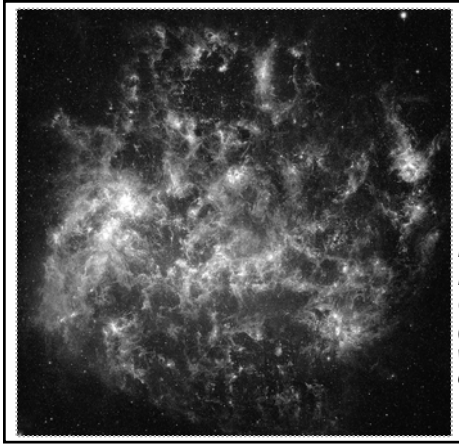


Clicker review – red giants

- *The main source of energy for a star as it grows in size to become a red giant is _____ .*

B.

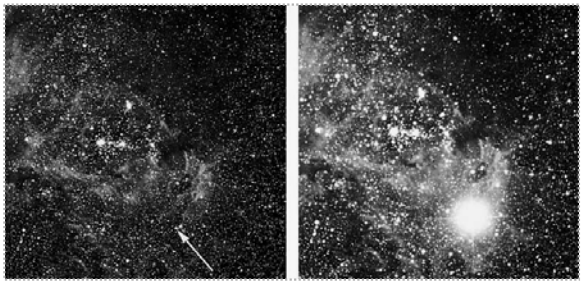
- *A.* gravitational contraction
- *B.* hydrogen fusion in a shell around core
- *C.* helium fusion in the core
- *D.* hydrogen fusion in the core



Story of SN 1987A in LMC

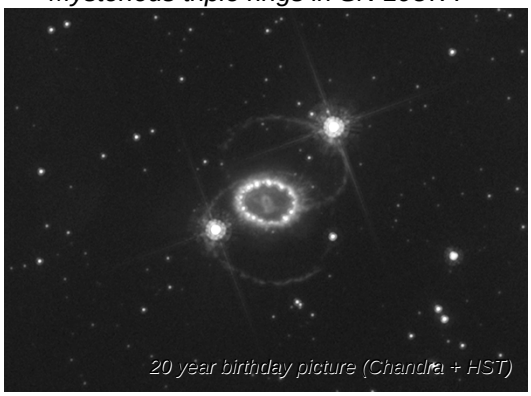
Large Magellanic Cloud (LMC) (10,000 tiles with Spitzer composite IR)

24 Feb 1987: SN in LMC (160,000 ly away)



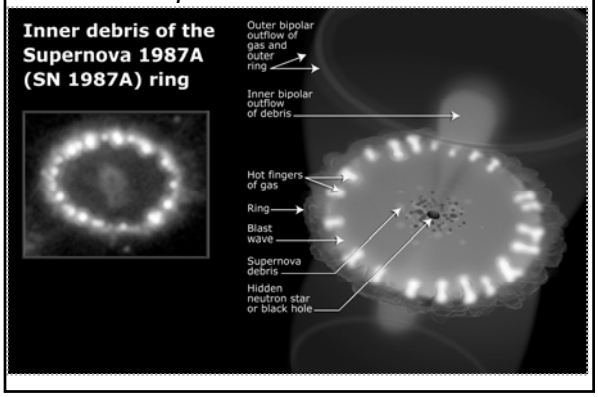
BEFORE *AFTER (SN 1987A)*

Mysterious triple rings in SN 1987A

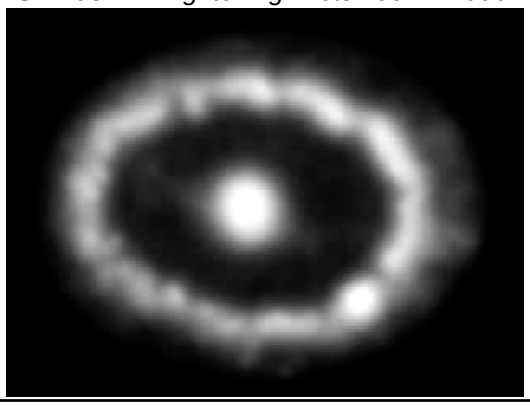


20 year birthday picture (Chandra + HST)

Supernova SN 1987A

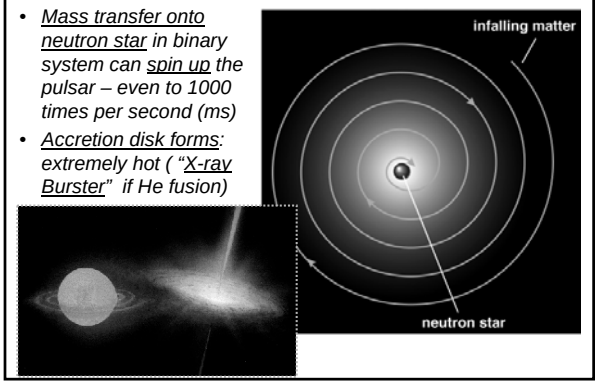


SN 1987A: Brightening knots 1994 > 2006

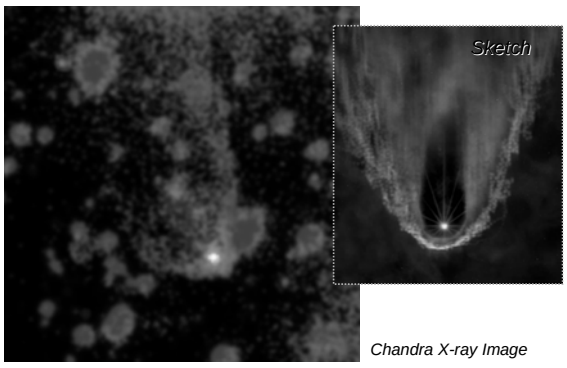


Making a <u>millisecond</u> pulsars – spin it up!

- *<u>Mass transfer onto neutron star</u> in binary system can <u>spin up</u> the pulsar – even to 1000 times per second (ms)*
- *<u>Accretion disk forms</u>: extremely hot ("<u>X-ray Burster</u>" if He fusion)*



"<u>Black Widow</u>" millisecond pulsar – evaporating companion star in cocoon has spun it up



Chandra X-ray Image

SNR "numbers game"

SUPERNOVA REMNANTS (SNR)

... EXPANDING DEBRIS OF EXPLOSION

DO NOT LAST VERY LONG BEFORE DISPERSING

- FOR ABOUT 5000 YEARS, SEEN IN X-RAY, VISIBLE, RADIO
- AFTER ~ 50,000 YRS, SHOCK WAVE SWEEPS UP MATERIAL AHEAD, BUT GAS HAS COOLED so RADIO EMISSION WEAK
- PROBABLY INVISIBLE AFTER ~ MILLION YEARS

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

THE NUMBERS GAME:

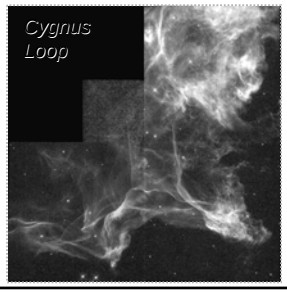
~ 150 SNR OBSERVED IN OUR GALAXY (MANY IN RADIO)
5 HAVE IDENTIFIABLE PULSARS

~ 50 SNR IN LMC

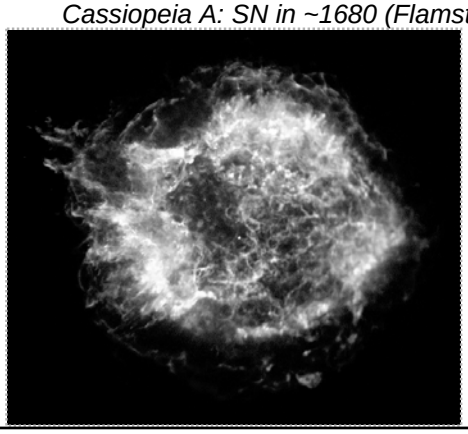
~ 10 SNR IN SMC

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)

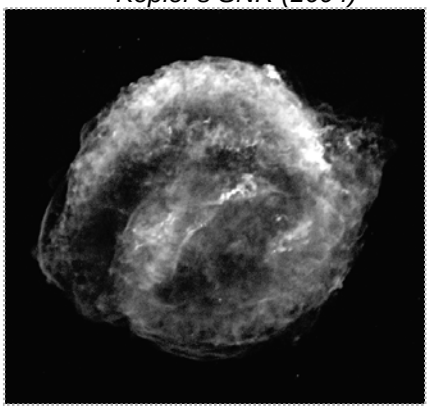


<u>Youngest</u> SNR in MW (Chandra X-ray image) synchrotron emission

Neutron star at center

Cass A: Viewed with Spitzer IR

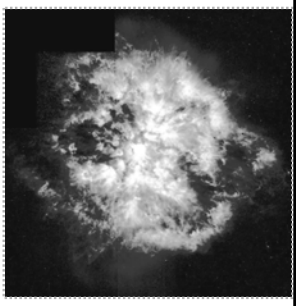
Kepler's SNR (1604)



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

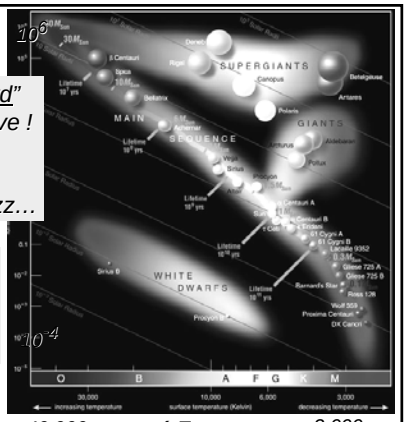
"prompt" Type Ia SN

"<u>We are made of star stuff</u>"



- *Discussion topic*
- *Respond <u>next Thur</u>*
- *How has this occurred, what processes in stellar evolution are involved?*

L



40,000 ← *Temperature* *3,000*

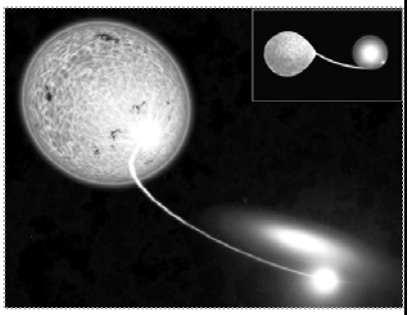
"<u>Stellar graveyard</u>" is very much alive !

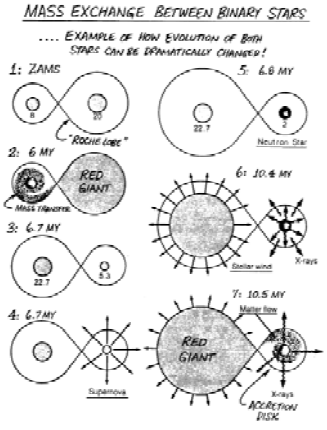
<u>Mass transfer</u> in binaries adds jazz…

white dwarfs, neutron stars or black holes -- all can play !

"<u>Compact Companions</u>" in Binary Systems

- *Mass transfer from red giant companion spirals onto <u>accretion disk</u>*
- *Inner parts become VERY hot -- glow in UV, X-rays*





Stages in mass exchange in binary system

Here consider two <u>massive</u> stars -- clock runs fast

ACCDISK

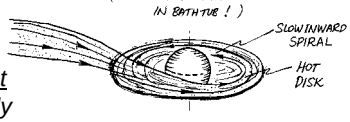
ACCRETION DISKS

Mass transfer
→ accretion disk

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!)



disk gets very hot
-- radiates brightly

GAS HEATS UP AS IT SPIRALS IN

⇒ RADIATES VISIBLE, UV, X-RAY ....

makes neutron stars and black holes visible!

White Dwarfs in Binary Systems

- *Again, mass transfer from red giant companion spirals onto an accretion disk*
- *But too much mass can take white dwarf over the edge!*