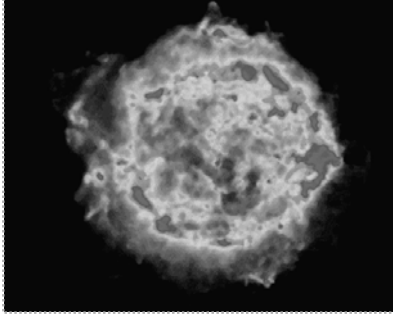


ASTR 1120: Stars & Galaxies



Cas A SNR
VLA - radio

Prof. Juri Toomre TA: Ben Brown
Lecture 23 Fri 4 Mar 05
zeus.colorado.edu/astr1120-toomre

Today in Bizarre-Land

- **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
- How **mass transfer from binary companion** can **spin-up pulsar**
- **Review Set 2** available today. Ben Brown runs review session next Wed night (9 Mar, here), **Second Mid-Term Exam** on Friday 11 March
- **Homework 6** due Monday -- re-read **18.4 Black Holes** carefully for Mon lecture

Clicker review – red giants

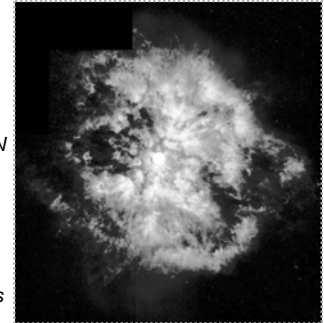
- The main source of energy for a star as it grows in size to become a red giant is _____ .

B.

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

How do SN and stellar winds touch us?

- All heavy elements are created and dispersed through our galaxy by stars
- Without supernovae, nothing heavier than **IRON** is made
- **WE ARE STAR STUFF!**
- Our atoms were once parts of stars that died more than 4.6 billion years ago -- swept up into solar system when Sun formed



Hot star: fierce winds



SN: Crab Nebula M1
4 July 1054

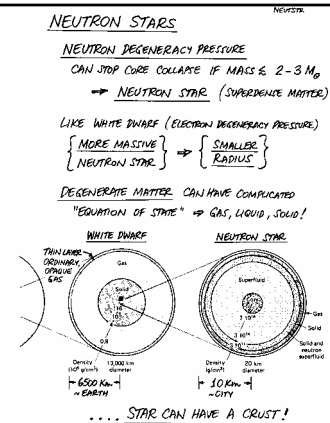
REMINDER

Neutron stars

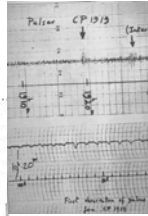
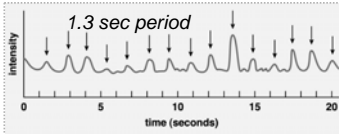
More massive, smaller in size!

Star with a crystal crust!

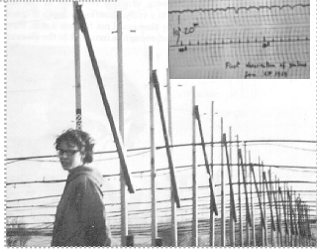
Idea of neutron stars first suggested in 1930s (Landau, Zwicky, Baade, Oppenheimer) ... but seemed like wild dreaming



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

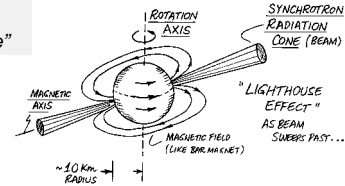
PULSARS :

- INGREDIENTS ... NEUTRON STAR WITH
1. RAPID SPIN
 2. FIERCE MAGNETIC FIELD
- DIRECT RESULT OF COLLAPSE

MAGNETIC FIELD NOT ALIGNED WITH SPIN (OR ROTATION) AXIS

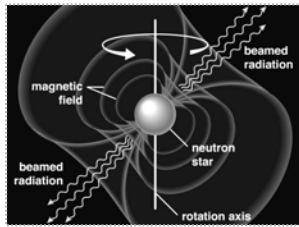
STRONG BEAMING OF LIGHT (VISIBLE, X-RAY...) BY RADIATION CONE

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



Thomas Gold 1968

Pulsars and Neutron Stars

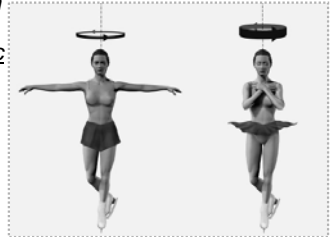


Pulsars are lighthouses in our Galaxy!



Why pulsars spin so fast:
Vast shrinking conserves angular momentum

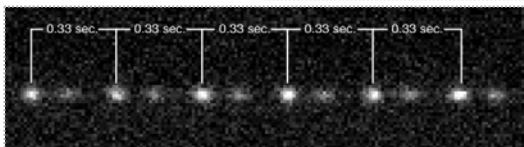
- Collapse to a neutron star increases both rotation and magnetic fields
- Newly collapsed neutron stars can rotate hundreds to thousands of times per second !



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

REMINDER

"Pulsar"
= rotating neutron star

PULSARS:
INGREDIENTS... NEUTRON STAR WITH

1. RAPID SPIN
2. FIERCE MAGNETIC FIELD

DIRECT RESULT OF COLLAPSE

MAGNETIC FIELD NOT ALIGNED WITH SPIN (OR ROTATION) AXIS

STRONG BEAMING OF LIGHT (VISIBLE, X-RAY...) BY RADIATION CONE

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

SYNCHROTRON RADIATION

Synchrotron radiation

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

SYNCHROTRON RADIATION "NON-THERMAL"
... DIFFERENT THAN THERMAL (BLACK-BODY) RADIATION IN HOW INTENSITY VARIES WITH WAVELENGTHS

RELATIVE INTENSITY vs. WAVELENGTH (SHORT to LONG)

SYNCHROTRON RADIATION EMITTED BY ELECTRONS SPIRALING ALONG MAGNETIC FIELD

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

RADIATION CAN BE IN VISIBLE AND/OR RADIO DEPENDS ON ELECTRON ENERGY & MAGNETIC FIELD STRENGTH (FASTER SPIRALING, HIGHER FREQUENCIES)

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

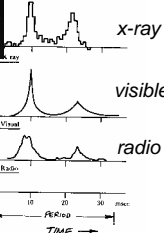
CRAB PULSAR: FROM SUPERNOVA IN 1054

- ROTATION PERIOD ~ 0.033 SEC (33 MILLISEC) (ABOUT 30 PULSES EACH SECOND)
- PULSES DETECTED IN VISIBLE, IR, X-RAY, & RADIO



CRAB NEBULA
SUPERNOVA REMNANT

PULSE PATTERNS:

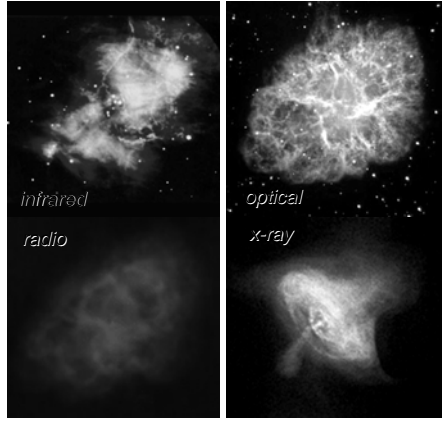


x-ray
visible
radio

- PULSAR DISCOVERED IN 1967 FOUND TO BE VERY RAPIDLY SLOWING DOWN IN SPIN (PULSE RATE)
- PULSAR "ON" FOR SMALL FRACTION OF EACH CYCLE
- PULSE SHAPES IN PULSARS CAN BE INTRICATE


PERIOD
TIME

Crab Nebula SNR

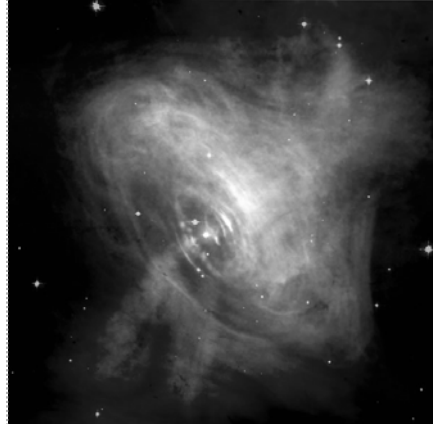


infrared
radio
optical
x-ray

Crab pulsar at work: Nov 00 – Apr 01



Chandra X-ray
HST Visible



Chandra X-ray view of Crab center

Gradual slowing down of pulsar rotation

PULSARS

ROTATING NEUTRON STAR SLOWS DOWN WITH TIME, PERIOD P GETTING LONGER

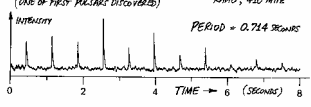
MAGNETIC FIELDS MAY ALSO WEAKEN

⇒ YOUNGEST SPIN FASTEST... SHORTEST PERIOD

Energy emitted in pulses comes from rotational kinetic energy

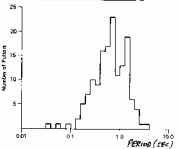
(Listen to pulsars from our website)

PULSE PATTERN FROM PSR 0529 + 54: (ONE OF FIRST PULSARS DISCOVERED) RADIO, ALSO ACTIVE



PERIOD = 0.714 SECONDS

DISTRIBUTION OF PULSAR PERIODS:



LIFETIME OF PULSAR

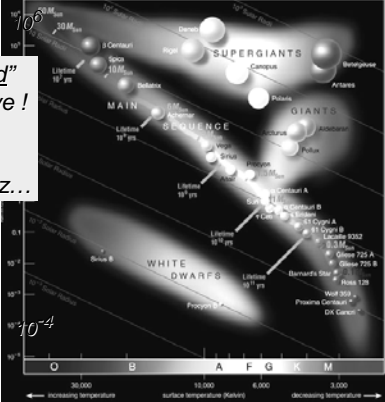
$$\approx \left(\frac{\text{PERIOD}}{\text{SLOWDOWN OF PERIOD WITH TIME}} \right)$$

$$\approx P \left(\frac{1}{\dot{P}} \right) \approx 10^7 \text{ YRS}$$

"Stellar graveyard" is very much alive!

Mass transfer in binaries adds jazz...

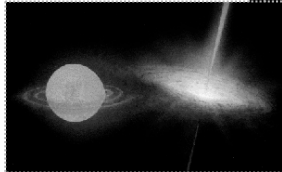
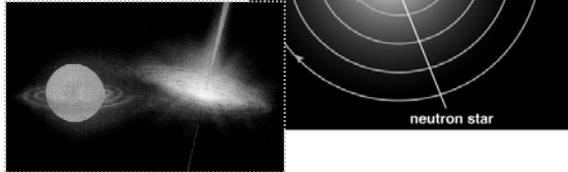
white dwarfs, neutron stars or black holes -- all can play!



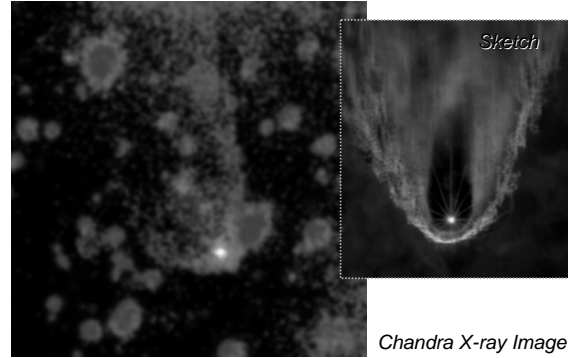
Temperature 40,000 ← 3,000

Making a millisecond pulsars – spin it up!

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



“Black Widow” millisecond pulsar – evaporating companion star in cocoon has spun it up



Clicker: Where have all the white dwarfs gone ..?

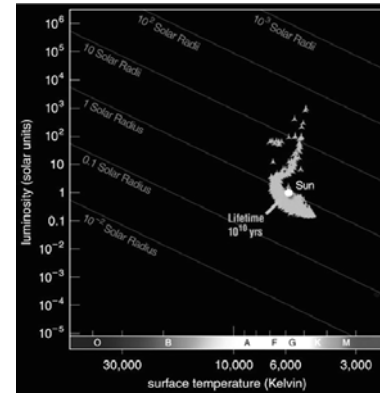
- Imagine two star clusters, one 10 billion years old, and one very young. Which is more likely to have a lot of white dwarfs?

- A. the old one
- B. the young one
- C. can't tell

A.

- Hint: what mass stars create white dwarfs?

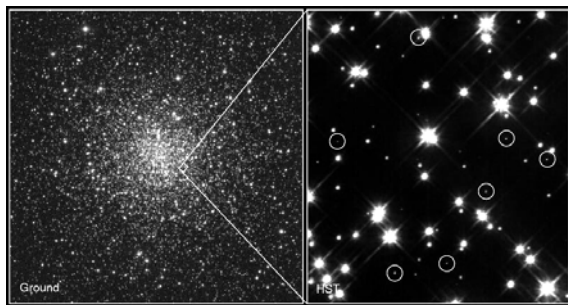
Old globular cluster – lots of white dwarfs



White dwarfs are mostly made by low-mass stars

Their evolution proceeds slowly, so must wait for cluster to age

Old globular clusters have white dwarfs!



M3 from ground

Close-up with Hubble

Observing Supernovae

- About 1 per century per galaxy (none in Milky Way since 1604) ☹
- Bright explosion visible for weeks/months - some visible in daytime!
- Remnant visible for 10,000+ years as huge bubbles and “veils” – longer in radio

