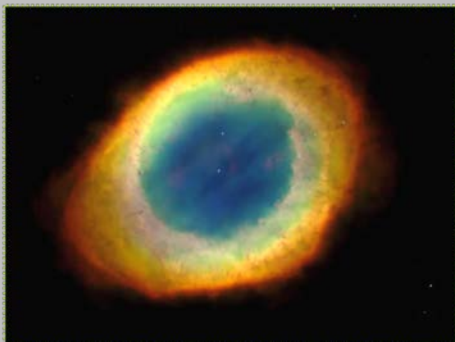
ASTR 1040: Stars & Galaxies



Ring Nebula

Prof. Juri Toomre TAs: Ryan Horton, Loren Matilsky

Lecture 17 Tues 23 Oct 2018

zeus.colorado.edu/astr1040-toomre

Today on Stellar Explosions

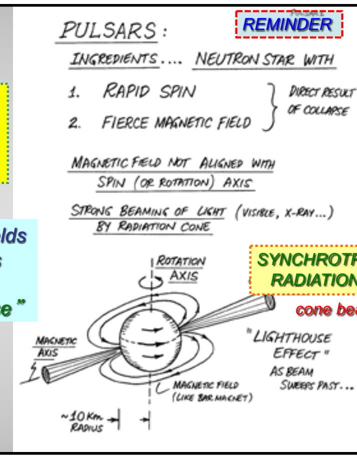
- Revisit *Pulsars* – spinning neutron stars with fierce magnetic fields; gradually slow down
- Beamed pulses from *synchrotron radiation*
- *Crab supernova (4 July 1054)* in splendid detail with Hubble and Chandra
- *Spinning up pulsars* through mass transfer from (surviving!) companions
- *White dwarf supernovae* from mass transfer in binary system, but also repeated *novae*
- Importance of *WD supernovae* as *"standard candles"*

Things to do

- Review *18.1 on mass transfer in binaries with white dwarfs: supernovae*
- Re-read *18.3* on *black holes* with care
- *Second Mid-Term Exam on Thur,* review on Wed evening 5pm-7pm here (pink sheet)

"Pulsar" = rotating neutron star

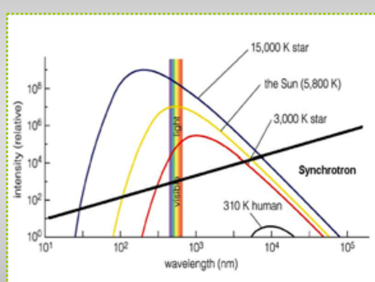
Fierce magnetic fields + sizzling electrons + fast rotation → finest "lighthouse"



Synchrotron Radiation

REMINDER

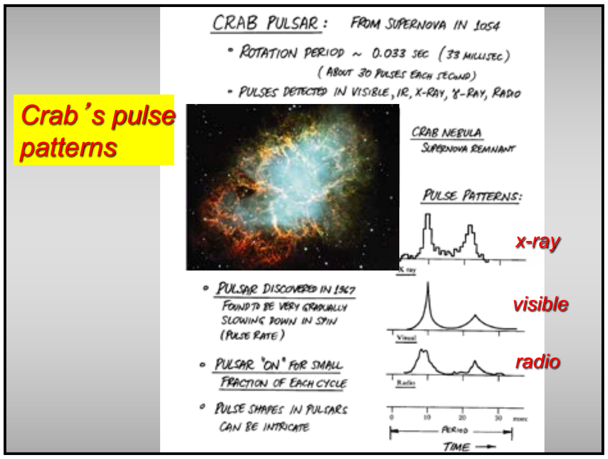
- *Fast electrons in strong magnetic fields (spiralling) forward beaming → neutron stars, black holes*
- *Different shape from thermal radiation: emits at all wavelengths, strongest in radio*



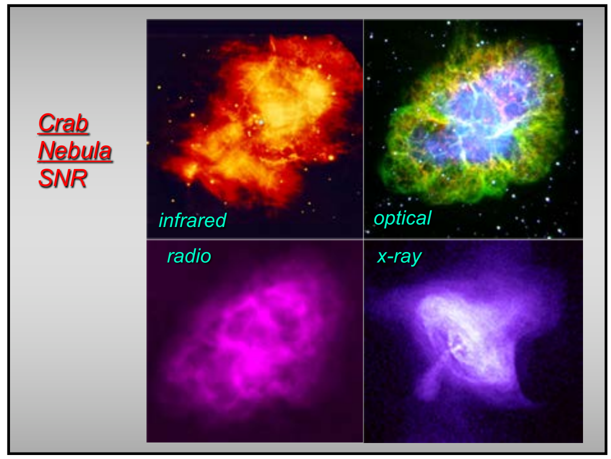
Back to famous friend !

SN: Crab Nebula M1

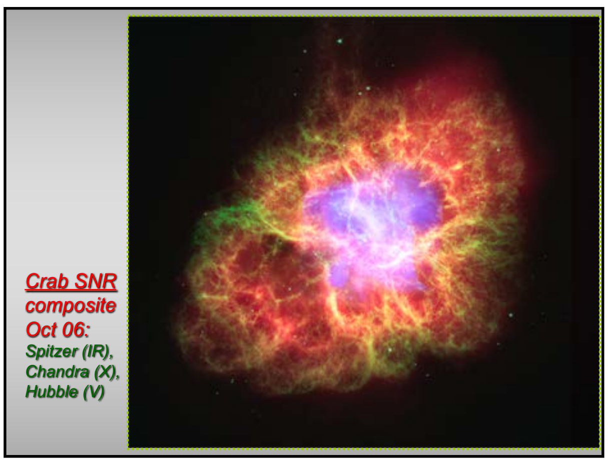
4 July 1054



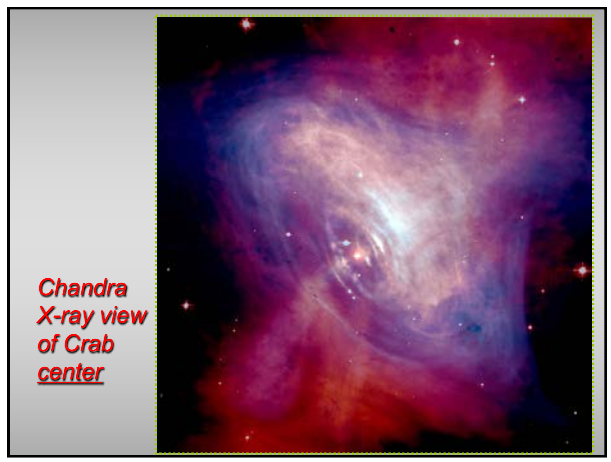
Crab's pulse patterns
CRAB PULSAR: FROM SUPERNOVA IN 1054
• ROTATION PERIOD ~ 0.033 SEC (33 MILLISEC)
(ABOUT 30 PULSES EACH SECOND)
• PULSES DETECTED IN VISIBLE, IR, X-RAY, γ-RAY, RADIO
CRAB NEBULA
SUPERNOVA REMNANT
PULSE PATTERNS:
x-ray
visible
radio
• PULSAR DISCOVERED IN 1967
FOUND TO BE VERY GRADUALLY SLOWING DOWN IN SPIN (PULSE RATE)
• PULSAR "ON" FOR SMALL FRACTION OF EACH CYCLE
• PULSE SHAPES IN PULSARS CAN BE INTRICATE
0
10
20
30
msec
PERIOD
TIME →



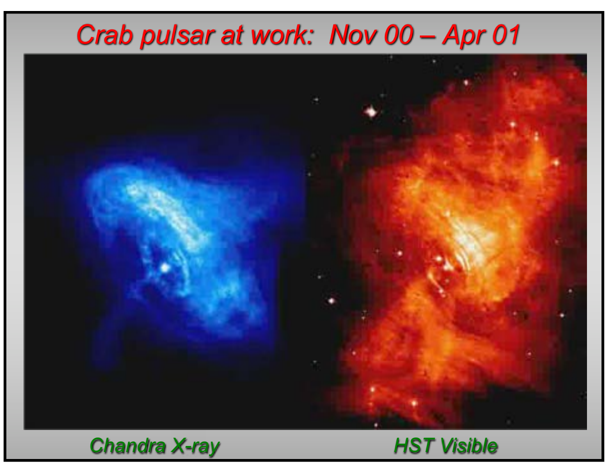
Crab Nebula SNR
infrared
optical
radio
x-ray



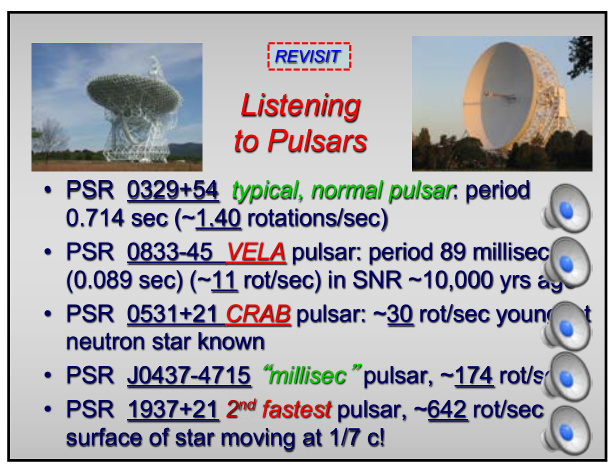
Crab SNR composite Oct 06:
Spitzer (IR), Chandra (X), Hubble (V)



Chandra X-ray view of Crab center



Crab pulsar at work: Nov 00 – Apr 01
Chandra X-ray
HST Visible



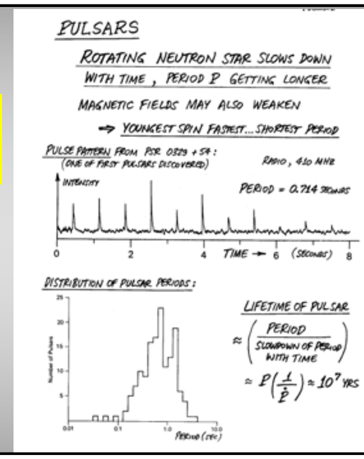
REVISIT
Listening to Pulsars
• PSR 0329+54 typical, normal pulsar: period 0.714 sec (~1.40 rotations/sec)
• PSR 0833-45 VELA pulsar: period 89 millisec (0.089 sec) (~11 rot/sec) in SNR ~10,000 yrs ag
• PSR 0531+21 CRAB pulsar: ~30 rot/sec young t neutron star known
• PSR J0437-4715 "millisec" pulsar, ~174 rot/s
• PSR 1937+21 2nd fastest pulsar, ~642 rot/sec surface of star moving at 1/7 c!

Briefly visit the web for pulsar "sound tracks" and varying pulse patterns

Jodrell Bank Observatory, UK

Gradual slowing down of pulsar rotation

Energy emitted in pulses comes from rotational kinetic energy

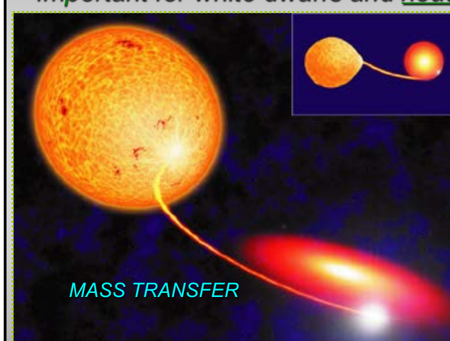


Revisit Clicker Question

Which of these stars formed EARLIEST (in the lifetime of the Universe)?

- A. Star A: 70% H, 28% He, 2% other
- B. Star B: 75% H, 25% He, 0% other
- C. Star C: 72% H, 27% He, 1% other
- D. Star D: 90% H, 10% He, 0% other
- E. It depends on their masses

MASS TRANSFER in evolving binary systems: important for white dwarfs and neutron stars



Binary WD: Hot accretion disks, novae, supernovae

Neutron star: Radiation with more vigor, can spin up the star

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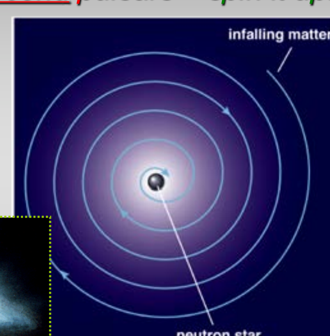
Neutron Stars in Binary Systems

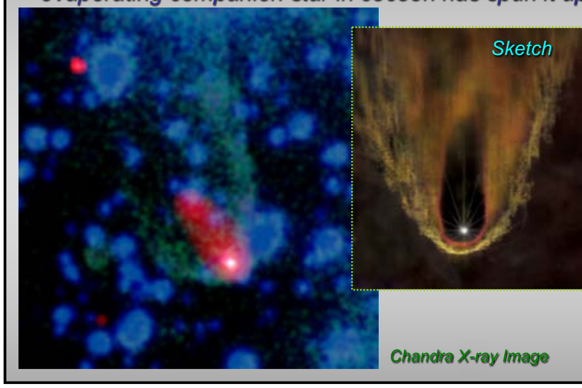
- *Mass transfer builds very hot accretion disk around neutron star:*
  - → *intense x-ray emission (continuosly)*
  - → *transfer of angular momentum can SPIN UP the NS*

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



Chandra X-ray Image

Binary Systems: The Algol Paradox

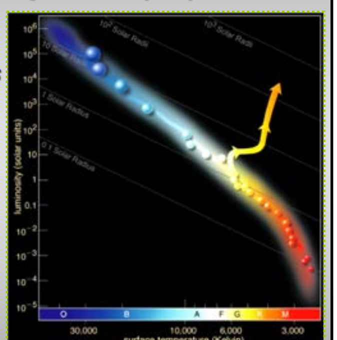
- Algol is a binary system consisting of a 3.7 solar mass main sequence star and a 0.8 solar mass red giant. Why is this strange?

A.

- A. A 3.7 star should have become a red giant before a 0.8 solar mass star
- B. Binary stars usually have the same mass
- C. 0.8 solar mass stars usually never become red giants

Clicker Puzzle: Algol Binary System

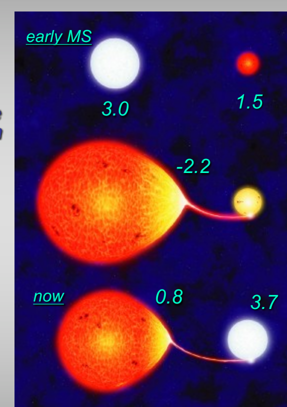
- A. Binary stars can have different masses but usually ARE formed at the same time.
- More massive star should have had a shorter main sequence lifetime



What happened?

Binary Mass Exchange

- The 0.8 solar mass star once was more massive (3.0), with a 1.5 mass companion
- As it became a red giant, it swelled and poured material onto its companion (lost 2.2)
- The red giant (0.8) is now less massive than its companion (3.7)
- Future: when the other star becomes red giant, it may pour gas back…?



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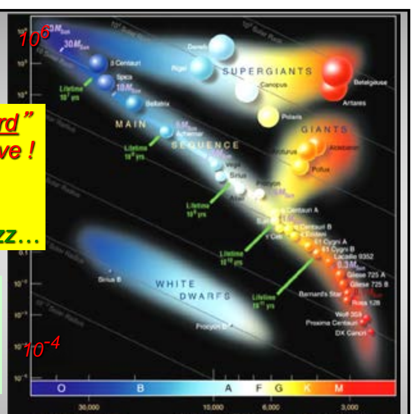


40,000 ← Temperature 3,000

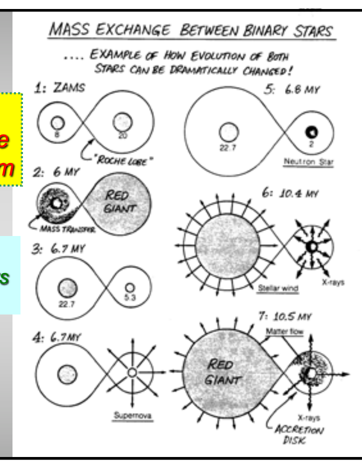
"Stellar graveyard" is very much alive !

Mass transfer in binaries adds jazz…

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

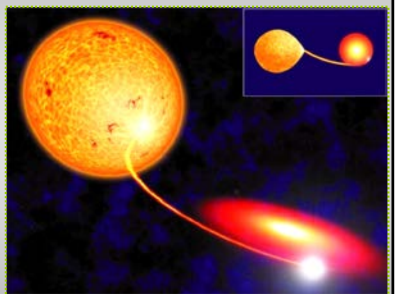
Stages in mass exchange in binary system

Here consider two massive stars -- clock runs fast



White Dwarfs in Binary Systems

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



WD snooze … → pyrotechnics

(in three flavors)

1 or 2: binary mass transfer → flash fusion on WD

NOVA

WHITE DWARF PYROTECHNICS

WDPYRO1

WD ALONE …. BORING zzzzz

BUT IN CLOSE BINARY, WOW!

TAKE WD: CARBON & OXYGEN   COMPANION: H & He

MASS TRANSFER (ACCRETION) DUMPS H & He ONTO WD SURFACE UNTIL …. THREE POSSIBILITIES:

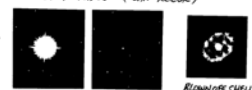
1. LOCALIZED NUCLEAR FLASH BURNING ON SURFACE (INTERMITTENT) ⇒ "CATACLYSMIC VARIABLE STAR"

2. ENOUGH "FUEL" PILES UP TO IGNITE INTENSE CNO CYCLE …. EXPLOSION BLOWS OFF (EJECTS!) OUTER LAYER

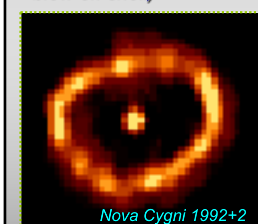
⇒ NOVA ("NEW", OR "GUEST" STAR)

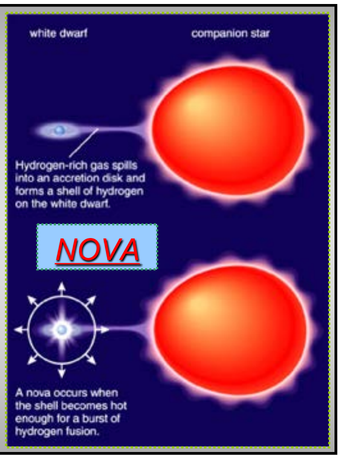
BRIGHTENS TO ~ $10^5 L_\odot$ FOR FEW WEEKS, THEN FADES (CAN RECUR)

NOVA HERCULIS (1935)

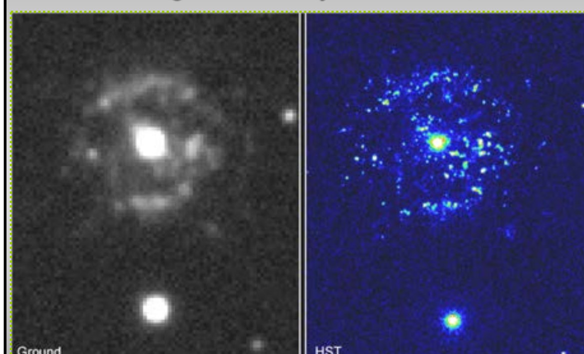


- Accretion of gas onto white dwarf can lead to H fusion on surface
- Star becomes much brighter → nova (may blow off shell)





Recurring Nova T Pyxidis ~ every 20 yrs



White Dwarf SUPERNOVA

3: If exceed 1.4 M_{SUN}

Collapse of WD, explosive fusion burning of "carbon star" – all gone!

Brightest SN: superb beacons for measuring distances

WHITE DWARF SURPRISES….

WDPYRO2

3. IF WD CLOSE TO $1.4 M_\odot$ LIMIT, ACCRETED MASS MAY TAKE IT "OVER THE EDGE"

⇒ STAR BEGINS TO COLLAPSE, INTERIOR HEATS UP, EXPLOSIVE NUCLEAR BURNING OF CARBON…

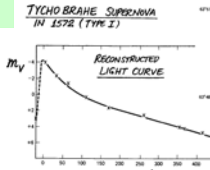
ENTIRE STAR BLOWS APART!

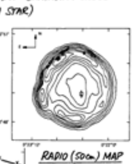
⇒ SUPERNOVA (TYPE I, NO H LINES)

BRIGHTENS TO $10^9 L_\odot$ (BRIGHTEST OF ALL!) FOR FEW WEEKS

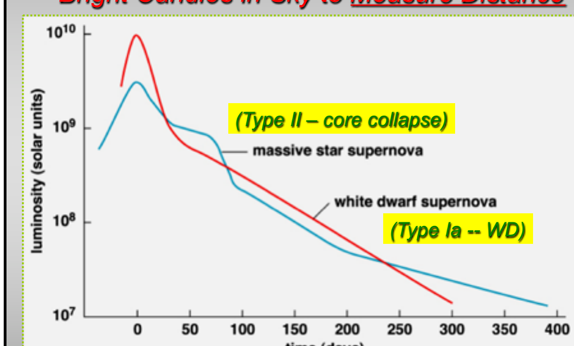
NOTHING LEFT BUT EXPANDING SHELL (NO NEUTRON STAR)

TYCHO BRAHE SUPERNOVA IN 1572 (TYPE I)



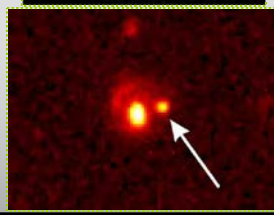


SUPERNOVA Light Curves
Bright Candles in Sky to Measure Distance

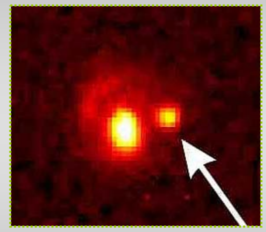


SUPERNOVAE in Other Galaxies

- Bright enough to be seen as sudden, bright point in other galaxies
- Many astronomers monitor nearby galaxies nightly to catch them
- 1 per 100 years per galaxy means that if you monitor 100 galaxies, see ~ 1 SN per year)
- If monitor a million galaxies, likely to find 30+ new ones each night!

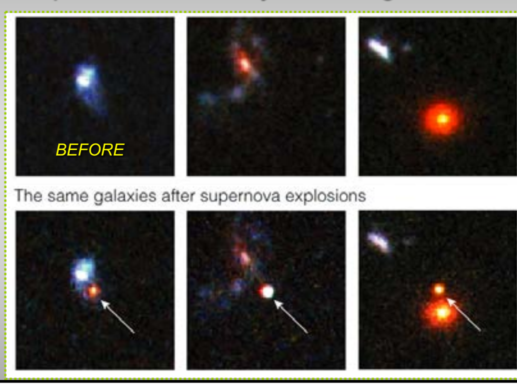


Bright enough to be seen halfway across observable universe



Useful for mapping the universe to the largest distances

Supernovae in very distant galaxies

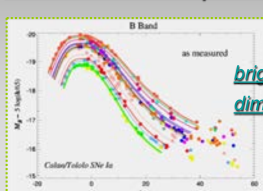


White dwarf SN as distance estimators

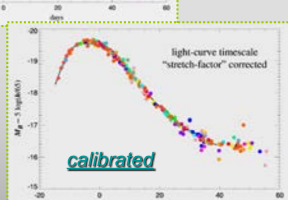
- "Standard explosion" = fusion of 1.4 solar masses of material
- Nearly the same amount of energy released

White dwarf supernovae

- Carbon fusion explosion: mass transfer in binary takes white dwarf `over the edge'
- Roughly same amount of energy released (calibrate)



brighter SN dim more slowly!



calibrated

Practical difficulty: White dwarf SN

- Need to catch them within a day or two of the explosion
- About 1 per galaxy per century
- Need to monitor thousands of galaxies to catch a few per year → galaxy clusters are useful