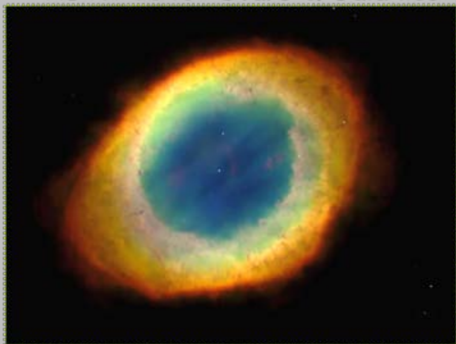
ASTR 1040: Stars & Galaxies



Ring Nebula

Prof. Juri Toomre TAs: Piyush Agrawal, Connor Bice
Lecture 17 Tues 14 Mar 2017
zeus.colorado.edu/astr1040-toomre

Today on Stellar Explosions

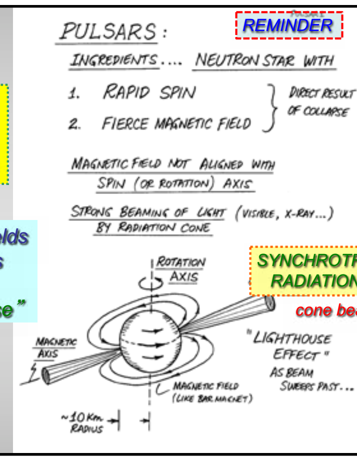
- Revisit *Pulsars* – spinning neutron stars with fierce magnetic fields; gradually slow down
- Beamed pulses from *synchrotron radiation*
- *Crab supernova (4 July 1054)* in splendid detail with Hubble and Chandra
- *Spinning up pulsars* through mass transfer from (surviving!) companions
- *White dwarf 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)
- Report on Observatory Night #5
- Happy *PI Day*, and *Einstein's birthday*

"Pulsar"
= rotating neutron star

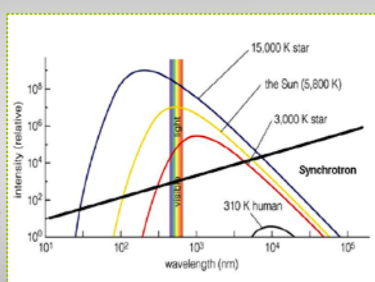
Fierce magnetic fields
+ sizzling electrons
+ fast rotation
→ finest "lighthouse"



REMINDER

Synchrotron Radiation

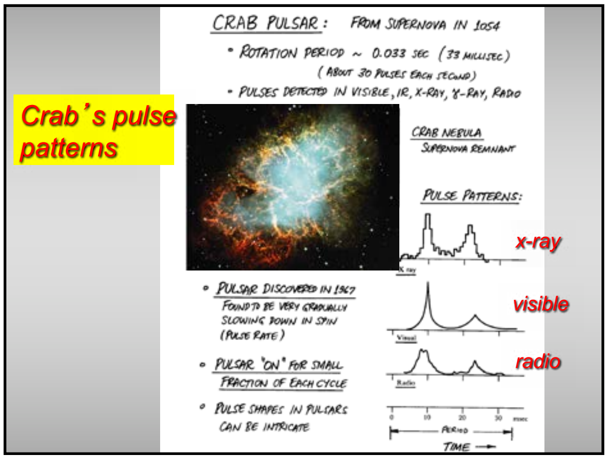
- *Fast electrons in strong magnetic fields → neutron stars, black holes*
- *Different shape from thermal radiation: emits at all wavelengths, strongest in radio*

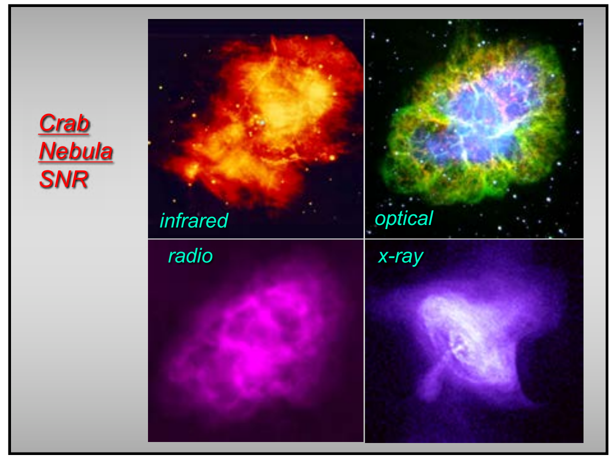


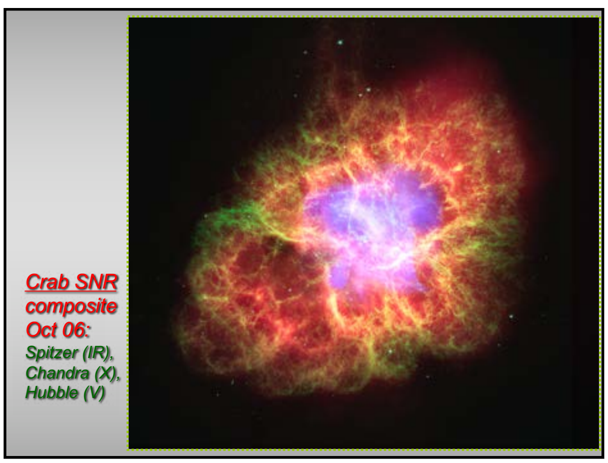
Back to famous friend !

SN: Crab Nebula M1

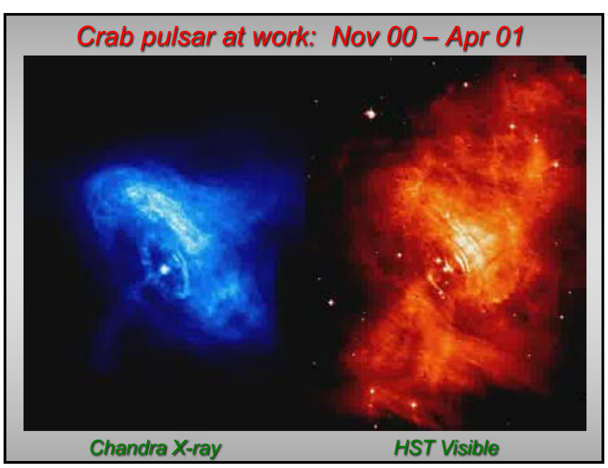
4 July 1054

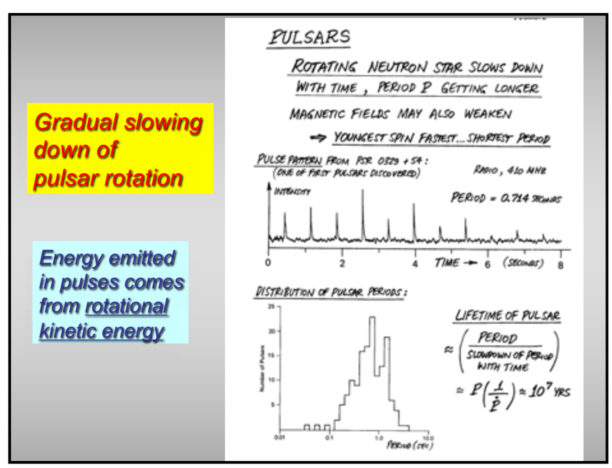

CRAB PULSAR: FROM SUPERNOVA IN 1054
• ROTATION PERIOD ~ 0.033 sec (33 MILLISEC)
(ABOUT 30 PULSES EACH SECOND)
• PULSES DETECTED IN VISIBLE, IR, X-RAY, γ-RAY, RADIO
Crab's pulse patterns
CRAB NEBULA
SUPERNOVA REMNANT
PULSE PATTERNS:
x-ray
visible
radio
• PULSAR DISCOVERED IN 1967
FOUND TO BE VERY GRADUALLY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

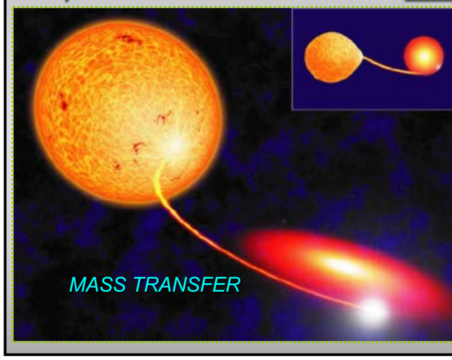

PULSARS
ROTATING NEUTRON STAR SLOWS DOWN WITH TIME, PERIOD P GETTING LONGER
MAGNETIC FIELDS MAY ALSO WEAKEN
⇒ YOUNGEST SPIN FASTEST... SHORTEST PERIOD
Gradual slowing down of pulsar rotation
PULSE PATTERN FROM PSR 0329+54:
(ONE OF FIRST PULSARS DISCOVERED)
RADIO, 410 MHz
INTENSITY
PERIOD = 0.714 SECONDS
TIME → (SECONDS)
Energy emitted in pulses comes from rotational kinetic energy
DISTRIBUTION OF PULSAR PERIODS:
LIFETIME OF PULSAR
≈ (PERIOD / SLOWDOWN OF PERIOD WITH TIME)
≈ P(1/Ṗ) ≈ 10^7 YRS

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 youn t neutron star known
- PSR J0437-4715 *"millisec"* pulsar, ~174 rot/s
- PSR 1937+21 *fastest* pulsar, ~642 rot/sec surf e of star moving at 1/7 c!

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



Binary WD: Hot accretion disks, novae, supernovae

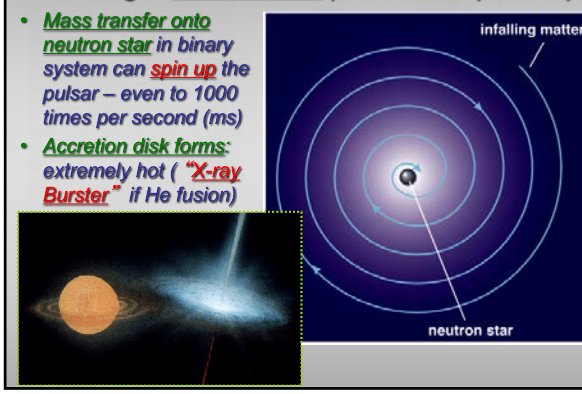
Neutron star: Radiation with more vigor, can spin up the star

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

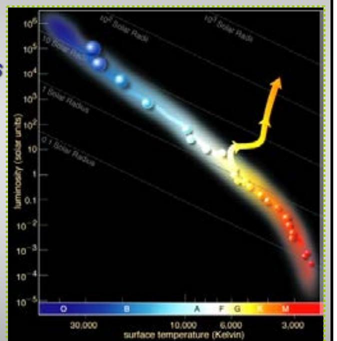
- *Algol is a binary system consisting of a 3.7 solar mass main sequence star and a 0.8 solar mass red giant. Why is this strange?*

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

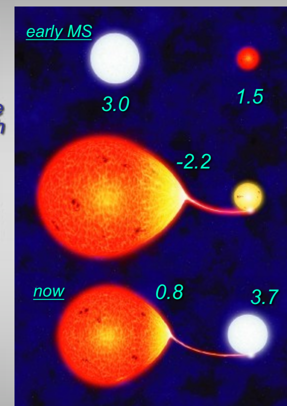
- **A.** Binary stars can have different masses but usually ARE formed at the same time.
- More massive star should have had a shorter main sequence lifetime

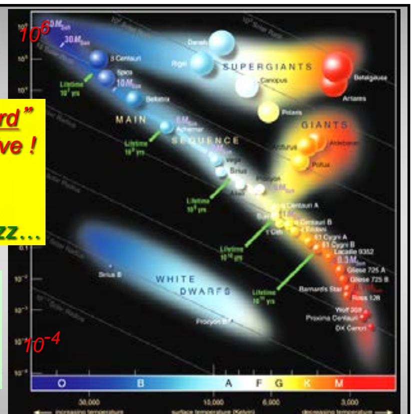


What happened?

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…?





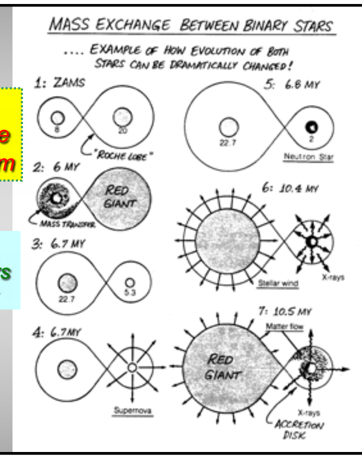
"Stellar graveyard" is very much alive !

Mass transfer in binaries adds jazz…

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

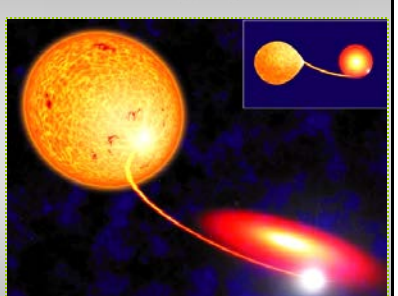
Stages in mass exchange in binary system

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!

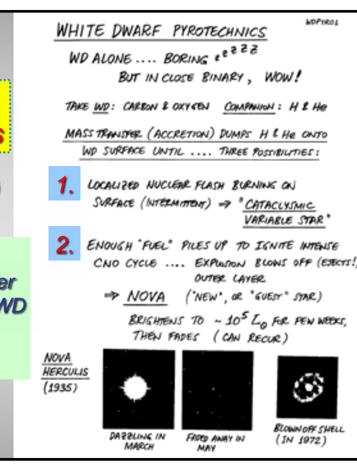


WD snooze … →pyrotechnics

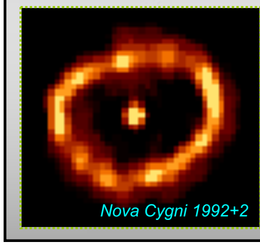
(in three flavors)

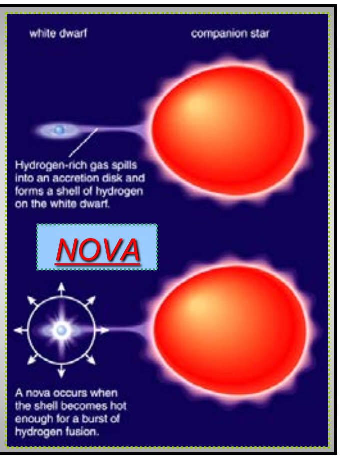
1 or 2: binary mass transfer → flash fusion on WD

NOVA

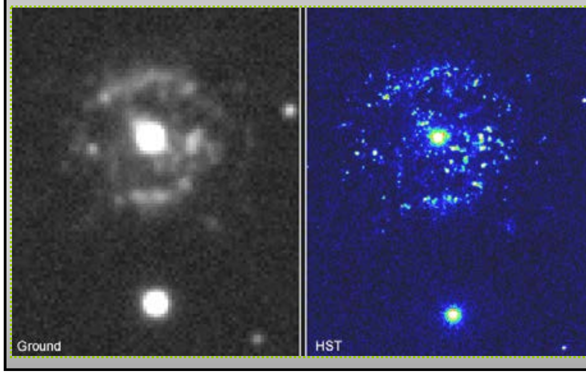


- Accretion of gas onto white dwarf can lead to H fusion on surface
- Star becomes much brighter → nova (may blow off shell)





Recurring Nova T Pyxidis ~ every 20 yrs

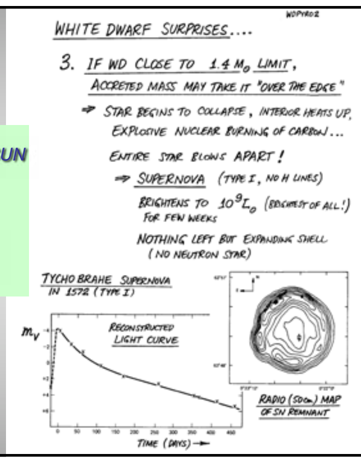


White Dwarf SUPERNOVA

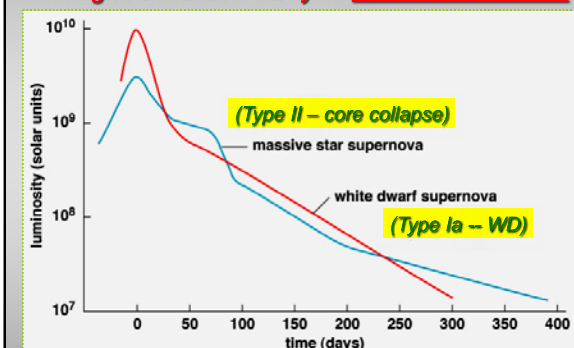
3: If exceed 1.4 M_{SUN}

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

Brightest SN: superb beacons for measuring distances

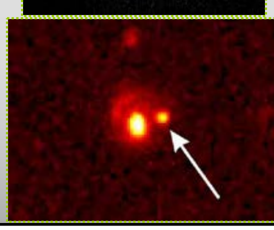


SUPERNOVA Light Curves
Bright Candles in Sky to Measure Distance

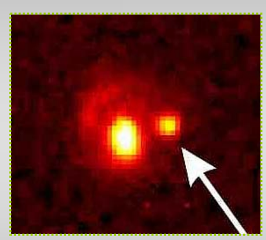


SUPERNOVAE in Other Galaxies

- 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!

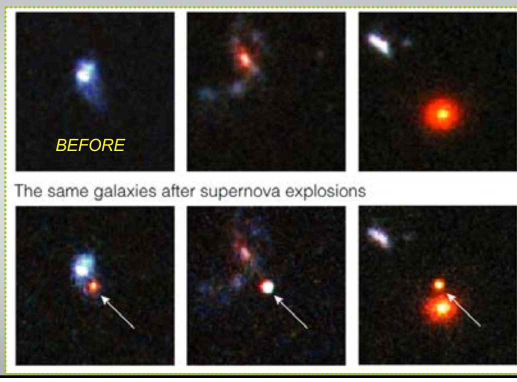


Bright enough to be seen halfway across observable universe



Useful for mapping the universe to the largest distances

Supernovae in very distant galaxies

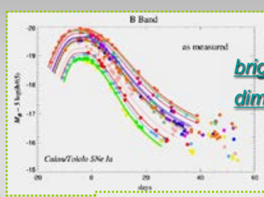


White dwarf SN as distance estimators

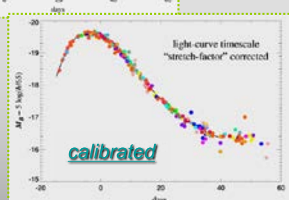
- *"Standard explosion" = fusion of 1.4 solar masses of material*
- *Nearly the same amount of energy released*

White dwarf supernovae

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



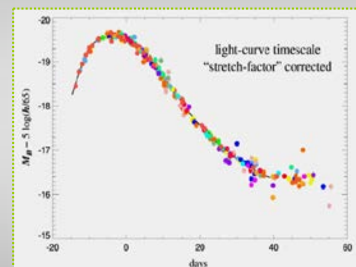
brighter SN
dim more slowly!



calibrated

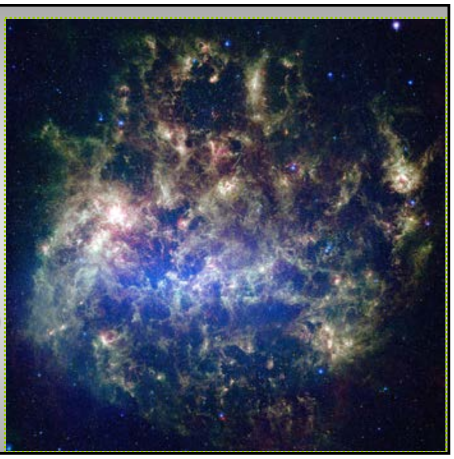
Practical difficulty: White dwarf SN

- *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*

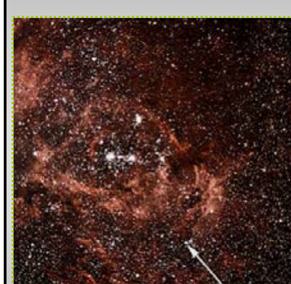


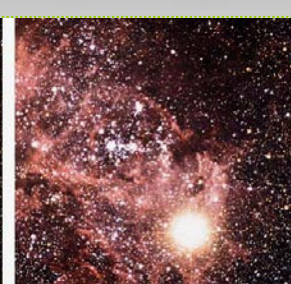
Nearest: Story of SN 1987A in LMC

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



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





BEFORE
blue supergiant

AFTER (SN 1987A)