ASTR 1040: Stars & Galaxies

Crab Nebula

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Lecture 16 Thur 5 March 2020

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Topics for Today

- Revisit: Massive stars end life with *supernova explosion*, when iron core exceeds 1.4 M_{sun}
- *Pulsars* – fast spinning neutron stars with fierce magnetic fields; gradually slow down
- Beamed pulses from *synchrotron radiation*

Things to do

- *Review 17.4 'Mass Exchange'*
- Re-read *Chap 18: `Bizarre Stellar Graveyard'* on *white dwarfs* (18.1), and *neutron stars* (18.2) with care
- *Homework #7 due, new HW #8 available*
- *Mid-Term Exam 2 next Thur (March 12)*
- *Review Session next Wed by Max, 6pm-8pm G130 Review Set 2 now available*

Several fates for massive star

1. Strong winds shrink star, may end as WHITE DWARF

2. Or core burns to Fe, eventually sudden CORE COLLAPSE !

SUPERNOVA

FINAL FATE OF MASSIVE STAR

TWO POSSIBILITIES .... REMINDER

1. LOSES ENOUGH MASS IN WIND / PLANETARY NEBULA
   $< 1.4\ M_\odot$ LEFT ⇒ WHITE DWARF
   (W.D. COMPOSED OF HEAVIEST ELEMENTS PRODUCED)
2. ENTIRE CORE BURNS TO IRON
   NO MORE NUCLEAR ENERGY CAN BE RELEASED!
   AND $> 1.4\ M_\odot$ LEFT
   COLLAPSE CANNOT BE STOPPED BY ELECTRON DEGENERACY PRESSURE
   ⇒ NEUTRON STAR OR BLACK HOLE

"Core collapse" (massive star) SUPERNOVA

"Rapid disassembly" of elements in core → neutrons + neutrinos

Neutron degeneracy pressure stiffens collapsing core --- + push of neutrinos

→envelope `bounces' ! →SHELL BLOWS OFF

STELLAR COLLAPSE (VERY RAPID)

GRAVITY MAKES IT GO ... BUT IRON CANNOT BURN, SO NO RESISTANCE REMINDER

1. ELEMENTS DISMANTLED
   $Fe \rightarrow \ldots Si \rightarrow \ldots O \rightarrow Ne \rightarrow C \rightarrow He \rightarrow H$
   ⇒ NEUTRONS
2. "INVERSE BETA DECAY"
   PROTONS + ELECTRONS JAMMED TOGETHER → NEUTRONS + NEUTRINOS
3. NEUTRINOS TRY TO ESCAPE
   ⇒ PUSH AGAINST INFALLING GAS
   ENVELOPES "BOUNCES" AGAINST CORE
   ⇒ {EXPLOSION} SUPERNOVA TYPE II
   "DEBRIS" FLIES INTO SPACE

WHAT'S LEFT ? 1. NOTHING ! 2. NEUTRON STAR (PULSAR) 3. BLACK HOLE

Supernova explosion creates elements heavier than iron:

magic of nucleosynthesis

SN shells, and what is left at center ?

SUPERNOVA

AFTER "CORE BOUNCE", OUTER REGIONS OF STAR BLOWN OFF EXPLOSIVELY ! REMINDER

HIGH-ENERGY RADIATION & PARTICLES, NEUTRONS AND NEUTRINOS COME FLOODING OUT

NUCLEOSYNTHESIS : NEUTRONS + VARIOUS NUCLEI
⇒ CREATE HEAVY ELEMENTS BEYOND IRON (LIKE SILVER, GOLD, MERCURY ...)
ONLY PLACE IN UNIVERSE TO MAKE THIS STUFF!

SUPERNOVA SHELLS (OR REMNANT): DO NOT LAST LONG BEFORE DISPERSING
FIRST ~ 1000 YEARS SEEN IN VISIBLE, X-RAY
AFTER ~ 10,000 YEARS SNOWPLOW MATERIAL AHEAD ⇒ RELATIVELY COOL ⇒ RADIO EMISSION

WHAT'S LEFT AT CENTER ?
1. NOTHING
2. PULSAR
3. BLACK HOLE

SN REMNANT BECOMES UNDETECTABLE AFTER ABOUT 1 MILLION YEARS

"Core Collapse SUPERNOVA"

- Exploding remnant of massive star disperses heavy elements through the galaxy
- Inside may be a neutron star – a remnant core of pure neutrons!

Crab Nebula (M1), first seen as SUPERNOVA on 4 July 1054 from China -- visible in daytime

Was Crab SN recorded in Chaco?
….and nothing recorded in Europe!

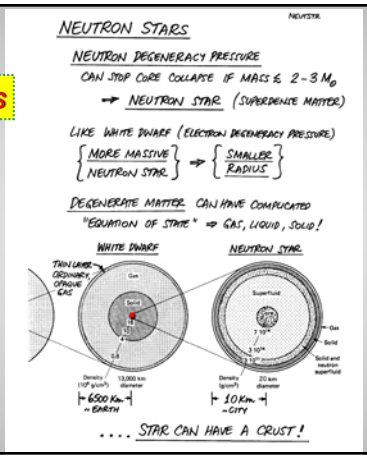
- Petroglyph from Chaco Canyon:
- Correct position relative to new moon for Crab Supernova, but some doubt

Neutron stars

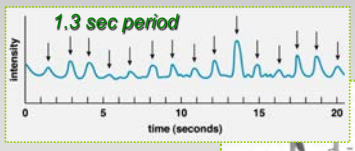
More massive, smaller in size!

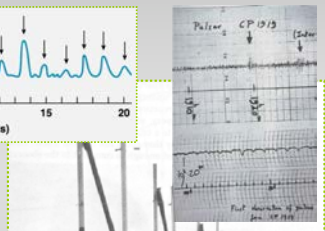
Star with a crystal crust !

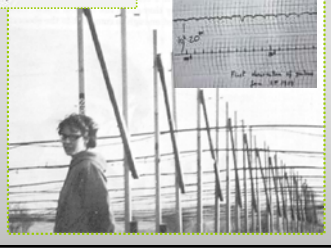
Idea of neutron stars first suggested in 1930s (Landau, Zwicki, Baade, Oppenheimer) … but seemed like wild dreaming



Observing the `First' Pulsar: BIG discovery





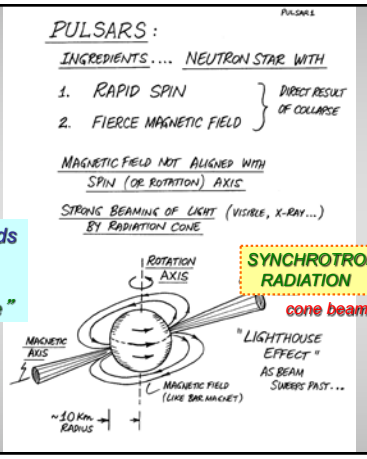


- Jocelyn Bell (Burnell): Cambridge (UK) graduate student in 1967 (+ Anthony Hewish) discovered pulsars by accident
- Little Green Men (LGM) ? Just WHAT could cause signal?

"Pulsar" = rotating neutron star

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

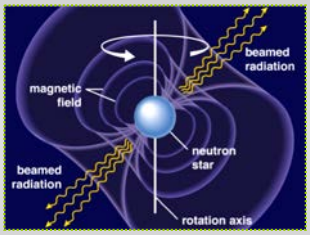
Thomas Gold 1968



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 !

Pulsars and Neutron Stars

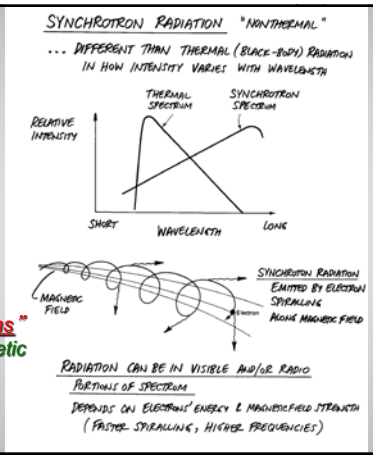


Pulsars are lighthouses in our Galaxy!

Synchrotron radiation

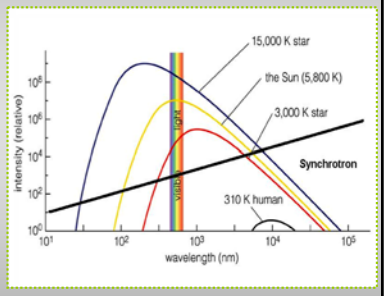
beaming from neutron star … and many other energetic places (quasars)

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



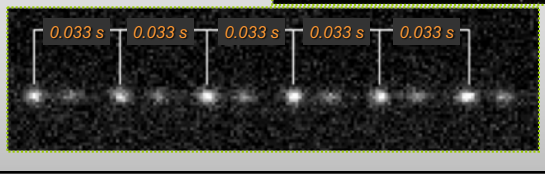
Synchrotron Radiation

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

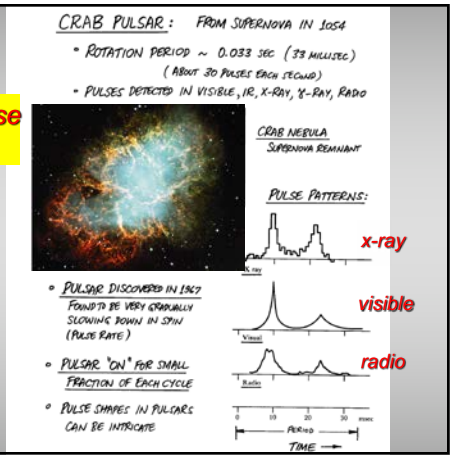


Mystery resolved when pulsar discovered in Crab Nebula (known to be supernova remnant) -- Messier 1 or M1 !

The Crab pulsar also pulses in visual light



Crab's pulse patterns

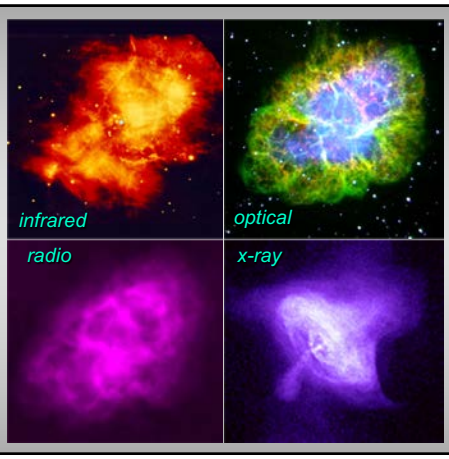


Clicker Question

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

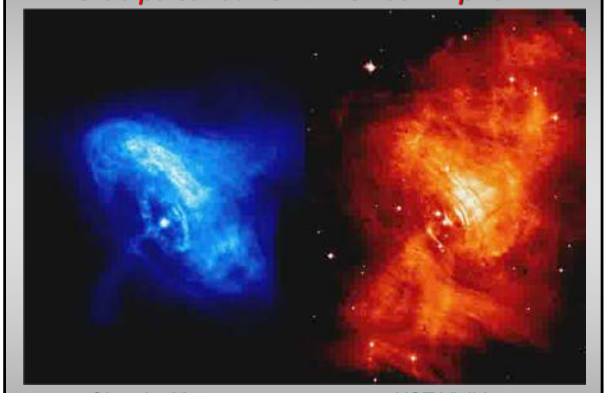
Crab Nebula SNR



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



Now on to travels within our galaxy with the big-sky of the planetarium

… and then the black-holes program