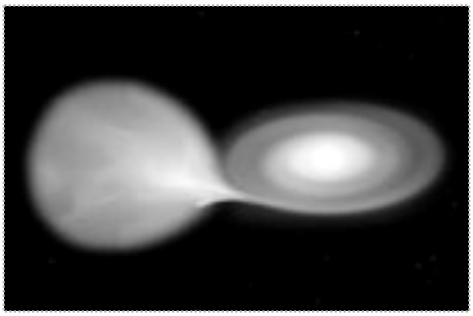
## ASTR 1120: Stars & Galaxies



*Prof. Juri Toomre TA: Ben Brown*

Lecture 24 Mon 7 Mar 05

*zeus.colorado.edu/astr1120-toomre*

## More Truly Bizarre Events

- *White dwarf supernovae* from mass transfer in binary system, but also repeated *novae*
- *Hot accretion disks* formed around object (white dwarf, neutron star, black hole) on receiving end of mass transfer
- Why more pulsars than supernova remnants (SNR)
- *Black holes,* their general properties, and their "care and feeding"

- *Second Mid-term Exam* this Friday, review session Wed 7pm, *Review Set 2* available
- *Homework Set 6* due today

## *Review – what is left behind?*

- *After a massive-star supernova explosion, the remains of the stellar core _____ .*

**B.**

- *A.* will always be a neutron star
- *B.* may be either neutron star or black hole
- *C.* will always be a black hole
- *D.* may be either a white dwarf, neutron star, or black hole

*Final fate of massive stars*

FINAL FATE OF MASSIVE STARS

.... RATHER UNCERTAIN IN DETAILS THAT DEPEND ON MASS LOSS BY STRONG WINDS

INFLUENCED BY { INITIAL MASS $M$ ; IRON CORE MASS $M_{CORE}$ }

CURRENT THINKING (THEORY/COMPUTER MODELLING) ....

1. IF HEAVYWEIGHT $M \leq (20-30)\,M_\odot$ :

EVOLUTION YIELDS $1.4\,M_\odot < M_{CORE} < (2-3)\,M_\odot$

⇒ CORE COLLAPSE & CORE BOUNCE SUPERNOVA (TYPE II)

→ *Neutron star*

⇒ NEUTRON STAR

2. IF TRULY MASSIVE $M \geq (20-30)\,M_\odot$ :

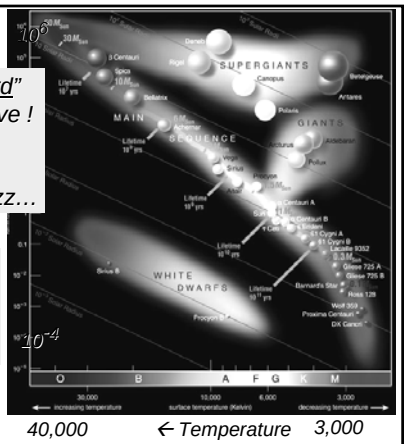
THEN PROBABLY GET $M_{CORE} > 3\,M_\odot$

⇒ COLLAPSE AND SUPERNOVA EXPLOSION

→ *Black hole*

⇒ BLACK HOLE

*L*




*40,000* ← *Temperature* *3,000*

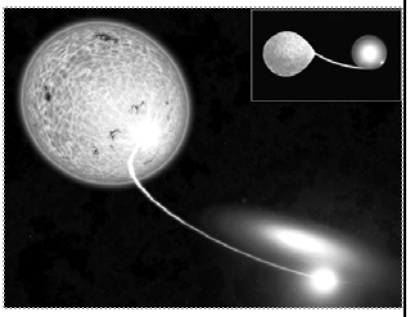
*"Stellar graveyard" is very much alive !*

*Mass transfer in binaries adds jazz…*

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

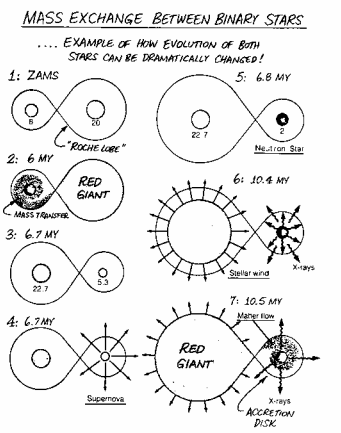
## *"Compact Companions" in Binary Systems*

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



*Stages in mass exchange in binary system*

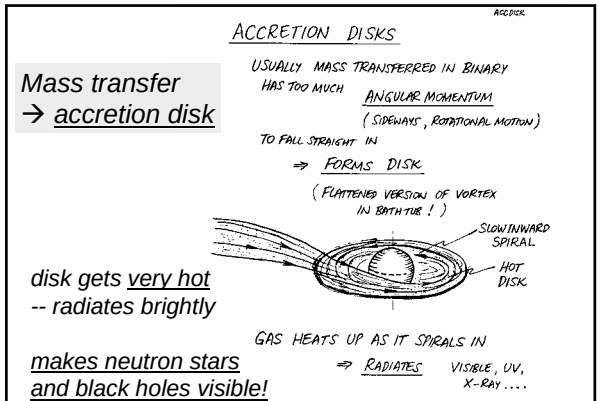
*Here consider two massive stars -- clock runs fast*




*Mass transfer → accretion disk*

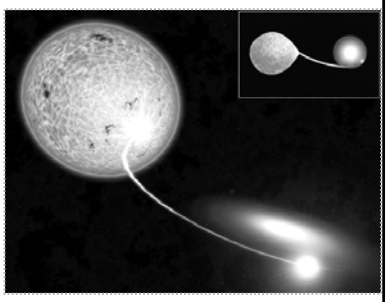
*disk gets very hot -- radiates brightly*

*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!*

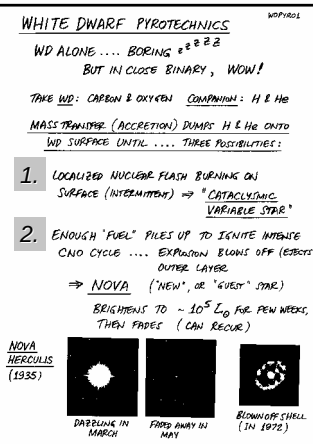


*WD snooze … →pyrotechnics*

*(in three flavors)*

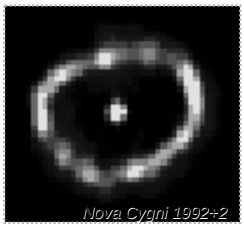
*1 or 2: binary mass transfer → flash fusion on WD*

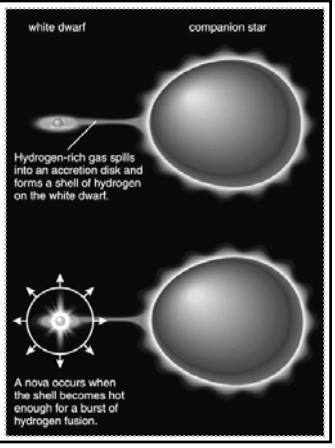
*NOVA*



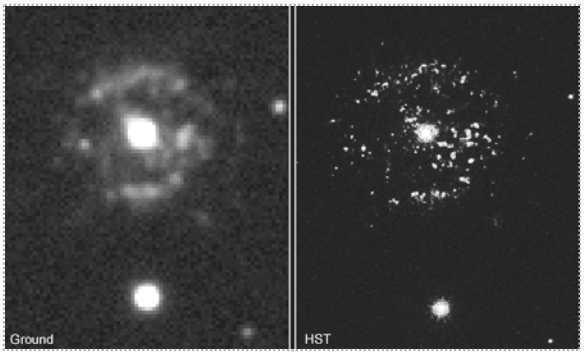

## *Nova*

- *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*

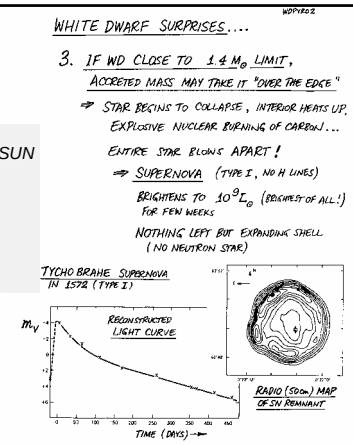


*White Dwarf SUPERNOVA*

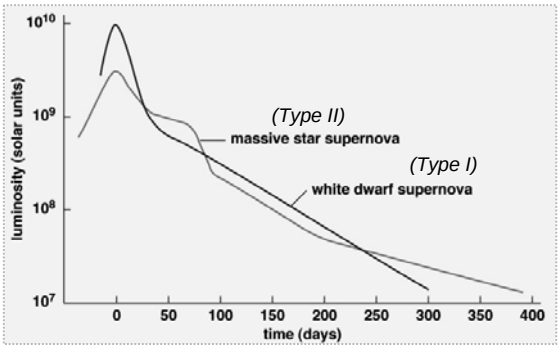
*3: If exceed 1.4 $M_{SUN}$*

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

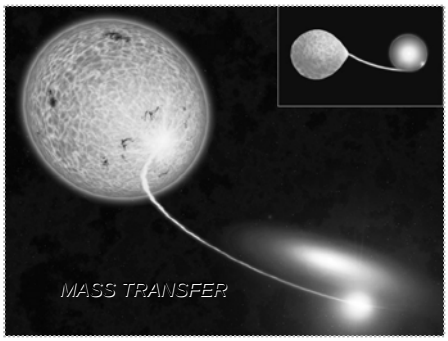
*Brightest SN: superb beacons for measuring distances*




*SUPERNOVA Light Curves*
*Bright Candles in Sky to Measure Distance*




*Since white dwarfs in evolving binary systems come "alive" – what about neutron stars ?*

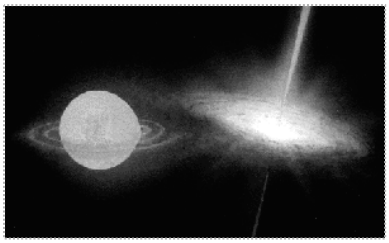



*Binary WD: Hot accretion disks, novae, supernovae*

*Neutron star: Radiation with more vigor, no SN*

## *Neutron Stars in Binary Systems*

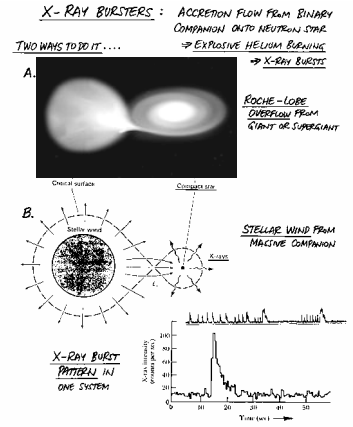
*If white dwarfs can do it, so can neutron stars!*



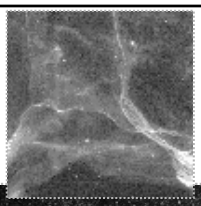
- *Mass transfer builds very hot accretion disk around neutron star:*
  - → *intense x-ray emission (continuosly)*
  - → *explosive helium burning (in bursts) on disk*

*"X-Ray Bursters"*

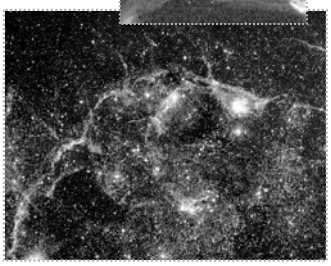
*Accretion flow onto neutron star (overflow or wind)*
*→ helium fusion flash burning*




## *Observing Supernovae*

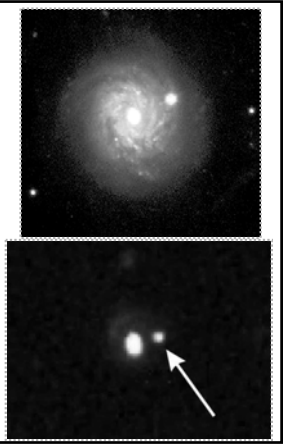


- *About 1 per century per galaxy (none in Milky Way since 1604) ☹*
- *Bright explosion visible for weeks/months - some visible in daytime!*
- *Remnant visible for 10,000+ years as huge bubbles and "veils" – longer in radio*



## *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)*



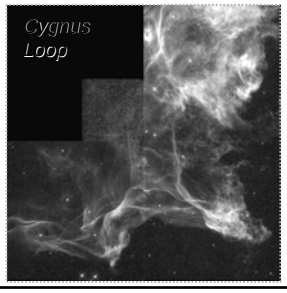
## *SNR "numbers game"*

SUPERNOVA REMNANTS (SNR)

... EXPANDING DEBRIS OF EXPLOSION

DO NOT LAST VERY LONG BEFORE DISPERSING

- FOR ABOUT 1,000 YEARS, SEEN IN X-RAY, VISIBLE, RADIO
- AFTER ~ 10,000 YRS, SHOCK WAVE SNOWPLOWS MATERIAL AHEAD, BUT GAS HAS COOLED ⇒ RADIO EMISSION ALONE
- PROBABLY INVISIBLE AFTER ~ MILLION YEARS




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

THE NUMBERS GAME:

~120 SNR DETECTED IN OUR GALAXY (MOSTLY 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

## *Review of "COMPACT OBJECTS"*

*all charming but bizarre !*

"COMPACT OBJECTS"

WHITE DWARFS

RADIUS: ~ 5,000 Km. (~ EARTH)
MASS: < 1.4 $M_\odot$ (CHANDRASEKHAR LIMIT)
DENSITY: $10^6$ x WATER
OBSERVED: INDIVIDUAL, AND IN BINARIES ⇒ NOVAE, CATACLYSMIC VARIABLES

NEUTRON STARS

RADIUS: ~ 10 Km. (BOULDER → NWOT)
MASS: < 2-3 $M_\odot$
DENSITY: $10^{15}$ x WATER (NUCLEAR DENSITY!)
OBSERVED: PULSARS, X-RAY BINARIES

BLACK HOLES

RADIUS: "HORIZON" DEPENDS ON MASS
MASS: ANY
DENSITY: DEPENDS ON MASS
OBSERVED: ? SEVERAL CANDIDATES

## *Clicker Review – White Dwarfs*

- *A white dwarf (WD) is gaining mass because of accretion in a binary system. What happens if its mass reaches the 1.4 solar mass limit?*

*C.*

- *A.* WD will collapse to become a black hole
- *B.* WD will collapse, becoming a neutron star
- *C.* WD will explode completely as a WD supernova
- *D.* WD will undergo a nova explosion

## *Reading Needed*

- Complete detailed reading *of 18.4 Black Holes*
- Overview read *S3 Spacetime and Gravity*, and more carefully *S3.4 New View of Gravity*

## *Black Holes – sort of courtesy of Albert*

- *Einstein's (1911) General Theory of Relativity: gravity is really the warping of spacetime around an object with much mass*
- *Light travels in "straight lines" – and its bending comes from spacetime being curved by gravity*