**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

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**Final fate of massive stars**

- Neutron star  \( \neutronstar \)
- Black hole  \( \blackhole \)

Final fate of massive stars:

1. Initial mass \( M \) and core mass \( M_{\text{core}} \)
2. Core collapse & core bounce
3. Supernova explosion
   - \( M_{\text{core}} > 3.2 M_\odot \)
   - \( \rightarrow \) Neutron star
4. \( M_{\text{core}} < 3.2 M_\odot \)
   - \( \rightarrow \) Black hole

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**“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

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**“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

Mass exchange

- 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!

Nova

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

WD snooze ...

pyrotechnics

(in three flavors)

1 or 2: binary mass transfer

flash fusion on WD

NOVA

Recurring Nova T Pyxidis ~ every 20 yrs
White Dwarf

SUPERNOVA

3: If exceed 1.4 $M_{\odot}$ Collapse of WD, explosive fusion burning of "carbon star" – all gone!

Brightest SN: superb beacons for measuring distances

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 (continuously)
  → explosive helium burning (in bursts) on disk

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 points 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”

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?
  - 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

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

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