Evolution of Close Binary Systems

- Before going on to the evolution of massive stars and supernovae II, we'll think about the evolution of close binary systems.
- There are many multiple star systems in the Galaxy, but for the vast majority, the separation of the stars is large enough that one star doesn't affect the evolution of the other(s).

The Algol Mystery

- Algol is a double-lined eclipsing binary system with a period of about 3 days (very short). The two stars are:

  Star A: B8, 3.4M_o main-sequence star

  Star B: G5, 0.8M_o `subgiant' star

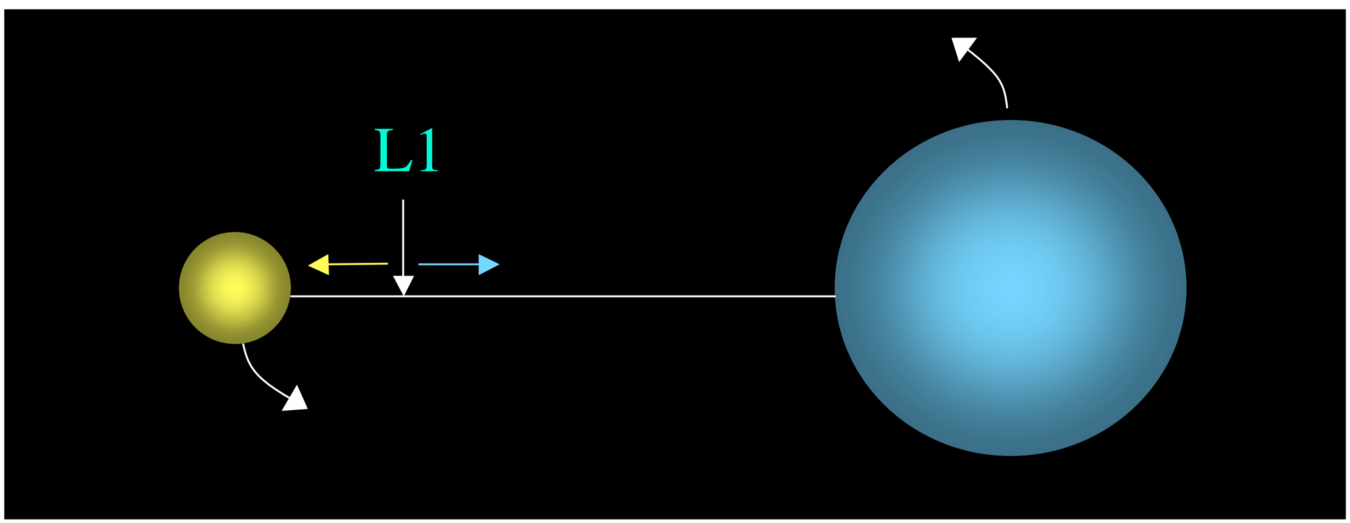
What is wrong with this picture?

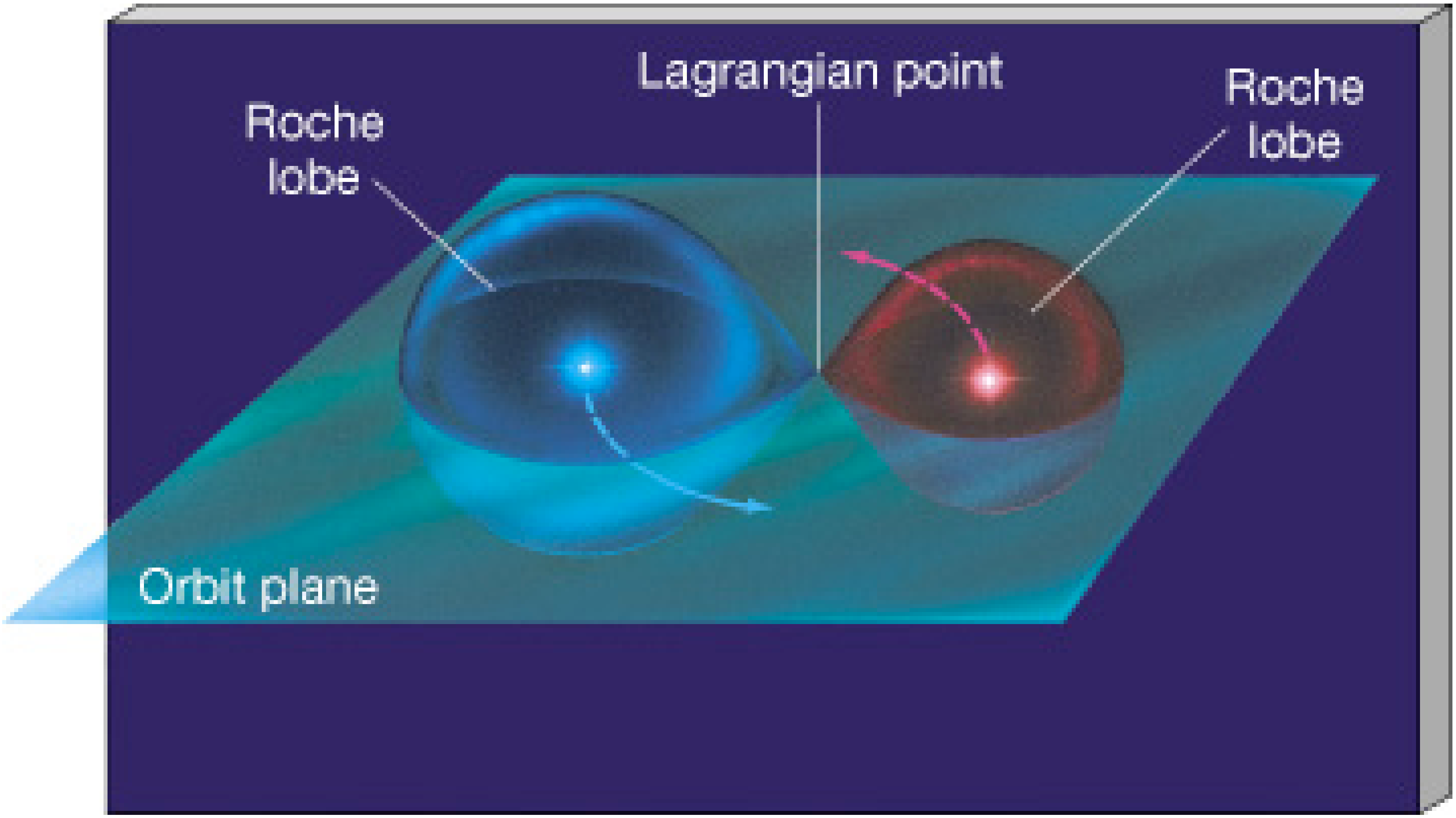
Algol

- The more massive star (A) should have left the main sequence and started up the RGB before the less massive star (B).
- What is going on here?
- The key is the short-period orbit.

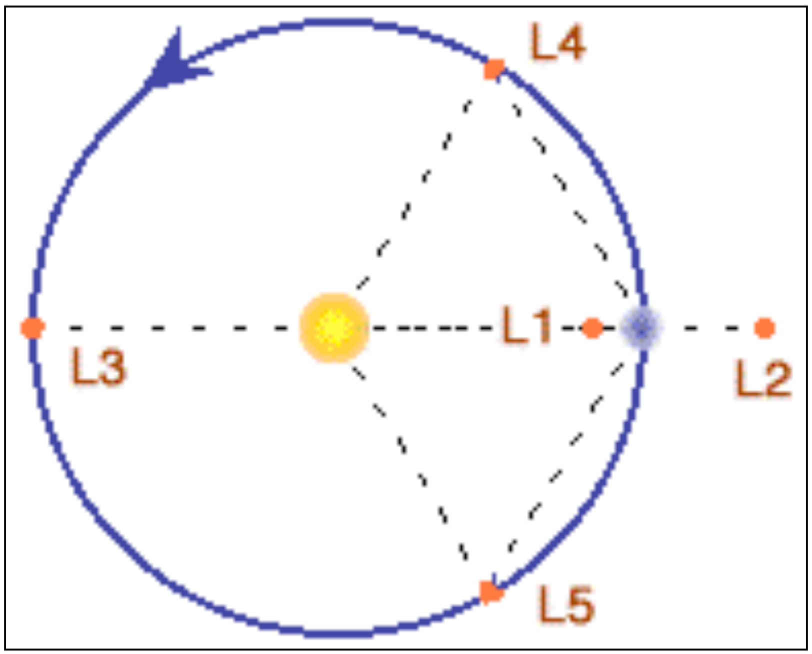
The Algol Story

- Originally the system contained Star A at $1.2M_o$ and Star B at $3.0M_o$.
- Between the two stars is a point where the gravitational forces of the two stars balance. This is called a Lagrange point.



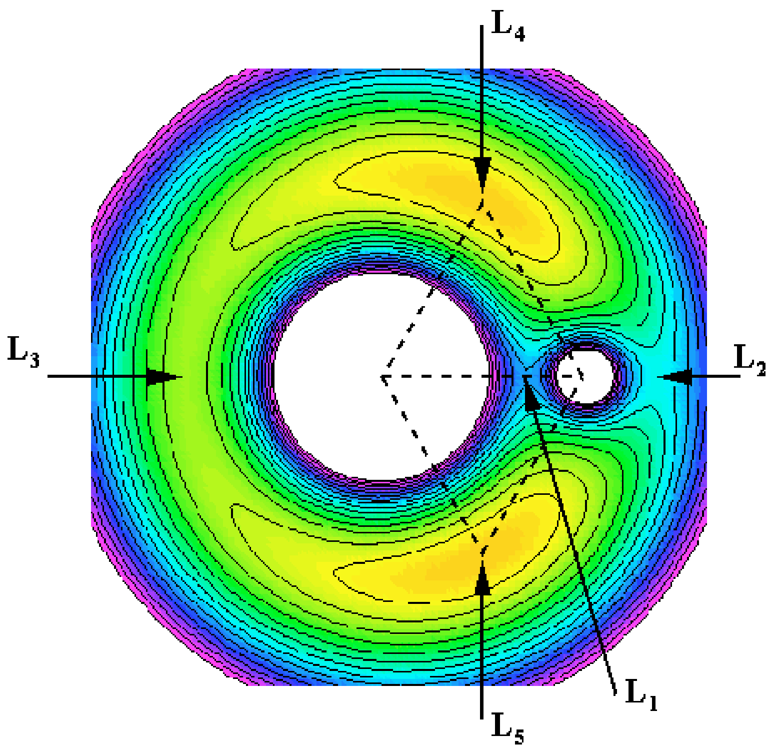

Lagrangian point
Roche
lobe
Roche
lobe
Orbit plane

Lagrange Points



- There are 5 Lagrange points in the Earth/Sun system. L1, L2 and L3 are unstable on a timescale of 23 days
- L3 is a popular spot for Vulcan.
- L2 is the proposed orbit forJWST
- L4 and L5 are stable and collect stuff

Lagrange Points



- You should be a little confused about how this all works.
- The Lagrange Points are only obvious in a rotating reference frame.

Algol cont.

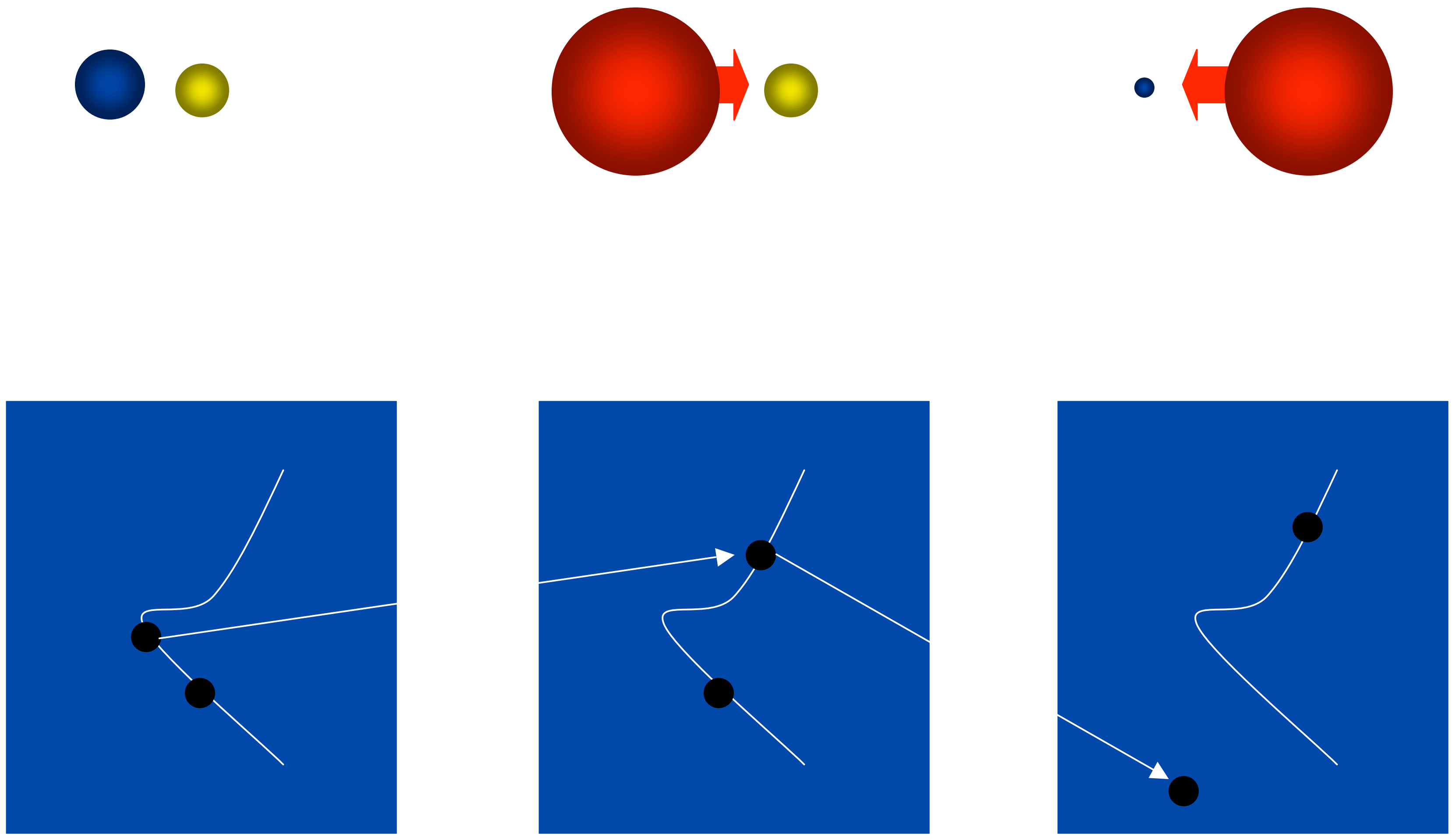
- Back to Algol. As Star B evolves and expands as it heads up the RGB.
- When its radius equals the distance of the the L1 point (called the Roche Radius) the material in Star B's envelope feels a stronger attraction to Star A and there is mass transferred from B to A.

Mass Transfer in Binaries

- In the case of Algol, Star B transferred $2.2M_o$ of material to Star A.

Star A: $1.2M_o$ -> $3.4M_o$

Star B: $3.0M_o$ -> $0.8M_o$

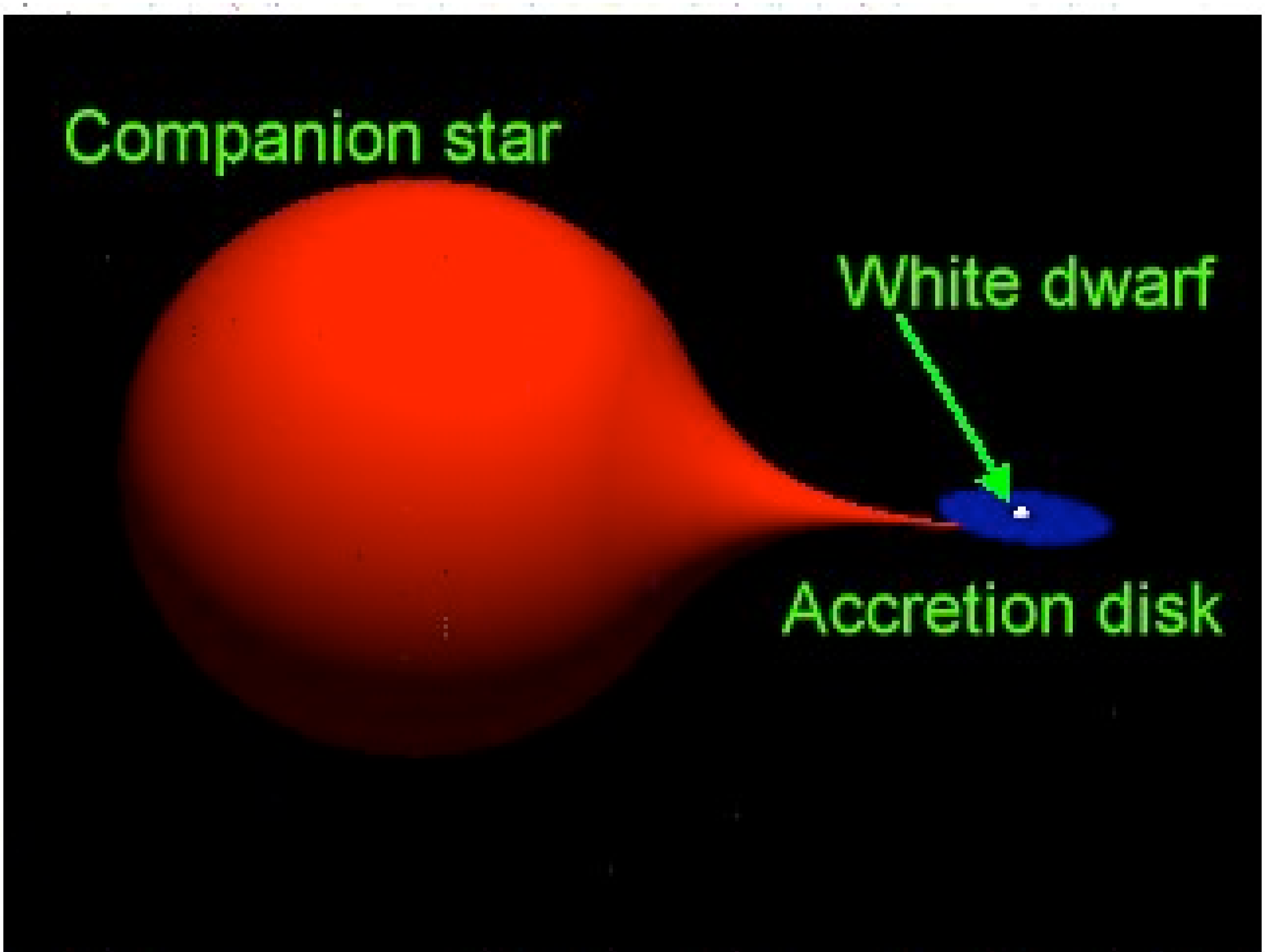


Mass Transfer Binaries

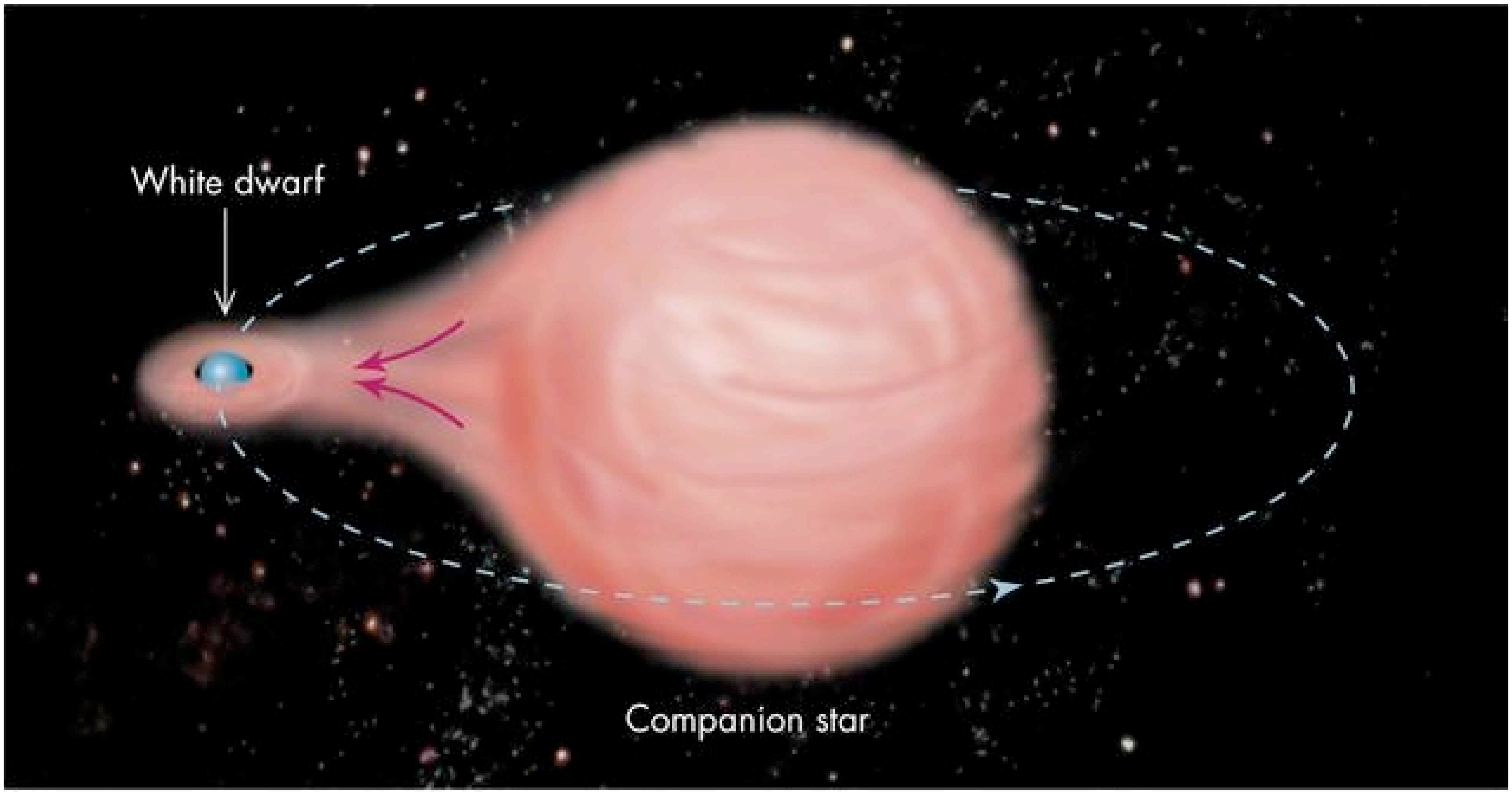
- Think about the continued evolution of Algol and you have the explanation for novae.
- If the original primary transfers most of its mass to the original secondary, you are left with a massive main-sequence star and a helium WD.
- When the original secondary starts to evolve up the RGB, it transfers some material back onto the helium WD.

Novae

- As the fresh hydrogen accumulates on the surface of the helium WD it is like an insulating blanket -- the temperature rises to 10^7k and there is a Hydrogen fusion explosion.
- The star brightens by anywhere from a factor of 10 to a factor of 10,000.
- In some cases, this takes a star from too-faint to see to bright-enough to see so these objects were called Nova -- new star.


Companion star
White dwarf
Accretion disk

Novae/Supernovae I

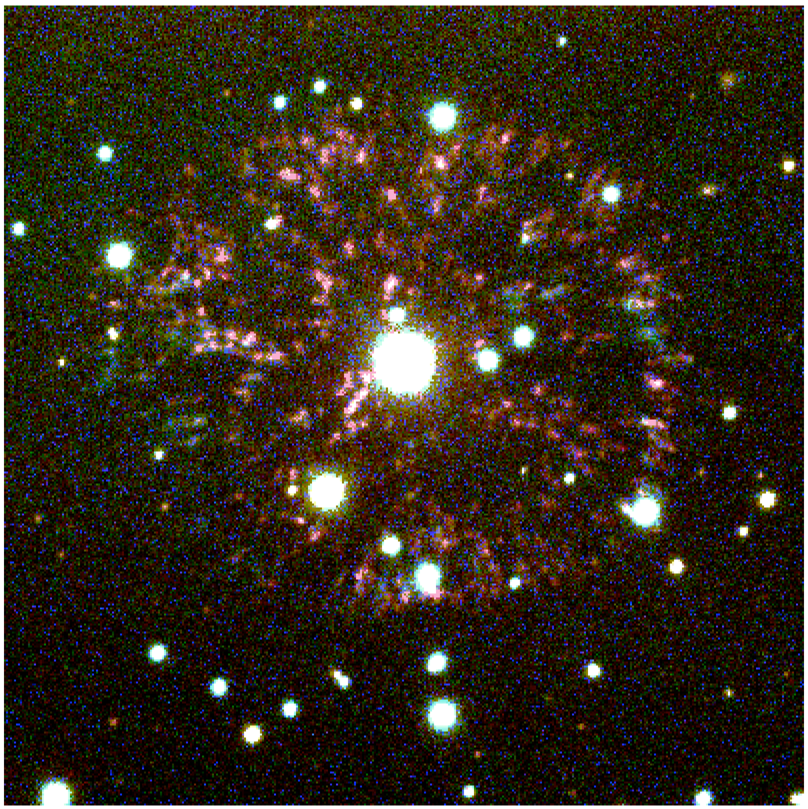


Note! Not to scale!

Novae

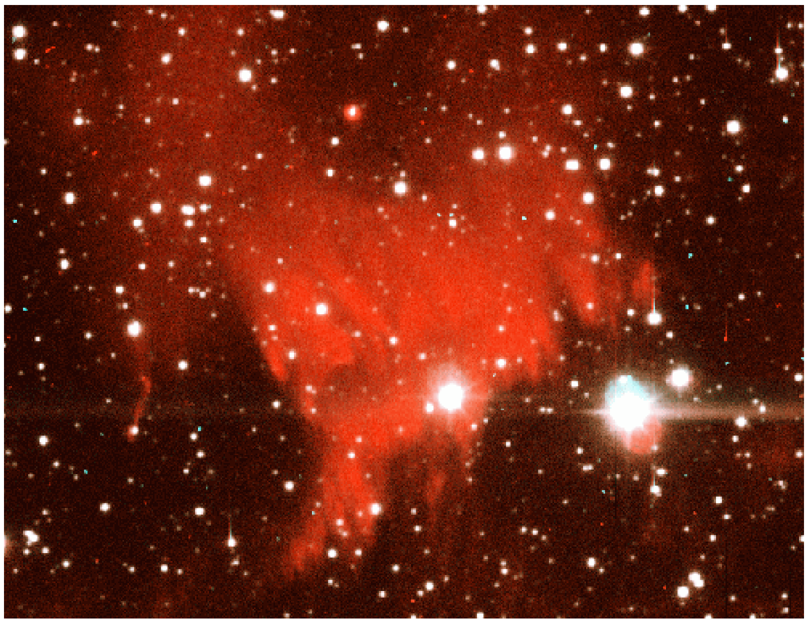
- Nova Vel 1998 (3rd magnitude)

Novae



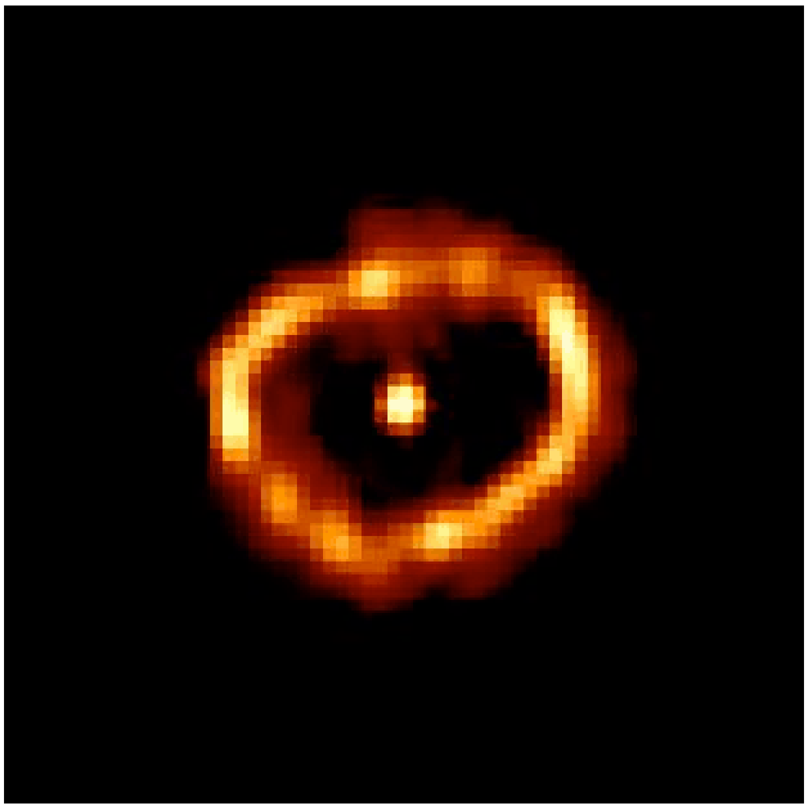
- Nova Persei became one of the brightest stars in the sky in 1901. Look there now and see the expanding shell from the explosion. The velocity of the material is ~2000km/sec

Novae



- Nova Cyg (1992) illuminated a cloud of nearby Hydrogen gas.
- The expanding shell of the nova could be seen a few years later with HST.

Novae

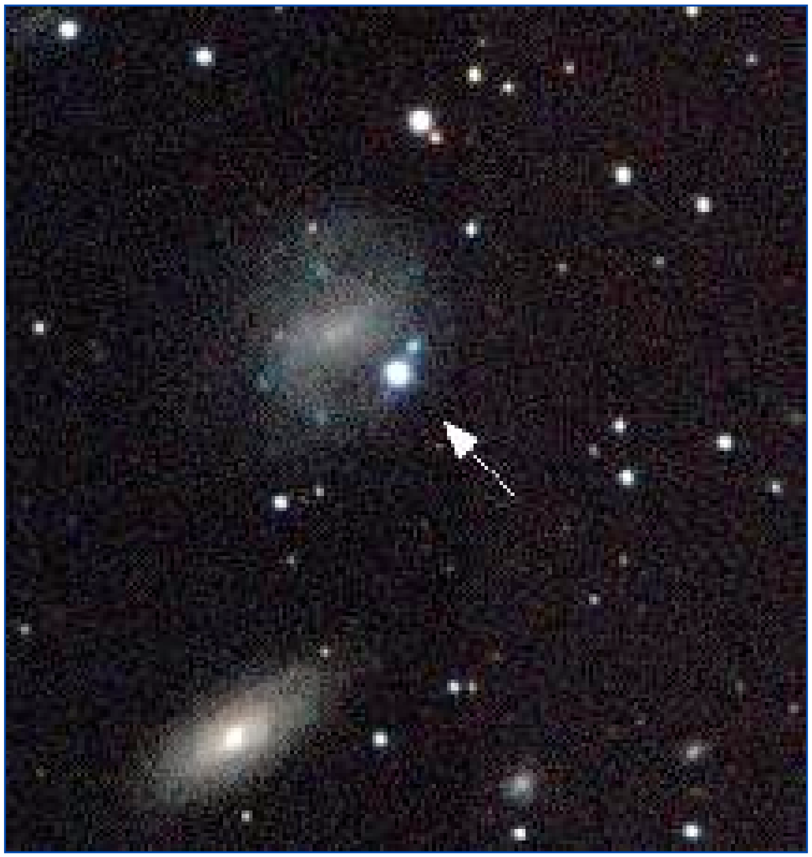


- Nova Cyg in 1994.
- Most nova are `recurrent'.
- Every year there are 20 - 30 novae observed in the Galaxy. `Naked eye' nova occur more like one per decade.

Mass Transfer in Binaries

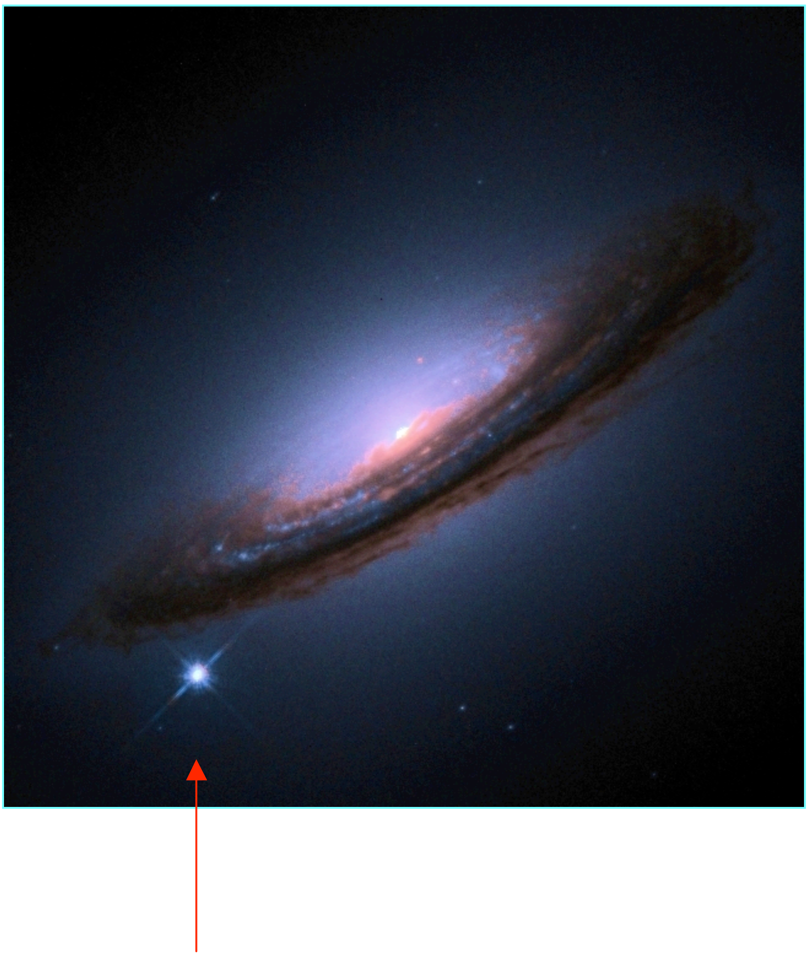
- The scenario that leads to nova explosions can produce an even wilder phenomenon.
- In the early 1900s `novae' were sometimes observed in other galaxies and were used to help set the distances to galaxies.
- But, when it became clear that even the nearest galaxies were much further away than anyone had thought this suggested that the extragalactic `nova' were much brighter than Galactic nova -- the term *supernova* was coined.

Supernova Type I



- Supernova are very luminous -- a bright as the combined light of all the stars in a small galaxy!
- They rise in brightness very quickly and then fade over timescales of months.

Supernova



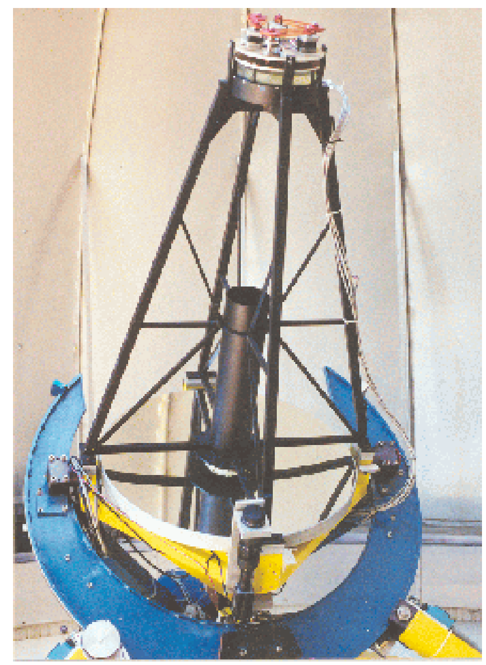
- Early on it was realized there were two distinct types of SN.
- SN I have no hydrogen in their spectra and are seen in all types of galaxies
- SN II have hydrogen and are only seen in spiral galaxies and near star-forming regions

Supernova I

- No hydrogen in the spectra
- Seen in all types of galaxies
- Seen everywhere within galaxies (halo and disk)
- Maximum brightness: $6 \times 10^9 L_o$
- A decade ago, 15 - 20 were discovered per year, last year 166

Supernova I

- There is a robotic telescope up at Mt. Hamilton that does an automatic search for SN every clear night.
- Take images of lots of galaxies, digitally subtract them, look for any residual.



Supernova I

- What is going on here? It took a long time to sort this out.
- Remember WD mass transfer binaries and the Chandrasekar limit.
- What would happen if mass transfer nudged the mass of a WD above the $1.4M_o$ limit for degenerate electron gas pressure?

Supernova I

- When a WD exceeds the Chandrasekar limit there is a violent version of the helium flash.
- The temperature skyrockets and within a second a fusion chain reaction fuses elements all the up to radioactive nickel.
- *This star has exploded in a runaway thermonuclear catastrophe!*

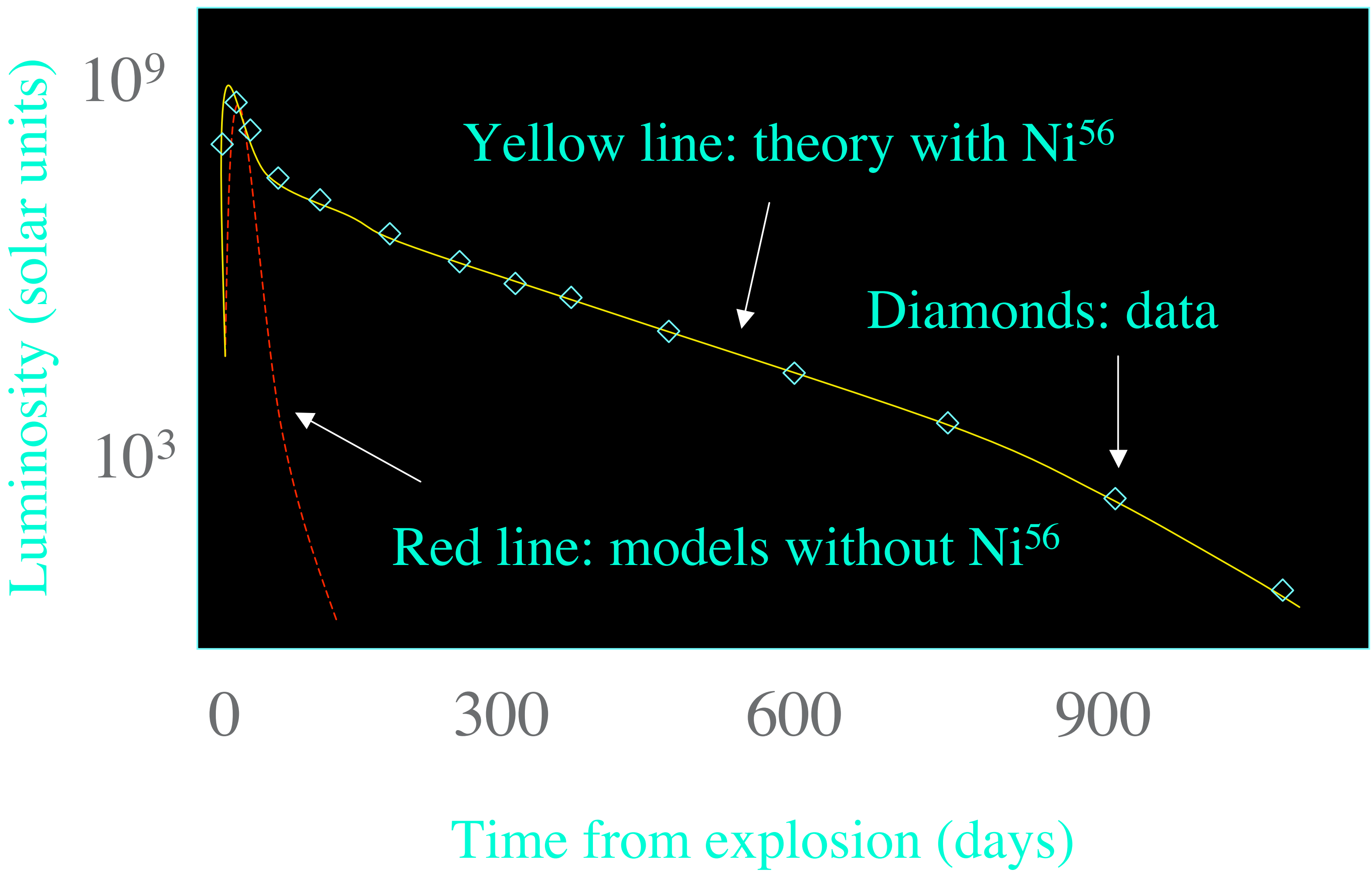
Supernova I

- What is RIGHT about this theory?

(1) Will see these objects in `old' populations.

(2) Models for the detonation of a $1.4M_o$ WD give the right total energy

(3) The predicted amount of radioactive Ni^{56} in the explosion fit the light curve perfectly



Yellow line: theory with Ni56
Diamonds: data
Red line: models without Ni56
10^9
10^3
Luminosity (solar units)
0
300
600
900
Time from explosion (days)

SN I

- What's WRONG with this theory?
- Five years ago, the answer went like this.
- The accreted mass of a Red Giant onto a WD would be hydrogen rich, yet the signature of SN I is no hydrogen. Obvious solution is to have the merger of two $0.7M_o$ helium WDs. Problem was, didn't have an examples of close helium-WD pairs!
- Now, we do.