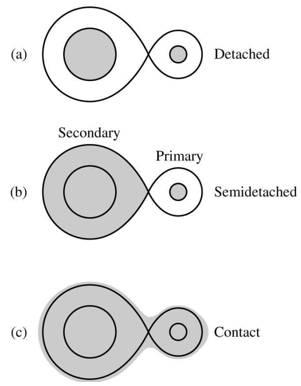
Evolution of close binary stars

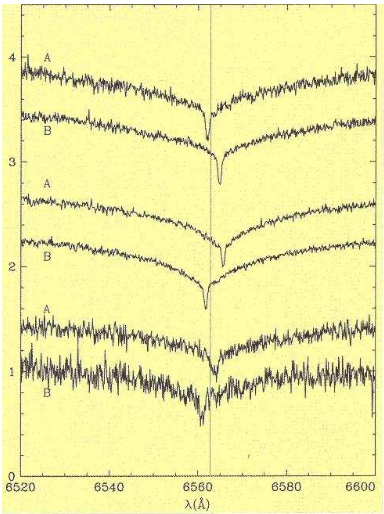
How to detect a compact object?

Binaries!



- Detached binaries:
  Doppler reflex motion of the visible star (as for Exo-Planets).
- Interacting binaries (semi-detached):
  Mass transfer from the normal star and accretion onto the companion

Carroll & Ostlie Fig. 18.4



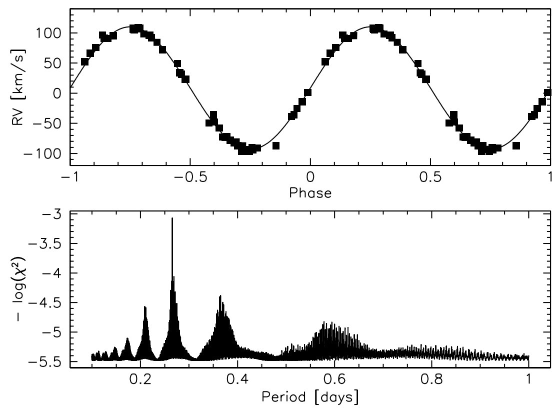
Reminder: Spectroscopic binaries: Mass of compact invisible object (as for the exo-planets) from 3rd Kepler:

$$\frac{a^3}{P^2} = \frac{G(M_1 + M_2)}{4\pi^2}$$

(a: semi-major axis, P: orbital period, $M_{1,2}$: Masses).

Derive from this: Mass function

$$\mathrm{MF} = \frac{M_2^3 \sin^3 i}{(1 + (M_1/M_2))^2} = \frac{K_1^2 P}{2\pi G}$$



C. Karl, U. Heber, R. Napiwotzki, S. Geier, Balt. Ast. 15, 1

measurement K_2 : velocity amplitude, P: period (power spectrum)

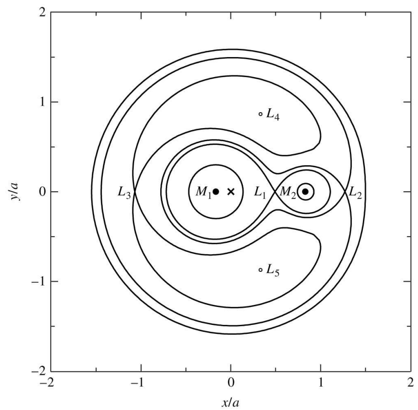
Mass function gives lower limit for M_2

How to distinguish between white dwarf, neutron star and black hole?

- If the lower limit to M_2 is less than the Chandrasekhar mass: no distinction possible.
- If the lower limit to M_2 is larger than Chandrasekhar mass but less than the Oppenheimer-Volkoff limit: Neutron star or black hole
- If the lower limit to M_2 is larger than the Oppenheimer-Volkoff limit: black hole
- If the companion is a pulsar: neutron star

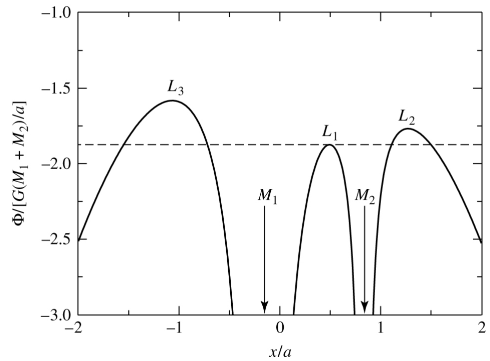
Semi-detachted systems

Gravitational potential of a binary



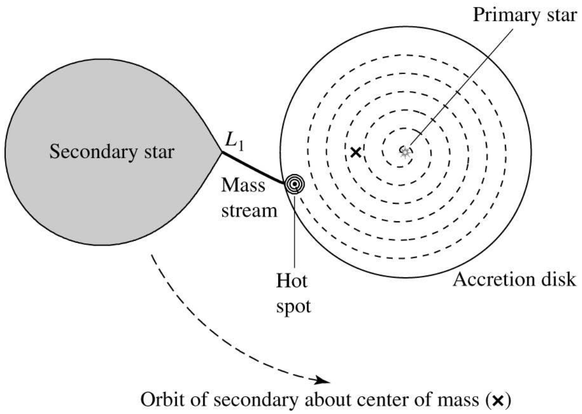
Equipotential contours, Carroll & Ostlie Fig. 18.3

$L_1 \ldots$ L5: Lagrangian points.

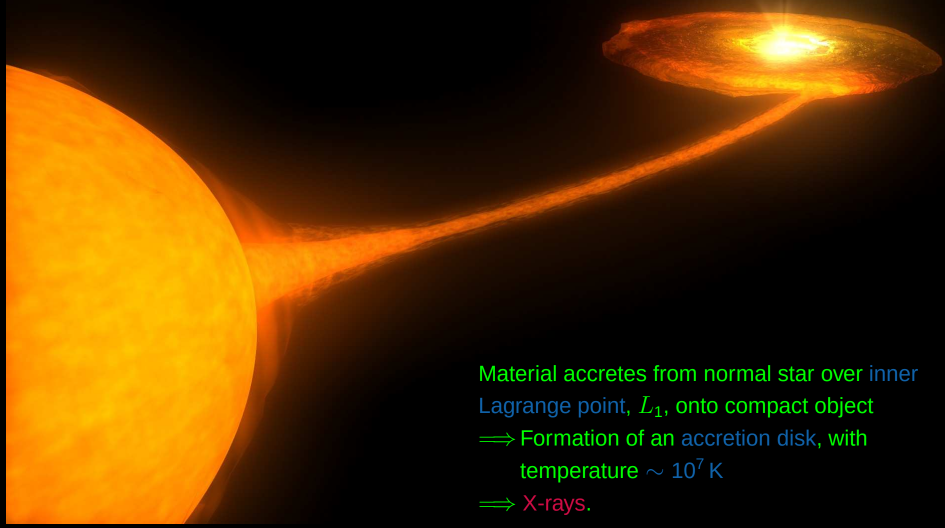


Effective gravitational potential, Carroll & Ostlie Fig. 18.2
Dashed line: Total energy rquired for material to flow through L1.

Semi-detachted systems



- Visible star = secondary = normal star
- Cataclysmic variable: primary is white dwarf
- X-ray binary: primary is a neutron star or black hole.



Material accretes from normal star over inner Lagrange point, L_1, onto compact object
$\Longrightarrow$ Formation of an accretion disk, with temperature $\sim 10^7$ K
$\Longrightarrow$ X-rays.

Accretion

Astrophysical energy sources:

1. Nuclear fusion

Reactions à la

$$4\mathrm{p} \longrightarrow {}^4\mathrm{He} + \Delta E_{\mathrm{nuc}}$$

Energy released:

Fusion produces $\sim 6 \times 10^{11}\,\mathrm{J\,g^{-1}}$

(i.e., $\Delta E_{\mathrm{nuc}} \sim 0.007 m_{\mathrm{p}} c^2$)

2. Gravitation

Accretion of mass m from ∞ to R_{S} on black hole with mass M gives

$$\Delta E_{\mathrm{acc}} = \frac{GMm}{R_{\mathrm{S}}} \quad \text{where} \quad R_{\mathrm{S}} = \frac{2GM}{c^2}$$

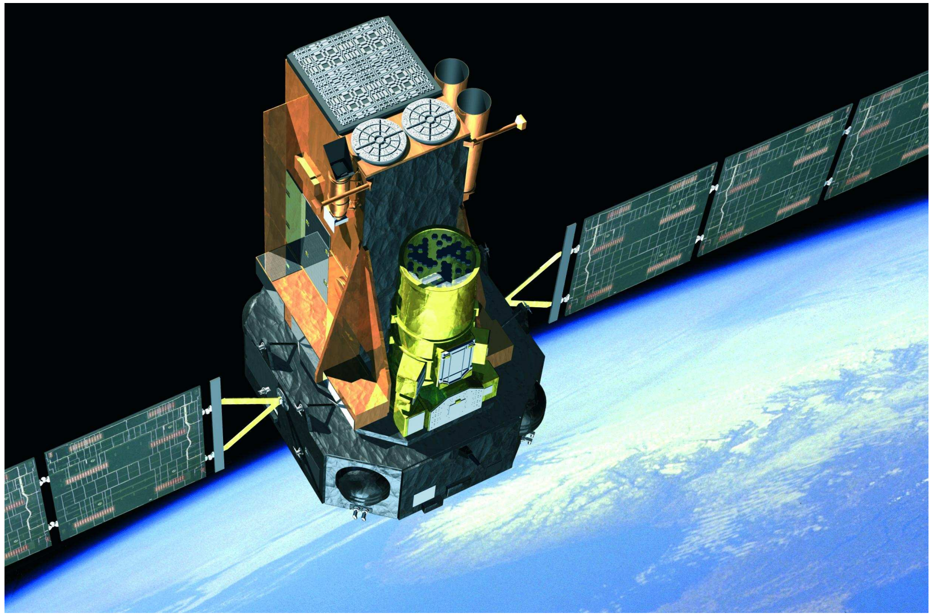
Accretion produces $\sim 10^{13}\,\mathrm{J\,g^{-1}}$

(i.e., $\Delta E_{\mathrm{acc}} \sim 0.1\, m_{\mathrm{p}} c^2$)

$\Longrightarrow$ Accretion of material is the most efficient astrophysical energy source.

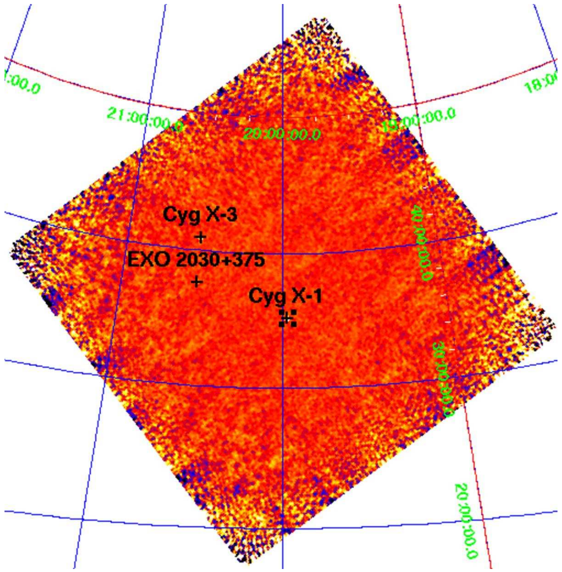
. . . thus accreting objects are the most luminous in the whole universe.

Note: energy gets radiated away from *outside* the Schwarzschild radius!

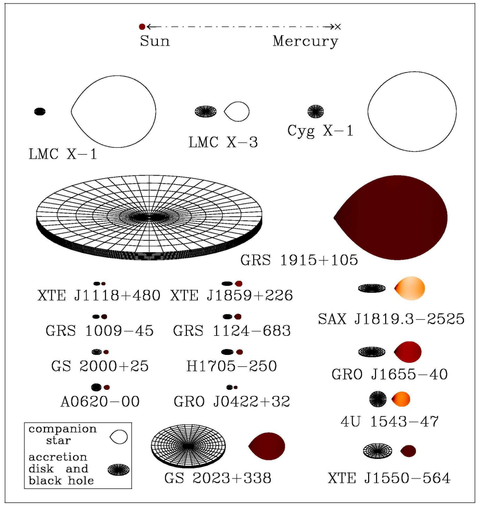


INTEGRAL

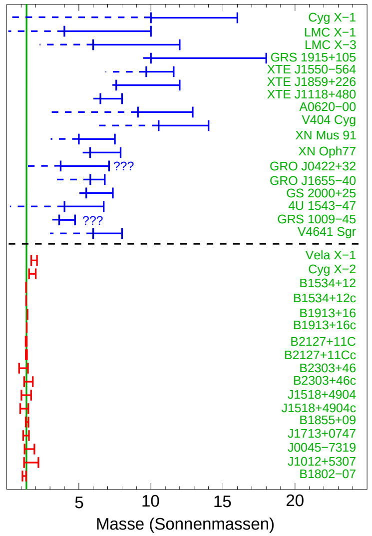
Accretion



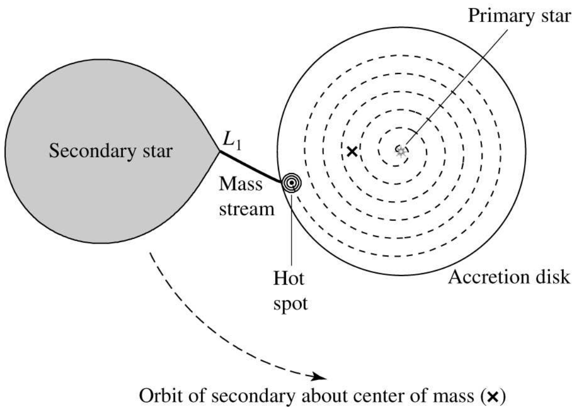
Mass determination



Orosz, 2003, priv. comm.



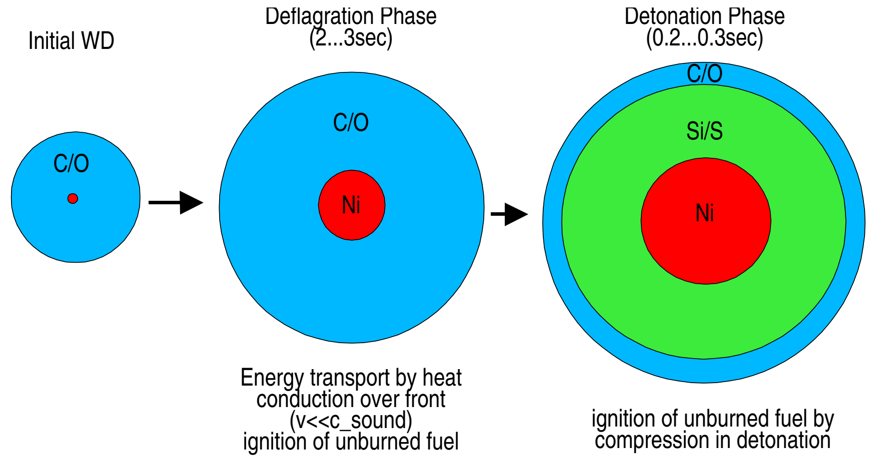
Explosions in binary systems: Novae



Novae: accretion of hydrogen onto the surface of a white dwarf:

- 10^{-5} $M_\odot$ . . . 10^{-4} $M_\odot$ Hydrogen accumulate.
- Electron gas is degenerate
- Temperature of a few million K
- hydrogen burning in the CNO cycle starts
- thermal run-way as in the core helium flash at the tip of the RGB
- explosion expell almost all accreted material

Explosions in binary systems: Supernovae– Type Ia

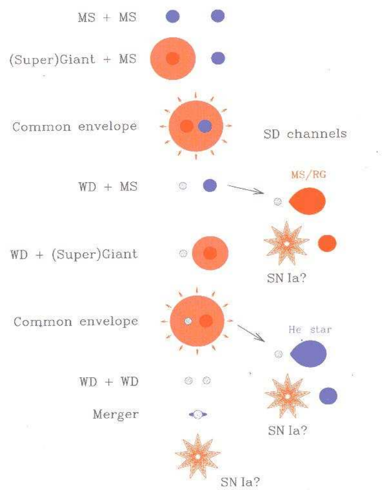


after P. Höflich

SNe Ia: thermonuclear runaway in carbon-oxygen white dwarfs close to Chandrasekhar limit

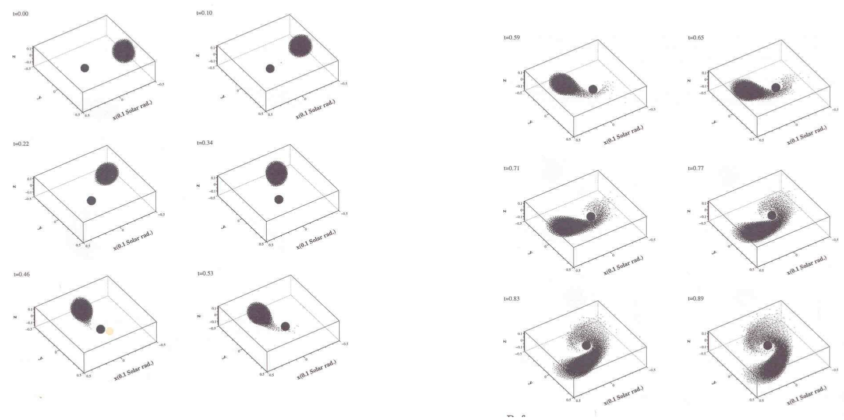
Explosions in binary systems: Supernovae– Type Ia

Thermonuclear explosion of a white dwarf at the Chandrasekhar limit



- orbital shrinkage by common envelope ejection
- single degenerate scenario: continous mass transfer to the white dwarf
  - white dwarf & normal star
  - white dwar & helium star
- Double degenerate scenario:
- two white dwarfs: orbital shrinkage by gravitational wave radiation: white dwarf merger.

White dwarf merger



The less massive (larger) white dwarf is disrupted with in one final orbit and acrreted by the more massive one. Explosion starts when approaching the Chandrasekhar limit.