# Catch me if you can:

## is there a 'runaway-mass' black hole in the Orion Nebula Cluster (ONC)?

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# Star cluster dynamics – two-body relaxation

particle (star) deflection due to two-body interaction:

$$|\Delta v_\perp| \approx \frac{2Gm}{bv}$$

cumulative interactions:

$$\langle \Delta v_\perp \rangle = 0$$

$$\frac{\langle (\Delta v_\perp)^2 \rangle}{\Delta t} = \int_{b_{\rm min}}^{b_{\rm max}} db\, 2\pi\, b\, n\, v\, (\Delta v_\perp(b))^2 = 8\pi\, n \frac{G^2 m^2}{v} \ln\left(\frac{b_{\rm max}}{b_{\rm min}}\right)$$

relaxation time:

$$t_{\rm relax} \approx v^2 \frac{\Delta t}{\langle (\Delta v_\perp)^2 \rangle} = \frac{v^3}{8\pi\, G^2 m^2 n \ln \Lambda}$$

$$\approx 100 \left(\frac{v}{10\,{\rm km\,s^{-1}}}\right)^3 \left(\frac{m}{M_\odot}\right)^{-2} \left(\frac{n}{10^3 {\rm pc}^{-3}}\right)^{-3} {\rm Myr}$$

# Star cluster dynamics – dynamical friction

$$\Delta \mathbf{v}_{\|} \approx -2\mathbf{v}\left(1+\frac{b^2 v^4}{G^2 M^2}\right)^{-1}$$

$$\left\langle \frac{\Delta v_{\|}}{\Delta t} \right\rangle \approx \int_{b_{\min}}^{b_{\max}} db\, 2\pi\, b\, \rho\, v\, \Delta v_{\|}(b) = \frac{4\pi\rho G^2 M}{v^2} \ln\left(\frac{1+b_{\max}}{1+b_{\min}}\right)$$

- massive stars loose kinetic energy $\longrightarrow$ sinking to the cluster centre: mass segregation
- transfer of the kinetic energy from massive stars to light ones: energy equipartition
- time-scale typically of the order of the crossing time (much shorter than the relaxation time)

# Star cluster dynamics – gravothermal catastrophe

kinetic temperature:

$$\frac{3}{2}k_{\rm B}T = \frac{1}{2}m\langle v^2\rangle$$

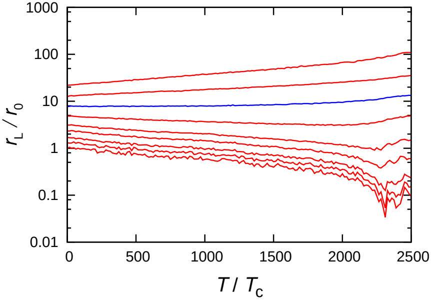
virial theorem:

$$E = \frac{1}{2}U = -K = \frac{3}{2}Nk_{\rm B}T$$

heat capacity:

$$C = \frac{dE}{dT} = -\frac{3}{2}k_{\rm B}T$$

energy loss $\longrightarrow$ warm up $\longrightarrow$ contraction




Lagrange radii containing 0.5, 1, 2, 5, 10, 25, 50, 75 and 90 per cent of the cluster mass

# Star cluster dynamics – further aspects

- gas: forms $\gtrsim 50\%$ of the cluster mass
- radiation from massive OB stars $\longrightarrow$ gas expulsion $\longrightarrow$ weakening of the mean gravitatinal potential $\longrightarrow$ cluster expansion (or even dissolution)
- primordial binaries: carry substantial fraction of the cluster energy
- three-body interactions: acceleration of stars to high velocities, shrinking of tight binaries
- "physical" stellar collisions — $R_\star \approx R_\odot (M_\star / M_\odot)^{0.6}$
- stellar evolution

# Orion nebula cluster

Observations:

- $D \approx 400\,\mathrm{pc}$
- age $\lesssim 2.5\,\mathrm{Myr}$
- $M_\mathrm{c} \approx 1800\,M_\odot$
- $M_\mathrm{gas} \lesssim 100\,M_\odot$
- $r_\mathrm{h} \approx 0.8\,\mathrm{pc}$
- $t_\mathrm{relax} \gtrsim 10\,\mathrm{Myr}$
- $N_\mathrm{OB} \approx 15$
- $\sigma \approx 2.5\,\mathrm{km\,s^{-1}}$
- $\sigma_\mathrm{core} \gtrsim 4\,\mathrm{km\,s^{-1}}$

HST image $\approx 3.5 \times 3.5\,\mathrm{pc}$

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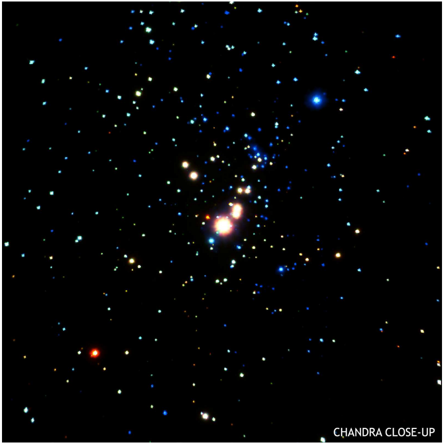


Chandra image $\approx 2.5 \times 2.5\,\mathrm{pc}$

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Model – initial conditions:

- $M_\mathrm{c} = 2700\,M_\odot$
- $M_\mathrm{gas} = 2700\,M_\odot$
- $r_\mathrm{h} \approx 0.1\,\mathrm{pc}$
- $t_\mathrm{relax} < 1\,\mathrm{Myr}$
- $N_\mathrm{OB} = 50$

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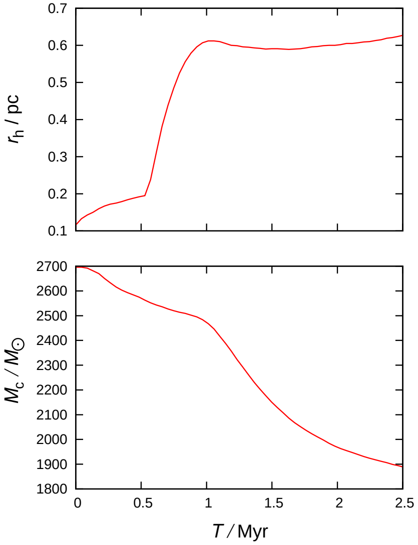

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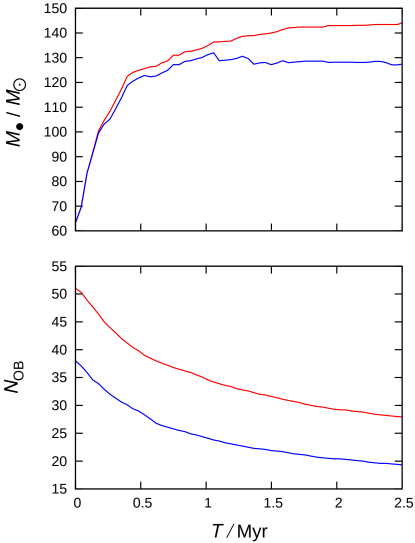

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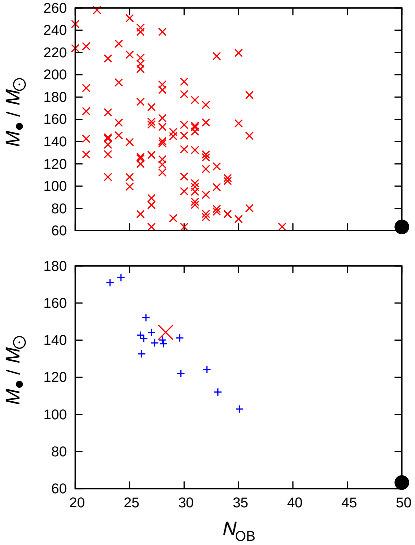

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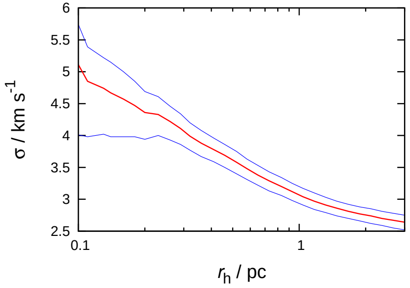
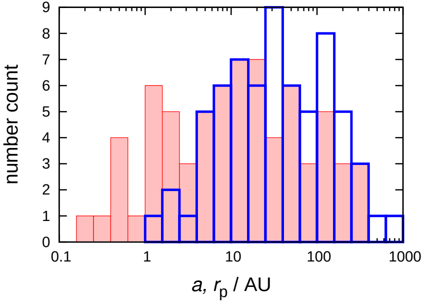


# Runaway-mass star or black hole?

No evidence for a runaway-mass star in the ONC $\longrightarrow$ direct collapse to an IMBH?

- possible detection through:
- secondary star with $v_{\rm orb} \gtrsim 10\,{\rm km\,s^{-1}}$ ($\approx 70\%$ probability)
- episodic accretion of stellar wind from a secondary O star ($\approx 50\%$ probability)




For comparison: Cyg-X1: $M_{\rm BH} \approx 10\,M_\odot$, $M_{\rm s} \approx 25\,M_\odot$, $a \approx r_{\rm p} \approx 0.2\,{\rm AU}$, $L \approx 2 \times 10^{37}{\rm erg\,s^{-1}}$

# Conclusions

- we introduced a viable model of the evolution of the ONC which is able to match all basic observables (mass and size, velocity dispersion, number of the OB stars)
- two modes of the removal of OB stars – ejection and collisions – are mutually correlated $\Longrightarrow$ low abundance of OB stars indicates presence of the massive merging object
- eventual detection of IMBH in the ONC may clear:
  - an open question about existence of intermediate-mass black holes
  - our view of the evolution of stars with mass $\gtrsim 100 M_{\odot}$
  - our view of the initial conditions (densities, mass function, mass segregation) of star clusters