Red giant–jet interactions in galactic nuclei



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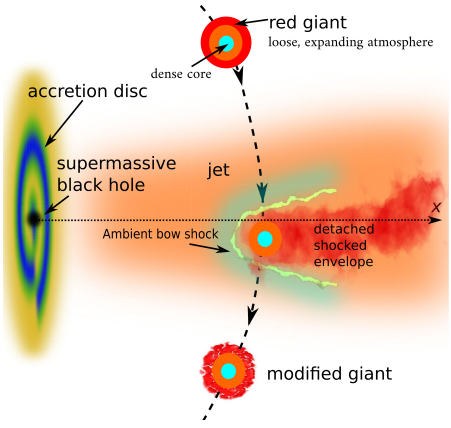
Motivation: Missing Red Giants

Why are red giants missing near the Galactic Centre?

- Deficit known for >30 years
- Bright giant depletion strongest near SMBH
- Proposed mechanisms:
  - tidal stripping
  - star–disc collisions
  - star–star collisions
  - jet-induced ablation

Can repetitive jet encounters reshape stellar populations?



From Zajaček+(2020)

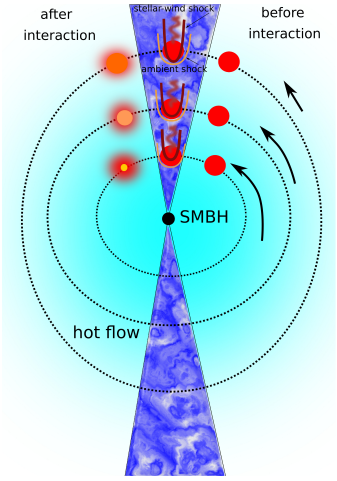
Physical Picture

Why are red giants missing near the Galactic Centre?

- Red giant orbit intersects AGN jet
- Bow shock develops
- Surface layers stripped
- Process repeats for many passages

Two shocks form:

- ambient shock
- stellar-envelope shock



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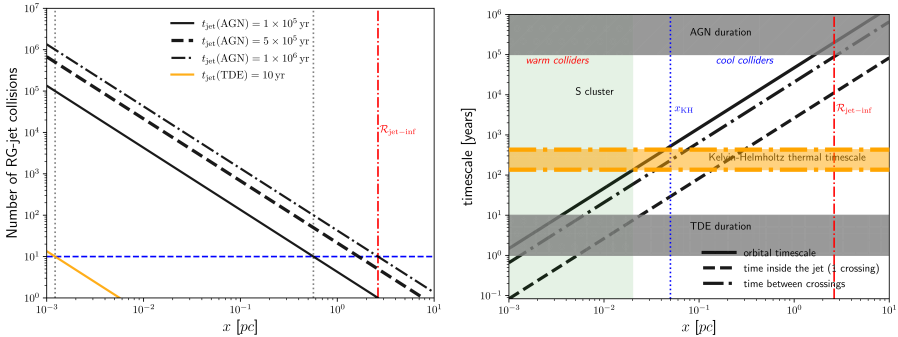
Why Repetitive Encounters Matter

For AGN activity:

$$t_{jet} \sim 10^5\,\mathrm{yr}$$

$$N_{cross} \propto x^{-3/2}$$



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- Thousands of encounters expected
- Interaction sphere: ~ 2.6 pc
- Warm colliders expected near S cluster

Galactic center - inner $\sim$1 pc is a region of mutual interactions of stars, gas, and dust within the gravitational potential of the SMBH (Zajaček+ 2020)

Ambient medium:
The ρ and T profiles of the ambient plasma - $n_{\rm a} \approx n_{\rm B} \left(\frac{r}{r_{\rm B}}\right)^{-1}$, $\quad T_{\rm a} \approx T_{\rm B} \left(\frac{r}{r_{\rm B}}\right)^{-1}$,
$n_{\rm B} = 26\,{\rm cm}^{-3}$, and $T_{\rm B} = 1.5 \times 10^7\,{\rm K}$ are the number density and the T at the Bondi radius.

The **number density** can be estimated as $n_{\rm j} = \dfrac{L_{\rm j}}{\mu m_{\rm H}(\Gamma - 1)c^2 v_{\rm j} \pi x^2 \tan^2\theta}$ and $M_\bullet = 4 \times 10^6\,M_\odot$

Calculations - CASTRO code - a benefit for high $\mathcal{M}$ flows, where $E_{\rm tot} - E_{\rm int}$ unreliable.
Complete set of conservative form of hydro equations:

$$\frac{\partial \rho}{\partial t} = -\vec{\nabla}\cdot(\rho\vec{v}), \qquad \frac{\partial \rho\vec{v}}{\partial t} = -\vec{\nabla}\cdot(\rho\vec{v}\vec{v}) - \vec{\nabla}p + \rho\vec{g},$$
$$\frac{\partial \rho E}{\partial t} = -\vec{\nabla}\cdot(\rho E + p)\,\vec{v} + \rho\vec{v}\cdot\vec{g}, \qquad \frac{\partial \rho e}{\partial t} = -\vec{v}\cdot\vec{\nabla}(\rho e) - (\rho e + p)\,\vec{\nabla}\cdot\vec{v},$$

enclosed with ideal gas EOS: $p = (\gamma - 1)\,\rho e$.

Simulation Setup

Red giant

- $M = 1 M_\odot$
- $R = 100 R_\odot$
- MESA model
- polytropic profile

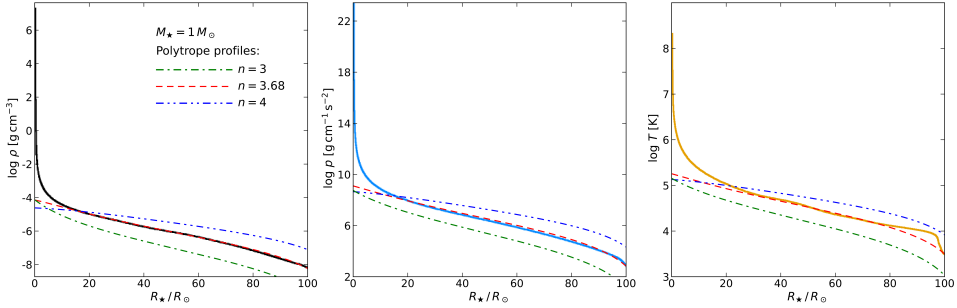
Jet luminosity

- 10^{42}
- 10^{44}
- 10^{48} erg/s
- $v_j = 0.33$ and $0.66c$

Numerics

- CASTRO
- 3D hydro
- AMR
- 2 AU domain

256^3 grid + adaptive refinement



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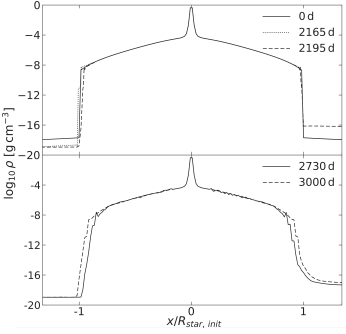
Simulation Setup

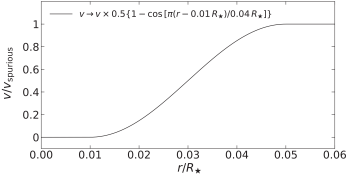
Major challenge - maintaining hydrostatic equilibrium within a star for a long time!!

- Used method proposed in Ohlmann& Springel+ 2017:

$$g_c(r) = -Gm_c \frac{h}{r^3} \begin{cases} -\frac{32}{3} + u^2\left(\frac{192}{5} - 32u\right) & \text{for } 0 \le u < 1/2 \\ \frac{1}{15u^3} - \frac{64}{3} + 48u - \frac{192}{5}u^2 + \frac{32}{3}u^3 & \text{for } 1/2 \le u < 1 \\ -\frac{1}{u^3} & \text{for } u \ge 1, \end{cases}$$

where $u = r/h$, h is the softening length, m_c is the mass of the stellar core, v damping: $\dot{v} = -v/\tau$.





- Core of the star $< 0.05 R_\star$ stabilized by additional "sponge term"

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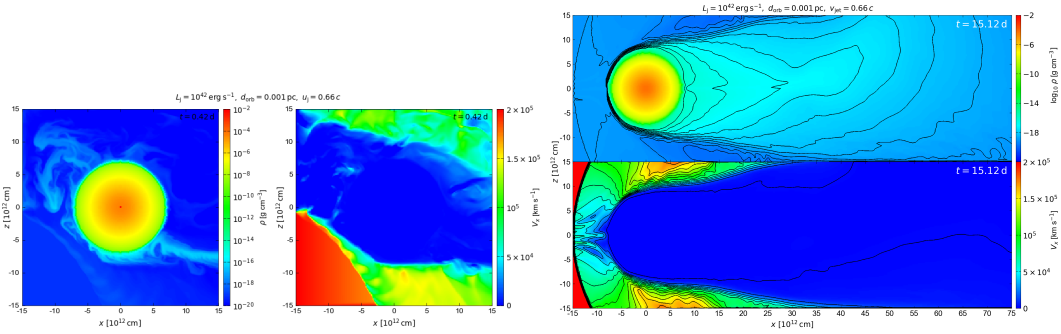
Jet Entry Dynamics

The jet streams horizontally from left to right



Entry → shock formation → downstream tail

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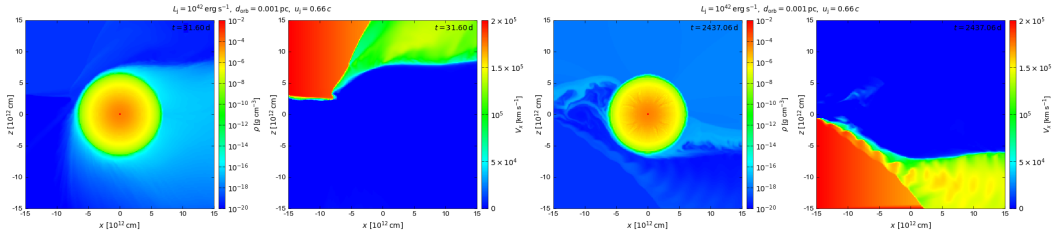
Repeated Stellar Passages

Passage 1 exit Passage 10 entry



Surface layers become progressively disturbed and heated

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Repeated Stellar Passages

Main Quantitative Result

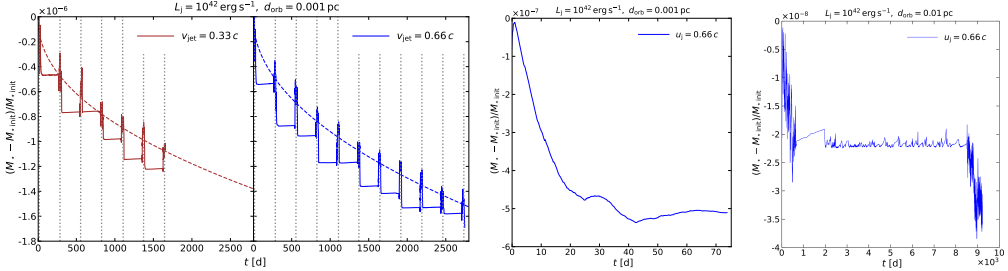
Mass loss evolution:

$$M \propto \sqrt{t}$$

Total cumulative loss during one AGN phase:

$$\Delta M \sim 10^{-4} M_{\odot}$$

- lower than analytical predictions at high luminosity
- still comparable to stellar-wind losses
- cumulative effect remains significant



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Star's Surface Heating

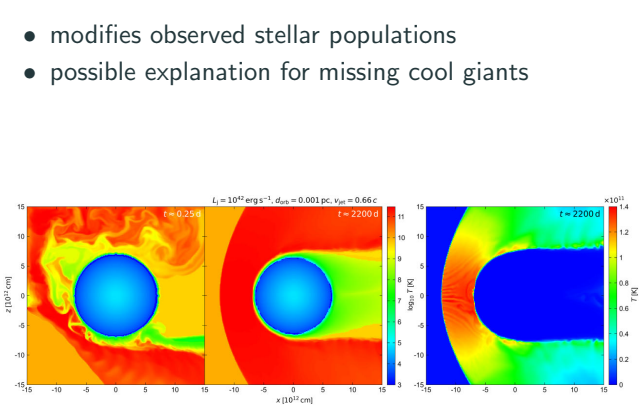
Surface temperature:

$$3600\,\mathrm{K} \rightarrow 8500\,\mathrm{K}$$

Possible transition:

M giant $\rightarrow$ A-type appearance

- modifies observed stellar populations
- possible explanation for missing cool giants



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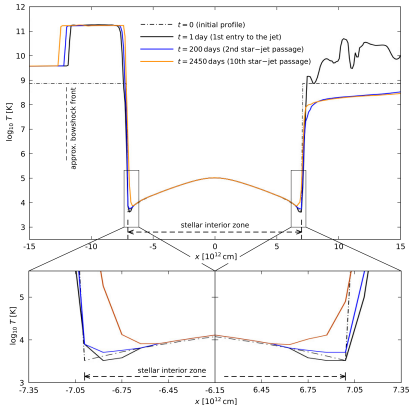

AGB Star Simulation Setup

AGB star

- $M_{\text{init}} = 1.6 M_{\odot}$
- $M_{\text{end of AGB}} \approx 0.65 M_{\odot}$
- $R \approx 180 R_{\odot}$
- MESA model

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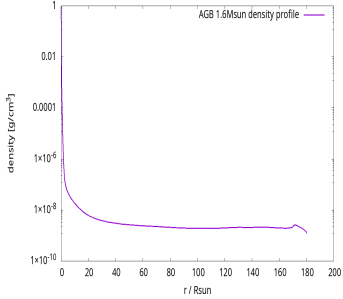

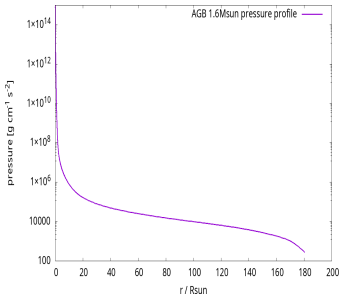

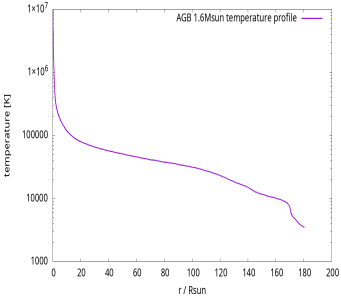

From Kurfürst+ in progress

Astrophysical Implications

Missing giants
partial explanation

Hot-star excess
spectral evolution?

Galaxy evolution
jets influence stars too

Jet feedback is not only gas feedback.

Conclusions

1. Repeated RG–jet encounters modeled in 3D (2D for larger orbital distance)
2. Ablation weaker than simple analytical estimates
3. Cumulative effects remain astrophysically important
4. Surface heating may alter observed stellar populations
5. Nuclear stars can retain signatures of past AGN activity

Thank you