Spoon-feeding giant stars to supermassive black holes

(episodic mass transfer from evolving stars and their contribution to the quiescent activity of galactic nuclei)

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Outline

1. Introduction

2. SMBH feeding

3. Results

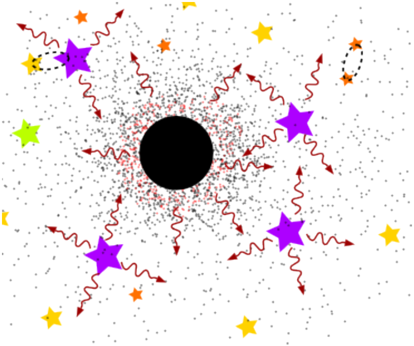
Background

- Quasar activity ⇒ SMBHs in the center of galactic halos
- Most of them present low-level activity likely due to sub-Eddington emission efficiency/accretion
- To undersand $L/L_{\mathrm{ed}} \ll 1$ we need to know what can provide a **minimum feeding** $\dot{M}$ that explains the quiescent luminosity ($L = \eta \dot{M} c^2$)
- If no gas ⇒ fuel can come from dense **stellar cluster** around the SMBH
- Nuclear SCs: like GCs, similar size ($r \sim 5\mathrm{pc}$) but more massive ($10^7 \mathrm{M}_\odot$) and brighter, placed in the center of ∼75% of late type spirals and dwarf ellipticals (Böker et al. 2002; Coté et al. 2006)

SMBH feeding

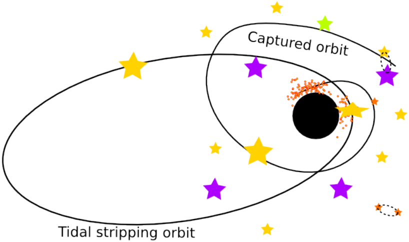
Indirect feeding

Material released must overcome a barrier to accrete onto the SMBH in the form of **feedback** (radiation pressure) from the stars themselves and the SMBH (inefficient process)



Direct feeding

Tidal interactions between stars and the SMBH that strip material from the stars to form a dynamically assembled viscous disk of gas falling onto the SMBH

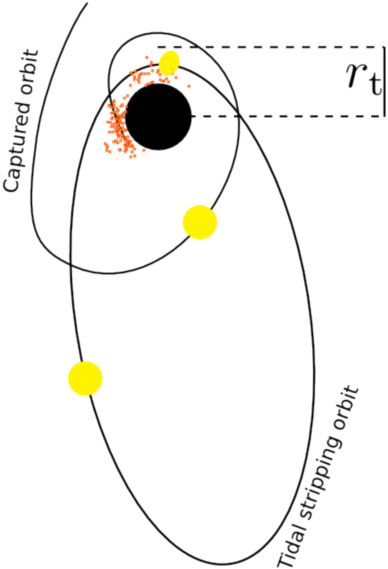


SMBH feeding

- Direct feeding condition:
  orbit pericenter ≤ **tidal radius**

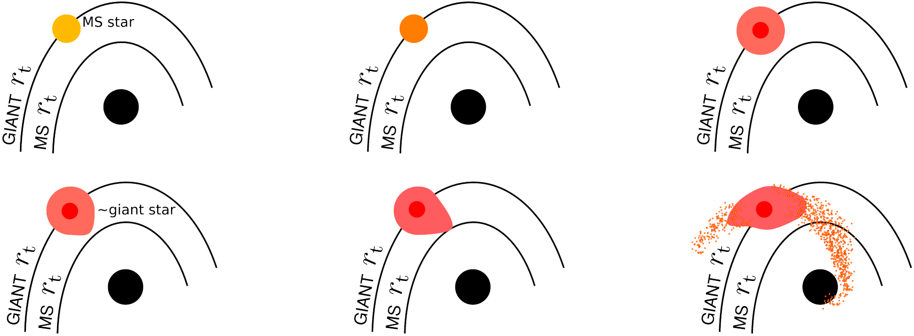
$$\mathbf{r}_{\rm t} = (M_{\rm BH}/M_*)^{1/3} R_* \qquad (1)$$

- **Full** tidal **distruption**
- **Partial** mass **stripping** and subsequent orbits
- Different $\dot{M} \rightarrow$ different L
- This work focuses on partial stripping: **spoon-feeding**



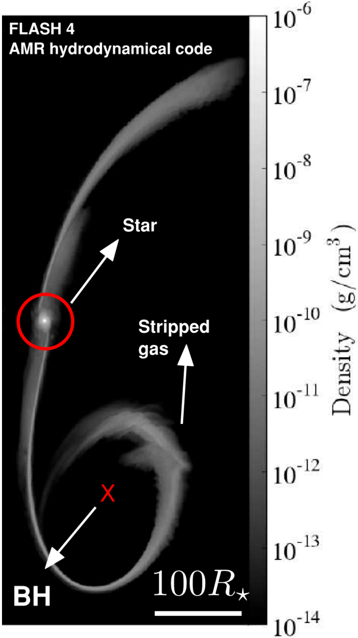
Spoon-feeding

- MS star with pericenter similar to that of a giant star tidal radius
- The star then evolves throuh the giant phase:
  - It expands feels the tidal force with increasing strength
  - Its recently developed dense core helps protect it against complete disruption and the surviving remnant therefore returns to pericenter after each orbital period.
  - The adjustment of the star's structure determines its future



Result 1 of many

- Too computationally expensive to simulate all the passages ⇒ semi-analitical method
- **Half** of the stripped material will fall onto the SMBH forming an **accreting** viscous **disk**
- The rest forms a **tail** of gas that may eventually fall at later times on the SMBH or come back to the star
- Mass loss $\Delta M \sim 10^{-2}\mathrm{M}_\odot$ depends on
- the impact parameter $\beta \equiv r_\mathrm{t}/r_\mathrm{peric} = 0.6$
- Subsequent encounters are dominated by the star response to the mass loss



Then?

Effects that can **modify the orbit** (pericenter) of the star:

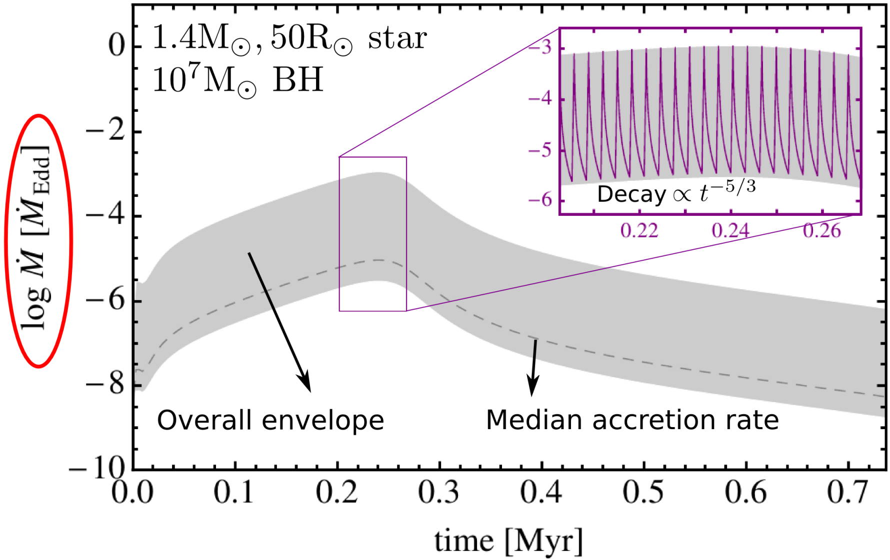
- **Encounters** with other stars (changes in orbital energy and angular momentum)
- **Asymmetry** in the ejected mass
- **Non-radial oscillations** leading to a transfer of orbital energy and momentum into stellar oscillation energy and angular momentum

But:

- Perturbations magnitude is a **small fraction** of the star binding energy and breakup momentum
- **So** The orbit **does not change** too much
- **So** **Analytic** description of the **mass loss** + stellar **evolution** for the changes in the structure
- **Effective stellar wind** for the evolution with mass loss + **MESA** evolution code

Result 2 of many

Profile of repeating "flaring" episodes due to spoon-feeding



Conclusions

- To understand the galactic nuclei quiescent luminosity we need to know the fuel sources
- They focus on the SMBH spoon-feeding
- An AMR simulation is used to develop a semi-analytical model
- The key quantities are the orbit of the star and its reaction to the mass loss
- They analyzed a single case of a 1.4 $M_{\odot}$ giant with $\beta = 0.6$ but the same method with different stars can provide different results

Appendix frame

"Each **mass loss** episode results in a **readjustment of the star's structure** and therefore a **new effective impact parameter** with each pericenter passage. The importance of the adjustment of the mass-losing star's structure in the context of extreme mass ratio circular binaries has been demonstrated by Dai et al. (2011) and Dai & Blandford (2011). We calculate the changes to the stellar properties using the MESA stellar evolution code (Paxton et al. 2011, 2013). Our stellar models are **non-rotating**, and the only source of **mass loss** is the interaction with the **black hole**. In the MESA models, we allow the star to adjust to the mass loss continuously by applying an **effective stellar wind** that carries away the outermost envelope material at a rate $\dot{M} = M/\tau_{\rm orb}$, **recalculated each pericenter**. Timesteps are chosen such that each orbital period, $\tau_{\rm orb}$, is resolved by ten steps, but our results are not sensitive to this choice."

$$\Delta M(\beta) = f(\beta)\left(\frac{M_* - M_c}{M_*}\right)^2 M_* \tag{2}$$

$$f(\beta) = \begin{cases} 0 \text{ if } \beta < 0.5 \\ \beta/2 - 1/4 \text{ if } 0.5 \le \beta \le 2.5 \\ 1 \text{ if } \beta > 2.5 \end{cases} \tag{3}$$

$$\beta \equiv \frac{r_{\rm t}}{r_{\rm p}} = \frac{R_*}{r_{\rm p}}\left(\frac{M_{\rm bh}}{M_*}\right)^{1/3} \tag{4}$$