The angular momentum of galaxies and their haloes: a tracer of galaxy evolution

Lorenzo Posti (University of Groningen)

*with G. **Pezzulli** (ETH), F. **Fraternali** (Groningen), E. **di Teodoro** (ANU)*

Mass & Angular Momentum

- Galaxy structure & morphology
- Scaling laws: mass-velocity, mass-size…
- Mass — Angular momentum:
  - *fundamental quantities*
  - *independent quantities*
  - *subject to conservation laws*

Mass ~ 2.6 x 10^{11} M_{sun}

J ~ 8 x 10^{14} M_{sun} kpc km/s

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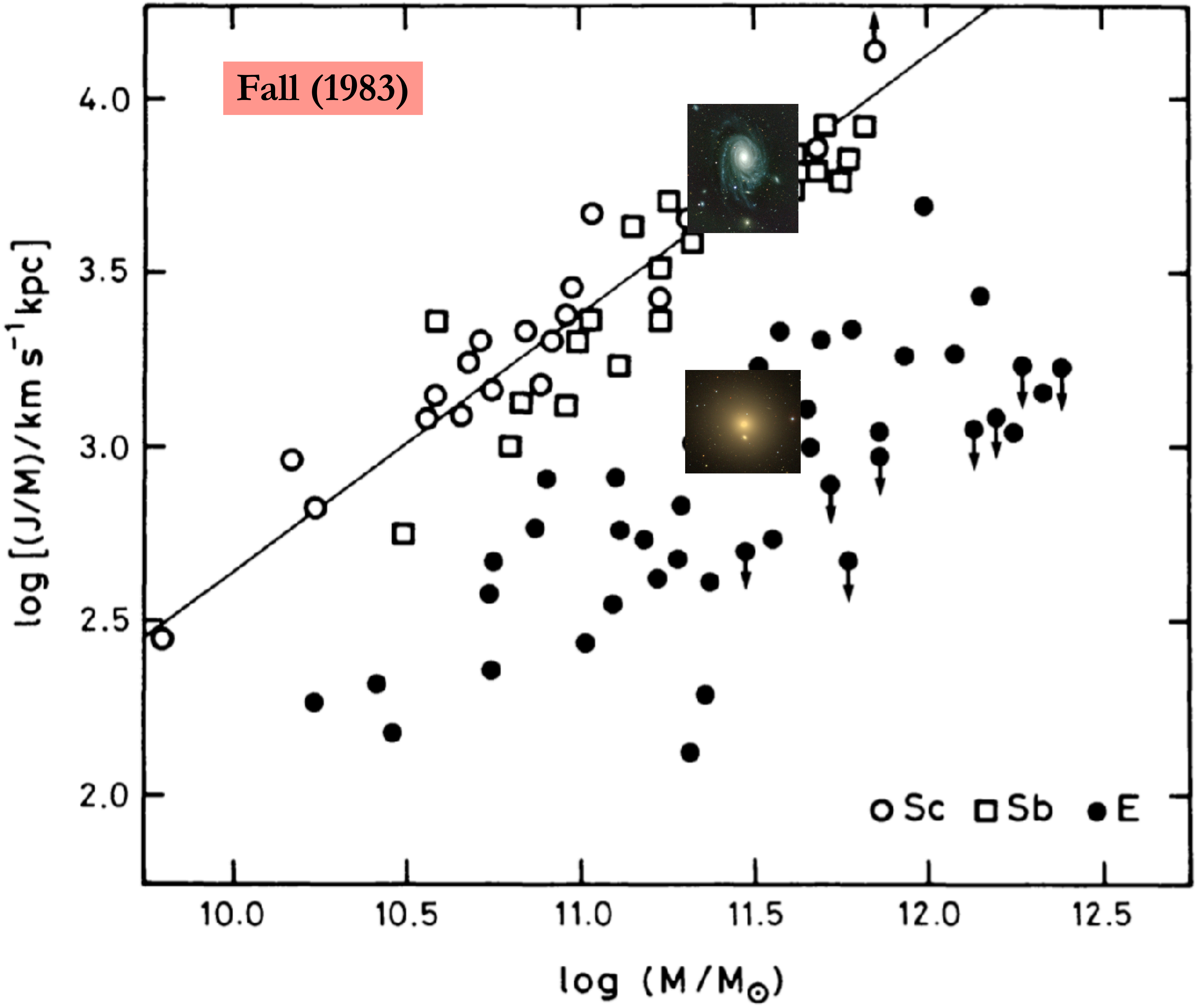
- j — M: the “**Fall relation**”
- Physical galaxy classification
- Morphology and size as a consequence of angular momentum



Measuring angular momentum in stars

$$\vec{j}_* = \vec{r}_* \times \vec{v}_*$$

Romanowsky & Fall (2012)
Obreschkow & Glazebrook (2014)
Butler et al. (2017)
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Observables

$$j_*(< R) = \frac{\int_0^R \mathrm{d}R' \;\; R'^2\, \Sigma_*(R')\, V_{*,\mathrm{rot}}(R')}{\int_0^R \mathrm{d}R' \;\; R'\, \Sigma_*(R')}$$

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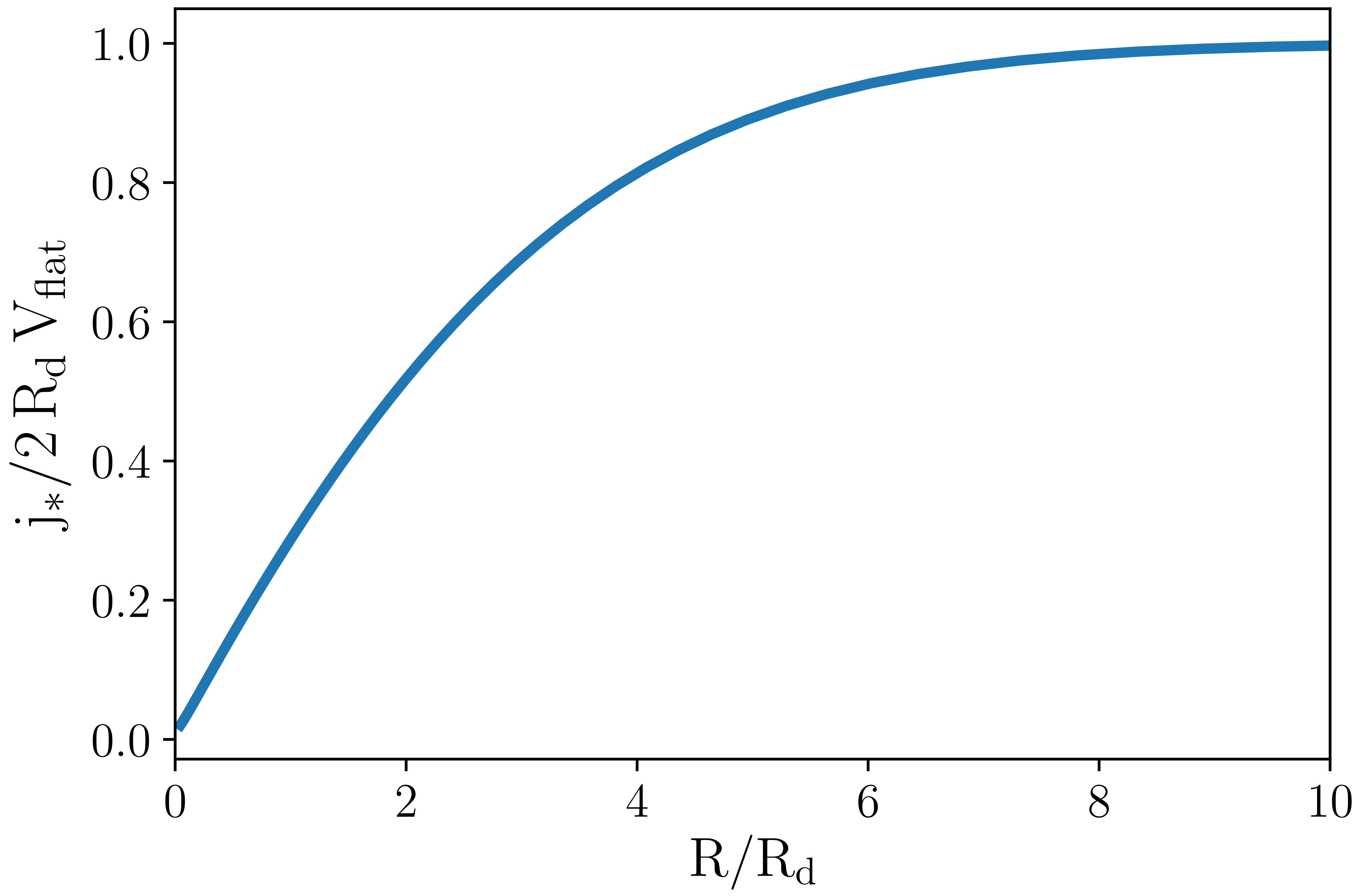

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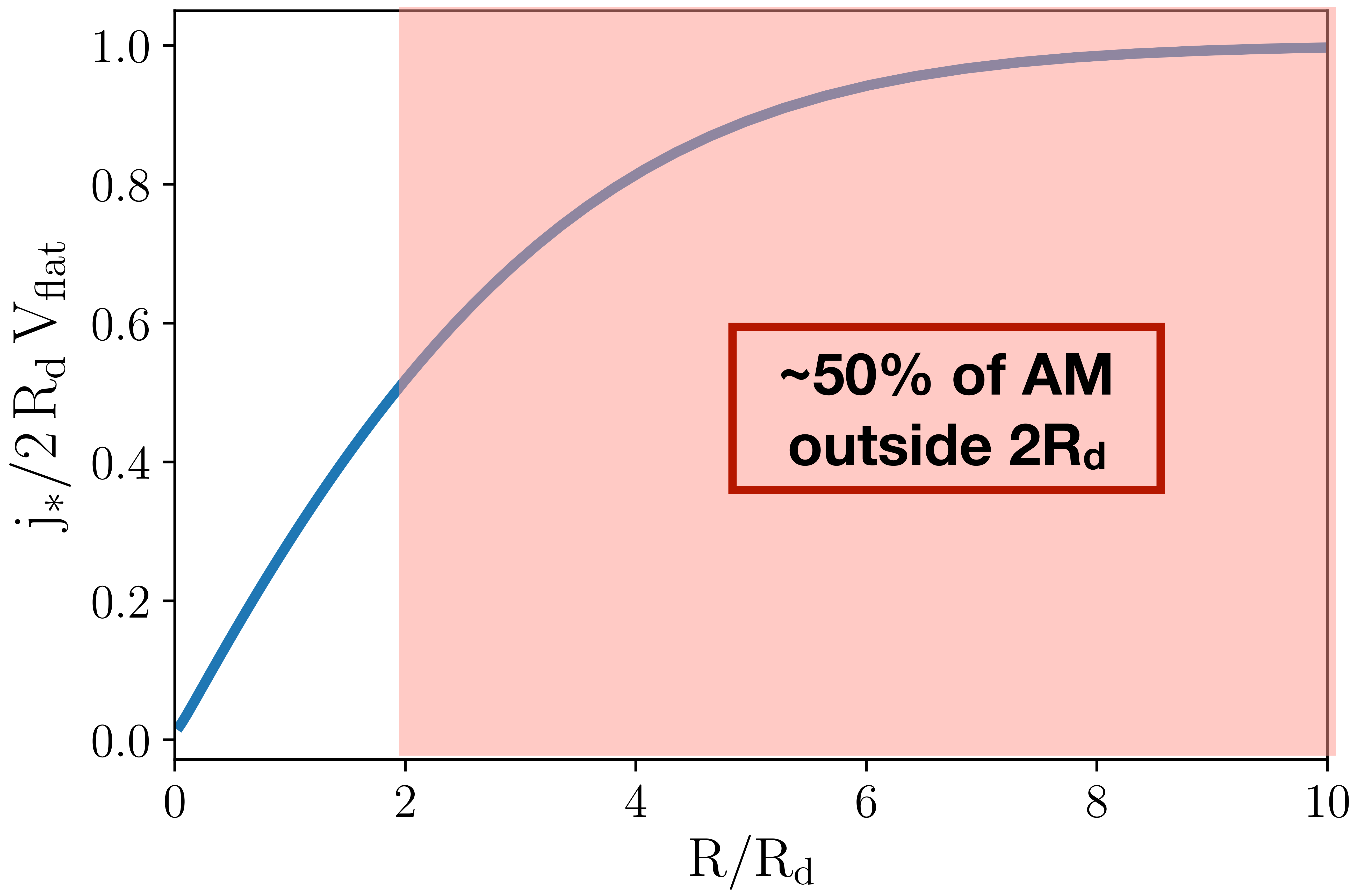

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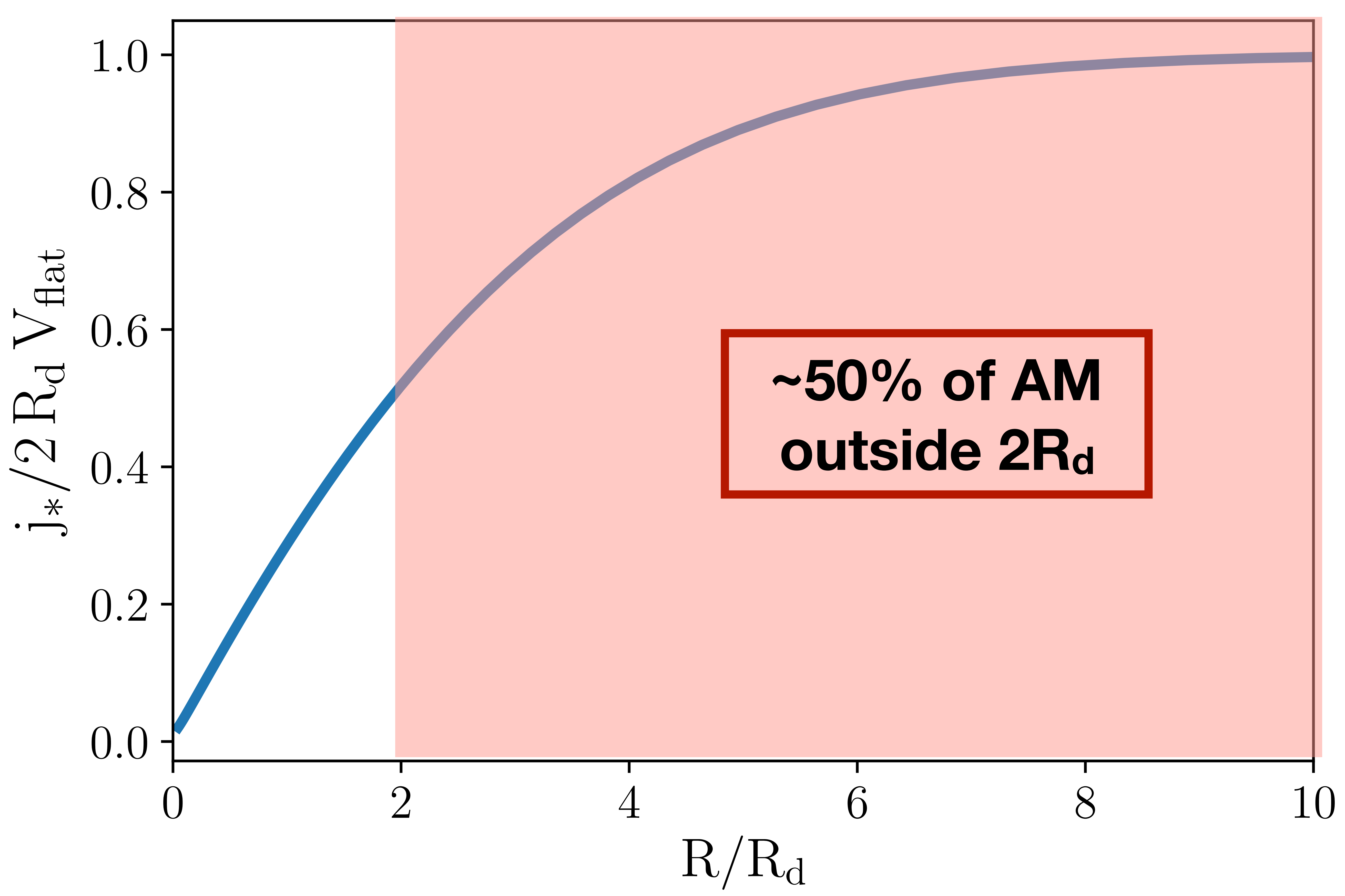
- j_* increases with radius
- Most AM is in the outskirts of galaxies
- j_* profile flattens out at about $\sim 5\ R_d$
- For exponential discs with flat V_{rot}:

$$j_* = 2R_\mathrm{d}V_\mathrm{flat}$$



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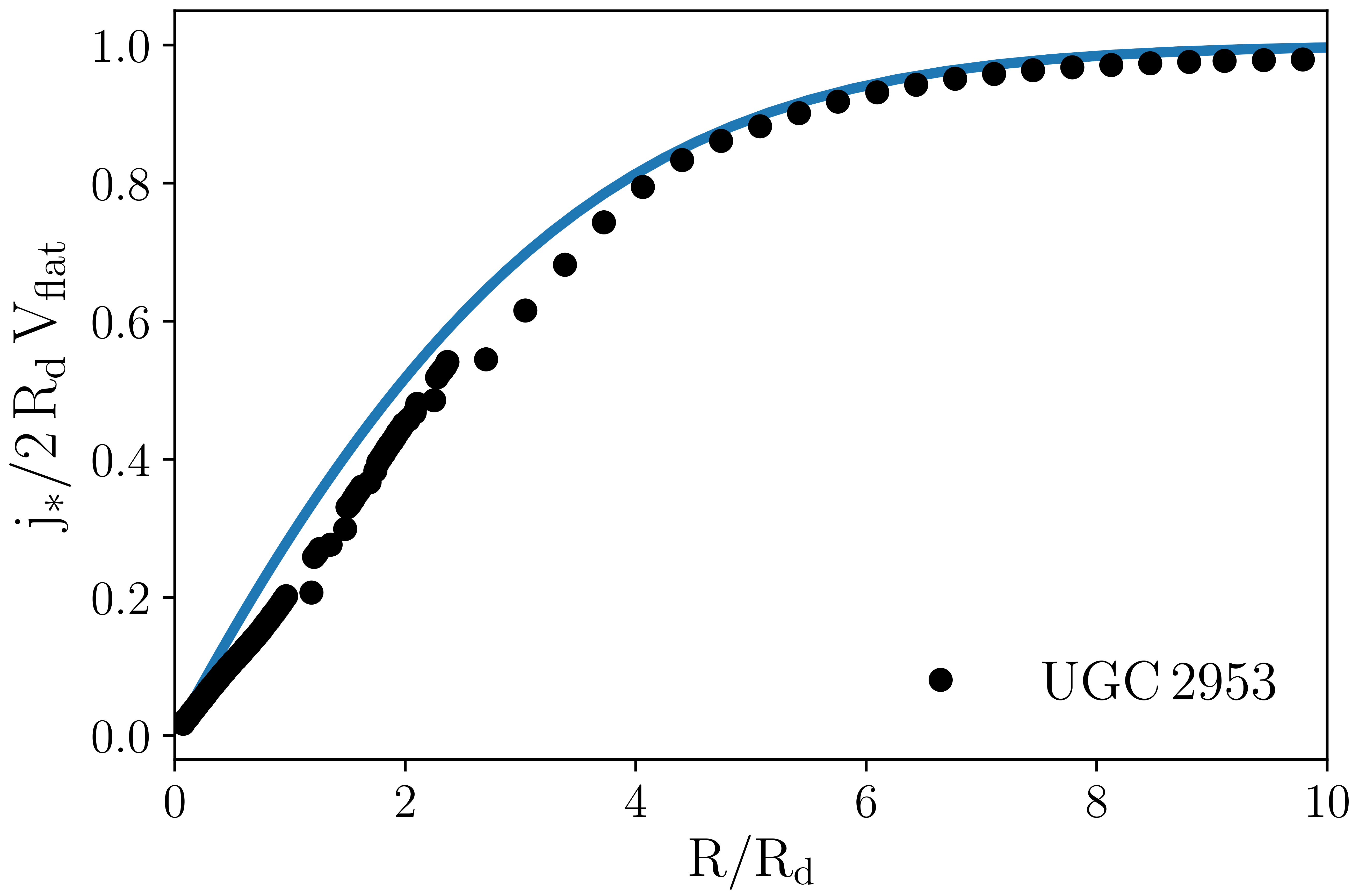

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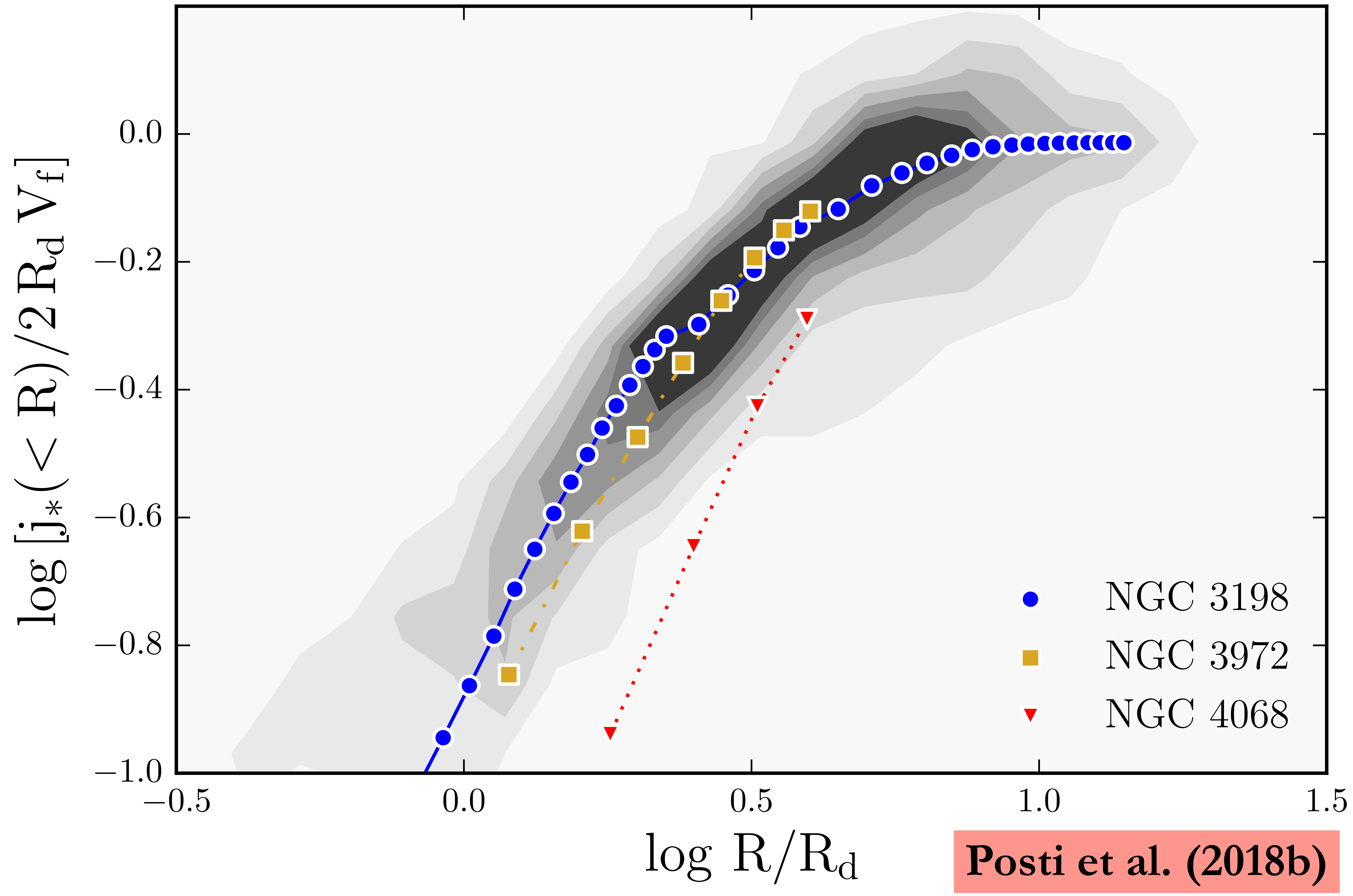

Posti et al. (2018b)

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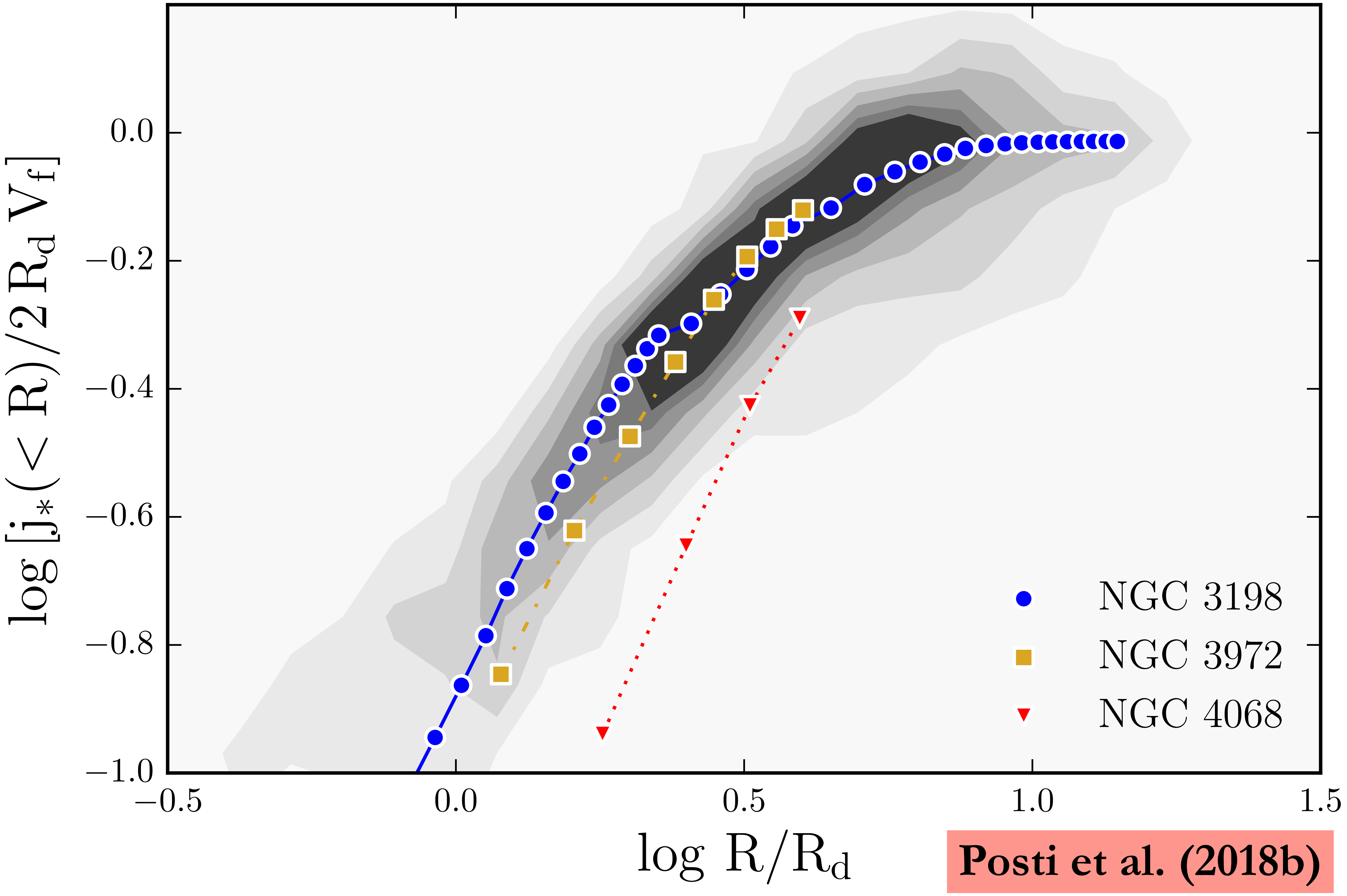
- Spirals of all types, $6.5 \lesssim \log M_*/M_\odot \lesssim 11.5$
- **<u>Same analysis</u>** from dwarfs to high-mass
- Asymmetric drift correction to get $V_{*,\mathrm{rot}}$
- Consider only galaxies with **observed converged j_* profiles**



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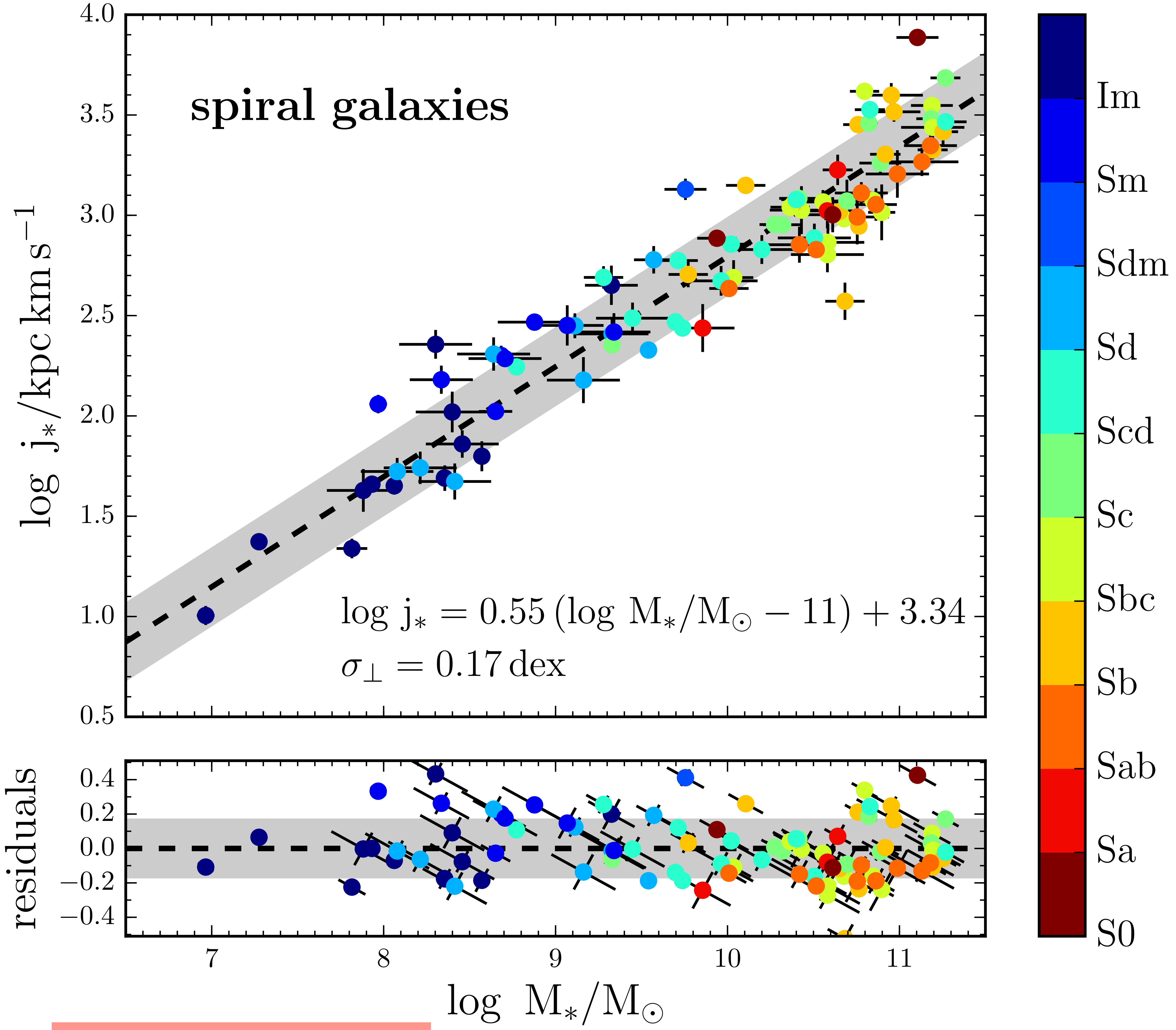
The Fall relation in the nearby Universe



Posti et al. (2018b)

- **Tight, single, unbroken power-law**
- **Valid for all masses: from dwarfs to high-mass**
- **Residuals correlate with morphology**

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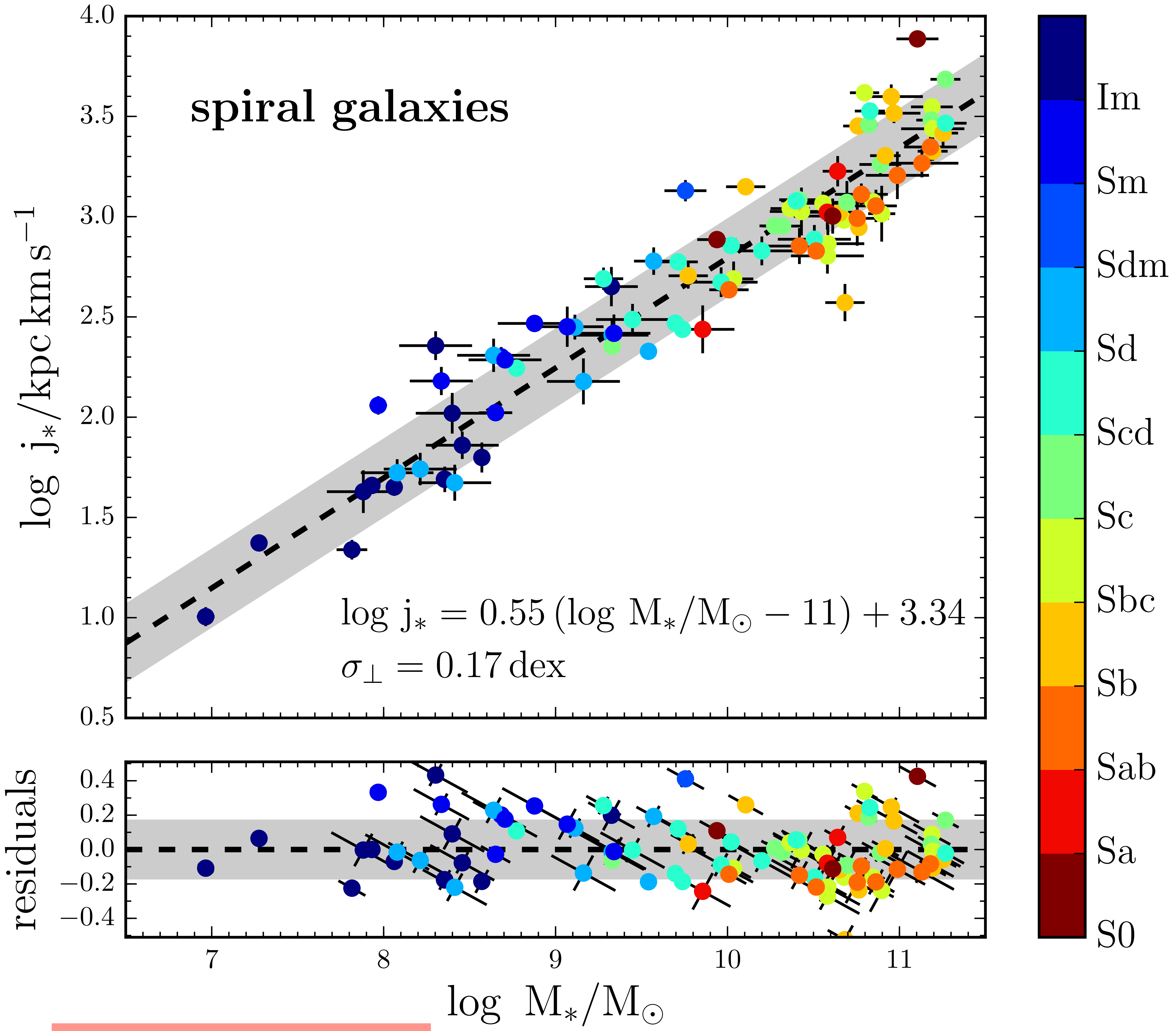
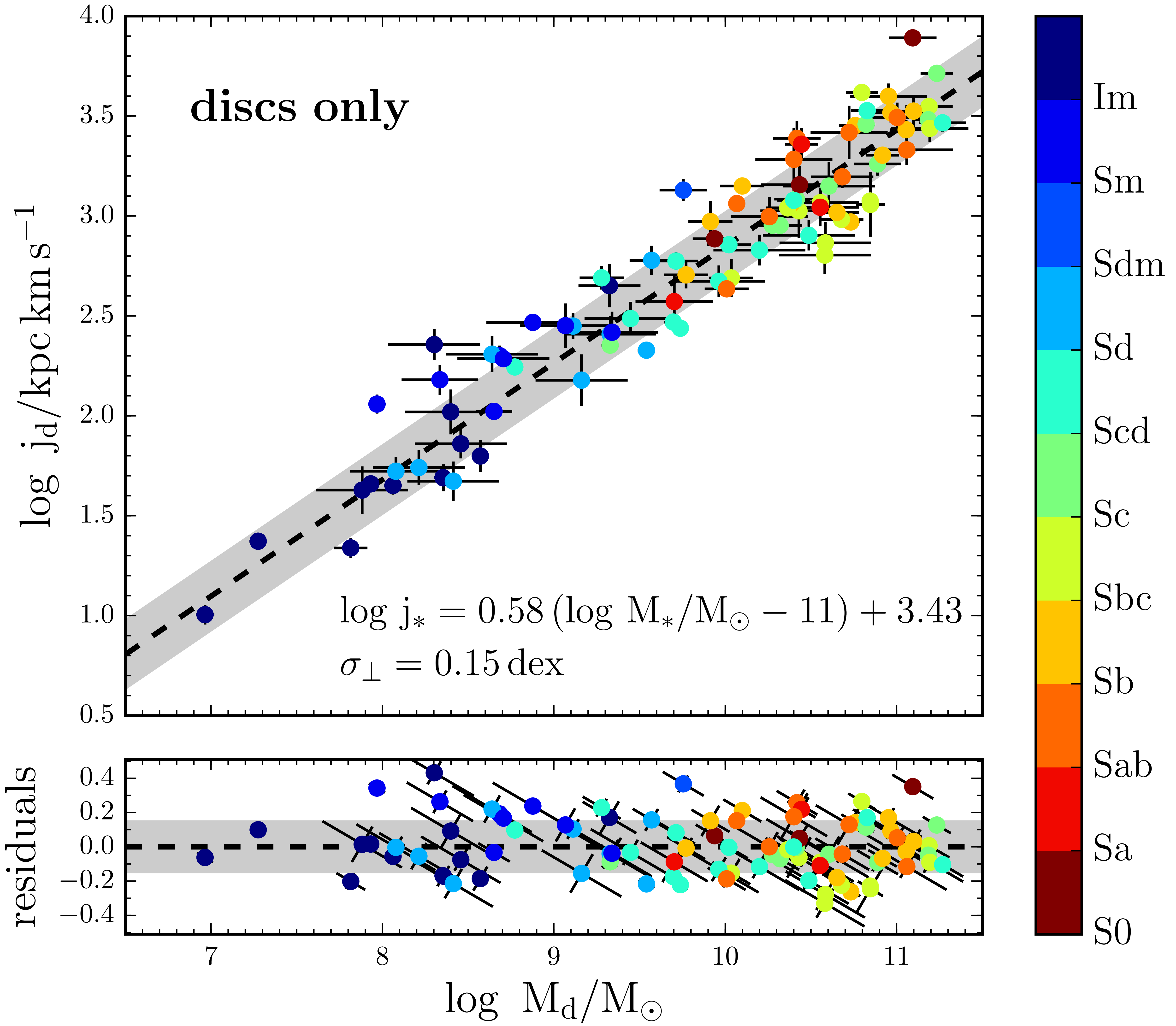
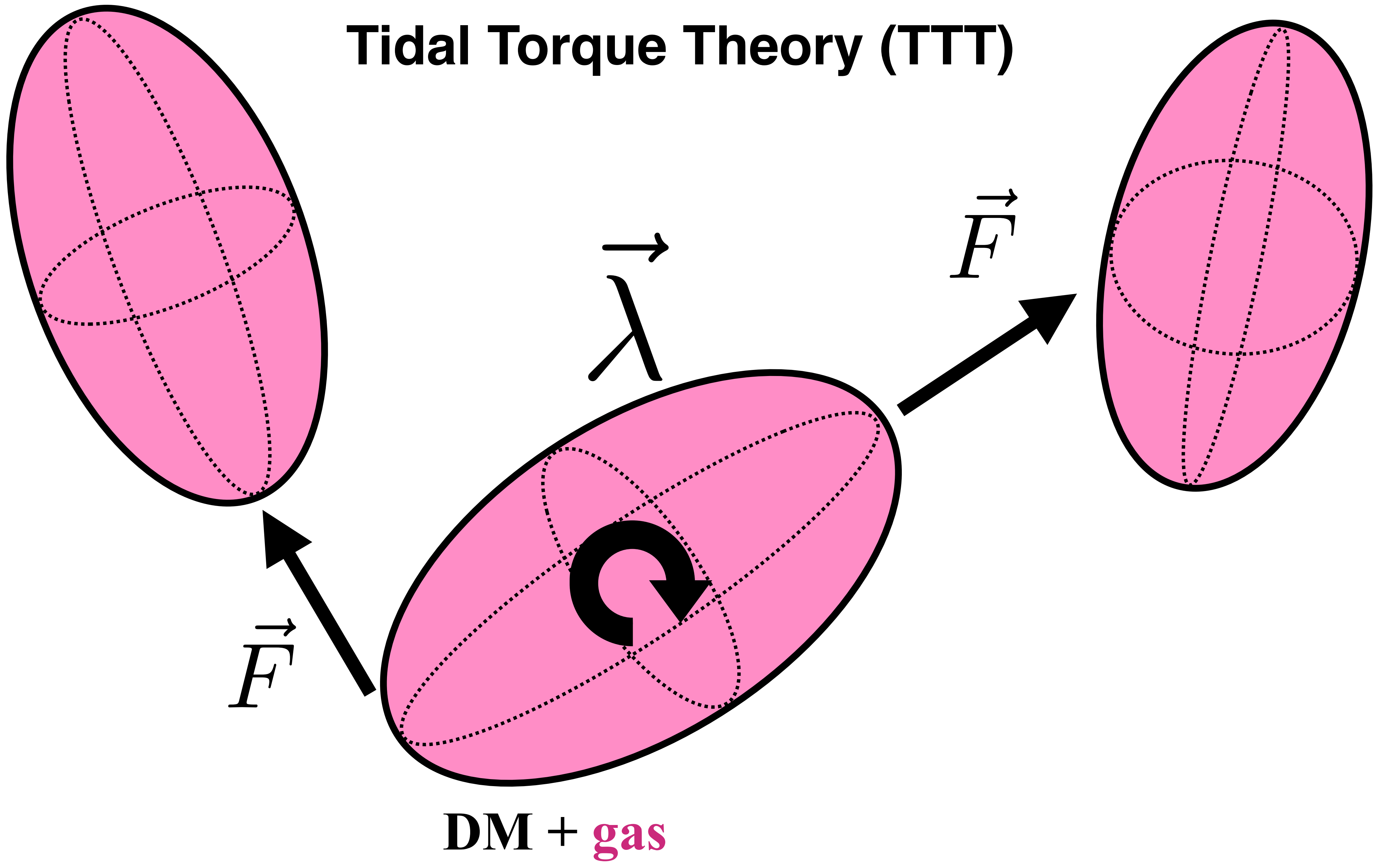




Posti et al. (2018b)

What do we learn from the Fall relation?



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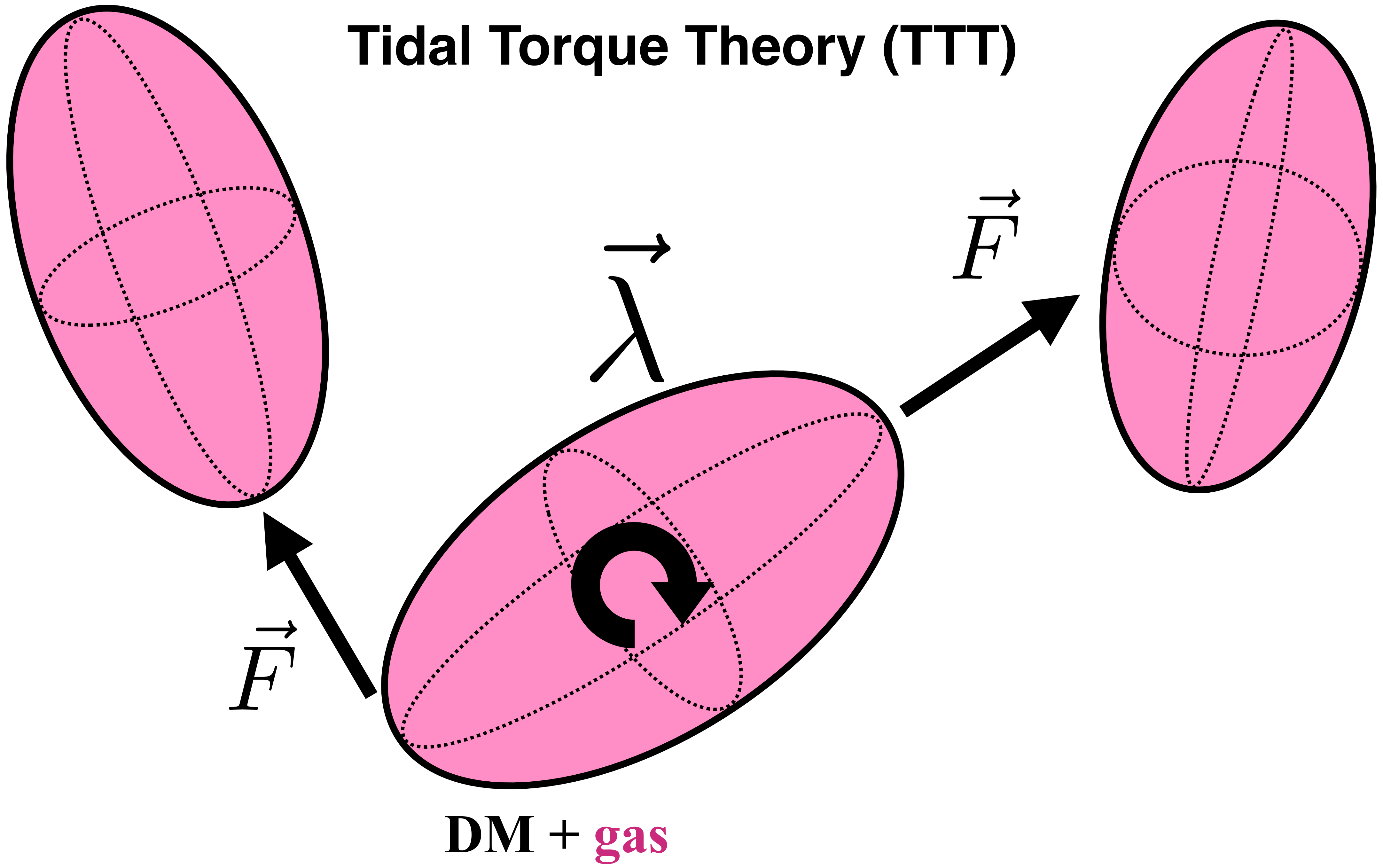
$$\lambda = \frac{J/M_\Delta}{2R_\Delta V_\Delta}$$

Peebles (1969)



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$$\lambda = \frac{J/M_\Delta}{2R_\Delta V_\Delta} \longrightarrow j_\Delta = \frac{J_\Delta}{M_\Delta} \propto \lambda M_\Delta^{2/3}$$

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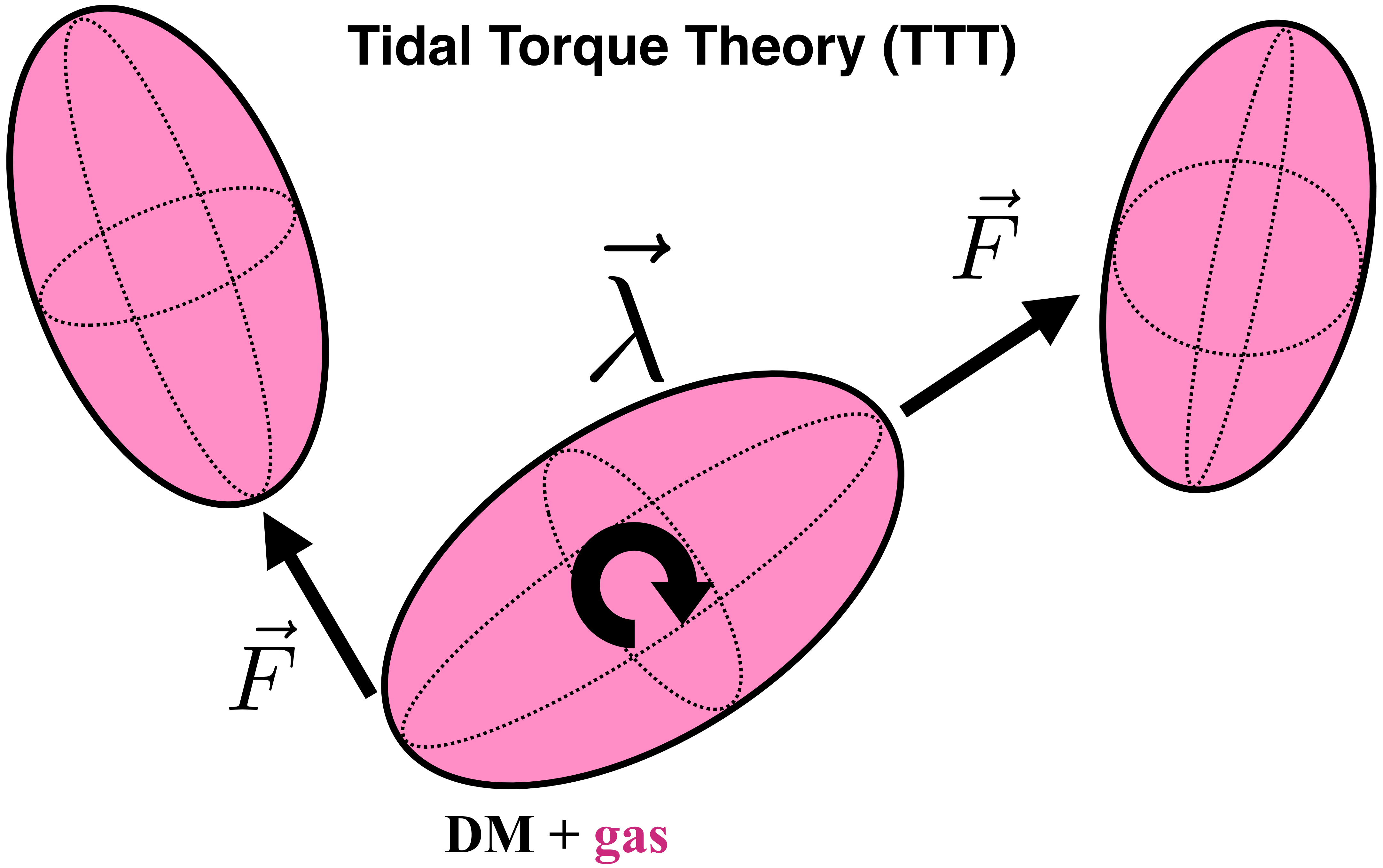

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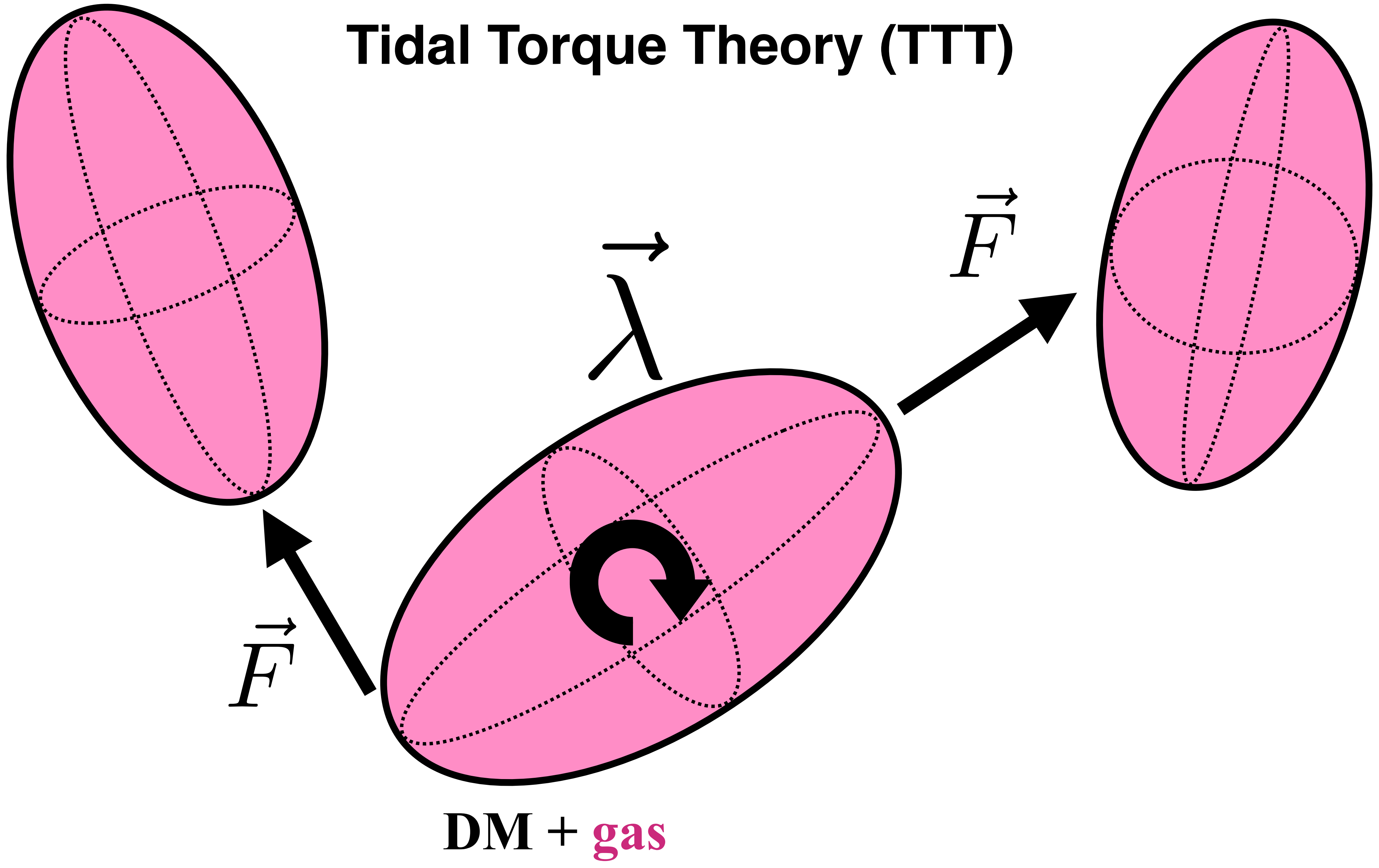

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$$j_\Delta = \frac{J_\Delta}{M_\Delta} \propto \lambda M_\Delta^{2/3}$$

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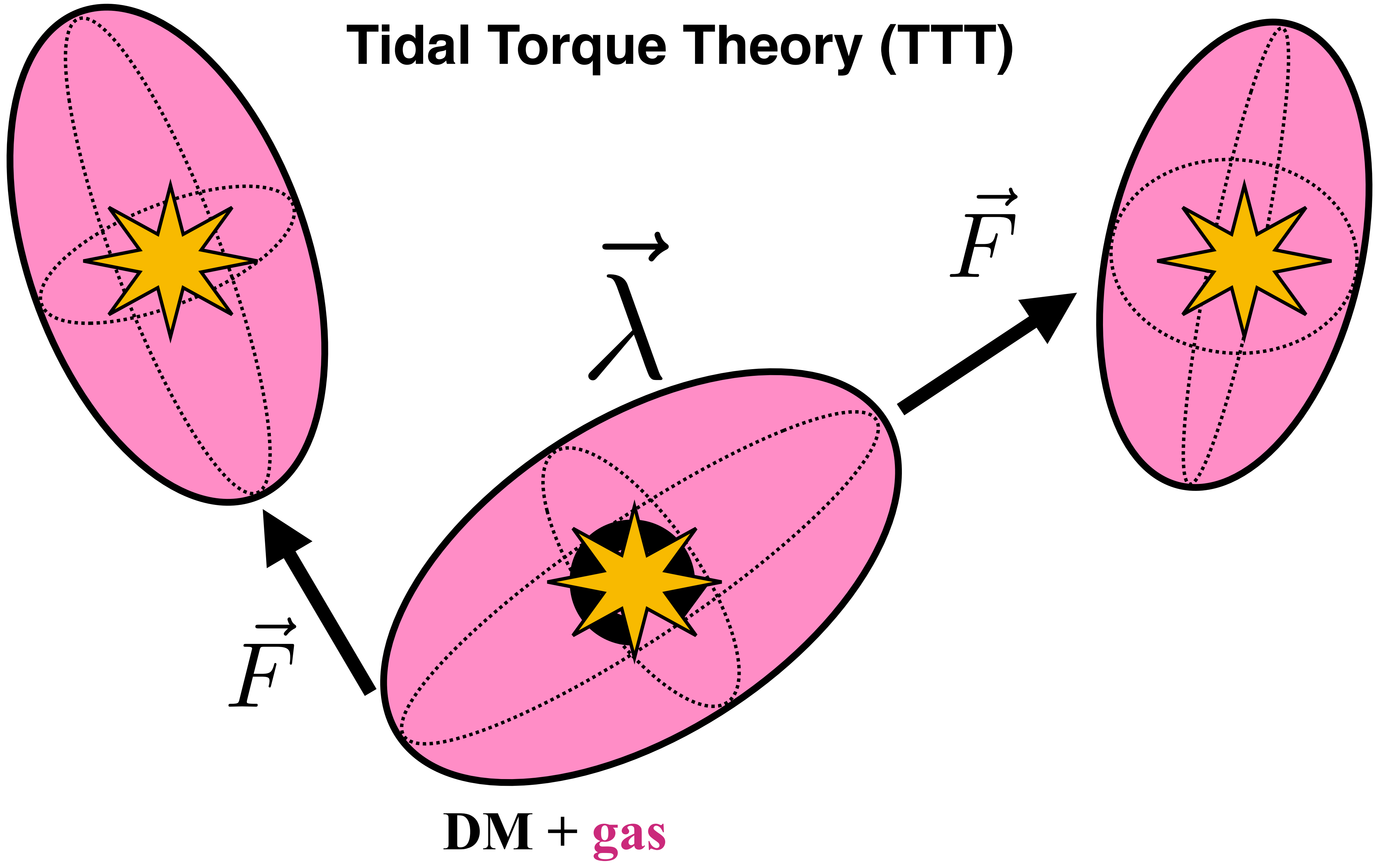
star formation efficiency

$$f_j \equiv \frac{j_*}{j_\Delta}$$

retained fraction of angular momentum



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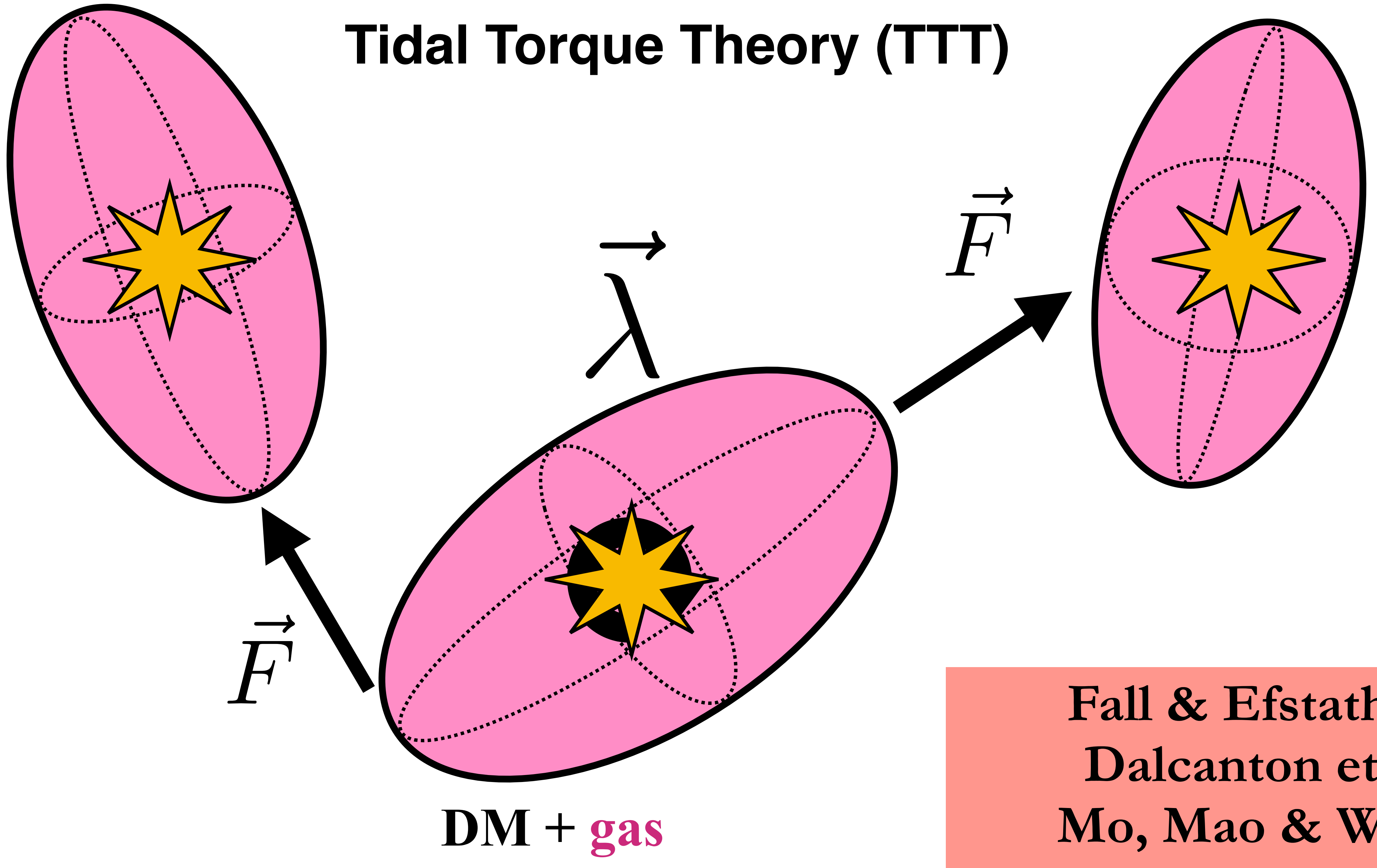

Fall & Efstathiou (1980)
Dalcanton et al. (1997)
Mo, Mao & White (1998)
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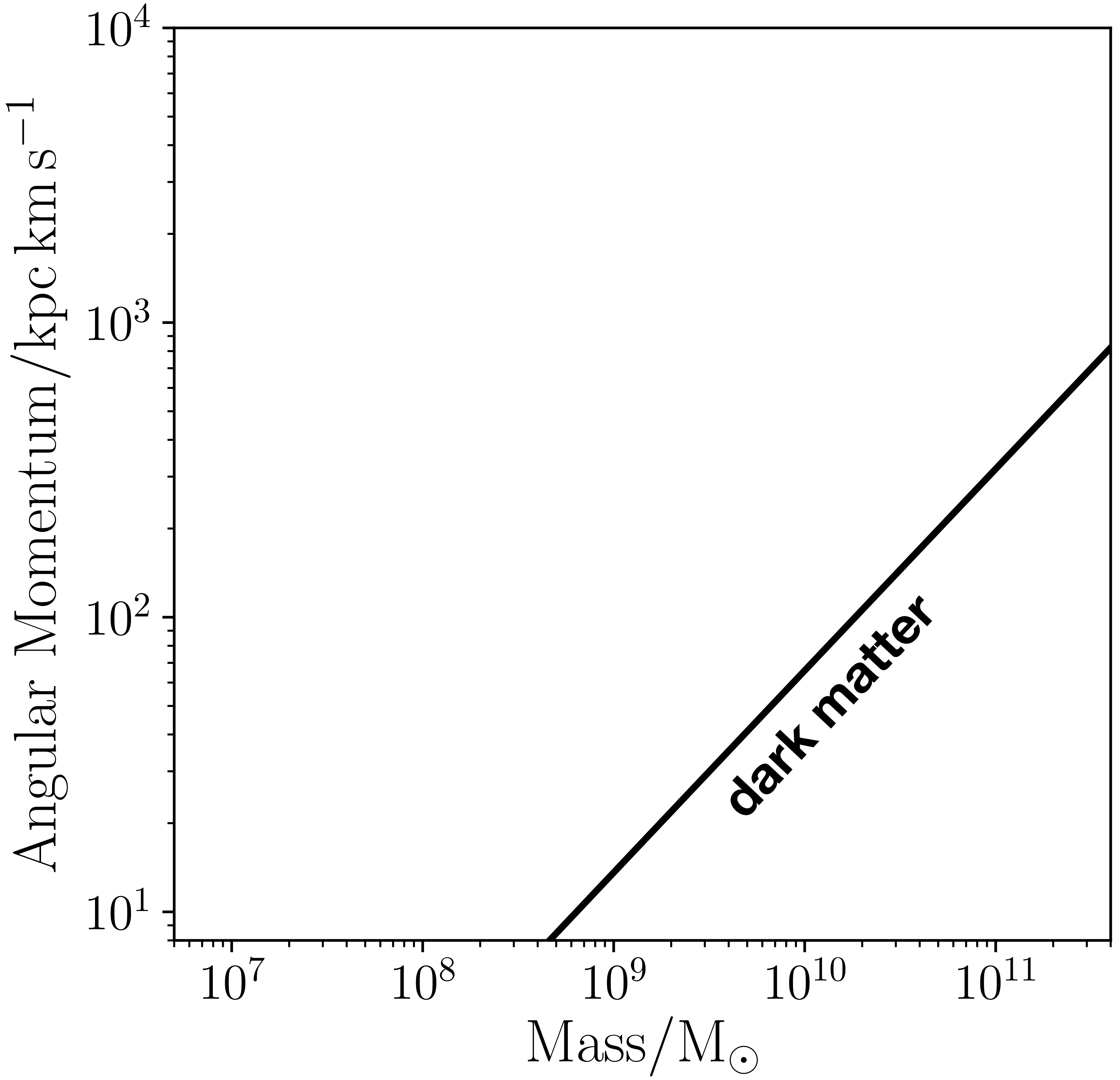

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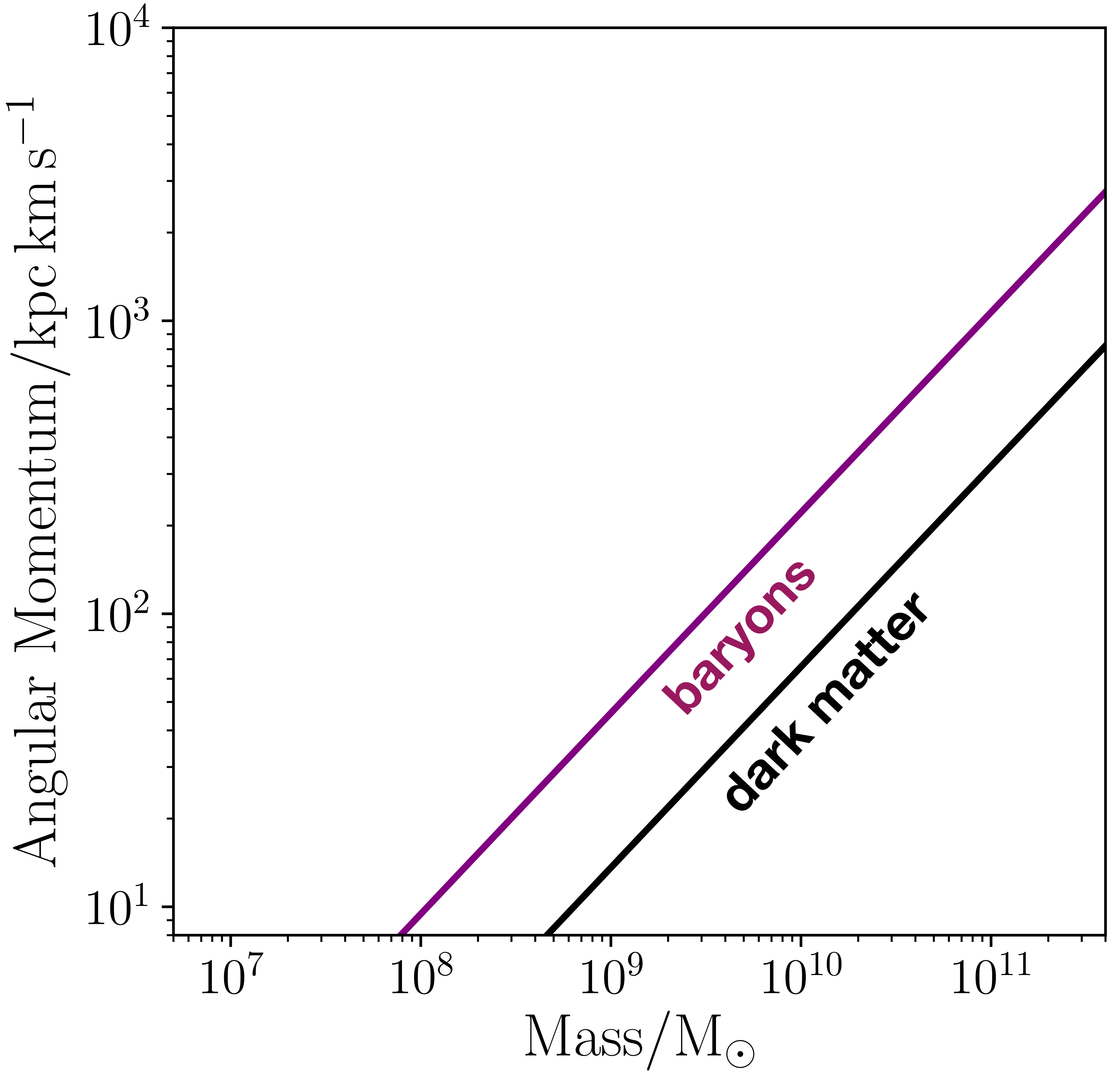

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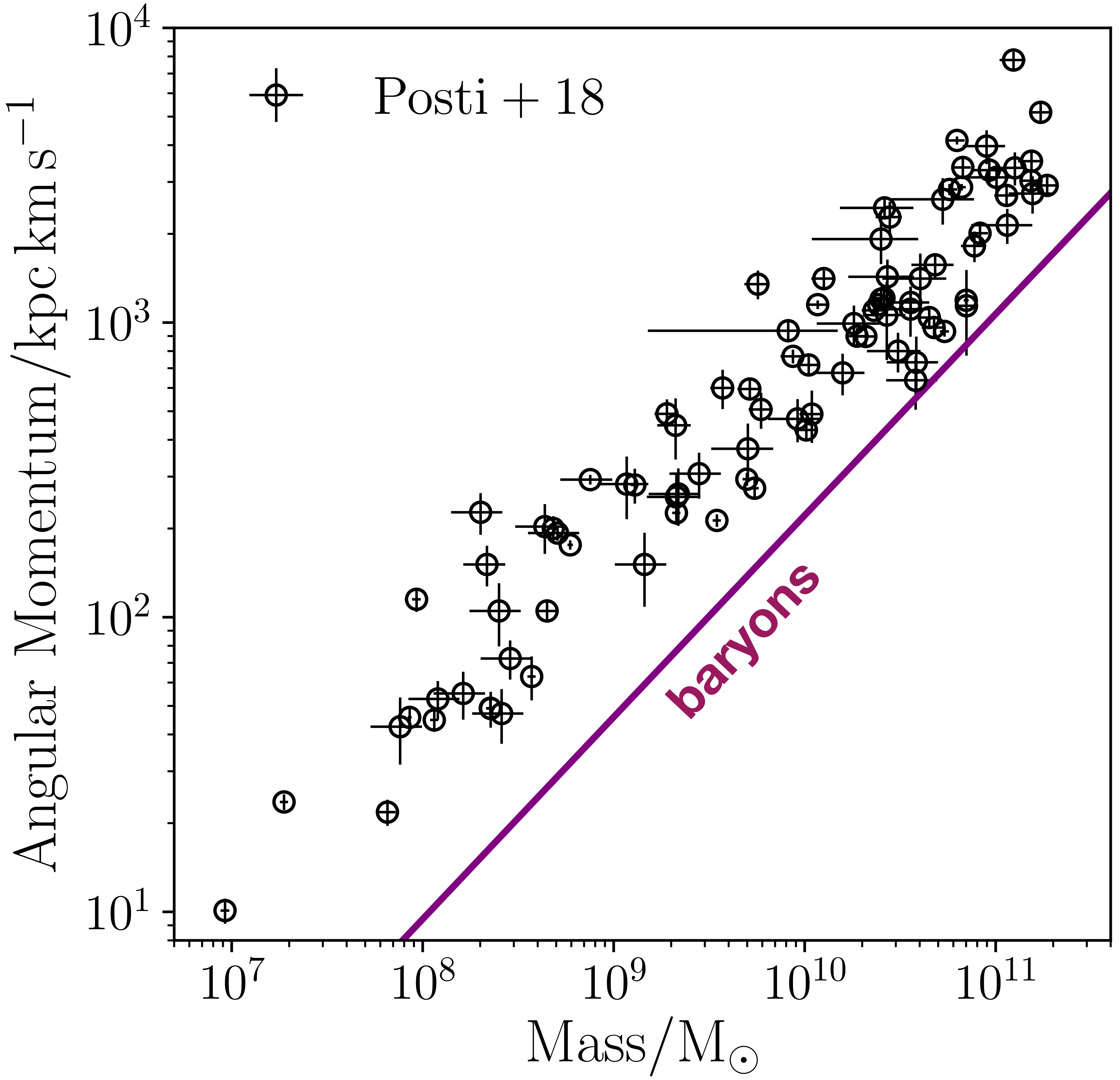

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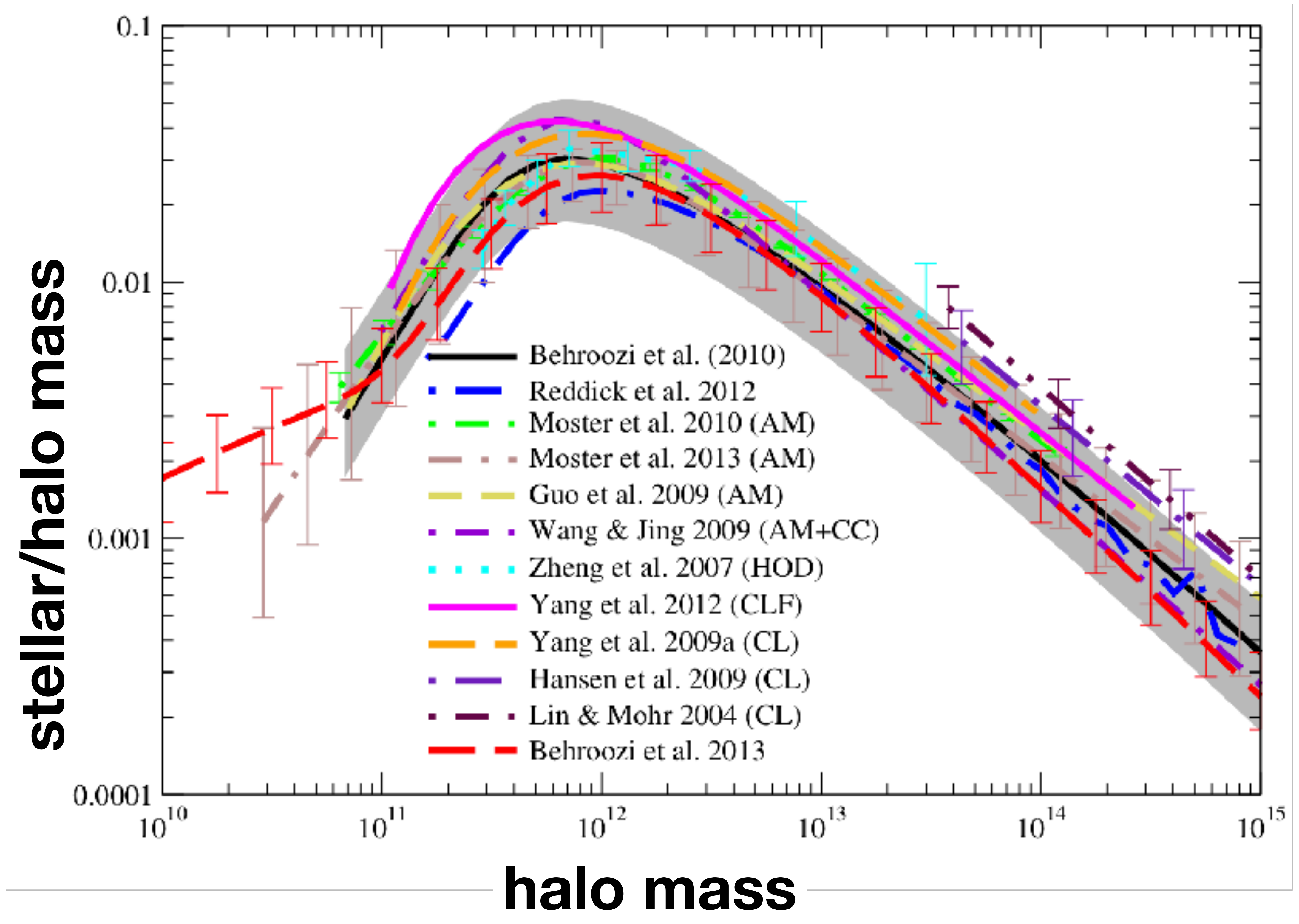

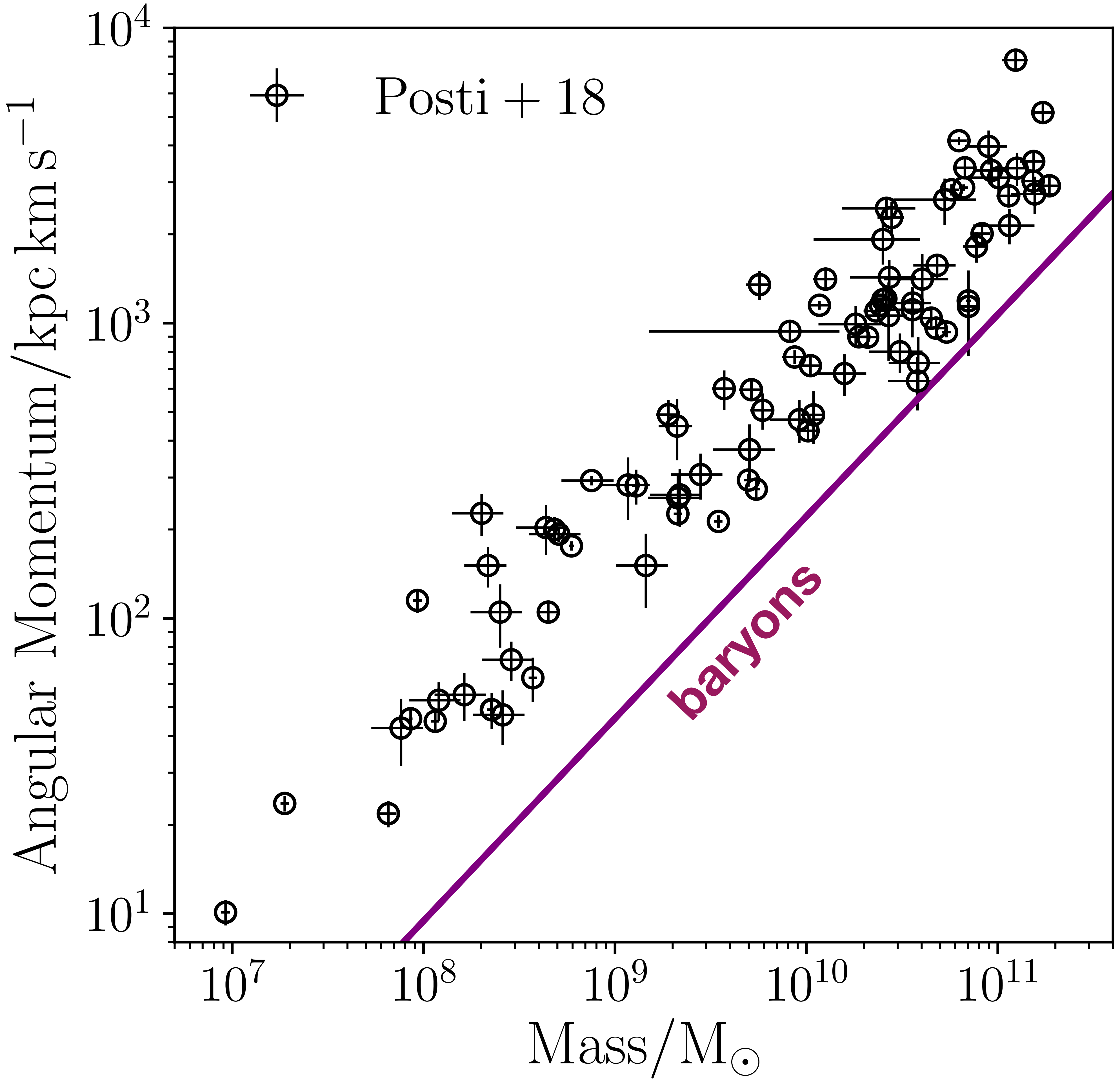

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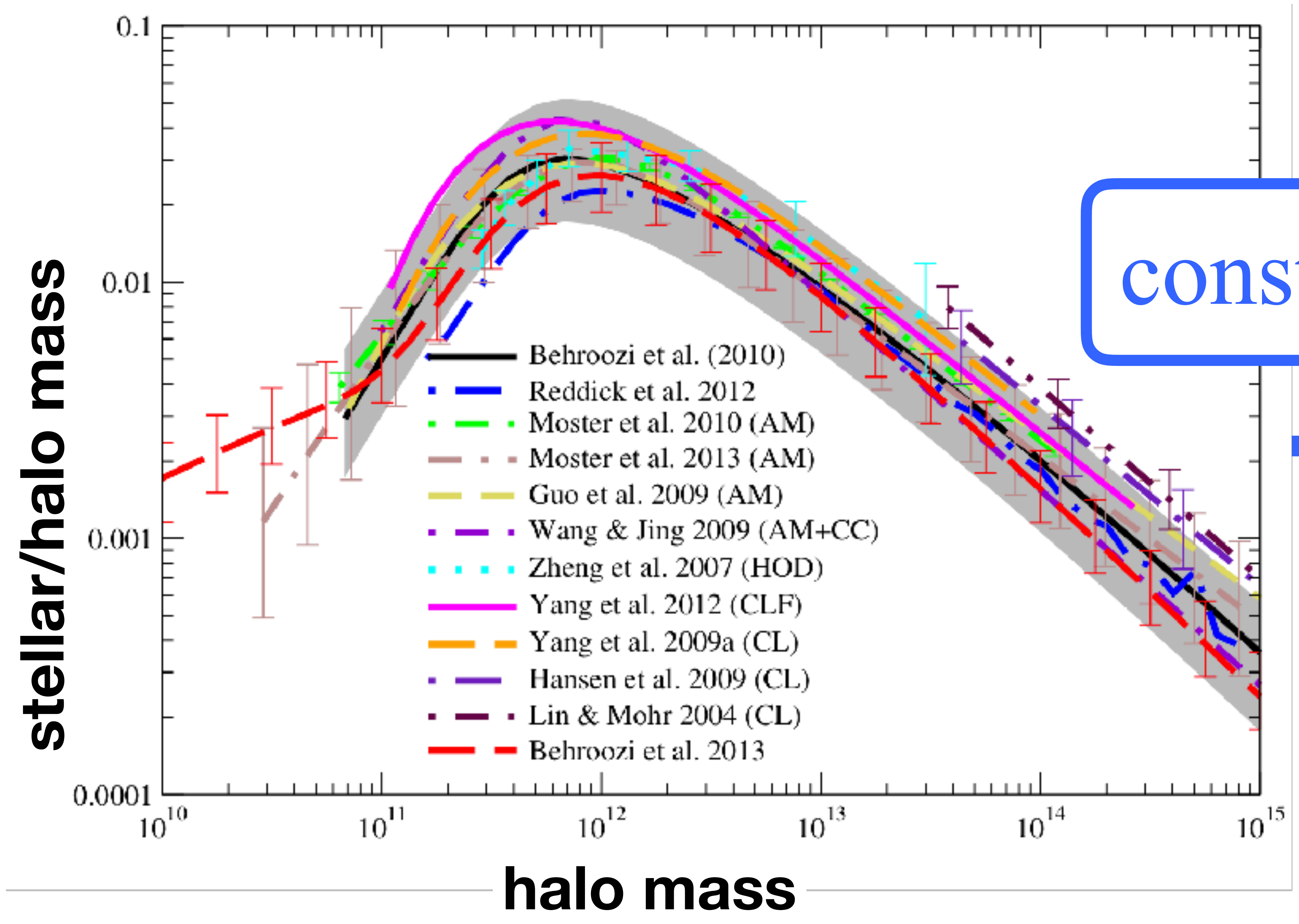
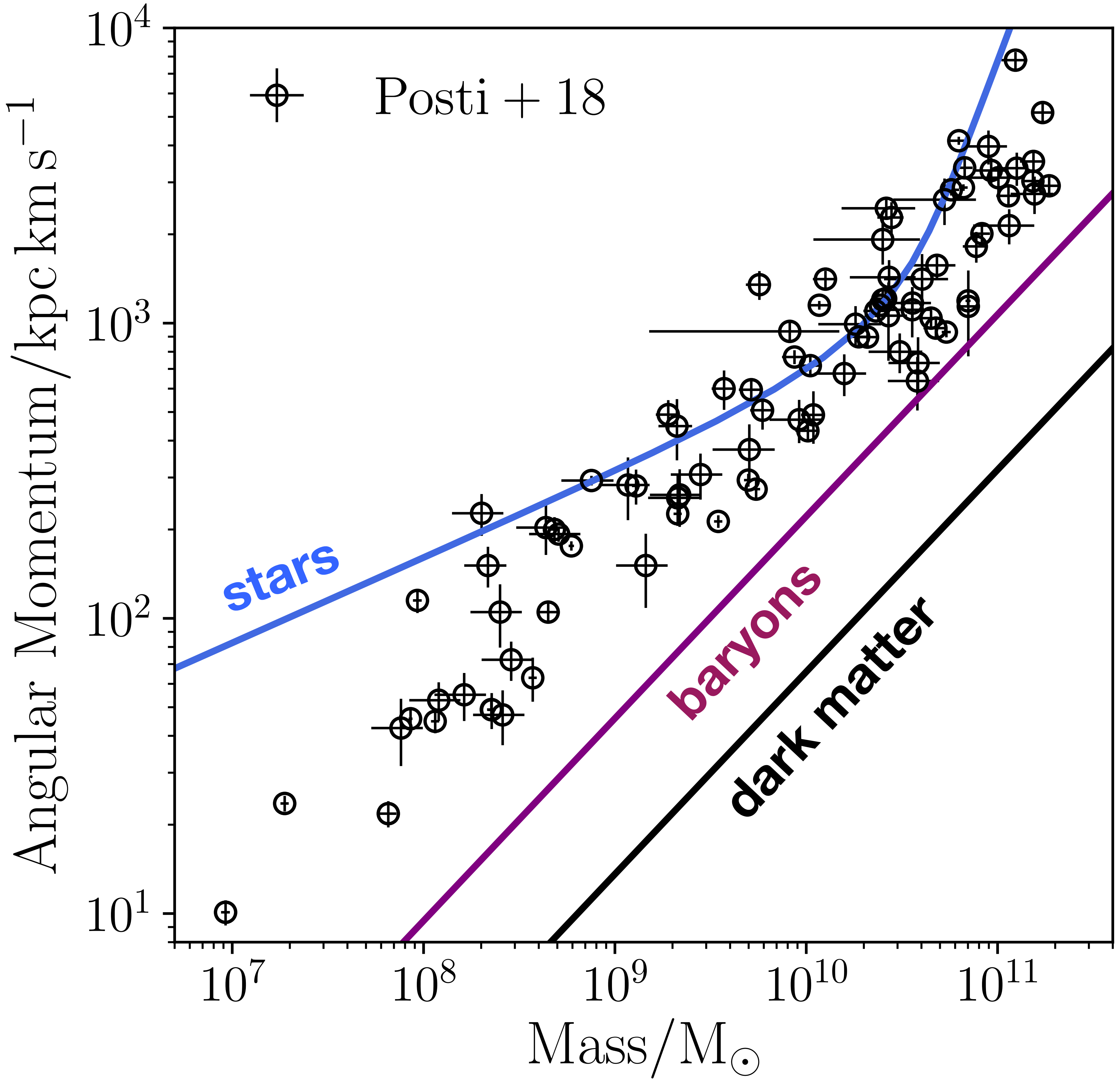


constant $f_j = 1$



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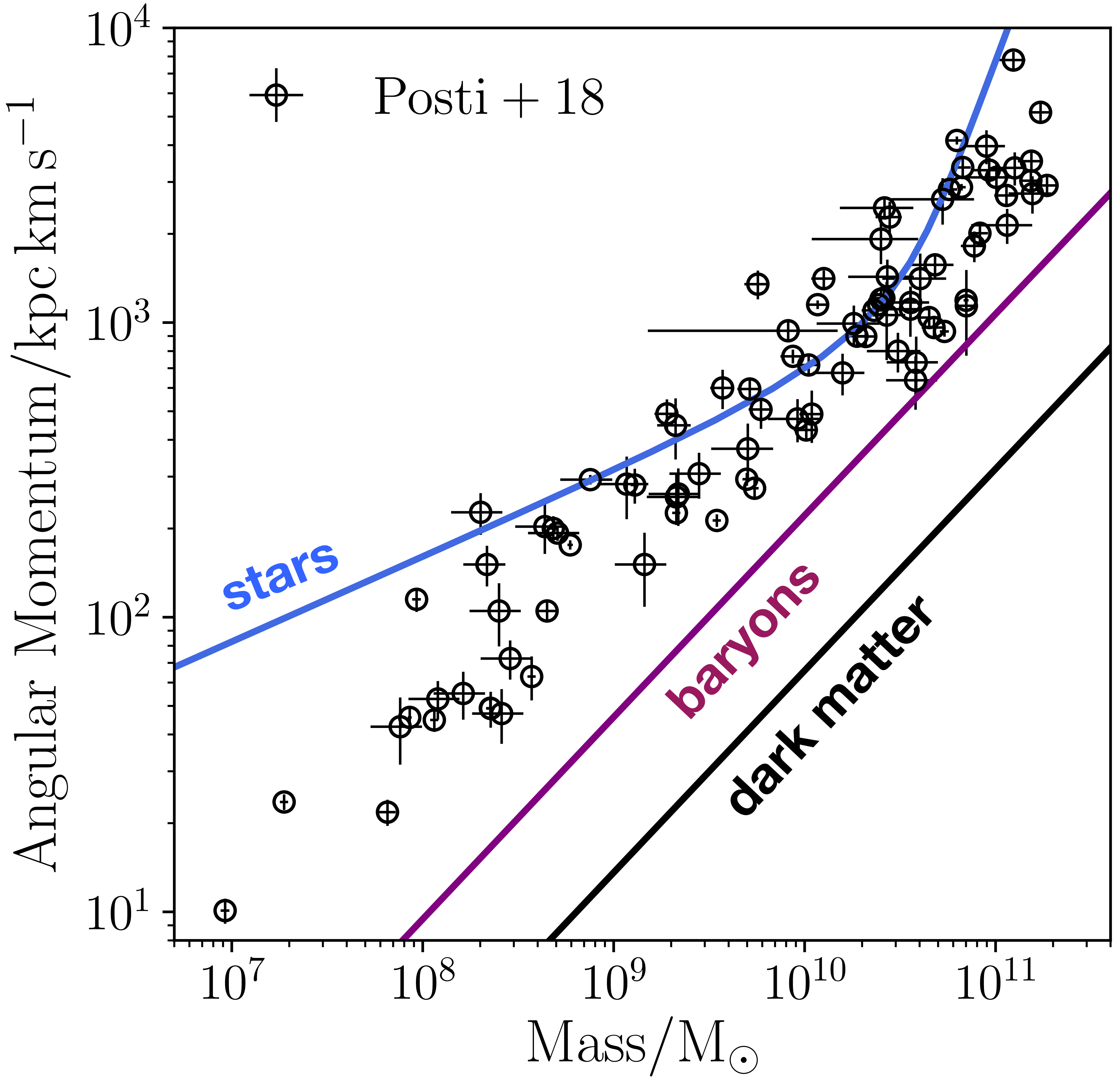
f_j must vary as a function of mass

f_j closely follows f_*



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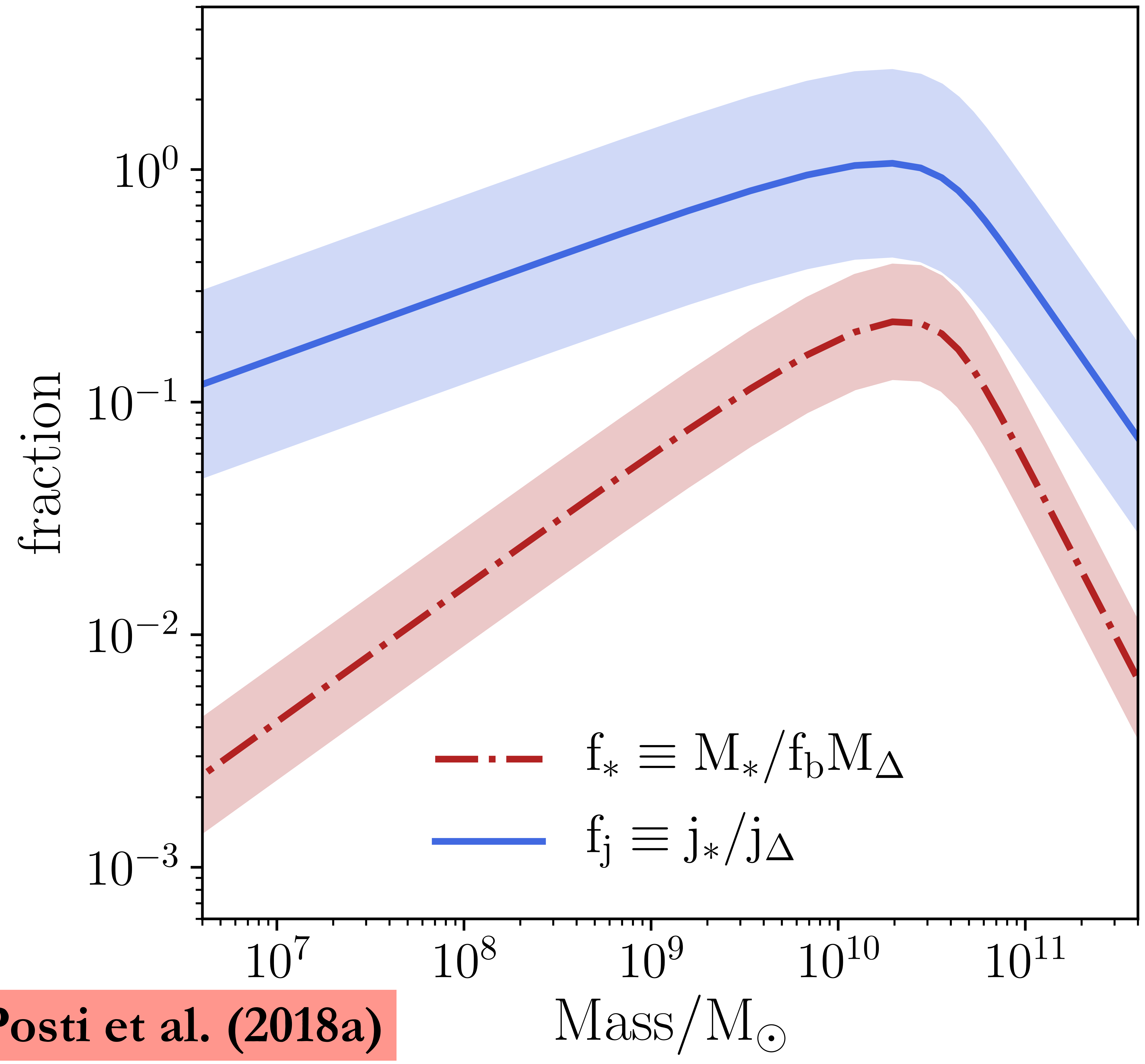
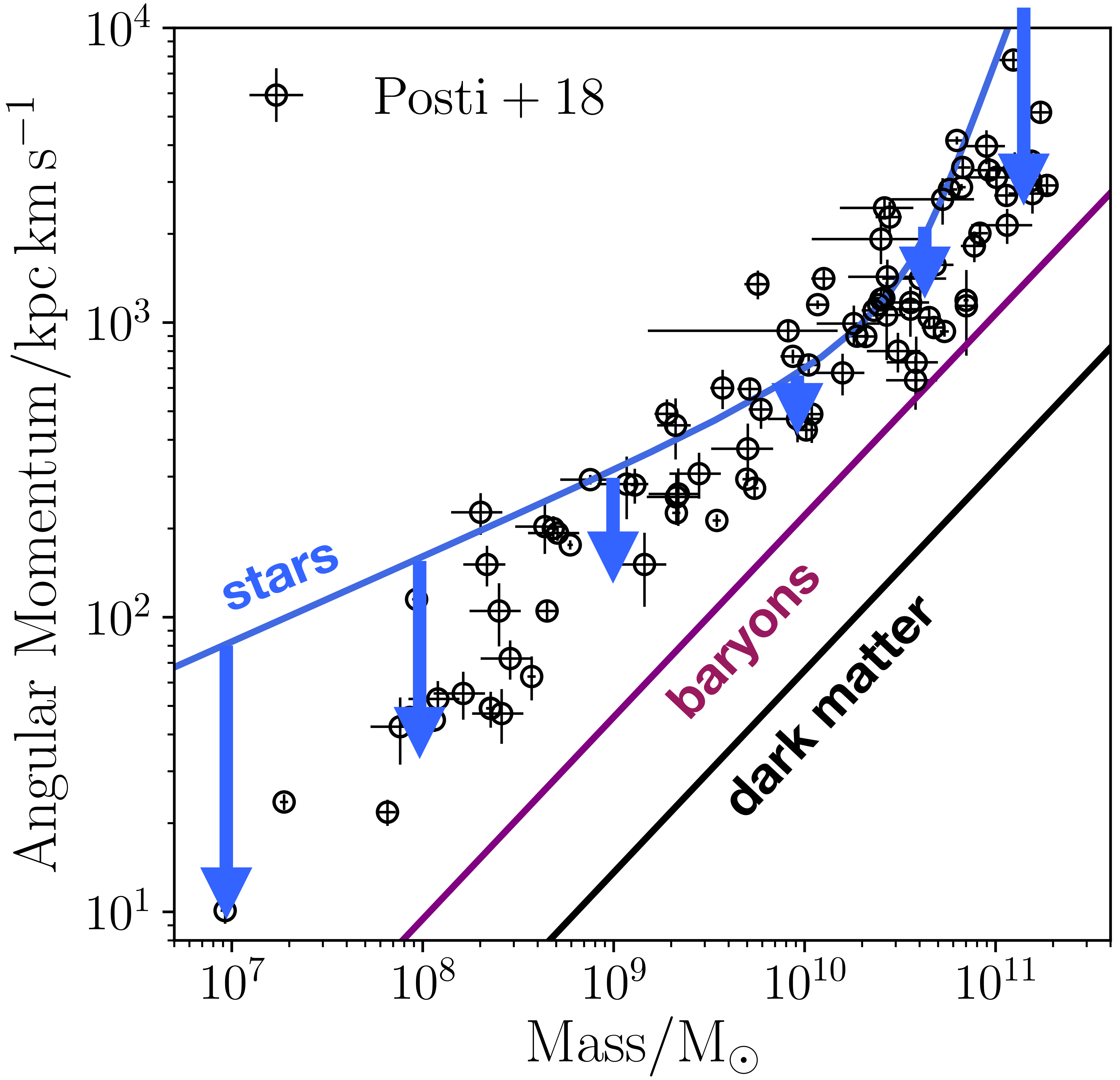
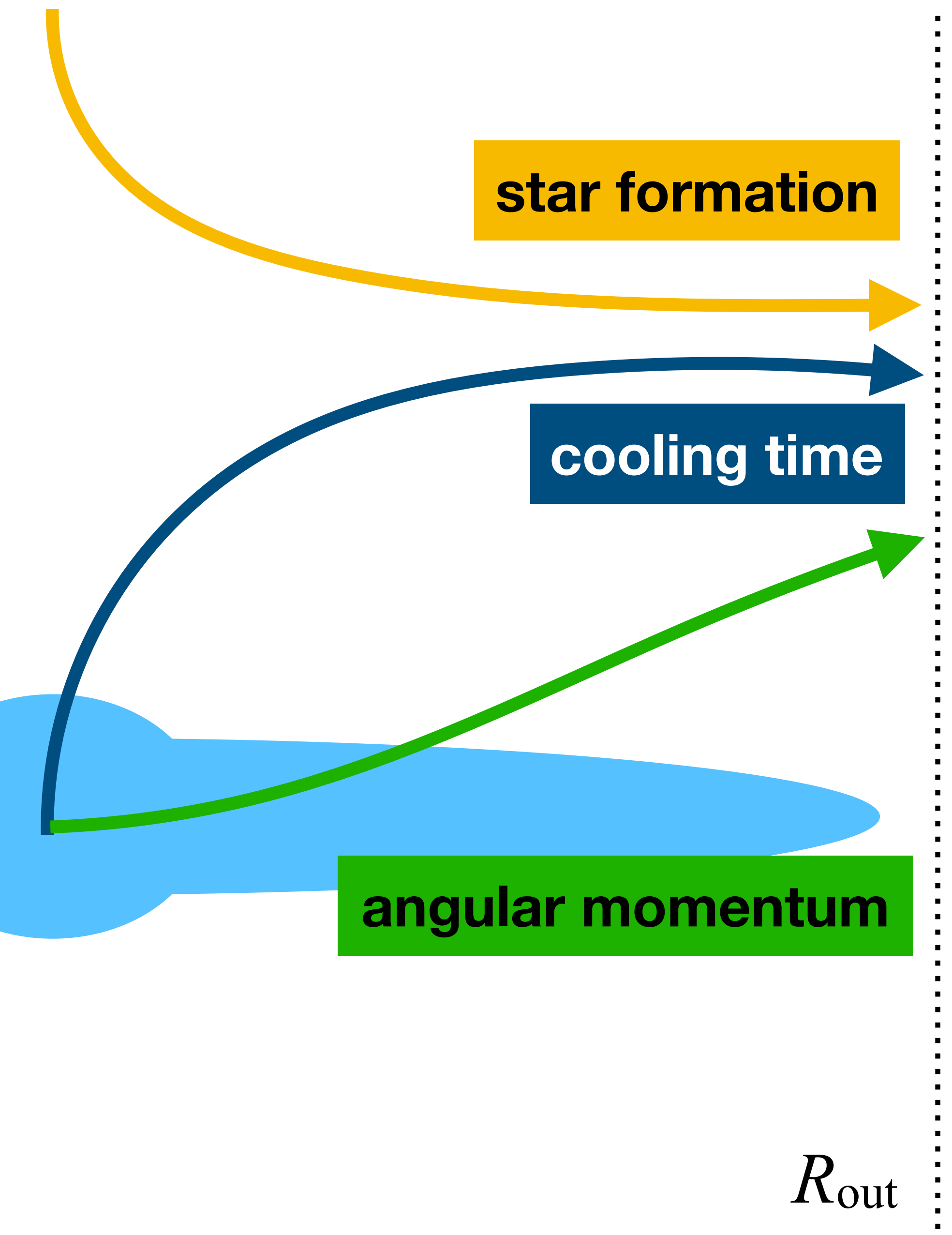


Posti et al. (2018a)



Which are the implications for galaxy formation?



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- Baryonic collapse is **biased** to low-j material

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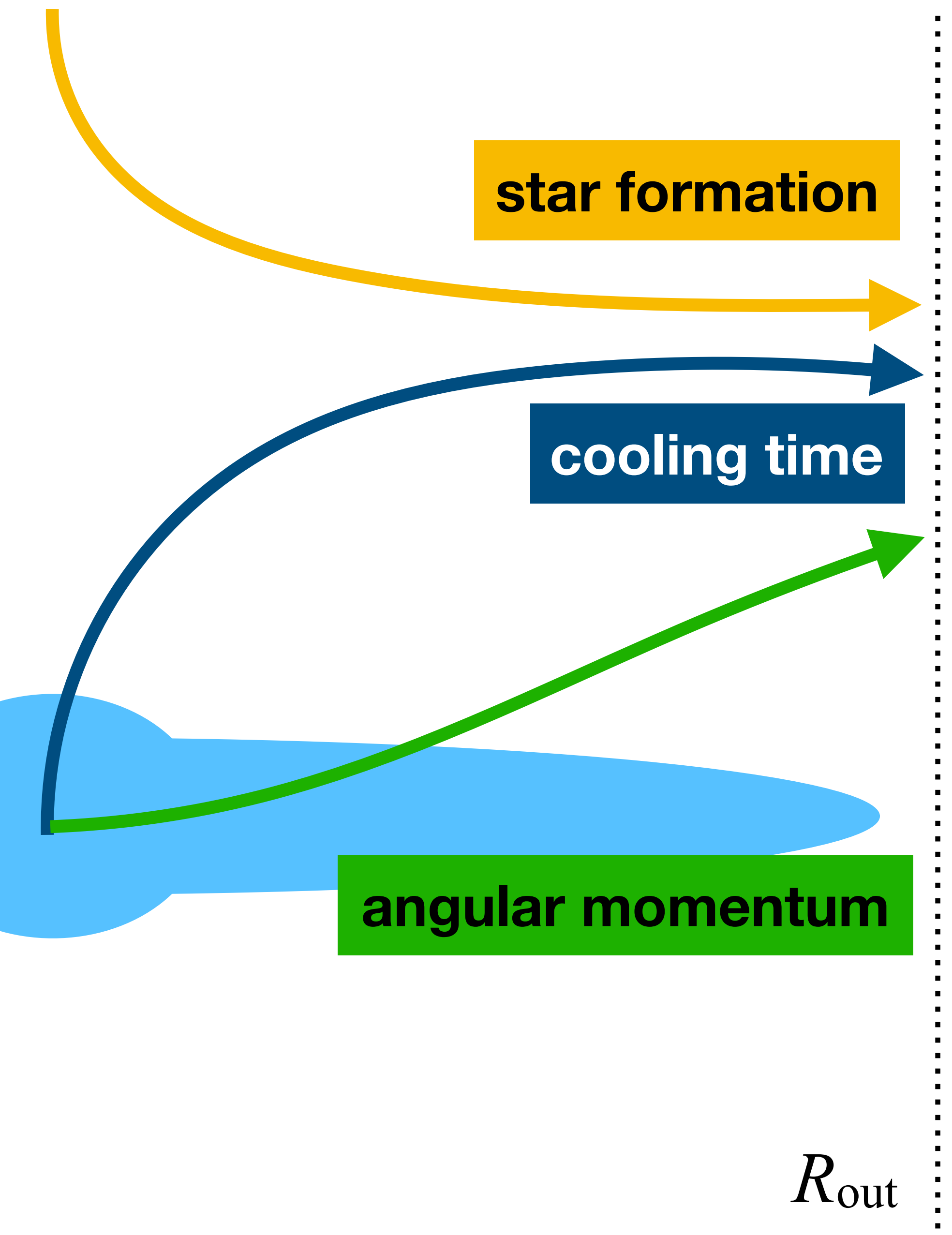

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e.g. Bullock et al. (2001)

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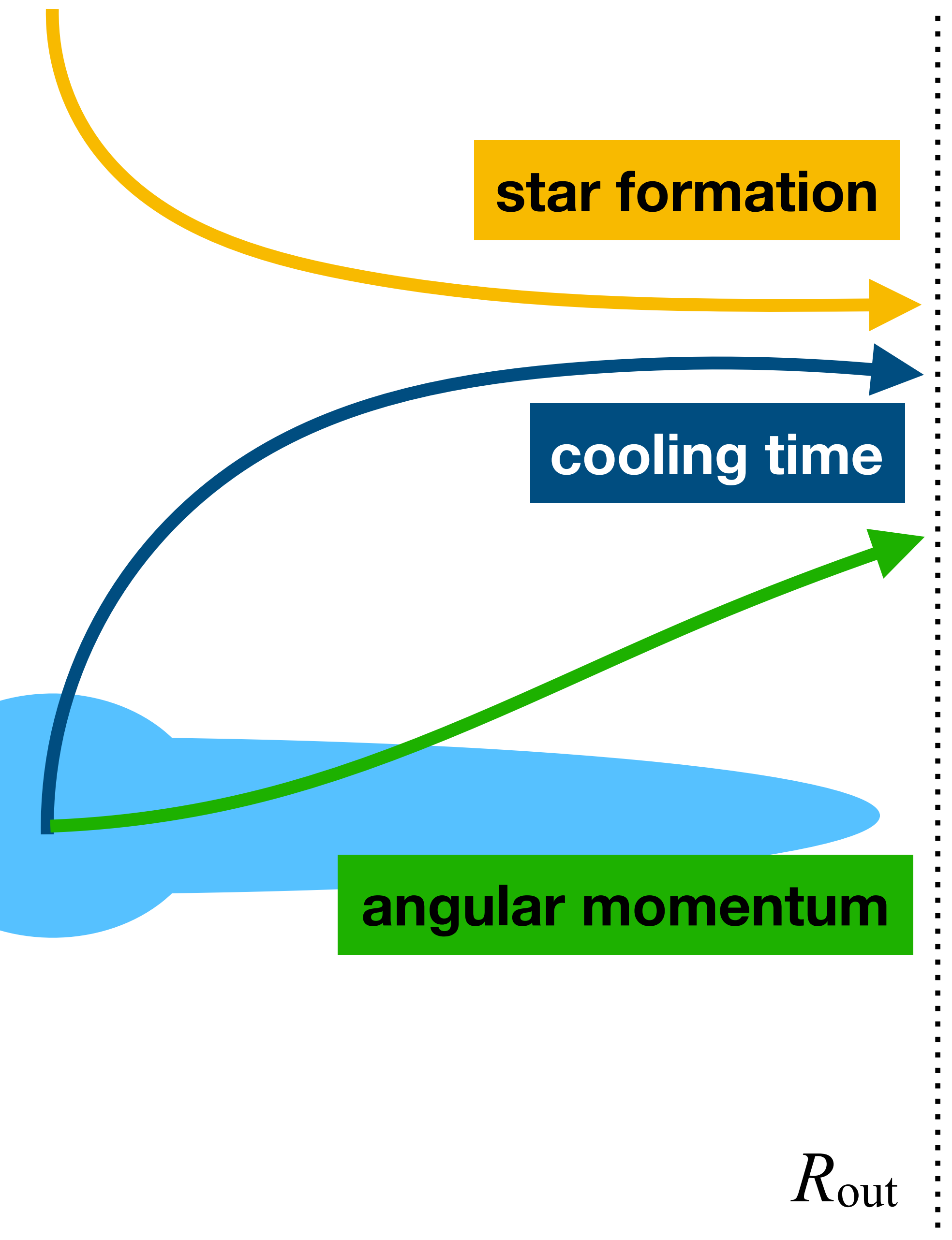

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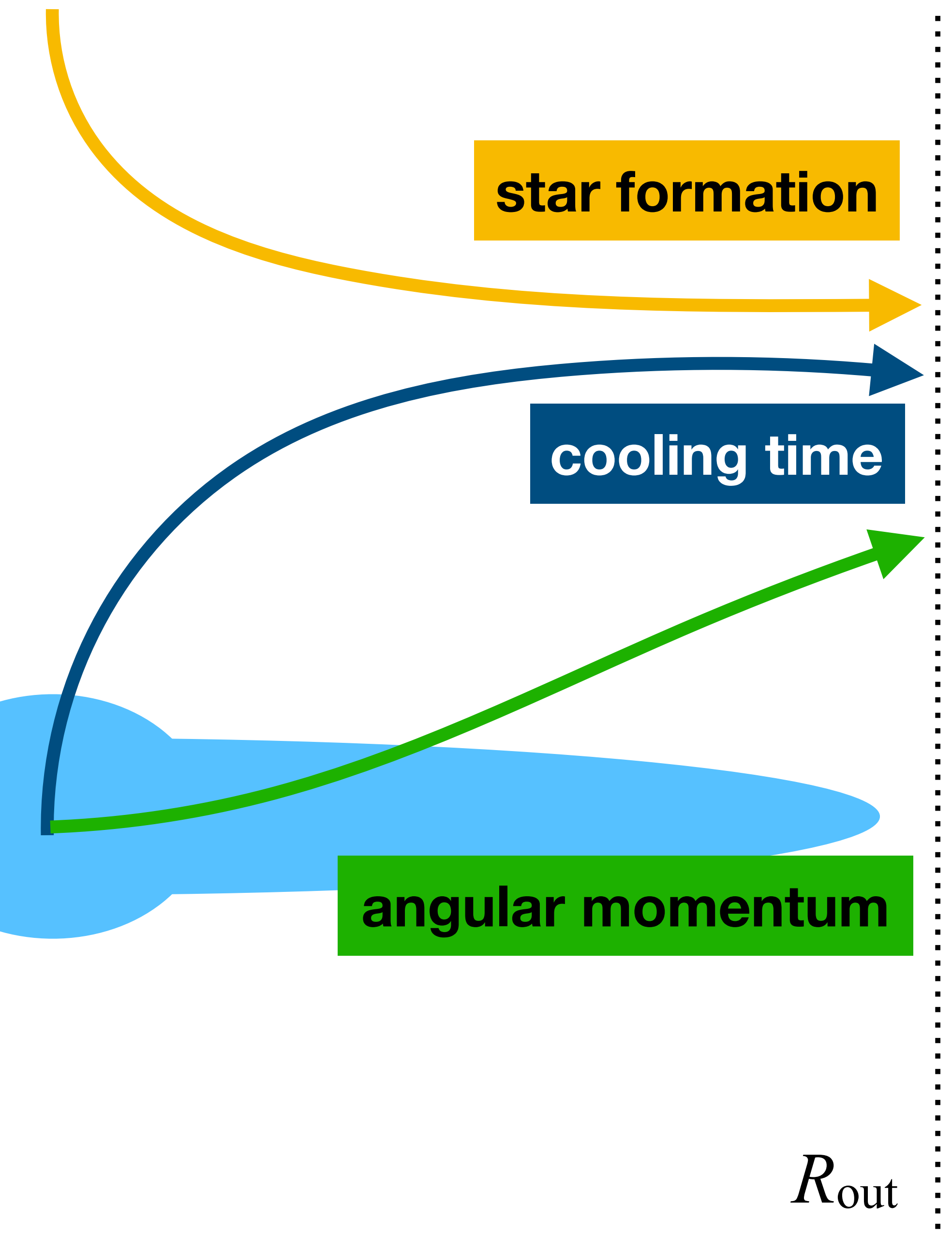

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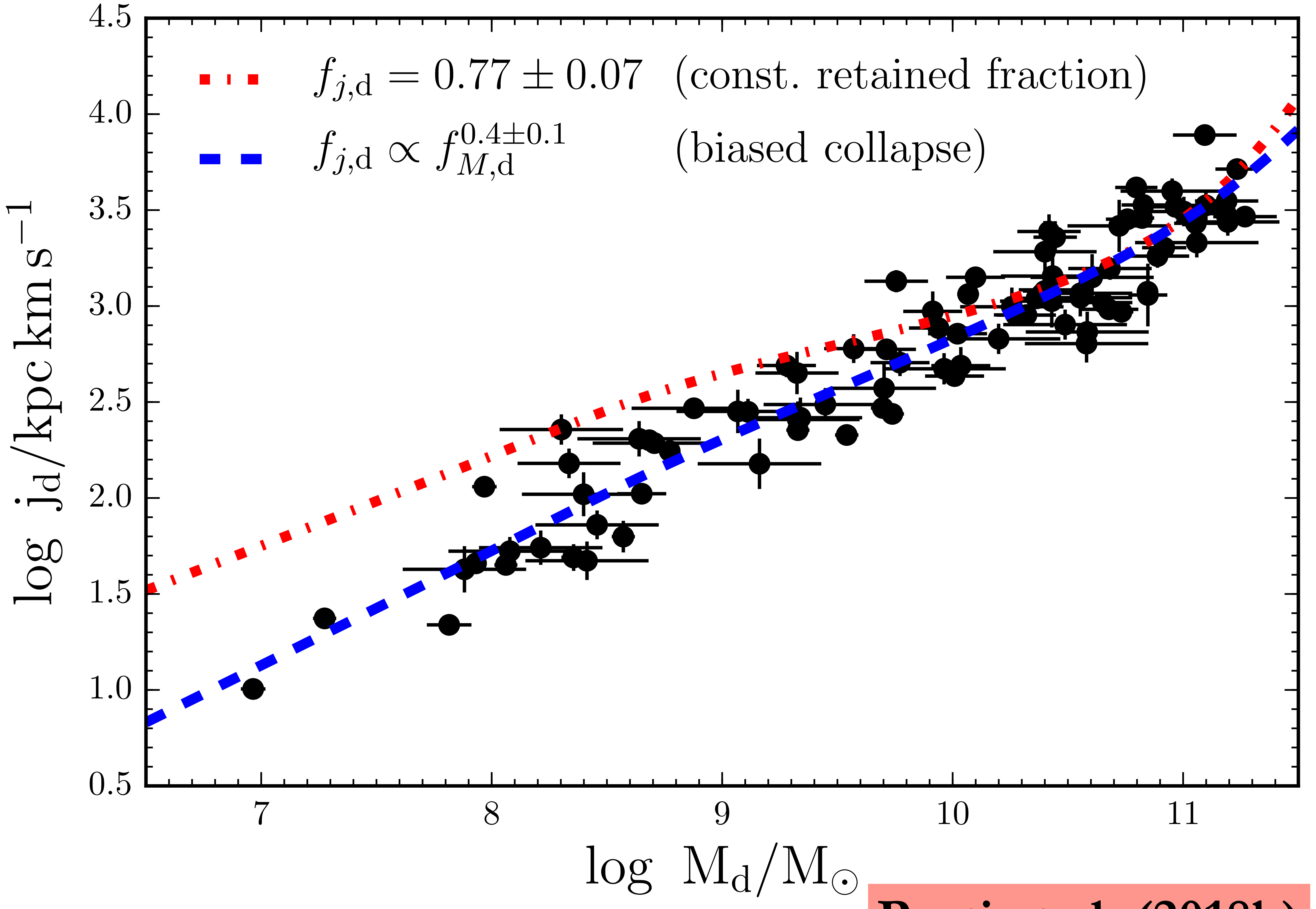

Posti et al. (2018b)

Conclusions

- The j-M relation ("*Fall relation*") is amongst the most **fundamental laws** of galaxy structure

- Most of the angular momentum is in the **outskirts**: need *extended rotation curves (HI)*!

- The Fall relation is a **single, unbroken power-law** from dwarf to massive spirals

- The *retained fraction of angular momentum* **follows** the *star formation efficiency*

$$\log f_j \propto \log f_*$$

$\Upsilon_\star V_\star$
V_{gas}
V_{DM}
model
V_{rot}
Velocity/km s^{-1}
Radius/kpc
log M_{halo} = $12.34^{+0.10}_{-0.09}$
log c = $1.02^{+0.11}_{-0.09}$
$\Upsilon_\star = 0.65^{+0.04}_{-0.05}$
UGC02953
$\chi^2_{red} = 6$
log $M_\star = 11.22^{+0.13}_{-0.13}$
$f_\star = 0.445^{+0.068}_{-0.077}$
log M_{halo}
log c
$\Upsilon_\star$

$f_b M_{halo}$
$M_\star/M_\odot$
$M_{halo}/M_\odot$
χ^2_{red}
$f_\star \equiv M_\star/f_b M_{halo}$
$M_\star/M_\odot$
χ^2_{red}