Are Dwarf Spheroidal and Ultra Faint Dwarf galaxies the most dark matter dominated stellar systems?

Leo I dwarf

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Warsaw, August 21, 2024

Are DSph and UFD the most …

- The presence of dark matter is invoked to explain many observational issues.

- Anyway, so far, its existence is *questionable* at least on "galactic scales".

Open cluster

NGC 265

$(M/L)_\odot < 1$

Globular cluster

M 80

$(M/L)_\odot \sim 2$

No DM

Dwarf galaxy

Leo I

$(M/L)_\odot \sim 4$

Ultra faint dwarf

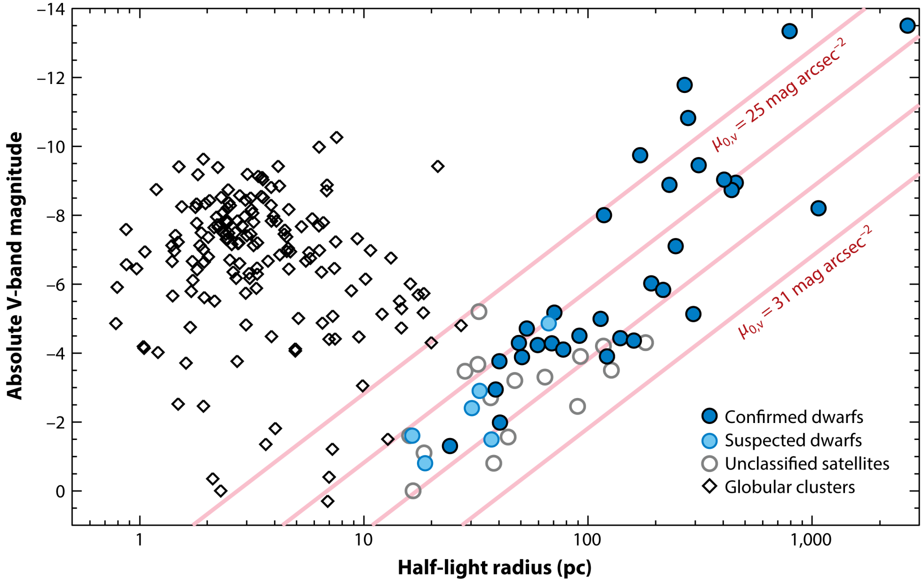
Eridanus

$(M/L)_\odot \sim 130$

Most DM dominated?

Milky Way satellites

(from Simon, J.D., ARAA, 2019, 57)

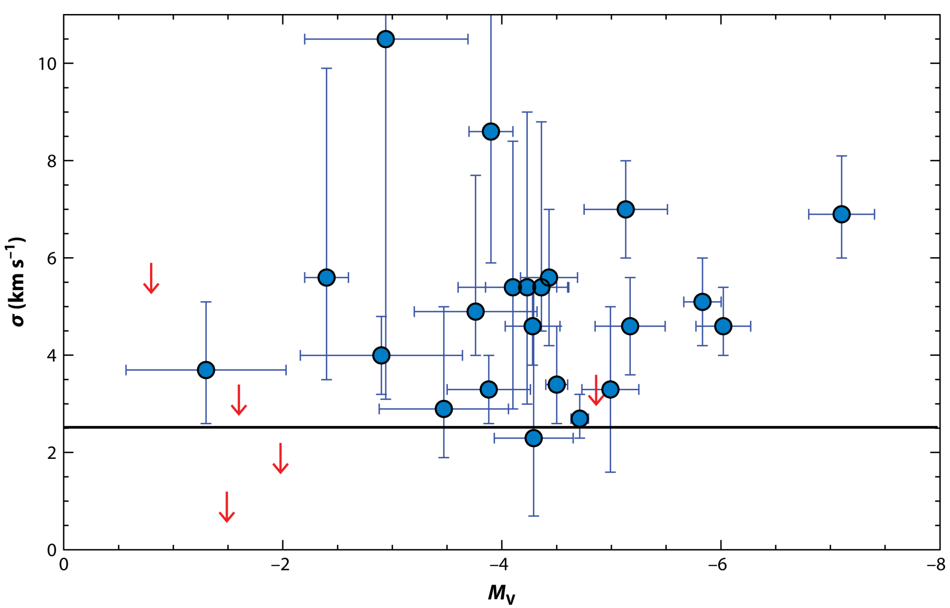


Simon JD. 2019.
Annu. Rev. Astron. Astrophys. 57:375–415

Annual Reviews

Milky Way UFDs

(from Simon, J.D., ARAA, 2019, 57)



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UFDs: $M_V > -7.7$ ($M < 10^5\, M_\odot$)

Most updated data base from Andrew Pace:
https://github.com/apace7/local_volume_database

Milky Way UFDs

29 UFDs: $\langle M_{dyn}/L \rangle = 512$

15 DSphs: $\langle M_{dyn}/L \rangle = 49$

M31 UFDs

8 UFDs: $\langle M_{dyn}/L \rangle = 449$

27 DSphs: $\langle M_{dyn}/L \rangle = 55$

If these very high values of M/L are actually due to huge DM content would make DSphs and UFDs:

- extremely interesting targets to look for direct 'detection' of DM particles via their *annihilation* and/or *decay* via Gamma ray observation with Cherenkov telescopes (CTA, under construction).

CTA at La Palma and Cerro Paranal

Dark matter line searches with the CherenkovTelescope Array,
S. Abeet al JCAP07, 2024, 04

Let's consider Ultra Faint Dwarf galaxies (UFDs)

As we said, they are considered as the ***most DM dominated*** objects in the Universe.

They are often *unresolved* or *poorly resolved* stellar systems.
So the above statement relies upon:

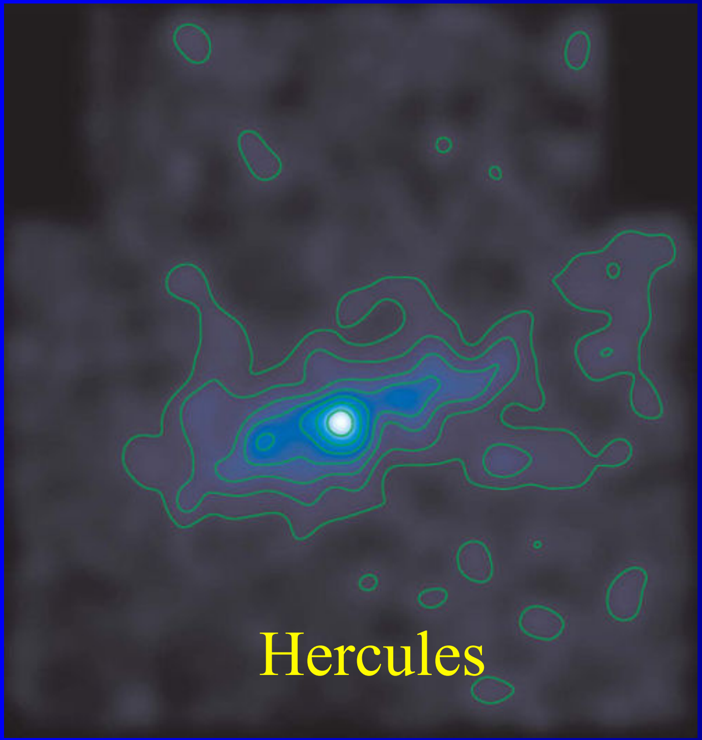
i) their large *integrated* 1D velocity dispersion, together with the
ii) hypothesis they are *virialized*.

Questionable …

Are DSph and UFD the most …

Virialized? In some case *yes* (e.g. Fornax) in many others *no* (e.g. Hercules, UMa2, Sextans,…).

(refer also to Fellhauer, this conference)

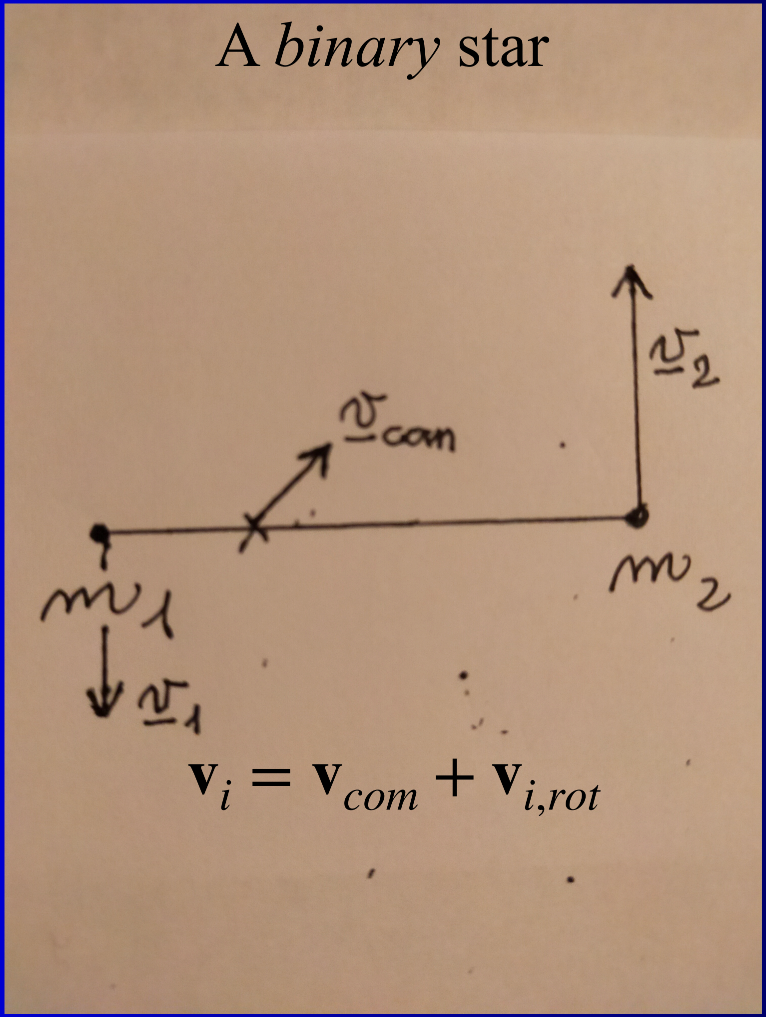


$L \sim 30{,}000\ L_\odot$ $(M/L)_\odot \sim 160$

$L \sim 4{,}000\ L_\odot$ $(M/L)_\odot \sim 770$

The role of (unresolved) binaries.

(Refer also to Wirth, this conference)



With $m_1 = m_2 = 1\ M_\odot$ and $a = 1$ AU

$$\sigma_b \sim \sqrt{G\frac{m_1 + m_2}{a}} \simeq 42.2\text{km/s}$$

in an open cluster σ ~1 km/s

The role of (unresolved) binaries.

$$M \le M_{vir} = \alpha \frac{R_{vir}}{G}\sigma^2_{com} < \alpha \frac{R_{vir}}{G}\sigma^2_{obs}$$

overestimate

Given a binary fraction $0 < f_b < 1$ over a population of single stars

$$\sigma^2_{obs} = (1 - f_b)\sigma^2_s + f_b\sigma^2_b \Longrightarrow \frac{\Delta M}{M} \equiv \frac{M_{obs} - M}{M} = f_b \left[\left(\frac{\sigma_b}{\sigma_s} \right)^2 - 1 \right]$$

Being $\sigma^2_{com} \propto M$ while σ^2_b is not:

binaries affect more the *low mass* systems

Are DSph and UFD the most …

(Rastello et l. 2020; Pianta, Capuzzo Dolcetta & Carraro; Flammini Dotti et al in prep.)

Table 1. Structural parameters of the simulated galaxies.

Object	R (pc)	M ($M_\odot$)	t_{rh} (Gyr)	X	Y	Z	Age (Gyr)	L_{bol} ($L_\odot$)	L_V ($L_{V,\odot}$)	L_B ($L_{B,\odot}$)
dSph	3×10^3	10^7	1.79×10^5	0.747	0.252	0.001	13	1.35×10^8	1.38×10^7	1.67×10^7
UFD	50	5×10^4	43.07	0.747	0.252	0.001	13	6.72×10^5	6.88×10^4	8.37×10^4

Binary population

$$\begin{cases} f(e) = 2e,\ 0 \le e \le 1 \\ g(a) = k/a,\ a_{min} \le a \le a_{max} \\ p(m_2/m_1) = (m_2/m_1)^{-q},\ q = 0, 0.4 \end{cases}$$

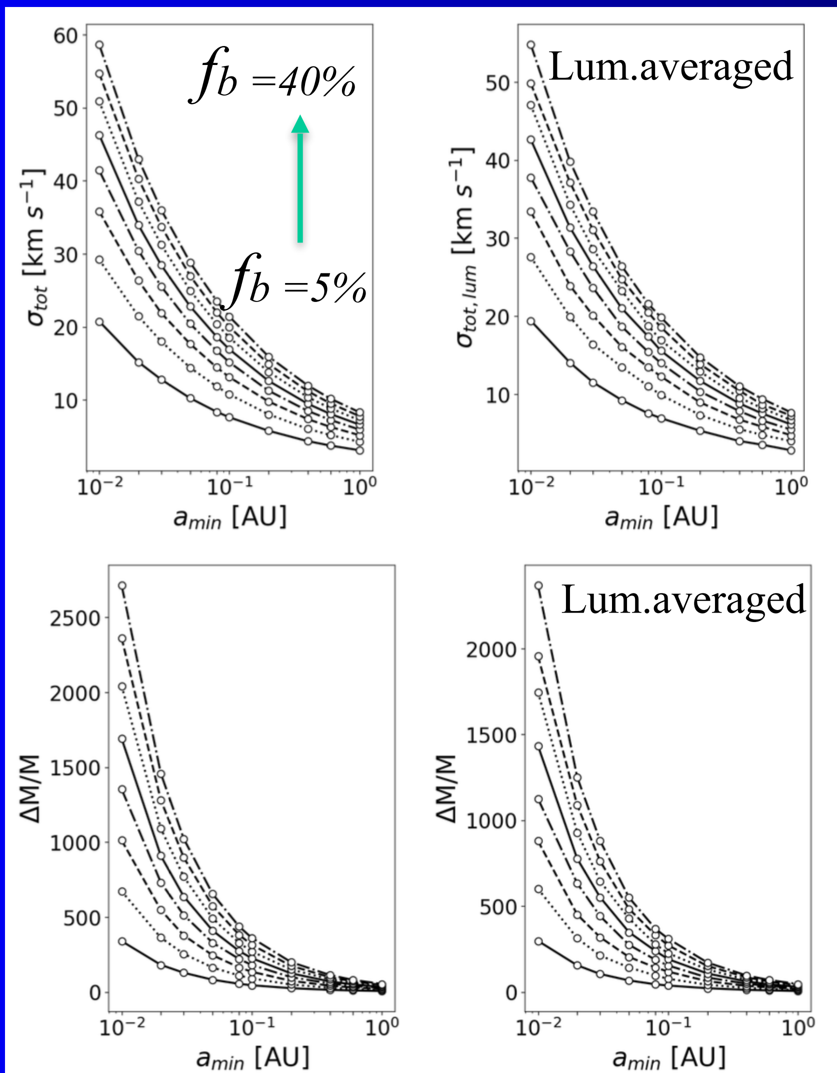
We account for RLOF

Table 2. Ranges of variation of parameters characterizing the binary populations.

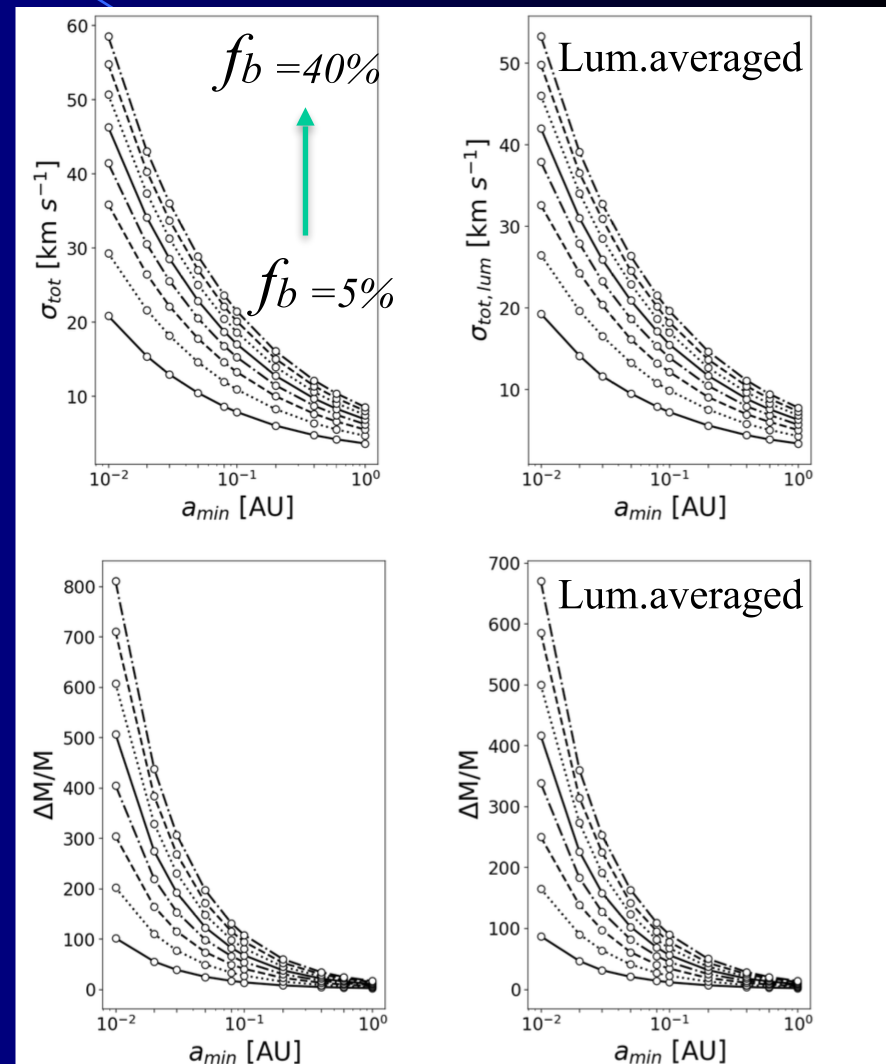
f_b	a_{min} (AU)	a_{max} (AU)	e
0.05–0.4	0.01–1	50–400	0–1

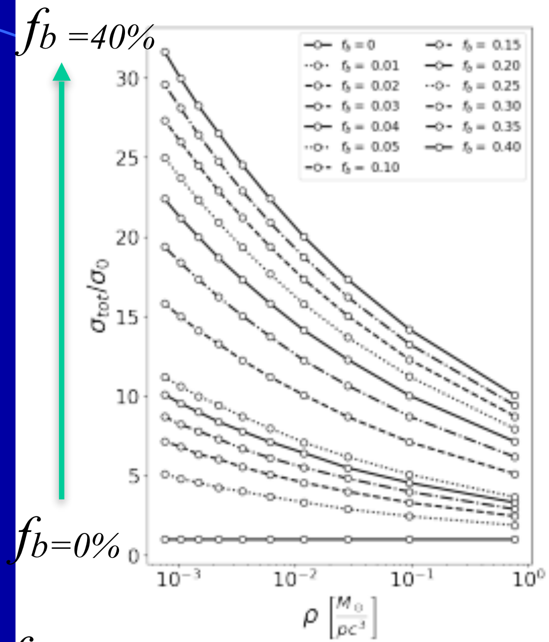
Are DSph and UFD the most …

UFD



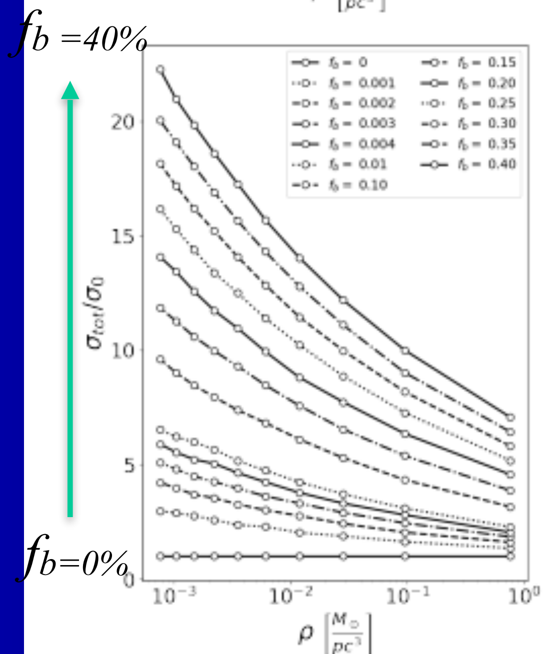
dSph





f_b =40%
f_b=0%
$f_b = 0$
$f_b = 0.01$
$f_b = 0.02$
$f_b = 0.03$
$f_b = 0.04$
$f_b = 0.05$
$f_b = 0.10$
$f_b = 0.15$
$f_b = 0.20$
$f_b = 0.25$
$f_b = 0.30$
$f_b = 0.35$
$f_b = 0.40$
σ_{tot}/σ_0
$\rho \left[\frac{M_\odot}{pc^3}\right]$

No RLOF



f_b =40%
f_b=0%
$f_b = 0$
$f_b = 0.001$
$f_b = 0.002$
$f_b = 0.003$
$f_b = 0.004$
$f_b = 0.01$
$f_b = 0.10$
$f_b = 0.15$
$f_b = 0.20$
$f_b = 0.25$
$f_b = 0.30$
$f_b = 0.35$
$f_b = 0.40$
σ_{tot}/σ_0
$\rho \left[\frac{M_\odot}{pc^3}\right]$

RLOF

Are DSph and UFD the most …

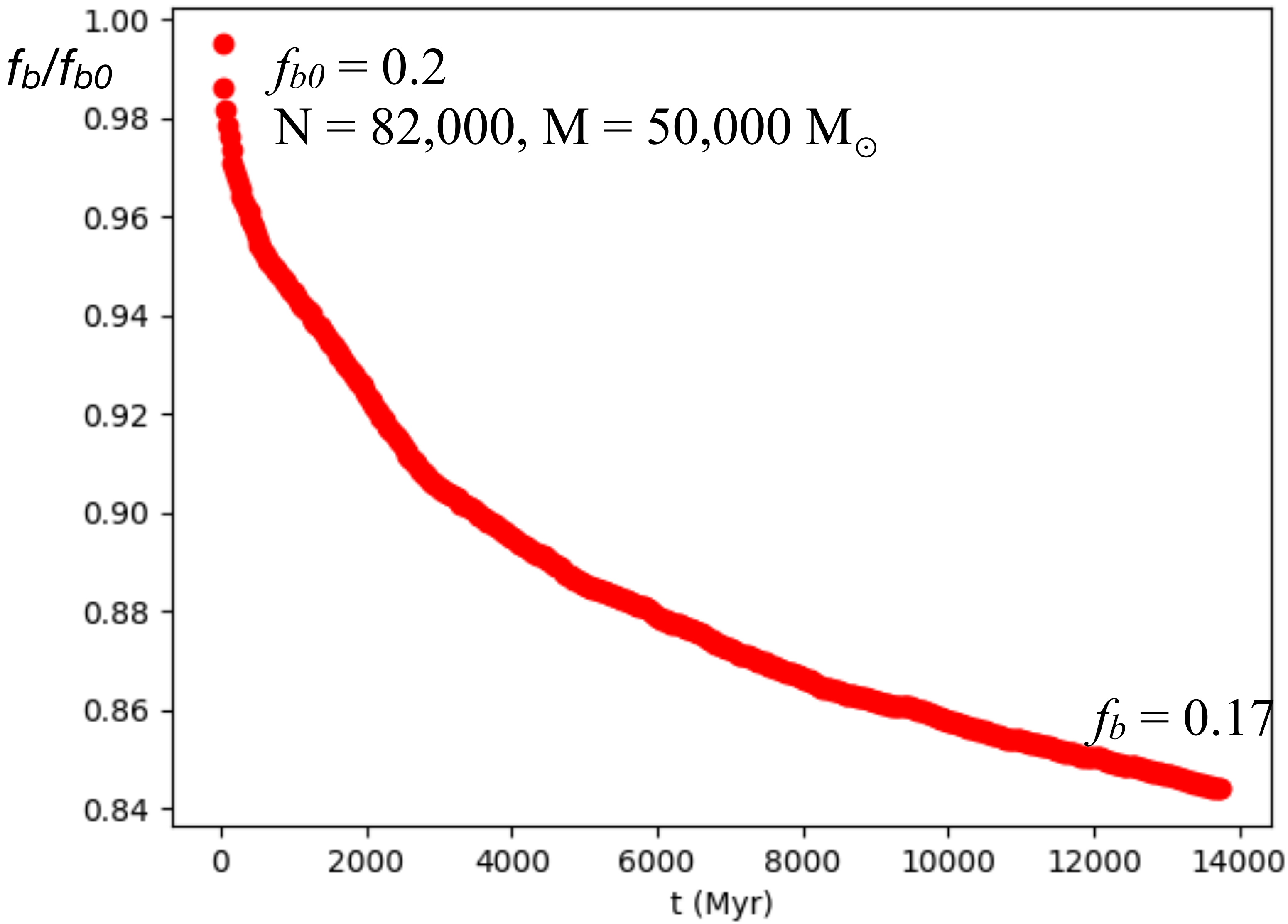
DSph

f_b	$(M/L_{bol})_\odot$	$(M/L_V)_\odot$
0.09	6.29	5.93
0.23	16.14	15.16
0.37	31.29	29.40
0.44	38.29	37.36

UFD

f_b	$(M/L_{bol})_\odot$	$(M/L_V)_\odot$
0.05	19.43	18.27
0.15	61.57	57.70
0.30	141.14	132.40
0.40	209.86	195.39

(Capuzzo Dolcetta, Flammini Dotti, Carraro & Spurzem, in prep.)

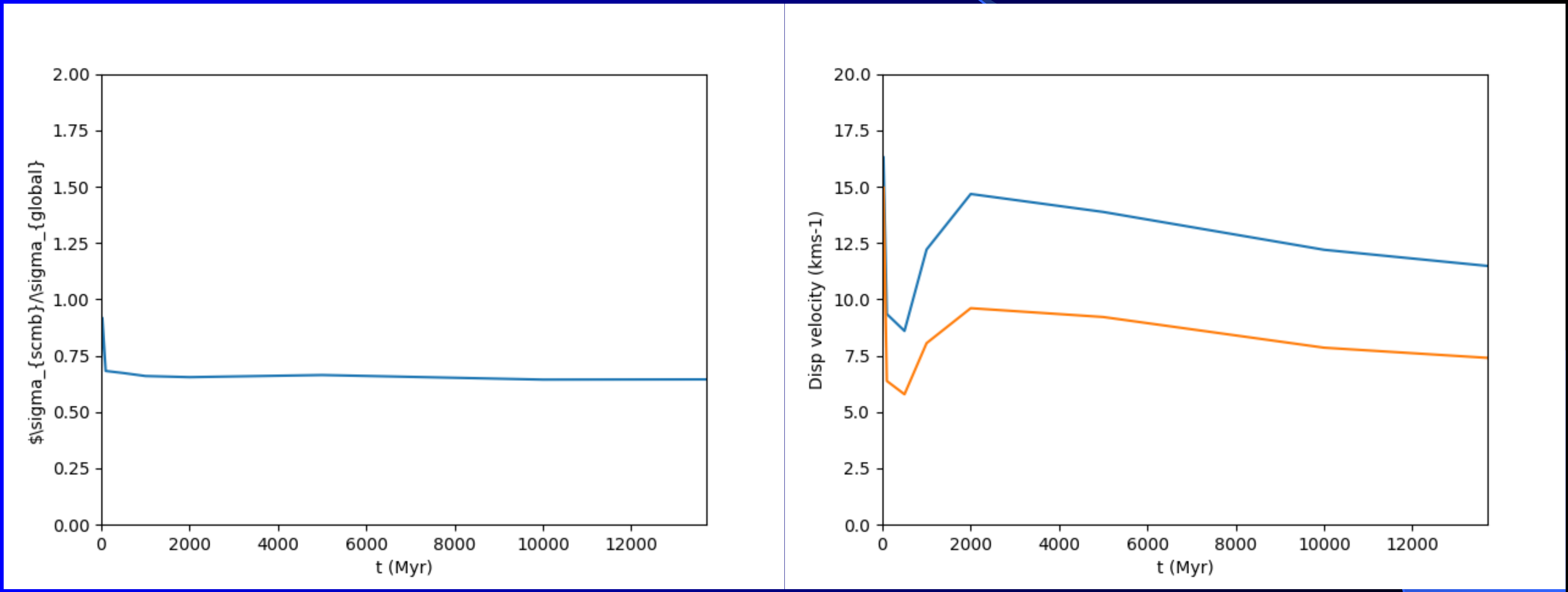


Conclusions

- Binaries may affect the velocity dispersion determination and so the dynamical mass evaluation;
- binary "inflation" is more relevant for low mass systems like UFDs rather than dSphs;
- the binary boost of velocity dispersion steeply increases at decreasing galaxy density;
- for UFDs, large mass-to-light ratios can be interpreted by

an unresolved binary population without invoking non baryonic DM.

END


$\sigma_{scmb}/\sigma_{global}
t (Myr)
Disp velocity (kms-1)
t (Myr)

Are DSph and UFD the most …

Table 3. Values of the mass-to-light ratio in the bolometric and V and B photometric bands for various binary fractions, in the case of our reference model.

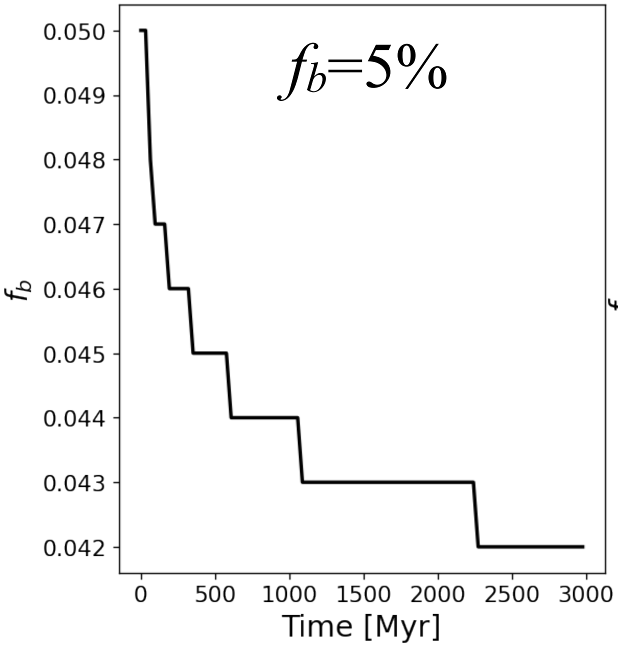
Object	f_b	$(M_{dyn}/L)_{bol}$ ($M_\odot/L_\odot$)	$(M_{dyn}/L)_V$ ($M_\odot/L_{V,\odot}$)	$(M_{dyn}/L)_B$ ($M_\odot/L_{B,\odot}$)
dSph	0	0.07	0.73	0.60
	0.05	0.63	6.15	5.06
	0.15	1.75	17.07	14.03
	0.30	3.41	33.38	27.44
	0.40	4.53	44.29	36.40
UFD	0	0.07	0.73	0.60
	0.05	1.95	19.04	15.65
	0.15	5.64	55.16	45.34
	0.30	11.26	110.13	90.53
	0.40	14.92	145.88	119.95

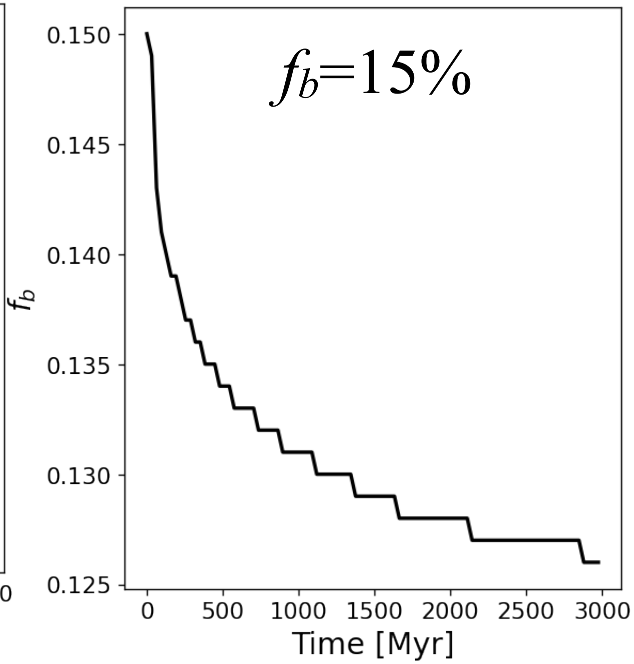
Table 4. As Tab. 3, but accounting for both RLOF and the luminosity cut-off (dSph case) and RLOF only for the UFD case. For the dSph, f_b refers to the actual binary fraction obtained after the luminosity cut procedure.

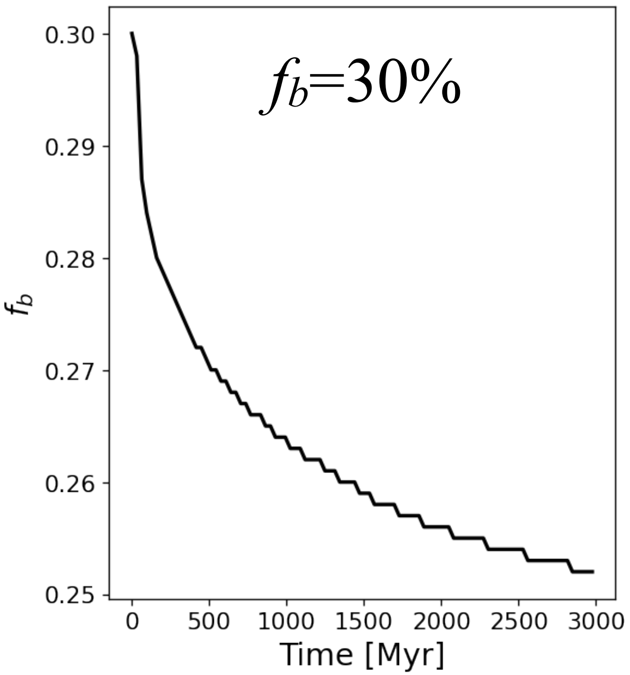
Object	f_b	$(M_{dyn}/L)_{bol}$ ($M_\odot/L_\odot$)	$(M_{dyn}/L)_V$ ($M_\odot/L_{V,\odot}$)	$(M_{dyn}/L)_B$ ($M_\odot/L_{B,\odot}$)
dSph	0	0.07	0.73	0.60
	0.09	0.44	4.33	3.56
	0.23	1.13	11.07	9.10
	0.37	2.19	21.46	17.64
	0.44	2.68	27.27	22.41
UFD	0	0.07	0.73	0.60
	0.05	1.36	13.34	10.96
	0.15	4.31	42.12	34.63
	0.30	9.88	96.65	79.45
	0.40	14.69	142.63	117.27

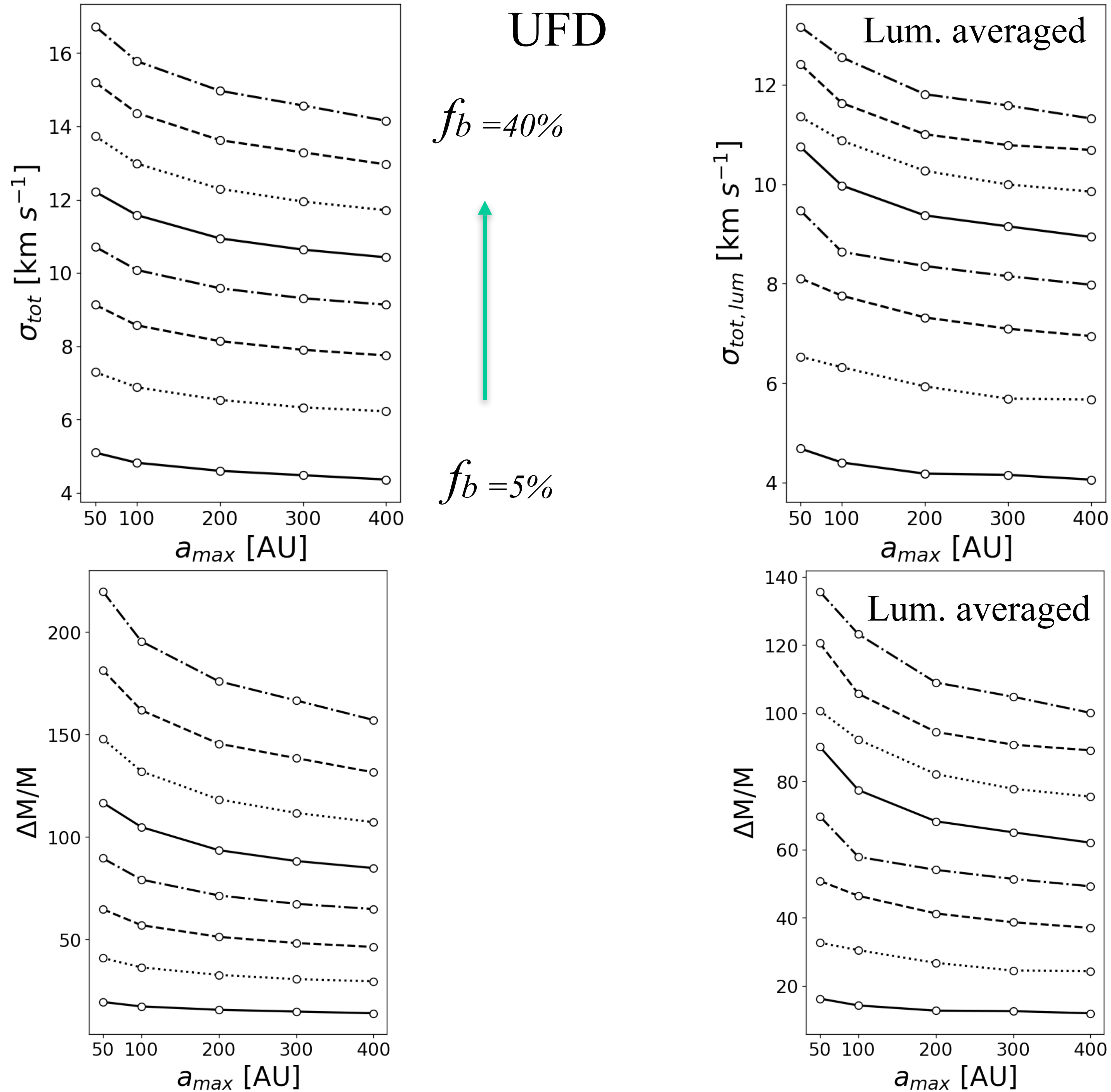
As expected the M/L enhancement due to unresolved binaries is *larger* for *fainter* dwarf galaxies (UFDs)

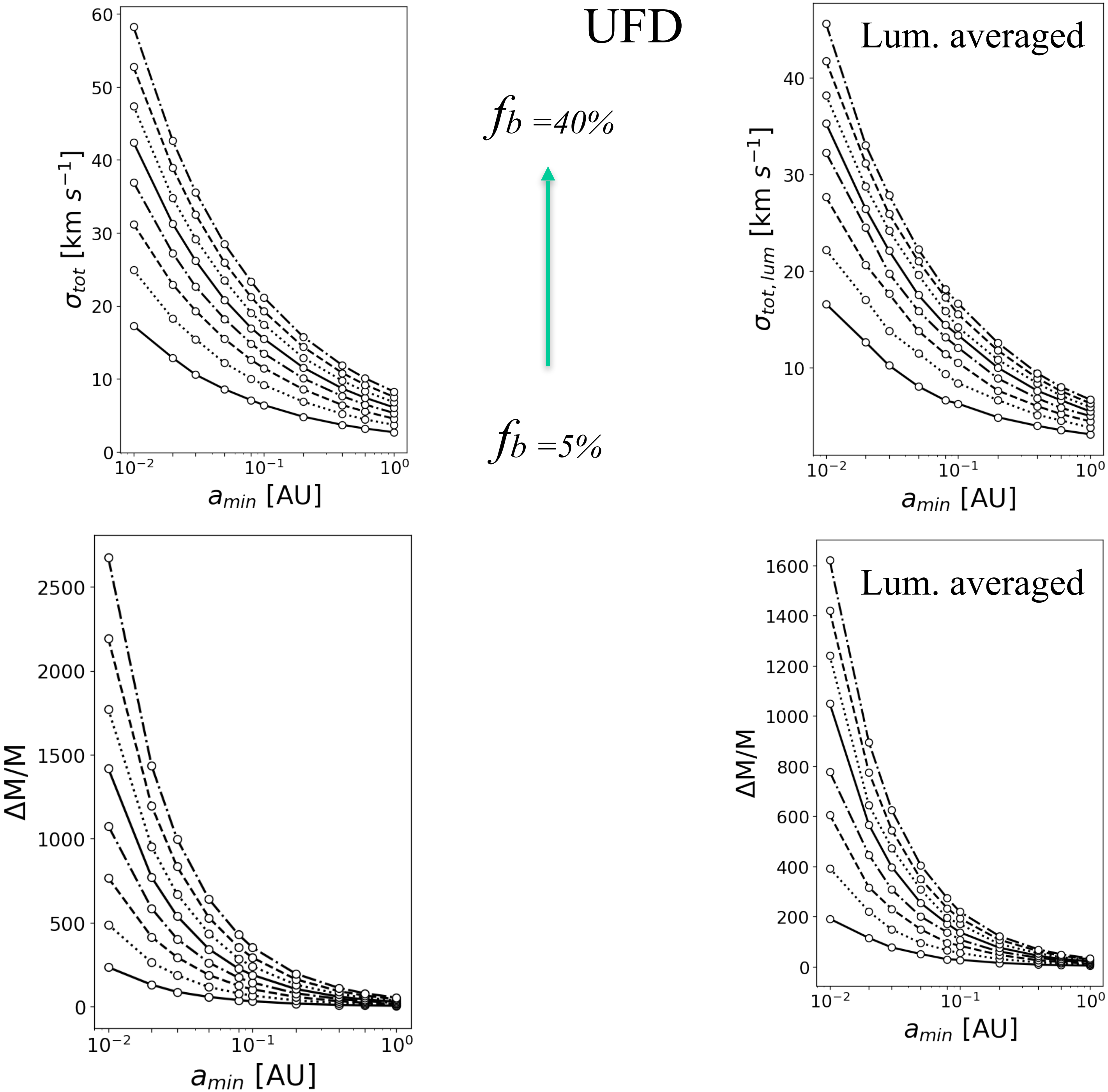
Time evolution of binary fraction



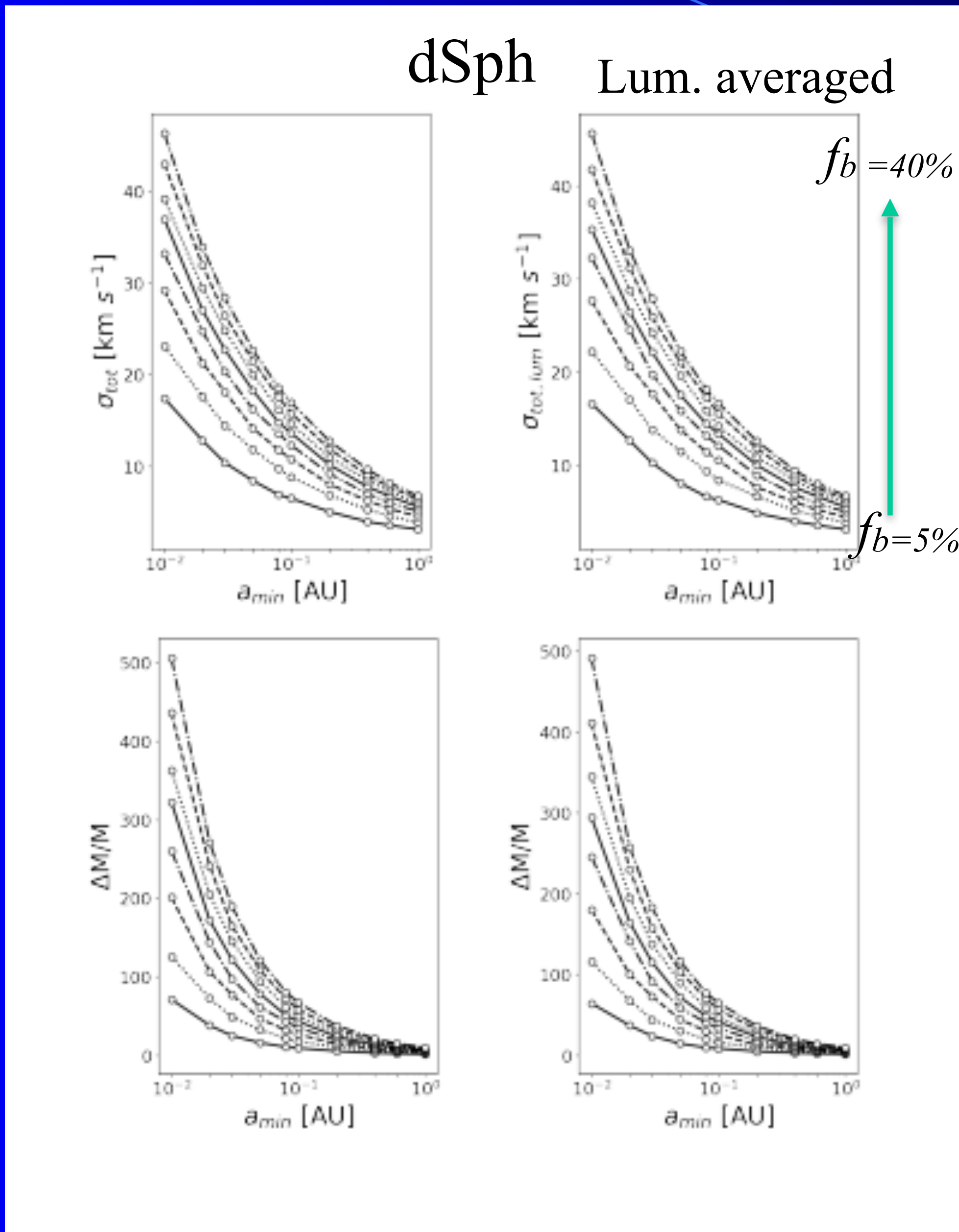


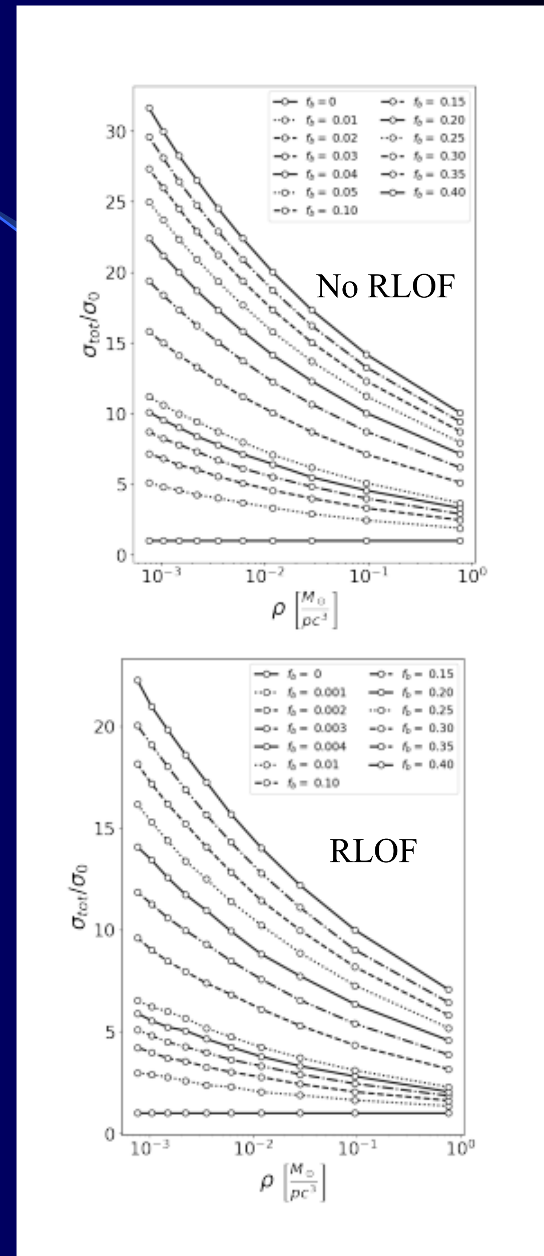



UFD
f_b =40%
f_b =5%
Lum. averaged
Lum. averaged
σ_{tot} [km s^{-1}]
$\sigma_{tot,lum}$ [km s^{-1}]
ΔM/M
ΔM/M
a_{max} [AU]
a_{max} [AU]
a_{max} [AU]
a_{max} [AU]


UFD
fb =40%
fb =5%
Lum. averaged
Lum. averaged
σtot [km s−1]
σtot,lum [km s−1]
ΔM/M
ΔM/M
amin [AU]
amin [AU]
amin [AU]
amin [AU]

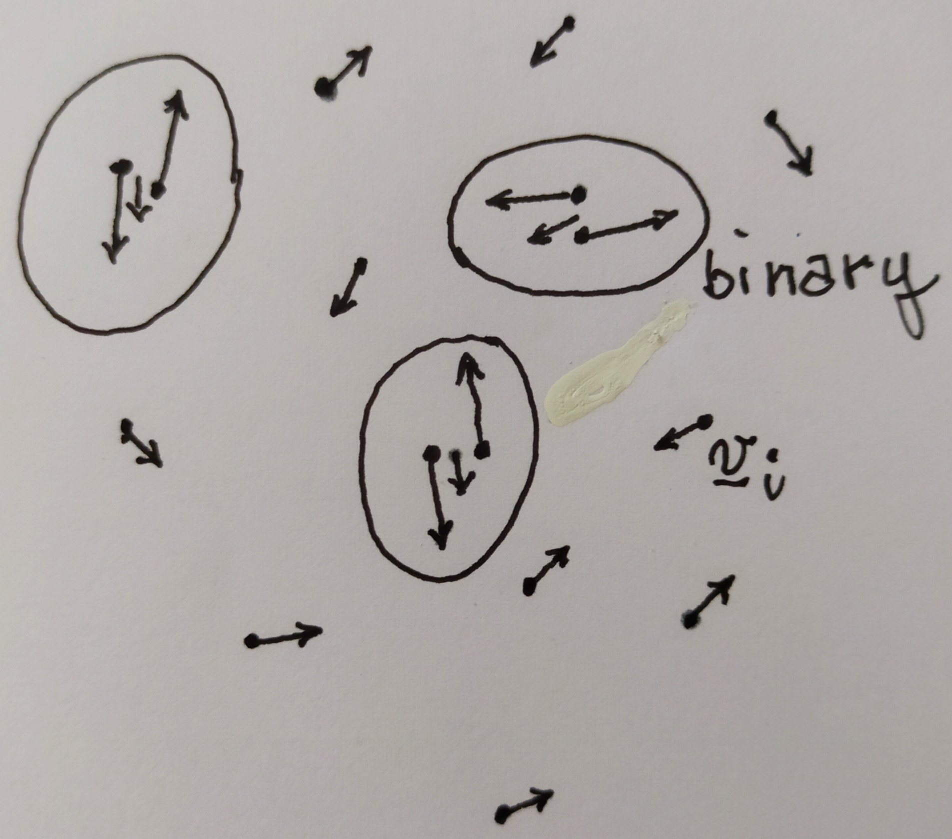
A possible alternative to dark matter…





A possible alternative to dark matter…

A system of single+binary stars



With $m_1 = m_2 = 1 M_\odot$ and $a = 1$ AU

$$\sigma_b \sim \sqrt{G \frac{m_1 + m_2}{a}} \simeq 42.2 \text{km/s}$$

The role of (unresolved) binaries.

$$M \leq M_{vir} = \alpha \frac{R_{vir}}{G} \sigma_{com}^2 < \alpha \frac{R_{vir}}{G} \left(\sigma_{com}^2 + \sigma_b^2 \right)$$

↓

overestimate

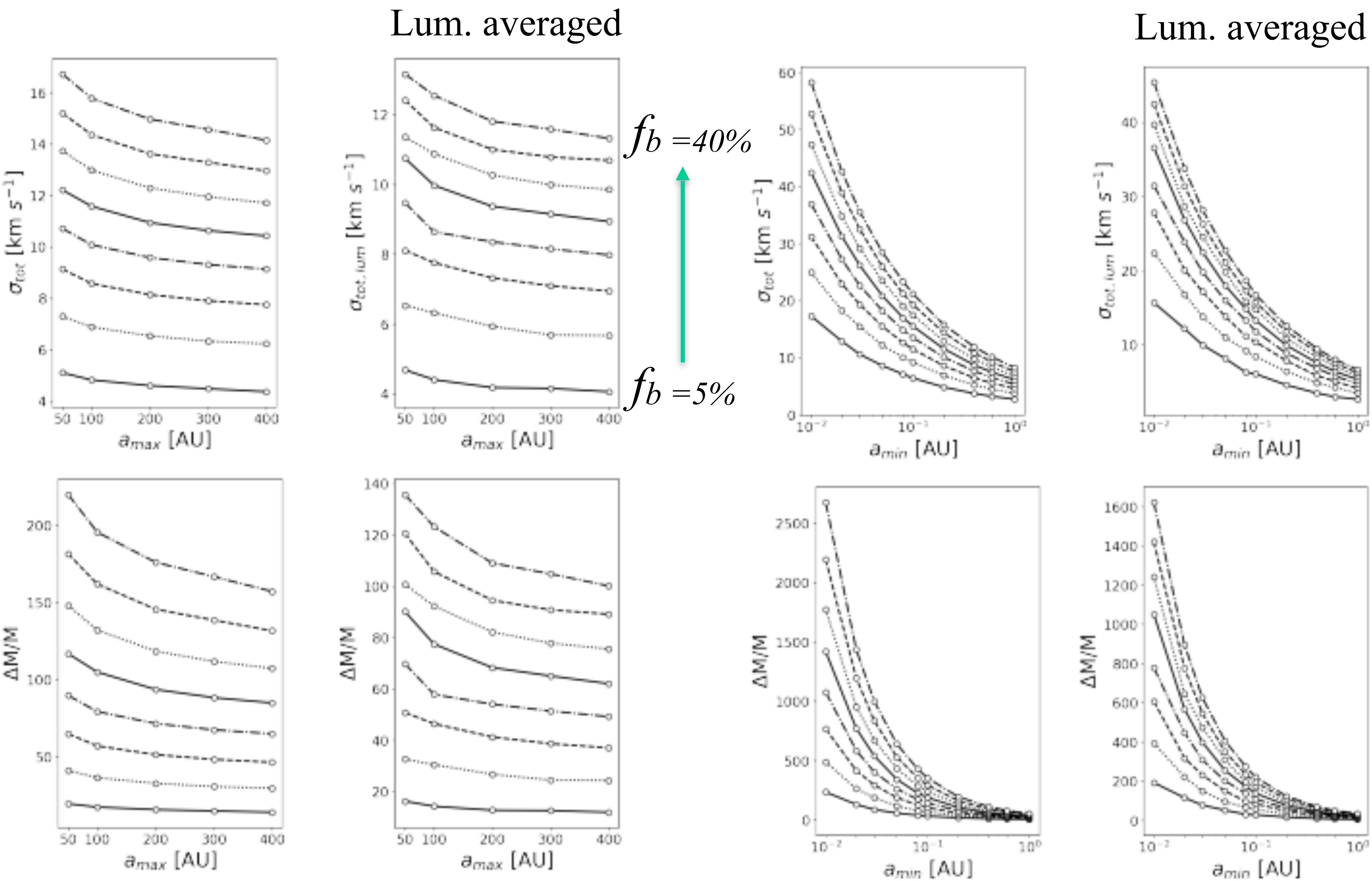
$$\sigma_{obs}^2 = (1 - f_b)\sigma_s^2 + f_b \sigma_b^2$$

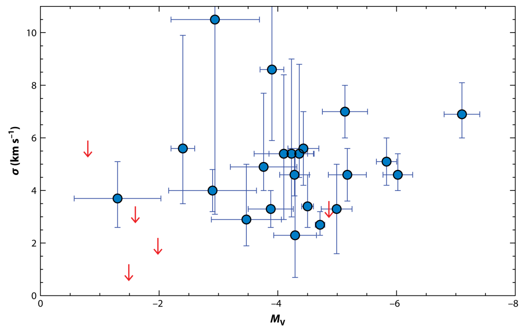
$$\Delta M / M = \frac{\sigma_{obs}^2 - \sigma_{com}^2}{\sigma_{com}^2}$$

Being $\sigma_s^2 \propto M$ while σ_b^2 is independent of *M*,

binaries affect more low mass system

A possible alternative to dark matter…





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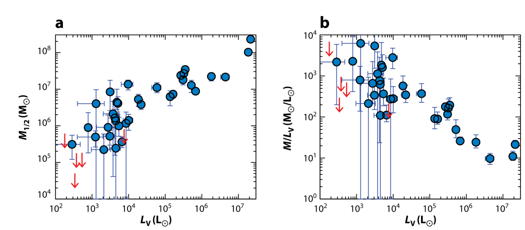

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