

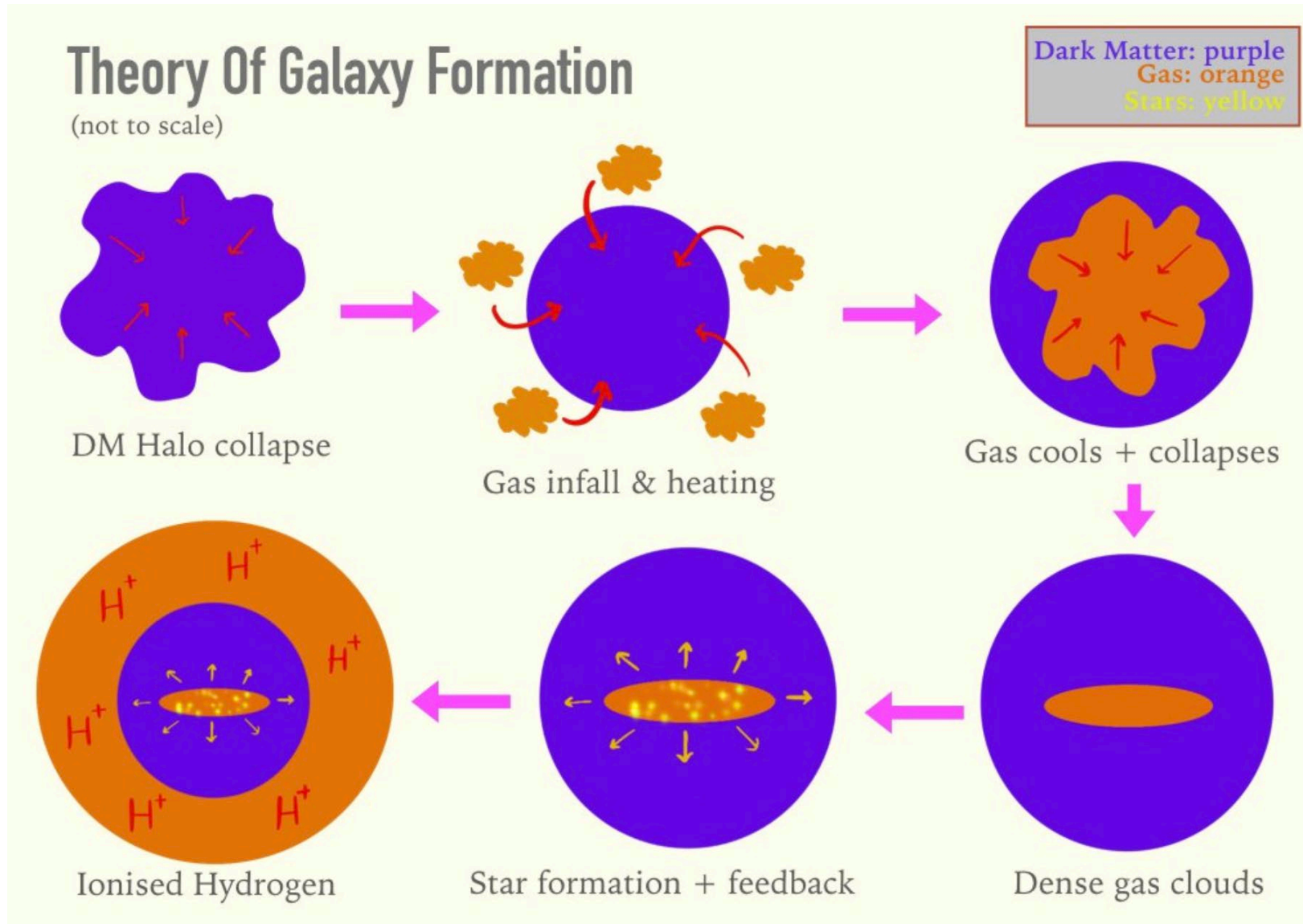
The Ubiquity of Failed L* Galaxies

报告人：容昱(特任研究员)

单位：中国科学技术大学

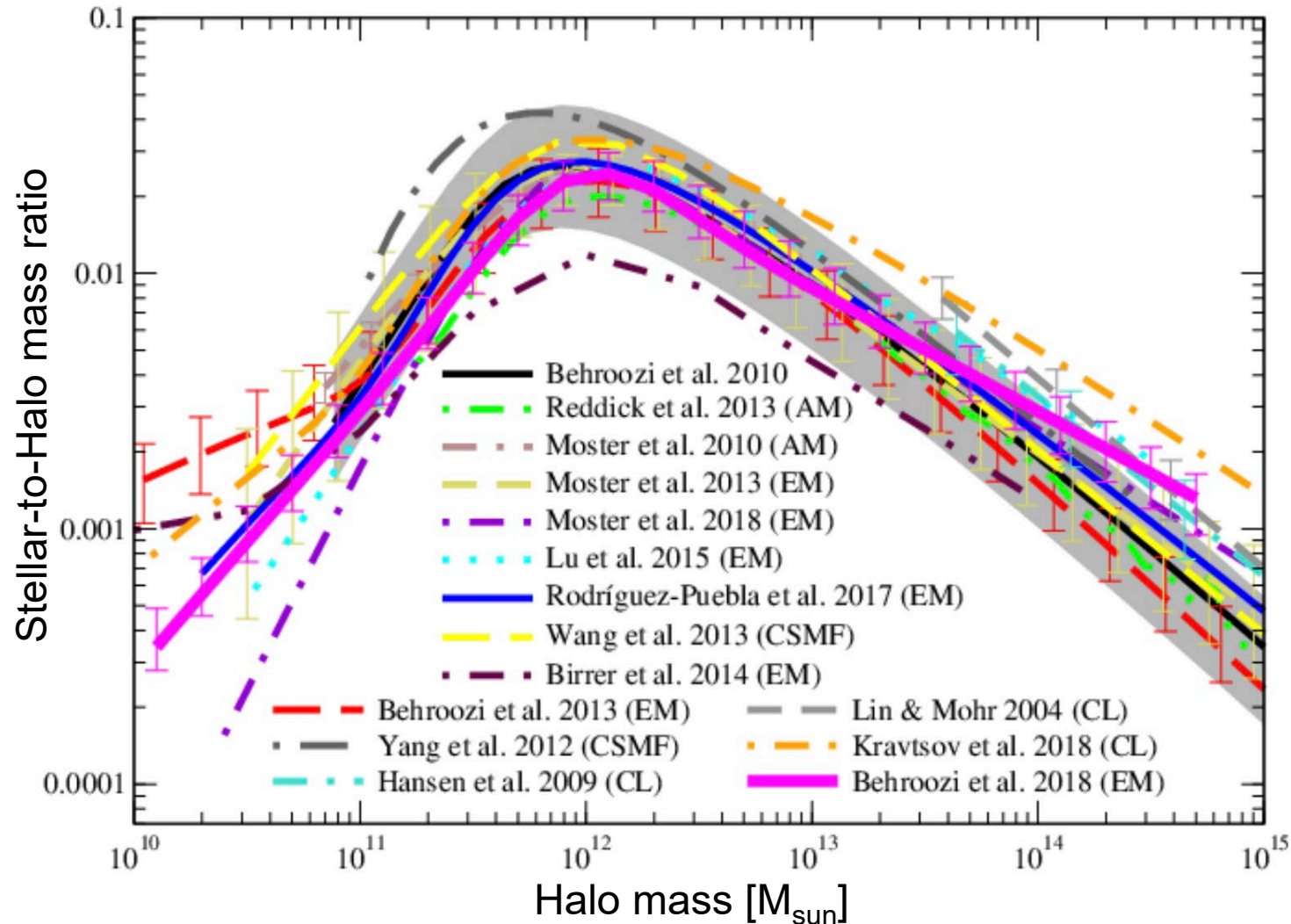
合作单位：USTC, NAOC, PUC

Galaxy formation



Stellar-to-halo mass ratio

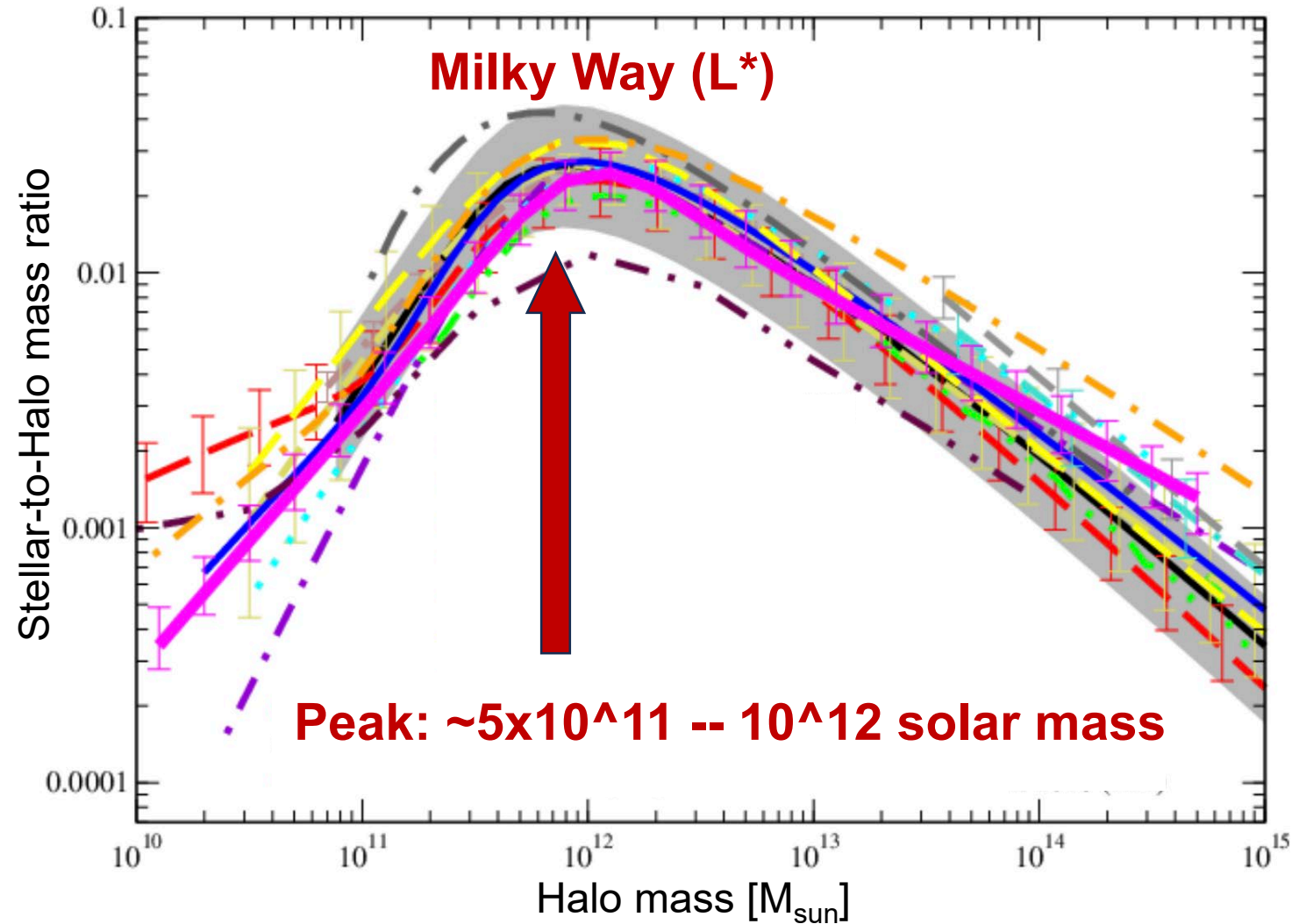
Lambda Cold Dark Matter model



Stellar-to-halo mass ratio

Lambda Cold Dark Matter model

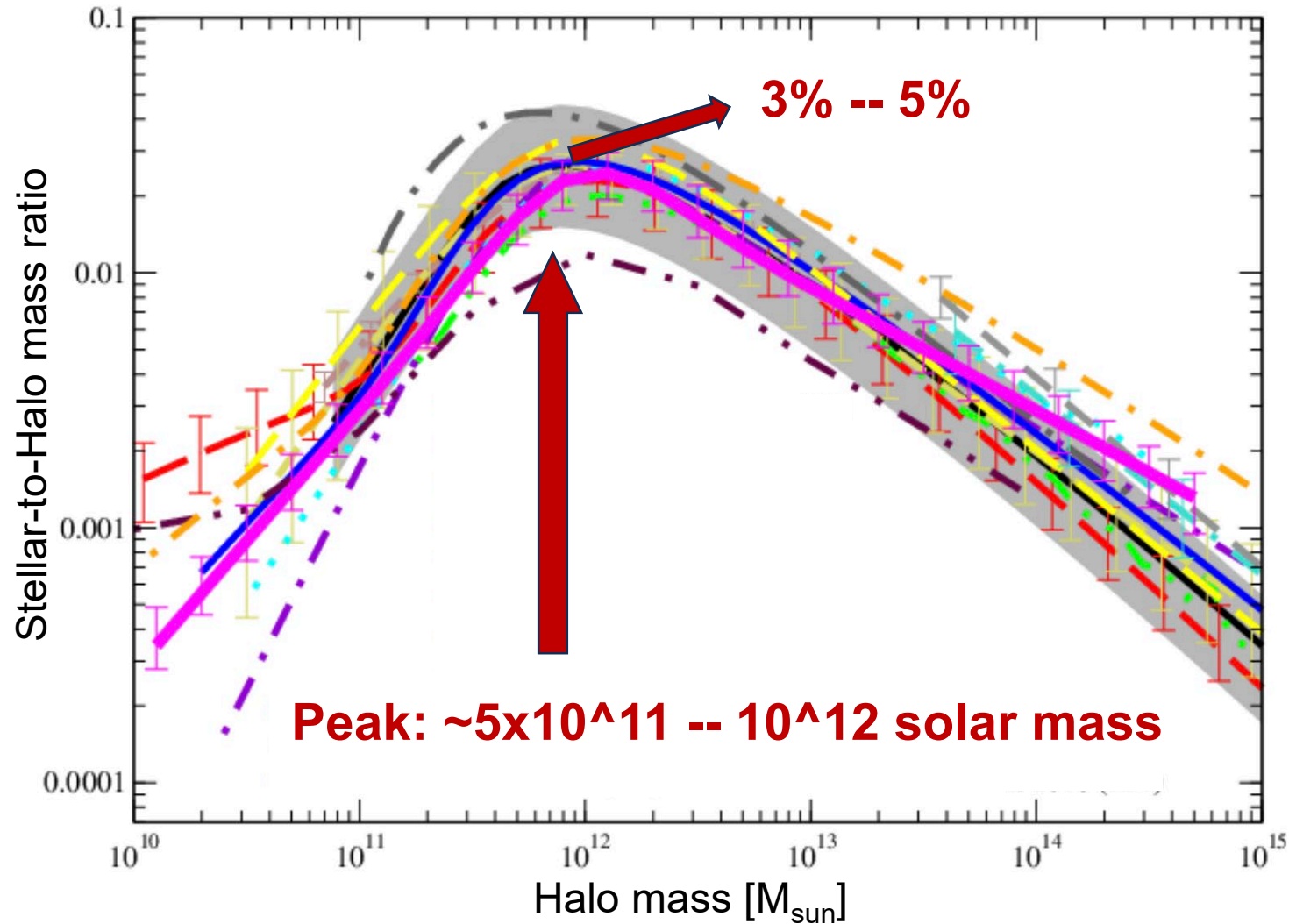
Standard galaxy formation model + Observations



Stellar-to-halo mass ratio

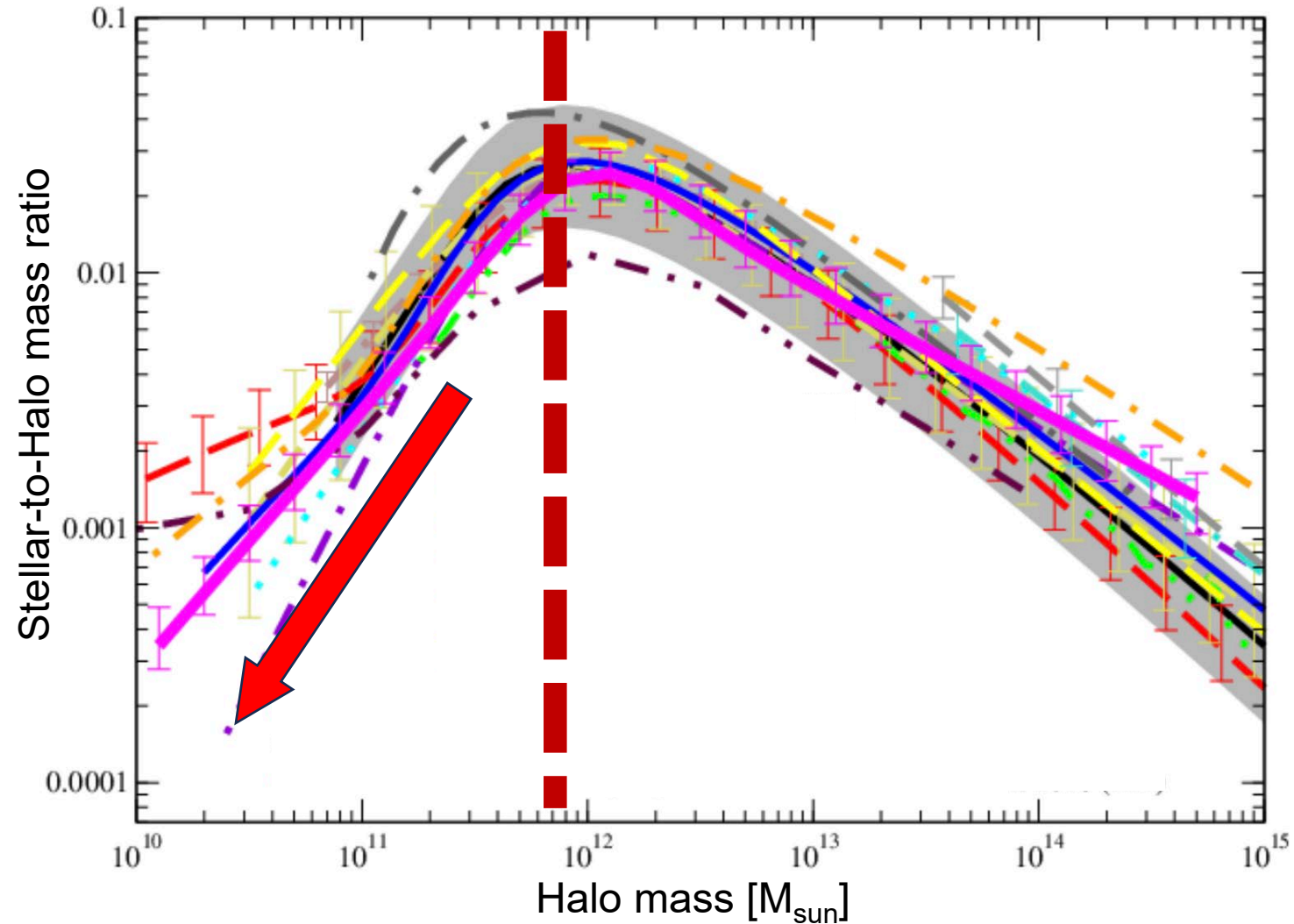
Lambda Cold Dark Matter model

Standard galaxy formation model + Observations



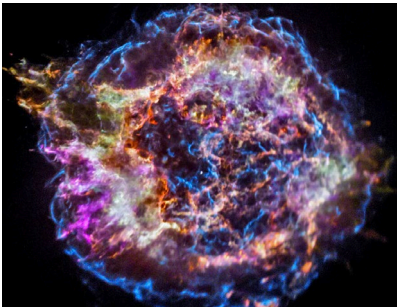
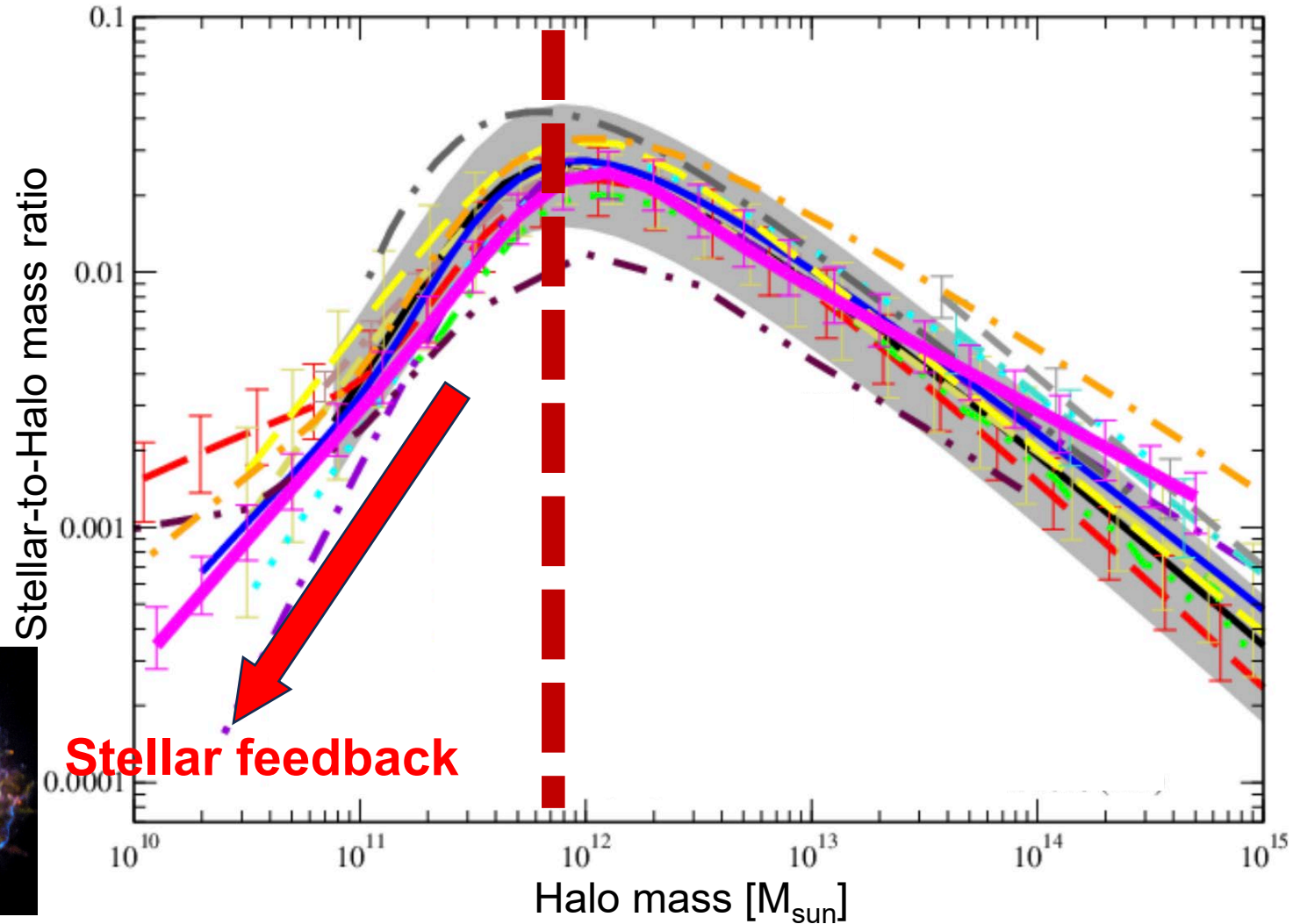
Stellar-to-halo mass ratio

Lambda Cold Dark Matter model



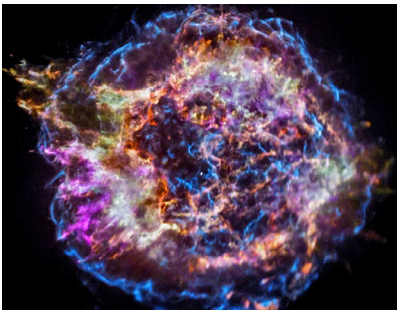
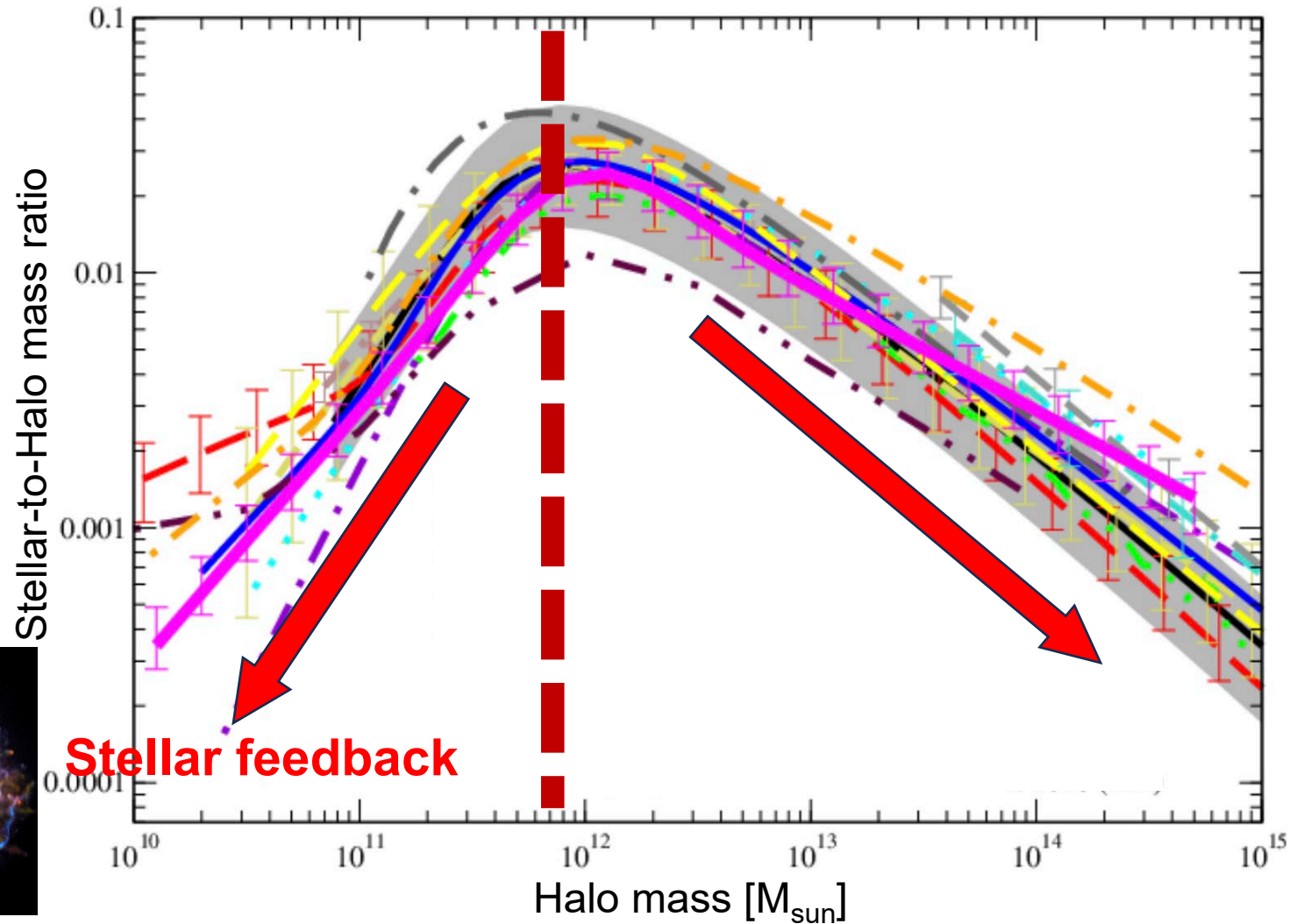
Stellar-to-halo mass ratio

Lambda Cold Dark Matter model



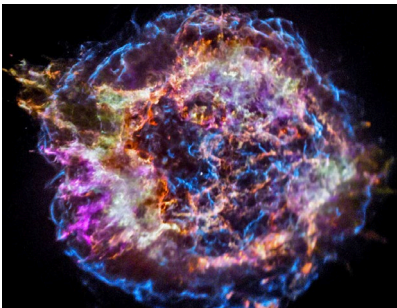
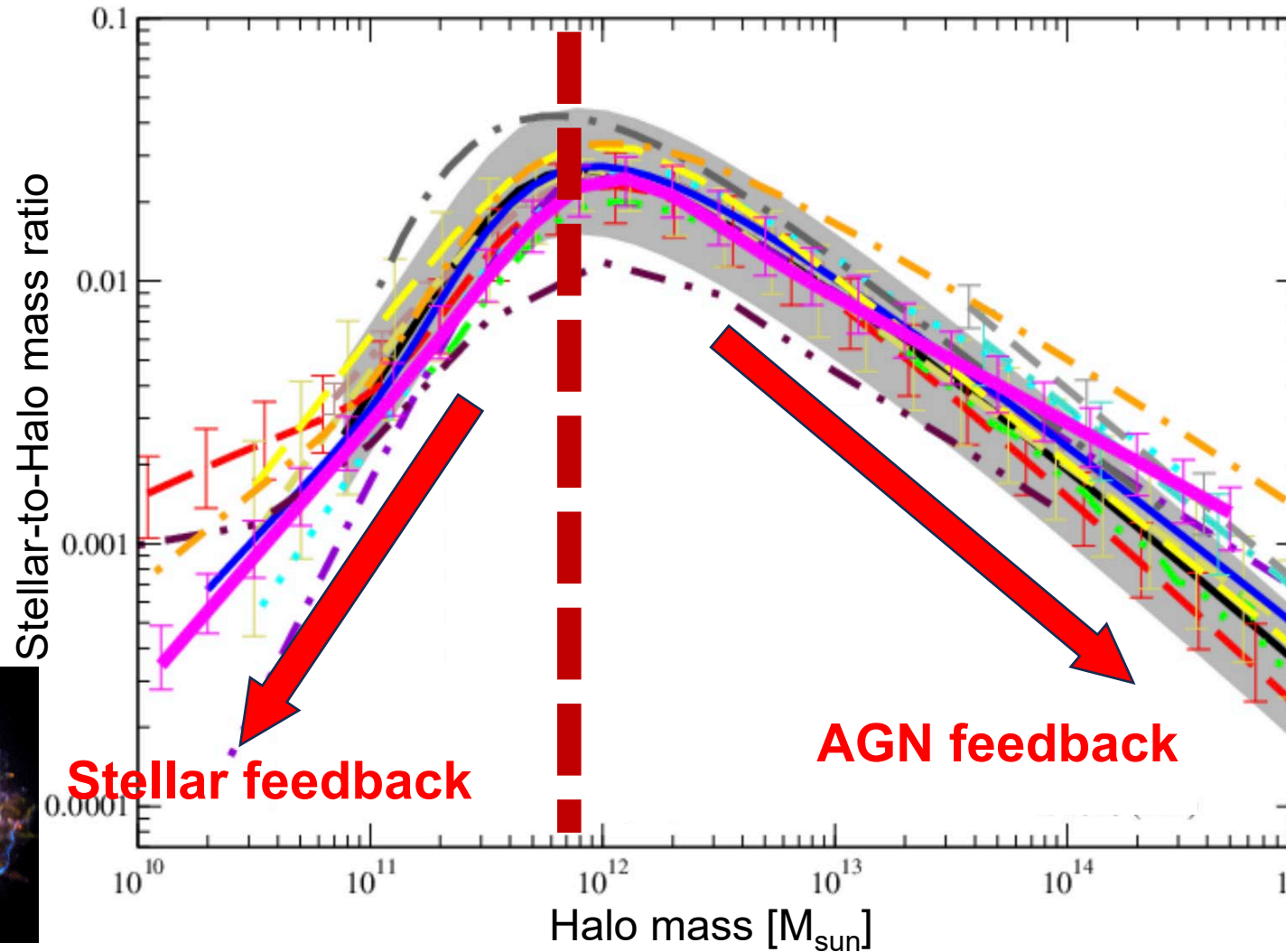
Stellar-to-halo mass ratio

Lambda Cold Dark Matter model



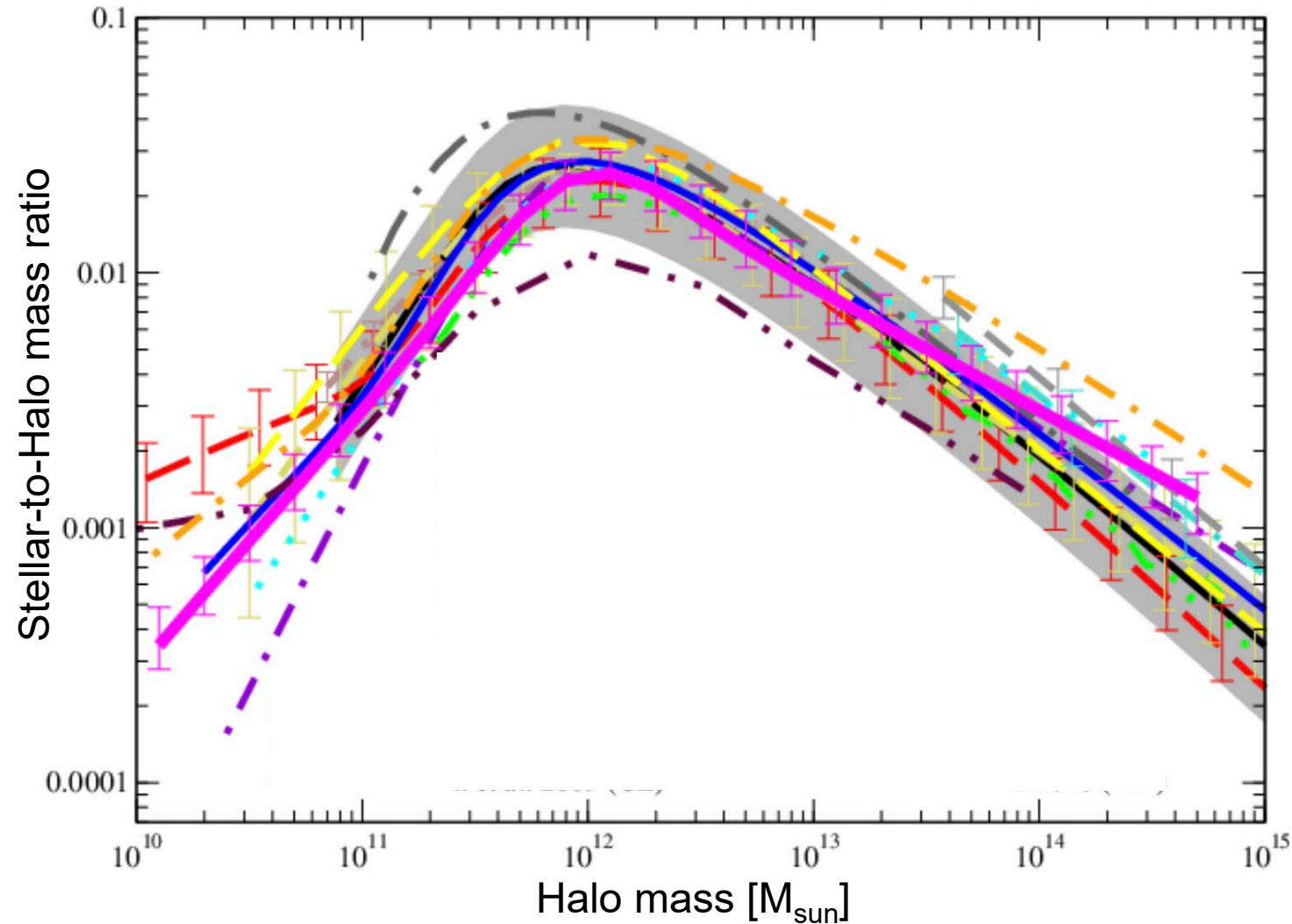
Stellar-to-halo mass ratio

Lambda Cold Dark Matter model

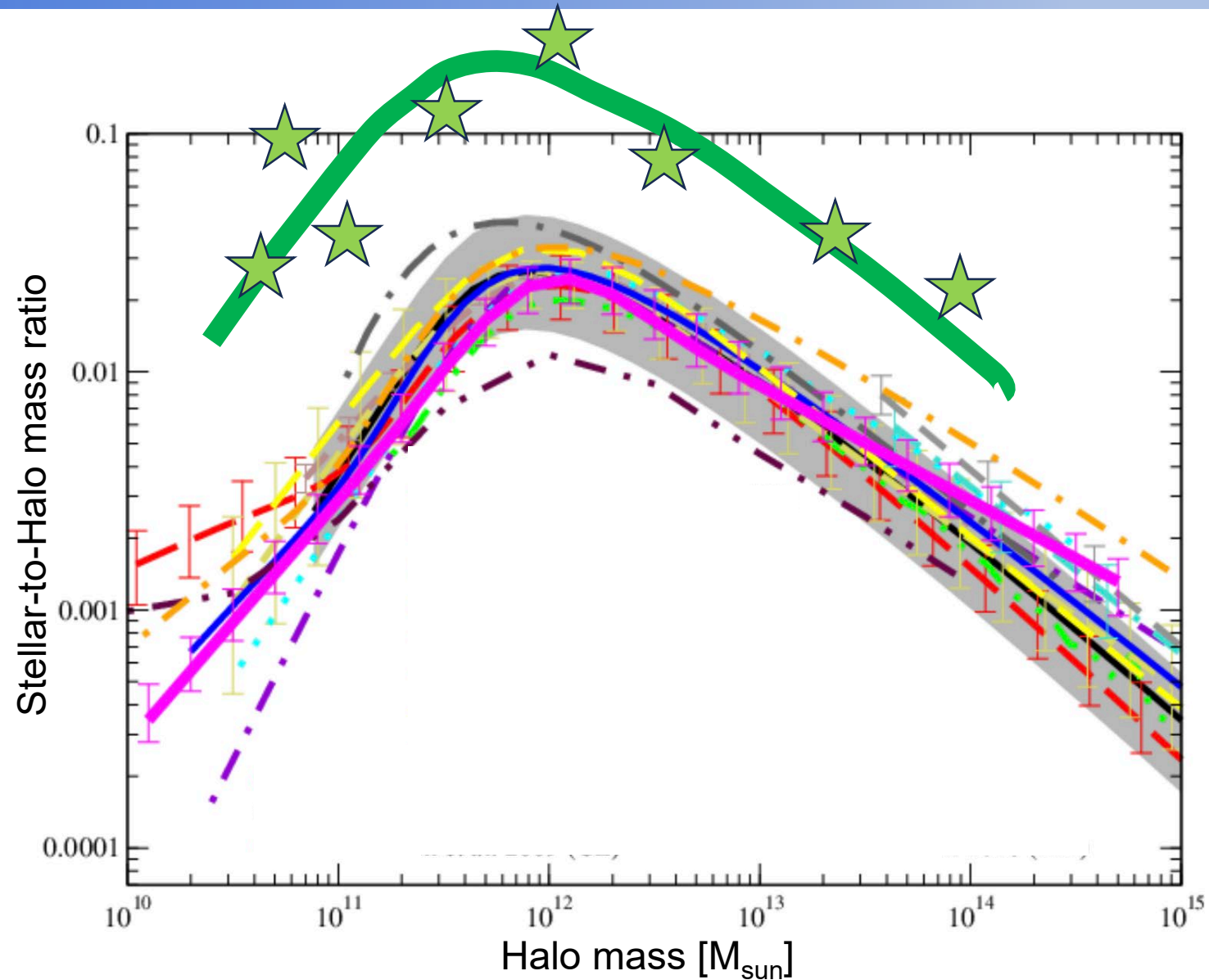


Beyond standard galaxy formation model

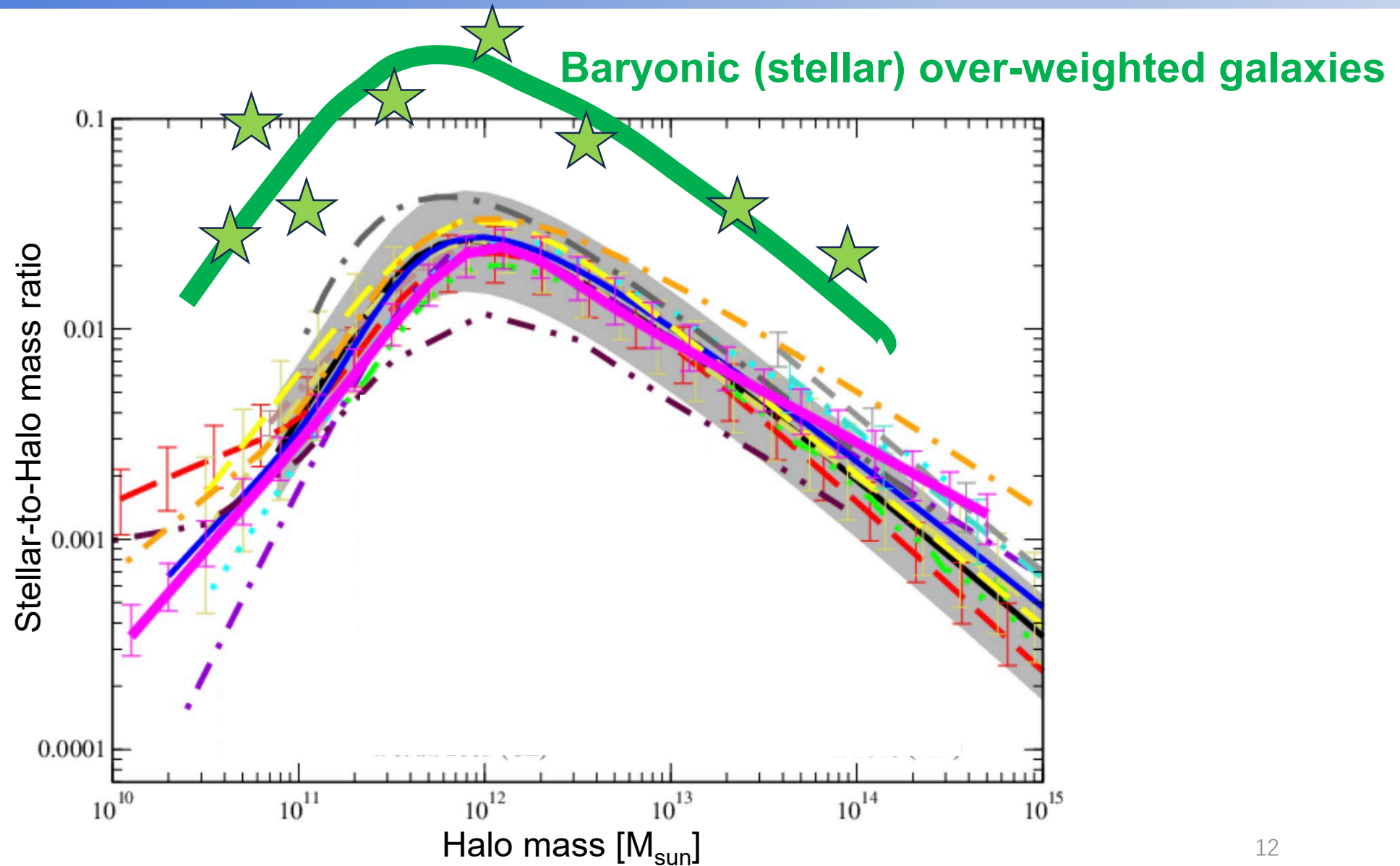
Standard galaxy formation model



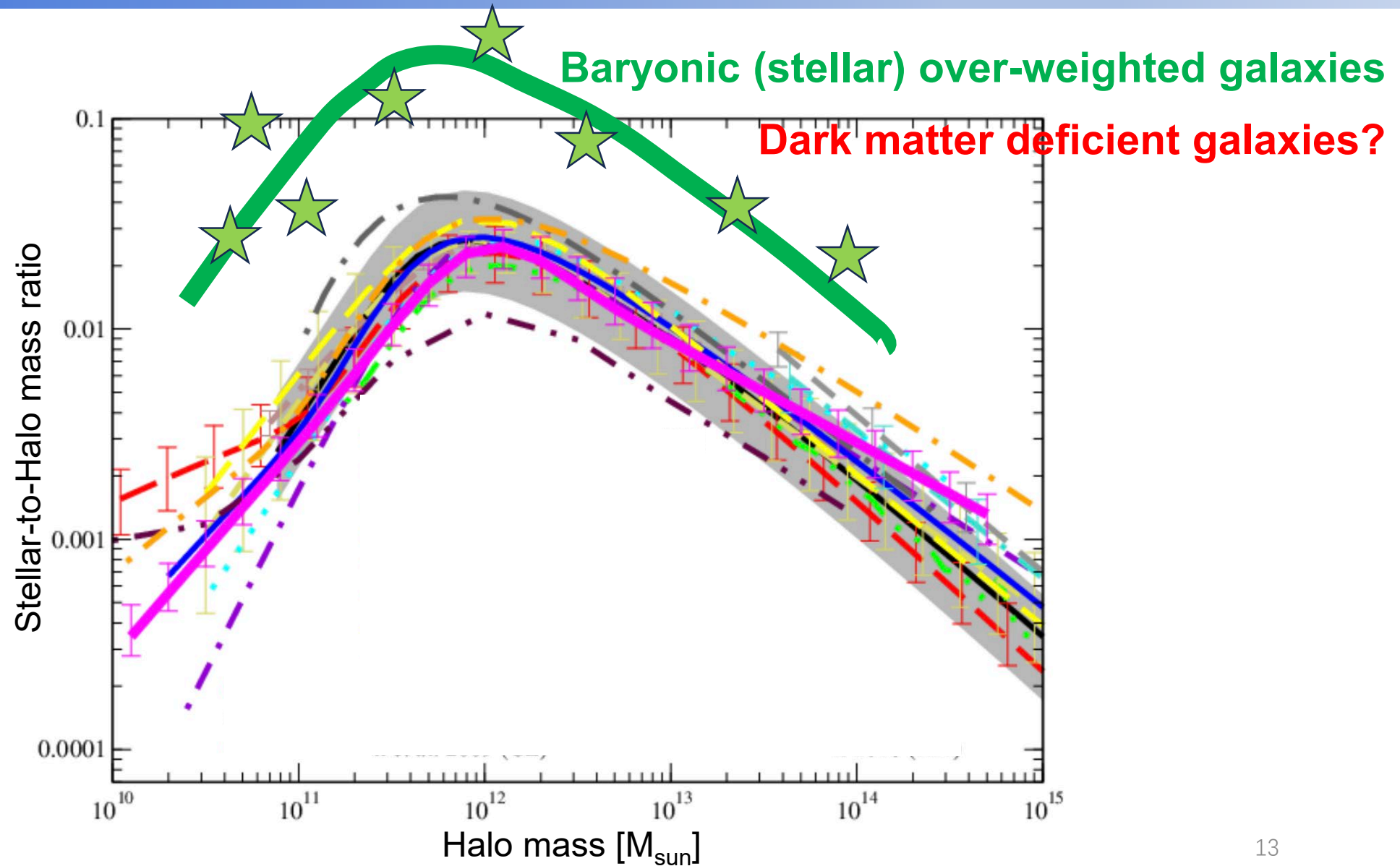
Beyond standard galaxy formation model



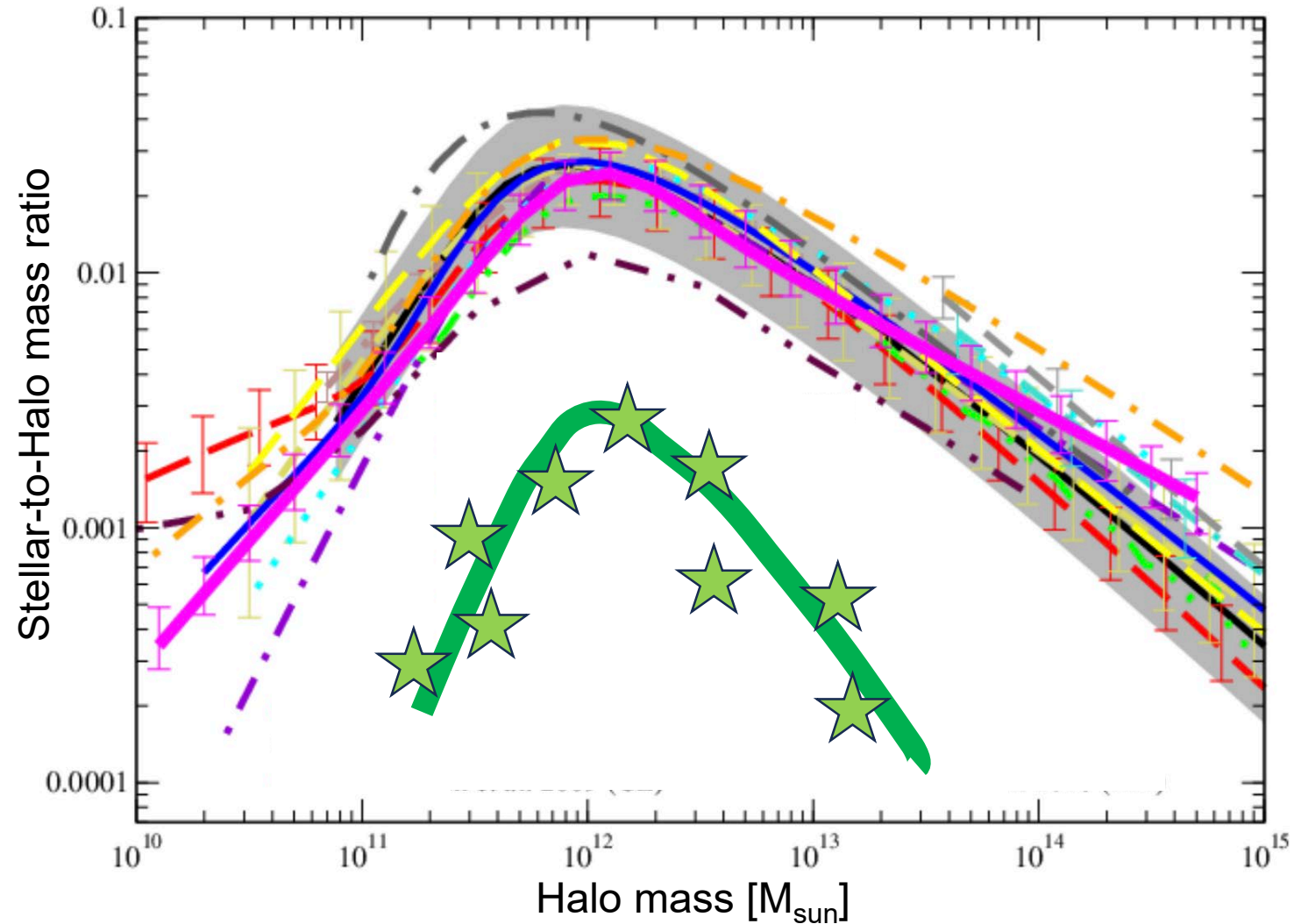
Beyond standard galaxy formation model



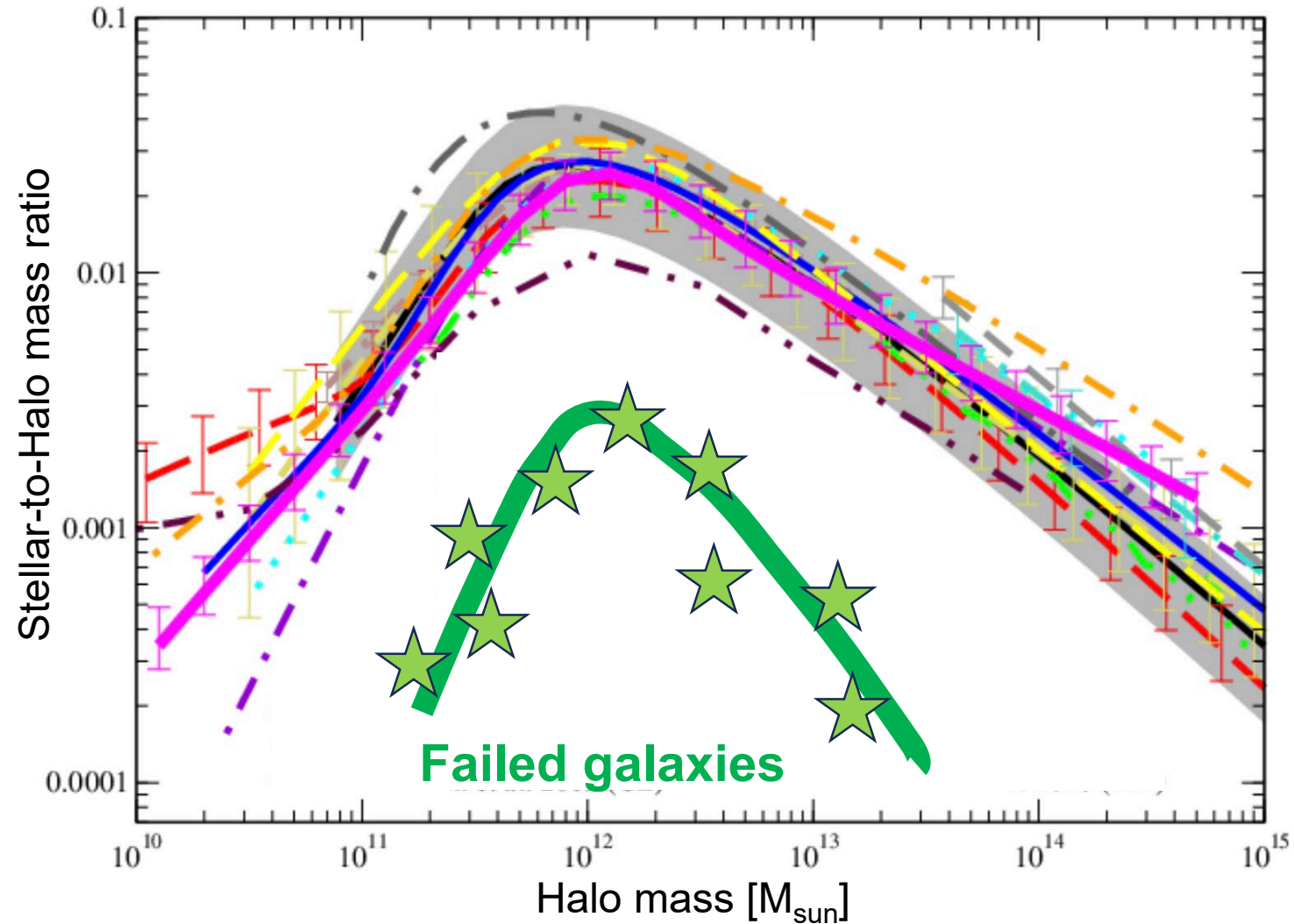
Beyond standard galaxy formation model



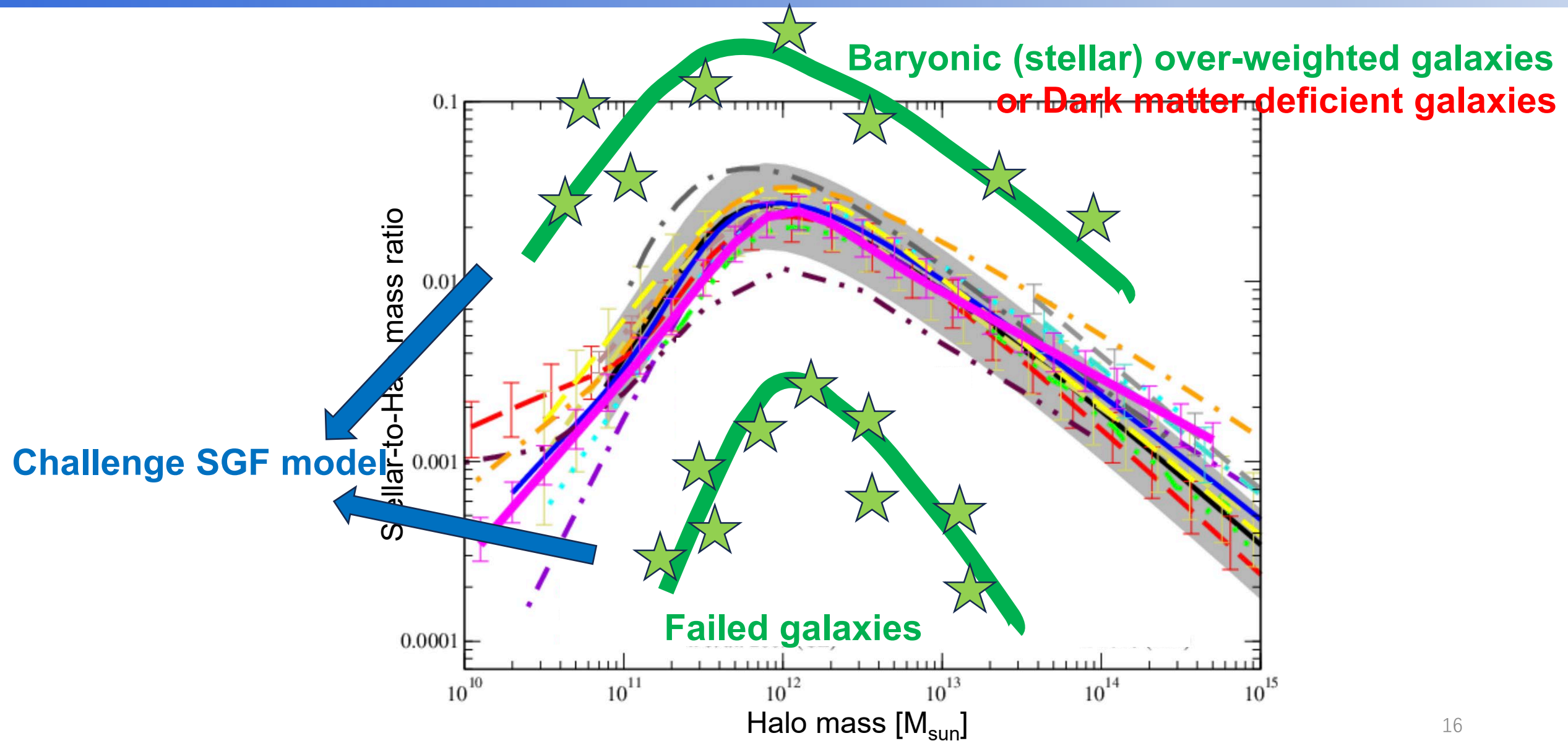
Beyond standard galaxy formation model



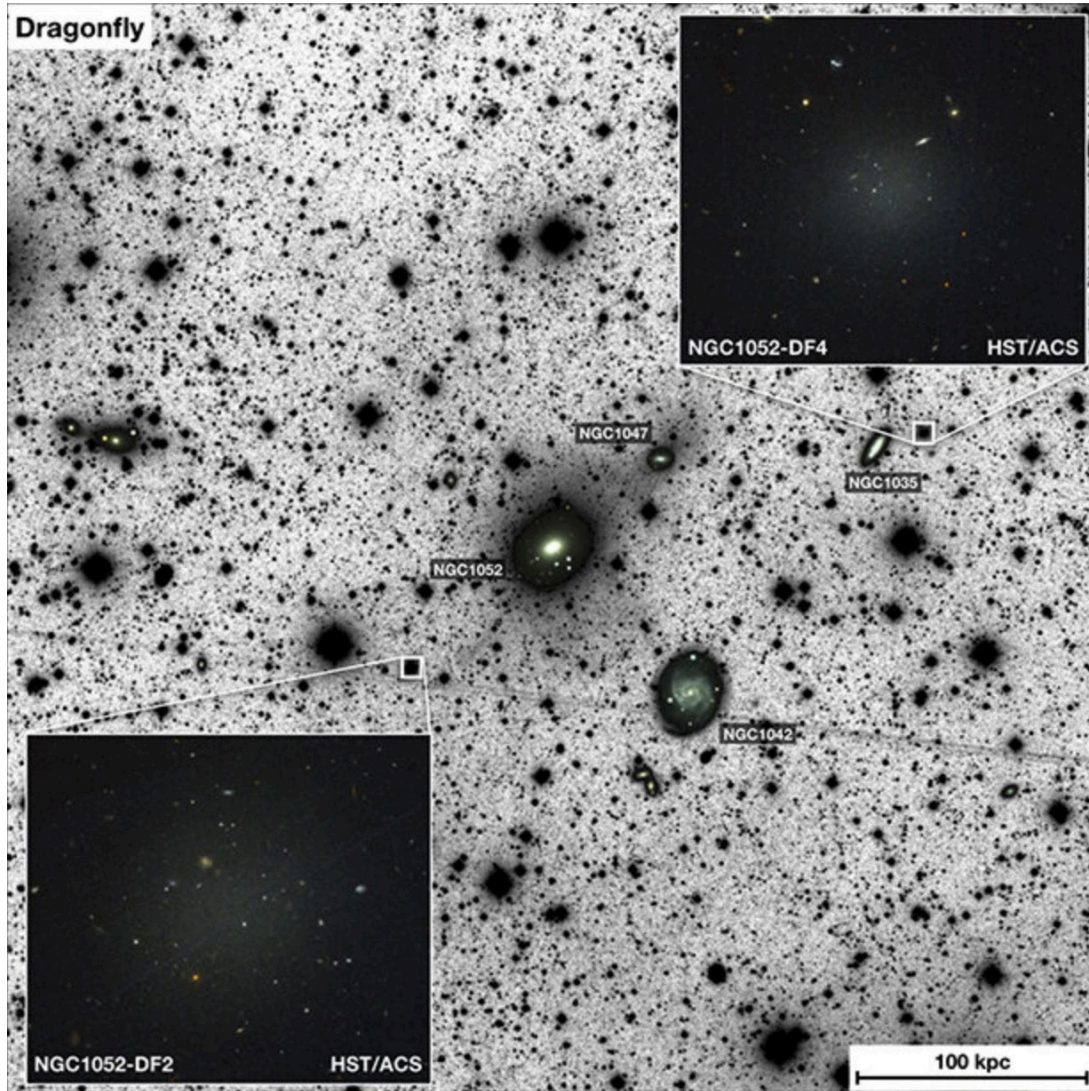
Beyond standard galaxy formation model



Beyond standard galaxy formation model



Challenge: (1) Dark matter deficient galaxies



NGC1052-DF2, DF4 (van Dokkum+2018, 2019)
Globular cluster dynamics

- **NGC1052-DF2:**

Stellar mass $\sim 2 \times 10^8$ solar mass

Total mass $\sim 3.4 \times 10^8$ solar mass

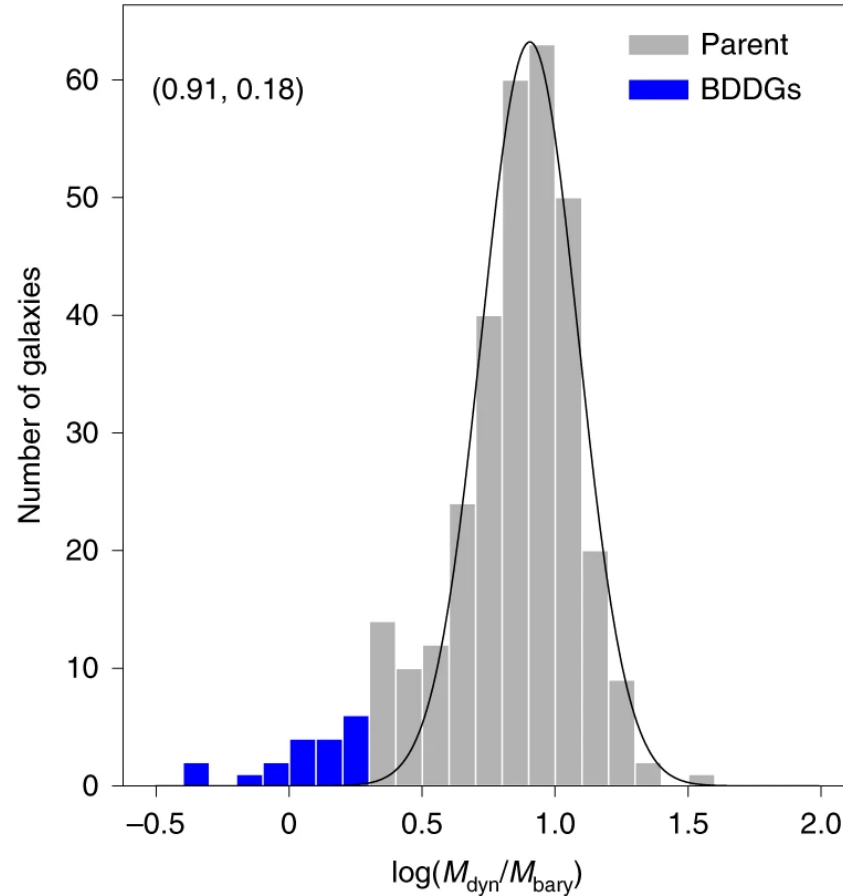
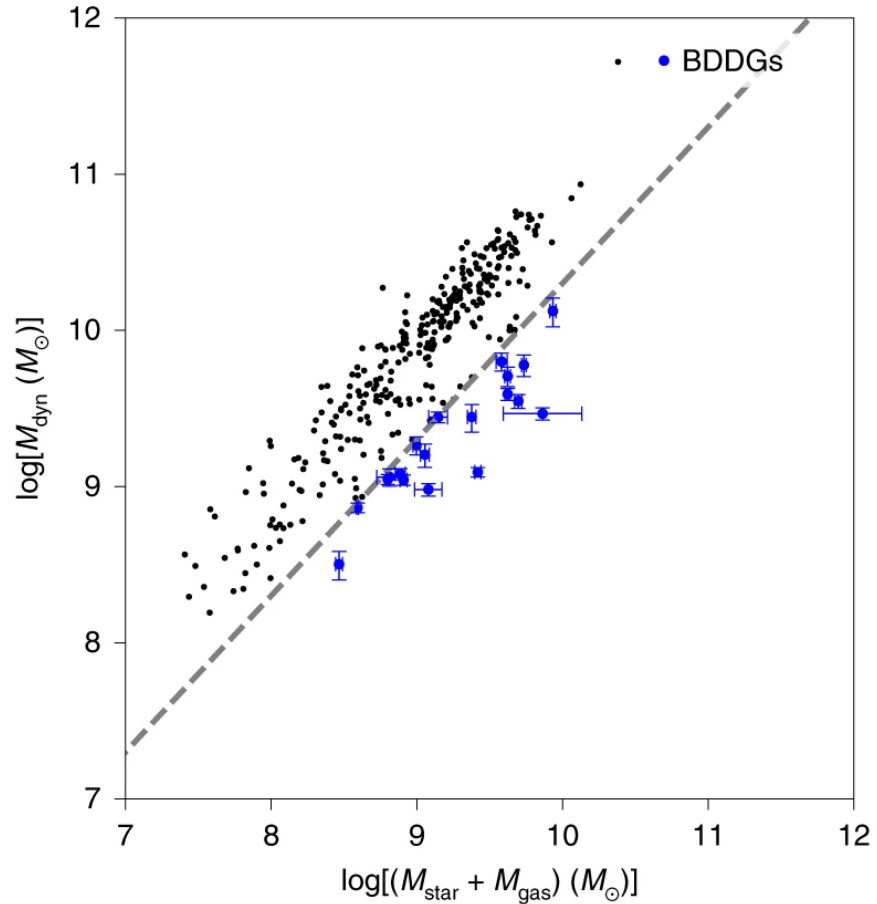
- **NGC1052-DF4:**

Stellar mass $\sim 1.5 \times 10^8$ solar mass

Total mass $\sim 0.4 \times 10^8$ solar mass

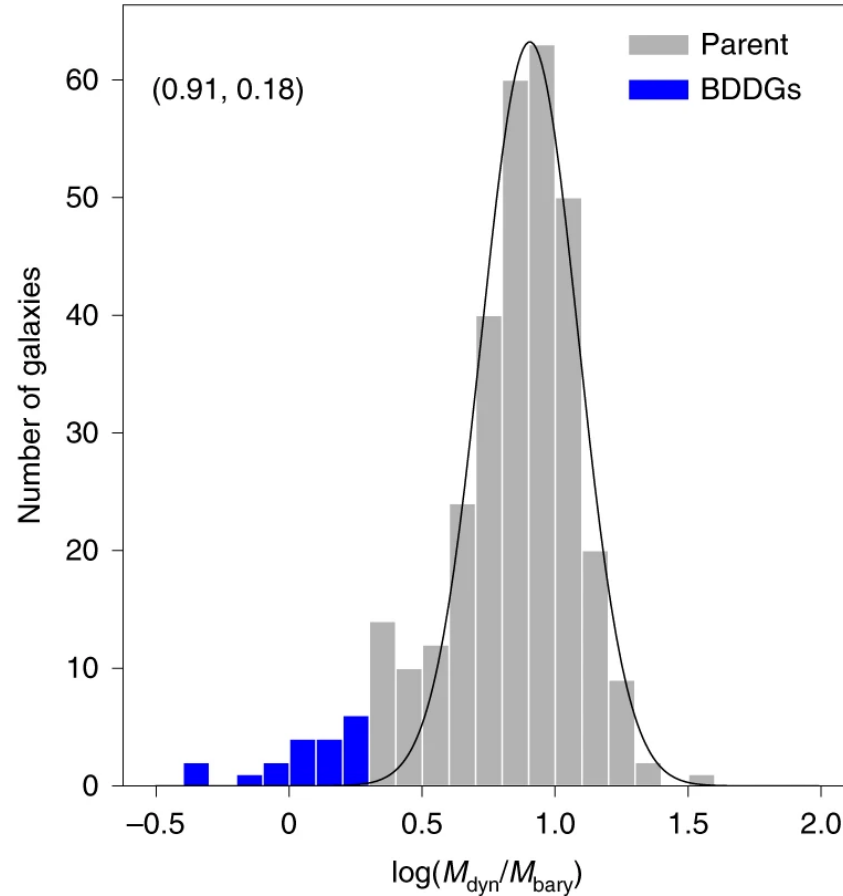
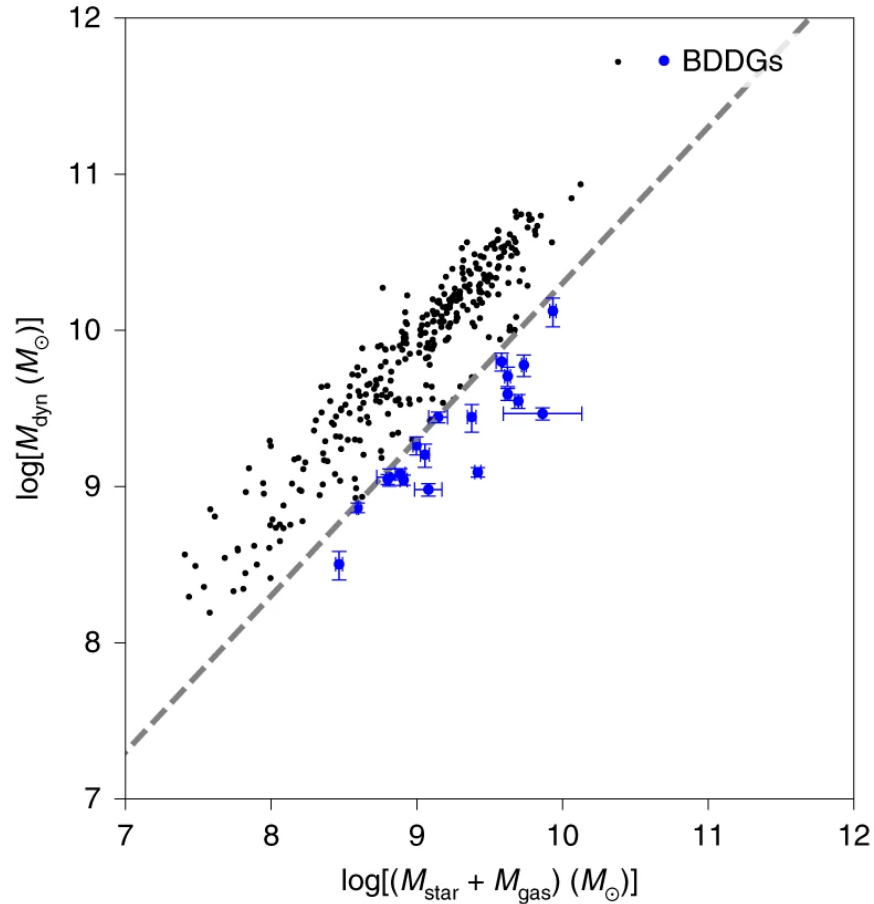
Dark matter deficient galaxies in group (cluster)

Challenge: (1) Dark matter deficient galaxies



Dark matter deficient dwarf galaxies in field (Guo+2020)

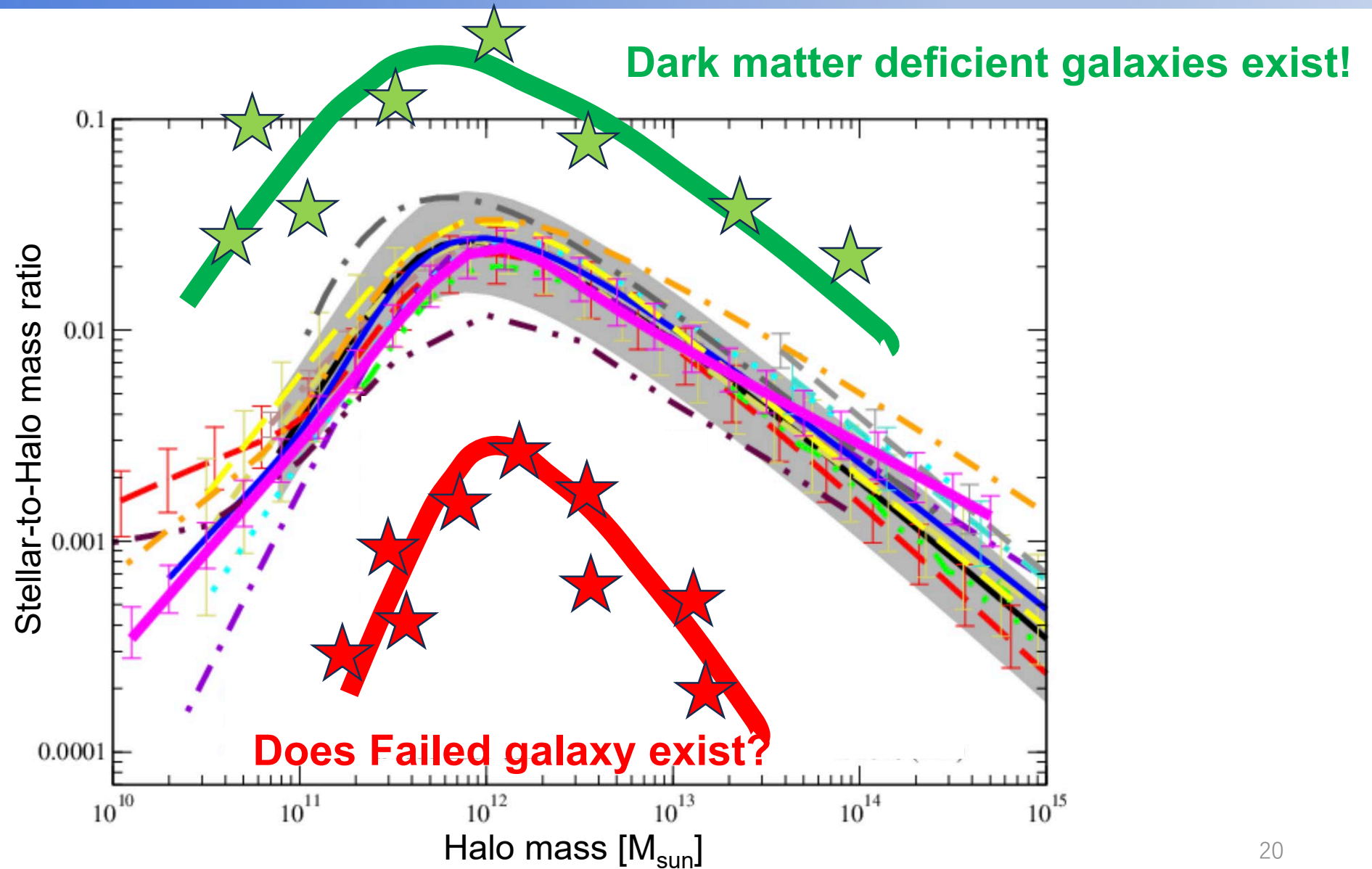
Challenge: (1) Dark matter deficient galaxies



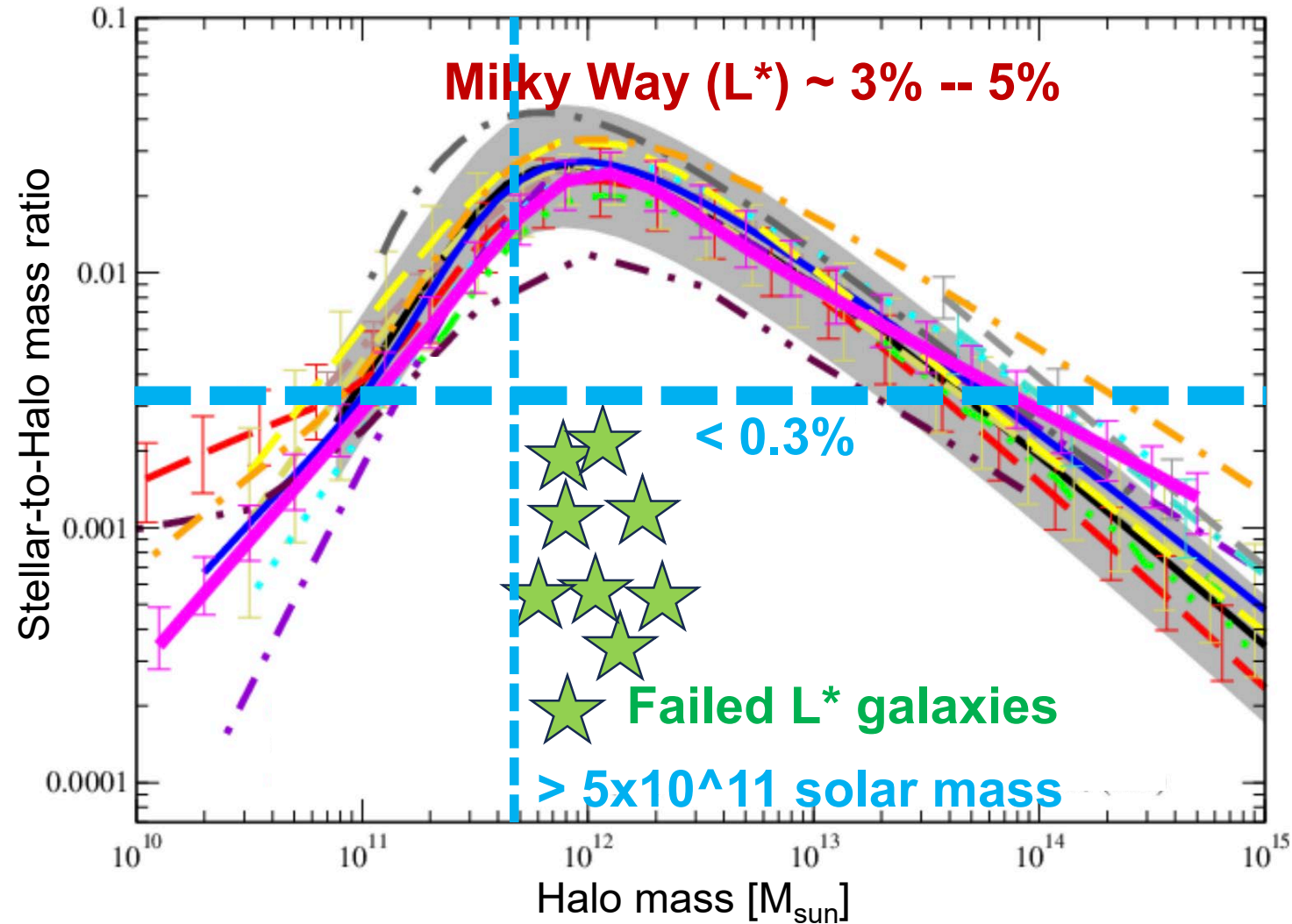
Bullet cluster

Dark matter deficient dwarf galaxies in field (Guo+2020, HI dynamics)

Beyond standard galaxy formation model



Searching for Failed L* Galaxies (FLGs)

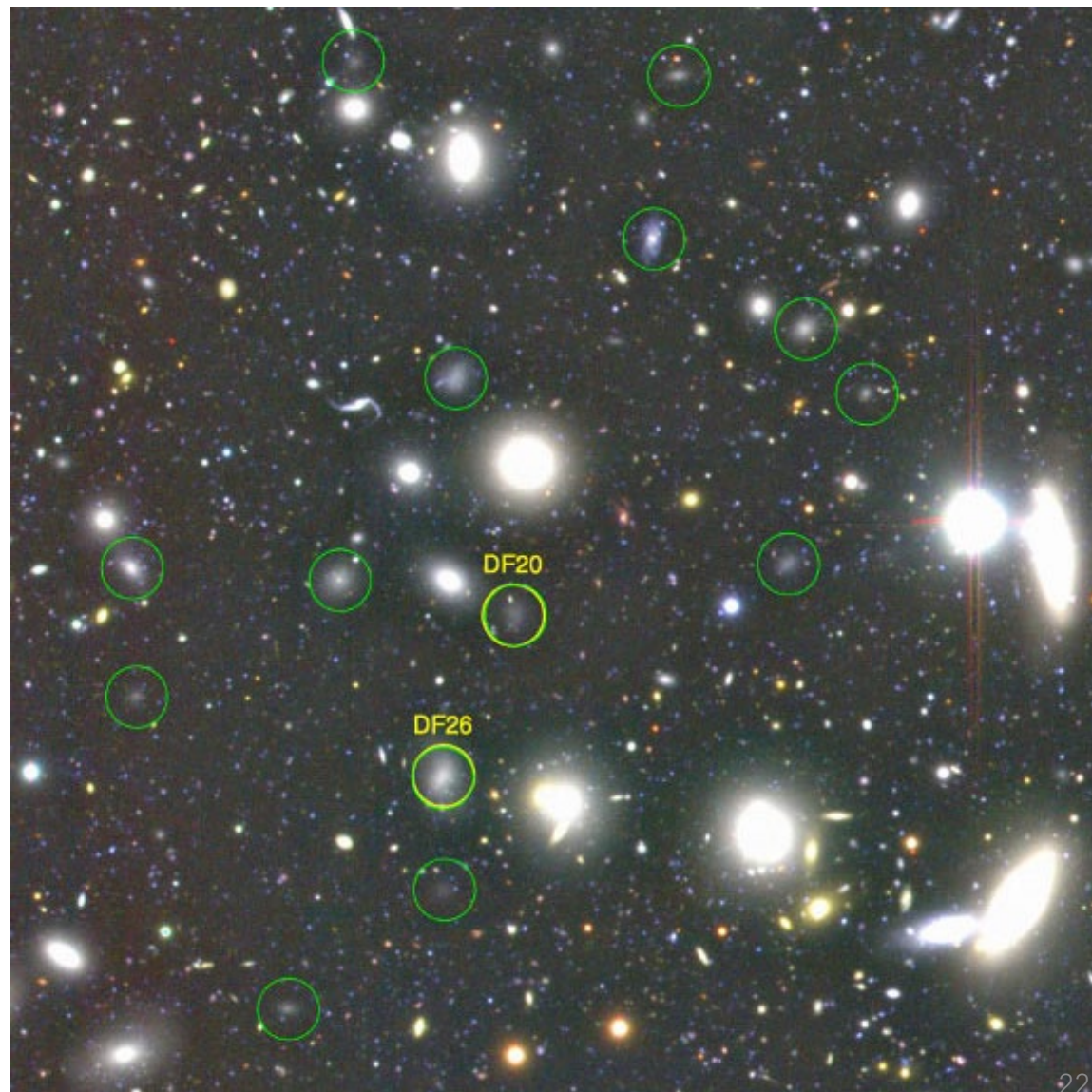


Searching for Failed L* Galaxies (FLGs)

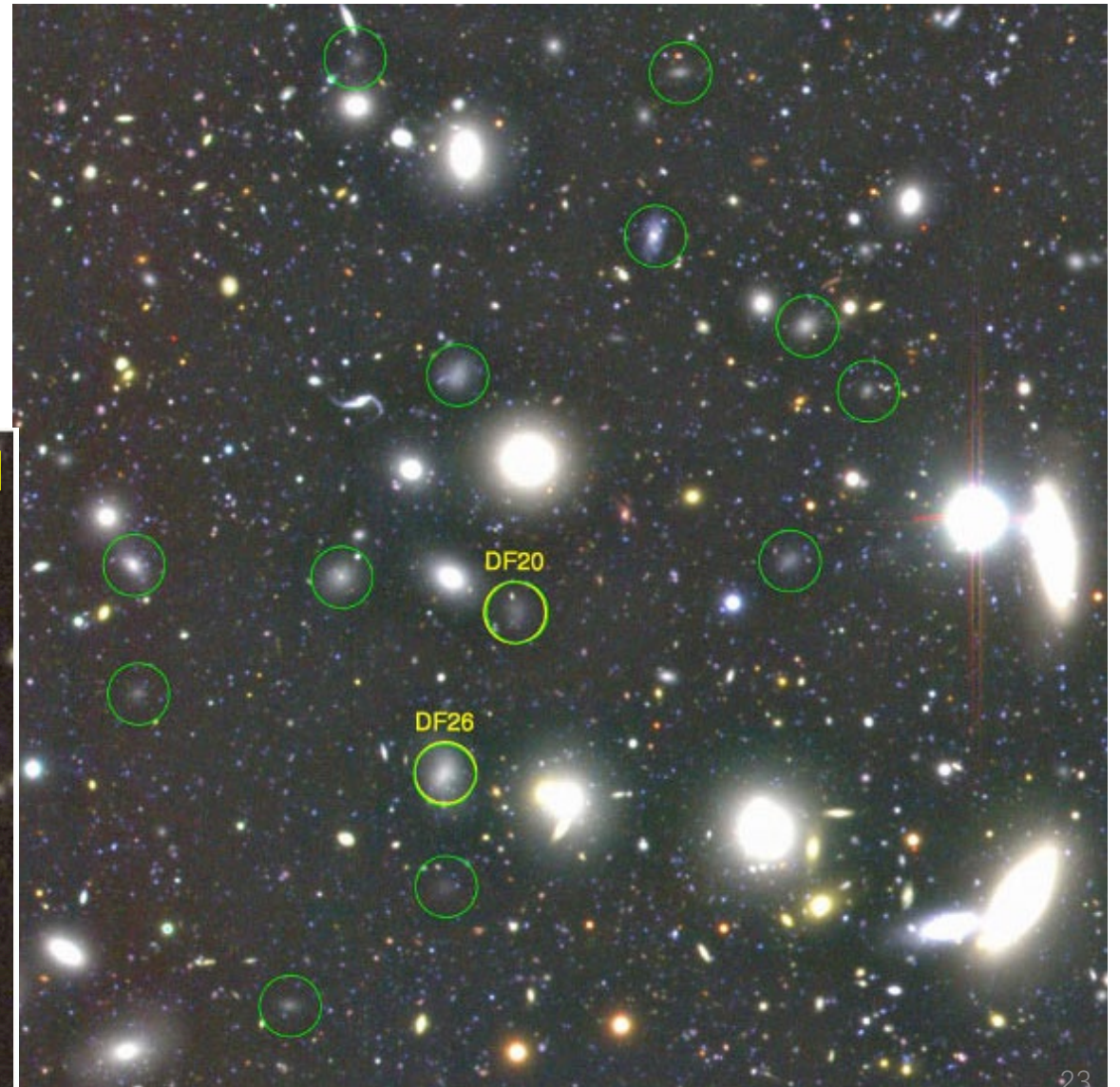
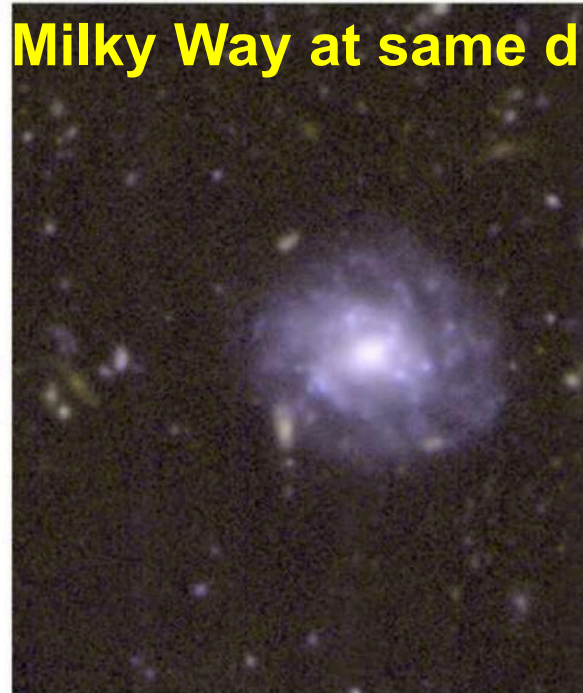
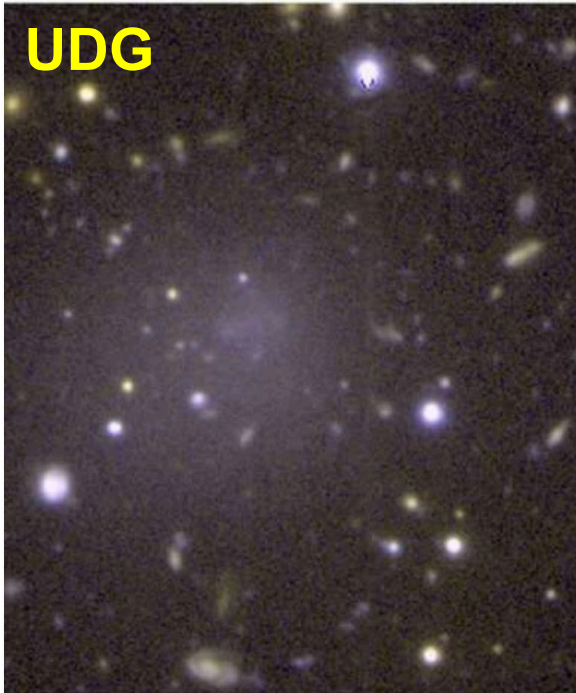


Ultra-diffuse galaxies (van Dokkum+15):

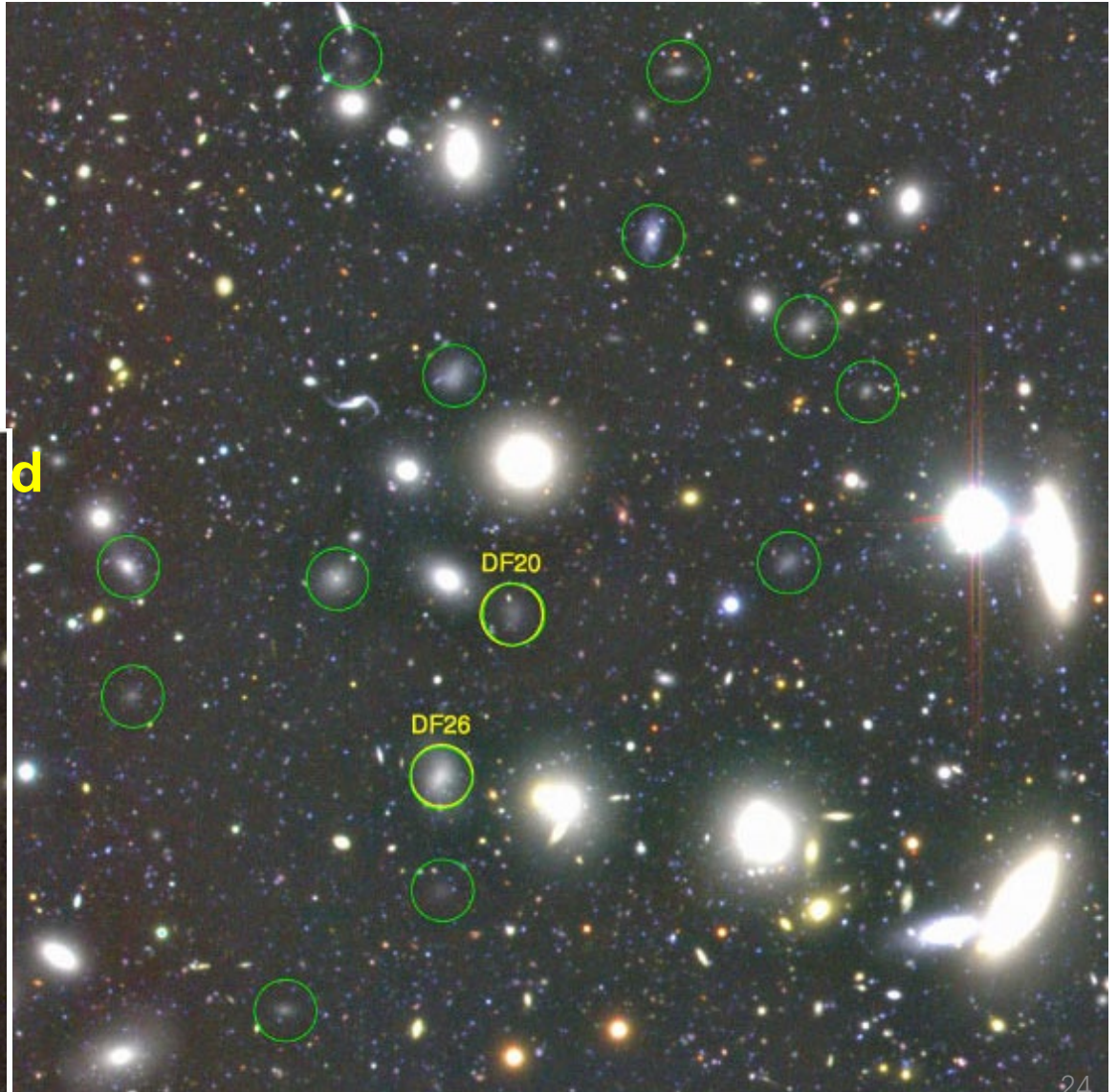
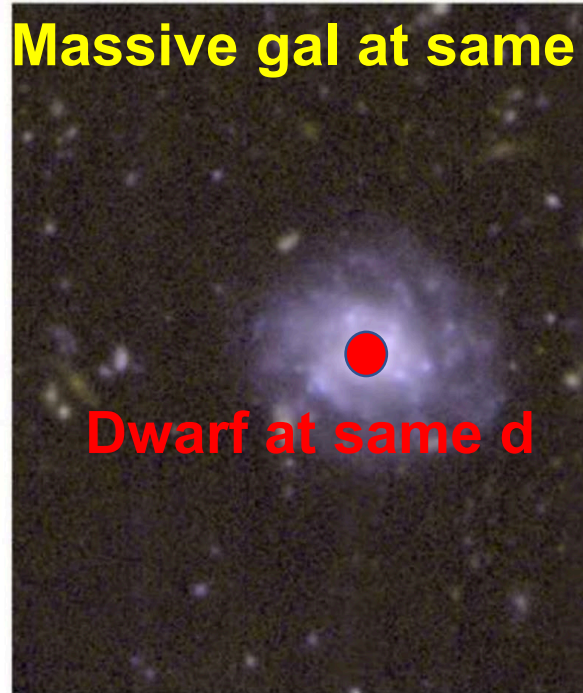
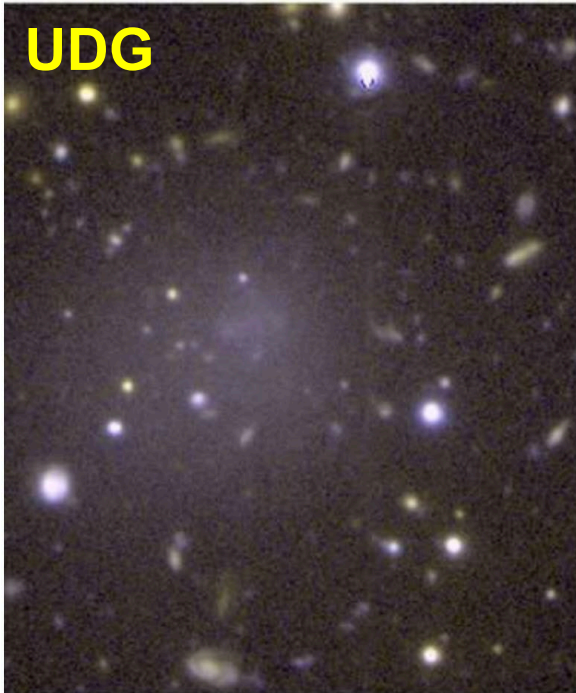
Milky Way size, 1/100-1/1000 stars



Searching for Failed L* Galaxies - UDG



Searching for Failed L^* Galaxies - UDG



Searching for Failed L* Galaxies - UDG

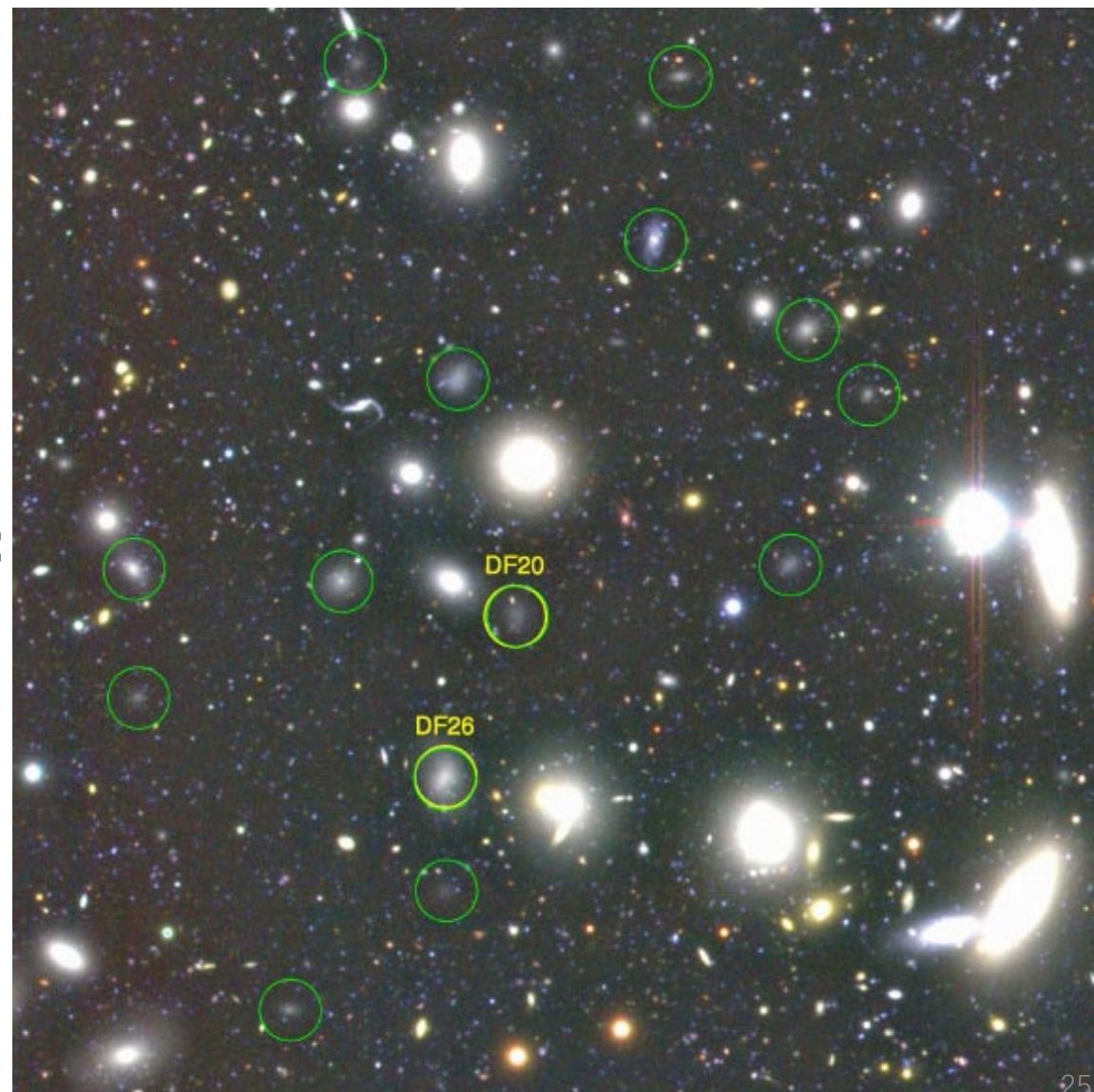


Ultra-diffuse galaxies (van Dokkum+15):

Milky Way size, 1/100-1/1000 stars

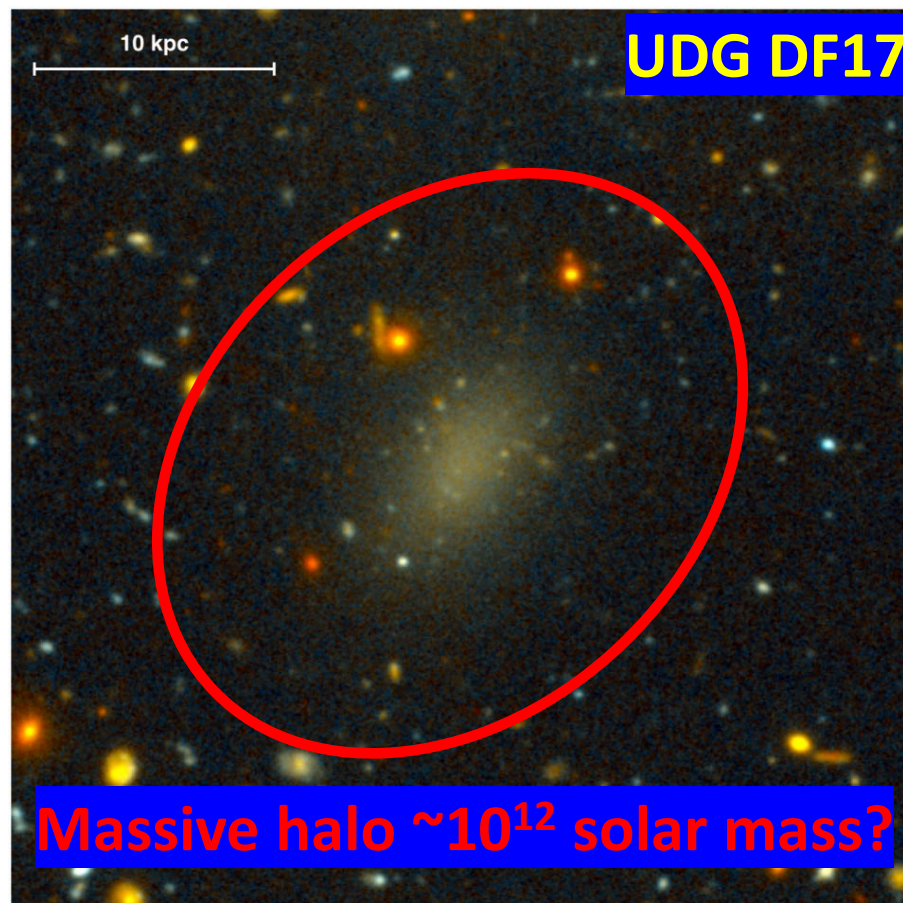
Coma, Virgo, Fornax, A2744,

HI-bearing UDGs

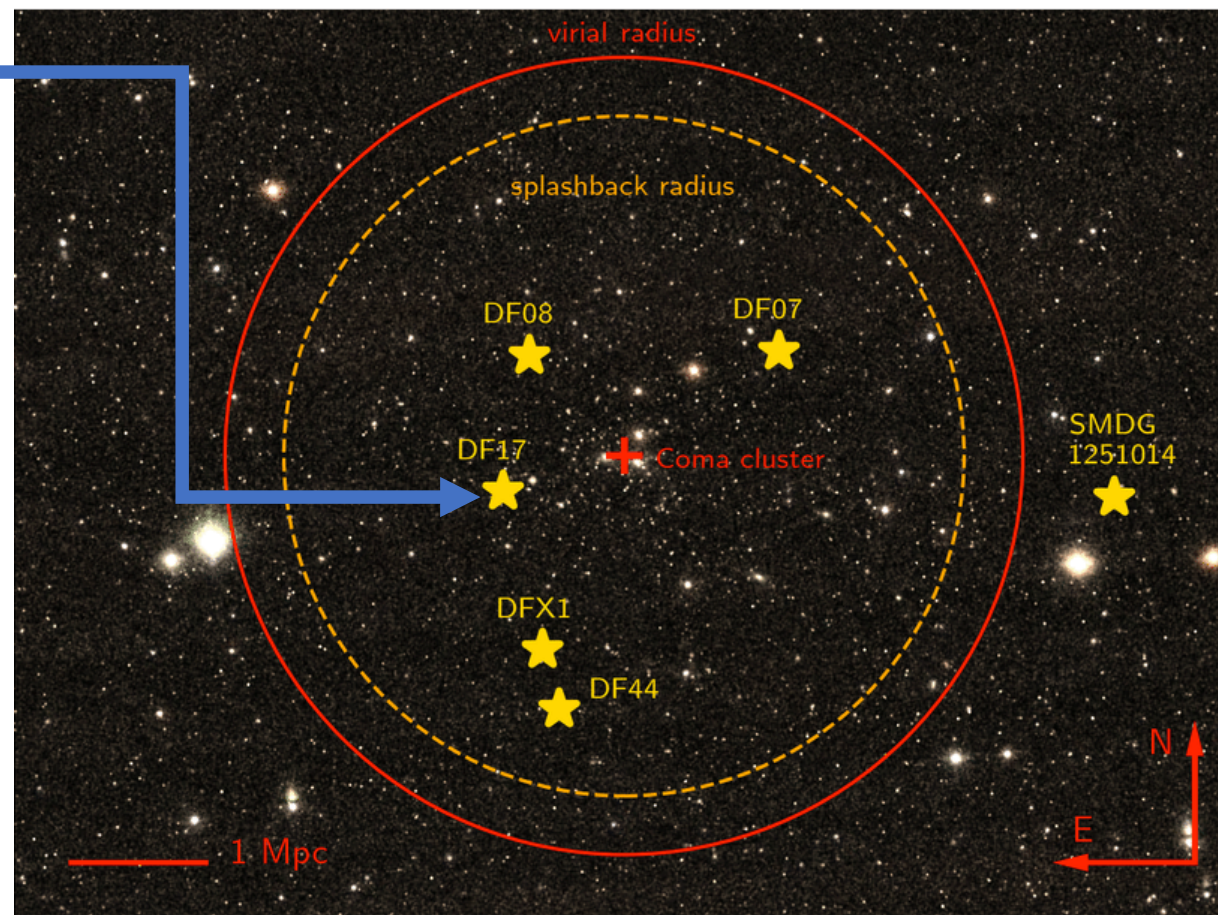


Searching for Failed L* Galaxies - UDG

UDG: Failed L* galaxy candidates?



Regular UDGs in Coma cluster



Searching for Failed L* Galaxies - UDG

DF44:

Globular cluster dynamics

halo mass $\sim 8 \times 10^{11}$ solar mass

Resolved stellar velocity map

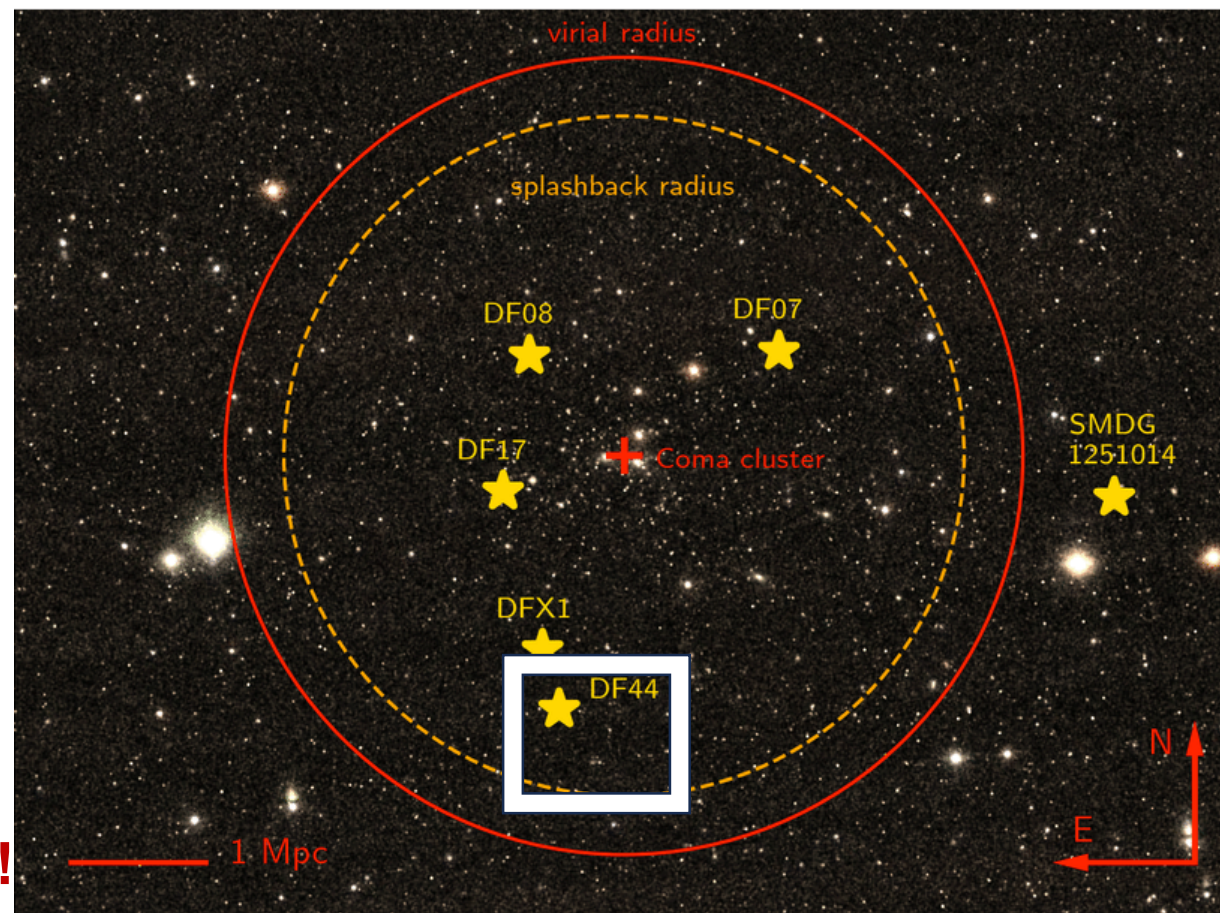
halo mass $\sim 1.6 \times 10^{11}$ solar mass

Weak lensing, X-ray, GC survey

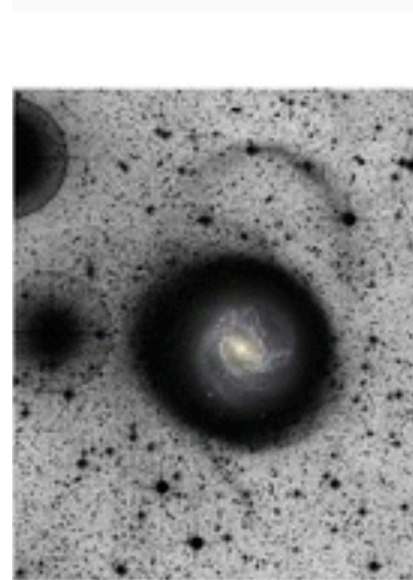
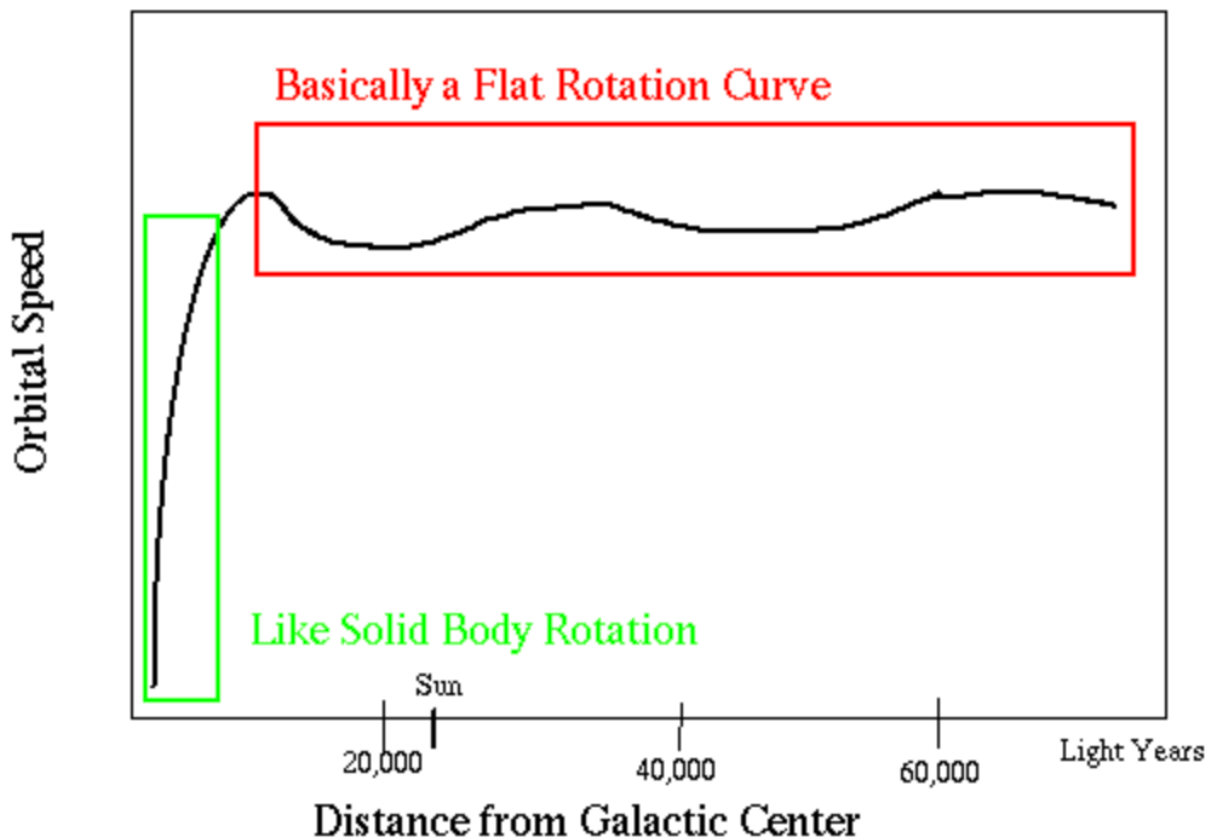
DF2, DF4: DM deficient UDGs

UDGs may not be good FLG candidates!

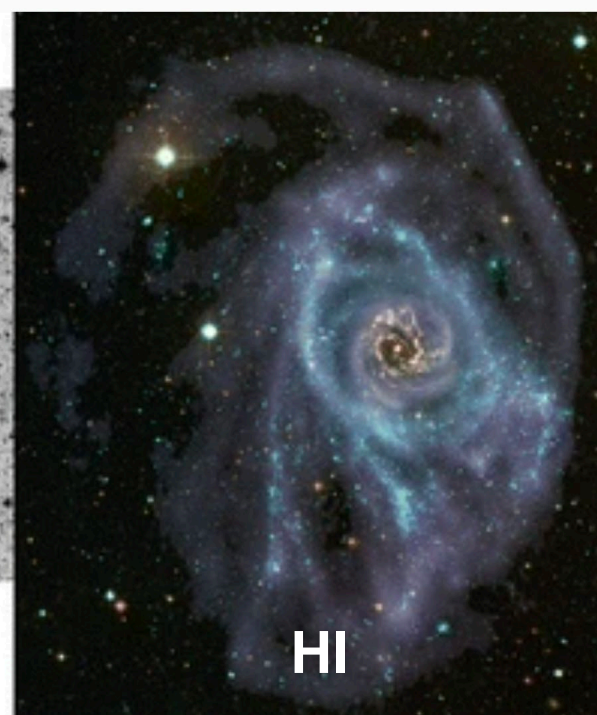
Regular UDGs in Coma cluster



Searching for FLG: HI dynamics

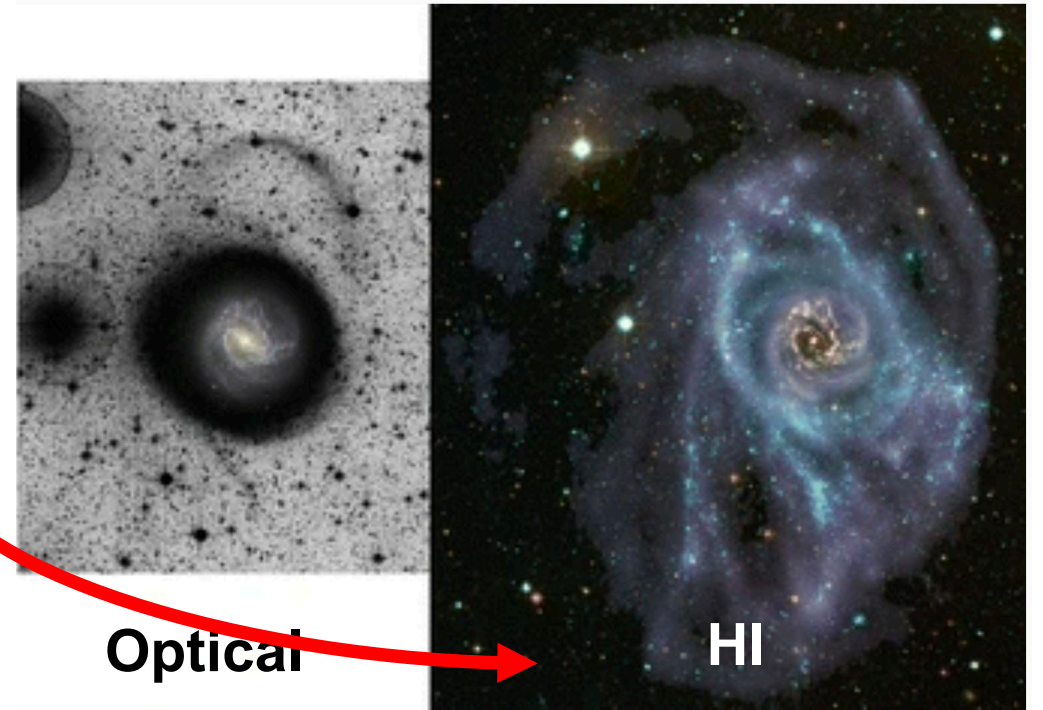
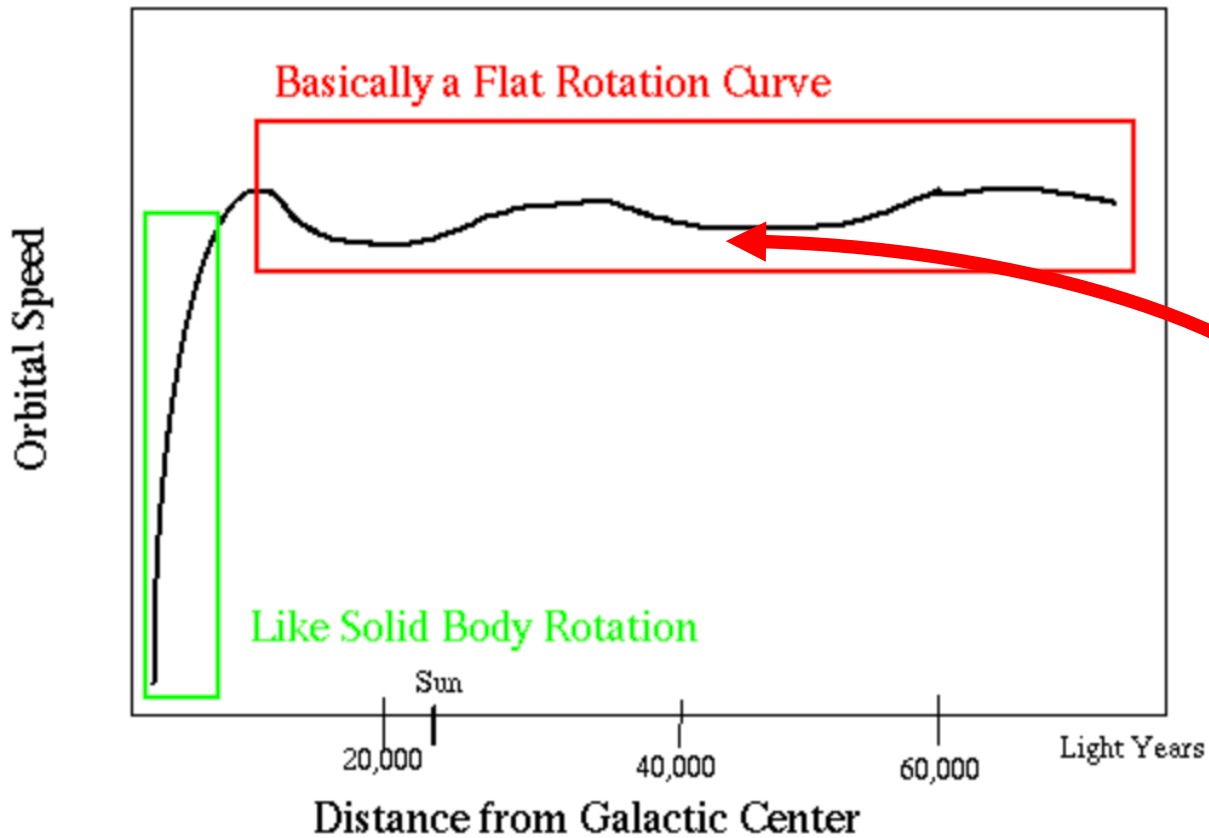


Optical

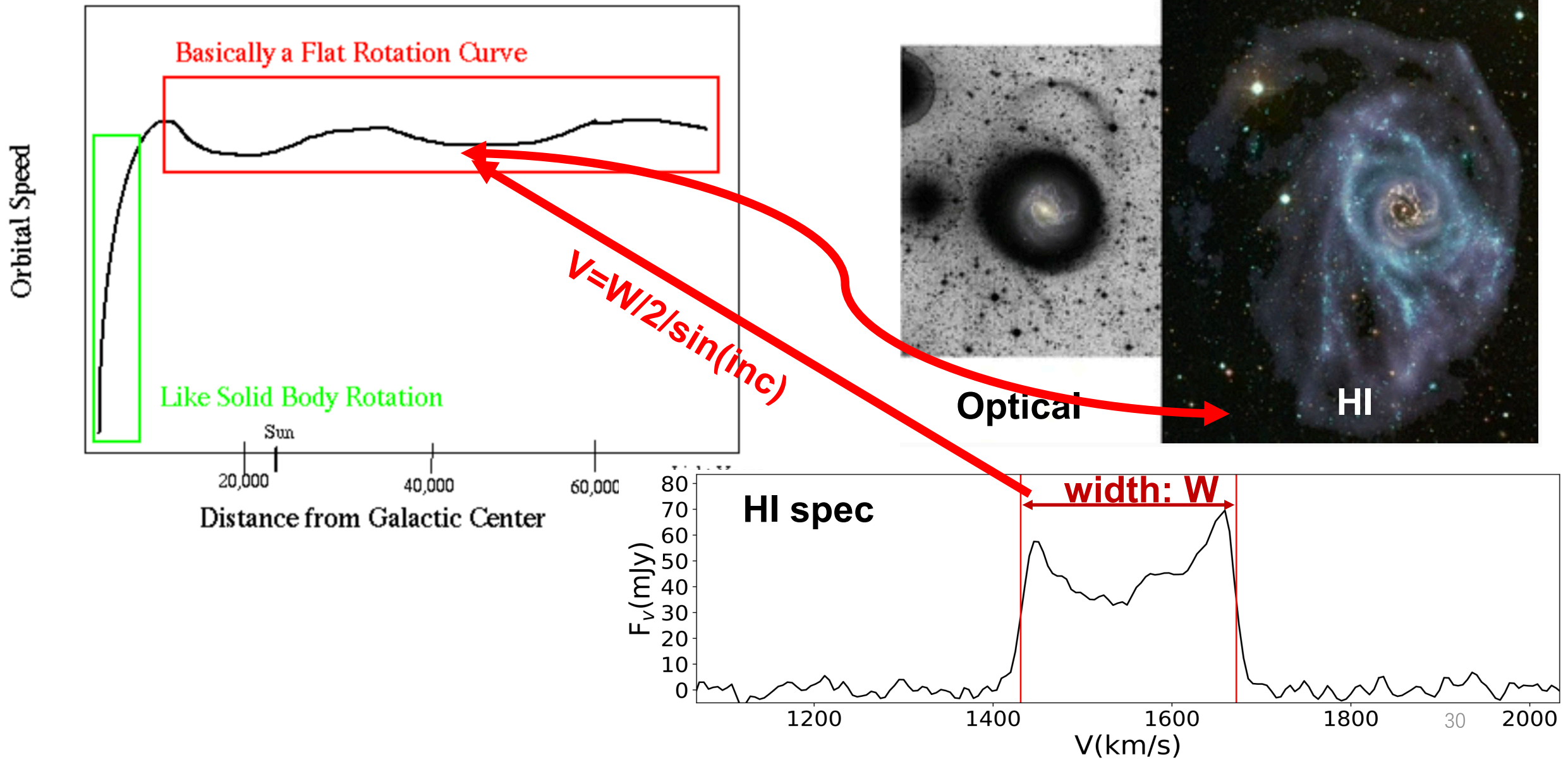


HI

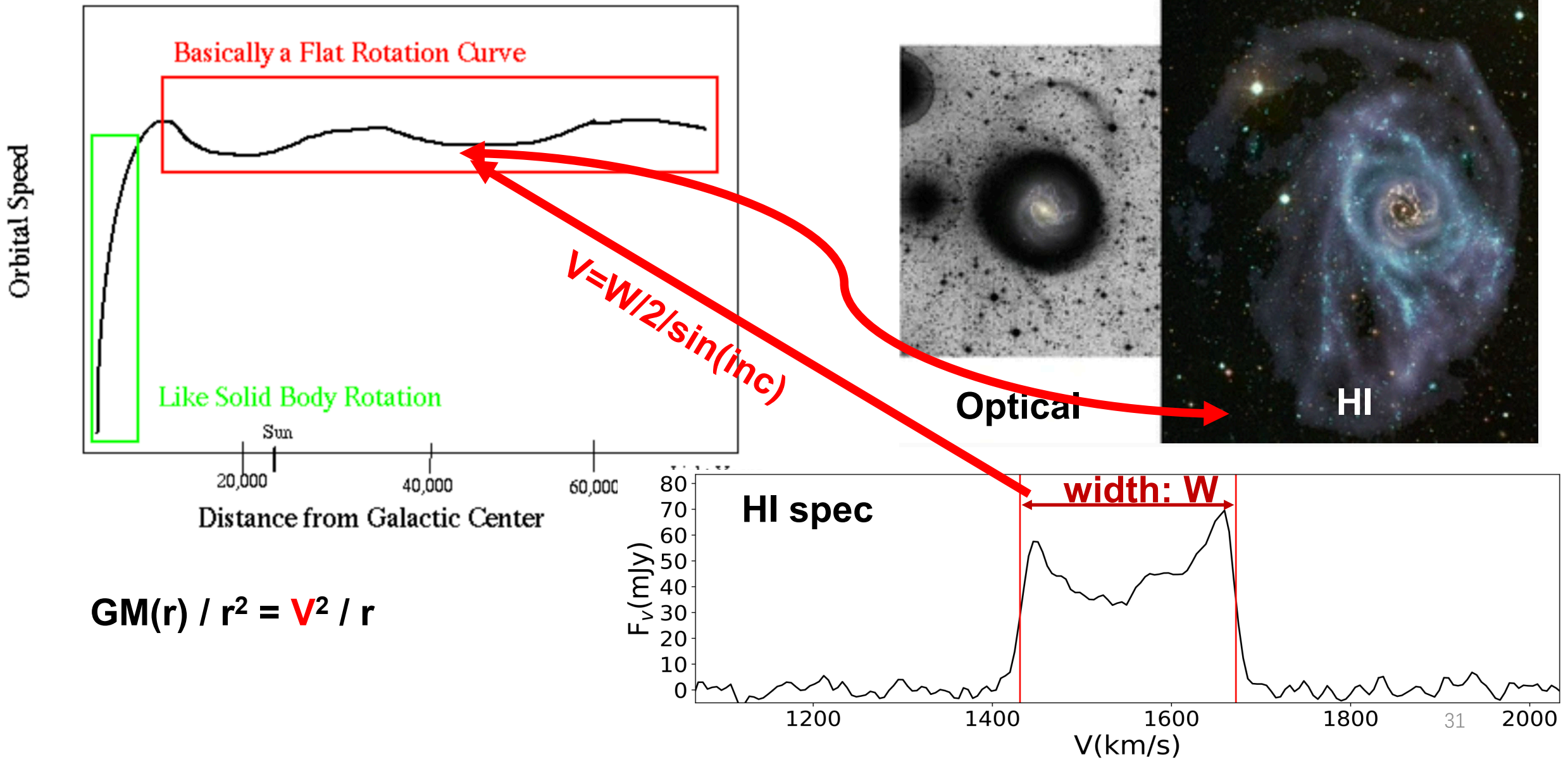
Searching for FLG: HI dynamics



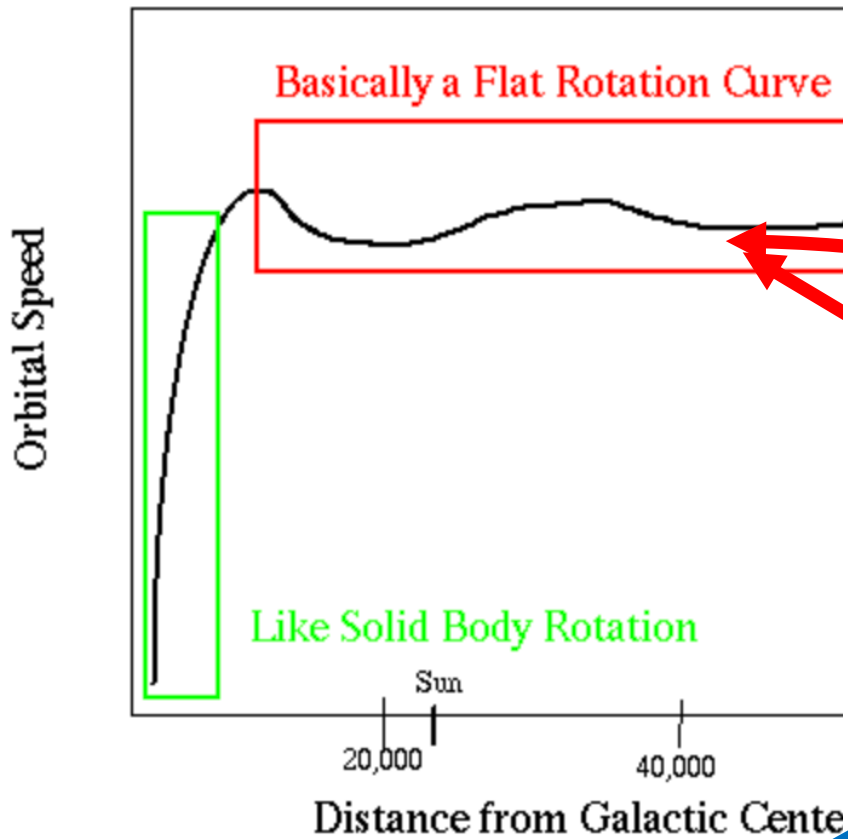
Searching for FLG: HI dynamics



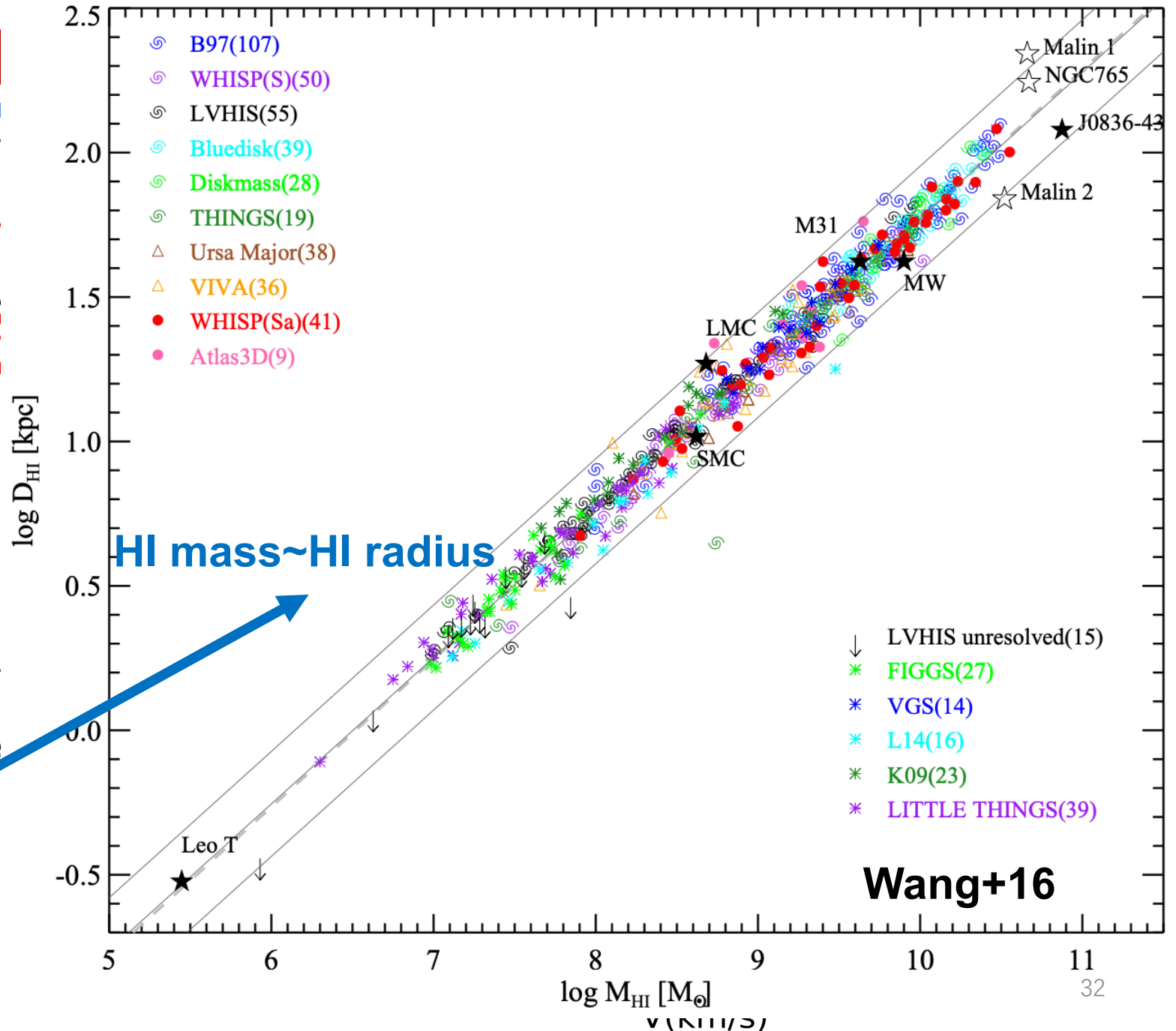
Searching for FLG: HI dynamics



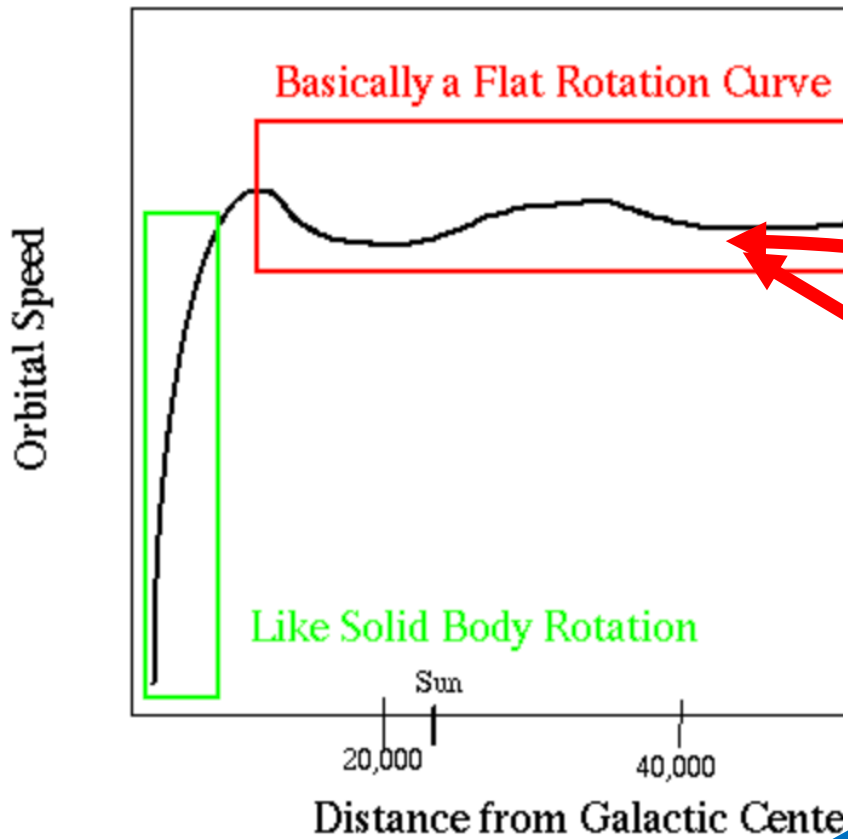
Searching



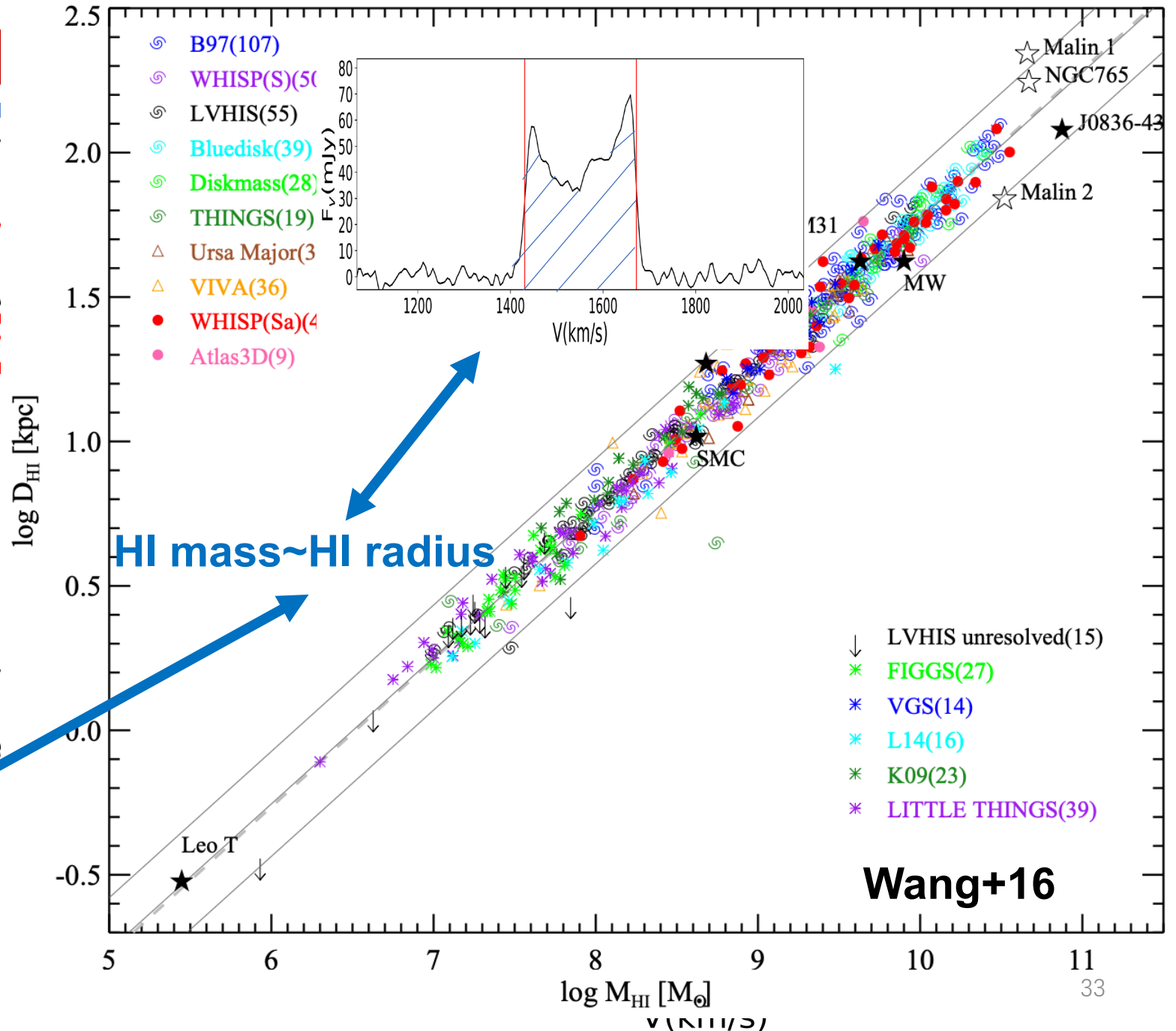
$$GM(r) / r^2 = V^2 / r$$



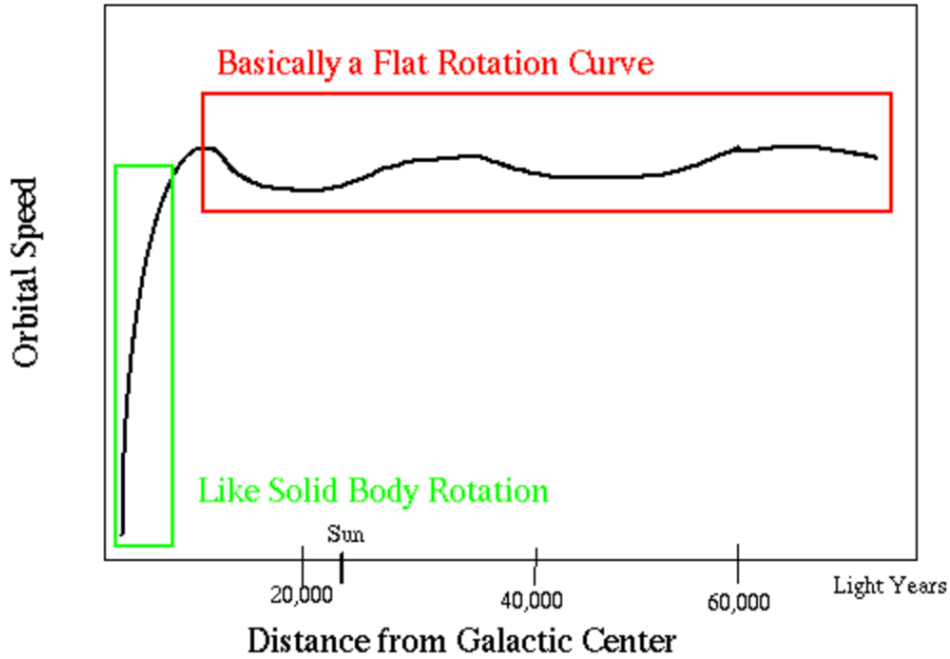
Searching



$$GM(r) / r^2 = V^2 / r$$



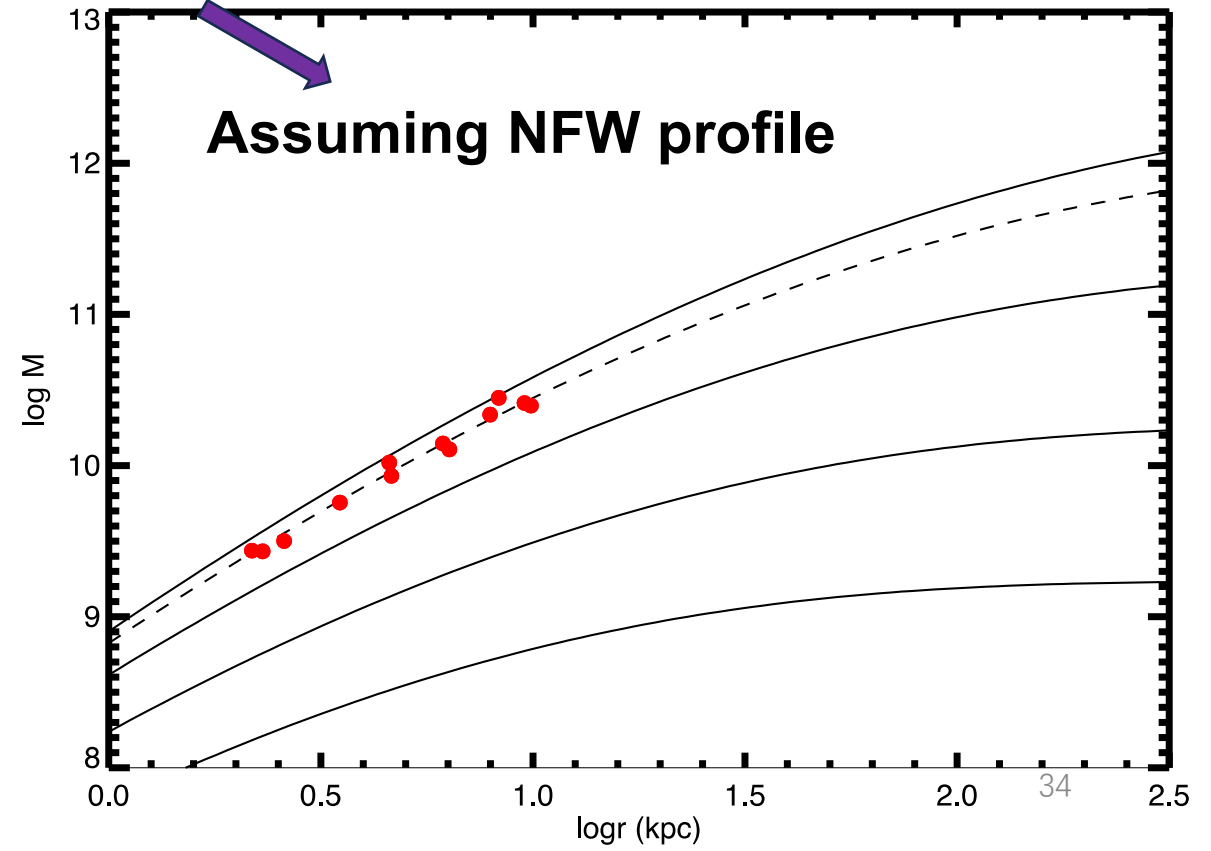
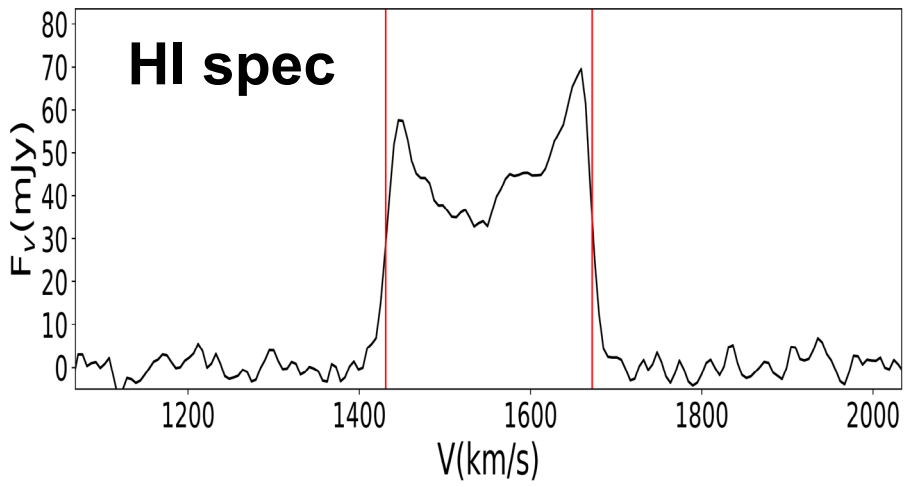
Searching for FLG: HI dynamics



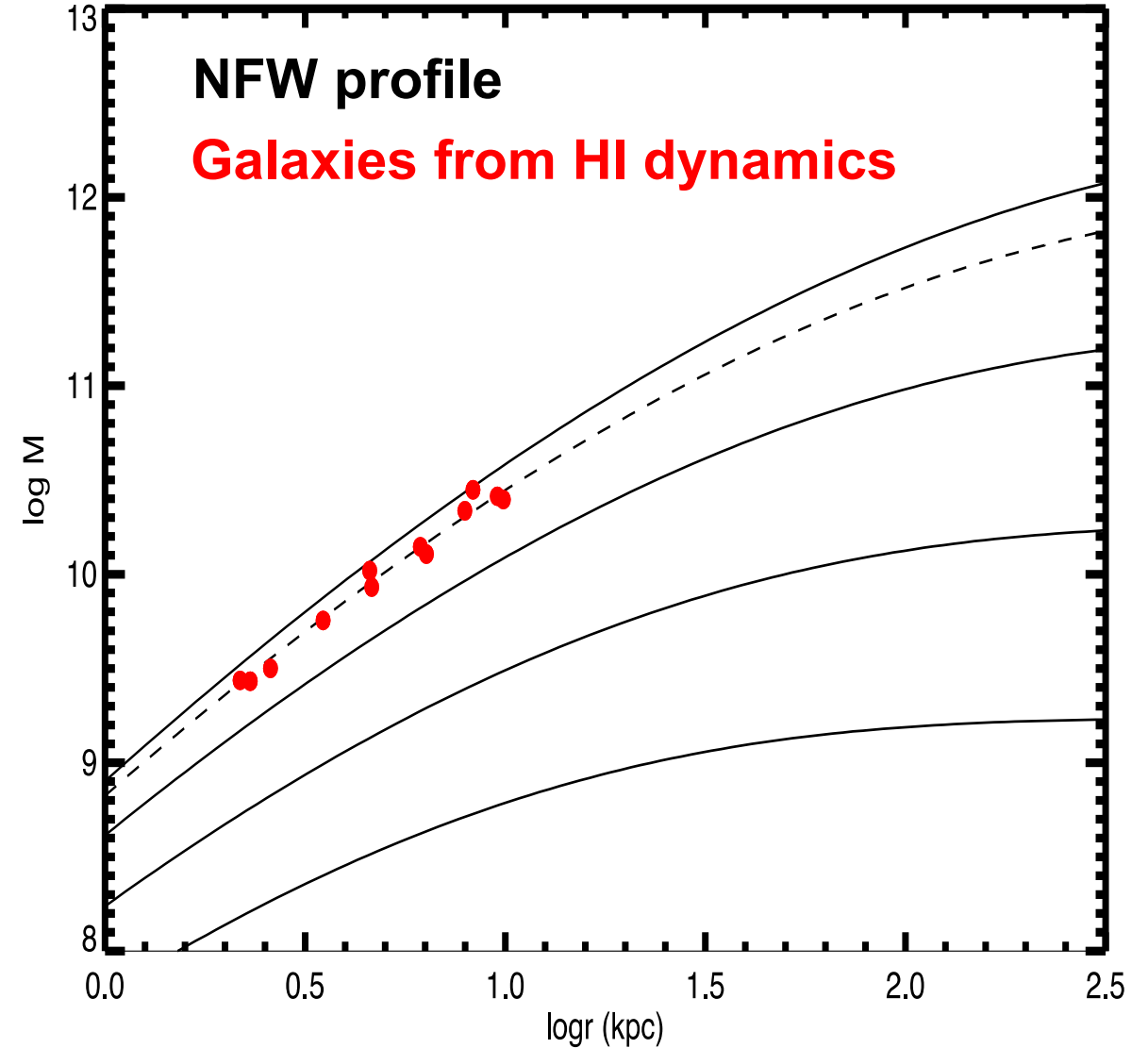
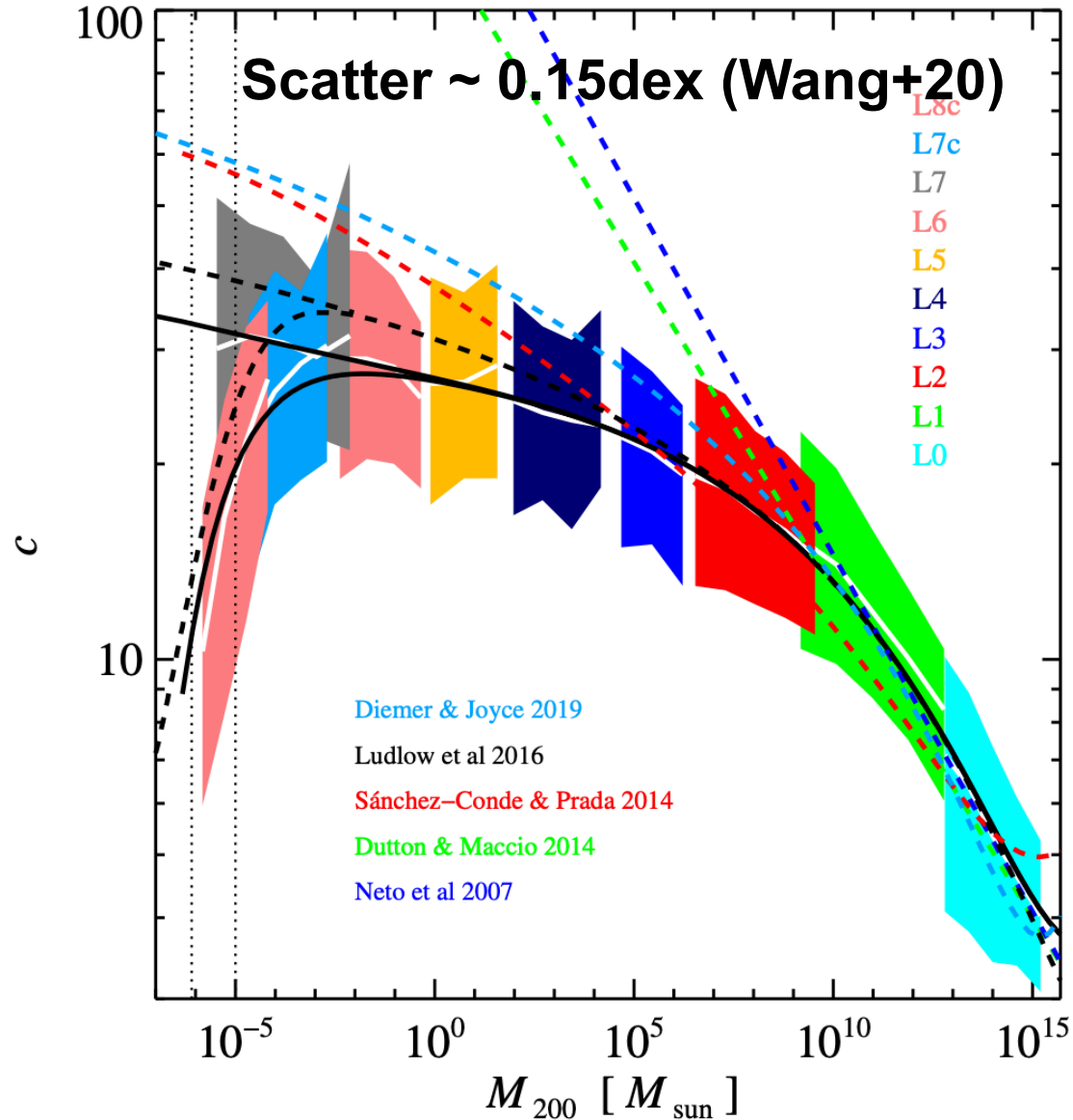
$$GM(r) / r^2 = V^2 / r$$

M_{stellar} M_{gas} M_{DM}

This diagram illustrates the components of the total mass $M(r)$ enclosed within a radius r . The equation $GM(r) / r^2 = V^2 / r$ is shown at the top. Three arrows point downwards from $M(r)$ to the labels M_{stellar} , M_{gas} , and M_{DM} . The M_{DM} label is enclosed in a purple box, and a purple arrow points from this box towards the plot on the right.

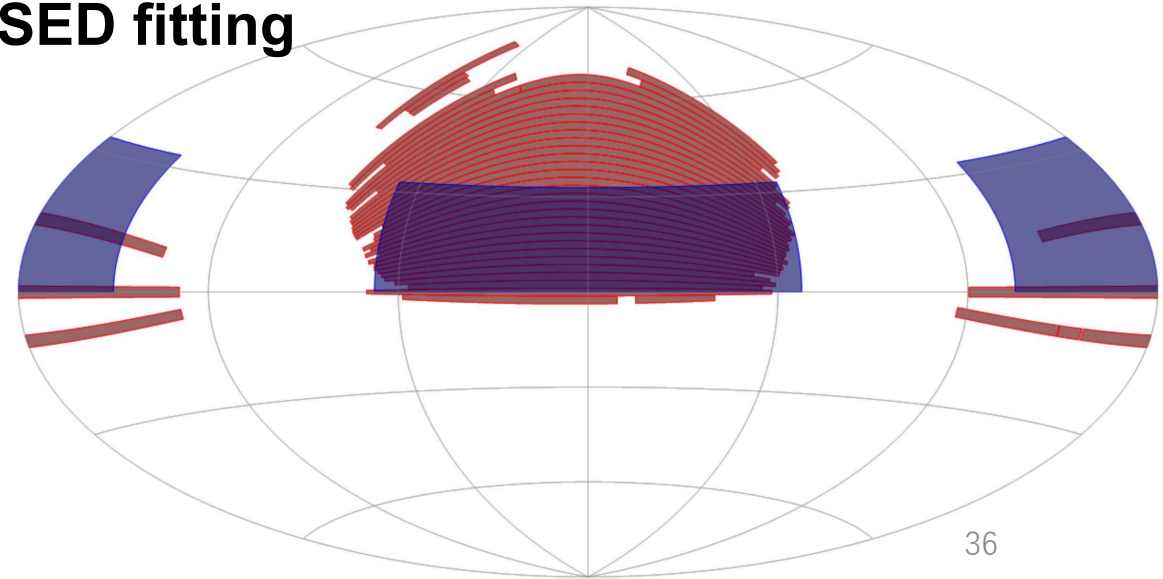


Searching for FLG: C- M_{halo} relation



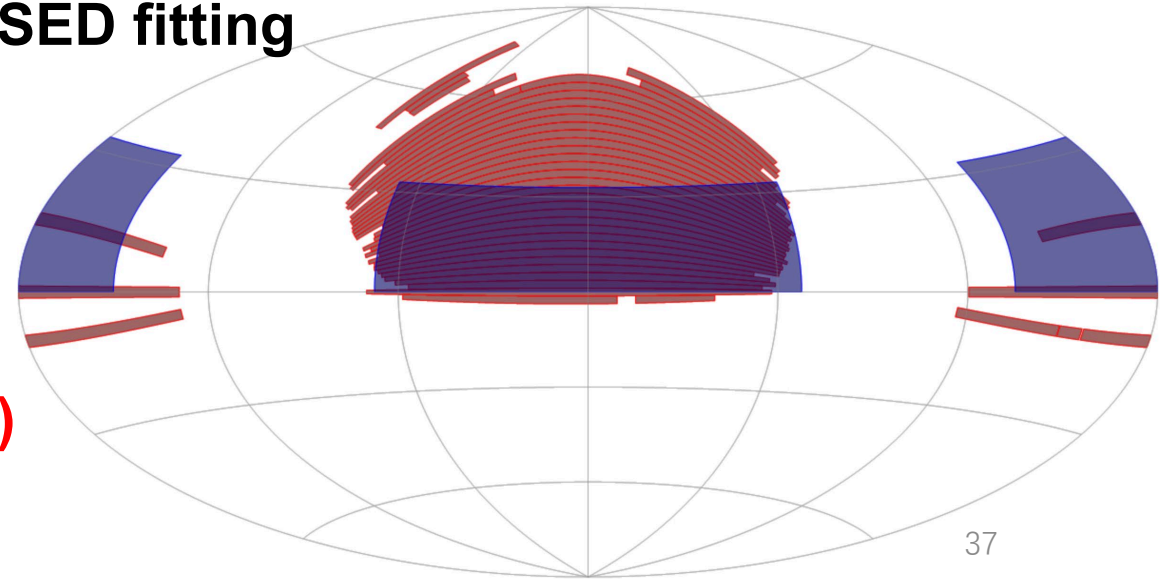
Searching for FLG: ALFALFA

- a_{100} , HI SNR > 10, good HI spec, regular, no spiral arms, no star companions
- no galaxy companions in $R < 3.5$ arcmin, $dv < 500$ km/s
- for HI SNR > 25, $W = W_{20}$; for $10 < \text{SNR} < 25$, $W = W_{50}$
- stellar mass ($< 10^9$ solar mass):
 - GALEX-SDSS-WISE: UV-optical-IR SED fitting
 - SDSS: g-i color
- halo mass ($> 5 \times 10^{11}$ solar mass):
 - NFW profile
 - HI inc = stellar inc
- stellar-to-halo mass ratio ($< 0.3\%$)

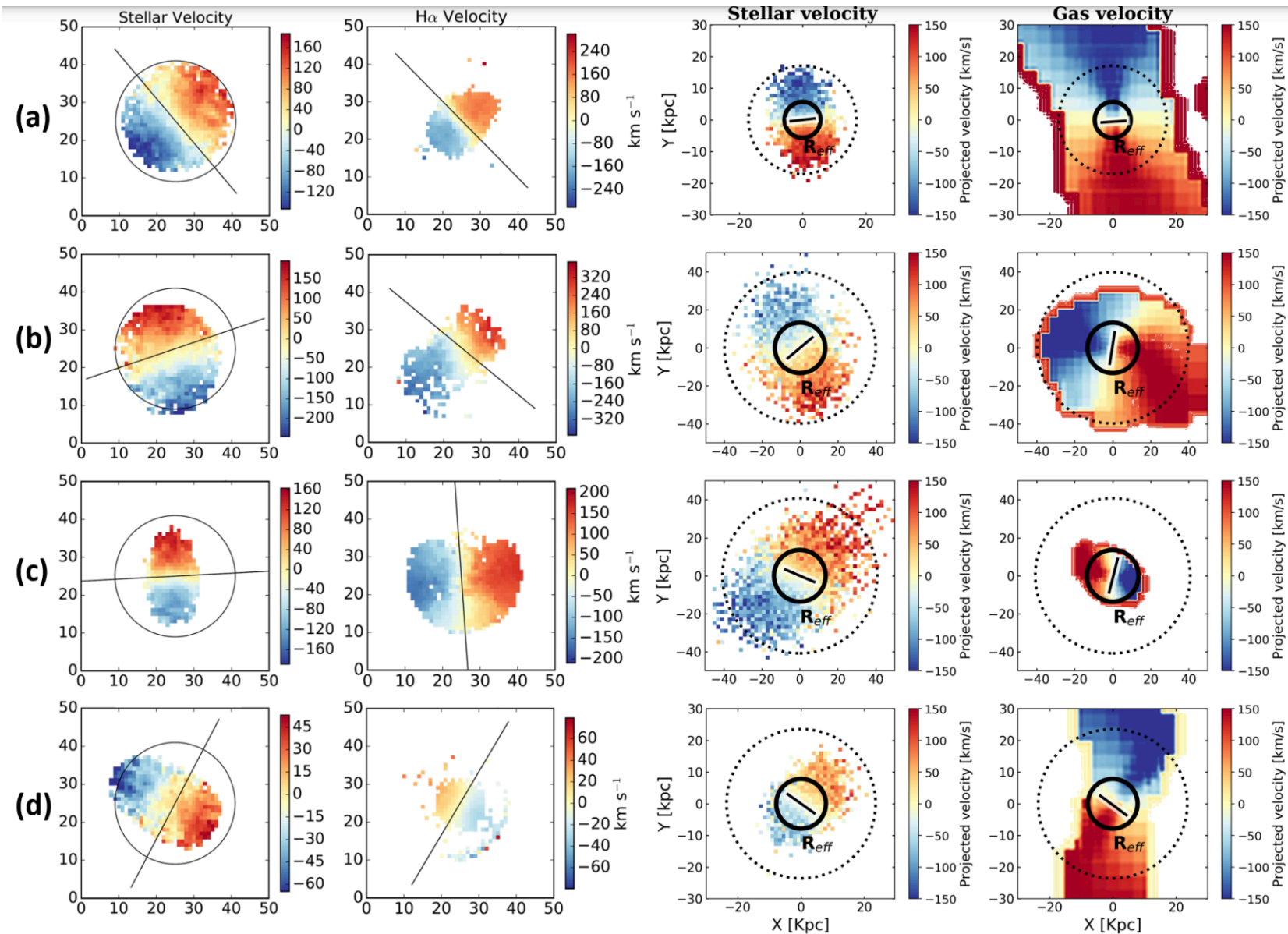


Searching for FLG: ALFALFA

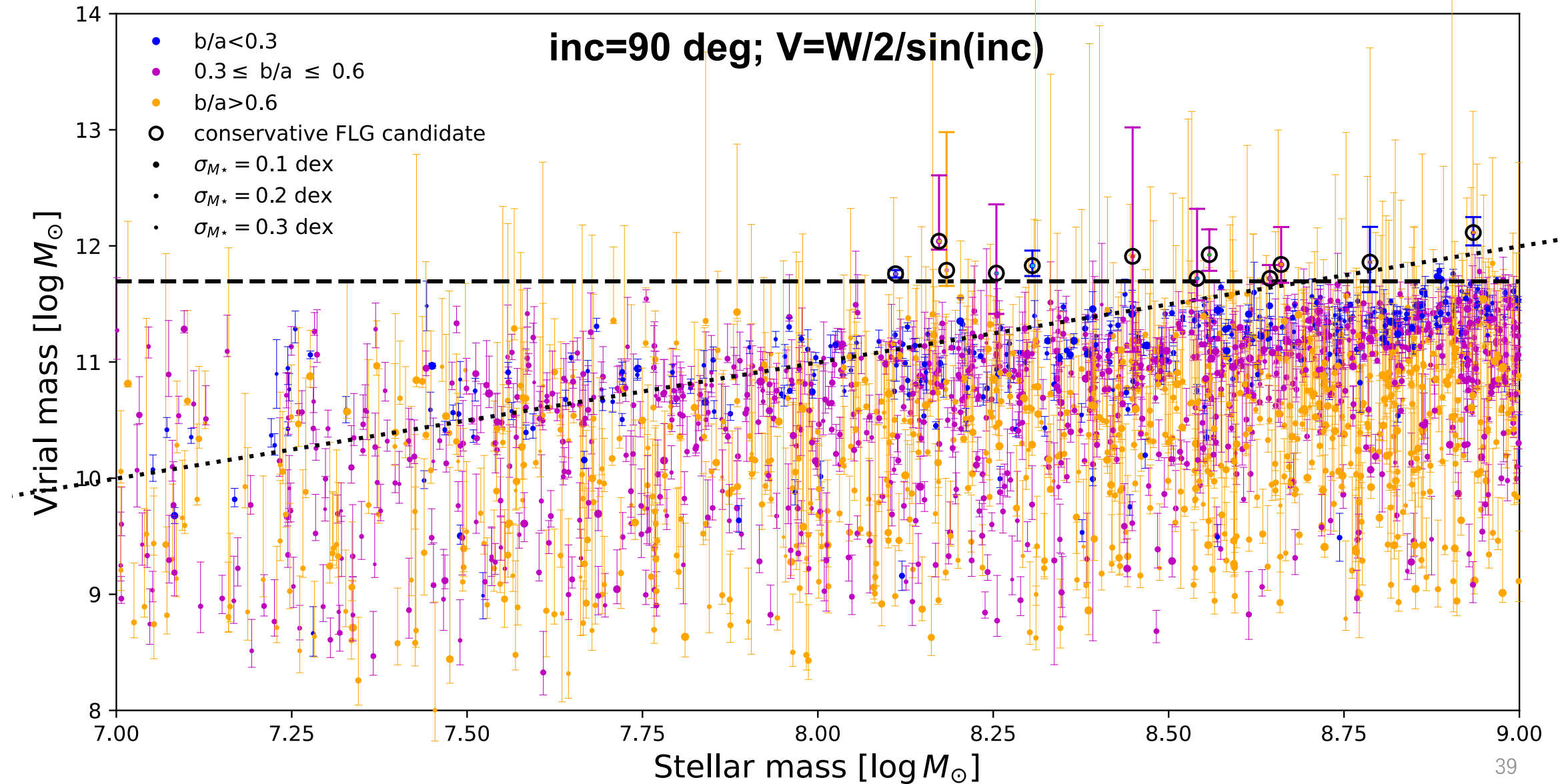
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- halo mass ($> 5 \times 10^{11}$ solar mass):
 - NFW profile
 - HI inc = stellar inc $V = W/2/\sin(\text{inc})$
- stellar-to-halo mass ratio ($< 0.3\%$)



Misalignment between HI and Stellar disks

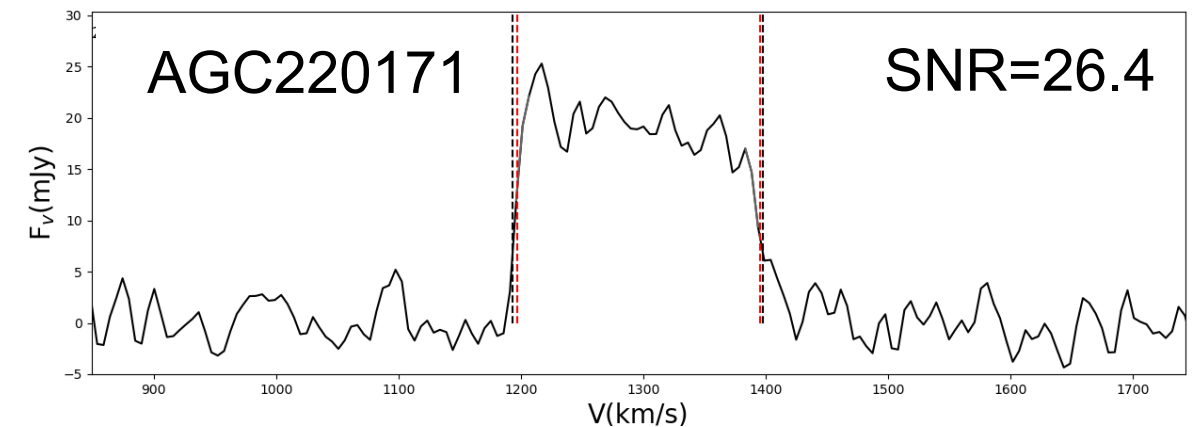
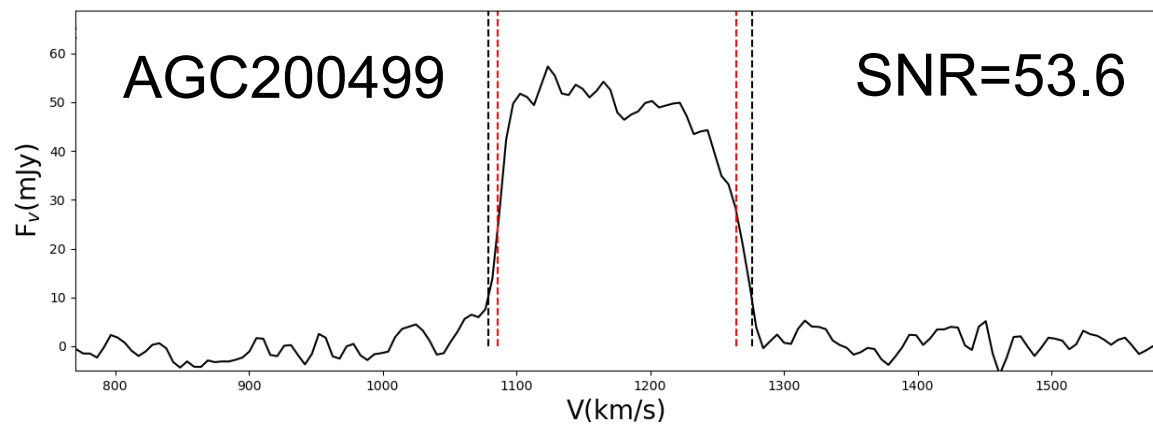
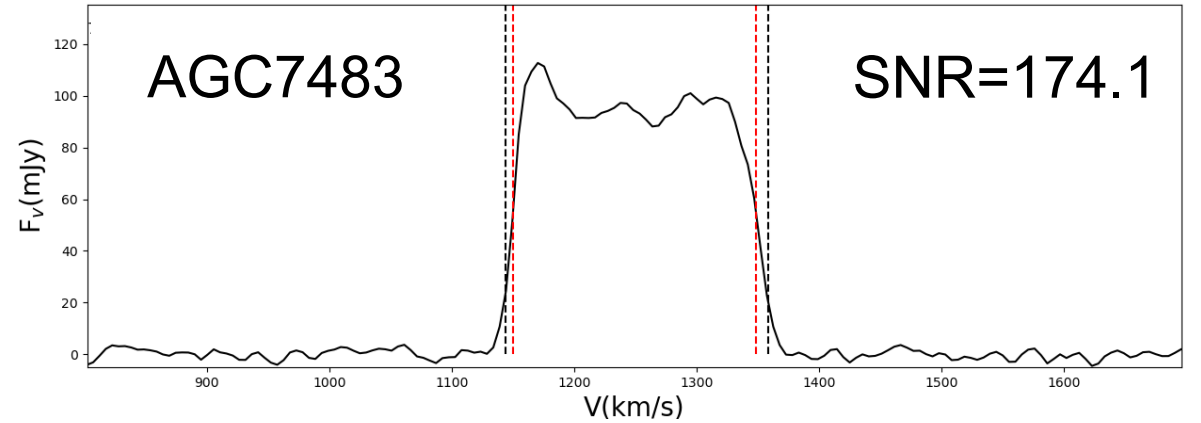
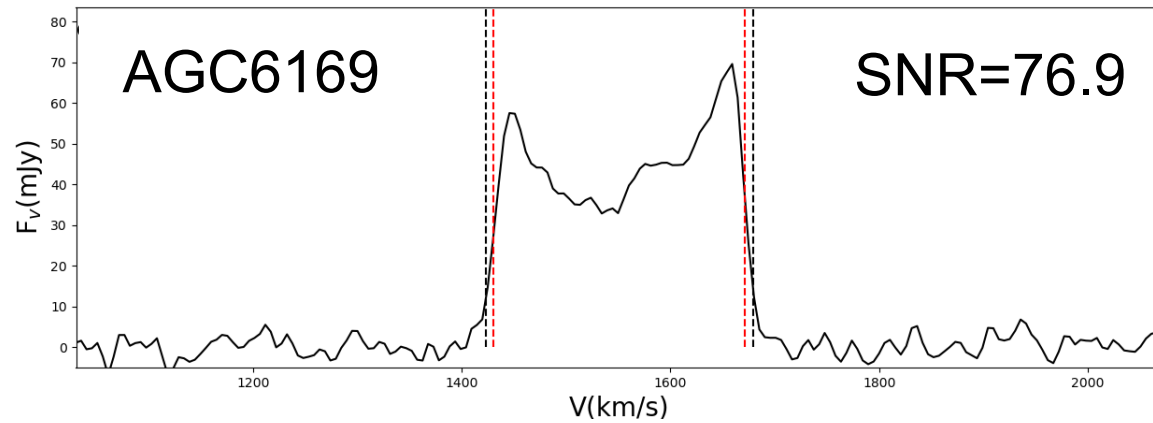


High-confidence FLG candidates



High-confidence FLG candidates

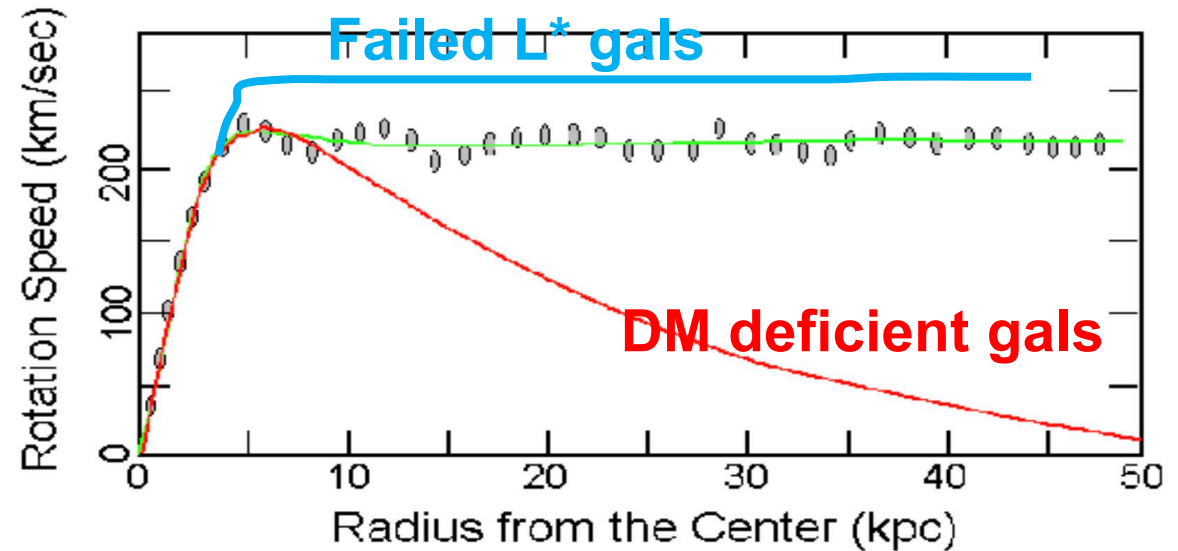
HI spec, W_{50} , W_{20}



High-confidence FLG candidates

1) Challenge against MOND

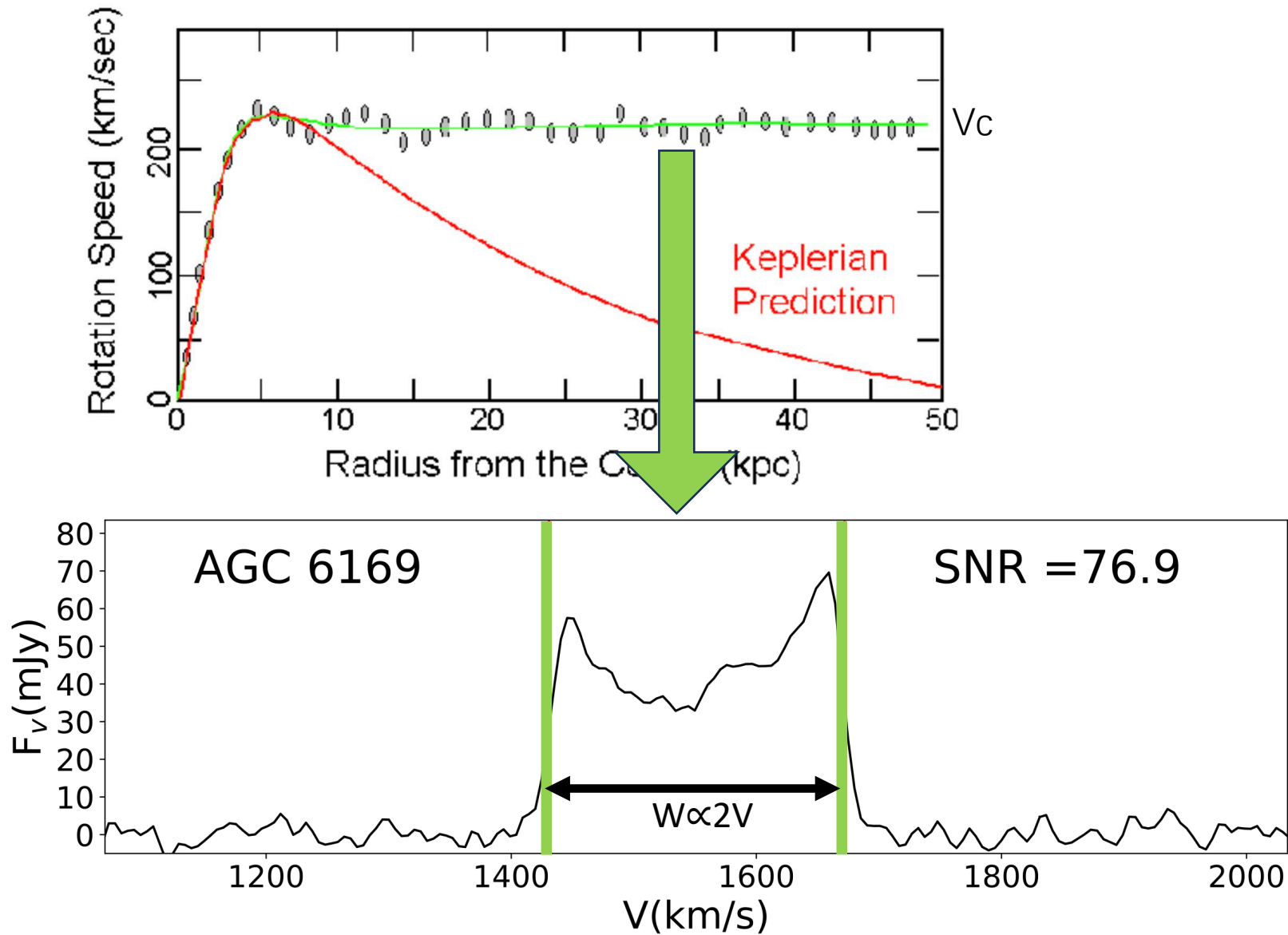
- ❑ Higher than expected rotation velocities



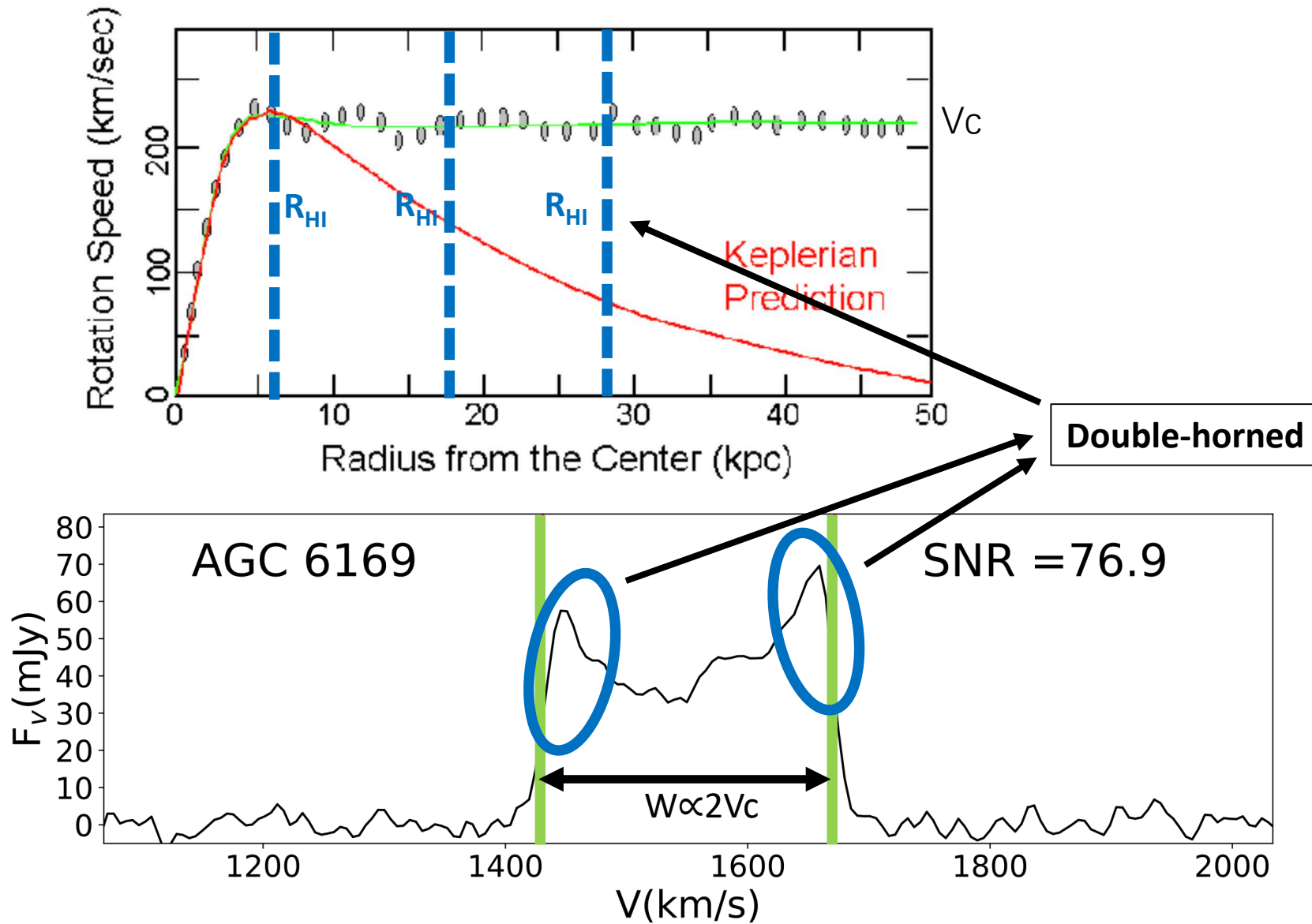
2) Challenge against standard galaxy formation model

- ❑ 50% in fields, 50% in high-density environments
 - High-density env: ram pressure or tidal stripping in early Universe
 - Low-density env: stronger than expected **AGN feedback** in early Universe?
- No isolated FLGs in cosmological simulations

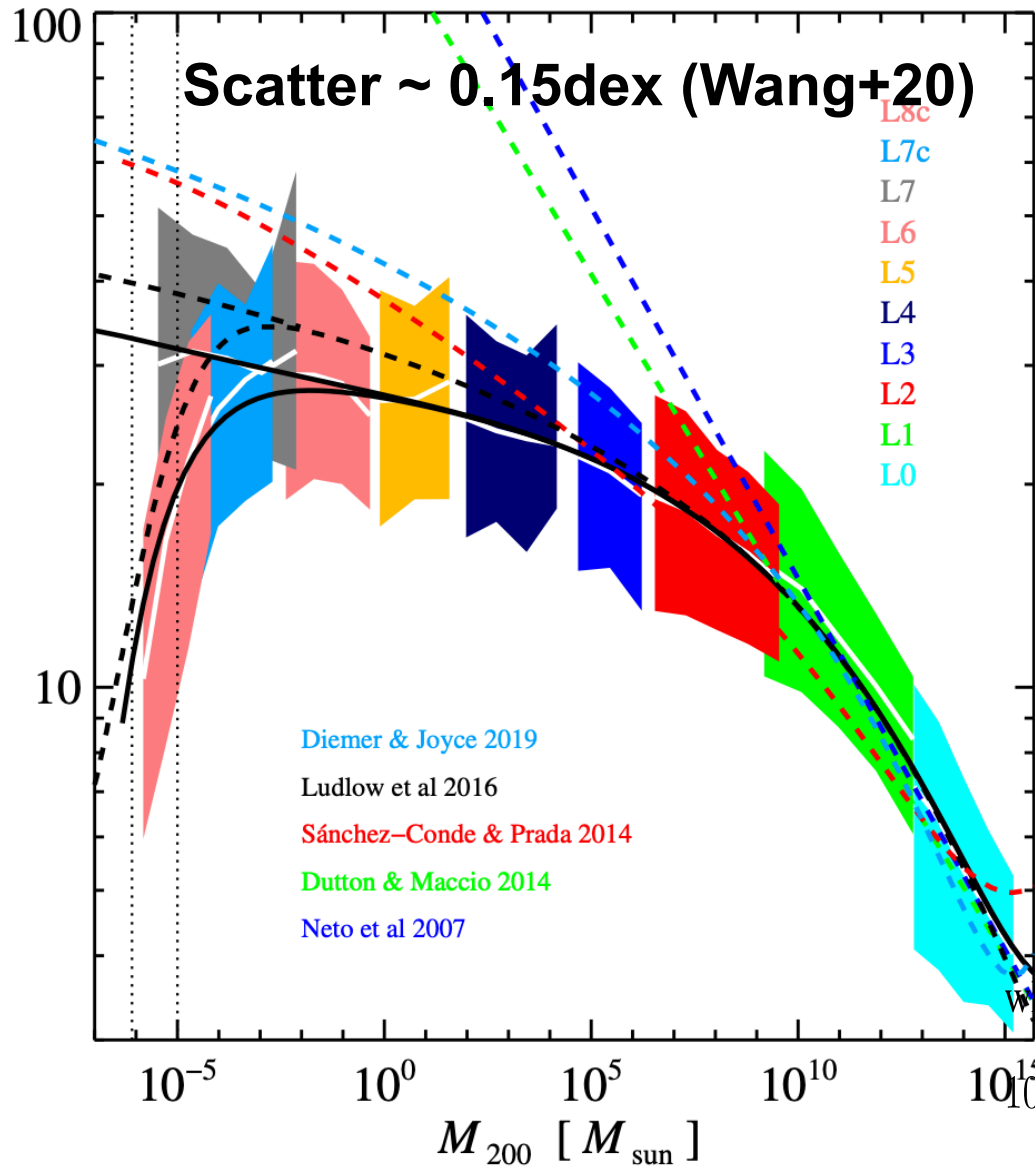
Selection effect (1) – prefer small z



Selection effect (1)



C- M_{halo} relation



NFW model

$$M_{\text{dy}}(< r_{\text{HI}}) = \int_0^{r_{\text{HI}}} 4\pi r^2 \rho_{\text{NFW}}(r) dr + M_b$$

$$= 4\pi \rho_0 r_s \left[\ln\left(\frac{r_s + r_{\text{HI}}}{r_s}\right) - \frac{r_{\text{HI}}}{r_s + r_{\text{HI}}} \right] + M_b,$$

$$M_{\text{vir}} = \int_0^{r_{200}} 4\pi r^2 \rho_{\text{NFW}}(r) dr = 4\pi \rho_0 r_s \left[\ln(1 + c) - \frac{c}{1 + c} \right],$$

$$c = \sum_{i=0}^5 c_i \left[\ln \frac{M_{\text{vir}}}{h^{-1} M_{\odot}} \right]^i,$$

where the dimensionless constants $c_i = [26.250, -0.424, -1.141 \times 10^{-3}, -3.007 \times 10^{-4}, -3.489 \times 10^{-6}, 2.480 \times 10^{-7}]$ for $i \in \{0, \dots, 5\}$.