The properties of DM with the local low-surface brightness universe

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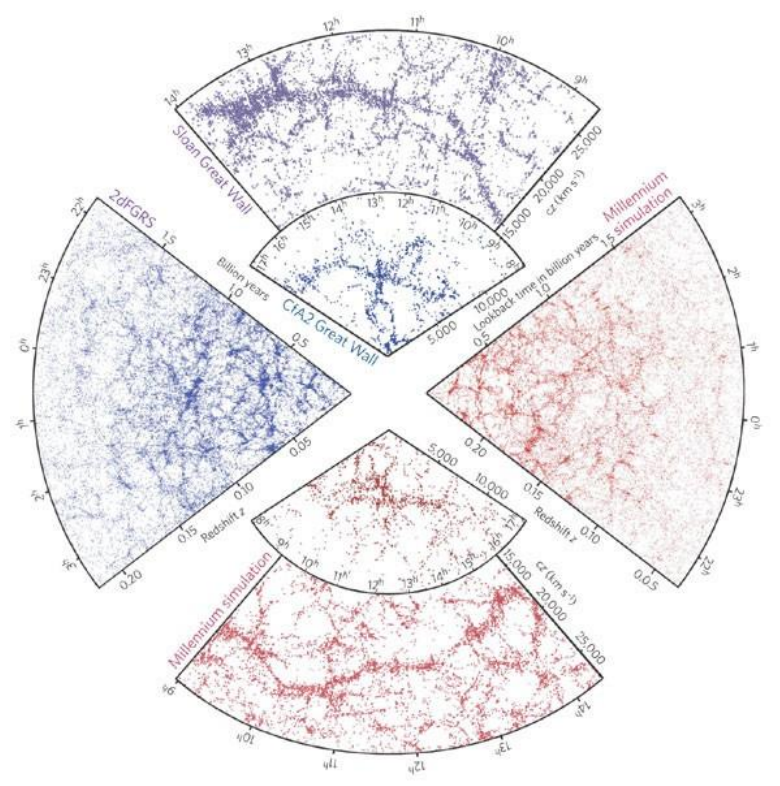
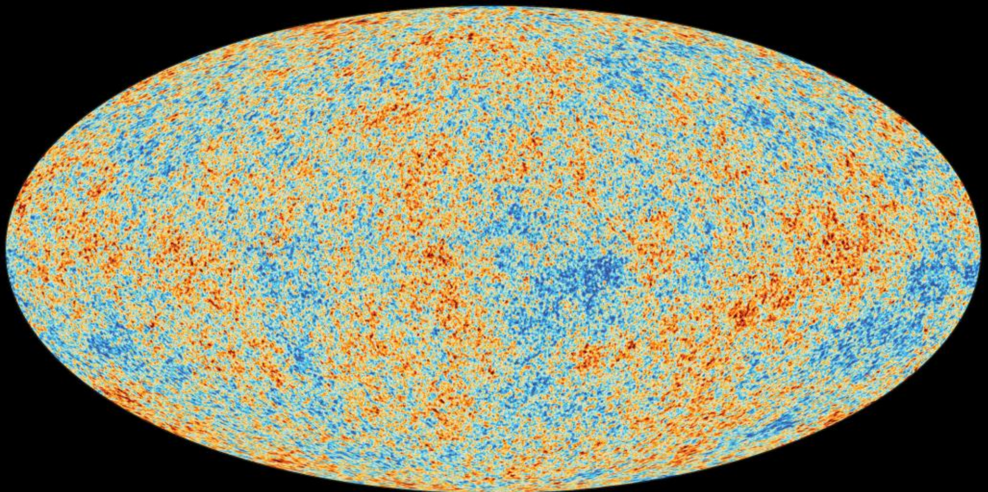
The large-scale success of *collisionless cold dark matter (CDM)*

A very simple dark matter model we can think of:

1. Cold, i.e. low non-relativistic velocities
2. Colisionless, i.e. only interacts gravitationally

Fits very well the large-scale structural properties (primordial and present-day) of the Universe





Anysotropies of the Cosmic Microwave Background (left) and large-scale structure of the galaxies in the present-day universe (top)

The cold dark matter (CDM) small scale problems

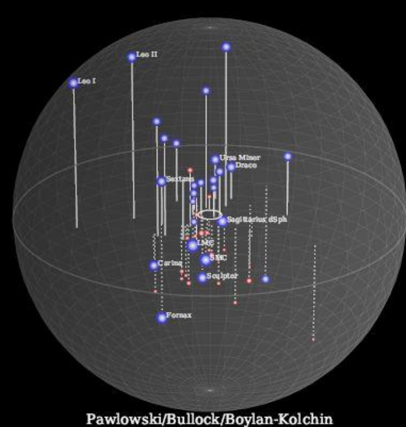
The CDM has the following problems when exploring galactic scales:

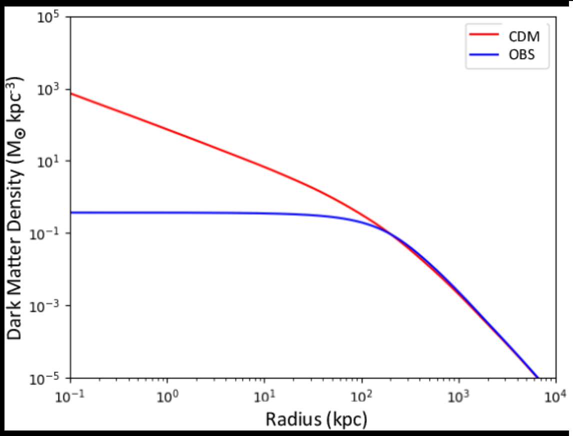
The missing satellites problem: There are much more dark matter subhalos than observed galaxy satellites

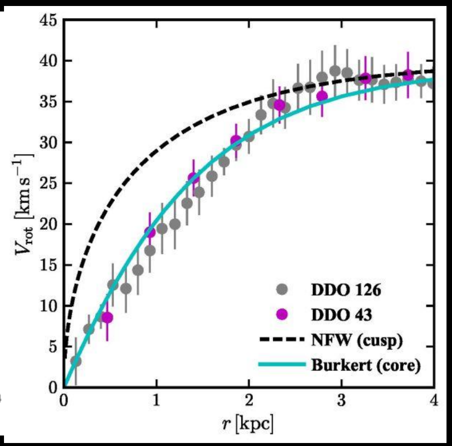
The too-big-to-fail problem: The observed satellites of the Milky Way are not massive enough to be consistent with predictions from CDM

The core/cusp problem:

Nearly all simulations form dark matter halos which have "cuspy" dark matter distributions, with density increasing steeply at small radii, while the rotation curves of most observed dwarf galaxies suggest that they have flat central dark matter density profiles ("cores")





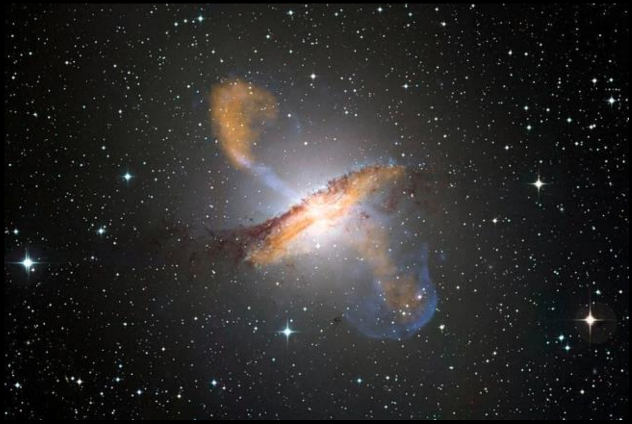


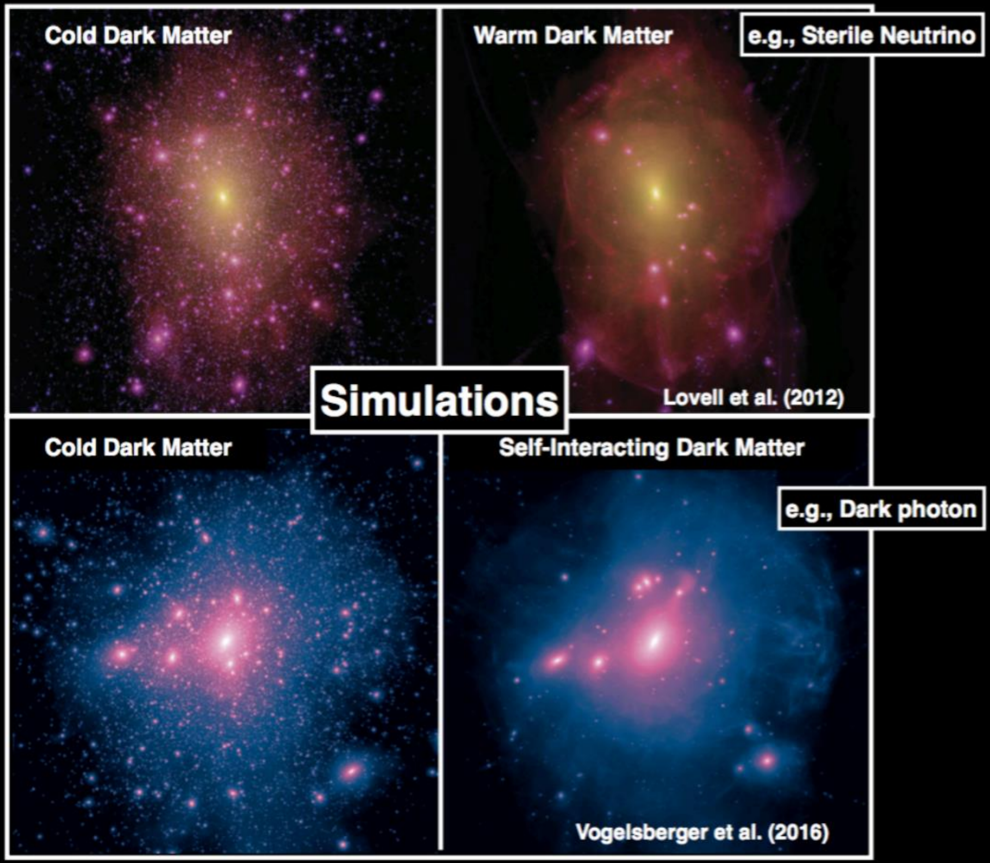
Is (collisionless) cold dark matter in trouble?

Are the small-scale problems enough evidence to abandon the simple colisionless cold dark matter model?

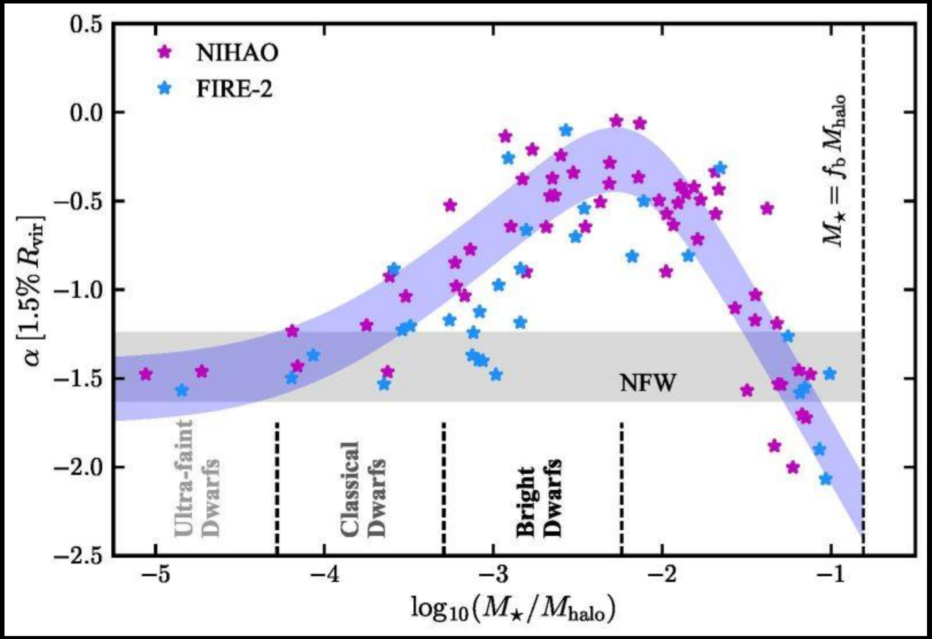
No, baryonic feedback

Yes, CDM is too simple





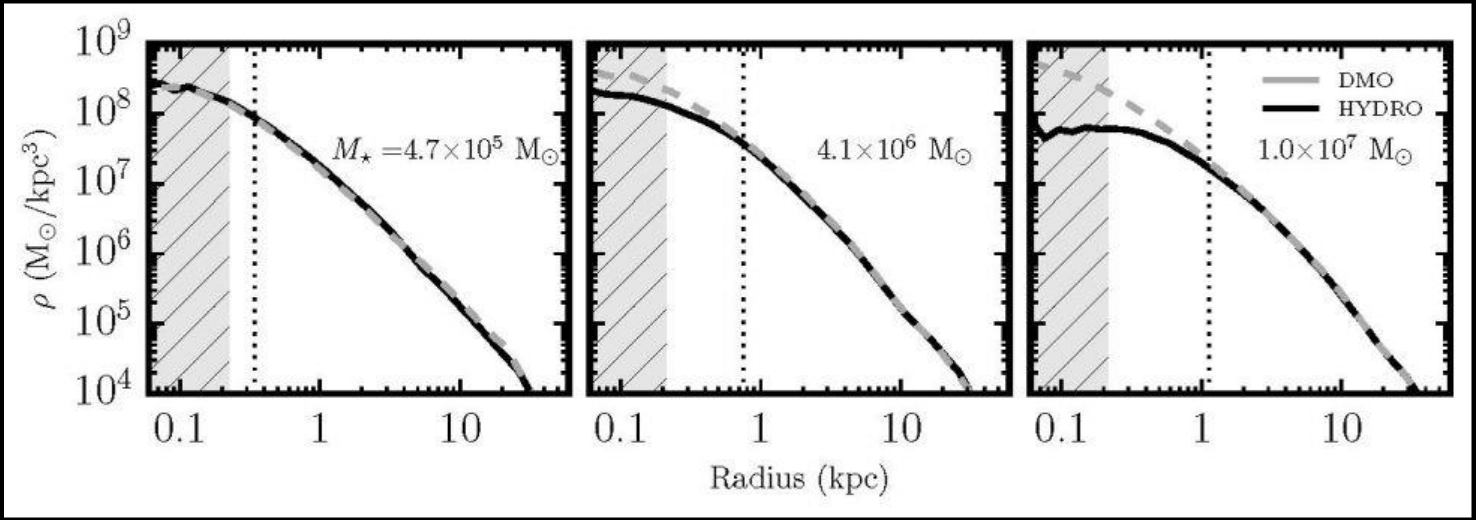
Why can very low surface brightness galaxies provide clues to dark matter properties?



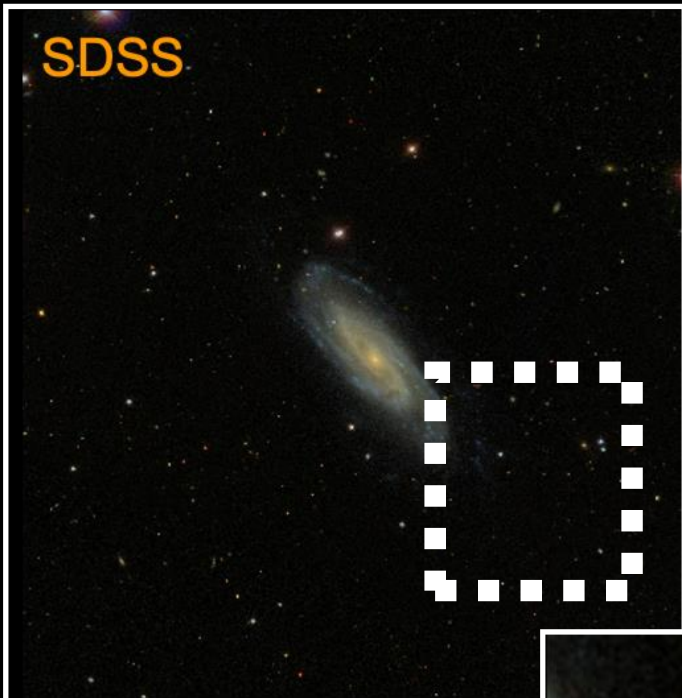
For systems with $M_*/M_{vir} < 10^{-4}$, feedback is likely to be ineffective in altering DM profiles significantly as compared with DM-only simulations.

This corresponds to a $M_* \sim 10^6\ M_{sun}$

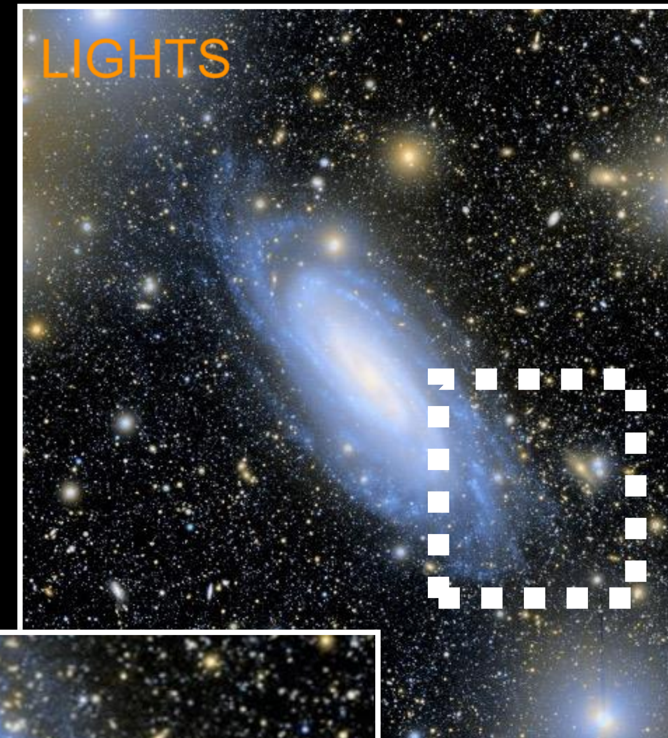
Bullock & Boylan-Kolchin (2017)



A tremendous advance in deep imaging over the last 20 years

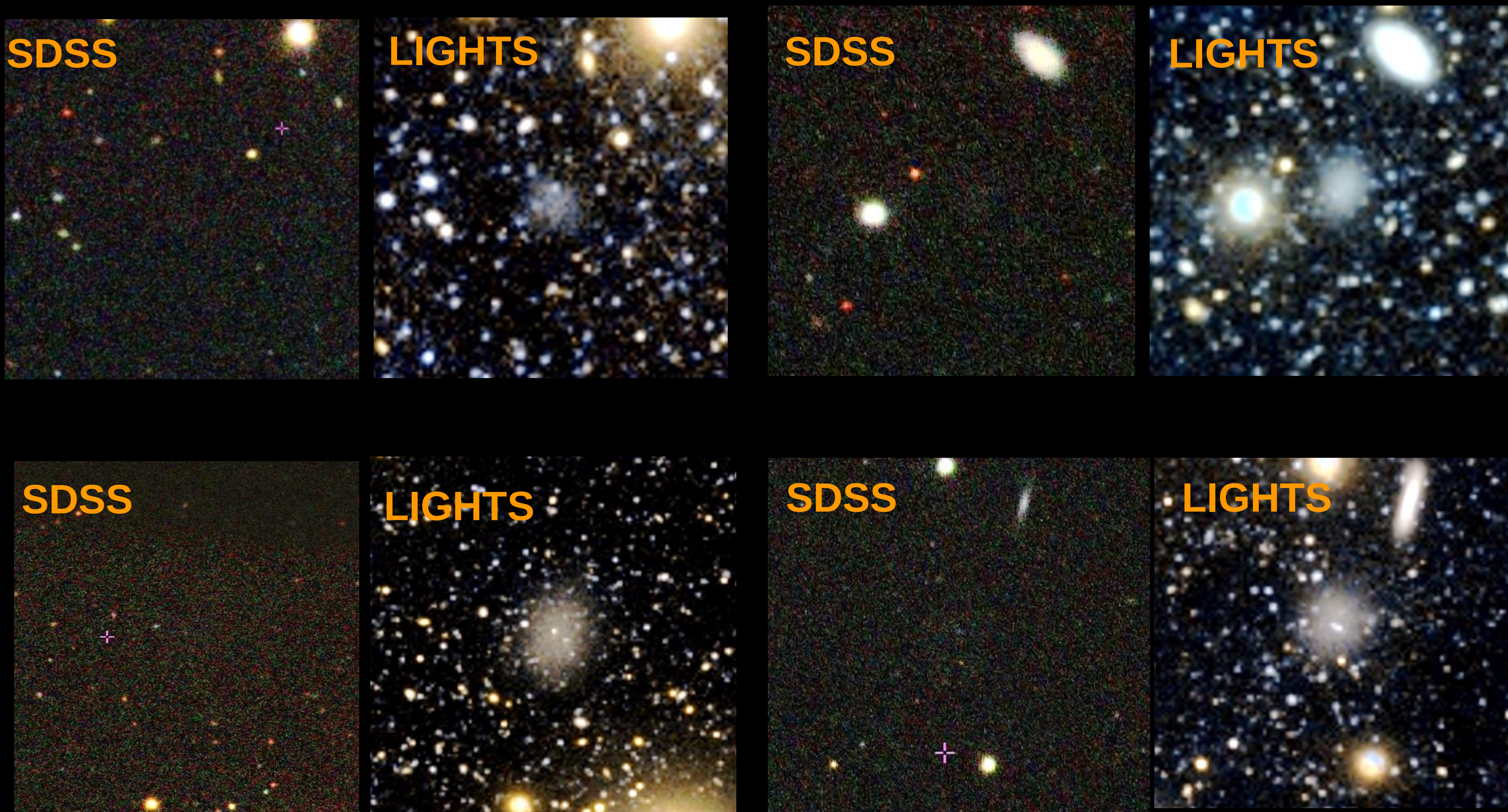


We are now getting views of the Universe 100x deeper than 20 years ago



NGC3198 as seen by SDSS and LIGHTS (Trujillo+21; Zaritsky+24)

Some examples of (almost) dark galaxies

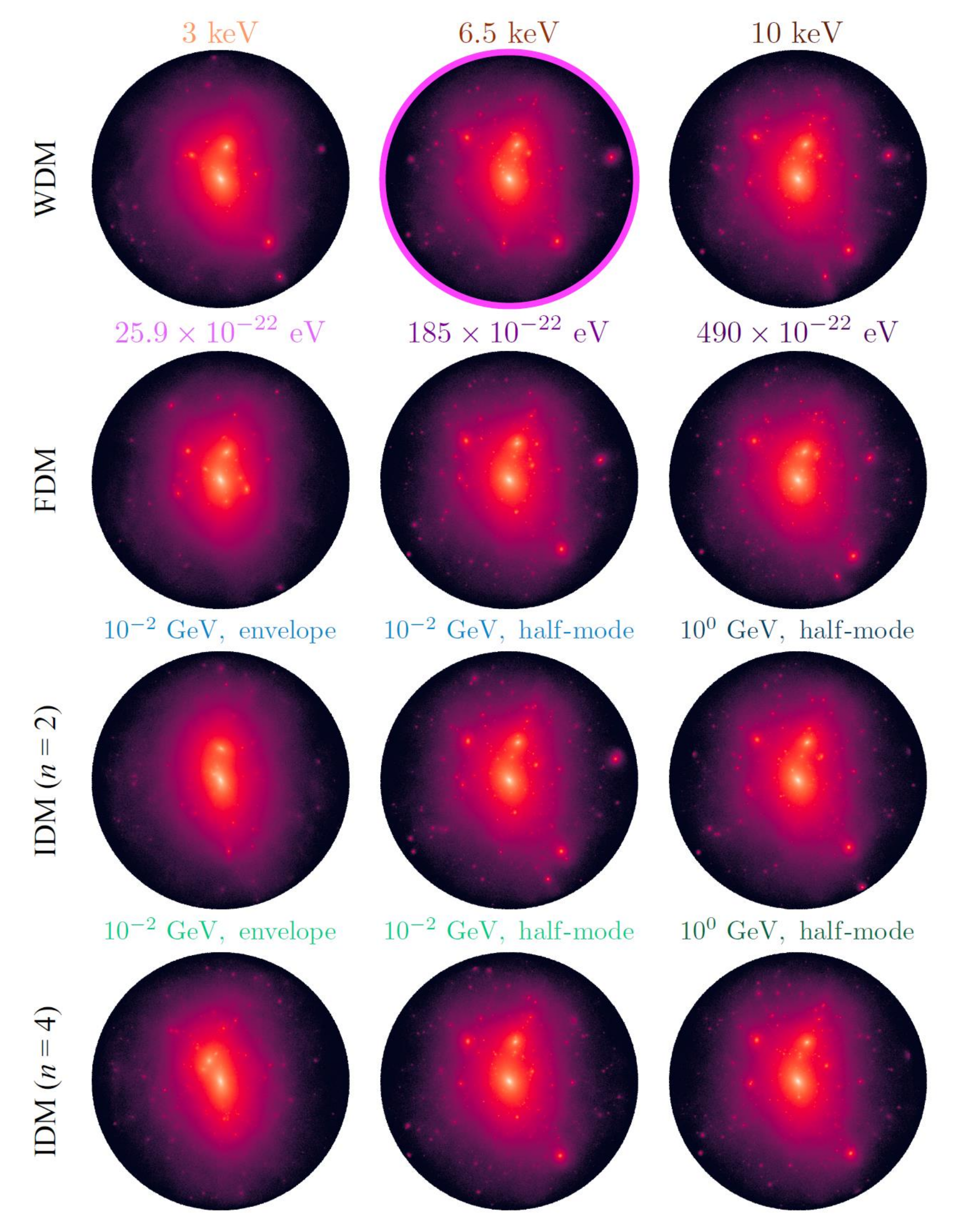


Collection of very low mass galaxies with $M_{*} \sim 10^{5}$-10^{6} M_{sun}

What kind of constraints on dark matter can we place with only the imaging information of a few hundred very low-mass ($M_*<10^6$ M_{sun}) galaxies?

a) Is the number of low-mass galaxies with M_*~10^5-10^6 M_{sun} a good discriminator?

Different dark matter models predict a huge difference in the number of subhalos containing low mass galaxies



Nadler+24

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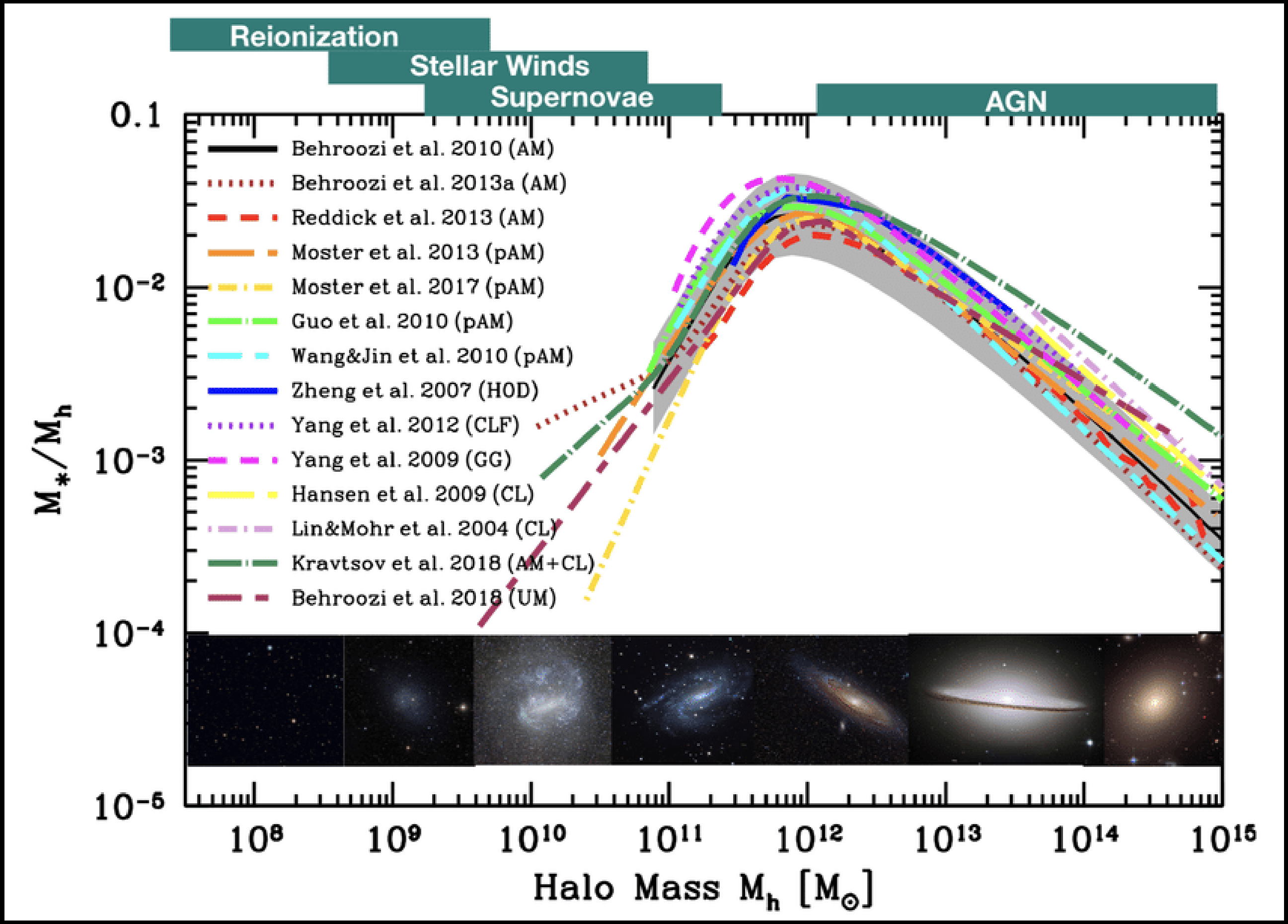
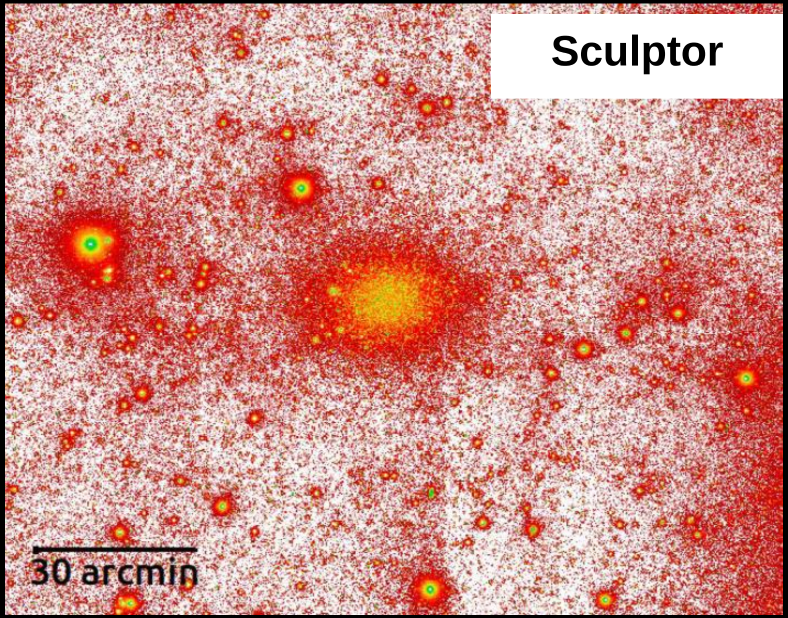
a) Is the number of low-mass galaxies with M_*~10^5-10^6 M_{sun} a good discriminator?

No, there is a large degeneracy in the stellar-to-halo mass ratio in the dwarf galaxy regime

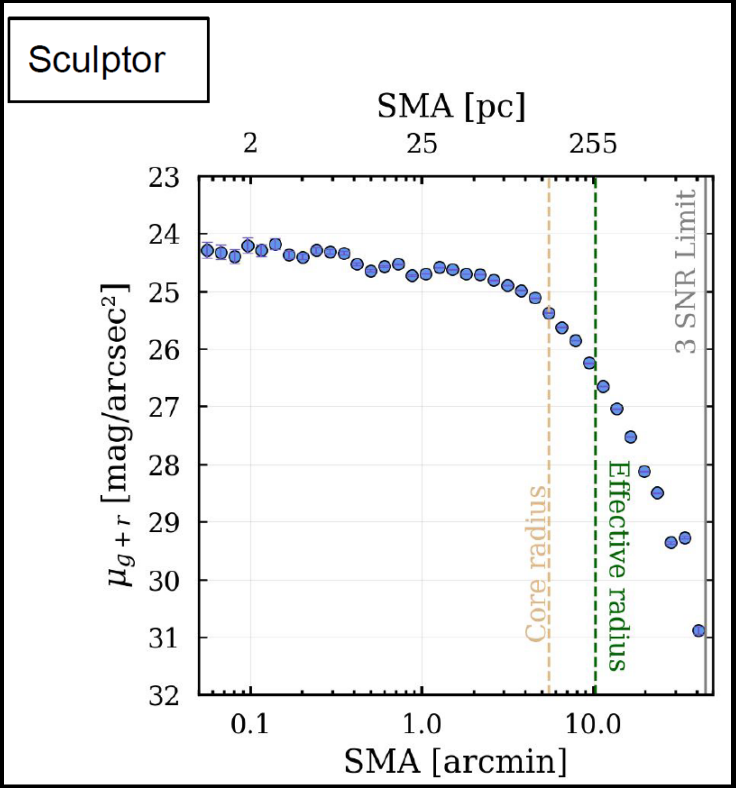


What kind of constraints on dark matter can we place with only the imaging information of a few hundred very low-mass ($M_* < 10^6\ M_{sun}$) galaxies?

b) Is the stellar profile of low-mass galaxies with $M_* \sim 10^5$-$10^6\ M_{sun}$ a good discriminator?



Guerra Arencibia+25, in prep



Yes, under very general circumstances, the Eddington Inversion Method predicts that if the stellar distribution has a core, then the dark matter profile is not cuspy!!!

(see Sanchez Almeida's talk)

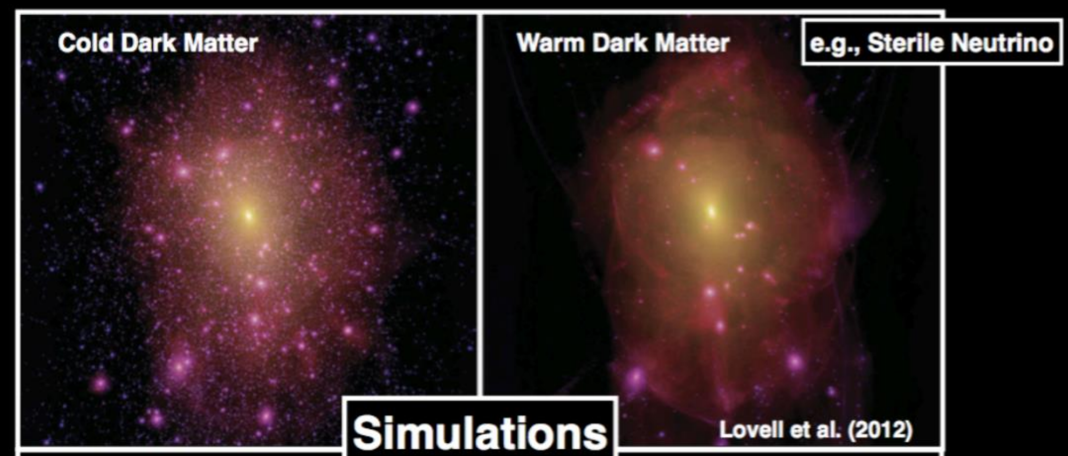
What kind of constraints on dark matter can we place with only the imaging information of a few hundred very low-mass ($M_* < 10^6$ M_{sun}) galaxies?

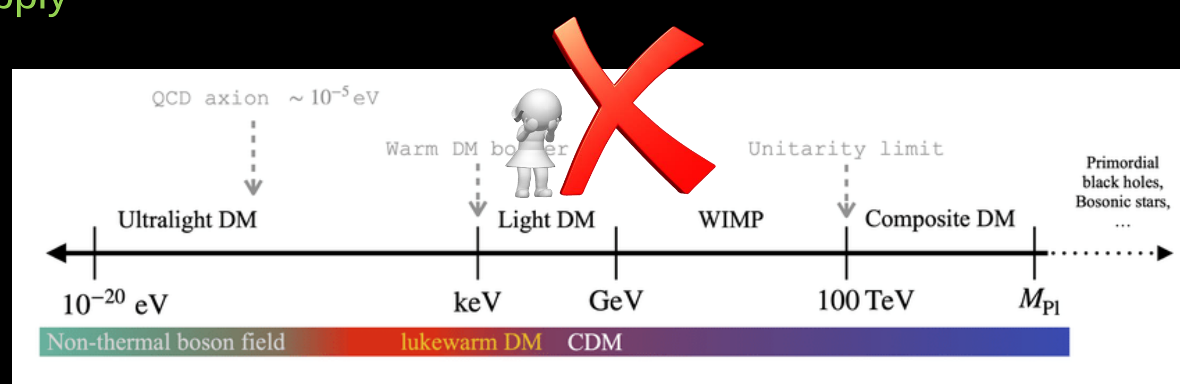
The presence of *stellar cores* in low-mass galaxies with $M_* \sim 10^5$-10^6 M_{sun} would reject the following dark matter models:

All collisionless dark matter models (independently) of the mass of the dark matter particle are incompatible with stellar cores

Colisionless *cold* and *warm* dark matter could be rejected (Macciò+19)

Caveat: The above does not apply to *fuzzy dark matter*





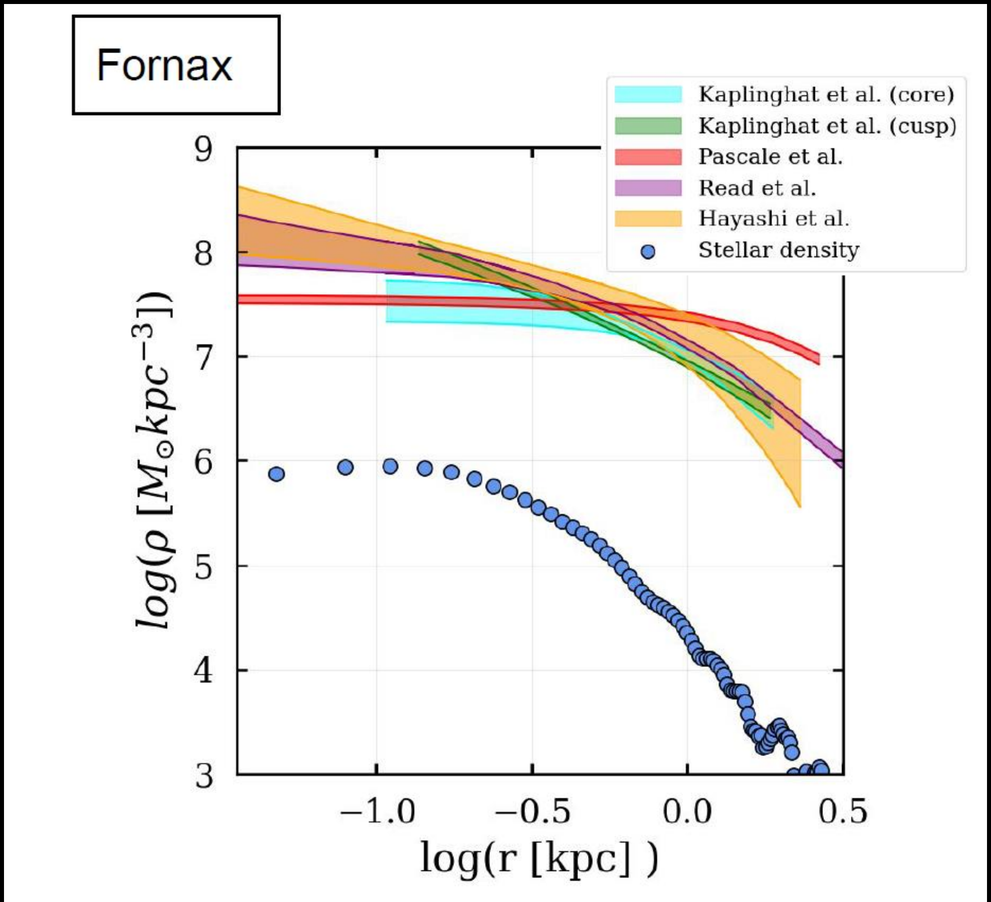
What kind of constraints on dark matter can we place with only the imaging information of a few hundred very low-mass ($M_*<10^6\ M_{sun}$) galaxies?

The ***size of stellar cores*** in low-mass galaxies with $M_*\sim10^5$-$10^6\ M_{sun}$ can also rejects dark matter models

EIM prediction: the size of stellar cores should be similar to the size of the dark matter core!!!

$R_{core,DM} \sim R_{core,*}$

(see Sanchez Almeida's talk)



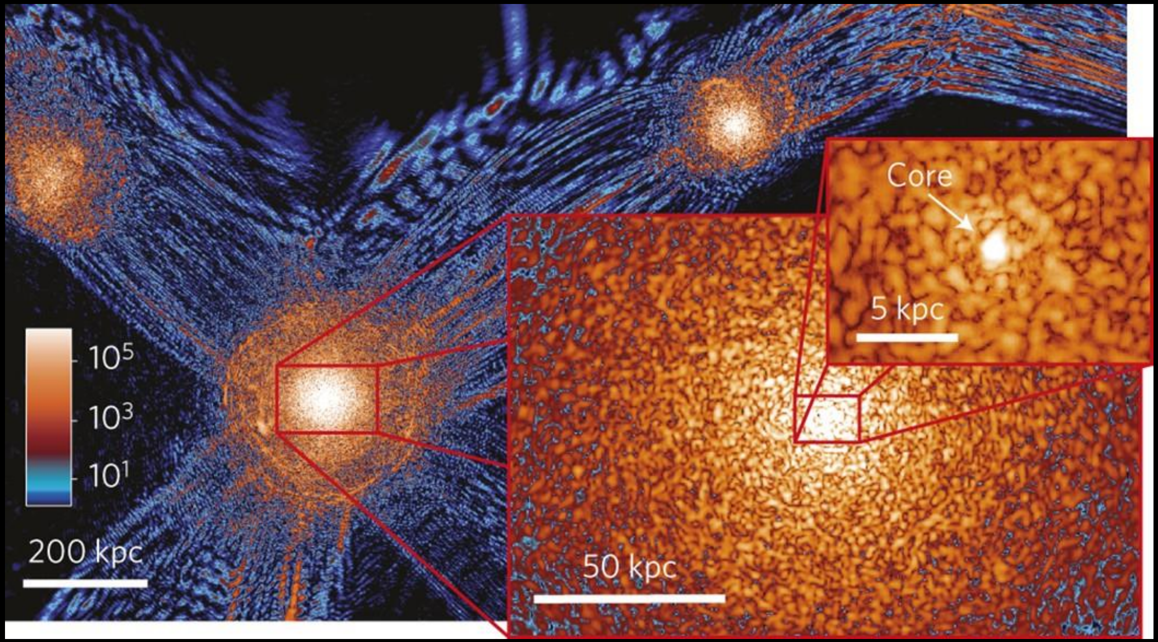
Battaglia & Nipoti +22; Guerra Arencibia+25, in prep

What kind of constraints on dark matter can we place with only the imaging information of a few hundred very low-mass ($M_*<10^6$ M_{sun}) galaxies?

The ***size of stellar cores*** in low-mass galaxies with $M_*\sim10^5$-10^6 M_{sun} could be used to reject Ultra-light dark matter (fuzzy dark matter)

A dynamical estimate of the central region of the galaxy plus the core radius from the stellar profile constrains the mass of the fuzzy dark matter particles.

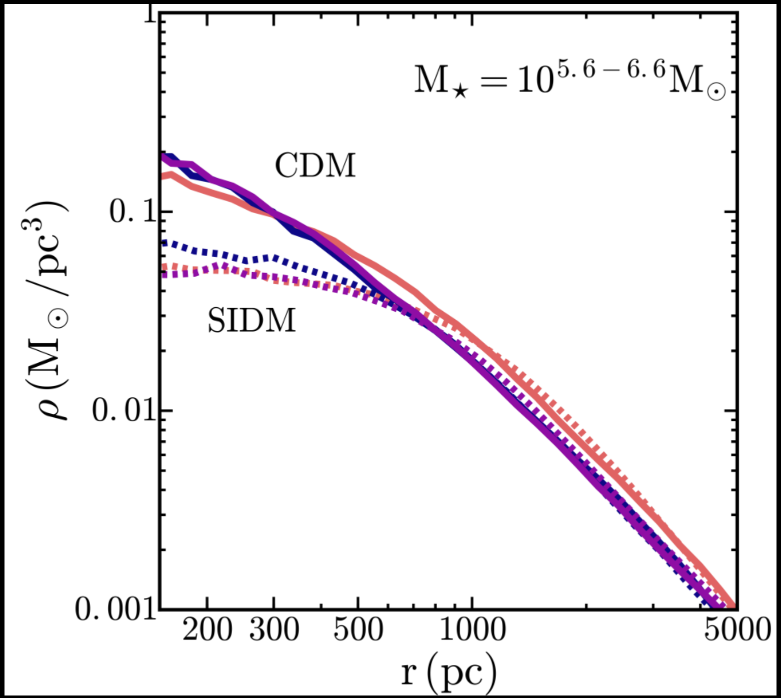
$$M_c \approx \frac{5.5\times10^9}{(m_B/10^{-23}\ \mathrm{eV})^2(\mathrm{r_c}/\mathrm{kpc})} M_\odot$$



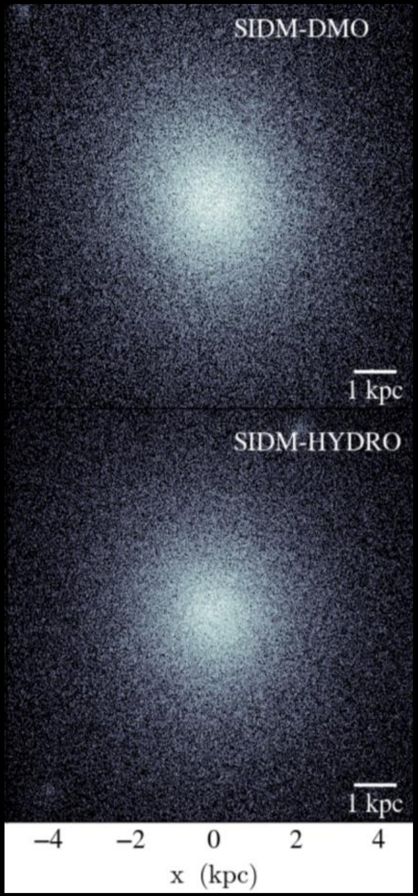
Schive+14

What kind of constraints on dark matter can we place with only the imaging information of a few hundred very low-mass ($M_{*}<10^6\ M_{sun}$) galaxies?

To reject *self-interacting dark matte*r models using low-mass galaxies with $M_{*}\sim10^5$-$10^6\ M_{sun}$ we need from you predictions of the size of the dark matter as a function of the cross section σ/m



An example of Self-Interacting Dark Matter hydrodynamical simulation with $\sigma/m = 1\ cm^2\ g^{-1}$



Robles+17

Conclusions

Take home messages:

1. For the first time, we have access to images of hundreds of very low-mass galaxies where feedback is predicted to play no role in modifying dark matter halos.

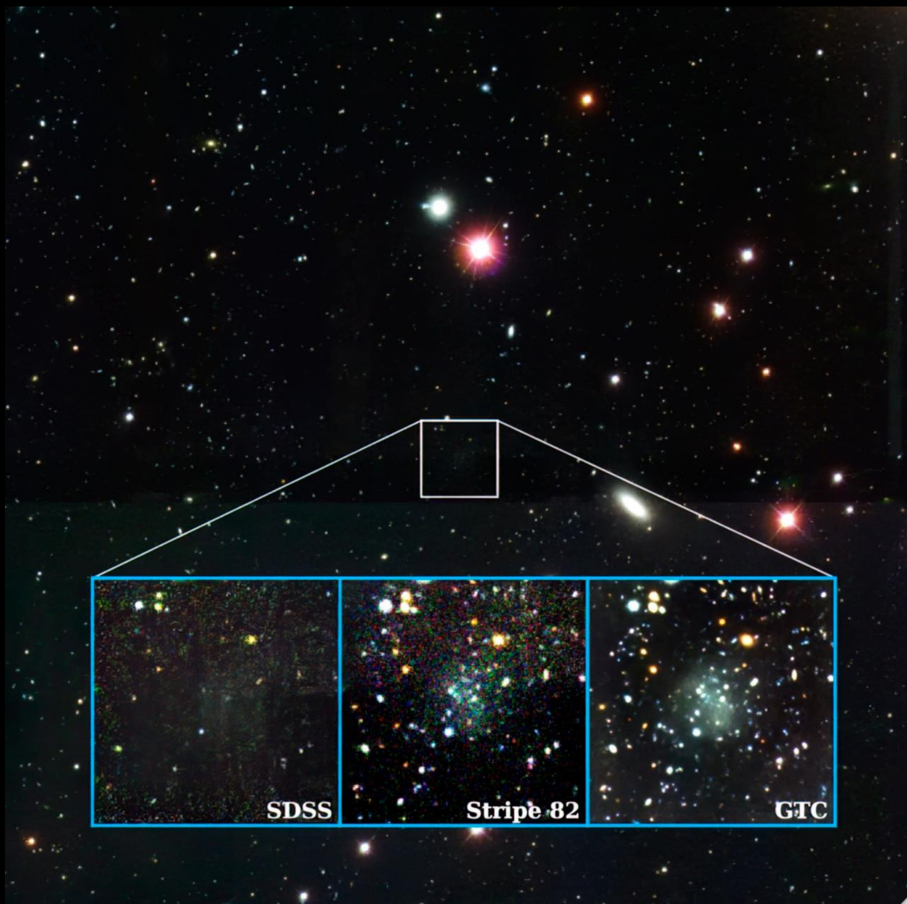
2. Under very general conditions (EIM), the presence of stellar cores is incompatible with dark matter halo cusps, thus ruling out *colisionless* dark matter models with "massive“ (>keV) dark matter particles (i.e. warm, cold...).

3. The size of the stellar cores is similar to the size of dark matter cores, thus opening the possibility to exclude other dark matter models such as ultra-light (fuzzy) dark matter and/or self-interacting dark matter models with a certain cross section σ/m.

Bonus material

(other IAC results with very diffuse galaxies)

Two examples of almost dark galaxies and their relation with the missing mass problem

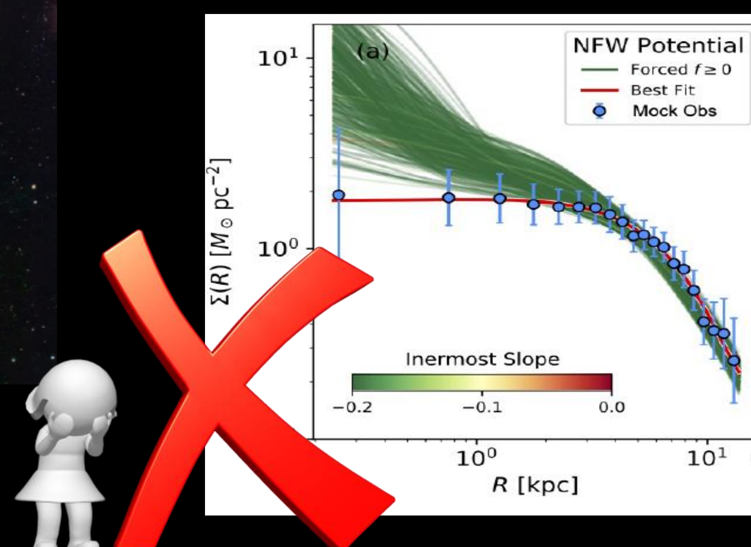


The Nube galaxy (Montes+23)

Nube is an almost dark galaxy

Nube is extremely extended

Nube does not fit with colisionless cold dark matter (Sanchez-Almeida+24)



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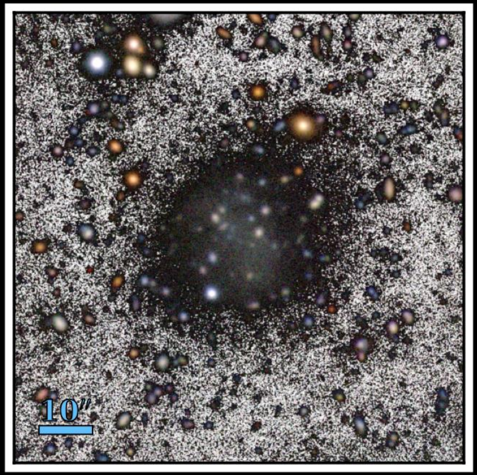

Nube is an almost dark galaxy

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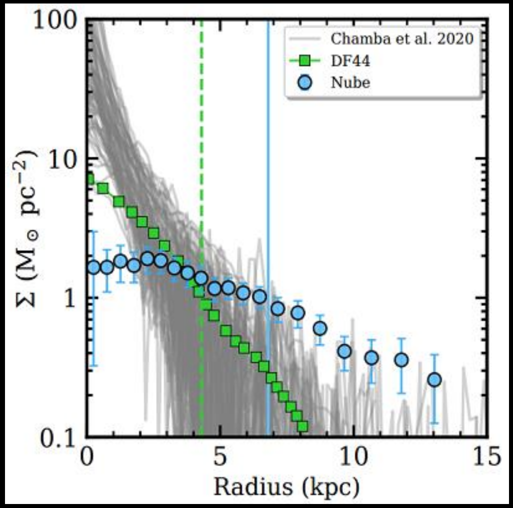
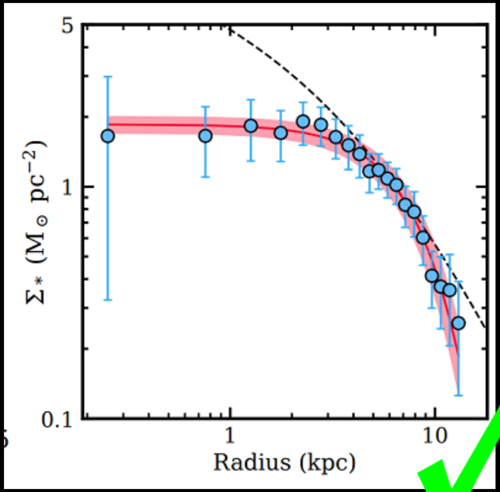
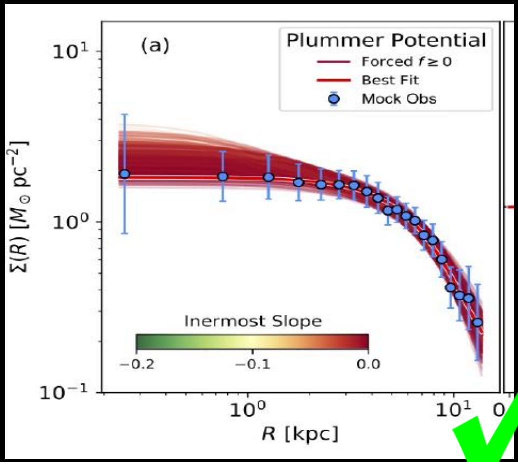


Nube fits with alternative dark matter models such as fuzzy dark matter or self-interaction dark matter

Fuzzy dark matter

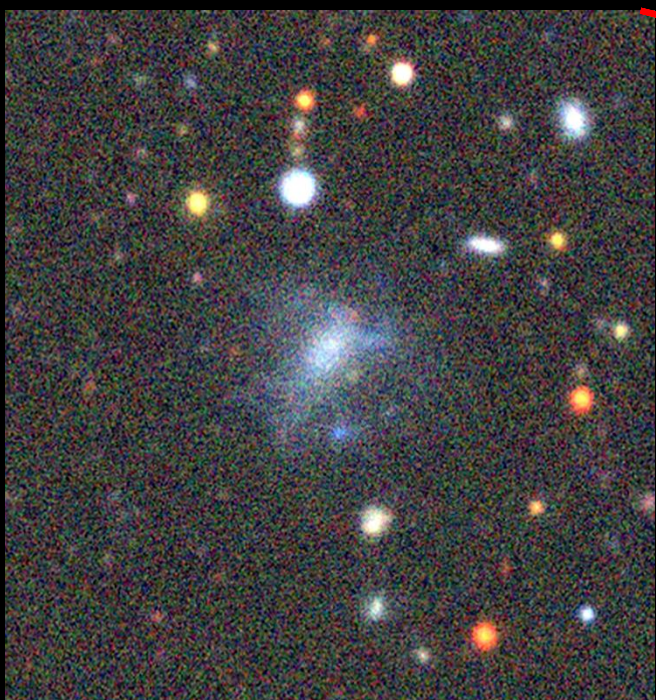


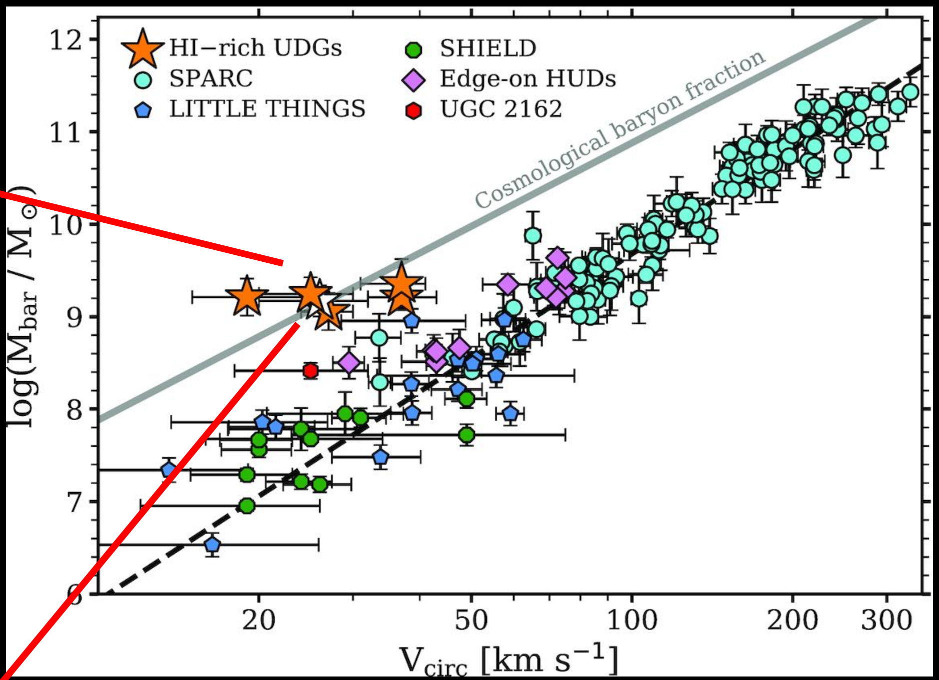
Self-interacting dark matter



Two examples of almost dark galaxies and their relation with the missing mass problem

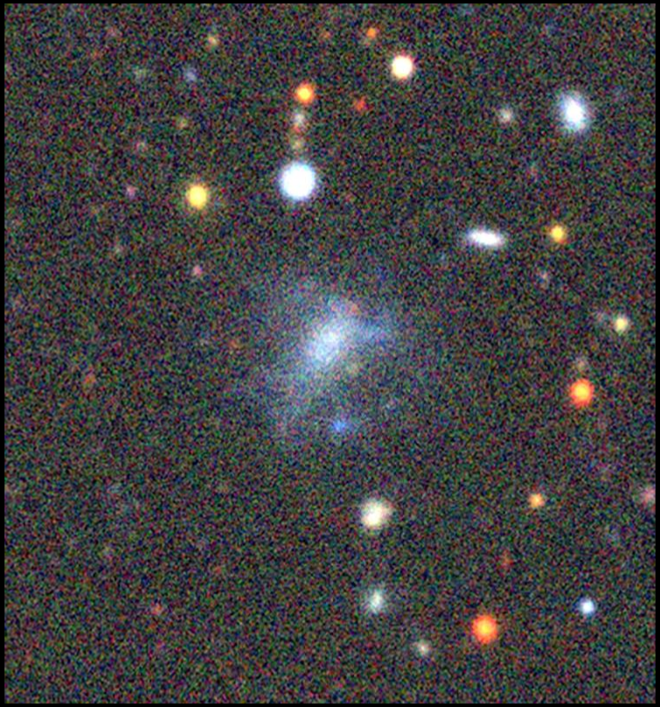
AGC 114905 an irregular looking galaxy with almost no dark matter

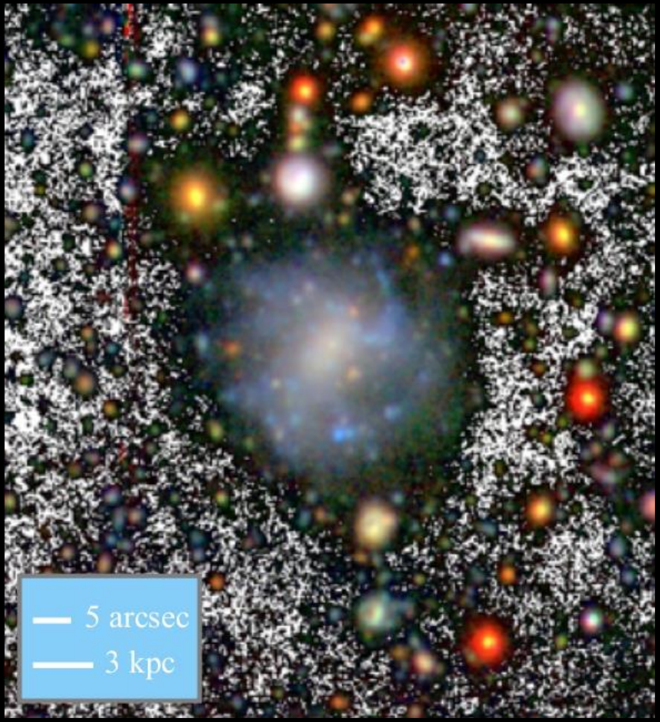




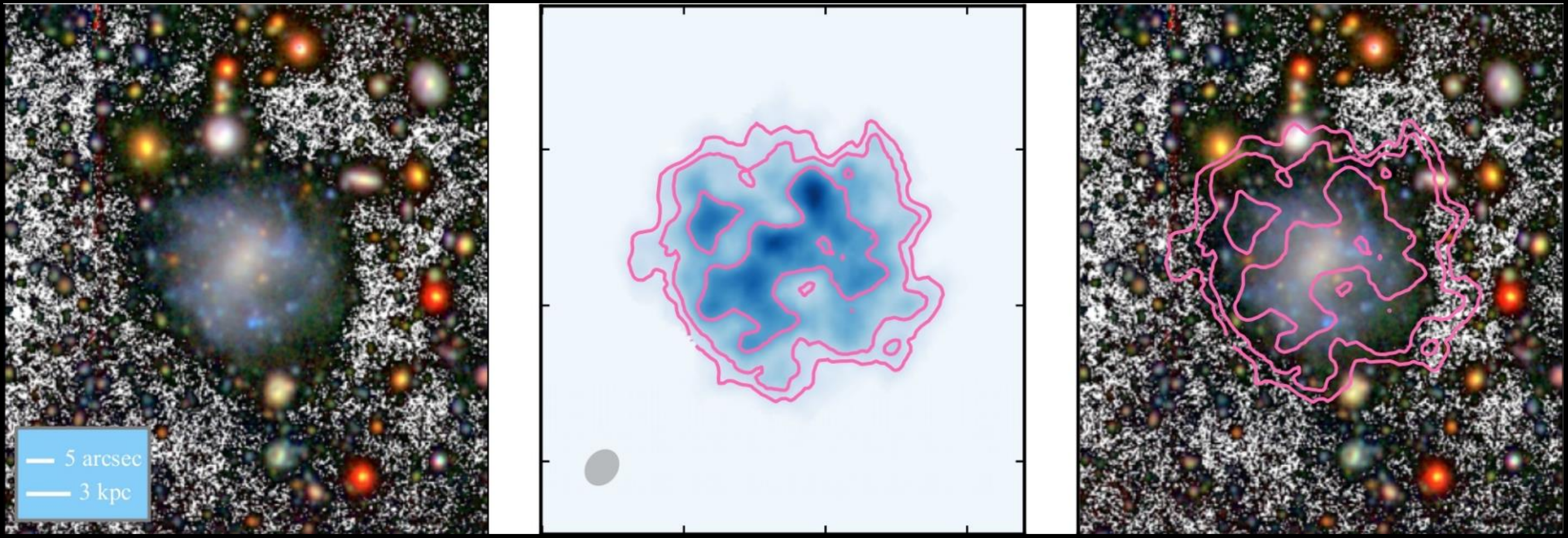
From “Irregular” to a beautiful spiral dwarf galaxy!

Ultra-deep imaging with the largest optical telescope reveals beautiful disk structure





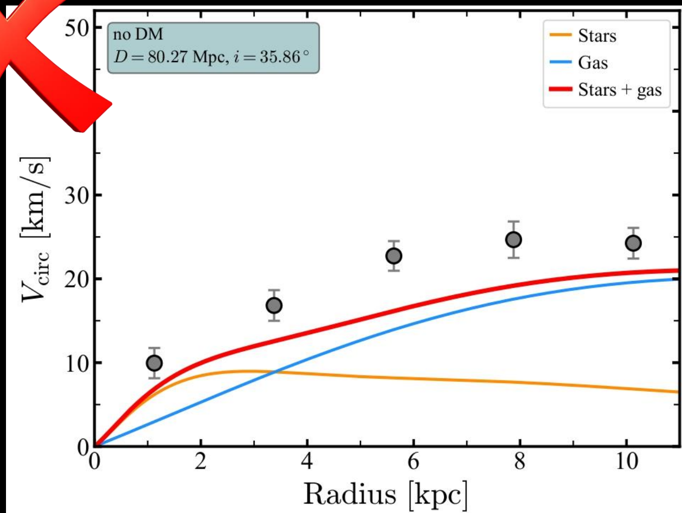
Stellar and gas disk to explore the dynamics



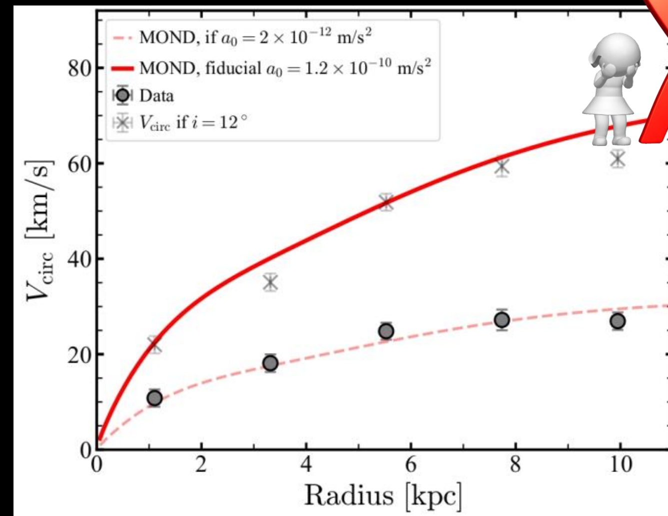
The combination of deep imaging of the stellar disk and the distribution of the gas allows us to study the rotation curve of these objects in detail.

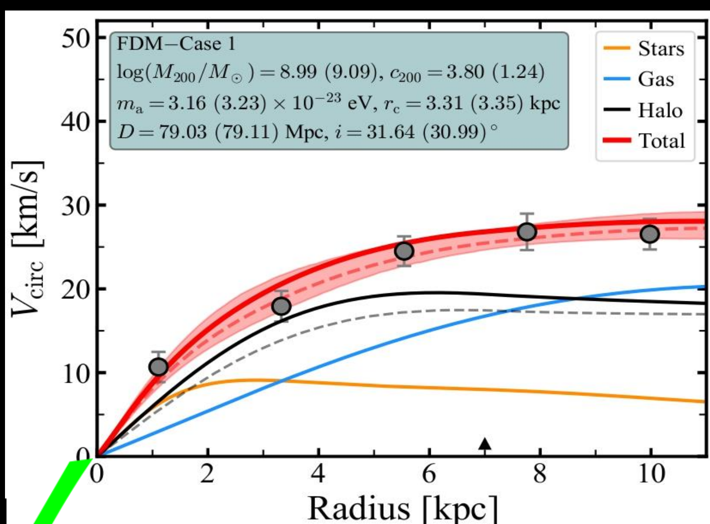
Two examples of almost dark galaxies and their relation with the missing mass problem

No dark matter

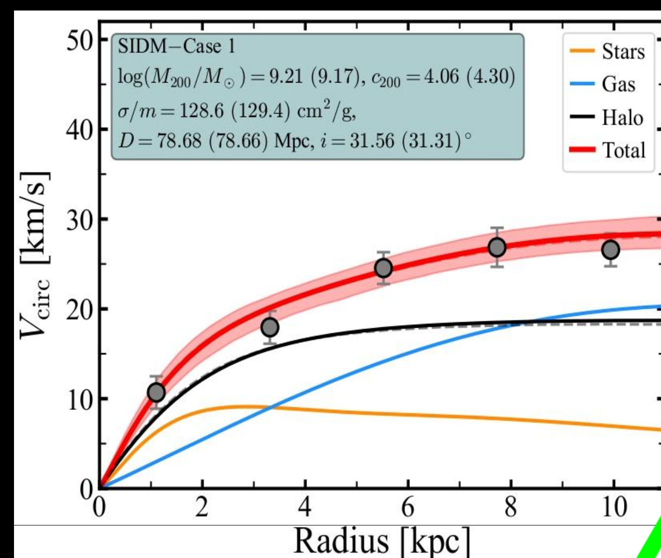


MOND





Fuzzy dark matter



Self-interacting dark matter