Too Big to Fail or Too Shy to Shine?

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Baryon Deficit

- Galaxies form through the collapse and accretion of baryonic material onto dynamically dominant dark matter halos.
- The cosmic baryon fraction is $\Omega_{baryon} / \Omega_{dark\ matter} = 0.15$

…. However

Most DM halos have trouble in retaining their baryons:

- The baryon fraction peaks for halos of mass ~ 10^{12} Msun, where it falls short of the cosmic value by a factor of 2-3
- In halos of mass ~ 10^{10} Msun the baryon deficit may be as high as 100

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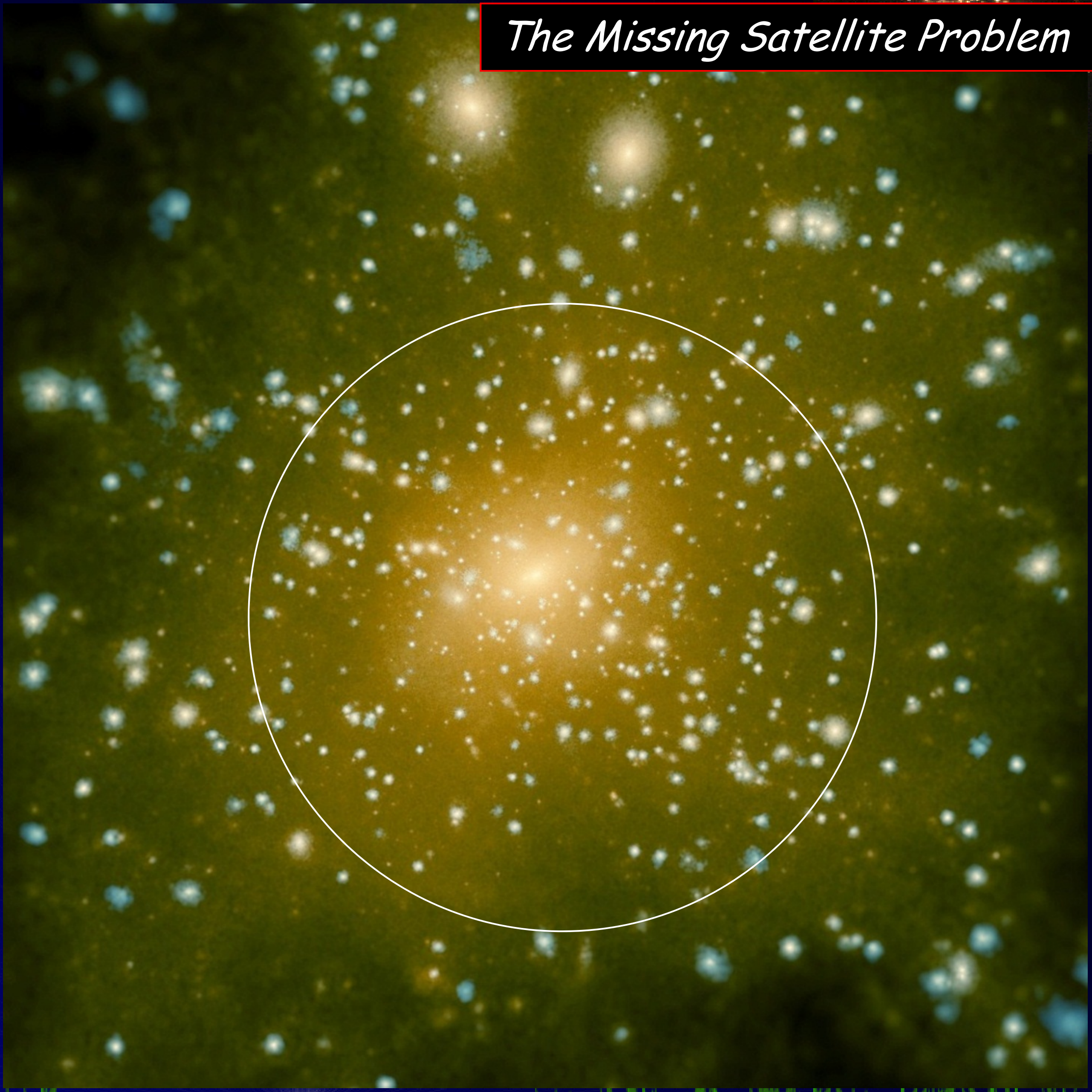
The Missing Satellite Problem

Numerical simulations predict the existence of lots of low mass sub-halos:
Do they exist in the expected numbers?



- Missing MW Satellites:
  Klypin+ 1999
  Moore+ 1999
- TBTF in MW:
  Boylan-Kolchin+ 2011
- TBTF in field:
  Ferrero+ 2012
  Papastergis+2015

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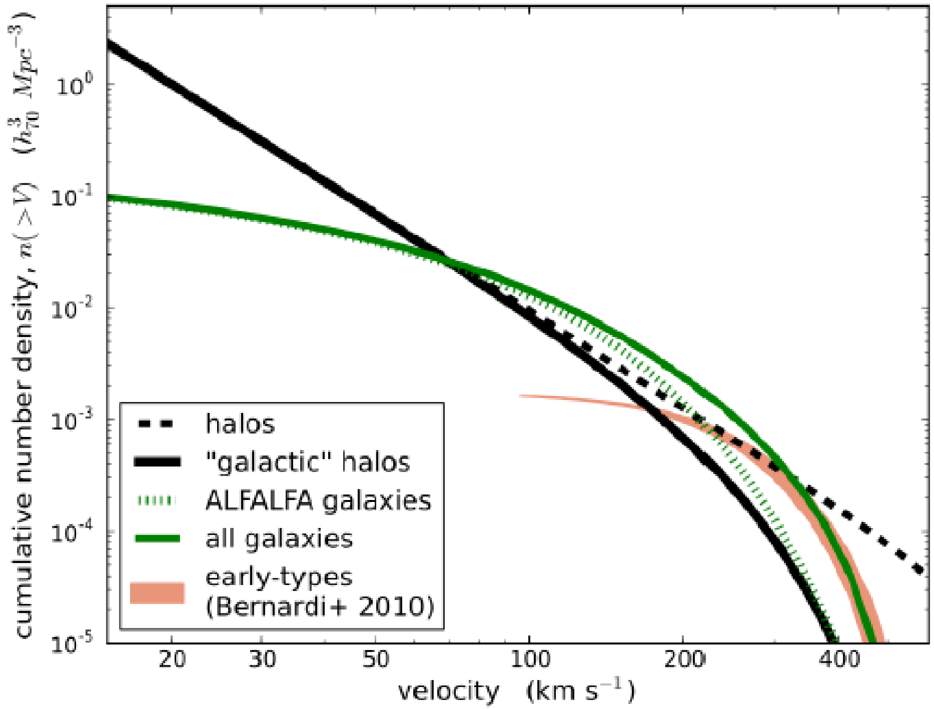
Galaxy and Halo velocity Width Functions



Papastergis+2015

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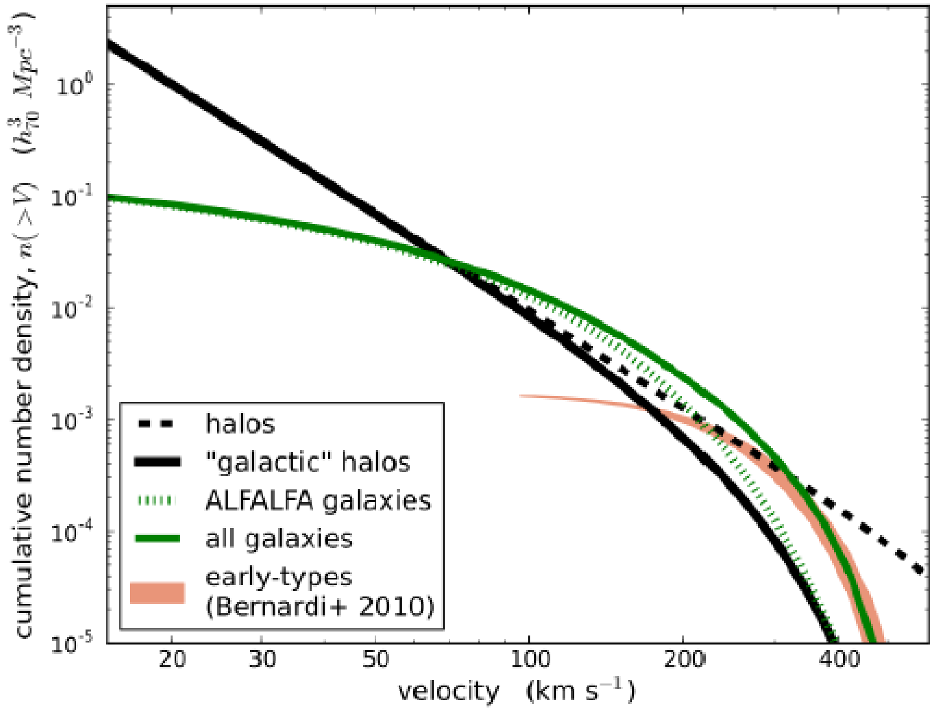
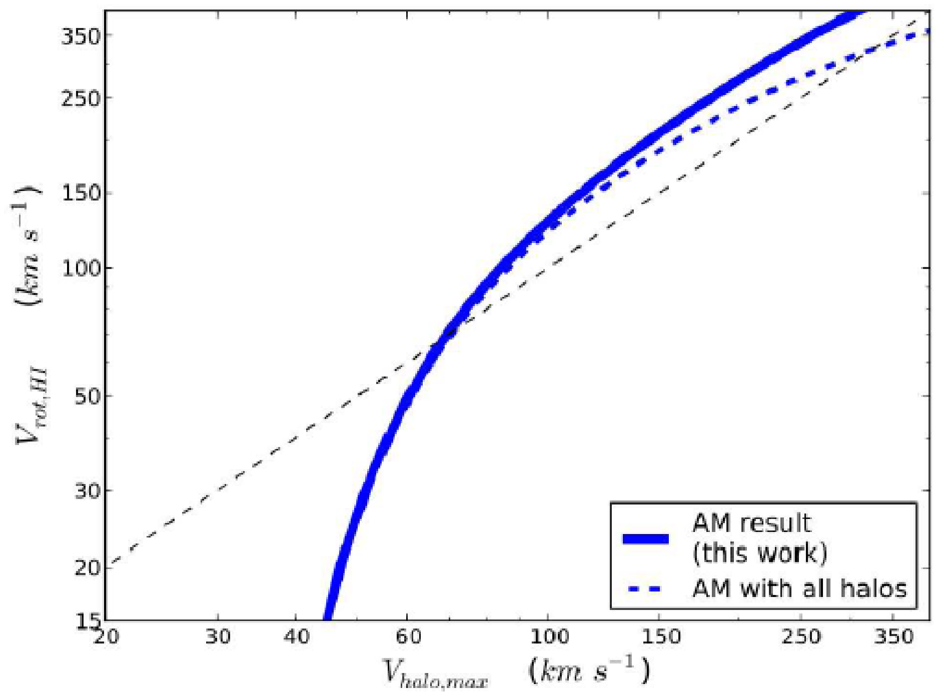
Papastergis +2015

Abundance Matching requires no objects to left of blue line





ΛCDM+AM predict that galaxies with V_{rot} ~15-20 km/s reside in halos of V_h ~ 40-45 km/s, and halos of V_h< 40 km/s expected to not host any galaxy. Let's test…

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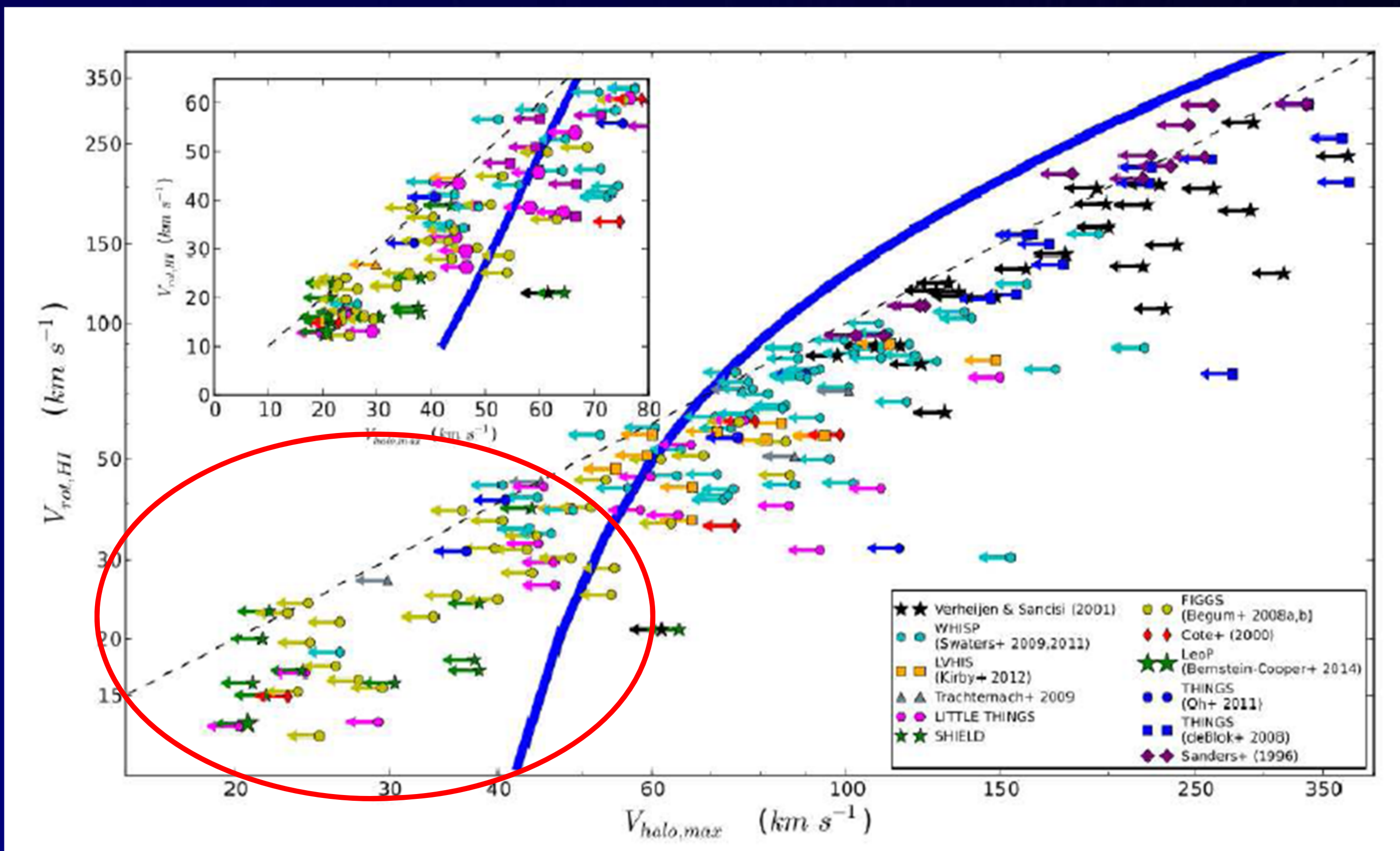
TEST ΛCDM/Abundance Matching (AM) result:

Get 194 galaxies with measured HI RCs and estimate Vrot, Vh for each. Note the Vh are upper limits. Blue line is AM boundary

Papastergis+2015



- AM requires that all galaxies be to the right of blue line
- All slow rotators within red ellipse are violating ΛCDM/AM

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➔ Halos hosting low Vrot galaxies appear to have Vh values much lower than predicted by AM

Note: the root of the problem is the difference in slope of the power law fits to V_{rot} and V_h functions. Solution?

- Either find a so far not budgeted population of galaxies to steepen the observed galaxies Vrot function …
- or “hide” a fraction of the simulated halos predicted by LCDM, lowering their Vh function power low slope

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- Consider Warm rather than Cold DM, which would suppress the formation of low mass halos.

- Implementation of baryonic physics, on finer and finer scales in simulations
- → promising results:

  Pontzen & Governato 2012
  Brooks &Zolotov 2014,
  Brooks, this workshop
  Sawala+ 2015

… but will processes that work for sub-halos within the unfriendly environment of the MW and M31 halos still work in dwarf (central) galaxies in the field?

Consider the following lines of evidence:

- Field(*) dwarf galaxies (M_* 10^7 to 10^9 Msun) showing no ongoing SF are extremely rare: < 1% according to Geha+2012
- The SF history of field dwarf galaxies is episodic: Tolstoy + 2009 with bursts of SF activity between long periods of quiescence

These two results alone require that a large fraction of field dwarfs be quiescent, unseen by shallow surveys and uncounted

- The typical duration of starburst events is 200-600 Myr, according to McQuinn+2009/10
- Halos of mass $< 10^{10}$ Msun may be able to form stars before reionization, but were unable to accrue fresh gas – and form stars – after reionization (Hoeft+2006). They may be able to form stars at more recent time, especially in low density environments (Ricotti 2009). ALFALFA detects sources of this type.

(*) "field" is defined as farther than 1.5 Mpc from a massive galaxy.

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Consider the following lines of evidence:

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These two results alone require that a large fraction of field dwarfs be quiescent, unseen by shallow surveys and uncounted…

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Consider the following lines of evidence:

- 99+% of field dwarfs show ongoing SF activity
- The SF history of field dwarf galaxies is <u>episodic</u>:

- The typical duration of starburst events is 200-600 Myr, according to McQuinn+2009/10
- Halos of mass $< 10^{10}$ Msun may have been able to form stars before reionization, but were unable to accrue fresh gas – and form stars – for a long time after reionization (Hoeft+2006). They may be able to form stars at more recent times, especially in low density environments (Ricotti 2009).
- ALFALFA detects sources of this type – "diversely faint" but not altogether dark - e.g. Leo P, and the objects Martha, Luke and Betsey will discuss later at this workshop
- This presents extraordinary possibilities of discovery for future extragalactic HI surveys: right here, now (z=0), when most field dwarfs are yet too shy to shine.

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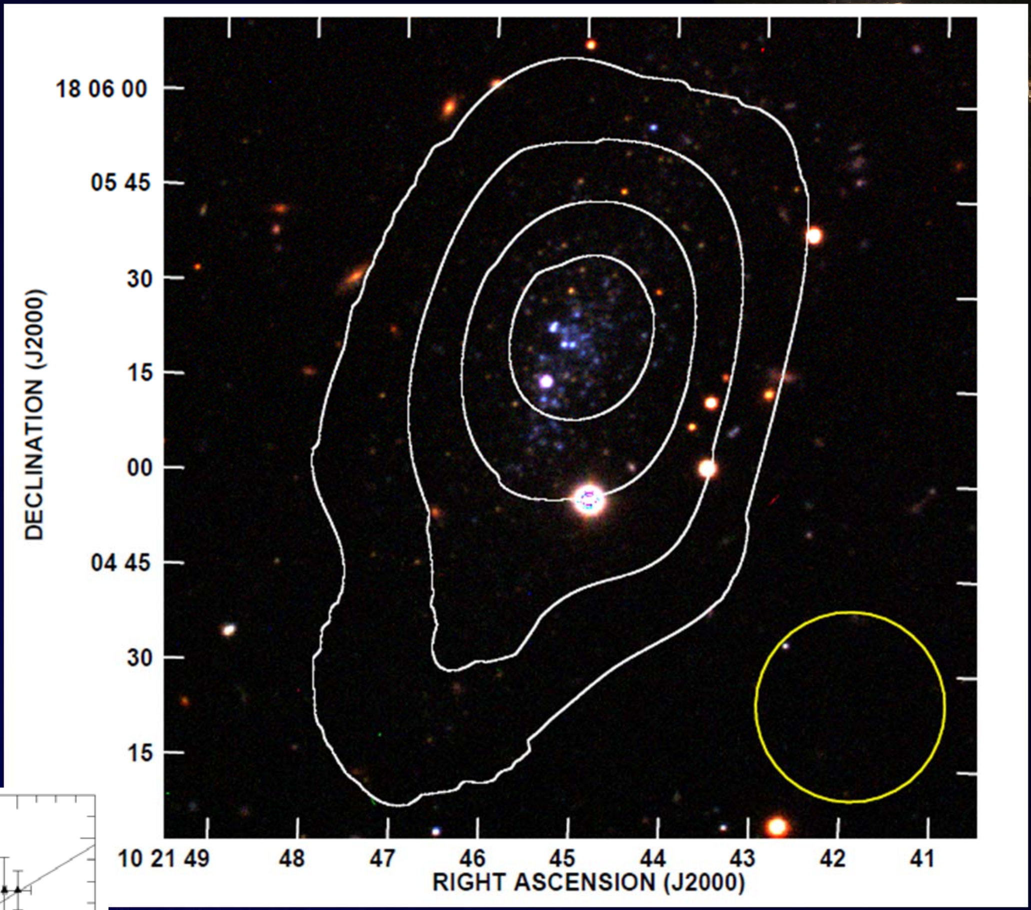
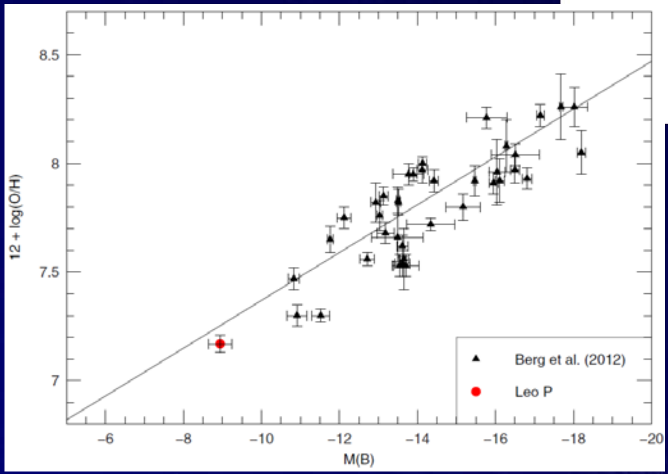
Leo P

Located 1.7 Mpc away
stellar mass $3.7 \times 10^5\ M_\odot$
HI mass 2.5 times as high
HI radius of half a kpc
Dynamical mass: $2.3 \times 10^7\ M_{sun}$
within that radius and
$(12+\log(O/H) = 7.16 \pm 0.4)$
making it the lowest metallicity,
star forming galaxy in the Local
Volume

1/50 sol





Had it been 2–3 times farther away, it would not have been detected by ALFALFA.

We'd call its DM host a "minihalo".

Summary:

- The ΛCDM /Abundance Matching paradigm predicts that the least massive galaxies with V_{rot} ~15-20 km/s are hosted by halos of V_h ~ 40-45 km/s, and that halos of V_h< 40 km/s are expected to not host any galaxy at all.
- Observational evidence appears to be incompatible with that result.
- A simple solution to this conflict may be that field dwarf galaxies form stars episodically. Between SF episodes, they are almost dark, as their optical and HI emissions are quenched, and thus uncounted by the AM census. Rather than TBTF, most dwarf galaxies may be

TSTS : TOO SHY TO SHINE

- A cautionary pause: It may be easier to identify a set of physical processes that will “hide” the galaxies hosted by halos of mass $< 10^{10}$ Msun than to do so for galaxies of mass between 10^{10} and 10^{11} Msun. The latter believed to be more effective in accretion and retention of baryons and thus to be counted.