

# The Missing Satellite Problem

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Galaxies: Structure Dynamics and Evolution

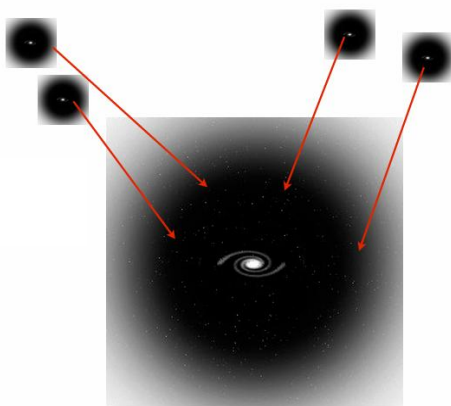
Frédérique van Holk & Bente Zandbergen - 16/04/2026

## From the lectures:

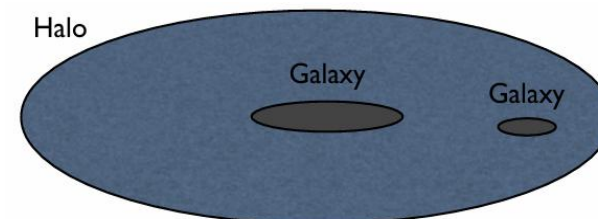
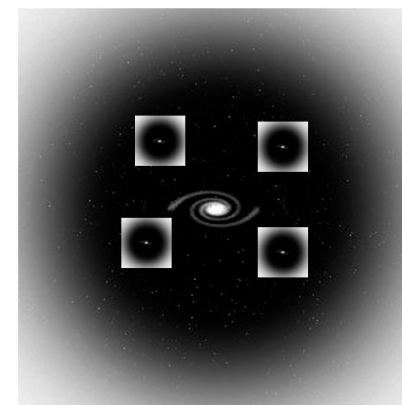
- Cold dark matter simulations predict dark matter haloes
- In these DM haloes, galaxies are expected to form
- When these haloes merge, galaxies with satellite galaxies emerge

# From the lectures:

Before Merger

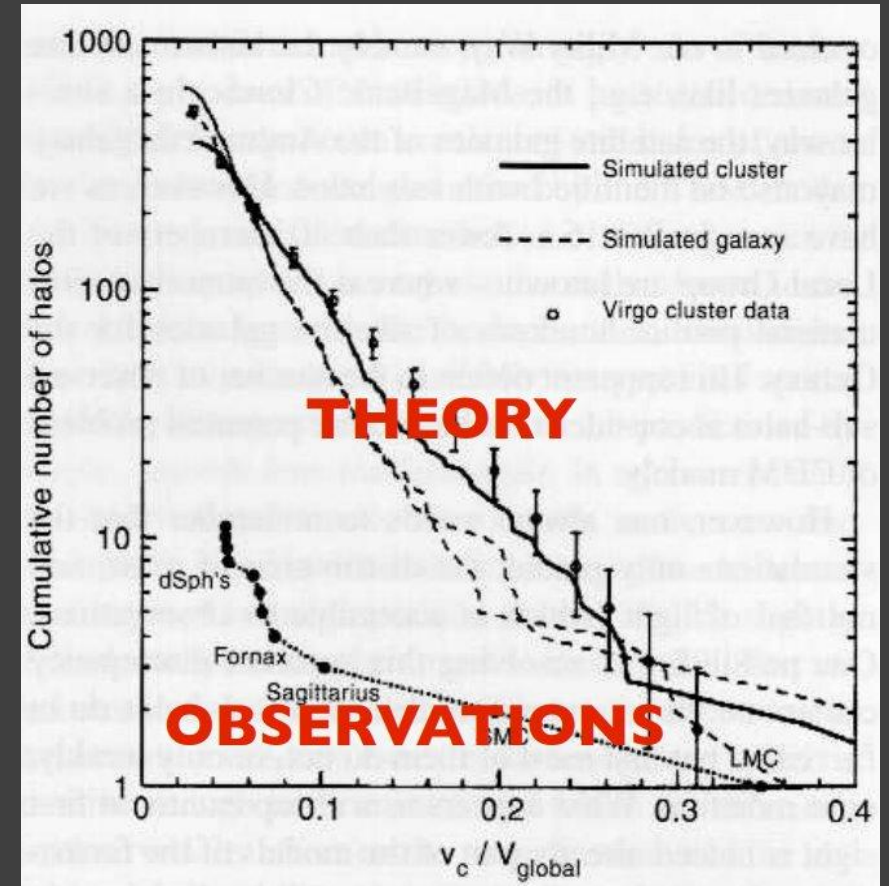


After Merger



Problem:  
**Large discrepancy between the number of observed and expected satellite galaxies of the MW**

1. Low mass haloes - paper 1
2. High mass haloes - paper 2



# The missing satellite problem

- For low-mass haloes, we see fewer satellite galaxies than expected
  - They might be too faint → Ultra faint dwarf (UFD) galaxies
- High-mass haloes seem too dense to host bright MW dwarf spheroids

# Paper 1: review on Ultra Faint Dwarf galaxies

- Oldest, most dark-matter dominated, most metal poor and least chemically evolved stellar systems known
- Absolute magnitudes fainter than  $M_V = -7.7$  ( $L < 10^5 L_\odot$ )
- Half-light radii ranging from 24 pc to 295 pc
- Relevance to study these small, faint galaxies:
  - Laboratory for CDM
  - Extreme limit of the galaxy-formation process
    - pristine relics from before the reionisation epoch

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REVIEWS

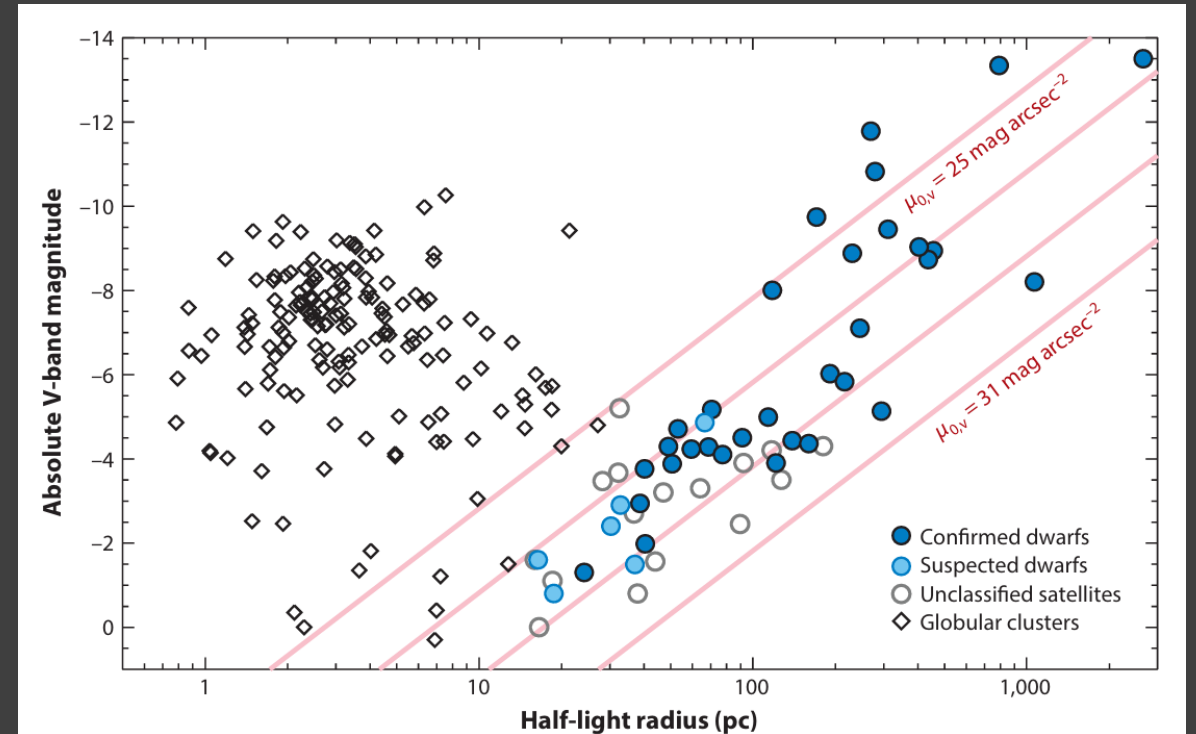
*Annual Review of Astronomy and Astrophysics*  
**The Faintest Dwarf Galaxies**

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# Properties of UFDs: stellar kinematics

- Classifying UFDs: globular clusters or satellite galaxies?
  - Size comparison
- Velocity dispersion of UFDs
  - Constrains dark matter content



# Properties of UFDs: Metallicities

- Observation: UFDs are enhanced in alpha elements (O, Mg, Ca, Si)
  - Normal IMF function + small CDM halo
    - SNe of massive stars strip the halo/satellite galaxy from gas
    - SFR halts early in the evolution process
    - Most stars are low in metallicity
  - In addition, tidal stripping of stellar mass leads to even lower metallicities

# Properties of UFDs: stellar populations

- Observation: UFDs contain old stars
  - Nearly all stars formed in the early Universe
  - Gas reionization approximately ended star formation
  - Pristine fossils from the era of reionization

# Properties of UFDs: dark matter

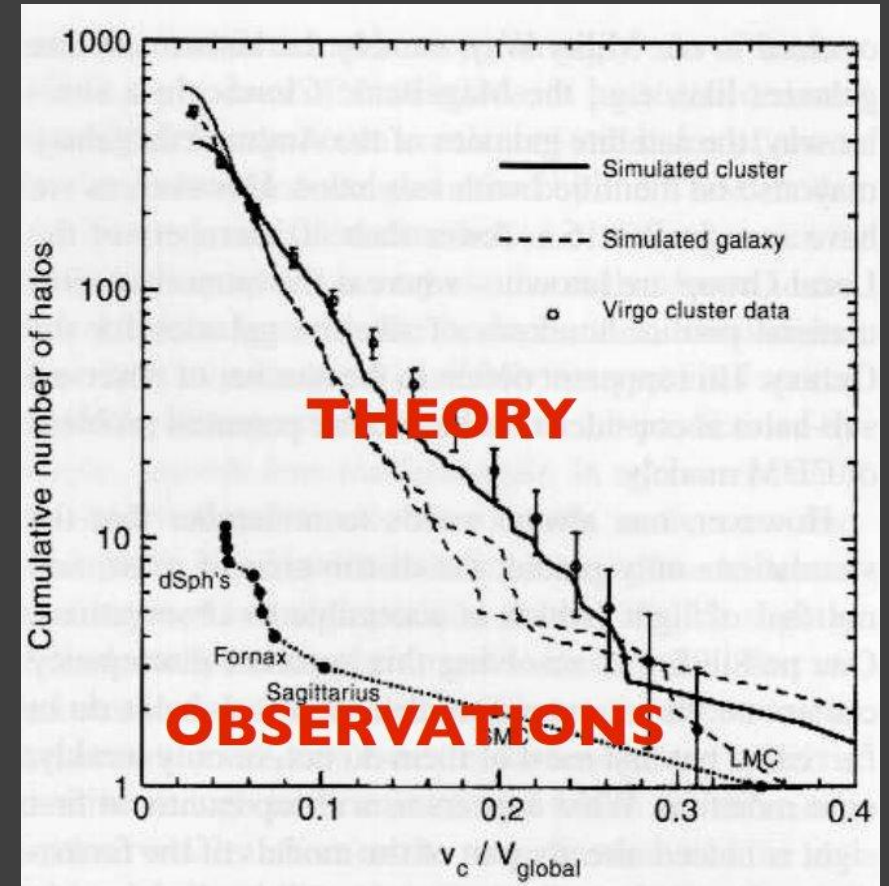
- Observation: highest DM-to-baryonic matter ratio in galaxies
  - Measurement of inner density profile of DM systems
  - Probes of dark matter on small scales (20-30 pc)
  - Number of UFDs set lower limit for amount of low-mass dark haloes
  - Relatively close by dark matter sources
  - Weak heating effects measurable due to 'gentle' internal dynamics

# Constraints

- Observation: UFDs host faint & few stars
  - What do statistics tell us?
  - Unknown formation mechanism
  - Hard to obtain density structures
- Future improvements:
  - Deeper and more complete surveys
  - High resolution and high dynamic range simulations
  - Photometric and spectroscopic follow-up of observations
- The solution to the missing satellite problem

Problem:  
**Large discrepancy between the number of observed and expected satellite galaxies of the MW**

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# Paper 2: Too big to fail

- Simulations show massive subhaloes with  $V_{\text{max}} > 30$  km/s
- But we do not find galaxies that match those circular velocities
- However, the massive subhaloes should contain galaxies; they are 'too big to fail' to make stars

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**Too big to fail? The puzzling darkness of massive Milky Way subhaloes**

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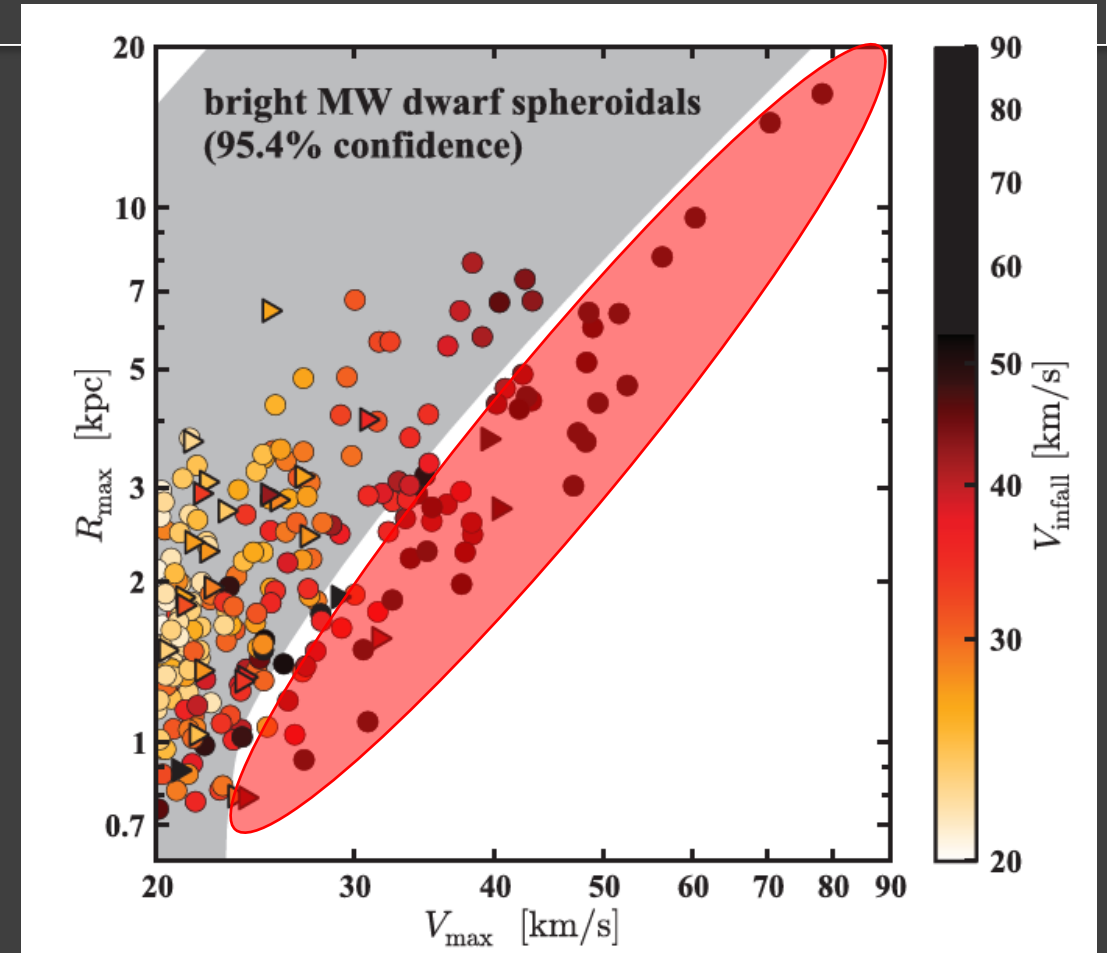
# Paper 2: Too big to fail

- Idea: match the MW satellites to the corresponding massive subhalo
- Methods: Simulations of bright galaxy-mass haloes with  $L > 10^5 L_{\odot}$ 
  - Use kinematic measurements:
    - $V_{\max}$  = maximum circular velocity
    - $R_{\max}$  = radius at which  $V_{\max}$  is attained
    - $V_{\text{infall}}$  = maximum circular velocity when the subhalo's mass was at a maximum

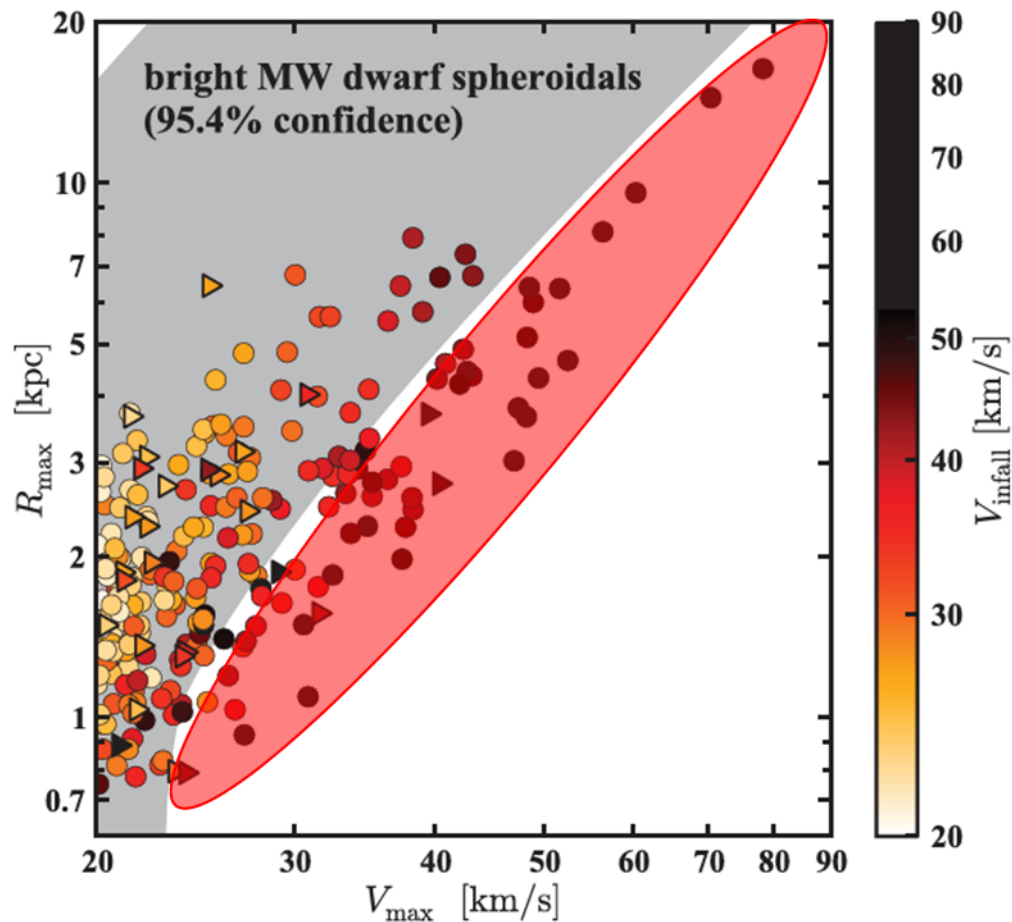
} Determine each subhalo's inner mass distribution

# Results

- Some subhaloes have central densities too high to host any bright MW dwarf spheroidals
- Use kinematic measurements:
  - $V_{\max}$  = maximum circular velocity
  - $R_{\max}$  = radius at which  $V_{\max}$  is attained
  - $V_{\text{infall}}$  = maximum circular velocity when the subhalo's mass was at a maximum



# Discussion: 2 scenerios



- Or: If there are no subhaloes, what is wrong with our theoretical prediction in the simulations?
  - Theoretical prediction still holds, subhalo mass function of the MW is a statistical anomaly
  - Dark matter distribution wrong on large scales

# Conclusion

## **Large discrepancy between the number of observed and expected satellite galaxies of the MW**

1. Low mass haloes (paper 1) → more observations needed to determine the number of UFDs
2. High mass haloes (paper 2) → we expect massive haloes with galaxies, but don't see them