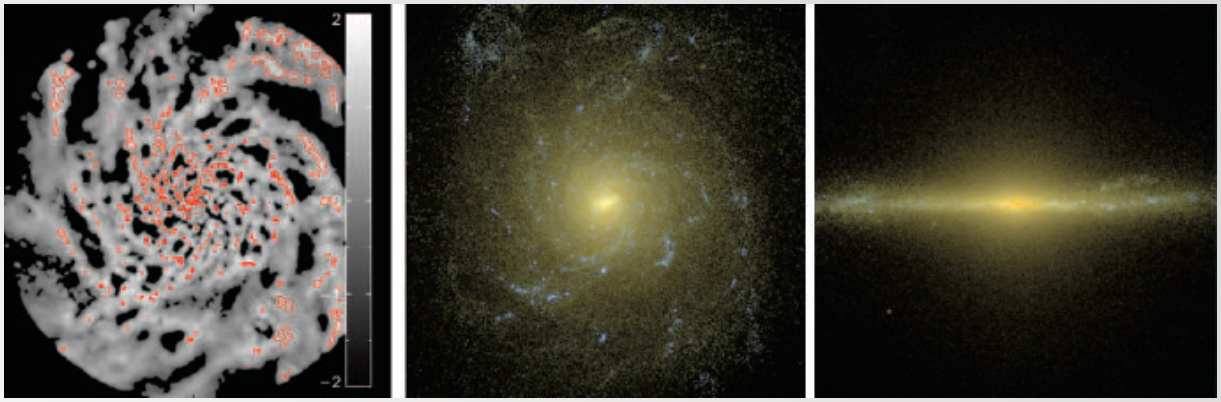
H2, outflows and the formation of Dark Matter cores



F. Governato - UW

A. Pontzen, S.H Oh+LITTLE THINGS team, Alyson Brooks, A.Zolotov, C. Christensen, P. Jonsson, P.Madau
T. Quinn, J. Wadsley & the N-Body Shop collaboration

Outline of This Talk

Understand how out(in)flows shape the central mass distribution of galaxies using cosmological hydro simulations

Make predictions of DM Cores properties vs galaxy stellar mass

Compare with observations.

GASOLINE, a treecode+SPH cosmological code: implementation of new physics and the modeling of outflows

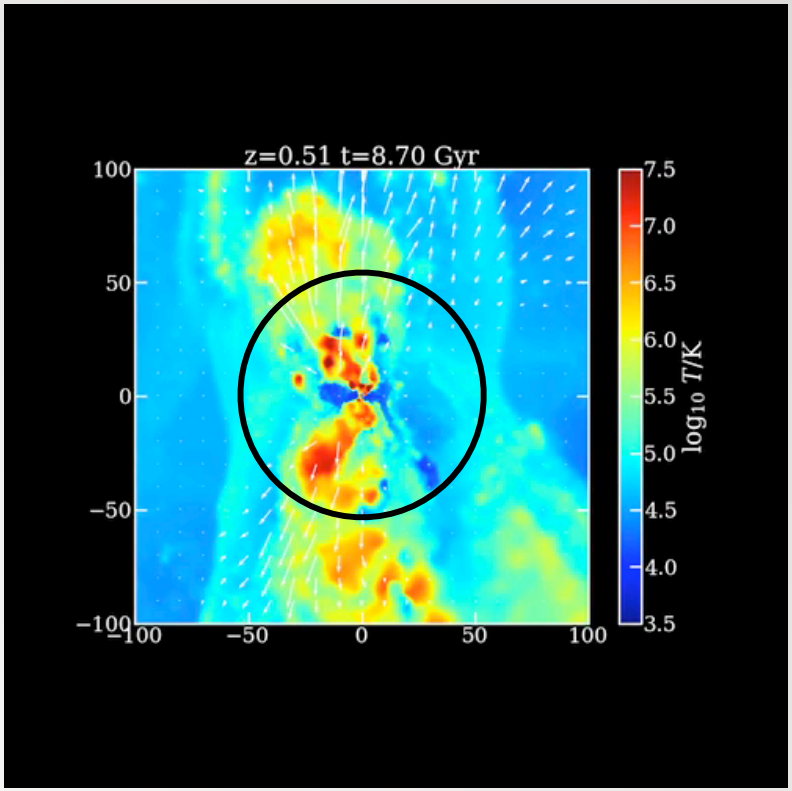
- SN energy coupled to gas *as thermal energy*
- Cooling shutoff turned of for 3-8 Myrs
- Metal lines cooling at all temperatures
- Resolution 50-160pc ~ 'resolved' SF regions down to z=0
- Star particles ~ 1000-10000 Msol
- Several million particles per (main) galaxy.

A High density Threshold for SF (a clumpy ISM) is necessary to form outflows with the thermal energy approach. Resolution must be high!

local energy/gas mass ratio sufficient to unbind gas!

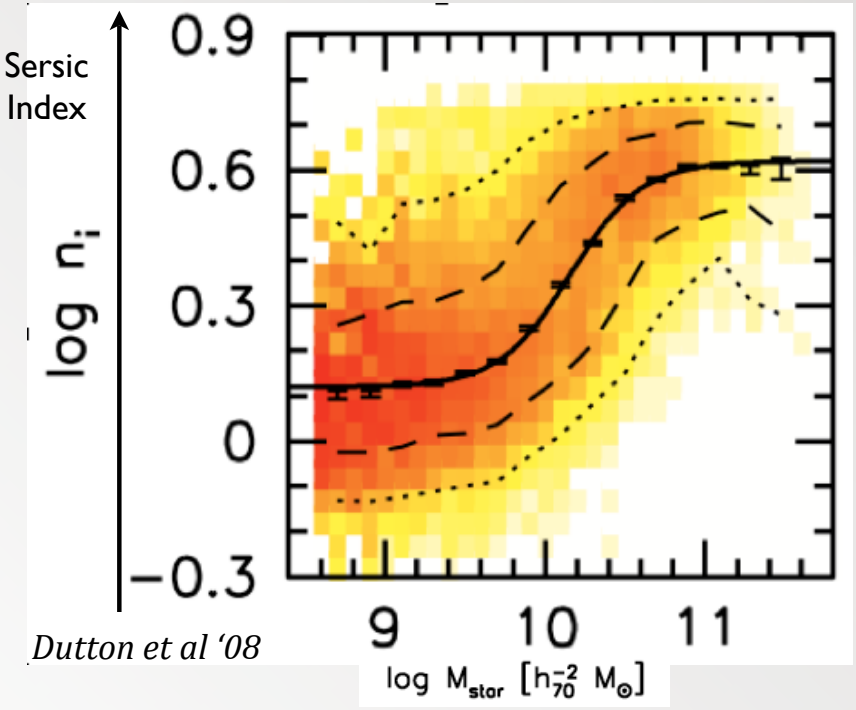
Buoyancy

Gas Outflows: Thermal Feedback & Buoyant Bubbles



Cosmological Dwarf Galaxy

The Problem with Dwarfs (1)

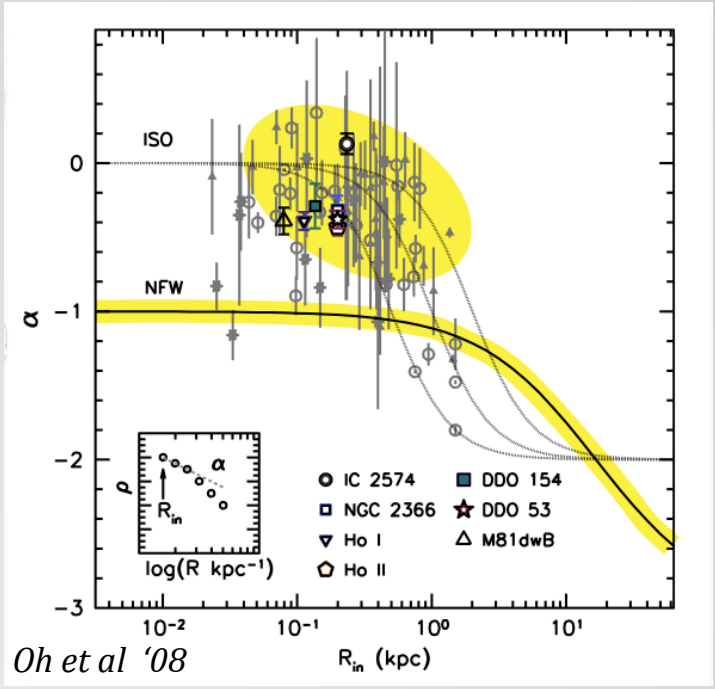


Dutton et al '08

- Dwarfs are bulgeless

rho ~ ρ $^{-?}$

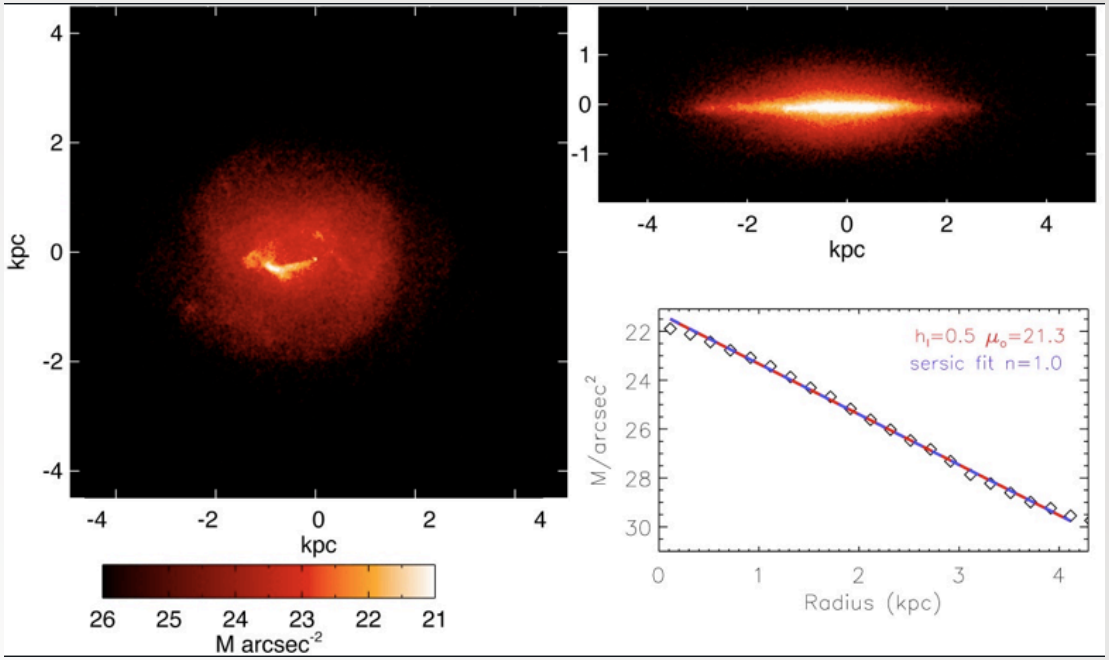
DM profile slope



Oh et al '08

- The Dark Matter Profile is not 'CDM-like'

Simulating a bulgeless dwarf galaxy?



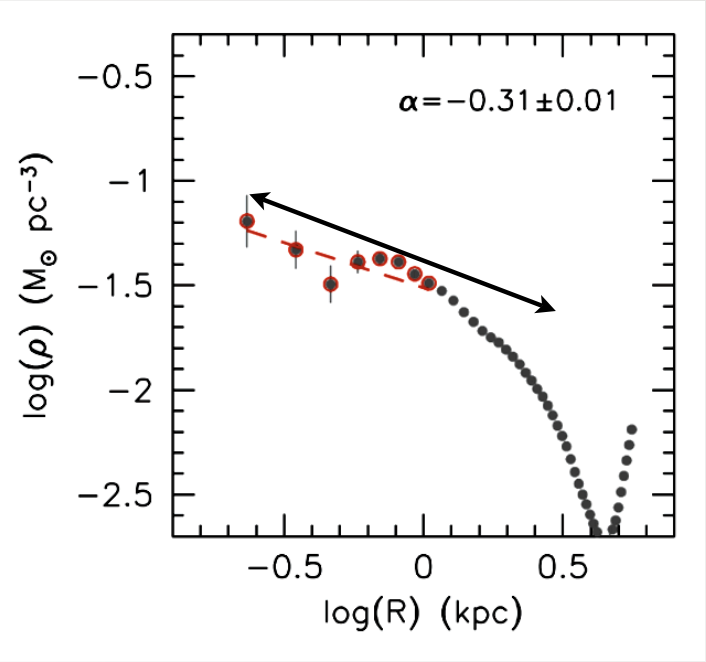
- Exponential stellar disk Rd = 1 kpc
- Gas rich: HI/stars mass ratio ~ 2
- Thin disk b/a
- Vc = 55 km/sec
- blue colors g-r = 0.5
- SFH bursty SFR = 0.01 sol. masses/yr

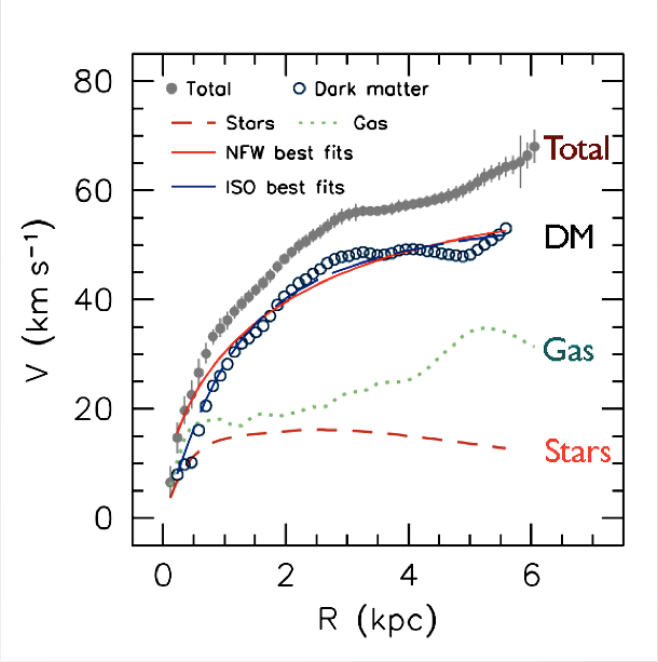
- just your regular dwarf...

Governator,....Jonsson... et al 2010

...with a Cored DM profile as the dwarfs in the THINGS survey!

..where α is the slope of a power-law fit to the DM profile



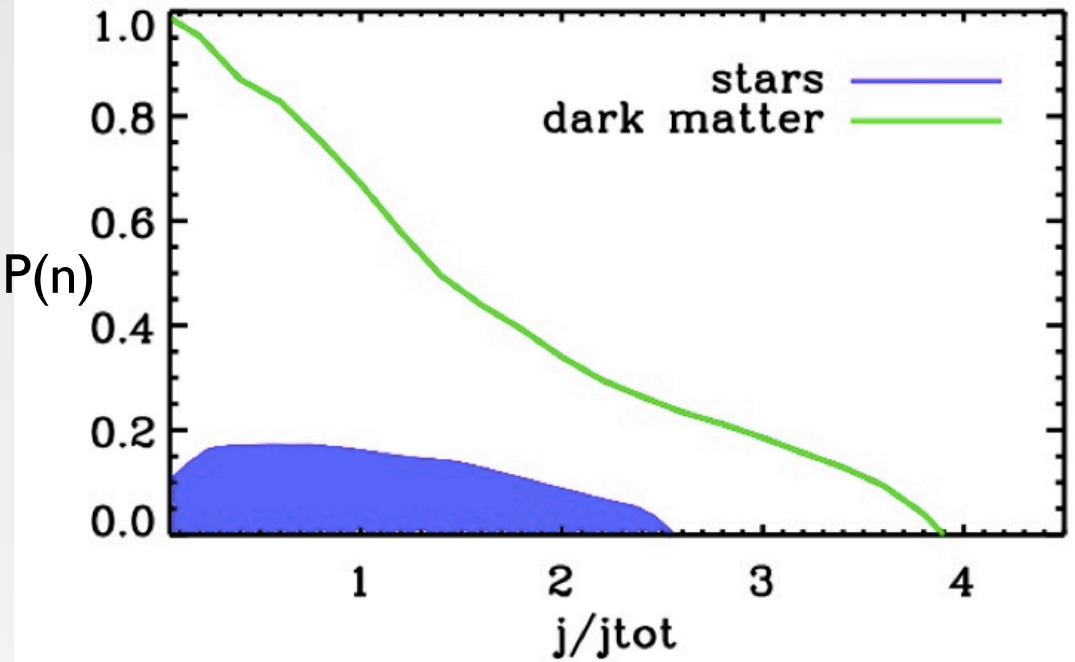


The inner density slope $\alpha = -0.31$ is consistent with those of the THINGS dwarfs ($\alpha = -0.29 \pm 0.07$).

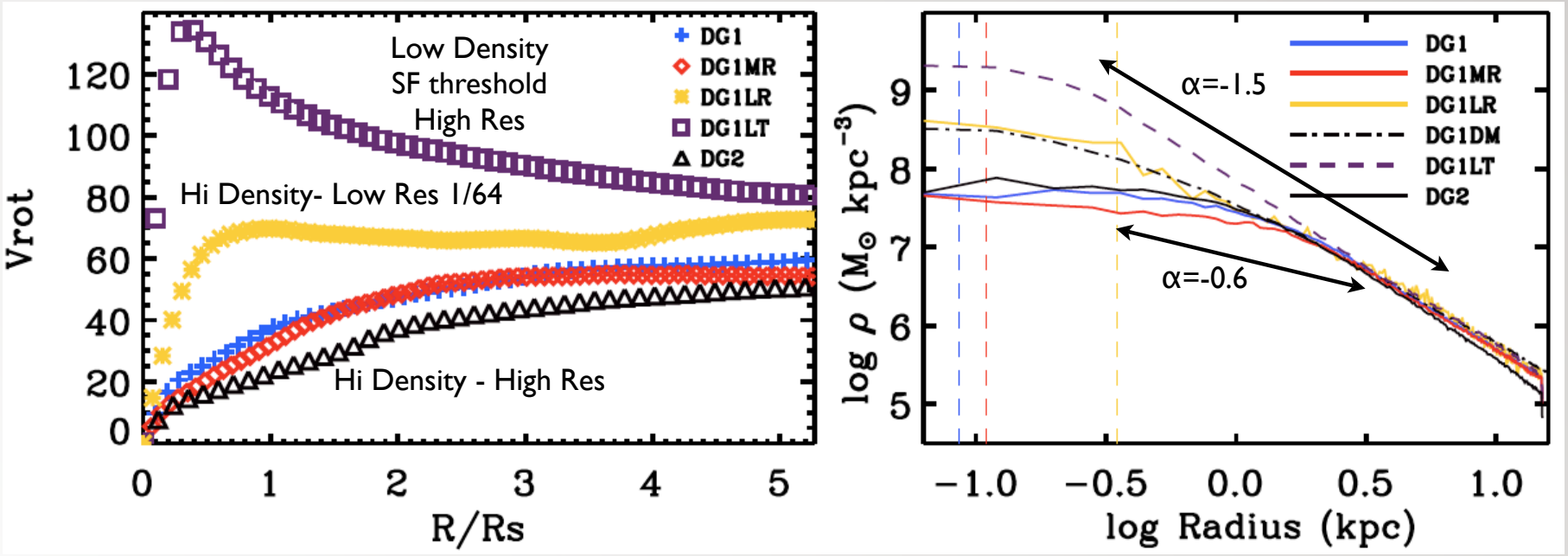
Note: the 'true' DM slope is -0.6

Oh et al 2011, AJ

Angular Momentum Distribution: A Bulgeless Galaxy



The Angular momentum distribution of a simulated bulgeless galaxy (Governato et al 2010). Low angular momentum gas has been removed by outflows. Only 5% of gas has been turned into stars.



G10, supplemental material

H2 in GASOLINE is here! Where/when do stars form?

(C.Christensen PhD Thesis)...(ala TGK '09)

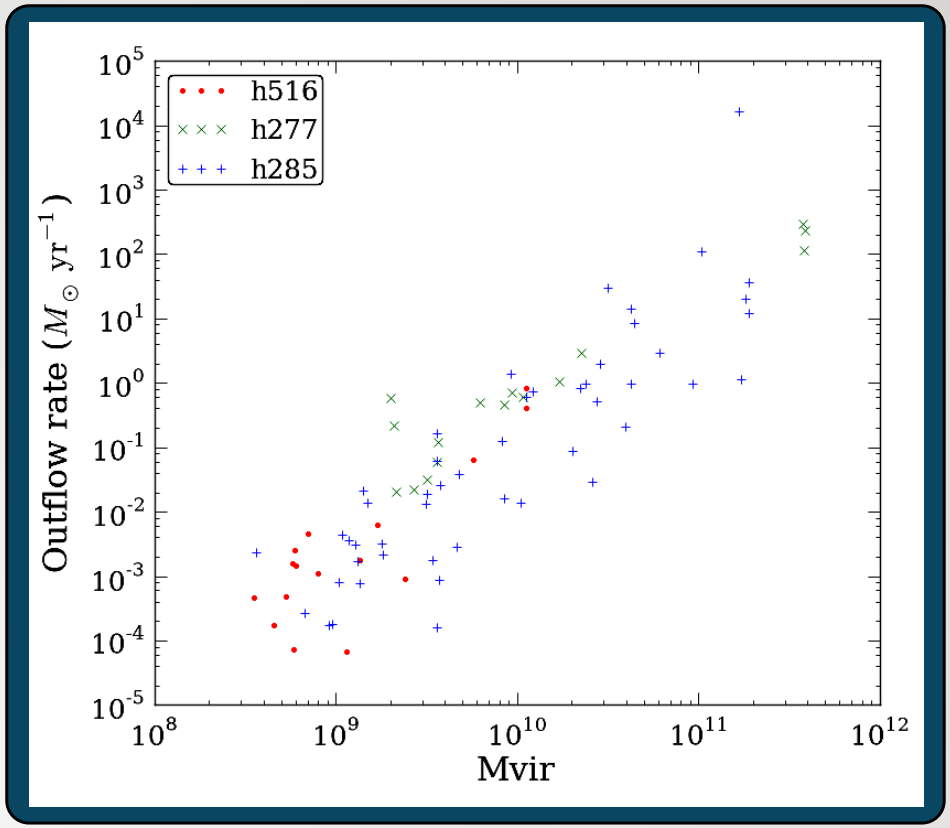
- **Star Formation regulated by local H2 fraction**
- **explicit metal dependent H2 formation**
- **H2 cooling**
- **H2 destruction by Lyman-Werner radiation**

We have now a sample of ~ 20 galaxies Vc from 10 to 100 km/sec @z=0 resolution 50-150pc. Stars naturally form in very dense gas.

Gas Outflows with Thermal Feedback: Temperature map

Pontzen & Governato '11

Thermal Heating + buoyancy

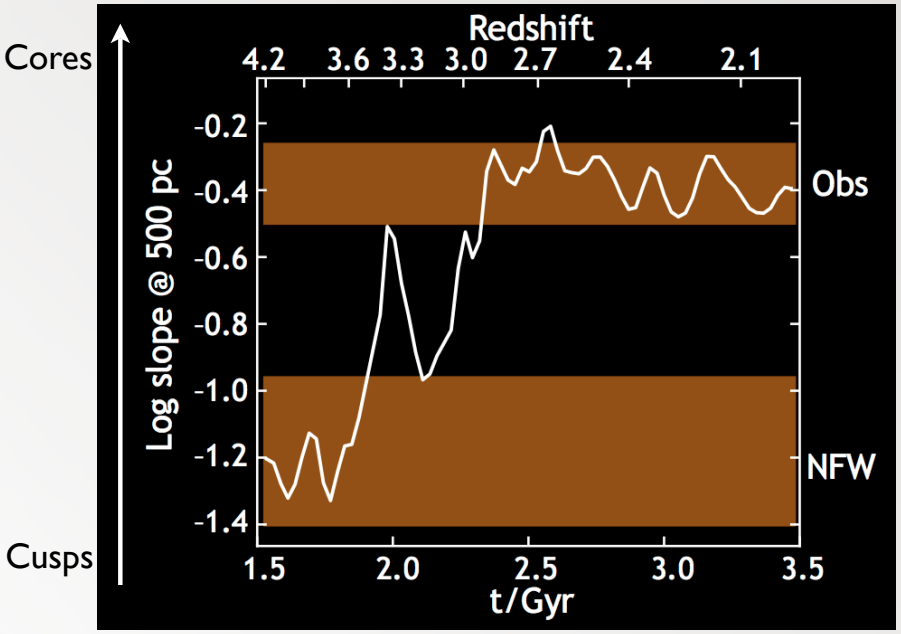


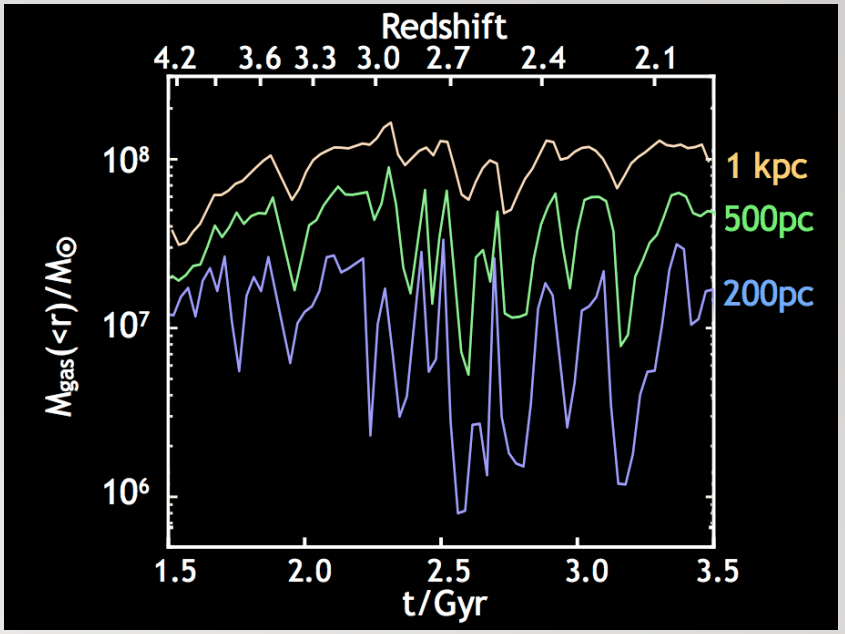
Pontzen+ FG in prep

Loading Factor: 2-5

Back to cores...

NON adiabatic, repeated gas flows transfer energy to the DM:'The Pontzen Scheme'

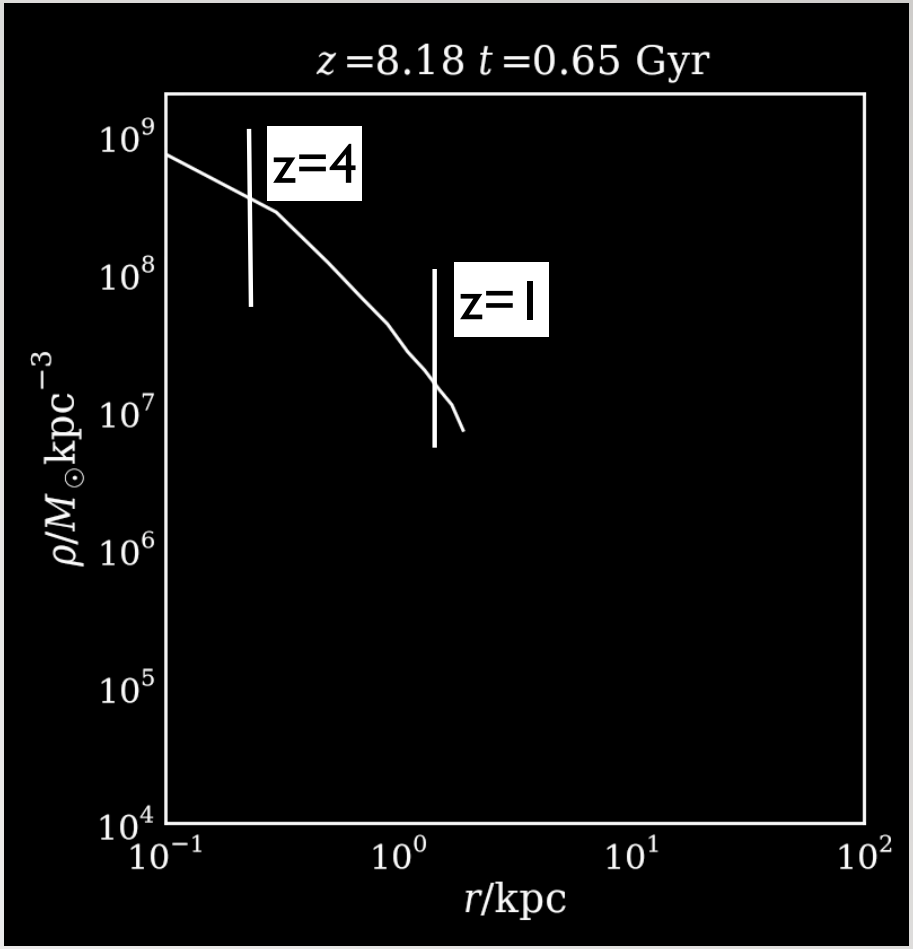




Pontzen, Governato 2011, submitted.

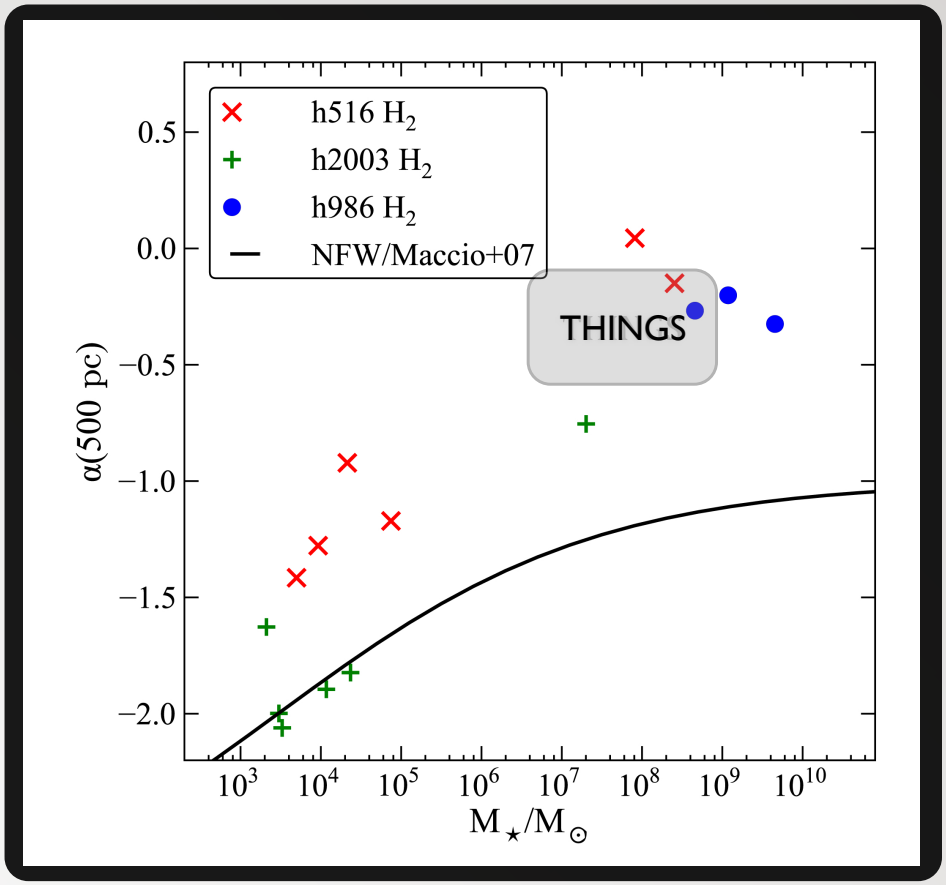
When do DM cores form?

- The central density DM decreases as outflows transfer energy to the DM.
- This process is most active at $4 > z > 1$ as SF peaks in the galaxy progenitors.



Pontzen & Governato 2011, submitted

The Slope of Dark Matter Halos: the Effect of Gas Outflows



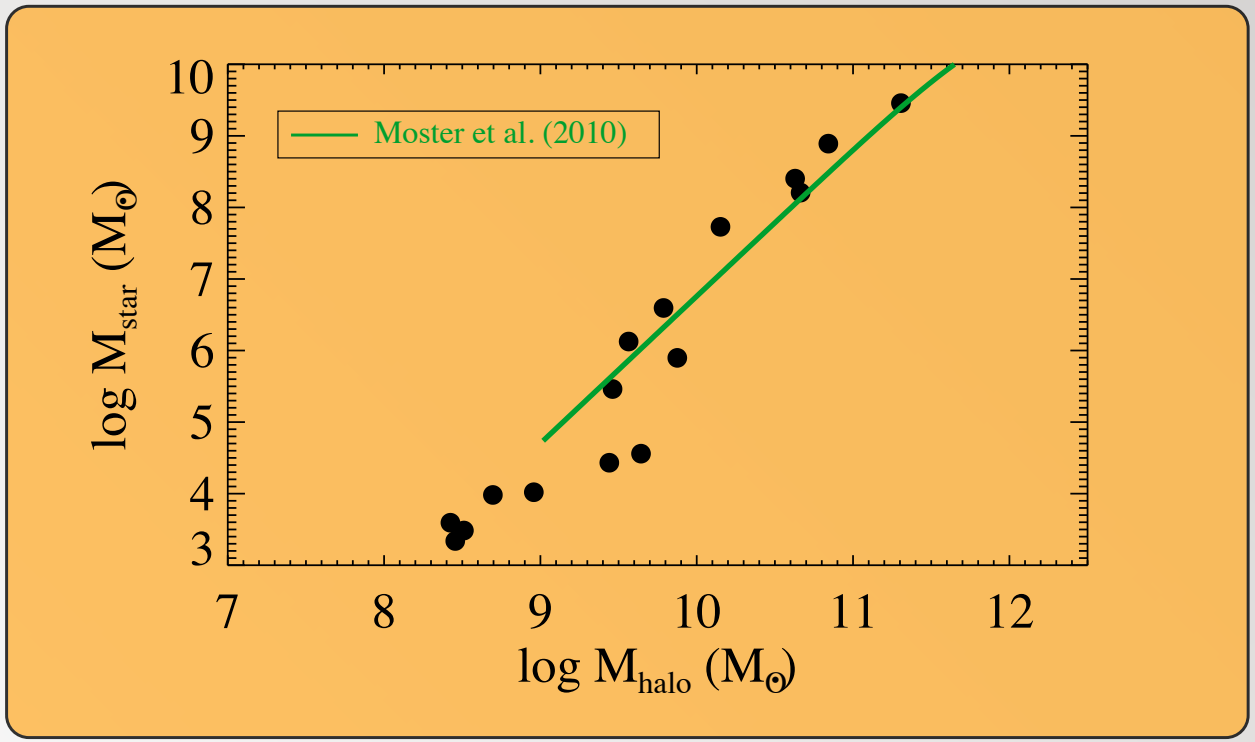
the typical high-z galaxy seen by HST should have cores!

Outflows in ultra faint galaxies are not sufficient to turn cusps into cores

Governato Zolotov, Pontzen et al '11 in prep

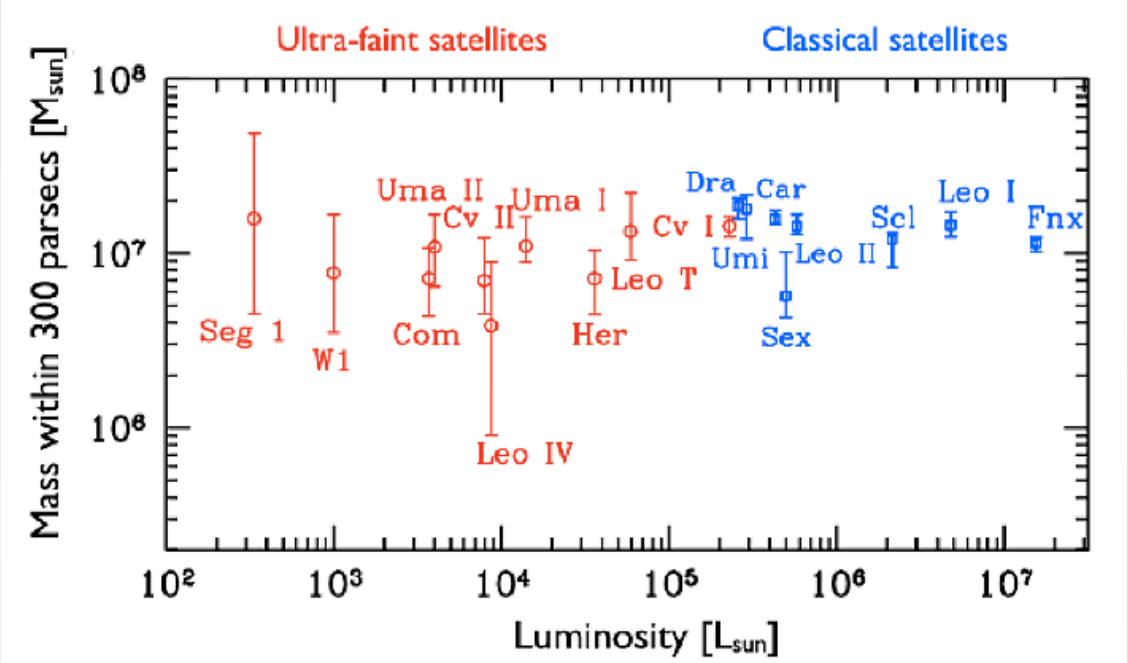
Enough predictions.
How about the existing observational constraints?

The Stellar Mass - Halo Mass Relation



Charlie
you did it first!

The Problem with Dwarfs (2): The Strigari Relation



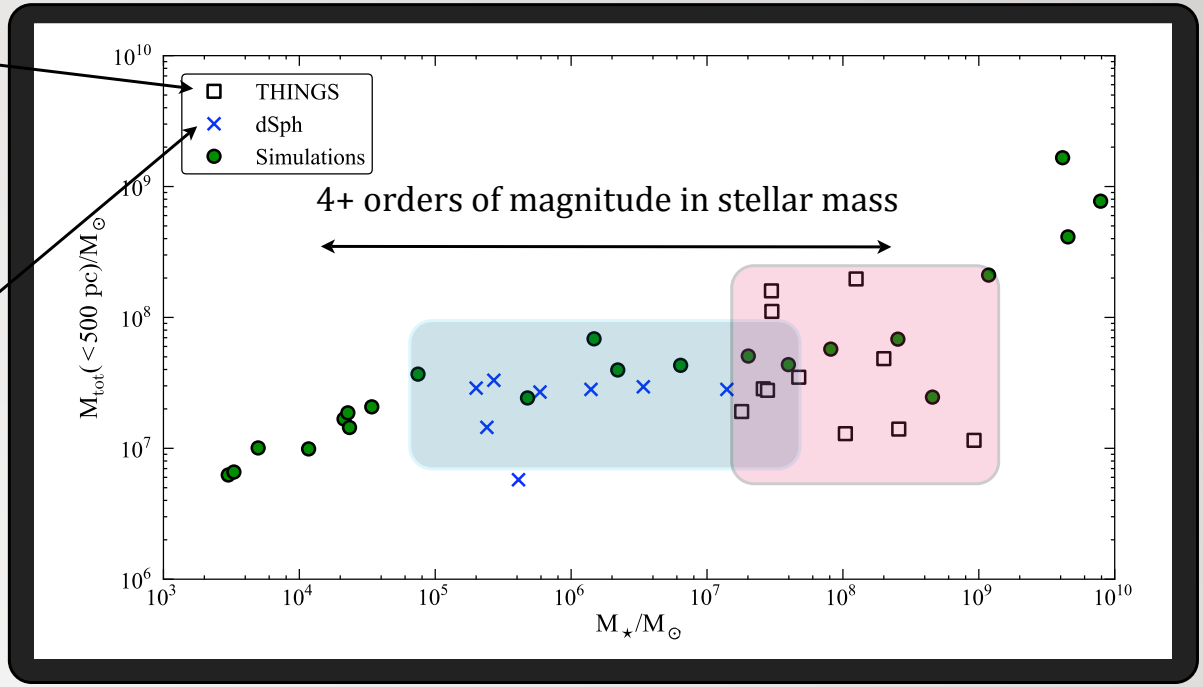
Strigari..Bullock et al 08

- "a hint of a new scale in galaxy formation" → **cosmic UV background?**
- "a characteristic scale for the clustering of dark matter" → **WDM?**

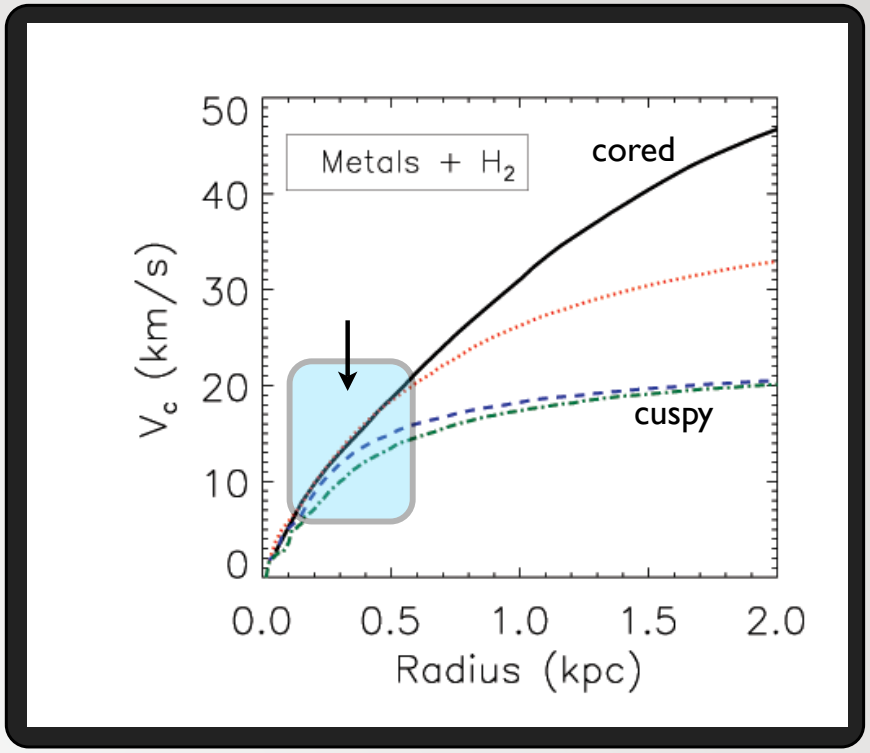
Simulations vs Observations: Central Total Mass vs Stellar Mass (aka the Strigari Relation)

From Se-Heon Oh

From Matt Walker

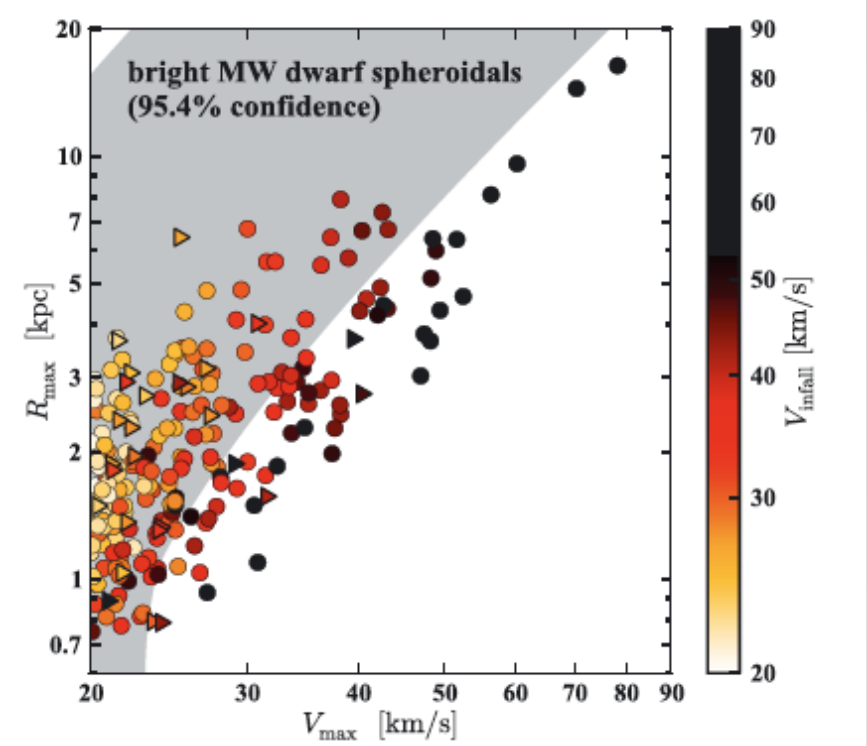


Rotation Curves of Galaxies

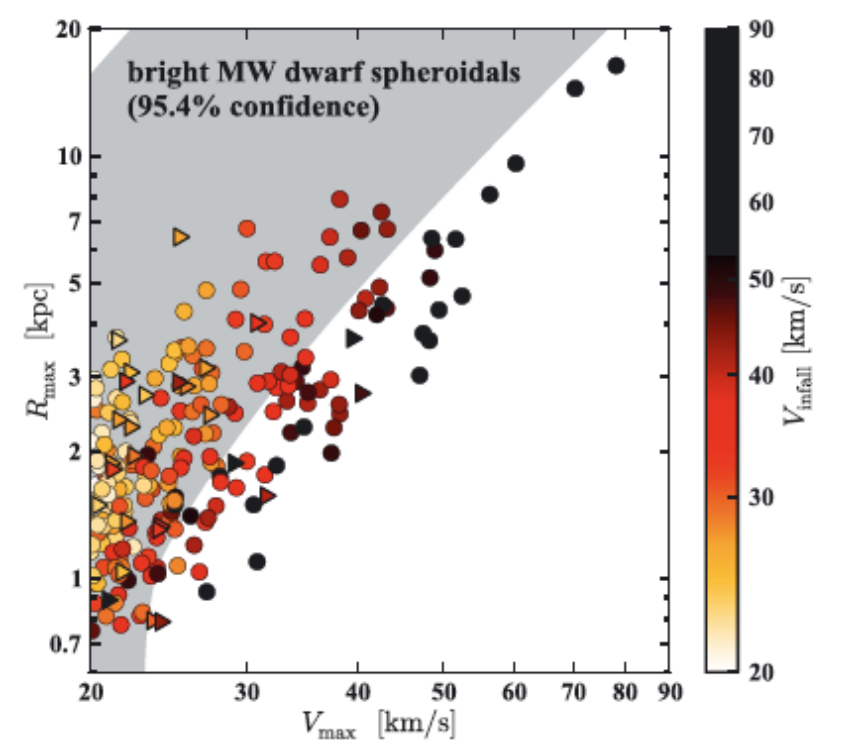


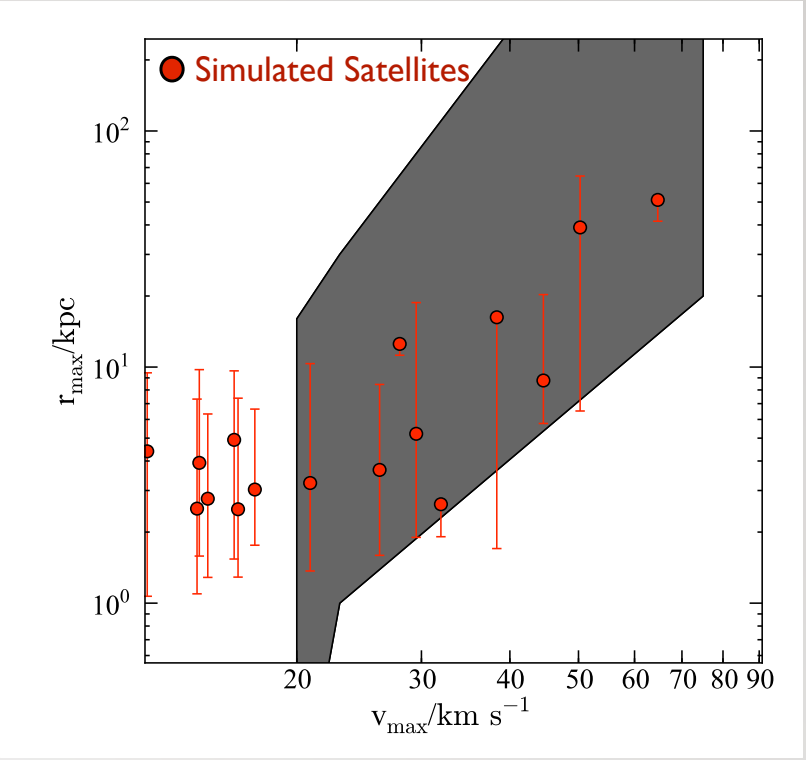
Transfer of energy to the Dark Matter brings down Vc at r < 1kpc

The Problem with Dwarfs (3): Rmax vs Vmax - Boylan Kolchin..Bullock et al '11



MW satellites Rmax vs Vmax Boylan Kolchin etal '11





Conclusions (and relevant papers)

Thermal Feedback: good!
Adiabatic outflows: not so good...

RAPID (Vout > Vrot) and repeated gas removal creates DM cores from 'cuspy' CDM halos.

30 < Vpeak < 110 Km/sec: cores
Superfaint dwarfs: cuspy

Outflows/Cores naturally explain the Stellar mass - Total mass and Rmax - Vmax relations

- Governato et al 2010
- C.Brook 2010, MNRAS
- Pontzen & Governato 2011 (astro-ph/1106.0499)

- Governato, Zolotov, Pontzen et al 2011 (submit soon!)