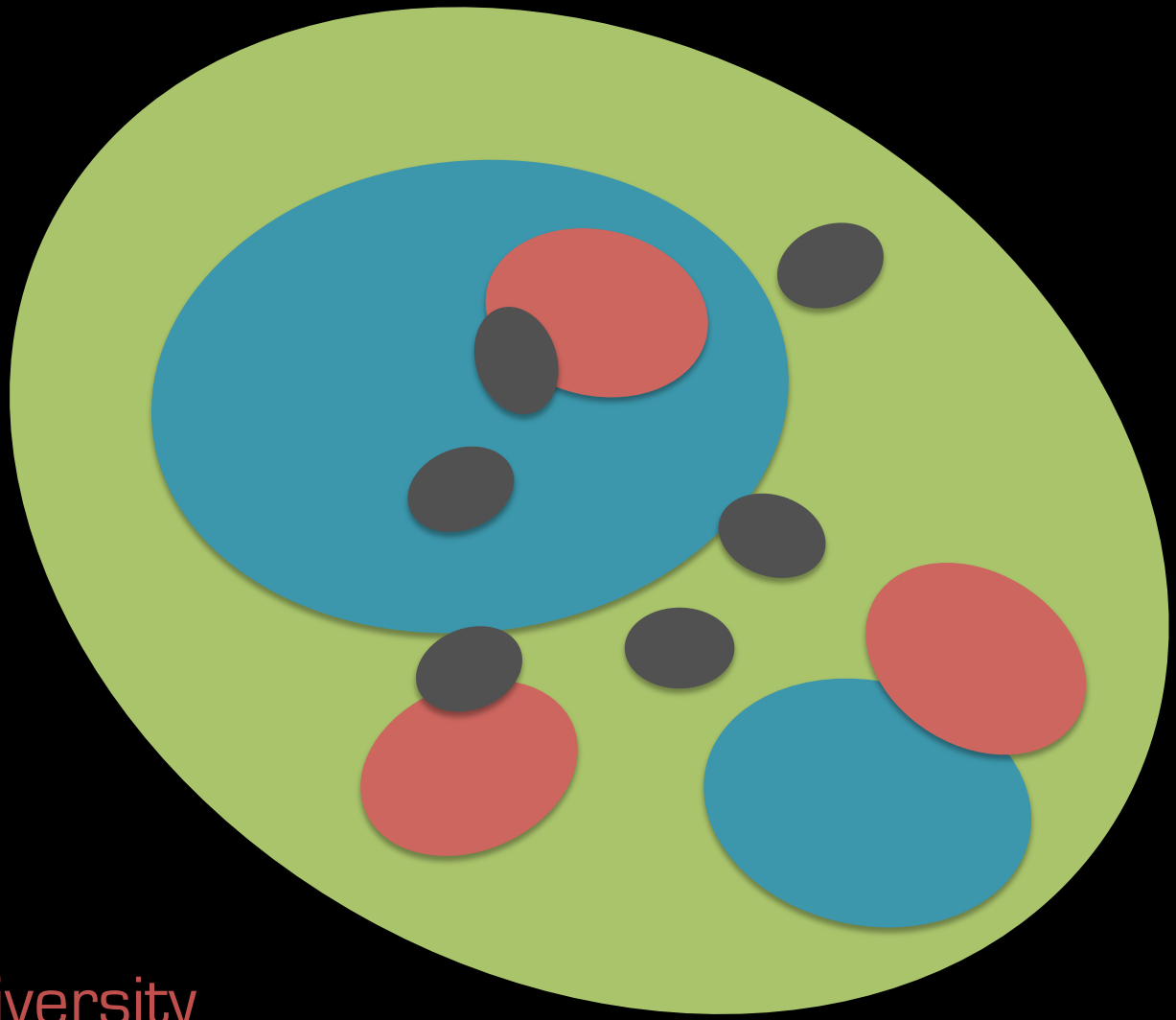
Small-scale structure

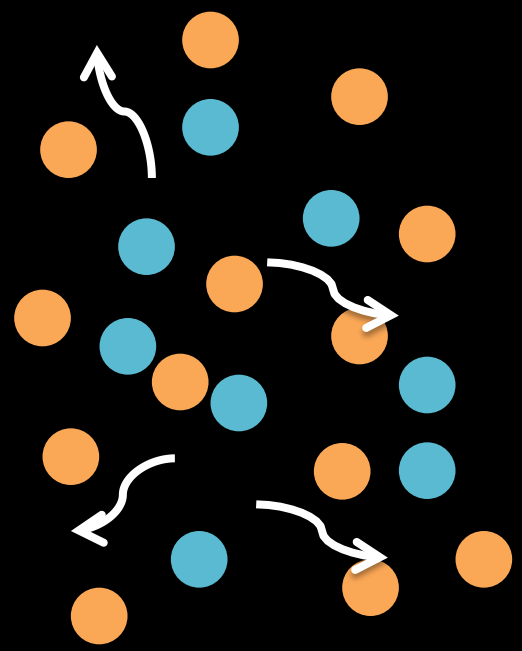


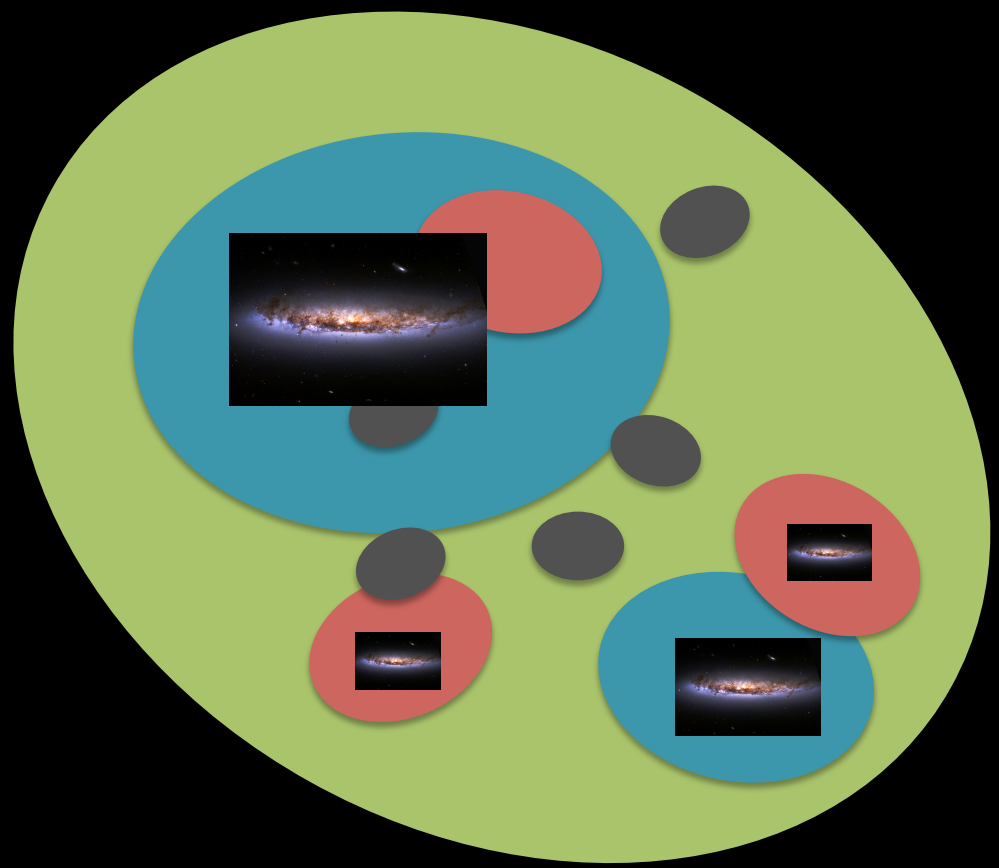
Annika Peter

CCAPP

The Ohio State University

Microphysics ⟷ Macrophysics





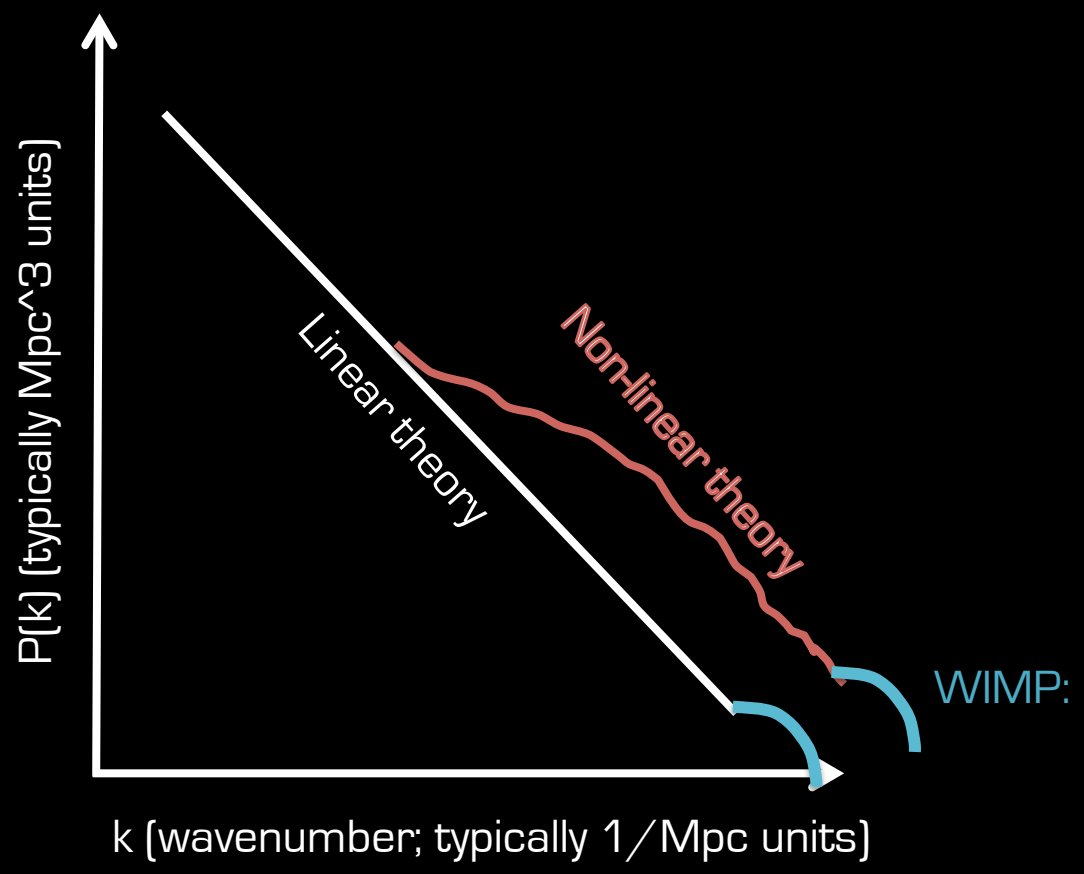
Baryons

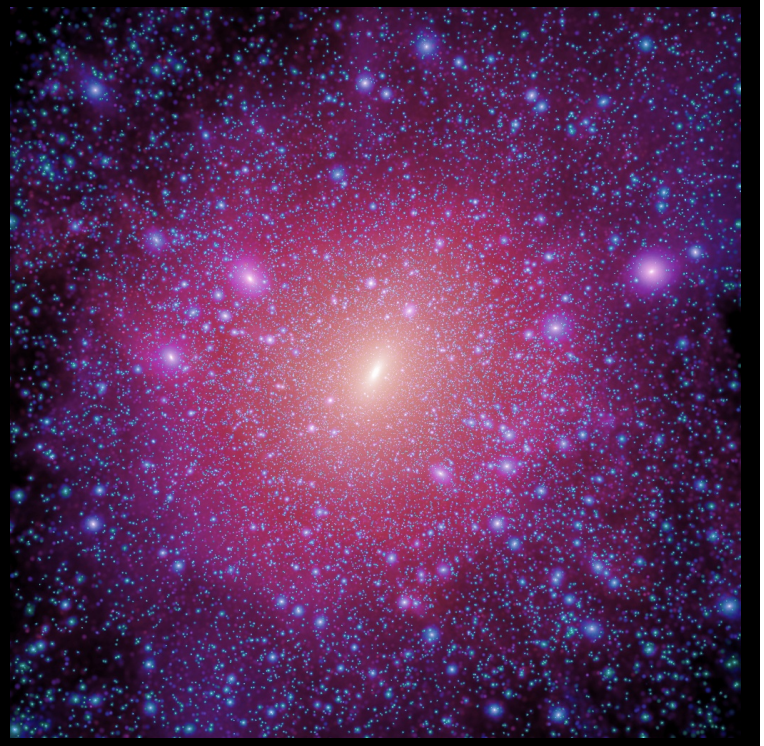
Dark matter

Maybe some mediators

Example: Cold Dark Matter (CDM)

- Micromodel: Cold, collisionless, totally stable

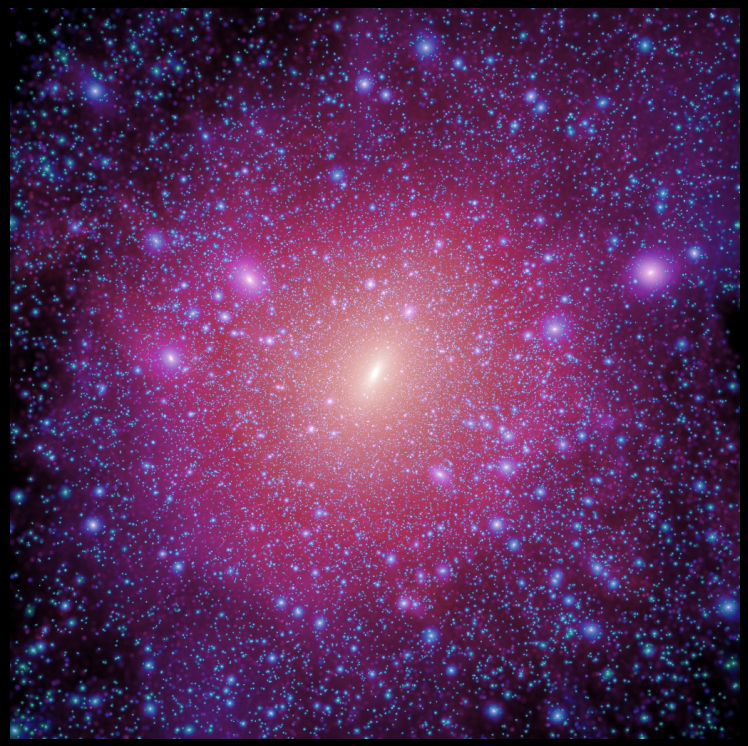




Springel+ 2008

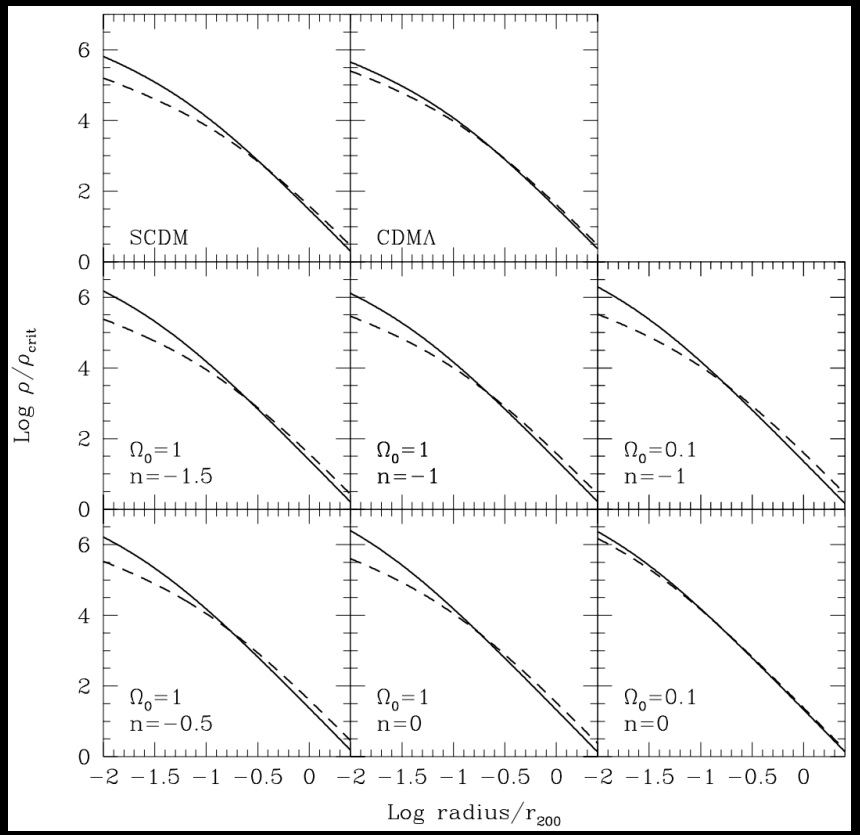
Example: Cold Dark Matter (CDM)
2 predictions

1. Scale-free hierarchy of structure



Springel+ 2008

2. Dense halos



NFW 1997

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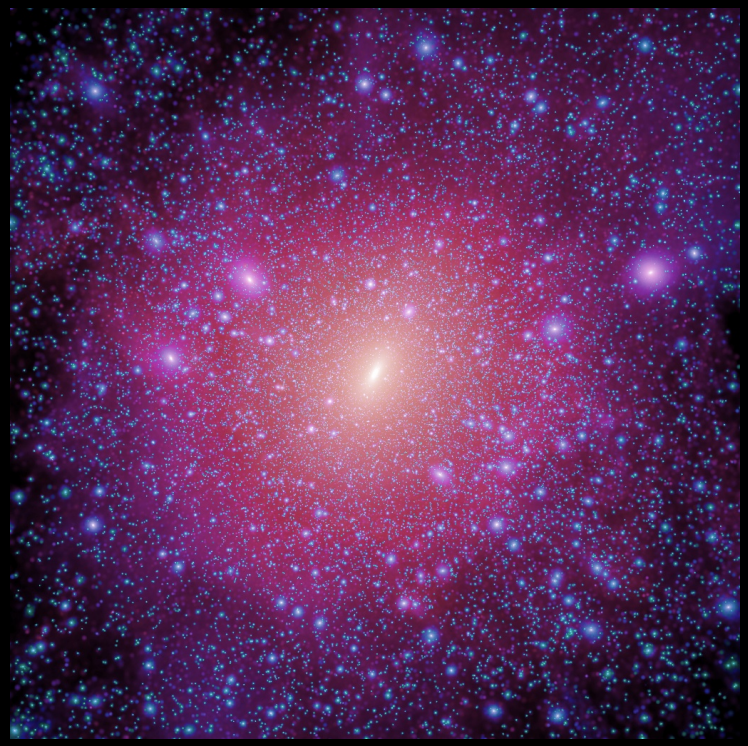
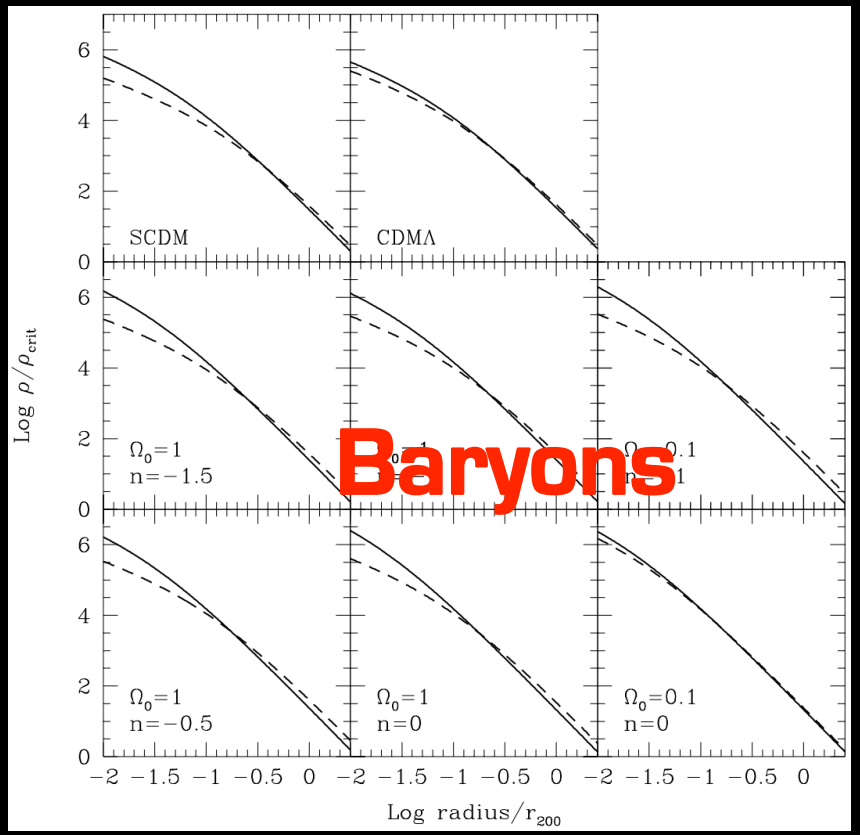


Springel+ 2008

2. Dense halos*

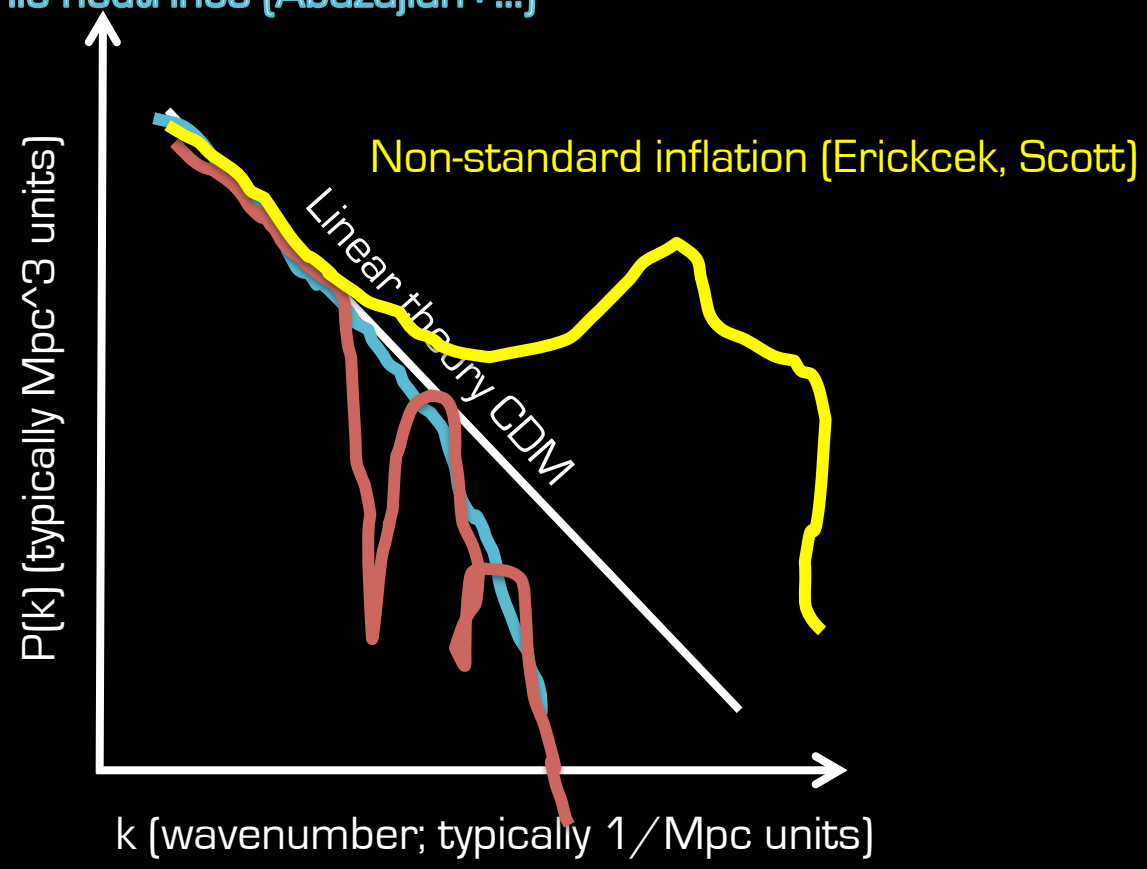


NFW 1997

Model variants

NB: $M \sim \lambda^3$

Late decays (SuperWIMPs; Feng, Kaplinghat+)
Strong baryon-DM coupling (Chen+, Dvorkin+)
Sterile neutrinos (Abazajian+...)

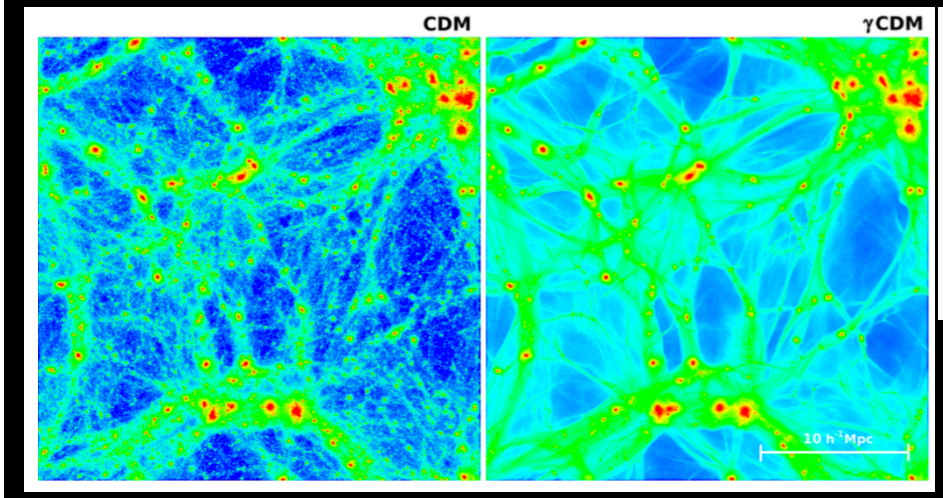


Dark acoustic oscillations from SIDM (Cyr-Racine+)
Strong kinetic coupling w/light species (Boehm+)

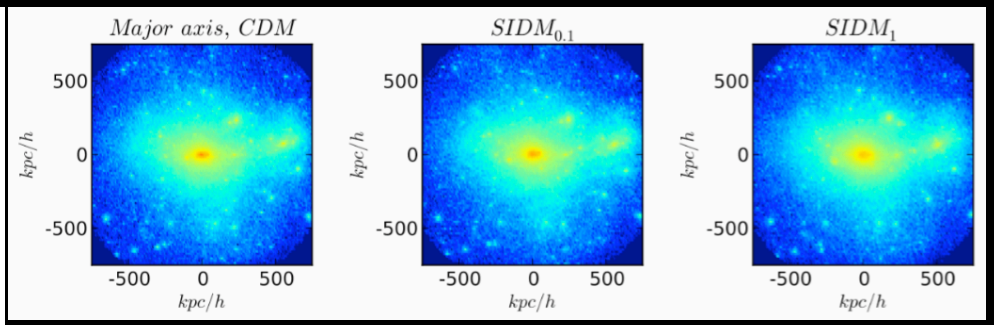
Model variants

1. Different small-scale halo hierarchy

2. Underdense or overdense relative to CDM



Schewtschenko+ 2014



AP+ 2013

Model variants

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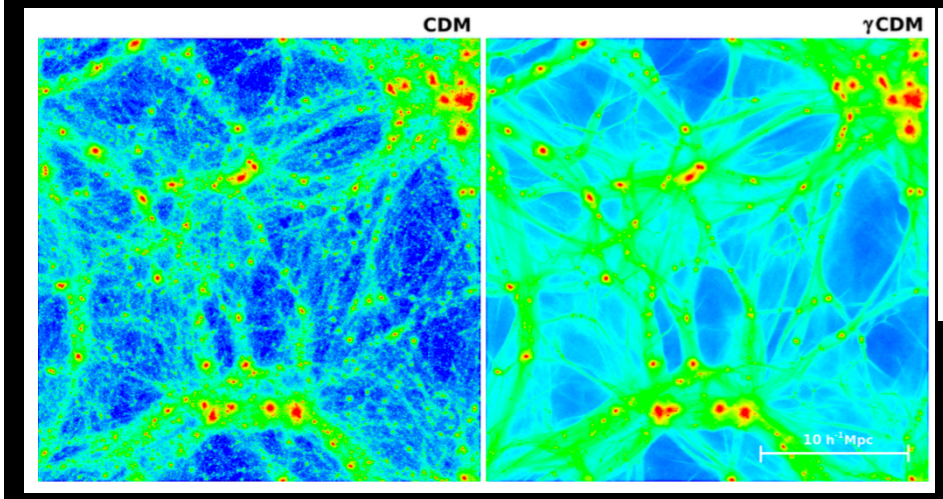
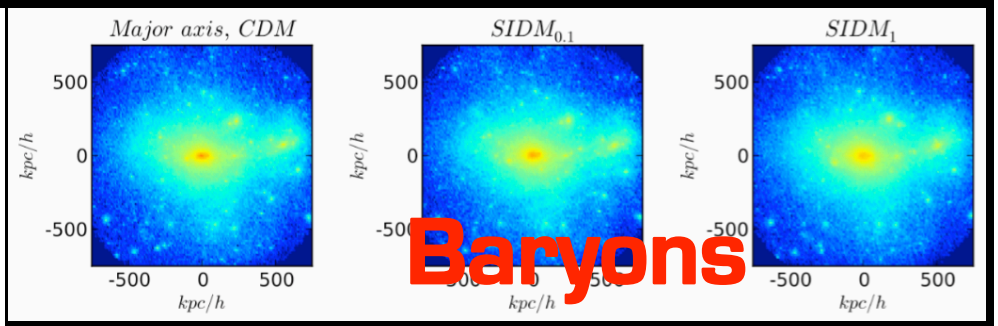


Schewtschenko+ 2014



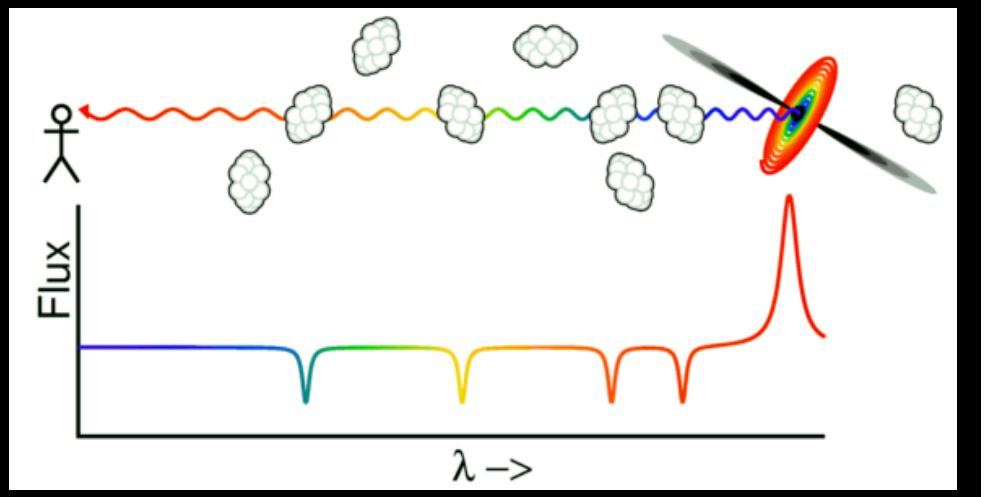
AP+ 2013

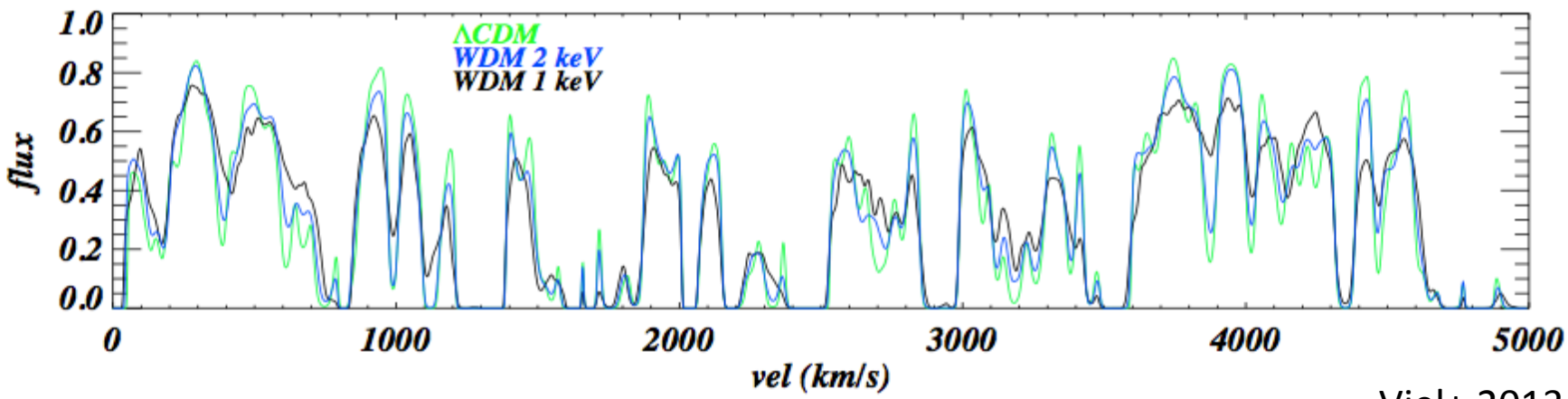
Probes

1. Linear scale
2. Non-linear: counts
3. Non-linear: density

(I won't talk about novel constraints like enhanced annihilation or microlensing from ultra-compact minihalos from non-standard thermal histories—interesting, but I have no time)

Linear(ish): Lyman-α forest



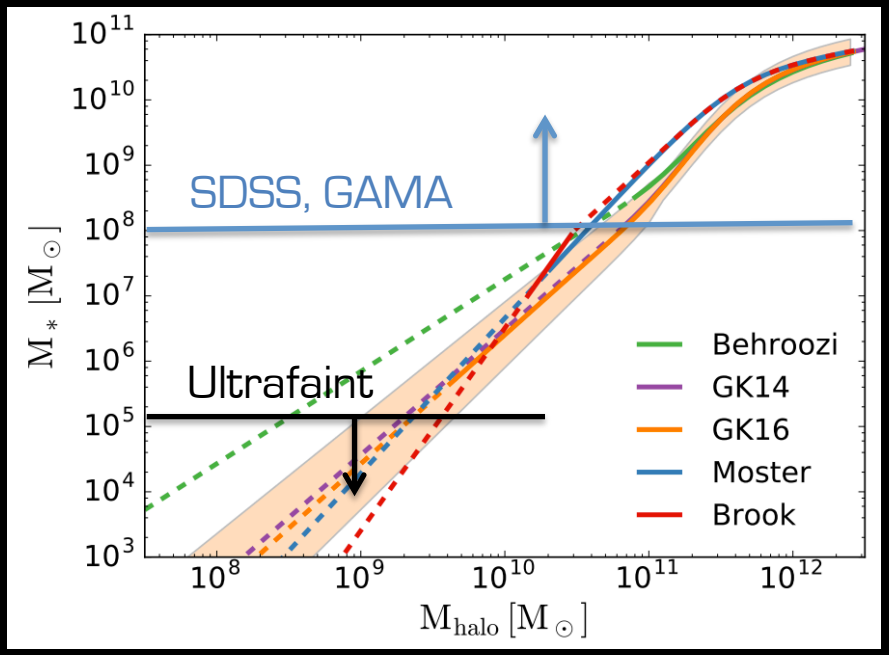


Viel+ 2013

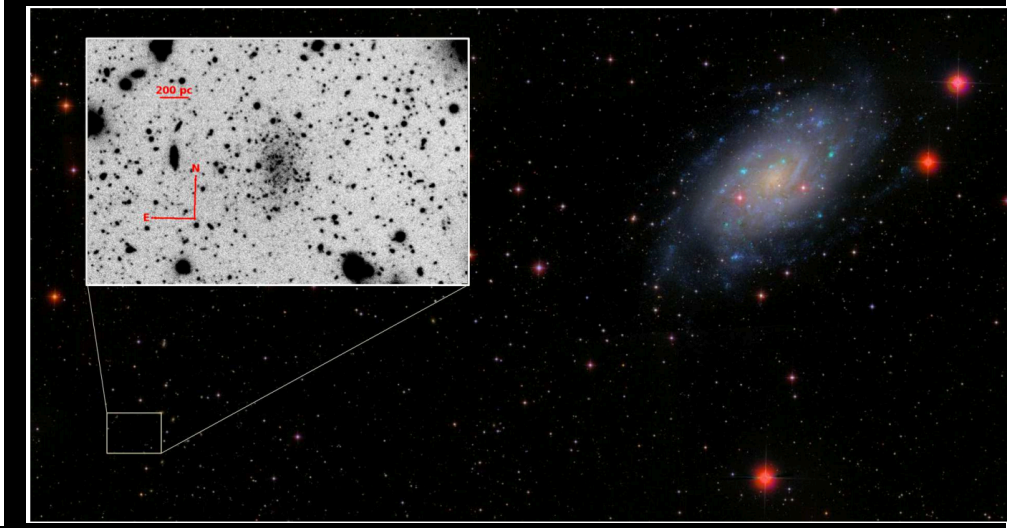
FIG. 2: Transmitted flux along a set of random LOSs for the ΛCDM (green curve) and WDM 1 keV (black curve) and WDM 2 keV (blue curve) models at $z = 4.6$. This figure refers to the reference (20,512) simulation without adding instrumental noise. The ΛCDM flux is clearly showing more substructure as compared to the WDM models.

Non-linear: halo counts

Visible tracers



Dooley, AP+ 2016b

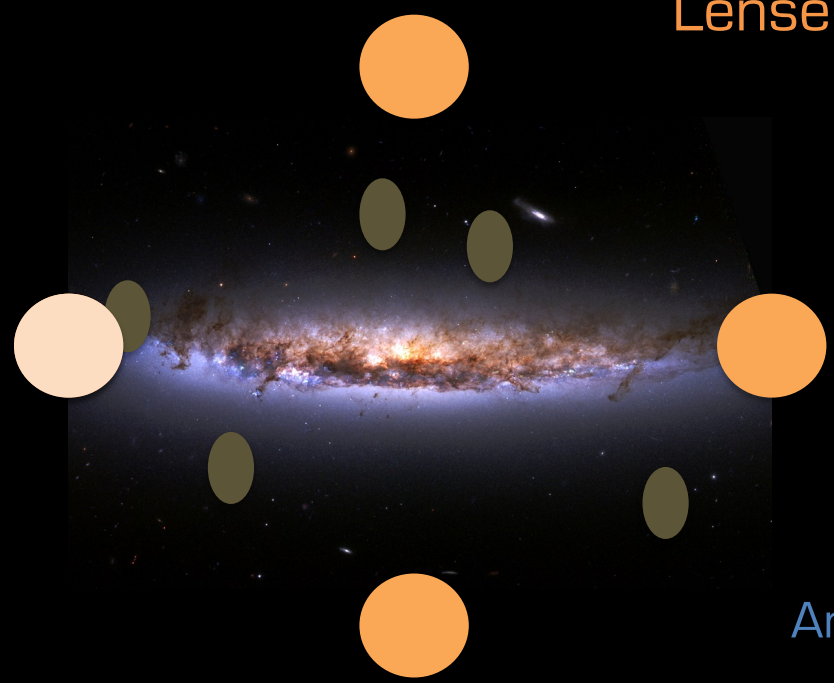


Carlin,...AP+ 2016

More on this in a few slides...

Non-linear: halo counts

Invisible tracers

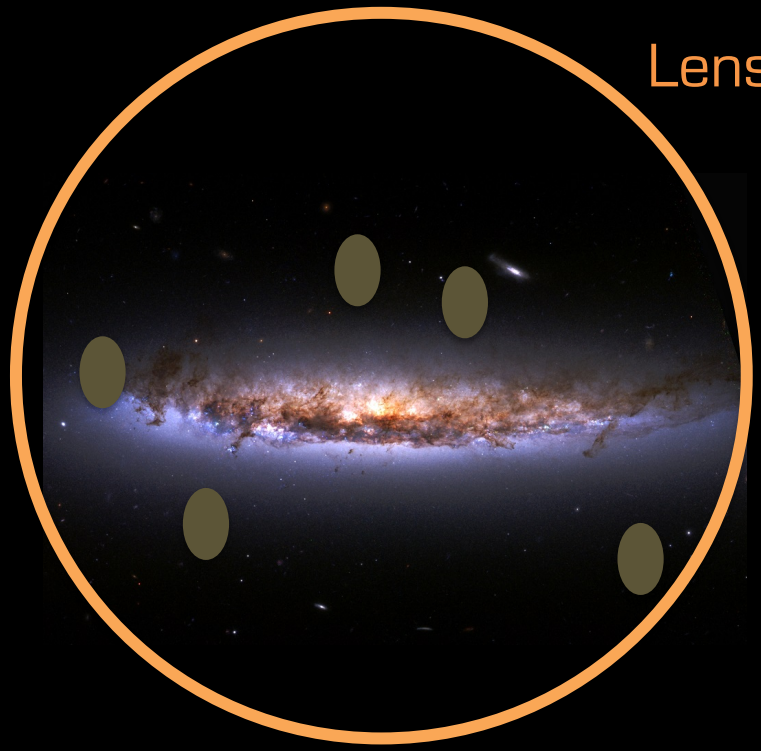


Flux ratio anomalies

Non-linear: halo counts

Invisible tracers

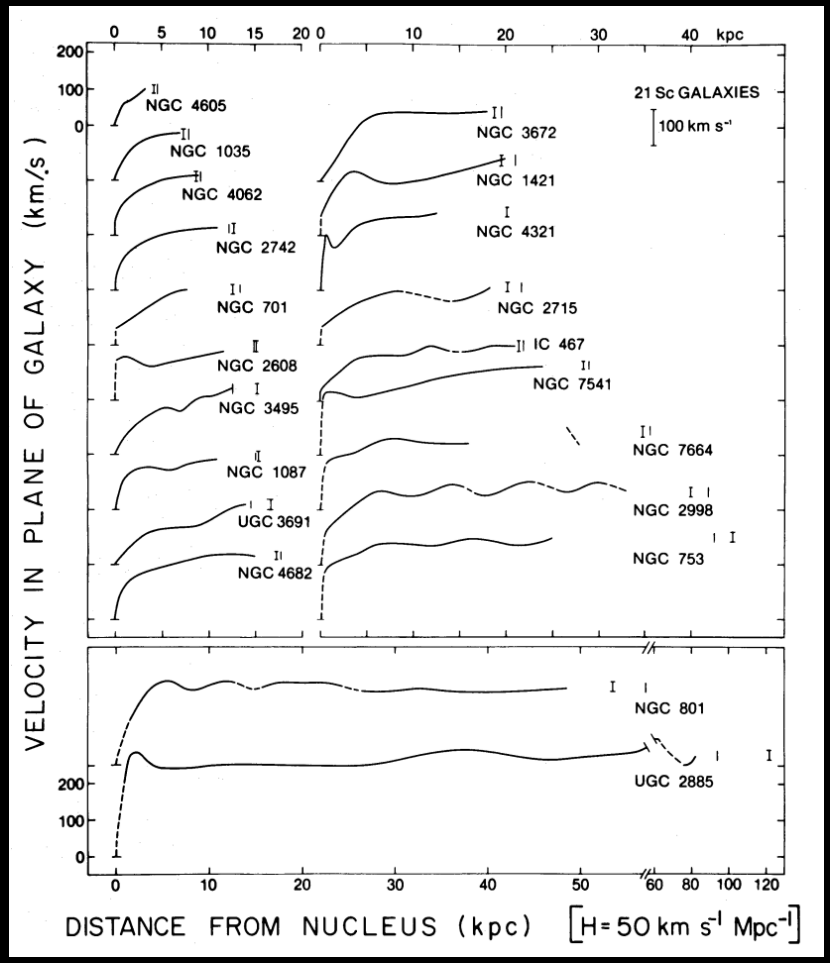
Among methods, can we achieve 10^4 $M_\odot$?



Lensed galaxies

Astrometric perturbations

Non-linear: density



Rubin+ 1980

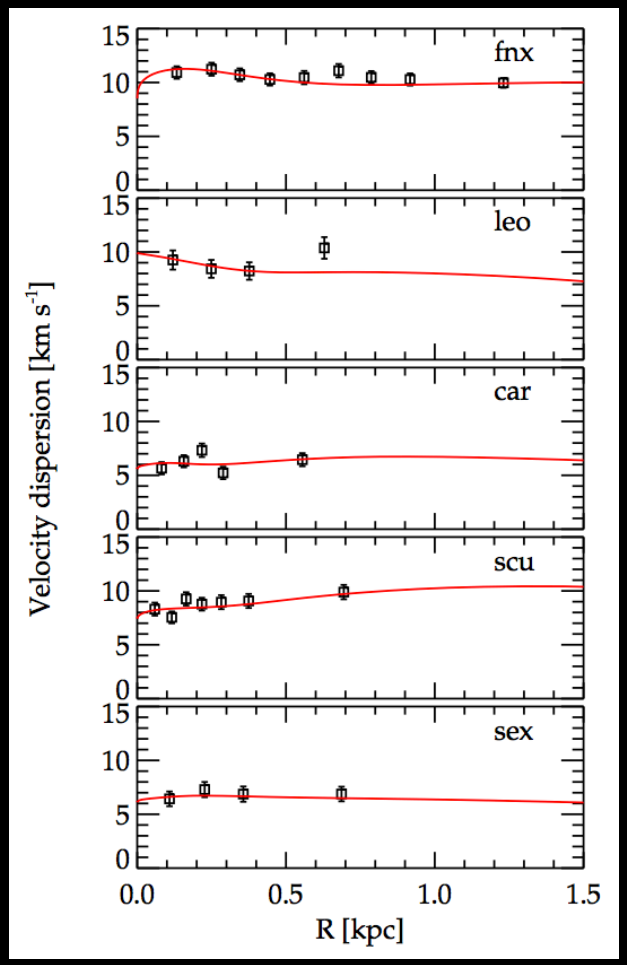
Vera Rubin

Image credit: NOAO

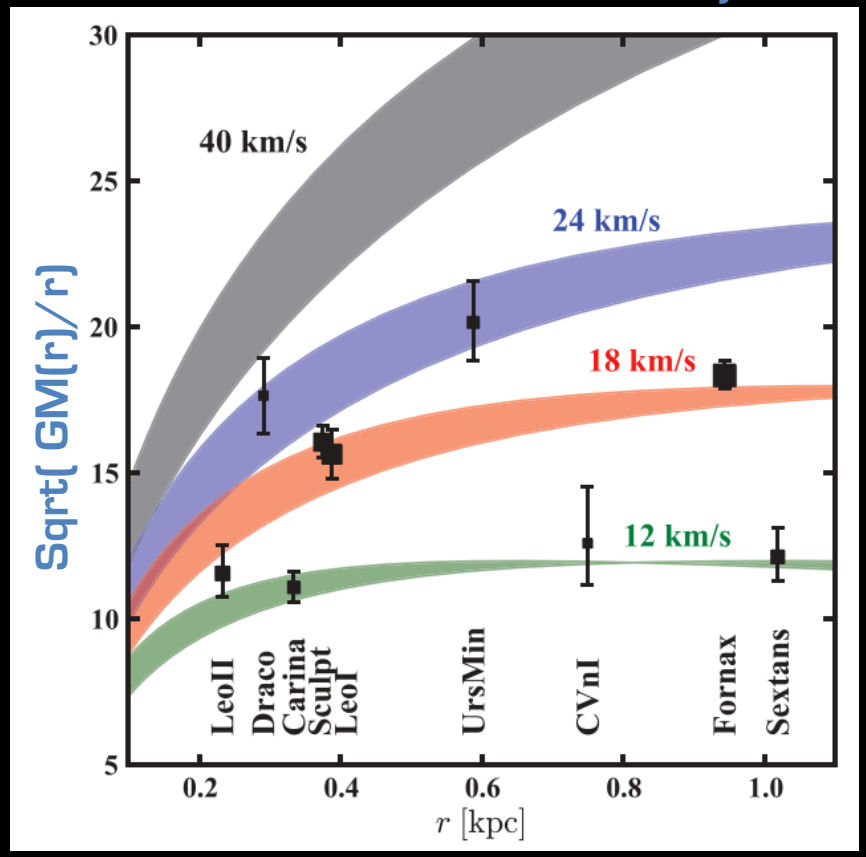
Non-linear: density

Halo density ←→ halo counting

CDM-no baryons



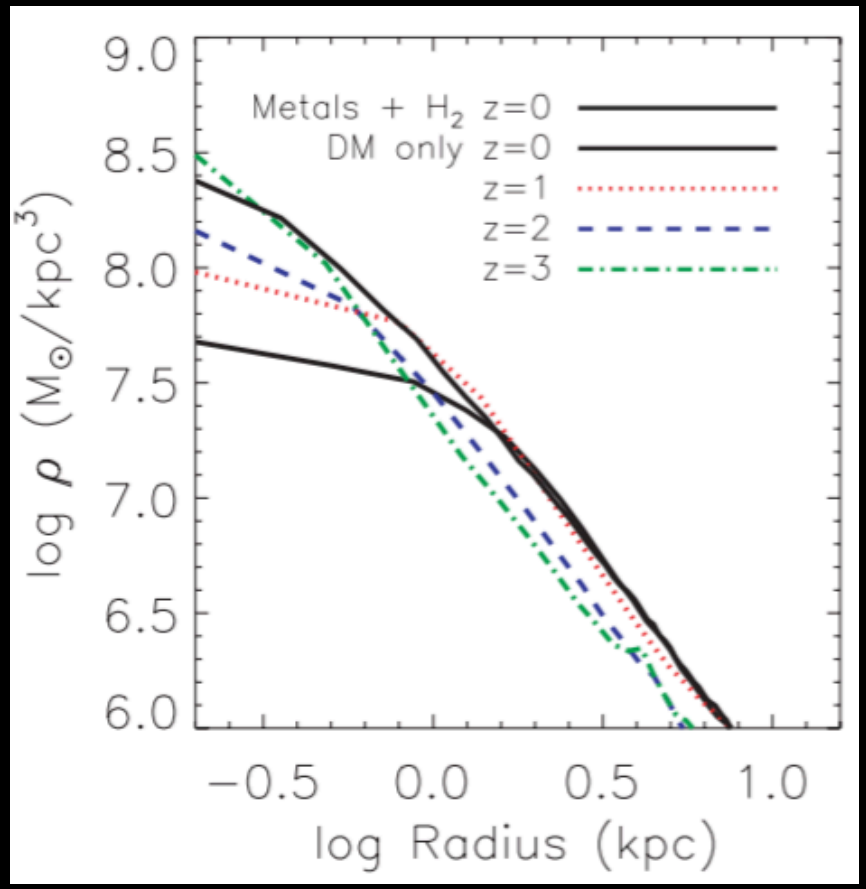
Strigari+2010 from Walker +2009 & Mateo+2008



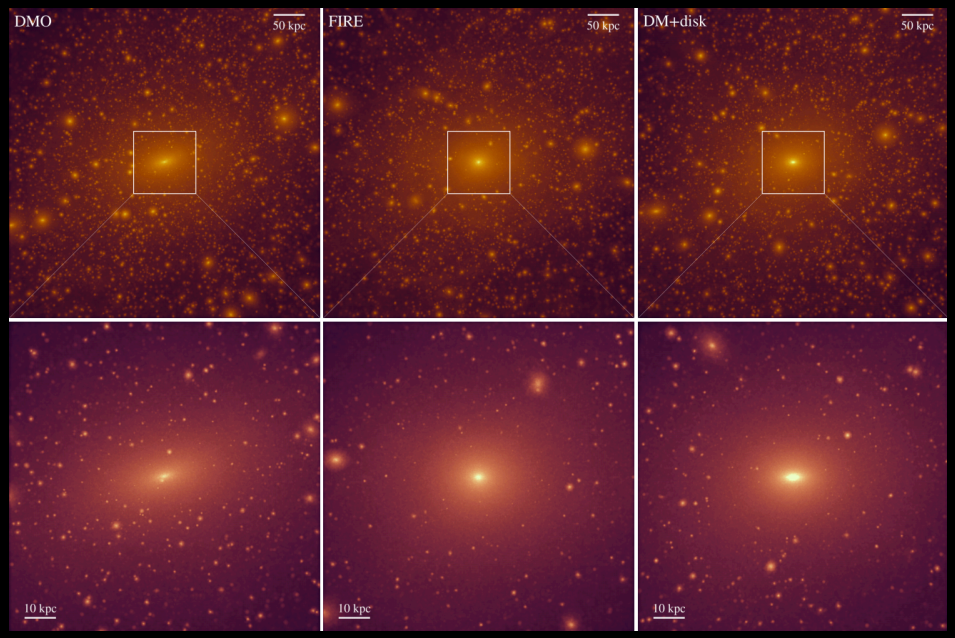
Boylan-Kolchin+ 2012

Challenges and opportunities

Challenges: baryons mess stuff up



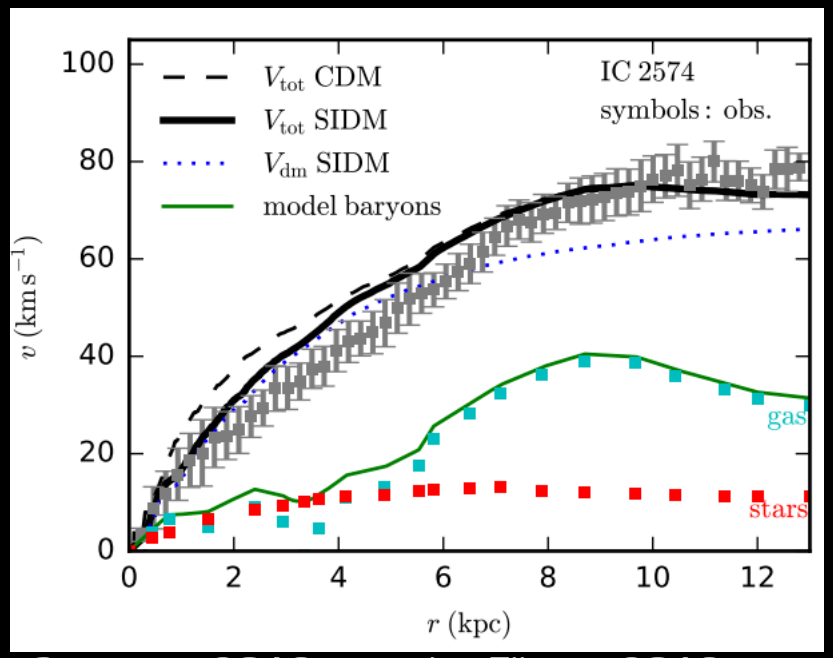
Governato+ 2012



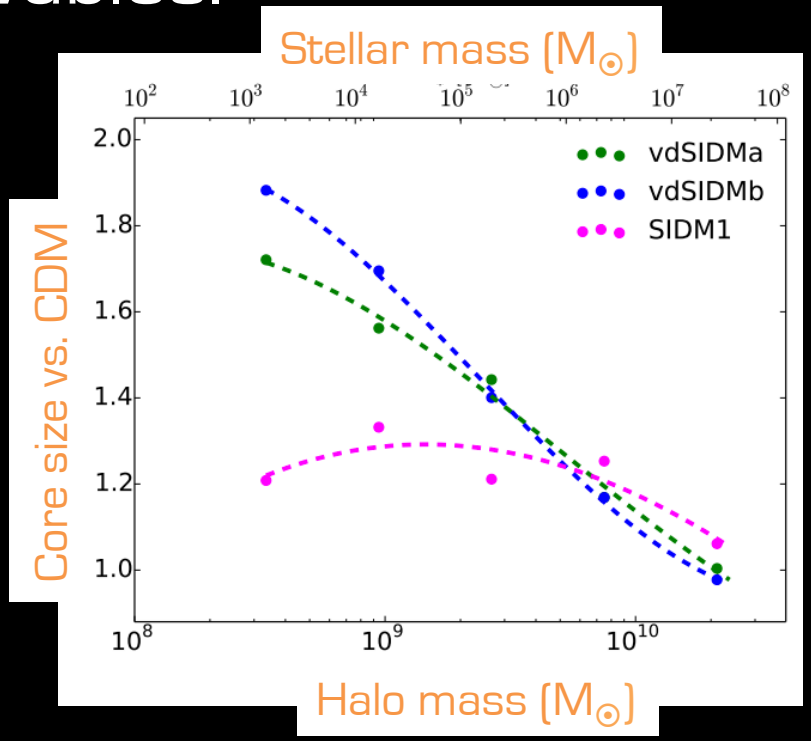
Garrison-Kimmel+ 2017

Opportunities

1. Simulations lead to better mapping among microphysics, phenomenological parameters, and observables.



Creasey+ 2016; see also Elbert+2016, Manoj's talk!



Dooley, AP+ 2016a

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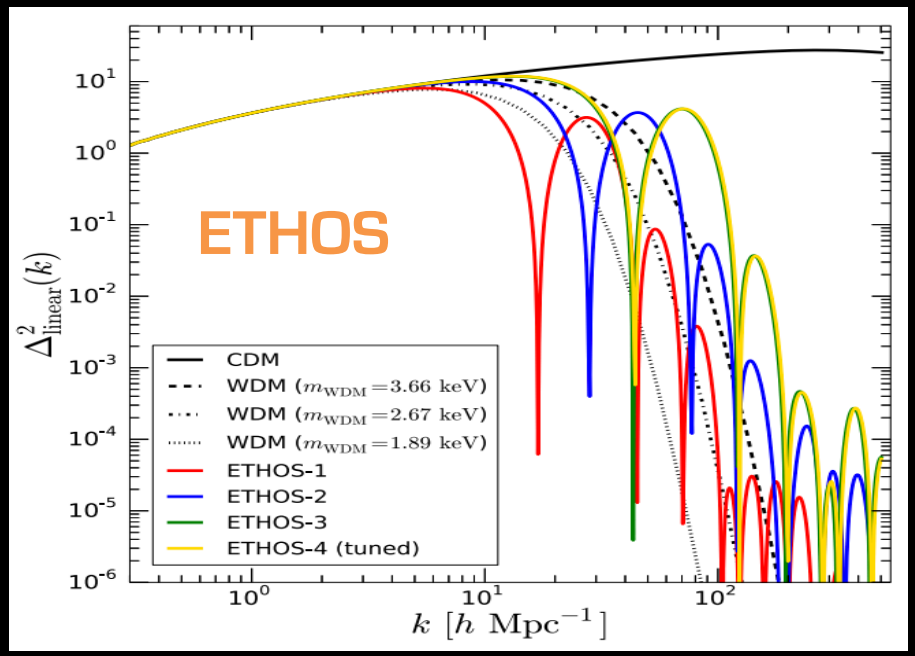
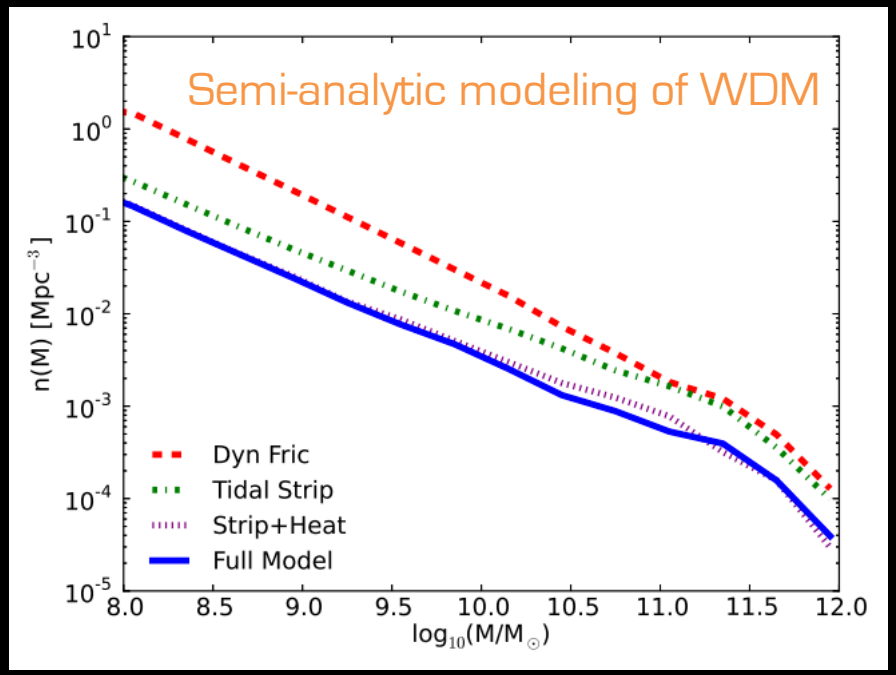


Vogelsberger+ 2016, Cyr-Racine+ 2016

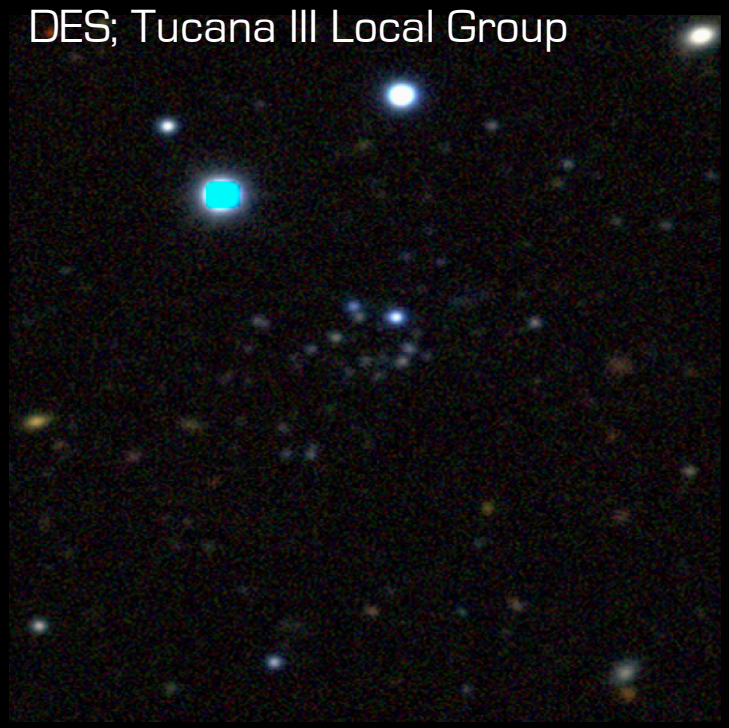


Pullen, Benson & Moustakas 2014

THE DATA ARE THERE--reduce, reuse, recycle

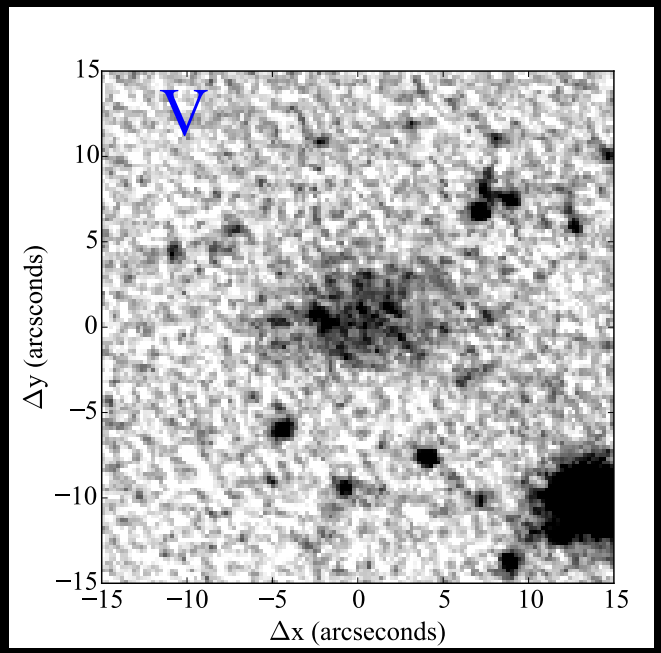
2. Wealth of data for finding faint things in and out of the Local Group.

DES; Tucana III Local Group



Luque+ 2016

Ultrafaint dwarf at 10 Mpc!!!
Peter/Kochanek LBT survey



Davis, Nierenberg, AP+ in prep.

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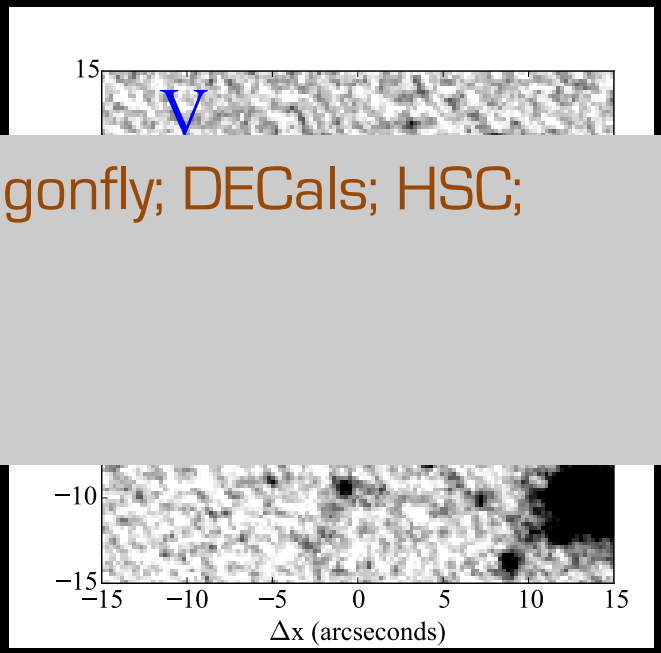


Davis, Nierenberg, AP+ in prep.

MADCASH; Sand+; reanalysis of SDSS; Dragonfly; DECals; HSC; amateur astronomers....

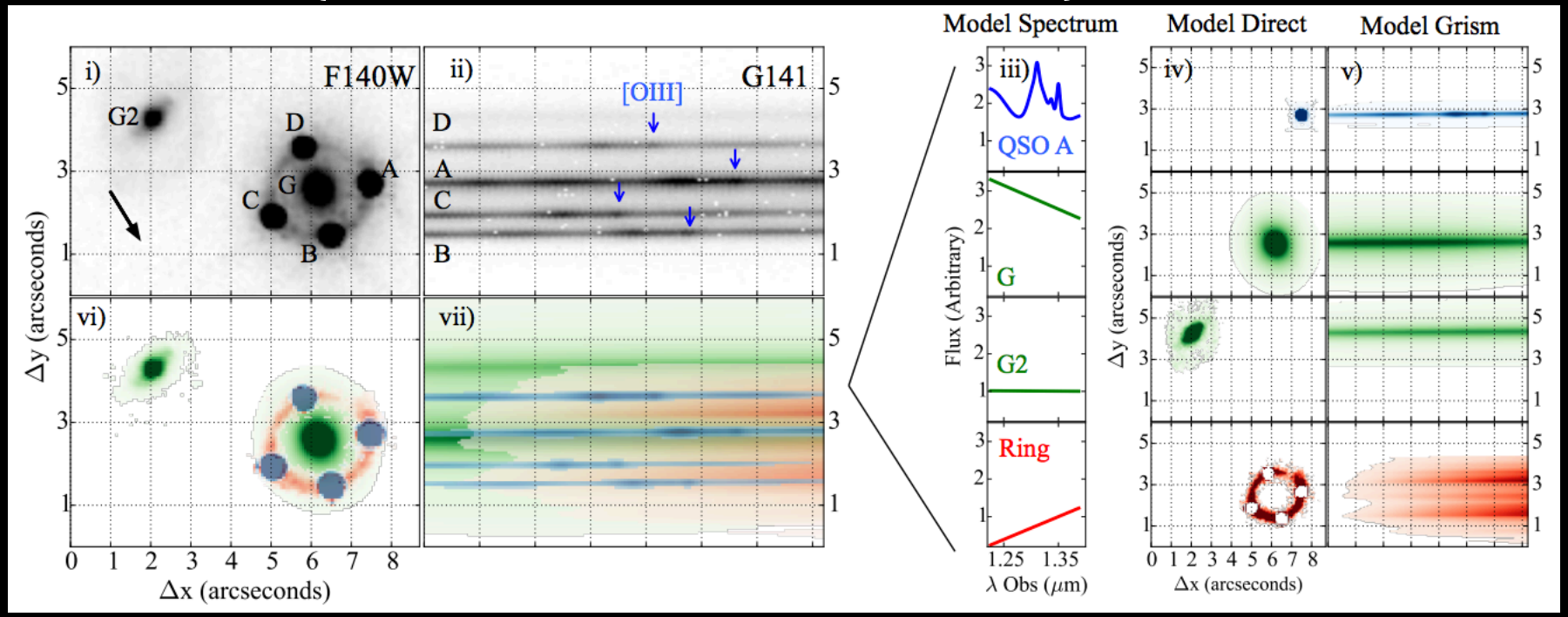
Future: LSST, WFIRST,...

Opportunities

3. Substructure lensing is becoming a real statistical tool.

Pre-2017: 7 suitable systems
2017: dozens (new methods + new DES discoveries)

CCAPP fellow
Anna Nierenberg

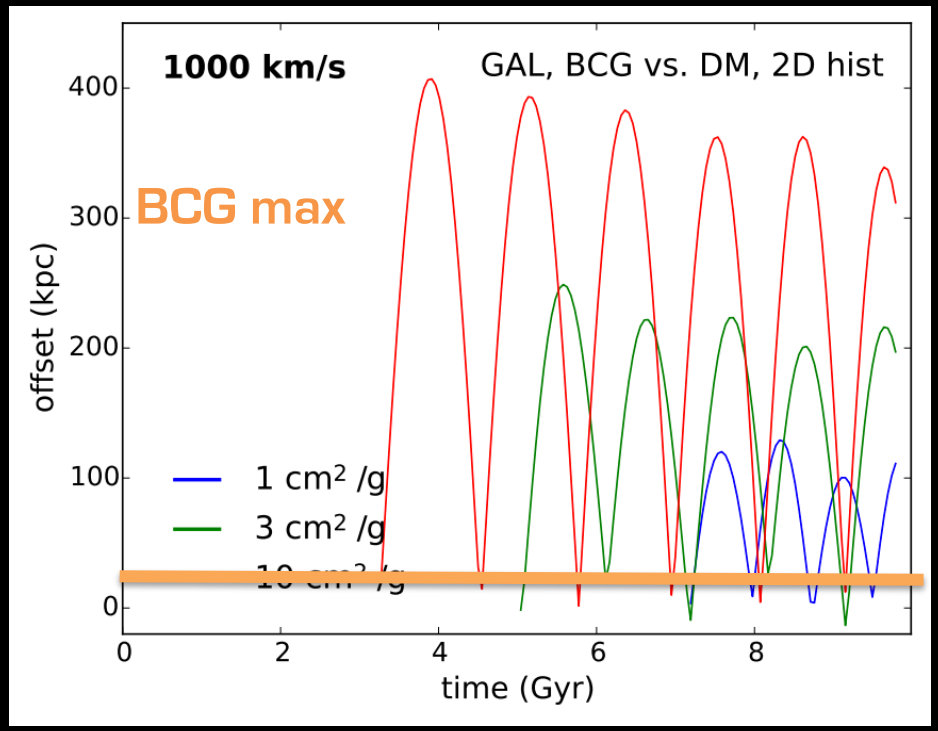


Nierenberg, ...AP+ 2017

Opportunities

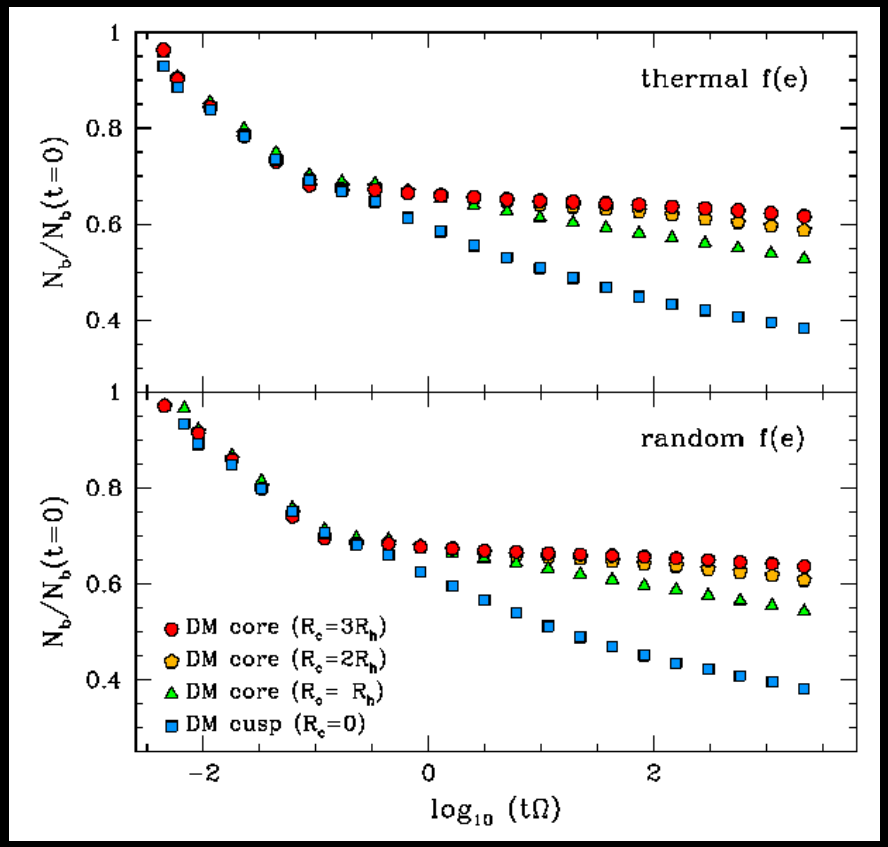
4. Creative new astronomical signatures.

Clusters



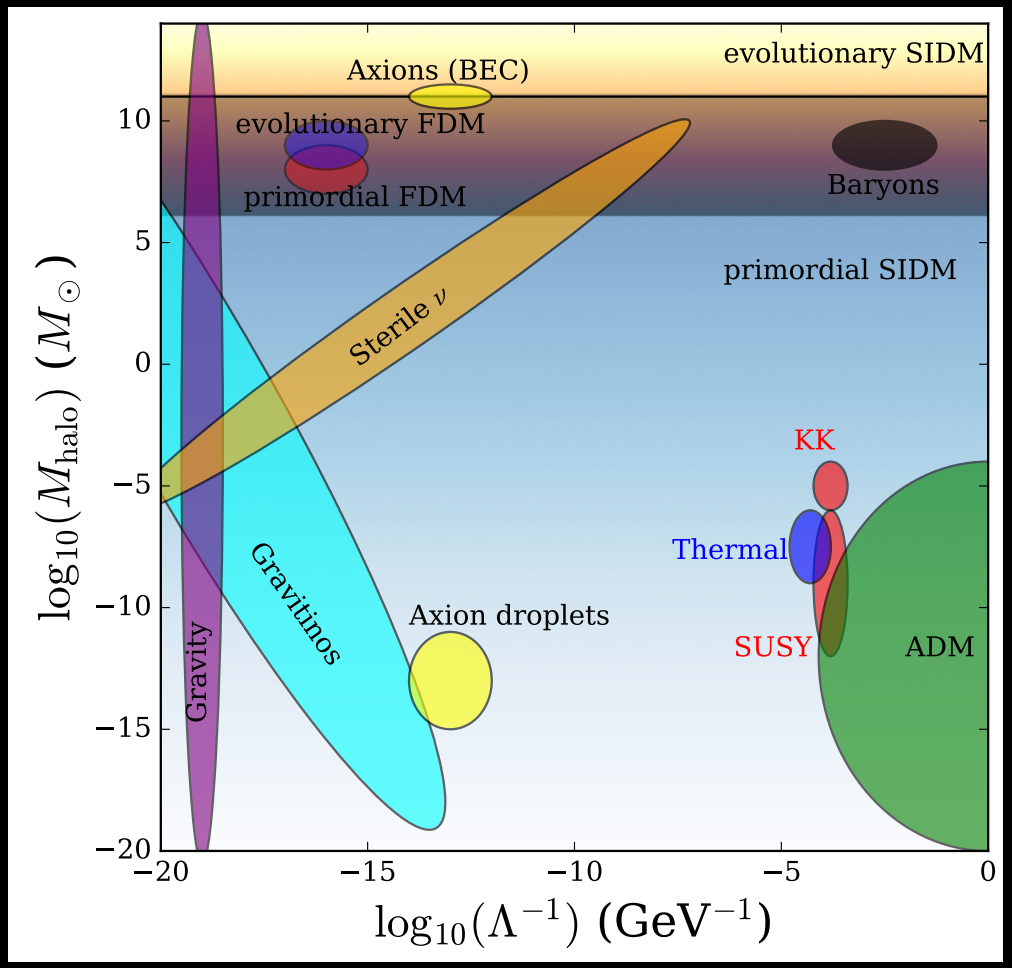
Kim, AP, Wittman 2016

Wide binaries probe subhalos



Penarrubia+ 2016

Map from particle to astro space (and back again)



Halo scale on which weirdness shows up

Coupling w/SM

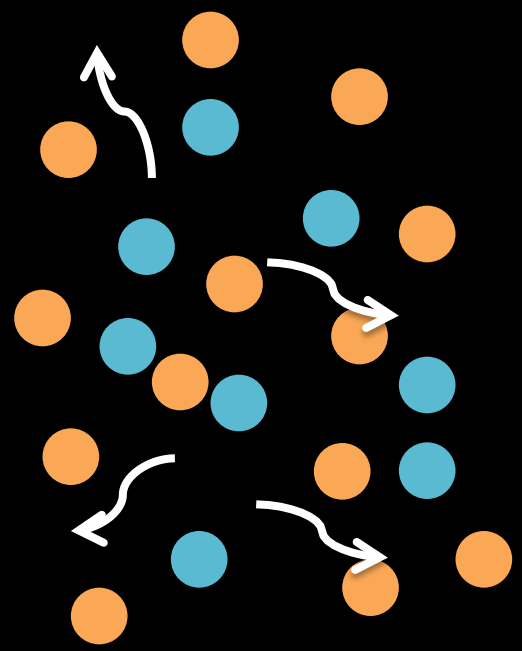
"There's gold in them thar dark matter phase space hills."

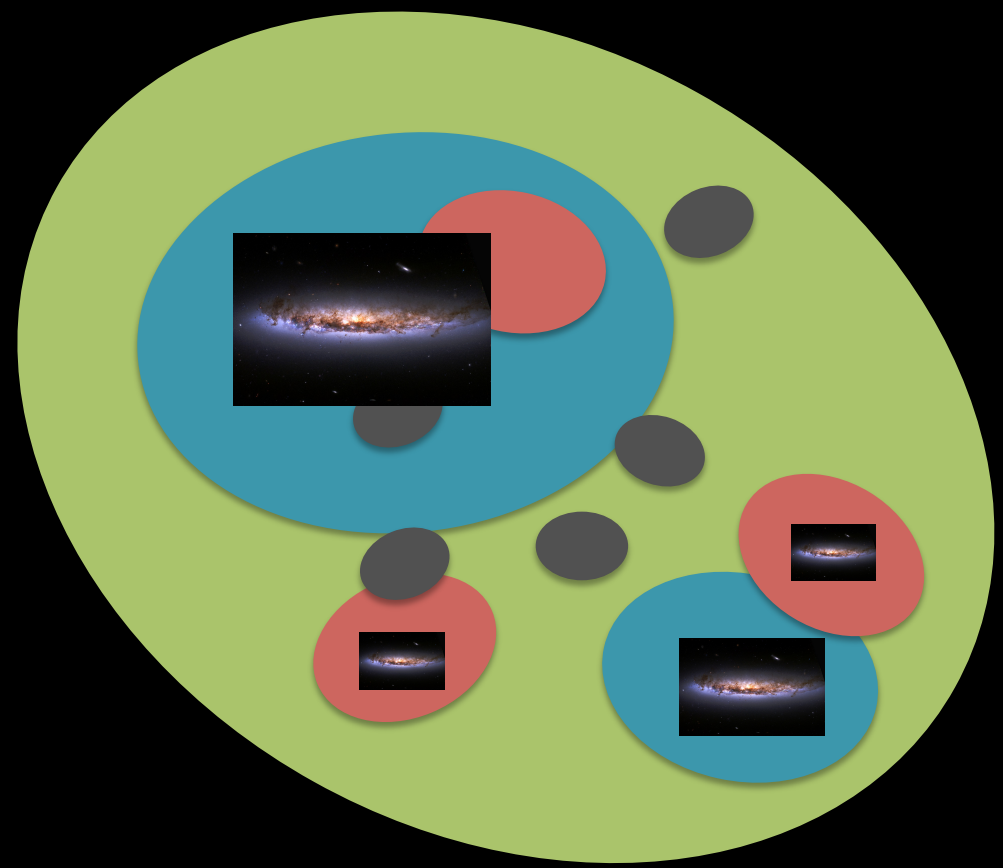
—Matt Buckley

M. Buckley & AP, in prep.

The technology and data are here:

Microphysics $\longleftrightarrow$ Macrophysics





Baryons

Dark matter

Maybe some mediators

Extra slides

Opportunities

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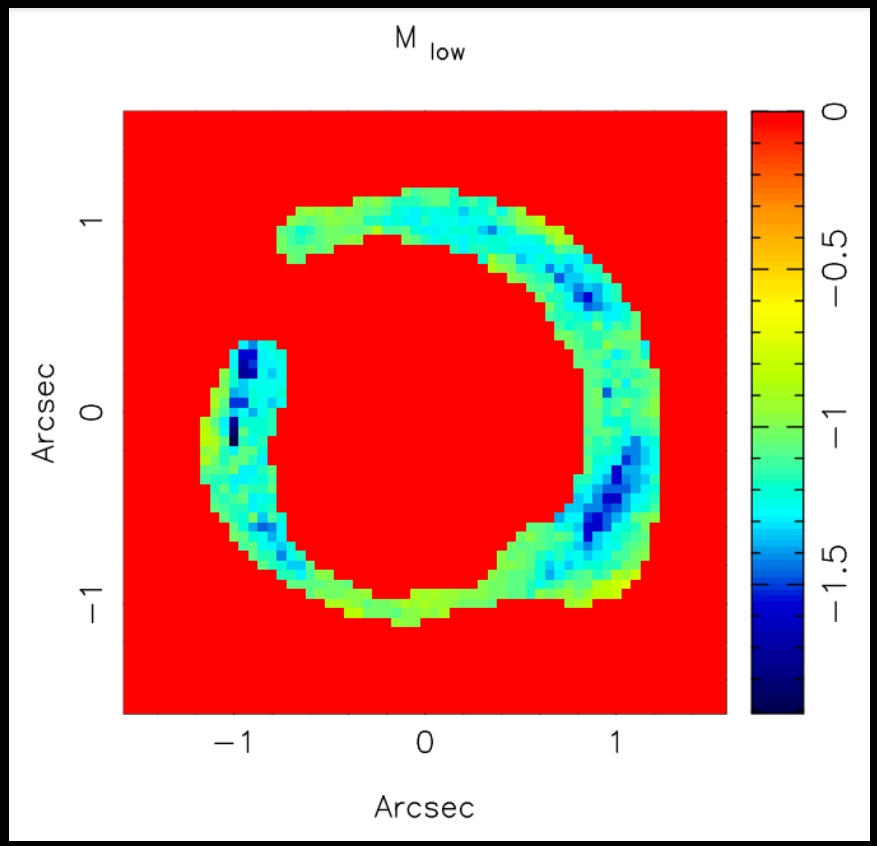
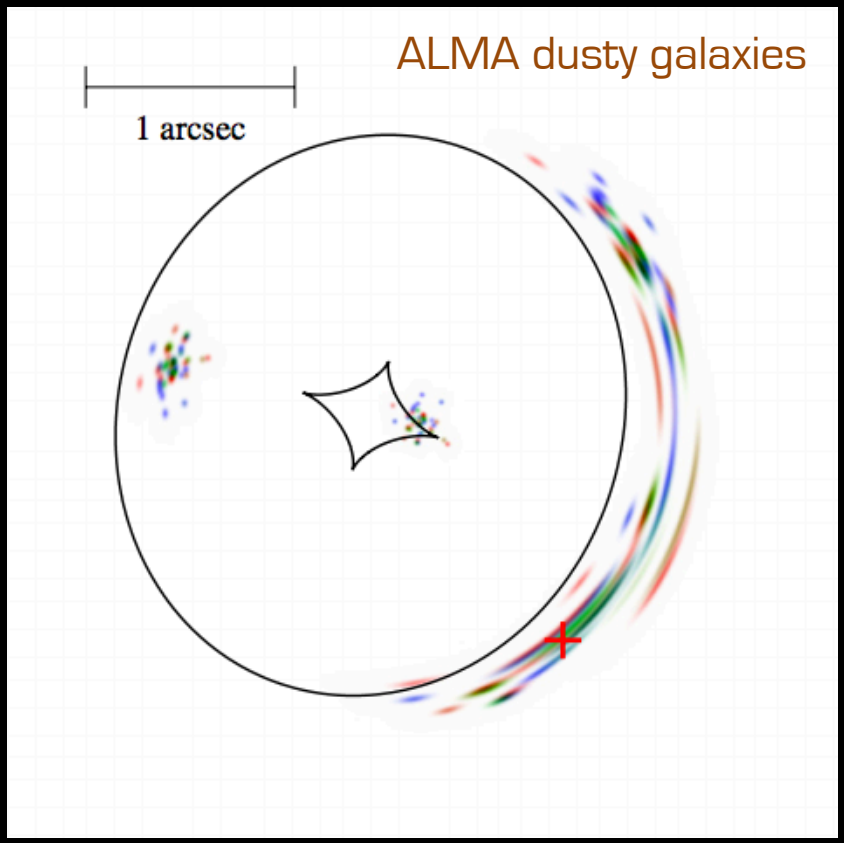


Vegetti+ 2014



Hezaveh+ 2012