Effect of DM substructures on rotation curves

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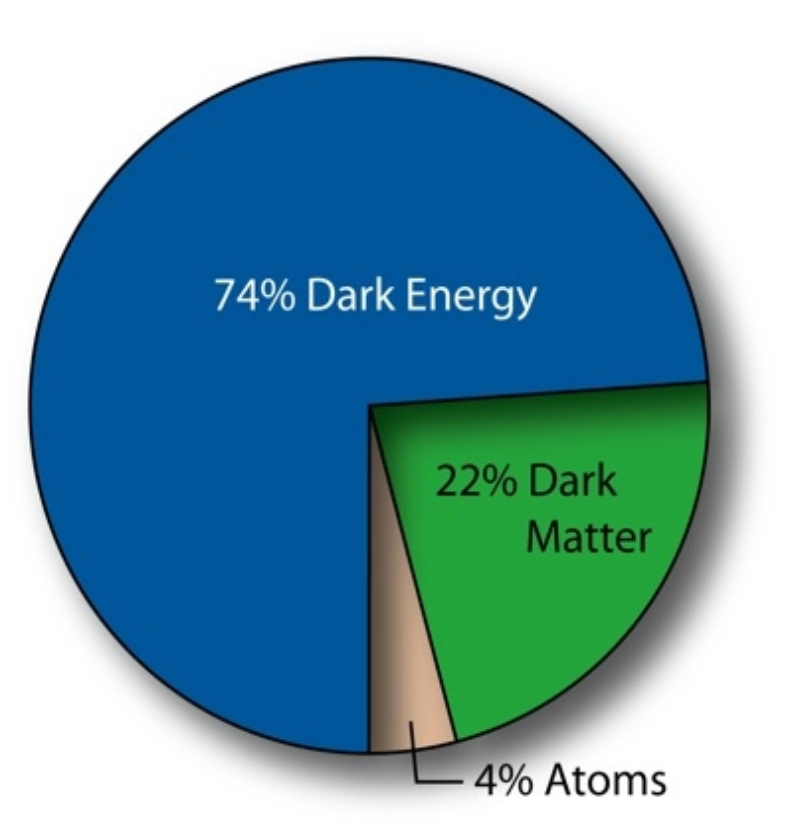
Based on Roy N., 2010, ApJ, 723, 781 and Dutta P. et al., 2010 (in preparation)

Let there be darkness ...

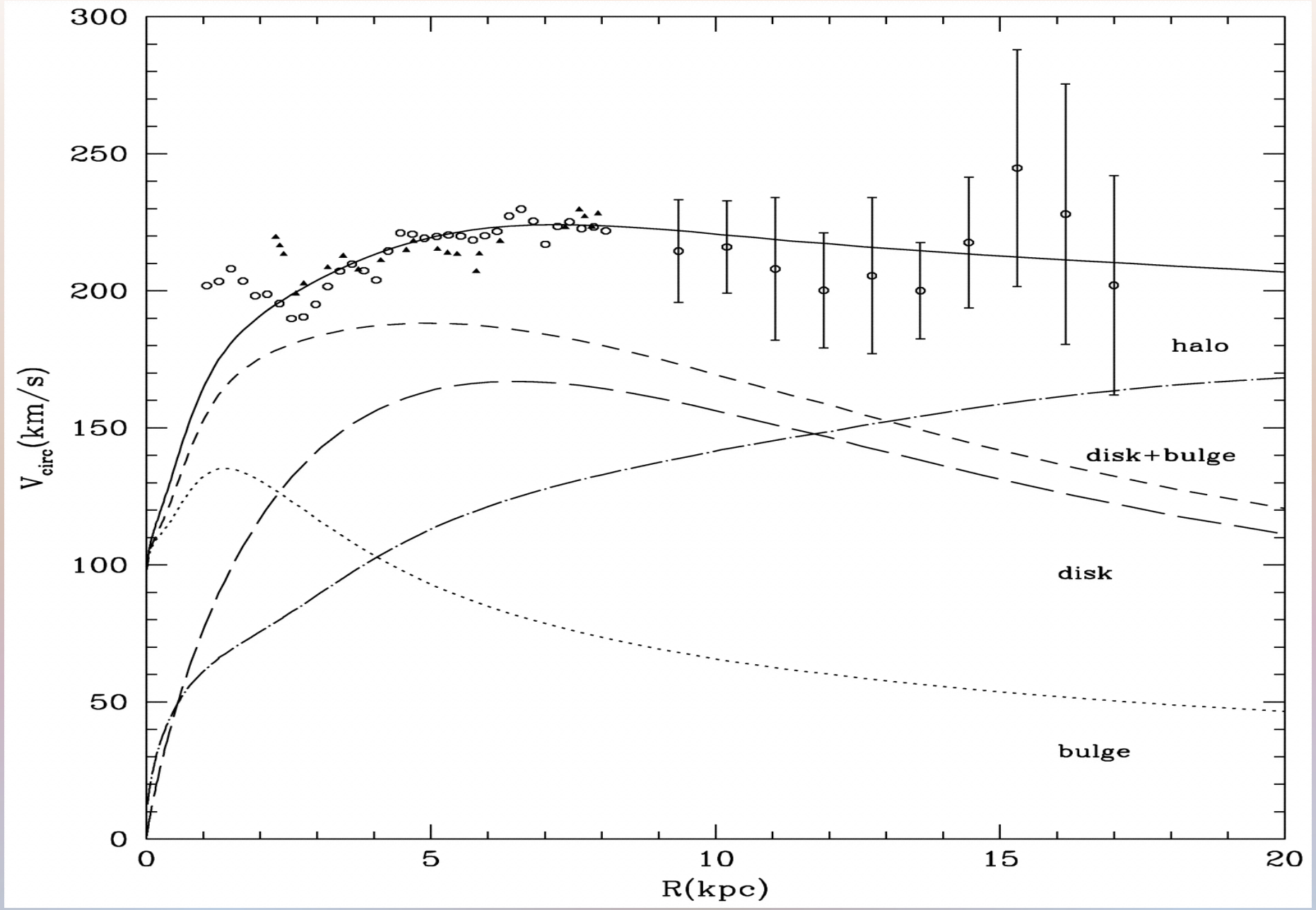


- **Galaxy rotation curves**
- **Velocity dispersion of ellipticals**
- **Gravitational lensing observations**
- **Theory of structure formation**
- **CMB power spectrum**
- **etc ...**

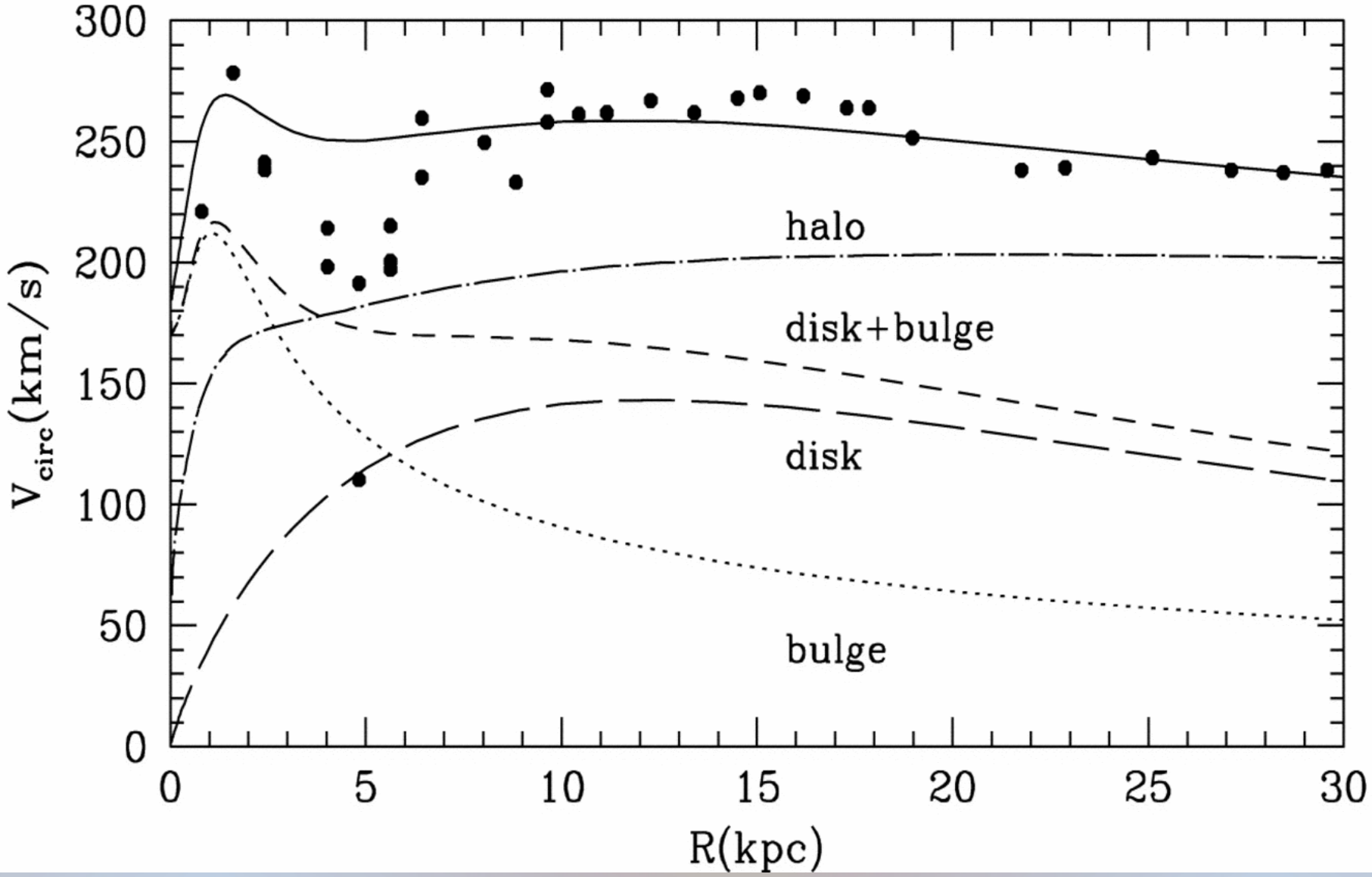
Dark Matter accounts for ~23% of the total mass-energy density of the Universe!

Alternatives: Modified dynamics or modified gravity!

(Milgrom 1983, Sanders 1986, Fahr 1990, Moffat 2006)



Credit: Klypin et al, 2002, ApJ, 573, 597



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Radial density profile ...

- **Isothermal:** $\rho(r) \sim 1/r^2$
- **Non-singular Isothermal:** $\rho(r) \sim 1/(r_c^2+r^2)$
- **NFW:** $\rho(r) \sim 1/[r(r_c+r)^2]$
- **Burkert:** $\rho(r) \sim 1/[(r_c+r)(r_c^2+r^2)]$
- **Different modifications of Isothermal and NFW profile ...**

NFW density profile

Navarro-Frenk-White 1996, 1997, …

Derived from numerical simulation by fitting analytical function to the density distribution.

Issues:

(1) Physical understanding (hierarchical assembly? Taylor & Navarro, 2001)

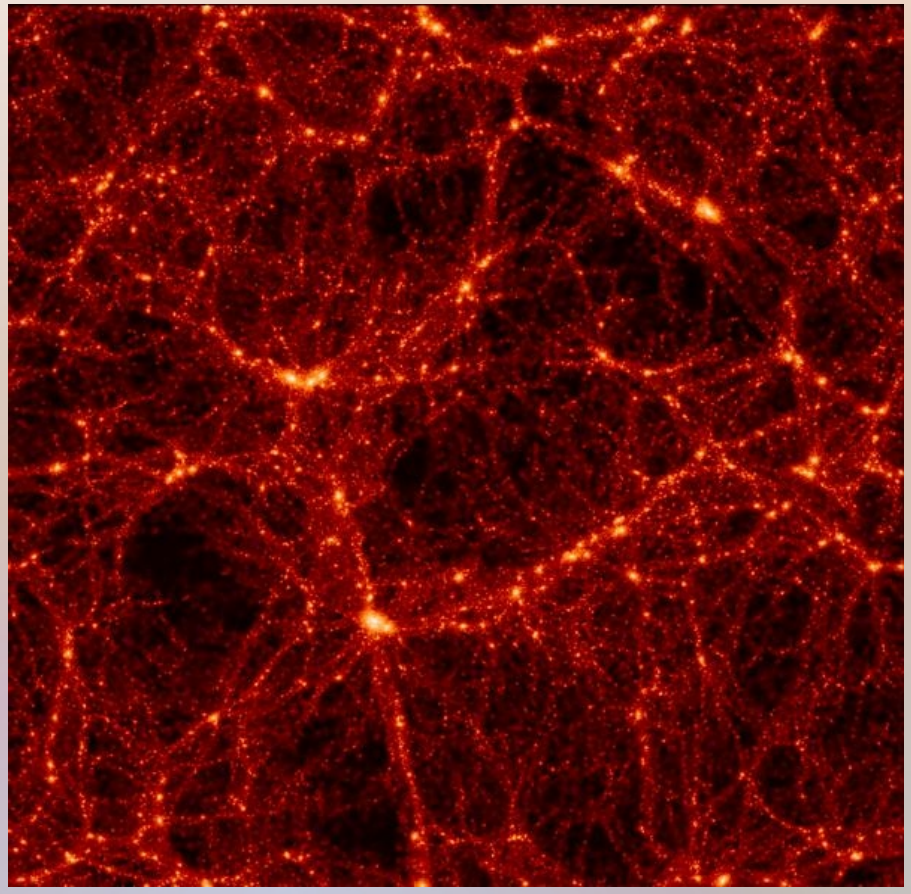
(2) Central cusp of NFW lacks observational support (e.g., de Blok 2007)

(3) Does not fit for LSBs and low mass dwarfs (e.g. Bosma & de Blok 2002)

(4) Issues of simulations at galactic scale (angular momentum, missing satellite)

The issue of DM density profile or mass distribution at galactic scale is far from being settled.

Dark matter substructures



Evidences from numerical simulations

Giocoli 2008, Madau 2008, Springel 2008, Elahi 2009, Ludlow et al. 2009

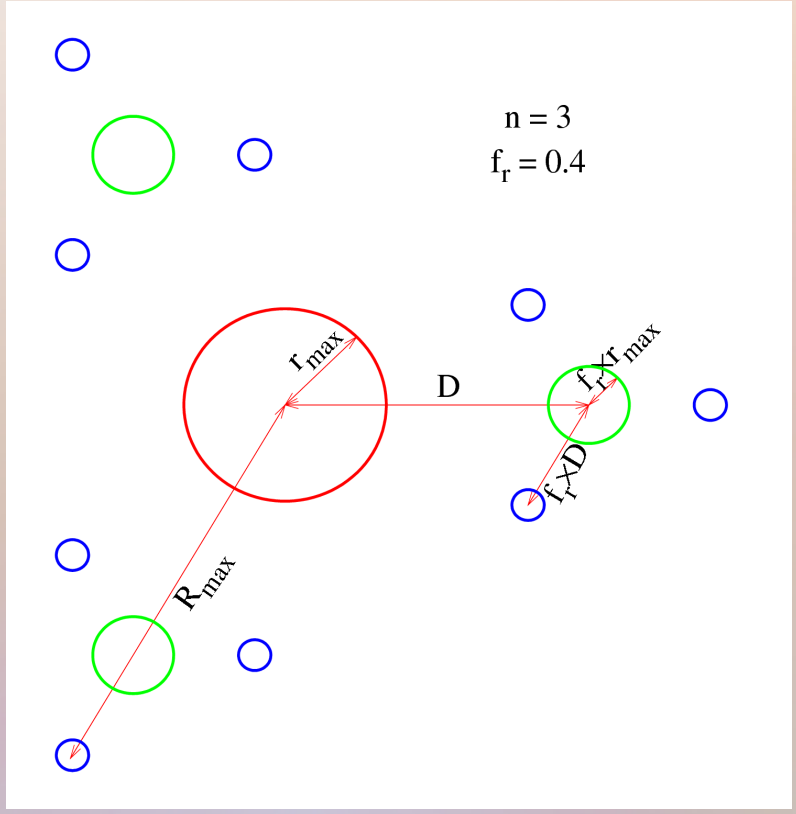
Observational hints:

Flux anomalies/Time delays in gravitational lensing (e.g. Chen 2009)

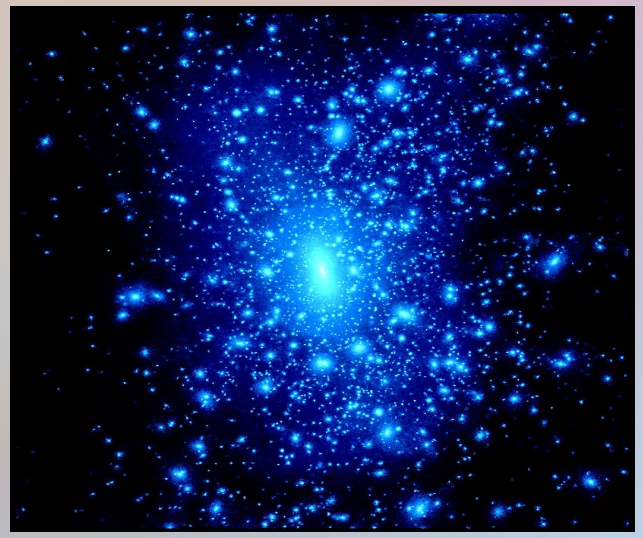
Enhanced gamma rays and leptonic cosmic rays (Elahi 2009, Pinzke 2009)

What may be the effect of substructures at galactic scale?

Effect of substructures on rotation curves



- A simple self-similar model
- A number of smaller clumps n
- Scaled core/cutoff radius f_r
- Scaled central density f_ρ
- A background density threshold ρ_{bg}



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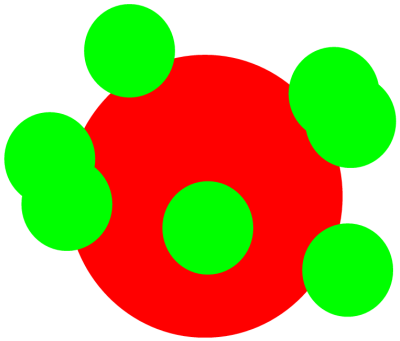

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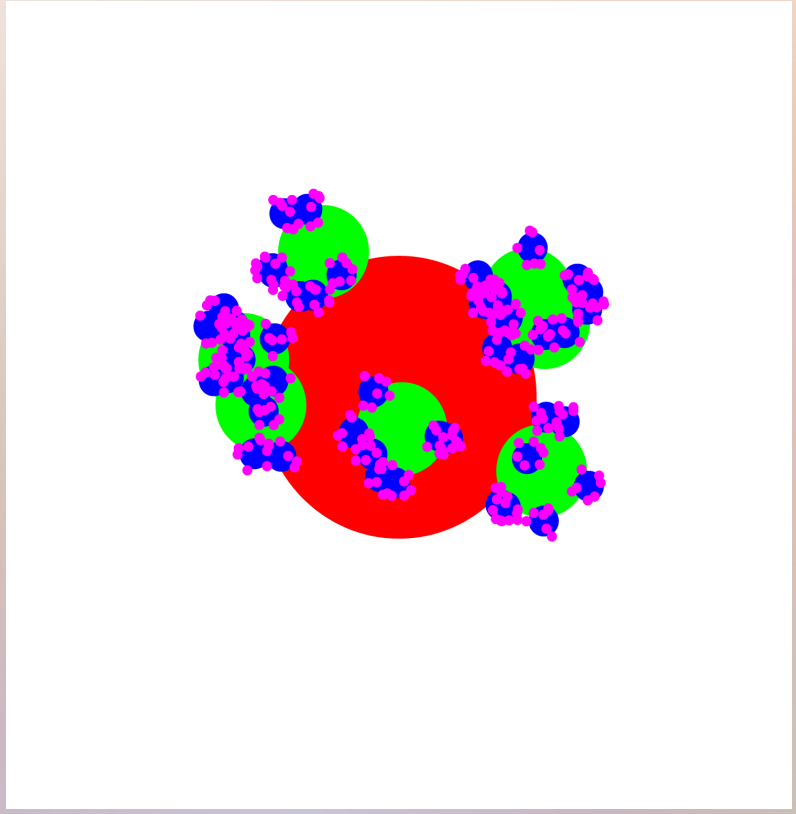

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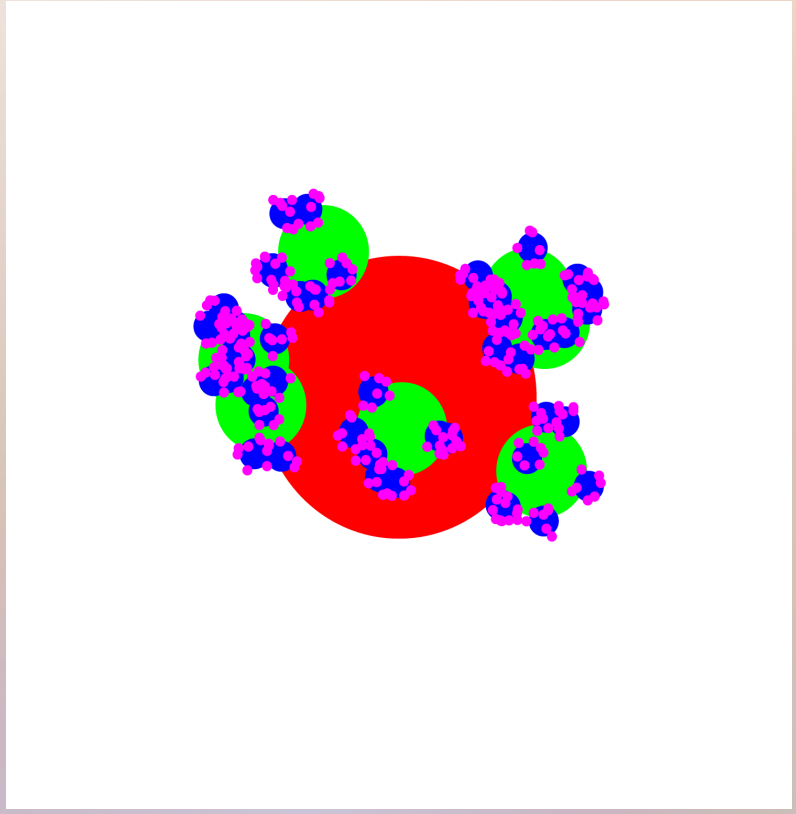

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This is a simplified model of a scale-free density distribution and a mass function

$N(m) \sim m^{-\alpha}$, $\alpha = -\log(n)/\log(f_r^3 f_\rho)$

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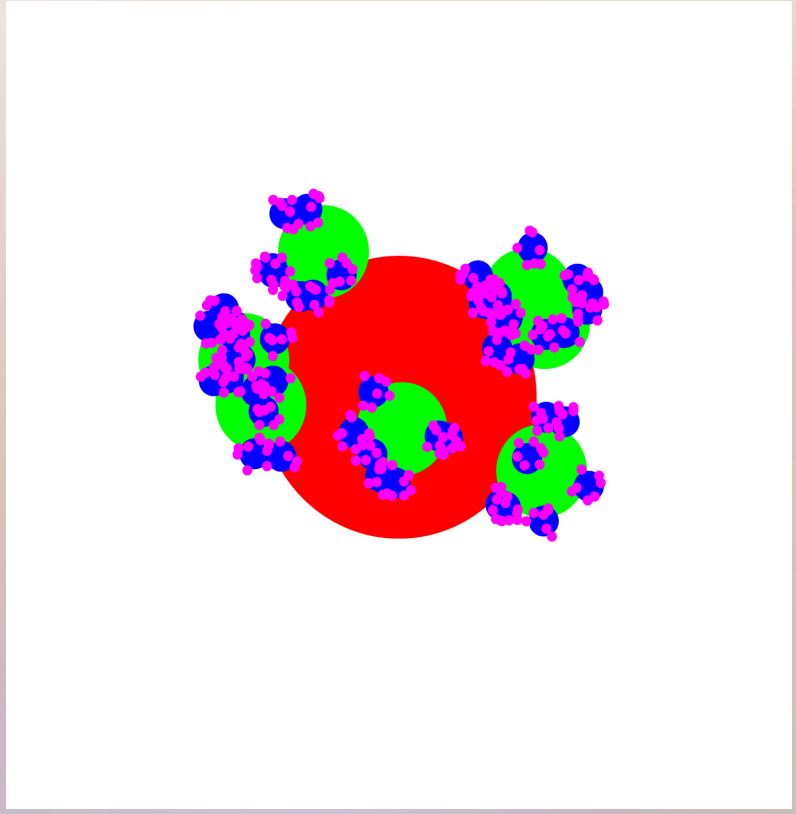

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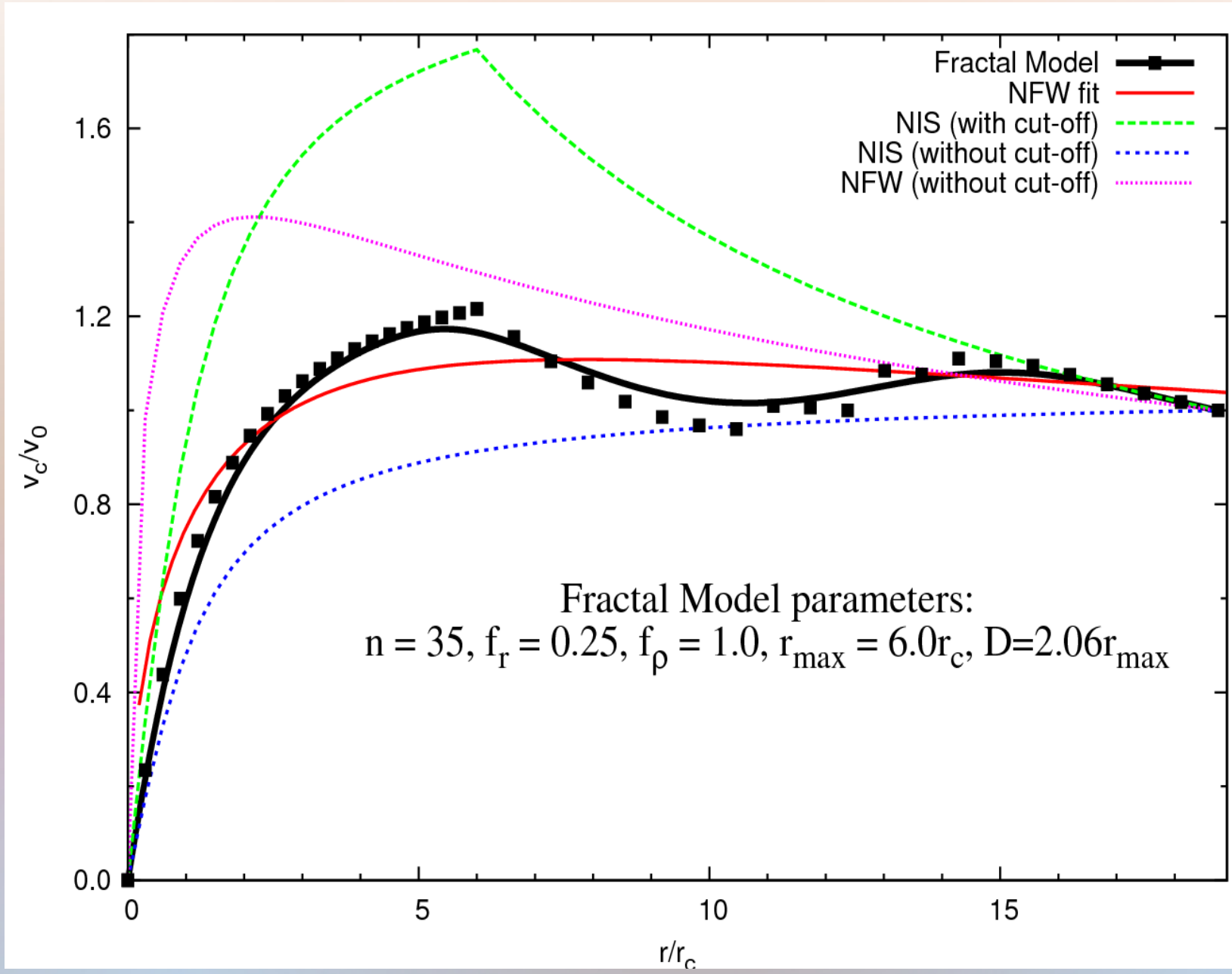
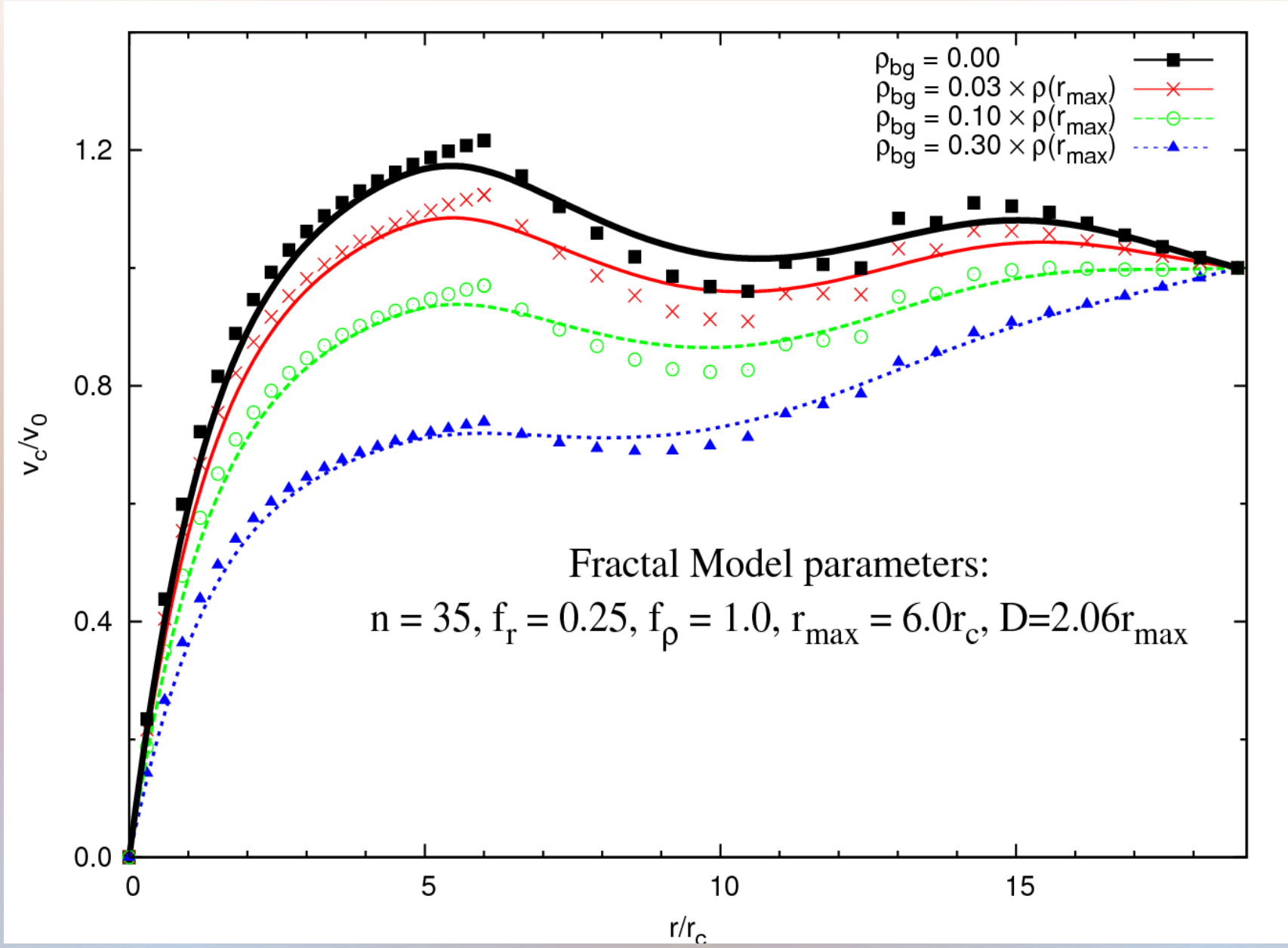
Some of the parameters can be constrained by considering virial & tidal stability.


Fractal Model
NFW fit
NIS (with cut-off)
NIS (without cut-off)
NFW (without cut-off)
1.6
1.2
0.8
0.4
0.0
v_c/v_0
0
5
10
15
r/r_c
Fractal Model parameters:
$n = 35, f_r = 0.25, f_\rho = 1.0, r_{max} = 6.0r_c, D=2.06r_{max}$


ρ_{bg} = 0.00
ρ_{bg} = 0.03 × $\rho(r_{max})$
ρ_{bg} = 0.10 × $\rho(r_{max})$
ρ_{bg} = 0.30 × $\rho(r_{max})$
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v_c/v_0
r/r_c
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0.8
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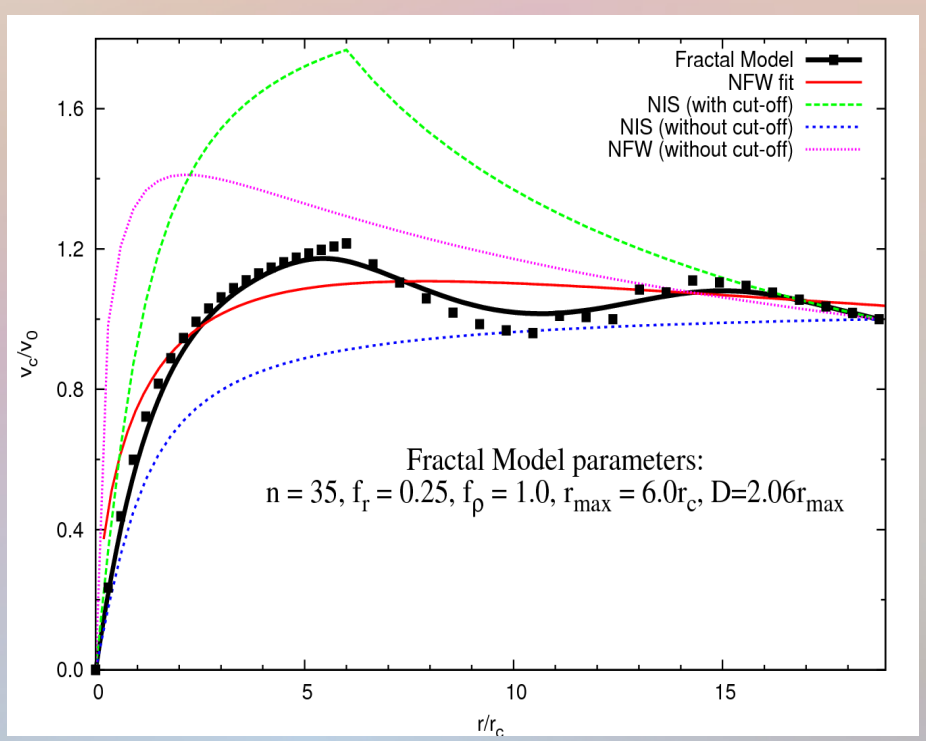
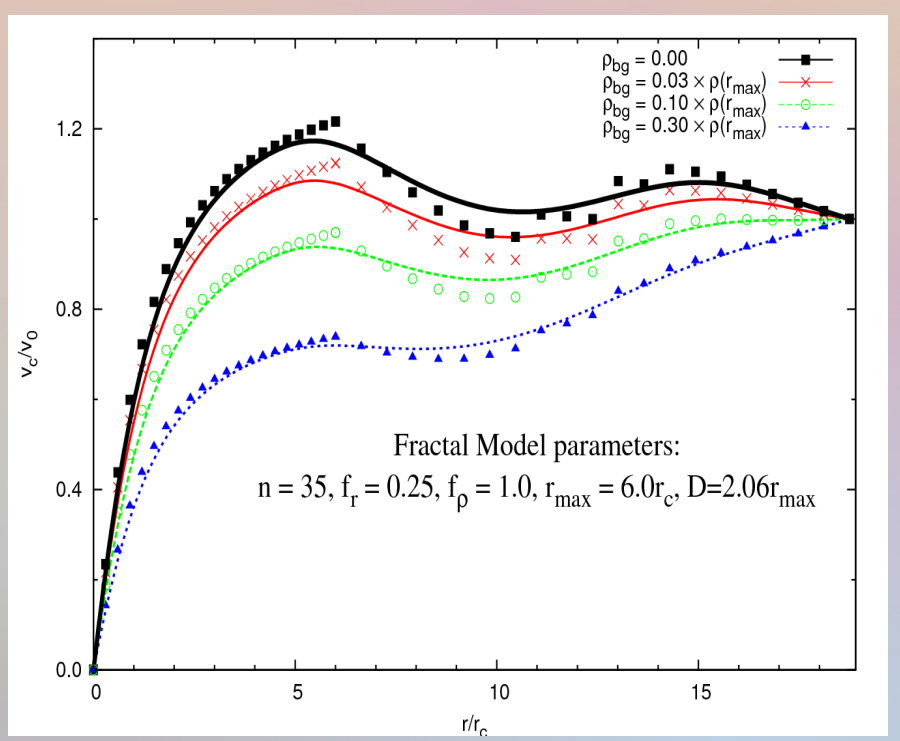
10
15

Effect on velocity fluctuations

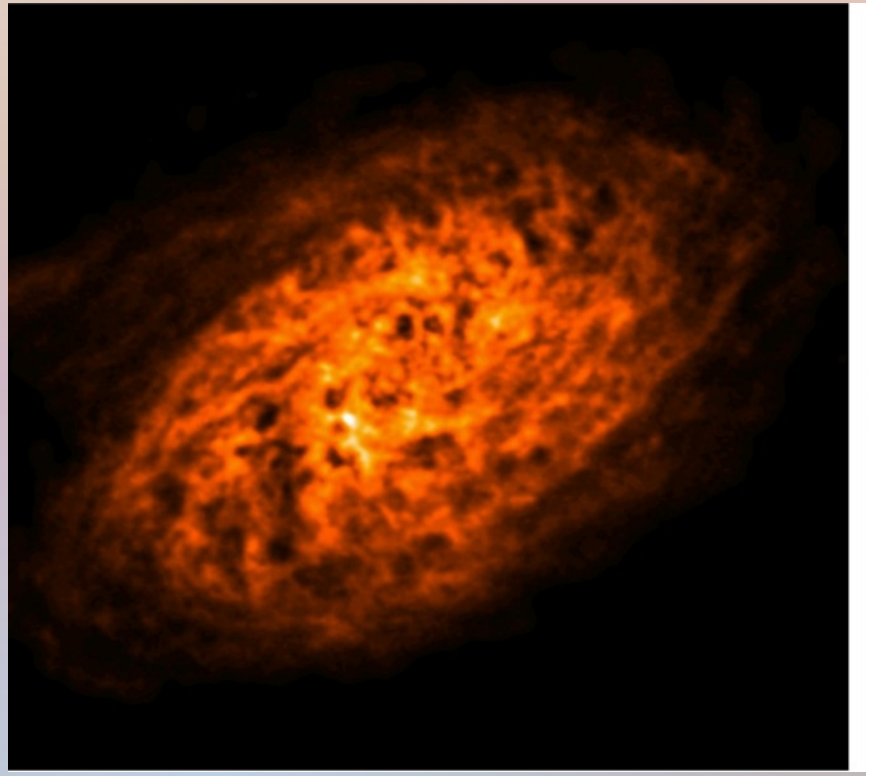
- **Predicts significant fluctuations of rotation velocity in both angular and radial directions.**
- **Since the density field is scale-free, velocity fluctuation power spectra is expected to be a power law.**

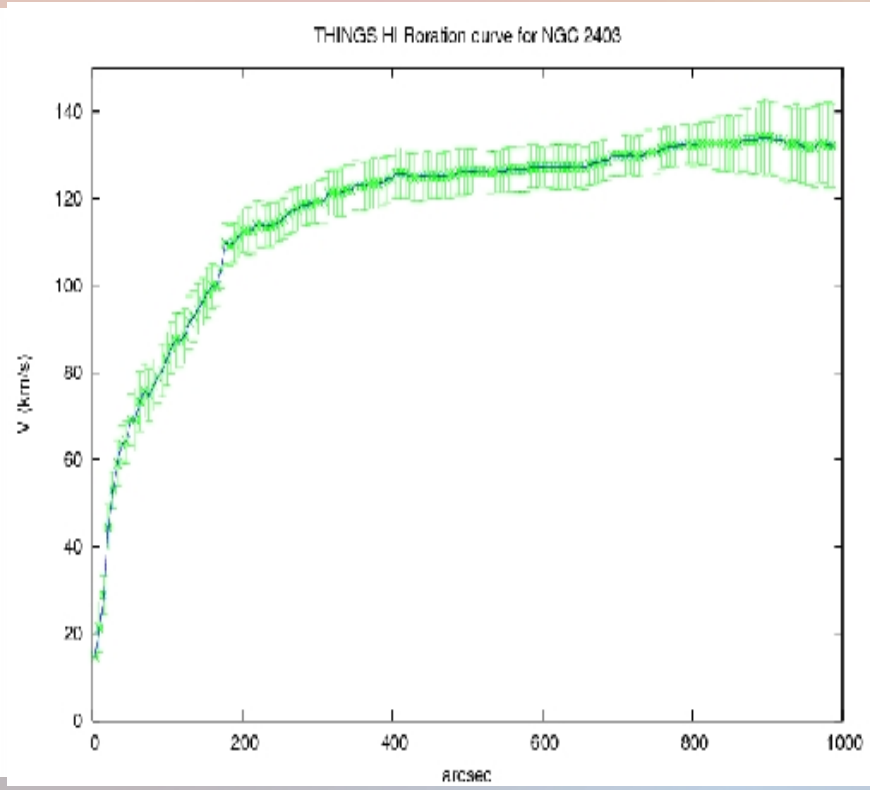




Velocity fluctuations power spectrum

- **Residual velocity power spectrum will have signature of substructures.**
- **We are using HI observations to model and subtract smooth large scale rotation, and to derive structure function and power spectrum.**
- **Work in progress – some hint of a power law scaling!**





NGC 2403 Credit: NRAO/AUI/NSF and Tom Oosterloo (ASTRON)

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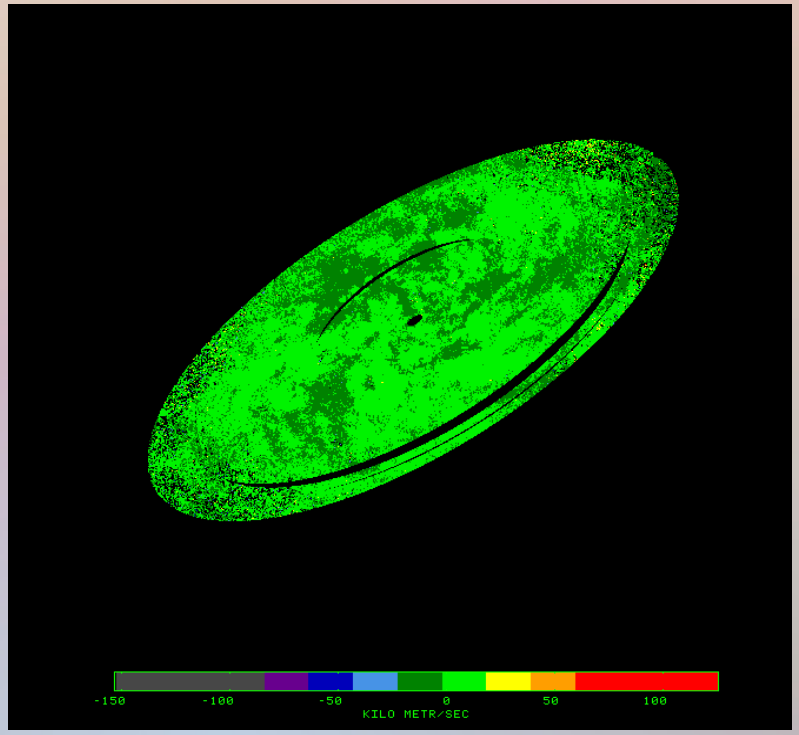

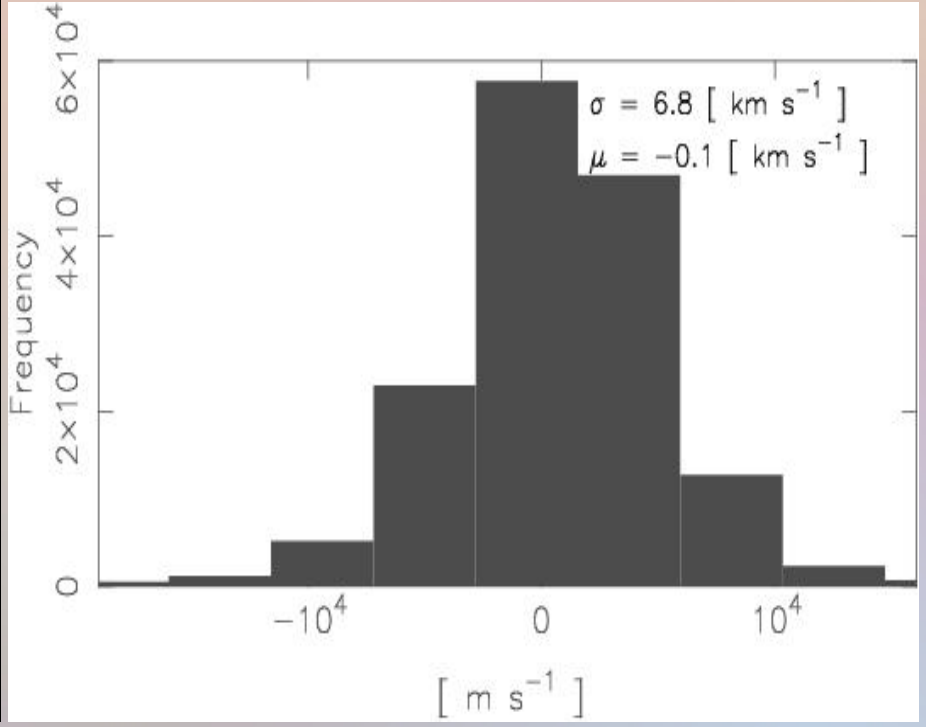

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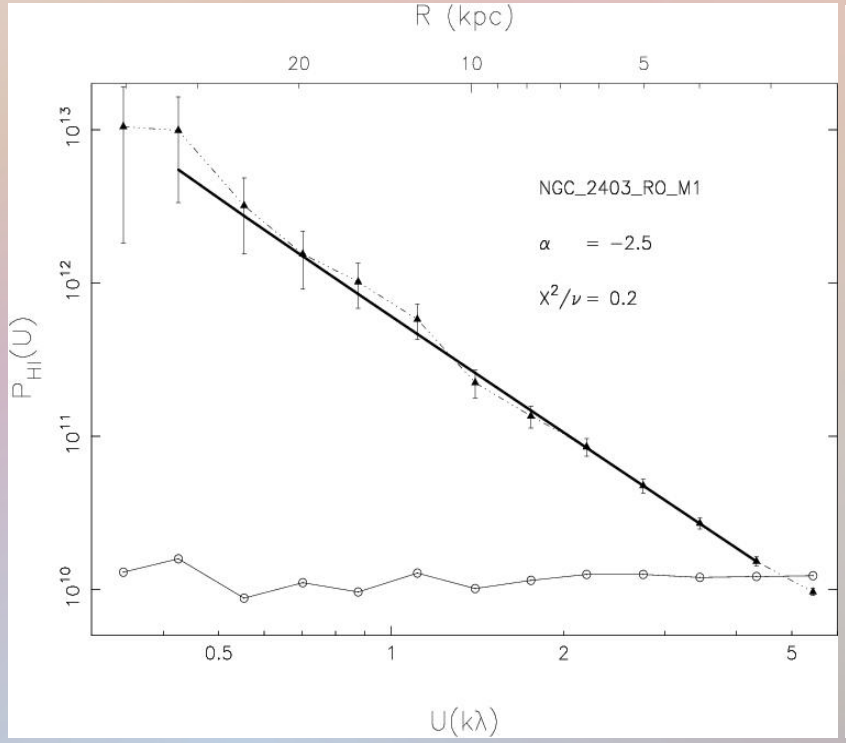

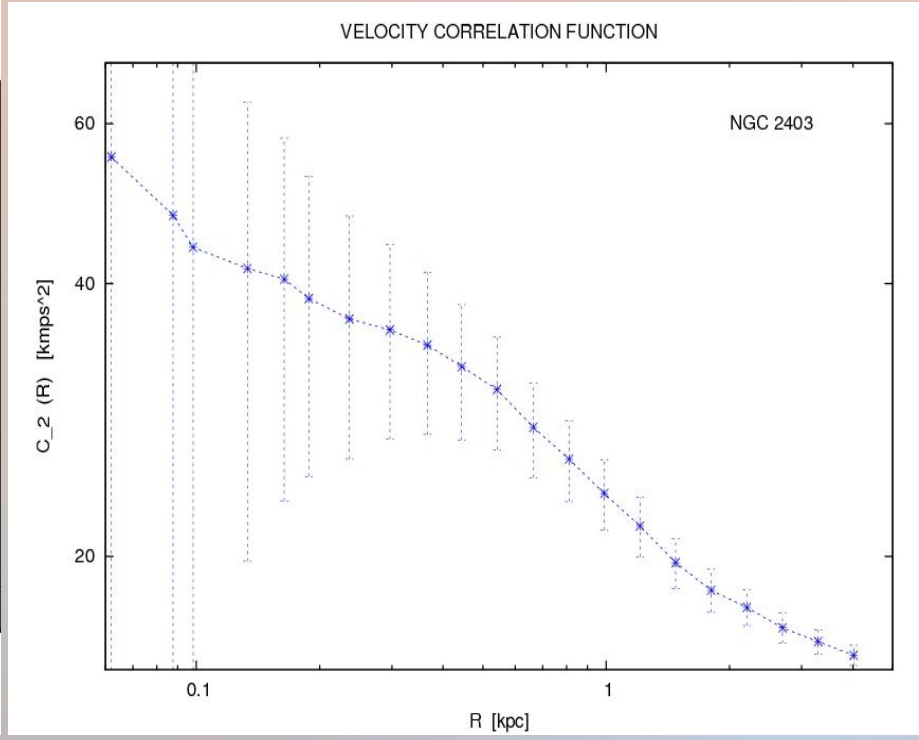

Conclusions:

- **DM halo substructure at galactic scale may significantly affect the rotation curve.**

- **A simple, self-similar substructure model predicts an NFW-like rotation curve. The NFW-like profile emerges out of the fractal geometry, independent of the density profile of individual clumps.**

- **The model predicts a scale-free power spectrum of the rotation velocity fluctuations. On the observational font, there is some hint of a power law scaling of the rotation velocity fluctuations power spectrum.**

Thank You !