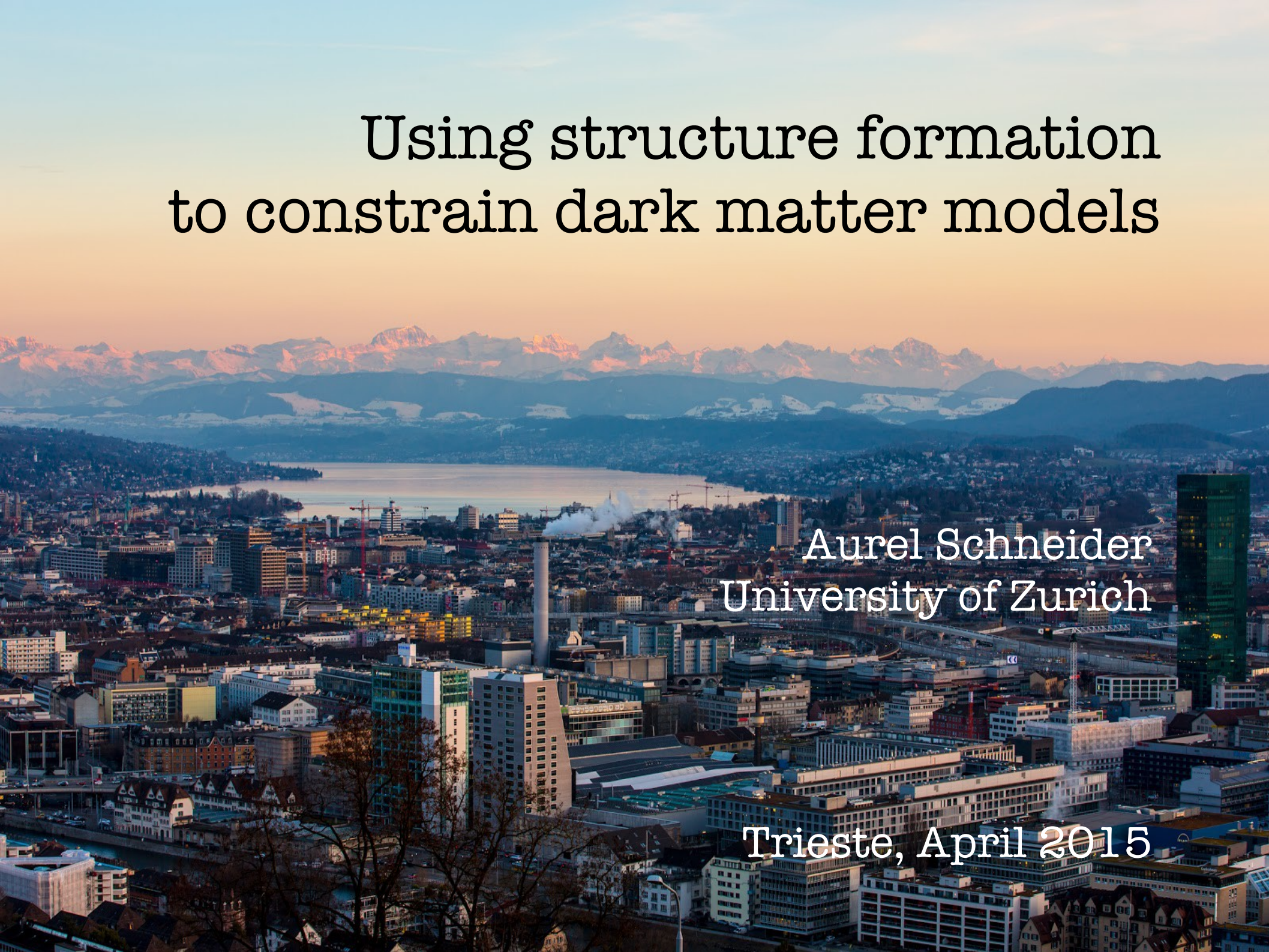
Using structure formation to constrain dark matter models



Aurel Schneider
University of Zurich

Trieste, April 2015

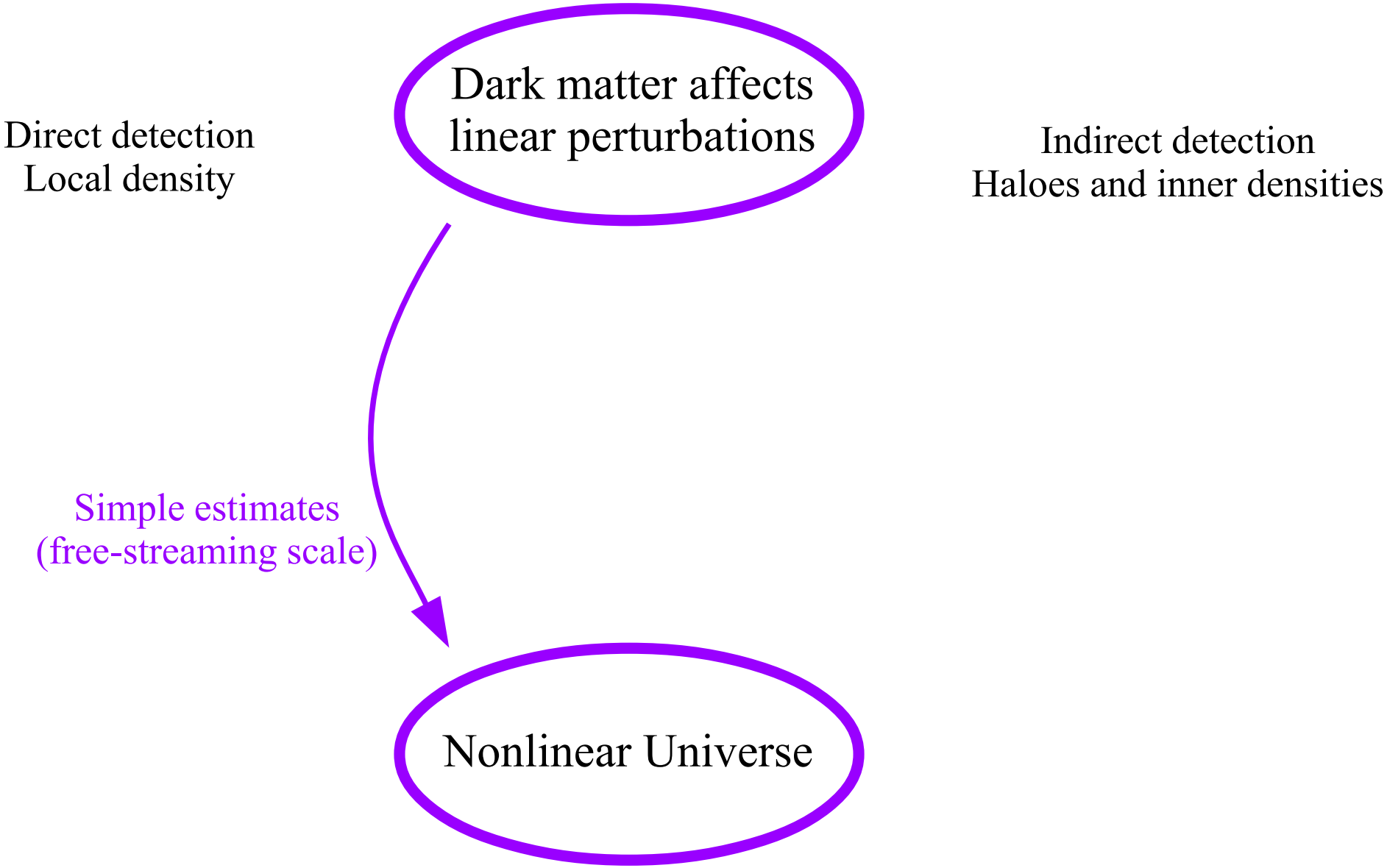
Probing DM scenarios with Astrophysics

Dark matter affects linear perturbations

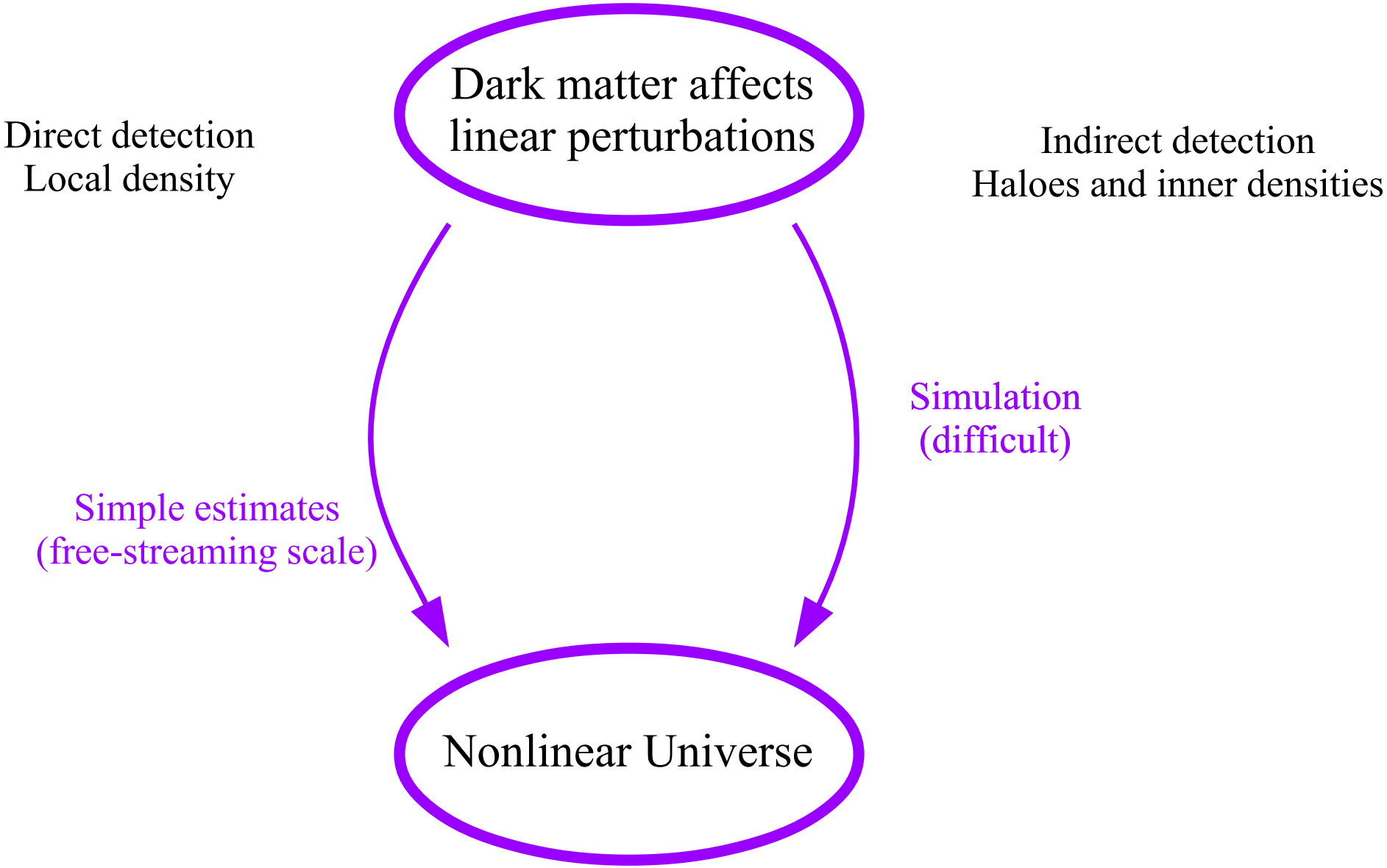
Direct detection
Local density

Indirect detection
Haloes and inner densities

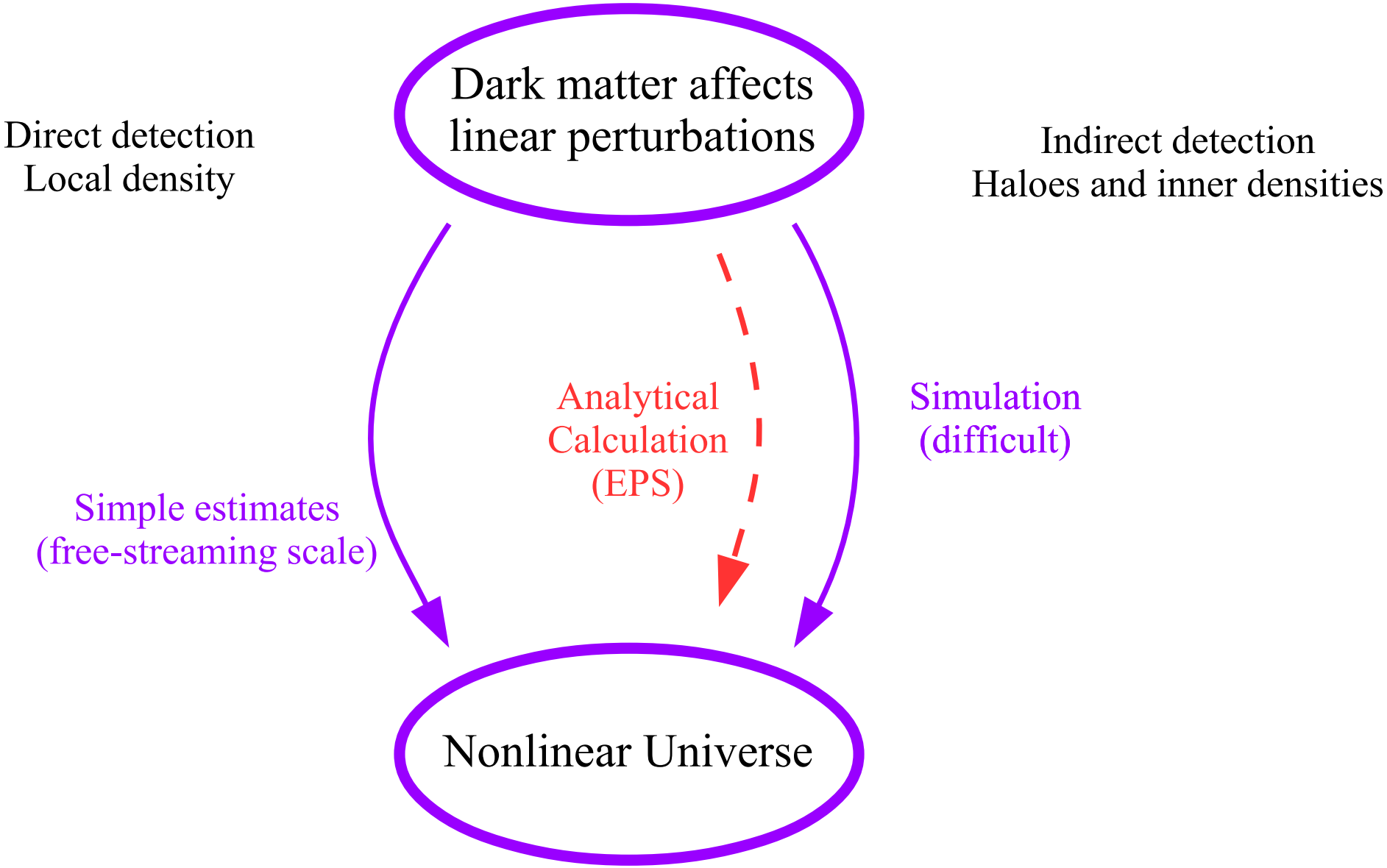
Probing DM scenarios with Astrophysics



Probing DM scenarios with Astrophysics



Probing DM scenarios with Astrophysics



Outline

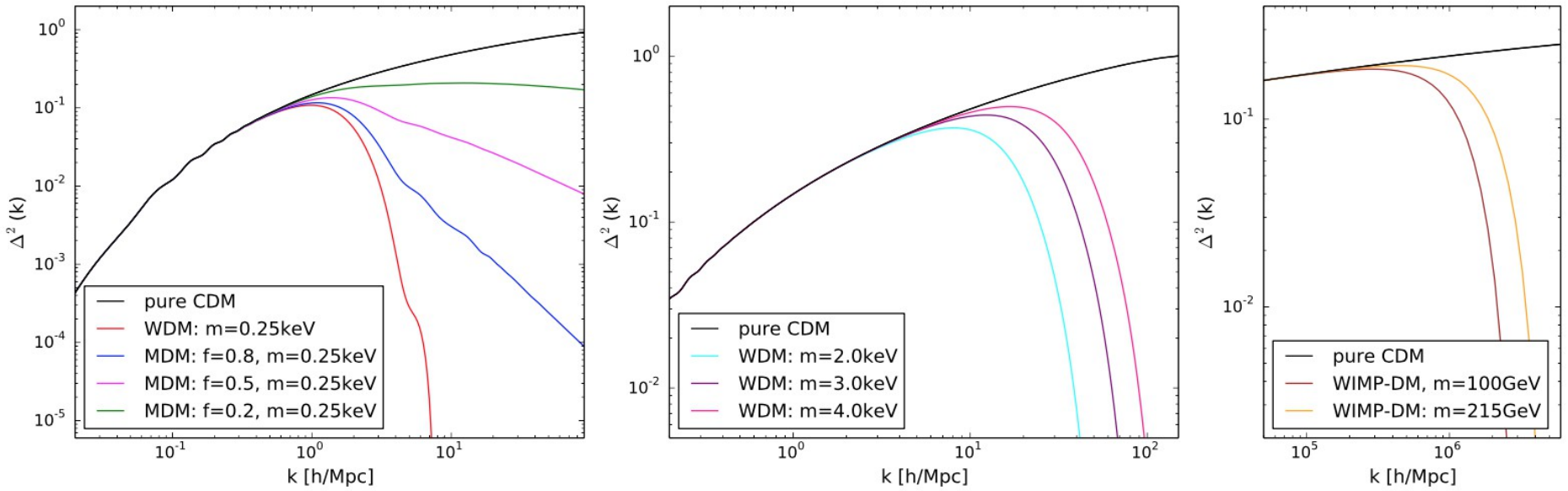
Modeling (suppressed) Structure Formation.

Constraining Dark Matter Models

Heading for a beer!

Modeling Structure Formation: Overview

All dark matter scenarios suppress perturbations !



Examples with strong suppression:

- warm DM (Bode et al 2001)
- interacting DM (Boehm et al 2005)
- self-interacting DM (Cyr-Racine et al 2012)
- ultra-light axion DM (Marsh and Silk 2013)
- mixed DM (Boyarsky et al 2009)
- decaying DM (Kaplinghat 2005)

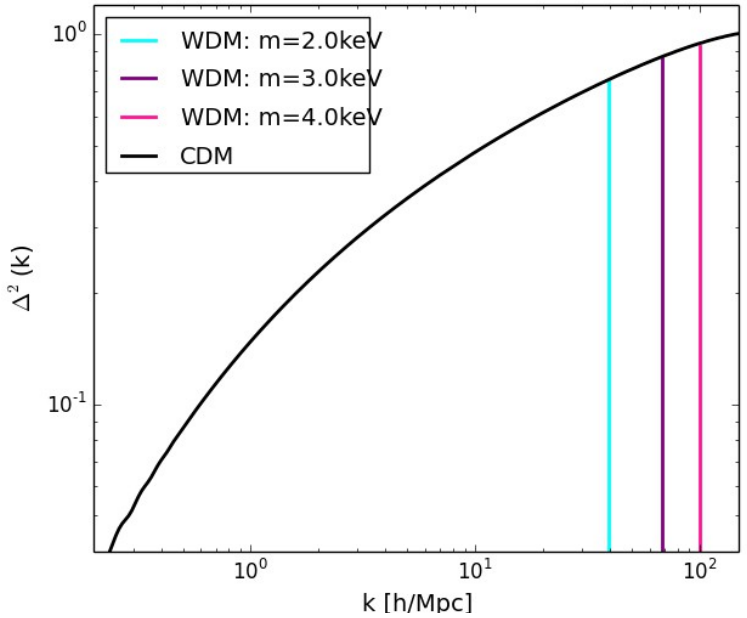
Modeling Structure Formation : Free-Streaming

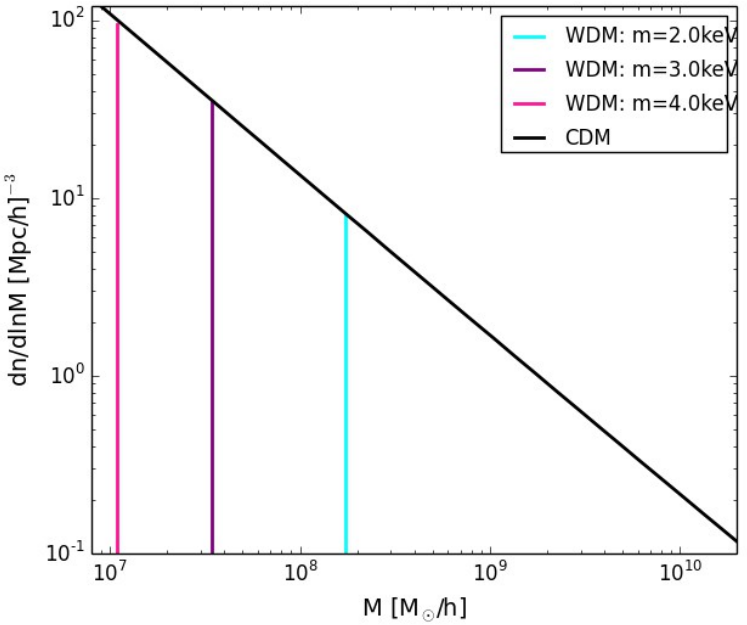
Free-streaming estimate :

$$\lambda_{FS} = \int \frac{\langle v(t) \rangle}{a(t)} dt$$

Or equivalent:

$$\lambda_s = \max(\lambda_J, t), \quad \lambda_J = \sqrt{\frac{\pi c_s^2}{4G\bar{\rho}}}$$



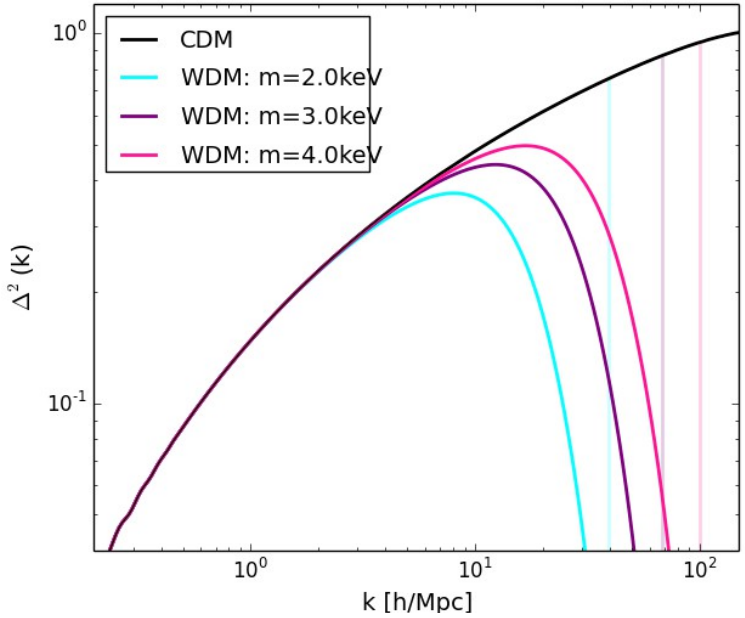


Modeling Structure Formation: Boltzmann solver

The proper Boltzmann calculation:

Codes:

- cmbfast (Seljak & Zaldarriage, 1996)
- camb (Lewis 2002)
- class (Lesgourgues, 2011)



Modeling Structure Formation: Sharp-k Model

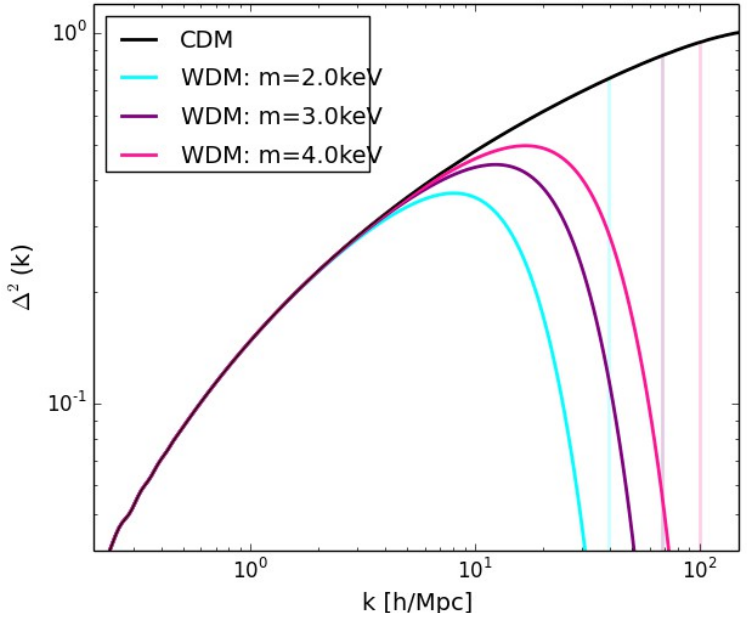
Extended Press-Schechter:

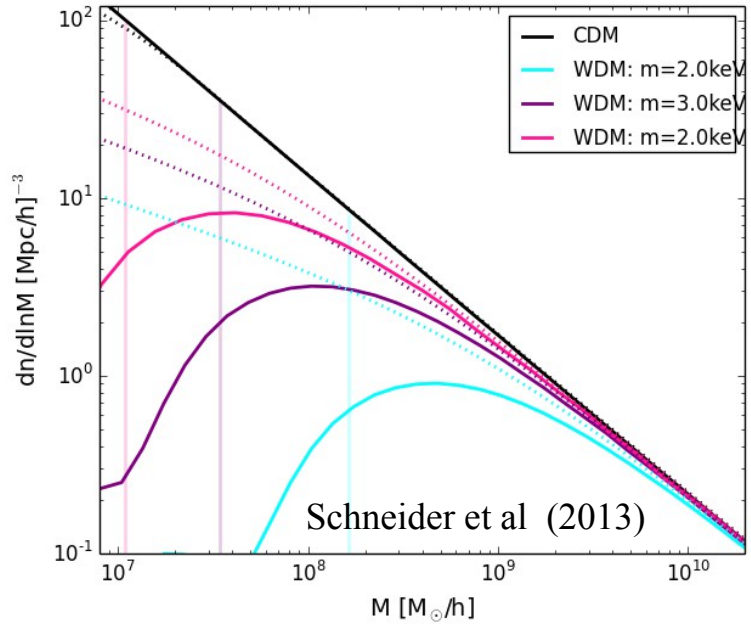
Requires sharp-*k* modification!

$$\frac{dn}{d\ln M} = \frac{1}{12\pi^2}\frac{\bar{\rho}}{M}\nu f(\nu)\frac{P(1/R)}{\delta_c^2 R^3}$$

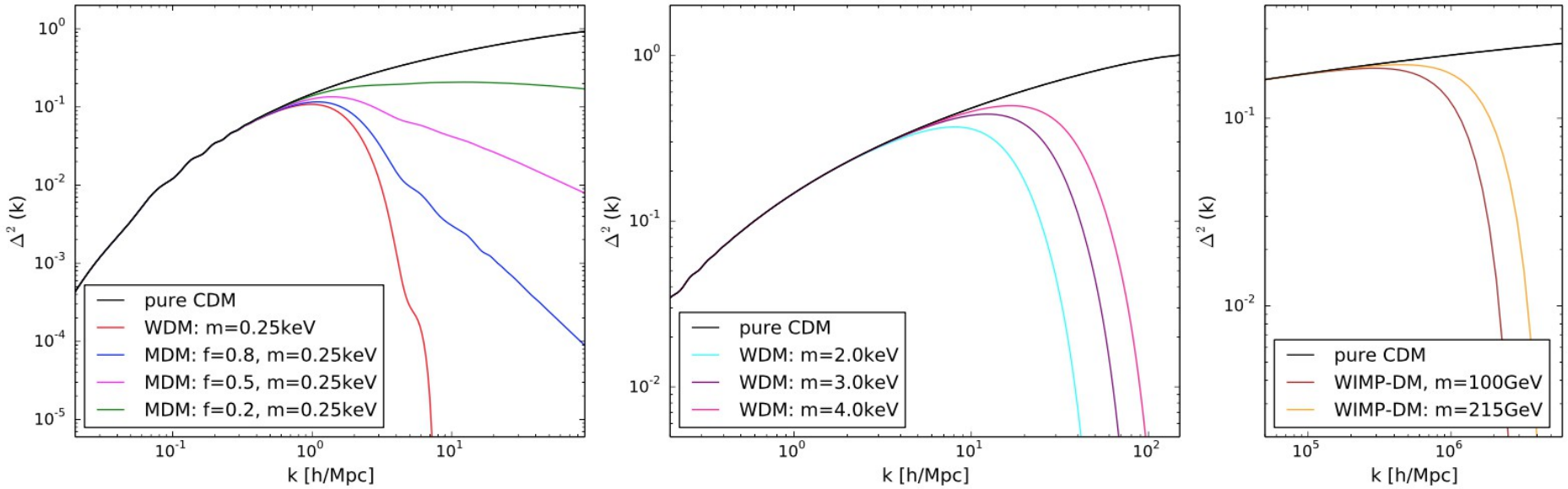
$$f(\nu) = A\sqrt{\frac{2\nu}{\pi}}\left[1+\nu^{-p}\right]e^{-\nu/2},$$

$$M = \frac{4\pi}{3}\bar{\rho}(cR)^3, \qquad c = 2.5$$



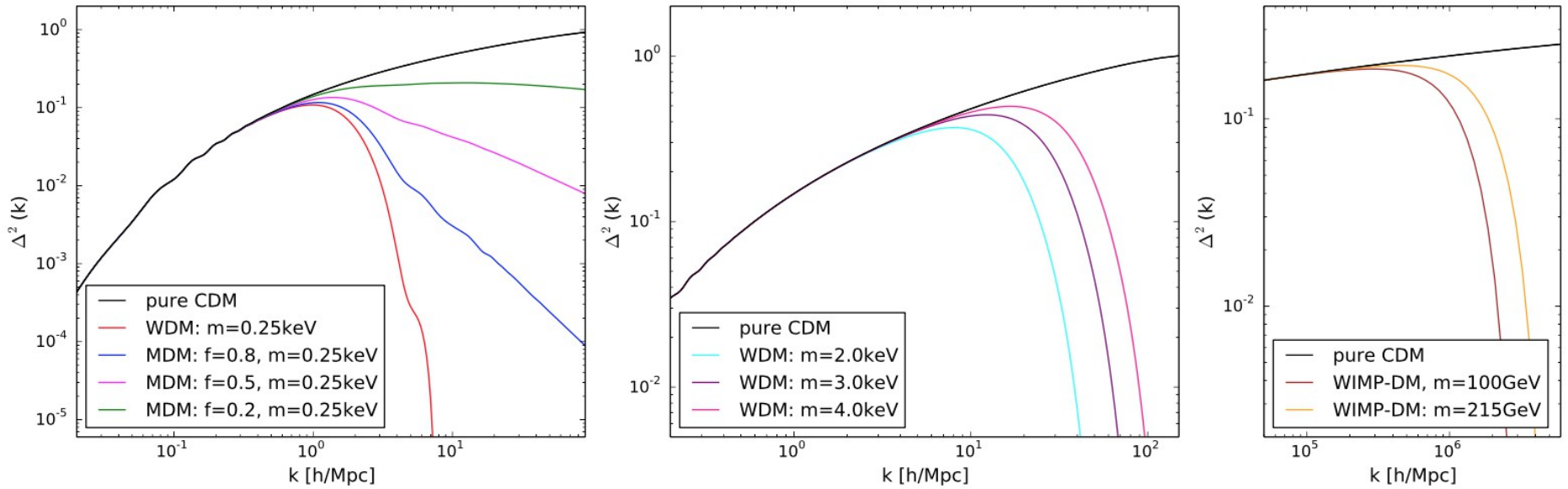


Modeling Structure Formation: Overview

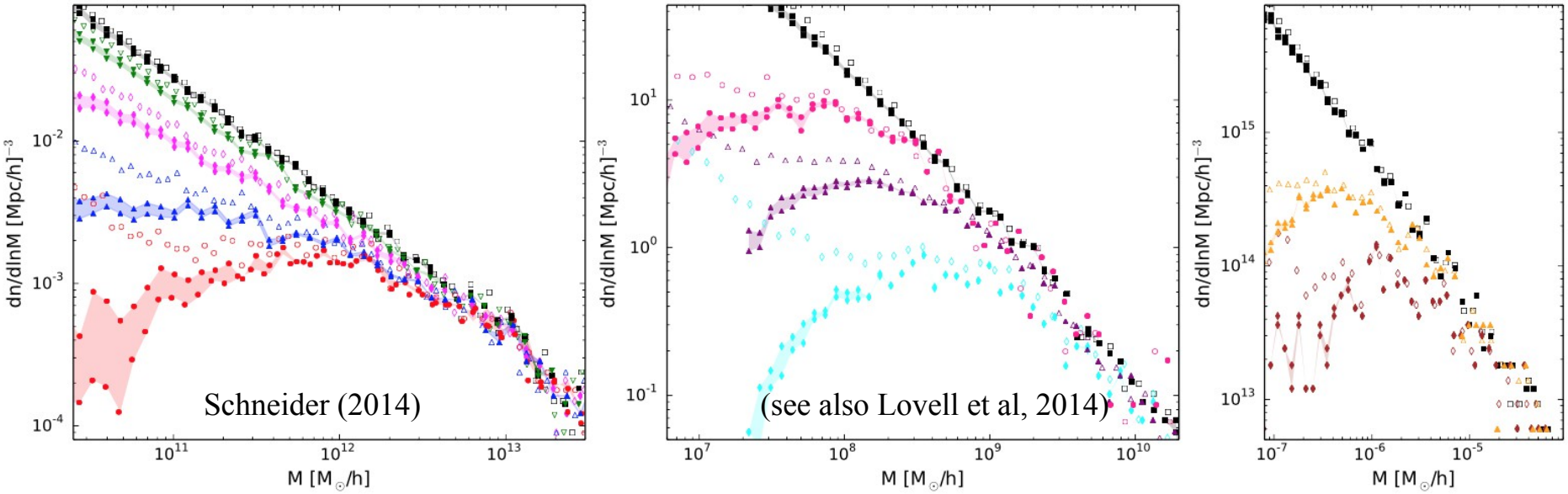


- Simulations: Best option but very painful (artificial clumping!)
- EPS: Sheth-Tormen model (does not work)
- EPS: sharp-*k* model (works)

Modeling Structure Formation: Simulations



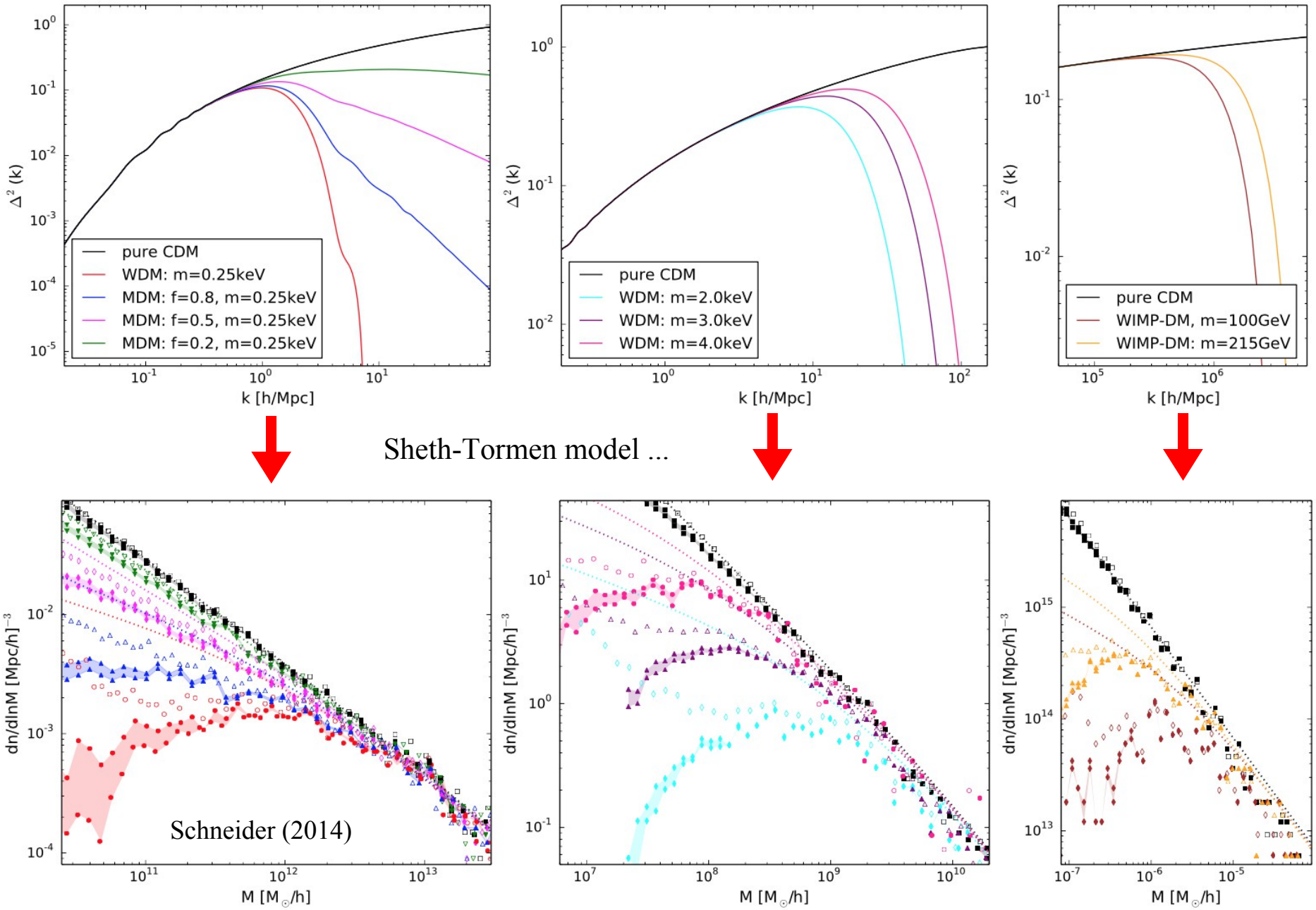
Numerical Simulations ...



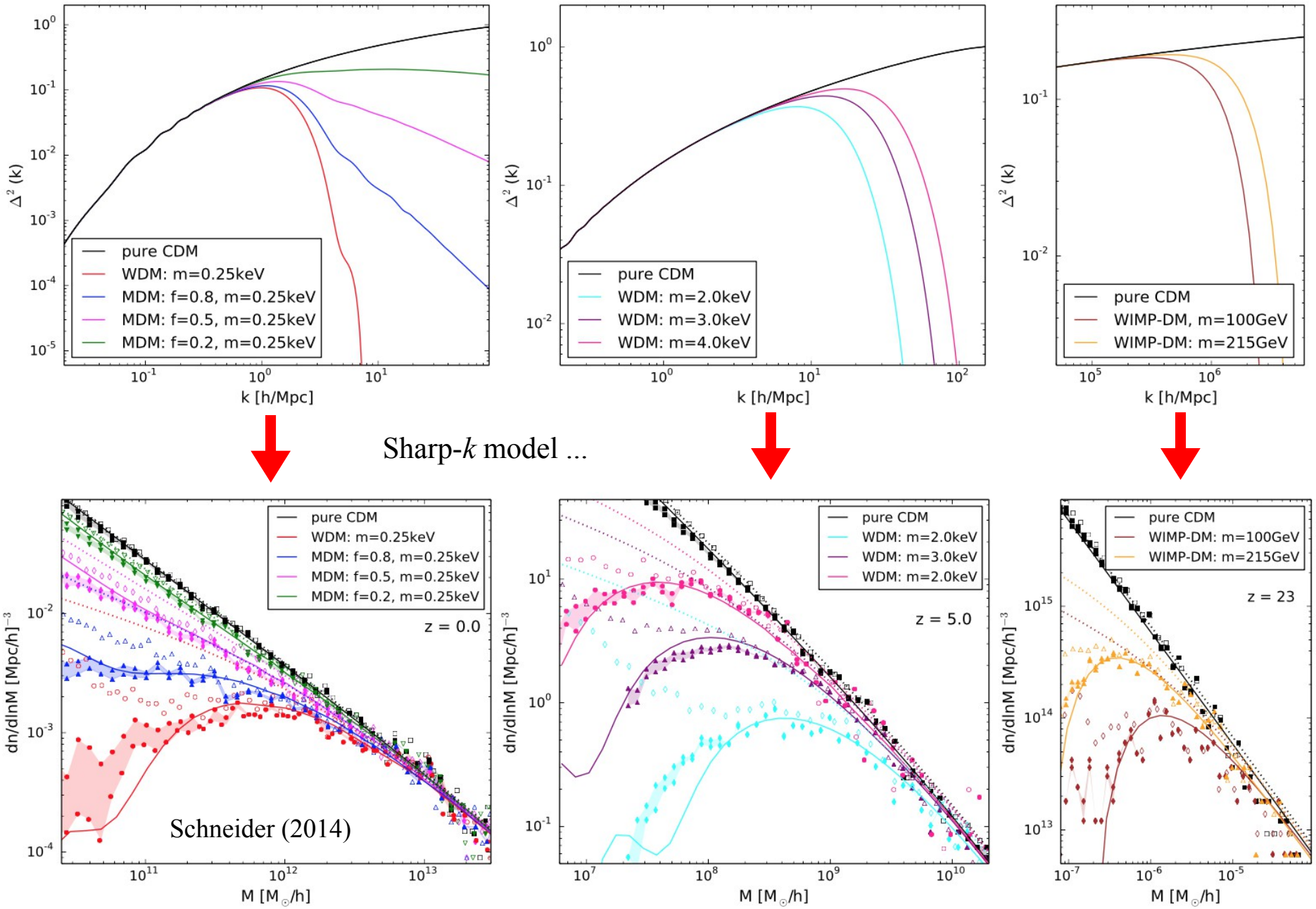
Schneider (2014)

(see also Lovell et al, 2014)

Modeling Structure Formation: ST model



Modeling Structure Formation: Sharp-k model



Outline

Modeling (suppressed) Structure Formation.

Constraining Dark Matter Models

Heading for a beer!

Constraining Dark Matter : Overview

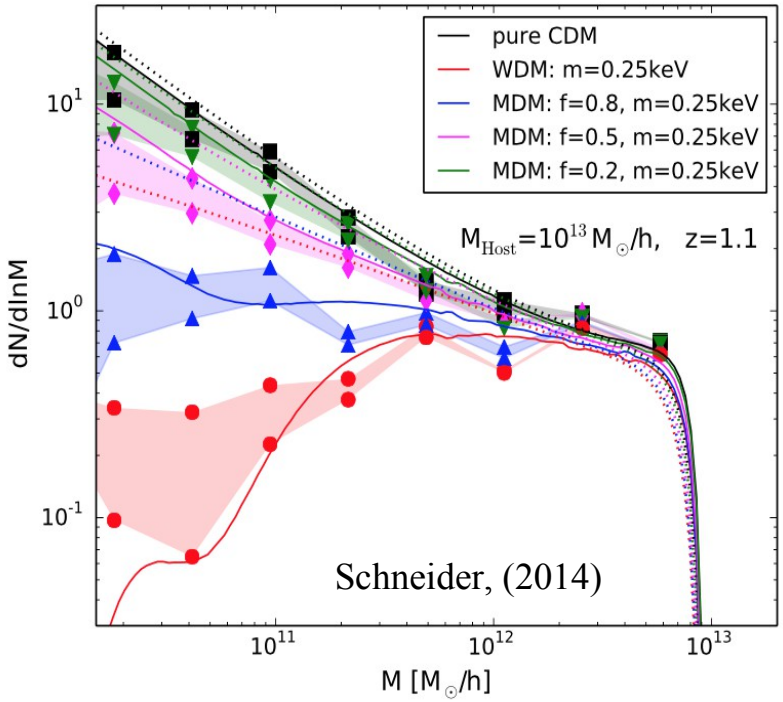
What can be used to constrain dark matter models:

- Dwarf galaxy counts
- Velocity functions
- Dwarf galaxy profiles
- Lyman-alpha forest
- ...

Constraining Dark Matter : Dwarf Galaxy Counts

Conditional mass function:

Number count of haloes ending up in a (Milky-Way) host.



$$\frac{dN(M|M_0)}{d\ln M} = \frac{1}{6\pi^2}\frac{M_0}{M} f(\delta_c, S|\delta_{c,0}, S_0)\frac{P(1/R)}{R^3}$$

$$f(\delta_c, S|\delta_{c,0}, S_0) = \frac{(\delta_c - \delta_{c,0})}{\sqrt{2\pi(S-S_0)}} \exp\left[-\frac{(\delta_c-\delta_{c,0})^2}{2(S-S_0)}\right]$$

Constraining Dark Matter : Dwarf Galaxy Counts

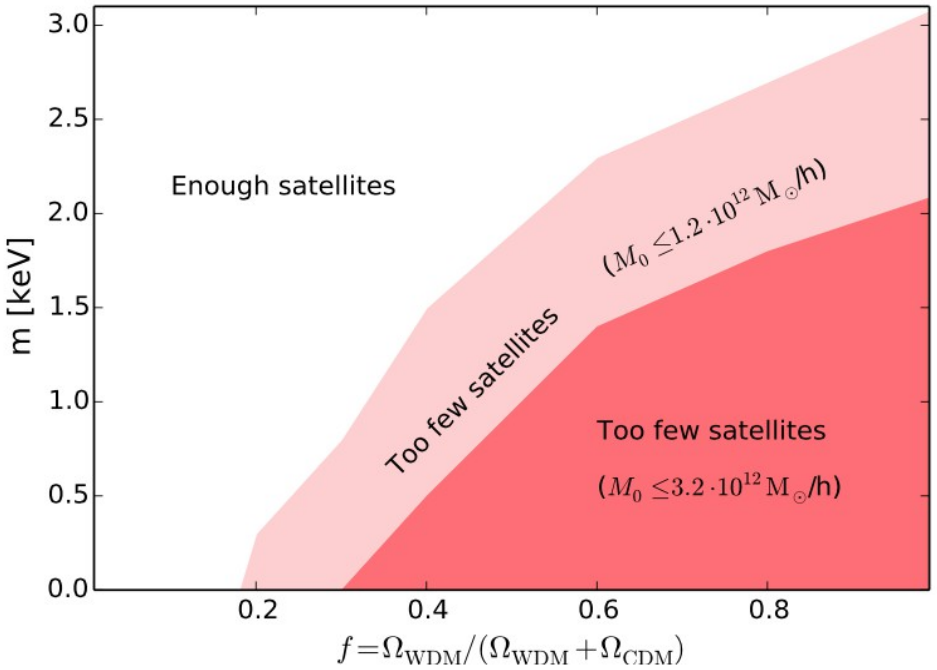
EPS model to estimate satellites (integrating cond. mass function):

$$\frac{dN_{\rm Sat}}{d\ln M} = \frac{1}{44.5}\frac{1}{6\pi^2}\left(\frac{M_0}{M}\right)\frac{P(1/R)}{R^3\sqrt{2\pi(S-S_0)}}$$

Method from Giocoli et al (2008)

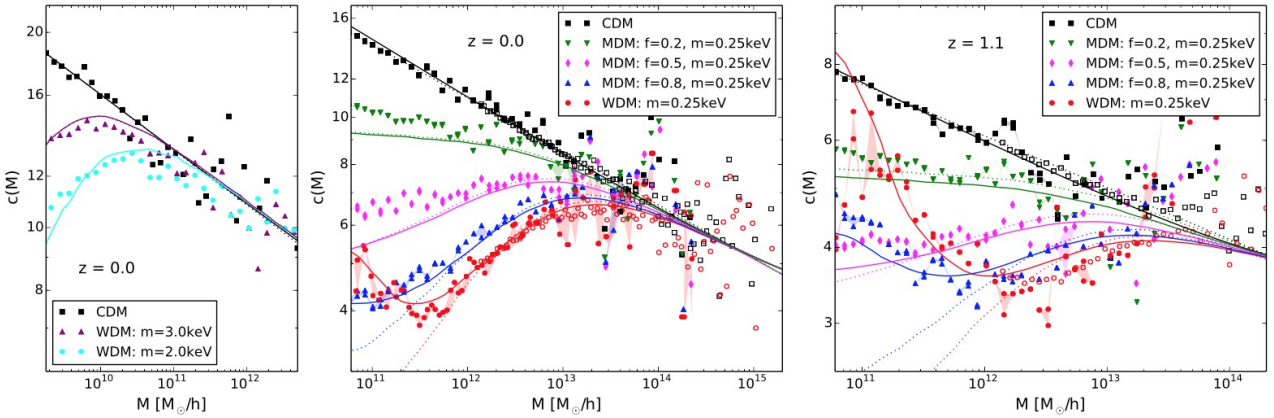
(see Schneider, 2014)

Scenario		$N_{\rm Sat}$ (EPS model)	$N_{\rm Sat}$ (Simulation)
WDM:	m=1.5 keV	9	12
WDM:	m=2.0 keV	25	27
WDM:	m=2.3 keV	32	30
CDM:	pure	158	158

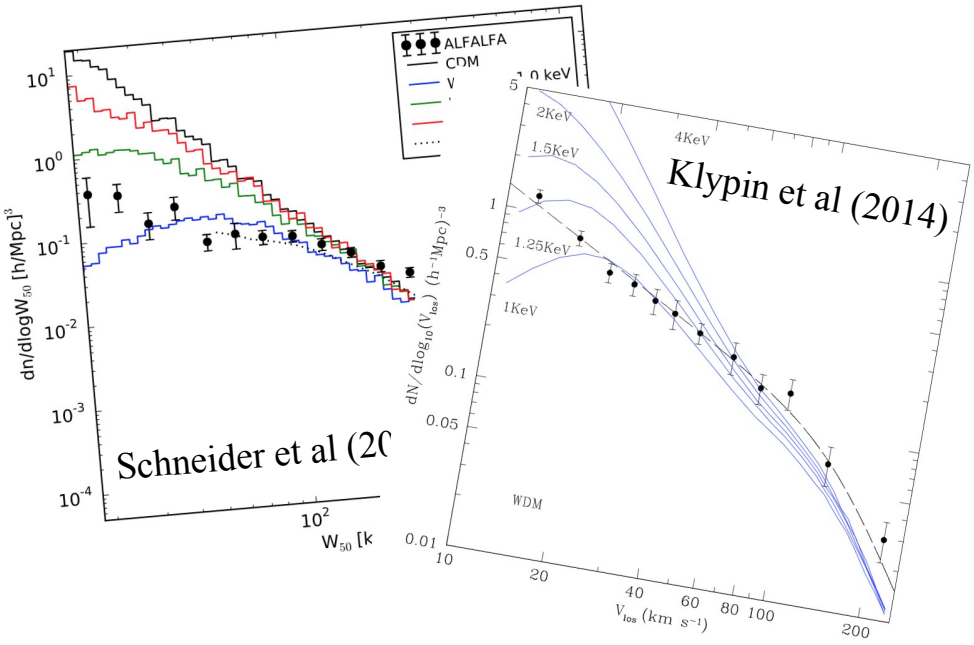


Constraining Dark Matter : Other possibilities...

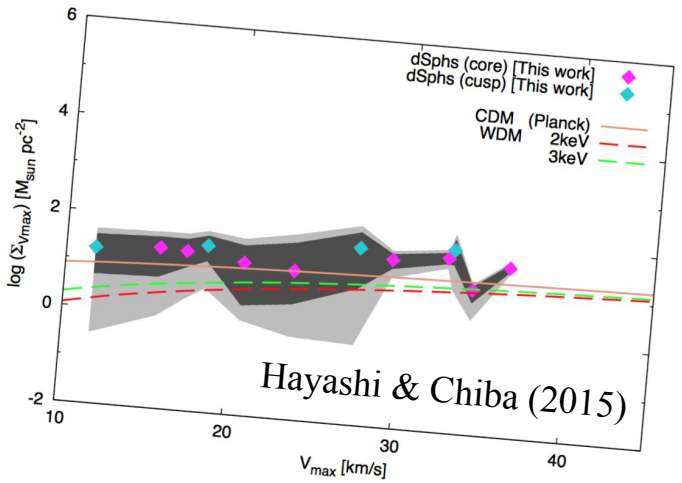
… Concentrations (profiles) with EPS:



… Velocity functions:



… Surface densities:



Conclusions :

Suppressed perturbations lead to suppressed halo formation

EPS is a fast/simple yielding good estimates of:

Mass function

Number of satellites

Concentrations

... this can be used to constrain various DM scenarios