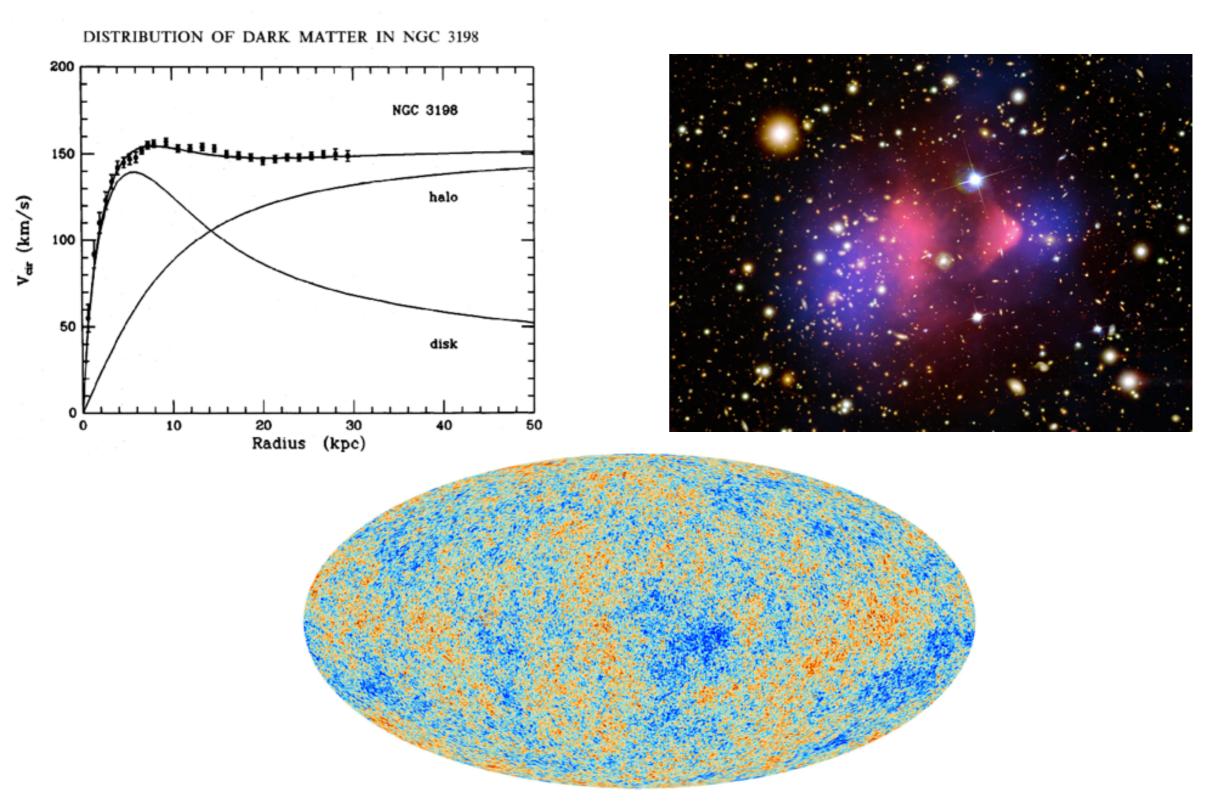
Non-Abelian dark matter & dark madiation

hep-ph 1505. XXXX

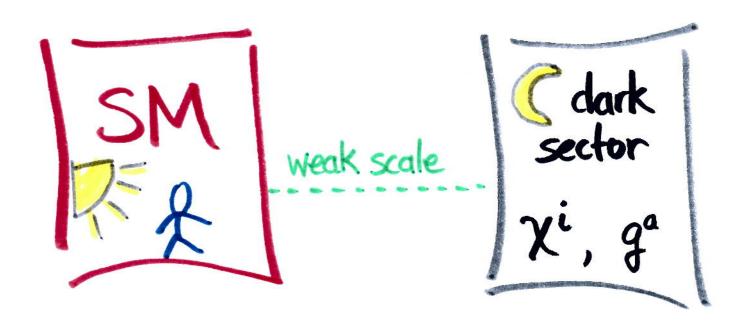
elle june

Manuel Buen-Abad Gustavo Marques Tavares Martin Schmaltz

Dark matter evidence



Non-Abelian dark sector



$$Su(N): i=1...N$$

 $a=1...N^{2}-1$

"A brief history of temperature

(Ism Jos]) equilibrium - Mx ... dark matter freeze-out

today 10 eV 2.7 K

DS I.OK 11

What is different?

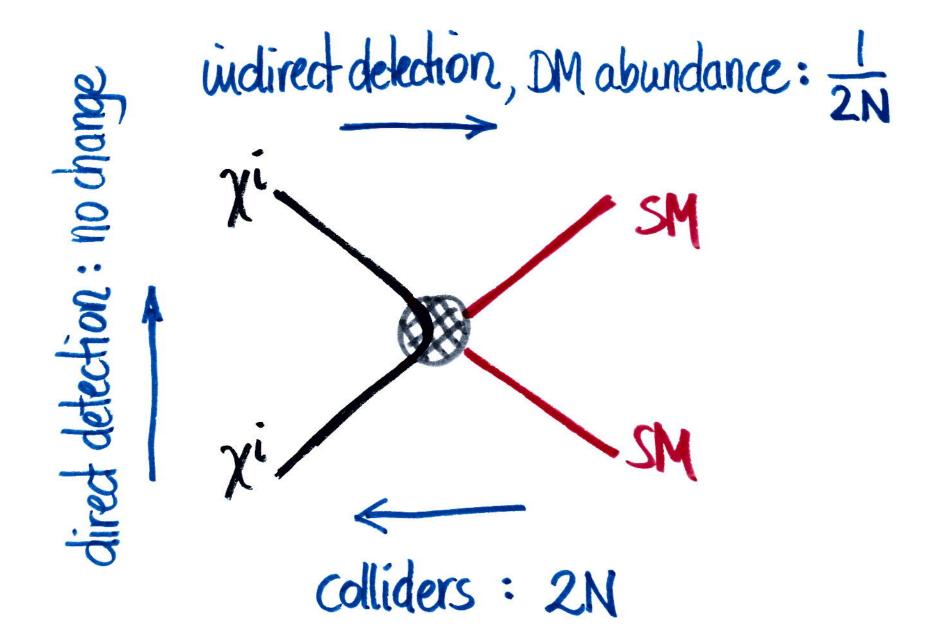
1. Xi i=1...N LHC, 100 TeV

2. ga dark radiation seeme N<4

3. DM couples to radiation & <10-8



dark matter Multiplicity same color



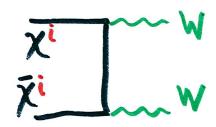
Example: Multiple "winos"

 $SU(2)_{\text{w}}$ triplet $\longrightarrow \begin{array}{c} \chi^{\pm i} \\ \chi^{\circ i} \end{array}$ 160 MeV

~ TeV Dirac mass MXX

Xoi = dark matter

DM abundance xi w

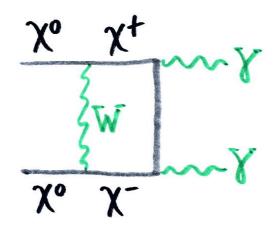


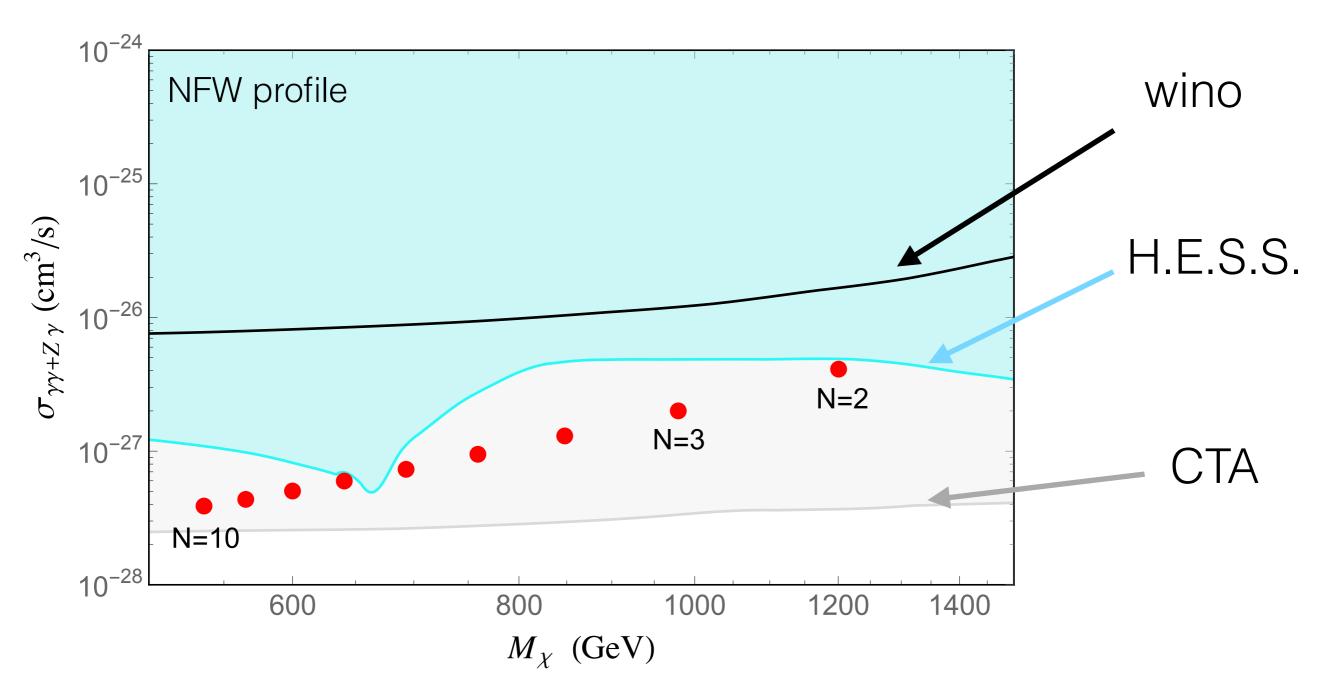
$$\frac{1}{2000} \sim \frac{1}{100} < 000 > \sim \frac{1}{100} < 0000 > \sim \frac{1}{100} < 0000 > \sim \frac{1}{100}$$

$$\langle \sigma v \rangle \sim \frac{\alpha_W}{M_\chi^2} \frac{1}{2N}$$

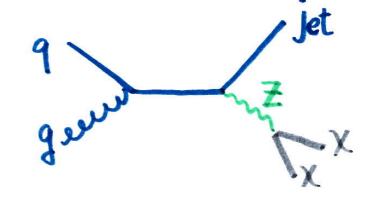
$$\Rightarrow$$
 $M_{\chi} = M_{\text{wino}} / \sqrt{2N}$

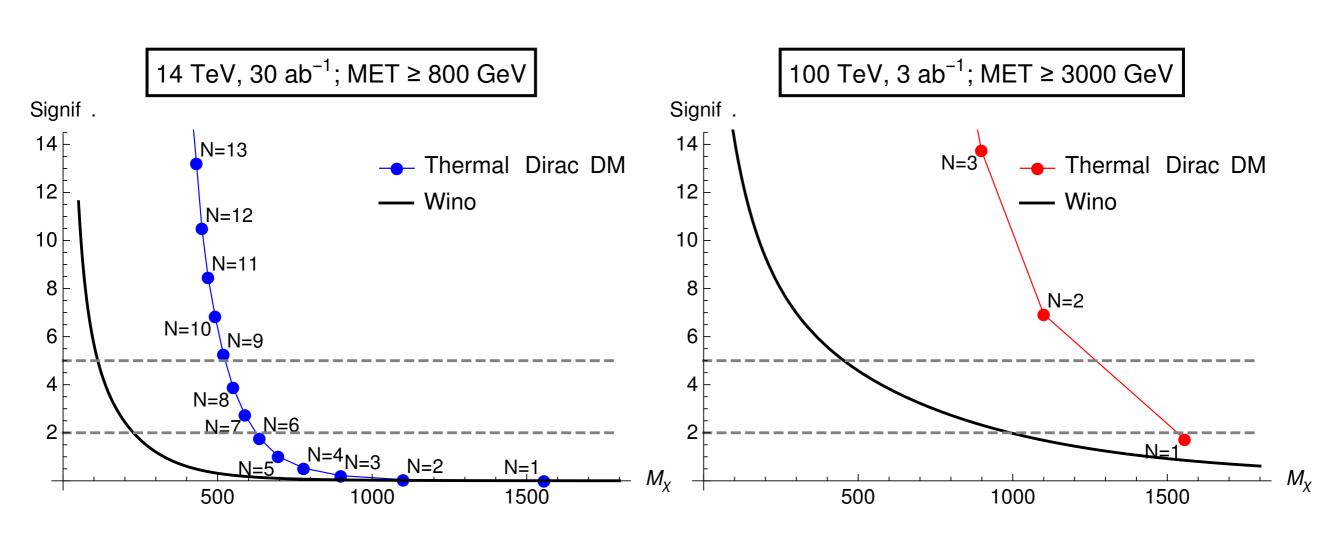
Indirect detection





Colliders: mono-jets





HL-LHC

100 TeV

2. dark gluons finding

no confinement $\Rightarrow \Lambda_{\sim} 10^{-4} \text{eV}$

$$(\mu/\Lambda)^{2b_0} = e^{1/dd}$$

$$\Rightarrow \alpha_d \lesssim 10^{-2}$$

Cosmology for model builders

to decide if a process is important compare

process Vs. Hubble

1 Nov

Are dark gluons in thermal equil.?

=> Yes, if
$$\alpha_d > \frac{1}{\alpha_{em}} \frac{10^{13}}{Mpl} \sim 10^{13}$$

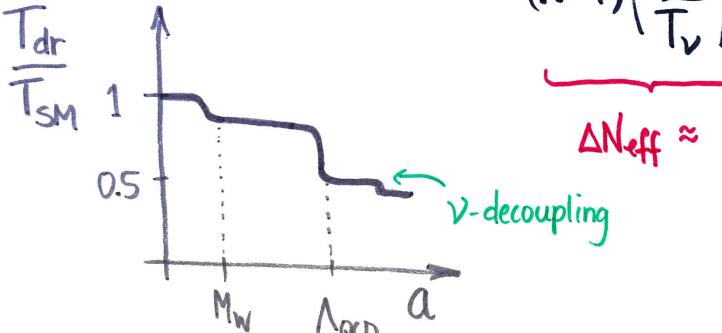
gluons in equilibrium at 10 GeV?

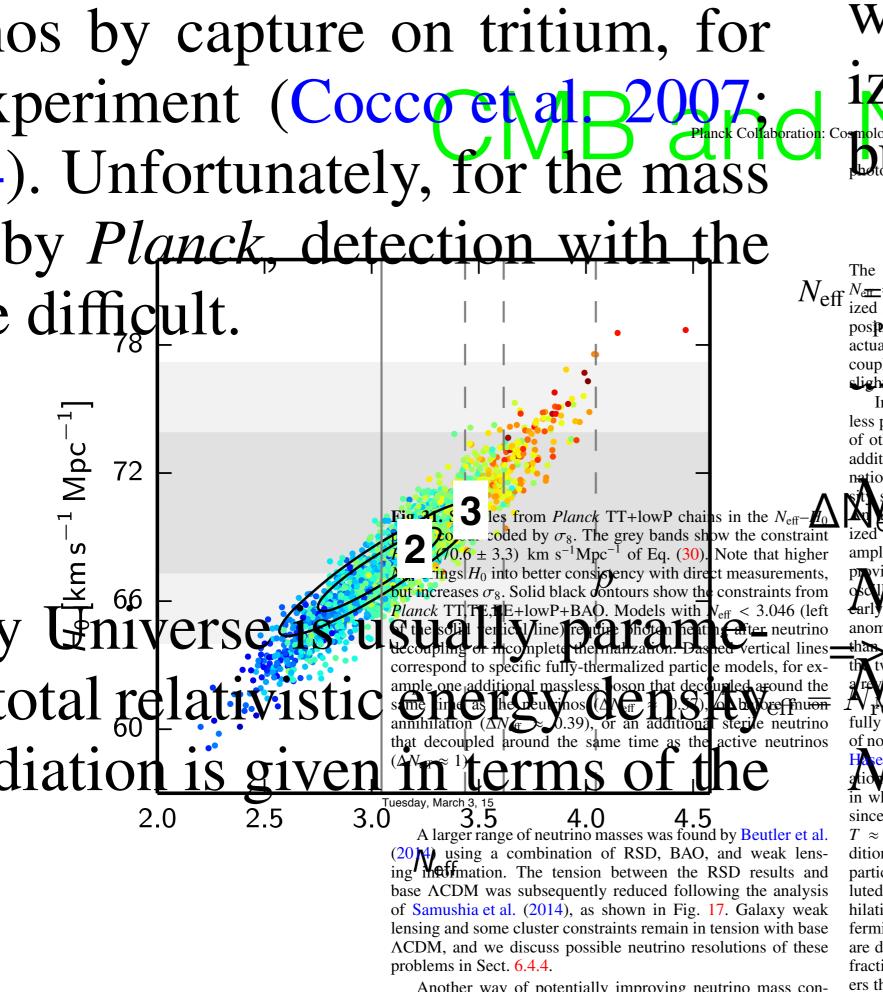
2 m / x

$$\Rightarrow$$
 yes, if $d_d > \frac{10^{11} \text{ Myz}}{\text{dem TMpe}} \approx 1$

After dark radiation decoupling

$$= (N^{2}-1)(\frac{T_{dr}}{T_{v}})^{4} 2 T_{v}^{4}$$





Another way of potentially improving neutrino mass constraints is to use measurements of the Ly α flux power spectrum

would require the stated ized or additional planticular include this representative include this representative.

Figure 19 1 shows

The numerical factors in this equation are included so that $N_{\rm eff} = 3$ for three standard model in the early Universe and decoupled well before electron-positional methods and accoupled well before electron-positional methods are not completely decoupled at electron-positron annihilation and are subsequently elightly heated (Mangano et al. 2002).

In this section we focus on additional density from massless particles. In addition to massless sterile neutrinos, a variety of other particles could contribute to N_{eff} . We assume that the additional massless particles are produced well before recombination, and neither interact nor decay so that their energy density scales with the expansion excells like massless neutrinos. At the like massless neutrinos and the like massless neutrinos at the like massless neutrinos. It is a like massless neutrinos at like massless neutrinos at like massless neutrinos at like massless neutrinos. It is a like massless neutrinos at like massless neutrinos at like massless neutrinos at like massless neutrinos. It is a like massless neutrinos at like massless neutrinos at like massless neutrinos. ample any sterile neutrino with mixing angles large enough to provide a potential resolution to short baseline reactor neutring Mation anomalies would most likely thermalize rapidly early (miverse. However, this solution to the neutrino oscillation anomalies requires approximately 1 eV sterile neutrinos, rather than the mass ess case considered in this section; exploration of two parameters $\frac{1}{100}$ and $\frac{1}{200}$ is exposed in Sect. 6.4.3 For every of sterile neutrinos see Abazajian et al. $\frac{(2012)}{(2012)}$. More Anerally the additional radiation does not need to be fully thermalized, for example there are many possible models of non-thermal radiation production via particle decays (see e.g., Hase kamp & Kersten 2013; Conlor & Marsh 2013). The ladiation conditions be produced at tempe at T > 10 MeV, in which case typically $\Delta N_{\rm eff} < 1$ for each additional species, since heating by photon production at muon annihilation (at $T \approx 100 \text{ MeV}$) decreases the fractional importance of the additional component at the later times relevant for the CMB. For particles produced at $T \gg 100$ MeV the density would be diluted even more by numerous phase transitions and particle annihilations, and give $\Delta N_{\rm eff} \ll 1$. Furthermore, if the particle is not fermionic, the factors entering the entropy conservation equation are different, and even thermalized particles could give specific fractional values of $\Delta N_{\rm eff}$. For example Weinberg (2013) considers the case of a thermalized massless boson, which contributes $\Delta N_{\rm eff} = 4/7 \approx 0.57$ if it decouples in the range 0.5 MeV < T <

M librathan authinos an M at 0.20 if it decouple

dark gluons are a perfect fluid

Free
$$T \sim \chi_d^2 T$$
 vs. $\frac{T^2}{Mpe} \sim 10^{-27} T$ (T=eV)

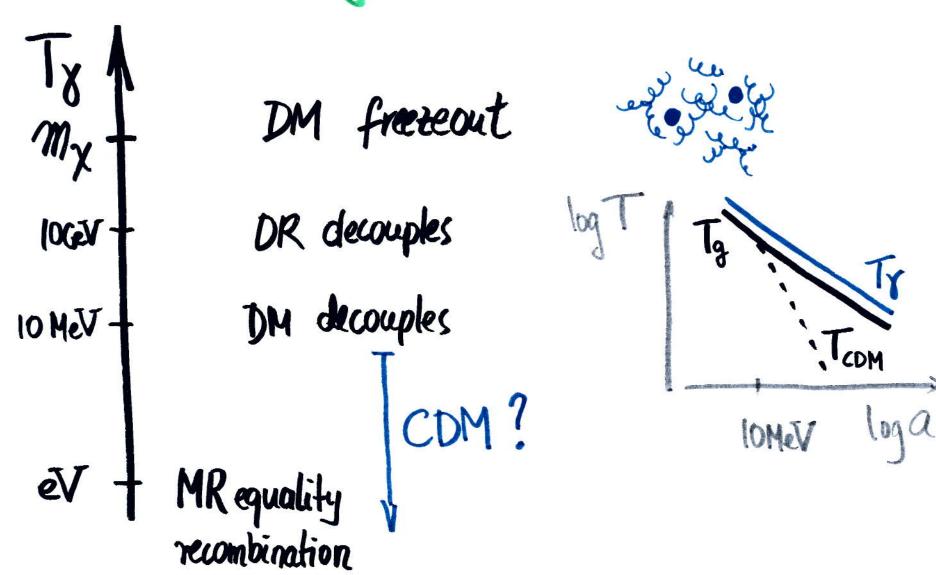
=> no viscosity, anisotropic stress (v, x) not free streaming CMB will tell!

2. dark radiation summary

- · perfect fluid for 10-13< dd < 10-2, T~1K
- · ΔNeff < 0.5 ⇒ N = 2,3
- Planck can distinguish & perfect free-streaming

3. DM-DR interactions and large scale structure

abnef history of dark time



are DM & DR coupled?

nov yu

DM DR apling

K 22 my

(d³k (d³p' (d³k' δ(Σp) (k-k')4 f(κ,T)

$$= \infty$$

forward scatters Saft scatters

Energy transfer rate

~
$$\alpha_d \log_{\alpha T^2} \frac{T^2}{M_{\chi}} \frac{T}{T_{\chi}}$$

Debye

Energy transfer rate & Hubble

TE = 0 109 x Mpe Tx Mpe

Mx Tx Mpe × 10-8

DM does not cool like non-relativistic matter CDM

$$T_{\chi} \sim \epsilon T_g$$
 but $V_{\chi} \sim \sqrt{\frac{T_{\chi}}{M_{\chi}}} \ll 1$.

does this generate an interesting signature?

growth of DM density perturbations

linear perturbations

$$\dot{\delta}_{DM} = -\theta_{DM} + 3\dot{\psi}$$

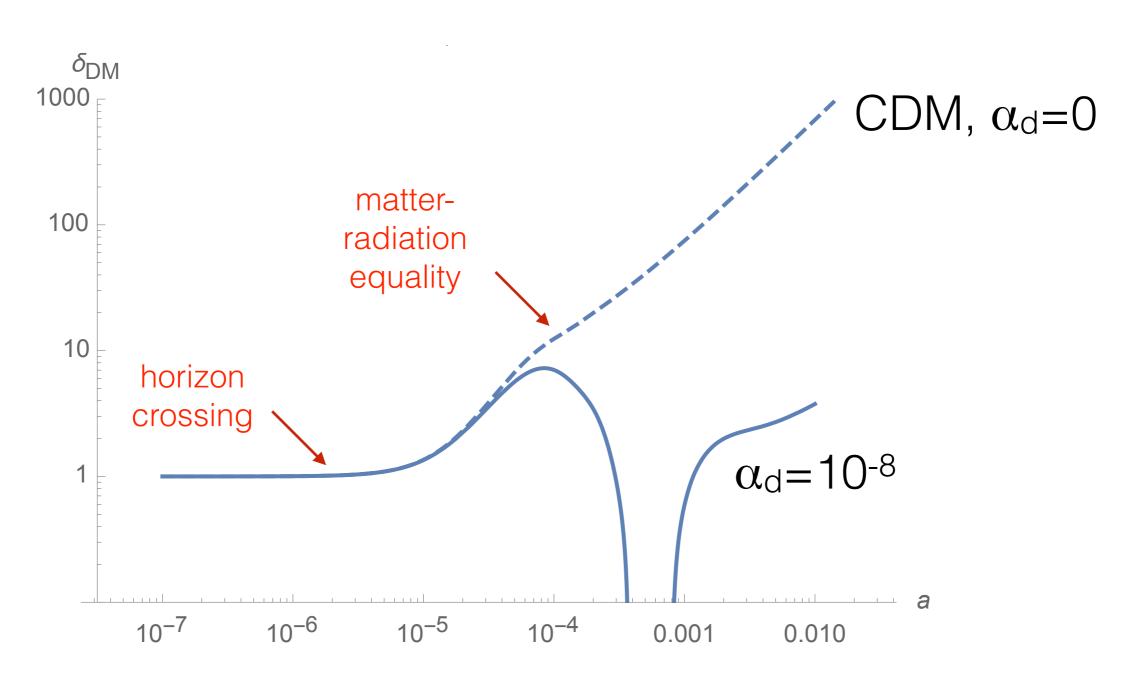
$$\dot{\theta}_{DM} = -\frac{\dot{a}}{a}\theta_{DM} + a\mathbf{\Gamma}_{V}(\theta_{DR} - \theta_{DM}) + k^{2}\psi$$

$$\dot{\delta}_{DR} = -\frac{4}{3}\theta_{DR} + 4\dot{\psi}$$

$$\dot{\theta}_{DR} = k^{2}\frac{\delta_{DR}}{4} + k^{2}\psi + \frac{3}{4}\frac{\rho_{DM}}{\rho_{DR}}a\mathbf{\Gamma}_{V}(\theta_{DM} - \theta_{DR})$$

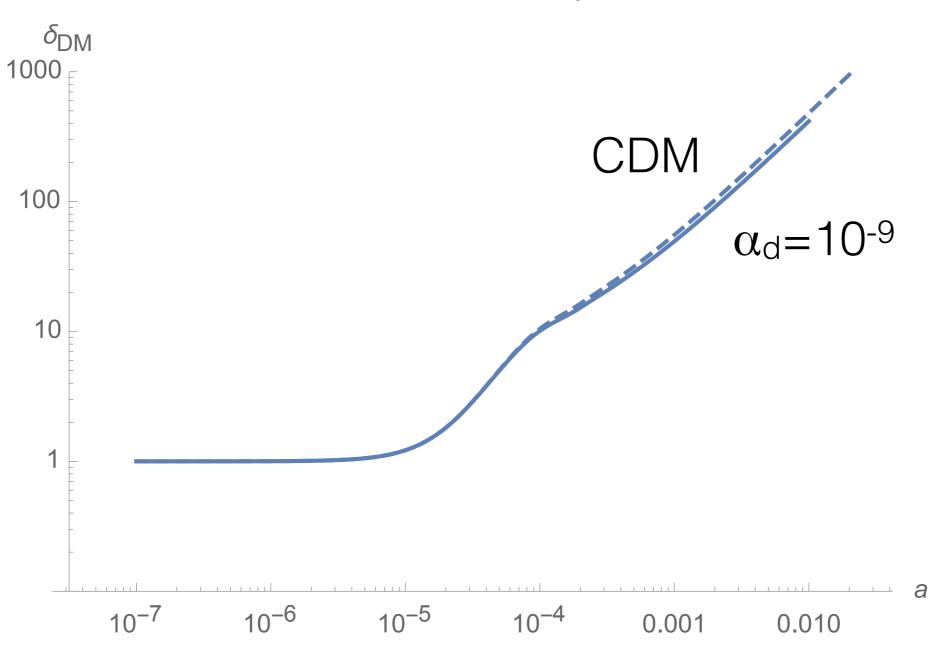
growth of perturbations

k=0.2 Mpc⁻¹

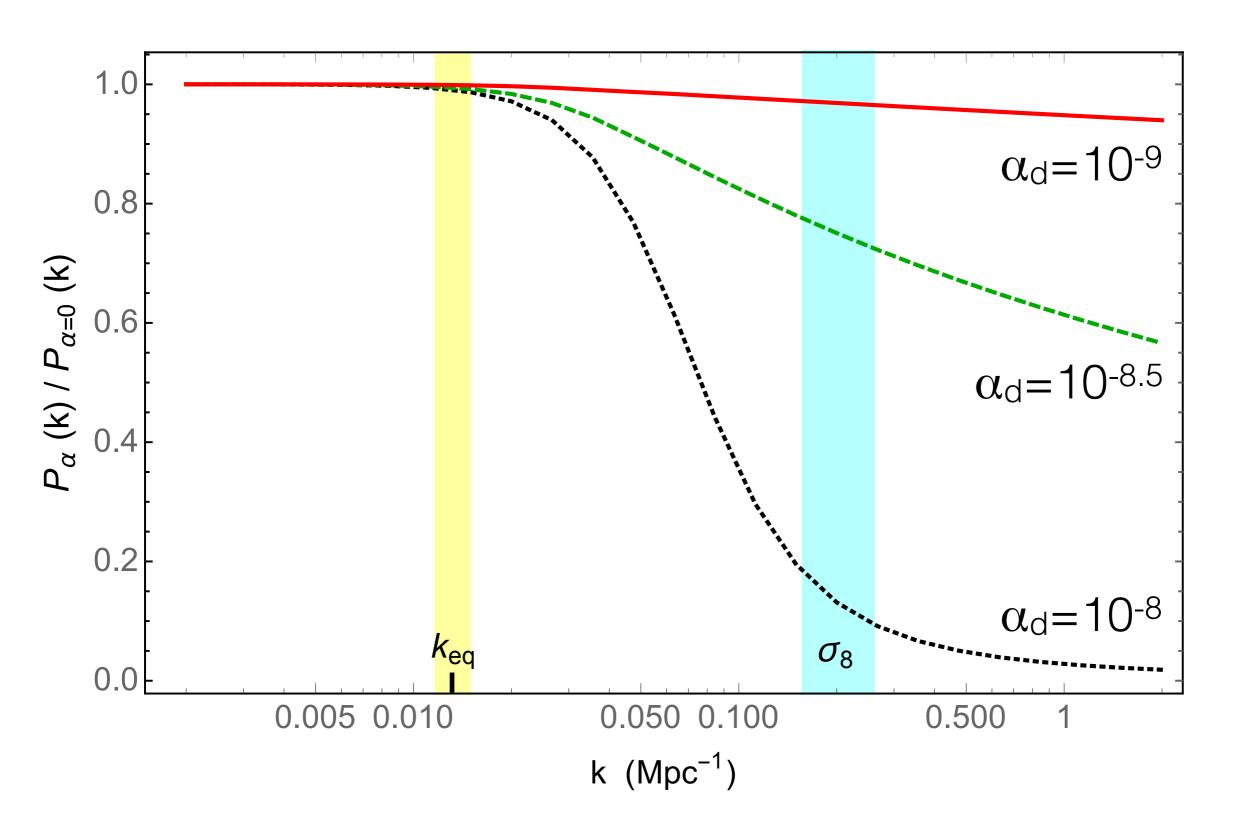


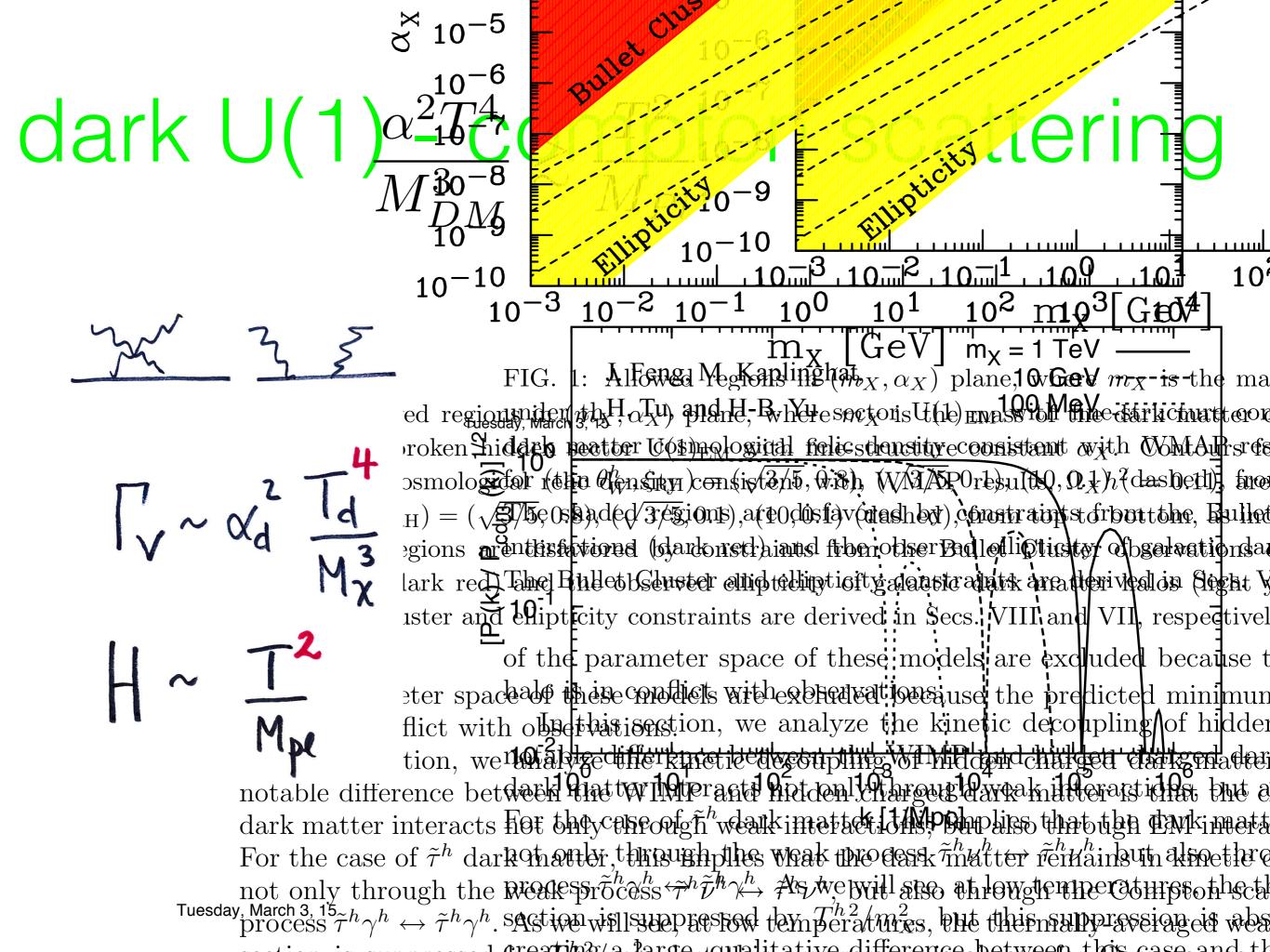
growth of perturbations

k=0.2 Mpc⁻¹

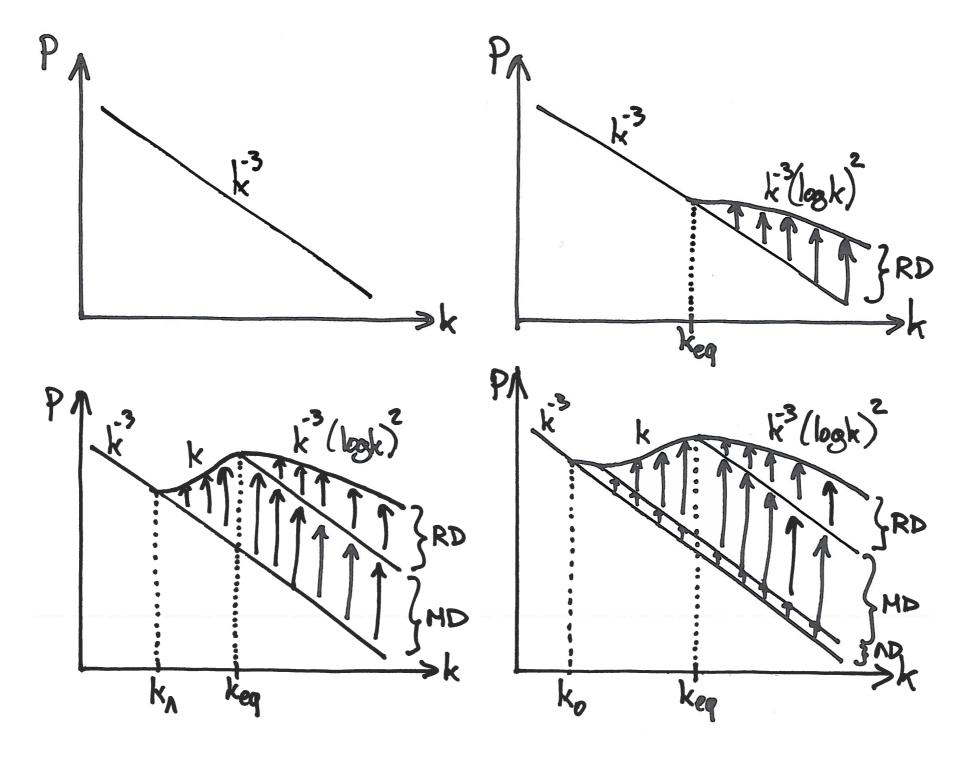


power spectrum change





ACDM growth of perturbations



Julien Lesgourgues, TASI 2012

tension in the data?

T_R

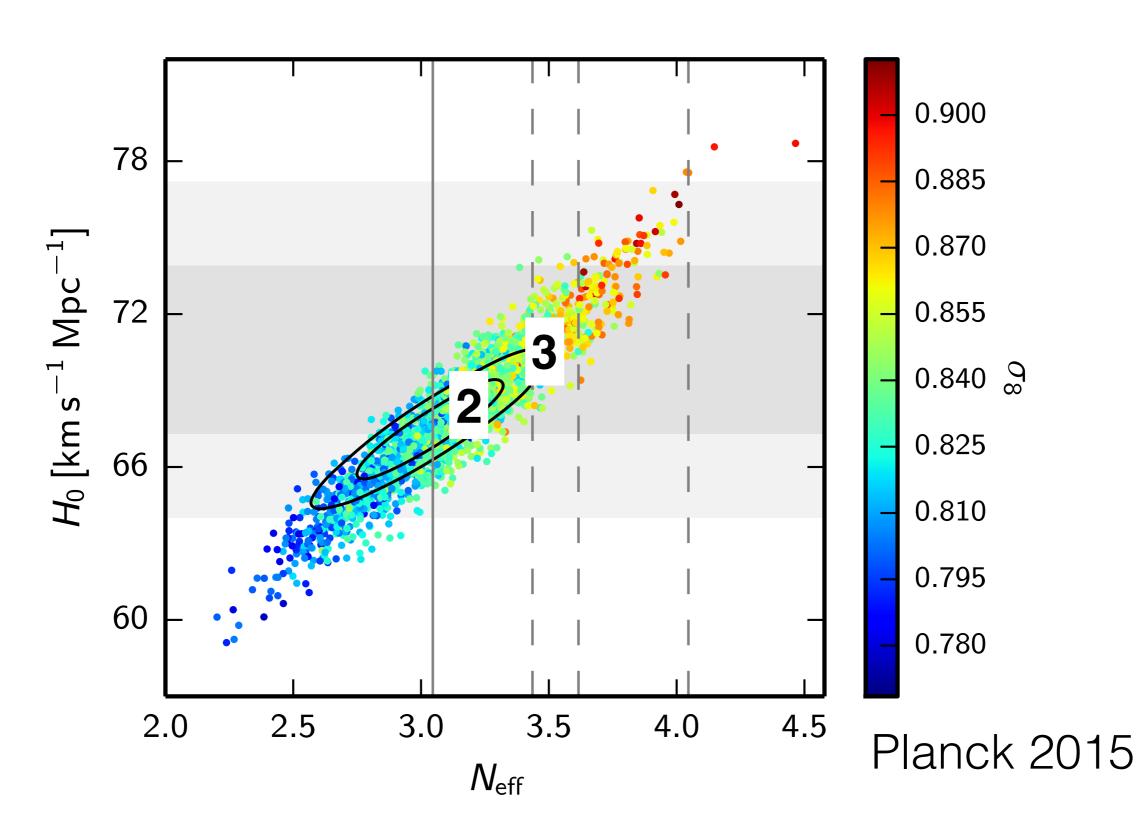
Planck CHB: 0.831 ± 0.013 67.6 ± 0.6 Planck CMB

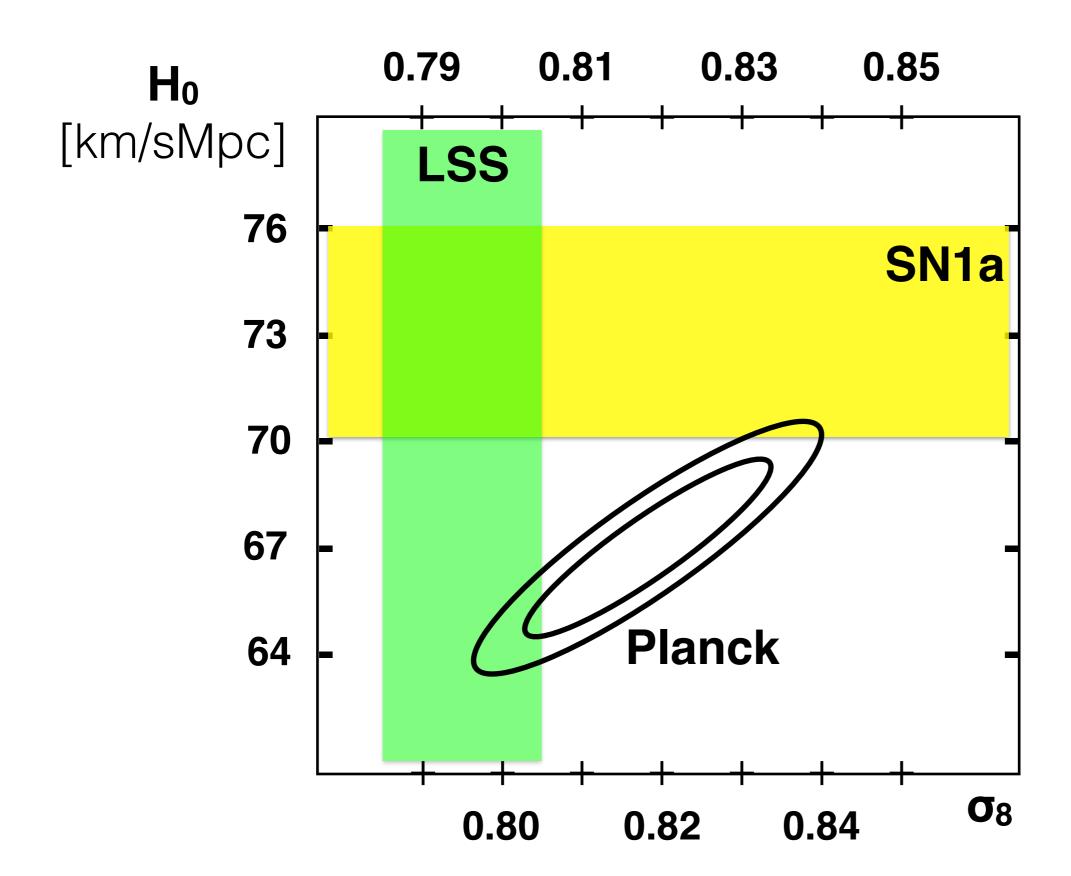
Plancklensing: 0.802 ± 0.012 73.0 ± 2.4 SN1a

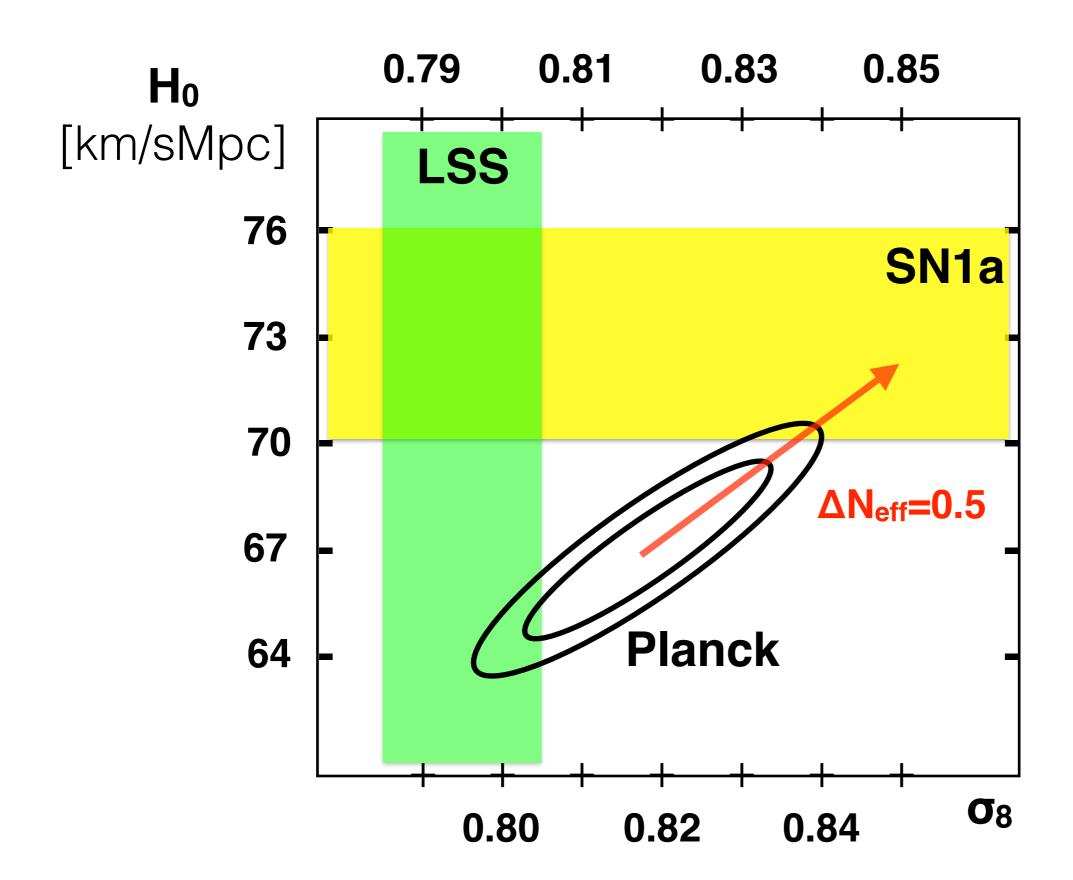
LSS combine: 0.795 ± 0.009 ~ "direct"

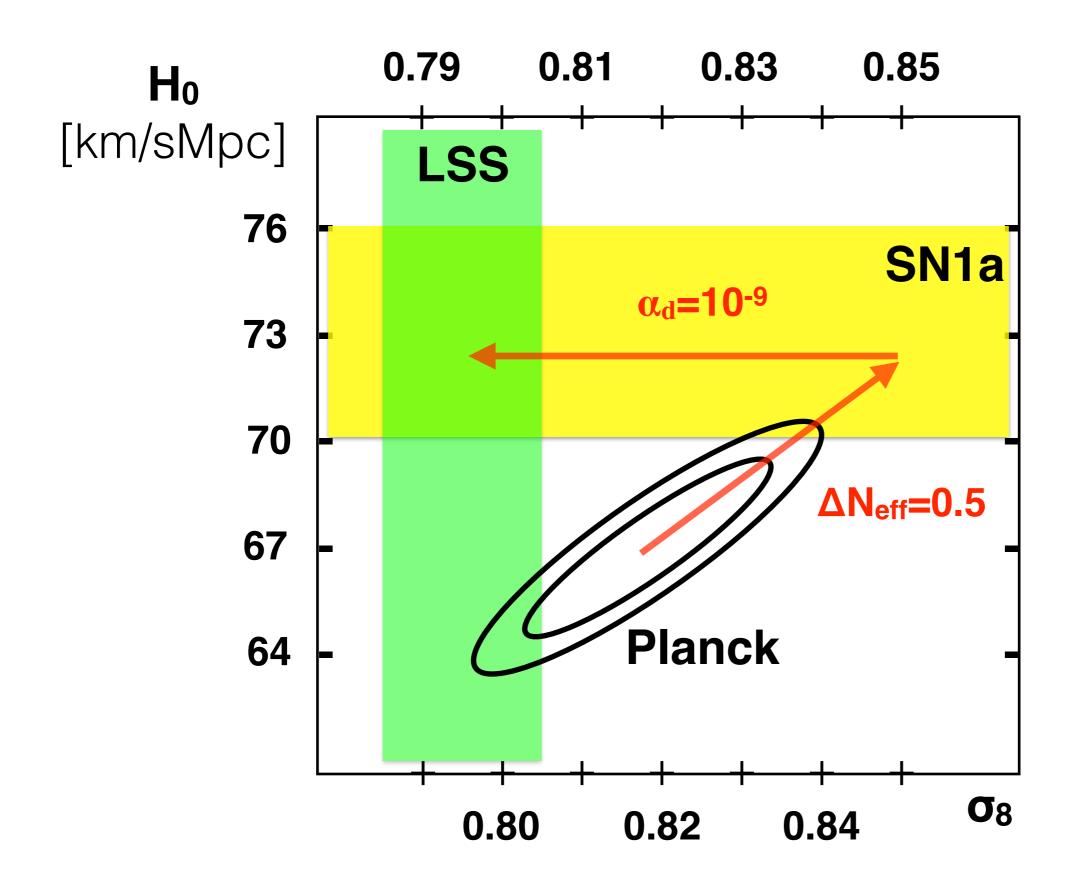
(Battye, Charnock, Moss 1409.2769)

cosmic concordance



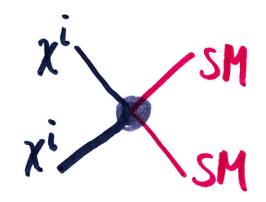






Conclusions?

multiplicity x'



2 dark radiation

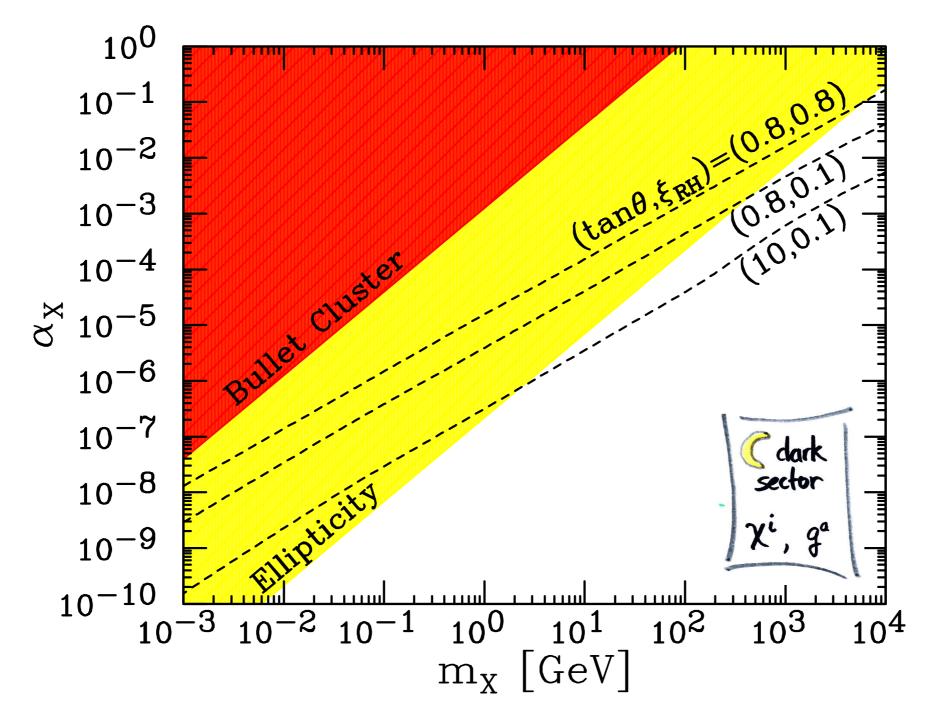
N = 2,3

3. DM-DR coupling



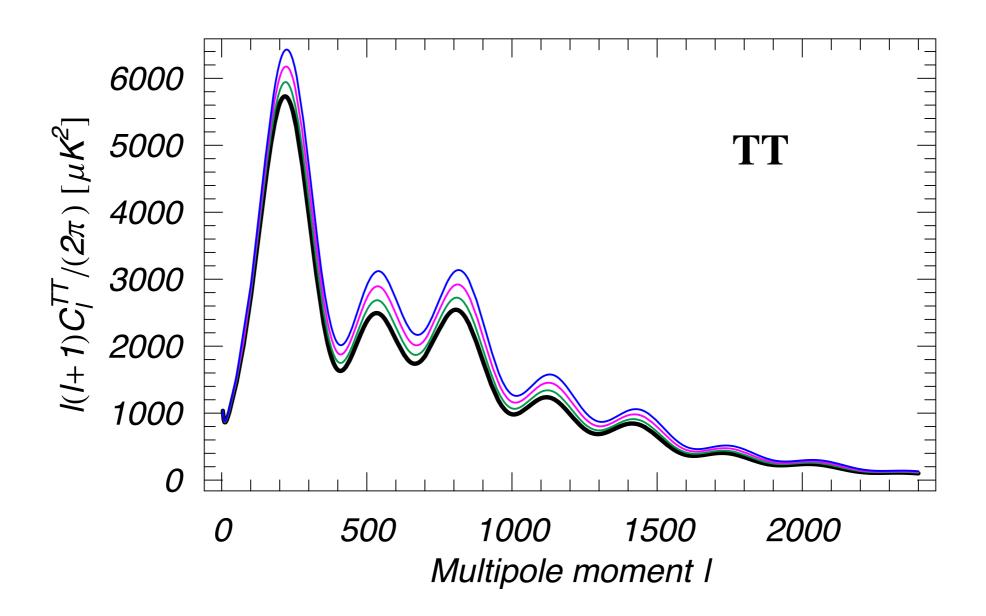
back up!

interacting dark matter bounds



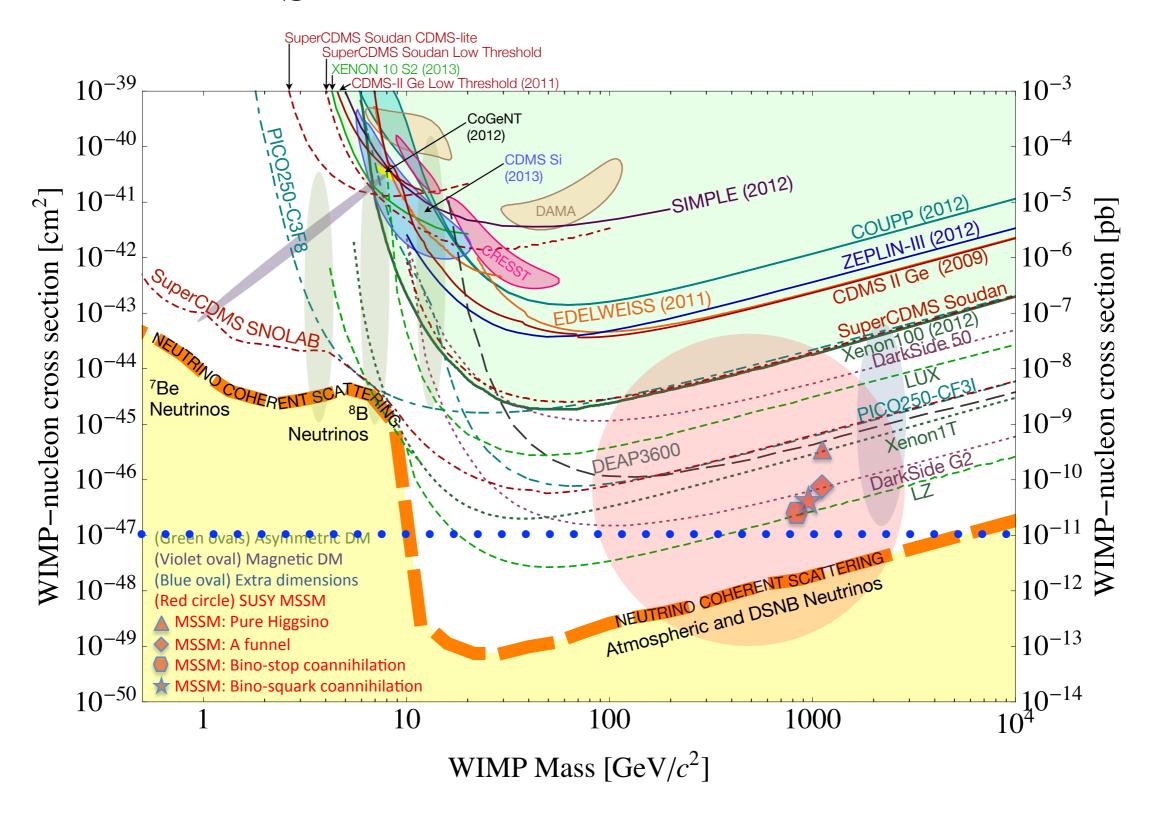
J. Feng, M. Kaplinghat, H. Tu, and H-B. Yu; JCAP 0907 (2009) 004 (arXiv:0905.3039)

CMB and free-streaming v's



A.Friedland, K.M. Zurek and S. Bashinsky, arxiv:0704.3271

$$\sigma_{SI} = 1.3 \times 10^{-47} \text{ cm}^2$$



Snowmass CF1 Summary: WIMP Dark Matter Direct Detection arxiv:1310.8327