Particle Physics Models for DM-DR interactions

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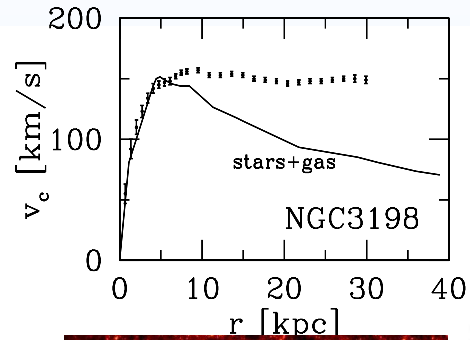
Based on P.Ko&Y.Tang, **1608.01083** *(PLB),* **1609.02307**

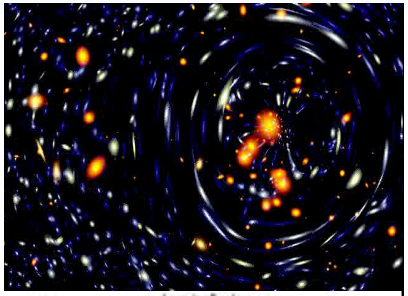
Yong Tang moved to U of Tokyo last month

Outline

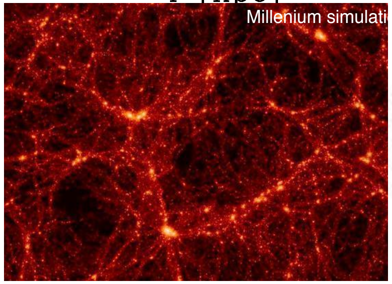
- Introduction & Motivation
  - Dark Matter evidence
  - Hubble constant and structure growth
- DM with dark gauge symmetries
- Interacting Dark Matter&Dark Radiation
  - U(1) dark photon
  - Residual Yang-Mills Dark Matter
- Summary

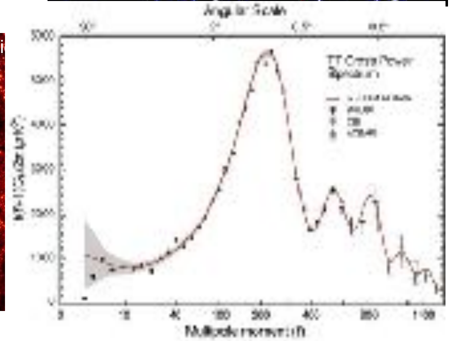
Dark Matter Evidence



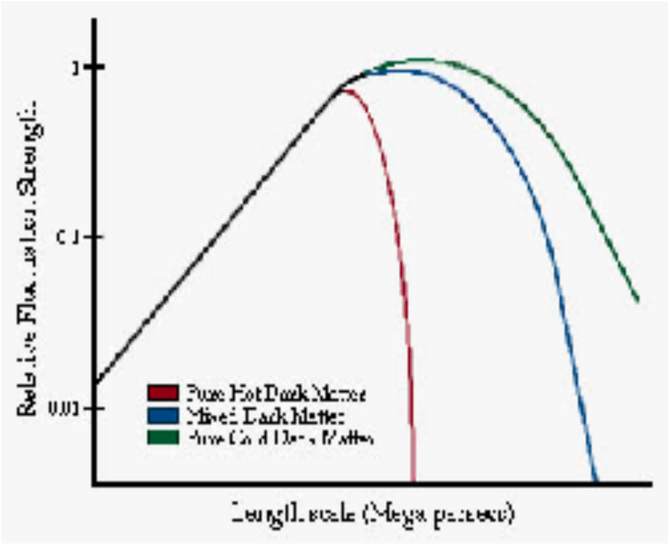


- Rotation Curves of Galaxies
- Gravitational Lensing
- Large Scale Structure
- CMB anisotropies, …





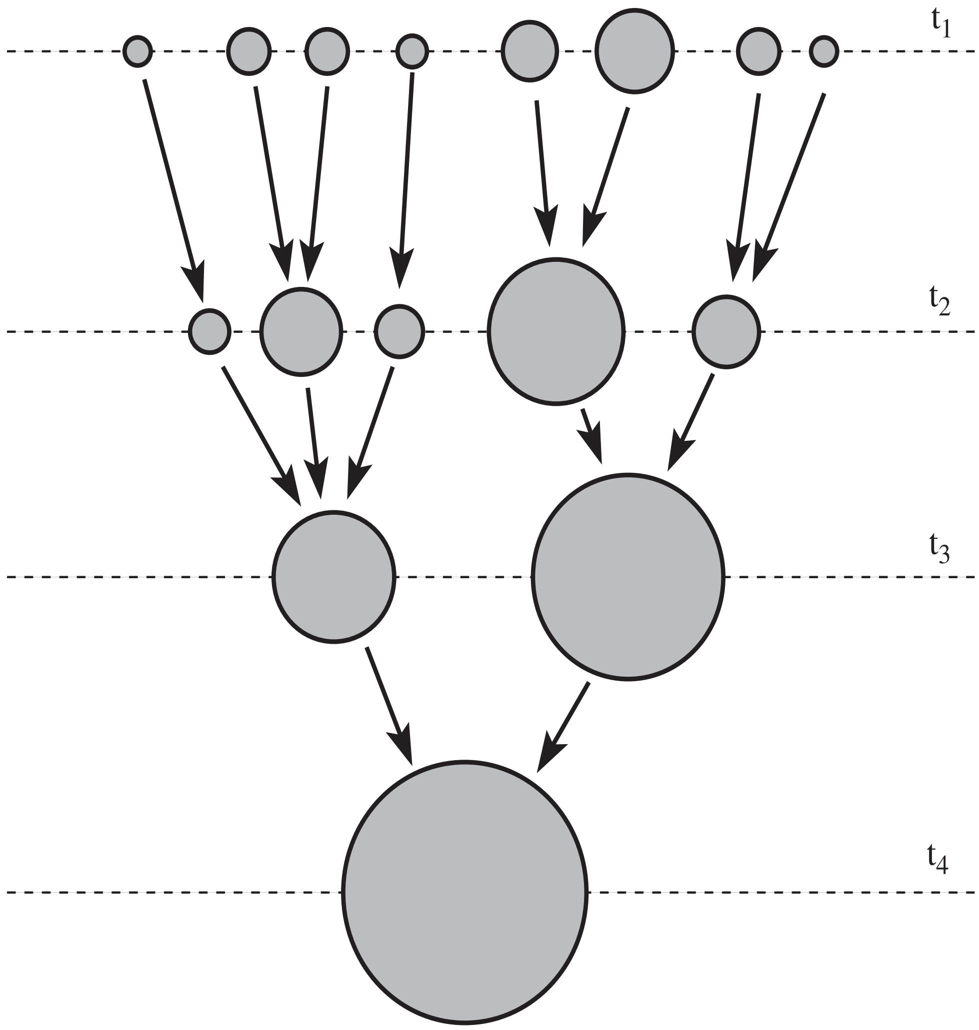
All confirmed evidence comes from gravitational interaction



CDM: negligible velocity, WIMP
WDM: keV sterile neutrino
HDM: active neutrino

Merger History of Dark Halo

- Standard picture
- DM halo grow hierarchically
- Small scale structures form first
- then merge into larger halo



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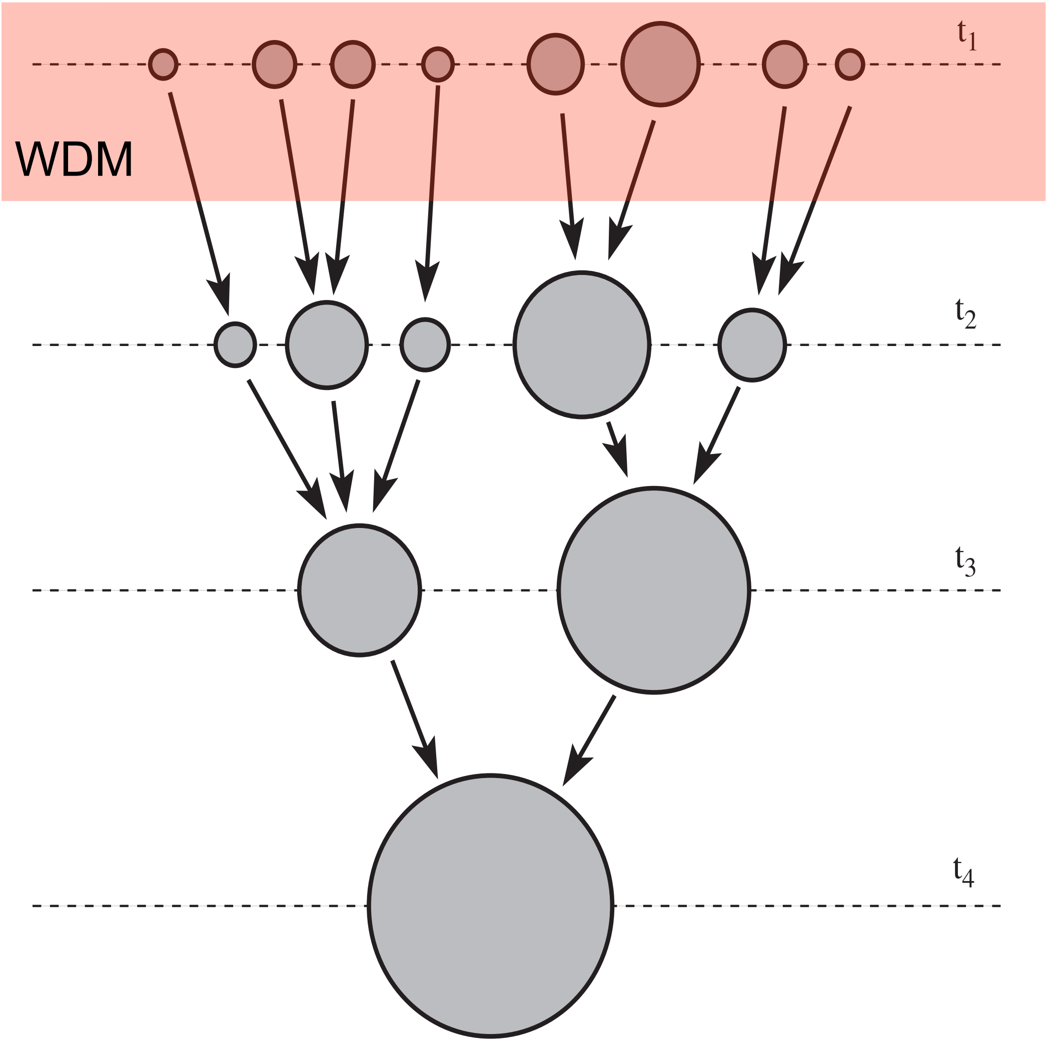

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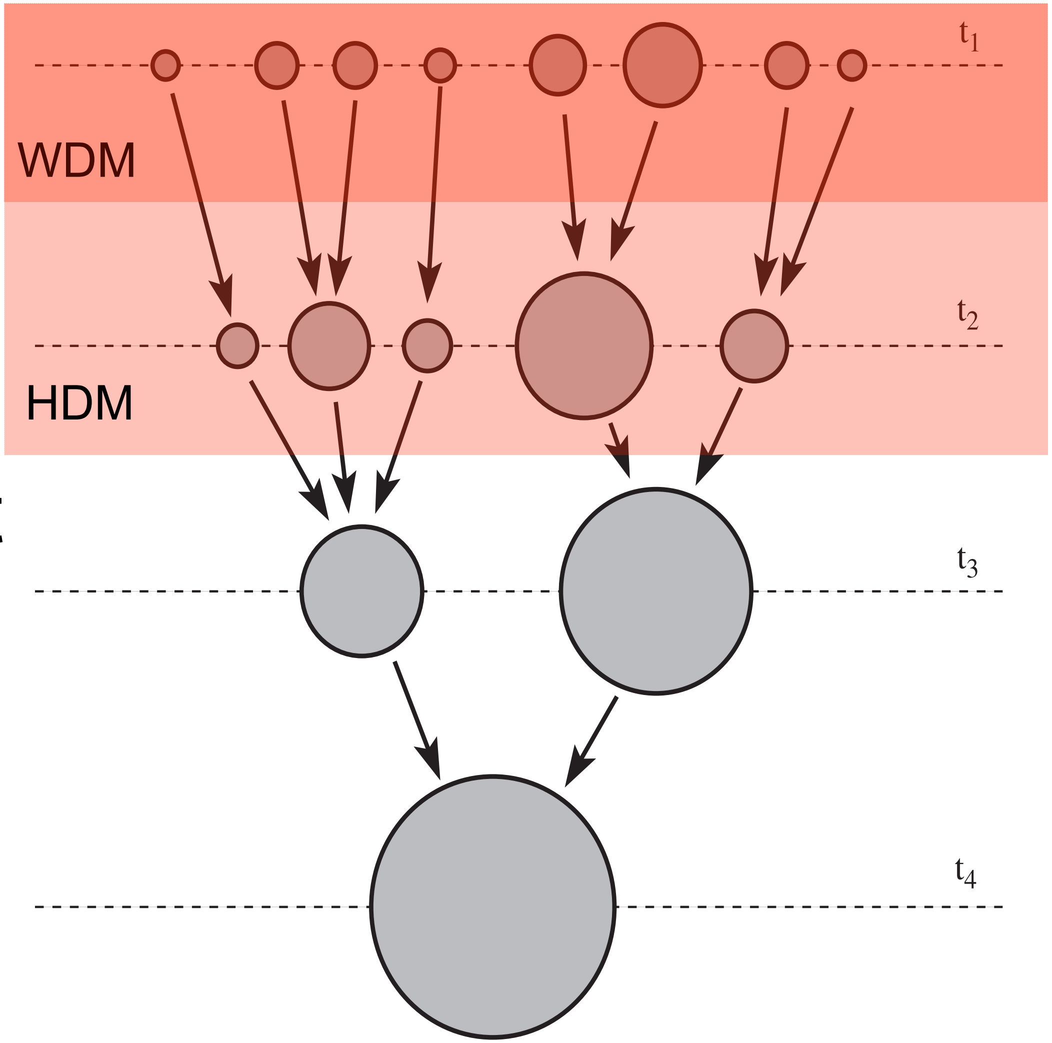
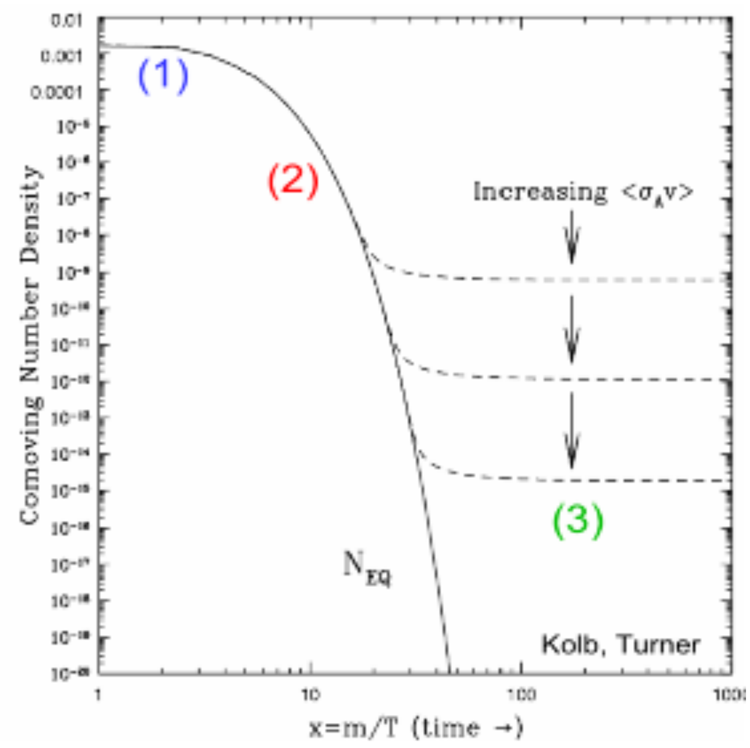
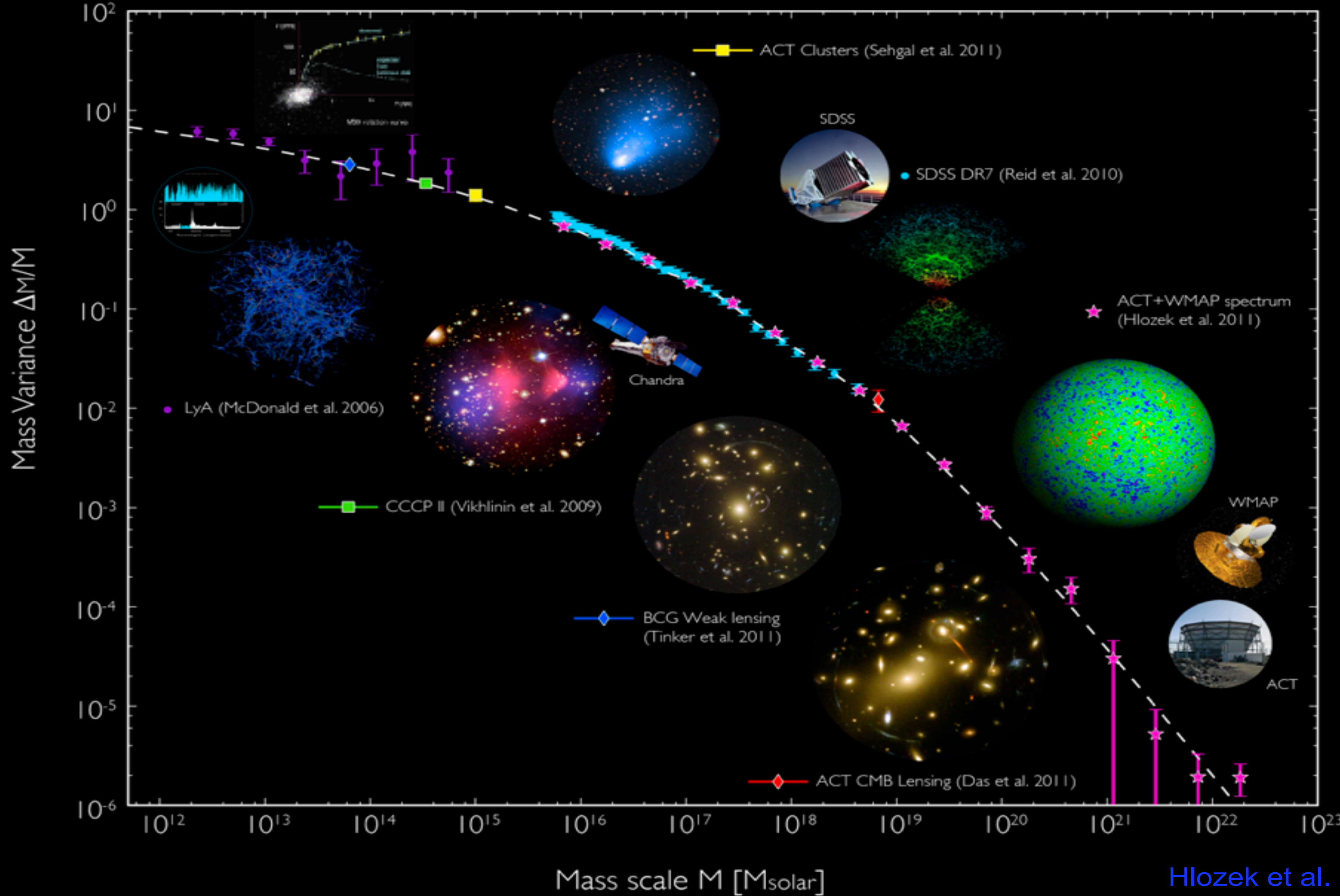


Weakly Interacting Massive Particle (WIMP)

- Mass around ~100GeV
- Coupling ~ 0.5
- Correct relic abundance Ω~0.3
- Thermal History
  - Equilibrium XX<>ff
  - Equilibrium XX >ff
  - Freeze-out
- Cold Dark Matter (CDM)



ΛCDM: successful on large scales



Hlozek et al. 2012

Why Interacting DM ?

- Theoretically interesting
  - Atomic DM, Mirror DM, Composite DM
  - Eventually, all DM is *interacting* in some way, the question is how strongly?
  - Self-Interacting DM $\frac{\sigma}{M_X} \sim \mathrm{cm}^2/\mathrm{g} \sim \mathrm{barn}/\mathrm{GeV}$
- Possible new testable signatures
  - *CMB, LSS, BBN*
  - Other astrophysical effects,…
- Solution of CDM controversies
  - *Cusp-vs-Core, Too-big-to-fail, missing satellite,…*
  - H_0, σ_8? 2-3σ, systematic uncertainty

Review talk by Silvia Galli

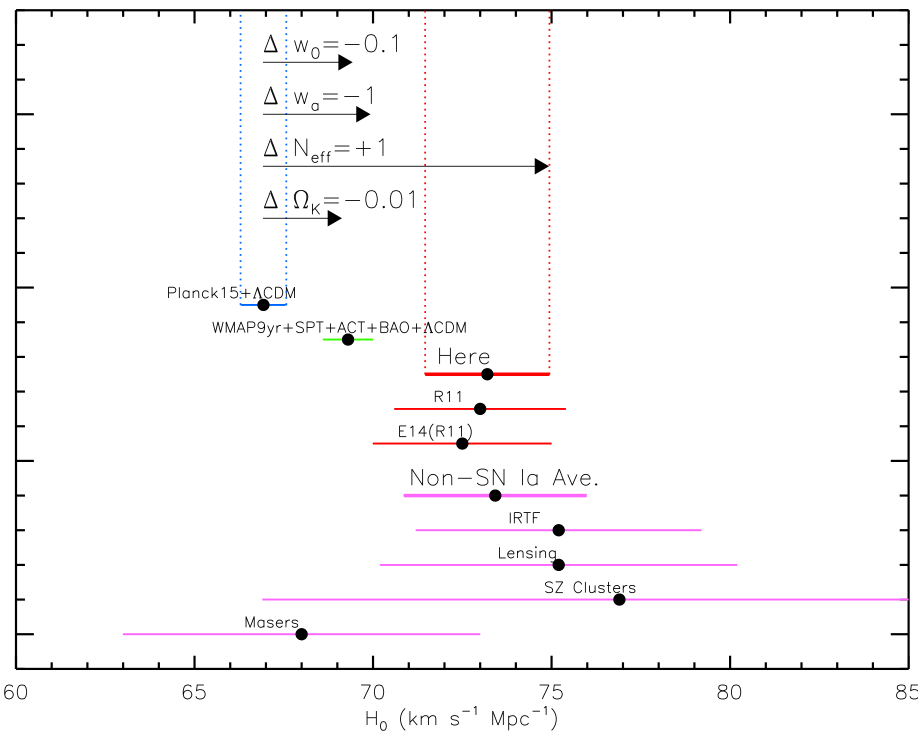
Tension in Hubble Constant?

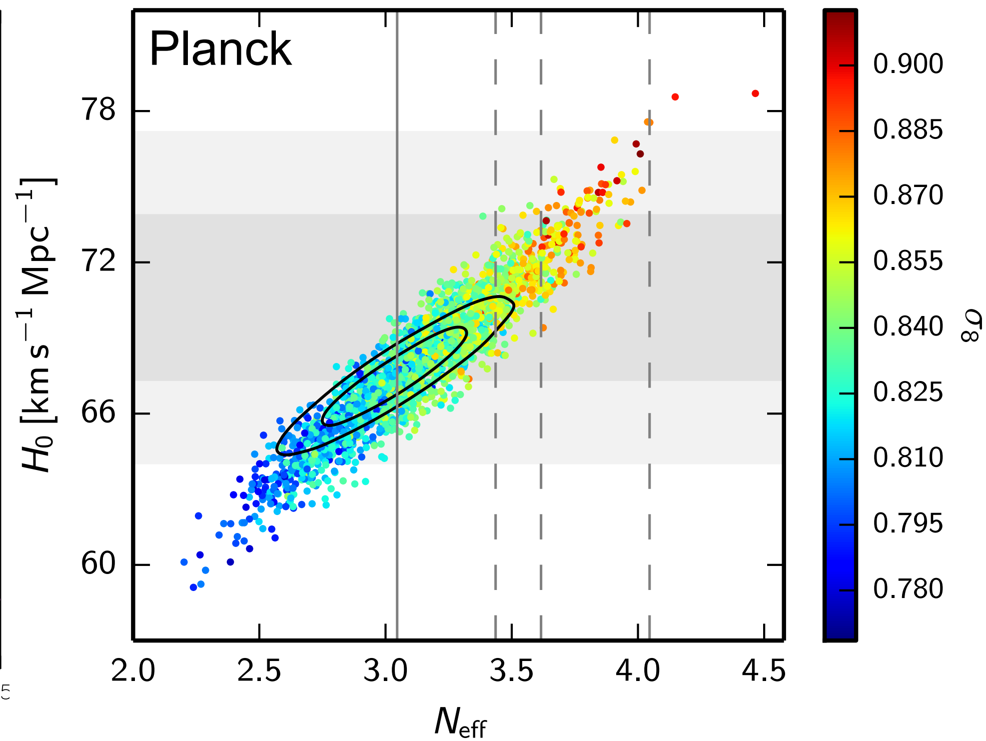
- Hubble Constant H_0 defined as the present value of

$$H \equiv \frac{1}{a}\frac{da}{dt} = \frac{\sqrt{\rho_r + \rho_m + \rho_\Lambda}}{M_p}$$

- Planck(2015) gives $67.8 \pm 0.9 \text{ km s}^{-1}\text{Mpc}^{-1}$
- HST(2016) gives $73.24 \pm 1.74 \text{ km s}^{-1}\text{Mpc}^{-1}$

RIESS ET AL.





Tension in σ₈ ?

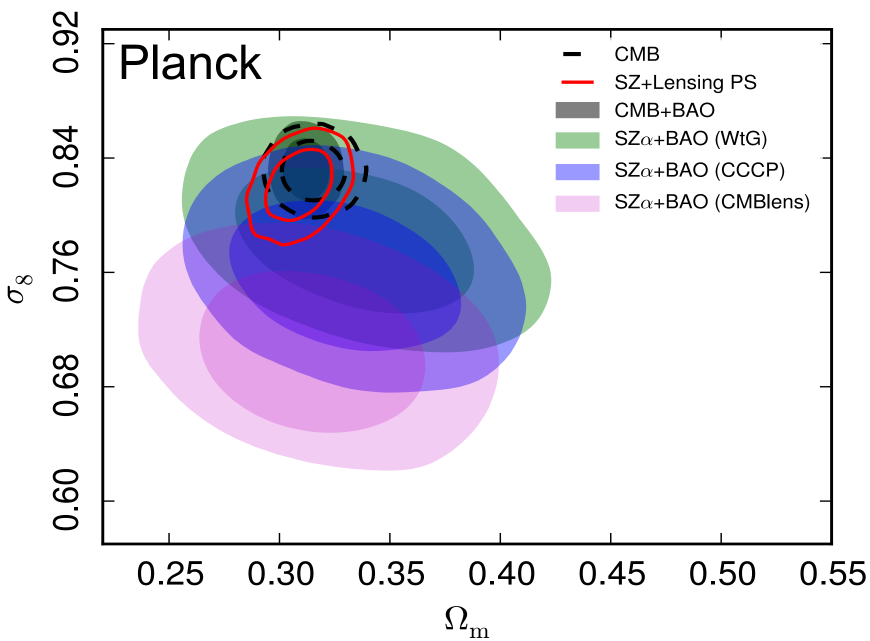
- Variance of perturbation field → collapsed objects

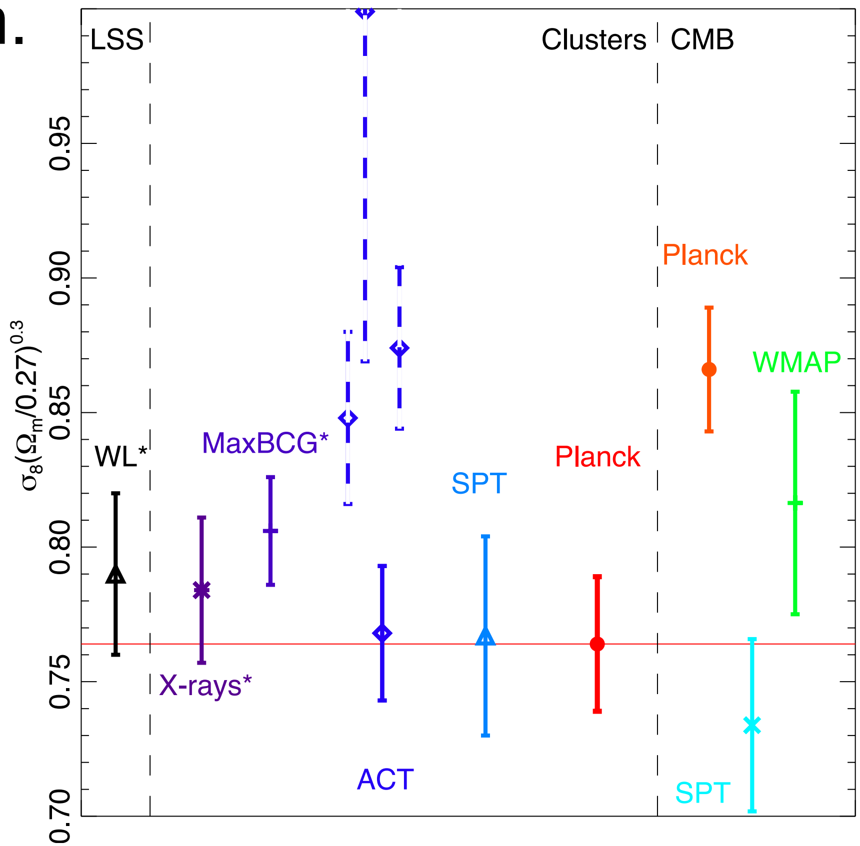
$$\sigma^2(R) = \frac{1}{2\pi^2}\int W_R^2(k)P(k)k^2dk,$$

- where the filter function $W_R(k) = \frac{3}{(kR)^3}\left[\sin(kR) - kR\cos(kR)\right],$

  P(*k*) is matter power spectrum.

- $\sigma_8 \equiv \sigma(8h^{-1}\mathrm{Mpc})$





Tension in σ_8 ?

Planck2015, Sunyaev–Zeldovich cluster counts

Data	$\sigma_8 \left(\frac{\Omega_m}{0.31}\right)^{0.3}$	Ω_m	σ_8
WtG + BAO + BBN	0.806 ± 0.032	0.34 ± 0.03	0.78 ± 0.03
CCCP + BAO + BBN **[Baseline]**	0.774 ± 0.034	0.33 ± 0.03	0.76 ± 0.03
CMBlens + BAO + BBN	0.723 ± 0.038	0.32 ± 0.03	0.71 ± 0.03
CCCP + H_0 + BBN	0.772 ± 0.034	0.31 ± 0.04	0.78 ± 0.04

Planck2015, Primary CMB

Parameter	[1] *Planck* TT+lowP	[2] *Planck* TE+lowP	[3] *Planck* EE+lowP	[4] *Planck* TT,TE,EE+lowP
$\Omega_b h^2$	0.02222 ± 0.00023	0.02228 ± 0.00025	0.0240 ± 0.0013	0.02225 ± 0.00016
$\Omega_c h^2$	0.1197 ± 0.0022	0.1187 ± 0.0021	$0.1150^{+0.0048}_{-0.0055}$	0.1198 ± 0.0015
$100\theta_{MC}$	1.04085 ± 0.00047	1.04094 ± 0.00051	1.03988 ± 0.00094	1.04077 ± 0.00032
τ	0.078 ± 0.019	0.053 ± 0.019	$0.059^{+0.022}_{-0.019}$	0.079 ± 0.017
$\ln(10^{10}A_s)$	3.089 ± 0.036	3.031 ± 0.041	$3.066^{+0.046}_{-0.041}$	3.094 ± 0.034
n_s	0.9655 ± 0.0062	0.965 ± 0.012	0.973 ± 0.016	0.9645 ± 0.0049
H_0	67.31 ± 0.96	67.73 ± 0.92	70.2 ± 3.0	67.27 ± 0.66
Ω_m	0.315 ± 0.013	0.300 ± 0.012	$0.286^{+0.027}_{-0.038}$	0.3156 ± 0.0091
σ_8	0.829 ± 0.014	0.802 ± 0.018	0.796 ± 0.024	0.831 ± 0.013
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.865 ± 0.019	1.907 ± 0.027	1.882 ± 0.012

Interacting Dark Matter

DM phenomenology often requires

- New force mediators (scalar, vector, ….) in order to solve some puzzles in the standard collision less CDM paradigm
- Extra particles in the dark sector (excited DM, dark radiation, force mediators, etc.) often used for phenomenological reasons
- Any good organizing principles for these extra particles ?
- Answer : Dark gauge symmetry (dark gauge boson/dark Higgs appear naturally, their dynamics is completely fixed by gauge principle)

DM with dark gauge symmetries

- SM based on Poincare + local gauge symmetry within 4-dim QFT : extremely successful and provides qualitative answers to light neutrino masses, nonobservation of proton (Lepton # and baryon # : accidental symmetry of the renormalizable SM, and broken only by higher dim operators)
- DM : either absolutely stable or long lived (could be due to local gauge symmetry or some accidental symmetry) and both can be accommodated by local dark gauge symmetries

Z2 sym as an example

$$\mathcal{L} = \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2} m_S^2 S^2 - \frac{\lambda_S}{4!} S^4 - \frac{\lambda_{SH}}{2} S^2 H^\dagger H.$$

- Simplest DM model in terms of # of new d.o.f.
- Very popular alternative to SUSY LSP
- But where does this Z2 come from ?
- Global or Local ?
- Global Z2 probably cannot make S love long enough due to Z2 breaking dim-5 operator

Fate of DM w/ global Z2

Consider Z_2 breaking operators such as

$$\frac{1}{M_{\text{Planck}}} S O_{\text{SM}}$$

keeping dim-4 SM operators only

The lifetime of the Z_2 symmetric scalar CDM S is roughly given by

$$\Gamma(S) \sim \frac{{m_S}^3}{M_{\text{Planck}}^2} \sim (\frac{m_S}{100\text{GeV}})^3 10^{-37} GeV$$

The lifetime is too short for 100 GeV DM

- NB: a very light scalar (such as axion) can be long lived enough to be a good DM

Higgs could be harmful to DM

- Spontaneously broken local U(1)X can do the job to a certain extent, but here still is a problem

Let us assume a local $U(1)_X$ is spontaneously broken by $\langle \phi_X \rangle \neq 0$ with

$$Q_X(\phi_X) = Q_X(X) = 1$$

Then, there are two types of dangerous operators:

$\phi_X^\dagger X H^\dagger H,$ and $\phi_X^\dagger X O_{\rm SM}^{(dim-4)}$

Problematic !

Perfectly fine !

- This type of argument applies to all DM models with ad hoc Z2 symmetries, DM being scalar, fermion or vector boson
- One way to avoid this problem is to make a judicious assignments of dark charges to the dark sector fields, thereby Z2 being a subgroup of local U(1)X
- Local U(1)X guarantees the stability of DM even in the presence of higher dimensional operators
- One can also consider local Z3 from U(1)X

SBaek, PKo, WIPark, 1407.6588, PLB

$$Q_X(\phi) = 2, \quad Q_X(X) = 1$$

$$\mathcal{L} = \mathcal{L}_{\rm SM} + -\frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{1}{2}\epsilon X_{\mu\nu}B^{\mu\nu} + D_\mu\phi_X^\dagger D^\mu\phi_X - \frac{\lambda_X}{4}\left(\phi_X^\dagger\phi_X - v_\phi^2\right)^2 + D_\mu X^\dagger D^\mu X - m_X^2 X^\dagger X$$
$$- \frac{\lambda_X}{4}\left(X^\dagger X\right)^2 - \left(\mu X^2\phi^\dagger + H.c.\right) - \frac{\lambda_{XH}}{4}X^\dagger X H^\dagger H - \frac{\lambda_{\phi_X H}}{4}\phi_X^\dagger\phi_X H^\dagger H - \frac{\lambda_{XH}}{4}X^\dagger X\phi_X^\dagger\phi_X$$

The lagrangian is invariant under $X \to -X$ even after $U(1)_X$ symmetry breaking.

Unbroken Local Z2 symmetry

(A model without phi was used by several groups for 511 keV and PAMELA)

$$X_R \to X_I\gamma_h^* \quad \text{followed by} \quad \gamma_h^* \to \gamma \to e^+e^- \qquad \text{etc.}$$

The heavier state decays into the lighter state

The local Z2 model is not that simple as the usual Z2 scalar DM model (also for the fermion CDM)

New windows for DM phenomenology

- DM (+ excited DM) + dark gauge boson + dark Higgs
- Singlet portals [Higgs portal, kinetic mixing for U(1)X, RH neutrino portal] thermalize DM efficiently, and provide tools for (in)direct detections and collider searches for DM
  (SBaek, PKo, WIPark, 1303.4280, JHEP, and other papers for collider searches for Higgs portal DM)
- In particular DM+DM > DG's, DH's open a new window for DM phenomenology

Unbroken Local Dark Sym

- Local dark symmetry can be either confining (like QCD) or not
- For confining dark symmetry, gauge fields will confine and there is no long range dark force, and DM will be composite baryons/mesons in the hidden sector
- Otherwise, there could be a long range dark force that is constrained by large/small scale structures and/or dark matter self interactions, and contributes to dark radiation

Spon. Broken local dark sym

- If dark sym is spont. broken, DM will decay in general, unless there is a residual unbroken (discrete) subgroup of dark gauge symmetry
- There will be a singlet scalar after spontaneous breaking of dark gauge symmetry, which mixes with the SM Higgs boson
- There will be at least two neutral scalars (and no charged scalars) in this case
- Vacuum stability improved by the new scalar and modified Higgs inflation assisted by Higgs portal
- Higgs Signal strengths universally reduced from "ONE"

Interacting DM & DR

- Light sterile fermion DR + Dark photon
- Nonabelian DM + DR

A Light Dark Photon

P.Ko, YT,1608.01083(PLB)

- Lagrangian

$$\mathcal{L} = -\frac{1}{4}V_{\mu\nu}V^{\mu\nu} + D_\mu\Phi^\dagger D^\mu\Phi + \bar{\chi}\left(i\not{D} - m_\chi\right)\chi + \bar{\psi}i\not{D}\psi$$
$$-\left(y_\chi\Phi^\dagger\bar{\chi}^c\chi + y_\psi\Phi\bar{\psi}N + h.c.\right) - V(\Phi, H),$$

- DM χ (+1), dark radiation ψ(+2), scalar(+2)
- *U(1)* symmetry (*unbroken*), massless dark photon V_μ
- Φ is responsible for the DM relic density

$$\Omega h^2 \simeq 0.1 \times \left(\frac{y_\chi}{0.7}\right)^{-4}\left(\frac{m_\chi}{\mathrm{TeV}}\right)^2.$$

- Φ can decay into ψ and *N*.

Dark Radiation δN_{eff}

- Effective Number of Neutrinos, N_{eff}

$$\rho_R = \left[1 + N_{\rm eff} \times \frac{7}{8}\left(\frac{4}{11}\right)^{4/3}\right]\rho_\gamma,$$

$$\rho_\gamma \propto T_\gamma^4$$

- In SM cosmology, N_{eff} =3.046, Neutrinos decouple around MeV, and then stream freely.
- Cosmological bounds

Joint CMB+BBN, 95% CL preferred ranges *Planck 2015, arXiv:1502.01589*

$$N_{\rm eff} = \begin{cases} 3.11^{+0.59}_{-0.57} & \text{He+}\textit{Planck}\text{ TT+lowP,} \\ 3.14^{+0.44}_{-0.43} & \text{He+}\textit{Planck}\text{ TT+lowP+BAO,} \\ 2.99^{+0.39}_{-0.39} & \text{He+}\textit{Planck}\text{ TT,TE,EE+lowP,} \end{cases}$$

Constraint on New Physics

$$\left.\begin{array}{r} N_{\rm eff} < 3.7 \\ m^{\rm eff}_{\nu,\,\rm sterile} < 0.52\ \rm eV \end{array}\right\} \text{95\%, } \textit{Planck}\text{ TT+lowP+lensing+BAO.}$$

Dark Radiation $\delta N_{\rm eff}$

- Massless dark photon and fermion will contribute

$$\delta N_{\rm eff} = \left(\frac{8}{7}+2\right)\left[\frac{g_{*s}\left(T_\nu\right)}{g_{*s}\left(T^{\rm dec}\right)}\frac{g_{*s}^D\left(T^{\rm dec}\right)}{g_{*s}^D\left(T_D\right)}\right]^{\frac{4}{3}},$$

where T_ν is neutrino's temperature,

g_{*s} counts the effective number of dof for entropy density in SM,

g_{*s}^D denotes the effective number of dof being in kinetic equilibrium with V_μ.

For instance, when $T^{\rm dec} \gg m_t \simeq 173{\rm GeV}$ for $|\lambda_{\Phi H}| \sim 10^{-6}$, we can estimate $\delta N_{\rm eff}$ at the BBN epoch as

$$\delta N_{\rm eff} = \frac{22}{7}\left[\frac{43/4}{427/4}\frac{11}{9/2}\right]^{\frac{4}{3}} \simeq 0.53, \tag{1}$$

$\boxed{\delta N_{\rm eff}\text{=0.4~1 for relaxing tension in Hubble constant}}$

Diffusion Damping

- Dark Matter scatters with radiation, which induces new contributions in the cosmological perturbation equations,

$$\dot{\delta}_\chi = -\theta_\chi + 3\dot{\Phi},$$

$$\dot{\theta}_\chi = k^2\Psi - \mathcal{H}\theta_\chi + S^{-1}\dot{\mu}\left(\theta_\psi - \theta_\chi\right),$$

$$\dot{\theta}_\psi = k^2\Psi + k^2\left(\frac{1}{4}\delta_\psi - \sigma_\psi\right) - \dot{\mu}\left(\theta_\psi - \theta_\chi\right),$$

where dot means derivative over conformal time $d\tau \equiv dt/a$ (a is the scale factor), θ_ψ and θ_χ are velocity divergences of radiation ψ and DM χ's, k is the comoving wave number, Ψ is the gravitational potential, δ_ψ and σ_ψ are the density perturbation and the anisotropic stress potential of ψ, and $\mathcal{H} \equiv \dot{a}/a$ is the conformal Hubble parameter. Finally, the scattering rate and the density ratio are defined by $\dot{\mu} = an_\chi\langle\sigma_{\chi\psi}c\rangle$ and $S = 3\rho_\chi/4\rho_\psi$, respectively.

Scattering Cross Section

The averaged cross section $\langle\sigma_{\chi\psi}\rangle$ can be estimated from the squared matrix element for $\chi\psi \to \chi\psi$:

$$\overline{|\mathcal{M}|^2} \equiv \frac{1}{4}\sum_{\text{pol}} |\mathcal{M}|^2 = \frac{2g_X^4}{t^2}\left[t^2 + 2st + 8m_\chi^2 E_\psi^2\right], \quad (9)$$

where the Mandelstam variables are $t = 2E_\psi^2(\cos\theta - 1)$ and $s = m_\chi^2 + 2m_\chi E_\psi$, where θ is the scattering angle, and E_ψ is the energy of incoming ψ in the rest frame of χ. Integrated with a temperature-dependent Fermi-Dirac distribution for E_ψ, we find that $\langle\sigma_{\chi\psi}\rangle$ goes roughly as $g_X^4/(4\pi T_D^2)$.

- *In general, the cross section could have different temperature dependence, depending on the underlying particle models.*

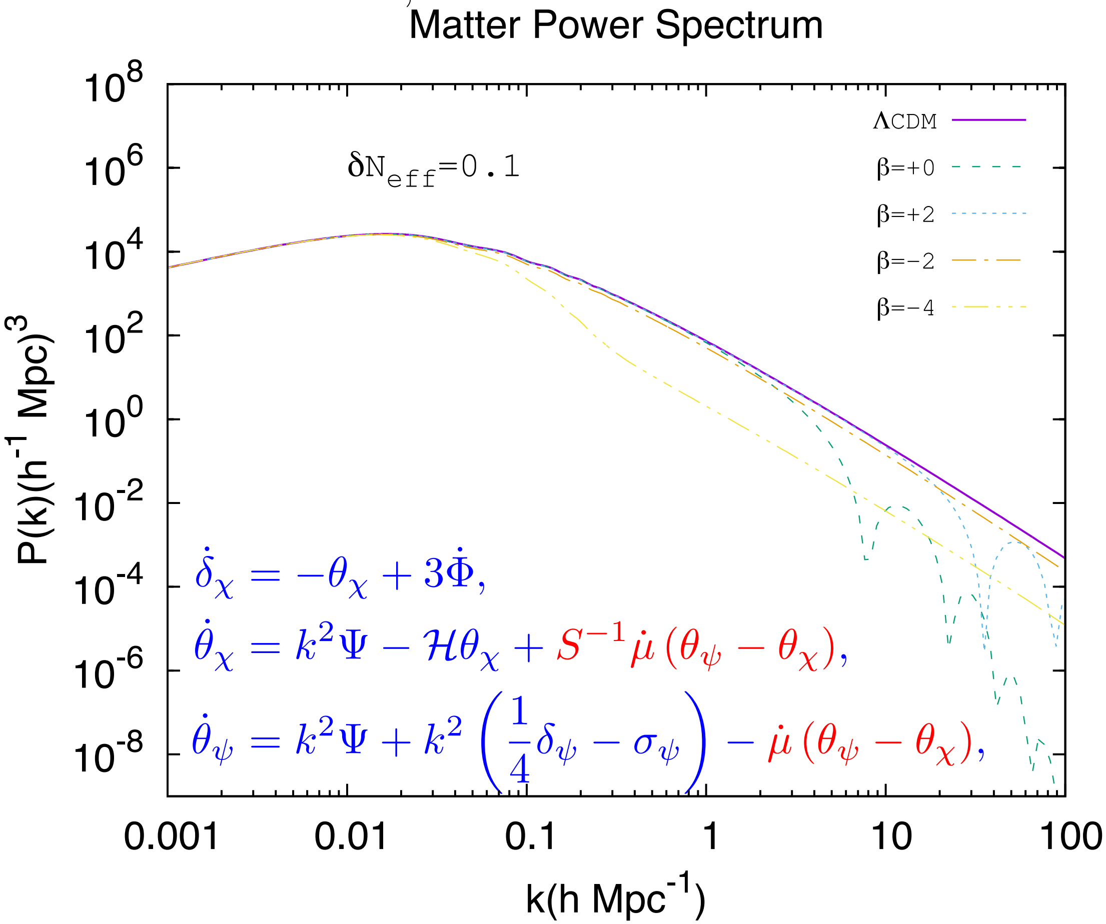
Effects on LSS

Parametrize the cross section ratio

Y.Tang,1603.00165(PLB)

$$u_0 \equiv \left[\frac{\sigma_{\chi\psi}}{\sigma_{\rm Th}}\right]\left[\frac{100{\rm GeV}}{m_\chi}\right], u_\beta(T) = u_0\left(\frac{T}{T_0}\right)^\beta,$$

where $\sigma_{\rm Th}$ is the Thomson cross section, $0.67\times10^{-24}{\rm cm}^{-2}$.



$$\dot{\delta}_\chi = -\theta_\chi + 3\dot{\Phi},$$

$$\dot{\theta}_\chi = k^2\Psi - \mathcal{H}\theta_\chi + S^{-1}\dot{\mu}\left(\theta_\psi - \theta_\chi\right),$$

$$\dot{\theta}_\psi = k^2\Psi + k^2\left(\frac{1}{4}\delta_\psi - \sigma_\psi\right) - \dot{\mu}\left(\theta_\psi - \theta_\chi\right),$$

Numerical Results

We take the central values of six parameters of ΛCDM from `Planck`,

$\Omega_b h^2 = 0.02227,$ Baryon density today

$\Omega_c h^2 = 0.1184,$ CDM density today

$100\theta_{\rm MC} = 1.04106,$ $100 \times$ approximation to r_*/D_A

$\tau = 0.067,$ Thomson scattering optical depth

$\ln\left(10^{10} A_s\right) = 3.064,$ Log power of primordial curvature perturbations

$n_s = 0.9681,$ Scalar Spectrum power-law index

which gives $\sigma_8 = 0.817$ in vanilla ΛCDM cosmology.

With the same input as above, now take

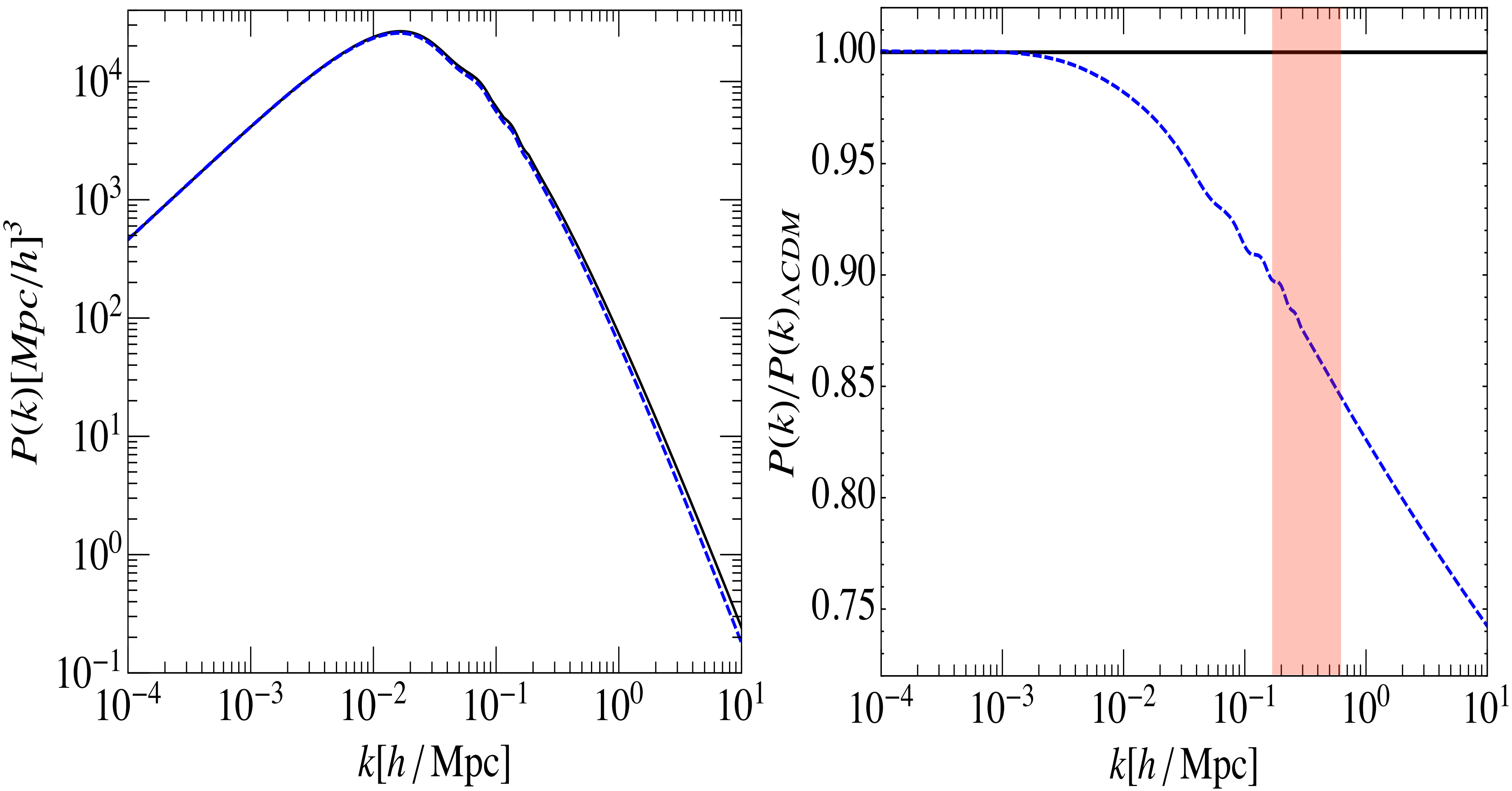
$$\delta N_{\rm eff} \simeq 0.53, m_\chi \simeq 100\text{GeV and } g_X^2 \simeq 10^{-8}$$

in the interacting DM case, we have $\sigma_8 \simeq 0.744$.

Modified Boltzmann code ***CLASS(Blas&Lesgourgues&Tram)***

Matter Power Spectrum

DM-DR scattering causes diffuse damping at relevant scales, resolving σ_8 problem



Results

We take the central values of six parameters of ΛCDM from `Planck` [1],

$$\Omega_b h^2 = 0.02227, \Omega_c h^2 = 0.1184, 100\theta_{\rm MC} = 1.04106,$$
$$\tau = 0.067, \ln\left(10^{10} A_s\right) = 3.064, n_s = 0.9681, \qquad (11)$$

which gives $\boxed{\sigma_8 = 0.817}$ in vanilla ΛCDM cosmology. With the same input as above, now we take $\boxed{\delta N_{\rm eff} \simeq 0.53,}$ $m_\chi \simeq 100\text{GeV}$ and $g_X^2 \simeq 10^{-8}$ in the interacting DM case, we have $\boxed{\sigma_8 \simeq 0.744}$ which is much closer to the value $\sigma_8 \simeq 0.730$ given by weak lensing survey CFHTLenS [3].

Residual Non-Abelian DM&DR

P.Ko&YT, 1609.02307

- Consider *SU(N)* Yang-Mills gauge fields and a Dark Higgs field Φ

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + (D_\mu\Phi)^\dagger(D^\mu\Phi) - \lambda_\phi\left(|\Phi|^2 - v_\phi^2/2\right)^2,$$

- Take *SU(3)* as an example,

$$A^a_\mu t^a = \frac{1}{2}\begin{pmatrix} A^3_\mu + \frac{1}{\sqrt{3}}A^8_\mu & A^1_\mu - iA^2_\mu & A^4_\mu - iA^5_\mu \\ A^1_\mu + iA^2_\mu & -A^3_\mu + \frac{1}{\sqrt{3}}A^8_\mu & A^6_\mu - iA^7_\mu \\ A^4_\mu + iA^5_\mu & A^6_\mu + iA^7_\mu & -\frac{2}{\sqrt{3}}A^8_\mu \end{pmatrix}.$$

- *SU(3)* → *SU(2)*

$$\langle\Phi\rangle = \begin{pmatrix} 0 & 0 & \frac{v_\phi}{\sqrt{2}} \end{pmatrix}^T, \Phi = \begin{pmatrix} 0 & 0 & \frac{v_\phi + \phi(x)}{\sqrt{2}} \end{pmatrix}^T,$$

The massive gauge bosons $A^{4,\cdots,8}$ as dark matter obtain masses,

$$m_{A^{4,5,6,7}} = \frac{1}{2}gv_\phi,\ m_{A^8} = \frac{1}{\sqrt{3}}gv_\phi,$$

and massless gauge bosons $A^{1,2,3}_\mu$. The physical scalar ϕ can couple to $A^{4,\cdots,8}_\mu$ at tree level and to $A^{1,2,3}$ at loop level.

$SU(N) \to SU(N-1)$

- *2N-1* massive gauge bosons: Dark Matter
- *(N-1)²-1* massless gauge bosons: Dark Radiation
- mass spectrum

$$m_{A^{(N-1)^2,\ldots,N^2-2}} = \frac{1}{2} g v_\phi, \; m_{A^{N^2-1}} = \frac{\sqrt{N-1}}{\sqrt{2N}} g v_\phi,$$

This can be proved by looking at the structure of f^{abc}. Divide the generators t^a into two subset,

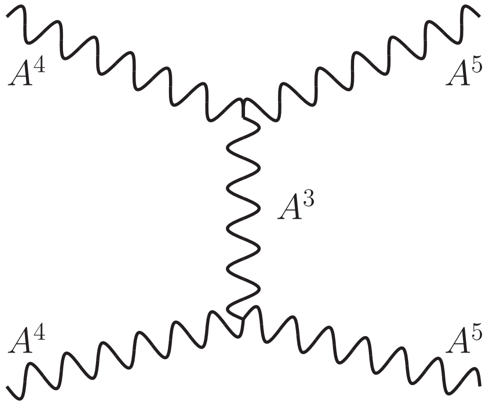
$$a \subset [1, 2, ..., (N-1)^2 - 1], a \subset [(N-1)^2, ..., N^2 - 1].$$

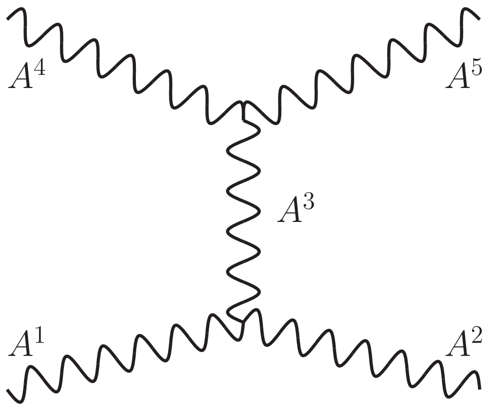
Since $[t^a, t^b] = i f^{abc} t^c$ for the first subset forms closed $SU(N-1)$ algebra, we have $f^{abc} = 0$ when only one of a, b and c is from the second subset. If one index is $N^2 - 1$, then other two must be among the second subset to give no vanishing f^{abc}, because t^{N^2-1} commutes with t^a from $SU(N-1)$.

Phenomenology

- Self-scattering processes

P.Ko&YT, 1609.02307





- Constraints

$$\delta N_{\rm eff} = \frac{8}{7}\left[(N-1)^2 - 1\right] \times 0.055,$$

$$g^2 \lesssim \frac{T_\gamma}{T_A}\left(\frac{m_A}{M_P}\right)^{1/2} \sim 10^{-7},$$

$$\frac{m_A}{T_{\rm reh}} \sim \ln\left[\frac{\Omega_b M_P g^4}{\Omega_X m_p \eta}\right] \sim \mathcal{O}(30).$$

- ***N<6 if thermal***
- ***small coupling,***
- ***non-thermal production,***
- ***low reheating temperature***

Schmaltz et al(2015) EW charged DM

Matter Power Spectrum

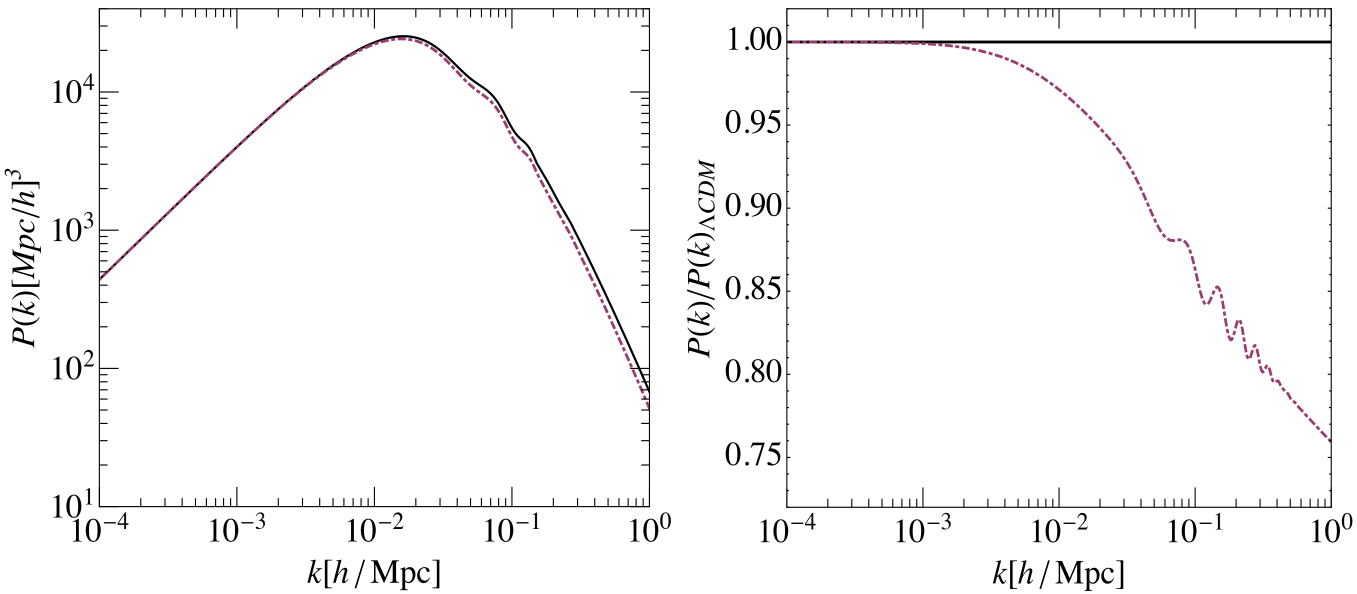


FIG. 3. Matter power spectrum $P(k)$ (left) and ratio (right) with $m_\chi \simeq 10\text{TeV}$ and $g_X^2 \simeq 10^{-7}$, in comparison with ΛCDM. The black solid lines are for ΛCDM and the purple dot-dashed lines for interacting DM-DR case, with input parameters in Eq. 21. We can easily see that $P(k)$ is suppressed for modes that enter horizon at radiation-dominant era. Those little wiggles are due to the well-known baryon acoustic oscillation.

Results

$$\Omega_b h^2 = 0.02227, \Omega_c h^2 = 0.1184, 100\theta_{\rm MC} = 1.04106,$$
$$\tau = 0.067, \ln\left(10^{10} A_s\right) = 3.064, n_s = 0.9681, \tag{21}$$

and treat neutrino mass the same way as `Planck` did with $\sum m_\nu = 0.06$eV, which gives $\sigma_8 = 0.815$ in vanilla ΛCDM cosmology. Together with the same inputs as above, we take $\delta N_{\rm eff} \simeq 0.5$, $m_\chi \simeq 10$TeV and $g_X^2 \simeq 10^{-7}$ in the interacting DM-DR case, we have $\sigma_8 \simeq 0.746$ which is much closer to the value $\sigma_8 \simeq 0.730$ given by weak lensing survey CFHTLenS [12].

- Within DM models with local dark gauge symmetry, we could increase Neff, H_0 whereas making σ_8 decrease, thereby relaxing the tension between H_0 and σ_8

Summary

- We discussed some cosmological effects with *interacting* Dark Matter and Dark Radiation within DM models with dark gauge symmetries
- This scenario is motivated theoretically and also from observational tensions, H_0 and σ_8
- We present two particle physics models:
  - A massless dark photon with *unbroken U(1)* gauge symmetry
  - *Residual non-Abelian* Dark Matter and Dark Radiation
- It is possible to resolve tensions simultaneously

Thanks for your attention.