University of Zurich[UZH]

Institute for Computational Science

Emulating 2-body Decaying Dark Matter with Neural Networks and Cosmological Observables

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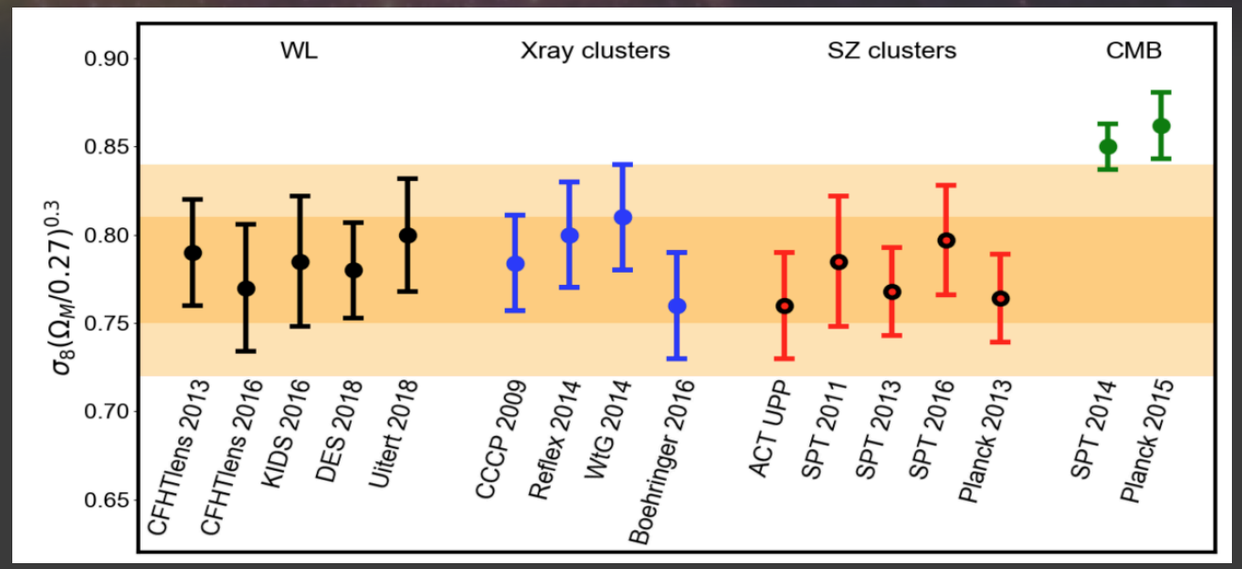
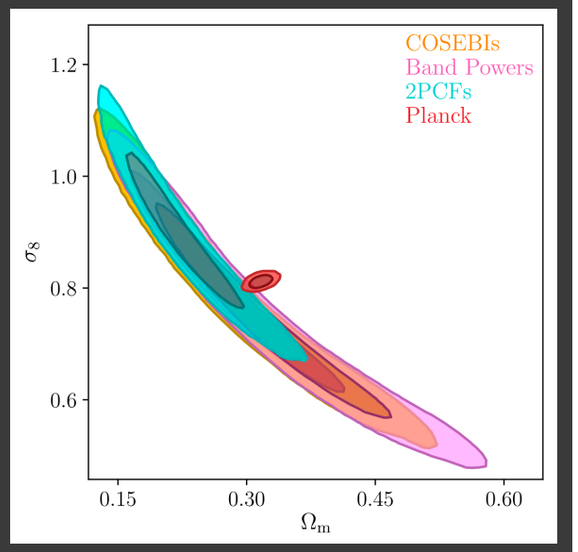
Motivation

- Nature of DM still unknown
- Cosmological tensions (σ_8, H_0)
- Minimal extension to ΛCDM
- 2-body decaying dark matter (2bDDM) reduces clustering (namely) at small scales → increase of σ_8 to compensate for it → reduce σ_8 tension
- Detectability - 2bDDM changes mass distribution - weak lensing can be sensitive to this effect

Douspis (2nd World Summit on Exploring the Dark Side of the Universe)

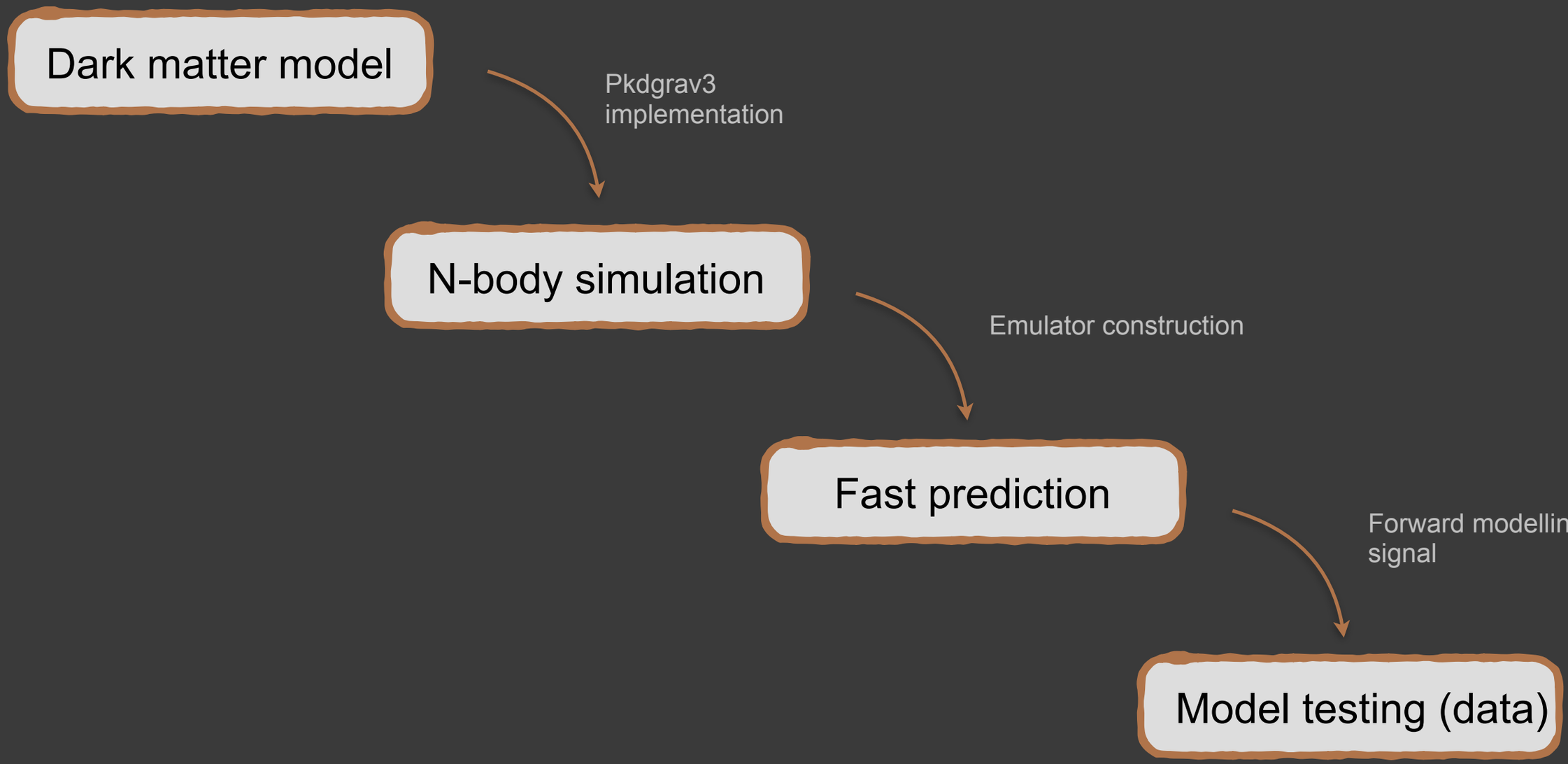




Asgari et al. 2021

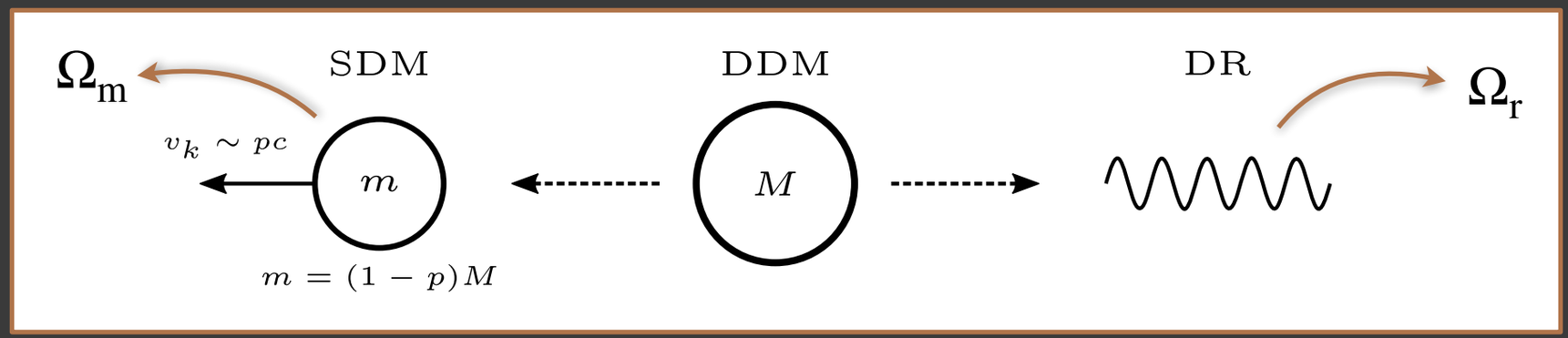
Heymans et al. 2020

Strategy


Dark matter model
Pkdgrav3 implementation
N-body simulation
Emulator construction
Fast prediction
Forward modelling of signal
Model testing (data)

Model

Model parameters
Decay rate Γ
Velocity kicks v_k
Fraction of DDM f



$$\varepsilon = \frac{1}{2}\left(1 - \frac{m^2}{M^2}\right)$$

Background - full:

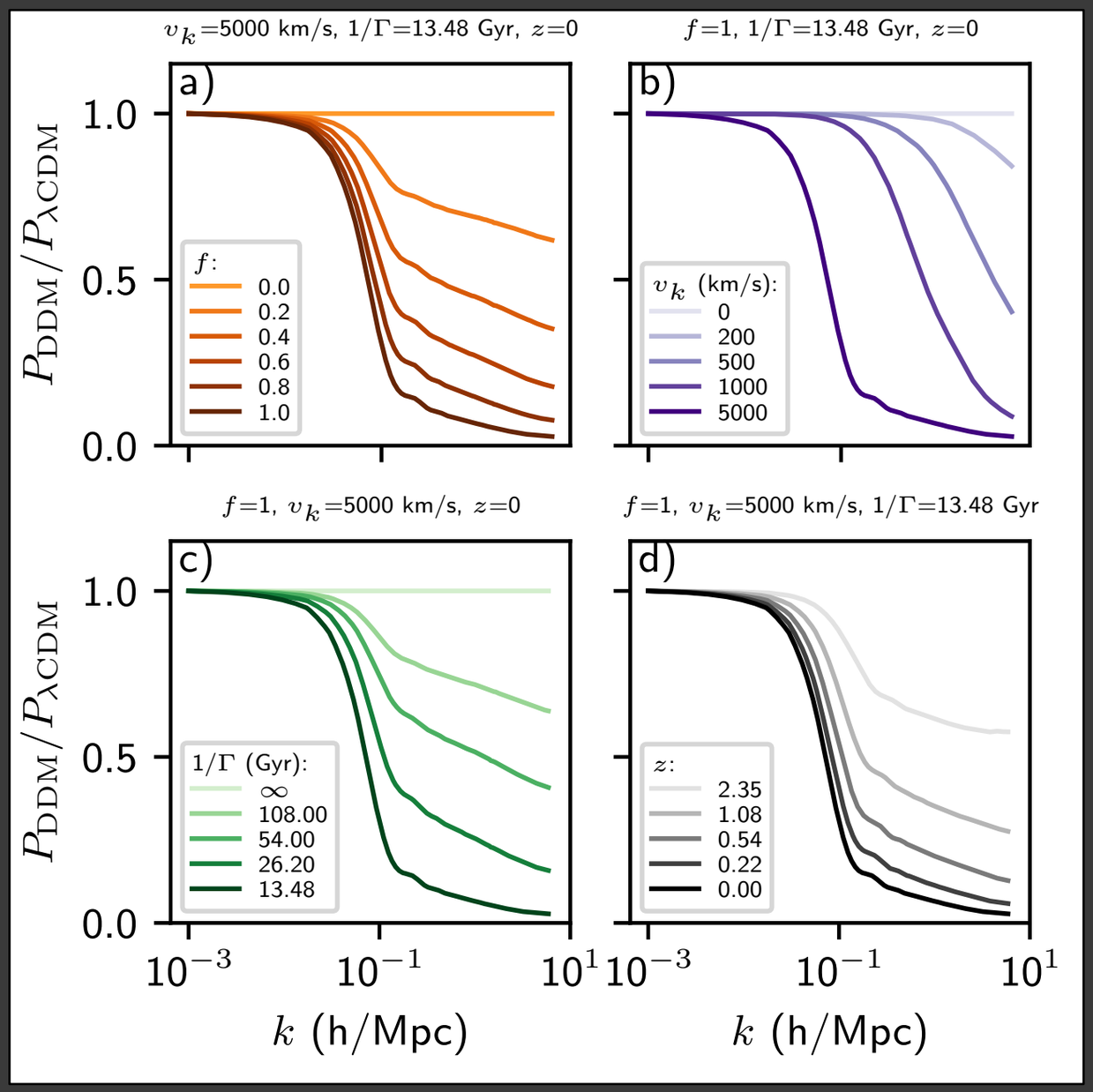
$$\dot{\rho}_{\rm DDM} + 3\mathcal{H}\rho_{\rm DDM} = -a\Gamma\rho_{\rm DDM}$$
$$\dot{\rho}_{\rm SDM} + 3\mathcal{H}\rho_{\rm SDM} = a\Gamma\frac{M^2+m^2}{2M^2}\rho_{\rm DDM}$$
$$\dot{\rho}_{\rm DR} + 4\mathcal{H}\rho_{\rm DR} = a\Gamma\frac{M^2-m^2}{2M^2}\rho_{\rm DDM}$$

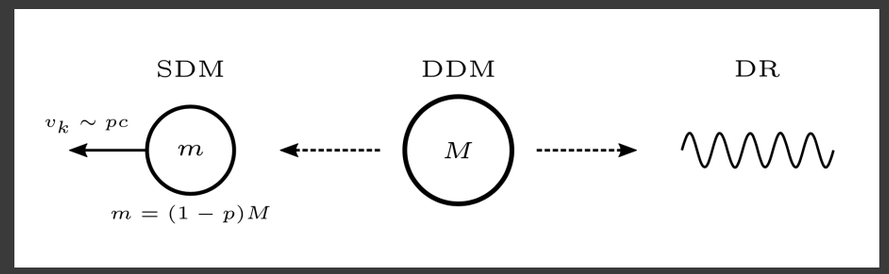
$v_k/c \ll 1$

Background - approximated:

$$\dot{\rho}_{\rm DDM} + 3\mathcal{H}\rho_{\rm DDM} = -a\Gamma\rho_{\rm DDM}$$
$$\dot{\rho}_{\rm SDM} + 3\mathcal{H}\rho_{\rm SDM} = a\Gamma\rho_{\rm DDM} + \mathcal{O}(\varepsilon)$$
$$\dot{\rho}_{\rm DR} + 4\mathcal{H}\rho_{\rm DR} = a\Gamma\rho_{\rm DDM} + \mathcal{O}(\varepsilon)$$

N-body simulations





Pkdgrav3 implementation: Potter et al. 2017

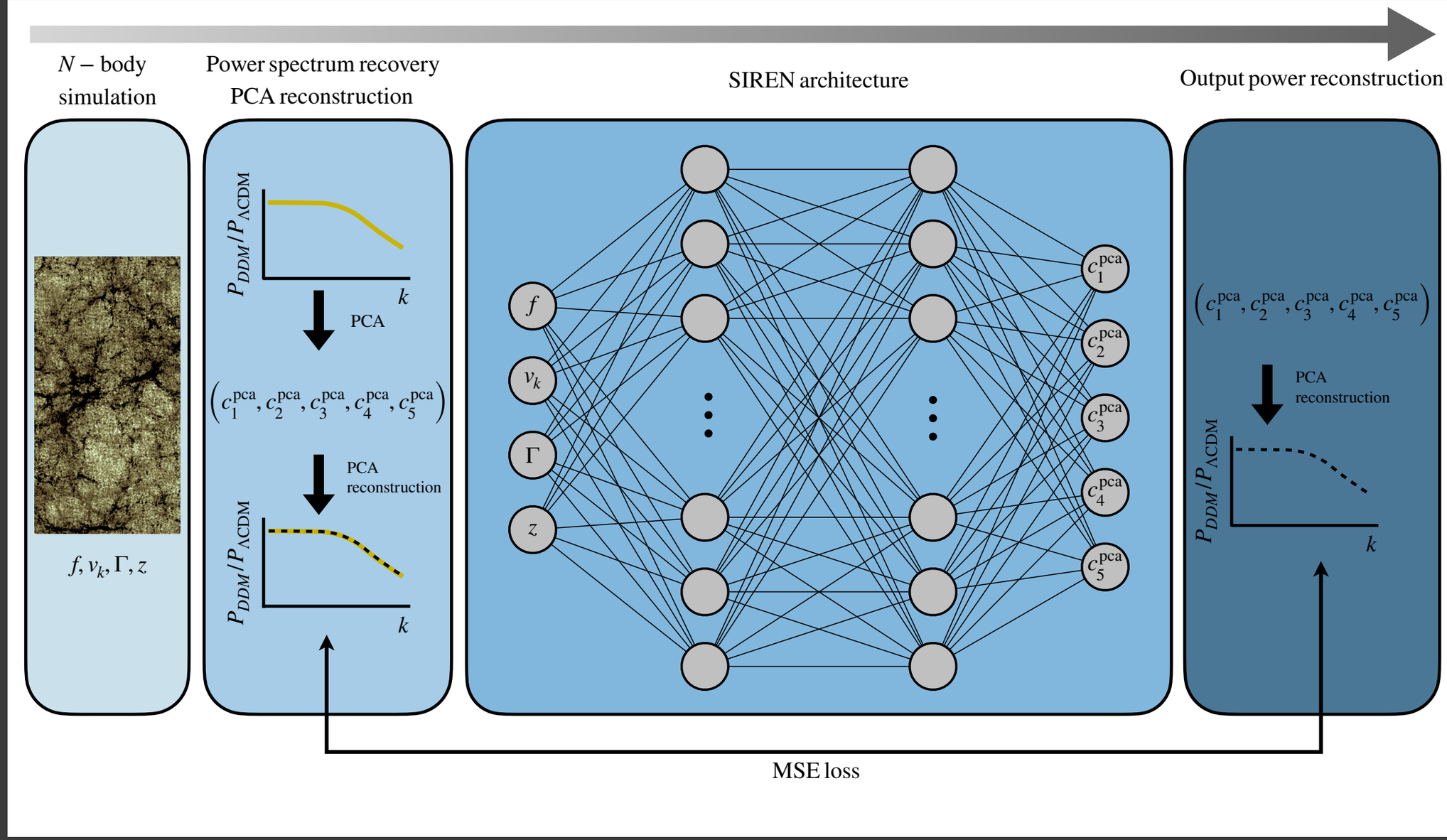
- Background unchanged
- Probabilistic assignment of velocity kicks to the particles
- Power spectra measured $z \in [0, 2.35]$

Model parameters:

Decay rate:	Γ	$(0 - 0.074)\,\mathrm{Gyr}^{-1}$
Velocity kicks:	v_k	$(0 - 5000)\,\mathrm{km/s}$
Fraction of DDM:	f	$(0 - 1)$

Fast prediction: 2-body DDM emulator

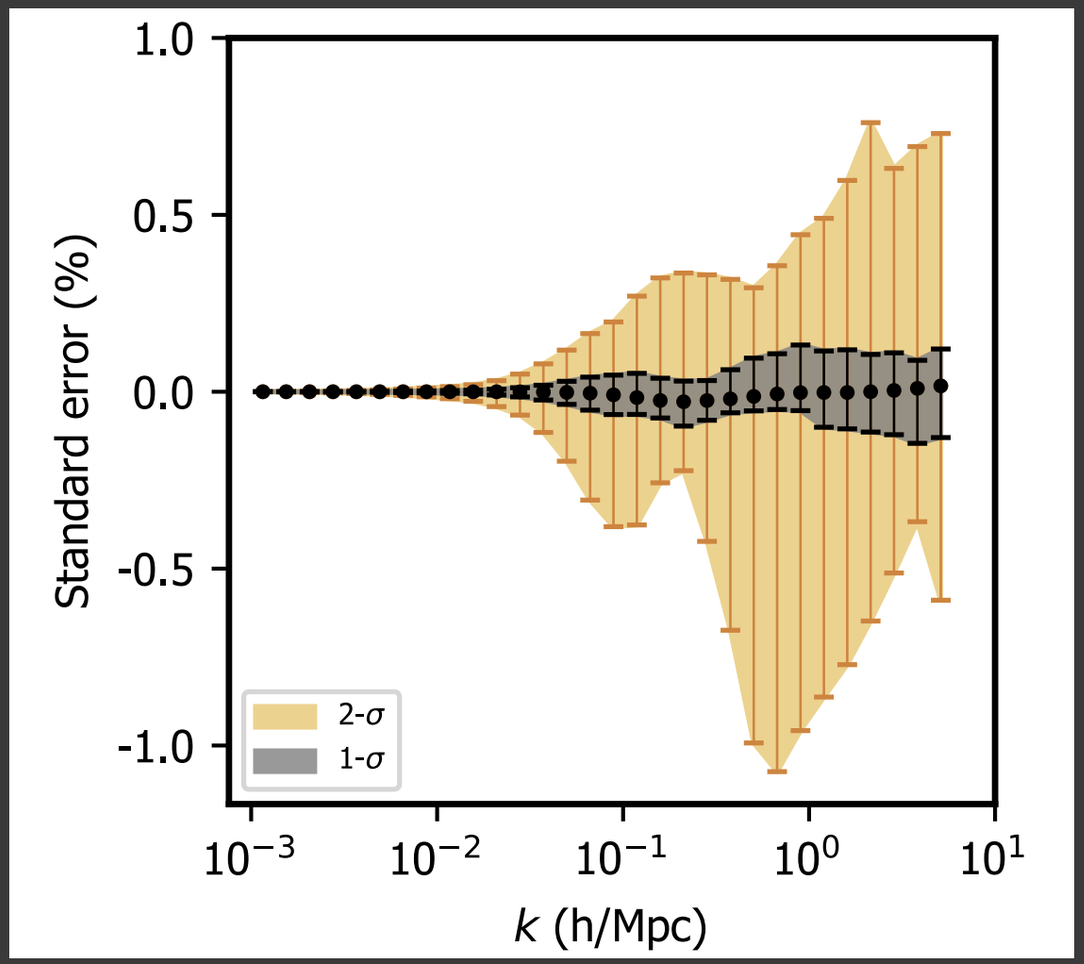
Sitzmann et al. 2019



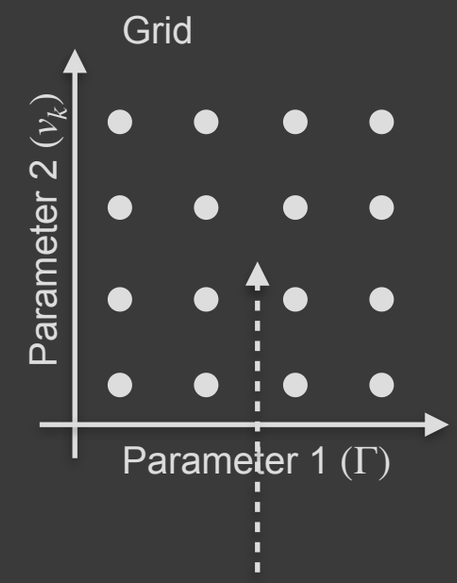
Fast prediction: - emulation performance:

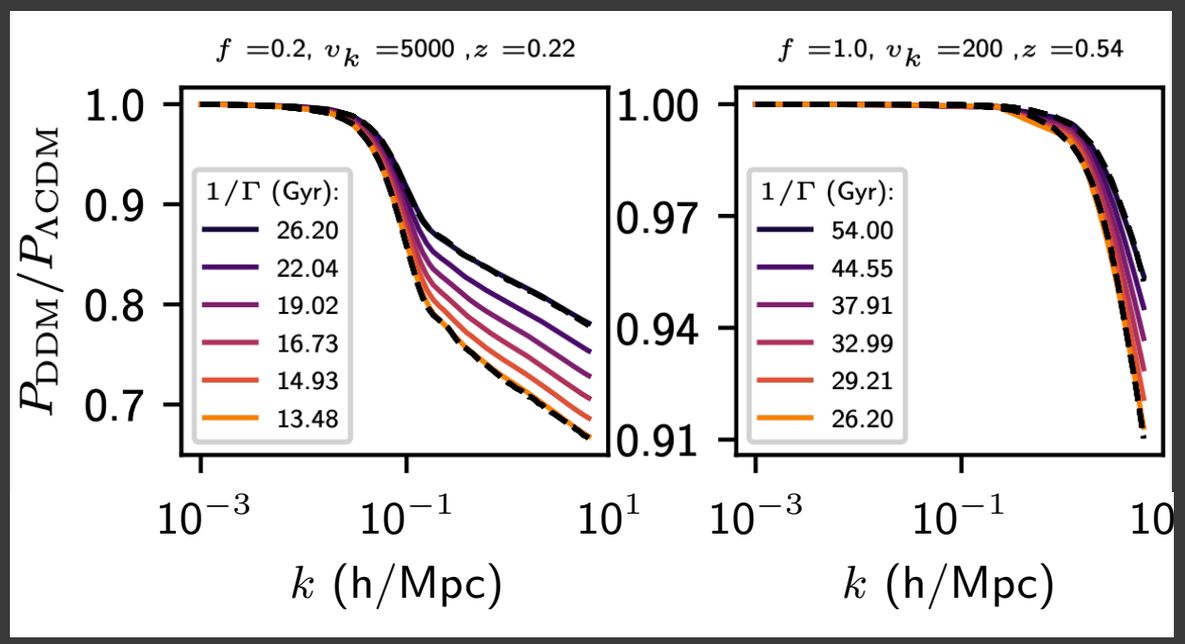
Training (SIREN network)

On average, up to 1% mismatch at all scales



Interpolation properties





Model inference

$$W_{\rm G}^{(i)}(\chi) = \frac{3H_0^2\Omega_{\rm m}}{2\,c^2}\frac{f_{\rm K}(\chi)}{a(\chi)}\int_{\chi}^{\chi_{\rm hor}} {\rm d}\chi'\; n_{\rm S}^{(i)}(\chi')\;\frac{f_{\rm K}(\chi'-\chi)}{f_{\rm K}(\chi')}$$

$$W_{\rm I}^{(i)}(\chi) = -A_{\rm IA}\left(\frac{1+z(\chi)}{1+z_{\rm pivot}}\right)^{\eta_{\rm IA}}\frac{C_1\rho_{\rm cr}\,\Omega_{\rm m}}{D\,(a[\chi])}\;n_{\rm S}^{(i)}(\chi)$$

$$W_{\rm EE}^{l}(\ell) = W_{\rm BB}^{l}(\ell) = \int_0^{\infty}{\rm d}\theta\,\theta\;T(\theta)\left\{{\rm J}_0(\ell\theta)\;g_+^{l}(\theta) + {\rm J}_4(\ell\theta)\;g_-^{l}(\theta)\right\}$$

$$C_{\rm ab}^{(ij)}(\ell) = \int_0^{\chi_{\rm hor}}{\rm d}\chi\;\frac{W_{\rm a}^{(i)}(\chi)\;W_{\rm b}^{(j)}(\chi)}{f_{\rm K}^2(\chi)}\;P_{\rm m,nl}\left(\frac{\ell+1/2}{f_{\rm K}(\chi)},z(\chi)\right)$$

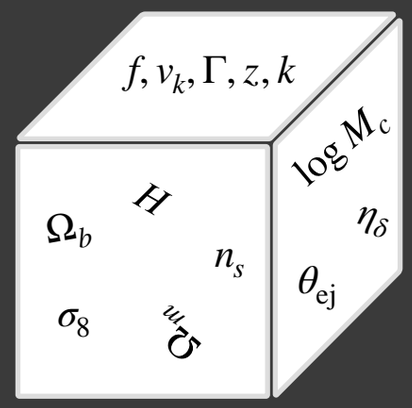
$$C_{\epsilon\epsilon}^{(ij)}(\ell) = C_{\rm GG}^{(ij)}(\ell) + C_{\rm GI}^{(ij)}(\ell) + C_{\rm IG}^{(ij)}(\ell) + C_{\rm II}^{(ij)}(\ell)$$

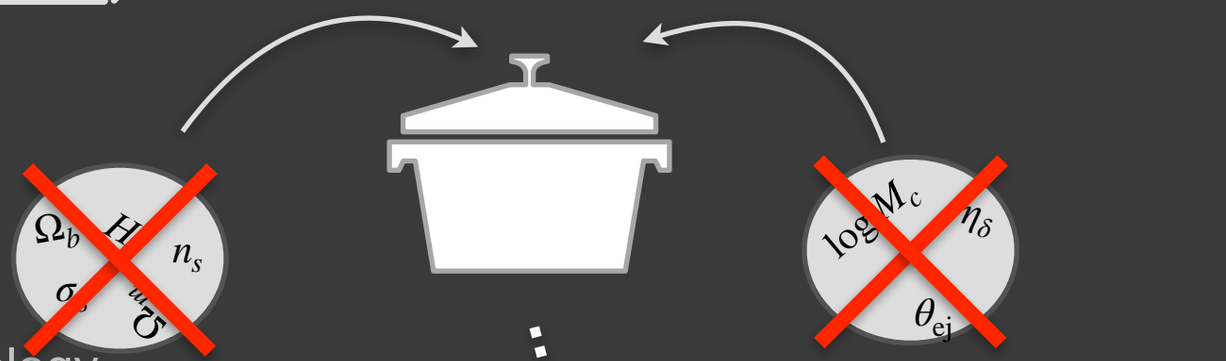
$$C_{{\rm E},l}^{(ij)} = \frac{1}{2\mathcal{N}_l}\int_0^{\infty}{\rm d}\ell\;\ell\left\{W_{\rm EE}^{l}(\ell)\;C_{\epsilon\epsilon,{\rm E}}^{(ij)}(\ell)\right\}$$

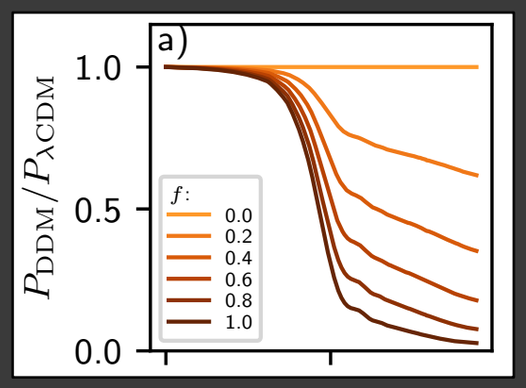
Asgari et al. 2021

Data $C_{E,l}^{(i,j)}$

Emulator







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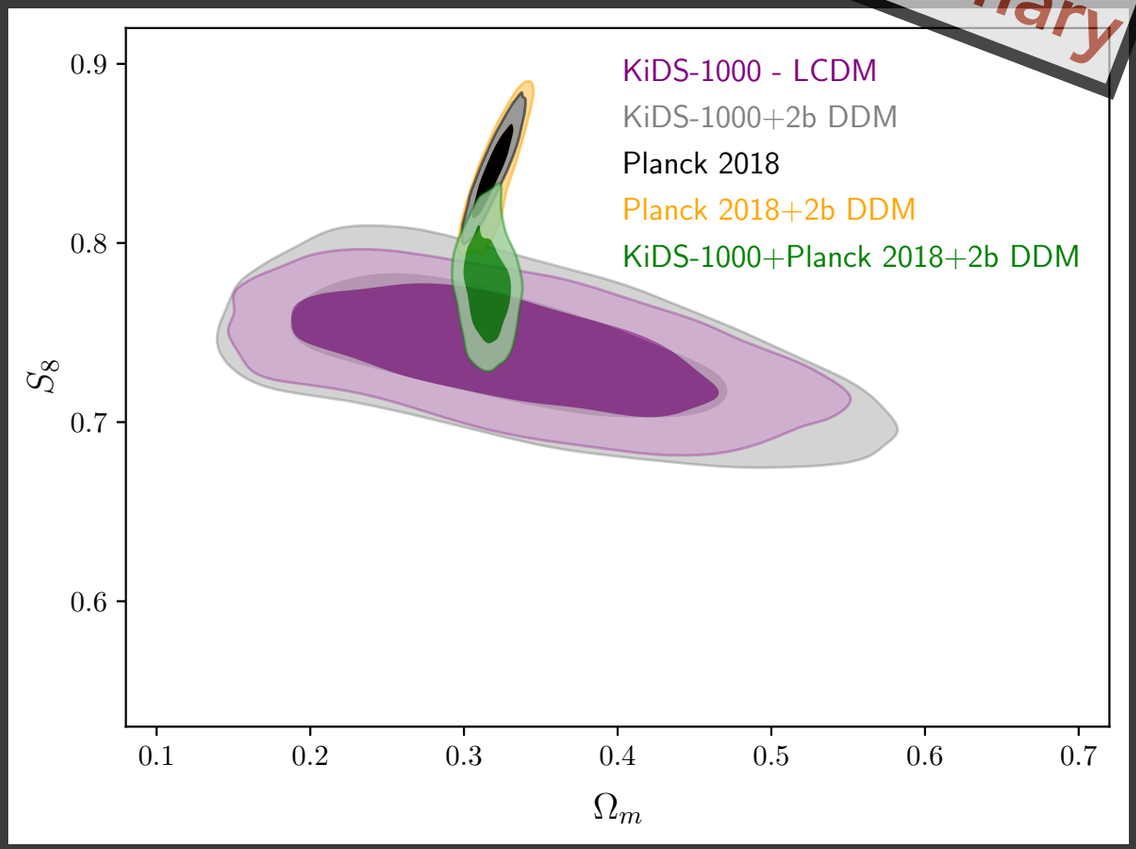
Cosmic Shear analysis: decaying DDM, KiDS-1000 and Planck 2018

Preliminary



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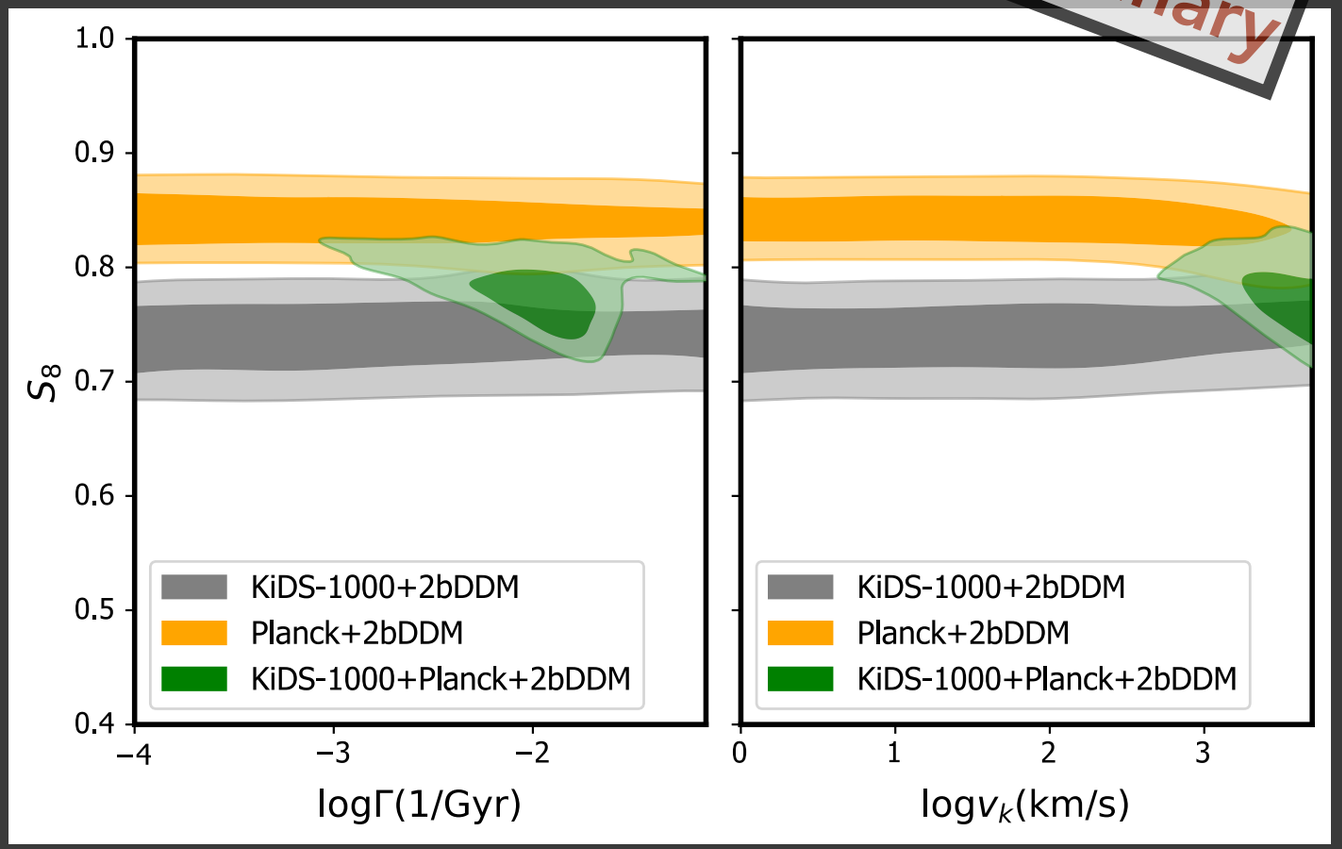
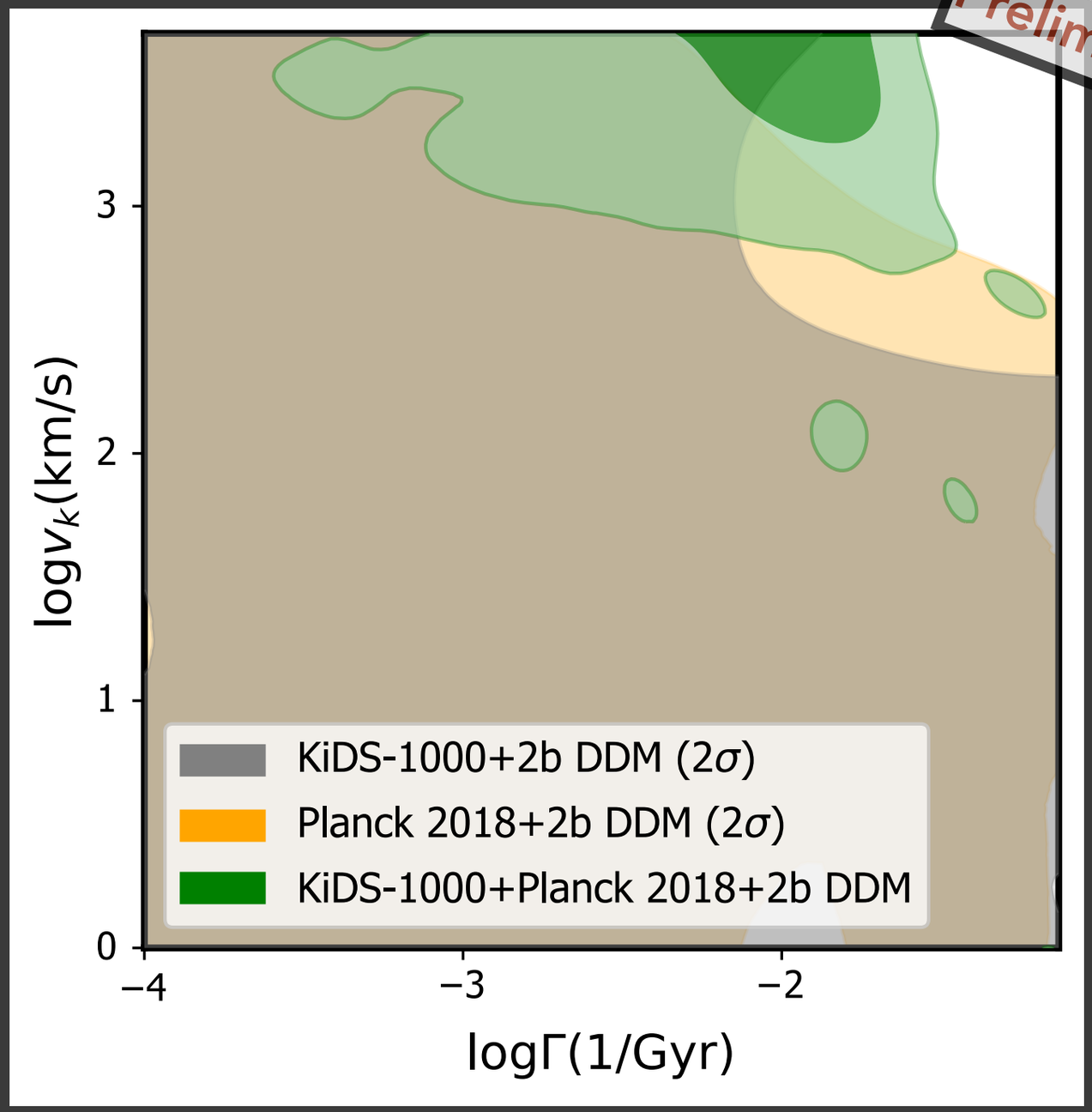


Asgari et al. 2021

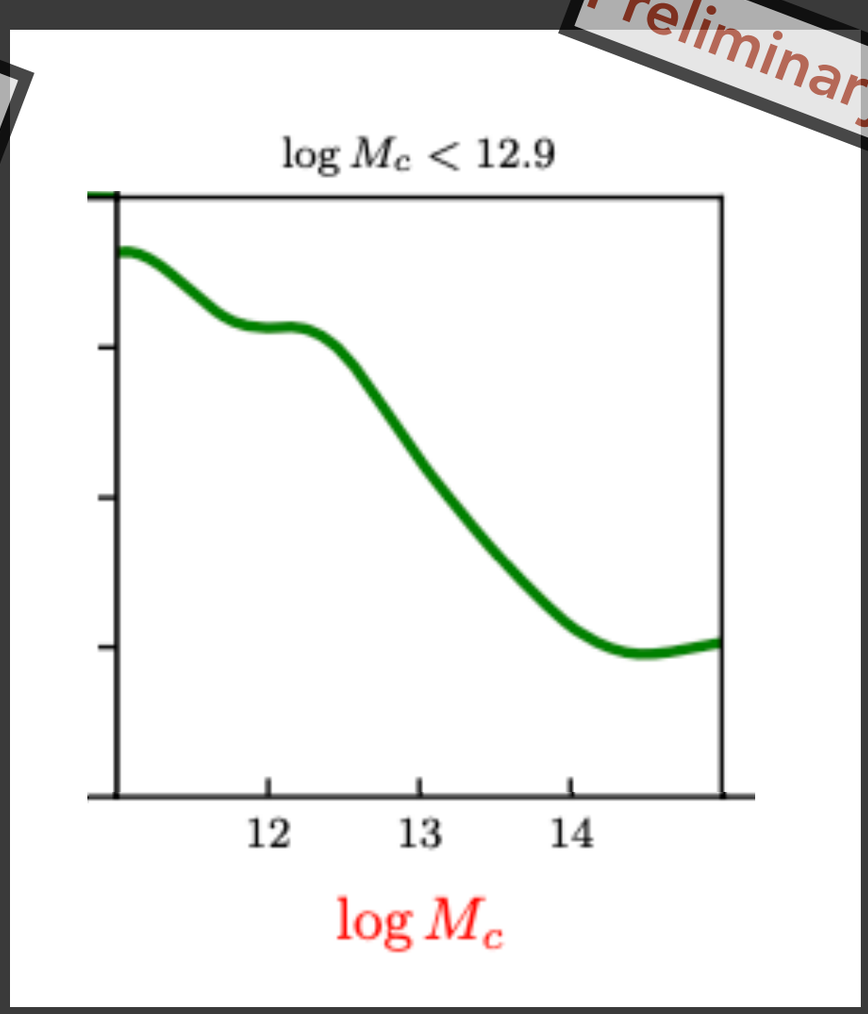
Planck collaboration 2018

Cosmic Shear analysis: decaying DDM, KiDS-1000 and Planck2018

Preliminary



Preliminary



Implications on baryons (included via *BCemu*) under investigation, paper appearing soon…

Giri & Schneider 2021

Comparison with Simon et al. 2022

Simon et al. 2022

DCDM→WDM+DR		
Parameter	w/ EFTofBOSS	w/ EFTofBOSS + S_8
$\log_{10}(\Gamma/[\mathrm{Gyr}^{-1}])$	unconstrained (-2.98)	$2.21(-2.08)^{+1.5}_{-0.6}$
$\log_{10}(\varepsilon)$	unconstrained (-3.84)	$-2.30(-1.92)^{+0.84}_{-1.10}$

This work:

$$\log(\Gamma\,[\mathrm{Gyr}^{-1}]) = -2.01^{+0.28}_{-0.11}$$

$$\log(\varepsilon) > -2.07$$ (due to the prior limitations)

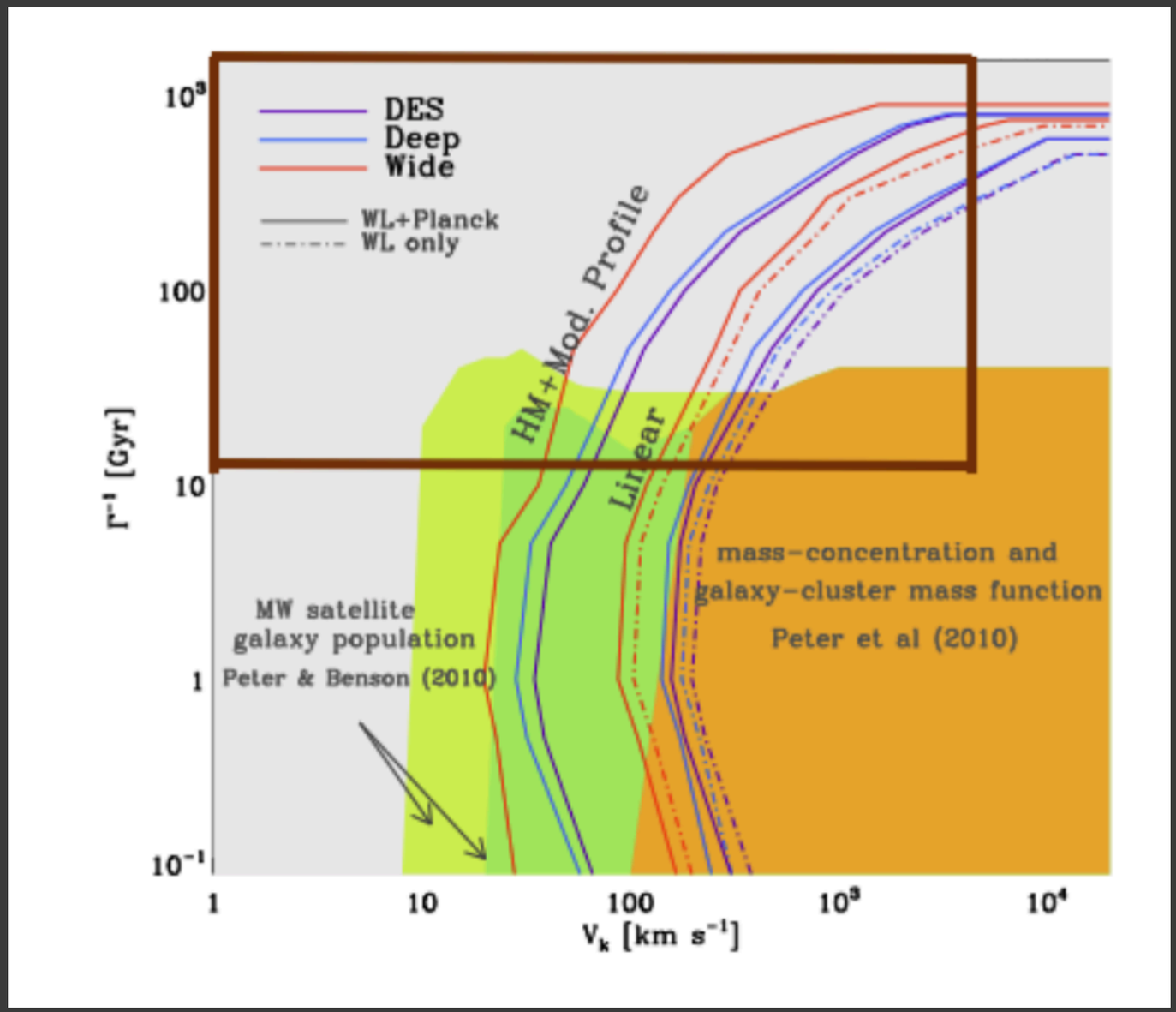
Constraints on 1-body decays

Preliminary

1bDDM	τ	f
KiDS-1000	>204 Gyr	<0.63
Planck 2018	>575 Gyr	<0.61
Combined	>468 Gyr	<0.60

Thank you!

Parameter domain choice for 2-body decays (Γ, v_k)



Wang & Zentner 2012