Vector Resoances and SIMPs

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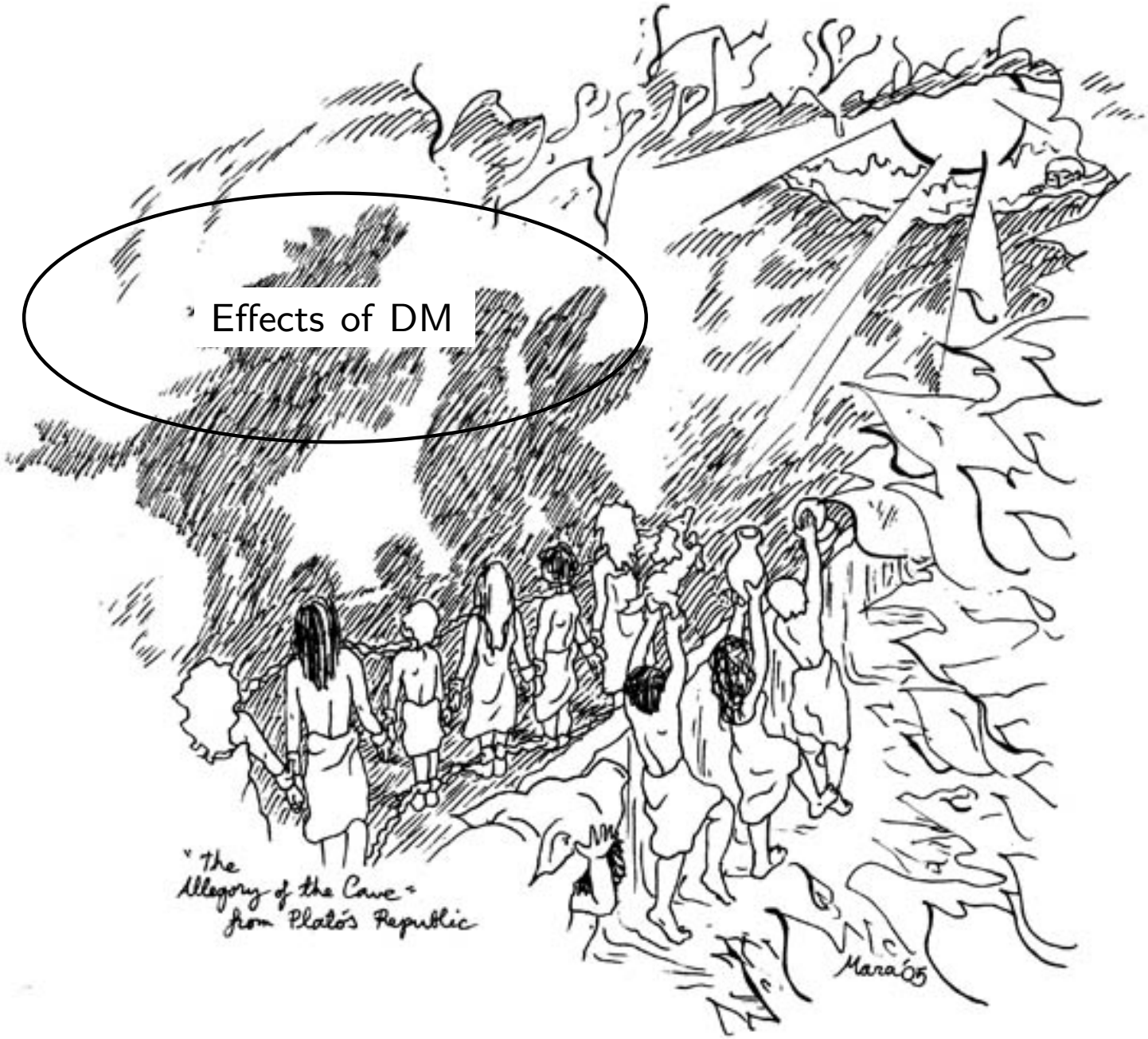
"The
Allegory of the Cave"
from Plato's Republic
Mara'05


Effects of DM
"The Allegory of the Cave" from Plato's Republic
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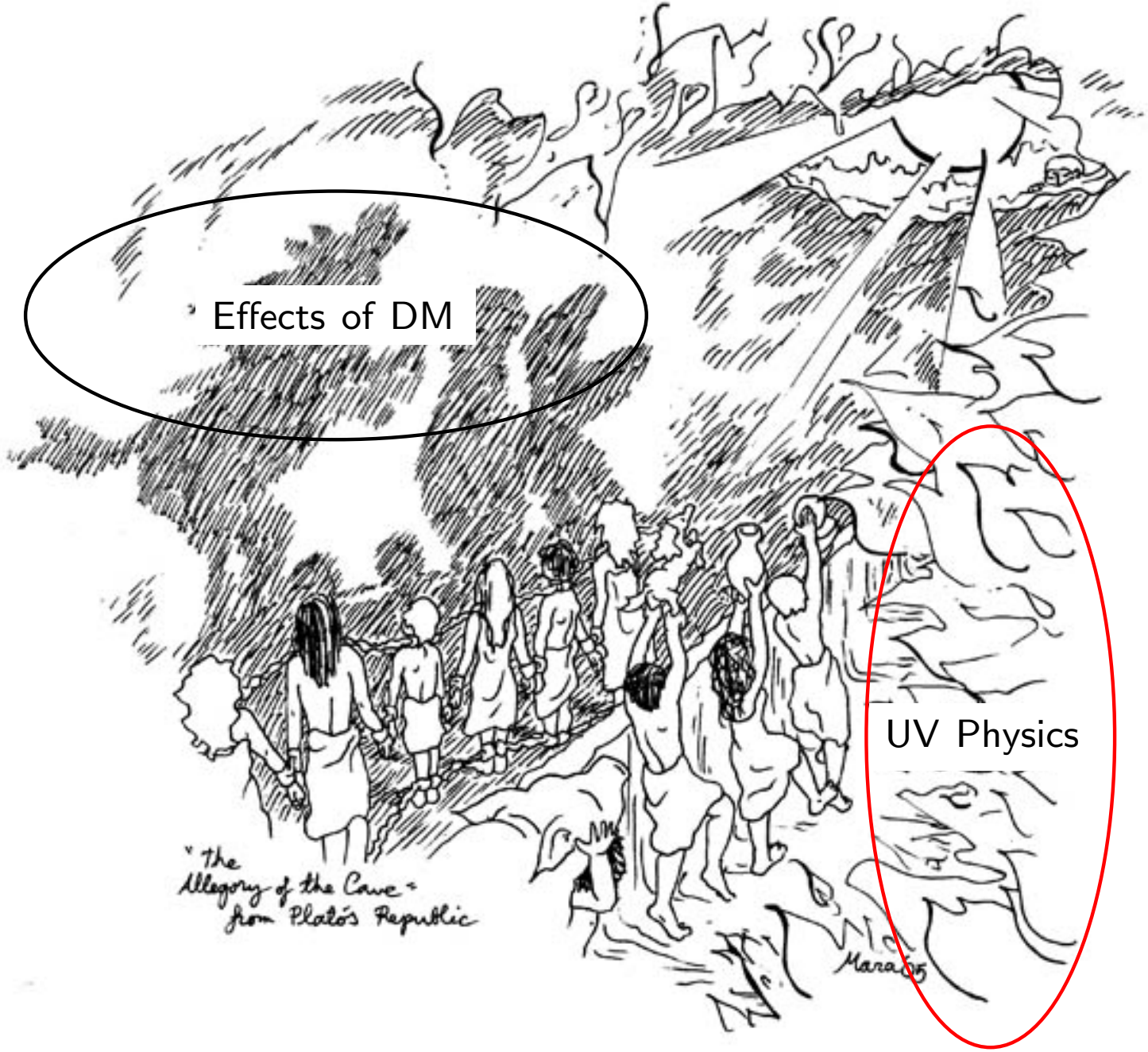
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UV Physics
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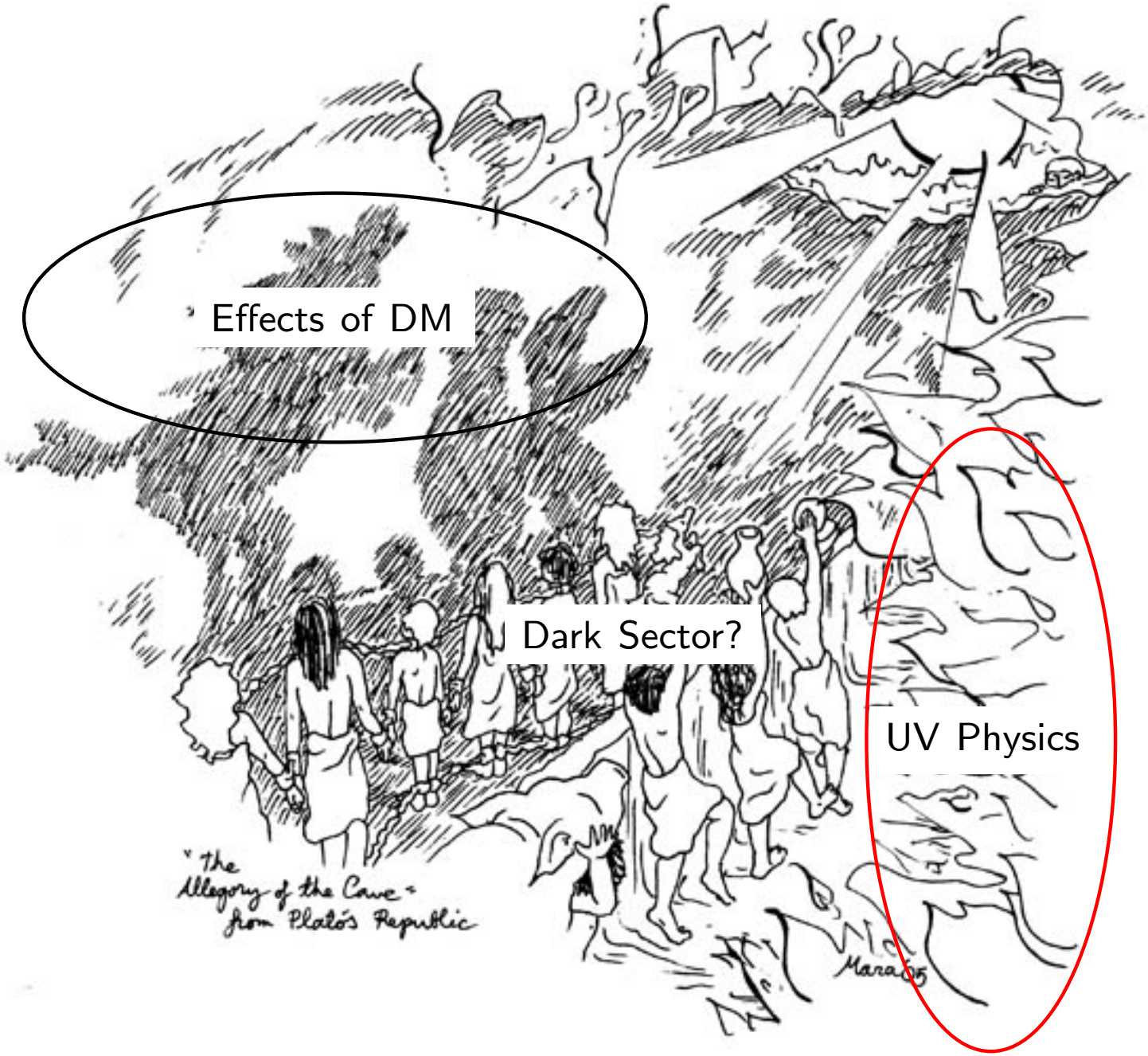
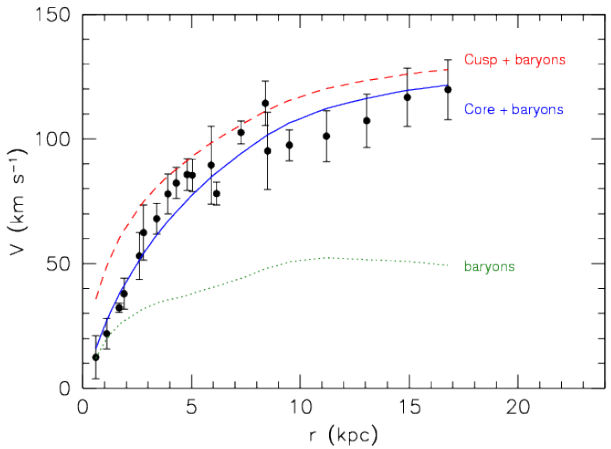
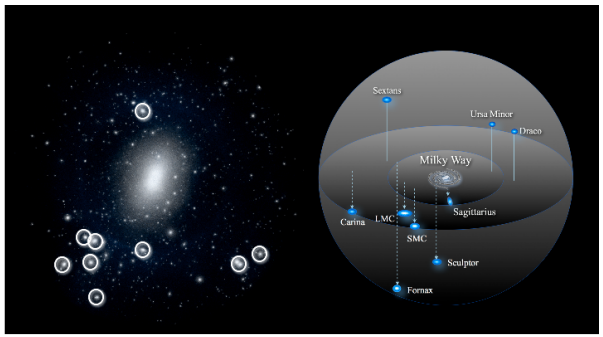

Effects of DM
Dark Sector?
UV Physics
"The Allegory of the Cave" from Plato's Republic

CDM Puzzles

Weak mass scale roughly fits correct relic density with mass $\sim TeV$, hence, the 'WIMP' miracle, however (D.H. Weinberg et al, 2013)...

- CDM simulations too 'cuspy' compared to observations
- Missing halos/too-big-too-fail
- CDM still hasn't been seen but needs DM-SM to 'freeze' out





Self-Interating DM

Introducing self interaction flattens DM density in Core.
$\rightarrow$ see S. Tulin,H.-B. Yu 2017 for a recent review $\leftarrow$

Constrained by Bullet Cluster observations $\sigma_{self} \lesssim 1\ cm^2/g$,
but $\sigma_{SIDM} \gtrsim 0.1\ cm^2/g$ $(\sim 10^{-24}\ cm^2/GeV)$

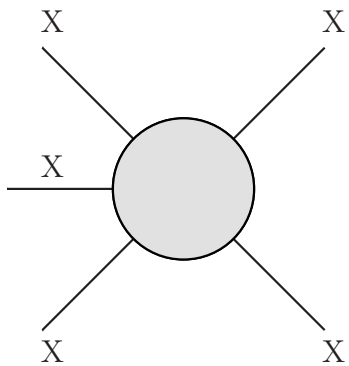
D.H. Weinberg et al, 2013

Weak scale implies $\sigma/m \sim 10^{-38}\ cm^2/GeV$

Strongly Interacting DM?

WIMP Relic is a balance between $\sigma_{ann.}$ and $\sigma scat$..
If DM-SM interaction is very weak ($\sigma_{SM} \ll \sigma_{2\to 2}$)?

Relic Denisty is fixed by 3-to-2...



...then $m_{DM} \sim \alpha_{eff}(T_{eq}^2 M_{Pl})^{1/3} \sim 100$ MeV, and this leads to a strong α_{eff} and can explain self-interaction cross section $\sim 10^{-24}\ cm^2/GeV$.

Y. Hochberg, E. Kuflik, T. Volansky, J.G. Wacker, 2014

SIMPlest Model

To produce relevant $\sigma_{scat.}$ use a strongly-coupled gauge theory ($SU(N_c)$):

$$\mathcal{L}_{SIMP} = -1/4 F^a_{\mu\nu} F^{\mu\nu a} + i \bar{Q}_i \not{D} Q_i$$

Where a global symmetry (G) $SU(N_f) \times SU(N_f)$ is broken to $SU(N_f)$, similarly to the SM QCD.
Since this is a strongly coupled theory, the $Q's$ show up via composite states (pions) **dark pions**, which are the cosmological DM.

Note: The Gauge and global symmetries can be $SU(N_c)$, $Sp(N_c)$, etc.

Y. Hochberg, E. Kuflik, T. Volansky, J.G. Wacker, 2014

Chiral Lagragnian

After chiral symmetry breaking there are $N_f^2 - 1$ pion fields with dynamics that can be approximated to leading order:

$$\mathcal{L}_\pi = \frac{f_\pi^2}{16} Tr\partial_\mu \Sigma \partial^\mu \Sigma^\dagger - 1/2 m_Q \mu^3 Tr\Sigma + c.c.,$$
where $\Sigma = exp(i2\pi/f_\pi)$ and $\pi = T_a \pi_a$.

Expanding Σ leads to even-pion interaction terms (no 3-to-2 yet).

The 3-to-2 terms are generated from Wess-Zumino-Witten Term (Wess,Zuimno 1971; Witten 1983):

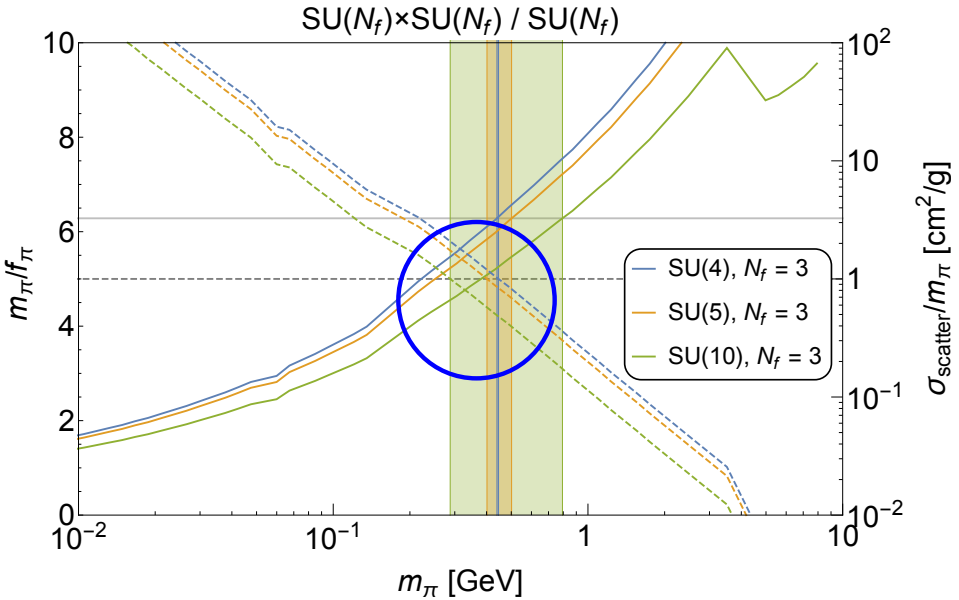
$$\mathcal{L}_{WZW} = \frac{2N_c}{15\pi^2 f_\pi^5} \epsilon^{\mu\nu\rho\sigma} Tr\left[\pi\partial_\mu\pi\partial_\nu\pi\partial_\rho\partial_\sigma\pi\right]$$

ChPT: Issues

- Strongly coupled theories are complicated, but UV Lagragian is very simple
- Can produce correct relic (QCD-like $SU(3) \times SU(3)/SU(3)$ are very constrained)
- Interesting alternative to WIMP paradigm

But...generically requires large m_π/f_π to be realistic:

Y. Hochberg et al 2014



ChPT: Vector Mesons

Leading order ChPT breaks down as NLO and NNLO effects *become sizable for large* m_π/f_π (M. Hansen et al 2015) after leading order vector mesons should be included as well.

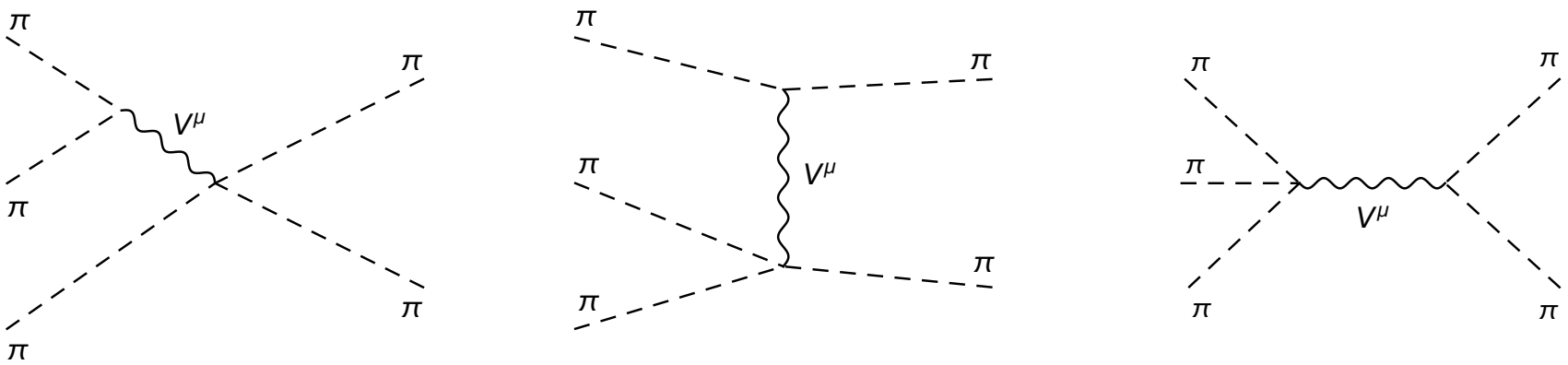
We expand the leading order ChPT with the vector meson ($N_f, N_c = 3$):

$$\mathcal{L} = \mathcal{L} + m_V^2 Tr[V_\mu V^\mu] - i2g_{V\pi\pi} Tr[V_\mu[\partial^\mu \pi, \pi]) + \mathcal{L}_{Anom} + \dots$$

where $V_\mu = T^a V_\mu^a$, $m_V = ag^2 f_\pi^2$, $g_{V\pi\pi} = 1/2ag$, and $\mathcal{L}_{Anom}$ is the anomalous term which generates $V\pi\pi\pi$ terms.

New Channels

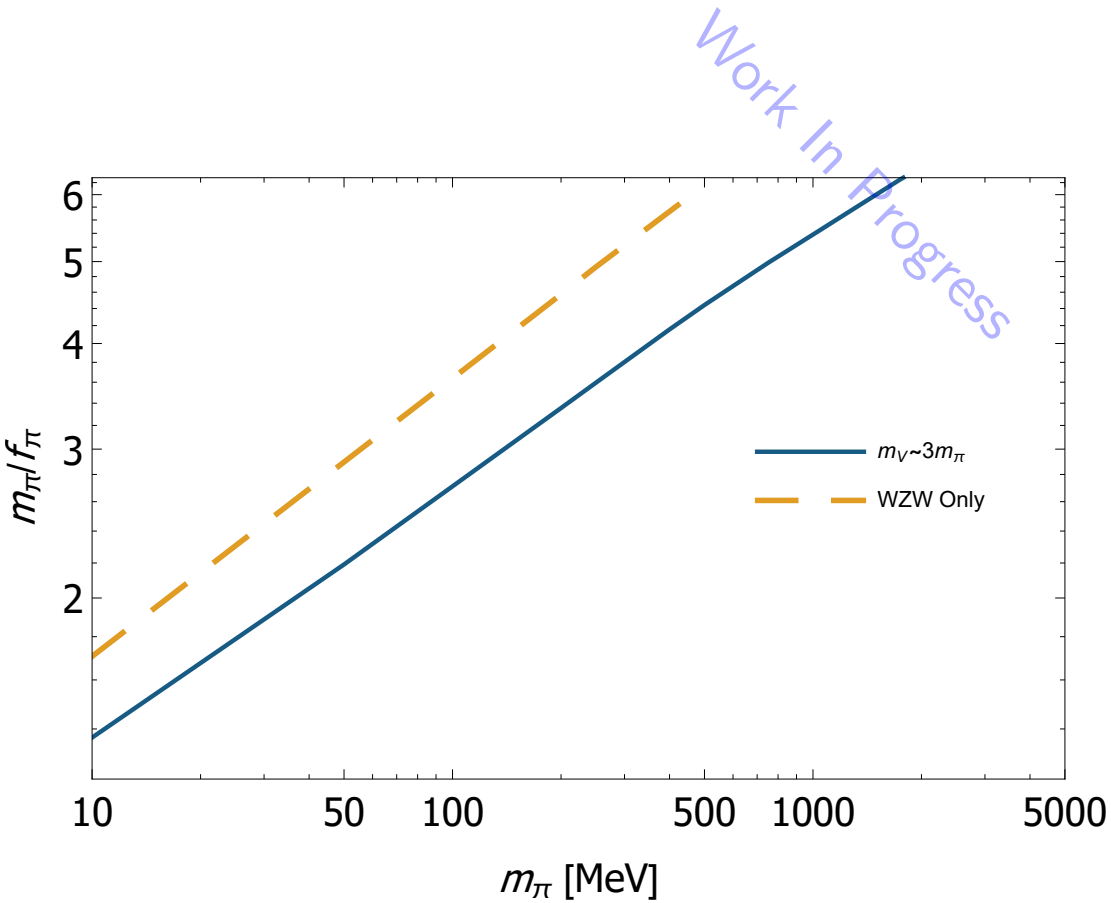
V^μ terms, analogous to WZW, generate new 3-to-2 interactions:



Leads to resonances near $m_V \approx 2m_\pi$ $(m_V \approx 3m_\pi)$
Near these resonance poles, care must be taken with the thermal average.

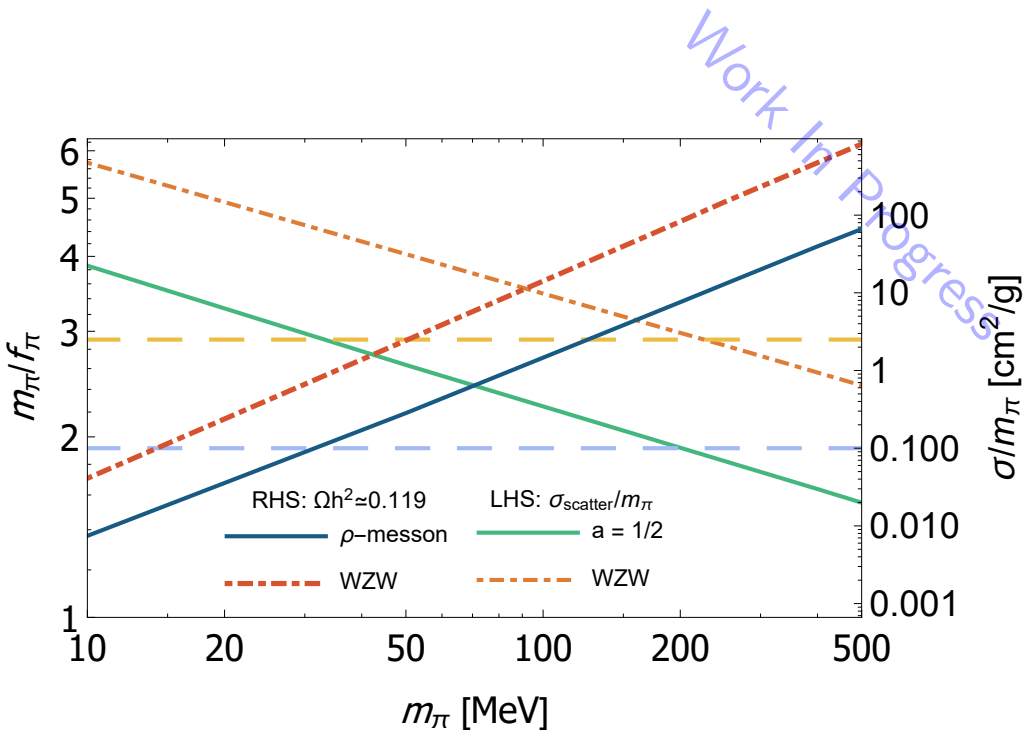
Thermal Average

Building on work in S-M. Choi, H.M. Lee et al 2017, the thermal average can be properly computed near resonance, and compared to the results of the 'SIMPlest' model:



Results

Fixing a, m_V/m_π, m_π while scanning the f_π with $\Omega h^2 \approx 0.119$ and then determining $\sigma_{scat.}$ yields:



Summary & Conclusions

- Interesting alternative to WIMP paradigm with 3-to-2 freezeout
- Can solve puzzles with CDM model
- Addition of Vector Mesons in a composite model have important consquences
- Vector resonances in 3-to-2 can make QCD-like SIMP models viable

Thank you!

Thank you for your time and attention!