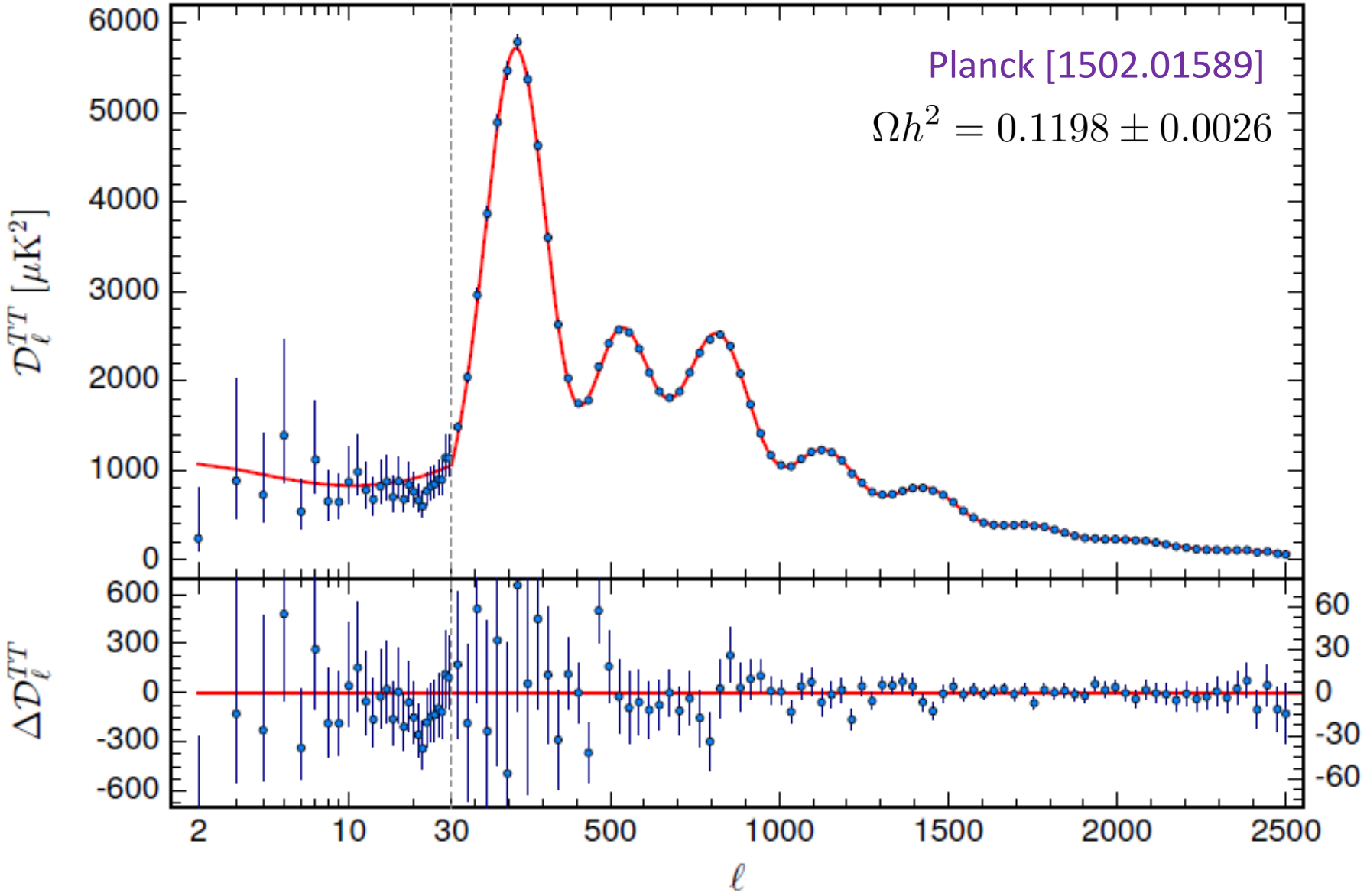
THEORY SUMMARY

Felix Yu
Johannes Gutenberg University, Mainz

Light Dark Matter 2017
Isola d'Elba, May 28, 2017

Dark matter is a fundamental puzzle



Treatise on the nature of dark matter

“What is?”

vs.

“What is it not?”

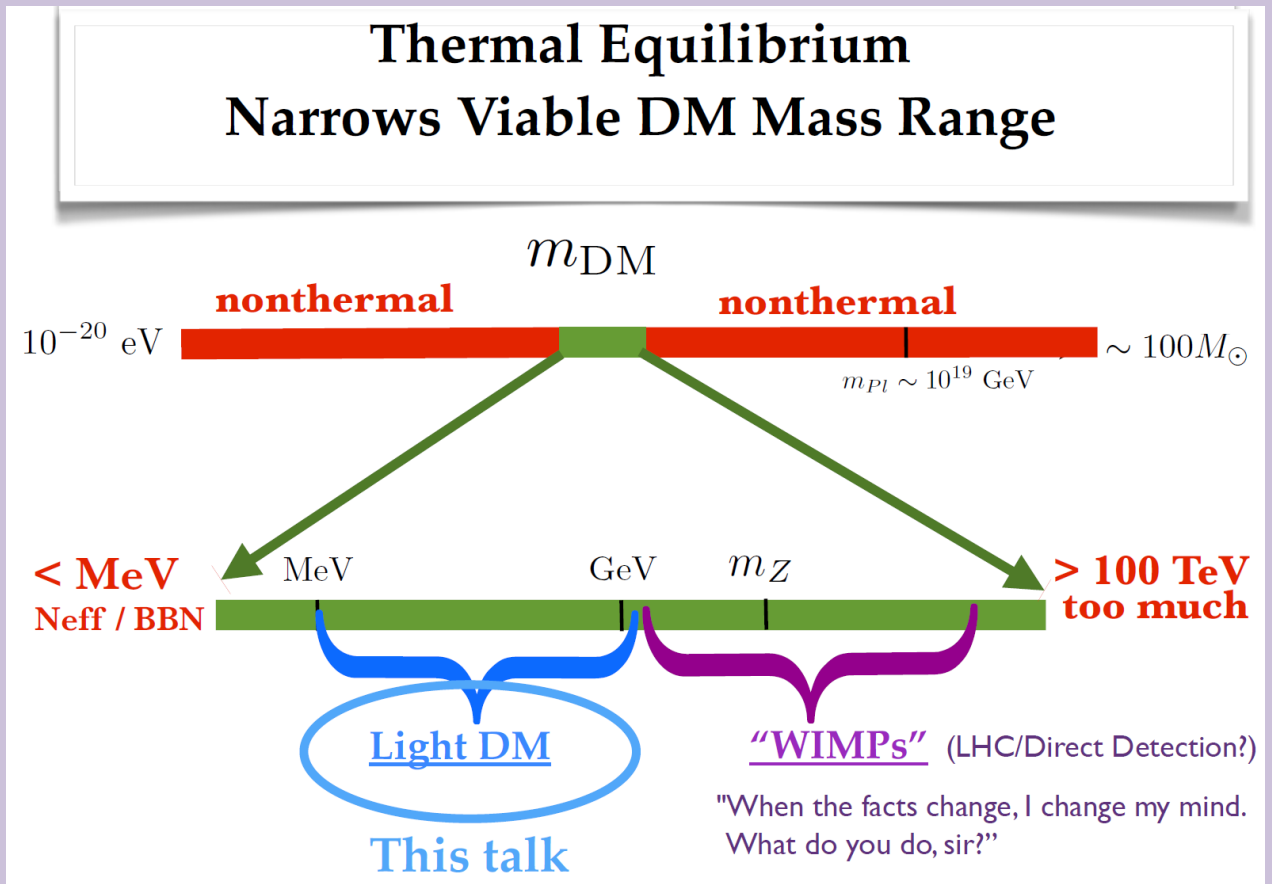
“What is?” *vs.* “What is it not?”

- Known properties: dark matter relic density, color neutral and (nearly) no electric charge

"What is?" vs. "What is it not?"

- Known properties: dark matter relic density, color neutral and (nearly) no electric charge

Not known: Mass

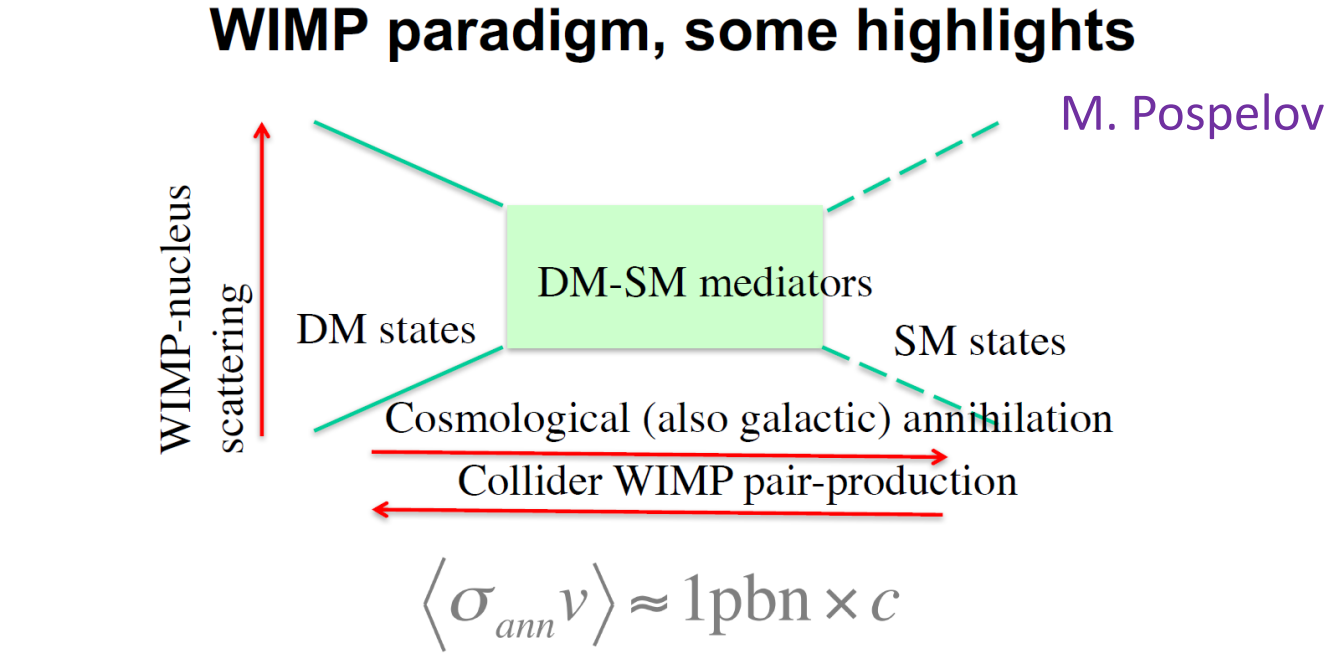


G. Krnjaic

"What is?" vs. "What is it not?"

- Known properties: dark matter relic density, color neutral and (nearly) no electric charge

Not known: Interactions



1. What is inside this green box? I.e. what forces mediate WIMP-SM interaction?

2. Do sizable annihilation cross section always imply sizable scattering rate and collider DM production? (What is the mass range?)

"What is?" vs. "What is it not?"

- Known properties: dark matter relic density, color neutral and (nearly) no electric charge

Schematically **not known: Interactions (and corresponding couplings)**

Beyond WIMPs → marginal operators

- Divorce dark sector from all SM gauge interactions
  - Ωh^2 from weak-like (i.e. perturbative) couplings and O(100) GeV masses
- Leading interactions at dim-4
  - Scalar Higgs portal $(\mu\phi + \lambda\phi^2)H^\dagger H$
  - Neutrino portal $y_n L H N$
  - Kinetic mixing portal $-\frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} F'^{\mu\nu}$
- Dimension-5
  - Axion portal $\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$

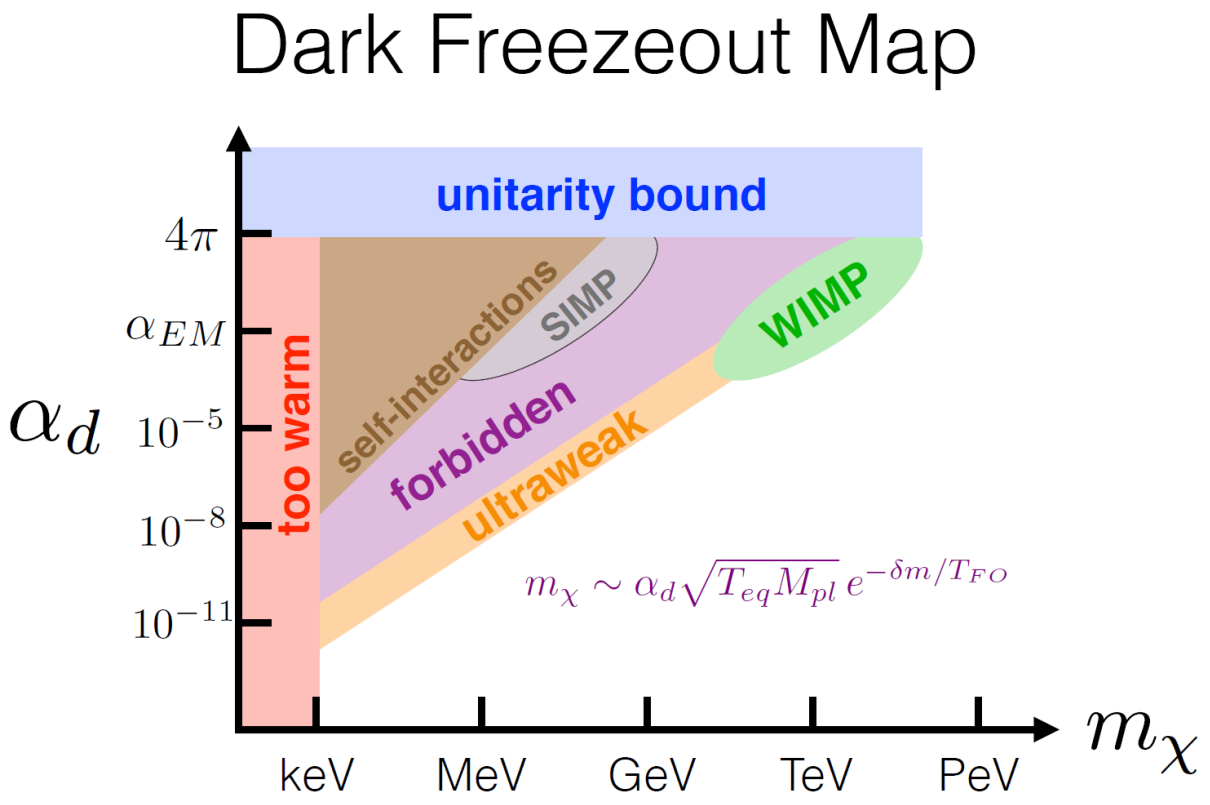
High COM energy for LHC tends to win only when other experiments lose kinematic reach

FY

"What is?" vs. "What is it not?"

- Known properties: dark matter relic density, color neutral and (nearly) no electric charge

Schematically
not known:
Self-interactions



Hand-in-hand: Theory and experiment

- Progressive, real knowledge about dark matter properties comes from experiment

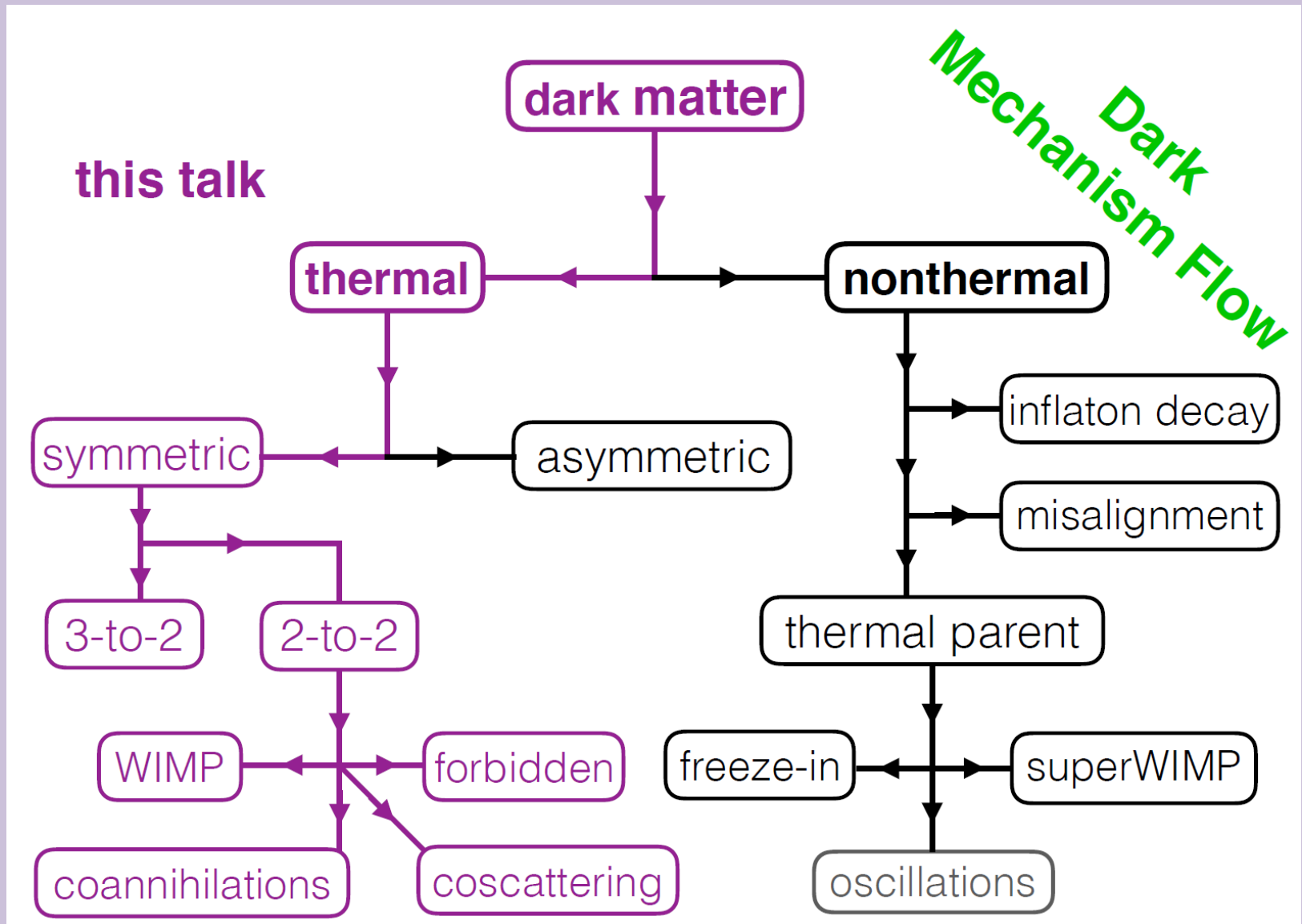
Measurements reflect Nature

- Era of exploratory physics
  - **Laboratory experiments:** Discover the scale, interaction, and coupling at which our SM description breaks down
  - **Theory:** Question all assumptions, complicate all connections, acknowledge there are no guarantees

A main theme for LDM2017

- How rich is dark sector physics?
  - Known properties of DM is inapplicable to dark sectors or mediators – main hope is posit a challenging signal and inventing a new experimental technique to discover
- Experiment
  - Host of opportunities to make discoveries
  - Beam dump, nuclear recoil, electron recoil, LSW, rare decays, …
- Theory
  - Simplicity is… too simple?

Flowchart for complement of simplicity



J. Ruderman

Exploring the dark wilderness

- Possible models span decades in scale and coupling
- Experiments span decades in sensitivity, multitudes of dark matter / dark sector / mediator production modes, SM targets, visible and invisible signatures, …

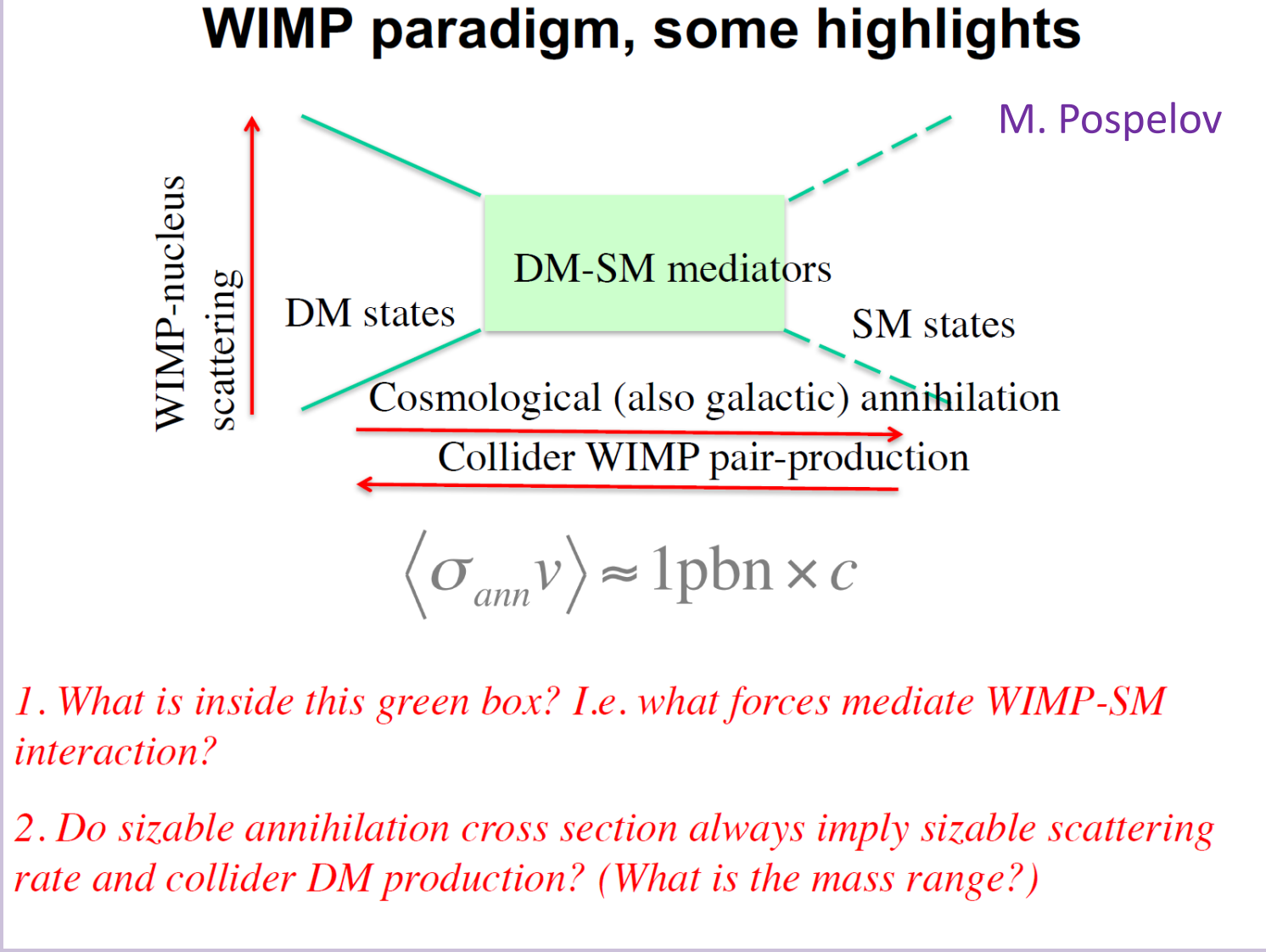
See summaries of current status in this and next sessions

Second theme: powerful sensitivity of experimental searches goes well beyond Dark Matter

- Personal view: Need experiment to point us in the right direction

Closing the loop, post-discovery?

Not known: Timescales, cosmological history



1. What is inside this green box? I.e. what forces mediate WIMP-SM interaction?

2. Do sizable annihilation cross section always imply sizable scattering rate and collider DM production? (What is the mass range?)

LDM2017: Time to think deeply in a beautiful setting about a wondrous problem

Double Dark Portal model

Liu, Wang, FY [1704.00730]

Kinetic mixing of *K* with hypercharge gauge boson *B*

$$\mathcal{L} \supset -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W^i_{\mu\nu}W^{i\,\mu\nu} - \frac{1}{4}K_{\mu\nu}K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W}B_{\mu\nu}K^{\mu\nu}$$
$$+ |D_\mu H|^2 + |D_\mu \Phi|^2 + \mu_H^2|H|^2 - \lambda_H|H|^4 + \mu_D^2|\Phi|^2 - \lambda_D|\Phi|^4 - \lambda_{HP}|H|^2|\Phi|^2$$
$$+ \bar{\chi}(i\not{D} - m_\chi)\chi$$

$U(1)_D$ charges

$\Phi \sim +1\ ,\ \chi \sim +1$

Scalar Higgs portal between dark Higgs Φ and SM *H*

- Two marginal operators: simultaneous vector portal and scalar portal couplings
  - Constraints driven by searches, not known from first principles (possible in UV completions)

Double Dark Portal model

Liu, Wang, FY [1704.00730]

- Fermion bilinears experience the new currents

$$\mathcal{L} \supset g Z_{\mu,\,\mathrm{SM}} J_Z^\mu + e A_{\mu,\,\mathrm{SM}} J_{\mathrm{em}}^\mu + g_D K_\mu J_D^\mu$$

$$= \tilde{Z}_\mu \left(g J_Z^\mu - g_D \frac{m_{Z,\,\mathrm{SM}}^2 t_W}{m_{Z,\,\mathrm{SM}}^2 - m_K^2} \epsilon J_D^\mu + g \frac{m_{Z,\,\mathrm{SM}}^2 (m_{Z,\,\mathrm{SM}}^2 - 2m_K^2) t_W^2}{2(m_K^2 - m_{Z,\,\mathrm{SM}}^2)^2} \epsilon^2 J_Z^\mu - e \frac{m_{Z,\,\mathrm{SM}}^2 t_W}{m_{Z,\,\mathrm{SM}}^2 - m_K^2} \epsilon^2 J_{\mathrm{em}}^\mu \right)$$

$$+ \tilde{K}_\mu \left(g_D J_D^\mu + g \frac{m_K^2 t_W}{m_{Z,\,\mathrm{SM}}^2 - m_K^2} \epsilon J_Z^\mu + e \epsilon J_{\mathrm{em}}^\mu + g_D \frac{(m_{Z,\,\mathrm{SM}}^4 c_W^2 - 2m_K^2 m_{Z,\,\mathrm{SM}}^2 + m_K^4) c_W^{-2}}{2(m_{Z,\,\mathrm{SM}}^2 - m_K^2)^2} \epsilon^2 J_D^\mu \right)$$

$$+ \tilde{A}_\mu e J_{\mathrm{em}}^\mu$$

  - $U(1)_D$- charged fermions pick up ε weak charge mediated by *Z*
  - SM charged fermions pick up ε weak charge and ε electric charge mediated by dark photon
  - Photon remains massless, long-range
    - (Singular behavior at $m_K = m_{Z,\,SM}$ is maximal mixing limit)