Recent progress in dark matter physics

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中国高能物理非加速器战略研讨会

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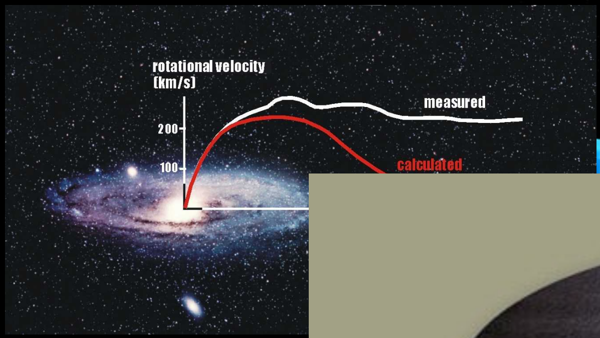
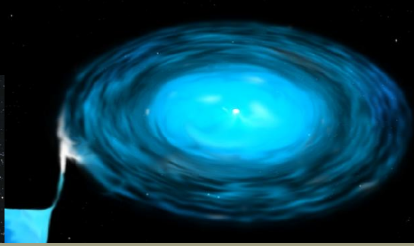
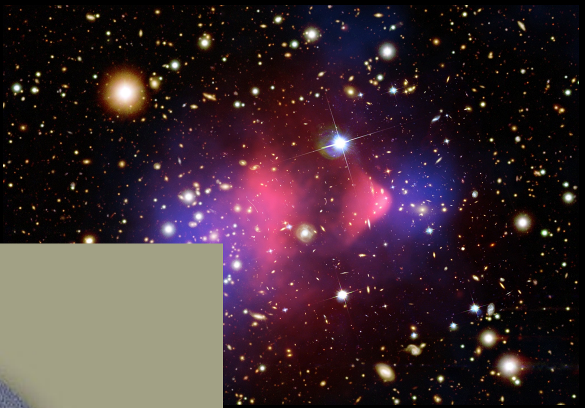
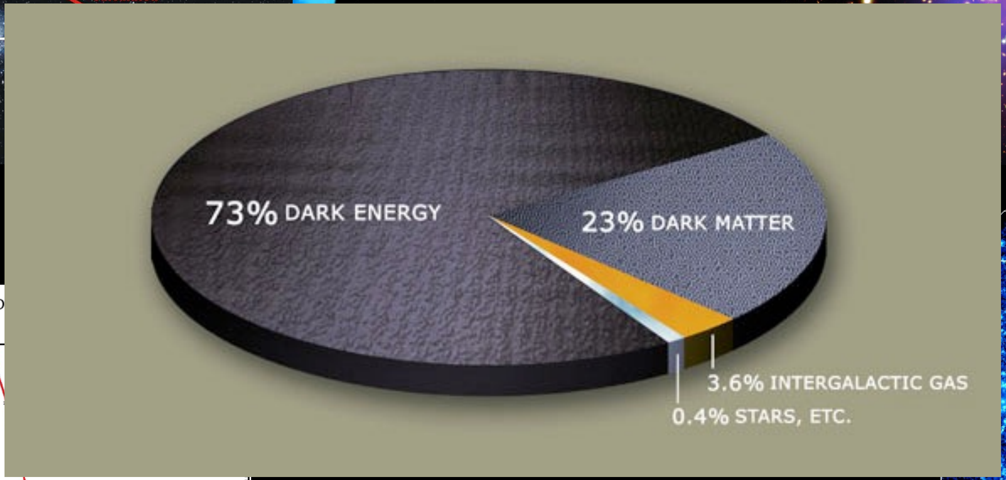
中国科学院高能物理研究所

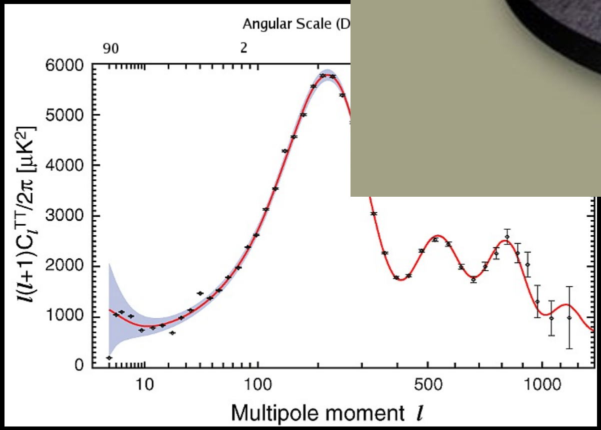
Evidences for DM

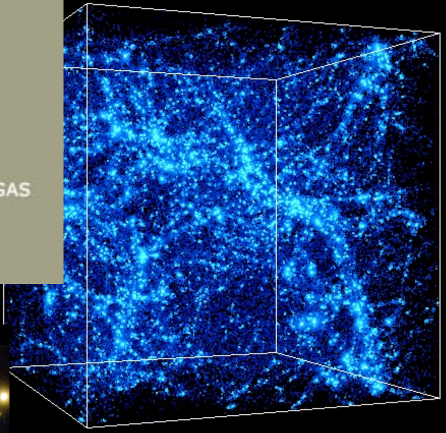


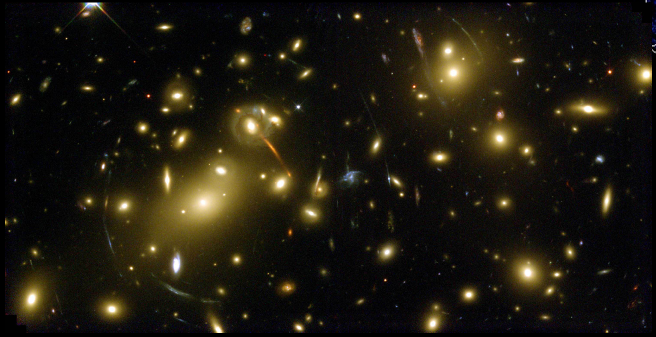






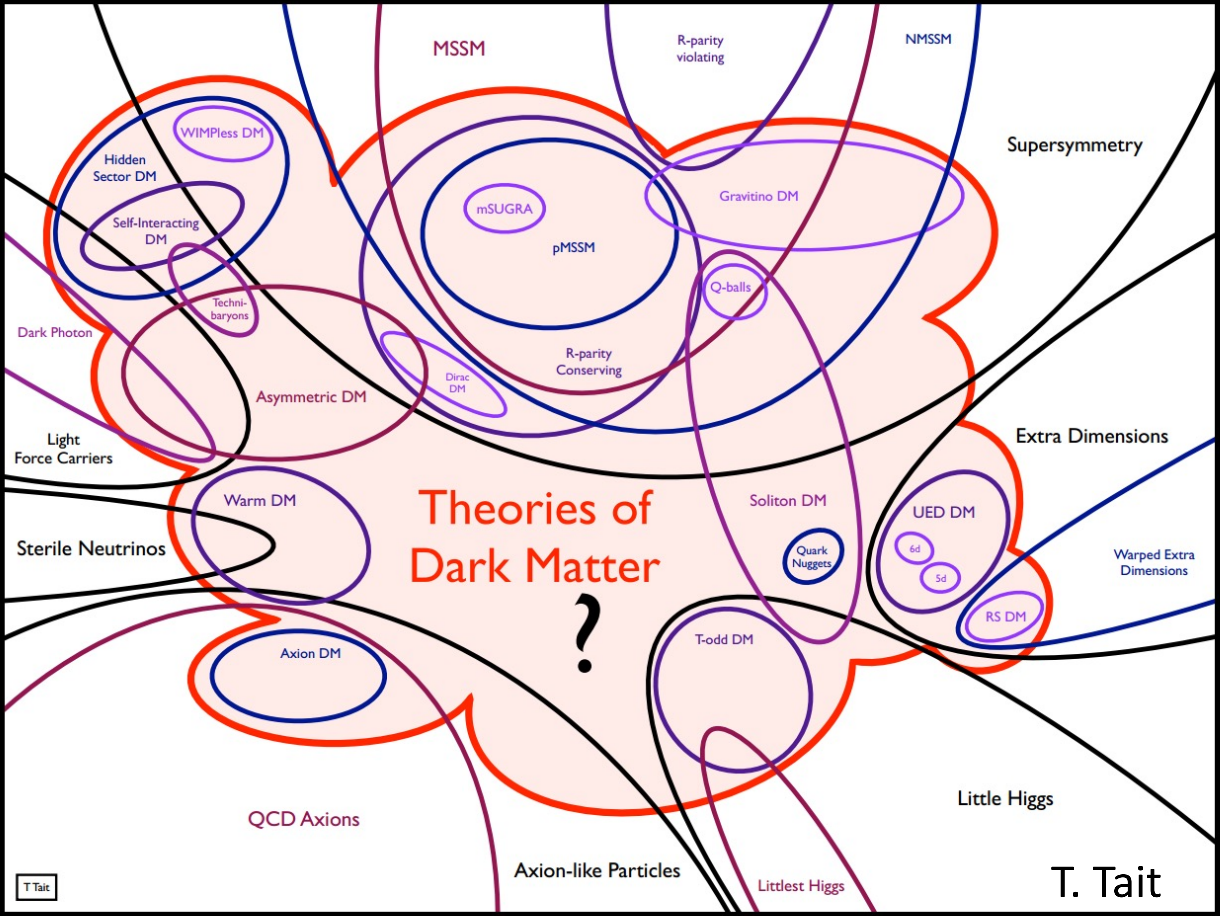






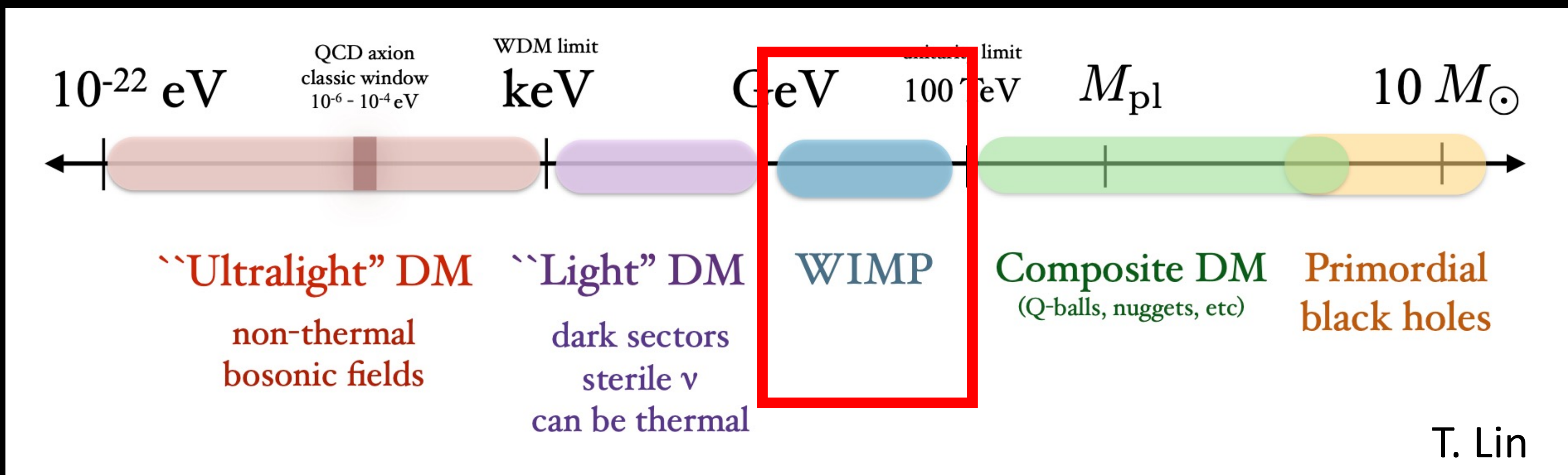
- All the evidences are from gravitational effects!
- We want to search for the particle natures of DM!

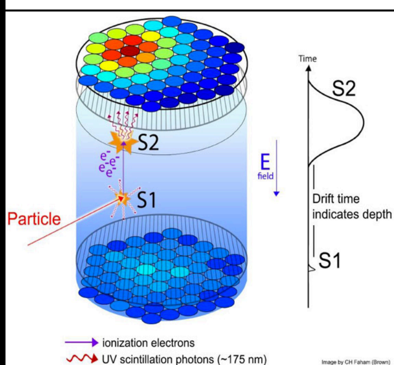
Models of DM

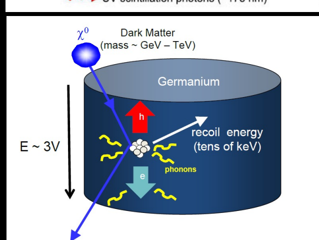


MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
mSUGRA
pMSSM
Gravitino DM
Q-balls
R-parity Conserving
Dirac DM
Dark Photon
Asymmetric DM
Light Force Carriers
Extra Dimensions
Warm DM
Theories of Dark Matter
?
Soliton DM
Quark Nuggets
UED DM
6d
5d
RS DM
Warped Extra Dimensions
Sterile Neutrinos
Axion DM
T-odd DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
T Tait
T. Tait

WIMP search







XENON10, ZEPLIN

XENON100, PandaX

XENON1T, LUX, PandaXII

XENONnT, LZ, PandaX4T

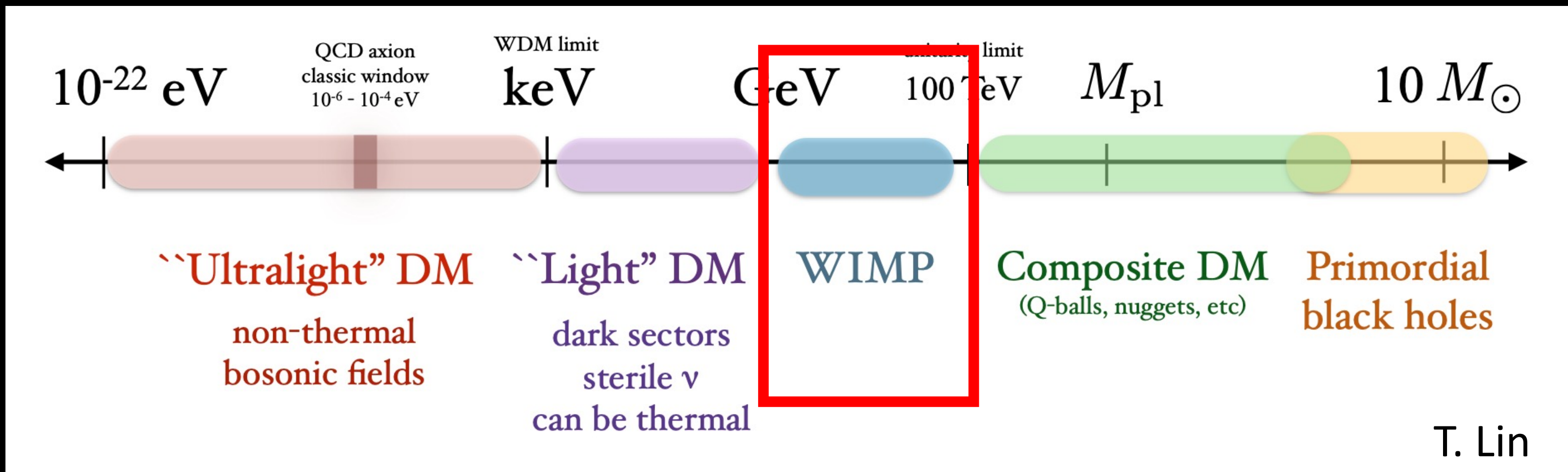
CDMS,CDEX CoGeNT

CDMSII, CDEX

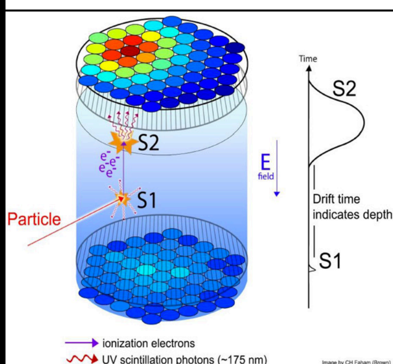
superCDMS, CDEX10

superCDMSSNO, CDEX50

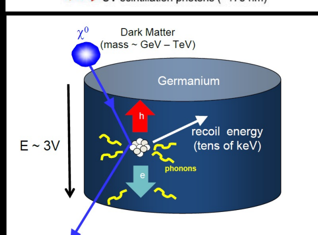
WIMP search



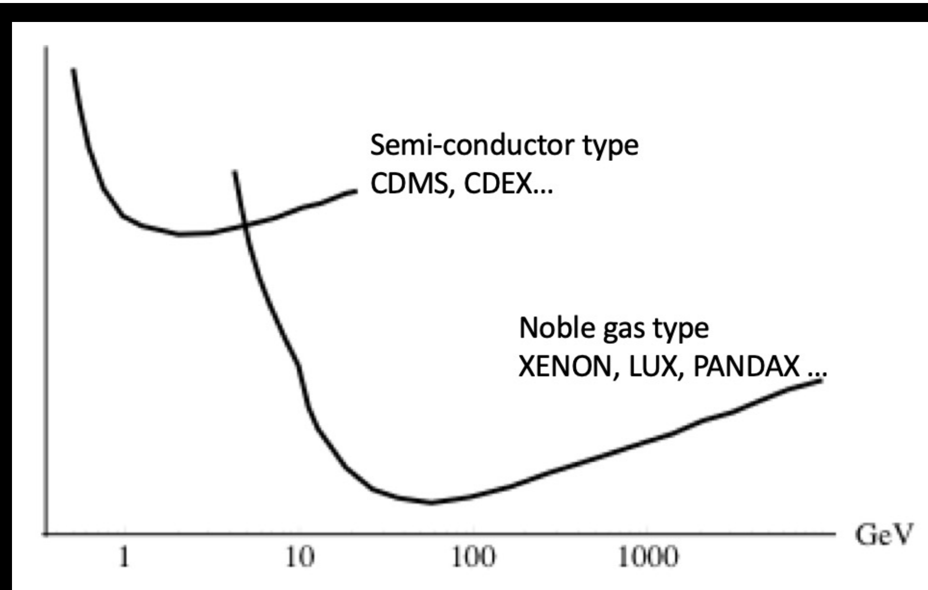
10^{-22} eV
QCD axion classic window 10^{-6} - 10^{-4} eV
WDM limit
keV
GeV
limit
100 TeV
M_{pl}
$10\ M_{\odot}$
``Ultralight" DM
non-thermal bosonic fields
``Light" DM
dark sectors
sterile ν
can be thermal
WIMP
Composite DM
(Q-balls, nuggets, etc)
Primordial black holes
T. Lin



Time
S2
S2
E field
S1
Particle
Drift time indicates depth
S1
ionization electrons
UV scintillation photons (~175 nm)

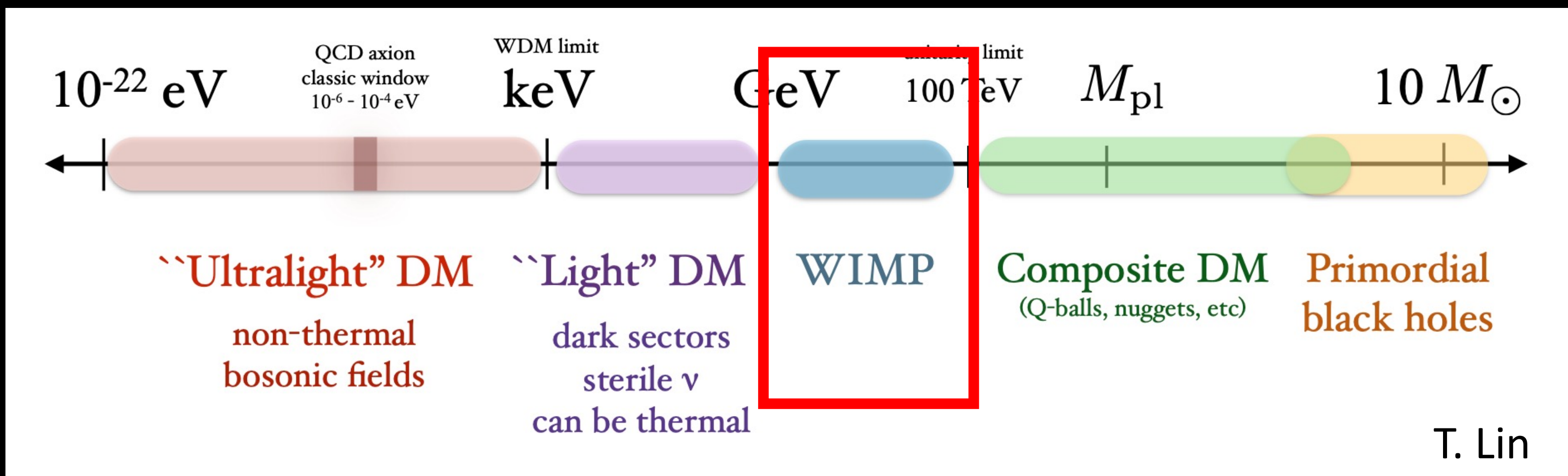


Dark Matter (mass ~ GeV – TeV)
Germanium
E ~ 3V
recoil energy (tens of keV)
phonons



Semi-conductor type
CDMS, CDEX...
Noble gas type
XENON, LUX, PANDAX ...
GeV
1
10
100
1000

WIMP search



QCD axion
classic window
10^{-6} - 10^{-4} eV
WDM limit
limit
10^{-22} eV
keV
GeV
100 TeV
$M_{\rm pl}$
10 $M_\odot$
``Ultralight" DM
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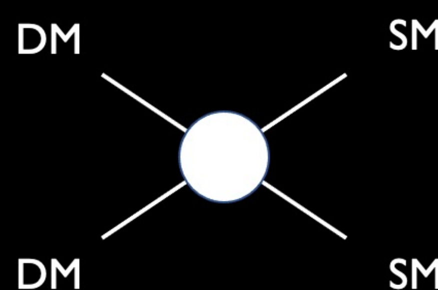
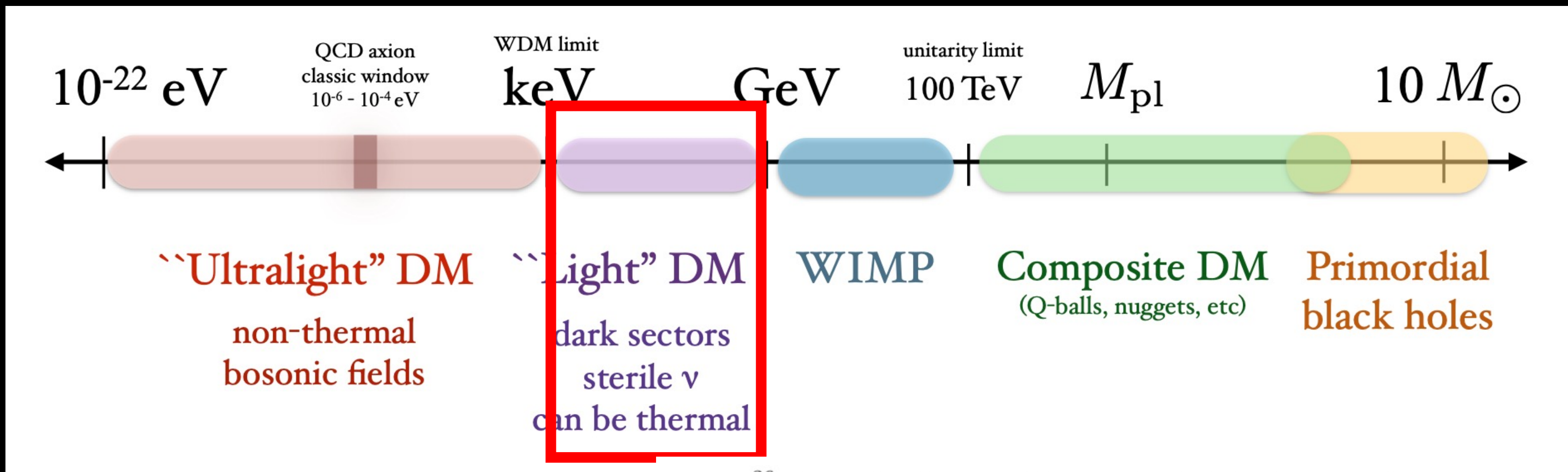
ALICE
CMS
ATLAS
LHCb



DM
SM
DM
SM

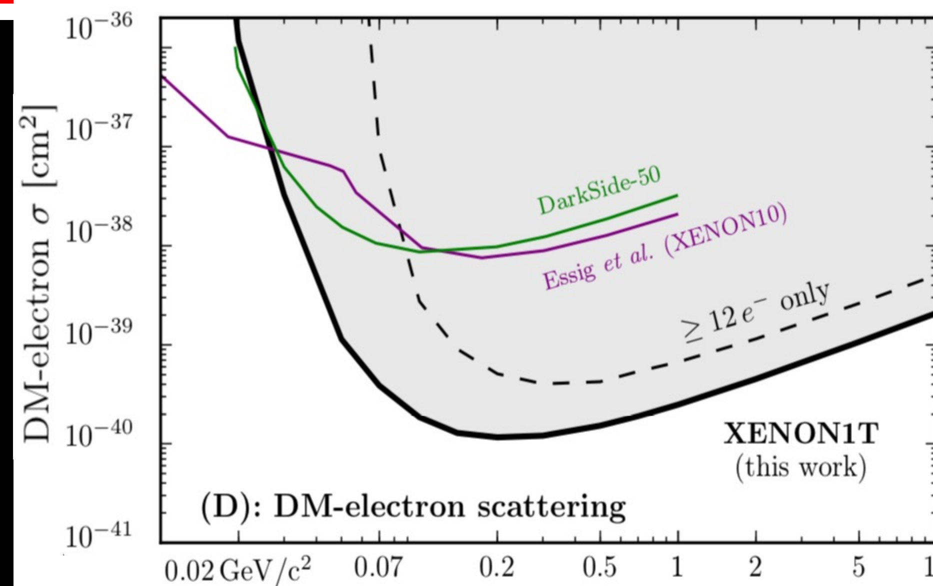
Light DM



$$E_{\rm recoil} \sim \frac{m_{\rm DM} m_T}{(m_{\rm DM} + m_T)^2} E_{\rm DM}$$

Using electron recoils

$$E_{ex} \sim 10 \text{ eV}$$
$$m_{DM} > 10 \text{ MeV}$$



Lighter DM ($m_{DM} < 10\ \mathrm{MeV}$)

- Lower the threshold (Using semi-conductor, superconductor, or skipper CCD technology, nano tubes …)

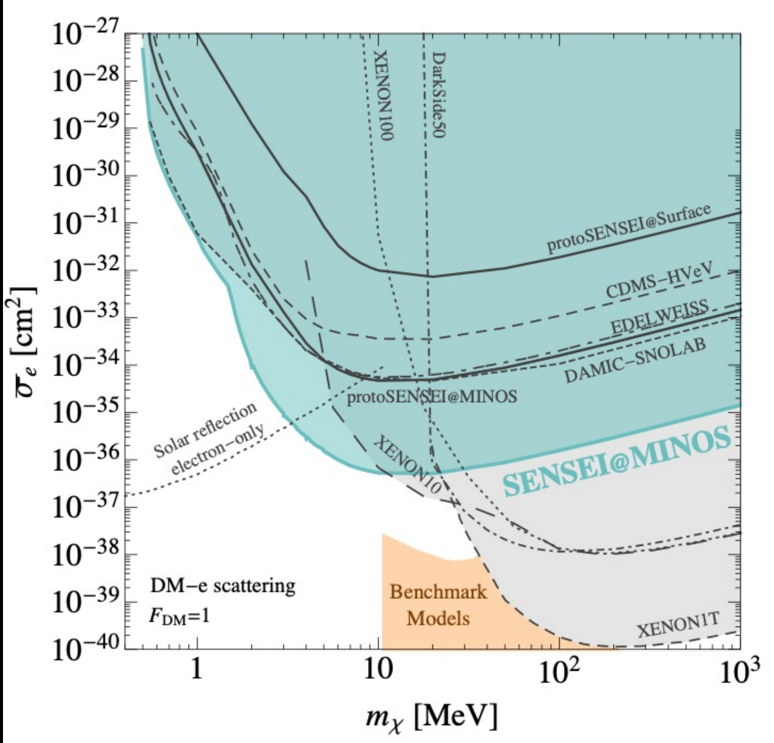
SENSEI Experiment:

Target: Skipper CCD

E_{er} threshold: 1.2 eV

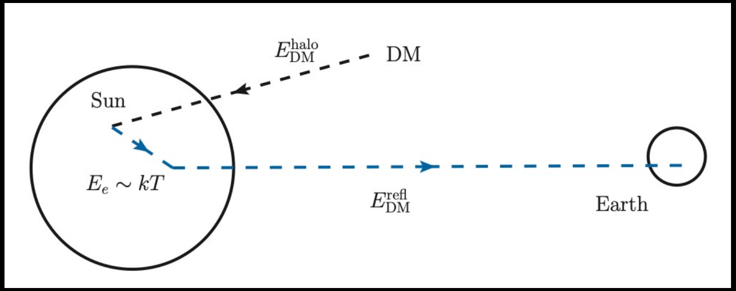
$m_D > 0.5\ \mathrm{MeV}$

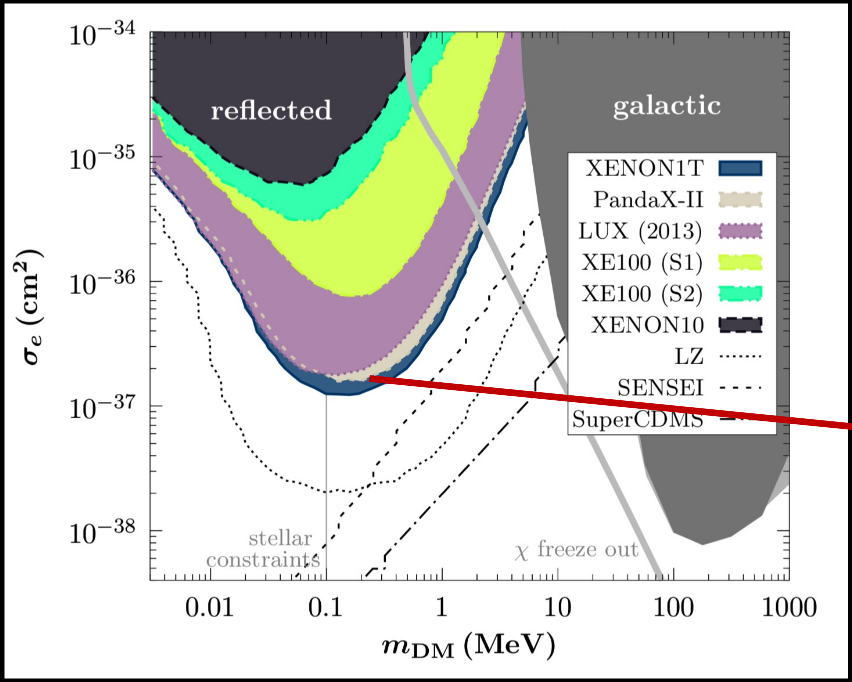
SENSEI 2004.11378, 48 gram-days

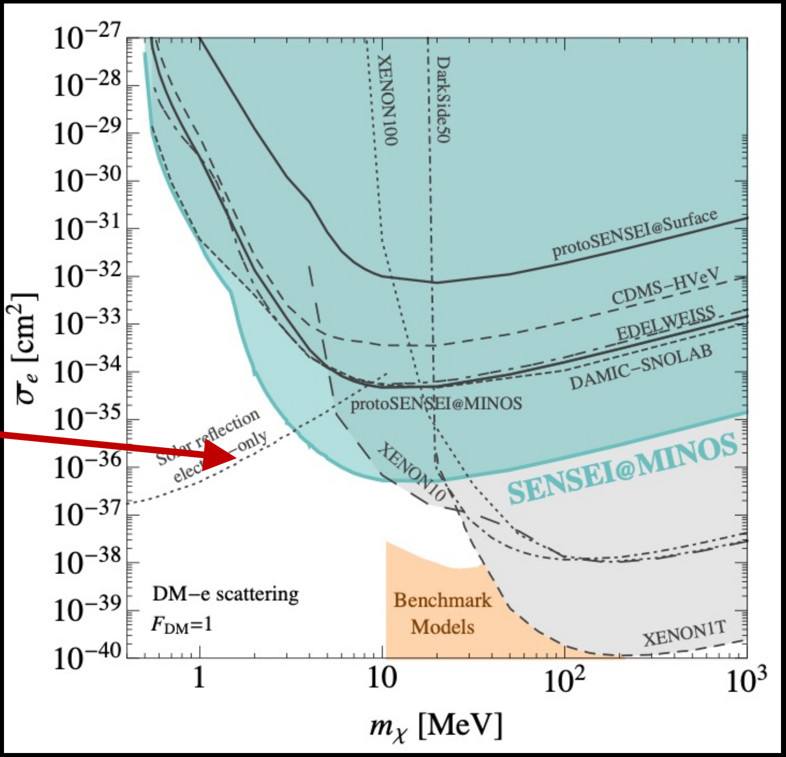


Boosted DM

- With the help from the Sun



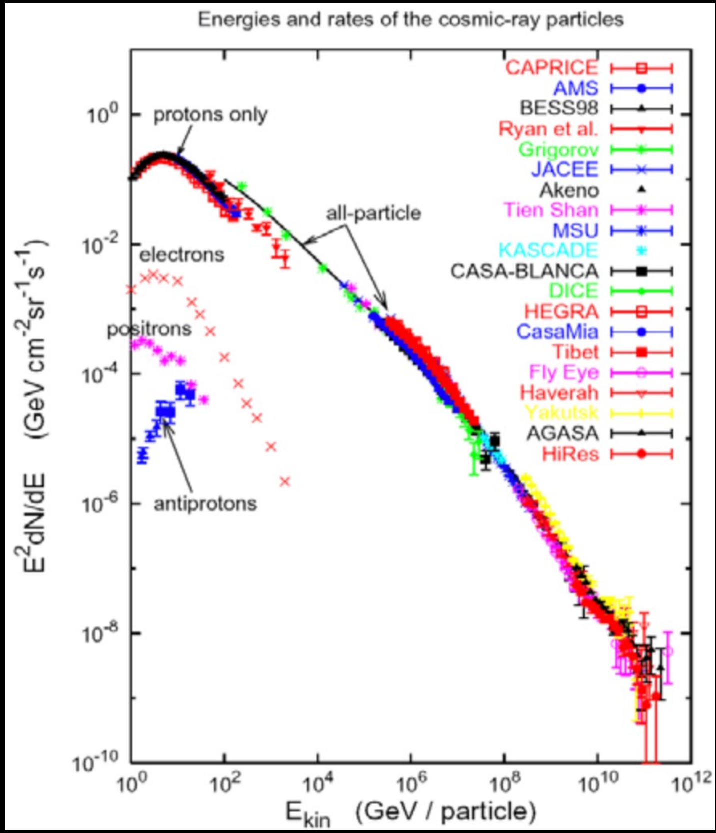




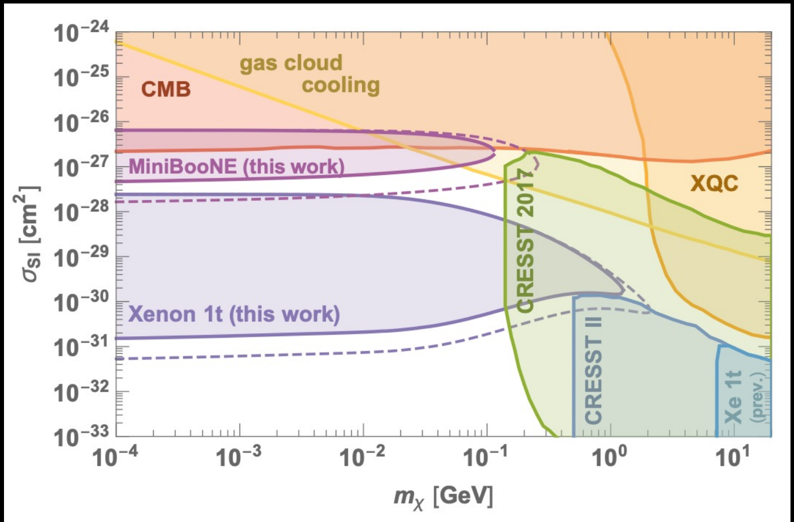
HA, M. Pospelov, J. Pradler, A. Ritz, PRL 120 (2018) 141801

Boosted DM

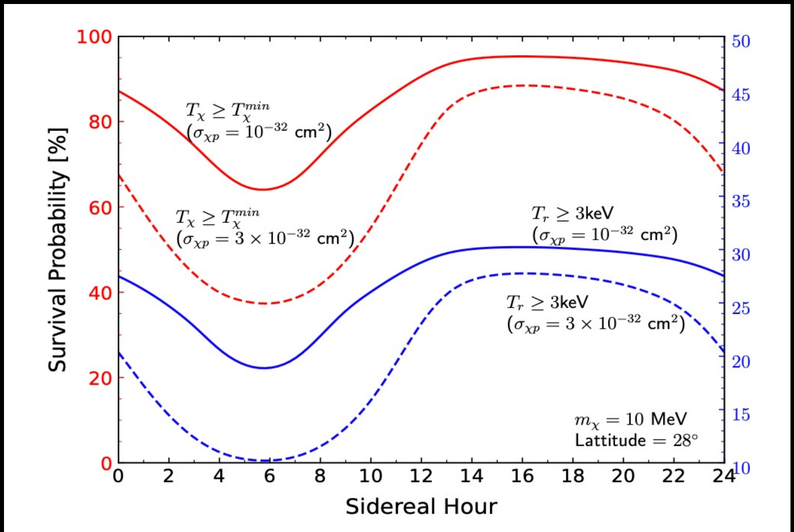
- With Cosmic rays



Bringmann, Pospelov, PRL 122 (2019) 171801



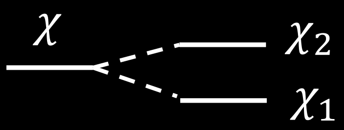
S.Ge, J.Liu, Q.Yuan, N.Zhou, PRL 126 (2021) 091804



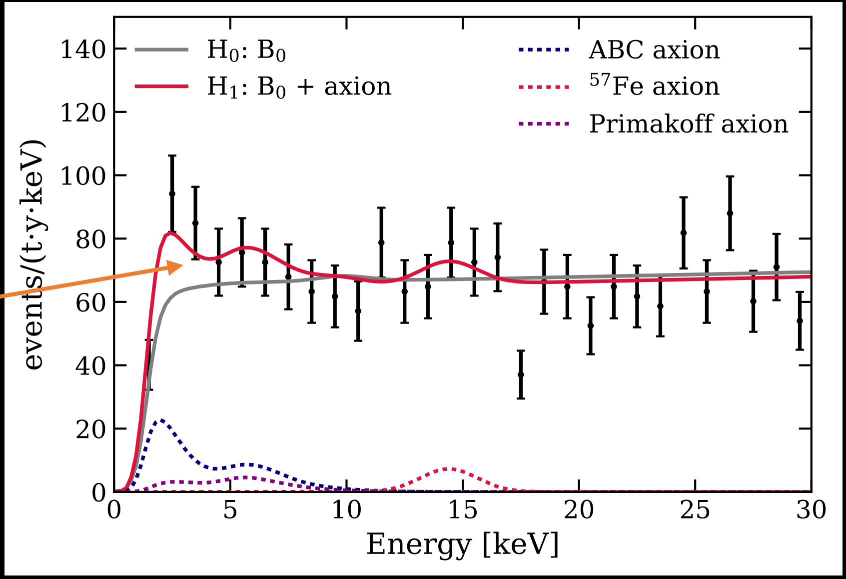
Boosted DM

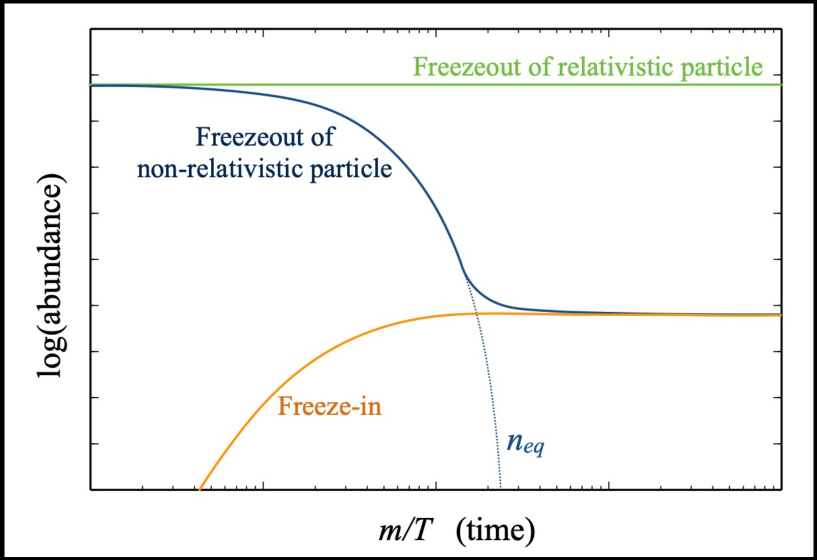
- Self boosting

Few keV gap



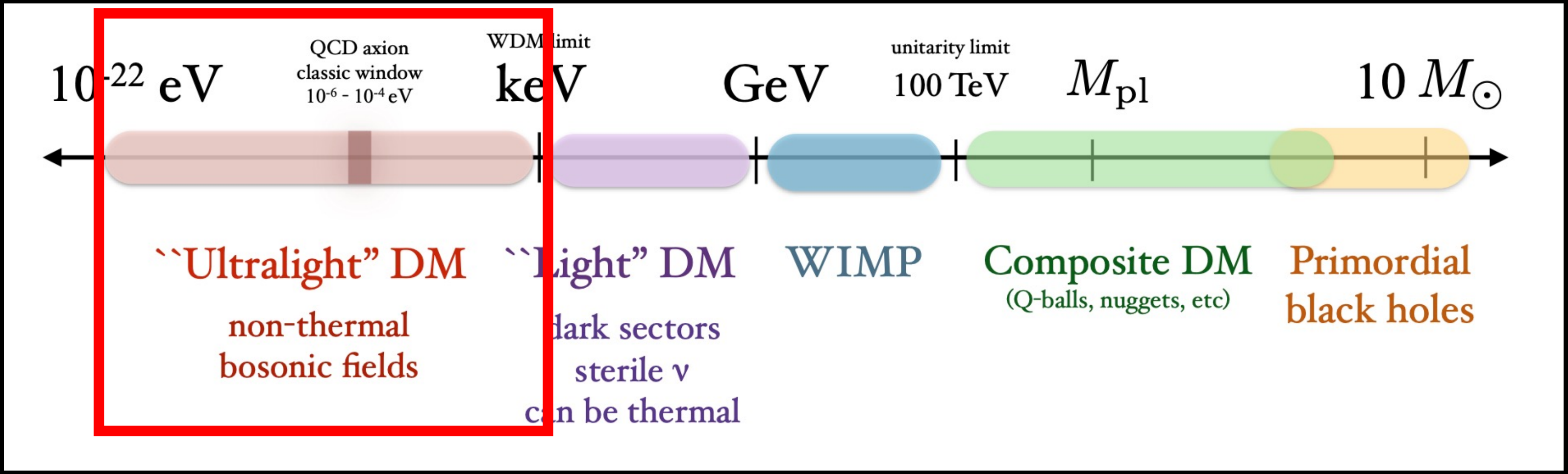
XENON1T, PRD 102 (2020) 072004





Freeze-out:
K. Harigaya, Y. Nakai, M.Suzuki, 2006.11938
J.Bramante, N. Song, 2006.14089
M.Baryakhtar, A.Berlin, H.Liu, N.Weiner, 2006.13918
…
Freeze-in:
HA, D.Yang, 2006.15672

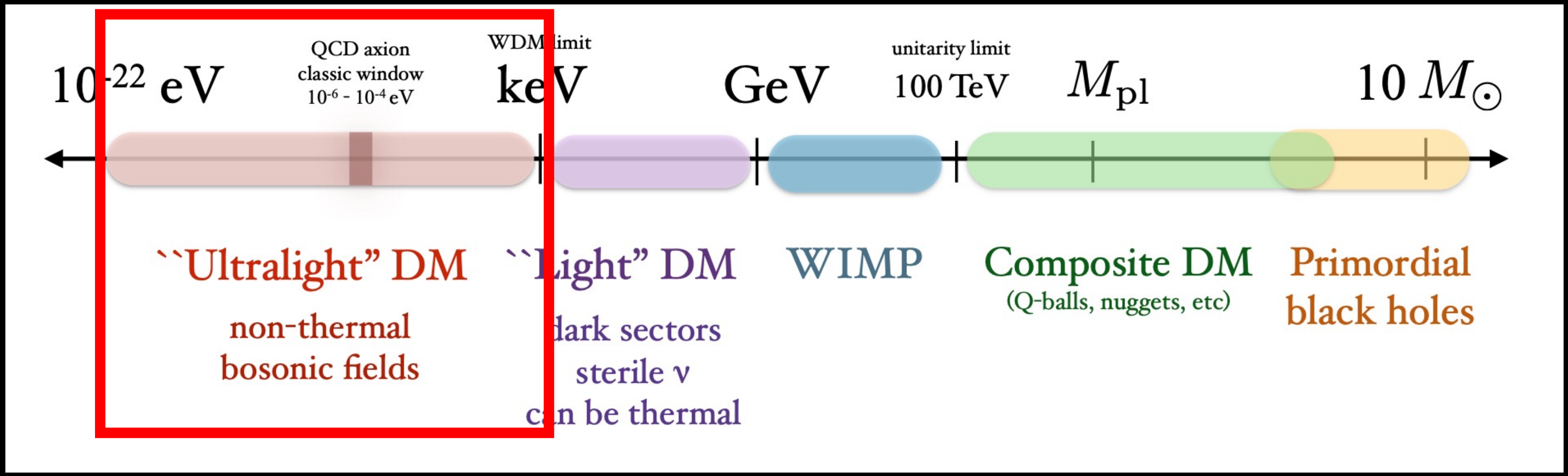
Ultralight bosonic DM



Why not ultralight fermions?

- Fermions lighter than about 1 keV cannot form the cores of dwarf galaxies. (Tremaine-Gunn bound)
- Fermions lighter than about 2 keV cannot be cold enough, fermi momentum is too large.

Ultralight bosonic DM



Axions and axion-like particles

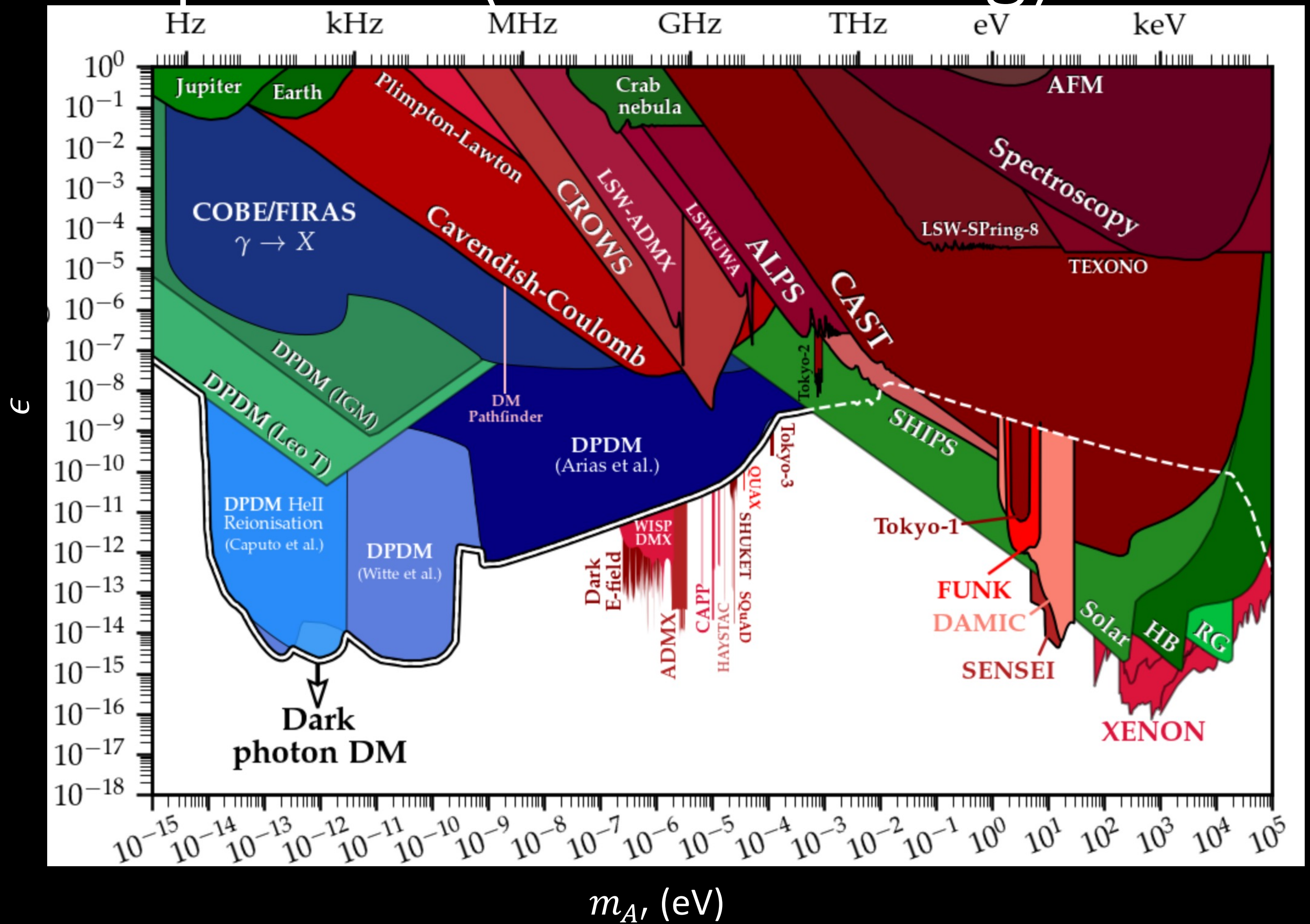
Pengfei's talk

$$aF_{\mu\nu}\tilde{F}^{\mu\nu} \qquad \partial_\mu a\bar{e}\gamma^\mu\gamma_5 e \qquad \partial_\mu a\bar{N}\gamma^\mu\gamma_5 N$$

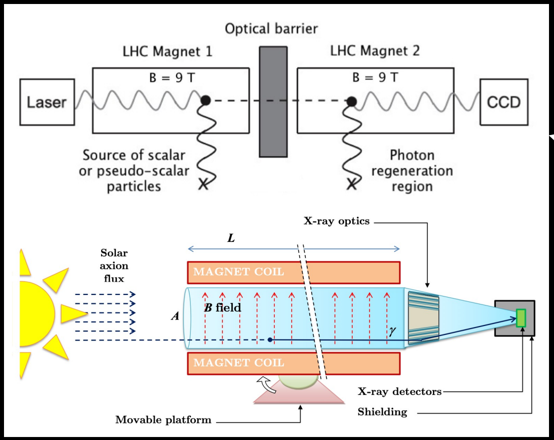
Dark photons

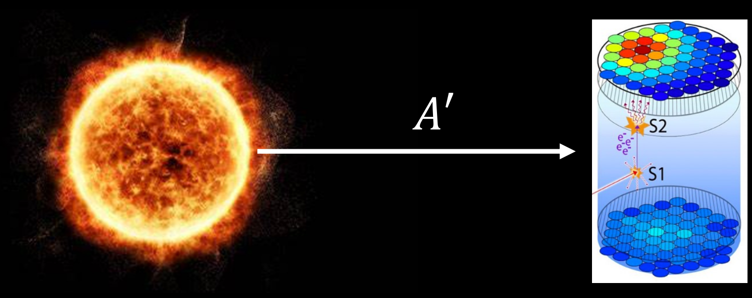
$$-\frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu} \qquad A'_\mu(J^\mu_B - J^\mu_L) \qquad A'_\mu(J^\mu_\mu - J^\mu_\tau)$$

Dark photon (kinetic mixing)

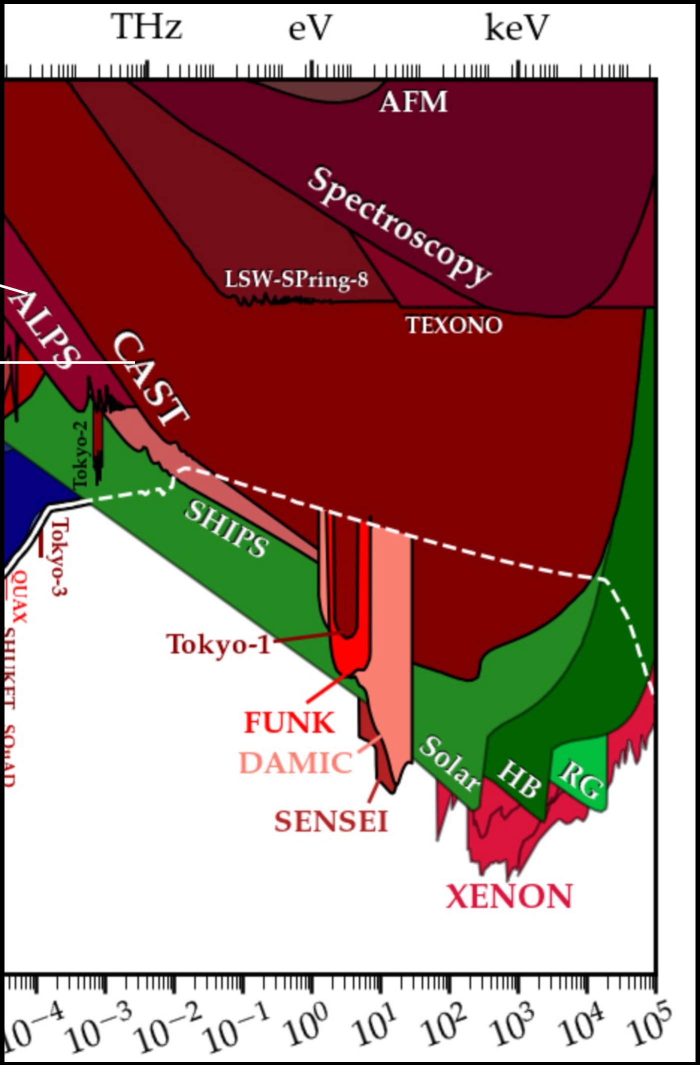


Dark photon





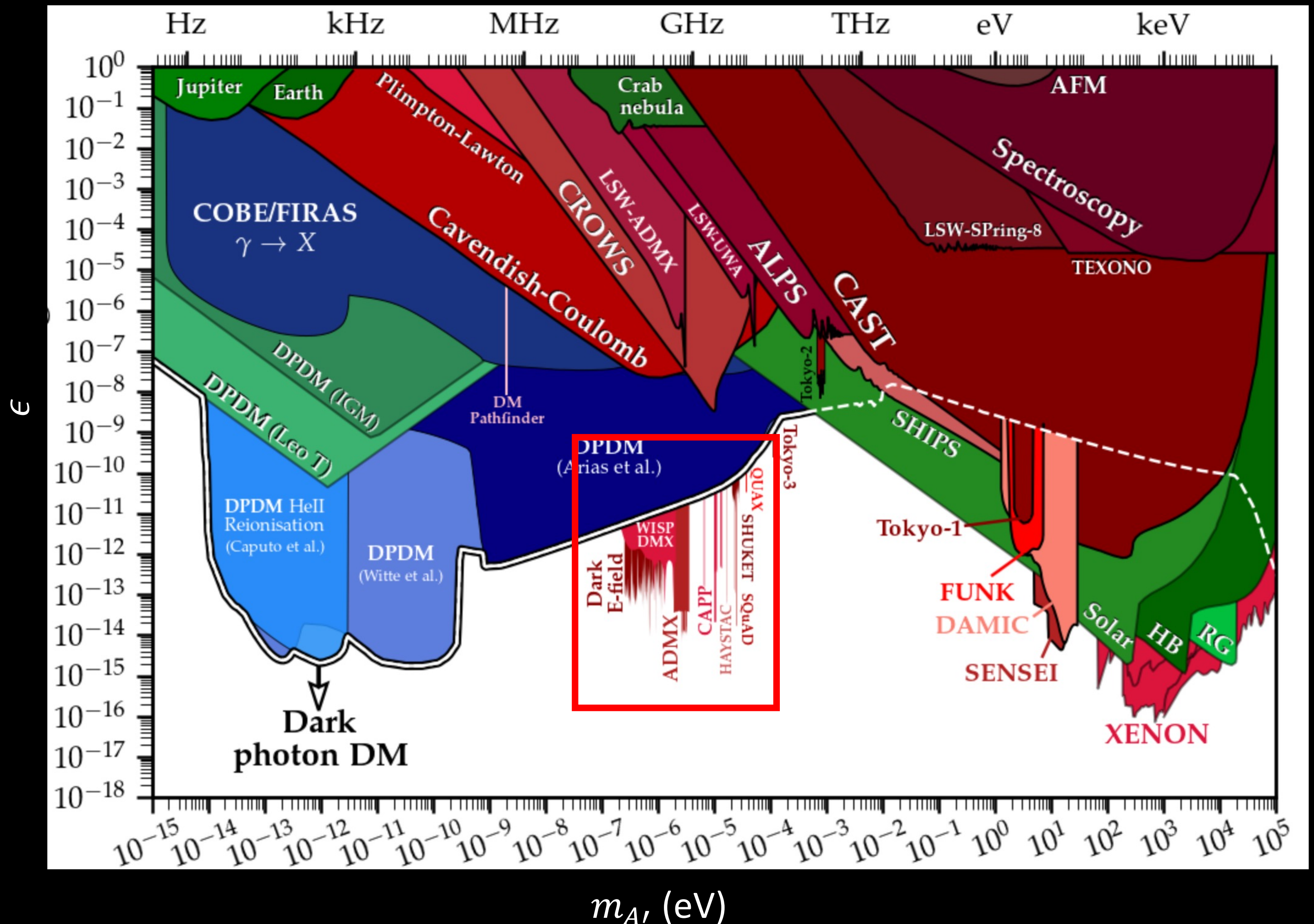
HA, Pospelov, Pradler, PLB 725 (2013) 190,
HA, Pospelov, Pradler, PRL 111 (2013) 041302
HA, Pospelov, Pradler, Ritz, PLB 747 (2015) 331
HA, Pospelov, Pradler, Ritz, PRD 102 (2020) 115022



Resonant transition

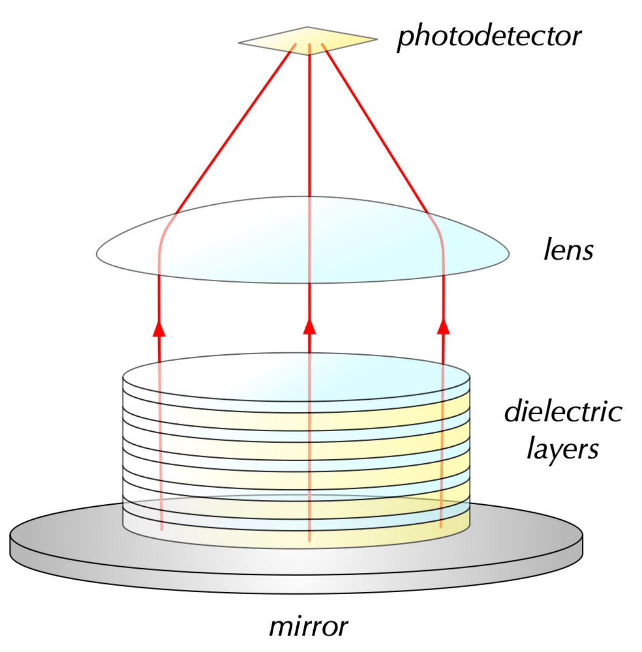
- Dispersion relations in the vacuum $$\boxed{-\frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}}$$
  - For photon: $\omega^2 - k^2 = 0$
  - For dark photon: $\omega^2 - k^2 = m_{A'}^2$
  - Photons cannot convert into dark photon in the vacuum.
  - The goal is to match the dispersion relations of A and A' to have resonant conversion.

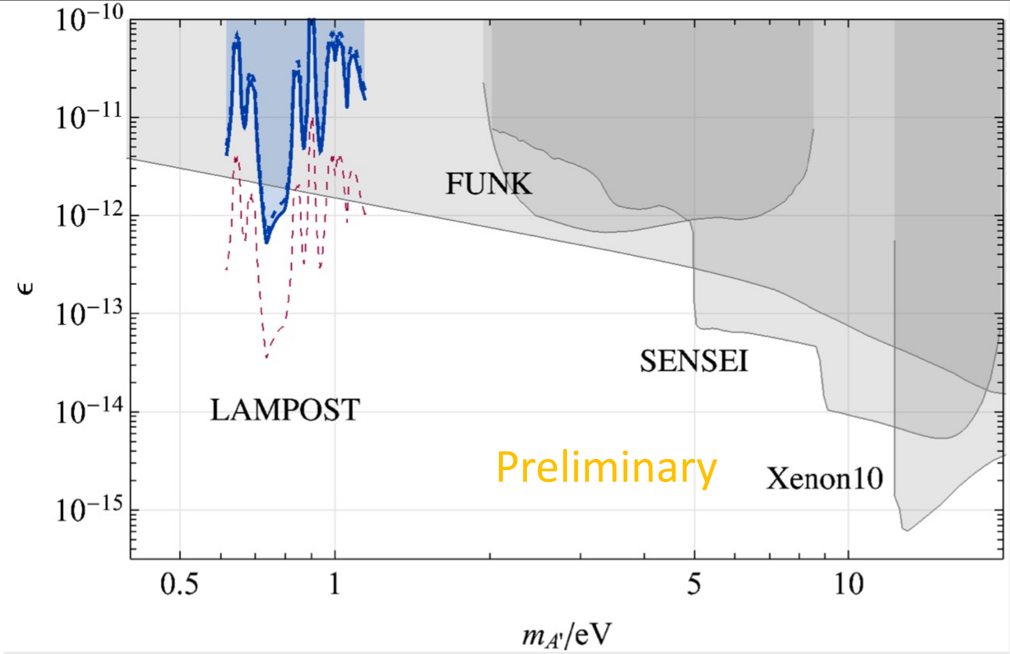
With resonant cavities



With uneven dielectric layers

LAMPOST



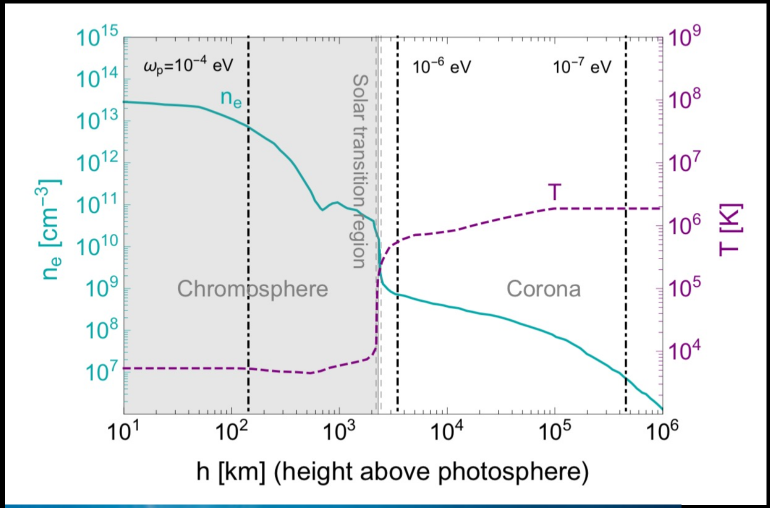


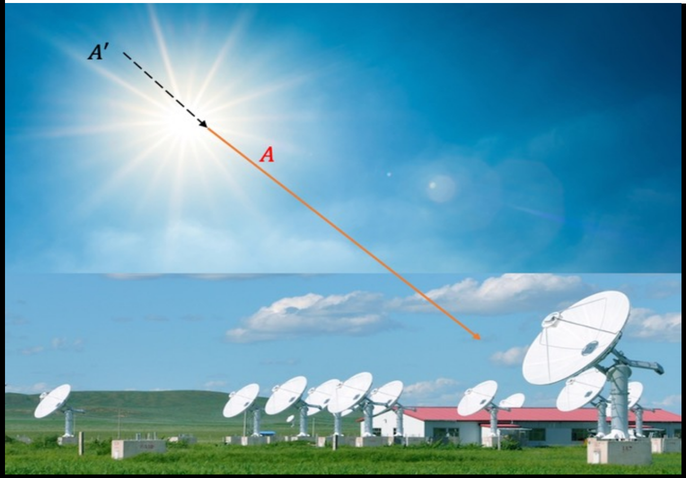
Baryakhtar, Huang, Lasenby, PRD98 (2018) 035006

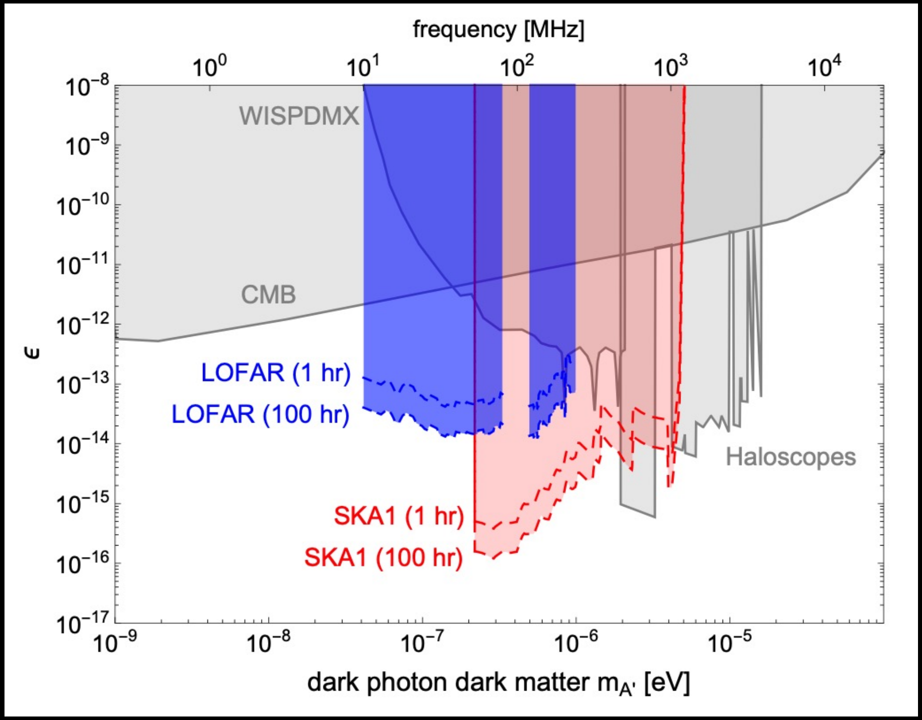
Resonant transition inside plasma

- Dispersion relations in plasma $\boxed{-\frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}}$
  - For photon: $\omega^2 - k^2 = \omega_p^2$ $\omega_p^2 = \frac{4\pi\alpha_{EM}n_e}{m_e}$
  - For dark photon: $\omega^2 - k^2 = m_{A'}^2$
  - Photons can convert into dark photon in the plasma if $\omega_p = m_{A'}$

With plasma in Sun’s corona



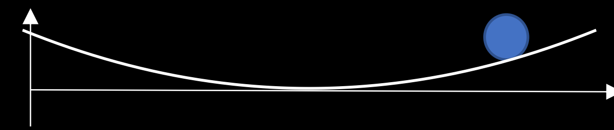




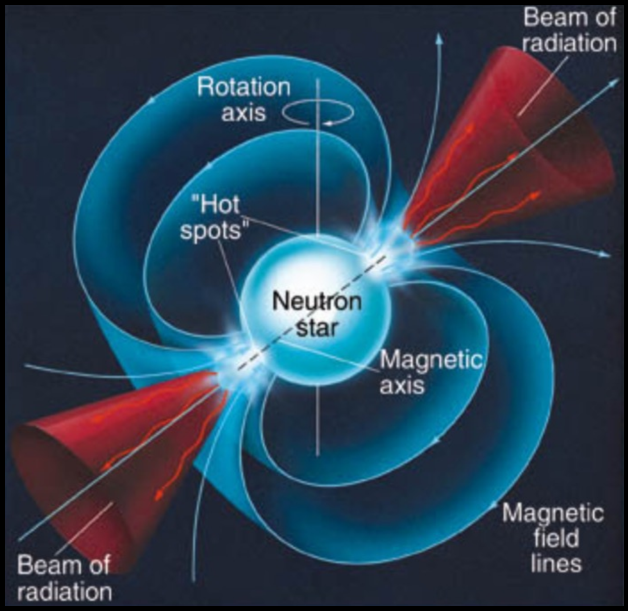
HA, F.P. Huang, J.Liu, W.Xue, PRL 126 (2021) 181102

Indirect detection of axion DM

- Use neutron star as magnetic field
- Atmospere of neutron star provides magnetic field



$$g_{a\gamma\gamma} a(\mathbf{x},t)\mathbf{E}(\mathbf{x},t)\cdot\mathbf{B}(\mathbf{x},t)$$



F.P.Huang et al. PRD 97 (2018) 123001
Hook, Kahn, Safdi, Sun, PRL 121 (2018) 241102

Dark photon coupled to baryon number

- Searching for dark photon dark matter with GW detectors

  A. Pierce, K.Riles, Y.Zhao, PRL 121 (2018) 061102

- Using LIGO to search for dark photon dark matter

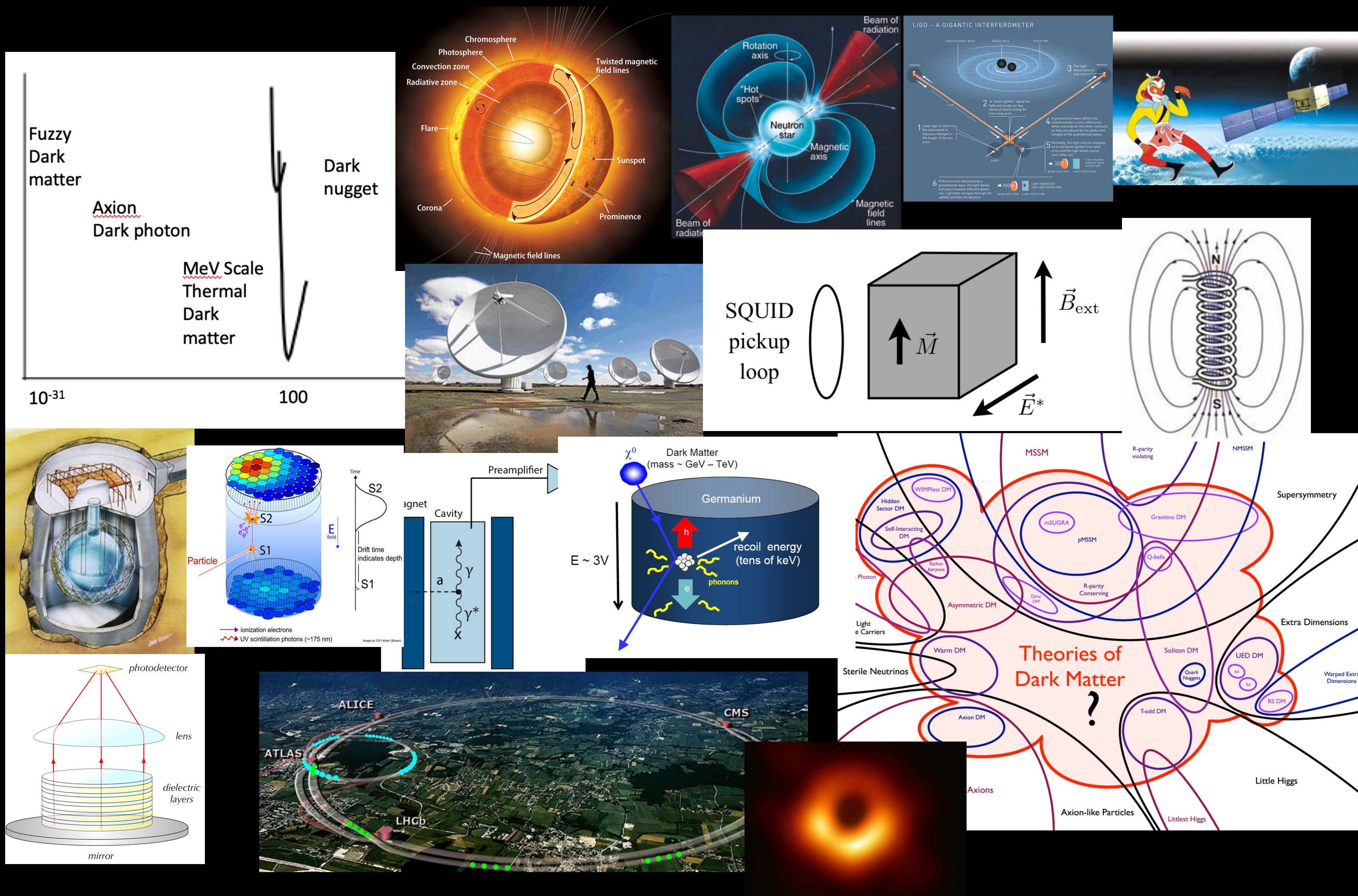
  H.-K Guo, K. Riles, F.-W. Yang, Y. Zhao, 1905.04316, …

- Using GAIA to search for dark photon dark matter

  H.-K. Guo, J. Shu, X. Xue, Q. Yuan, Y. Zhao, 1902.05962

- …

Summary



Fuzzy Dark matter
Axion
Dark photon
MeV Scale Thermal Dark matter
Dark nugget
10^{-31}
100
Chromosphere
Photosphere
Convection zone
Radiative zone
Twisted magnetic field lines
Flare
Sunspot
Corona
Prominence
Magnetic field lines
Beam of radiation
Rotation axis
"Hot spots"
Neutron star
Magnetic axis
Magnetic field lines
LIGO – A GIGANTIC INTERFEROMETER
SQUID pickup loop
$\vec{M}$
$\vec{B}_{\text{ext}}$
$\vec{E}^*$
N
S
Particle
S2
S1
E field
Drift time indicates depth
ionization electrons
UV scintillation photons (~175 nm)
Preamplifier
Cavity
a
γ
γ*
x
χ^0
Dark Matter (mass ~ GeV – TeV)
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Asymmetric DM
Light e Carriers
Warm DM
Sterile Neutrinos
Theories of Dark Matter
?
Soliton DM
Extra Dimensions
UED DM
Warped Extra Dimensions
RS DM
Axion DM
T-odd DM
Axions
Axion-like Particles
Little Higgs
photodetector
lens
dielectric layers
mirror
ALICE
CMS
ATLAS
LHCb