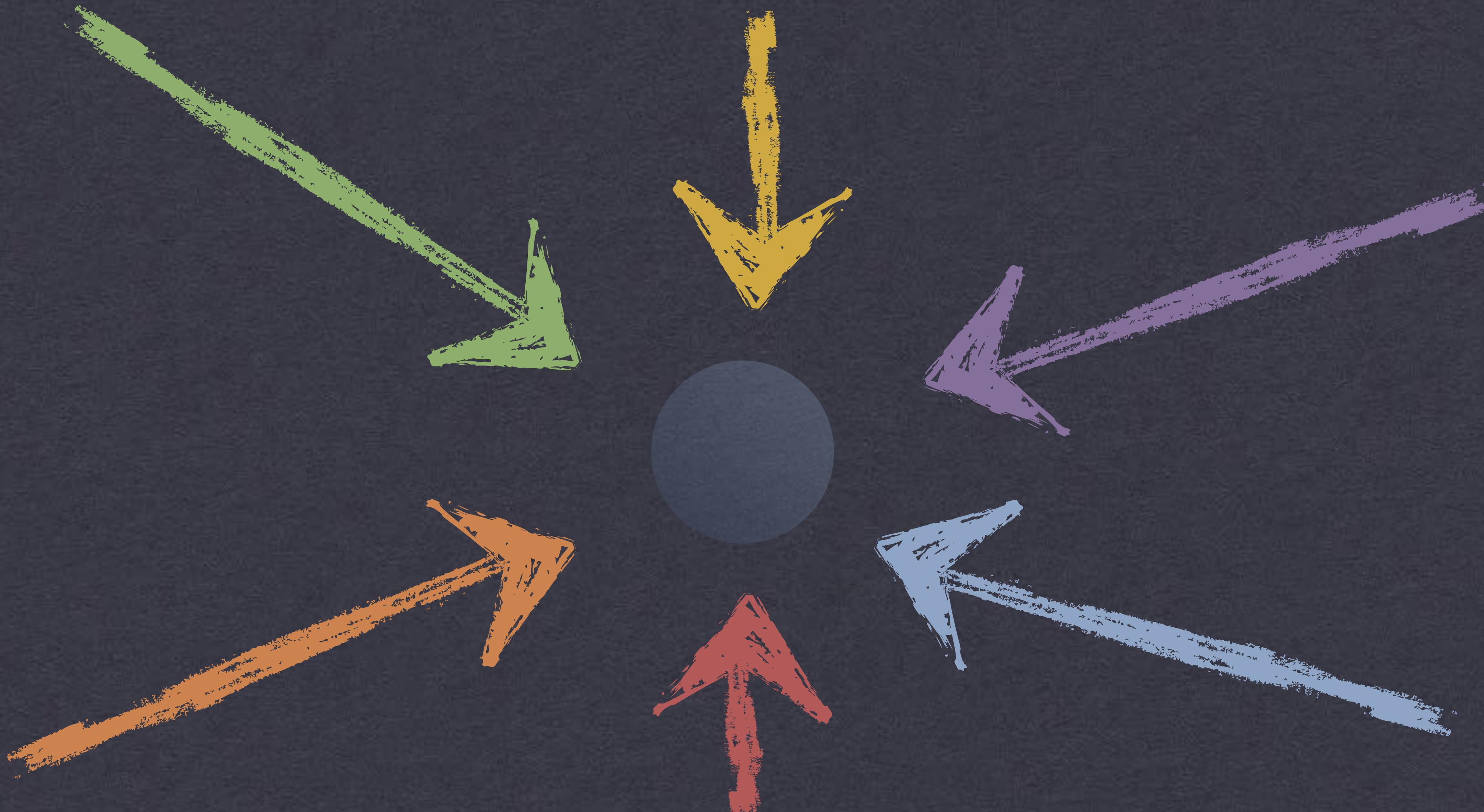


EXPLORING DARK MATTER FROM ALL DIRECTIONS

SPENCER CHANG (U. OREGON, NTU)

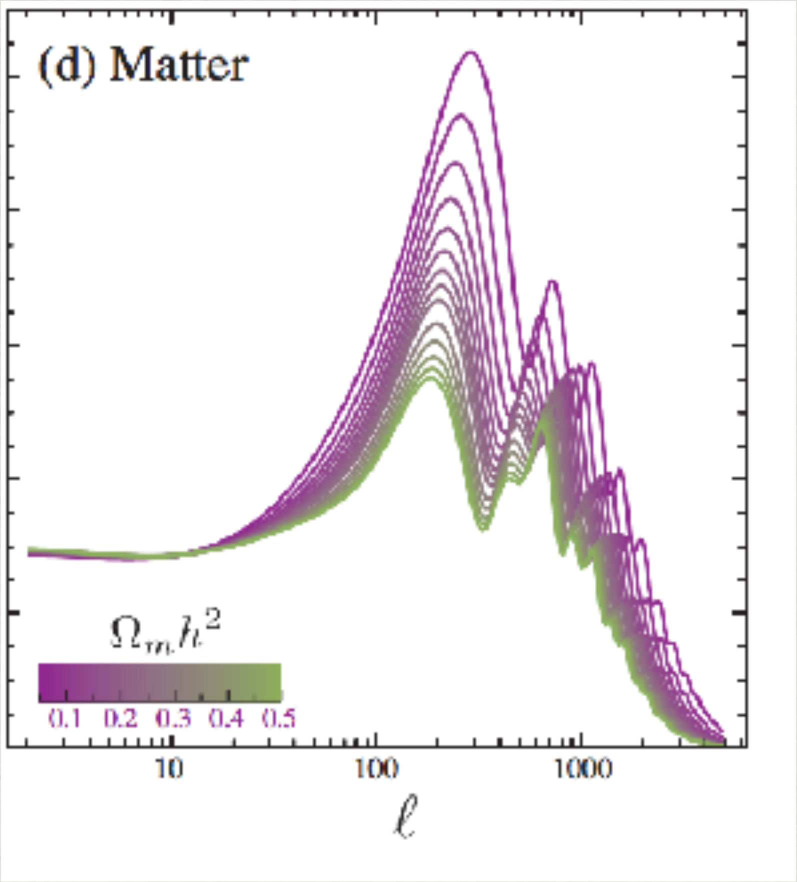
COSMOLOGY/PARTICLES WORKSHOP NTU 2018

Dark Matter Everywhere and Not a Direct Signal (We Think)

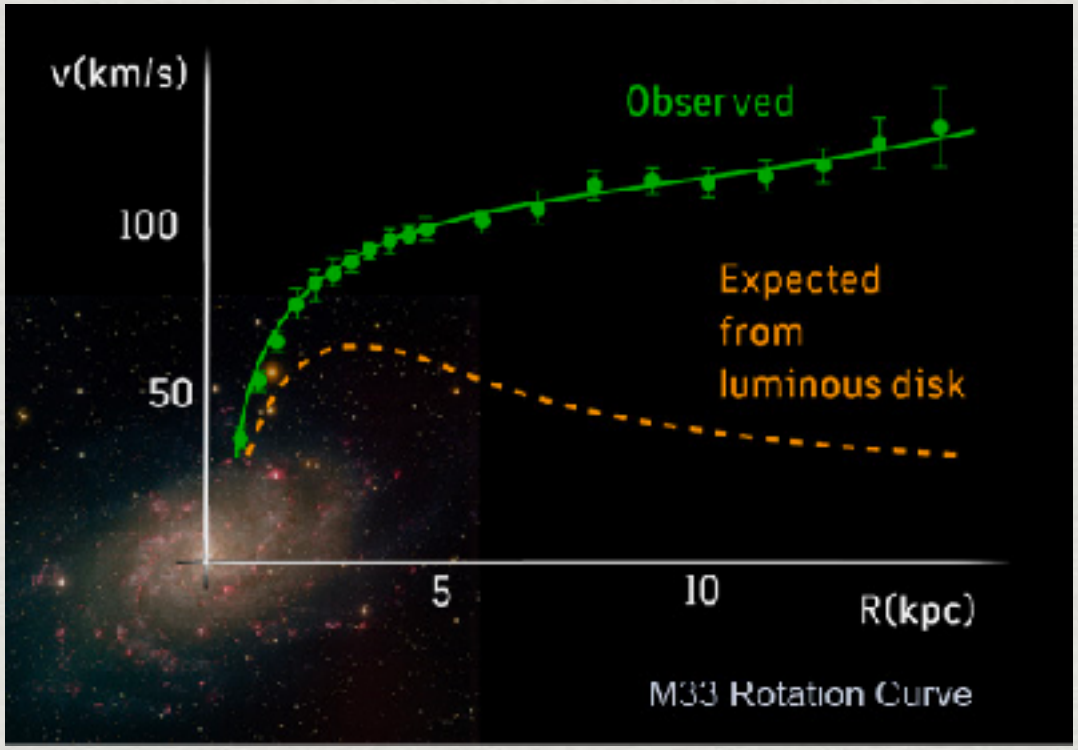
Dark Matter Everywhere and Not a Direct Signal (We Think)

Credit: Sean Carroll

Evidence of Dark Matter comes from many sources



Hu, Donaldson



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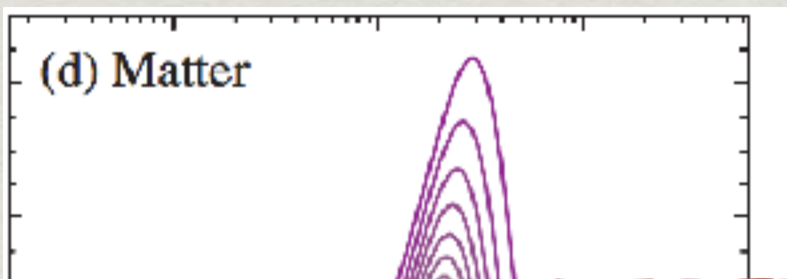
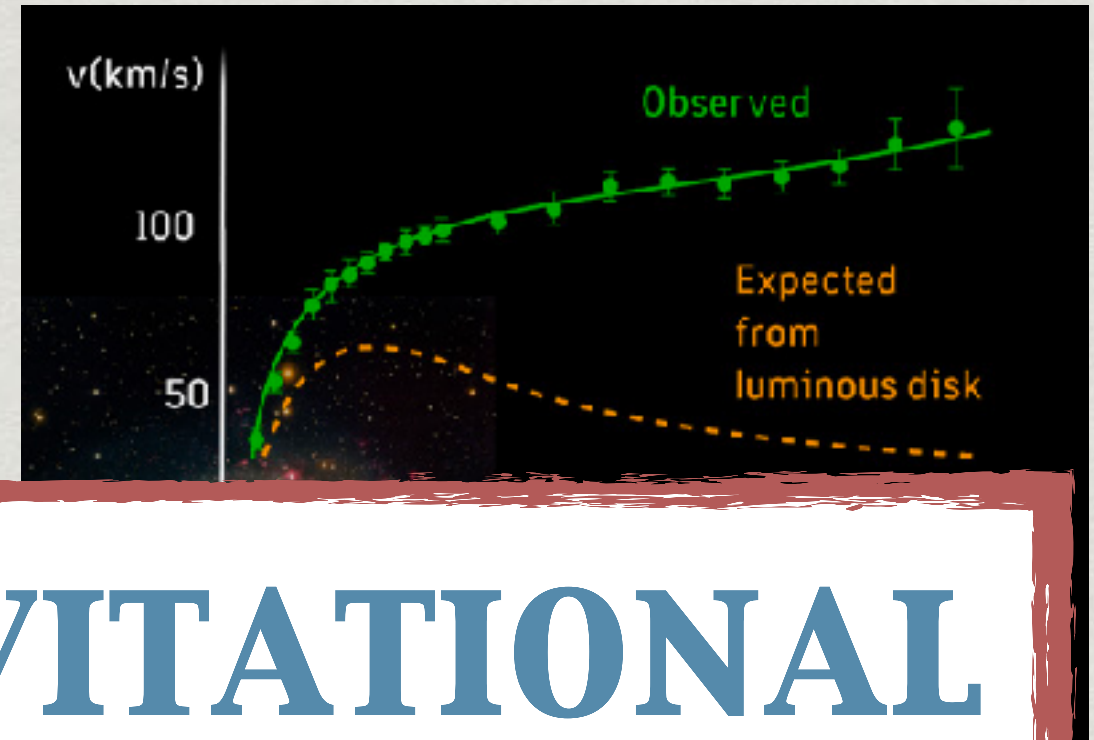
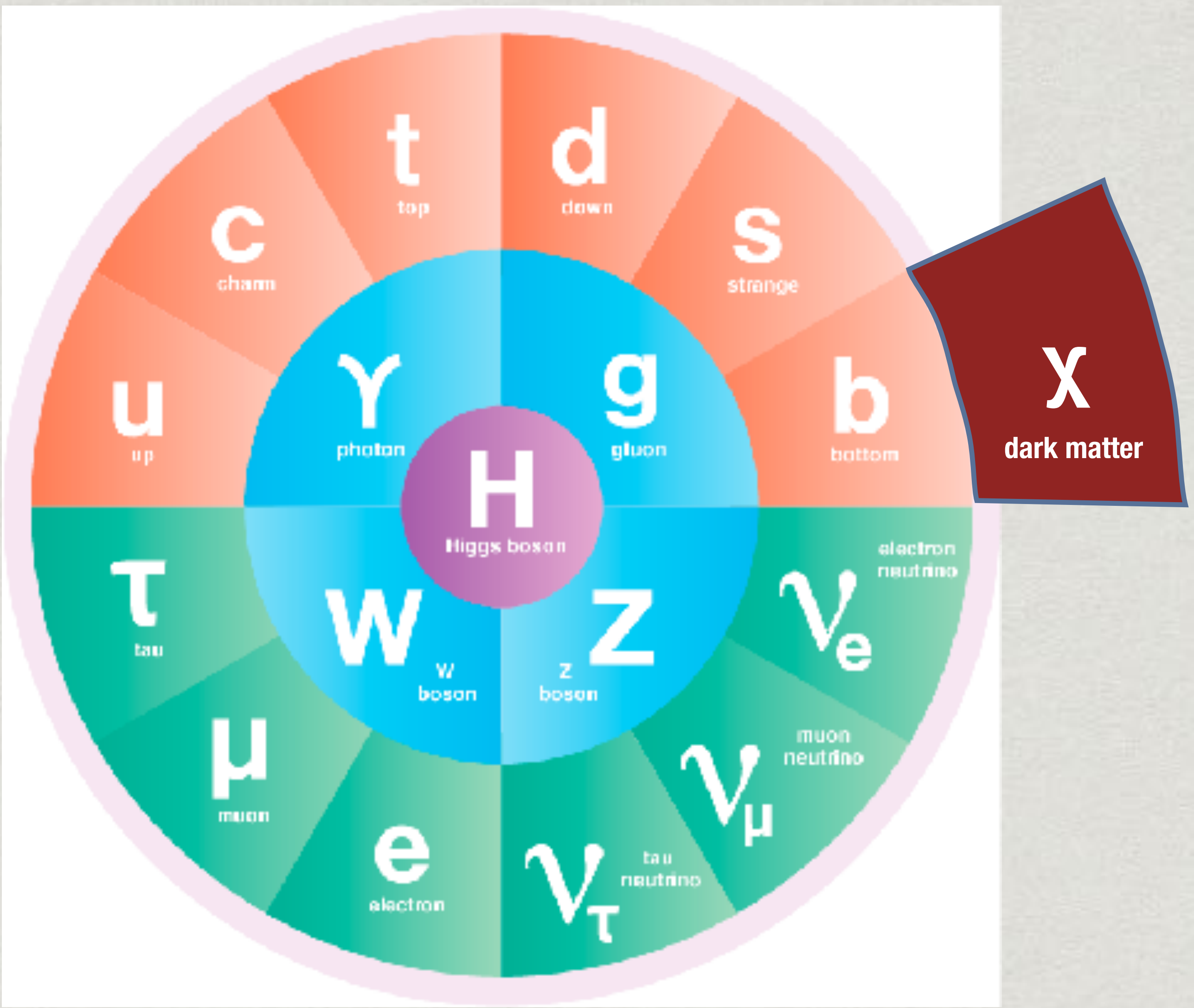




Only Gravitational Effects So Far...

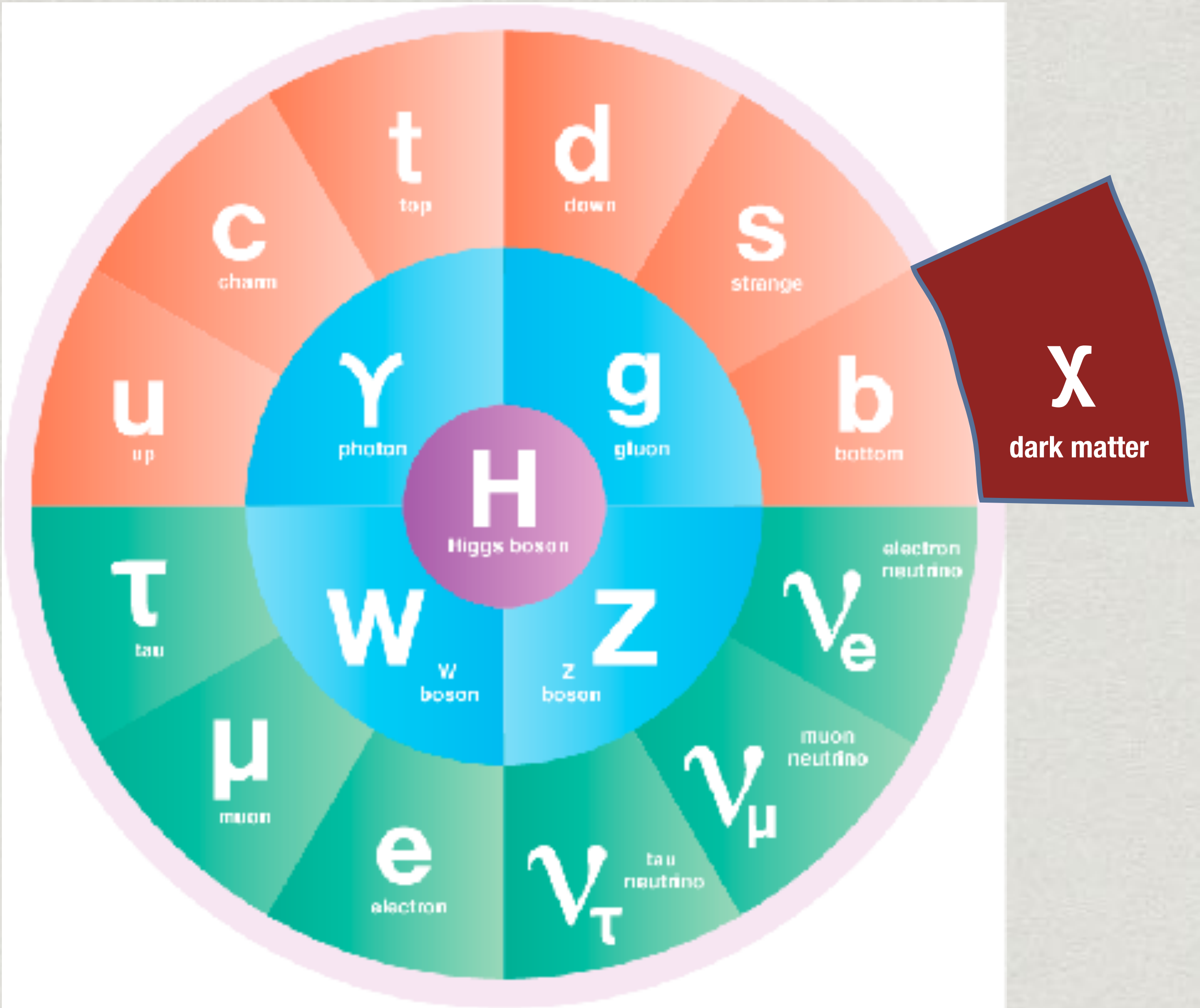
But what is DM fundamentally?



Symmetry Magazine

How does it fit into the Standard Model of particle physics?

But what is DM fundamentally?



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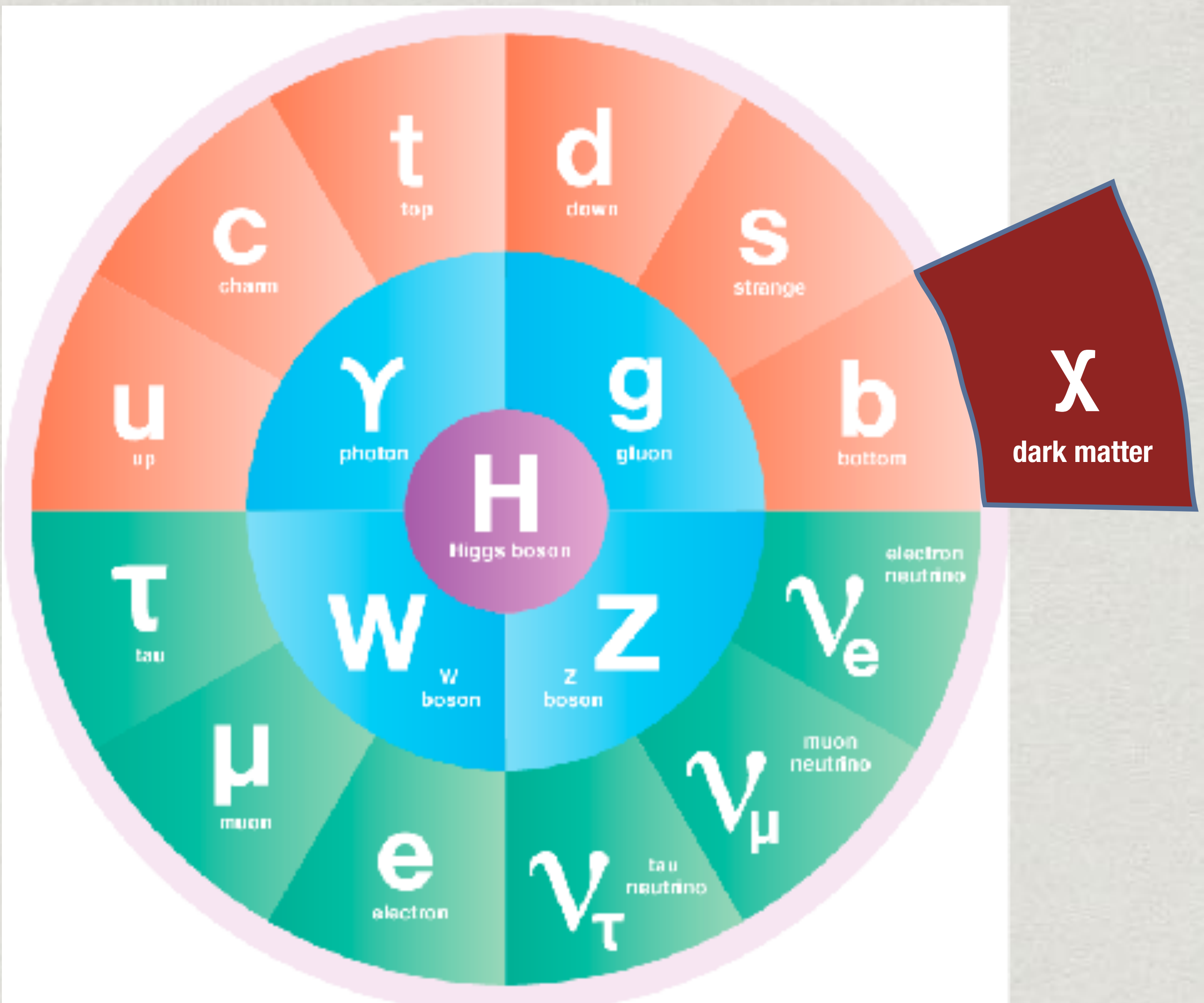
How does it fit into the Standard Model of particle physics?

What is its spin, mass?
What are its interactions?

But what is DM fundamentally?



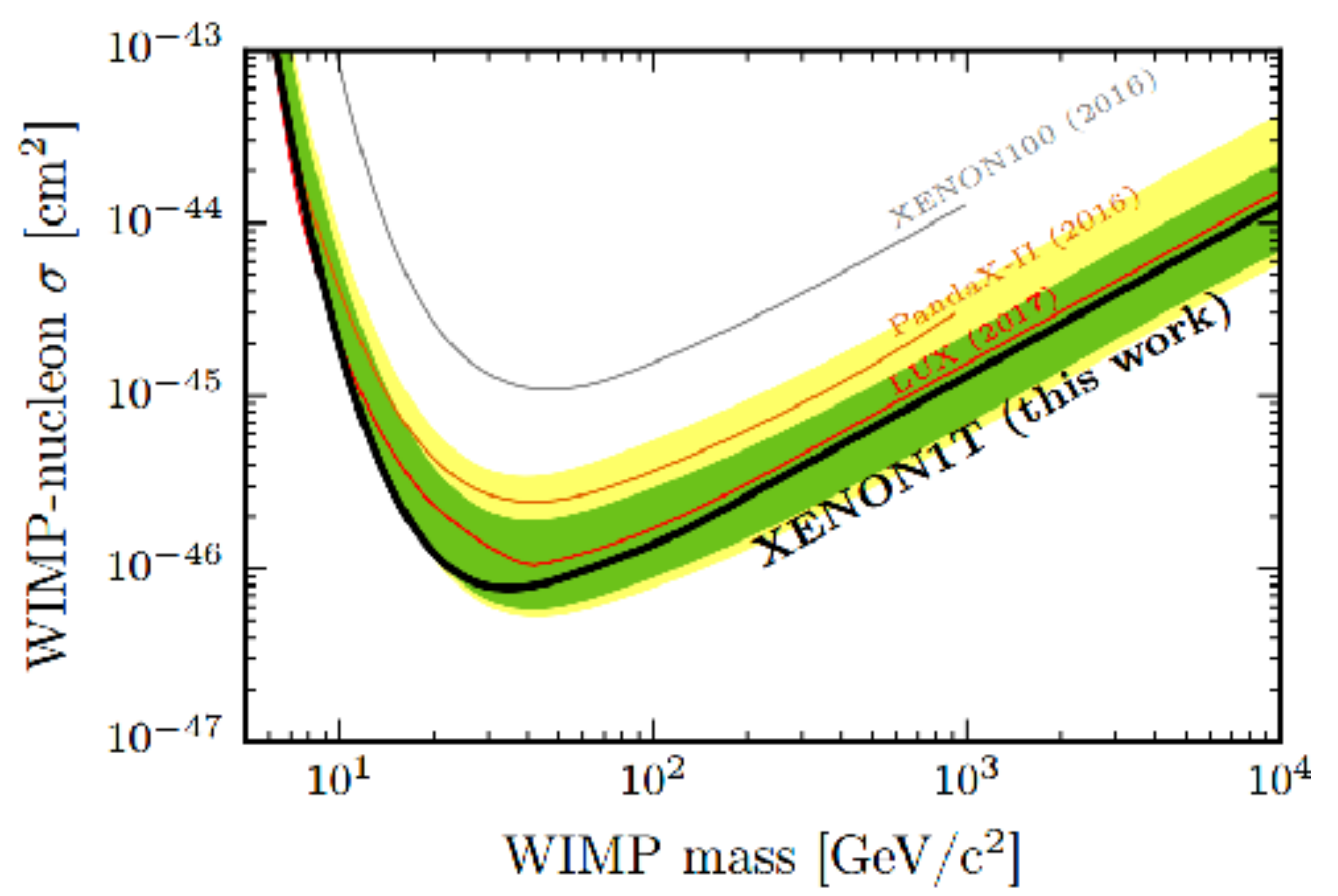
Symmetry Magazine

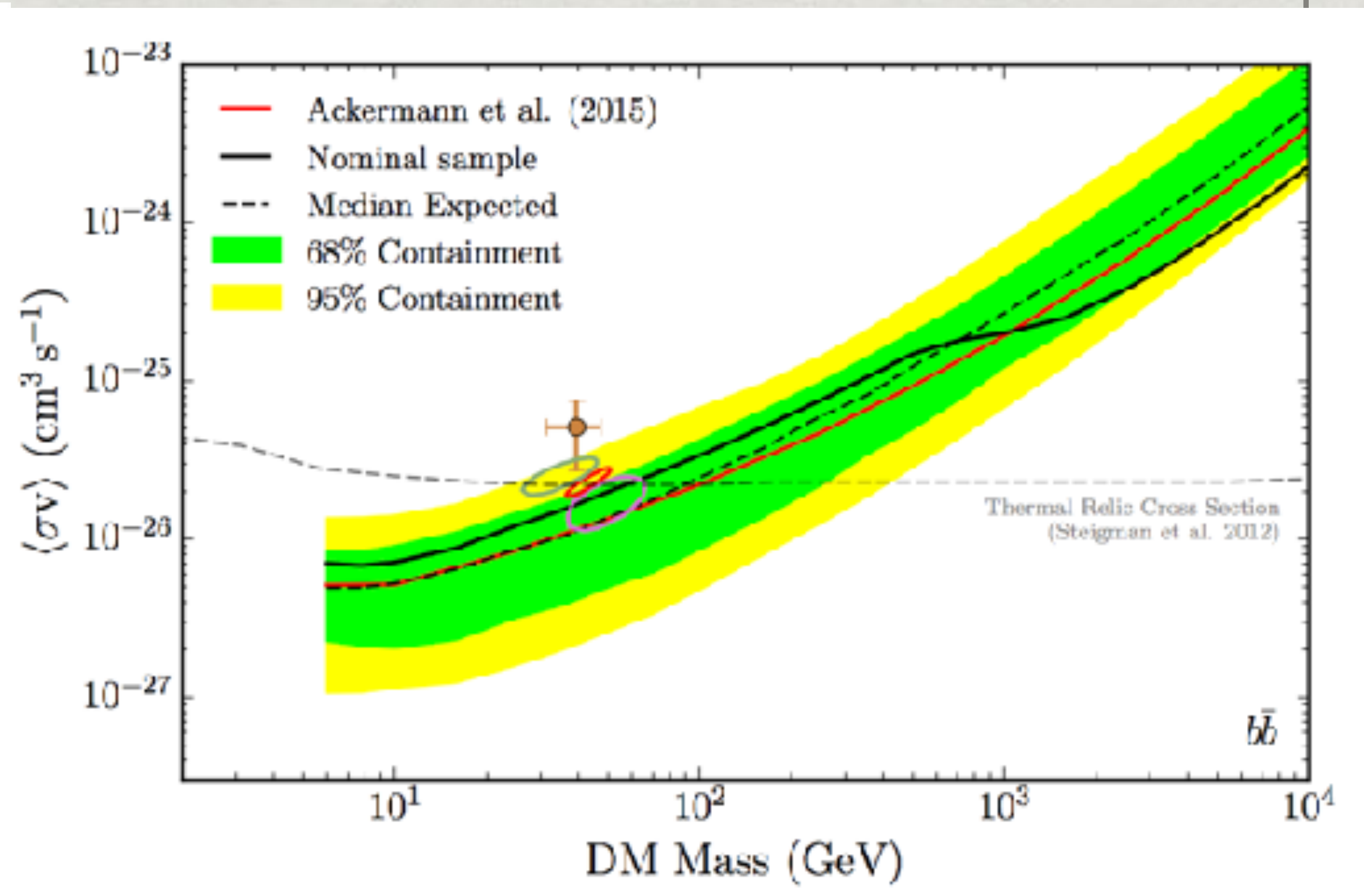
How does it fit into the Standard Model of particle physics?

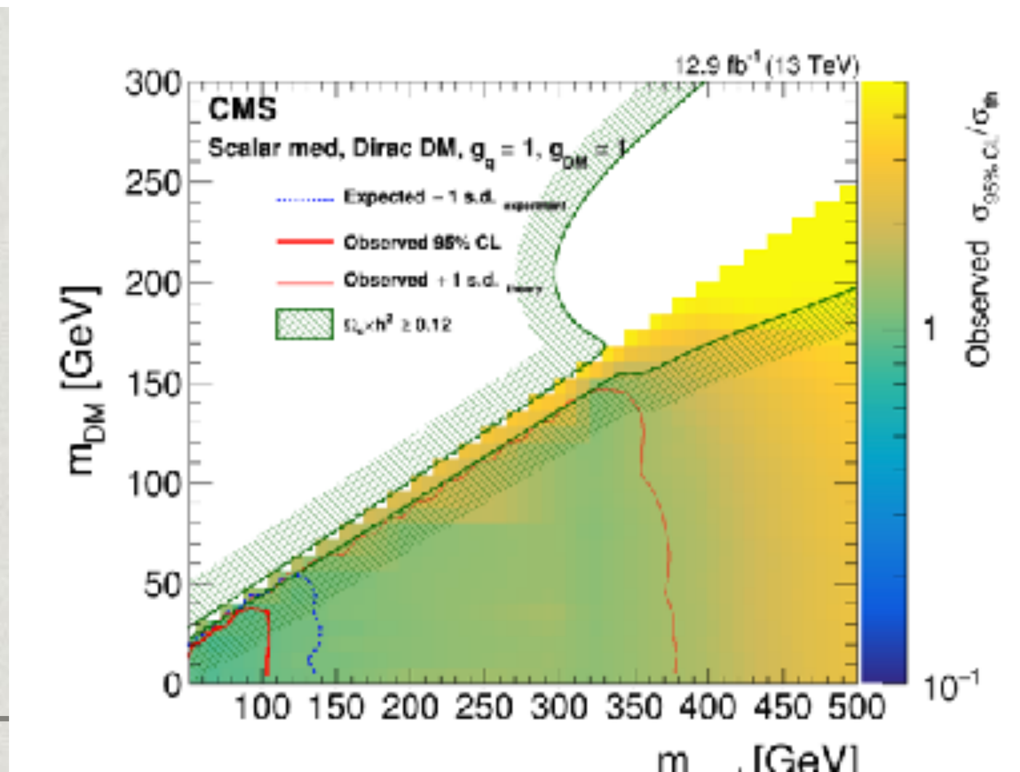
What is its spin, mass?
What are its interactions?

How will that affect cosmology, astrophysics, and particle physics?
E.g. relic abundance (WIMP, asymmetric DM, FIMP)

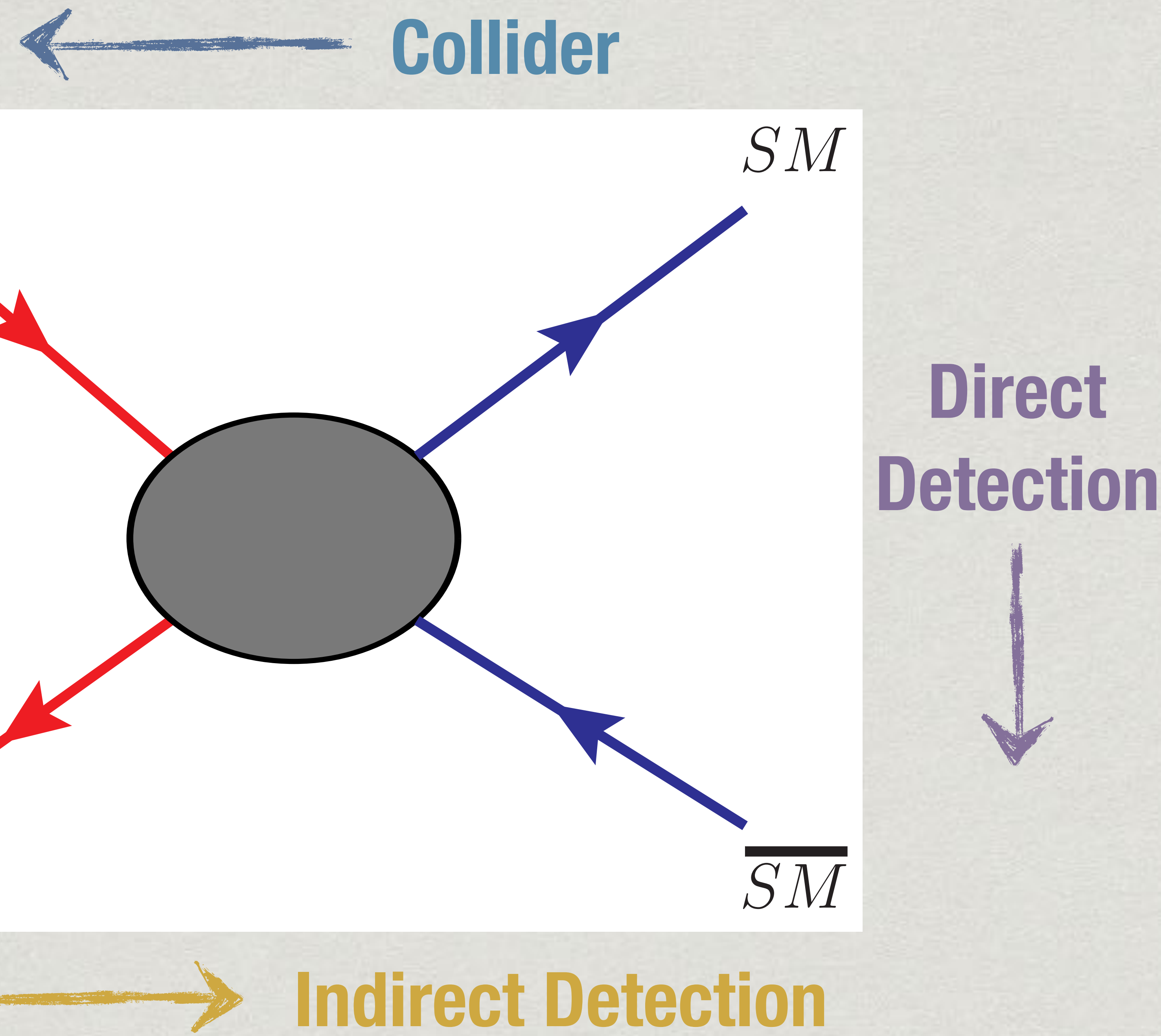
So far no hints, just limits...







WIMP Program



DM searches are all facing different challenges. To maximize success, need effort from multiple fields including cosmology, astrophysics, particle theory, expt, & condensed matter

Outline (3 Interesting Developments In My Opinion)

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- Direct Detection Experiments

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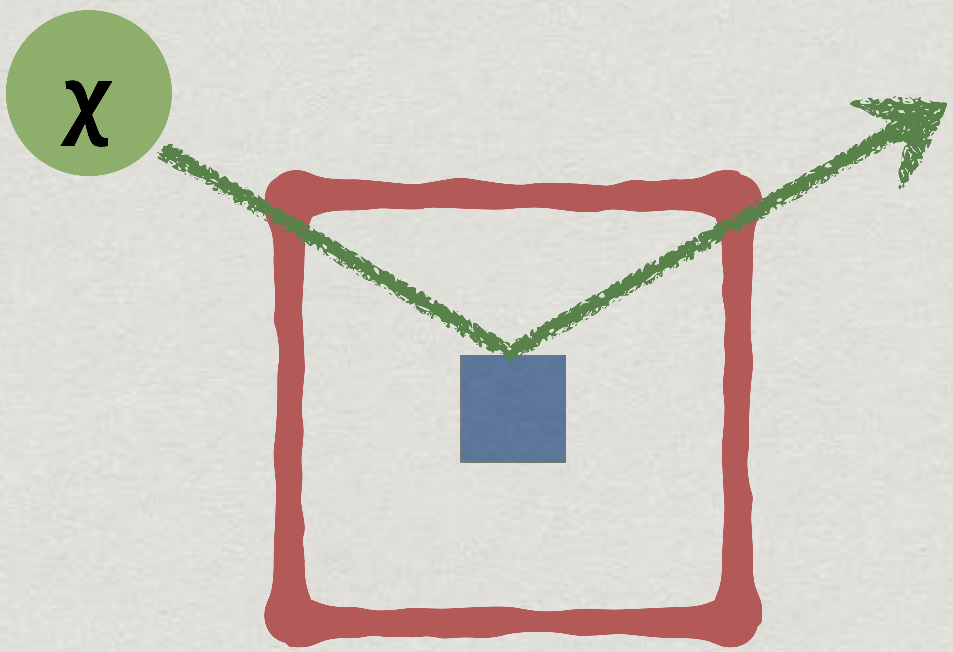
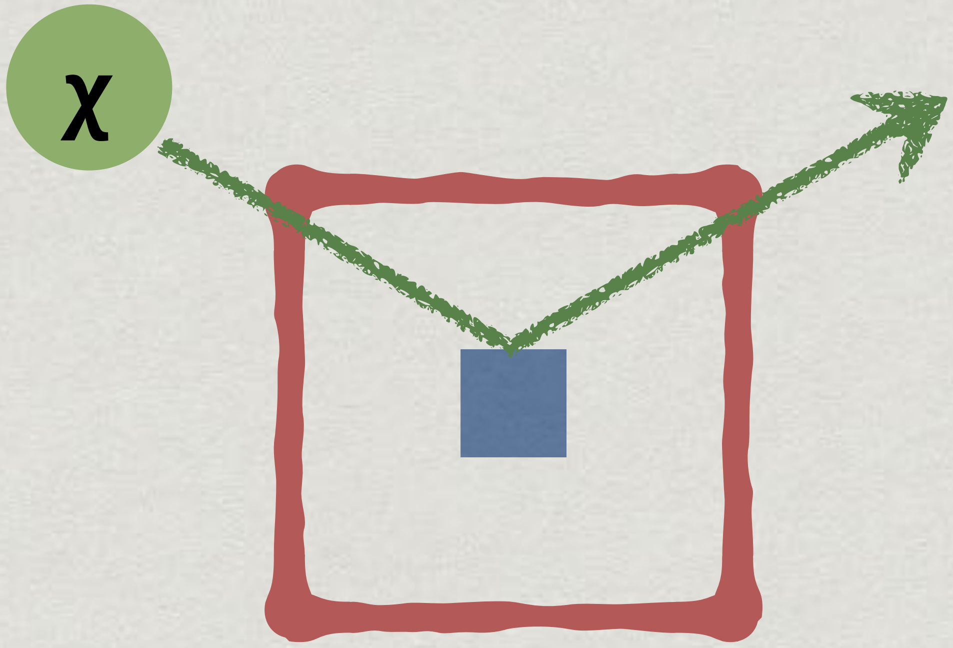
- Gravity Wave Probes of DM

Direct Detection Experiments



Looking for local dark matter scattering off detectors

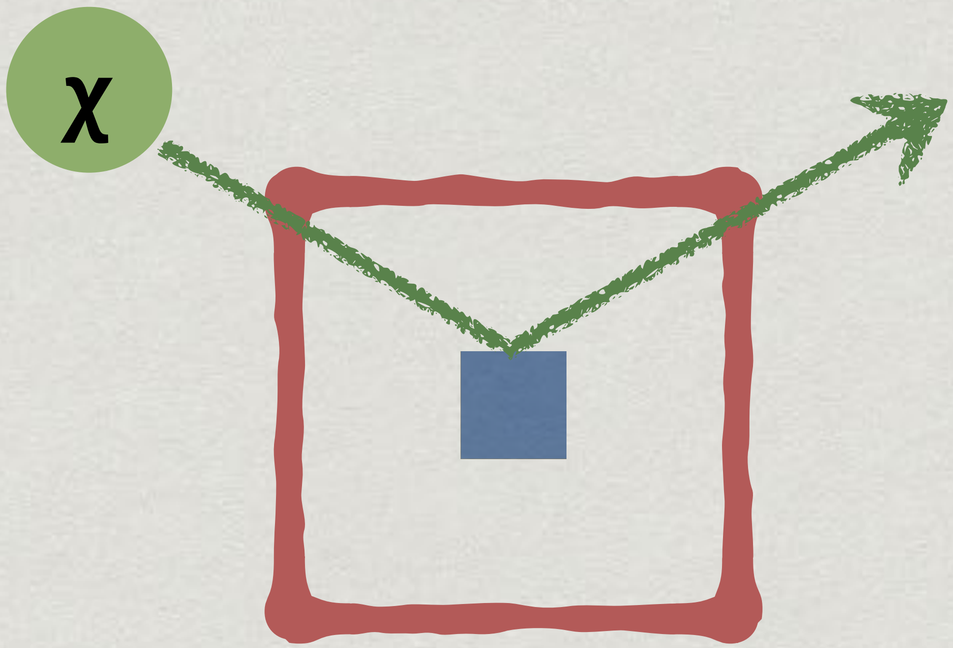
Direct Detection Experiments



Looking for local dark matter scattering off detectors

Event Rate $$\frac{dR}{dE} = N_T n_{DM} \int \frac{d\sigma}{dE} v f(\vec{v}) d^3 v$$

Direct Detection Experiments



Looking for local dark matter scattering off detectors

Event Rate $$\frac{dR}{dE} = N_T n_{DM} \int \frac{d\sigma}{dE} v f(\vec{v}) d^3 v$$

Signal requires multiple inputs to be reliably calculated

Material Response Theory

$$\frac{dR}{dE} = N_T n_{DM} \int \boxed{\frac{d\sigma}{dE}} v f(\vec{v}) d^3 v$$

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Nuclei Recoils

Nuclei response functions and form factors for general DM interactions worked out by Fitzpatrick, Haxton, et.al.

DMFormFactor Mathematica Package

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DMFormFactor Mathematica Package

Electron Recoils

Semiconductor and Scintillator Responses analyzed by Essig, Yu, et.al.

DFT calculation of electronic structure QEDark

DM Velocity Distributions

$$\frac{dR}{dE} = N_T n_{DM} \int \frac{d\sigma}{dE} \boxed{v f(\vec{v})} d^3 v$$

Usually assume Boltzmann dist. but recent mergers will lead to other kinematic structures (e.g. streams)

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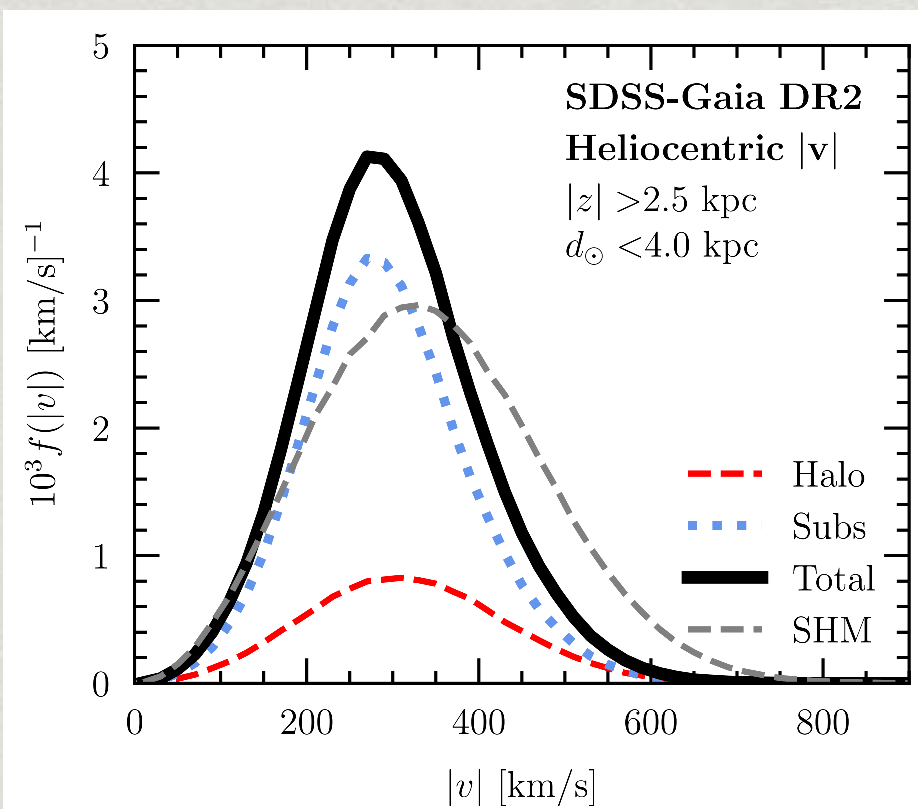
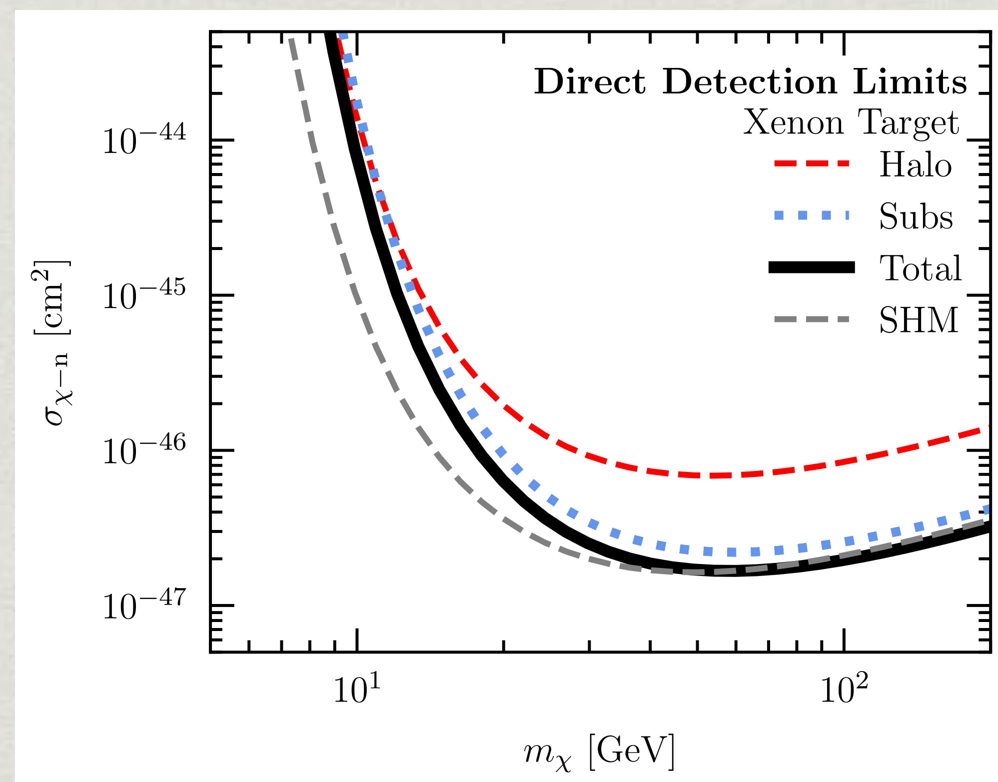


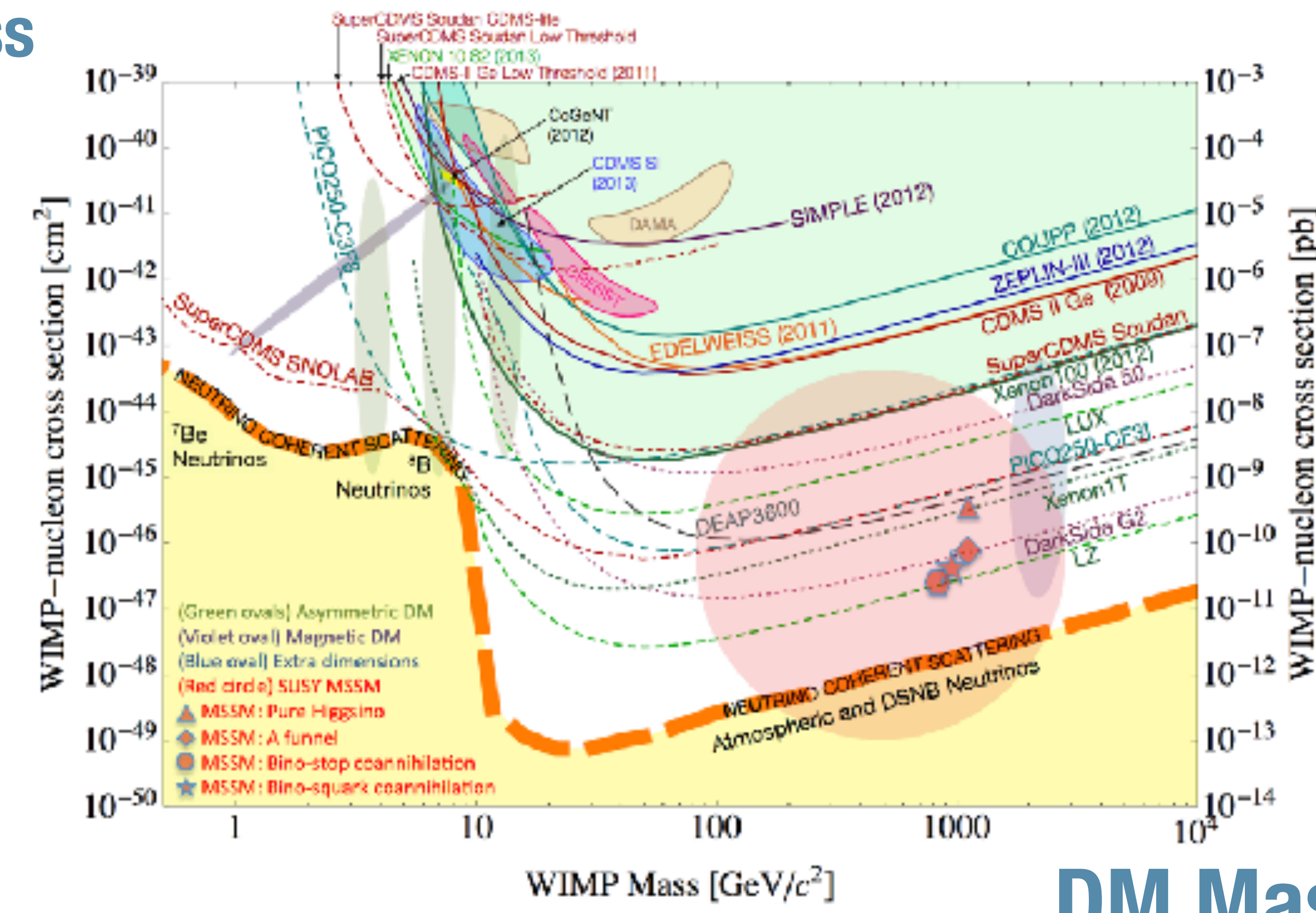


Necib et.al. 1807.02519 takes GAIA data, use low metallicity stars as tracers of DM distribution

Detection Technologies

Snowmass 2013

DM cross section



DM Mass

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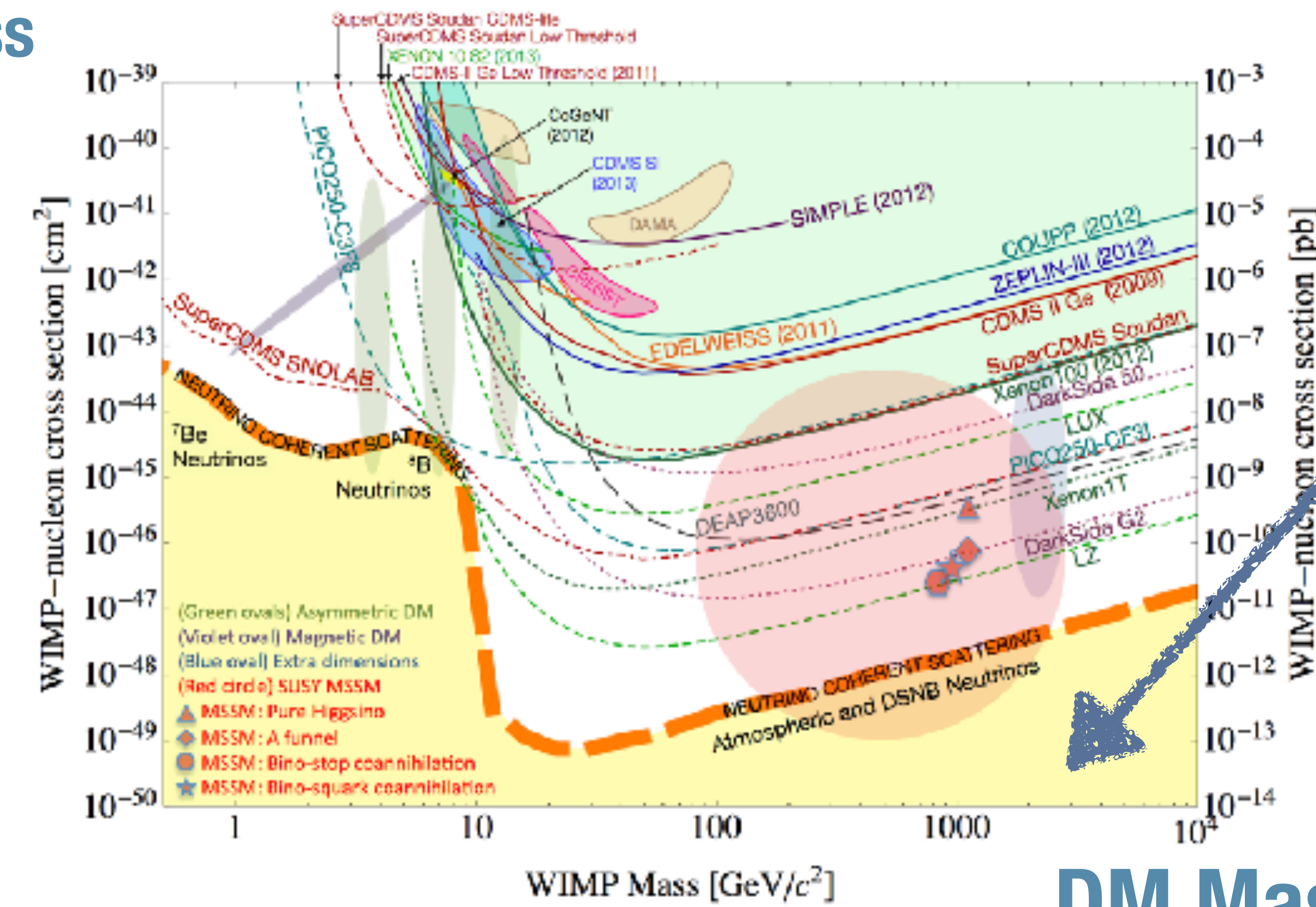

Neutrinos as irreducible background

DM Mass

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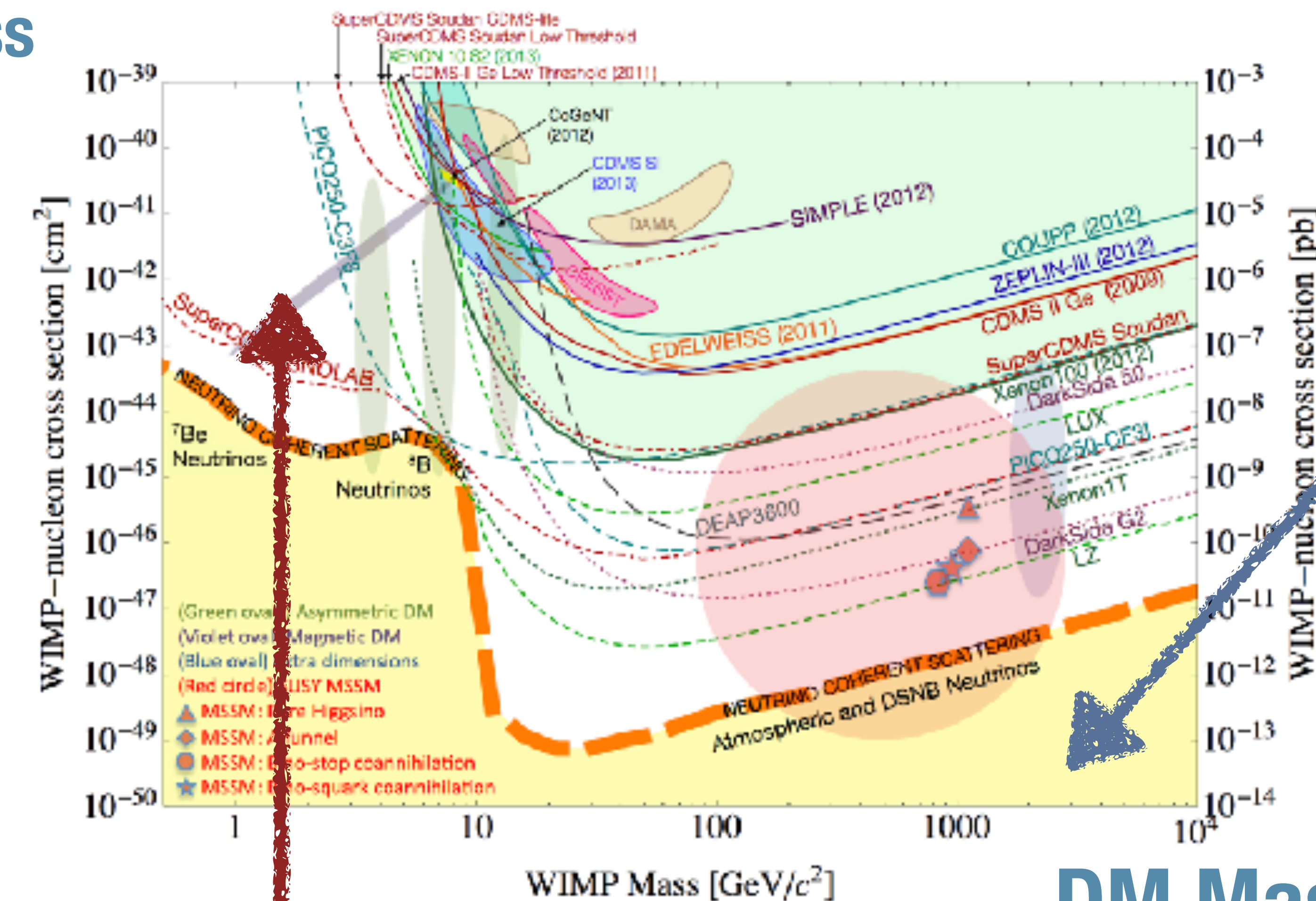


DM Mass

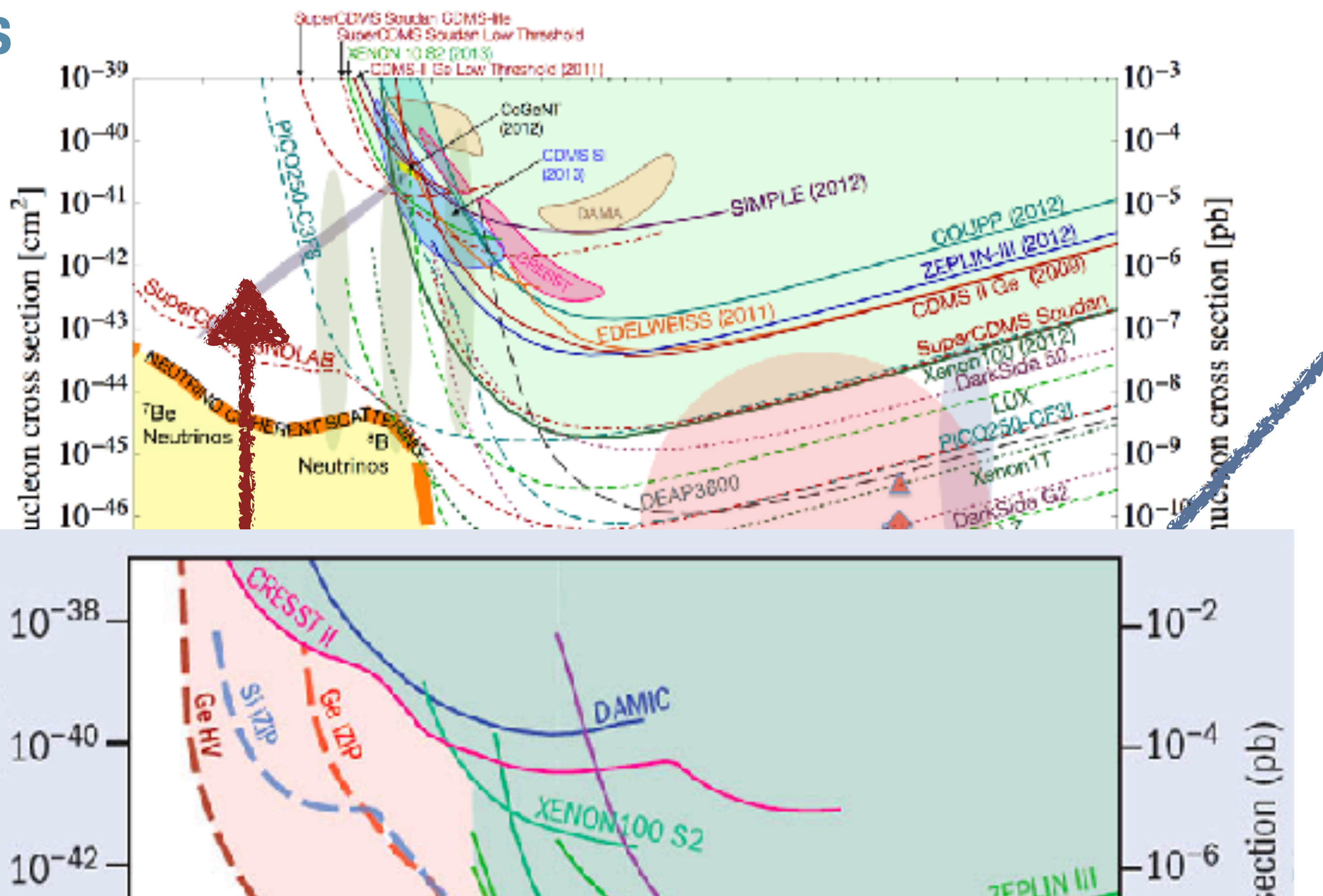
Neutrinos as irreducible background

Lighter Dark Matter largely unconstrained

Detection Technologies

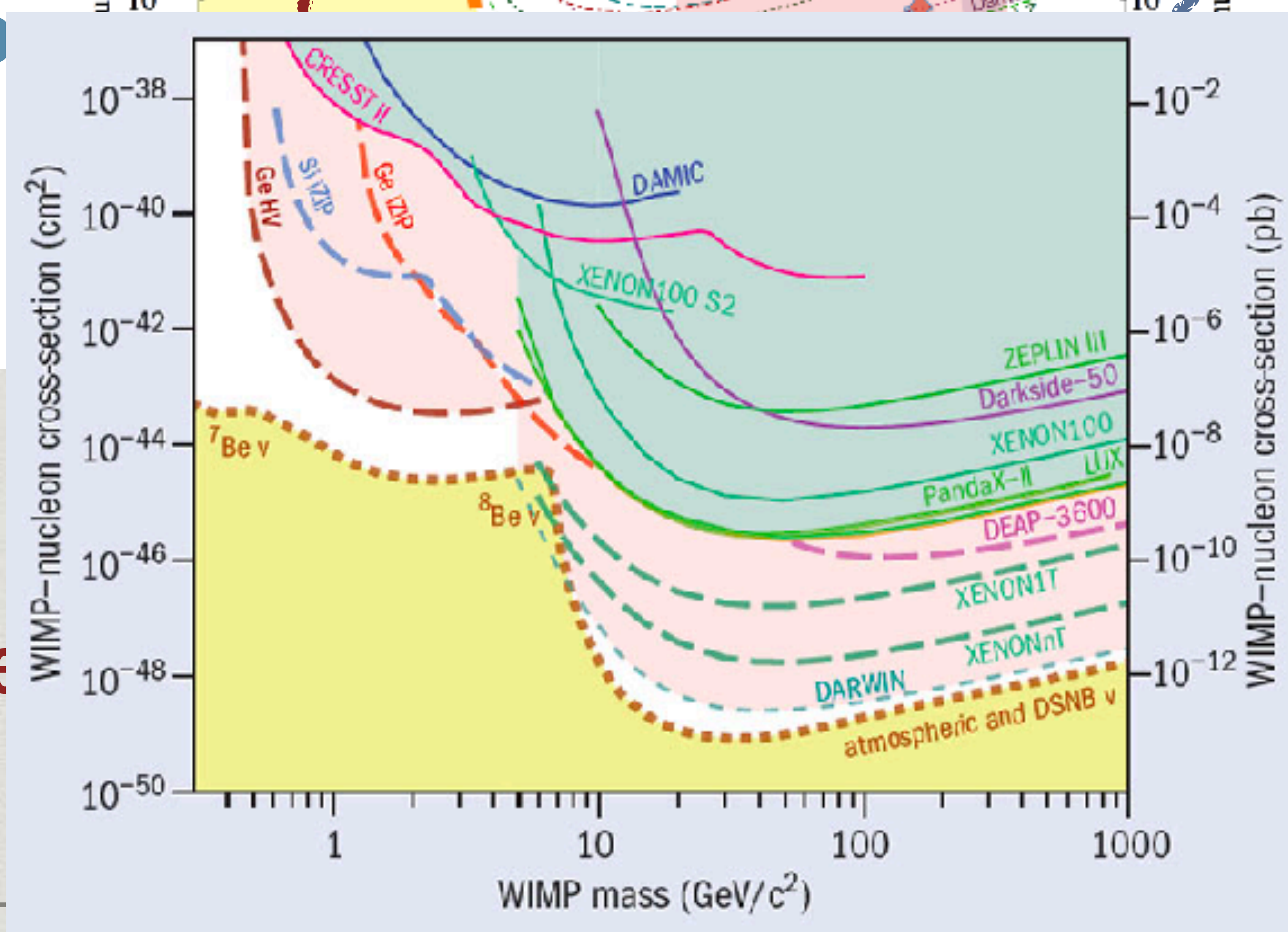
Snowmass 2013

DM cross sectio



Neutrinos as irreducible background

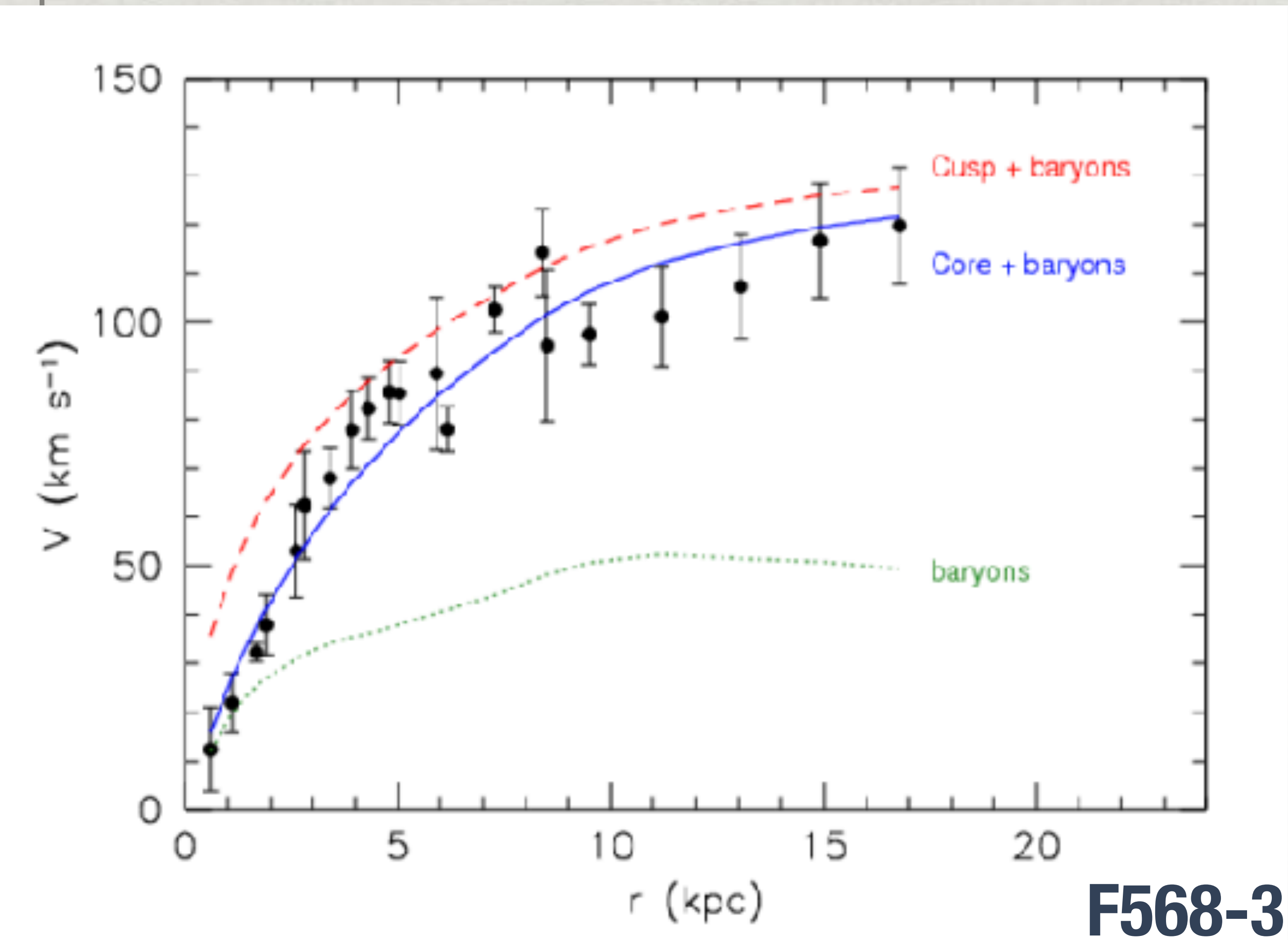
Matte



New Detectors fill the gaps,
100 GeV: DARWIN,
1 GeV: HV CDMS,
10 MeV: SENSEI

Small Scale Problems

Core vs Cusp



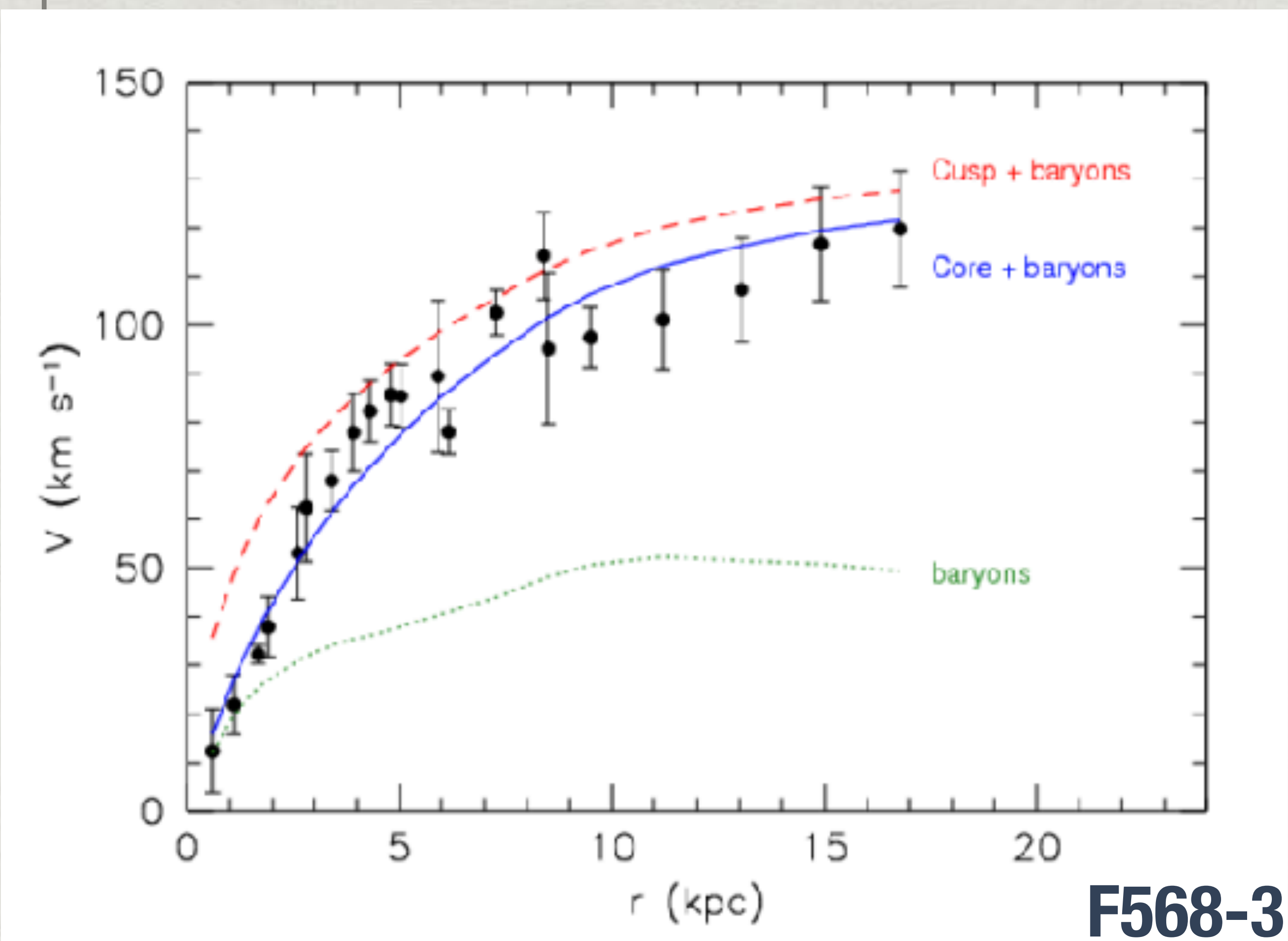
F568-3

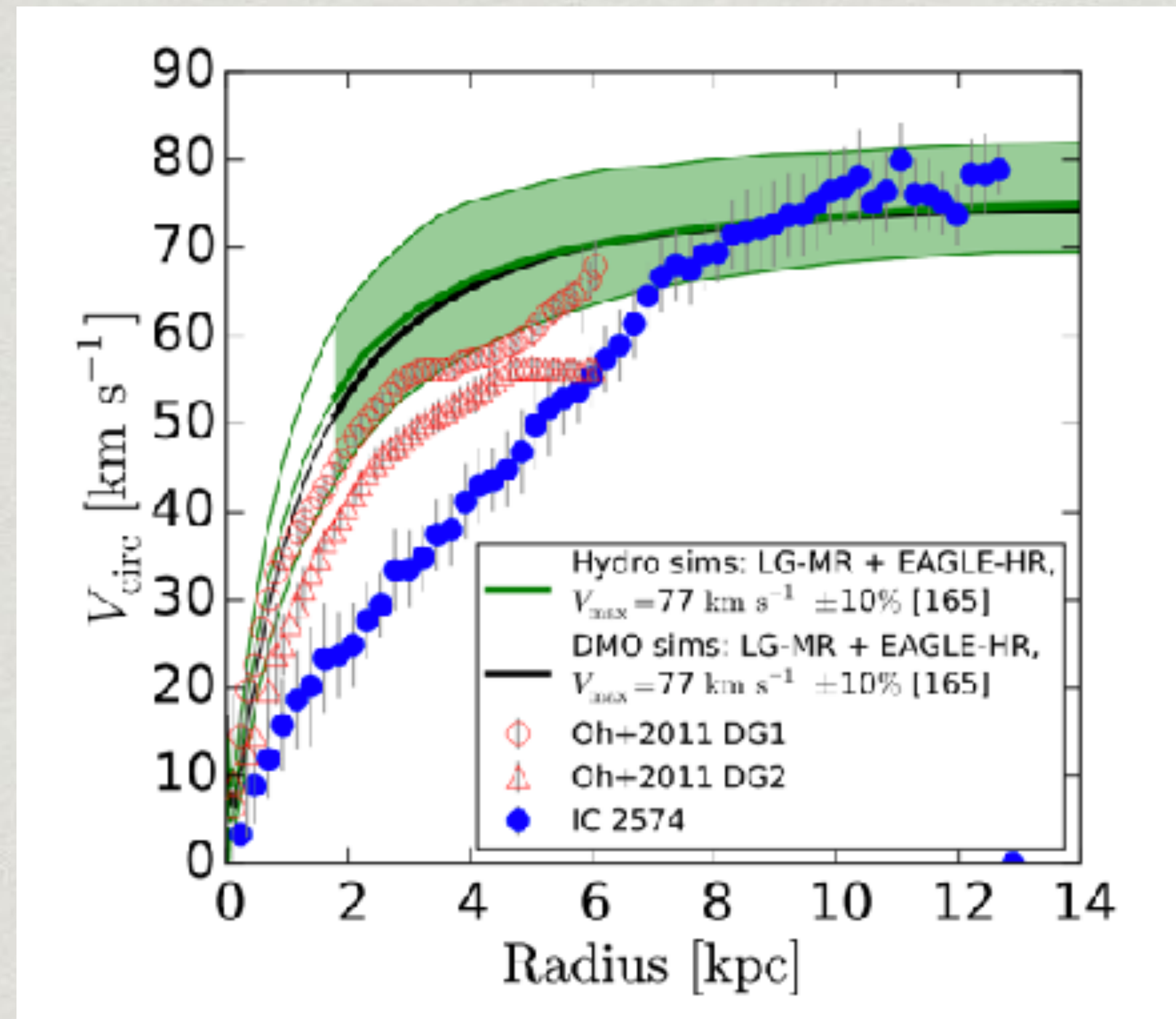
Low Surface Brightness Galaxies have cores rather than cusps at inner radii

Small Scale Problems

Core vs Cusp

Diversity Problem (Oman et.al.)





Low Surface Brightness Galaxies have cores rather than cusps at inner radii

Dwarf Galaxies with similar asymptotics have diverse inner radii behavior

Self Interacting Dark Matter
(Spergel & Steinhardt)

Self interactions between dark matter
$\sigma/m \sim$ cm^2/g can have interactions that affect galactic distributions

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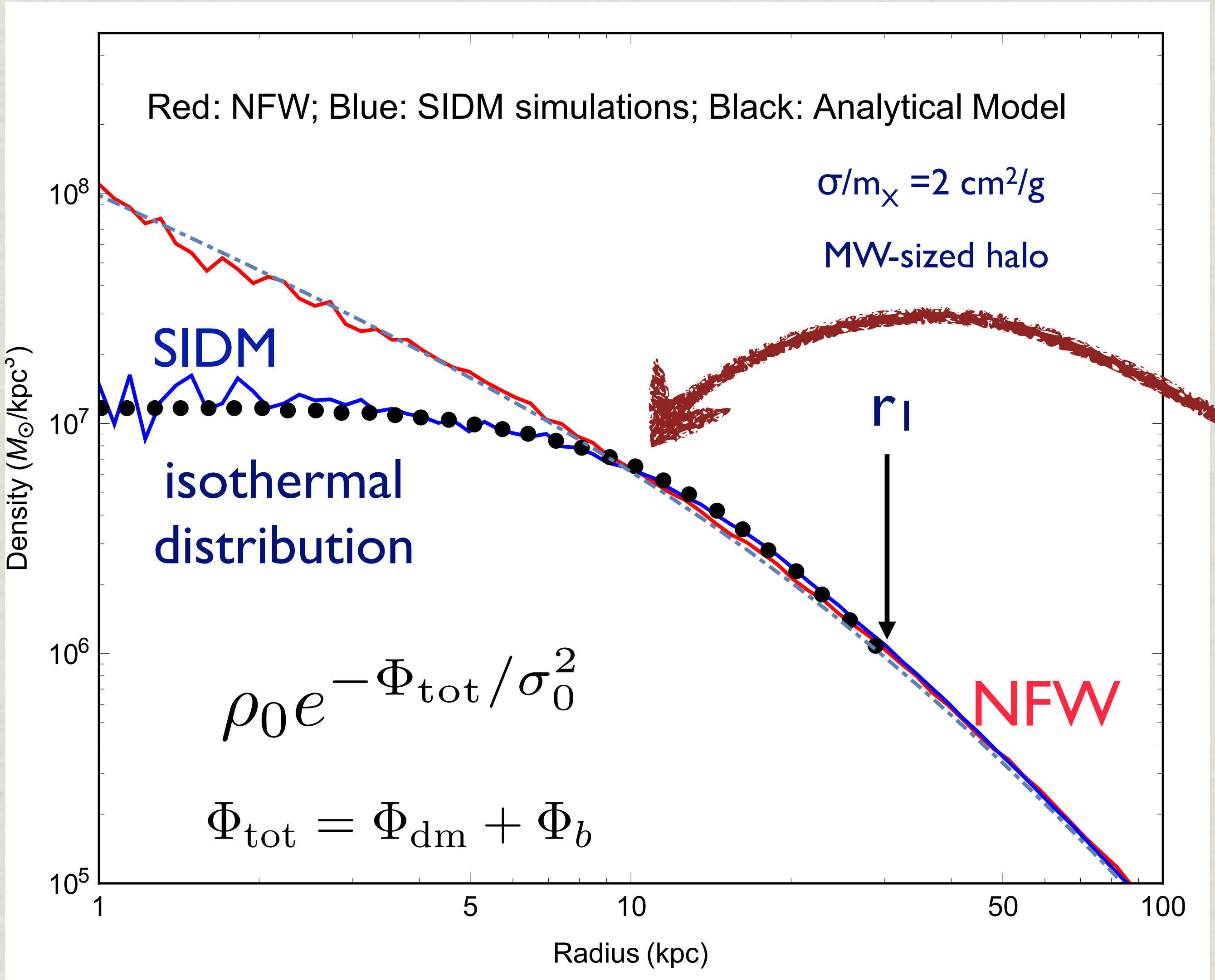
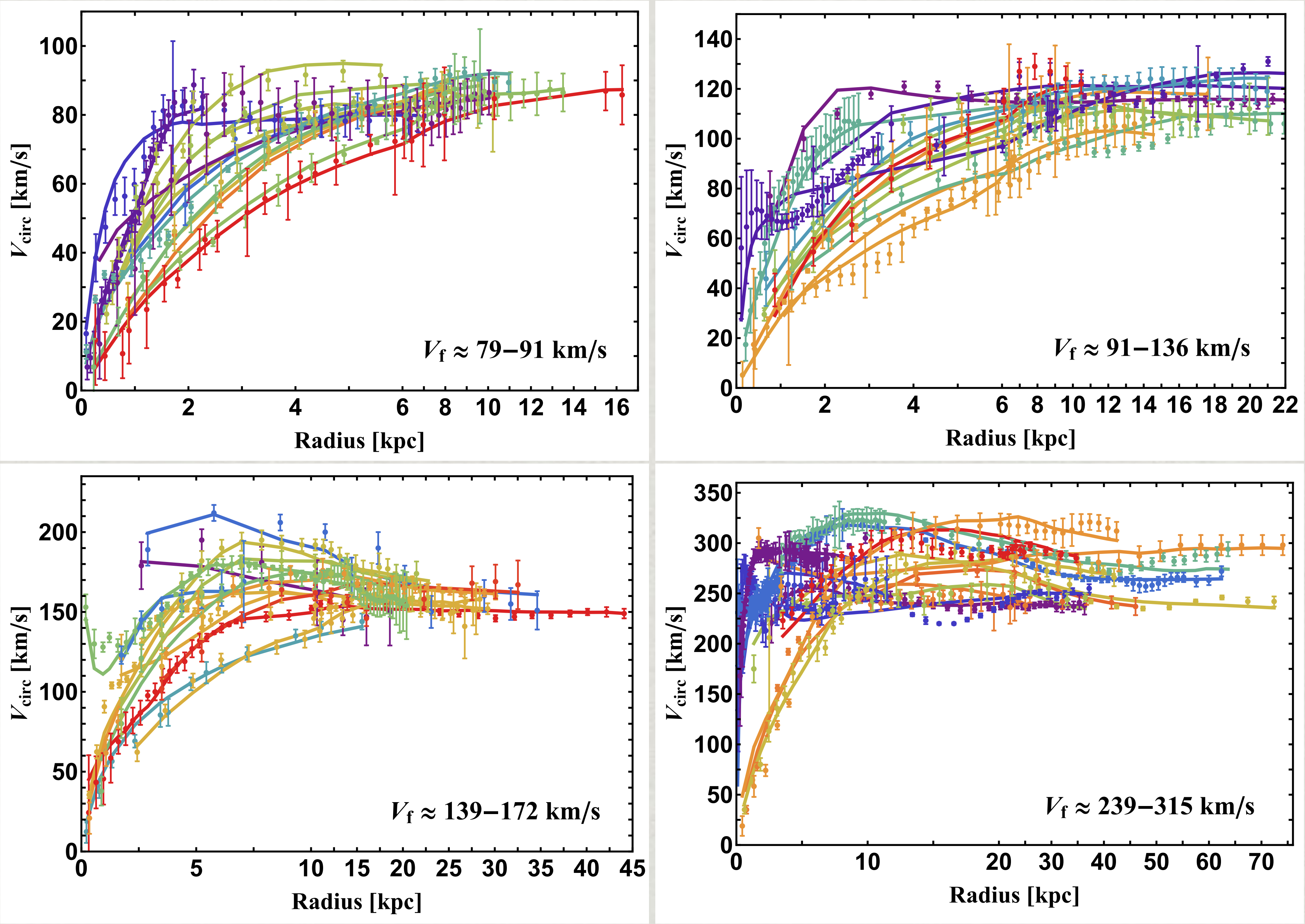
Self interactions between dark matter $\sigma/m \sim cm^2/g$ can have interactions that affect galactic distributions



Kaplinghat, Yu, et.al. show that inner radii DM can be thermalized with normal NFW profiles at large radii

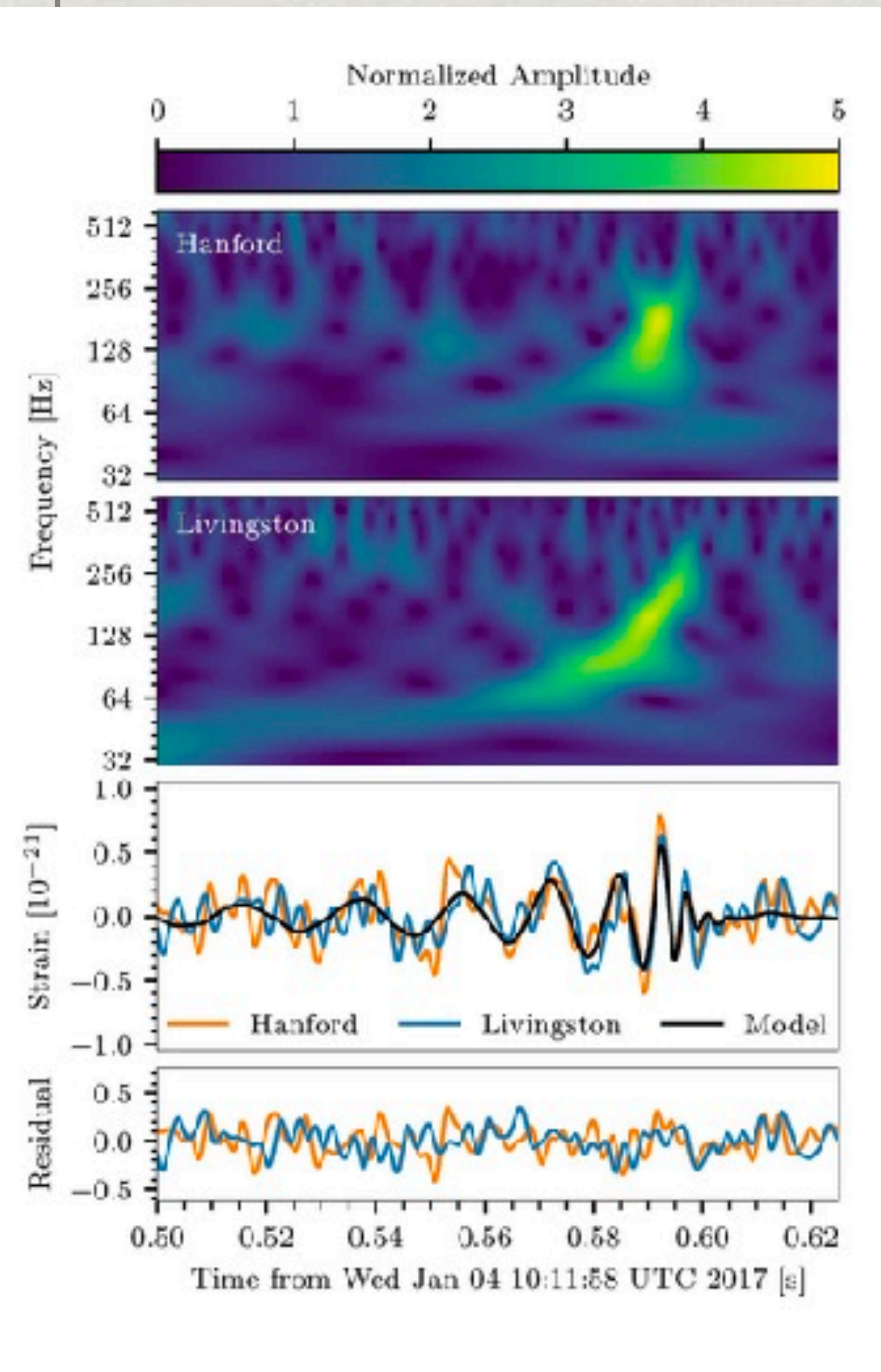
Galaxy Rotation Curve Diversity

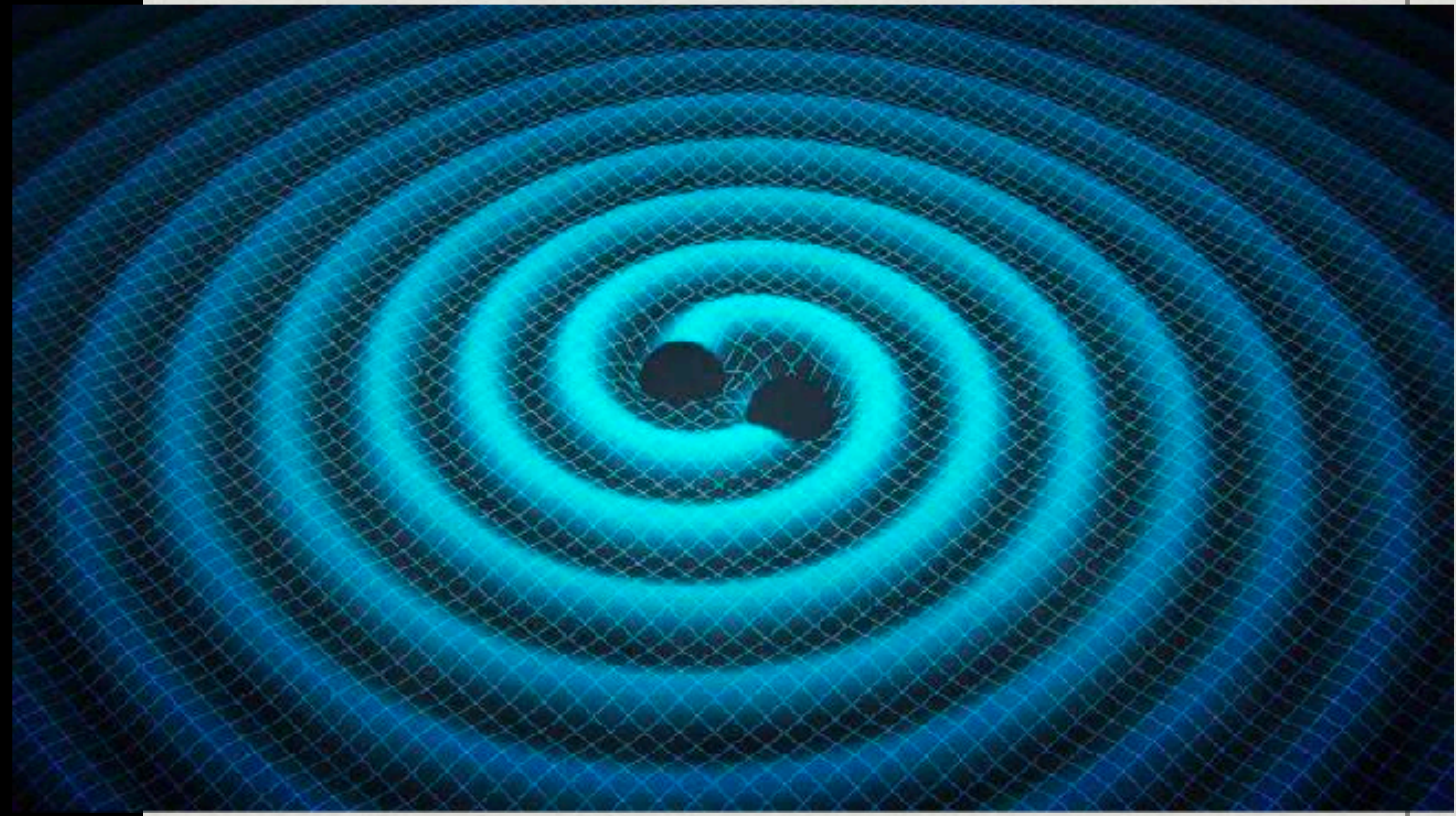


Recent analysis shows that SIDM can fit galaxy rotation curves better than CDM or MOND with few parameters

Ren et.al. 1808.05695

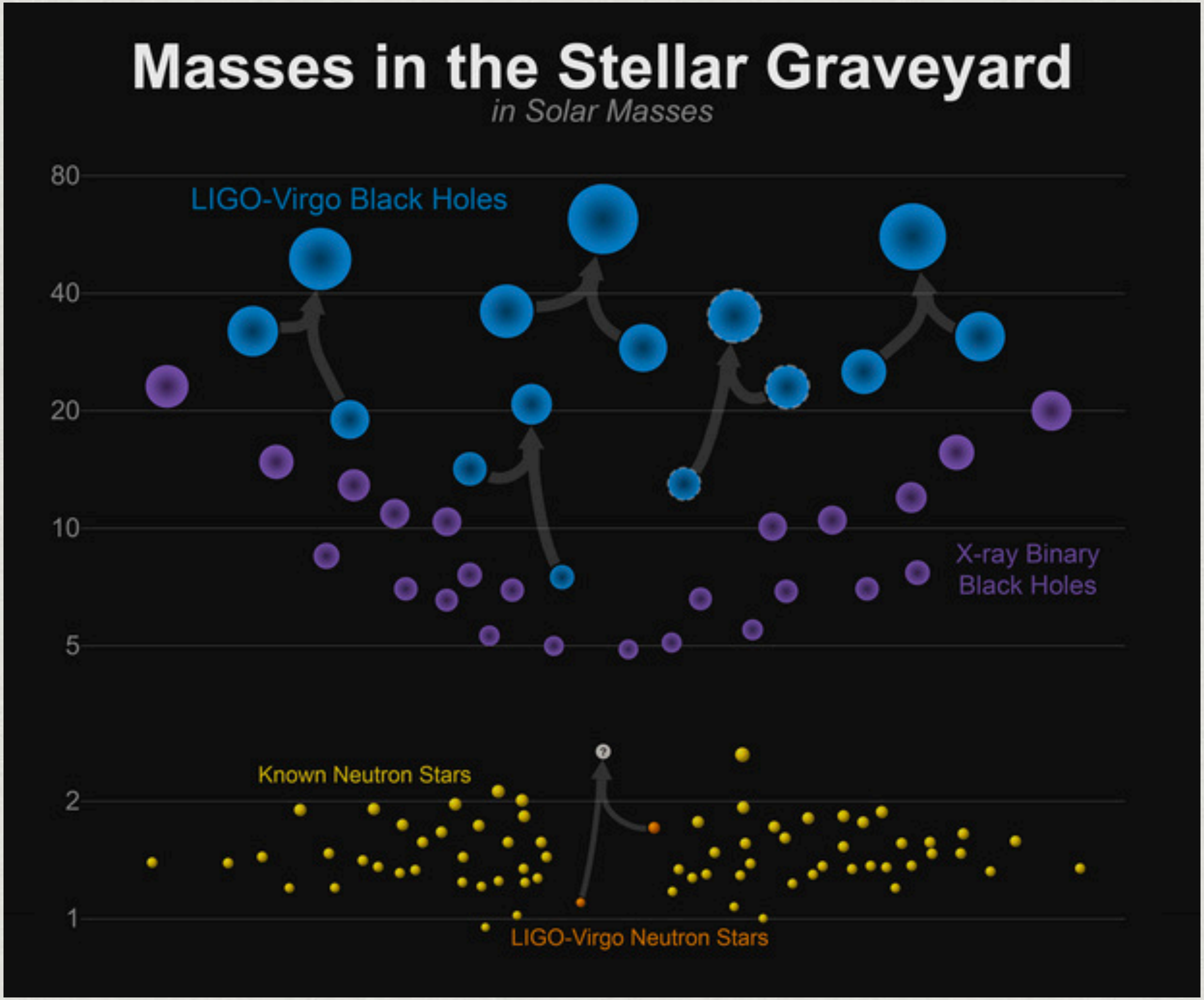
LIGO/VIRGO and Dark Matter





Gravity wave era as a astronomical probe is just beginning!

GW Black Hole Census



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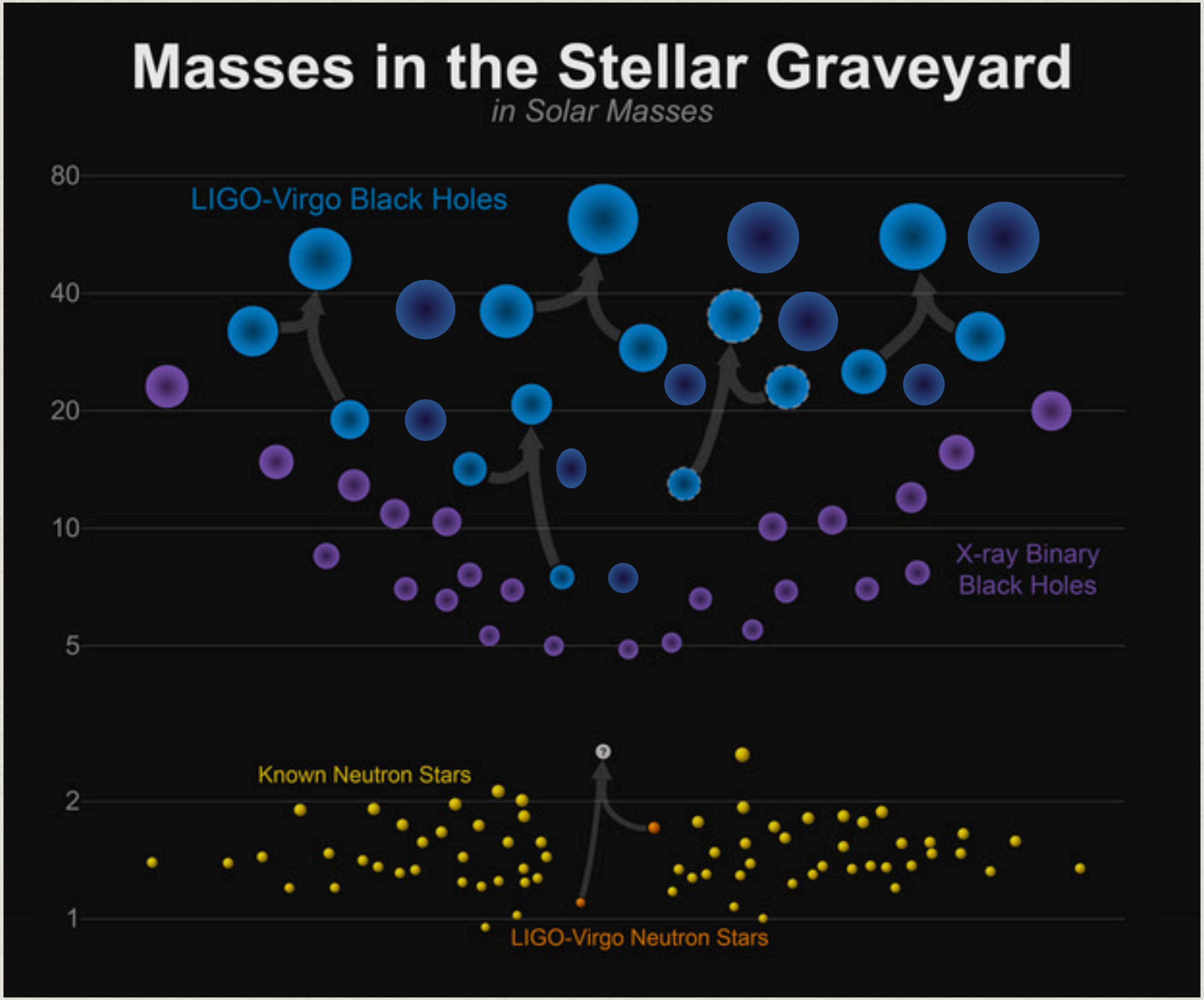

Primordial Black Hole DM

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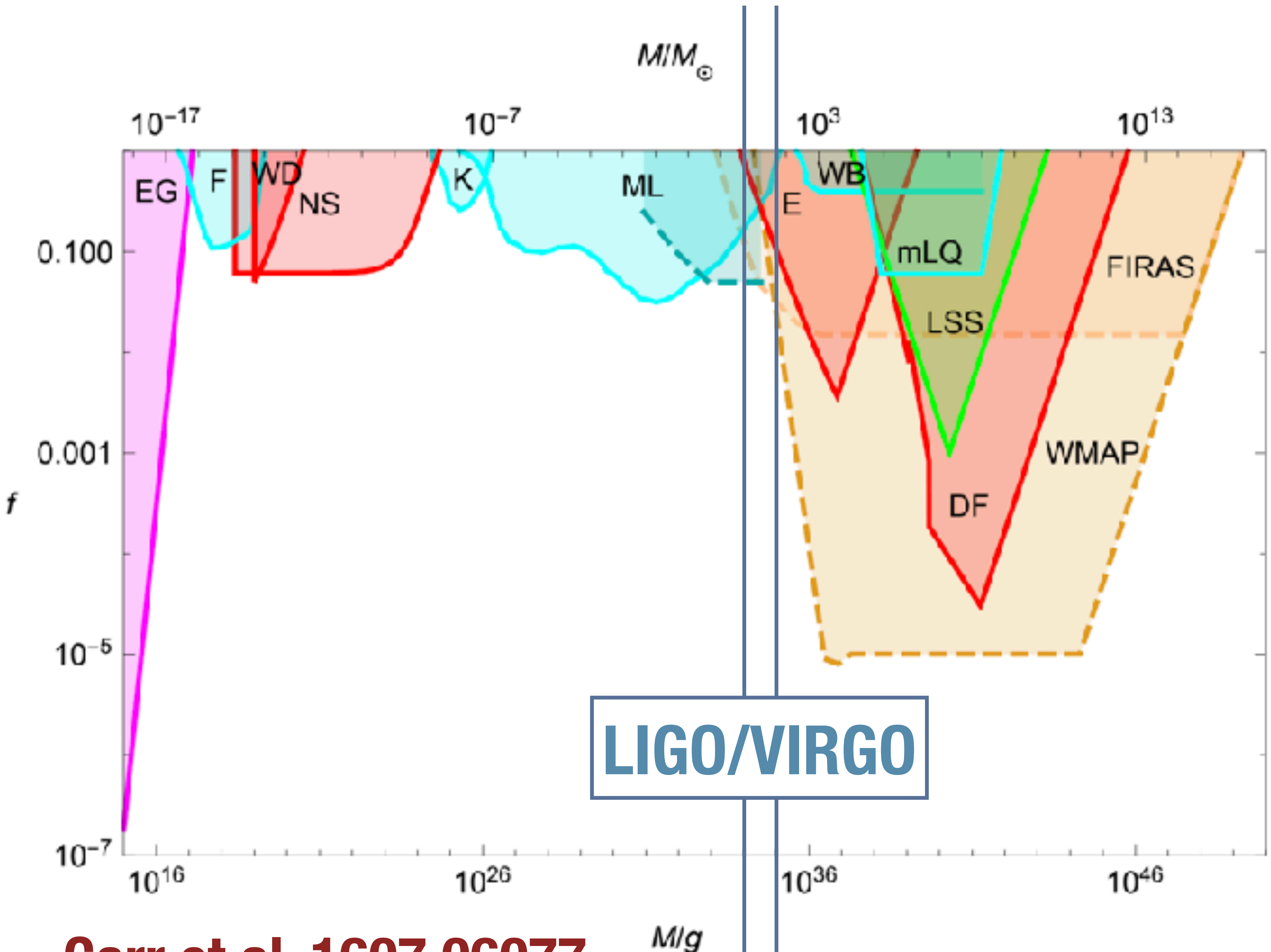
After first LIGO detection, Bird et.al. asked if observation could be consistent with primoridal BHs

Primordial Black Hole DM



Carr et.al. 1607.06077

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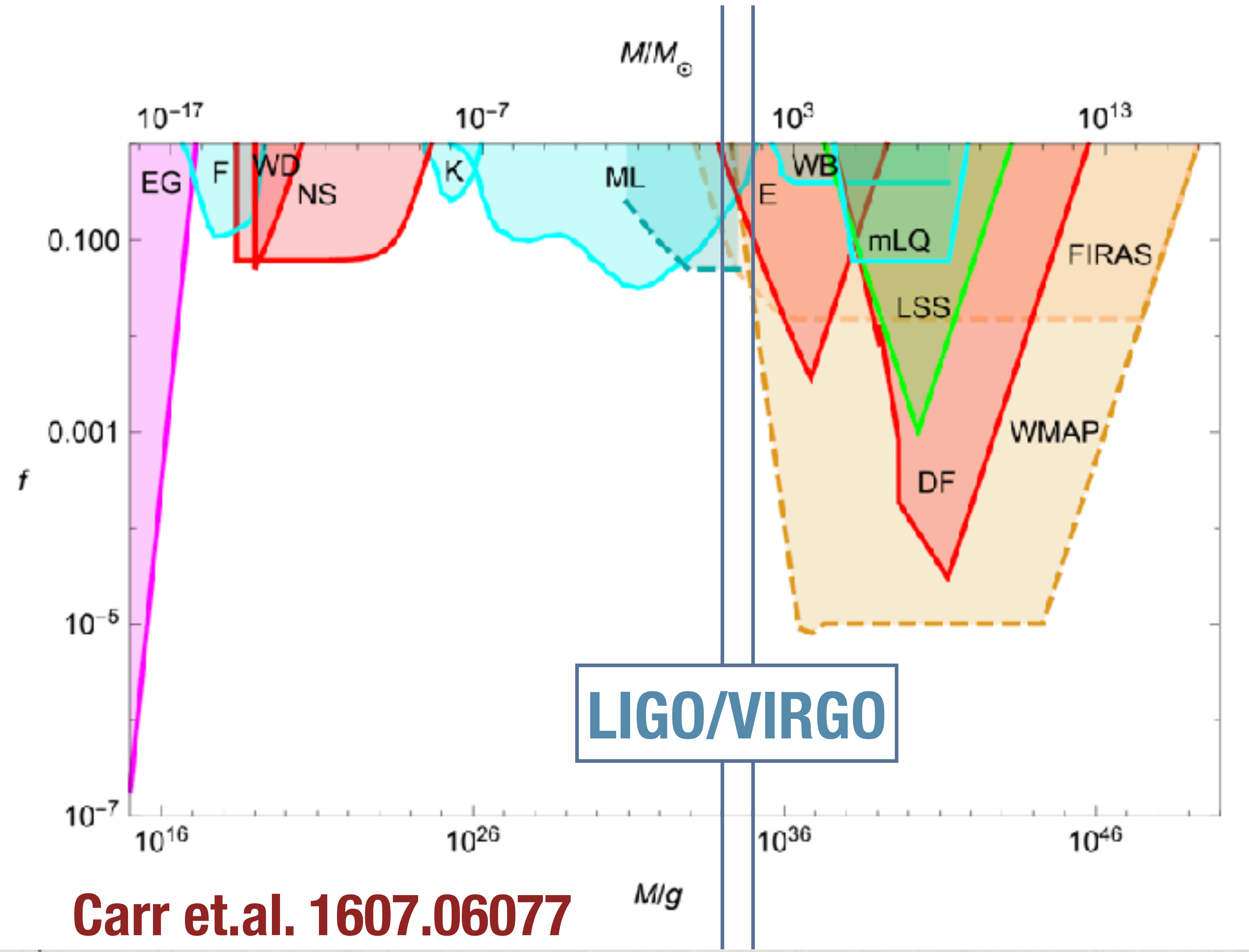

Carr et.al. 1607.06077

After first LIGO detection, Bird et.al. asked if observation could be consistent with primoridal BHs

Strong constraints, but if true, gives different regime of dark matter with potential insights to inflation and early Universe

Superradiance of Ultralight Bosonic DM

In presence of a boson of light enough mass (w/ Compton wavelength close to BH radius), spinning BH will generate bosons due to superradiance and spin down

Superradiance of Ultralight Bosonic DM

m_{DM} ~ 1/(G M_{sun}) ~ 10^{-10} eV

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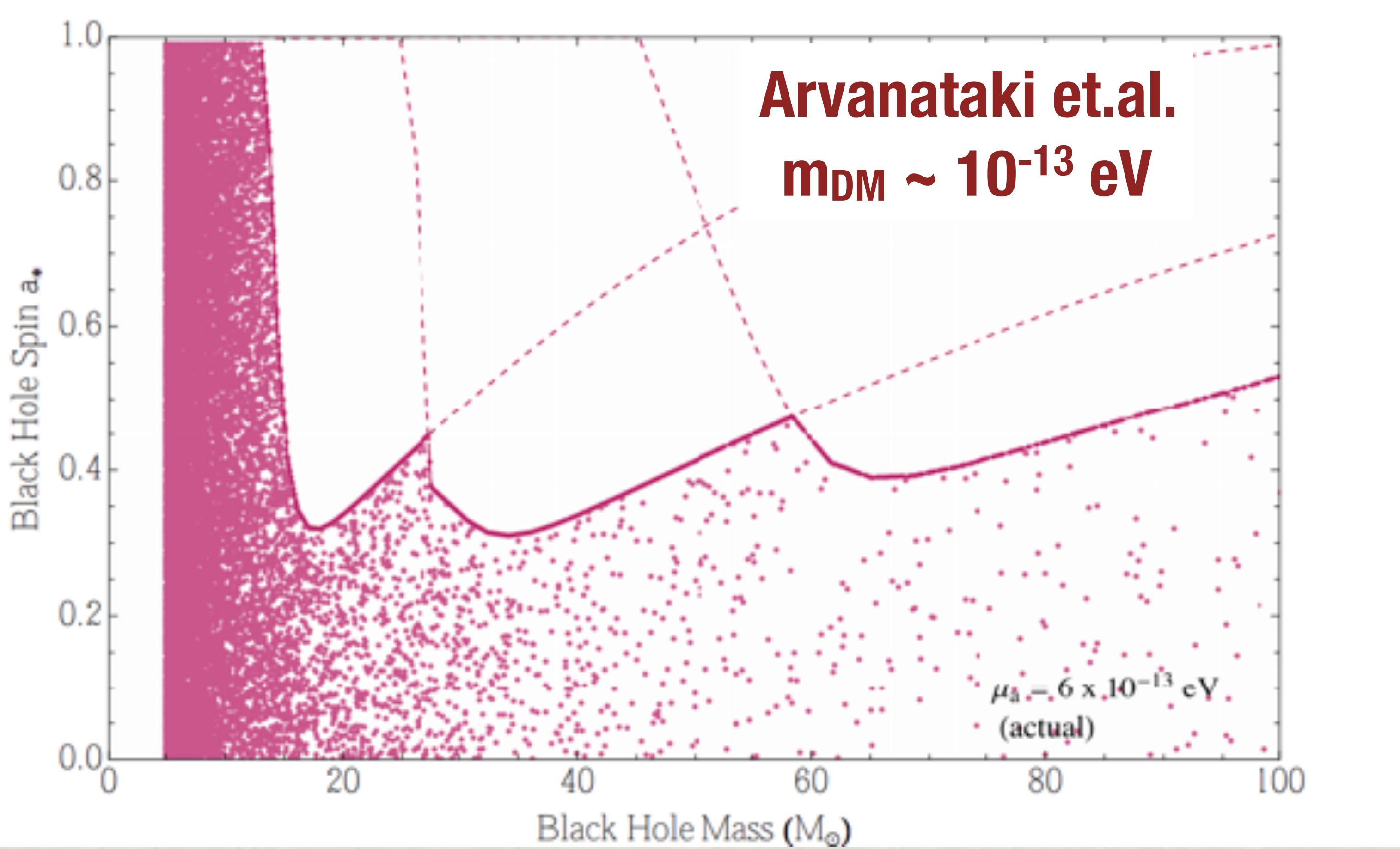

Arvanataki et.al.
$m_{DM} \sim 10^{-13}$ eV

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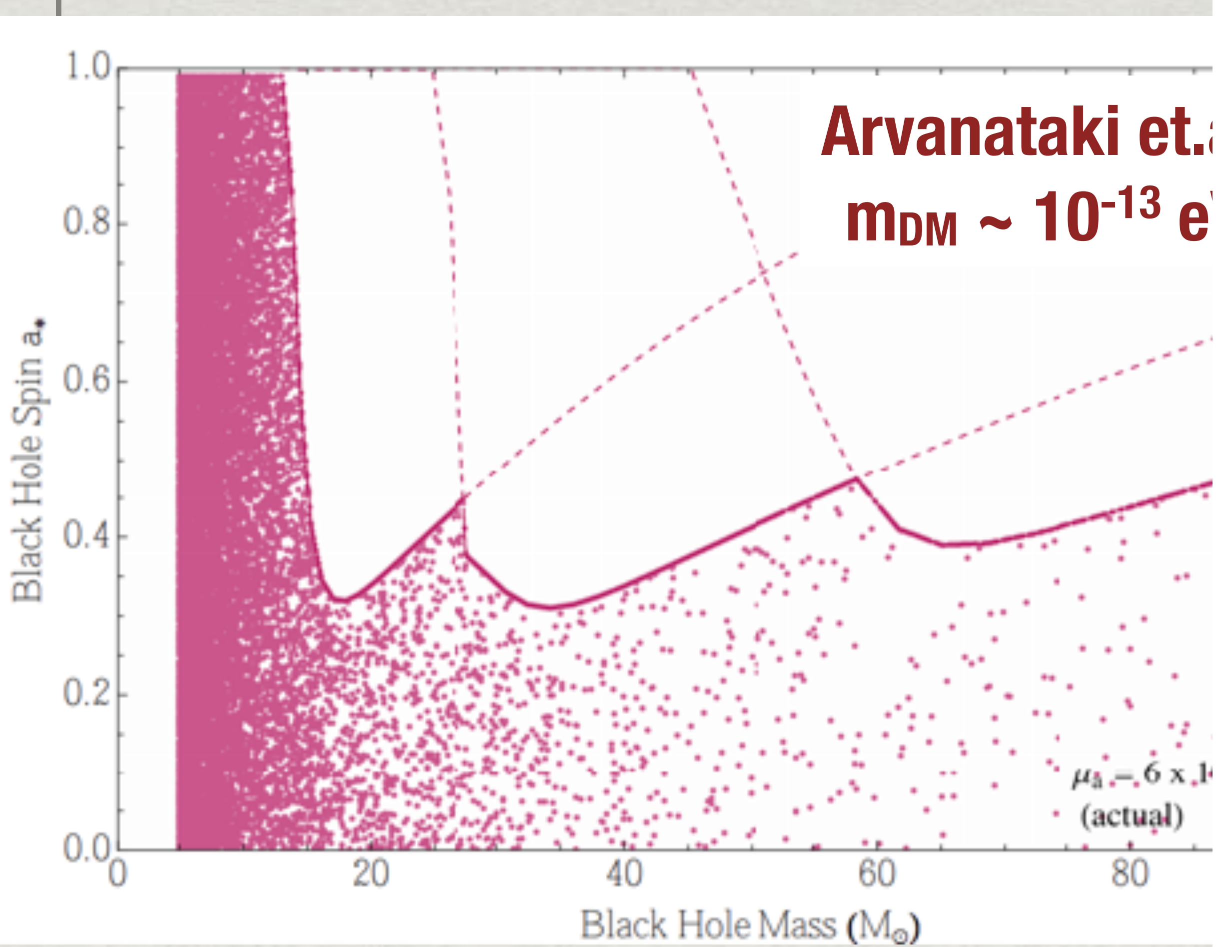
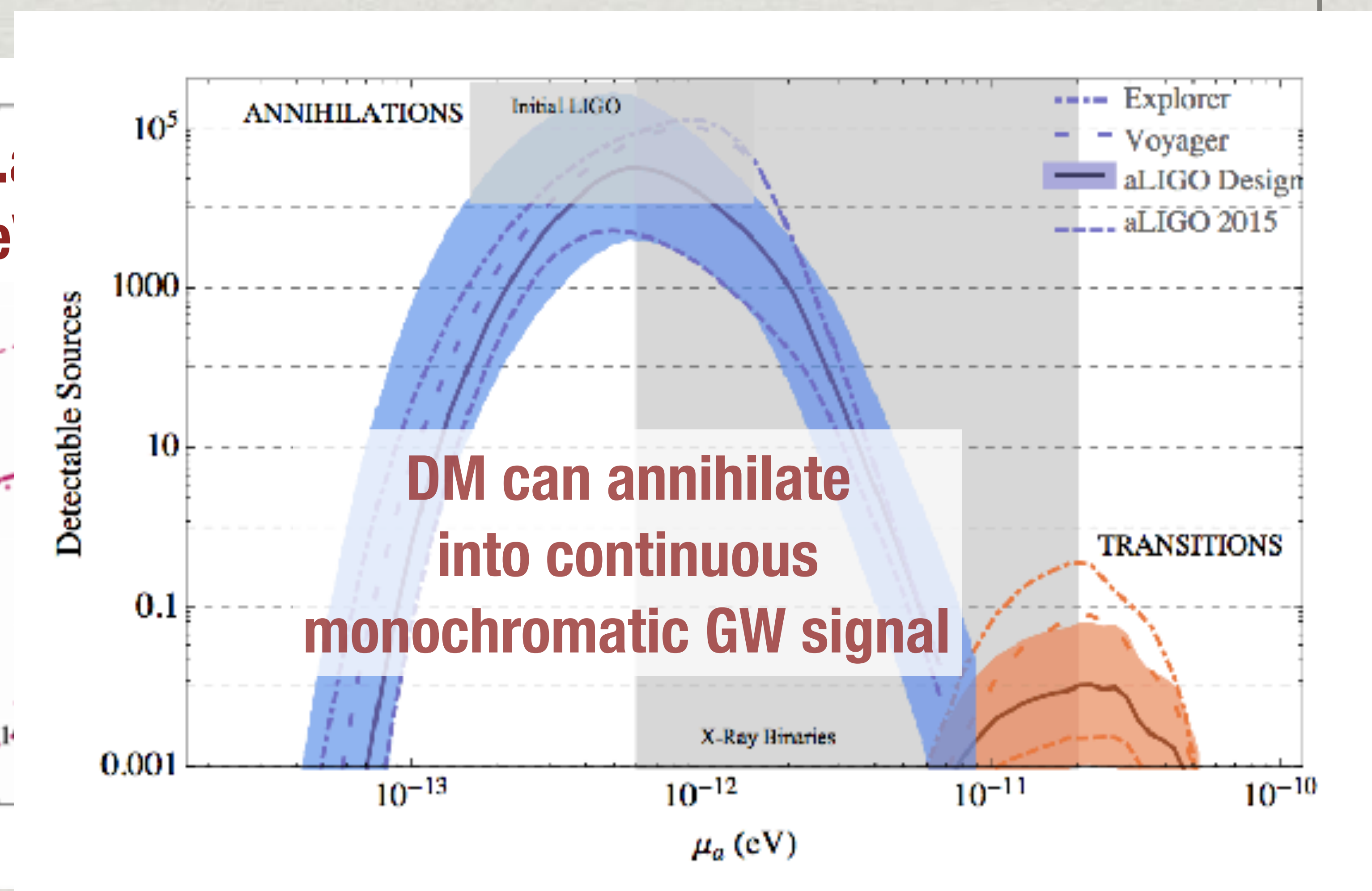
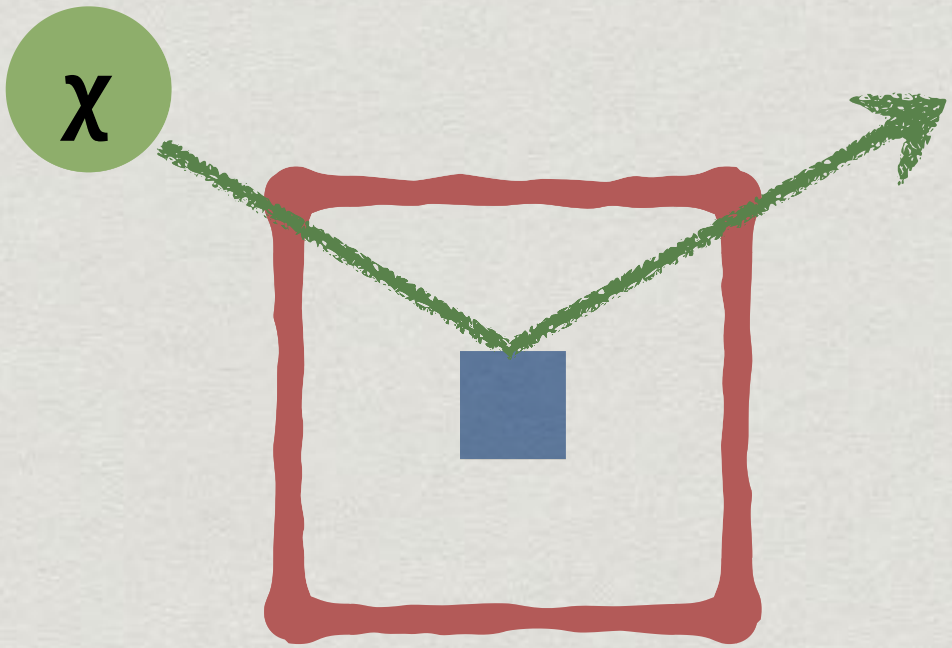
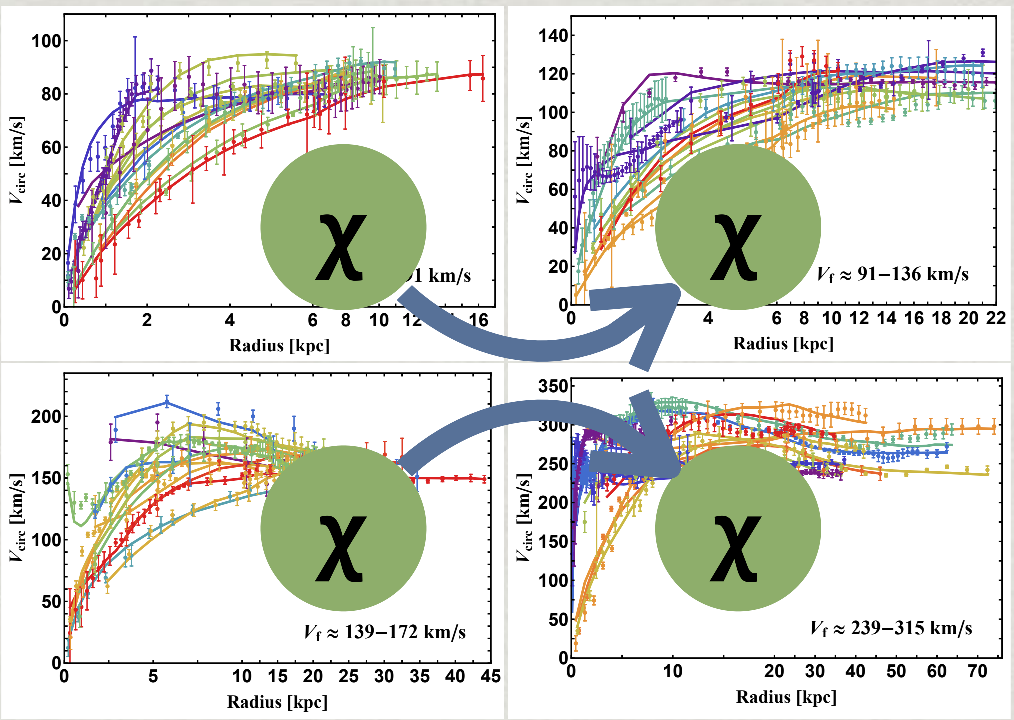
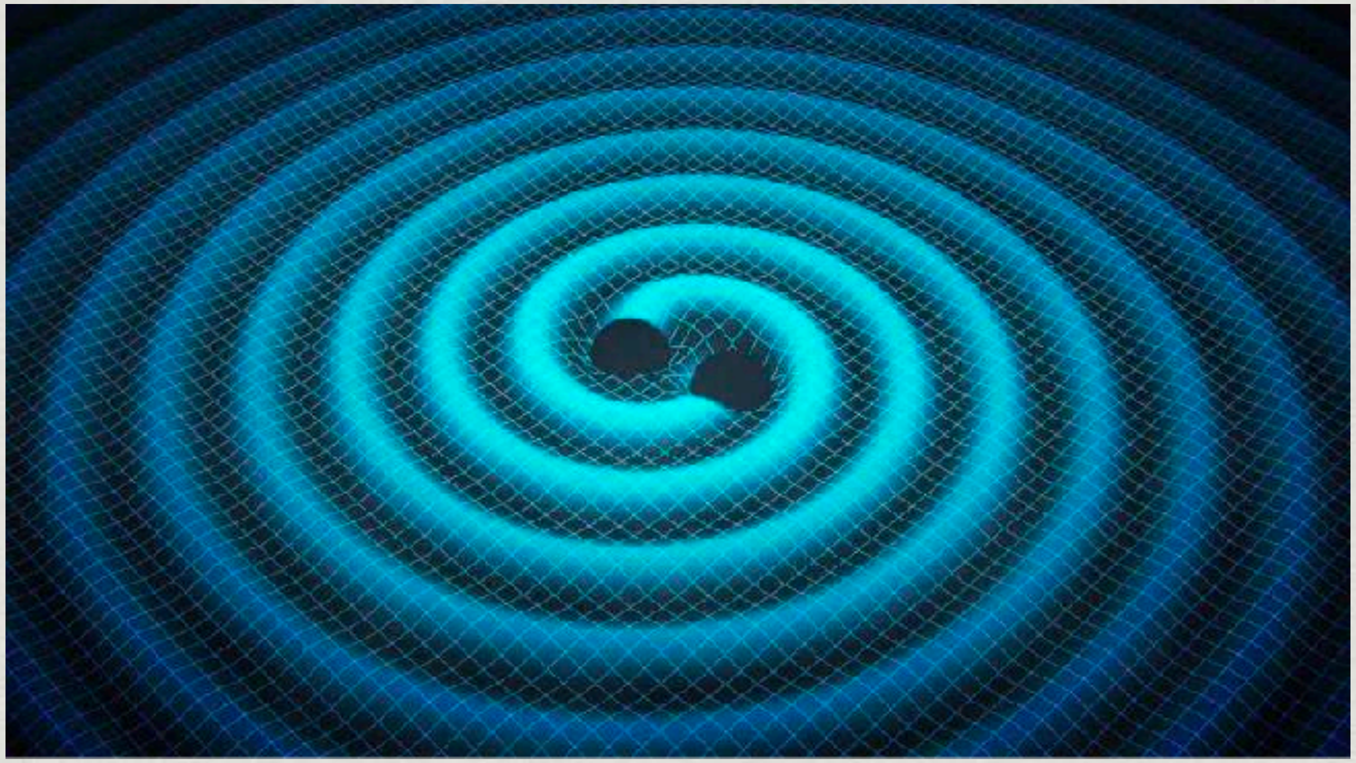




Visual Summary







Conclusions

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- Uncovering dark matter's fundamental nature needs input from all possible sources (experiment and theory)
- 3 Examples I'm particularly interested in (direct detection, self interacting DM, GW probes of DM)
- Much I could have discussed (e.g. 21cm/EDGES), some of which you will hear about at this conference

LOOKING FOR DARK MATTER IN TAIPEI?

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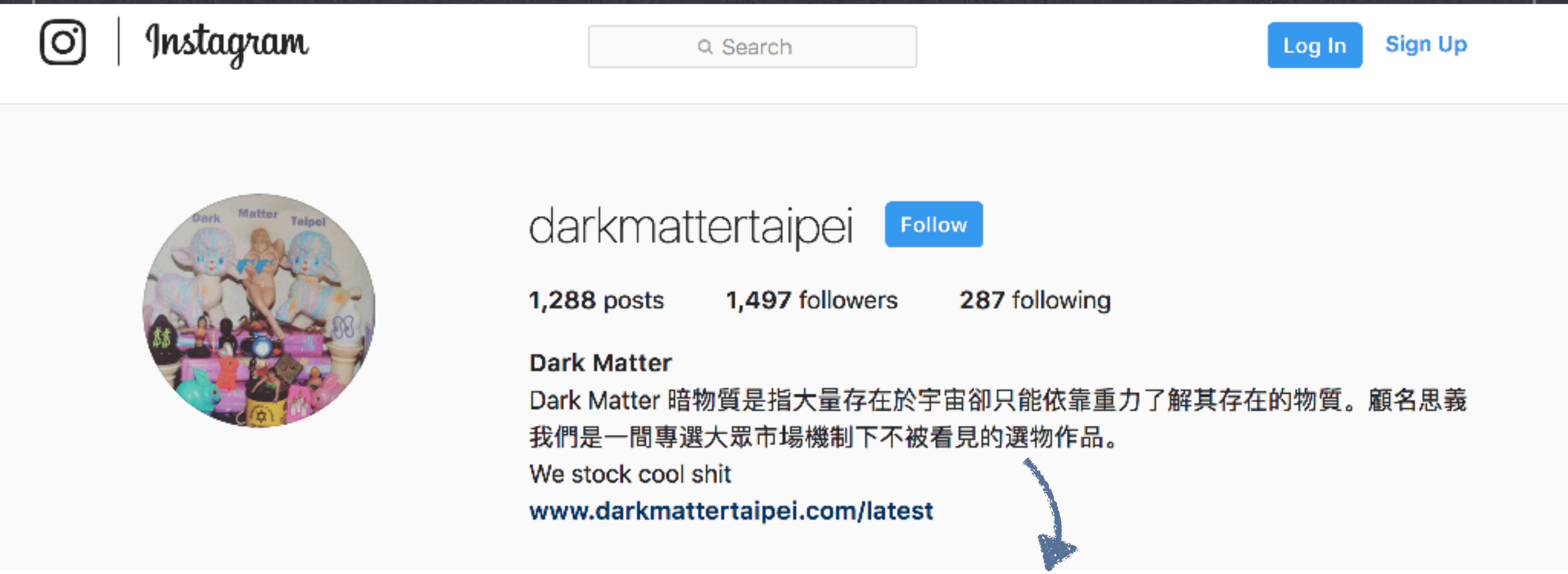


Google Translate: Dark matter refers to a substance that exists in the universe but can only rely on gravity to understand its existence. As the name implies, we are a selection of works that are not seen under the mass market mechanism.

THANKS FOR YOUR ATTENTION AND ENJOY THE WORKSHOP!

EXTRA SLIDES

NECIB ET.AL.

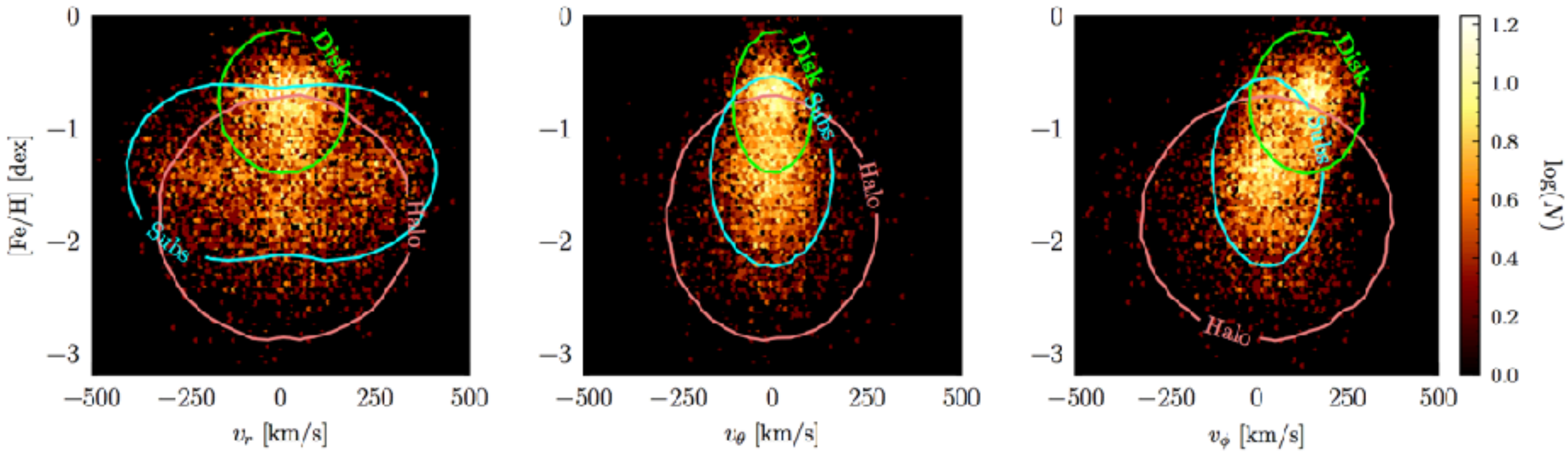
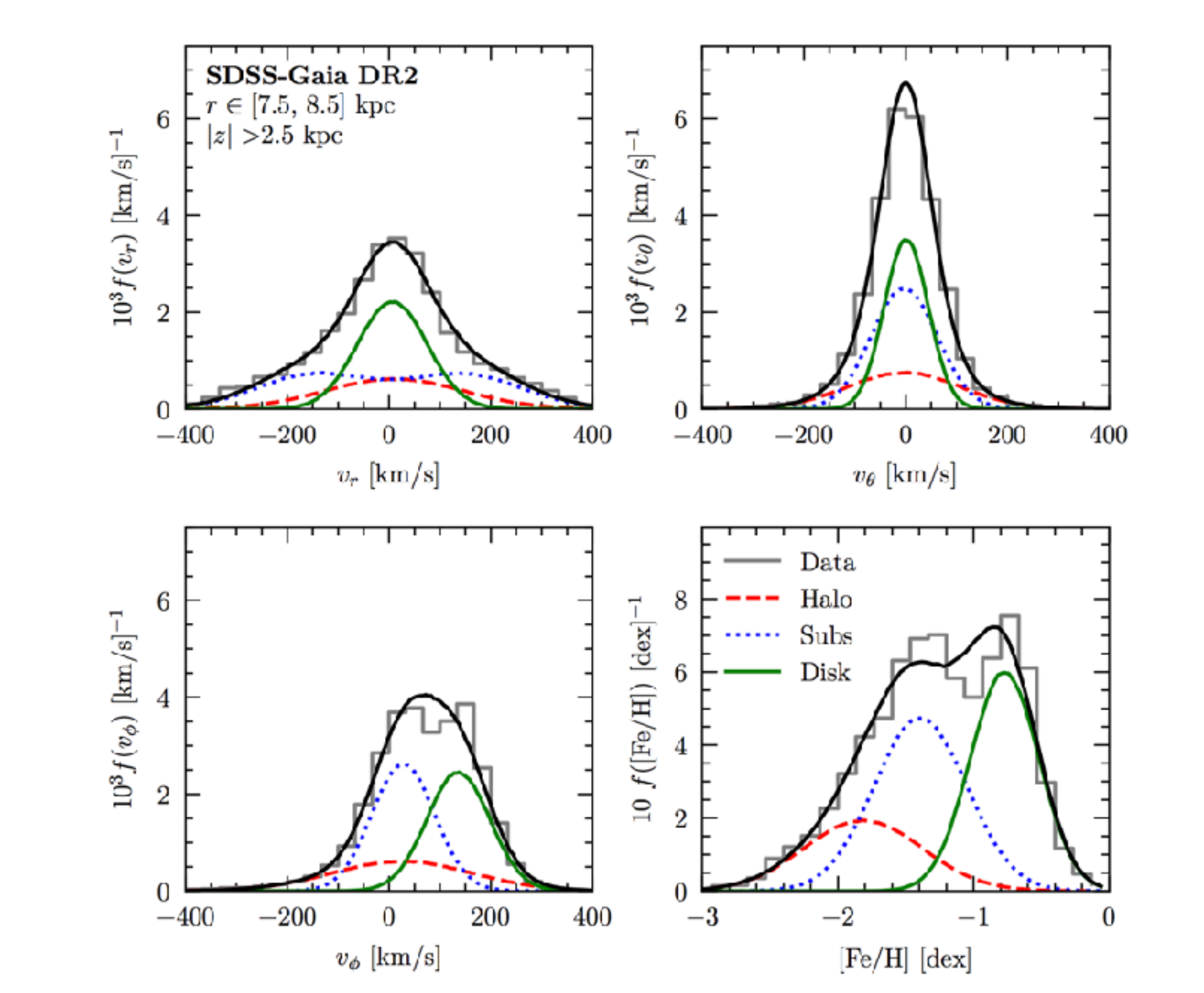


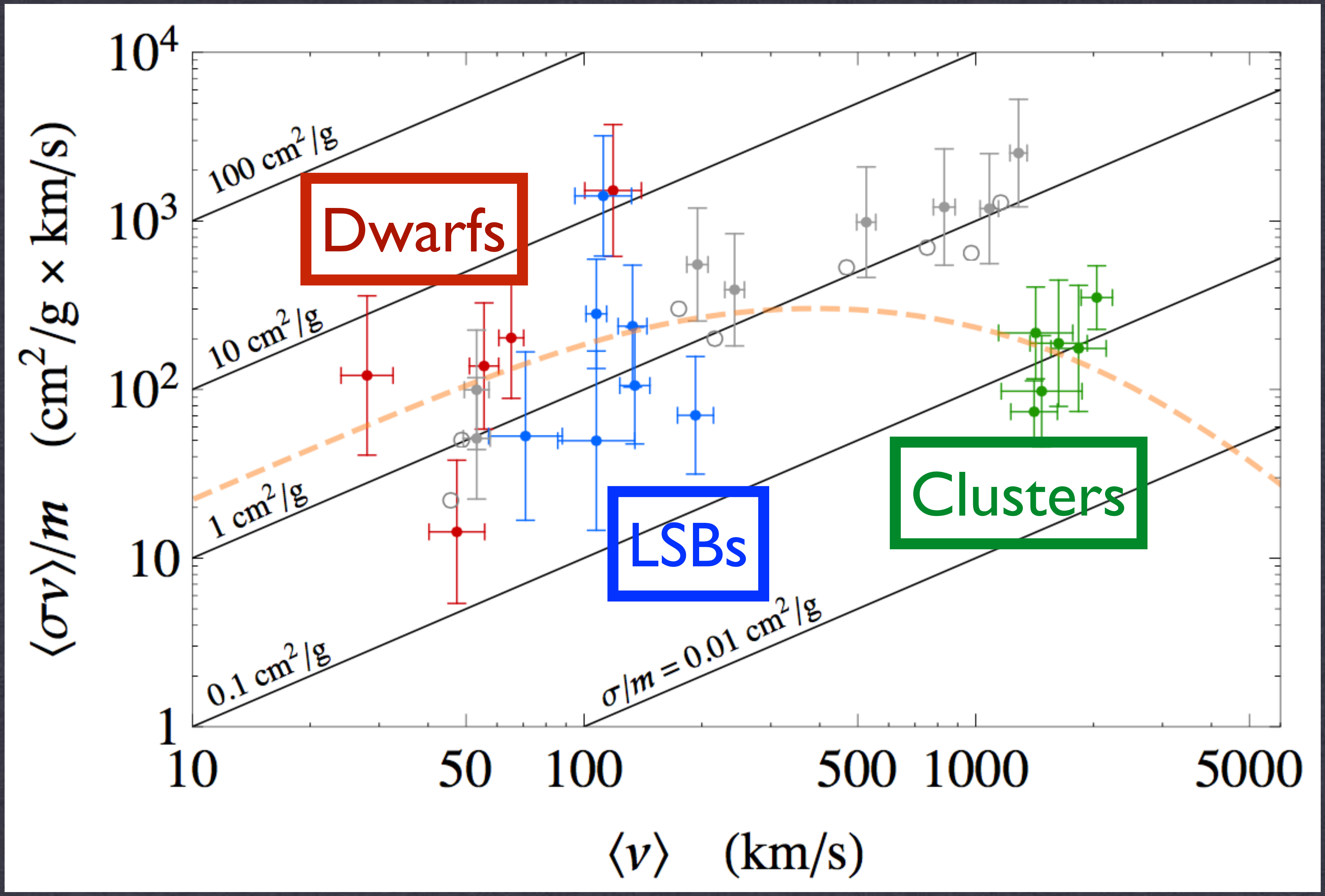
Figure 2. Chemo-dynamic distribution of stars in the SDSS-*Gaia* DR2 sample within $r \in [7.5, 8.5]$ kpc and $|z| > 2.5$ kpc. The panels show how the distributions vary in iron abundance [Fe/H] and the spherical Galactocentric radial coordinates v_r (left), v_θ (middle), and v_ϕ (right). The disk population is pronounced at [Fe/H] ~ -0.8 and a nearly isotropic halo population is apparent at [Fe/H] $\lesssim -1.8$. A highly radial population at [Fe/H] ~ -1.4 constitutes a large fraction of the sample and is an example of kinematic substructure. The 95% contours of the posterior distributions recovered from the likelihood analysis are also shown (see Sec. 2.3); the disk, halo, and substructure best-fits are shown in green, pink, and blue, respectively.

NECIB ET.AL.

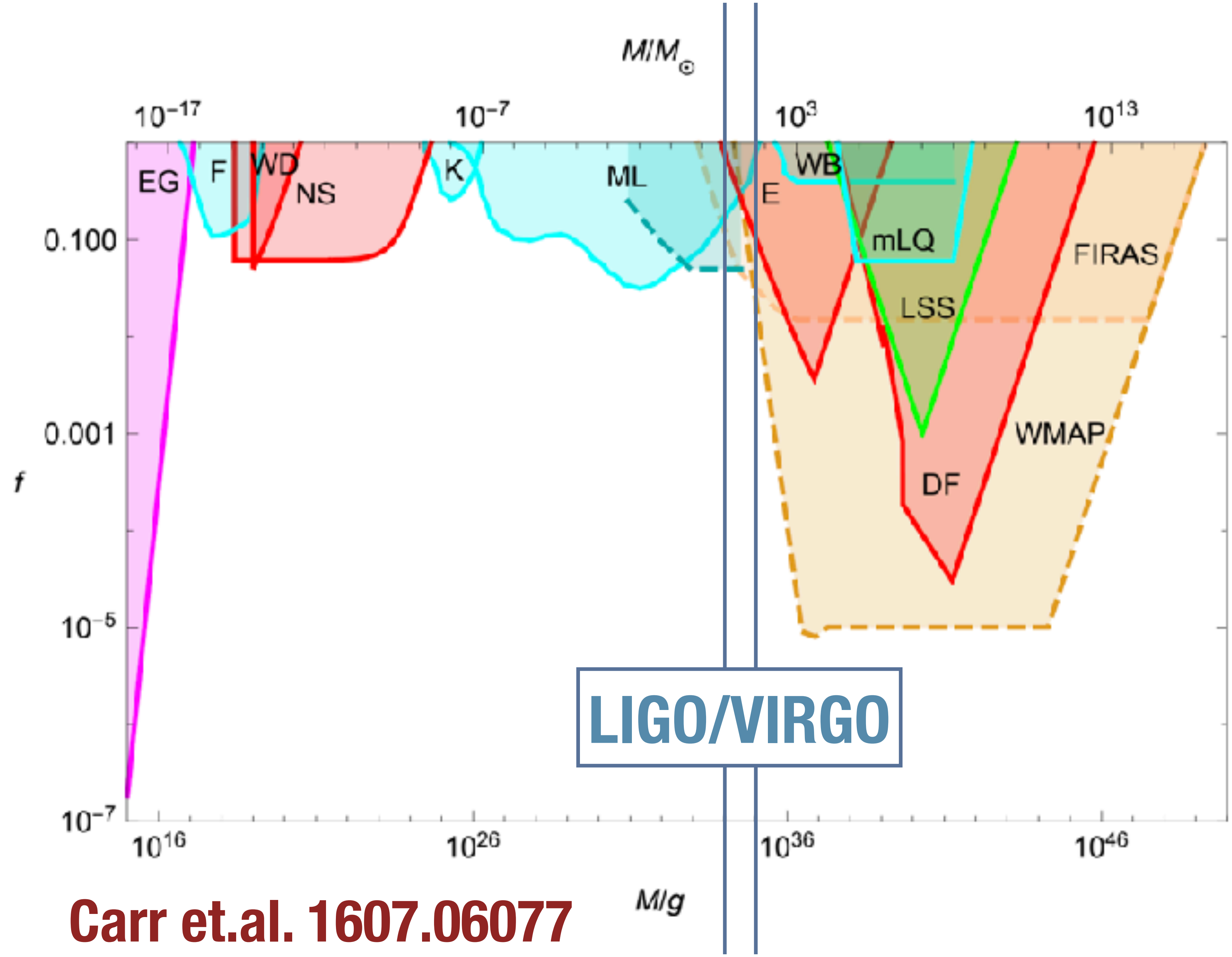


SDSS-Gaia DR2
$r \in [7.5, 8.5]$ kpc
$|z| > 2.5$ kpc
$10^3 f(v_r)$ [km/s]$^{-1}$
v_r [km/s]
$10^3 f(v_\theta)$ [km/s]$^{-1}$
v_θ [km/s]
$10^3 f(v_\phi)$ [km/s]$^{-1}$
v_ϕ [km/s]
$10\ f$([Fe/H]) [dex]$^{-1}$
[Fe/H] [dex]
Data
Halo
Subs
Disk

SIDM AT DIFFERENT SCALES



Slide from H. Yu



Carr et.al. 1607.06077

FIG. 3: Constraints on $f(M)$ for a variety of evaporation (magenta), dynamical (red), lensing (cyan), large-scale structure (green) and accretion (orange) effects associated with PBHs. The effects are extragalactic γ-rays from evaporation (EG) [11], femtolensing of γ-ray bursts (F) [187], white-dwarf explosions (WD) [188], neutron-star capture (NS) [36], Kepler microlensing of stars (K) [189], MACHO/EROS/OGLE microlensing of stars (ML) [27, 190] and quasar microlensing (broken line) (ML) [191], survival of a star cluster in Eridanus II (E) [192], wide-binary disruption (WB) [37], dynamical friction on halo objects (DF) [33], millilensing of quasars (mLQ) [32], generation of large-scale structure through Poisson fluctuations (LSS) [14], and accretion effects (WMAP, FIRAS) [15]. Only the strongest constraint is usually included in each mass range, but the accretion limits are shown with broken lines since they are are highly model-dependent. Where a constraint depends on some extra parameter which is not well-known, we use a typical value. Most constraints cut off at high M due to the incredulity limit. See the original references for more accurate forms of these constraints.