Terrestrial and Astrophysical Probes of Early-Universe Relics

M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **104**, 075023 (2021) [arXiv:2106.00022].
M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **104**, 095032 (2021) [arXiv:2108.08852].
A. Arza, M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **105**, 095007 (2022) [arXiv:2112.09620].

M.A.F., P.W. Graham, and S. Rajendran. Phys. Rev. D **101**, 115021 (2020) [arXiv:1911.08883]

Dark Matter in Compact Objects, Stars, and in Low Energy Experiments
University of Washington Program INT-22-2B
Virtual talk

August 30, 2022

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JOHNS HOPKINS
UNIVERSITY

Overall plan of my talk

I will try to cover two quite different topics within the theme of the program:

- ❖ Part I: A new signal of ultralight dark-photon and axion-like particle dark matter in terrestrial magnetometer data

  M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **104**, 075023 (2021) [arXiv:2106.00022].
  M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **104**, 095032 (2021) [arXiv:2108.08852].
  A. Arza, M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **105**, 095007 (2022) [arXiv:2112.09620].

- ❖ Part II: Using white dwarfs to constrain a different early-universe relic: charged massive particles (CHAMPs)

  M.A.F., P.W. Graham, and S. Rajendran. Phys. Rev. D **101**, 115021 (2020) [arXiv:1911.08883]

Time permitting

Earth as a Transducer for Dark-Matter Detection

Dark Matter in ~~Compact Objects, Stars, and in~~ Low Energy Experiments

Outline - Part I

- Motivation
  - Ultralight Bosonic Dark Matter (dark photons and ALPs / axions)
- Phenomenology of the photon—dark-photon or photon—axion system
- A new signal of DM:

  Magnetic field oscillating coherently & in-phase across the entire surface of Earth, with a known spatial and vectorial pattern
- Results of a search with SuperMAG data
- Outlook and future directions

Dark Matter

- ~27% of the energy budget of the universe
- Want to detect non-gravitationally!
- A menagerie of possible DM candidates exist
- Candidates span ~80 orders of magnitude in mass:

MACHOs ($\sim 30 M_\odot$)

Small-scale structure

$\sim 10^{-17}\,\mathrm{eV}$

This talk

Lensing

$\sim 10^{-21}\,\mathrm{eV}$ $\sim 10\,\mathrm{eV}$ $\sim \mathrm{keV}$ $\sim \mathrm{MeV}$ $\sim \mathrm{GeV}$ $\sim 100\,\mathrm{TeV}$ $\sim 10^{-10}\,M_\odot\ (10^{56}\,\mathrm{eV})$

Fuzzy DM

Ultralight bosonic DM

Sterile ν "Sub-GeV" DM WIMPs

WIMPzillas, Blobs/Nuggets, etc.

PBHs

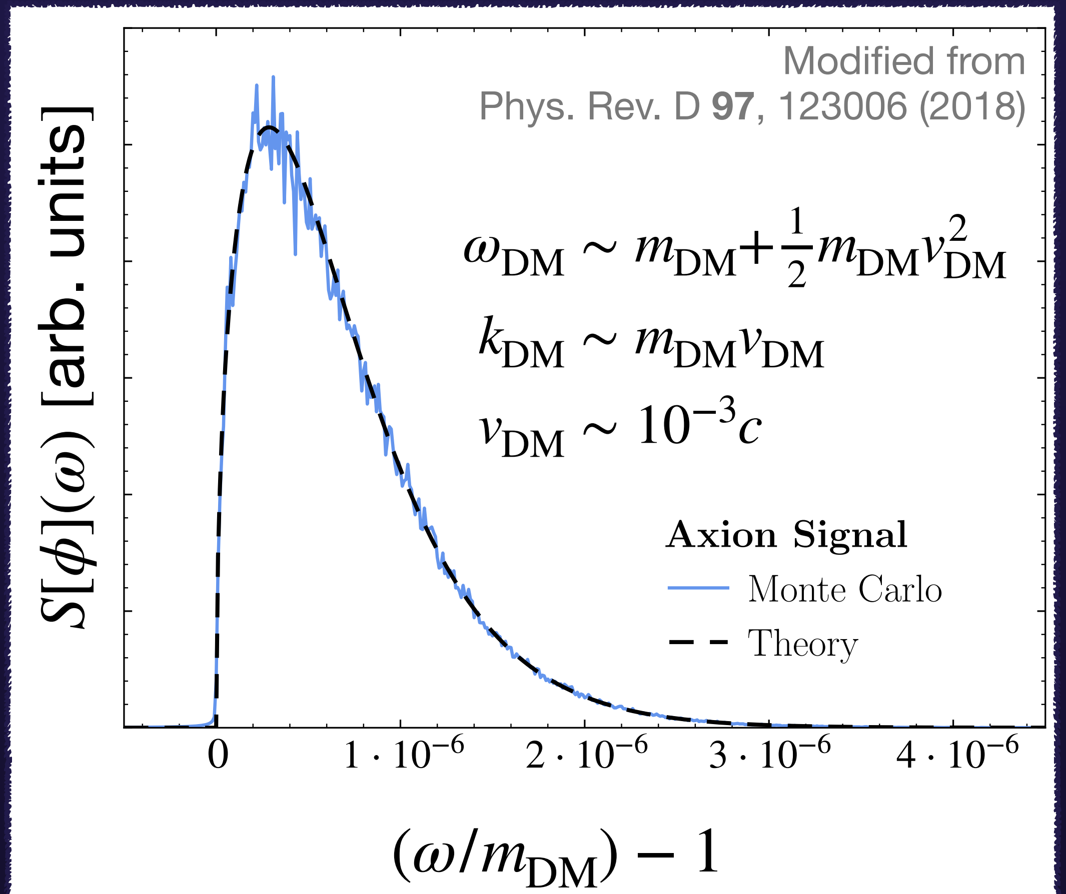
Insert your favorite DM candidate here

- No single experimental approach can cover all candidates
- This talk: ultralight bosonic DM around $m_{\mathrm{DM}} \sim 10^{-17}\,\mathrm{eV}$

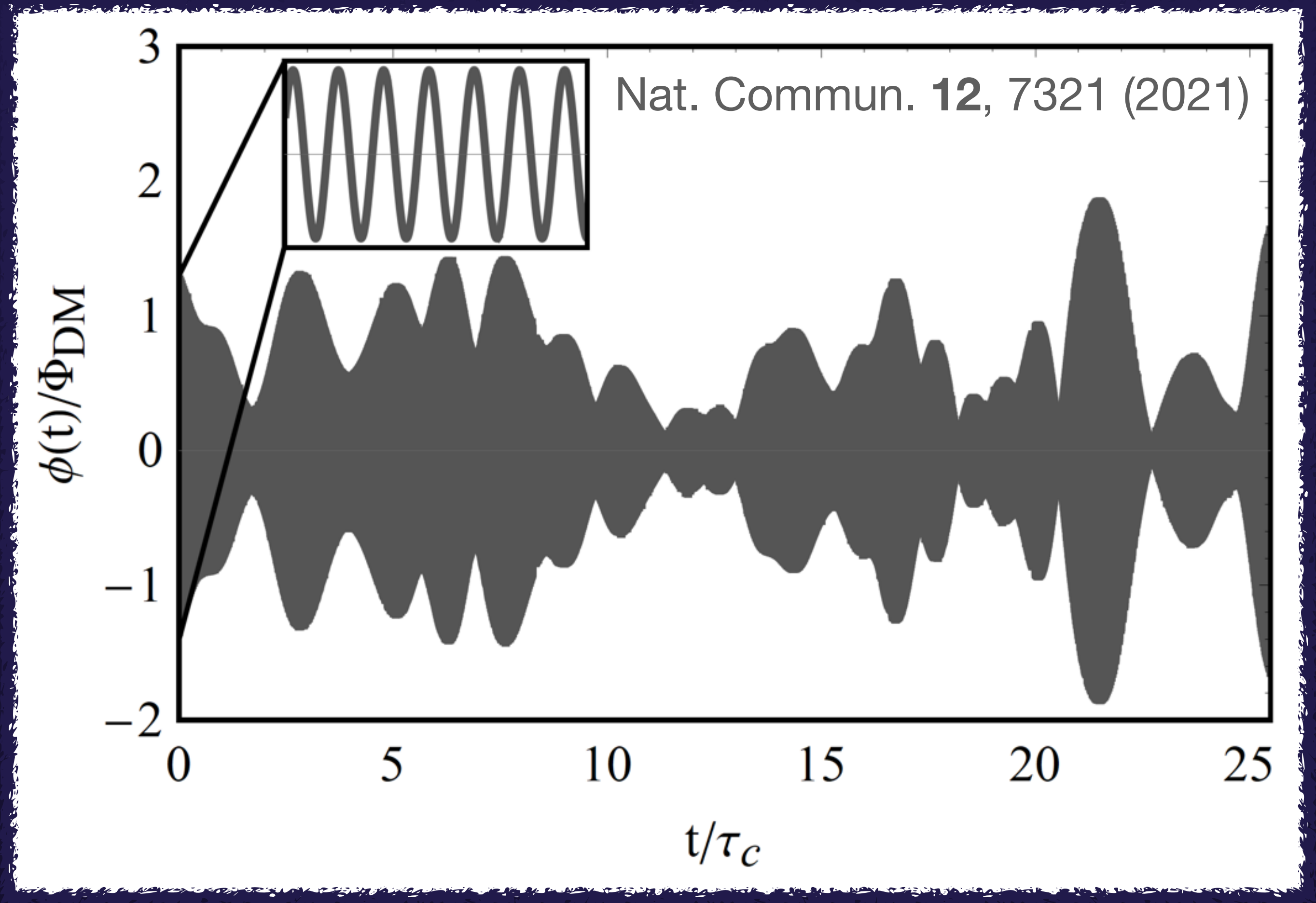
Ultralight Bosonic Dark Matter I

- For $m_{\mathrm{DM}} \lesssim 10\,\mathrm{eV}$, overlapping DM particle de Broglie wavelengths
- Classical field description

$$\phi(\mathbf{x}, t) \sim \frac{\sqrt{\rho_{\mathrm{DM}}}}{m_{\mathrm{DM}}} \cos(\omega_{\mathrm{DM}} t - \mathbf{k}_{\mathrm{DM}} \cdot \mathbf{x}) \sim \frac{\sqrt{\rho_{\mathrm{DM}}}}{m_{\mathrm{DM}}} \cos(m_{\mathrm{DM}} t)$$



Modified from Phys. Rev. D **97**, 123006 (2018)



Nat. Commun. **12**, 7321 (2021)

$$T_{\mathrm{coh}} \sim v_{\mathrm{DM}}^{-2}\, T_{\mathrm{osc}} \sim 10^6\, T_{\mathrm{osc}}$$

$$\lambda_{\mathrm{coh}} \sim v_{\mathrm{DM}}^{-1}\, \lambda_{\mathrm{Compton}} \sim 10^3\, \lambda_{\mathrm{Compton}}$$

- Search strategies can **leverage oscillatory phenomenology**

JCAP 06 (2012) 013 [arXiv:1201.5902]

Ultralight Bosonic Dark Matter II

$$F^{(\prime)}_{\mu\nu} \equiv \partial_\mu A^{(\prime)}_\nu - \partial_\nu A^{(\prime)}_\mu$$

$$\tilde{F}^{\mu\nu} \equiv \frac{1}{2}\epsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}$$

Kinetically Mixed Dark Photon Dark Matter (DPDM)

Phys. Lett. B 166 (1986) 196–198; Phys. Rev. D 84 (2011) 103501 [arXiv:1105.2812]

$$\mathscr{L} = \mathscr{L}_{\mathrm{SM}} - \frac{1}{4}(F')^2 + \frac{1}{2}m_{A'}^2(A')^2 \boxed{+\frac{\epsilon}{2}FF'} \qquad (\epsilon \ll 1)$$

Electromagnetically Coupled Axions

Phys. Rev. Lett. 38 (1977) 1440–1443; Phys. Rev. Lett. 40 (1978) 223–226; Phys. Rev. Lett. 40 (1978) 279–282.
JHEP 06 (2006) 051 [arXiv:hep-th/0605206]; Phys. Rev. D 81 (2010) 123530 [arXiv:0905.4720]

Note: ϵ is dimensionless, $g_{\phi\gamma}$ has dimensions of $(\mathrm{mass})^{-1}$

$$\mathscr{L} = \mathscr{L}_{\mathrm{SM}} + \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 \boxed{- g_{\phi\gamma}\phi F\tilde{F}}$$

Disclaimer: in this talk "axions" means "axion-like particles (ALPs)"

Mixings with SM EM sector **cause observable EM effects**:

- oscillatory with period set by fundamental physics parameter m_{DM}
- narrowband / phase-coherent over long times
- spatially uniform / phase-coherent over large distances

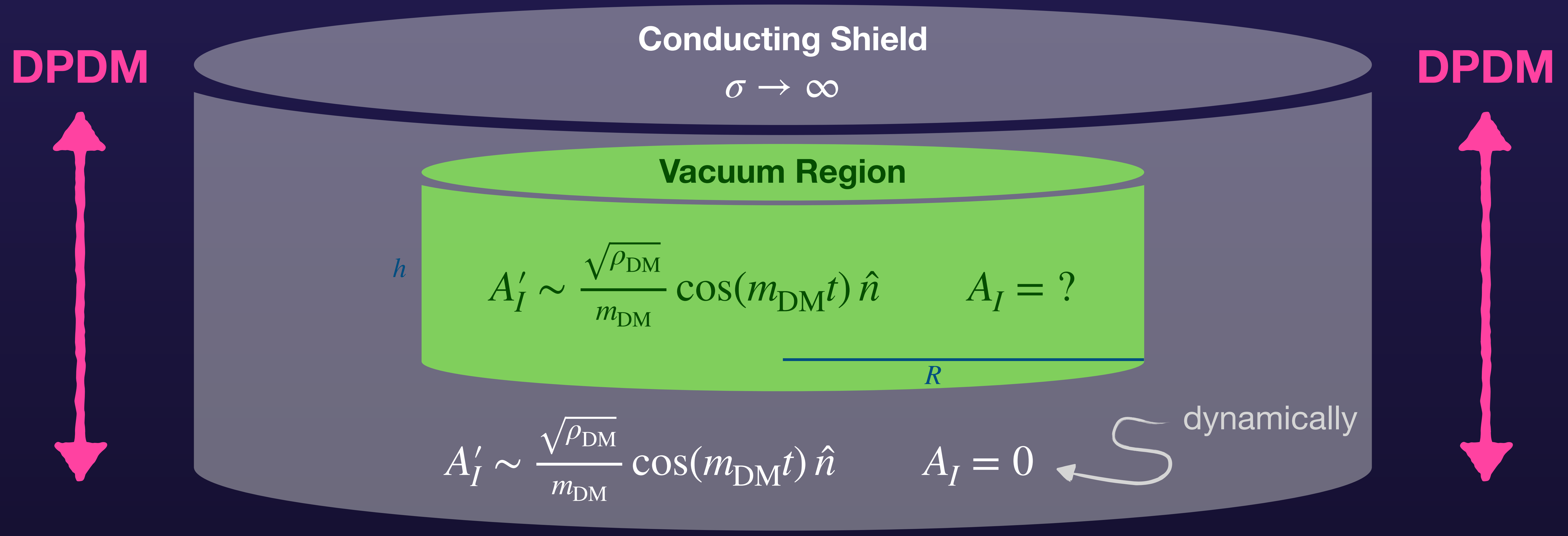
Phys. Rev. D **92** (2015) 075012 [arXiv: 1411.7382]
IEEE Trans. Appl. Supercond. 27 (2017) 4, 1400204 [arXiv:1610.09344]
Springer Proc. Phys. 245 (2020) 139-145 [arXiv:1906.08814]

DPDM Pheno I

- Focus on $\mathscr{L} = \mathscr{L}_{\rm SM} - \frac{1}{4}(F')^2 + \frac{1}{2}m_{A'}^2(A')^2 + \frac{\epsilon}{2}FF'$ $(\epsilon \ll 1)$
- Same physics, different basis:

Interaction basis $\mathscr{L} \supset -\frac{1}{4}(F_I)^2 - \frac{1}{4}(F_I')^2 + \frac{1}{2}m_{A'}^2(A_I' + \varepsilon A_I)^2 - J_{\rm EM}A_I$

A_I couples to charges.
A_I' does not (sterile state).



DPDM

Conducting Shield
$\sigma \to \infty$

Vacuum Region

h

$A_I' \sim \frac{\sqrt{\rho_{\rm DM}}}{m_{\rm DM}}\cos(m_{\rm DM}t)\,\hat{n}$ $A_I = ?$

R

$A_I' \sim \frac{\sqrt{\rho_{\rm DM}}}{m_{\rm DM}}\cos(m_{\rm DM}t)\,\hat{n}$ $A_I = 0$

dynamically

DPDM

TO LEADING ORDER IN
$\epsilon \ll 1$

SETUP AKIN TO DM RADIO

Magnetoquasistatic Limit
$m_{A'}R, m_{A'}h \ll 1$

- Detectable field A_I in the vacuum region? Expand mass term: $\mathscr{L} \supset -(J_{\rm EM} - \varepsilon m_{A'}^2 A_I') \cdot A_I$
- **DPDM field A_I' acts as oscillating background current sourcing EM: $J^\mu_{\rm eff} \sim -\varepsilon m_{A'}^2 (A_I')^\mu$.**
- Non-relativistic limit: $\mathbf{J}_{\rm eff} \sim -\varepsilon m_{A'}^2 \mathbf{A}_I' \sim -\varepsilon m_{A'}\sqrt{\rho_{\rm DM}}\cos(m_{A'}t)\,\hat{\mathbf{A}}_I'$.

* or region of high plasma frequency

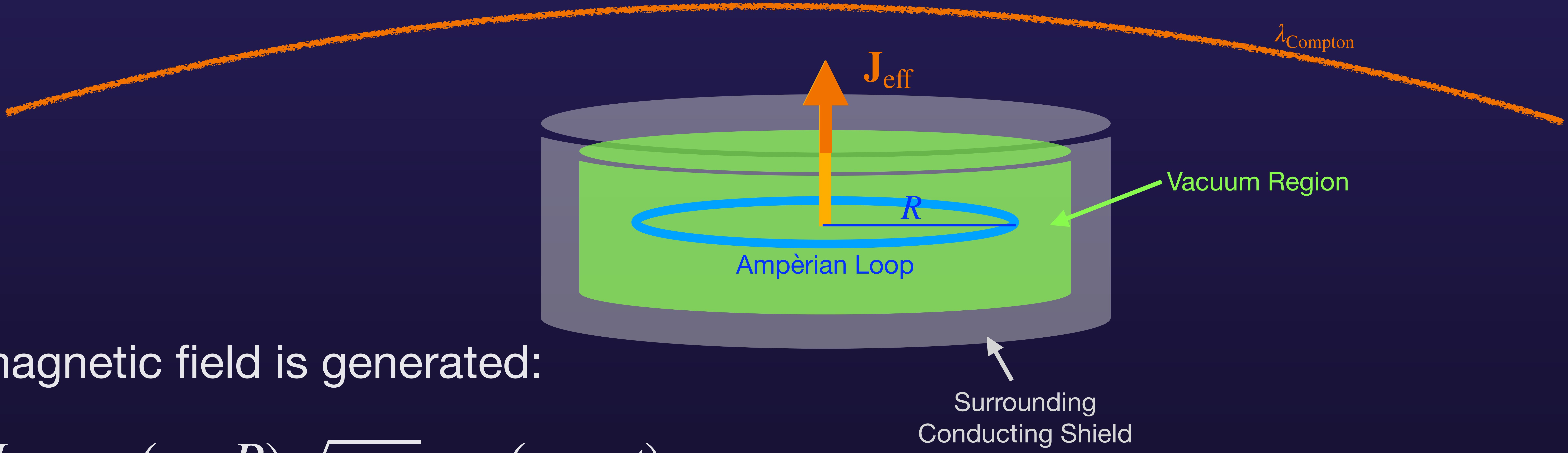
Phys. Rev. D **92** (2015) 075012 [arXiv: 1411.7382]
IEEE Trans. Appl. Supercond. 27 (2017) 4, 1400204 [arXiv:1610.09344]
Springer Proc. Phys. 245 (2020) 139-145 [arXiv:1906.08814]

DPDM Pheno II

- Apply the Ampère-Maxwell Law to this simple geometry

$$\iint \mathbf{J}\cdot\mathbf{dA} = \oint \mathbf{B}\cdot\mathbf{dl} \Rightarrow R^2 J_{\text{eff}} \sim BR$$

Displacement current term is higher-order



- A circumferential magnetic field is generated:

$$B_\phi(r \sim R) \sim RJ_{\text{eff}} \sim \varepsilon(m_{A'}R)\sqrt{\rho_{\text{DM}}}\cos(m_{\text{DM}}t)$$

- Suppressed by a ratio of length scales: $m_{A'}R \sim R/\lambda_{\text{Compton}}$.
- Electric field further suppressed by $(m_{A'}R)^2$, $v_{\text{DM}}(m_{A'}R)$

“You’re gonna need a bigger boat”

- DPDM fields source magnetic fields in a vacuum gap in an electromagnetically shielded region.
- Effects decouple as DPDM mass drops below the inverse size of the box.
    - What if we want to look for DPDM with $m_{A'} \lesssim 1/(1\,\mathrm{meter}) \sim 2 \times 10^{-7}\,\mathrm{eV}$?
- Options? **OUR WORK PICKS UP HERE**
    - ~~Build a more sensitive magnetometer?~~ OK, but noise.
    - ~~Build Death Star 4.0?~~ Impractical, at best.
    - Find a pre-existing natural shield?
- What about the Earth?
    - It’s big enough: $1/R_\oplus \sim 3 \times 10^{-14}\,\mathrm{eV}$
    - But is it a shield?

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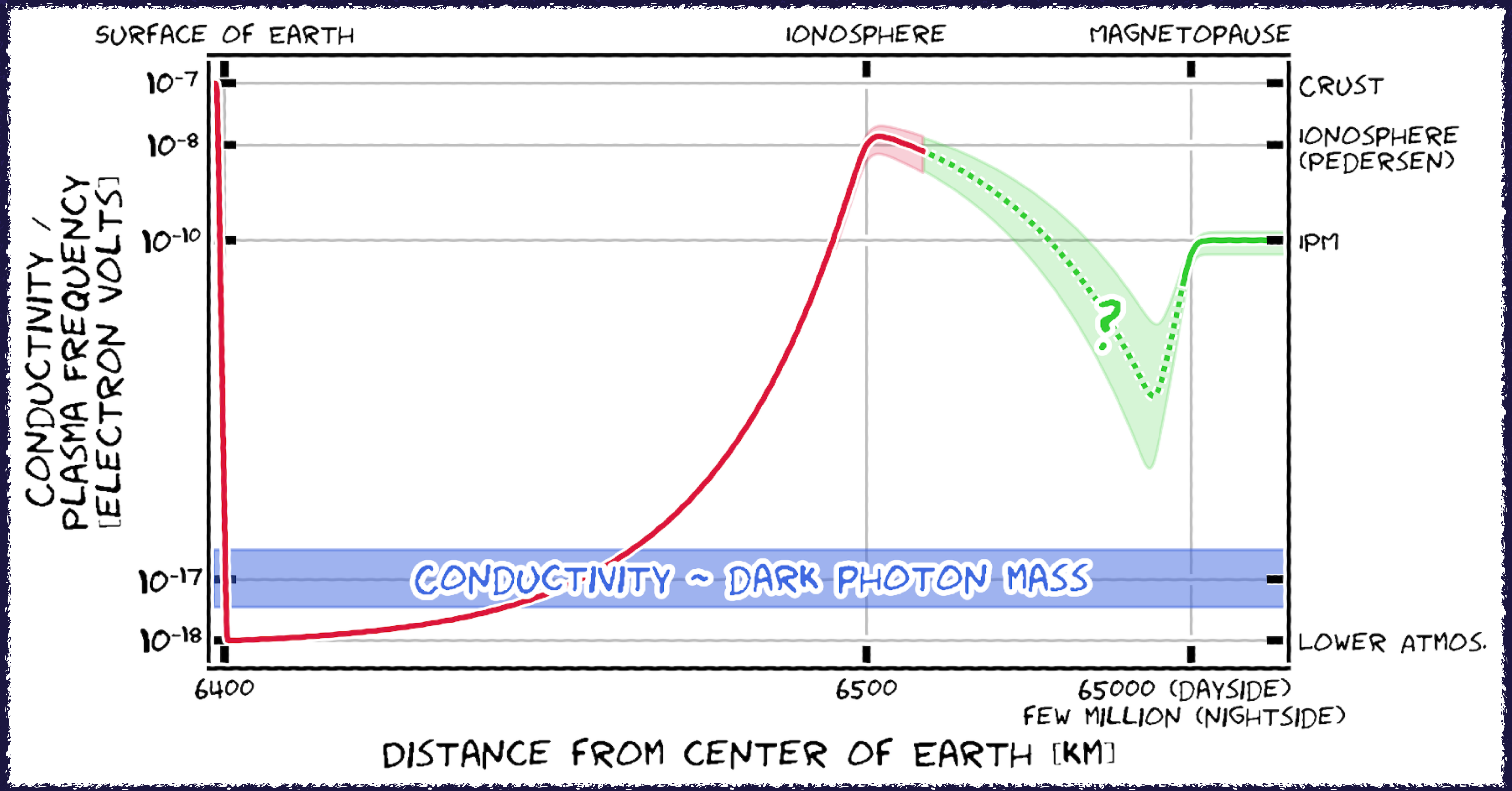
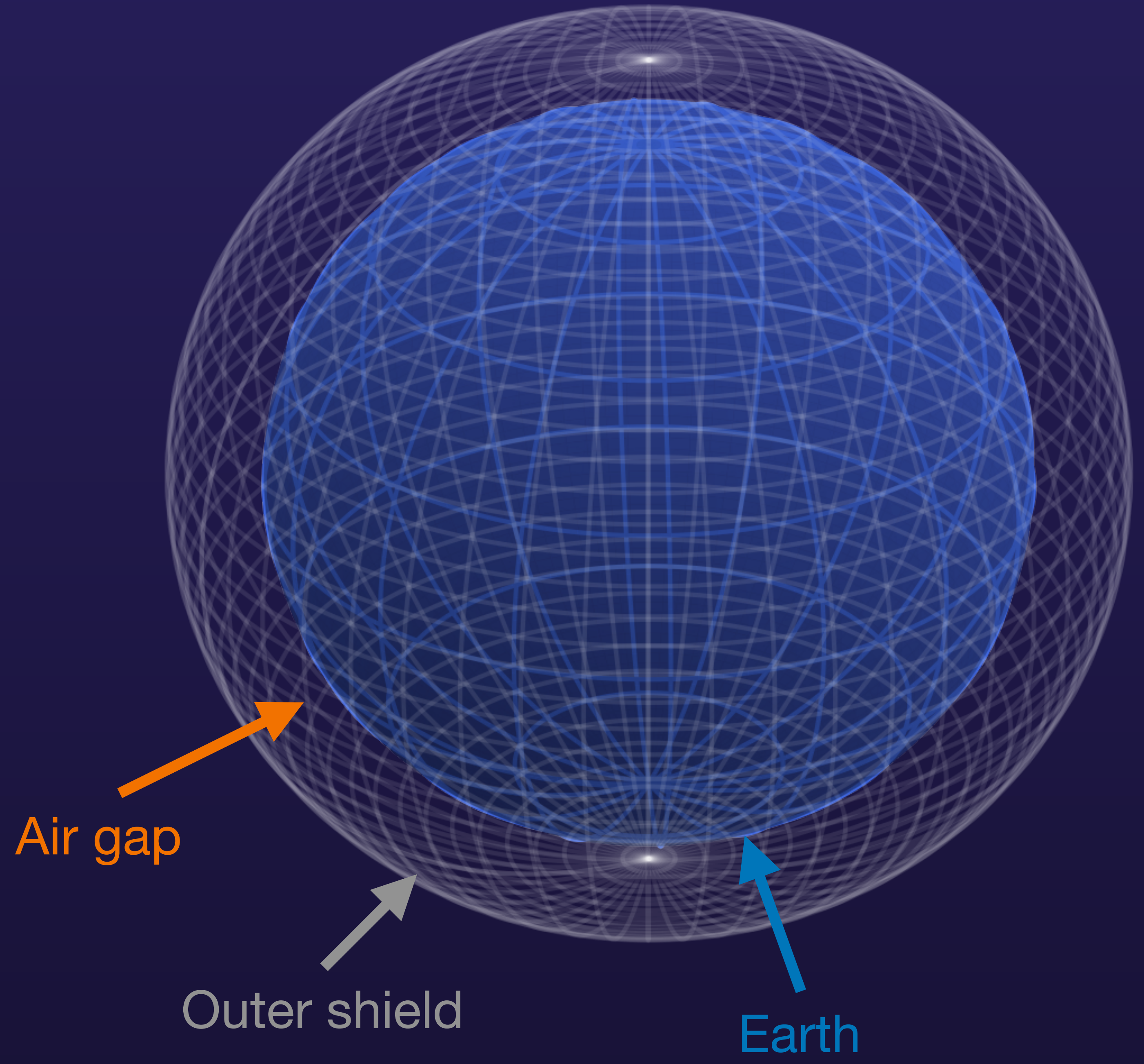
PRD **104**, 095032 (2021)

Near-Earth Conductivity Environment

- Is the Earth a shield? It depends; for some masses, yes!



Simplified model



- The ground / interior is a region of high conductivity (“inner shield”)
- The lower atmosphere is a region of low conductivity (“vacuum gap”)
- The ionosphere / interplanetary medium beyond is a region of high conductivity / plasma frequency (“outer shield”)
- A nested conductor-insulator-conductor sandwich!

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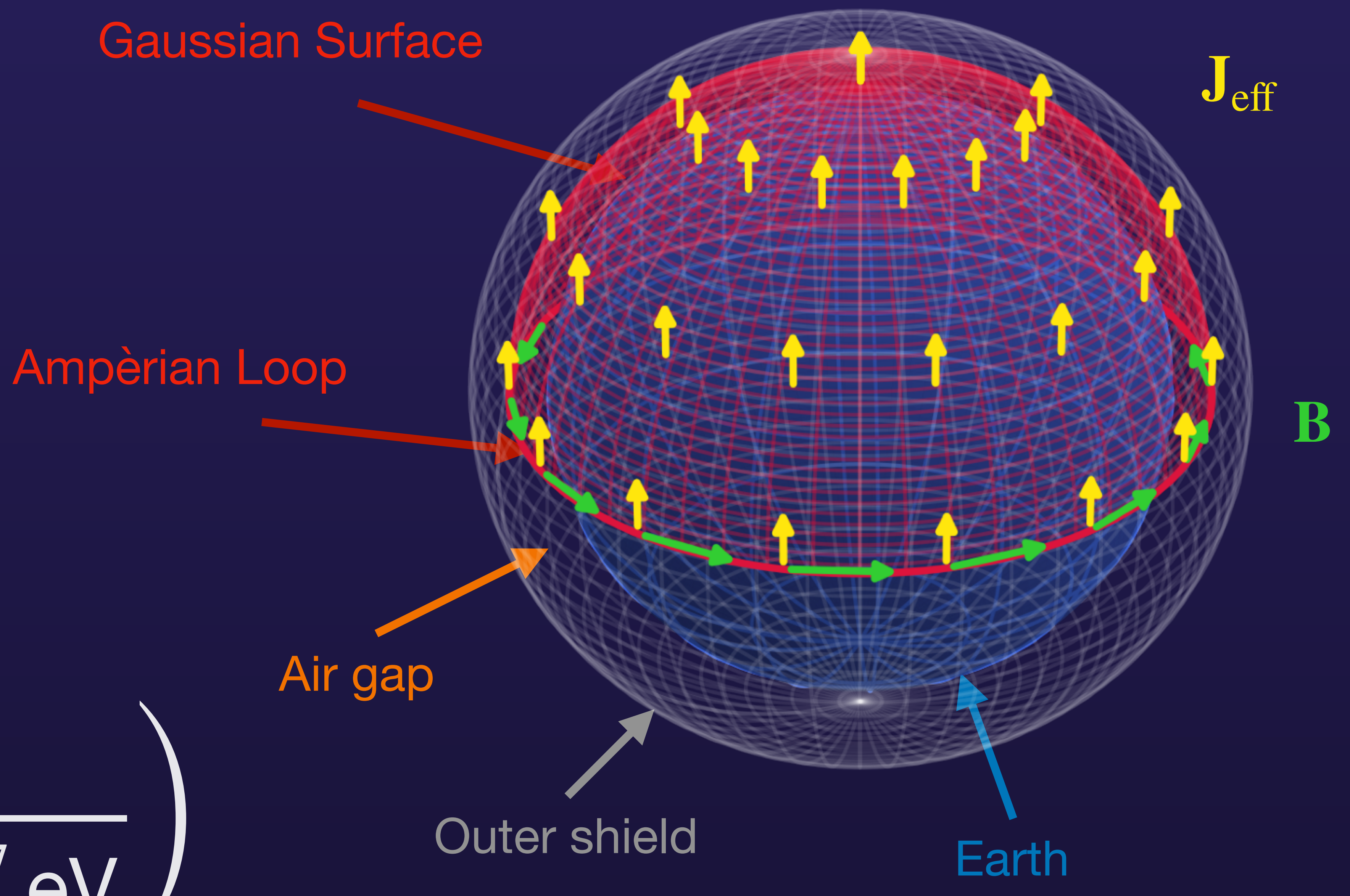
A new signal of DPDM I

- Spherical conductor, surrounded by a (vacuum-like) air gap, surrounded by a shield (ionosphere / IPM)
- What is the field on the ground?
- Run a similar Ampèrian loop argument:

$$\iint \mathbf{J}\cdot d\mathbf{A} = \oint \mathbf{B}\cdot d\mathbf{l} \Rightarrow R_\oplus^2 J_{\text{eff}} \sim BR_\oplus$$

Displacement current term is higher-order

$$|B| \sim \varepsilon(m_{A'}R_\oplus)\sqrt{\rho_{\text{DM}}} \sim 0.7\,\text{nG} \times \left(\frac{\varepsilon}{10^{-5}}\right) \times \left(\frac{m_{A'}}{4\times 10^{-17}\,\text{eV}}\right)$$



- **A PERSISTENT, GLOBAL, NARROWBAND MAGNETIC FIELD OSCILLATION WITH A KNOWN PATTERN, IN-PHASE OVER THE ENTIRE SURFACE OF EARTH**
- The field is **very small**, but **spectral and spatial features differ from noise sources**
- **Suppressed by** $(m_{A'}R_\oplus)$**, not** $(m_{A'}h_{\text{atmos.}}) \ll (m_{A'}R_\oplus)$**!**

$1\,\text{G} = 10^{-4}\,\text{T}$

A new signal of DPDM II

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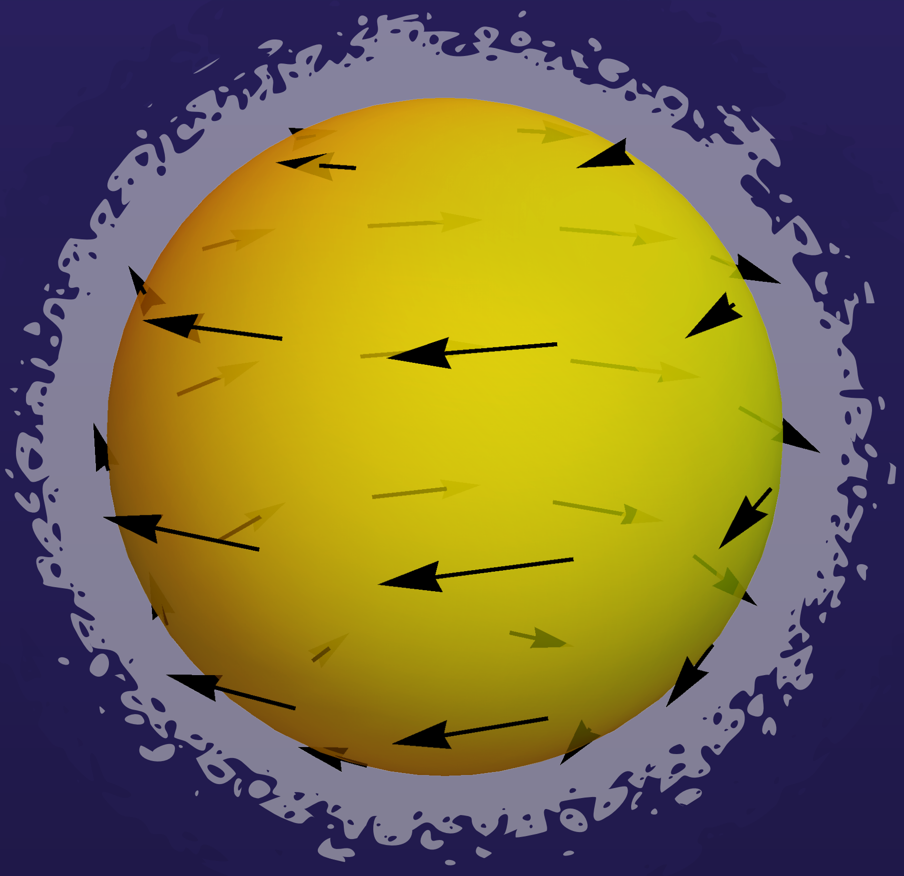
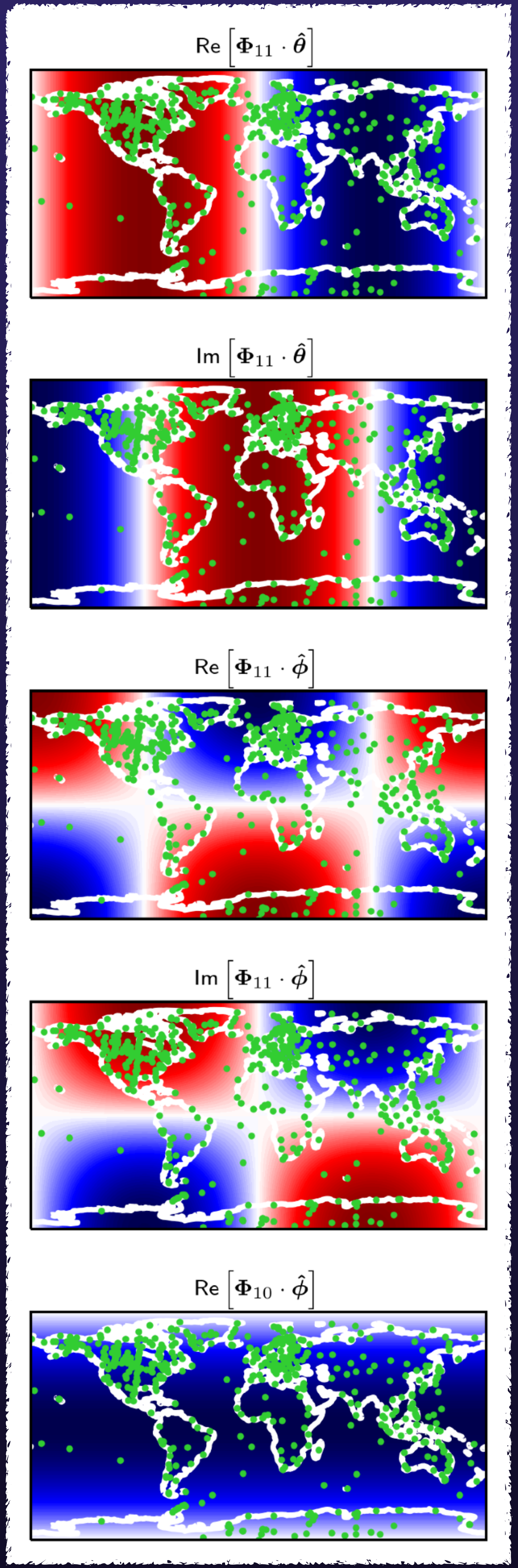




- Performing the computation rigorously, we find

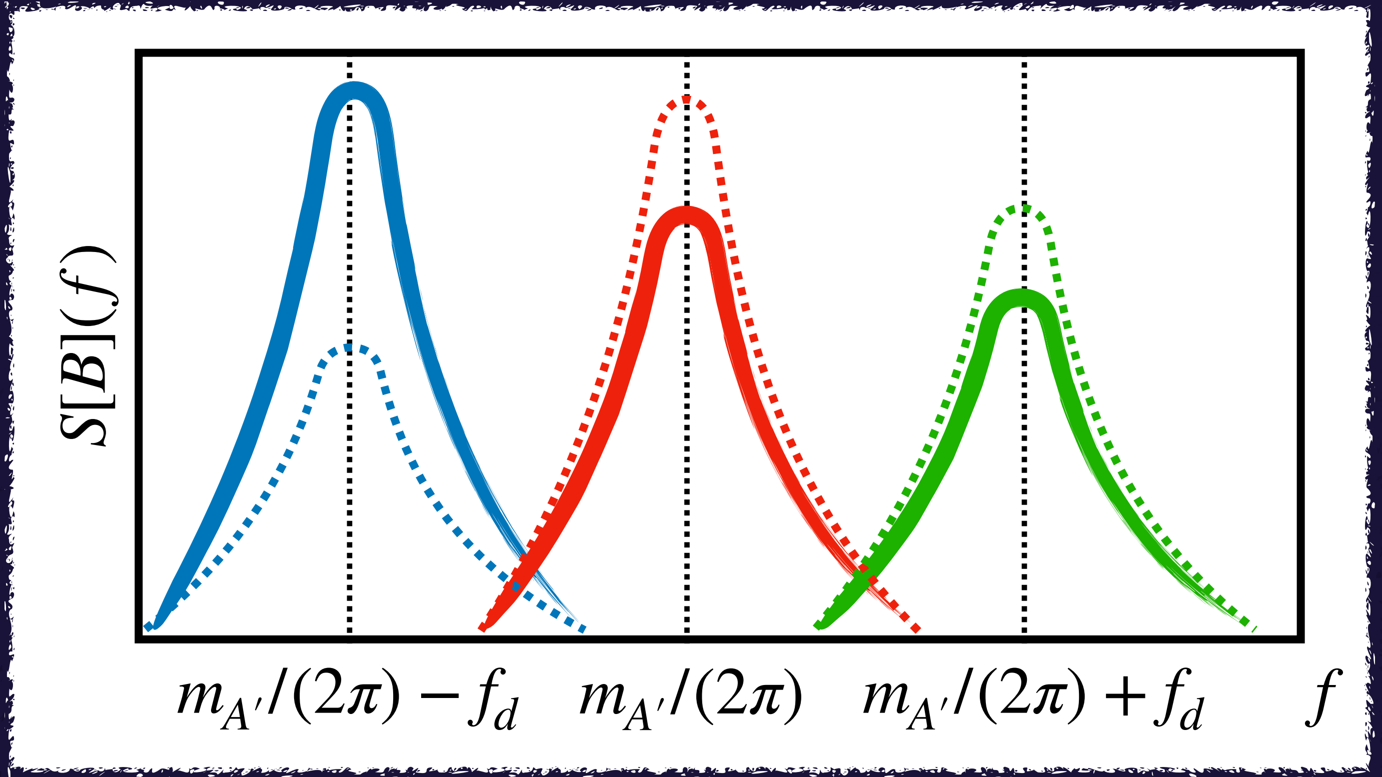
$$\mathbf{B}(\Omega,t) = \sqrt{\frac{\pi}{3}}\varepsilon m_{A'}^2 R_\oplus \sum_{m=-1}^{1} A'_m \mathbf{\Phi}_{1m}(\Omega) e^{-i(m_{A'}-2\pi f_d m)t}$$

\+ higher-order terms + TE fields

where $\frac{1}{2}m_{A'}^2\langle|A'|^2\rangle_{T\gg T_{\mathrm{coh}}} = \rho_{\mathrm{DM}}$

- Signal found in one type of Vector Spherical Harmonic (VSH): $\mathbf{\Phi}_{1m}(\Omega)$
- Field evaluated at ground magnetometer station at $\Omega=(\theta,\phi)$. Earth frame (rotating).
- DPDM polarization state $\mathbf{A}'$ fixed in inertial space (within coherence time / patch)
- Non-trivial frequency structure
  Sensitive to DPDM polarization state

Sidebands offset by
$f_d = 1/(\text{siderial day})$



- Signal derivation holds for $10^{-21}\,\mathrm{eV} \lesssim m_{A'} \lesssim 1/R_\oplus \sim 3\times10^{-14}\,\mathrm{eV}$
- Complications and caveats arise in real world: this signal remains (leading-order TM field in an $m_{A'}L$ expansion)

Note: mass range $1/L_{\text{magnetosphere}} \sim 10^{-16}\,\mathrm{eV} \lesssim m_{A'} \lesssim 3\times10^{-14}\,\mathrm{eV} \sim 1/R_\oplus$ can have large corrections

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What about the axion?

Rough translation for amplitude

$$\boxed{\varepsilon m_{A'} \leftrightarrow g_{\phi\gamma} B_{\oplus}}$$

Assuming DM field-amplitude normalisations
[BUT: different pattern]

- A similar signal arises, because of the Earth's static geomagnetic field $\mathbf{B}_{\oplus}$!
- $\mathscr{L} \supset \frac{g_{\phi\gamma}}{4}\phi F\tilde{F} = g_{\phi\gamma}\phi \mathbf{E}\cdot\mathbf{B} \longrightarrow g_{\phi\gamma}(\partial_t\phi)\mathbf{B}_{\oplus}\cdot\mathbf{A} \sim -ig_{\phi\gamma}m_{\phi}\phi\mathbf{B}_{\oplus}\cdot\mathbf{A}$
- Once again, looks like an effective current: $\mathbf{J}_{\text{eff}} = ig_{\phi\gamma}m_{\phi}\phi\mathbf{B}_{\oplus}$
- $\hat{\mathbf{B}}_{\oplus}$ plays the role of $\hat{\mathbf{A}}'_I$

[Earth Planets Space **73** (2021) 49]

- Use the International Geomagnetic Reference Field (IGRF-13) model for $\mathbf{B}_{\oplus}$

Fixed by IGRF-13

$$\mathbf{B}(\Omega, t) = -i(g_{\phi\gamma}\phi_0)(m_{\phi}R_{\oplus})\sum_{l,m}\frac{C_{lm}}{l}\mathbf{\Phi}_{lm}(\Omega)e^{-im_{\phi}t}$$

where $\frac{1}{2}m_{\phi}^2\langle\phi_0^2\rangle_{T\gg T_{\text{coh}}} = \rho_{\text{DM}}$

$$B \sim 1\,\text{nG} \times \left(\frac{g_{\phi\gamma}}{10^{-10}\,\text{GeV}^{-1}}\right)$$

- Signal still found in one type of VSH, but get higher multipoles l from Earth's field
- Sourcing magnetic field is co-rotating with the ground-based detectors: frequency content now only at $f = m_{A'}/(2\pi)$

$1\,\text{G} = 10^{-4}\,\text{T}$

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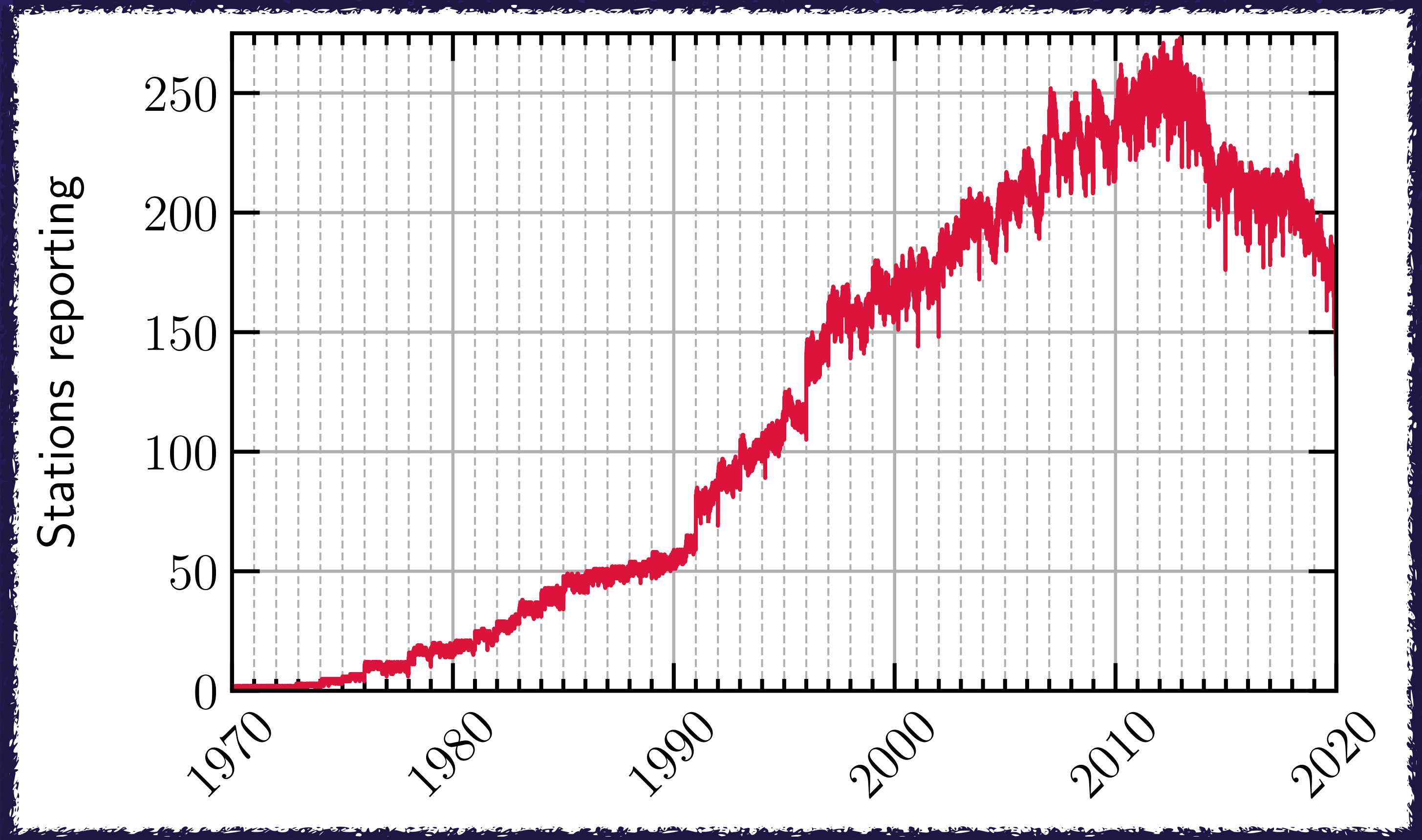
PRD **105**, 095007 (2022)

Signal Properties

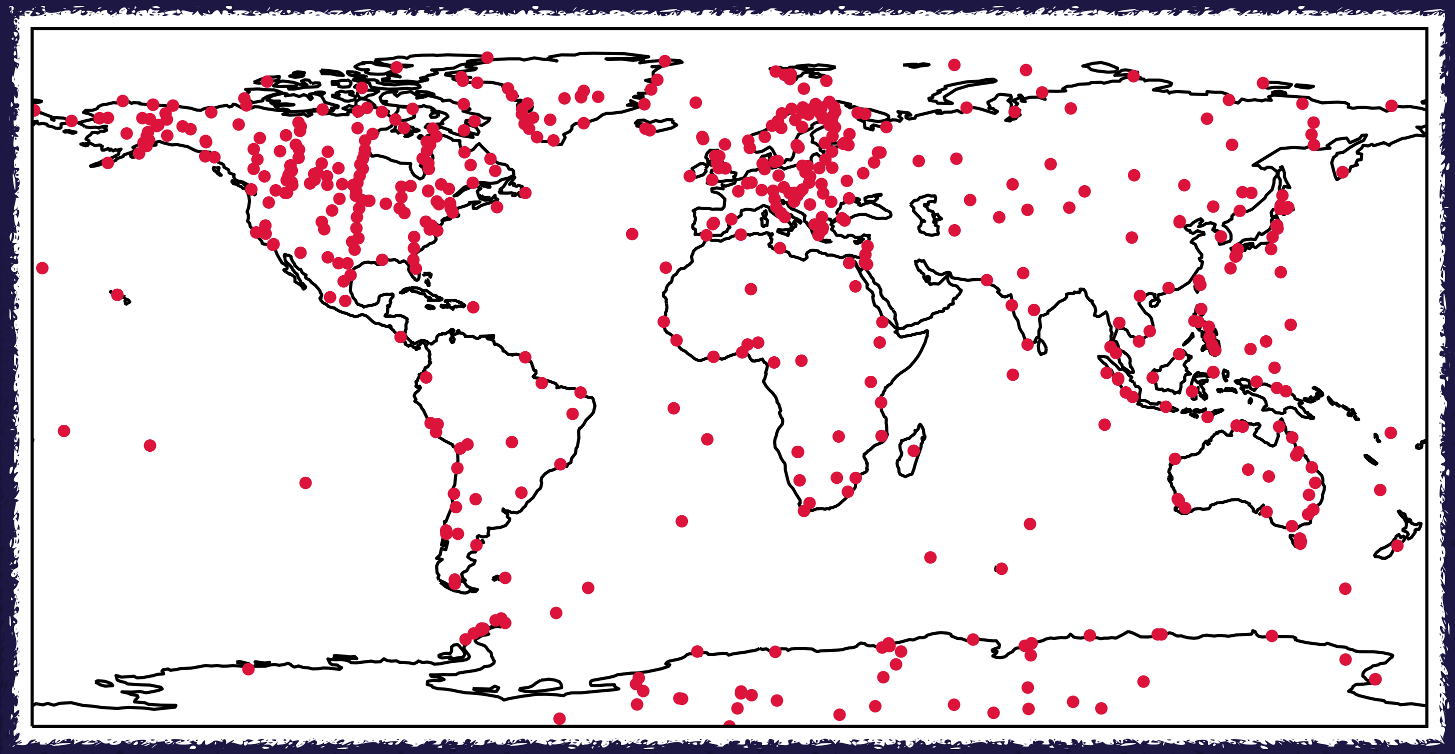
- In both cases, the **Earth acts as a transducer** to convert **dark-matter oscillations** to an **oscillating magnetic field:**
  - narrowband frequency peaked near $\omega \sim m_{\mathrm{DM}}$
  - long coherence time and length
  - present globally & in-phase across the whole surface of the Earth
  - known pattern
- We would like to implement a search for these signals. How?
- This is a perfect signal to search for using a network of geographically distributed vector magnetometers that record time-series field data
- They must be unshielded! Unfortunately, GNOME doesn't work for this [Ann. Phys. (Berl.) **525** (2013) 659]

SuperMAG

https://supermag.jhuapl.edu
Eos **90** (2009) 230-231
J. Geophys. Res. Space Phys. **117** (2012) A09213



- Geophysics to the rescue!
- Collaboration based at JHU-APL (J. W. Gjerloev, PI). Many contributors.
  See acknowledgments slide at end of talk
- Make publicly available a database of:
  - Unshielded magnetic field measurements
  - at $\mathcal{O}(500)$ unshielded magnetometer stations; maximally, $\mathcal{O}(250)$ reporting at any single time
  - widely geographically distributed over the Earth's surface
  - in time-series
  - with 60s resolution*
  - since ~1970 (more data at later times)
  - in a common data format
  - in a data-driven co-ordinate reference frame (average magnetic E-W nulled; reference to IGRF)
- **A near-ideal dataset to analyse for our dark-matter signals**



*a smaller dataset with 1s resolution is also available… see later in the talk

Search for a signal - Analysis Overview (DPDM)

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PRD **105**, 095007 (2022)

Search for:

narrowband excess magnetic field power
with the correct spatial configuration

over a

broadband magnetic field background
estimated from data

PRD **104**, 095032 (2021)

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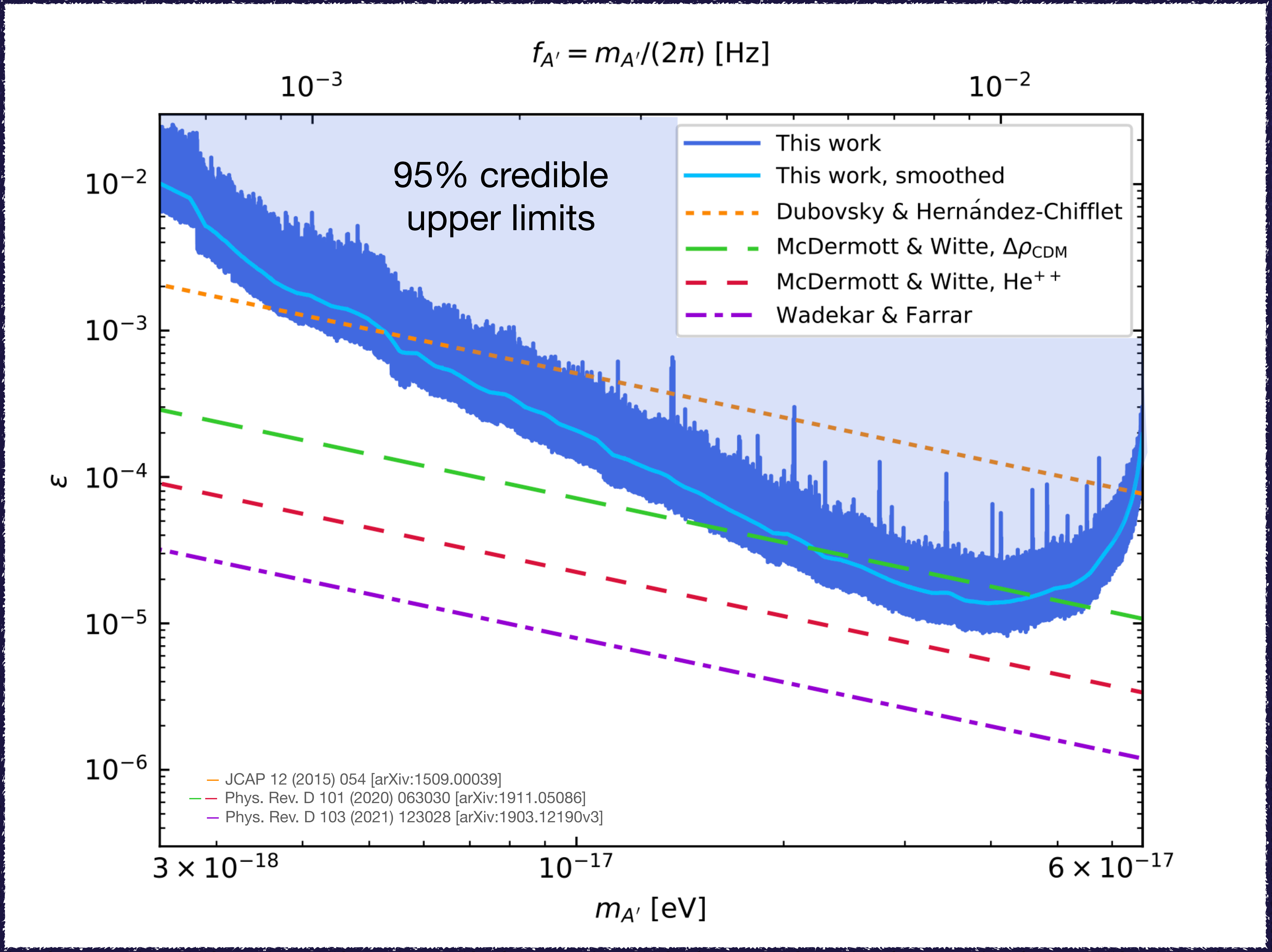
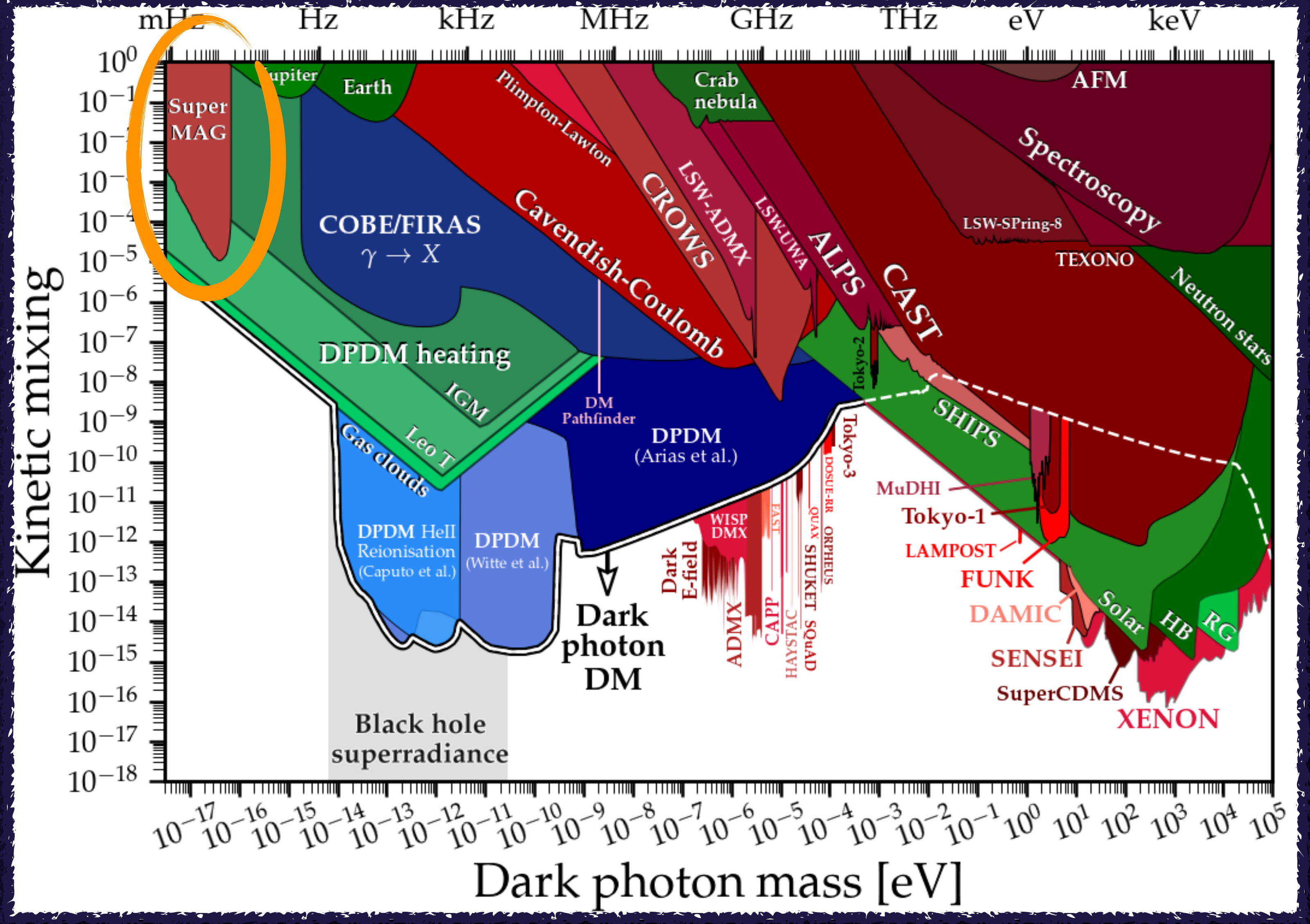
DPDM Results I - Limits



- ❖ Complementary to astrophysical limits
- ❖ Very different systematics!
- ❖ First “direct” constraints on this piece of parameter space.



https://cajohare.github.io/AxionLimits/
PRD **104,** 095029 (2021) [arXiv:2105.04565]

DPDM Results II - Signal candidates?

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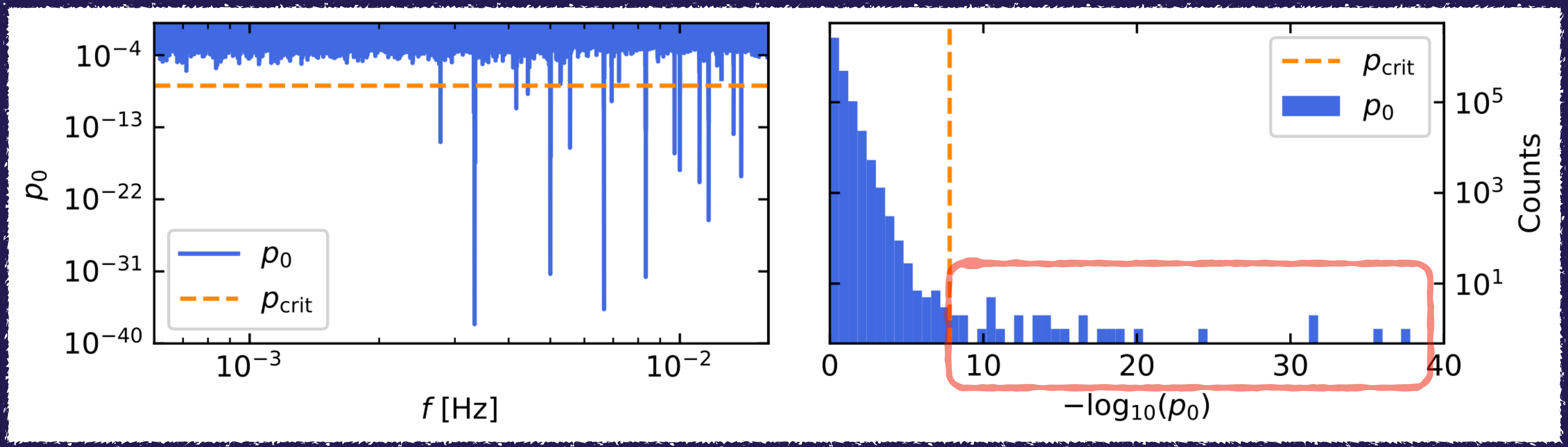
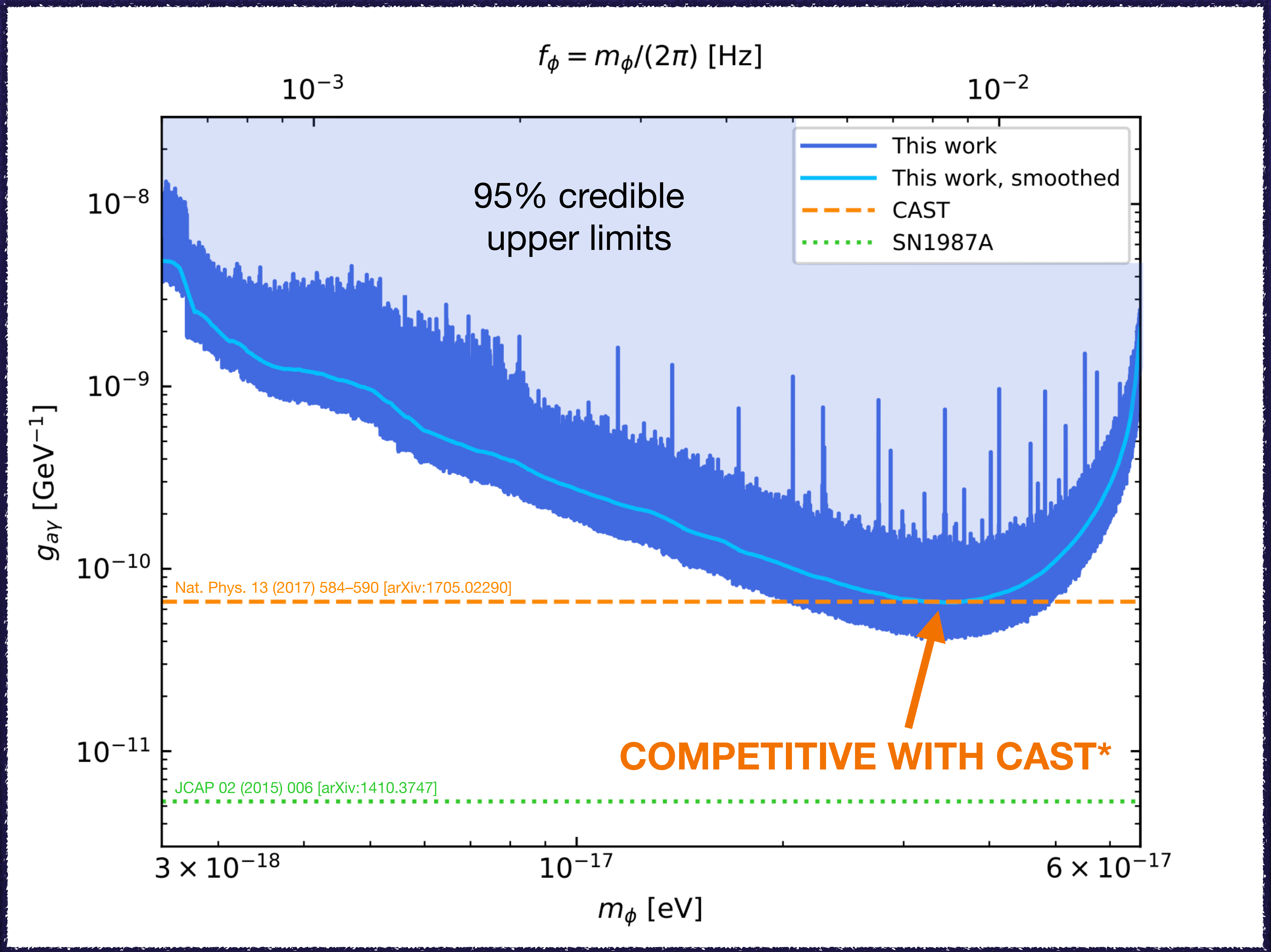
PRD **104**, 095032 (2021)



- ❖ 30 naive signal candidates identified
- ❖ Reject 24 completely on the basis of **robustness tests** for spatial consistency, temporal constancy.
- ❖ 6 remaining candidates are in tension with at least one of the checks (or are otherwise problematic); further work might be required to definitively exclude.
- ❖ E.g.: candidate at 3.344939mHz has a 6.1σ global significance, but $p = 0.034$ on the temporal constancy robustness check ($p = 0.97$ on the spatial check).
- ❖ **We do <u>not</u> claim any robust evidence for a DPDM signal**

PRD **105**, 095007 (2022)

Axion Results



COMPETITIVE WITH CAST*

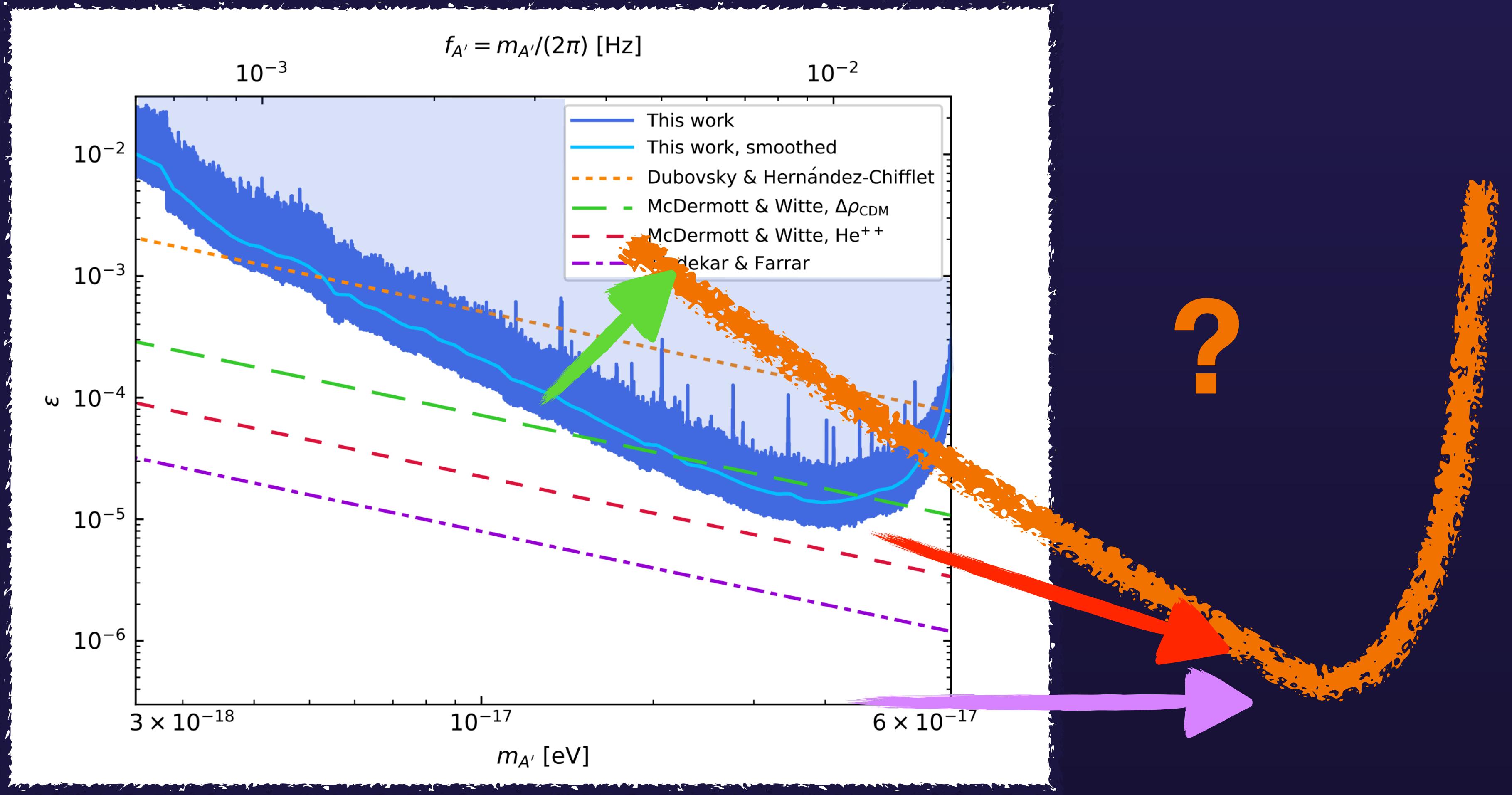
- Analysis proceed similarly, but simpler.
- Similar naive signal candidates exist (27).
- Again reject most (23) outright with robustness checks.
- Some weak signals remain (4), but have tensions with checks.
- **We do not claim any robust evidence for an axion signal**

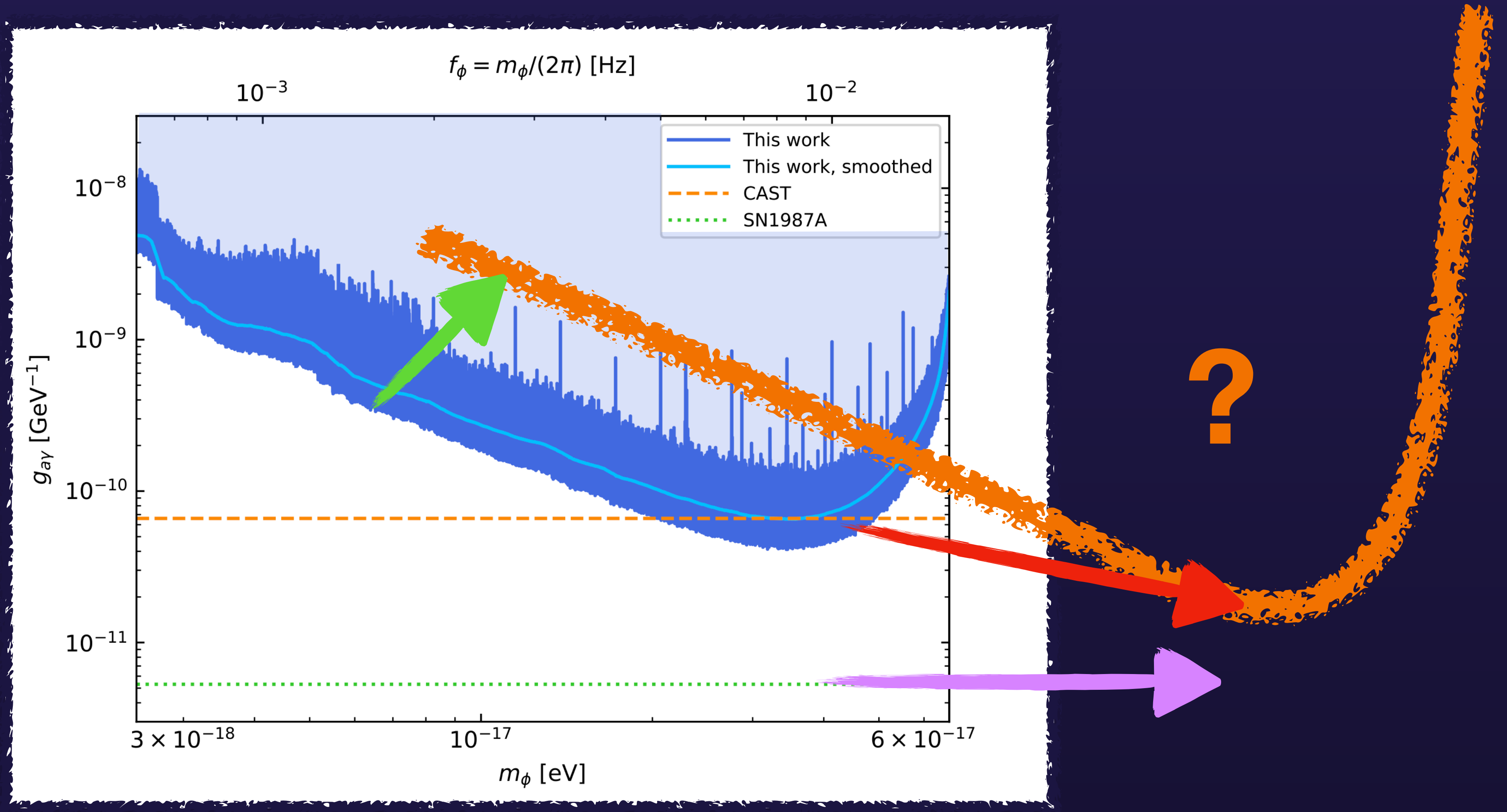
*CAST does not need to assume the axion is all of the dark matter

Outlook and Future Directions

- SuperMAG has 1s resolution data available. But less of it (fewer stations, less time).
- Limit of our 60s-cadence analysis at high frequencies is the measurement sampling frequency.
- In 60s data, noise falls with increasing frequency.
- Potential to **sacrifice some sensitivity*** with data quantity, but **push to higher frequency**.

*In fact, we might not even lose sensitivity. Less total time duration at 1s, but more data per time.





- **Win in a relative sense?** More competitive with astro limits? CAST?
- **Watch this space. Analysis in progress** (in formal collaboration with SuperMAG).
- Even higher frequencies? A dedicated network of higher-frequency magnetometers: SNIPE Hunt

There was a poster about this at the APS DAMOP Meeting in June

Summary

- Earth is a transducer to generate new signals of dark-photon and axion dark matter

  Coherent, narrowband oscillating magnetic fields that have particular vectorial spatial pattern over whole surface of the Earth

- Distributed networks of unshielded magnetometers are DM detectors
- Search in SuperMAG magnetic field data:
  - **No robust candidates of either DM type**
  - **New limits, complementary to existing constraints**
- Search in other existing data is underway. Extend reach to new parameter space?
- Dedicated search push to even higher frequencies being considered

Questions on this part of the talk?

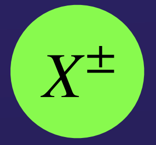
White Dwarfs as Amplifiers for CHAMP Detection

THE SHORT STORY

(*Maybe some very tiny fraction of*) Dark Matter in Compact Objects~~, Stars, and in Low Energy Experiments~~

Old NS existence bounds CHAMP abundances

[Gould, Draine, Nussinov, Romani, *Phys. Lett. B* 238 (1990) 337]



Charged Massive Particles (CHAMPs)
$[m_X \gtrsim 10^{11}\,\mathrm{GeV}]$

… get dragged into galaxies, distributed like DM $\sigma/m_X \ll (\sigma/m)_{\mathrm{SM}}$…

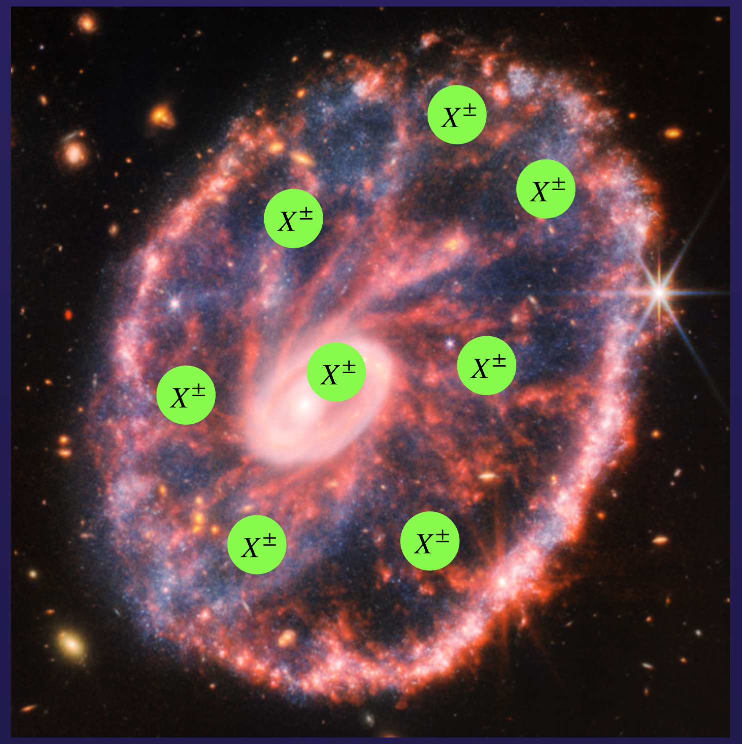
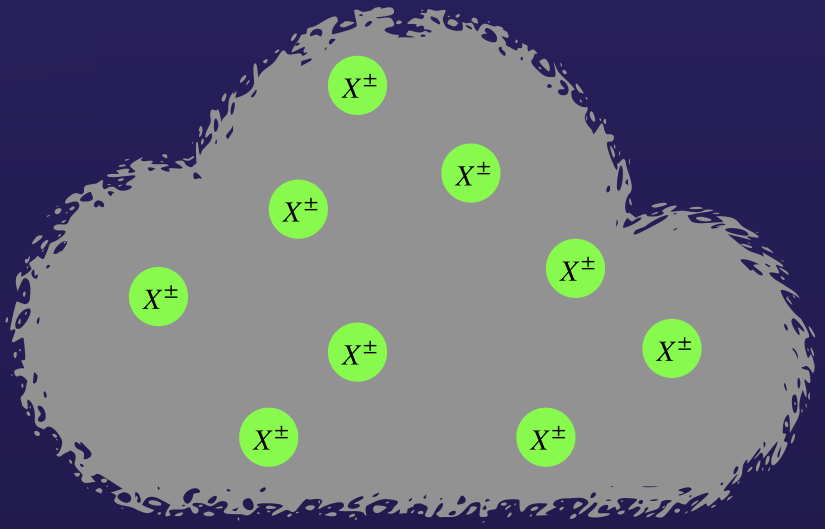
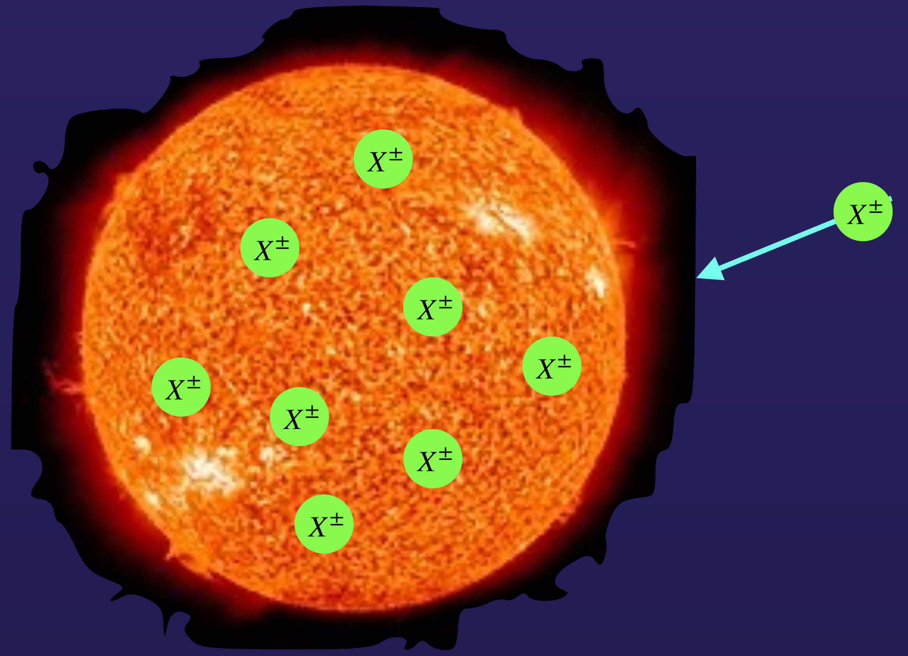


IMAGE: NASA, ESA, CSA, STScI, Webb ERO Production Team

X^- bind as $(\mathrm{He}X)^+$

… but they can get trapped in denser protostellar gas clouds…



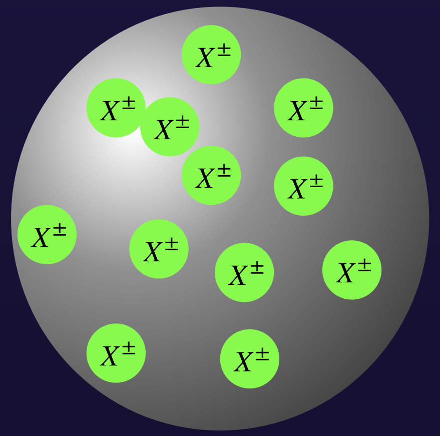


… and contaminate stars from birth (or get captured directly)

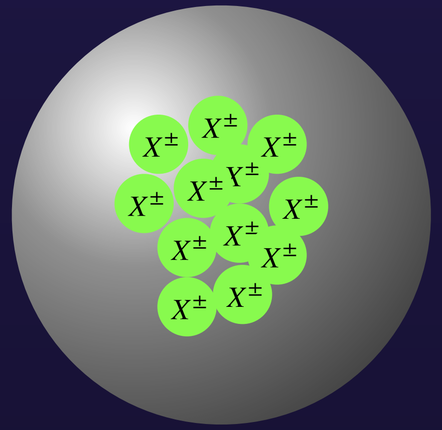
$M \sim 10 - 30\,M_\odot$

which evolve to…

Neutron Stars

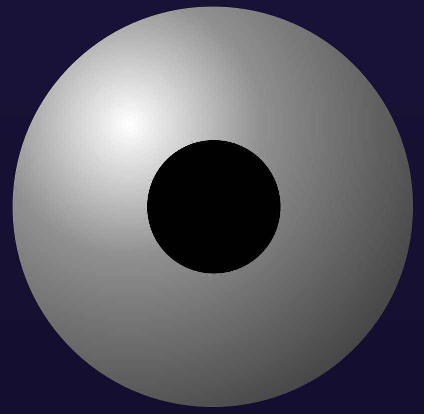


…where the CHAMPs sink…



…and self-gravitate…
$(M_X^{\mathrm{tot}} > M_{\mathrm{s.g.}})$

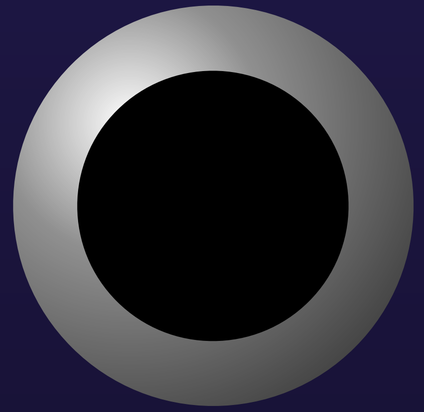
… and can form a mini black hole inside the NS…



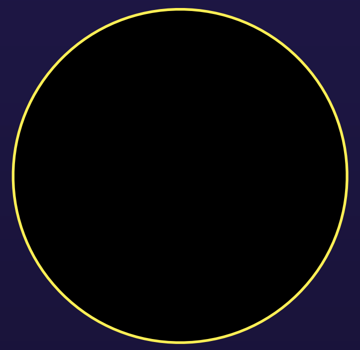
$$M^X_{\mathrm{Chand.}} \sim 1.4 M_\odot \times \left(\frac{Q_X m_p}{m_X} \right)^2$$

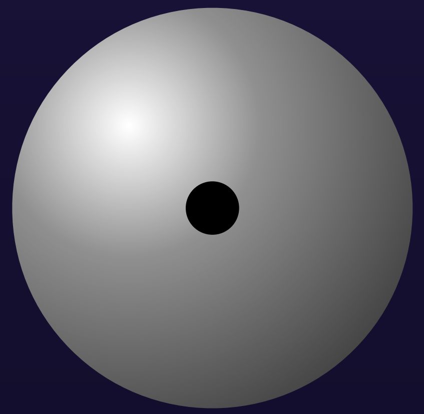
…which can…

grow



… and destroy the NS



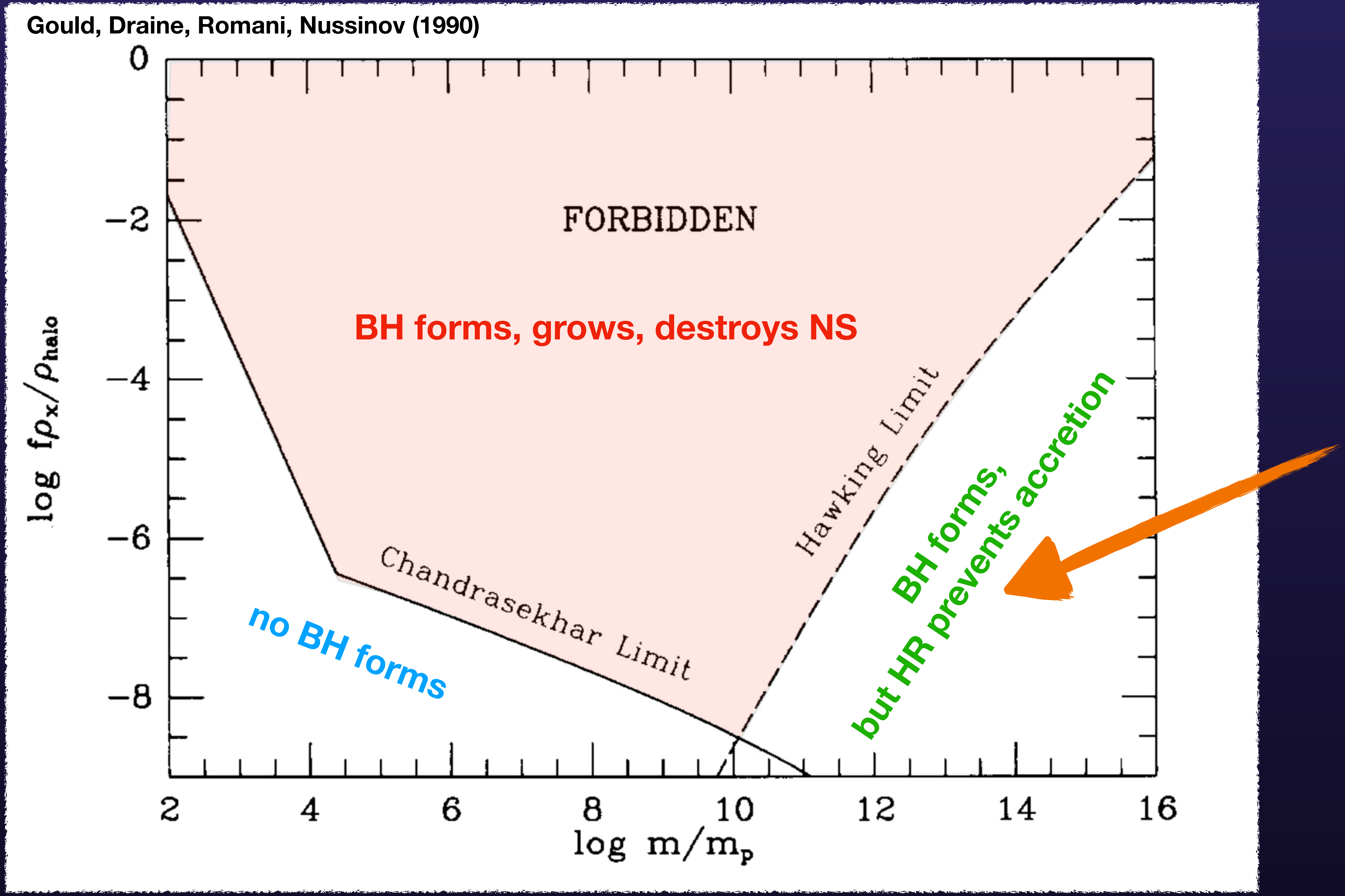


evaporate

… and leave the NS effectively untouched

Old Neutron Star Bounds

$$M^X_{\text{Chand.}} \sim 1.4 M_\odot \times \left(\frac{Q_X m_p}{m_X}\right)^2$$



Gould, Draine, Romani, Nussinov (1990)

OUR QUESTION

Can we find a system where this region CAN be bounded?

Possibly orders of magnitude of improvement to be had

Old WD existence bounds CHAMP abundances

$X^{\pm}$

Charged Massive Particles (CHAMPs) $[m_X \gtrsim 10^{11}\,\mathrm{GeV}]$

… get dragged into galaxies, distributed like DM $\sigma/m_X \ll (\sigma/m)_{\mathrm{SM}}$…

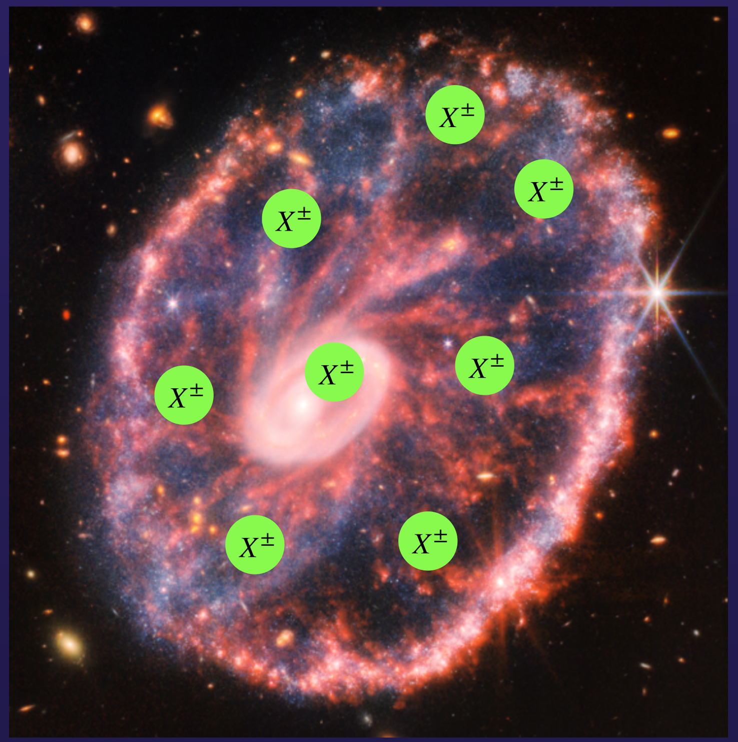
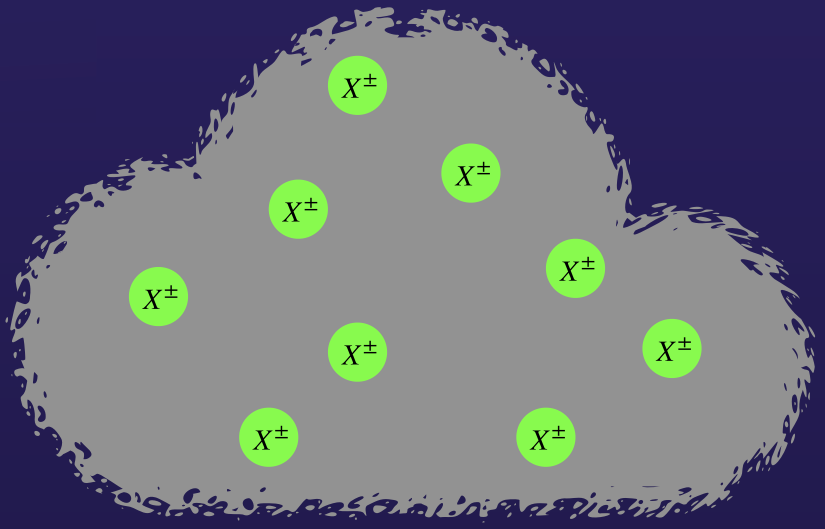
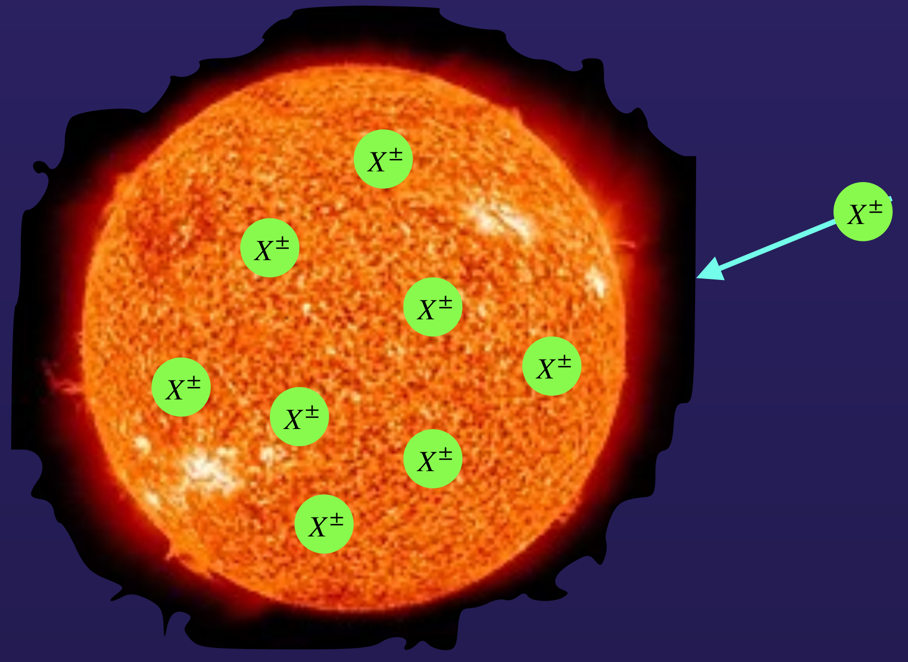


IMAGE: NASA, ESA, CSA, STScI, Webb ERO Production Team

X^{-} bind as $(\mathrm{He}X)^{+}$

… but they can get trapped in denser protostellar gas clouds…



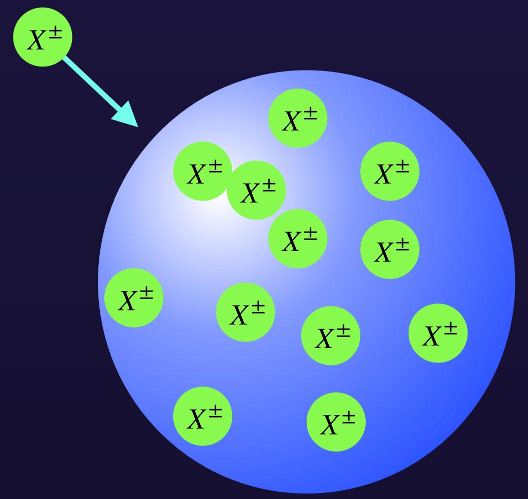


… and contaminate stars from birth (or get captured directly)

$M \sim 2-8\,M_{\odot}$

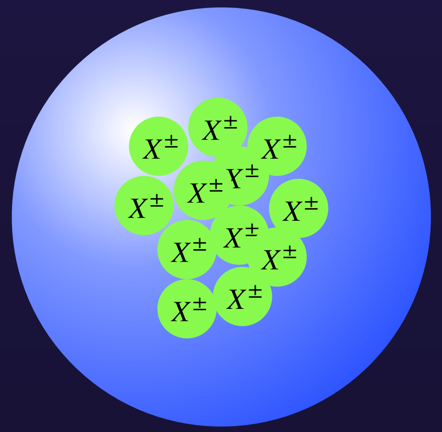
which evolve to…

White Dwarfs



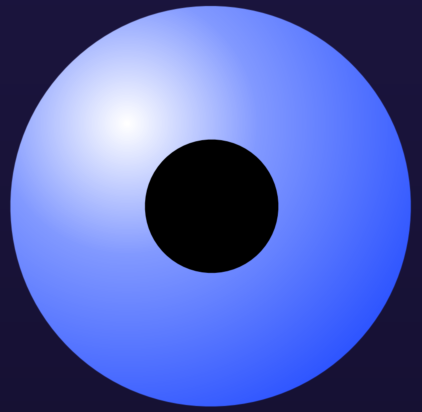
which maybe also still accrete some CHAMPs

…where the CHAMPs sink…



…and self-gravitate… $(M_X^{\mathrm{tot}} > M_{\mathrm{s.g.}})$

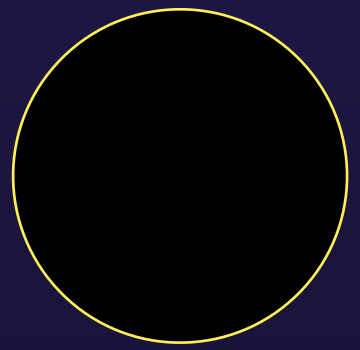
… and can form a mini black hole inside the WD…

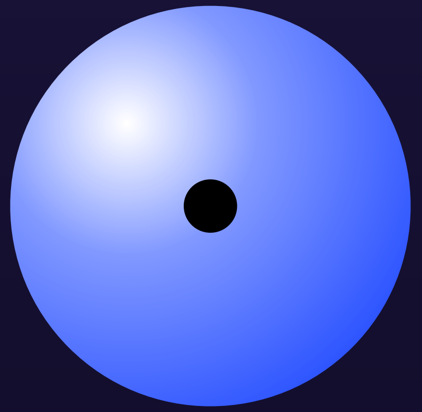


…which can…

grow

… and destroy the WD





evaporate

… and trigger the supernova instability

Under very general conditions, a BH born inside a WD such that it evaporates will do so within the WD lifetime (~Gyr), **and will trigger the Type-Ia SN instability (runaway carbon burning)**

Bramante, Acevedo (2019) Janish, Narayan, Riggins (2019)

PRD **101**, 115021 (2020)

Old White Dwarf Bounds - X^+

Require

enough CHAMPs to get into the WD

via

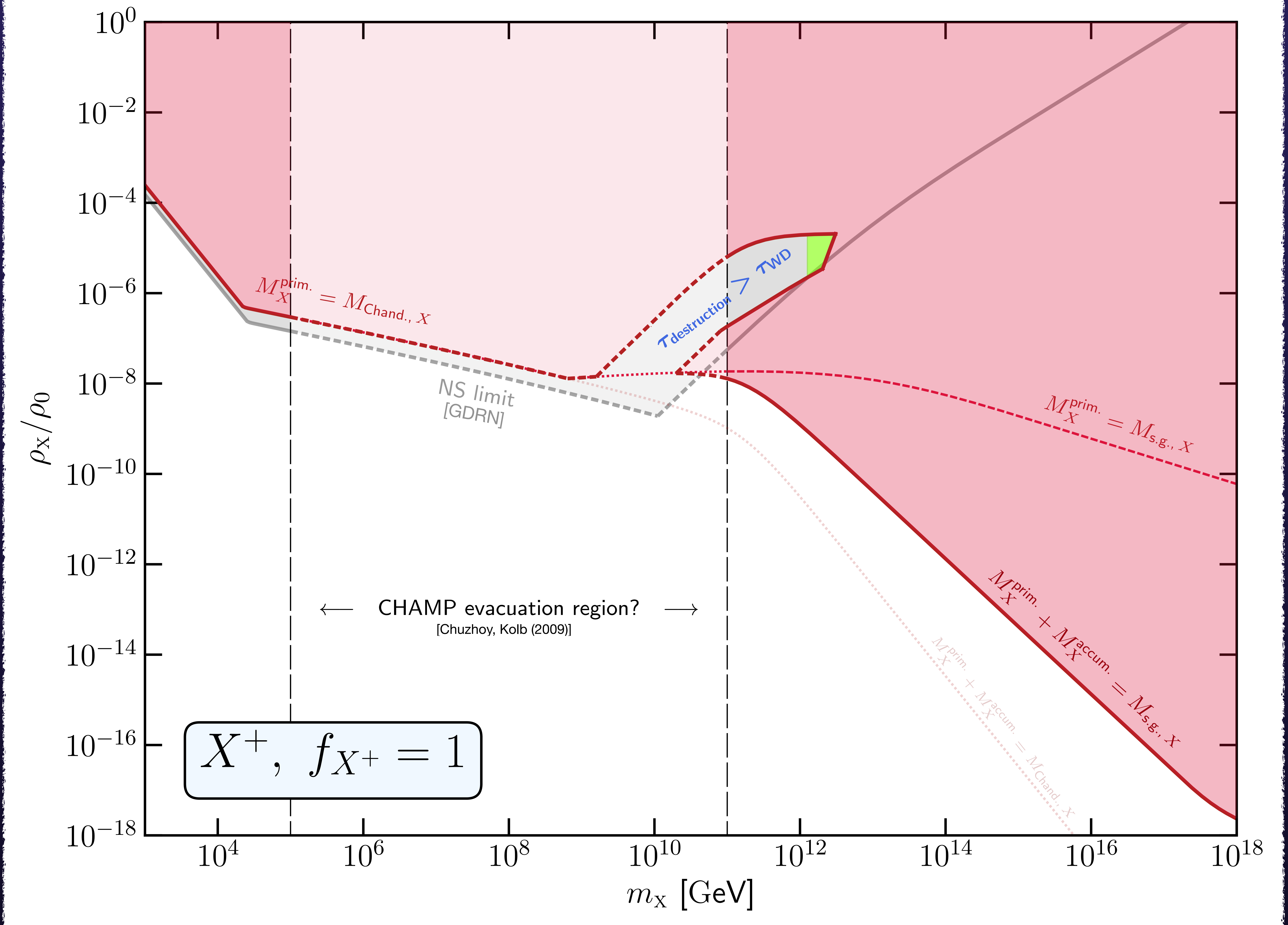
primordial contamination
and
accretion

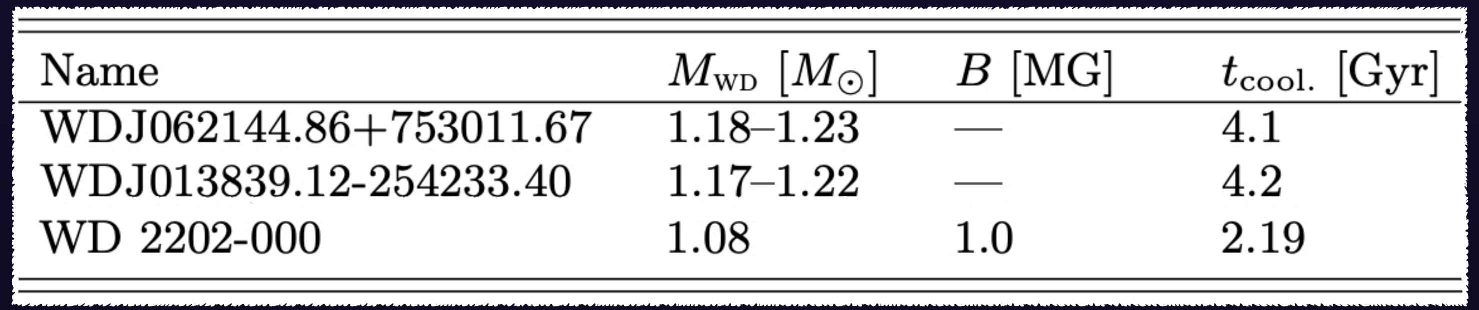
to achieve the larger of a

self-gravitating mass of CHAMPs
or
a Chandrasekhar mass of CHAMPs

AND

destroy the WD within its cooling age





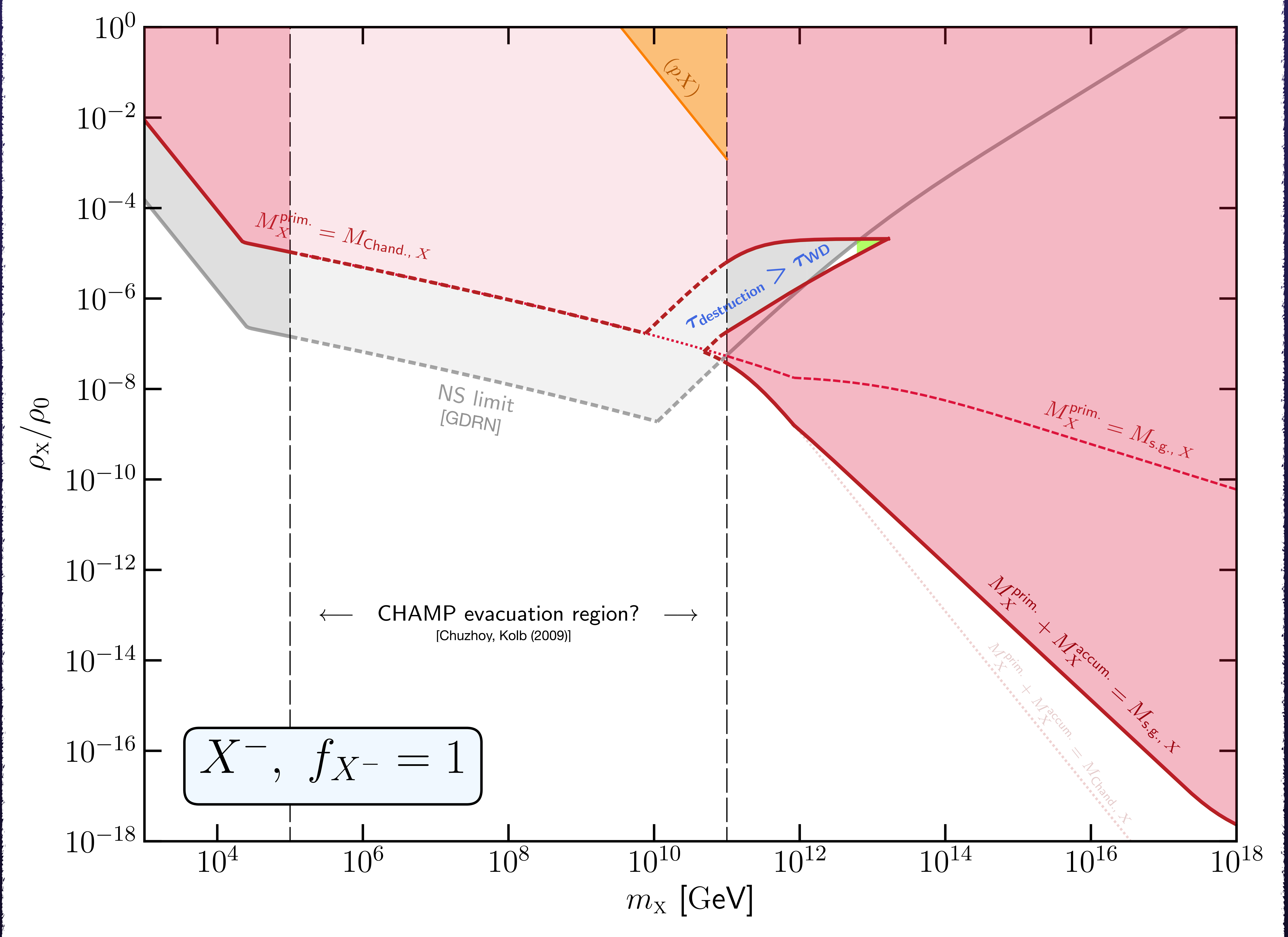
Name	M_{WD} $[M_\odot]$	B [MG]	$t_{\text{cool.}}$ [Gyr]
WDJ062144.86+753011.67	1.18–1.23	—	4.1
WDJ013839.12-254233.40	1.17–1.22	—	4.2
WD 2202-000	1.08	1.0	2.19

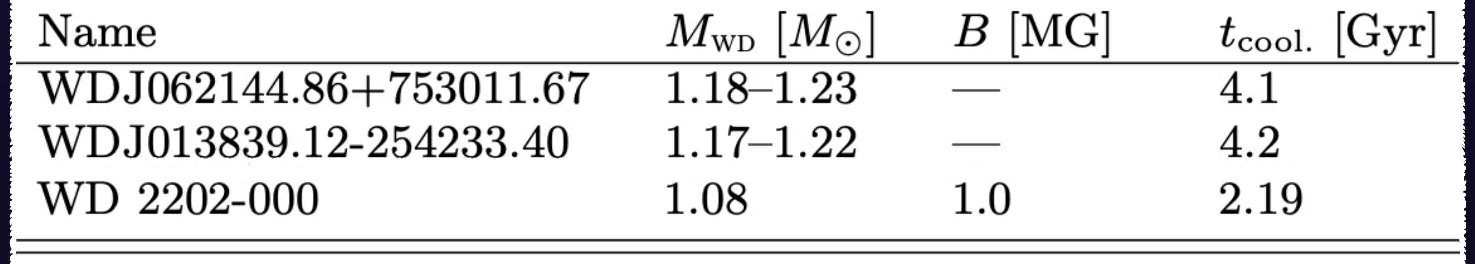
Old White Dwarf Bounds - X^-

X^- **exist in WD as** $(CX)^{5+}$ **or** $(OX)^{7+}$ **objects.**

Binding energies are 3-4 MeV.

$$M^X_{\text{Chand.}} \sim 1.4 M_\odot \times \left(\frac{Q_{(NX)} m_p}{m_X} \right)^2$$





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Summary

- Charged massive particles (CHAMPs) contaminate white dwarfs
- If sufficient total CHAMP mass in the WD (larger of Chandrasekhar and self-gravitating masses), form mini black hole inside the WD
- BH either accretes up in mass, or Hawking radiates down in mass. Either way destroys WD, except if it takes too long.
  - Other supernova trigger mechanisms discussed in the paper
- Dramatic, orders of magnitude improvement of GDRN galactic abundance bounds on high-m_X CHAMPs
- Speculation: trigger for Ca-Rich Gap Transients? Correct spatial morphology?

Concluding remarks

I told you about:

- A new signal of ultralight dark-photon and axion-like particle dark matter in terrestrial magnetometer data, and new limits

  M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **104**, 075023 (2021) [arXiv:2106.00022].
  M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **104**, 095032 (2021) [arXiv:2108.08852].
  A. Arza, M.A.F., P. W. Graham, S. Kalia, D. F. Jackson Kimball. Phys. Rev. D **105**, 095007 (2022) [arXiv:2112.09620].

- Using white dwarfs to constrain a different early-universe relic: charged massive particles (CHAMPs), and new limits

  M.A.F., P.W. Graham, and S. Rajendran. Phys. Rev. D **101**, 115021 (2020) [arXiv:1911.08883]

Thanks!

Questions?