Celestial Bodies as Dark Matter Detectors

Tim Linden

Stockholms universitet

Celestial Bodies vs. Direct Detection

Xenon-1T

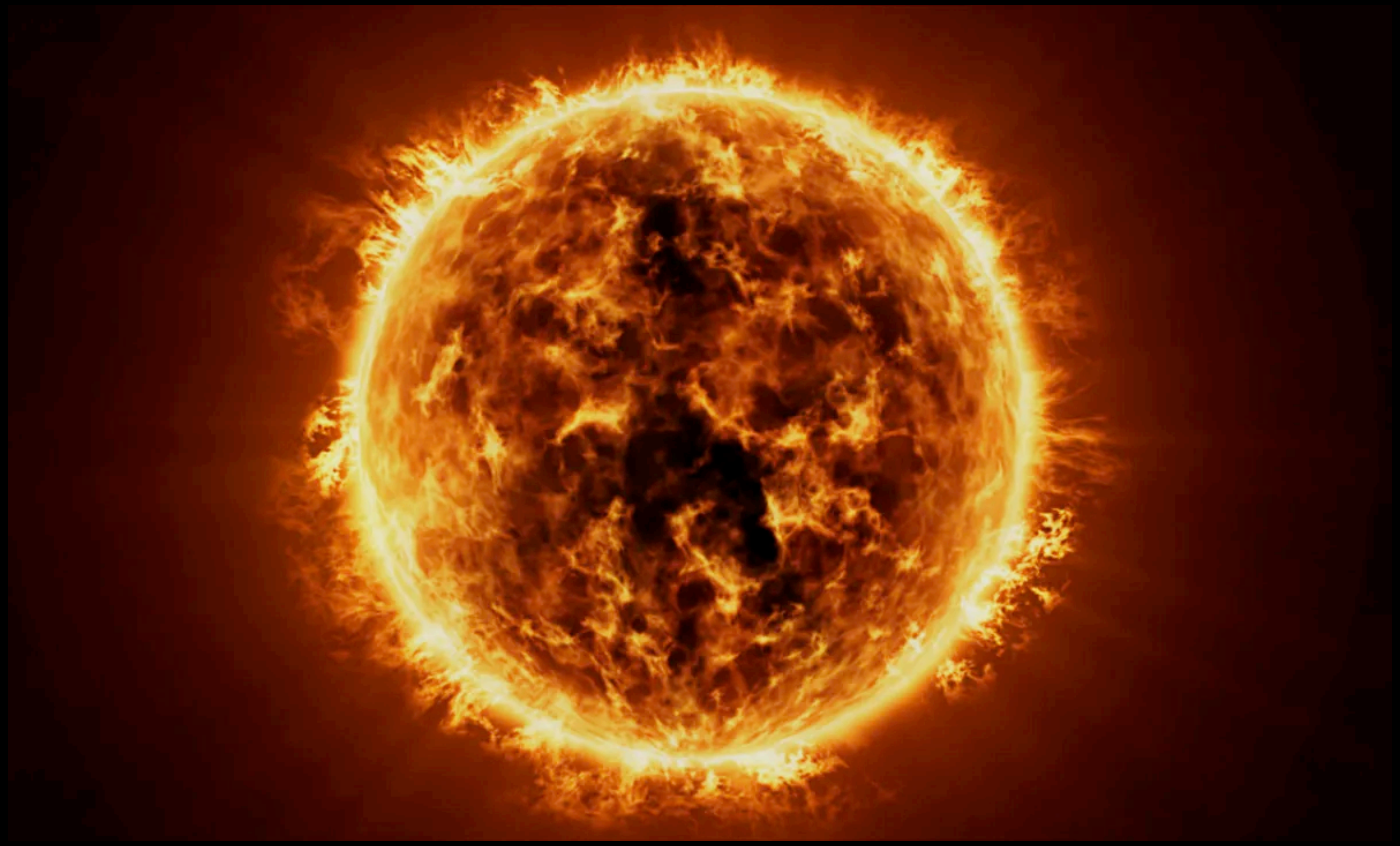
- 1000 kg
- 700 days

7×10^{5} kg day

Celestial Body

- 3×10^{30} kg
- 2×10^{10} days

6×10^{40} kg day



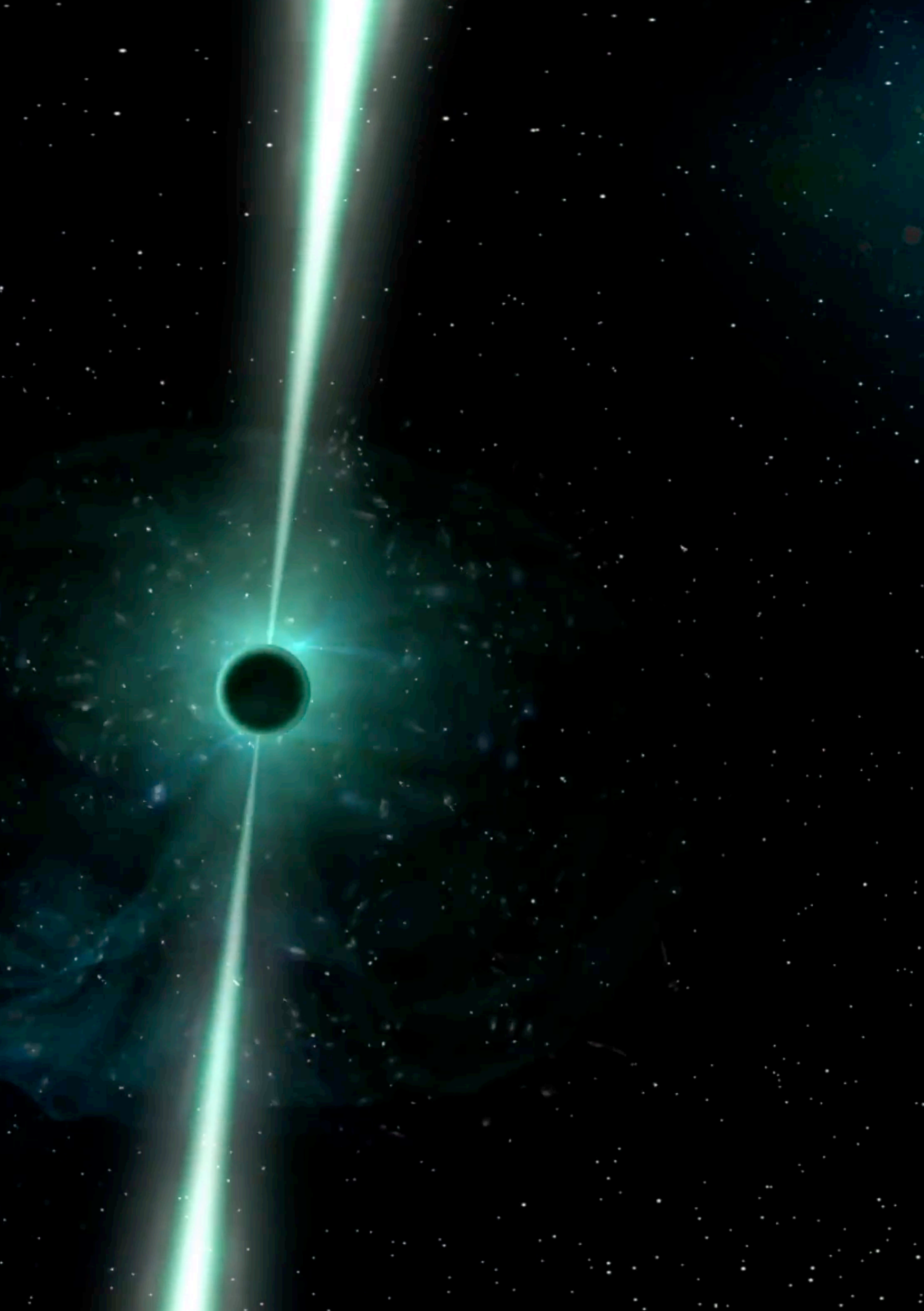
Precision Physics is Possible

- Neutron star spin among the best measured quantities in physics.

PSR J1713+0747

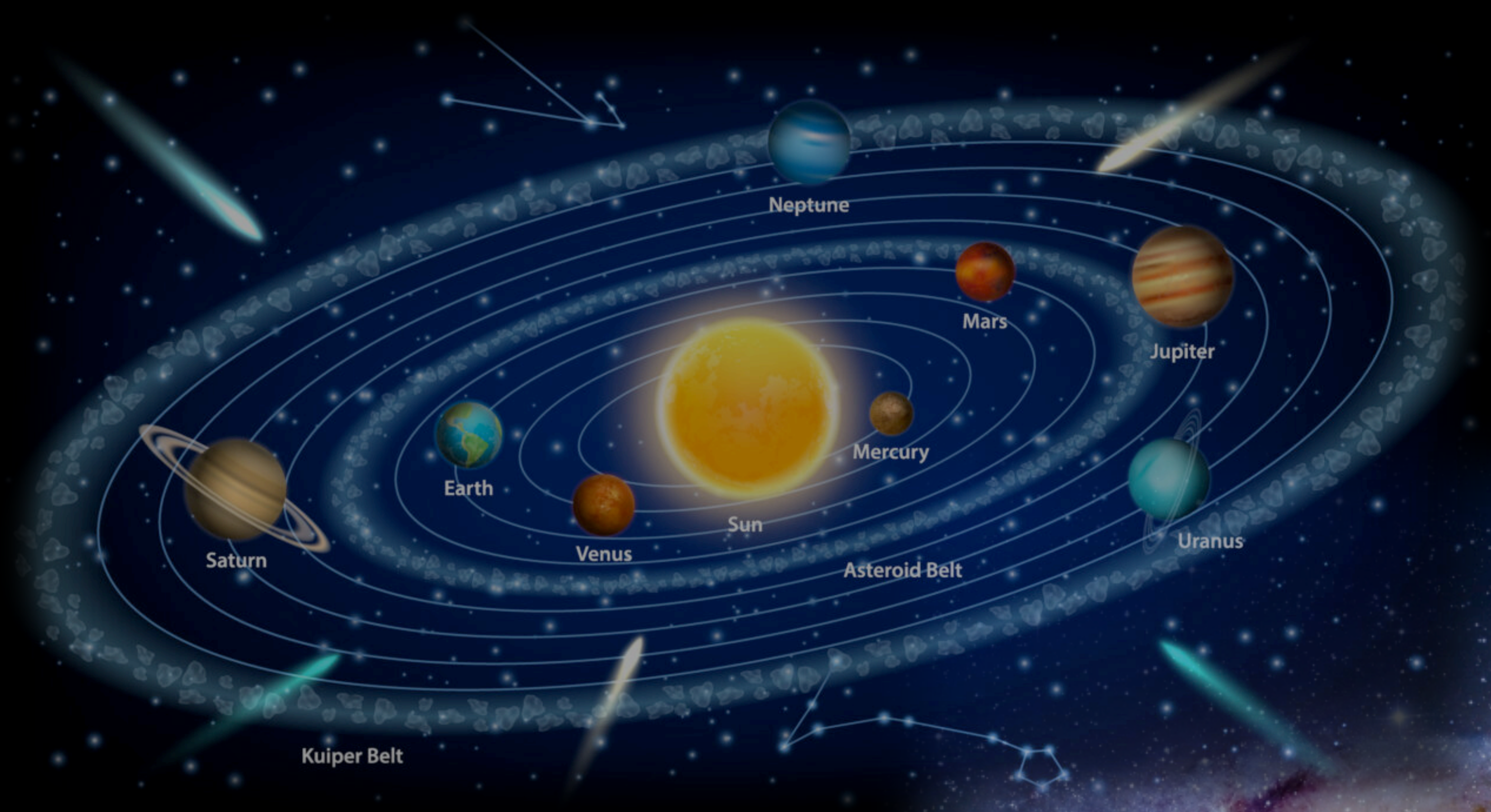
$F = 218.8118437960826270 \pm 0.0000000000000988\ s^{-1}$

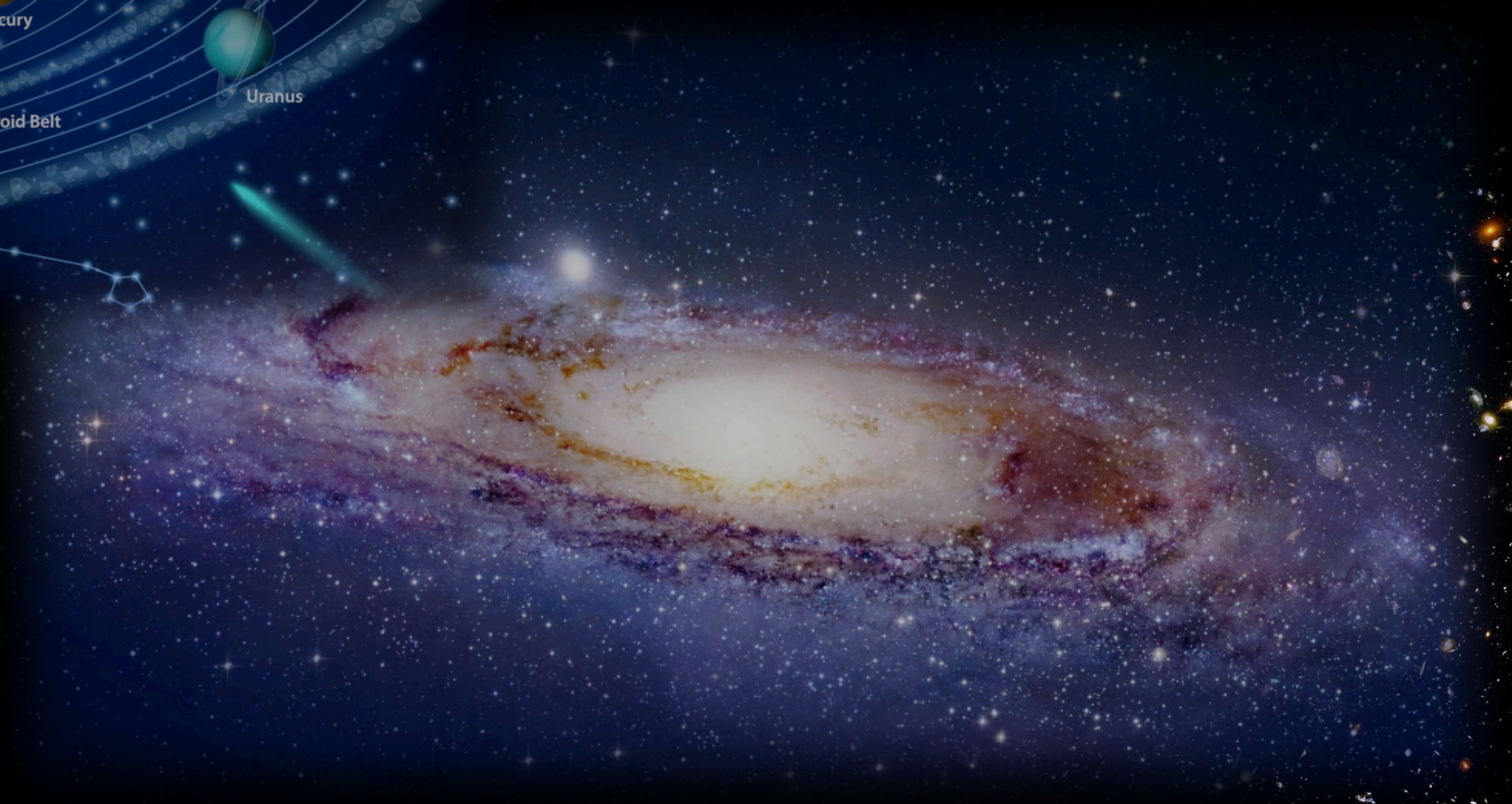
$F' = -4.083888637248 \pm 0.0000143324982645 \times 10^{-16}\ s$



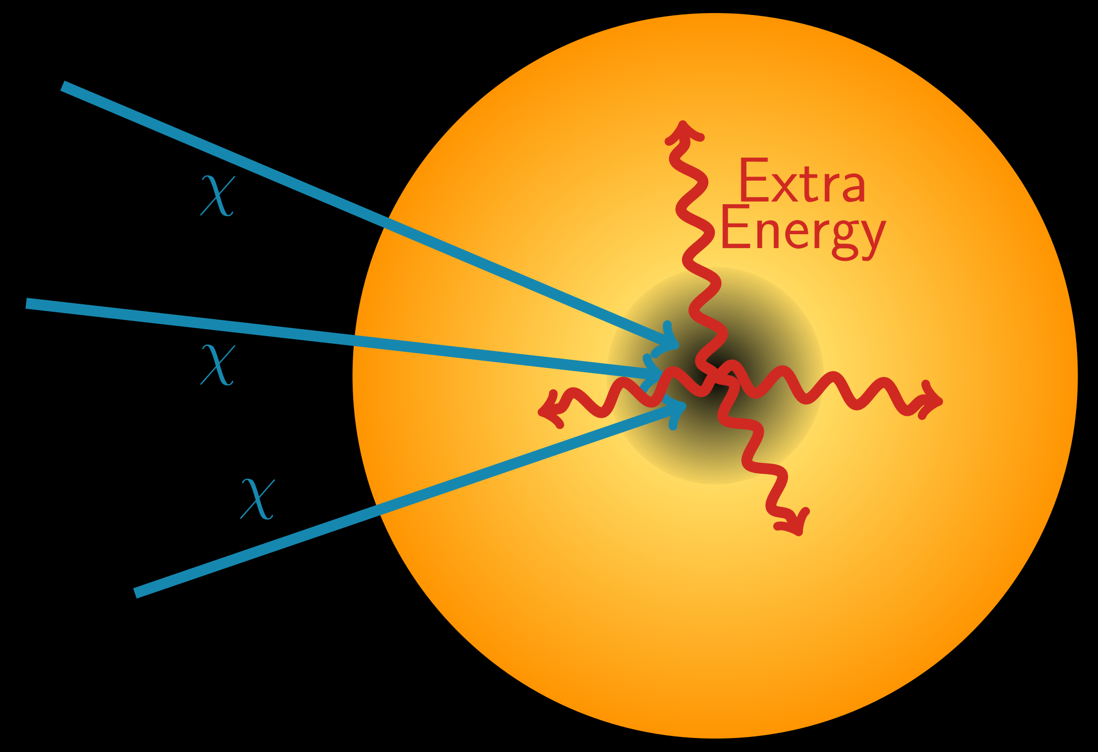
NANOGrav Collaboration (1801.02617)

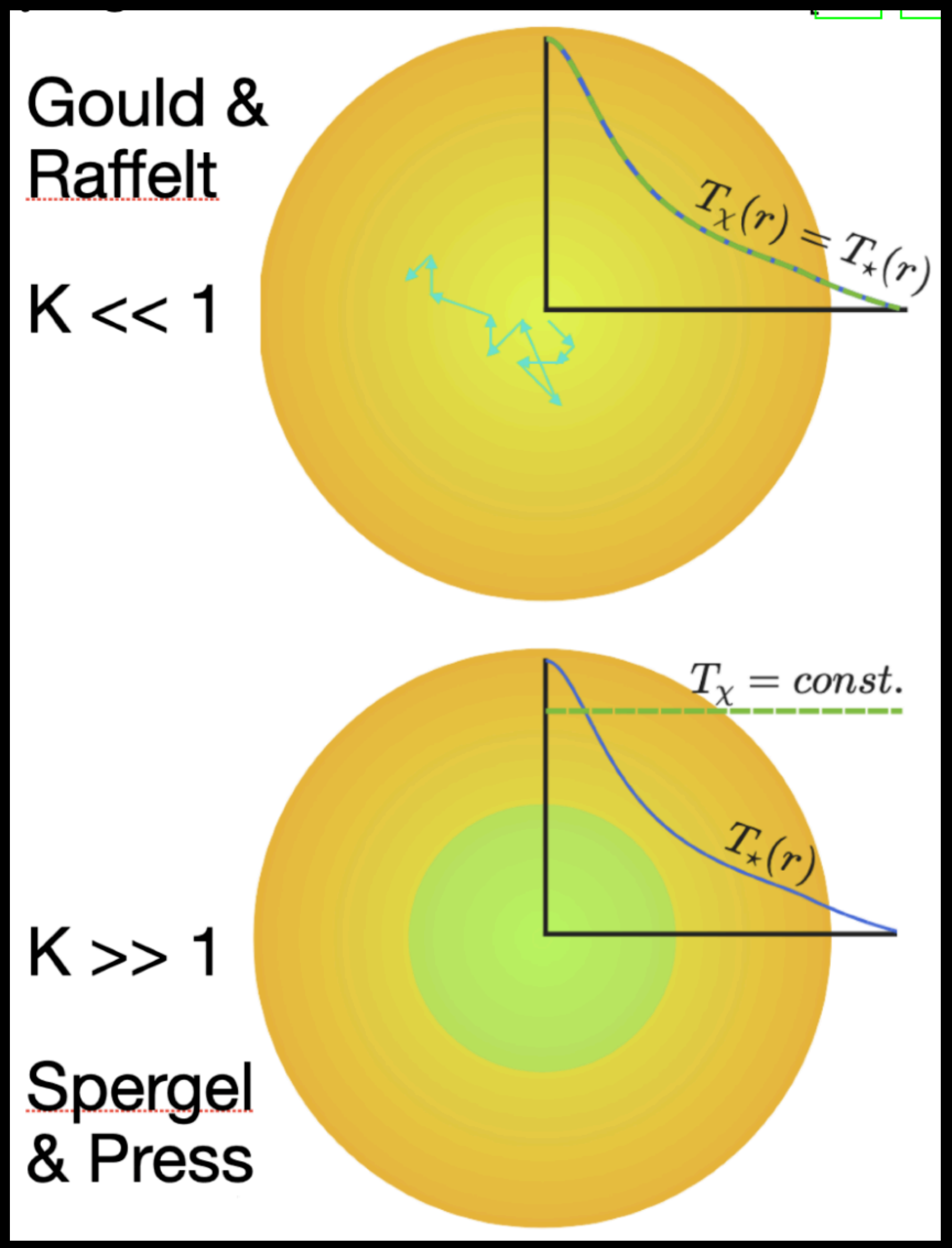
A Multitude of Targets

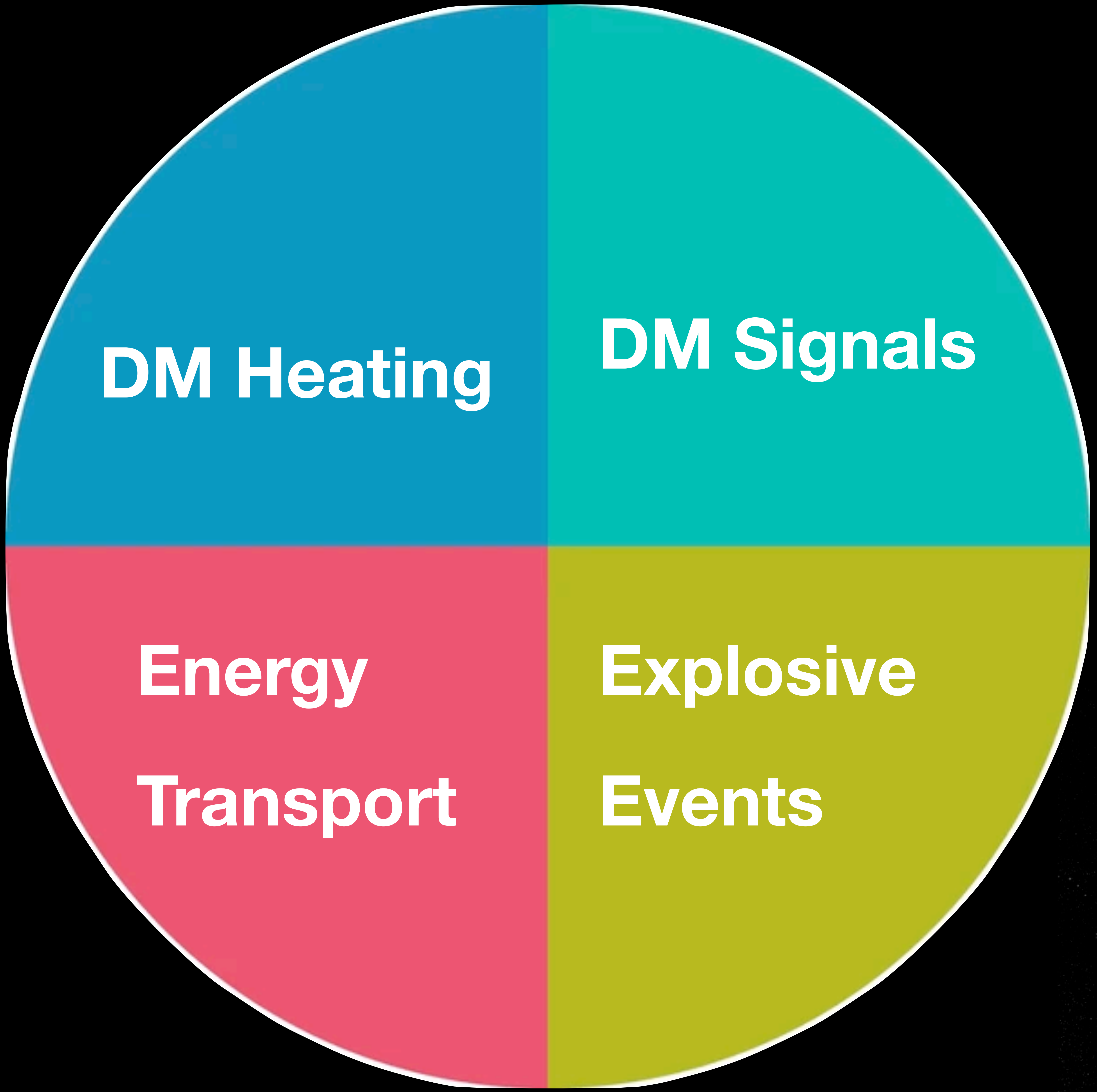


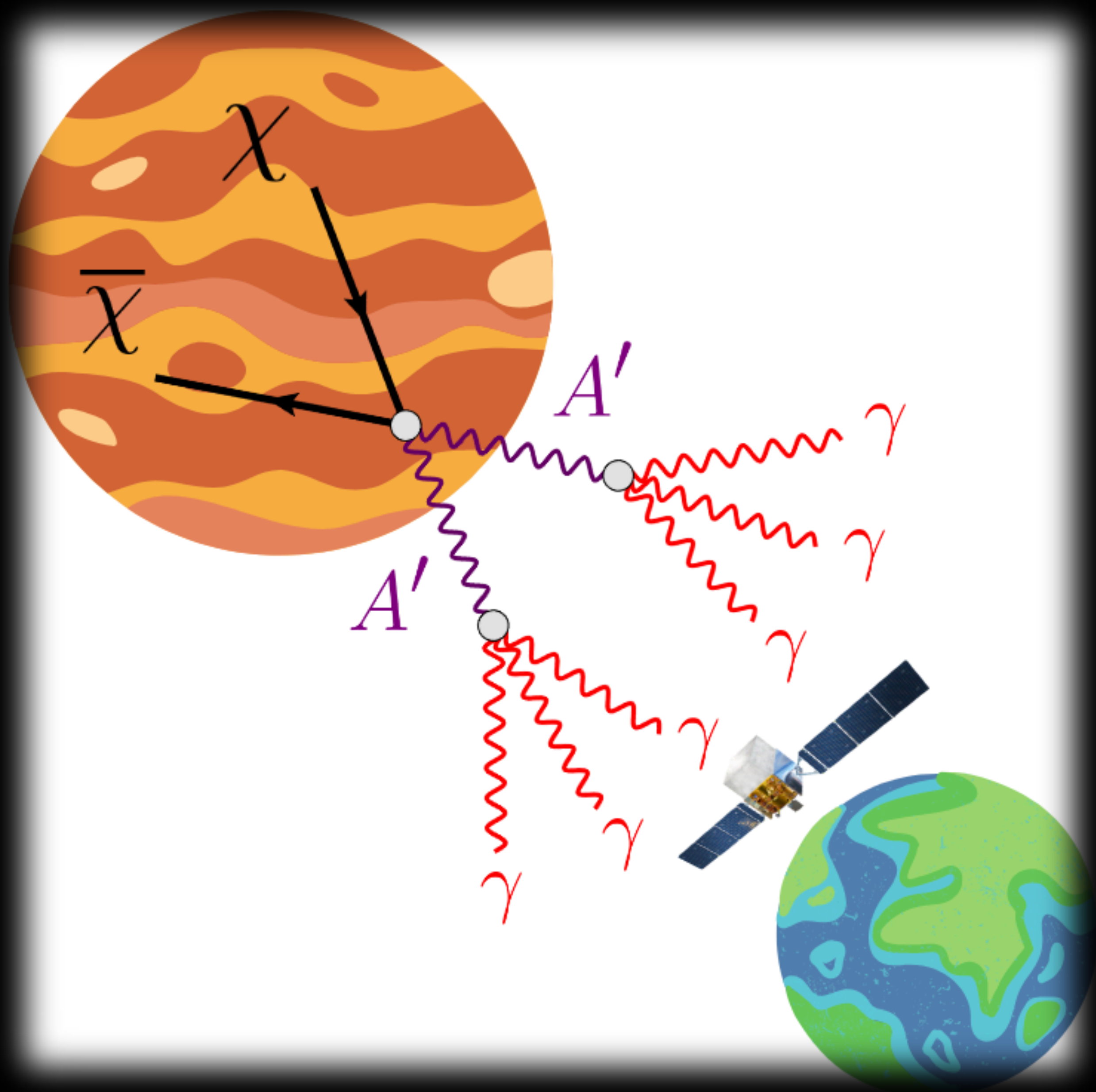


A Multitude of Signatures





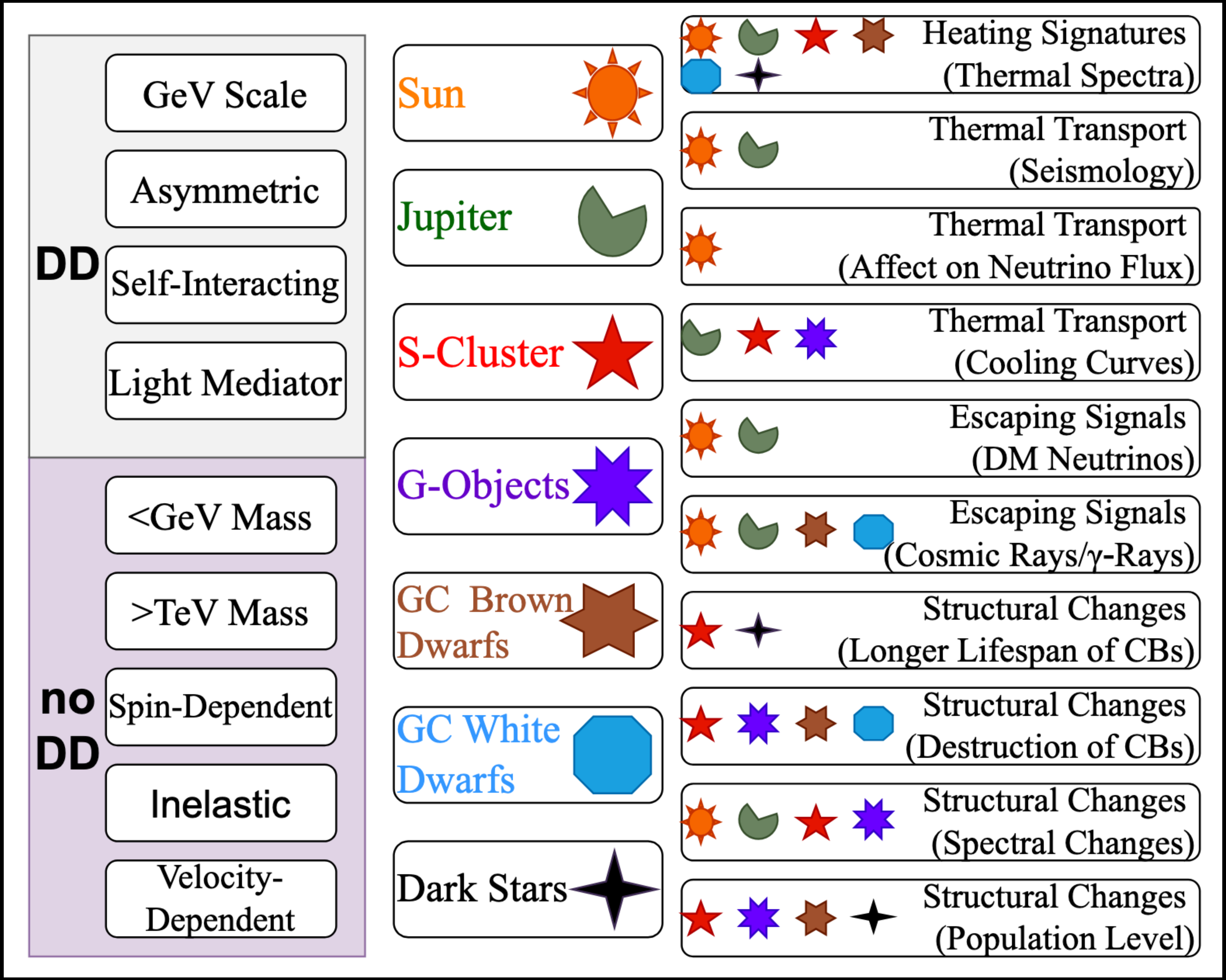




A Multitude of Dark Matter Models

A Multitude of Dark Matter Models

A Cacophony Of Studies



How to Do Science in the High-Risk High-Reward Regime

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- Miracles can be correlated

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$$A - M \geq 0$$

Possible detections

How to Do Science in the High-Risk High-Reward Regime

“Wear your ~~character~~ theory as lightly as a cap.”

A Few Recent Studies

1.) Stellar Heating at the Galactic Center (2311.16228; 2405.12267)

2.) SuperK Neutrino Searches in the Sun (2501.14864)

3.) Missing Pulsars at the Galactic Center (1405.1031)

4.) Unusual Supernovae (2211.00013)

Immortal Stars at the Galactic Center

See also: work on Dark Stars (e.g., Spolyar & Freese)


SLAC-PUB-17770

Dark Branches of Immortal Stars at the Galactic Center

Isabelle John,[1,*] Rebecca K. Leane,[2,3,†] and Tim Linden[1,‡]

[1] Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden
[2] Particle Theory Group, SLAC National Accelerator Laboratory, Stanford, CA 94035, USA
[3] Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94035, USA

We show that stars in the inner parsec of the Milky Way can be significantly affected by dark matt... nihilation, producing population-level effects that are visible in a Hertzsprung-Russell (H... We establish the dark HR diagram, where stars lie on a new stable *dark main* s... ...inosities, but lower temperatures, than the standard main sequence ... ...stars continuously replenishes, granting these stars immortali... ...coming telescopes could detect the dark main se...

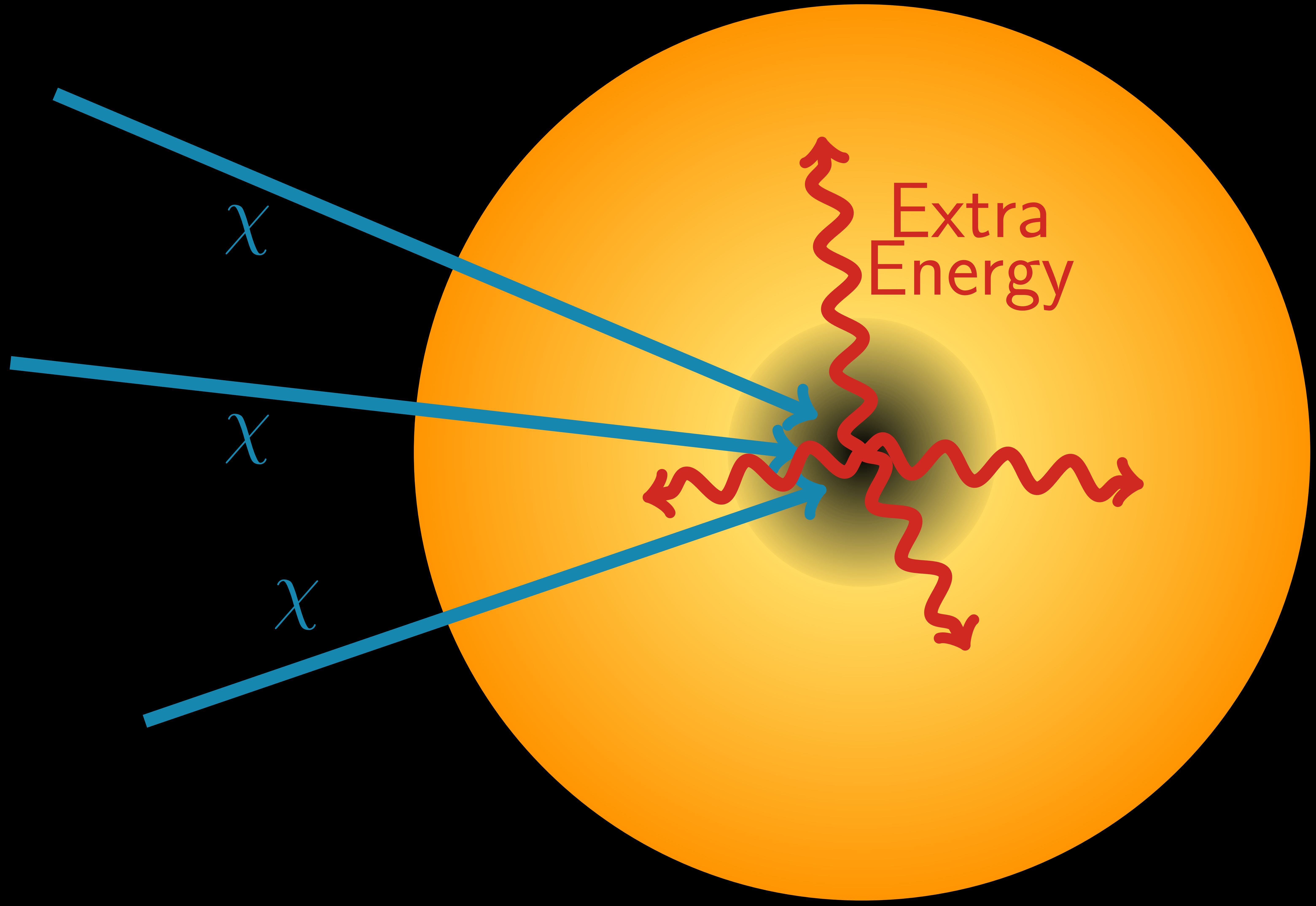
Dark Matter Scattering Constraints from Observations of Stars Surrounding Sgr A*

Isabelle John,[1,*] Rebecca K. Leane,[2,3,†] and Tim Linden[1,‡]

Dark stars at the Galactic centre – the main sequence

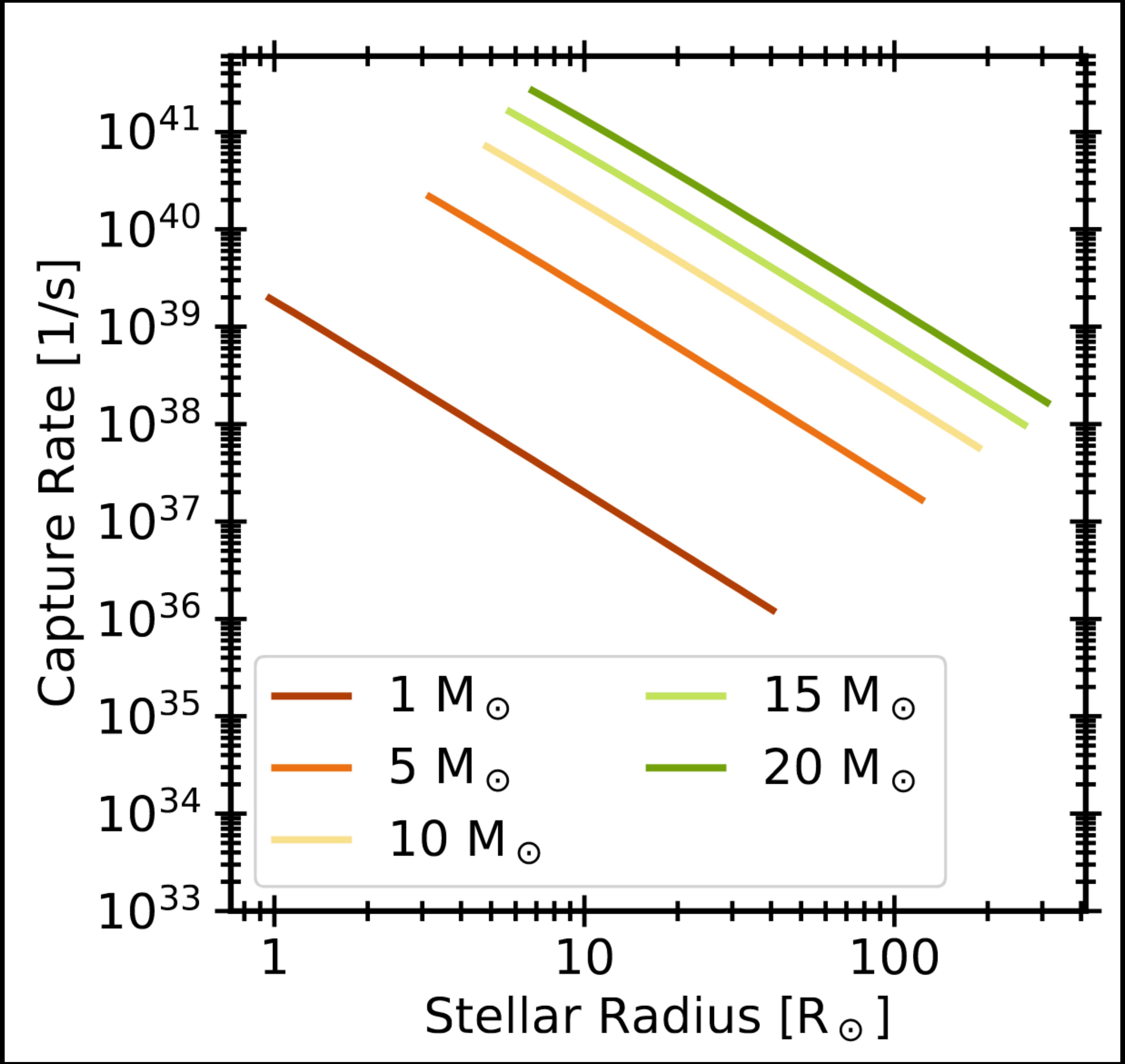
Pat Scott[1*], Malcolm Fairbairn[2,3*] and Joakim Edsjö[1*]

Immortal Stars at the Galactic Center



- Dark Matter annihilation provides an additional power source that heats the star.
- The star maintains equilibrium - it expands if too much power is injected.

Immortal Stars at the Galactic Center



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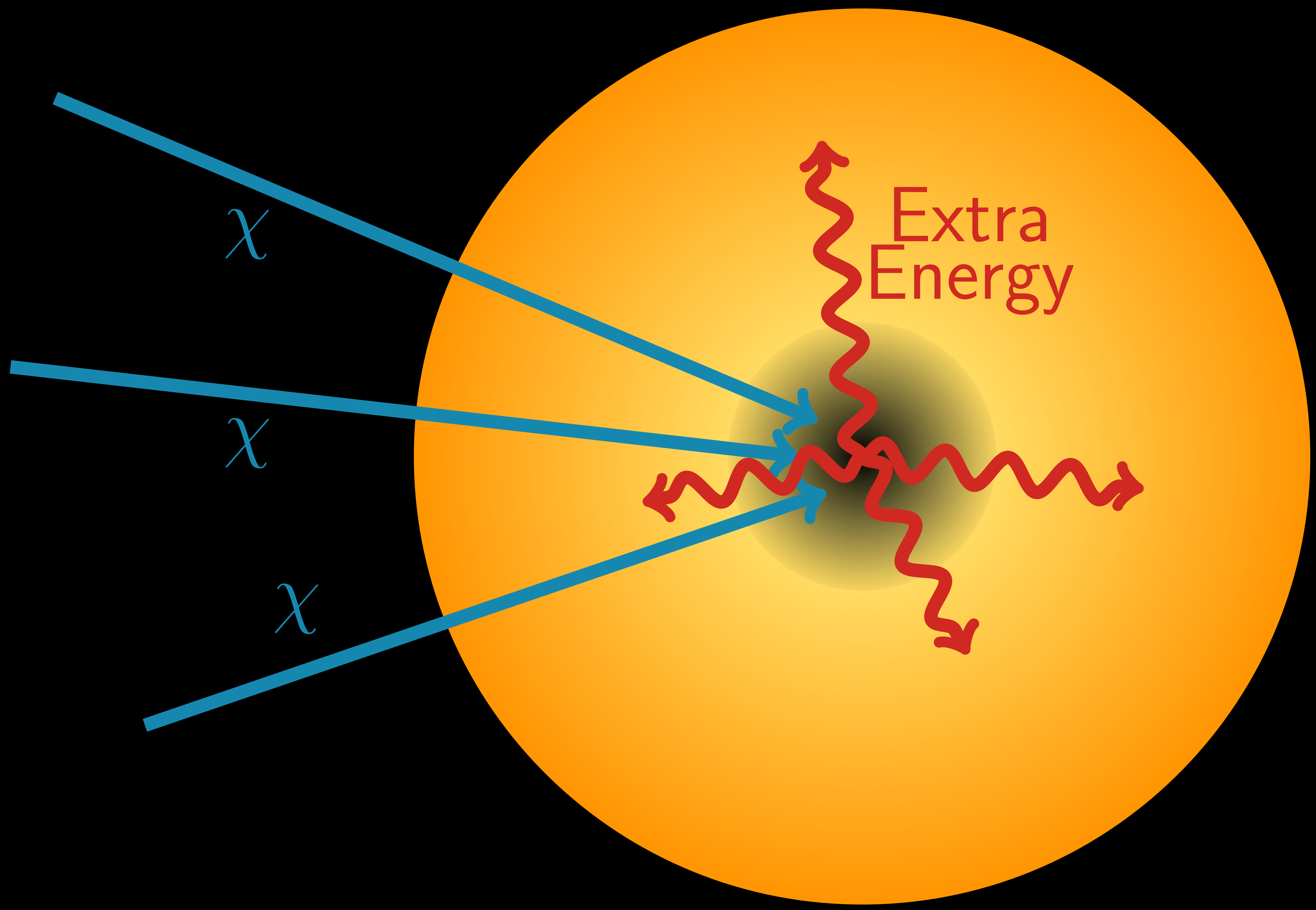
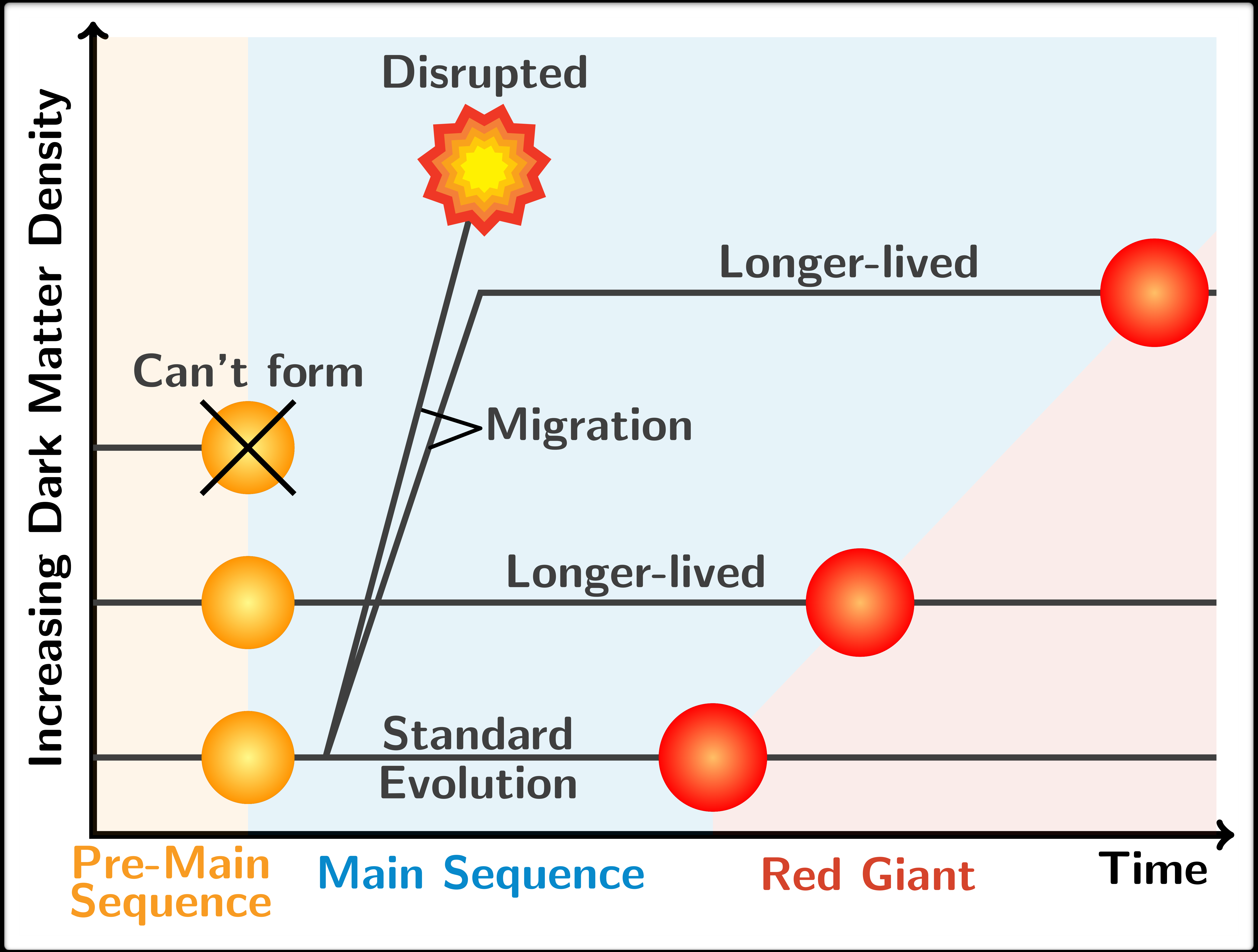
Immortal Stars at the Galactic Center



- "Miracle" - Very high dark matter densities at the galactic center.
- Standard WIMP DM
- Standard (though relatively high) dark matter density (low mass WIMPs)

Immortal Stars at the Galactic Center



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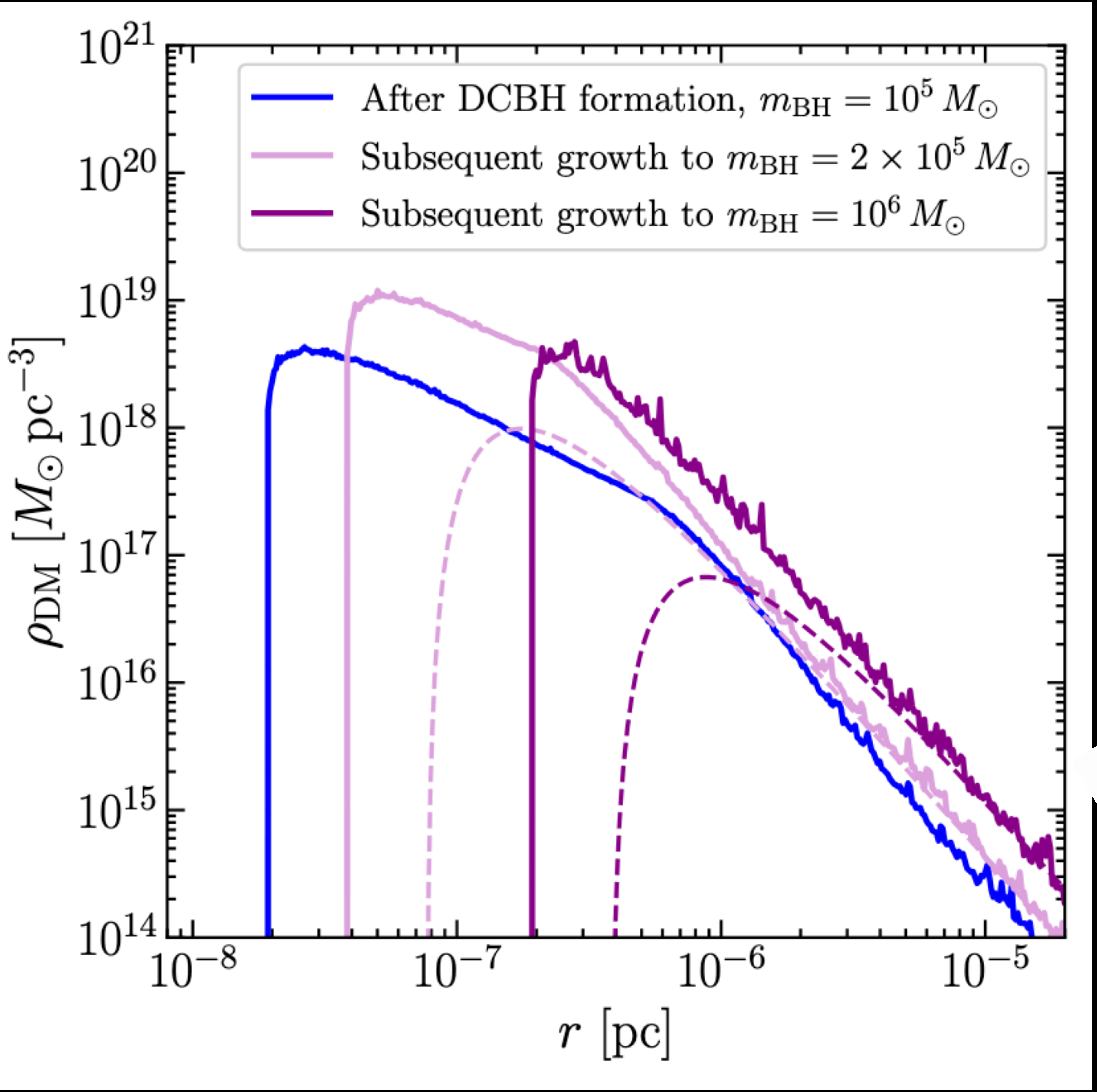


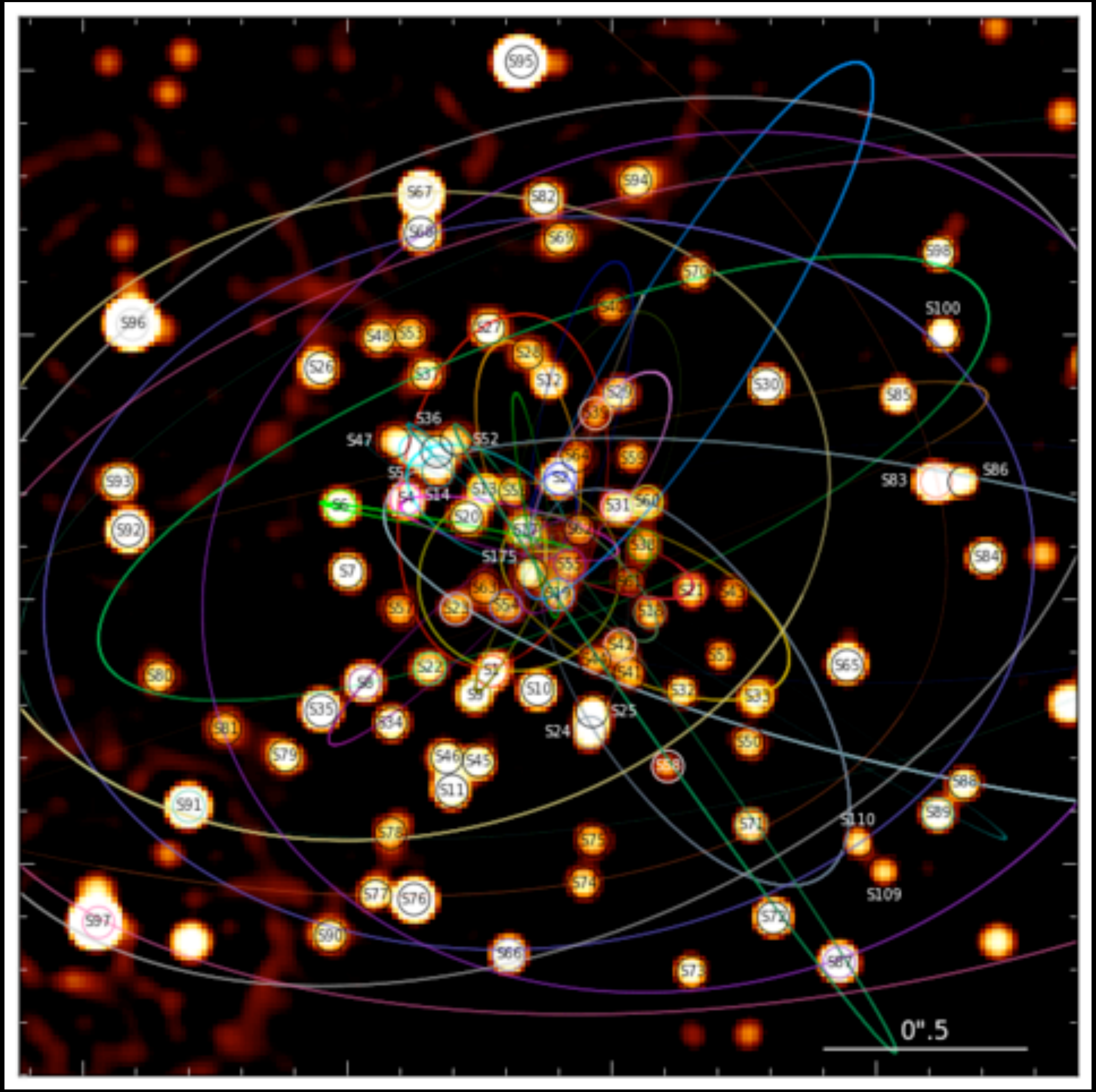
Dark Matter Mounds: towards a realistic description of dark matter overdensities around black holes

Gianfranco Bertone[1], A. Renske A. C. Wierda[1,2] Daniele Gaggero[3], Bradley J. Kavanagh[4] Marta Volonteri[1,5] and Naoki Yoshida[6,7]

[1] Gravitation Astroparticle Physics Amsterdam (GRAPPA), University of Amsterdam, Amsterdam, 1098 XH, Netherlands
[2] Department of Physics, KTH Royal Institute of Technology, The Oskar Klein Centre, AlbaNova, SE-106 91 Stockholm, Sweden
[3] INFN Sezione di Pisa, Polo Fibonacci, Largo B. Pontecorvo 3, 56127 Pisa, Italy
[4] Instituto de Física de Cantabria (IFCA, UC-CSIC), Avenida de Los Castros s/n, 39005 Santander, Spain
[5] Institut d'Astrophysique de Paris, Sorbonne Université, CNRS, UMR 7095, 98 bis bd Arago, 75014 Paris, France
[6] Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan
[7] Kavli Institute for the Physics and Mathematics of the Universe (WPI), UT Institute for Advanced Study, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan

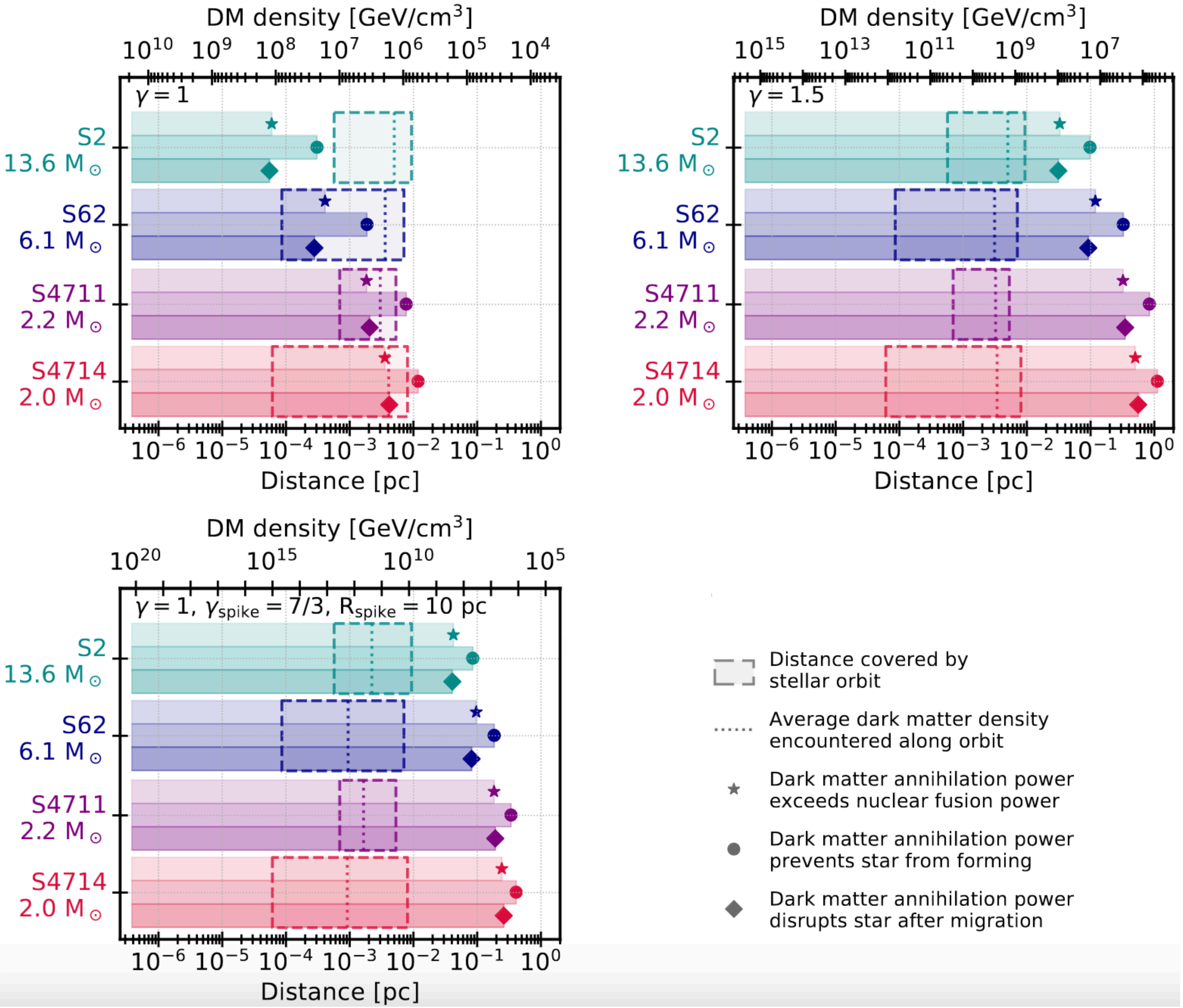
Dark matter overdensities around black holes can be searched for by looking at the characteristic imprint they leave on the gravitational waveform of binary black hole mergers. Current theoretical predictions of the density profile of dark matter overdensities are based on highly idealised formation scenarios, in which black holes are assumed to grow adiabatically from an infinitesimal seed to their final mass, compressing dark matter cusps at the center of galactic halos into very dense ...

Immortal Stars at the Galactic Center



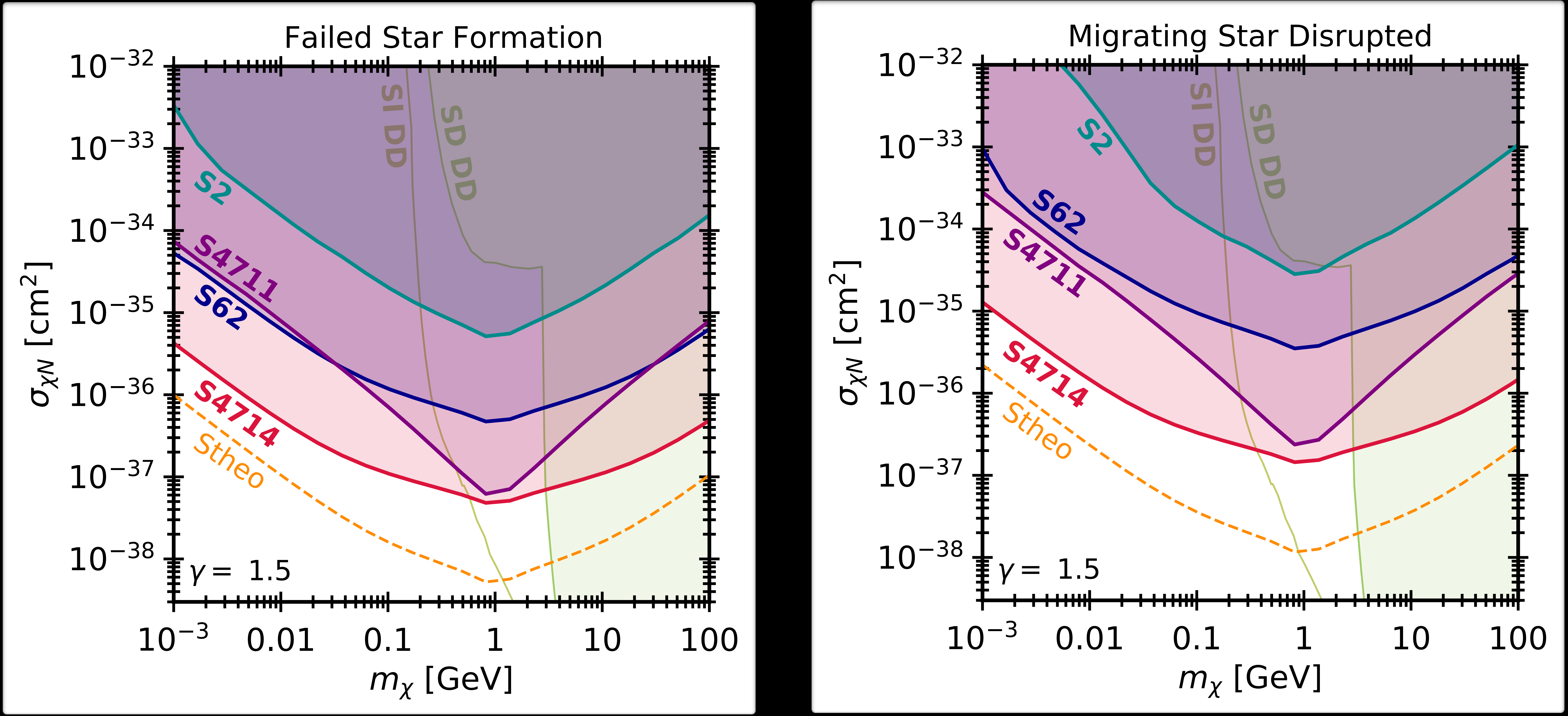
Many stars

within 0.016 pc



DM density [GeV/cm^3]
$\gamma = 1$
$\gamma = 1.5$
$\gamma = 1$, $\gamma_{spike} = 7/3$, $R_{spike} = 10$ pc
S2
13.6 $M_\odot$
S62
6.1 $M_\odot$
S4711
2.2 $M_\odot$
S4714
2.0 $M_\odot$
Distance [pc]
Distance covered by stellar orbit
Average dark matter density encountered along orbit
Dark matter annihilation power exceeds nuclear fusion power
Dark matter annihilation power prevents star from forming
Dark matter annihilation power disrupts star after migration

Immortal Stars at the Galactic Center



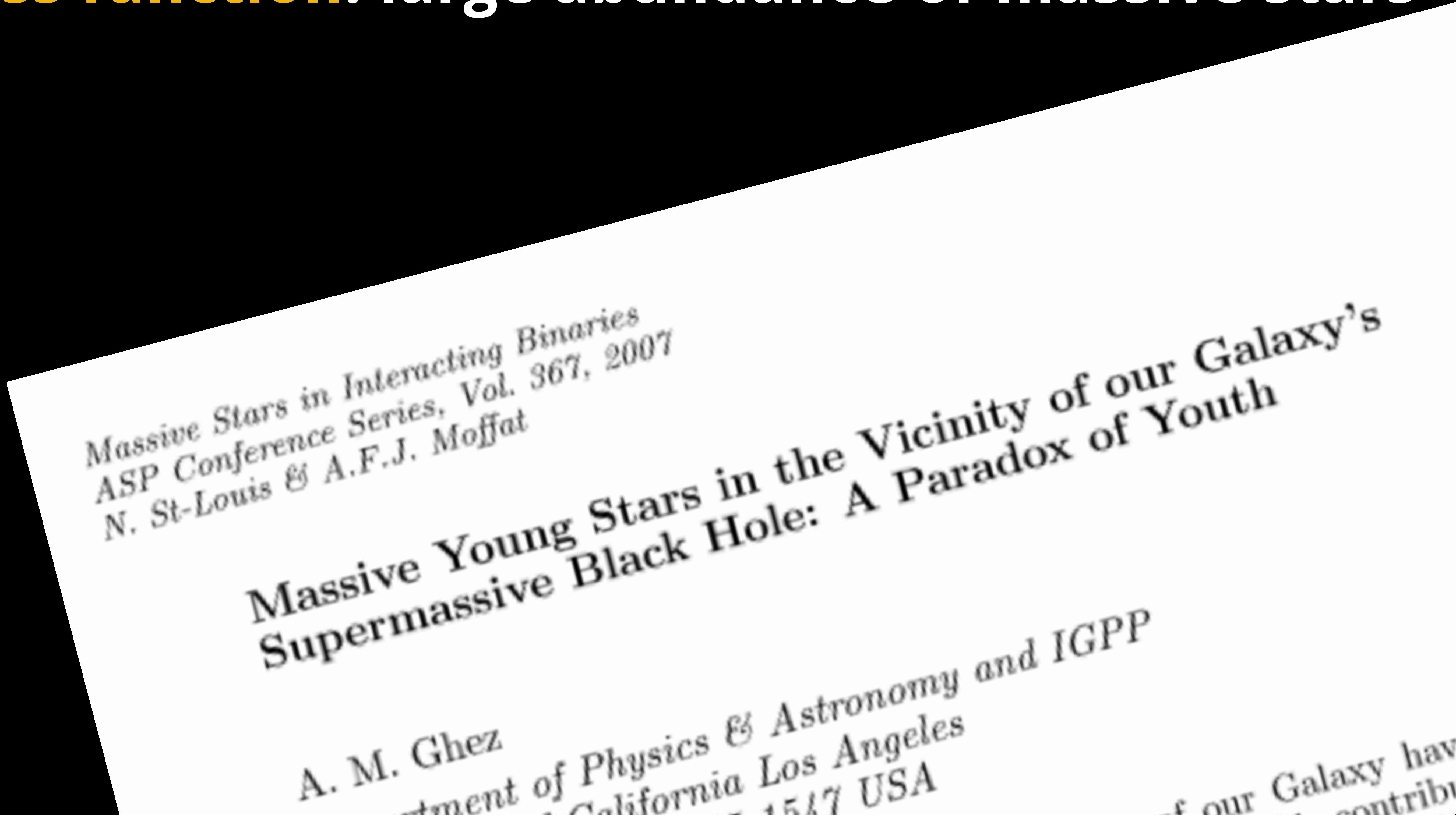
Immortal Stars at the Galactic Center

Origin not well understood: in situ formation or migration?

Paradox of Youth: Spectroscopically old but bright as young stars

Conundrum of Old Age: Lack of old stars

Top-heavy initial mass function: large abundance of massive stars

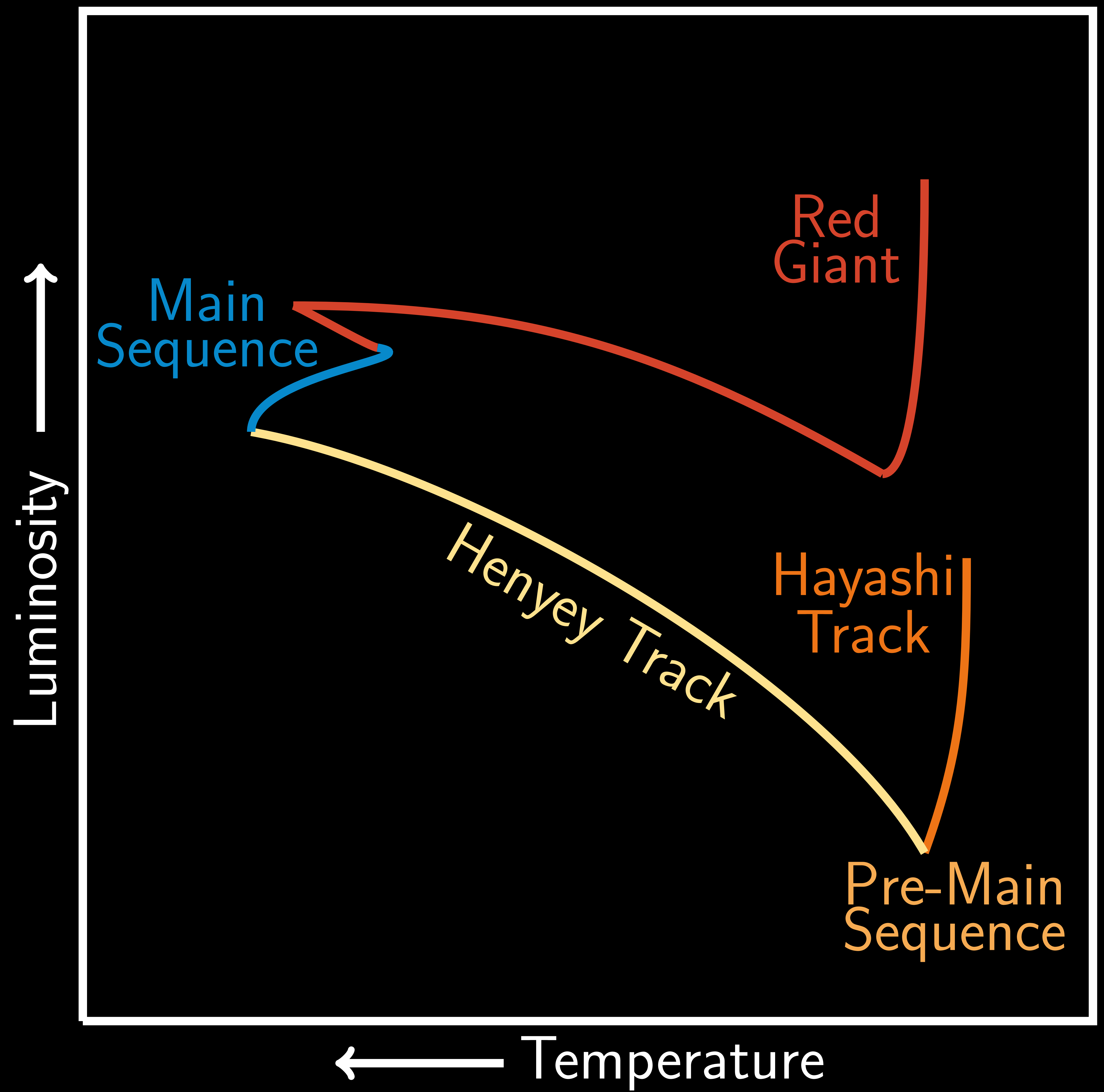


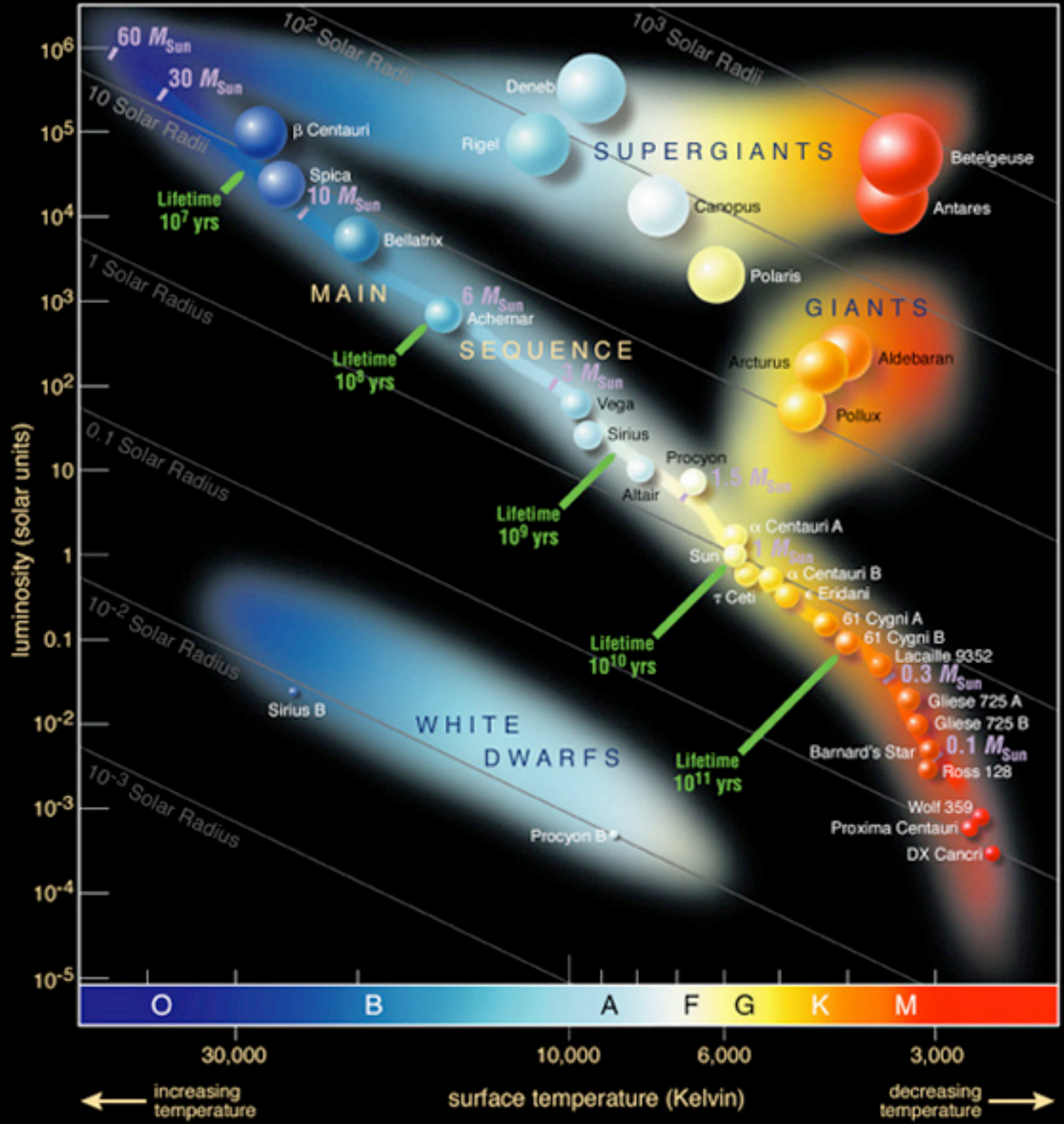
Massive Stars in Interacting Binaries
ASP Conference Series, Vol. 367, 2007
N. St-Louis & A.F.J. Moffat

Massive Young Stars in the Vicinity of our Galaxy's Supermassive Black Hole: A Paradox of Youth

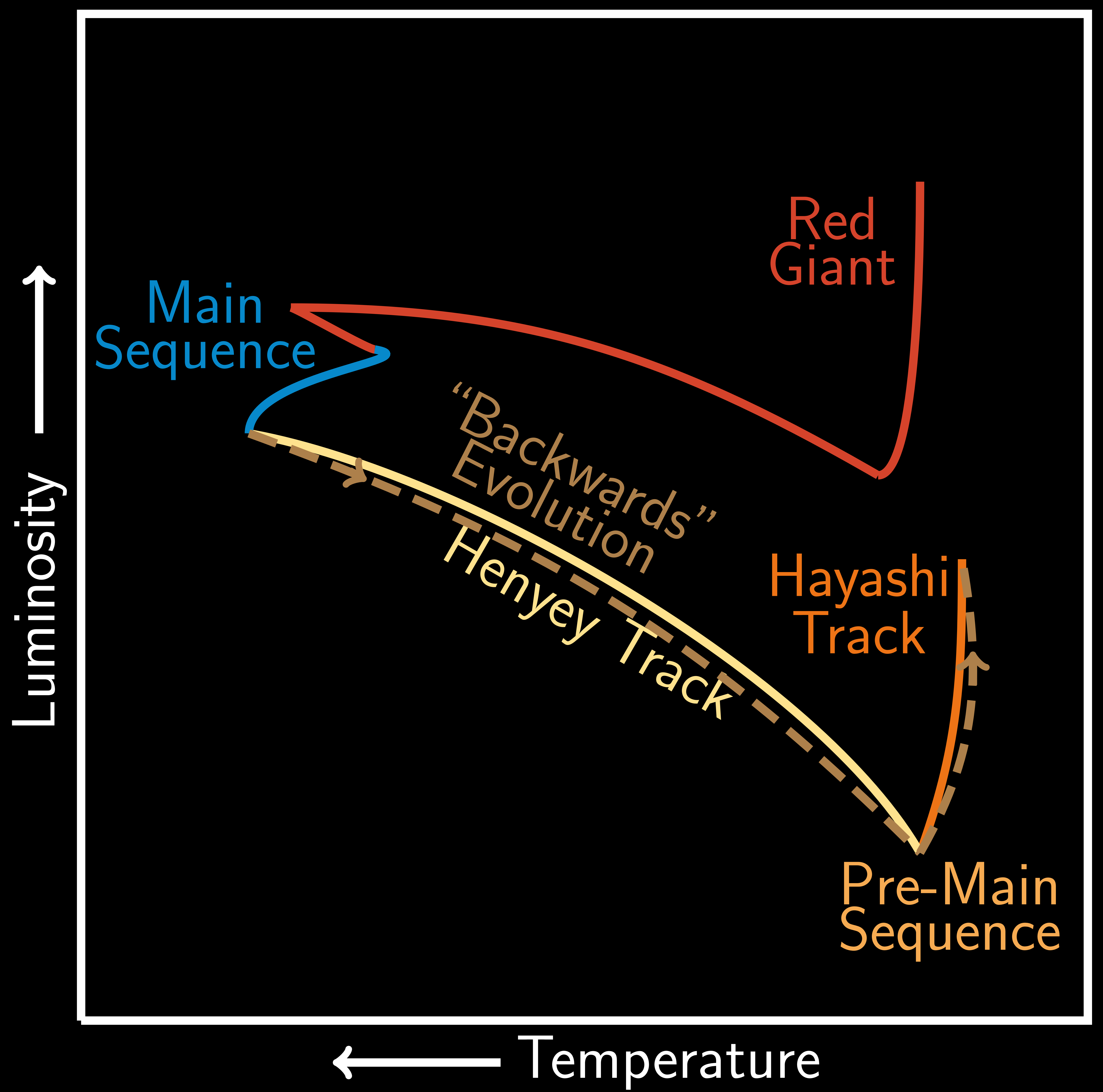
A. M. Ghez

Immortal Stars

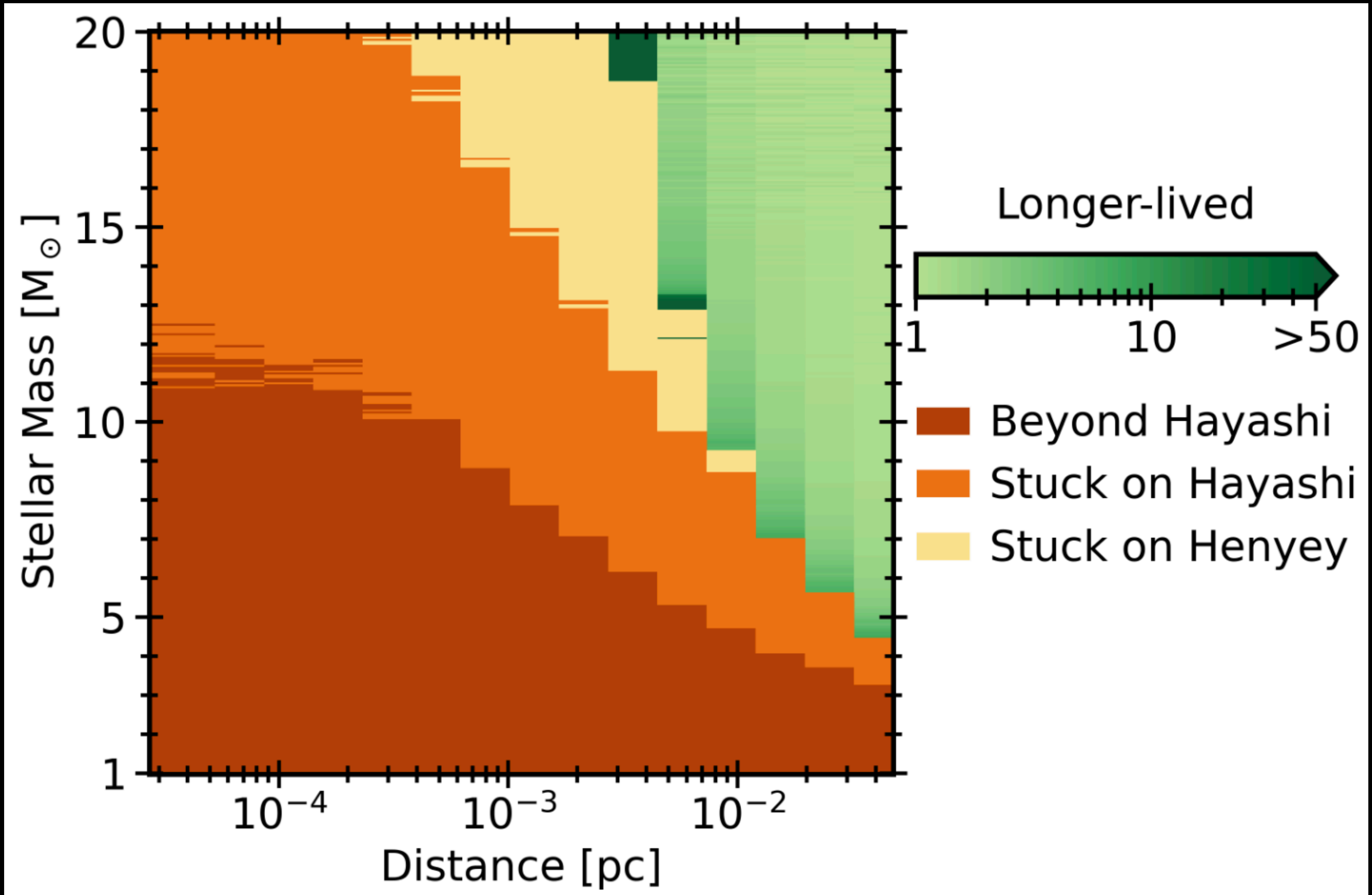


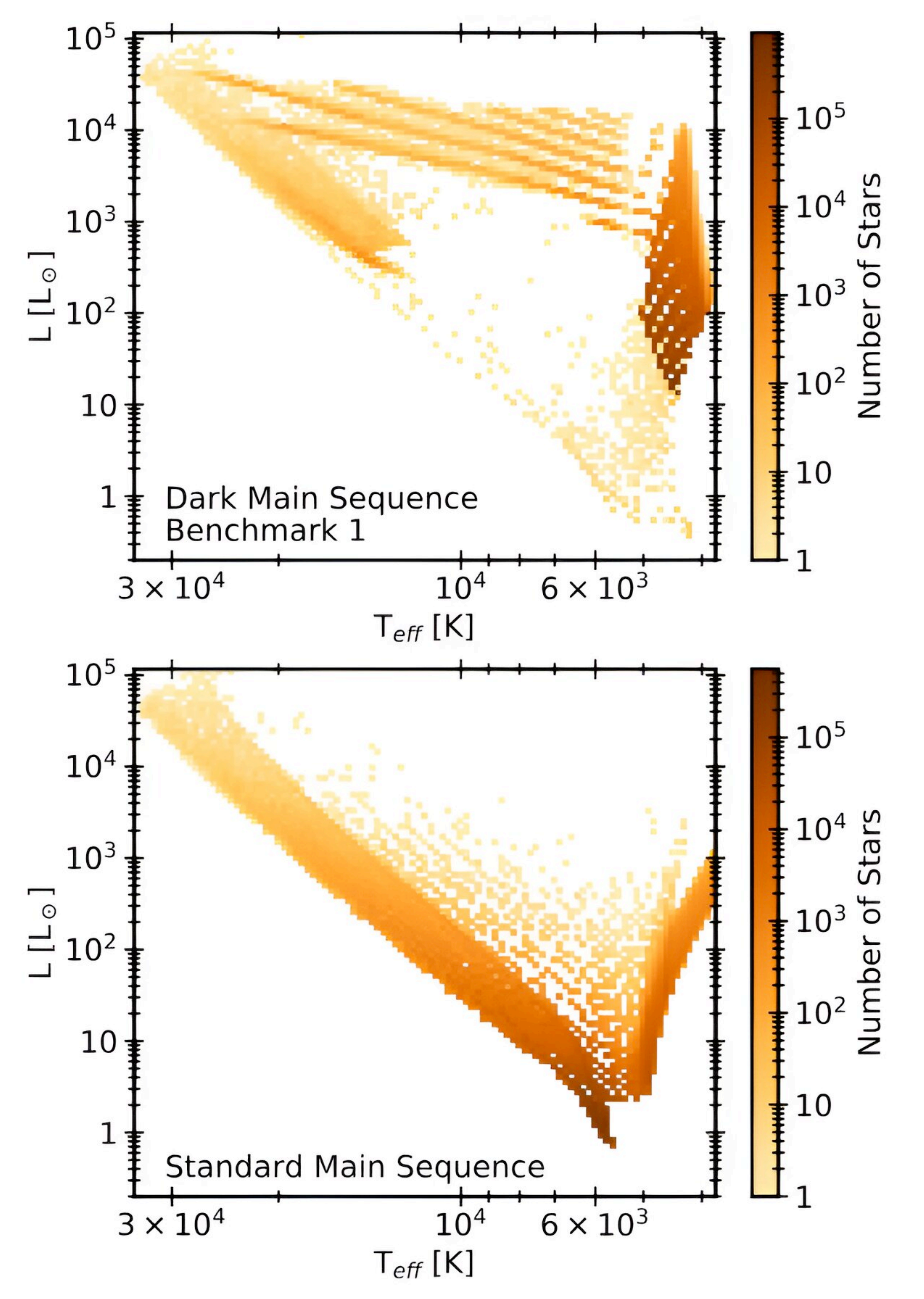


luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
60 M_{Sun}
30 M_{Sun}
10 M_{Sun}
6 M_{Sun}
3 M_{Sun}
1.5 M_{Sun}
1 M_{Sun}
0.3 M_{Sun}
0.1 M_{Sun}
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Canopus
Polaris
Betelgeuse
Antares
Arcturus
Aldebaran
Pollux
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature


Red
Giant
Main
Sequence
"Backwards"
Evolution
Henyey Track
Hayashi
Track
Pre-Main
Sequence
Luminosity
Temperature

Immortal Stars





The type of signature observers can actually search for.

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Super-Kamiokande

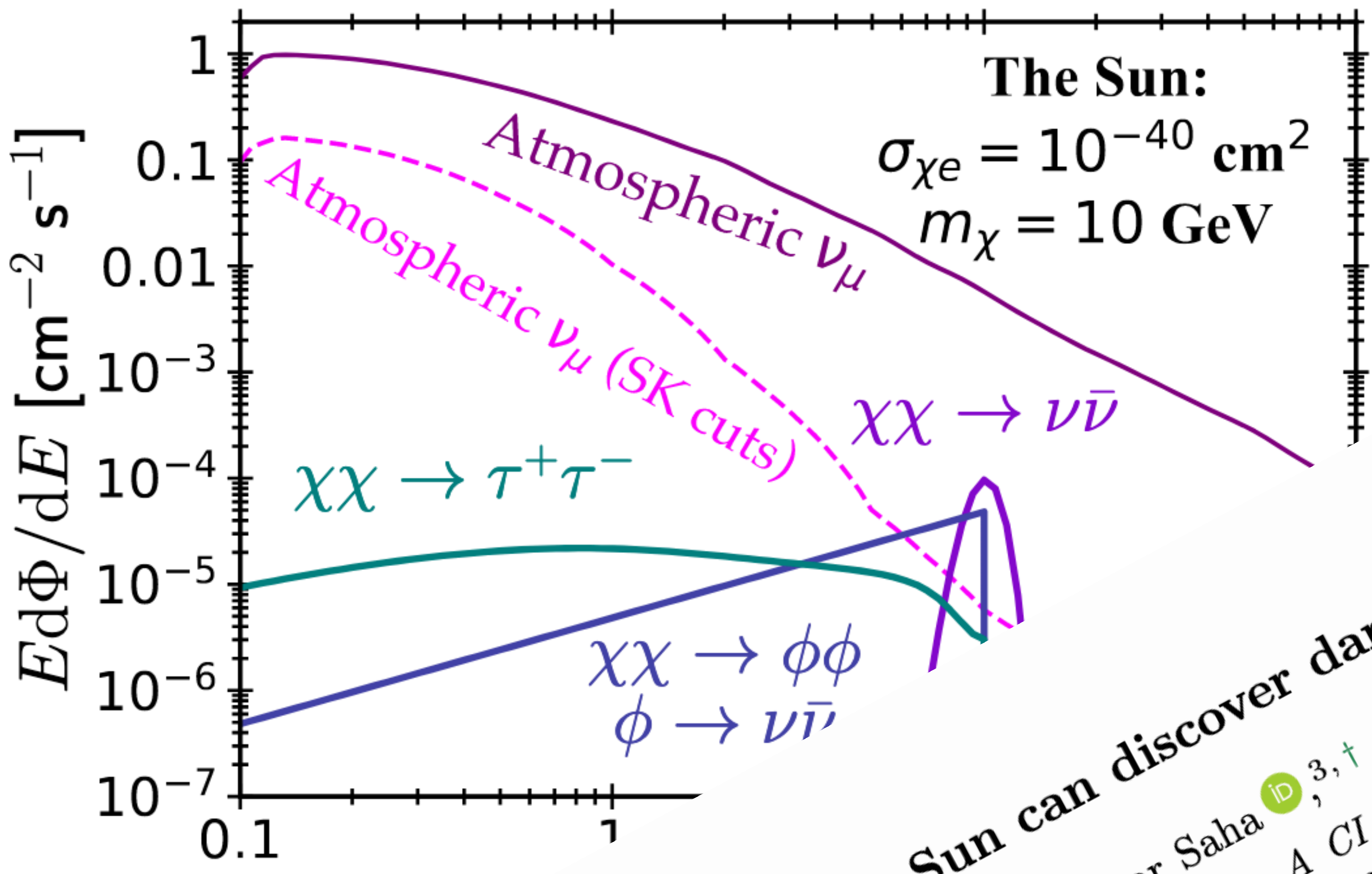
Super-Kamiokande Strongly Constrains Leptophilic Dark Matter Capture in the Sun

Thong T.Q. Nguyen,[1,*] Tim Linden,[1,†] Pierluca Carenza,[1,‡] and Axel Widmark[1,2,§]

[1] *Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden*
[2] *Columbia University, 116th and Broadway, New York, NY 10027 USA*

The Sun can efficiently capture leptophilic dark matter that scatters with free electrons. If this dark matter subsequently annihilates into leptonic states, it can produce a detectable neutrino flux. Using 10 years of Super-Kamiokande observations, we set constraints on the dark-matter/electron scattering cross-section that exceed terrestrial direct detection searches by more than an order of magnitude for dark matter masses below 100 GeV, and reach cross-sections as low as $\sim 4 \times 10^{-41}$ cm^{-2}.

Introduction. — Detecting the particle interactions of dark matter is a cornerstone in our efforts to study beyond the standard model physics [1–3]. Many of the most ...nsitive constraints depend on searching for rare scat... interactions between the dark matter particle and ... model particles [4–11].
...rate strategies motivate current searches. ...lar, used in terrestrial detectors, uses un... to avoid astrophysical backgrounds ...o single dark matter interactions. ...een an effort to "go big", us... objects to constrain rare ...f the large background. ...e scattering of dark



DAMA/LIBRA and leptonically interacting Dark Matter

CERN-PH-TH/2009-116

...him Kopp,[1,*] Viviana Niro,[1,†] Thomas Schwetz,[1,‡] and Jure Z...

[1] Max-Planck-Institute for Nuclear Physi... PO Box 103980, 69029 Heidelberg, G...
[2] Theory Division, Physics Dep... CERN, CH-1211 Geneva 23...

Abstra...

HRI-RECAPP-2023-03

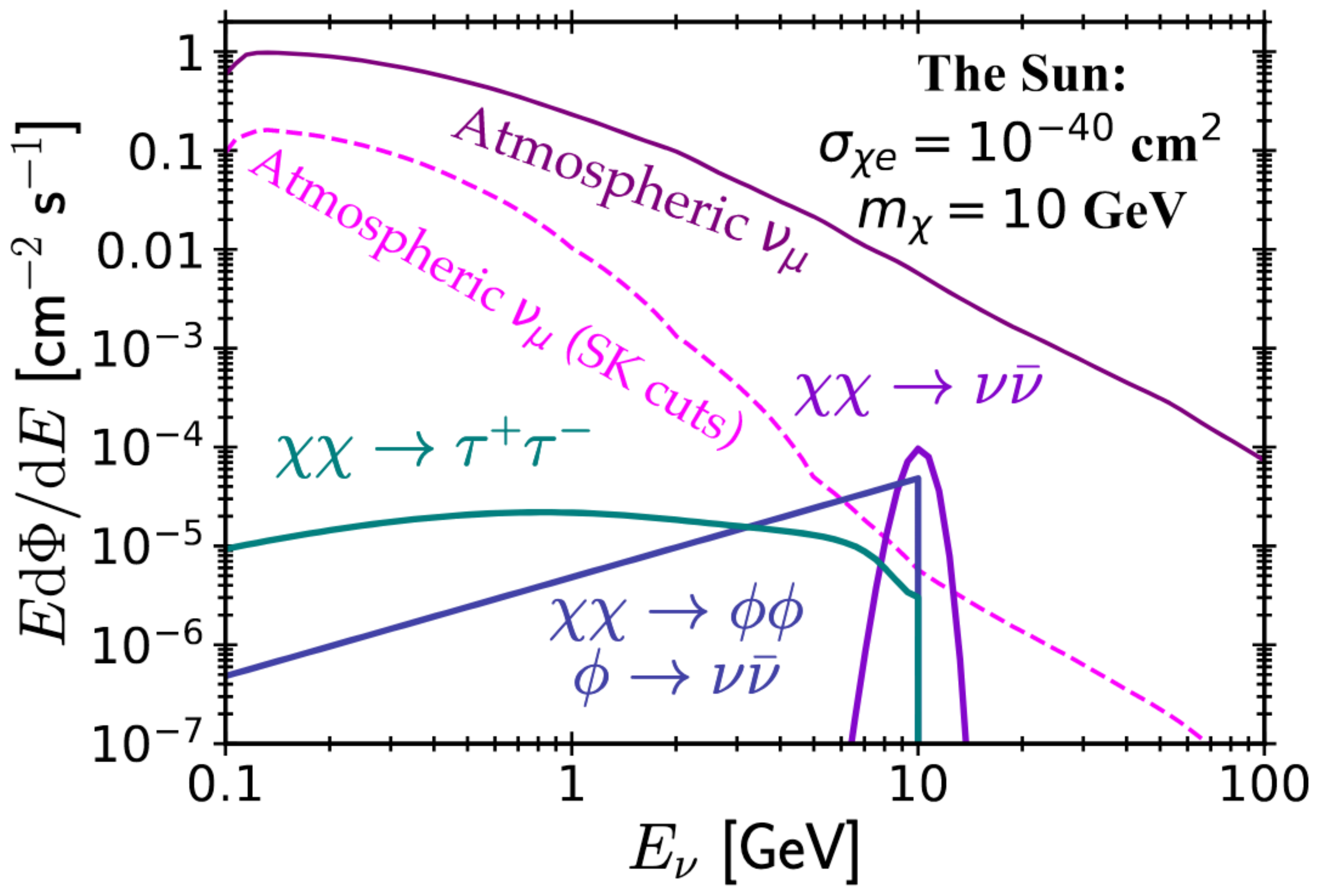
Neutrinos from the Sun can discover dark matter-electron scattering

Tarak Nath Maity,[1,2,3,*] Akash Kumar Saha,[3,†] Sagnik Mondal,[3,‡] and Ranjan Laha[3,§]

[1] Harish-Chandra Research Institute, A CI of Homi Bhabha National Institute, Chhatnag Road, Jhunsi, Prayagraj (Allahabad) 211019, India
[2] Regional Centre for Accelerator-based Particle Physics, Harish-Chandra Research Institute, Prayagraj (Allahabad) 211019, India
...y Physics, Indian Institute of Science, C. V. Raman Avenue, Bengaluru 560012, ...

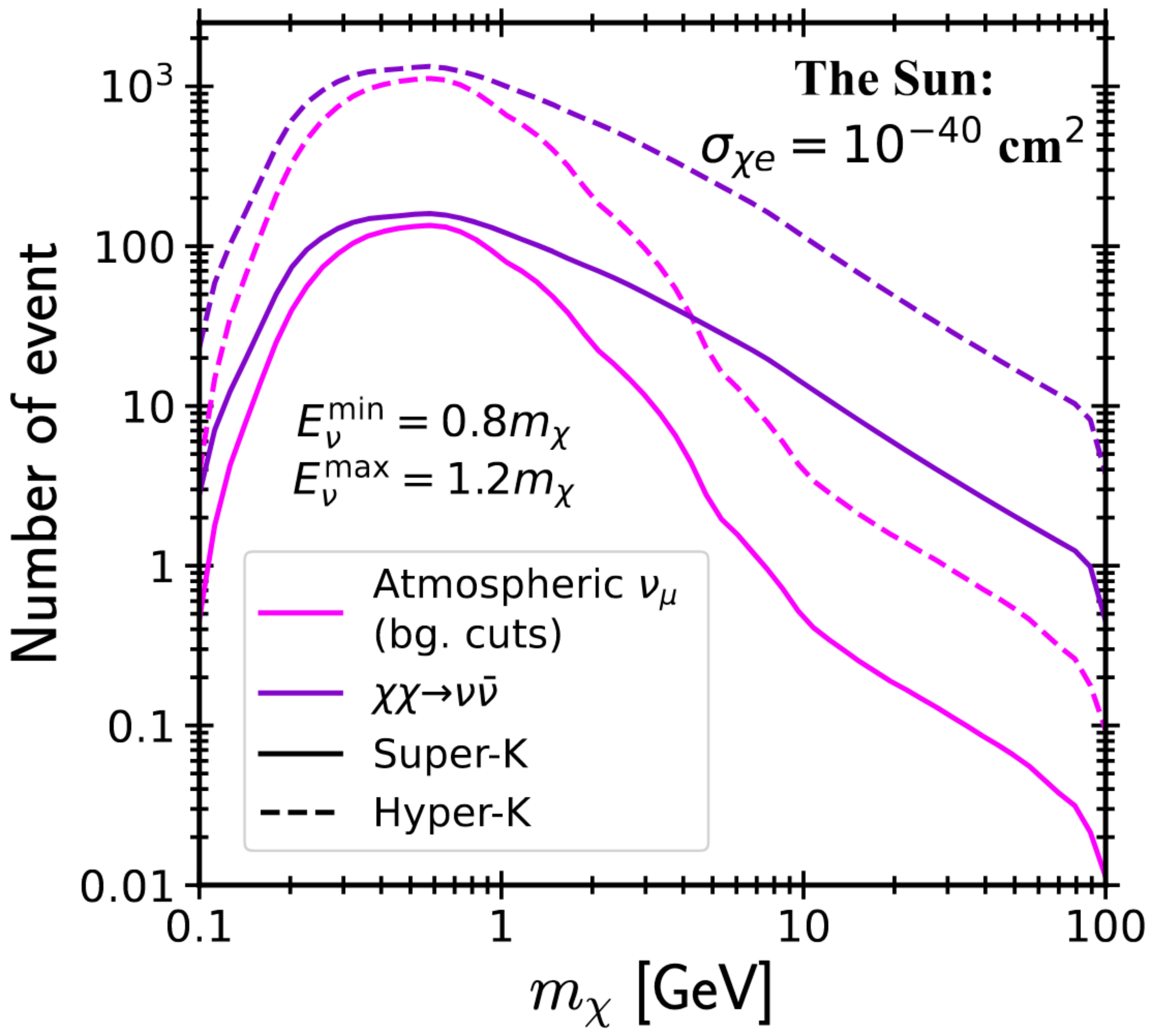
(Dated: August 25, 2023)

Super-Kamiokande



- **"Miracle" - Dark Matter must be leptophilic.**
- **Standard annihilation cross-sections and unconstrained scattering rate.**
- **Significant annihilation rate to neutrinos (or taus).**

Super-Kamiokande



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3.) Attack the biggest uncertainty, and then move on. ✅

- Every individual study is individually unlikely.

Detecting Dark Matter with Imploding Pulsars in the Galactic Center

Joseph Bramante
Department of Physics, 225 Nieuwland Science Hall,
University of Notre Dame, Notre Dame, IN 46556, USA

Tim Linden
Kavli Institute for Cosmological Physics 5640 South Ellis Avenue
University of Chicago Chicago, IL 60637

...f old millisecond pulsars observed at the galactic center of the Mil...
...matter accumulating in and destroying neutron stars. In reg...
...tter clumped in a pulsar can exceed the Schwarzschil...
...ich destroys the pulsar. We examine what d...
...nd find regions of parameter space wher...
...n star population within the g...
...cond pulsars in globular c...
...masses might cau...
...pulsar c...

THE PECULIAR PULSAR POPULATION OF THE CENTRAL PARSEC

Jason Dexter
Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA
Ryan M. O'Leary
Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA

Draft version April 14, 2018

ABSTRACT

Pulsars orbiting the Galactic center black hole, Sgr A*, would be potential probes of its mass, distance and spin, and may even be used to test general relativity. Despite predictions of large populations of both ordinary and millisecond pulsars in the Galactic center, none have been detected within 25 pc by deep radio surveys. One explanation has been that hyperstrong temporal scattering prevents pulsar detections, but the recent discovery of radio pulsations from a highly magnetized neutron ...
...magnetar) within 0.1 pc shows that the temporal scattering is much weaker than predicto...
...gue that an intrinsic deficit in the ordinary pulsar population is the most likely reason f...
...etections to date: a "missing pulsar problem" in the Galactic center. In contrast...
...iscovery of a single magnetar implies efficient magnetar formation in the regi...
...n the central parsec form magnetars rather than ordinary pulsars, thei...
...the missing pulsars. Efficient magnetar formation could be caus...
...s, or could be further evidence of a top-heavy initial mass f...
...ncy surveys should already be able to detect bright milli...
...poral scattering.

...axy: center — pulsars: general — pulsars: in...

...ODUCTION

...Milky Way contains a...
...and B stars both...
...6; Paumar...
...xtendi...

The Galactic centre pulsar population

Jayanth Chennamangalam[1⋆] and D. R. Lorimer[1,2†]
[1] *Department of Physics and Astronomy, West Virginia University, PO Box 6315, Morgantown, WV 26506, USA*
[2] *National Radio Astronomy Observatory, PO Box 2, Green Bank, WV 24944, USA*

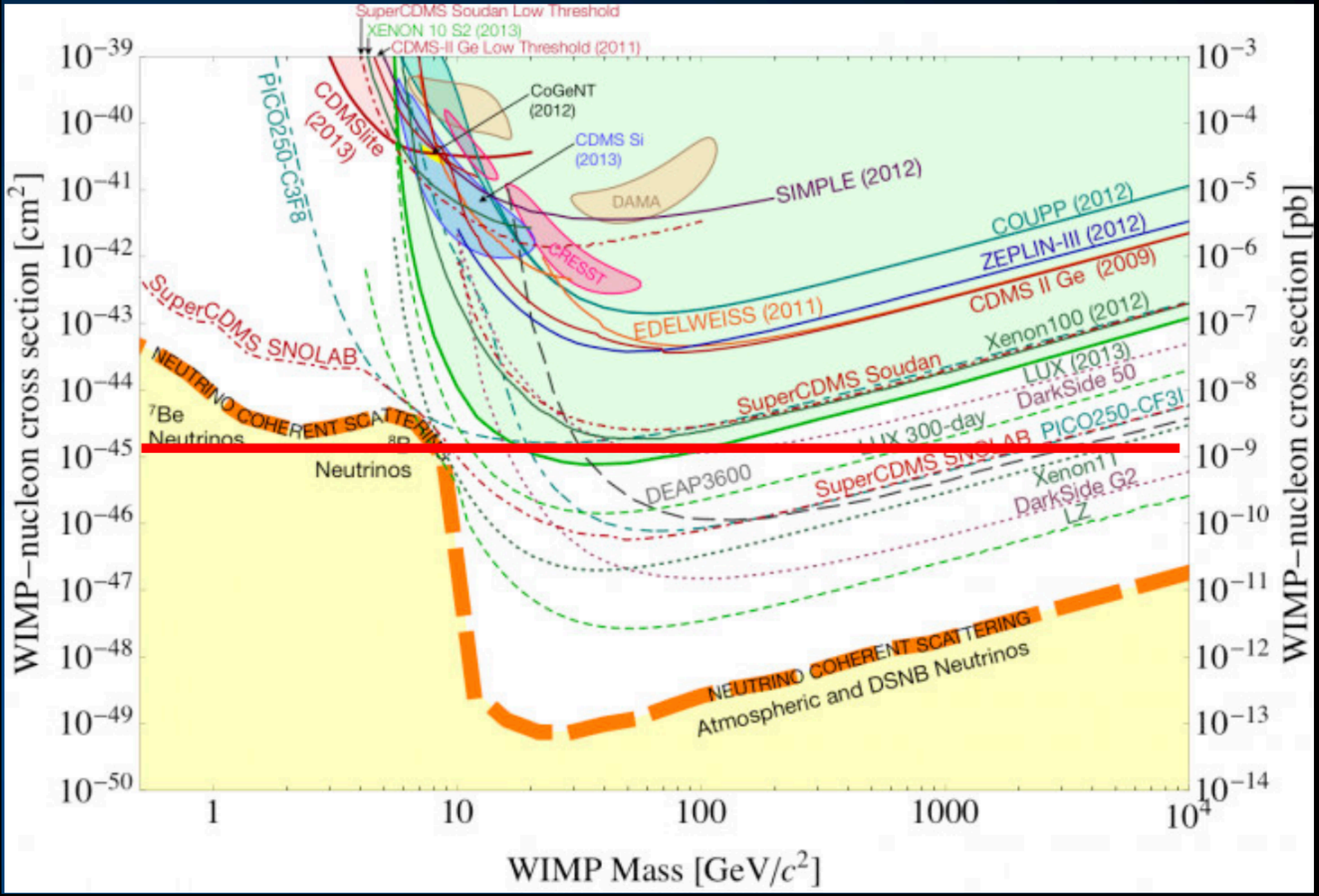
...ust 2021

ABSTRACT

The recent discovery of a magnetar in the Galactic centre regi...
Spitler et al. to characterize the interstellar scattering in that di...
that the temporal broadening of the pulse profile of the magnetar...
than that predicted by models of the electron density of that r...
...uestion of what the plausible limits for the number of potenti...
...the number of pulsars beaming towards the Earth – in th...
...er, using reasonable assumptions – namely, (i) the...
...Galactic centre region is the same as that in th...
...ar formation rate, (iii) the scattering in th...
...milar, and (iv) the spin and lum...
...ative of the entire inner pa...
...of pulsars in the inner...
...ure to conclude...
...observation...

Neutron Stars as the Optimal Dark Matter Detectors

- **Direct detection cross-sections near 10^{-46} cm^2 produce ~1 event/(ton yr)**

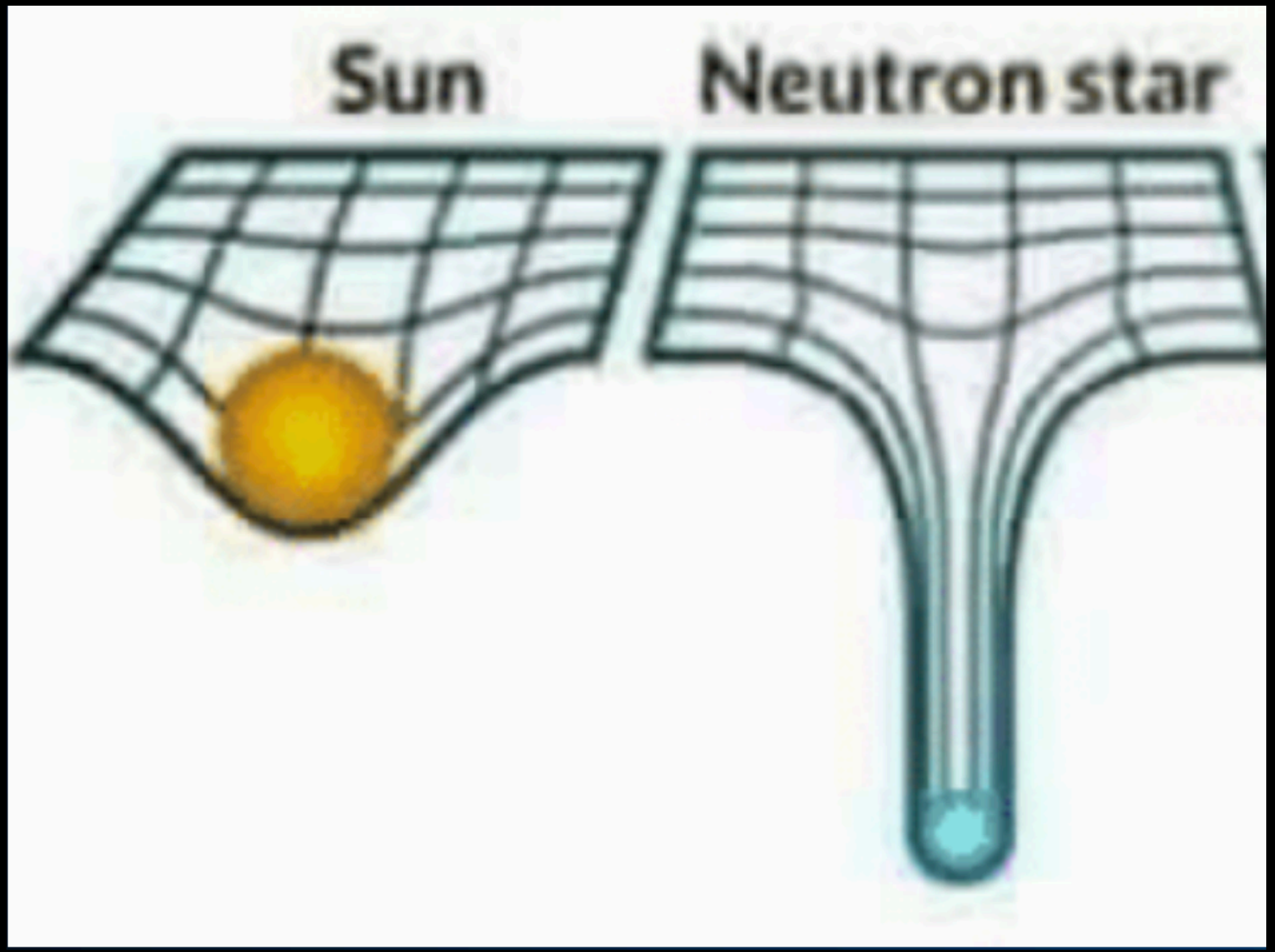


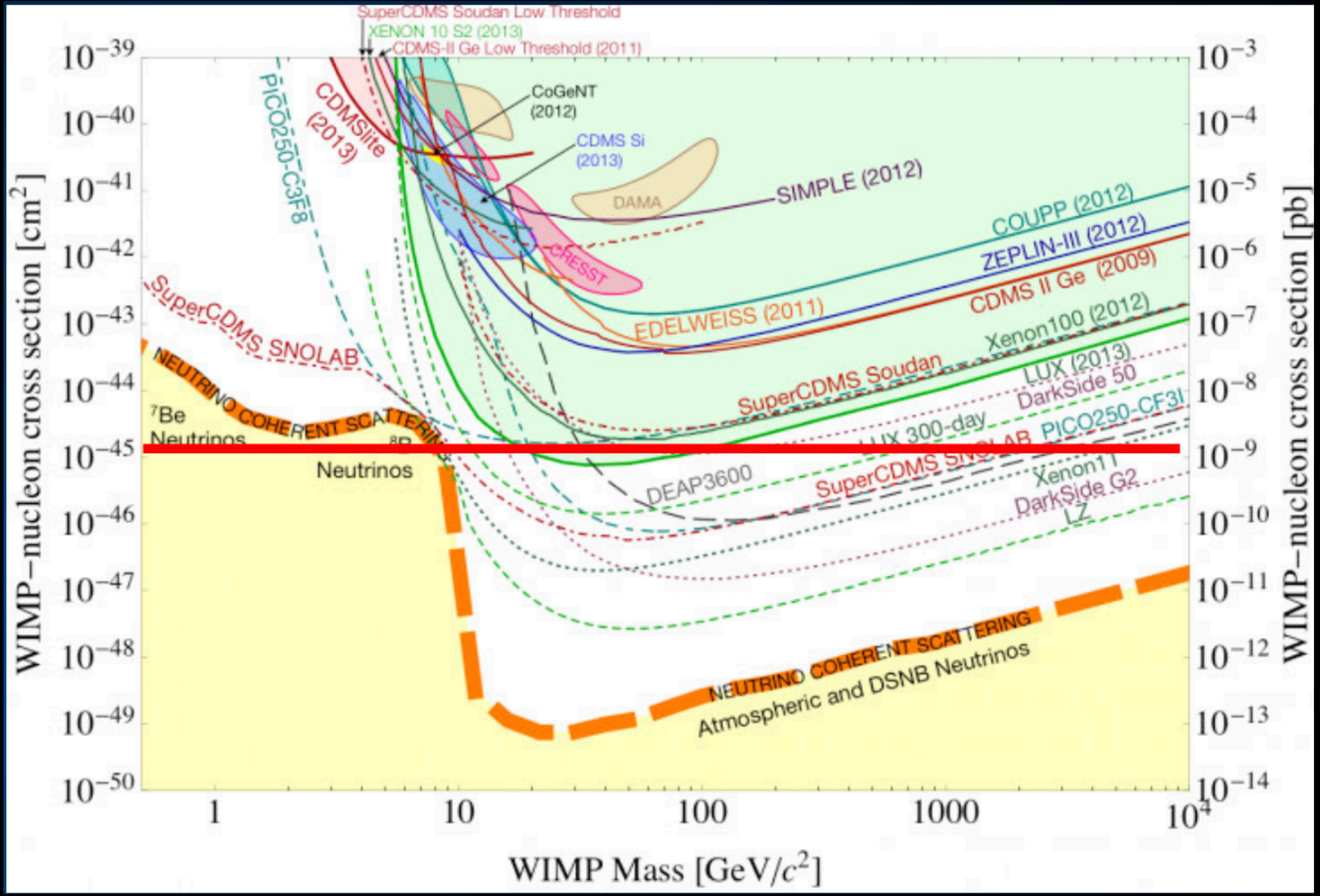
- **Sensitivity peaks near Xenon mass, and falls off significantly at higher or lower masses.**

$$\sigma_{\rm sat}^{\rm single} \simeq \pi R^2 m_{\rm n}/M \simeq 2\times 10^{-45}\ {\rm cm}^2 \left(\frac{1.5\ M_\odot}{M}\right)\left(\frac{R}{10\ {\rm km}}\right)^2$$

Neutron Stars as the Optimal Dark Matter Detectors

- Direct detection cross-sections near 10^{-46} cm^2 produce ~1 event/(ton yr)





$$b_{\rm max} = \left(\frac{2GMR}{v_x^2}\right)^{1/2}\left(1-\frac{2GM}{R}\right)^{-1/2}$$

Neutron Stars as the Optimal Dark Matter Detectors

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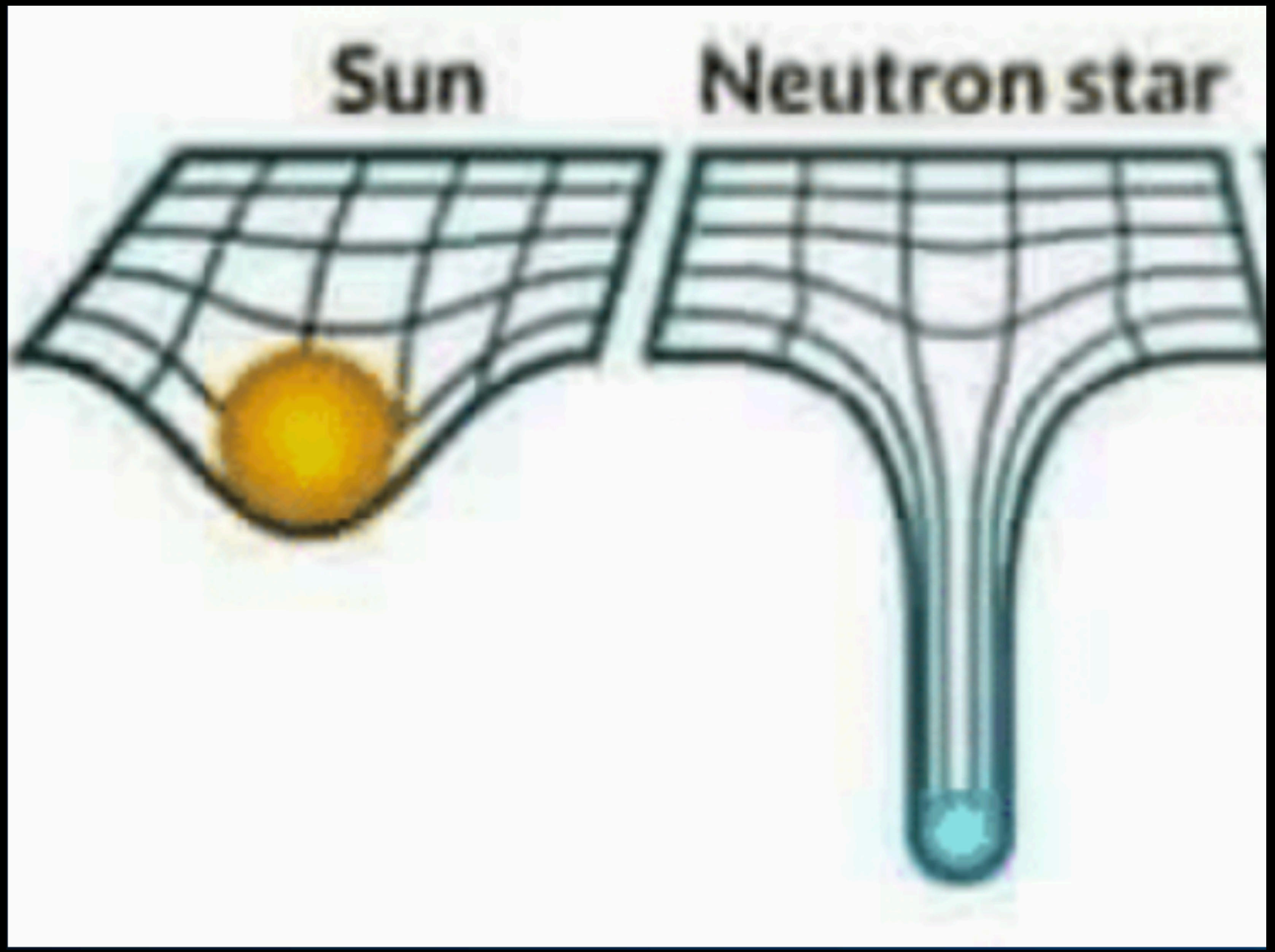
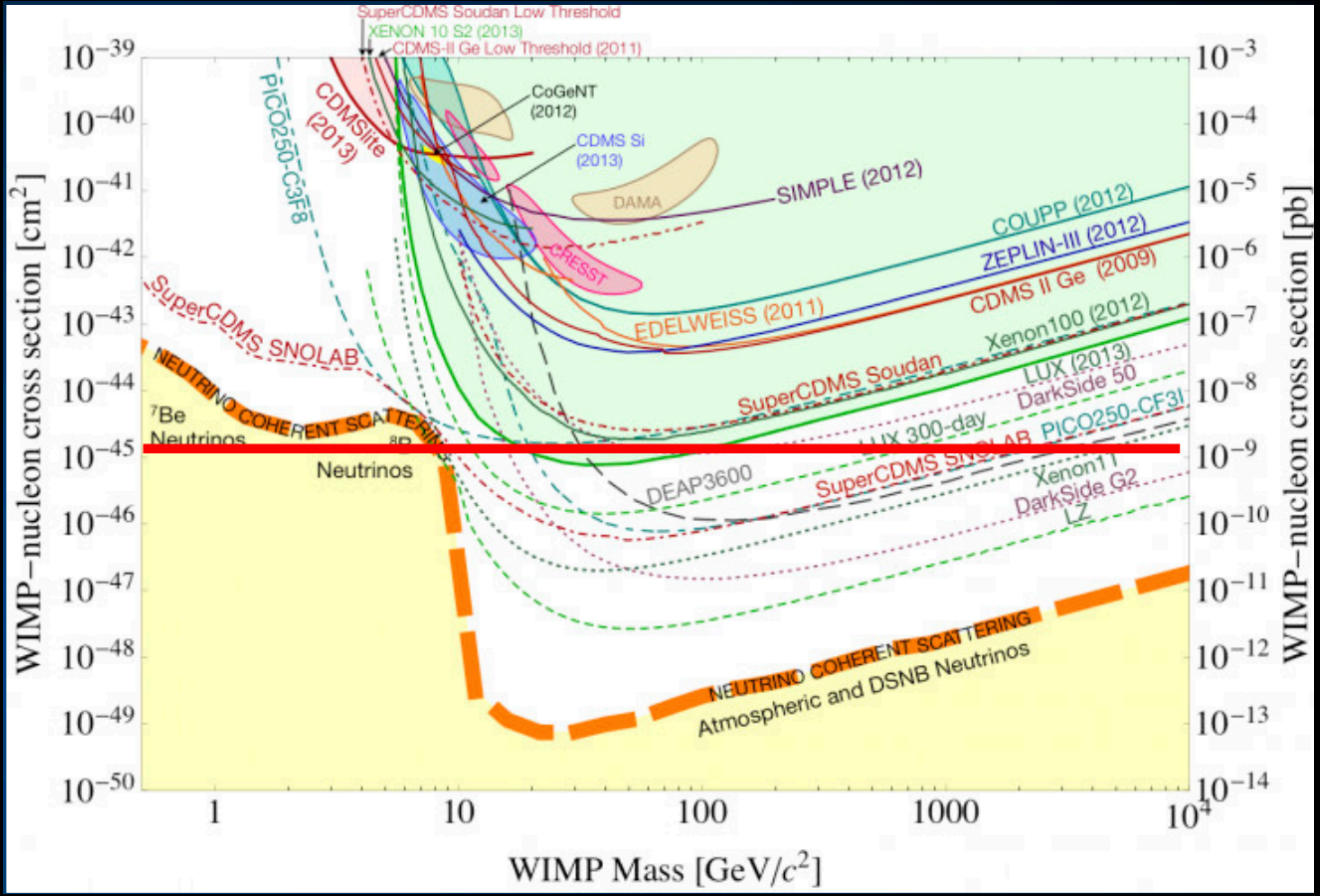
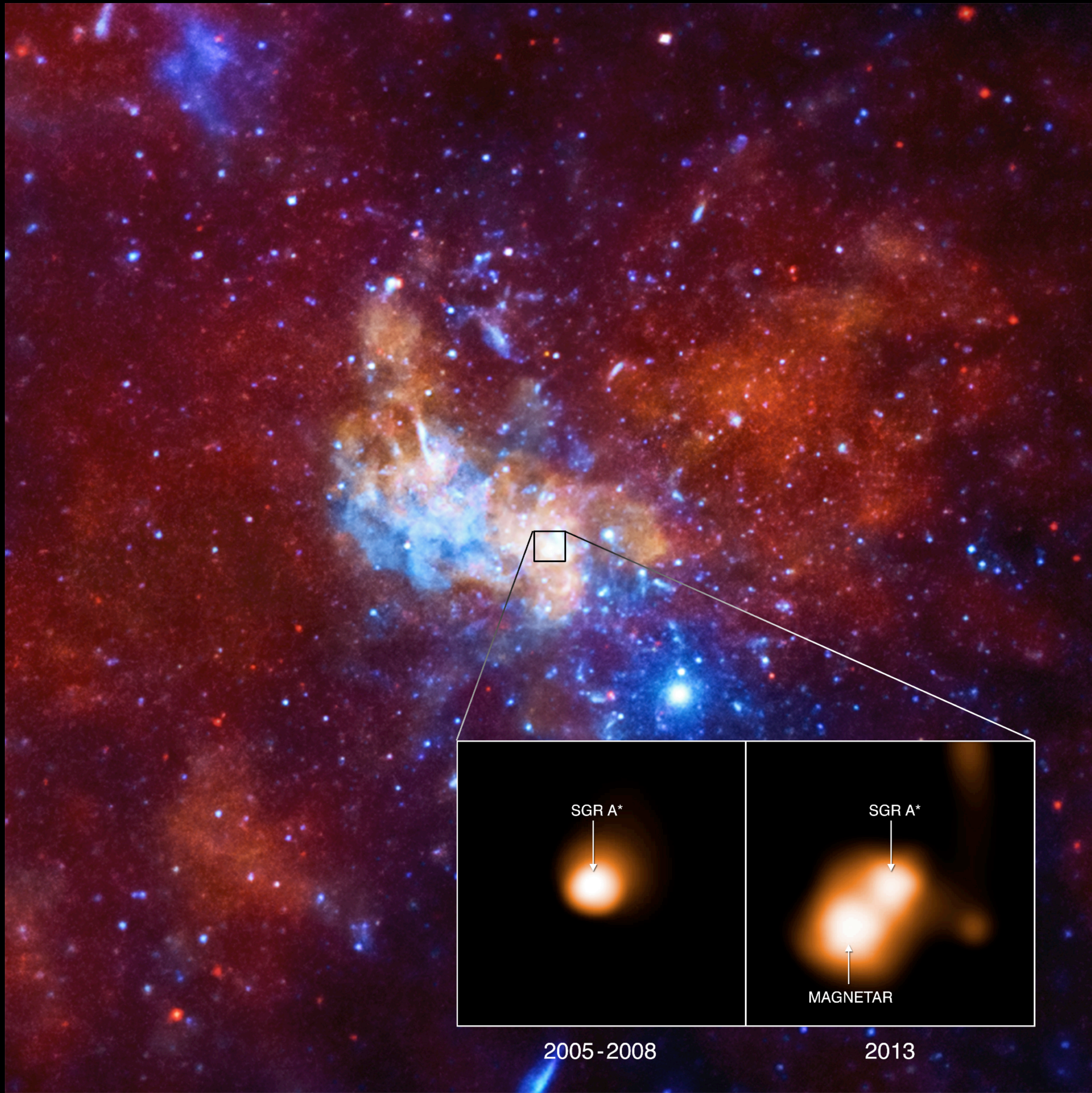




$$v_{esc} = \sqrt{\frac{2GM}{r}} \sim 0.7c$$

The 2013 GC Magnetar Detection

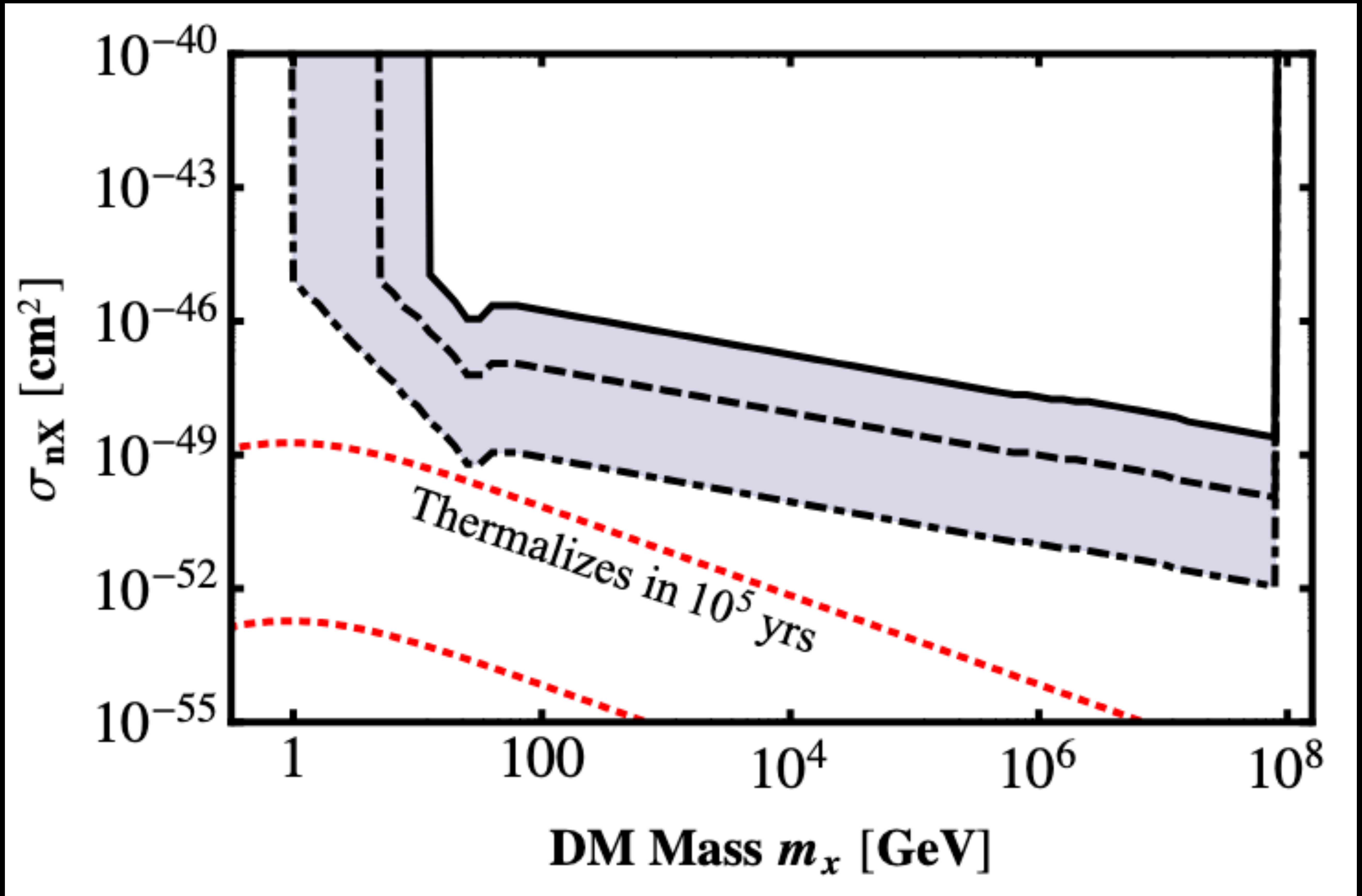
- Before 2013, it was thought that pulse dispersion made GC pulsars invisible.
- Magnetar observed (First in X-rays!) in 2013.
- Largest pulse dispersion of any existing pulsar, but not sufficient to make GC pulsars invisible.



Dark Matter interactions in NS

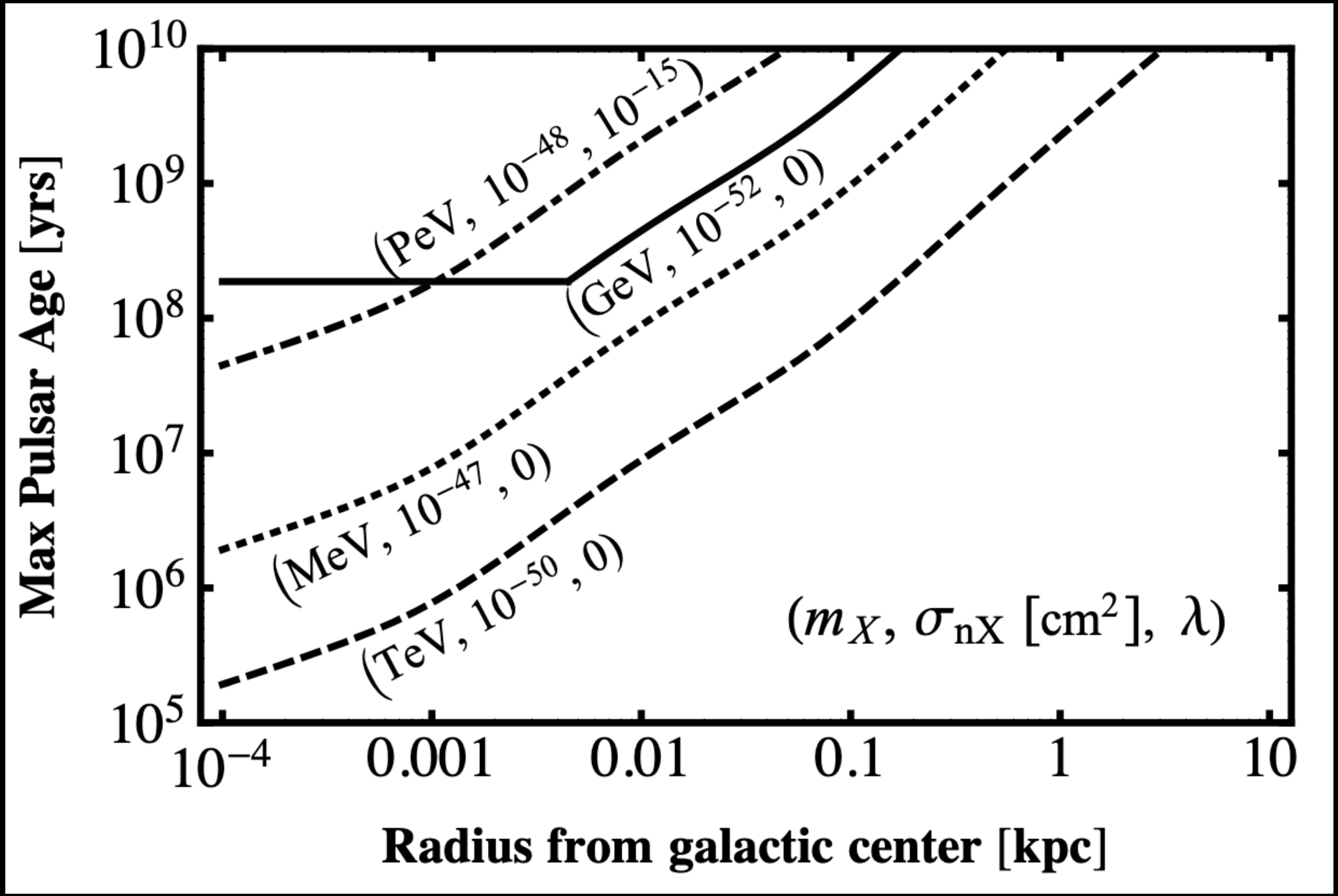
- Dark Matter accumulation can eliminate these pulsars:

- Need DM to either be non-annihilating massive fermions or bosons (to avoid Fermi degeneracy pressure)



Dark Matter interactions in NS

- Dark Matter accumulation can eliminate these pulsars:
- Need DM to either be non-annihilating massive fermions or bosons (to avoid Fermi degeneracy pressure)
- A New Astrophysical observable! A maximum age for pulsars that depends on GC radius.



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- Miracles can be correlated

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- Every individual study is individually unlikely.


LTH-1321

White Dwarfs in Dwarf Spheroidal Galaxies: A New Class of Compact-Dark-Matter Detectors

Juri Smirnov,[1,2,*] Ariel Goobar,[2,†] Tim Linden,[2,‡] and Edvard Mörtsell[2,§]

[1] Department of Mathematical Sciences, University of Liverpool, Liverpool, L69 7ZL, United Kingdom
[2] The Oskar Klein Centre, Department of Physics, Stockholm University, AlbaNova, SE-10691 Stockholm, Sweden

Recent surveys have discovered a population of faint supernovae, known as Ca-rich gap transients, inferred to originate from explosive ignitions of white dwarfs. In addition to their unique spectra and luminosities, these supernovae have an unusual spatial distribution and are predominantly found at large distances from their presumed host galaxies. We show that the locations of Ca-rich gap transients are well matched to the distribution … dwarf spheroidal galaxies surrounding large galaxies, in accordance with a scenario where dark matter inter… …s induce thermonuclear explosions among low-mass white dwarfs that may be otherwise difficult to ig… …ndard stellar or binary evolution mechanisms. A plausible candidate to explain the observed eve… …ial black holes with masses above 10^{21} grams.

…ed a new population of super… [1, 2], called Ca-Rich Gap …ype Ia SN, which trace …ted at a much larger …ies. Additionally, … originate from …sekhar limit, …minantly

Dark Matter Triggers of Supernovae

Peter W. Graham,[1] Surjeet Rajendran,[2] and Jaime Varela[2]

[1] Stanford Institute for Theoretical Physics, Department of Physics, Stanford University, Stanford, CA 94305
[2] Berkeley Center for Theoretical Physics, Department of Physics, University of California, Berkeley, CA 94720

Abstract

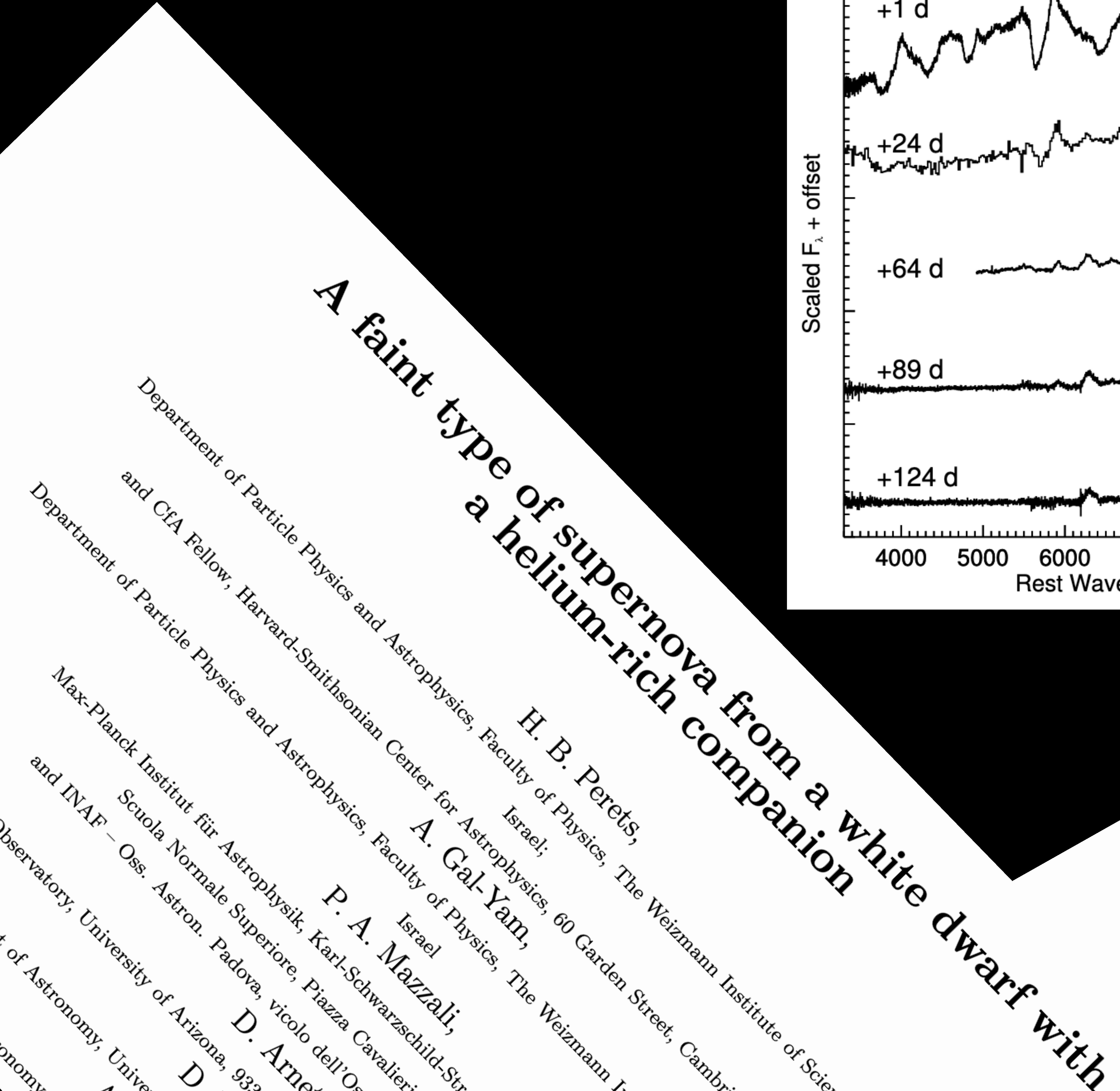
The transit of primordial black holes through a white dwarf ca… …tory of the black hole through dynamical friction. Fo… …itiate runaway thermonuclear fusion causing … …he observed distribution of white d… …with masses ~ 10^{19} gm - … …les with masses a… …of a popu…

White Dwarfs as Dark Matter Detectors

…eter W. Graham,[1] Ryan Janish,[2] Vijay Narayan,[2] Surjeet Rajendran,[2] and Paul Riggins[2]

…Institute for Theoretical Physics, Department of Physics, Stanford University, Stanford, CA, 94305
[2] Berkeley Center for Theoretical Physics, Department of Physics, University of California, Berkeley, CA 94720, USA

…that is capable of sufficiently heating a local region in a white dwarf will trigger … ignite a type Ia supernova. This was originally proposed by Graham et al. and …ordial black holes which transit and heat a white dwarf via dynamical friction. …r dark matter (DM) candidates that heat through the production of high-… particles, and show that such particles will efficiently thermalize the … supernovae. Based on the existence of long-lived white dwarfs and … derive new constraints on ultra-heavy DM with masses greater … particles through DM-DM annihilations, DM decays, and D… …medium. As a concrete example, we place bound… …ace complementary to terrestrial bounds. We put… …warfs, considering the formation and self-gra… …decays and annihilations within the co… …this work provide an alternativ… …ary progenitors.

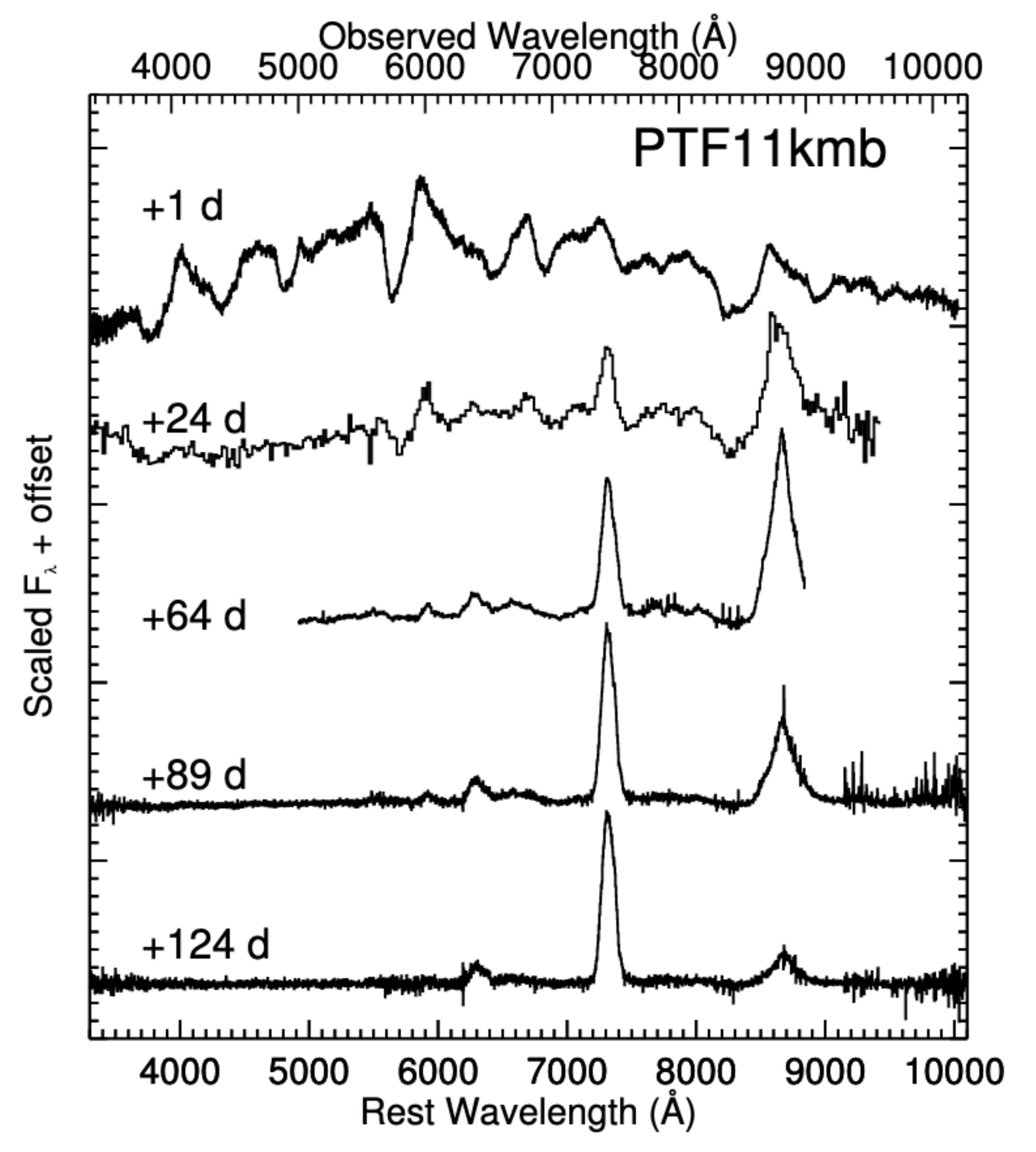

A faint type of supernova from a white dwarf with
a helium-rich companion

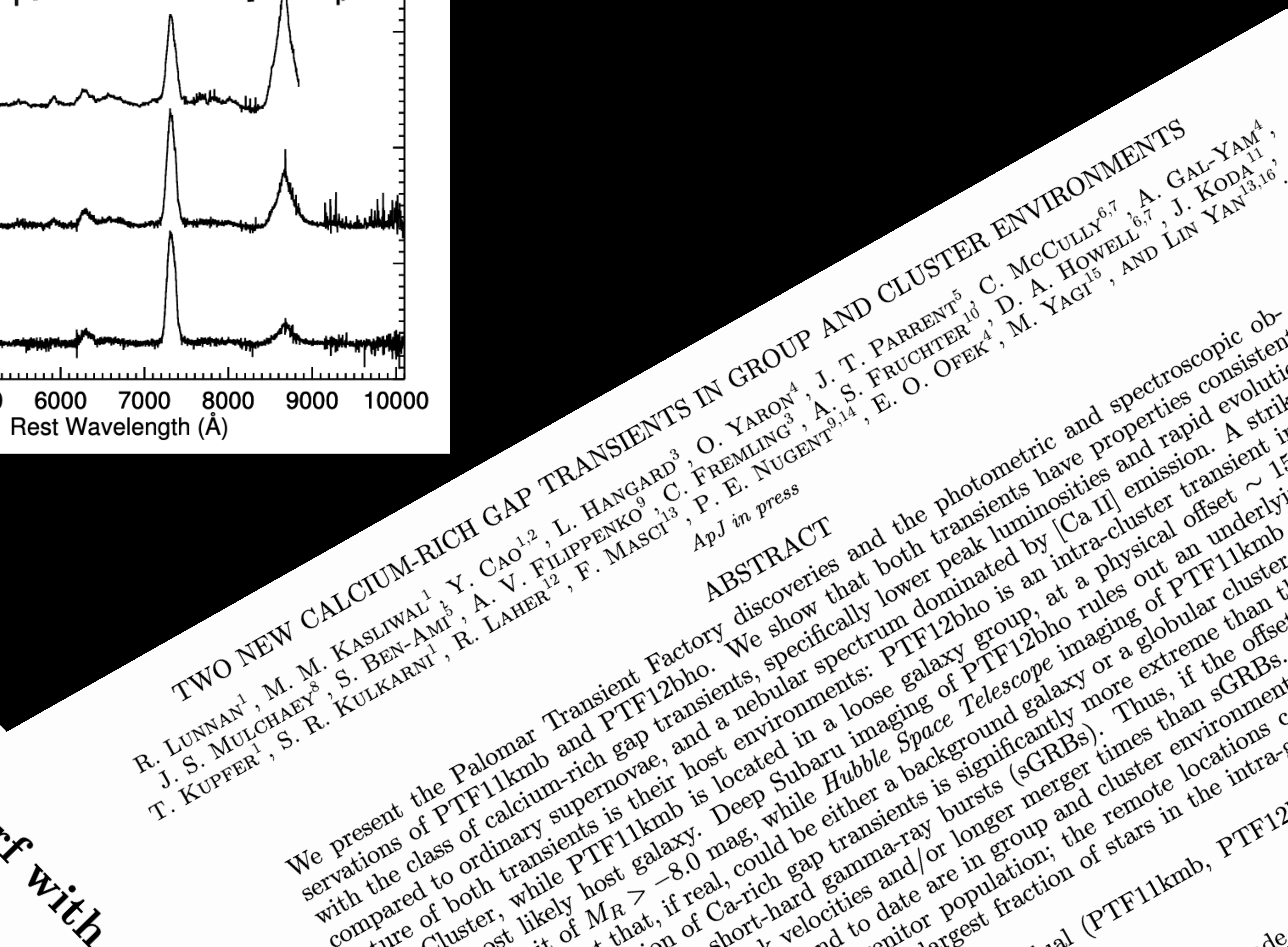
H. B. Perets,
Department of Particle Physics and Astrophysics, Faculty of Physics, The Weizmann Institute of Scie
Israel;
and CfA Fellow, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambri

A. Gal-Yam,
Department of Particle Physics and Astrophysics, Faculty of Physics, The Weizmann I
Israel

P. A. Mazzali,
Max-Planck Institut für Astrophysik, Karl-Schwarzschild-Str
Scuola Normale Superiore, Piazza Cavalieri
and INAF – Oss. Astron. Padova, vicolo dell'Os

D. Arne
Observatory, University of Arizona, 93
of Astronomy, Unive




TWO NEW CALCIUM-RICH GAP TRANSIENTS IN GROUP AND CLUSTER ENVIRONMENTS

R. Lunnan[1], M. M. Kasliwal[1], Y. Cao[1,2], L. Hangard[3], O. Yaron[4], J. T. Parrent[5], C. McCully[6,7], A. Gal-Yam[4],
J. S. Mulchaey[8], S. Ben-Ami[5], A. V. Filippenko[9], C. Fremling[3], A. S. Fruchter[10], D. A. Howell[6,7], J. Koda[11],
T. Kupfer[1], S. R. Kulkarni[1], R. Laher[12], F. Masci[13], P. E. Nugent[9,14], E. O. Ofek[4], M. Yagi[15], and Lin Yan[13,16],

ApJ in press

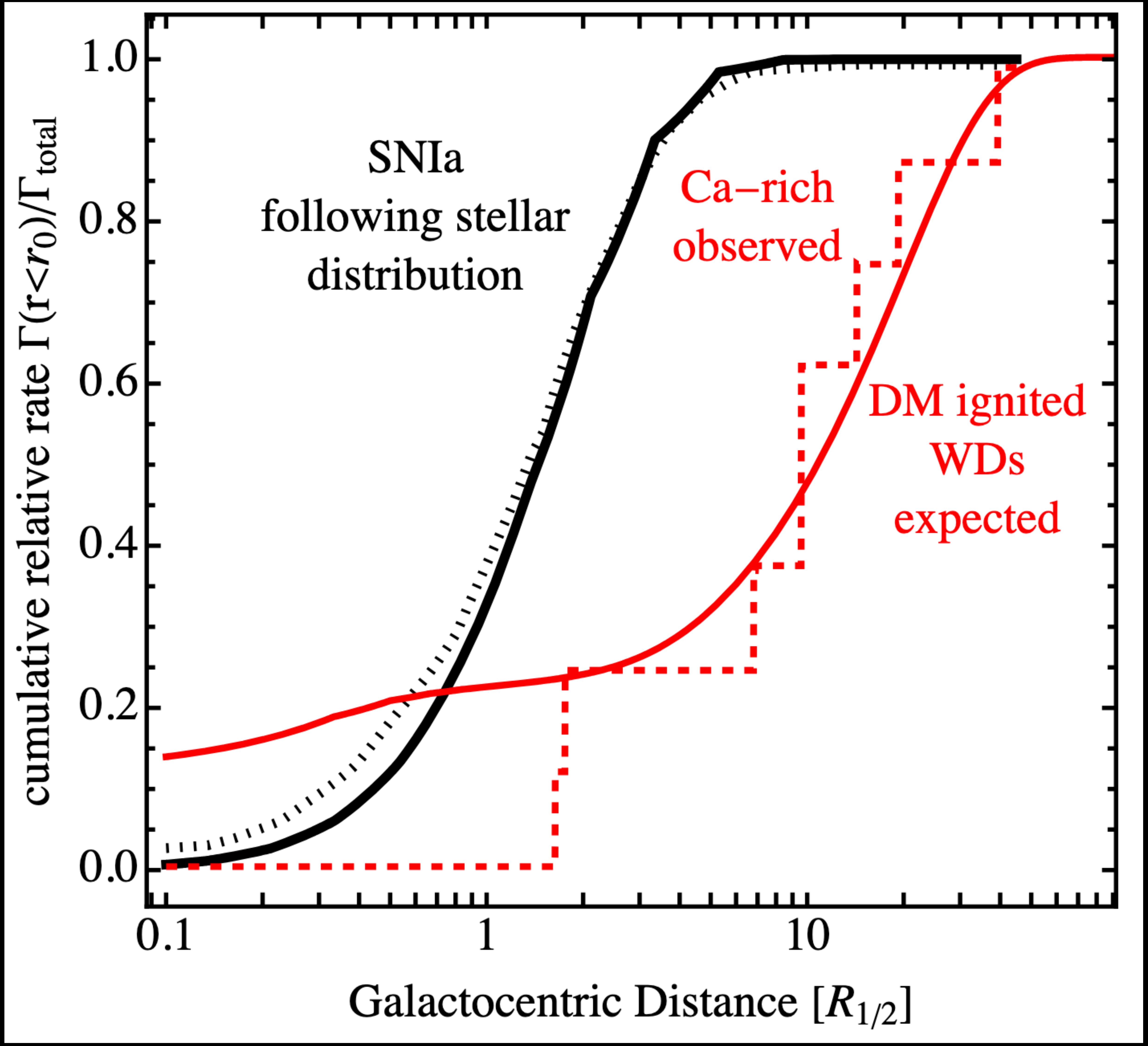
ABSTRACT

We present the Palomar Transient Factory discoveries and the photometric and spectroscopic ob-
servations of PTF11kmb and PTF12bho. We show that both transients have properties consistent
with the class of calcium-rich gap transients, specifically lower peak luminosities and rapid evolutio
compared to ordinary supernovae, and a nebular spectrum dominated by [Ca II] emission. A strik
ture of both transients is their host environments: PTF12bho is an intra-cluster transient i
Cluster, while PTF11kmb is located in a loose galaxy group, at a physical offset ~ 15
ost likely host galaxy. Deep Subaru imaging of PTF12bho rules out an underlyi
it of $M_R > -8.0$ mag, while *Hubble Space Telescope* imaging of PTF11kmb
t that, if real, could be either a background galaxy or a globular cluster
ion of Ca-rich gap transients is significantly more extreme than th
short-hard gamma-ray bursts (sGRBs). Thus, if the offset
k velocities and/or longer merger times than sGRBs.
nd to date are in group and cluster environment
enitor population; the remote locations c
largest fraction of stars in the intra-
ial (PTF11kmb, PTF12

Fitting both the Number and Distribution of Ca-Rich Transients

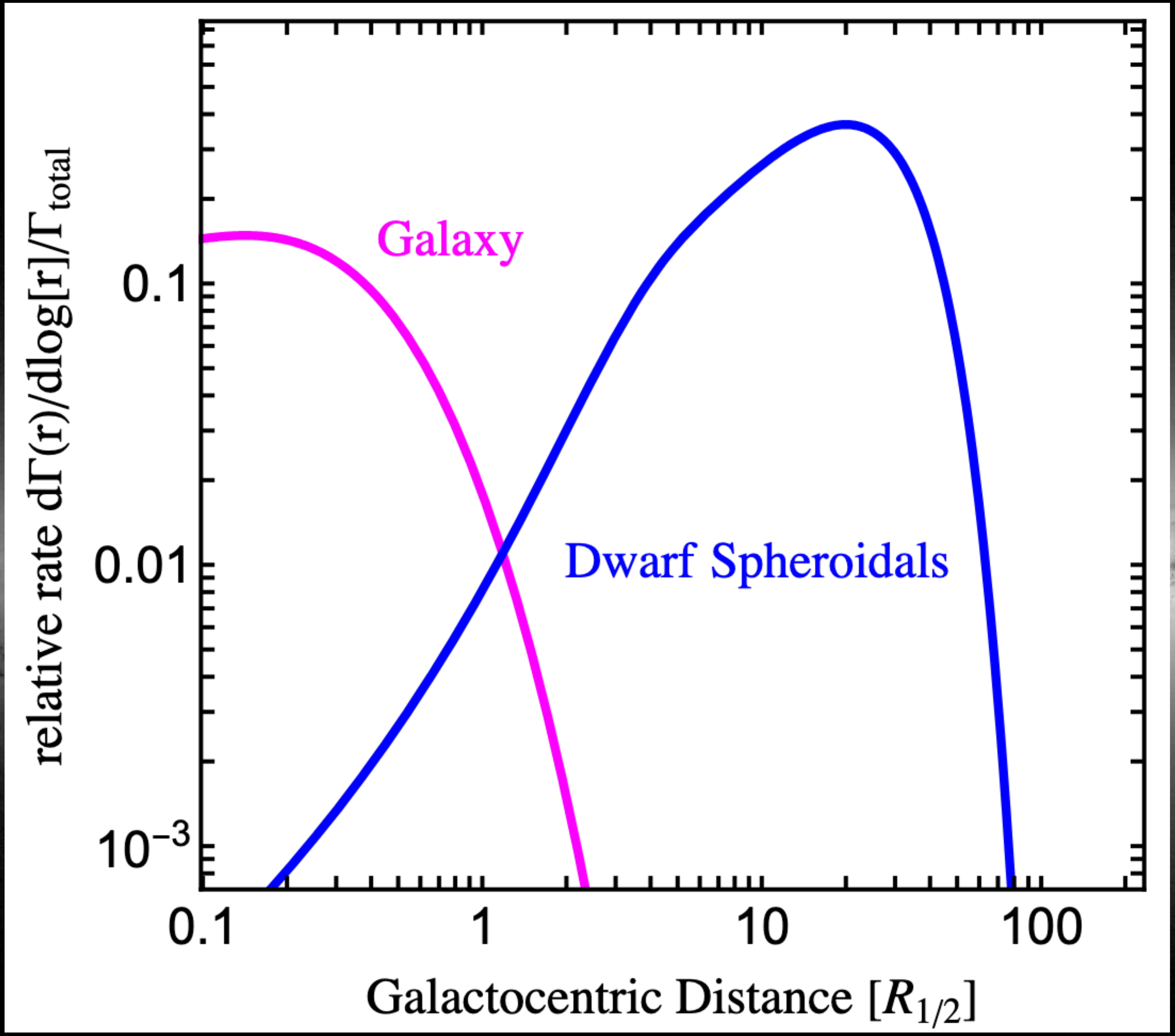
- **Low-luminosity and high-calcium content of Ca-rich population indicates low-mass progenitors (~0.6 $M_{\odot}$, far below the Chandrasekhar mass)**

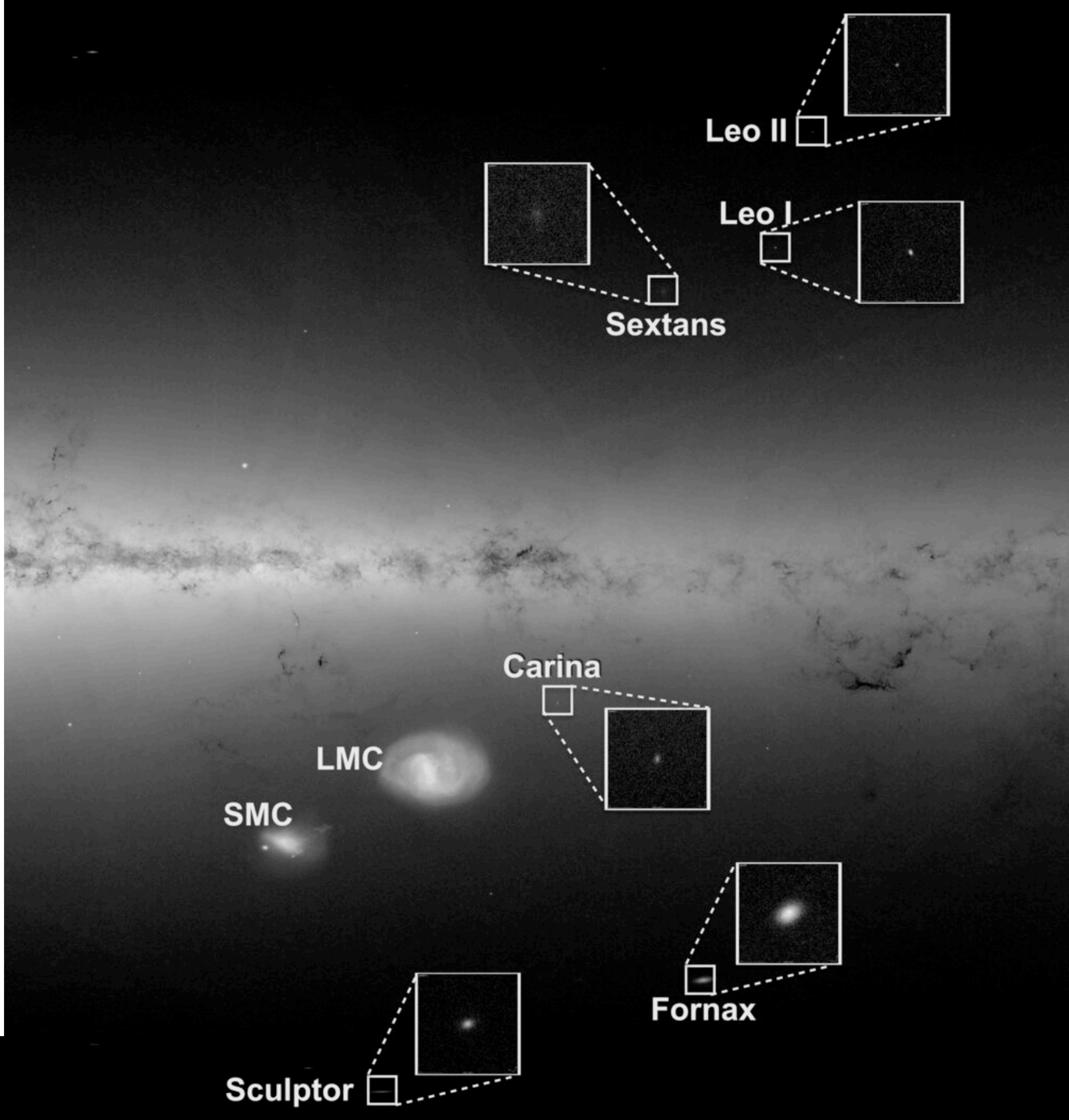
- **Distribution of events in galactic center radius is also unusual.**



$$C_X \simeq \sqrt{\frac{6}{\pi}} \left(\frac{\rho_X}{\bar{v}_X}\right) \frac{\xi N_B v_{\rm esc}^2}{m_X} \left[1 - \frac{1 - \exp(-B^2)}{B^2}\right] f\left(\sigma_{nX}\right) \tag{1}$$

$$v_{esc} = 10.9 \left(\frac{M}{10^7 M_\odot}\right)^{1/3} \left[\frac{1+z}{9.5}\right]^{1/2} \frac{\rm km}{\rm s}$$

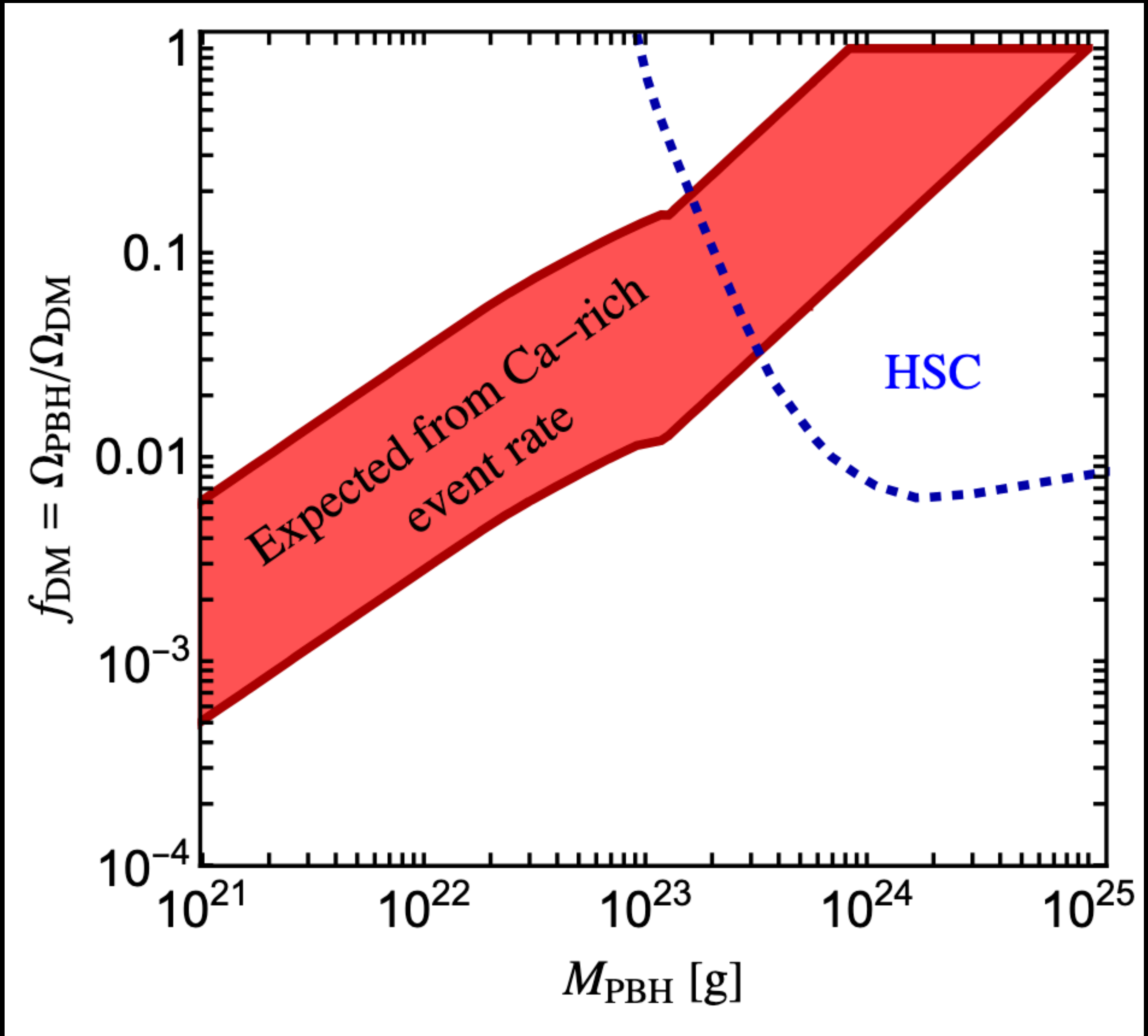

relative rate dΓ(r)/dlog[r]/Γ total
0.1
0.01
10^{-3}
Galaxy
Dwarf Spheroidals
0.1
1
10
100
Galactocentric Distance [$R_{1/2}$]


Leo II
Leo I
Sextans
Carina
LMC
SMC
Fornax
Sculptor

Fitting both the Number and Distribution of Ca-Rich Transients

- “Miracle” - Dark Matter must be relatively low-mass black holes (but can be a subdominant portion of the total dark matter density).

- Standard kinematic interactions rates and dark matter abundance.



Observational Follow-Ups are Motivated

- Searches for Ca-Rich SNe are a key science component for upcoming LSST analyses.

- JWST follow-ups of these sources can potentially detect nearby dwarf galaxies.

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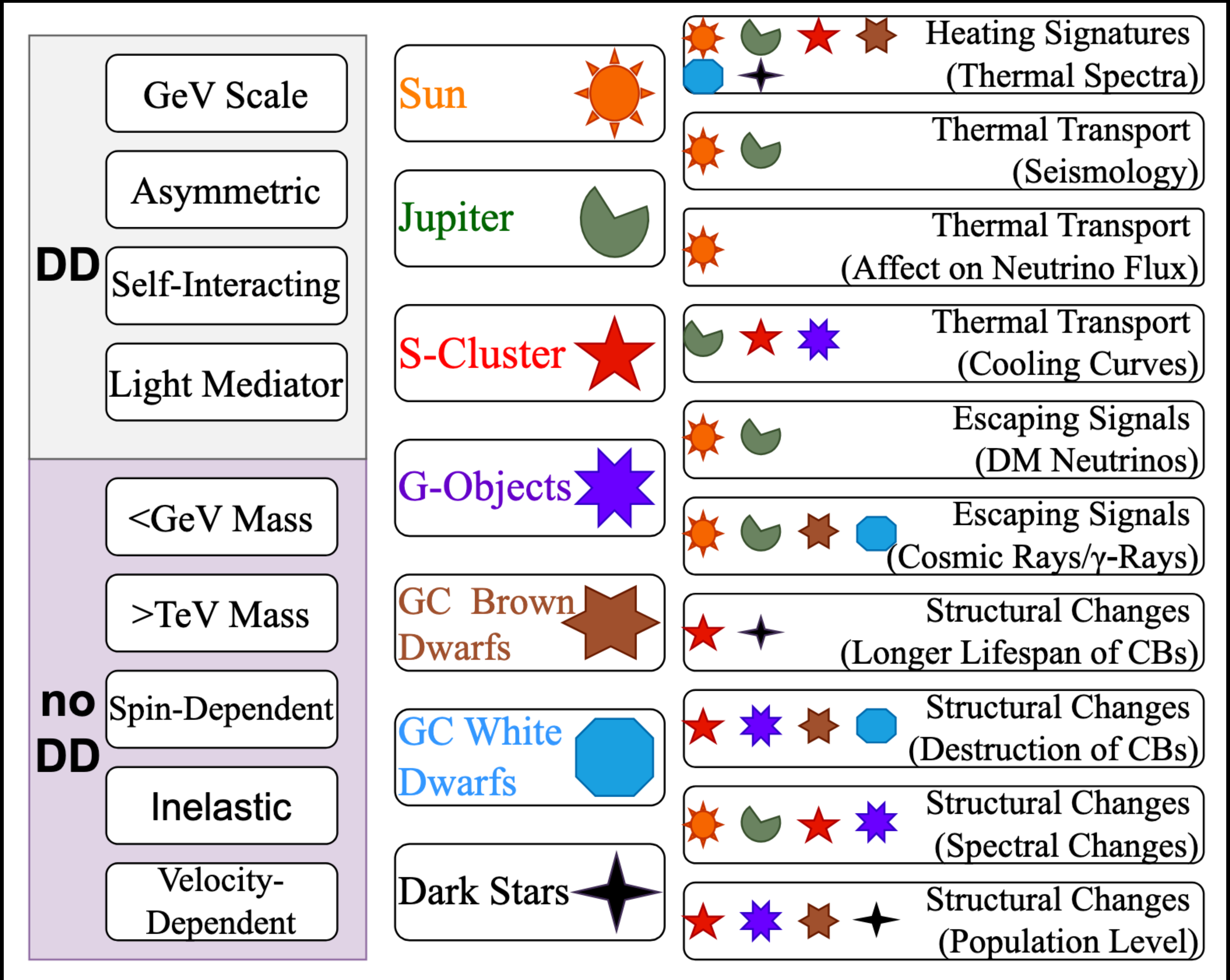
How to Do Science in the High-Risk High-Reward Regime

- “What we need to do is combine to form a larger collaboration that can push the type of dedicated experiments that are capable of setting strong limits on dark matter in celestial bodies.”

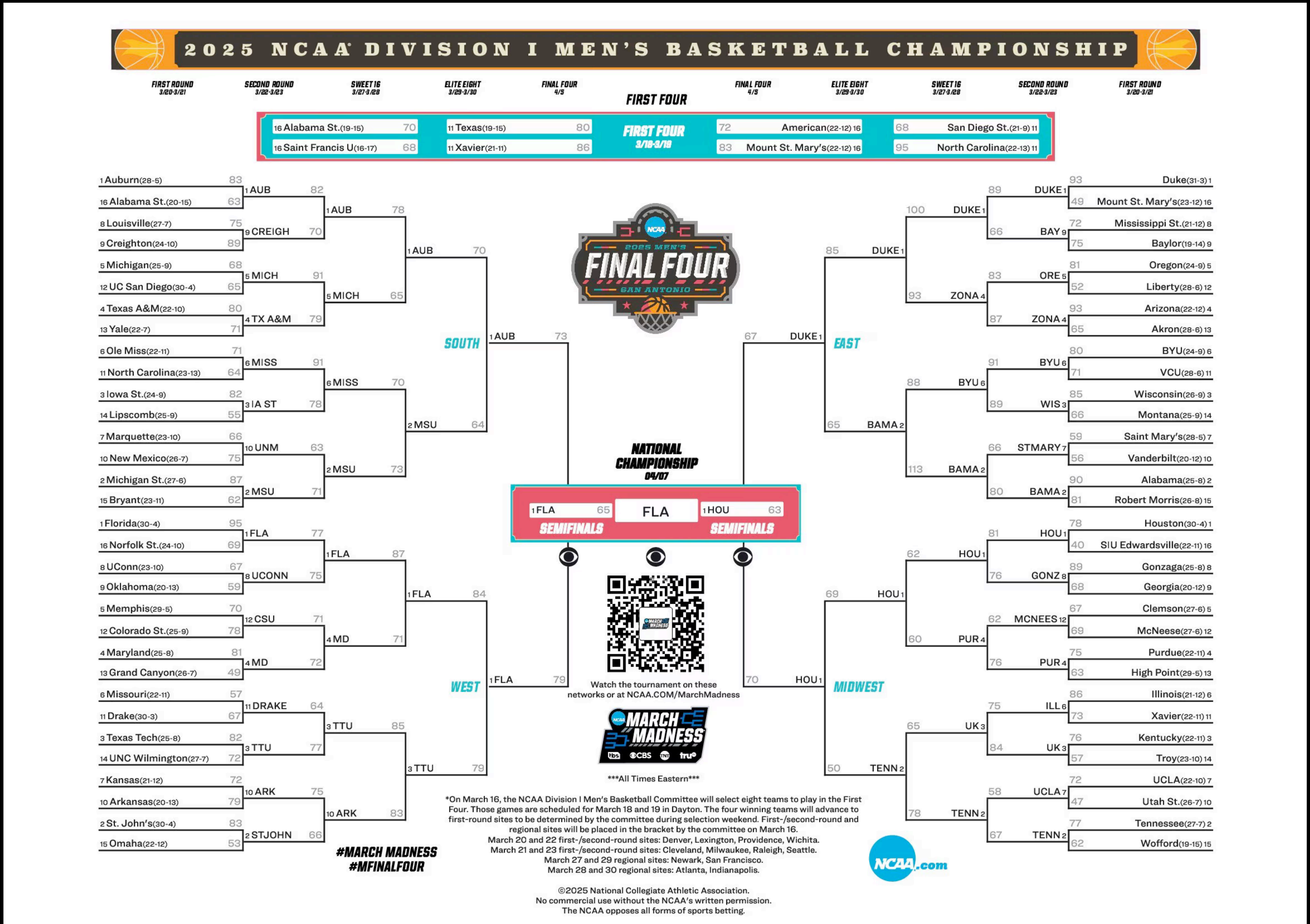
How to Do Science in the High-Risk High-Reward Regime

- “In order to get funding, we need to couple our astrophysical searches with a dedicated experimental program.”

Conclusions



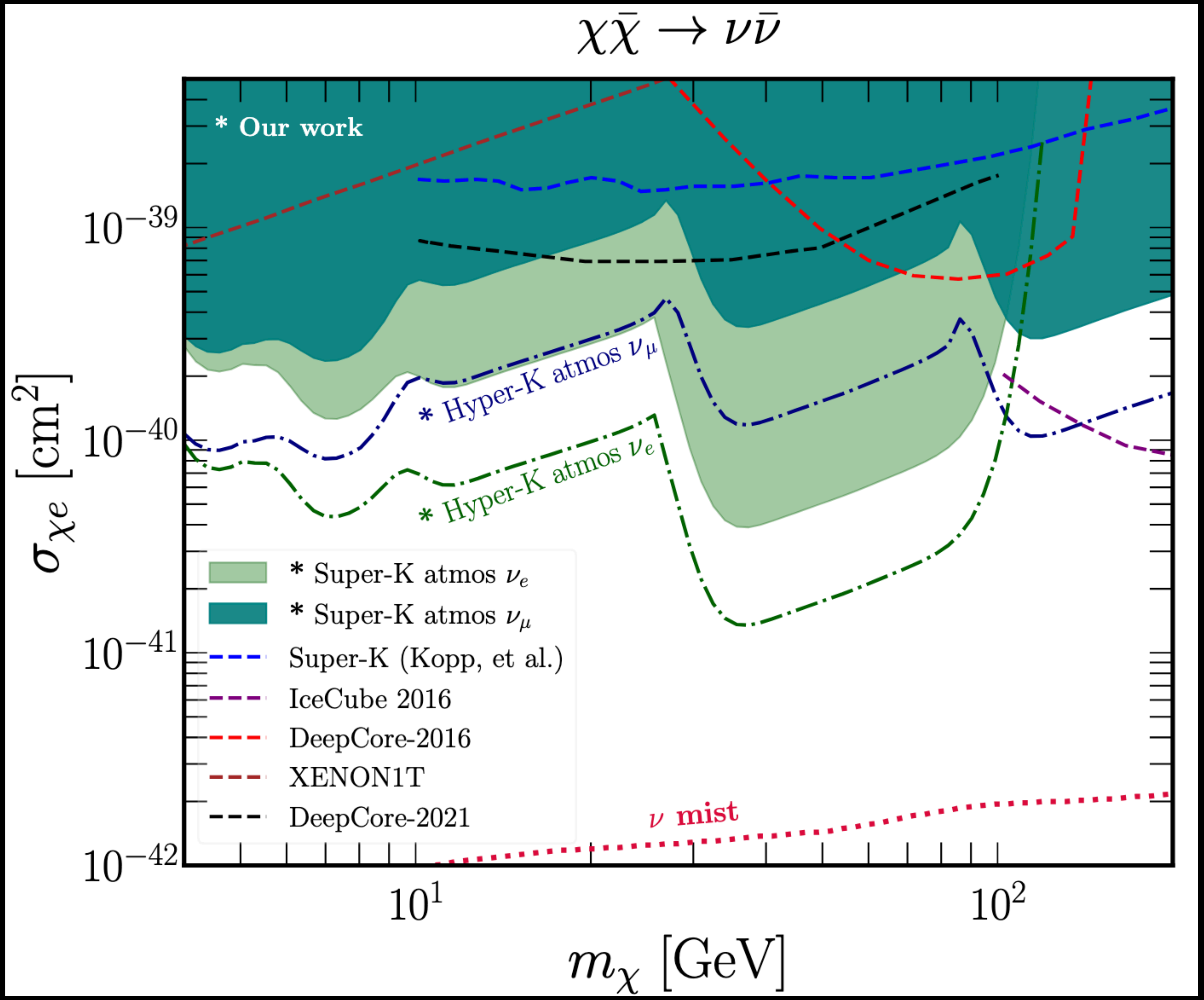
Conclusions

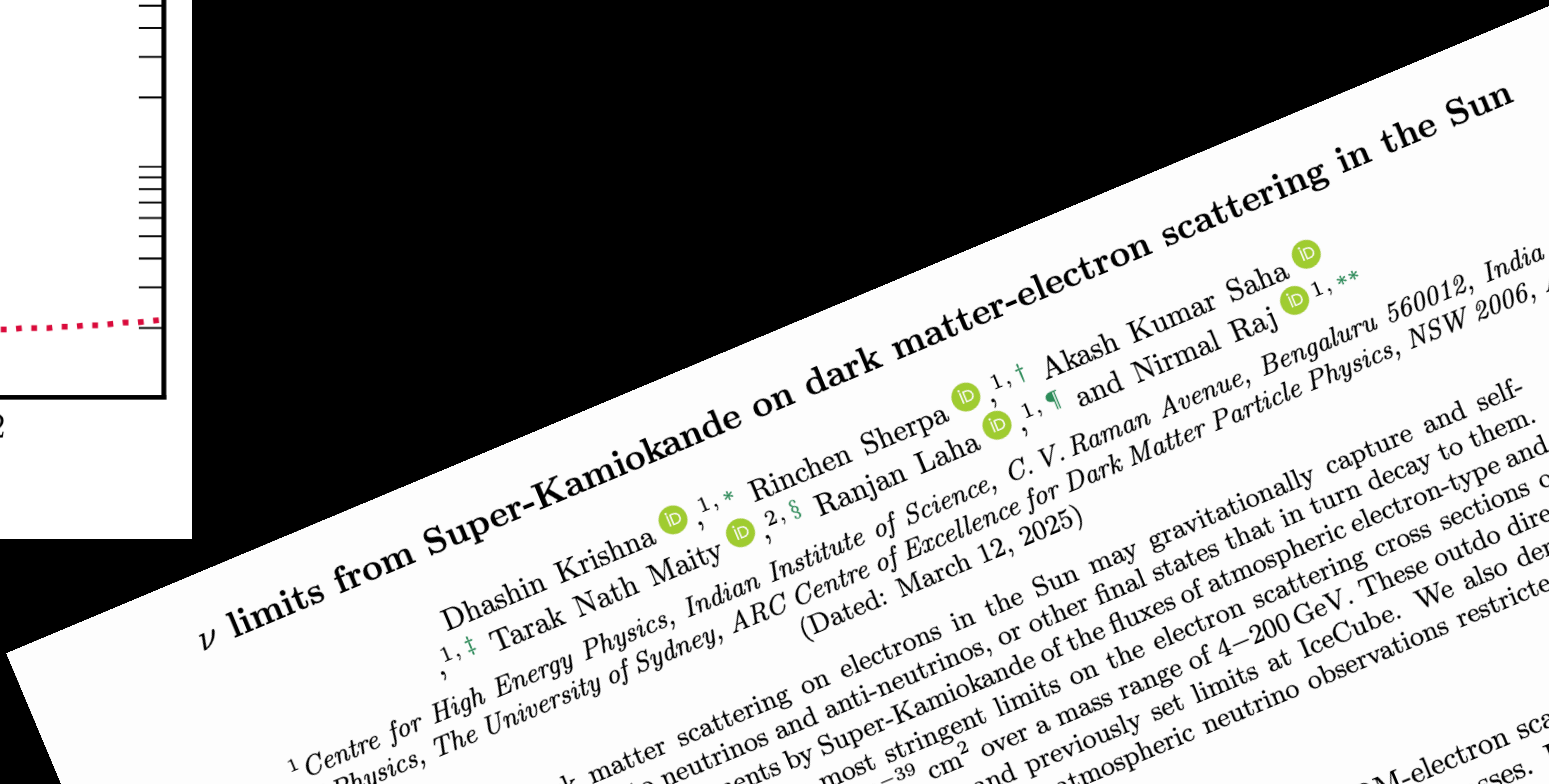


Super-Kamiokande

- When the cross-sections are velocity or momentum dependent, the high velocity of electrons makes constraints much stronger, probing the theoretical targets for leptophilic DM.

A Note Regarding 2503.07713




ν limits from Super-Kamiokande on dark matter-electron scattering in the Sun

Dhashin Krishna [1,*] Rinchen Sherpa [1,†] Akash Kumar Saha
[1,‡] Tarak Nath Maity [2,§] Ranjan Laha [1,¶] and Nirmal Raj [1,**]

[1] Centre for High Energy Physics, Indian Institute of Science, C. V. Raman Avenue, Bengaluru 560012, India
Physics, The University of Sydney, ARC Centre of Excellence for Dark Matter Particle Physics, NSW 2006,

(Dated: March 12, 2025)

k matter scattering on electrons in the Sun may gravitationally capture and self-
neutrinos and anti-neutrinos, or other final states that in turn decay to them.
ents by Super-Kamiokande of the fluxes of atmospheric electron-type and
most stringent limits on the electron scattering cross sections
$^{-39}$ cm^2 over a mass range of 4–200 GeV. These outdo dire
and previously set limits at IceCube. We also de
atmospheric neutrino observations restricte

A Note Regarding 2503.07713

Gould, 1987a (Astrophys.J. 321 (1987) 560)

$$R(w \to v) = \frac{4\mu_+^4}{\pi^{\frac{1}{2}}} N\sigma \frac{v}{w} \int_0^\infty dx \int_{-\infty}^\infty dy \kappa^3 (x+y) e^{-\kappa^2 u^2} \theta(v - \mid y \mid) \theta(x - w) \quad \text{(A11)}$$

$$= \frac{2}{\pi^{\frac{1}{2}}} \frac{\mu_+^2}{\mu} N\sigma \frac{v}{w} [\chi(-\alpha_-, \alpha_+) + \chi(-\beta_-, \beta_+) e^{-\frac{M}{2T}(v^2 - w^2)}]. \quad \text{(A15)}$$

Garani & Palomares-Ruiz (1702.02768)

$$\begin{aligned} R_i(w \to v) &= \int n_i(r) \frac{\mathrm{d}\sigma_i}{\mathrm{d}v} |\boldsymbol{w} - \boldsymbol{u}| f_i(\boldsymbol{u}, r) \, \mathrm{d}^3\boldsymbol{u} \\ &= \frac{2}{\sqrt{\pi}} \frac{n_i(r)}{u_i^3(r)} \int_0^\infty \mathrm{d}u \, u^2 \int_{-1}^1 \mathrm{d}\cos\theta \, \frac{\mathrm{d}\sigma_i}{\mathrm{d}v} |\boldsymbol{w} - \boldsymbol{u}| \, e^{-u^2/u_i^2(r)} \,, \end{aligned} \quad \text{(A.1)}$$

A Note Regarding 2503.07713

$$C = \left[\left(\frac{8}{3\pi}\right)^{\frac{1}{2}}\sigma n_W \bar{v}\right]\left[\frac{M_B}{m}\right]\left[\frac{3{v_{\rm esc}}^2}{2\bar{v}^2}\left\langle\hat{\phi}\right\rangle\right]\left[\xi_\eta(\infty)\right]\left\langle \frac{\hat{\phi}}{\left\langle\hat{\phi}\right\rangle}\left(1-\frac{1-e^{-A^2}}{A^2}\right)\frac{\xi_1(A)}{\xi_\eta(\infty)}\right\rangle, \qquad (2.31)$$

Moreover, the distribution of energy loss is uniform over this interval. On the other hand, scattering from velocity w to a velocity less than v, requires an energy loss of *at least*

$$\frac{\Delta E}{E} \geq \frac{w^2 - v^2}{w^2} = \frac{u^2}{w^2}. \qquad (2.11)$$

Combining expressions (2.9) and (2.11) gives the probability that a given scattering will leave the WIMP with less than escape energy,

$$\frac{\mu_+^2}{\mu} \cdot \left(\frac{\mu}{\mu_+^2} - \frac{u^2}{w^2}\right)\ \theta\left(\frac{\mu}{\mu_+^2} - \frac{u^2}{w^2}\right). \qquad (2.12)$$

The rate of scattering from w to less than v is just the product of the total rate of scattering, $\sigma n w$, with the conditional probability (2.12). This result may be written,

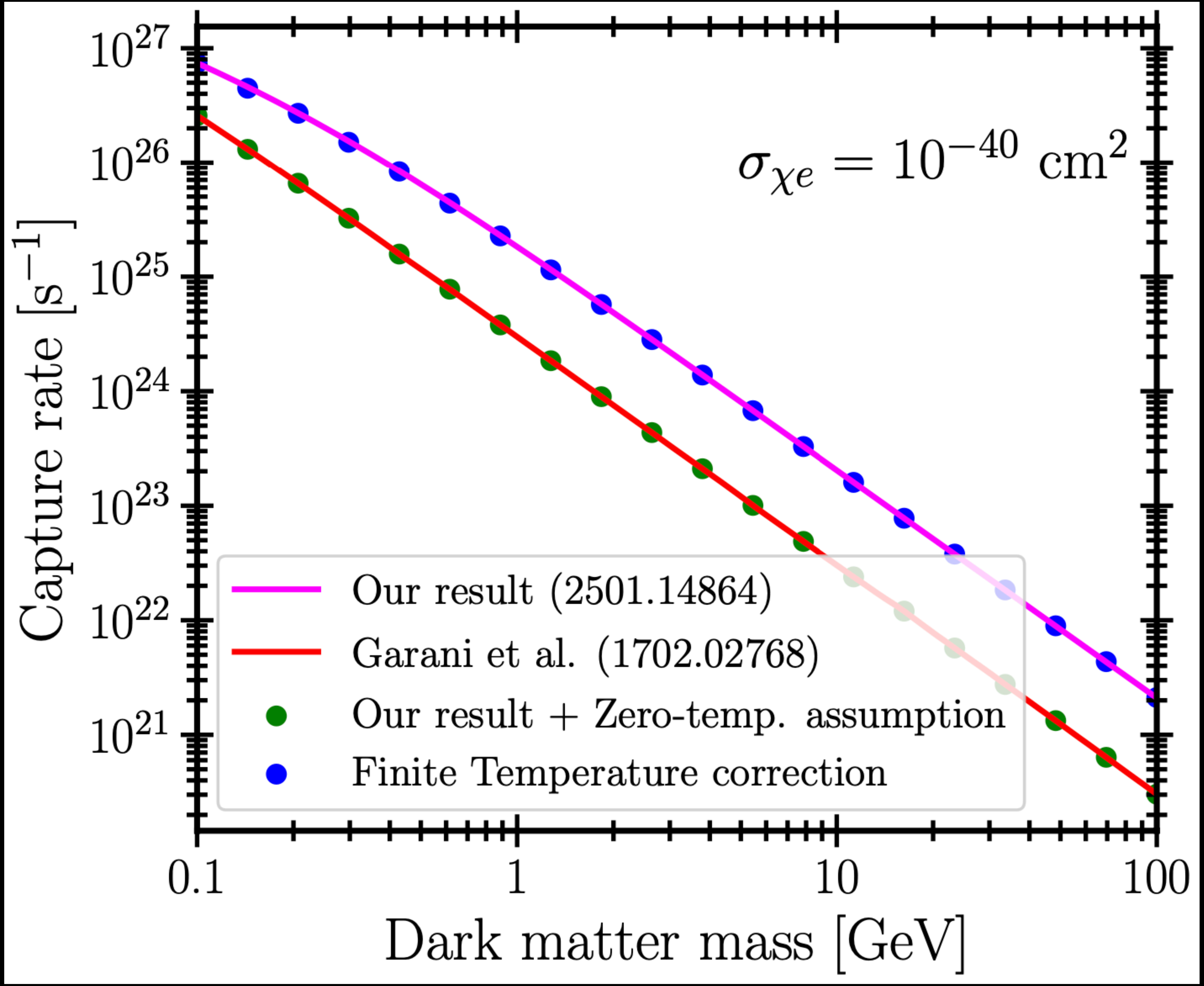
$$\Omega_v^-(w) = \frac{\sigma n}{w}\left(v^2 - \frac{\mu_-^2}{\mu}u^2\right)\ \theta\left(v^2 - \frac{\mu_-^2}{\mu}u^2\right). \qquad (2.13)$$

Gould, 1987b (Astrophys.J. 321 (1987) 571)

A Note Regarding 2503.07713

- **Incorrectly adding a zero-temperature kinematic cutoff significantly suppresses the leptophilic dark matter capture rate in the Sun (by a factor of ~7).**

- **Correcting this error leads to stronger limits in many studies.**



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$$A - M \geq -1$$

Constraints