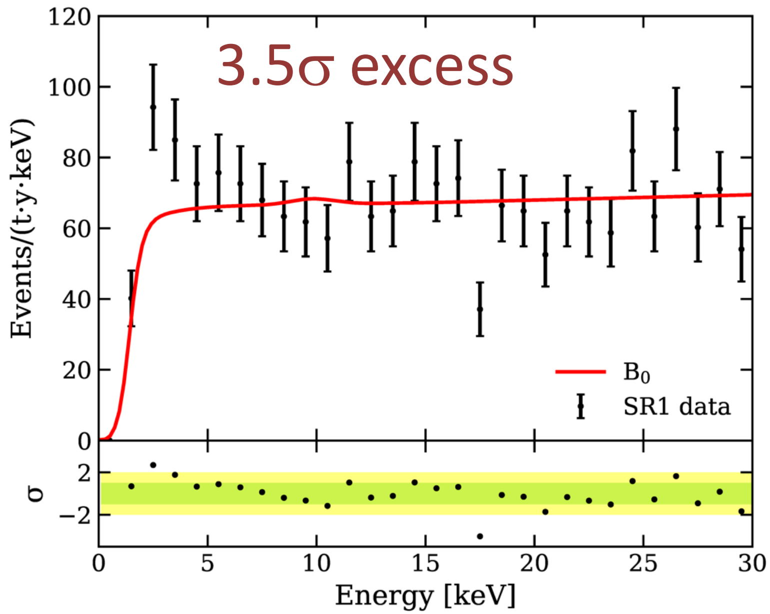
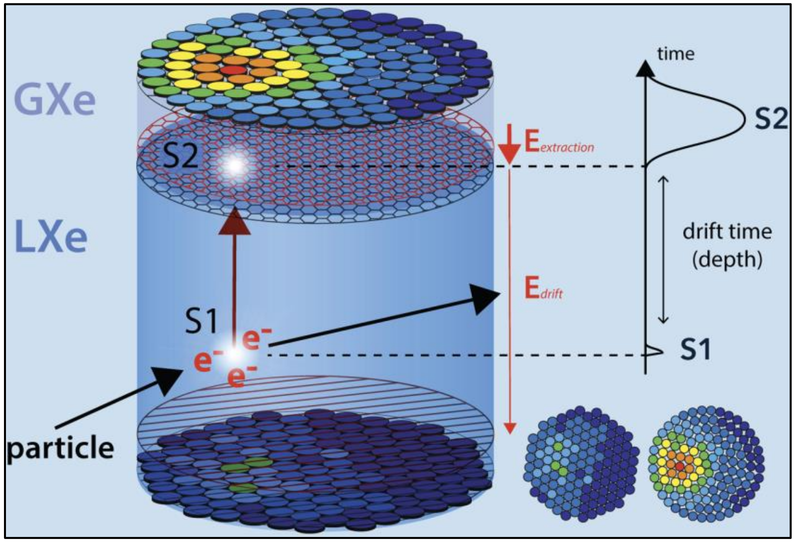
# Can the XENON1T Excess Be Explained by Solar Axions, ALPs or Hidden Photons?

**Georg Raffelt**
**MPI Physik, München**




**Talk commissioned by Béla Majorovits on short notice**
**For MADMAX Collaboration Meeting 28–30 Sept 2020**

# Betteridge's law of headlines

Aka Davis's Law or Hinchliffe's Rule

From Wikipedia, the free encyclopedia

**Betteridge's law of headlines** is an adage that states: "Any headline that ends in a question mark can be answered by the word *no*." It is named after Ian Betteridge, a British technology journalist who wrote about it in 2009, although the principle is much older.[1][2] Like similar "laws" (e.g., Murphy's law), it is intended to be humorous rather than the literal truth.[3][*failed verification*] The adage fails to make sense with questions that are more open-ended than strict yes–no questions.[4]

The maxim has been cited by other names since 1991, when a published compilation of Murphy's Law variants called it "Davis's law", a name that also crops up online without any explanation of who Davis was.[5][6][7][8] It has also been referred to as the "**journalistic principle**" and in 2007 was referred to in commentary as "an old truism among journalists".[9][10][11]

**Contents** [hide]

1 History
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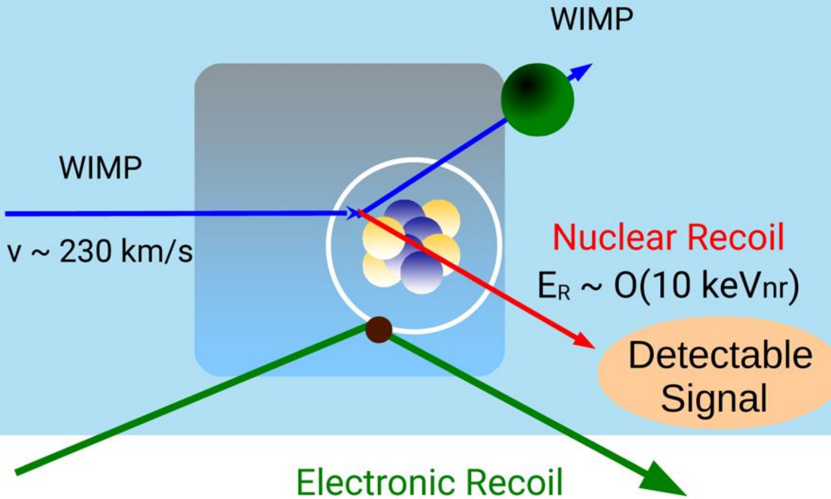
## History [ edit ]

Ian Betteridge's name became associated with the concept after he discussed it in a February 2009 article, which examined a previous TechCrunch article that carried the headline "Did Last.fm Just Hand Over User Listening Data to the RIAA?".(Schonfeld 2009):

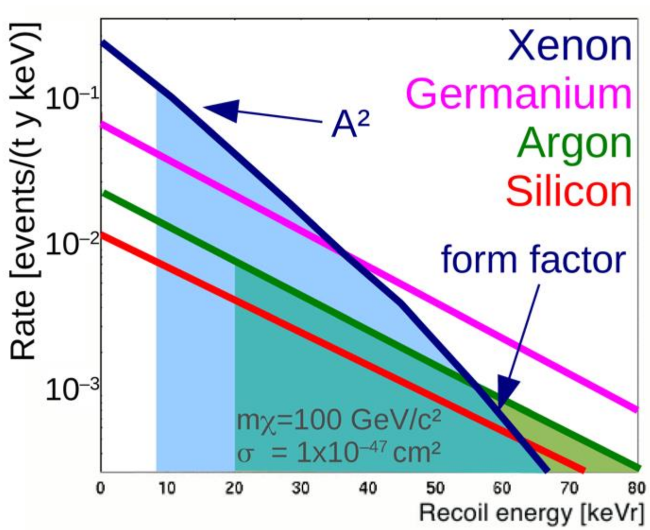
> This story is a great demonstration of my maxim that any headline which ends in a question mark can be answered by the word "no." The reason why journalists use that style of headline is that they know the story is probably bullshit, and don't actually have the sources and facts to back it up, but still


# Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
➡ nuclear recoil

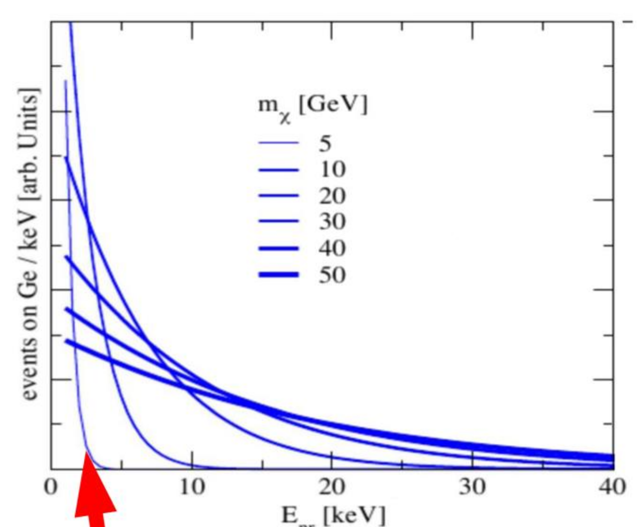



Recoil Spectra:




tiny!

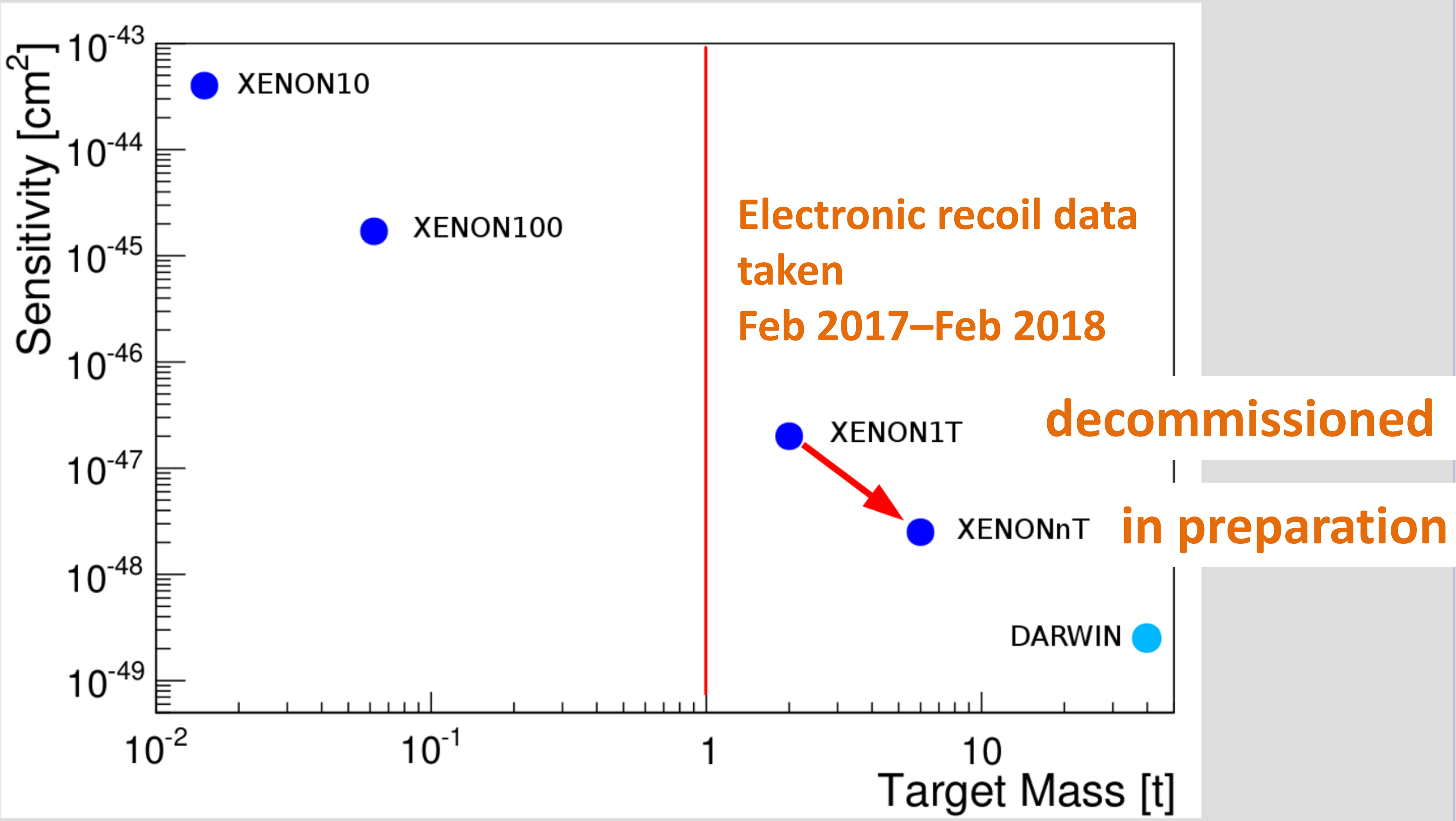
tiny!




low mass → low threshold

# XENON1T Detector at LNGS

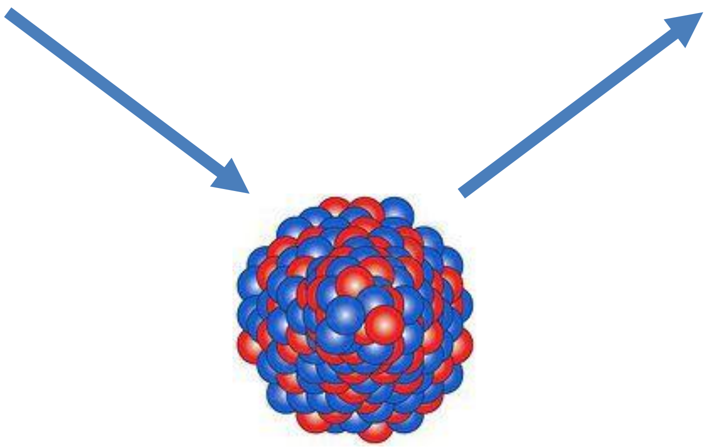
# XENON Instruments




The XENON collaboration develops and operates
dark matter detectors of increasing size and sensitivity

# keV-Range Energy Depositions

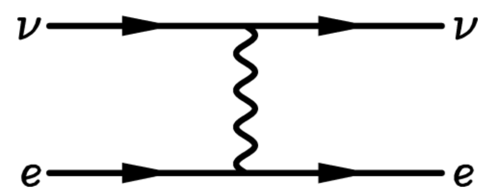
## Nuclear recoil



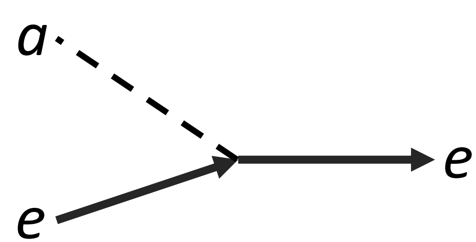
Dark-matter WIMPs

Coherent scattering of
10 MeV solar neutrinos

## Electronic recoil (ER)




Solar neutrinos with large
dipole moments

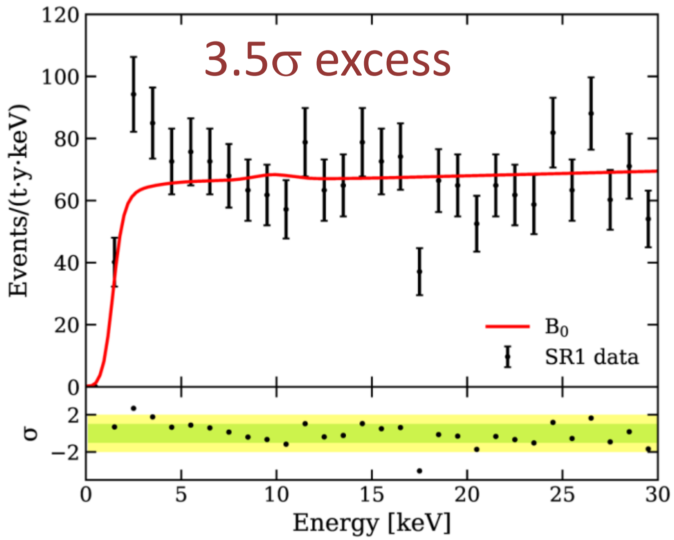


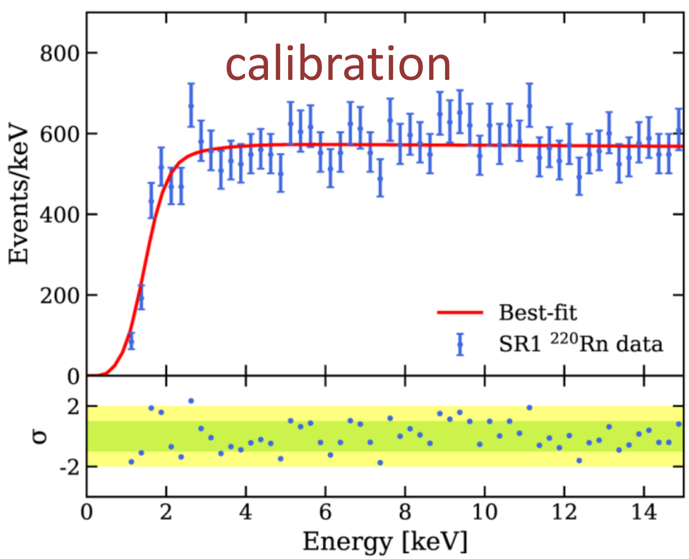

Solar axions (keV energies)

keV-mass bosonic DM particles
(ALP-like, hidden photons, …)

# Observation of Excess Electronic Recoil Events in XENON1T

**arXiv:2006.09721 (17 June 2020), accepted in PRD**

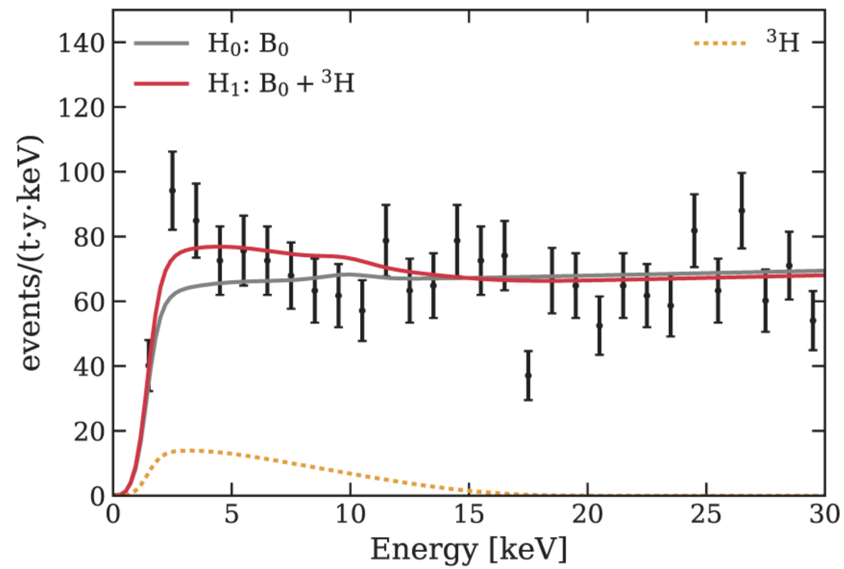



## Beta decay of tritium?

Q = 18.6 keV, half-life 12.3 years

abundant, but removed by purification system




**Fitted tritium signal:**

$$150 \pm 51\ \text{events}/(\text{ton} \times \text{year} \times \text{keV})$$

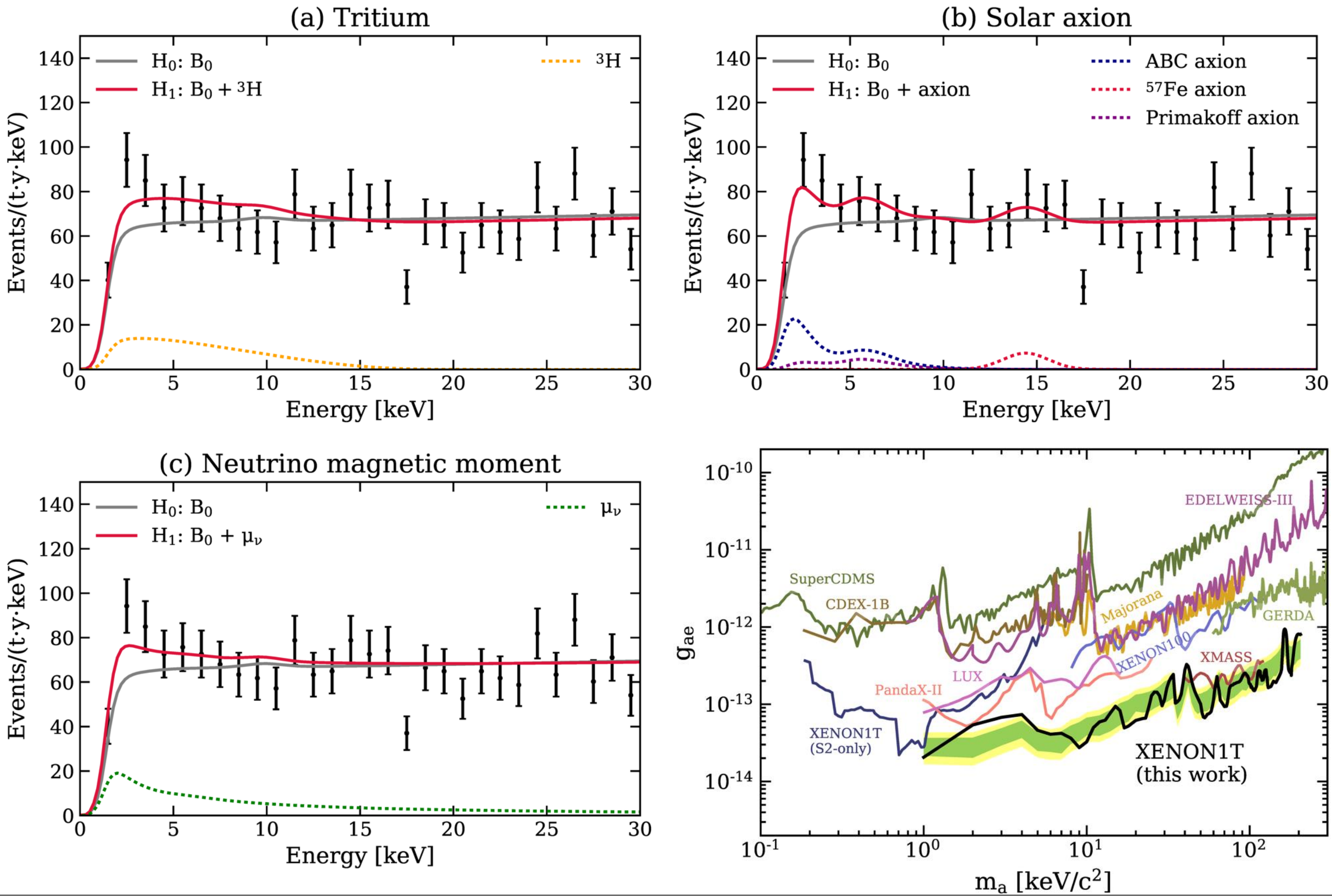
$$T/Xe = 6.2 \pm 2.0 \times 10^{-25}\,\text{mol/mol}$$

**Around 3 tritium atoms per kg of xenon**

**But 100 × expected and other contaminants**

# Observation of Excess Electronic Recoil Events in XENON1T

**arXiv:2006.09721 (17 June 2020), accepted in PRD**



# Some Quick Blog Links

17 June — Resonannes, Particle Physics Blog: **Hail the XENON excess**
http://resonaances.blogspot.com/

The Reference Frame https://motls.blogspot.com/2020/06/xenon1t-our-excess-is-due-to-tritium.html
**XENON1T: our excess is due to tritium junk, axions, or magnetic neutrinos**

18 June — CosmoQuest: **Observation of Excess Events in the XENON1T Dark Matter Experiment**
https://cosmoquest.org/x/2020/06/observation-of-excess-events-in-the-xenon1t-dark-matter-experiment/

19 June — physicsworld, Particle and nuclear
**XENON1T may have detected something very interesting, or maybe not**
https://physicsworld.com/a/xenon1t-may-have-detected-something-very-interesting-or-maybe-not/

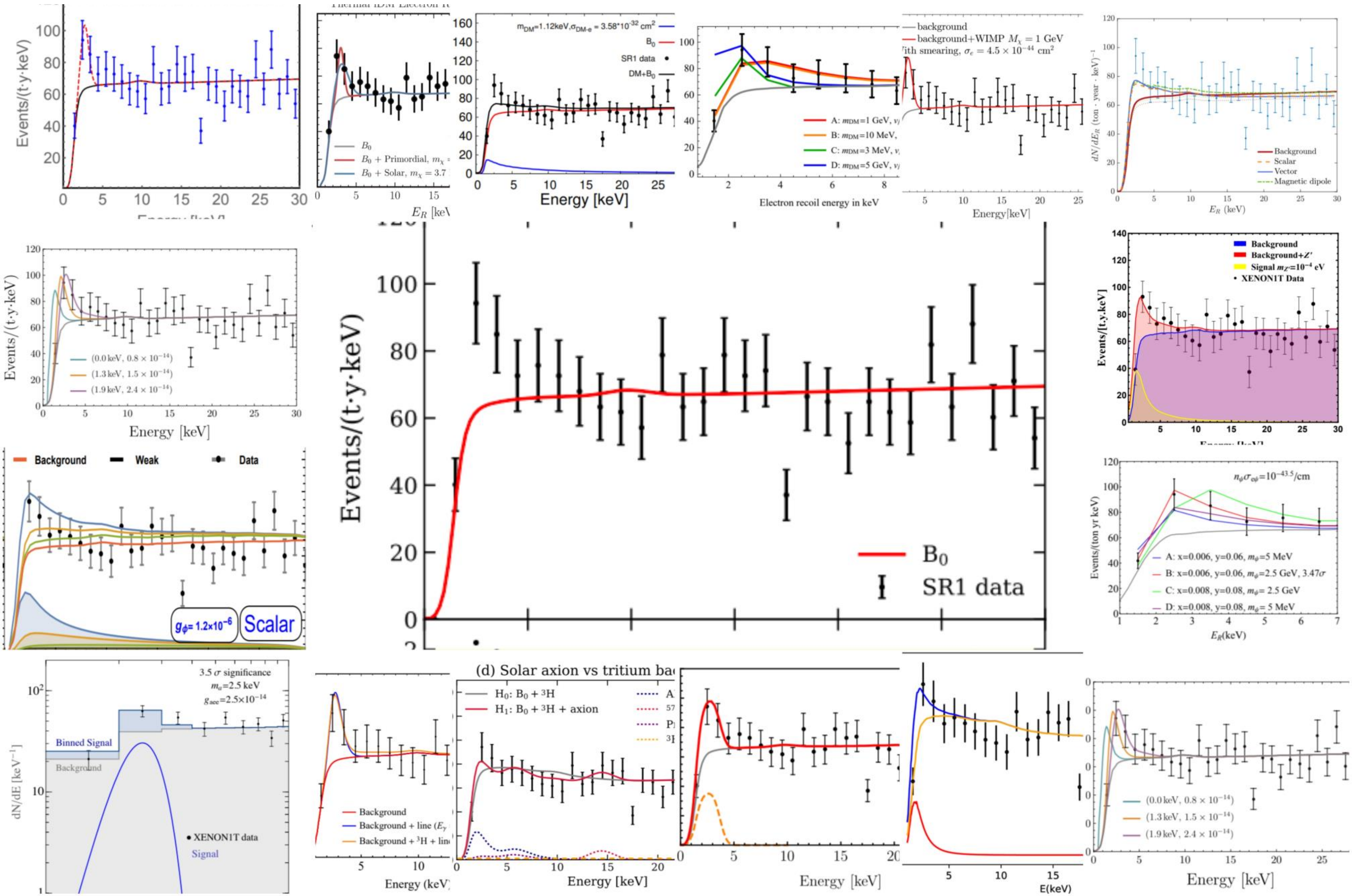
22 June — Centrales Forschungsnetz Aussergewöhnlicher Himmels-Phänomene
**Astronomie: Observation of Excess Events in the XENON1T Dark Matter Experiment**
https://www.hjkc.de/_blog/2020/06/22/15595-astronomie-observation-of-excess-events-in-the-xenon1t-dark-matter-experiment/

30 June — ParticleBites: The high energy physics reader's digest
**The XENON1T Excess : The Newest Craze in Particle Physics**
https://www.particlebites.com/?p=7260

AlphaGalileo
**Observation of Excess Events in the XENON1T Dark Matter Experiment**
https://www.alphagalileo.org/en-gb/Item-Display/ItemId/194613

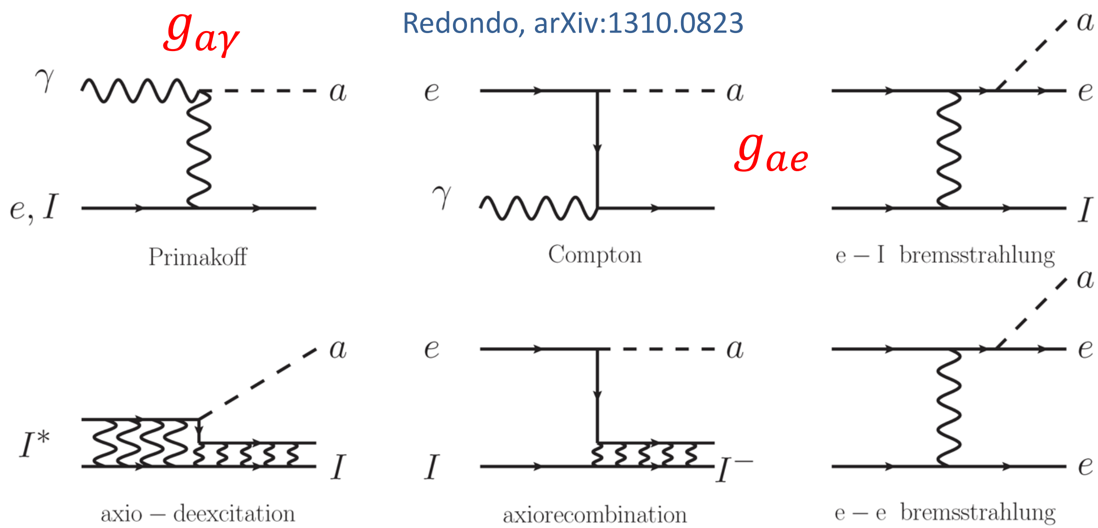
# Collage of fits up to 29 June 2020, Mostly dark matter

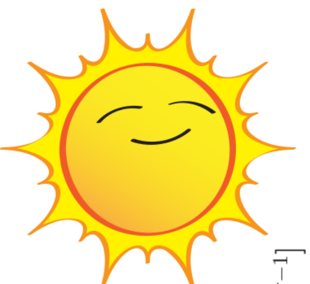
https://twitter.com/OzAmram/status/1277609718085816326

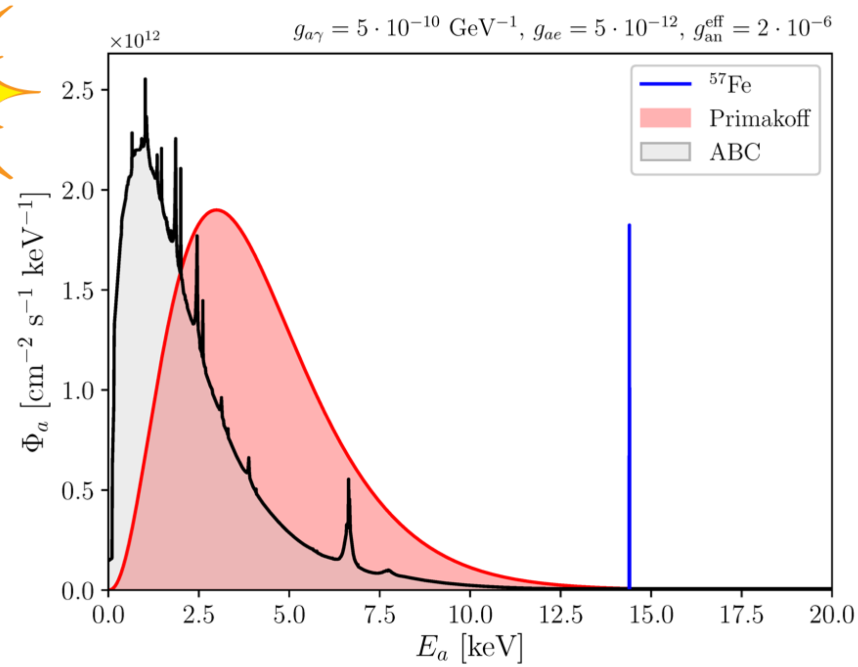


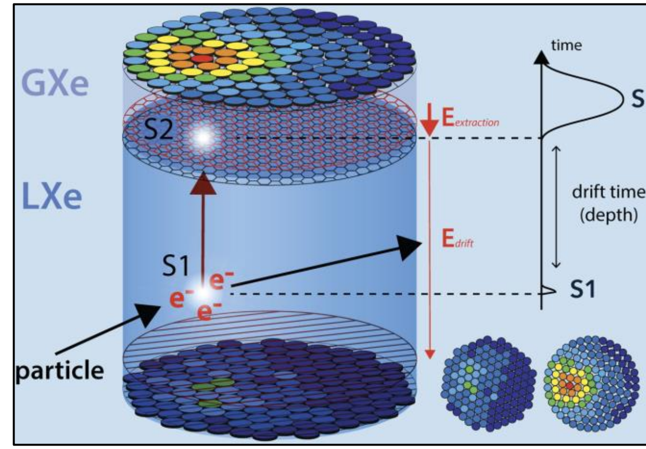
# Solar Axions/ALPs

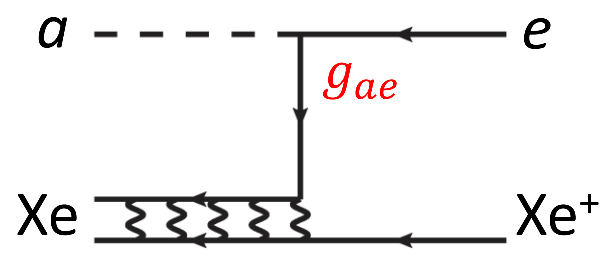
Redondo, arXiv:1310.0823



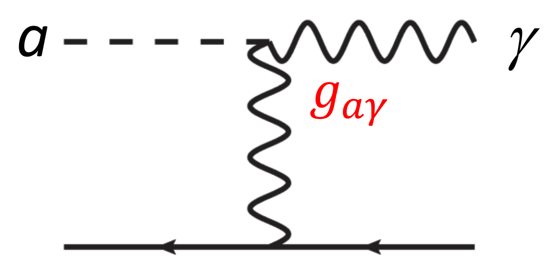






XENON Collab. 2006.09721

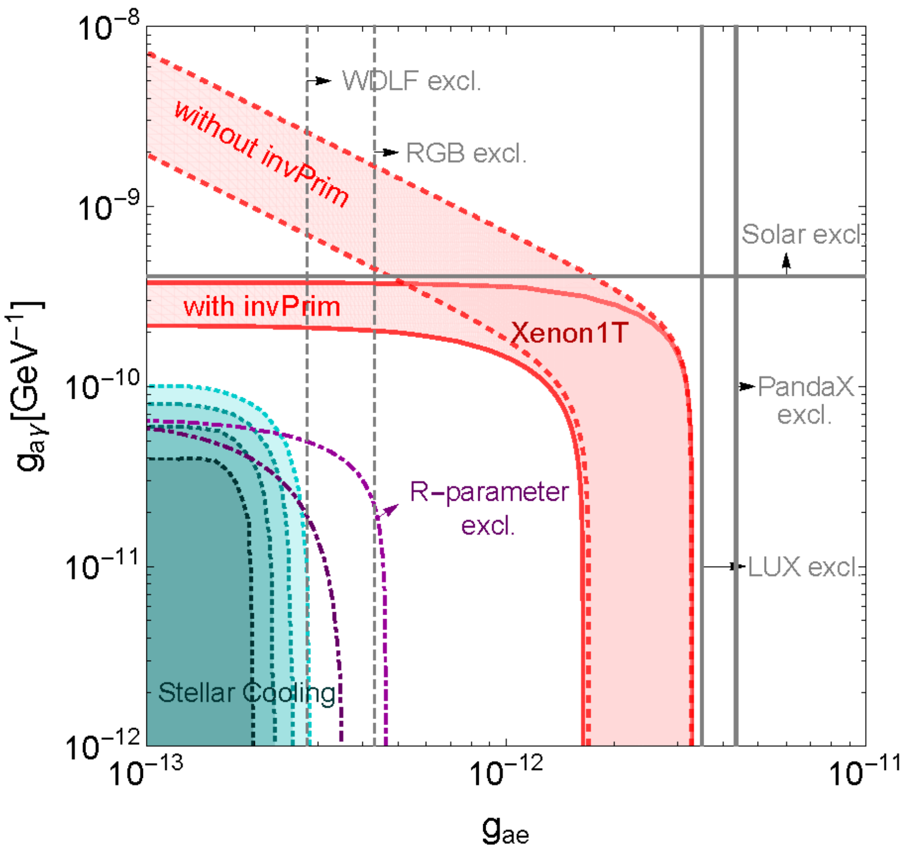



Dent+ 2006.15118, Gao+ 2006.14598

# XENON1T Results for Solar Axions/ALPs

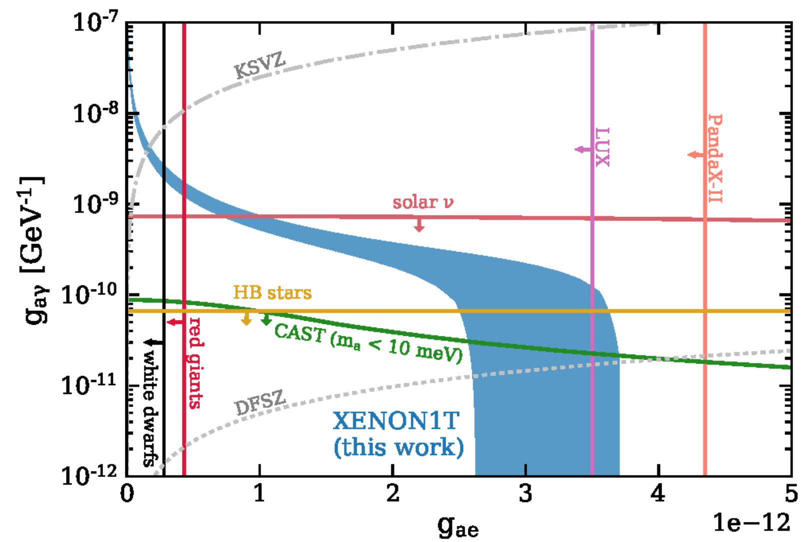
## Gao+ 2006.14598

### Including Primakoff detection




## XENON Collab. 2006.09721

### Only axio-electric detection



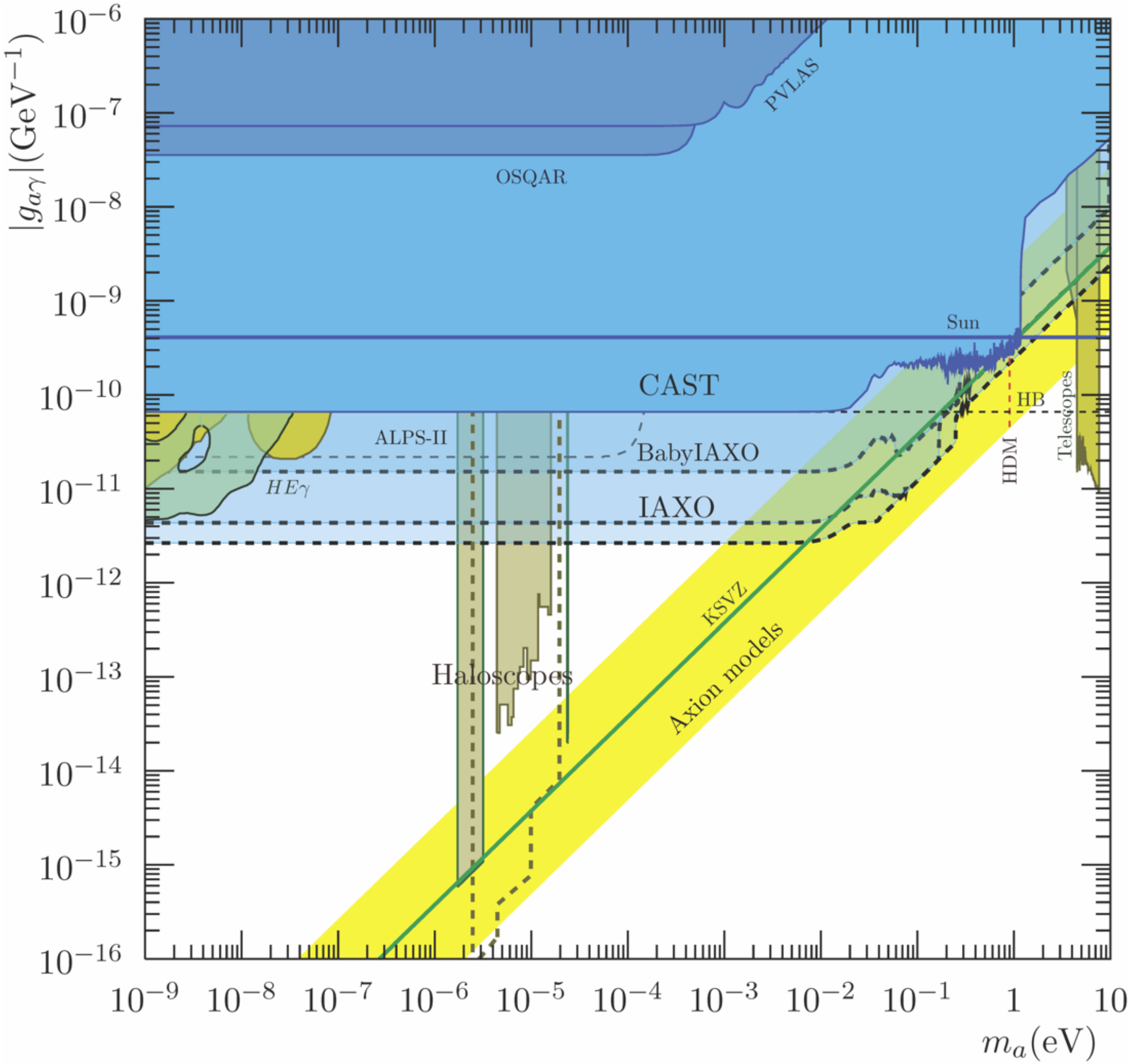

**XENON1T excess cannot be due to solar axions/ALPs by a large margin**

Let's point a magnet at the sun…

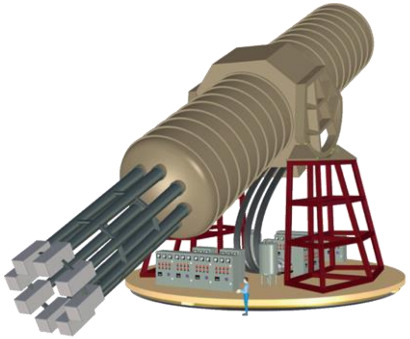
…and look for X-Rays!

By CAST student Sebastian Baum

# IAXO Sensitivity Forecast




**XENON1T Excess**



**Physics potential of the International Axion Observatory (IAXO)**
**JCAP 1906 (2019) 047, arXiv:1904.09155**

Editors' Suggestion

# Solar Axions Cannot Explain the XENON1T Excess

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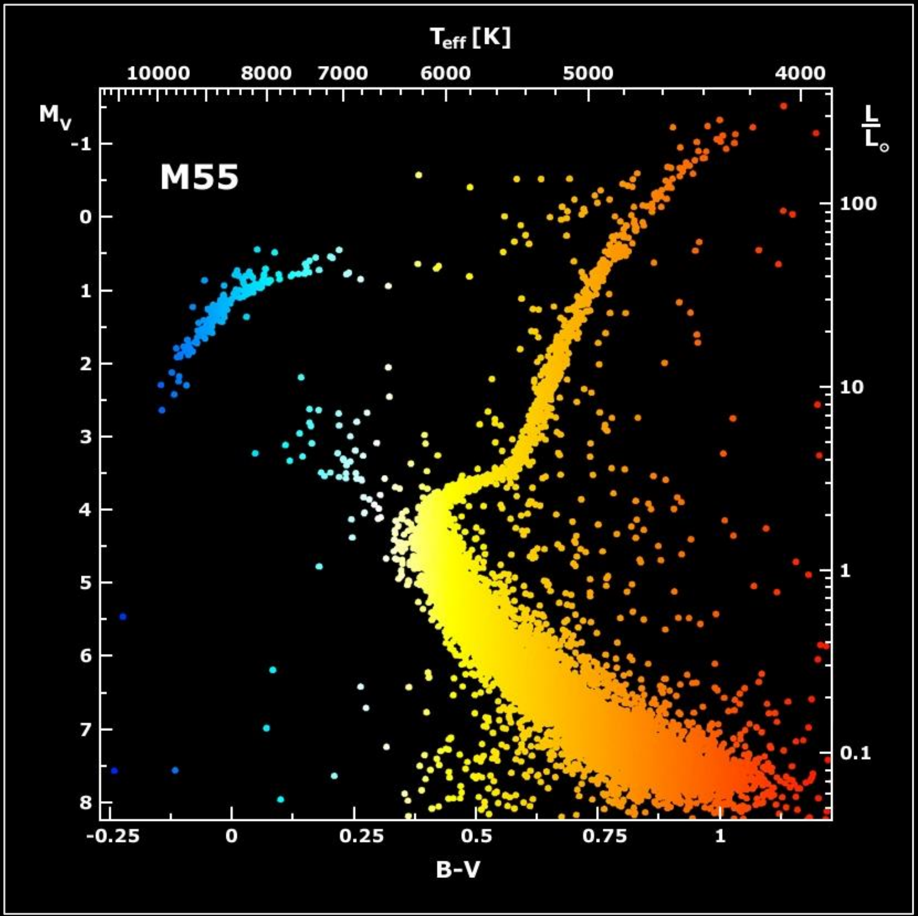
(Received 3 July 2020; revised 23 July 2020; accepted 30 July 2020; published 24 September 2020)

We argue that the interpretation in terms of solar axions of the recent XENON1T excess is not tenable when confronted with astrophysical observations of stellar evolution. We discuss the reasons why the emission of a flux of solar axions sufficiently intense to explain the anomalous data would radically alter the distribution of certain type of stars in the color-magnitude diagram in the first place and would also clash with a certain number of other astrophysical observables. Quantitatively, the significance of the discrepancy ranges from $3.3\sigma$ for the rate of period change of pulsating white dwarfs and exceeds $19\sigma$ for the $R$ parameter and for $M_{I,\mathrm{TRGB}}$.

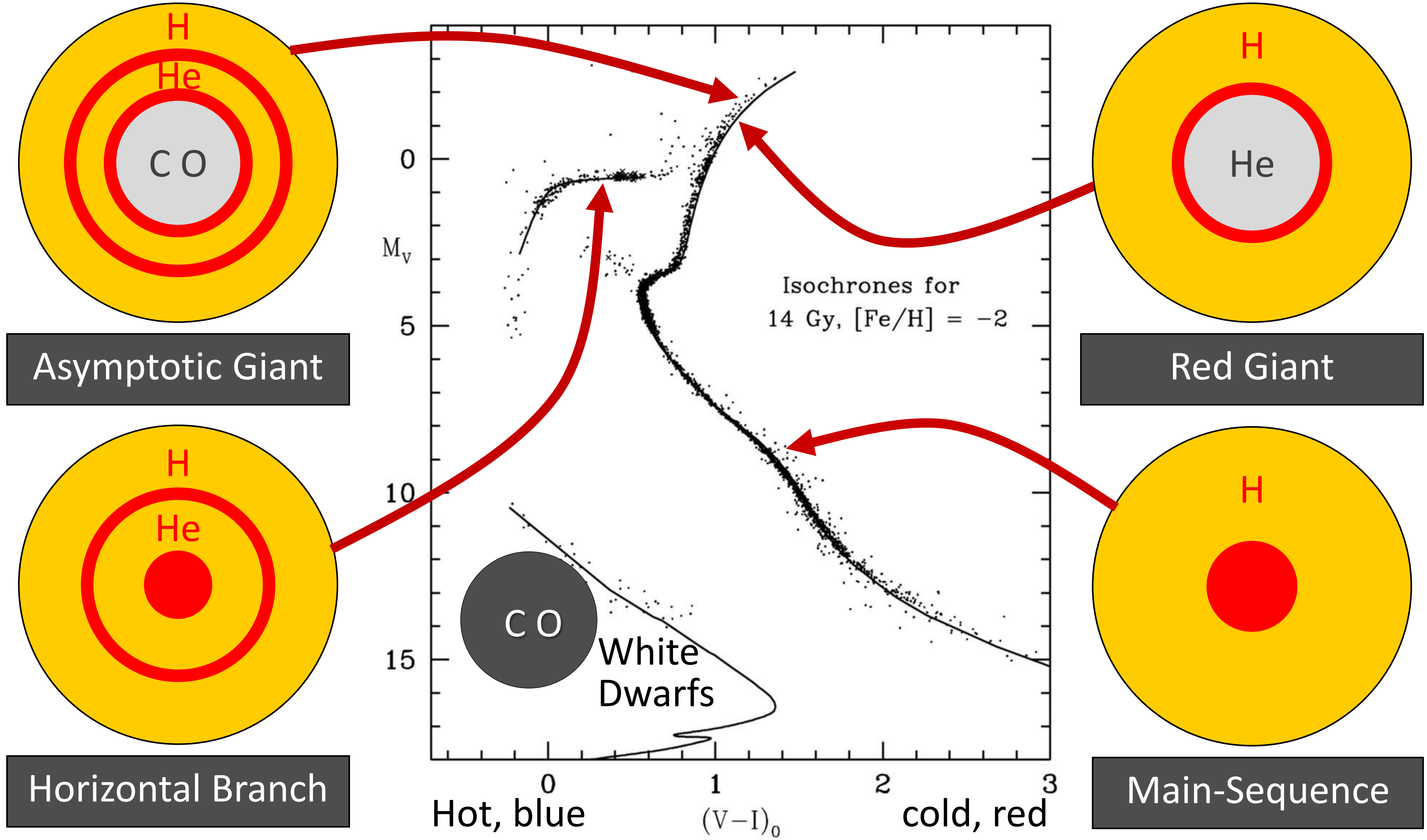
DOI: 10.1103/PhysRevLett.125.131804

*Introduction.*—The XENON1T collaboration [1] has reported an excess in low-energy electronic recoil data below 7 keV and peaking around 2–3 keV. The collaboration cautions that the excess could be due to an unaccounted background from $\beta$ decays due to a trace amount of tritium, but they also explore the possibility that the and because the location of the peak around 2–3 keV corresponds roughly to the maximum of the axion energy spectrum for the ABC processes, the Primakoff and $^{57}$Fe components are both allowed to be absent as long as there is a nonzero ABC component. This selects $g_{ae}$ as the crucial coupling to attempt to explain the data in terms of the QCD

# Galactic Globular Cluster M55

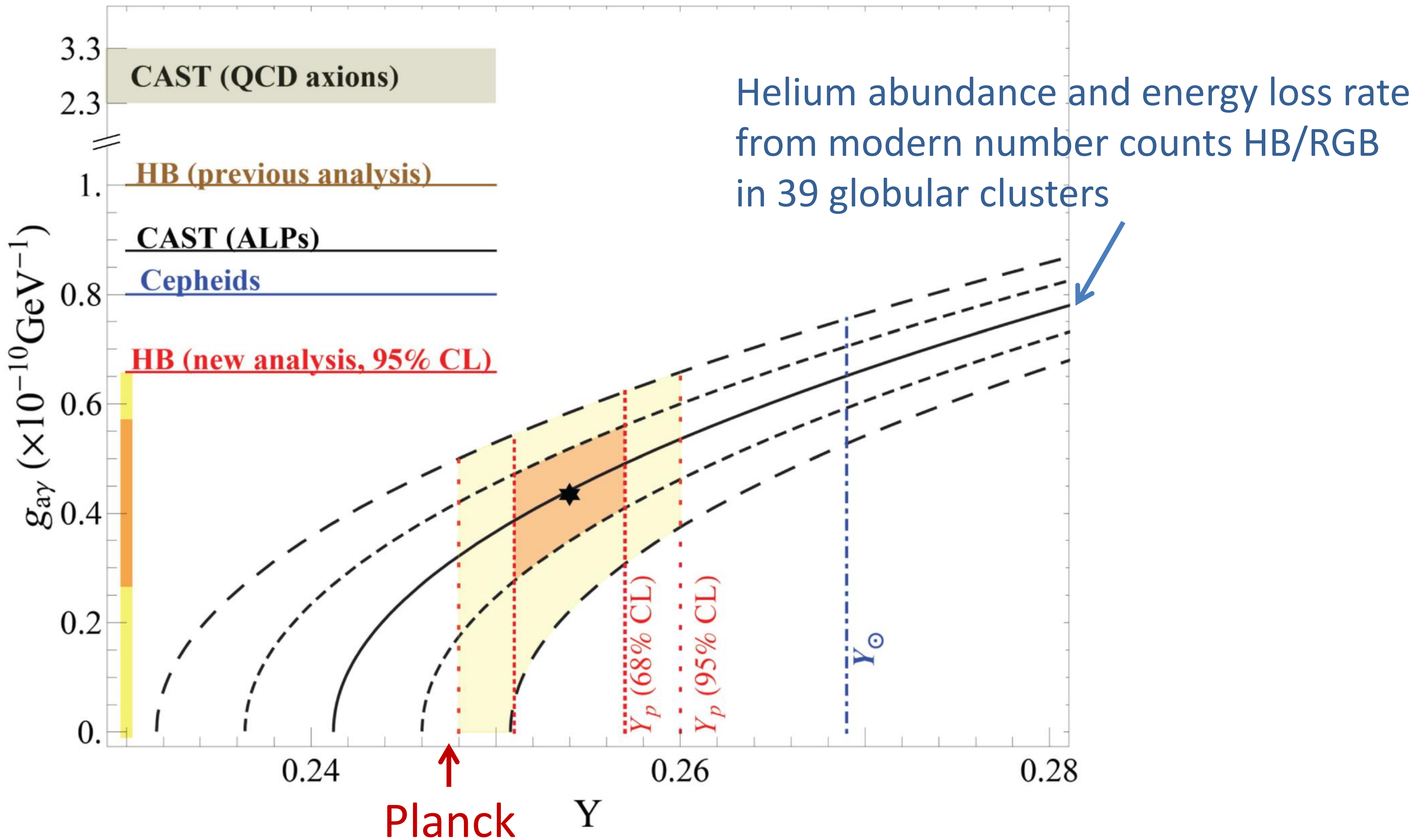


# Color-Magnitude Diagram for Globular Clusters




Color-magnitude diagram synthesized from several low-metallicity globular clusters and compared with theoretical isochrones (W.Harris, 2000)

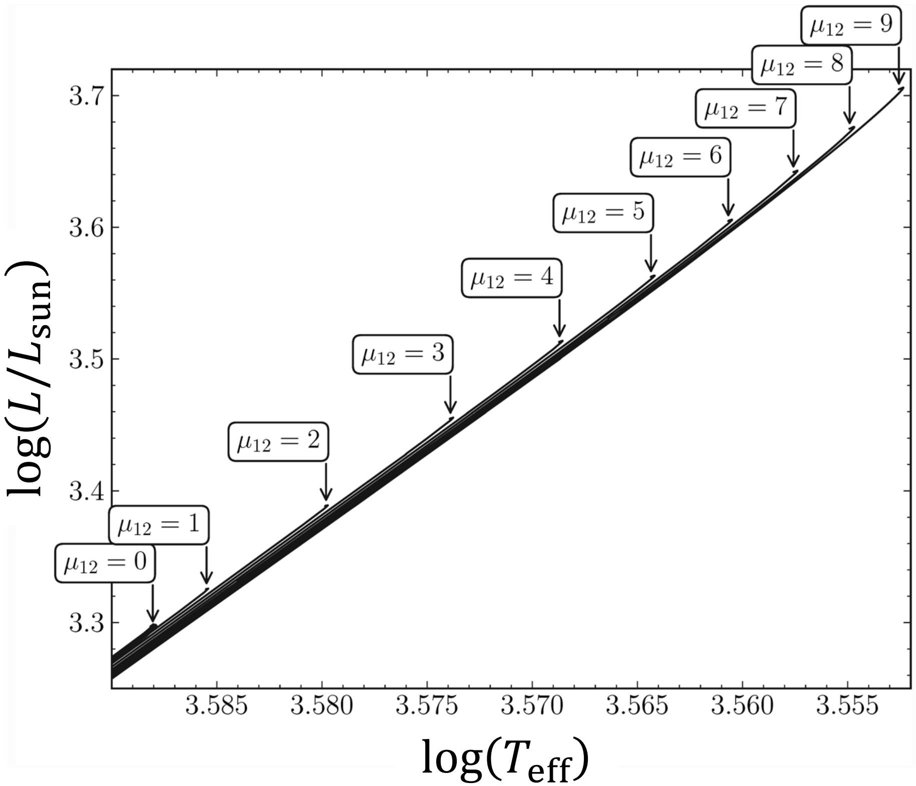
# ALP Limits from Globular Clusters

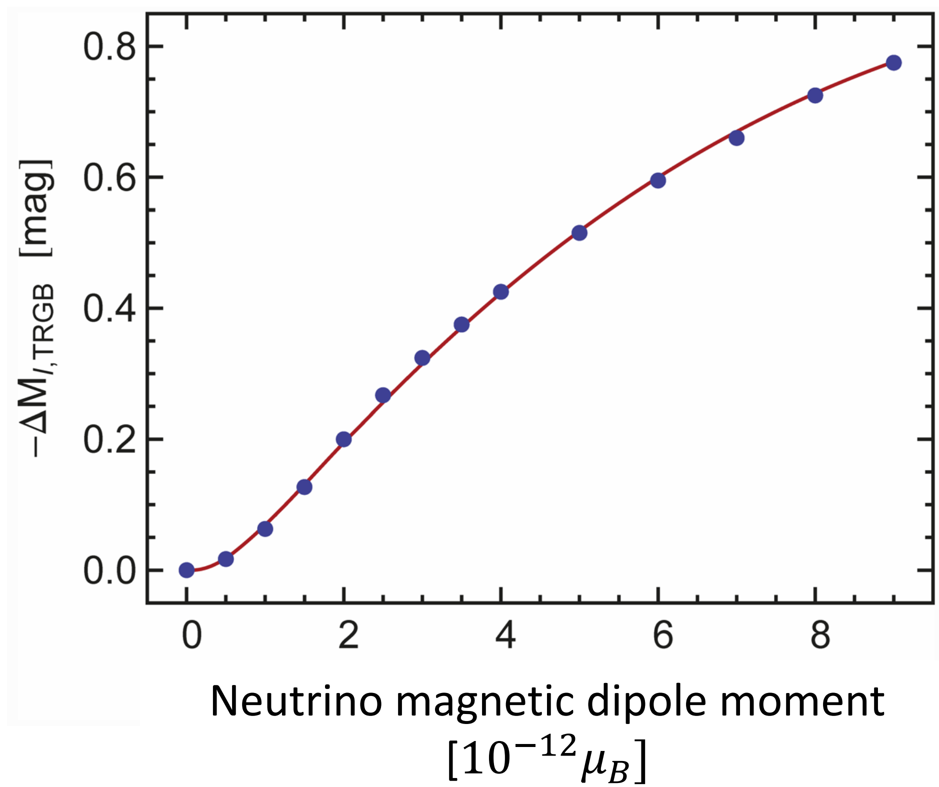



Ayala, Dominguez, Giannotti, Mirizzi & Straniero, arXiv:1406.6053

# Helium Ignition for Low-Mass Red Giants

Brightness increase at He ignition by nonstanderd neutrino losses

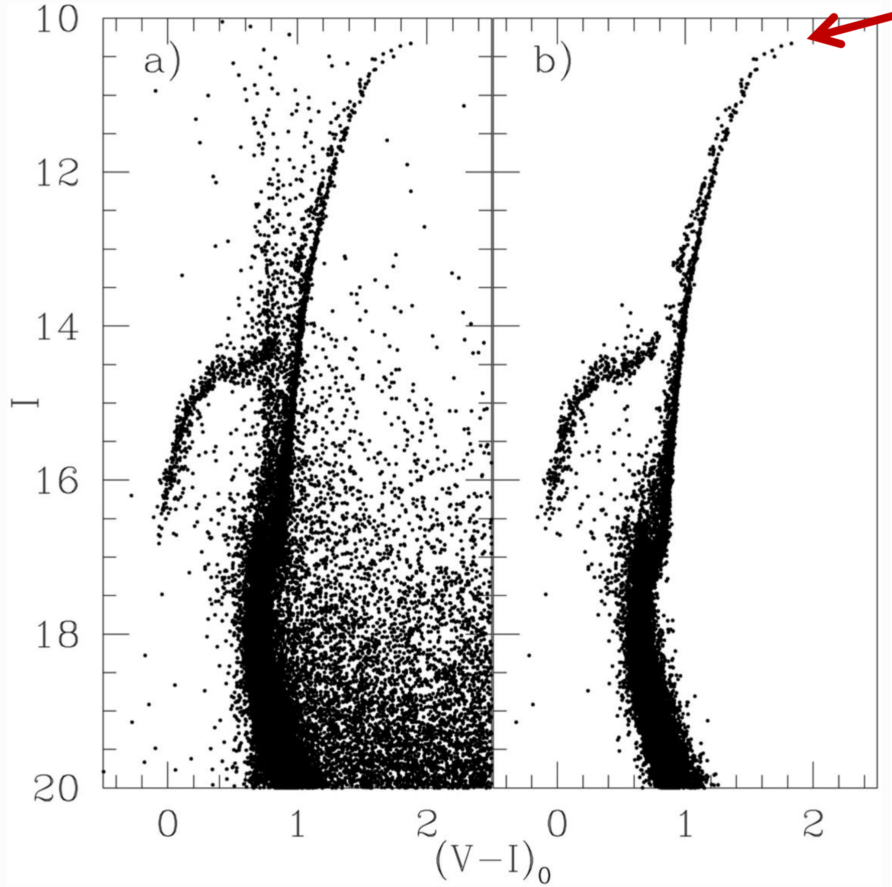


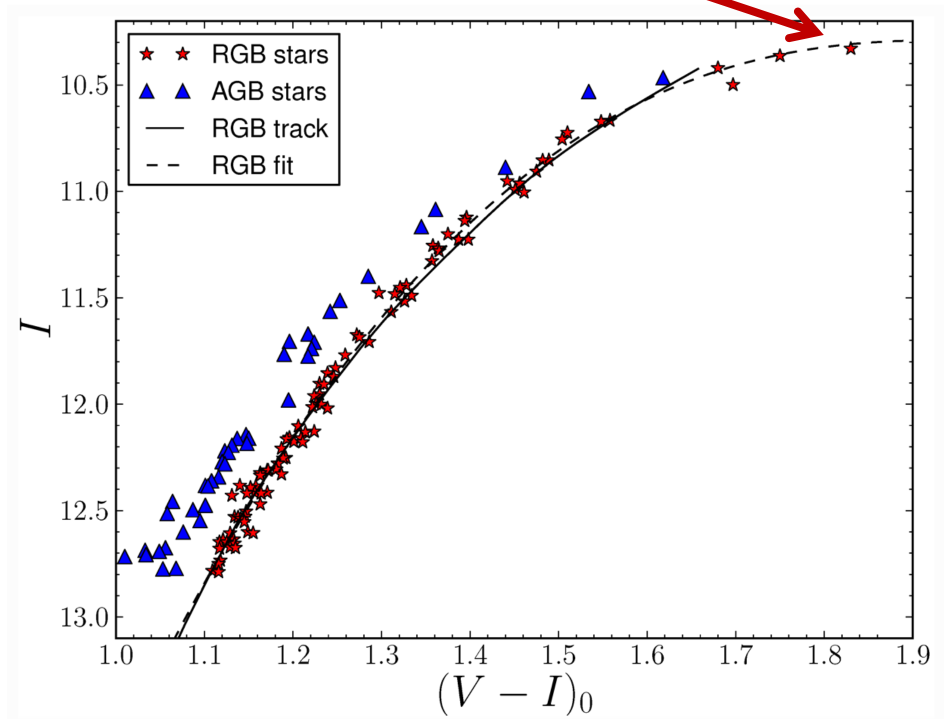




Viaux, Catelan, Stetson, Raffelt, Redondo, Valcarce & Weiss, arXiv:1308.4627

# Color-Magnitude Diagram of Globular Cluster M5

Brightest red giant
measures nonstandard energy loss



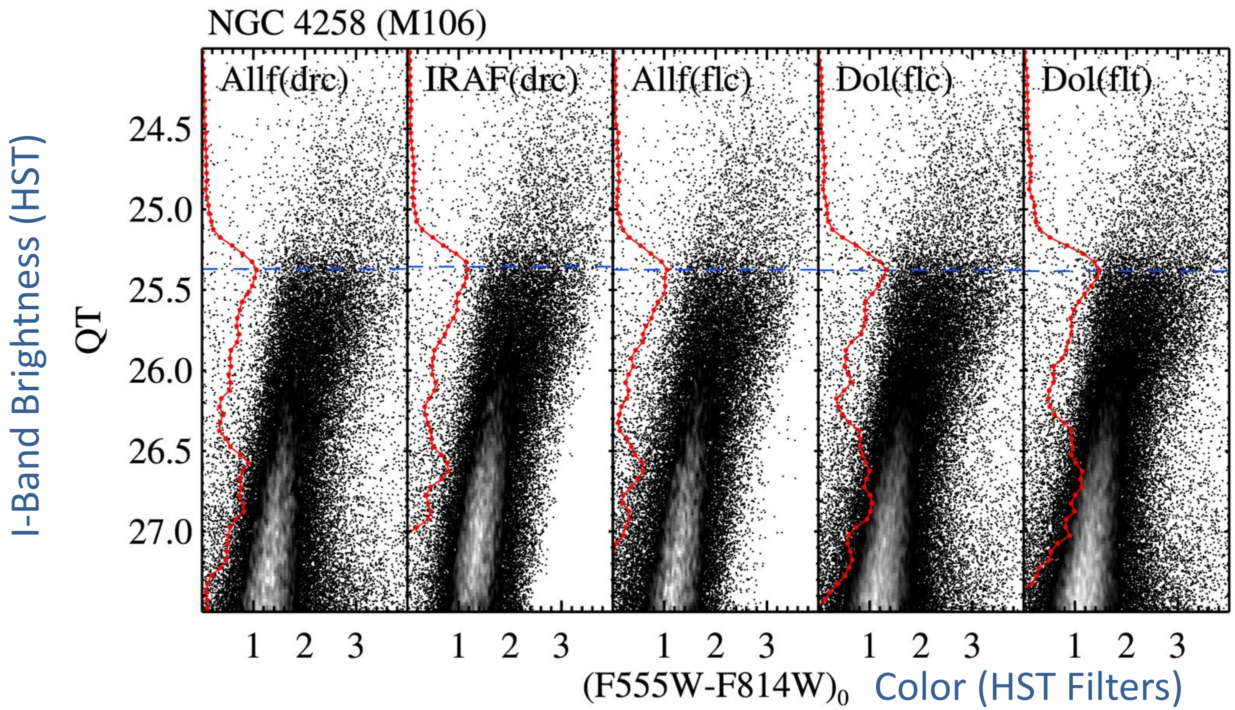

CMD (a) before and (b) after cleaning

CMD of brightest 2.5 mag of RGB

Viaux, Catelan, Stetson, Raffelt, Redondo, Valcarce & Weiss, arXiv:1308.4627

# Tip of the Red-Giant Branch in the Galaxy NGC 4258

THE ASTROPHYSICAL JOURNAL, 835:28 (17pp), 2017 January 20 JANG & LEE



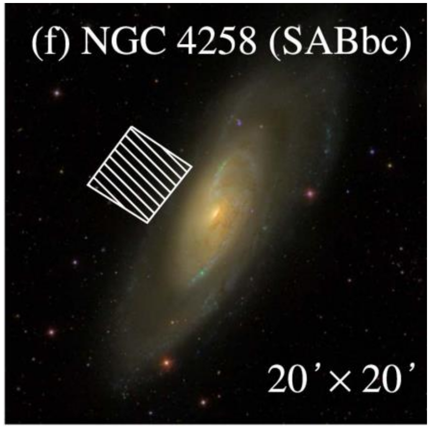
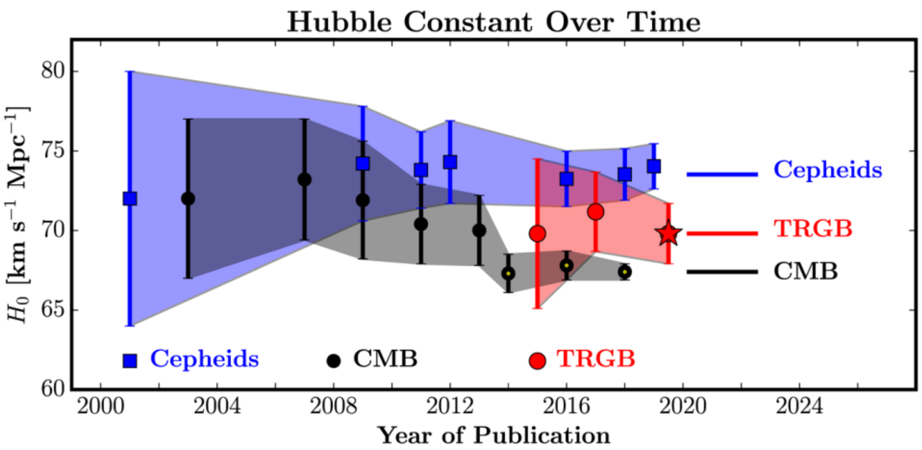



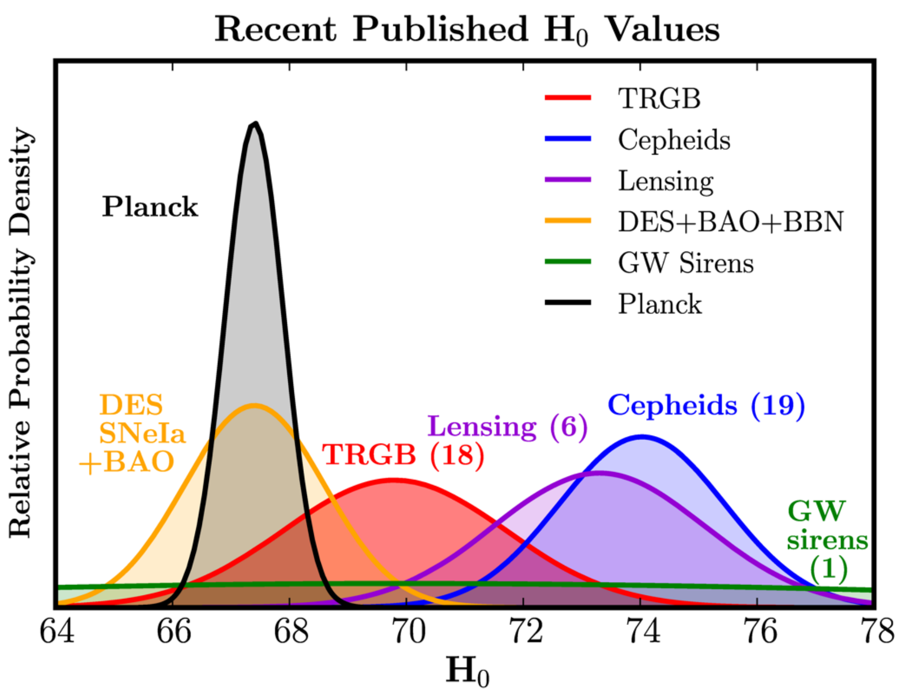

**Figure 7.** $QT$ – $(F555W - F814W)_0$ CMDs of NGC 4258 from five different reduction methods : ALLFRAME on drc, IRAF/DAOPHOT on drc, ALLFRAME on flc, DOLPHOT on flc, and DOLPHOT on flt (from left to right). Edge detection responses are shown by the solid lines. Note that the estimated TRGB magnitudes (dashed lines) agree very well.

## NGC 4258 hosts a water megamaser
## → Quasi-geometric distance determination
## → Among the best absolute TRGB calibrations

# Determinations of the Hubble Constant

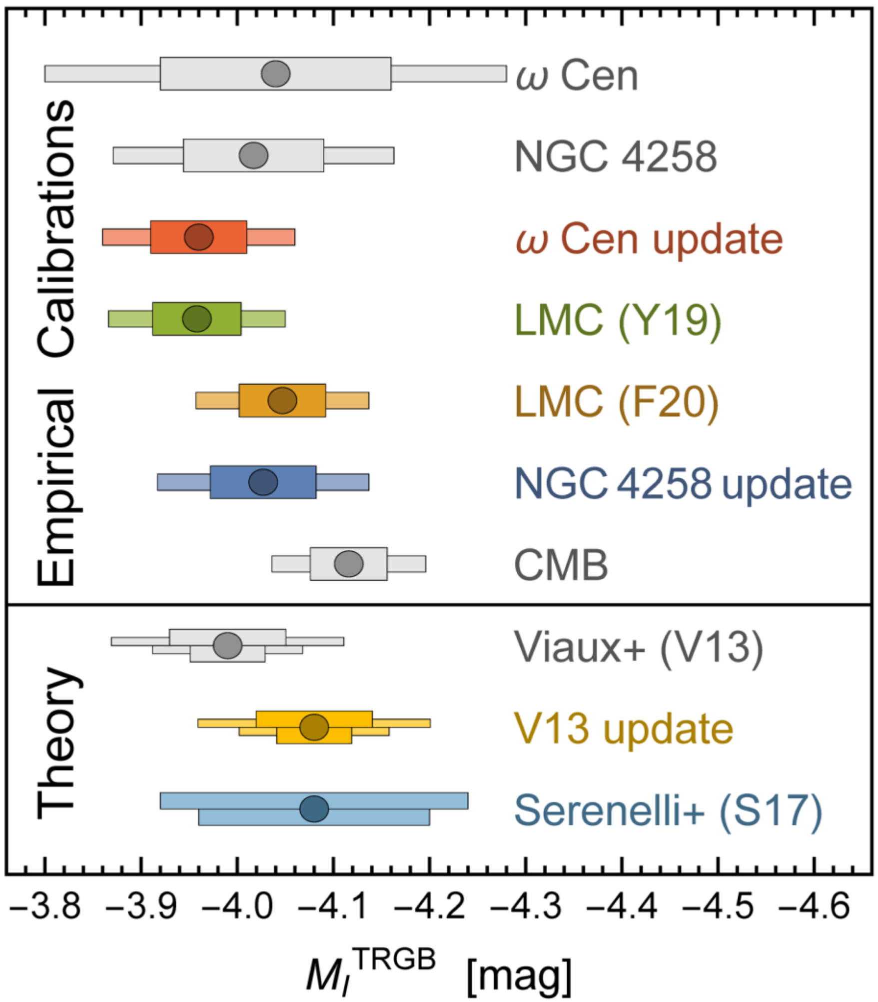



Freedman et al. 2019,
ApJ 882:34




Freedman et al. 2020
ApJ 891:57

# Axion Bounds from TRGB Calibrations




Updated TRGB Calibrations
Capozzi & Raffelt, arXiv:2007.03694

Bounds from "water megamaser" galaxy NGC 4258, compared with stellar evolution theory (95% CL)

$$g_{ae} < 1.6 \times 10^{-13}$$

$$\mu_\nu < 1.5 \times 10^{-12} \mu_{\rm B}$$

XENON1T interpretation:

$$g_{ae} \sim 3 \times 10^{-12}$$

$$\mu_\nu \sim 2 \times 10^{-11}$$

# Hidden Photon Interpretation

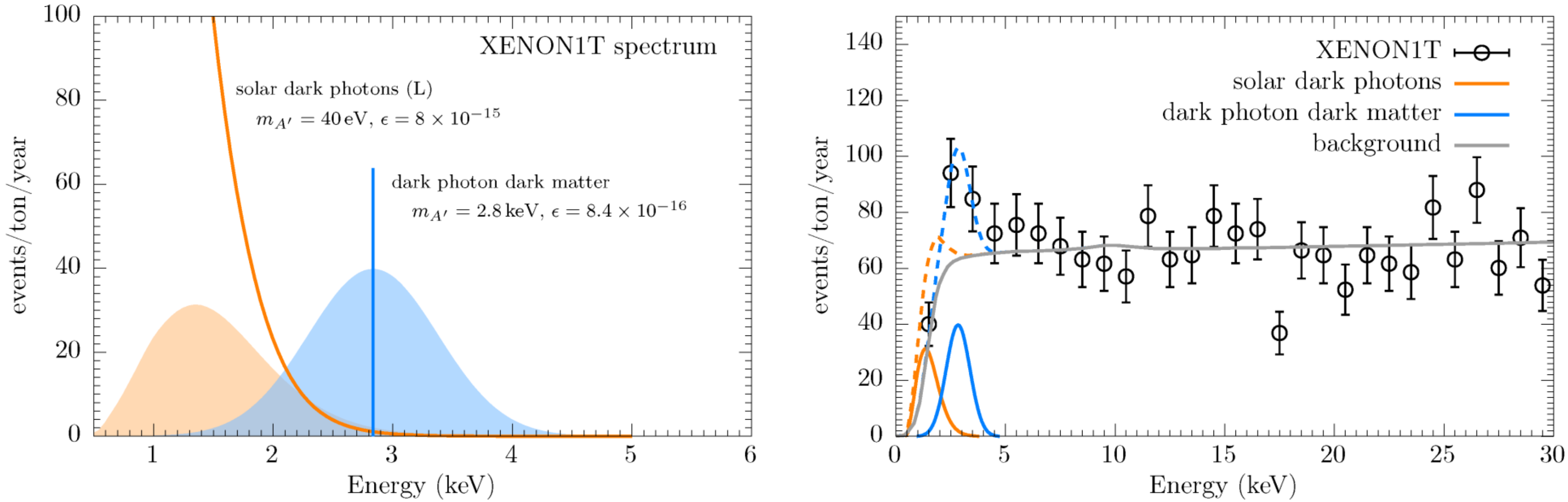



FIG. 2. *Left panel:* The best dark photon dark matter fit and exemplary parameter point for a solar generated (longitudinal) dark photon flux. The lines show the theoretical electron recoil spectra, the shaded regions show the spectra with detection efficiency and resolution folded in. *Right panel:* XENON1T-reported data on recoil events with an S1 signal component [9]. The reported background prediction is shown by the gray line. The blue solid (dashed) line shows the signal (signal+background) for absorption of dark photon dark matter. The orange line shows an exemplary signal for a solar dark photon-generated flux; $m_{A'}$ and $\epsilon$ as per left panel.

- **Hidden-photon dark matter provides good fit (m = 2.8 keV)**
- **Solar hidden photons too soft – poor fit to XENON1T excess**

**An, Pospelov, Pradler & Ritz, arXiv:2006.13929 (24 June 2020)**

# Updated Hidden Photon Bounds

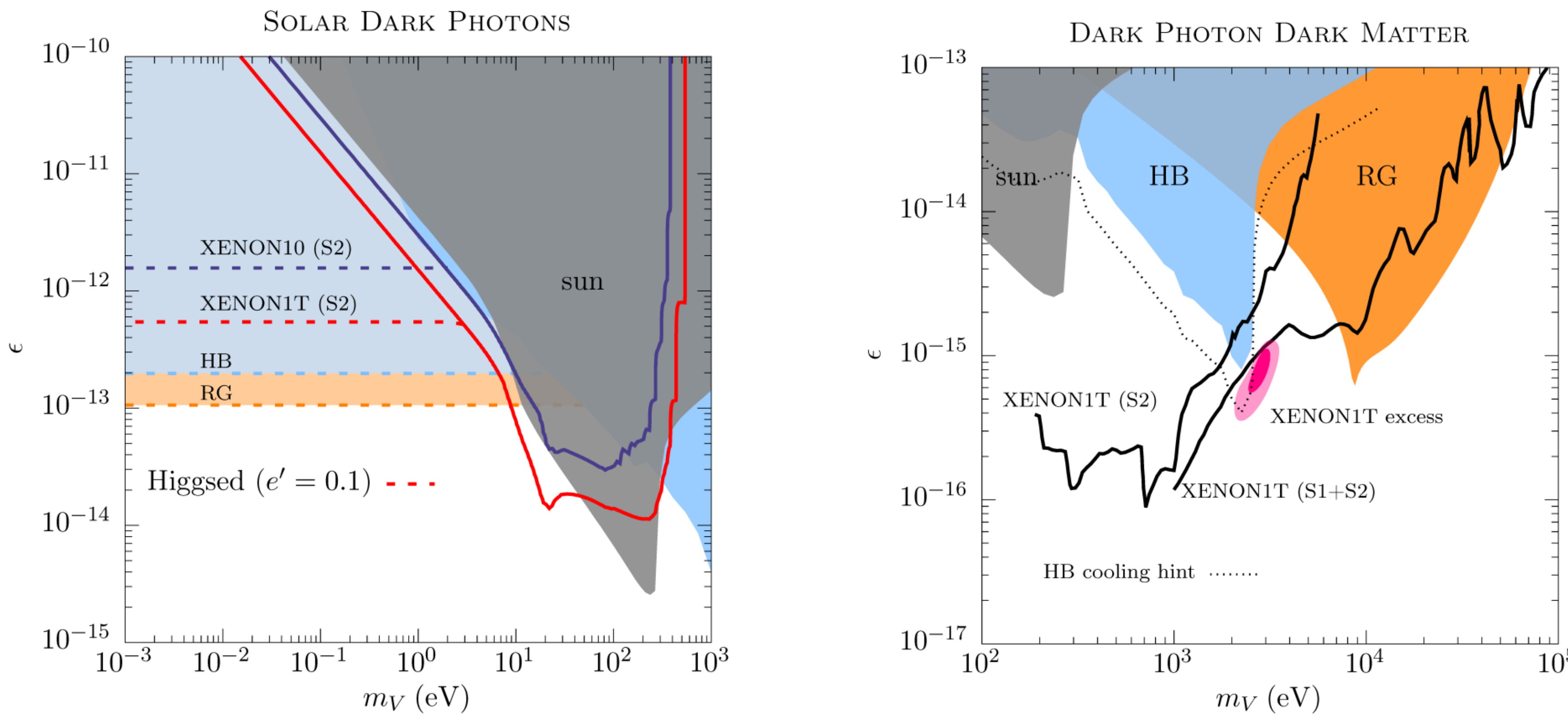



FIG. 1. *Left panel:* Direct detection constraints at 90% C.L. on solar-generated dark photon fluxes in the parameter space of vector mass $m_{A'}$ versus kinetic mixing parameter $\epsilon$. The red (blue) line is derived from the S2-only reported data by XENON1T [8] (XENON10 [26]). Solid lines apply to a "hard" Stückelberg mass and dashed lines show how the constraint continues for a "soft" Higgsed dark photon mass with $e' = 0.1$ and following [22]. Cooling constraints from the sun, and for HB and RG stars as labeled are derived following [6, 24]. *Right panel:* Dark photon dark matter parameter space showing the favored region from a fit to XENON1T data [9] ($1\sigma$ and $2\sigma$ ellipses). Official limits by the XENON1T collaboration using S2 [8] and S1+S2 [9] data are shown by the solid black lines as labeled. The HB constraint (and cooling hint, dotted line) are taken from [31] and the solar and RG constraints are derived following [6, 24]; see the main text for a discussion of the latter bounds.

**An, Pospelov, Pradler & Ritz, arXiv:2006.13929 (24 June 2020)**

# Summary

**Electron-recoil excess events in XENON1T (3.5 $\sigma$) can be attributed to**

- **Statistical fluctuation**
  **("extraordinary claims require extraordinary evidence")**
- **Tritium contamination (~3 atoms per kg xenon)**
  **– strong conflict with estimated purification**
  **– but not proven or disproven**
- **Dark matter signal (MANY scenarios, e.g. keV-range hidden photons)**
- **Solar neutrinos with non-standard interactions**

**Solar axion or neutrino MDM interpretation in strong conflict with CAST and/or stellar energy-loss limits**

**Solar hidden photons provide poor spectral fit**

**$\rightarrow$ Need to wait for XENONnT to pin down origin of excess events**