Millimeter-wave probes of axion dark matter with neutron stars

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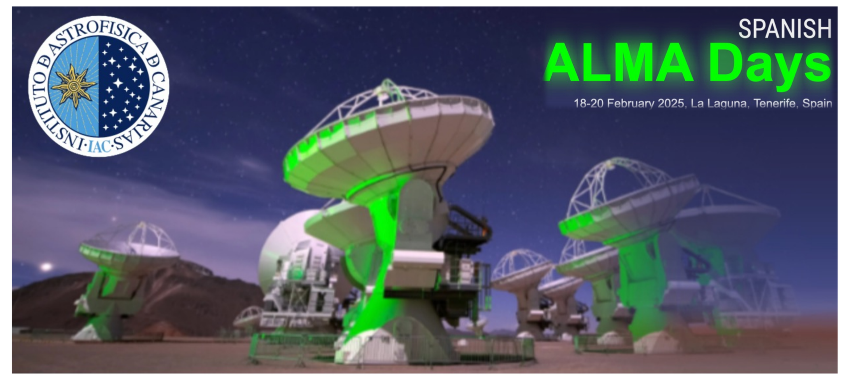

NEUTRON STARS: PULSARS AND MAGNETARS

Neutron stars (NSs) are compact objects with extreme magnetic fields. Pulsars are rotation-powered NSs, while magnetars are powered by their magnetic fields. Particle acceleration, tied to the plasma Lorentz factor (γ), and pair production rates (relative to a multiplicity factor *κ*) are expected to peak along open magnetic field lines in pulsars, or in unscreened NS regions.

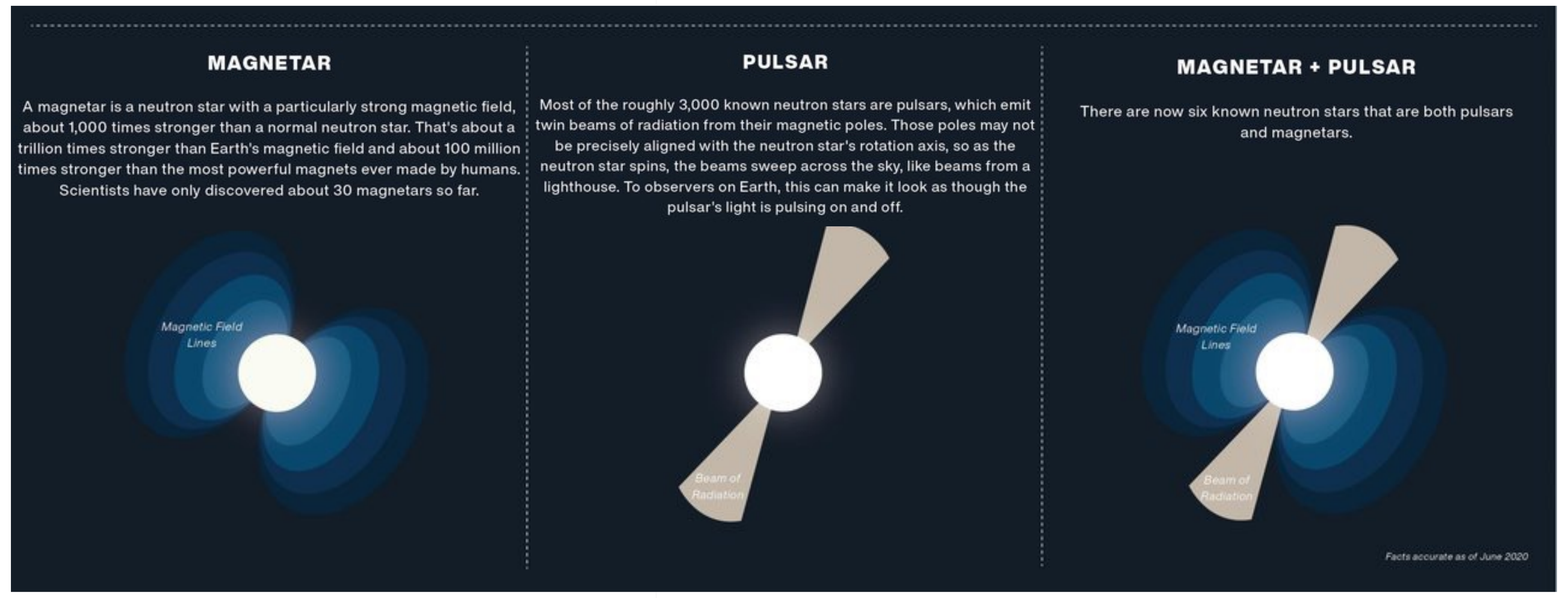

Fig. 1. Pulsars and magnetars are believed to be neutron stars. Credits JPL.

THE MAGNETAR SGR 1745-2900

SGR 1745-2900 is one of the most promising sources in the sky for testing the existence of dark matter (DM). The Galactic Center represents a region of high dark matter density, up to 10^9 times denser than our local halo. With its ultra-strong magnetic field, SGR 1745-2900 is considered a promising astrophysical laboratory, despite observational challenges such as its distance and proximity to the central black hole, Sagittarius (Sgr) A*.

Some facts about SGR 1745-2900

Magnetic field at surface: 1.6×10^{14} G
Distance to Earth: ~8 Kpc
Distance to Sgr A*: ~0.1 pc
Coordinates: 17:45:40, -29:00:29 (Galactic Center)
Radius and mass: ~1.4 $M_\odot$ and ~10 km.

PROBING DARK MATTER WITH NEUTRON STARS

Because of its light mass and weak coupling, the AXION is a compelling dark matter candidate. Axions convert to photons in a strong magnetic field. When ambient axion dark matter falls toward a pulsar or magnetar, a narrow emission feature emerges at a frequency given by the axion mass, $\omega \sim m_a$.

Previous dark matter probes with neutron stars neglected the pair multiplicity to plasma Lorentz factor ratio, κ/γ, and searched for axion at ω/2π<40 GHz. However, a √κ/γ factor shifts to the blue, from cm to mm wave, the axion-induced emission signal. This approach would enable access to heavier axions.

THEORY

The flux originating from axion dark matter conversion in an accretion-like process reads

$$S \propto \frac{1}{d^2} \times g_\gamma^2 \times R_* \times m_a^{4/3} \times B_0^{1/3} \times \Omega_*^{-8/3}$$
$$\times \rho_a \times M_* \times \frac{1}{v_0} \times v_a \times \left(\frac{\kappa}{\gamma}\right)^{-3/2} \times \Omega_c$$

Eq. 1. Flux originating from axion dark matter conversion. In Eq. 1, S is the flux, d is distance to the observer, g_γ is the axion-photon coupling, R_* is the star radius, m_a is the axion mass, B_0 is the magnetic field strength, Ω_* is the star spin period, ρ_a is the local dark matter density, M_* is the star mass, v_0 is the star velocity, v_a is the axion velocity, κ is the pair multiplicity factor, γ is the plasma Lorentz factor, and Ω_c is a dilution factor.

Take-away

Since the axion-induced signal flux scales as $S \propto \rho_a \times B_0^{1/3}$ (see Eq. 1 above), we are interested in Galactic, highly magnetic NS in regions with high DM density.

ALMA's ROLE IN AXION DARK MATTER DETECTION

Recent work shows that a plausible explanation for the absence of axion traces in the cm-wave spectra of magnetars to date is a blue shift caused by the plasma properties in the magnetosphere. According to this finding, the axion-induced signal from NSs might be mm wave rather than a cm wave.

ALMA is an excellent choice to conduct the first observational search for axion dark matter in the millimeter-wave spectrum of the most promising source for a detection, the magnetar SGR 1745-2900, as it provides high resolution and sensitivity.

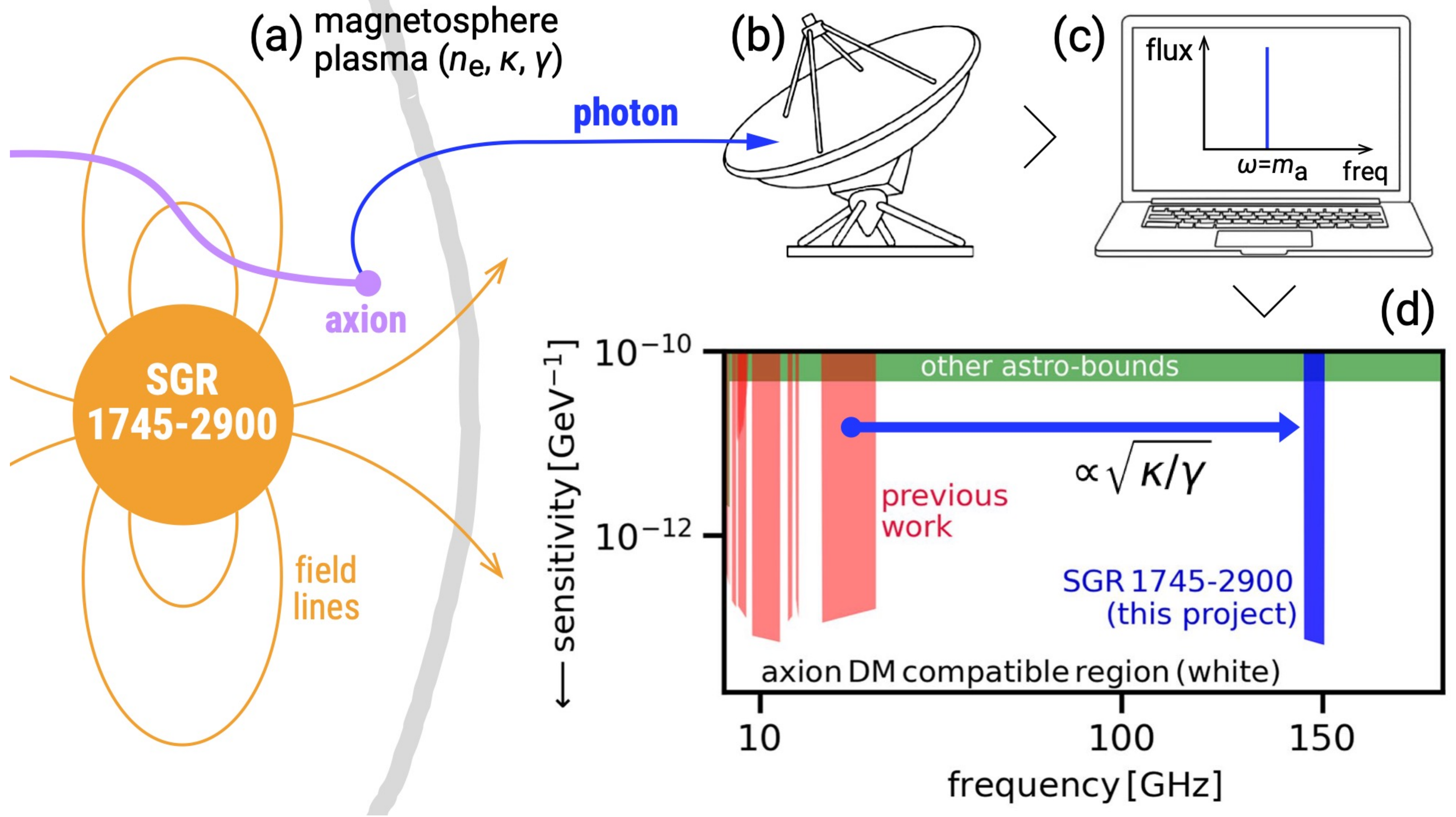

Fig. 2. Workflow of the 2024.1.00310.S Cycle 11 project. (a) ambient dark matter axions, in purple, are converted into photons in the magnetospheric plasma of SGR 1745-2900; (b) photons, in blue, are radiated with a frequency $\omega \sim m_a$; (c) an emission feature originating from axion conversion emerges on the SGR 1745-2900 continuum; (d) sensitivity forecast (simulation), where the blueshift scales as √κ/γ.

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References

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2. arXiv:2301.10144 [hep-ph]