Radio signals and Fast Radio Bursts from axion dark matter and axion star through SKA

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based on my work arXiv:2004.06486 with James Buckley, Bhupal Dev, Francesc Ferrer and arXiv:1803.08230 with Kenji Kadota, Toyokazu Sekiguchi, Hiroyuki Tashiro

轴子物理研讨会@IHEP

June 29th, 2020

In memoriam: Prof. Roberto Peccei (1942-2020)

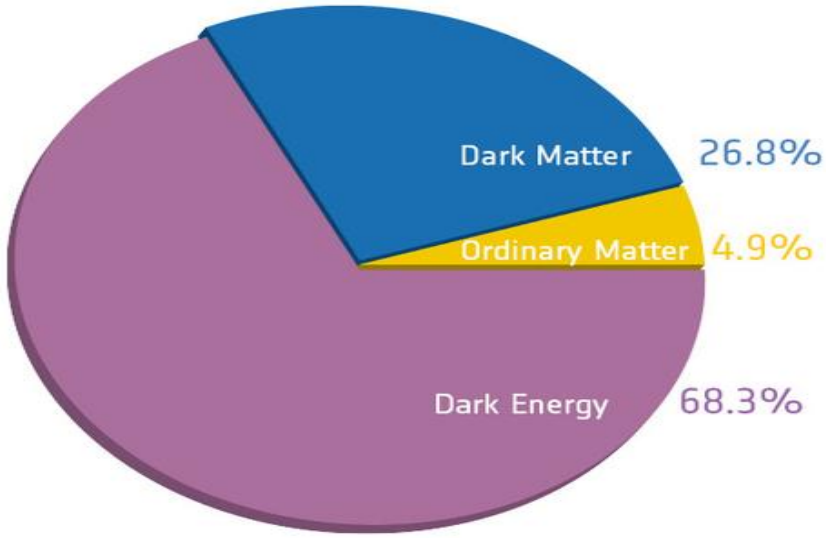
Peccei, along with Stanford University colleague Helen Quinn, made major contributions to physics, including the Peccei-Quinn Symmetry — an elegant theory that ties together several branches of physics and has important implications for our universe. The Peccei-Quinn Symmetry predicts the existence of very light particles called axions, which may nevertheless be the dominant source of mass in the universe. Axions, the subject of intense experimental and theoretical investigation for four decades, may be the mysterious "dark matter" that account for most of the matter in the universe.

——from UCLA website.

Outline

- ➢Research motivation
- ➢Explore axion cold dark matter (DM) by SKA-like radio telescope
- ➢Fast radio bursts from axion stars moving through pulsar magnetospheres
- ➢Summary

Motivation:Dark Matter



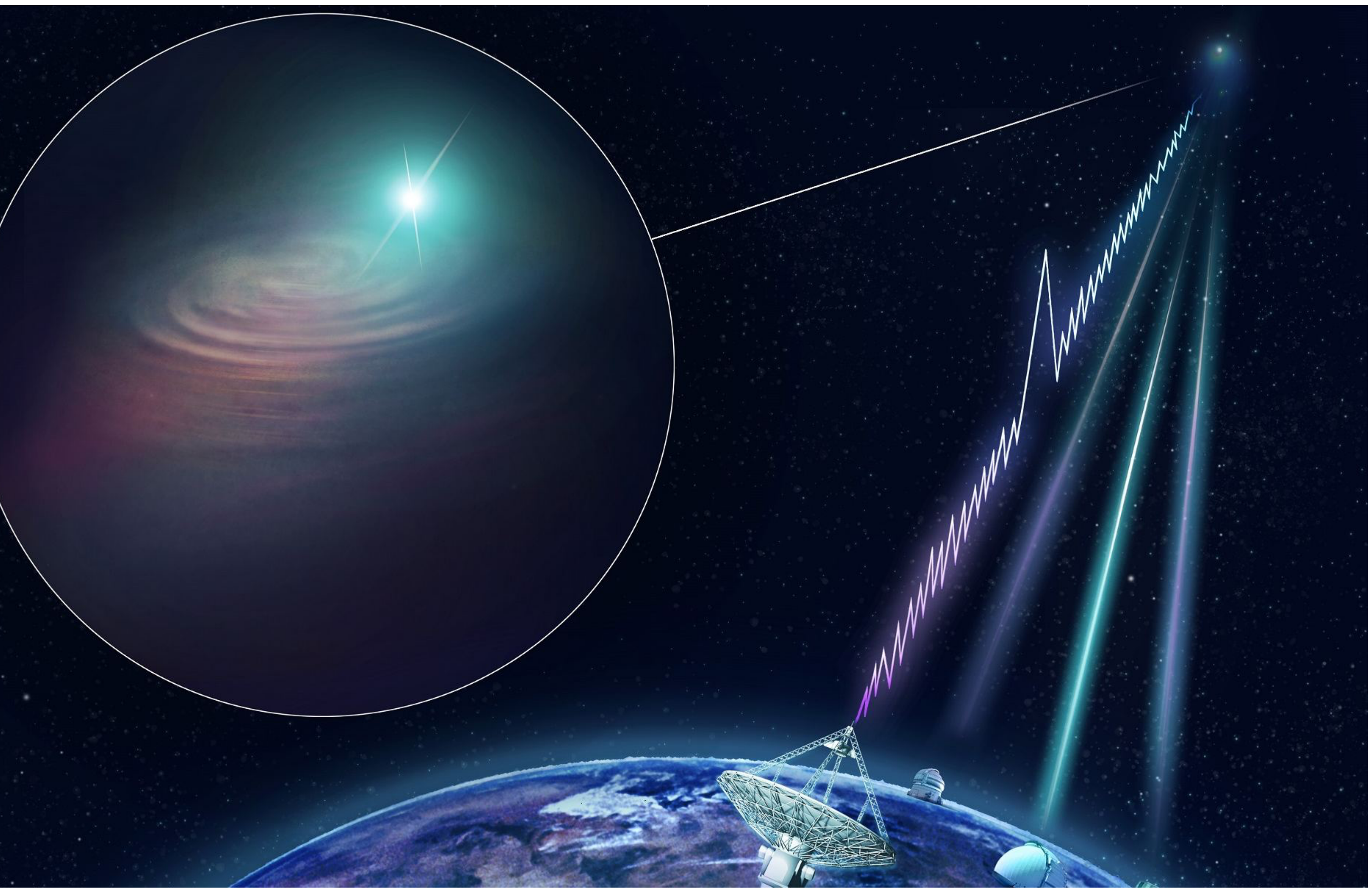
What is the nature of the dark matter (DM)?
A lot of experiments have be done.
However, there is no signals of new physics at LHC and dark matter direct search.
This situation may just point us towards new approaches, especially (my personal interest)
Radio telescope experiments (SKA, FAST, GBT…)

Axions, that arise from a natural solution to the strong CP-problem, or more generic axion-like particles (ALPs) predicted by string theory, are promising DM candidates. In recent years, an increased interest on axion DM has bolstered a broad experimental program.

I will focus on new approaches to explore axion cold DM or axion star by SKA-like radio telescope.

Motivation: FRBs

In recent ten years, Fast Radio Bursts (FRBs) become the most mysterious phenomenon in astrophysics and cosmology, especially from 2013(D. Thornton, et al., (2013) Science, 341, 53). They are intense, transient radio signals with large dispersion measure, light years away. However, their origin and physical nature are still obscure.



$\mathcal{O}(0.1)$ to $\mathcal{O}(100)$ Jy

$\mathcal{O}(10^{38})$ to $\mathcal{O}(10^{40})$ erg

Duration: milliseconds

$$0.1 \lesssim z \lesssim 2.2$$

We focus on FRBs events with frequency range 800 MHz to 1.4GHz mainly observed by Parkes, ASKAP, and UTMOST.

We do not include other non-repeating FRBs with frequencies lower than 800 MHz, like the events from CHIME and Pushchino, which may be better explained by a lighter axion or other sources.

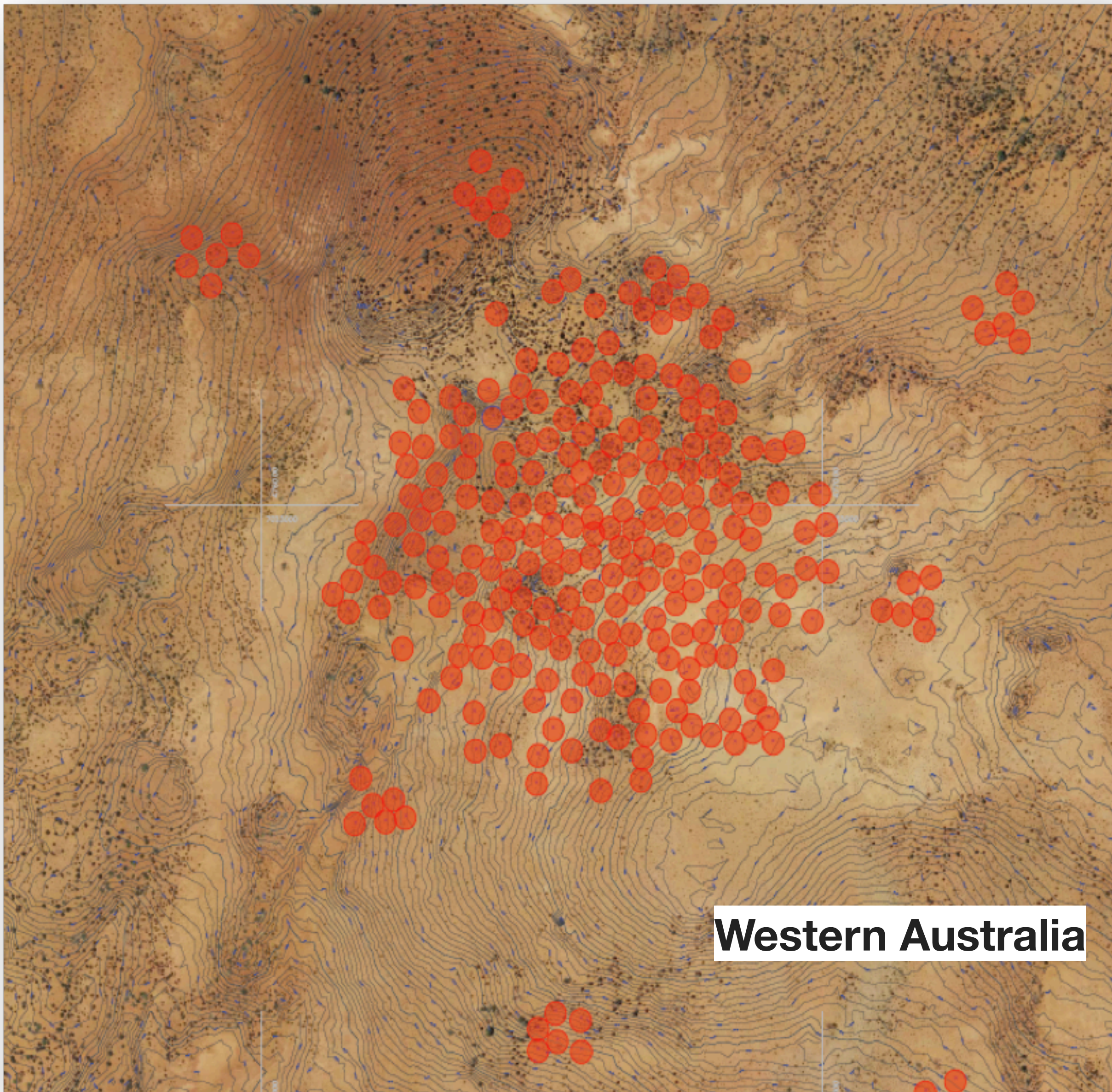
From Universe Today

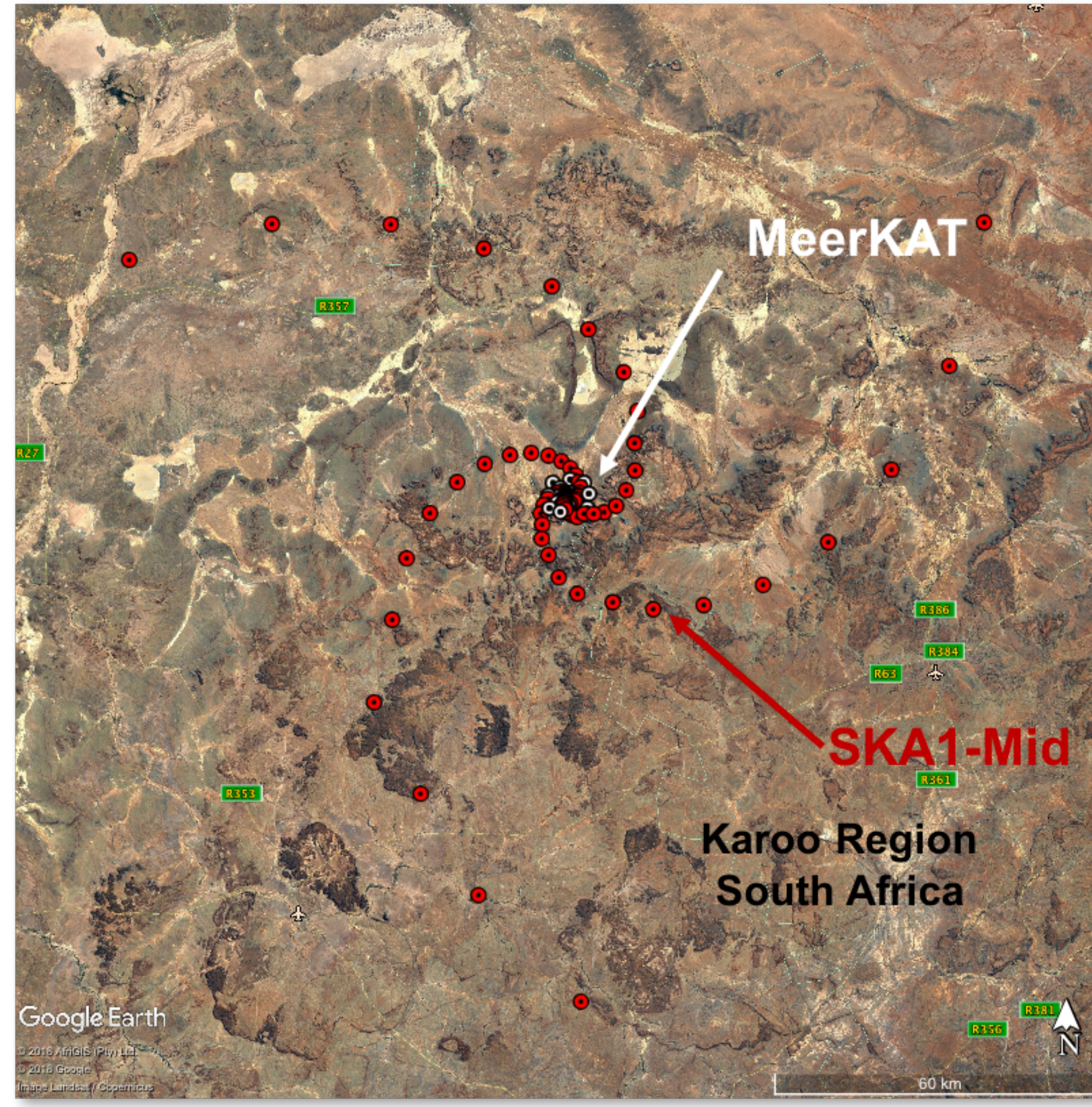
The Square Kilometre Array (SKA)

Early science observations are expected to start in near future with a partial array.

credit: SKA website

The Square Kilometre Array (SKA)





Organisations from 13 countries are members of the SKA Organisation – Australia, Canada, China, France, Germany, India, Italy, New Zealand, Spain, South Africa, Sweden, The Netherlands and the United Kingdom.

Early science observations are expected to start in near future with a partial array.

credit: SKA website

Powerful SKA experiments

High sensitivity: SKA surveys will probe to sub-micro-Jy levels The extremely high sensitivity of the thousands of individual radio receivers, combining to create the world's largest radio telescope will give us insight into many aspects of fundamental physics

- **How do galaxies evolve? What is dark energy?**
- **Strong-field tests of gravity using pulsars and black holes**
- **The origin and evolution of cosmic magnetism**
- **Probing the Cosmic Dawn**
- **Flexible design to enable exploration of the unknown, such as axion DM,**

credit: SKA website

The Five-hundred-meter Aperture Spherical radio Telescope (FAST)

In operation since 25th Sep. 2016

Credit:FAST website

The Green Bank Telescope (GBT)

GBT is running observations roughly 6,500 hours each year

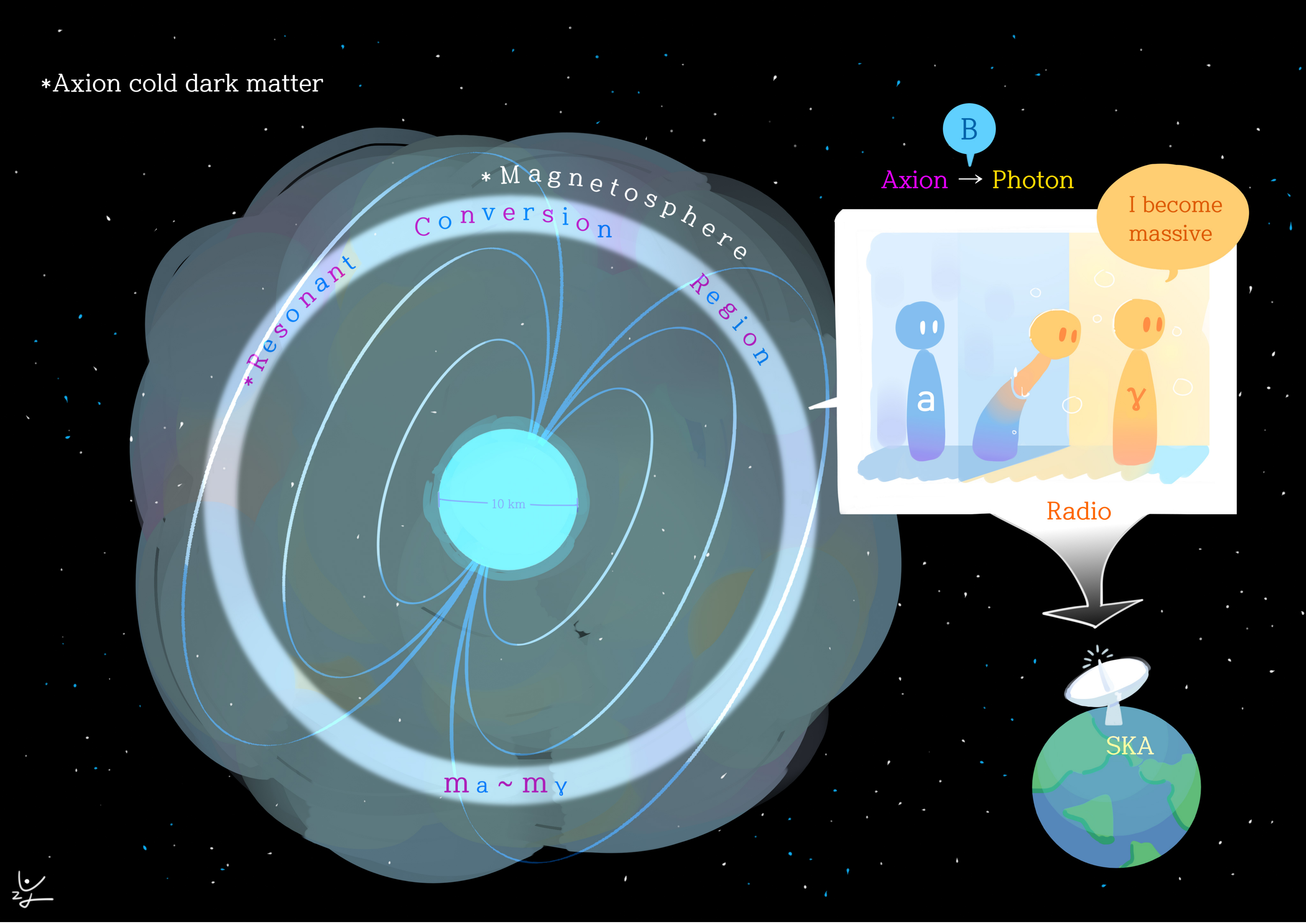
credit:GBT website

I.Explore the axion cold DM by SKA

Axion or axion-like particle motivated from strong CP problem or string theory is still one of the most attractive and promising DM candidate.

We firstly study using the SKA-like experiments to explore the resonant conversion of axion cold DM to radio signal from magnetized astrophysical sources, such as neutron star, magnetar and pulsar.

FPH, K. Kadota, T. Sekiguchi, H. Tashiro, Phys.Rev. D97 (2018) no.12, 123001, arXiv:1803.08230



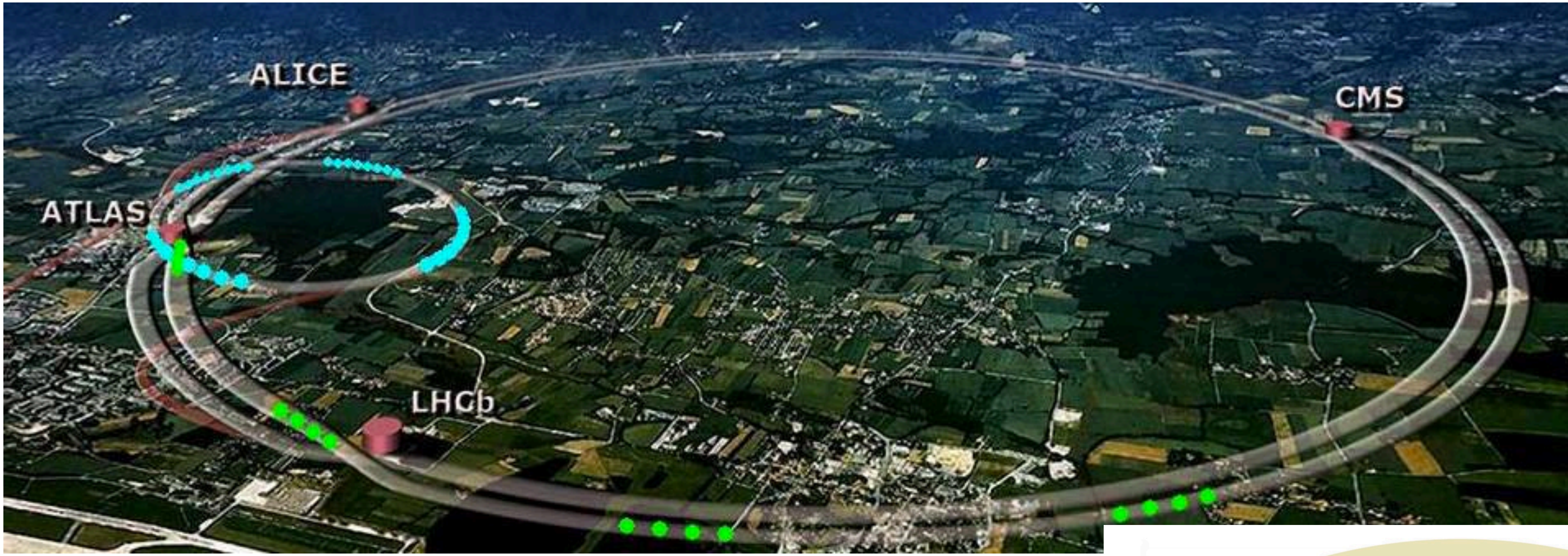
FPH, K. Kadota, T. Sekiguchi, H. Tashiro, Phys.Rev. D97 (2018) no.12, 123001

Radio telescope search for the resonant conversion of cold DM axions from the magnetized astrophysical sources

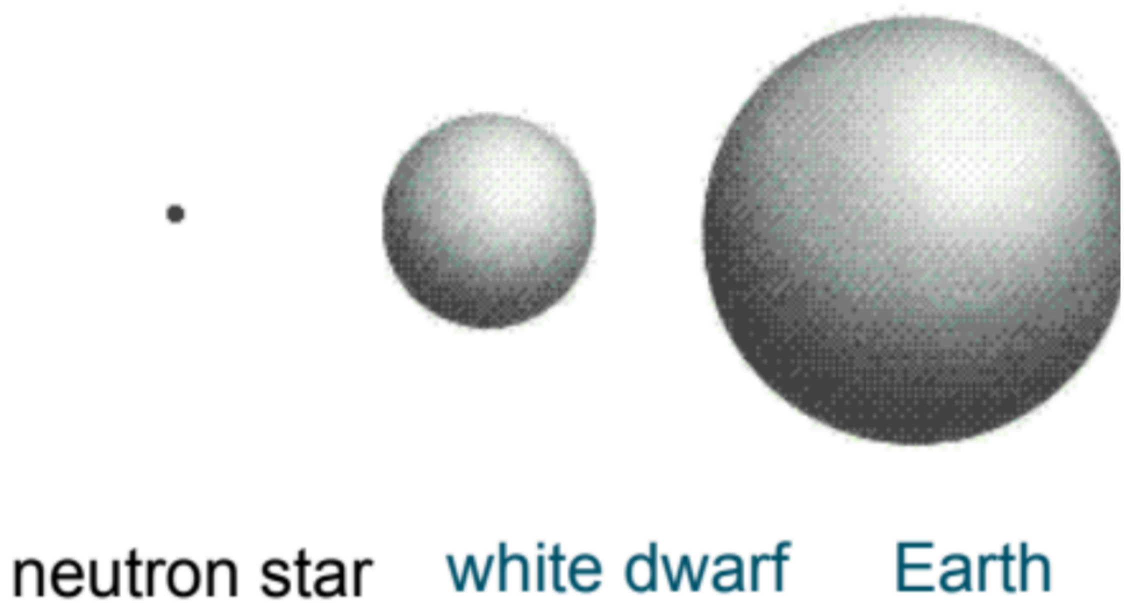
Three key points:

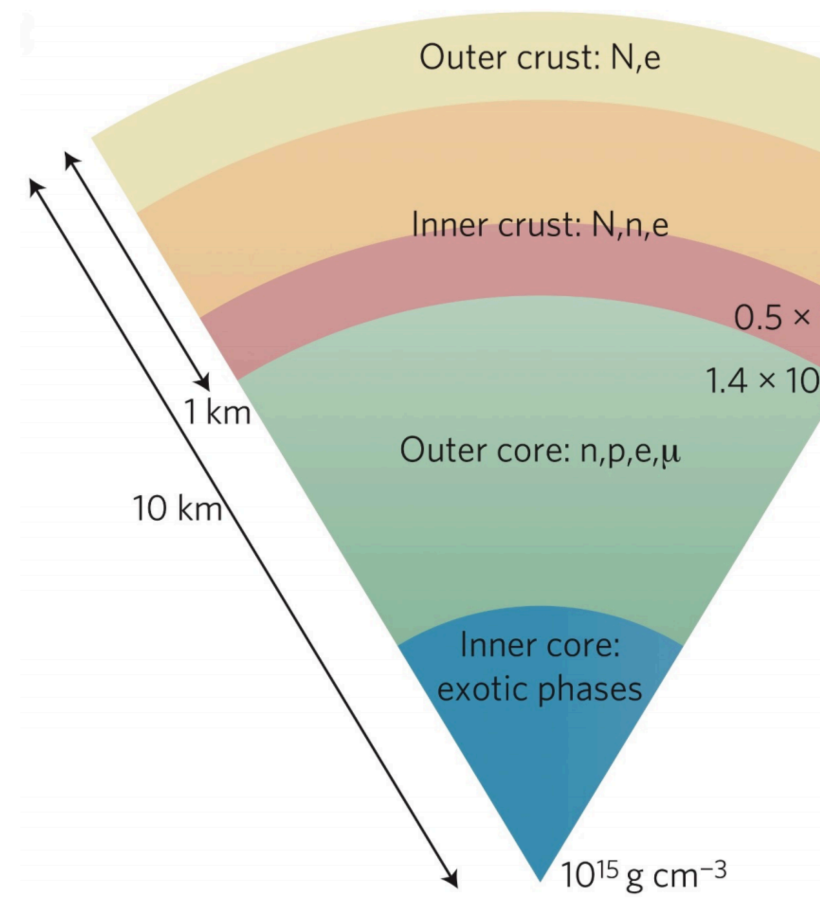
- ➢Cold DM is composed of non-relativistic axion or axion-like particles, and can be accreted around the neutron star
- ➢Neutron star (or pulsar and magnetar) has the strongest position-dependent magnetic field in the universe
- ➢Neutron star is covered by magnetosphere and photon becomes massive in the magnetosphere

Quick sketch of the neutron star size

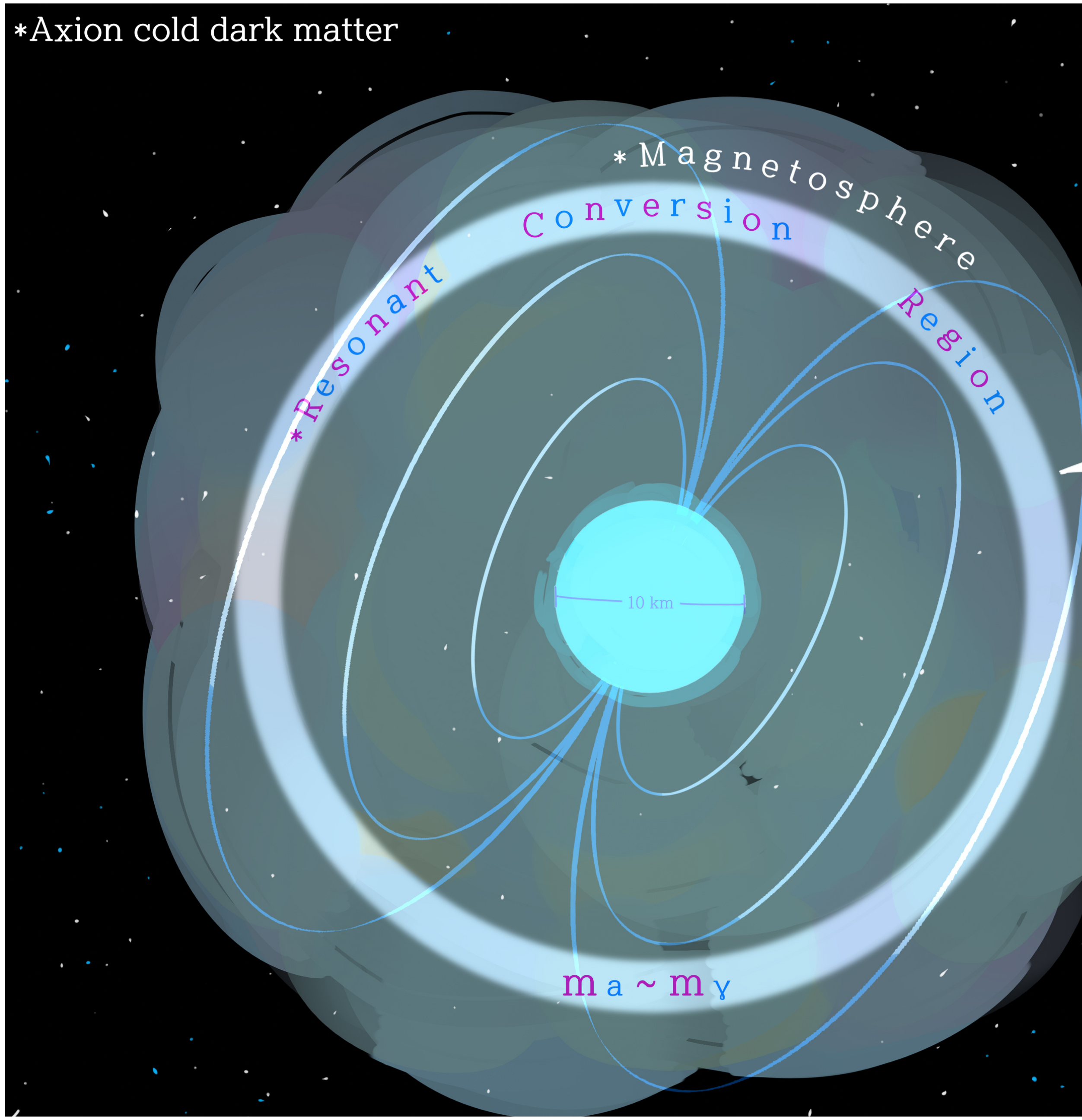


Radius of the neutron star is slightly than the radius of the LHC circle.





Strong magnetic field in the magnetosphere of Neutron star, Pulsar, Magnetar: the strongest magnetic field in the Universe



1. **Mass: from 1 to 2 solar mass**

2. **Radius:** $r_0 \sim 10 - 20\text{km}$

   The typical diameter of neutron star is just half-Marathon.

3. **Strongest magnetic field at the surface of the neutron star**

$$B_0 \approx 10^{12} - 10^{15}\text{G}$$

$$B_0 \sim 3.3 \times 10^{19} \sqrt{P\dot{P}} \quad \text{G}$$

P is the period of neutron star

4. **Neutron star is surrounded by large region of magnetosphere, where photon becomes massive.**

Alfven $r \sim 100 r_0$

Axion-photon conversion in magnetosphere

The Lagrangian for axion-photon conversion the magnetosphere

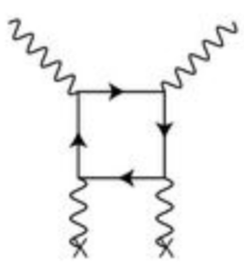
$$L = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}(\partial_\mu a \partial^\mu a - m_a^2 a^2) + L_{\text{int}} + L_{\text{QED}}$$

Massive Photon: In the magnetosphere of the neutron star, photon obtains the effective mass in the magnetized plasma.

$$L_{\text{QED}} = \frac{\alpha^2}{90 m_e^4}\frac{7}{4}(F_{\mu\nu}\tilde{F}^{\mu\nu})^2 \; + \ldots$$

$$m_\gamma^2 = Q_{\text{pl}} - Q_{\text{QED}}$$

$$Q_{\text{QED}} = \frac{7\alpha}{45\pi}\omega^2\frac{B^2}{B_{\text{crit}}^2}$$

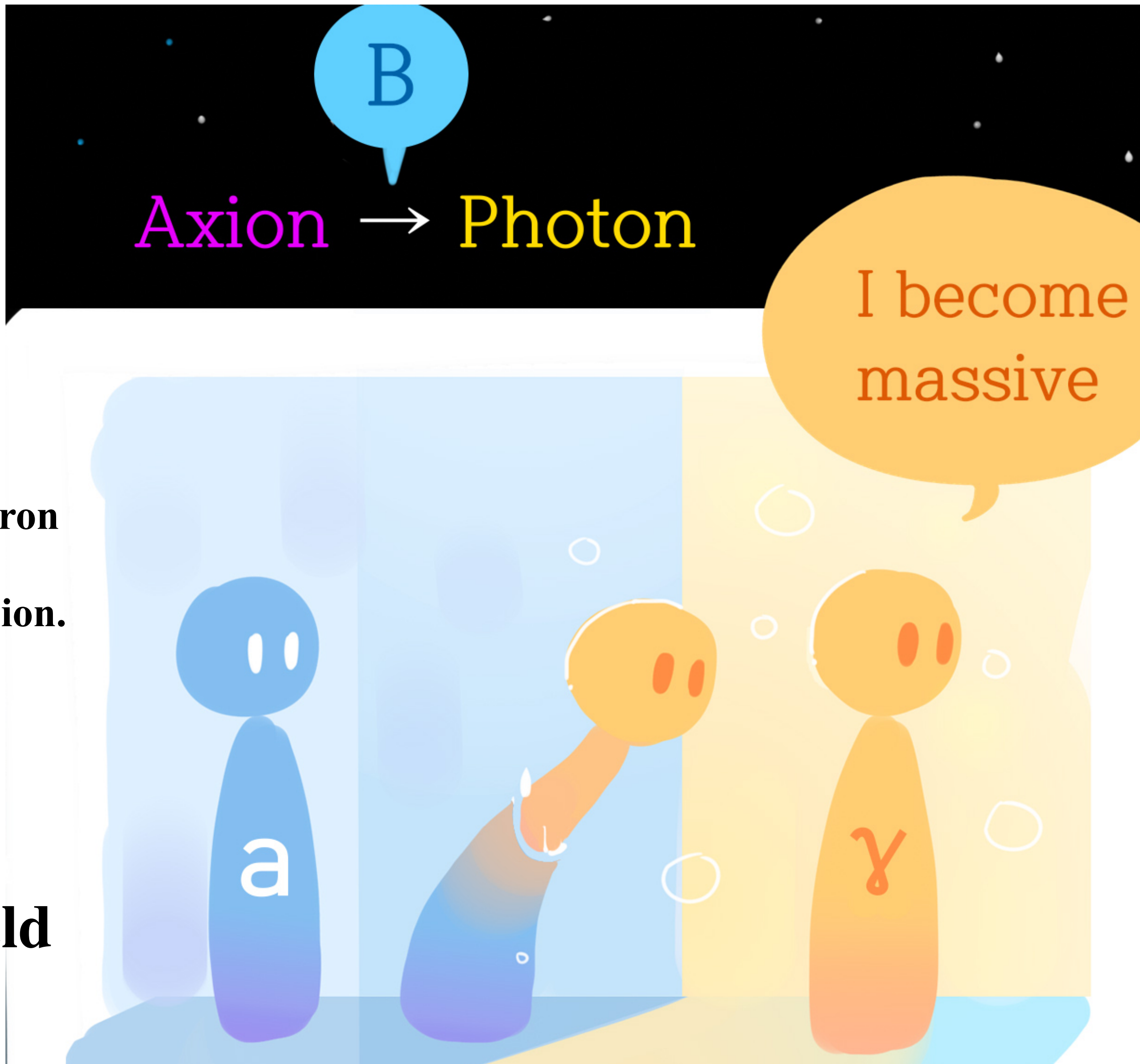


$$Q_{\text{plasma}} = \omega_{\text{plasma}}^2 = 4\pi\alpha\frac{n_e}{m_e}$$

$$\frac{Q_{\text{pl}}}{Q_{\text{QED}}} \sim 5\times 10^8 \left(\frac{\mu\text{eV}}{\omega}\right)^2 \frac{10^{12}\ \text{G}}{B}\frac{1\ \ \text{sec}}{P}$$

For relativistic axion from neutron star, QED mass dominates and there is no resonant conversion.

$$L_{\text{int}} = \frac{1}{4}g\tilde{F}^{\mu\nu}F_{\mu\nu}a = -g\mathbf{E}\cdot\mathbf{B}a,$$



Axion-photon conversion in external magnetic field

G. Raffelt and L. Stodolsky, Phys. Rev. D 37, 1237 (1988)

Axion-photon conversion in magnetosphere

The axion-photon conversion probability

$$p_{a\to\gamma} = \sin^2 2\tilde{\theta}(z)\,\sin^2[z(k_1 - k_2)/2]$$

$$\sin 2\tilde{\theta} = \frac{2gB\omega}{\sqrt{4g^2B^2\omega^2 + (m_\gamma^2 - m_a^2)^2}}$$

$$m_\gamma^2(r) = 4\pi\alpha\frac{n_e(r)}{m_e}$$

Here, for non-relativistic axion cold dark matter, the QED mass is negligible compared to plasma mass.

$$n_e(r) = n_e^{\mathrm{GJ}}(r) = 7\times 10^{-2}\,\frac{1s}{P}\,\frac{B(r)}{1\ \mathrm{G}}\,\frac{1}{\mathrm{cm}^3}$$

$$B(r) = B_0\left(\frac{r}{r_0}\right)^{-3}$$

Here, we choose the simplest electron density distribution and magnetic field configuration to clearly see the physics process.

Thus, the photon mass is position r dependent, and within some region the photon mass is close to the axion DM mass.

The Adiabatic Resonant Conversion

The resonance radius is defined at the level crossing point

$$m_\gamma^2(r_{\rm res}) = m_a^2$$

At the resonance, $|m_\gamma^2 - m_a^2| \ll gB\omega$ and $m_{1,2}^2 \approx m_a^2 \pm gB\omega$.

Within the resonance region, the axion-photon conversion rate is greatly enhanced due to large mixing angle.

$$\sin 2\tilde{\theta} = \frac{(2gB\omega/m_\gamma^2)}{\sqrt{(4g^2B^2\omega^2/m_\gamma^4) + (1-(m_a/m_\gamma)^2)^2}}$$

$$\equiv \frac{c_1}{\sqrt{c_1^2 + (1-f(r))^2}},$$

N.B. Only for the non-relativistic axion, the resonant conversion can be achieved. For relativistic axion, QED effects make it impossible.

The adiabatic resonant conversion requires the resonance region is approximately valid inside the resonance width. Coherent condition is also needed.

$$\delta r > l_{\rm osc} = \frac{2\pi}{|k_1 - k_2|_{\rm res}}$$

$$|d\tilde{\theta}/dr|_{\rm res} < l_{\rm osc}^{-1}$$

$$|d\ln f/dr|_{\rm res}^{-1} > 650[m]\left(\frac{m_a}{\mu\mathrm{eV}}\right)^3\left(\frac{v_{\rm res}}{10^{-1}}\right)\left(\frac{1/10^{10}\ \mathrm{GeV}}{g}\right)^2 \times \left(\frac{10^{12}\ \mathrm{G}}{B(r_{\rm res})}\right)^2\left(\frac{\mu\mathrm{eV}}{\omega}\right)^2$$

Adiabatic resonant conversion is essential to observe the photon signal.

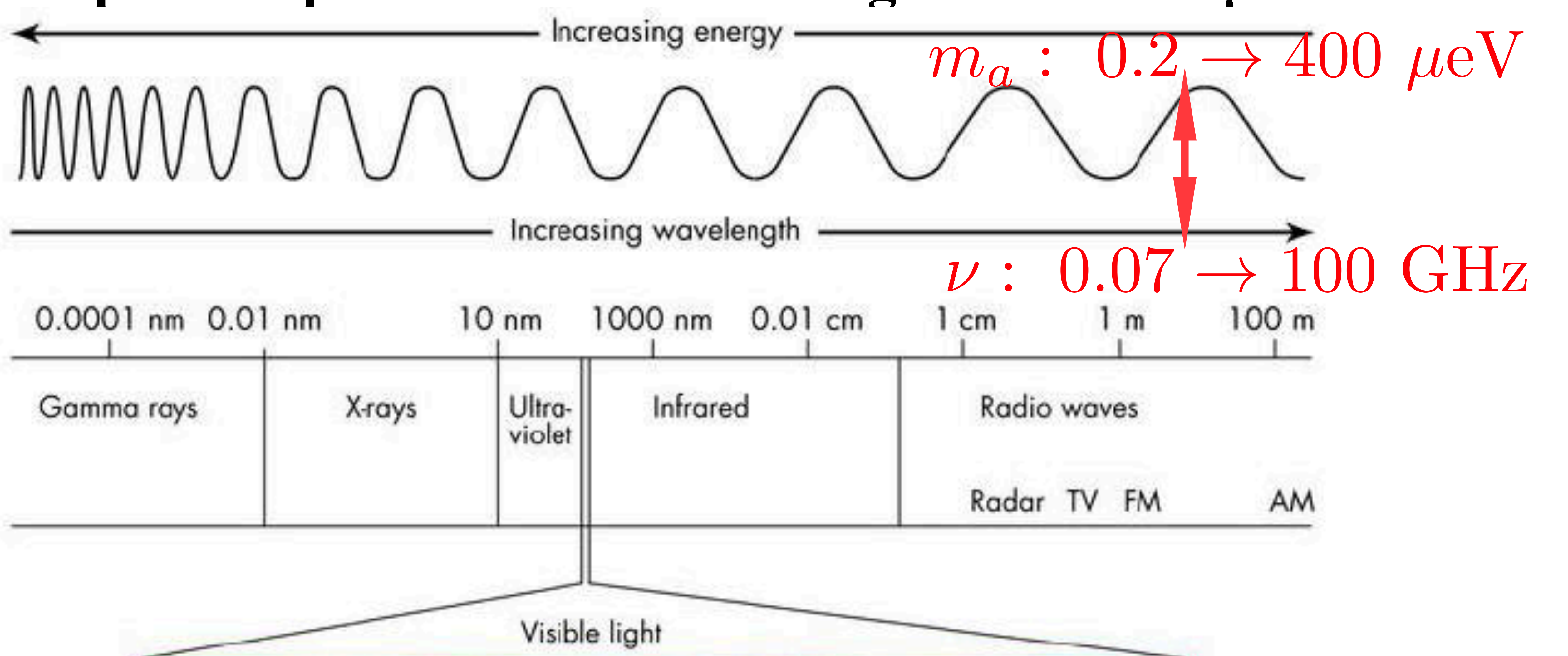
Radio Signal

Line-like radio signal for non-relativistic axion conversion:

$$\nu_{\rm peak} \approx \frac{m_a}{2\pi} \approx 240 \frac{m_a}{\mu eV} {\rm MHz}$$

1 GHz ~ 4 μeV

The FAST covers 70 MHz–3 GHz, the SKA covers 50 MHz–14 GHz, and the GBT covers 0.3–100 GHz, so that the radio telescopes can probe axion mass range of 0.2–400 μeV



Radio Signal

Signal: For adiabatic resonant conversion, and the photon flux density can be estimated to be of order

$$S_\gamma = \frac{dE/dt}{4\pi d^2 \Delta\nu} \sim 4.2\mu Jy \frac{\left(\frac{r_{\rm res}}{100\ {\rm km}}\right)\left(\frac{M}{M_{\rm sun}}\right)\left(\frac{\rho_a}{0.3\ {\rm GeV/cm^3}}\right)\left(\frac{10^{-3}}{v_0}\right)\left(\frac{g}{1/10^{10}\ {\rm GeV}}\right)\left(\frac{B(r_{\rm res})}{10^{12}\ {\rm G}}\right)\left(\frac{\omega}{\mu{\rm eV}}\right)\left(\frac{\mu{\rm eV}}{m_a}\right)^2}{\left(\frac{d}{1\ {\rm kpc}}\right)^2\left(\frac{m_a/2\pi}{\mu{\rm eV}/2\pi}\right)\left(\frac{v_{\rm dis}}{10^{-3}}\right)},$$

where d represents the distance from the neutron star to us. The photon flux peaks around the frequency $\nu_{\rm peak} \sim m_a/2\pi$, and $\Delta\nu \sim \nu_{\rm peak} v_{\rm dis}$ represents the spectral line broadening around this peak frequency due to the DM velocity dispersion $v_{\rm dis}$.

Sensitivity: The smallest detectable flux density of the radio telescope (SKA, FAST, GBT) is of order

$$S_{\rm min} \approx 0.29\mu Jy \left(\frac{1\ {\rm GHz}}{\Delta B}\right)^{1/2}\left(\frac{24\ {\rm hrs}}{t_{\rm obs}}\right)^{1/2}\left(\frac{10^3\ {\rm m^2/K}}{A_{\rm eff}/T_{\rm sys}}\right)$$

Radio Signal

Signal: For a trial parameter set, $B_0 = 10^{15}$ G, $m_a = 50\ \mu$eV
$P = 10$ s, $g = 5 \times 10^{-11}$ GeV^{-1}, $r_0 = 10$ km, $M = 1.5 M_{sun}$, $d = 1$kpc

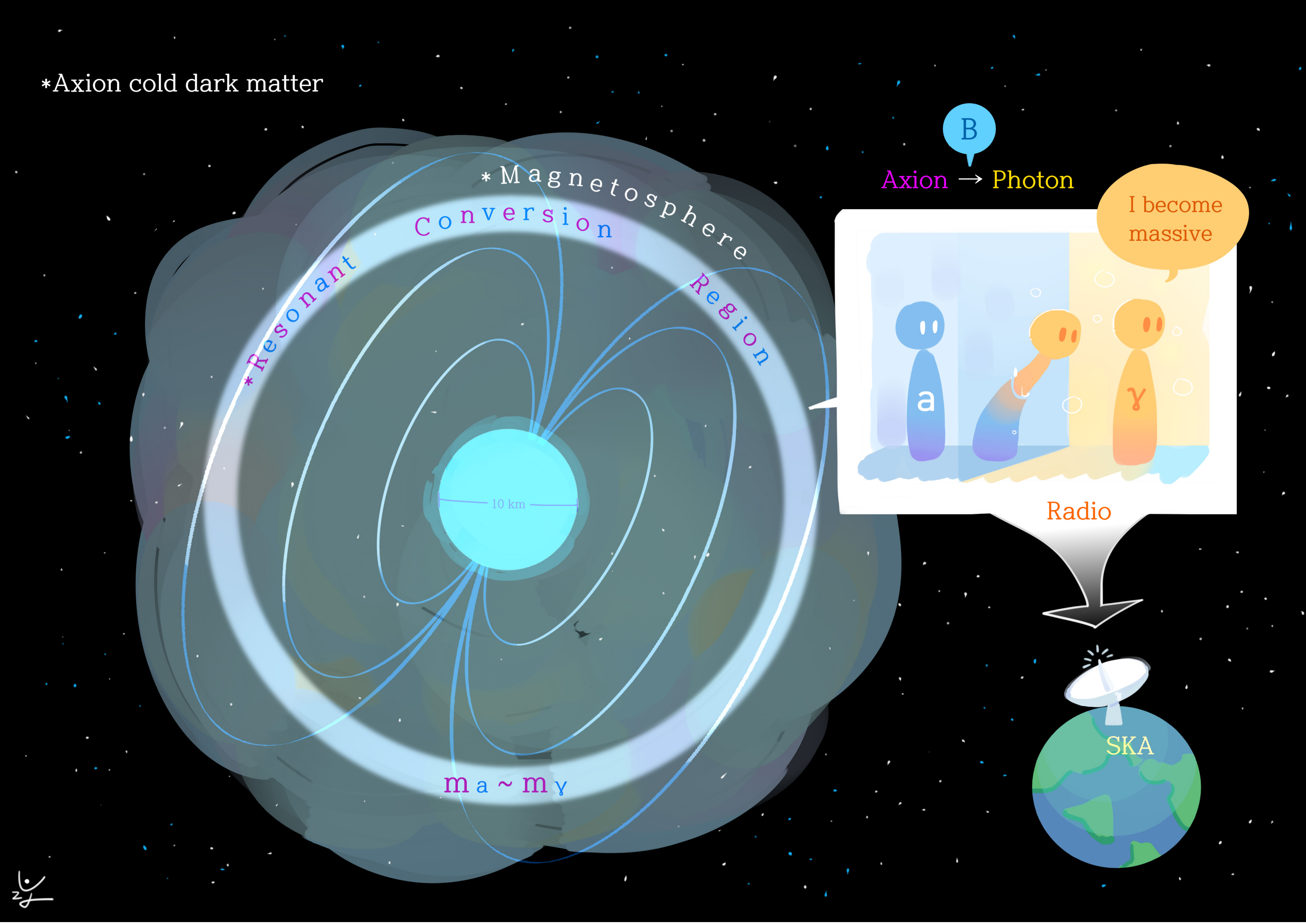
satisfies the constraints of the adiabatic resonance conditions and the existed axion search constraints produces the signal $S \sim 0.51$ μJy.

Sensitivity: $S_{min} \sim 0.48 \mu Jy$ for the SKA1

$S_{min} \sim 0.016 \mu Jy$ for the SKA2 with 100 hour observation time

SKA-like experiment can probe the axion DM and the axion mass which corresponds to peak frequency.

More detailed study taking into account astrophysical uncertainties and more precise numerical analysis is still working in progress.



FPH, K. Kadota, T. Sekiguchi, H. Tashiro, Phys.Rev. D97 (2018) no.12, 123001

Radio telescope search for the resonant conversion of cold dark matter axions from the magnetized astrophysical sources
Fa Peng Huang, Kenji Kadota (IBS, Daejeon), Toyokazu Sekiguchi (Tokyo U., RESCEU), Hiroyuki Tashiro (Nagoya U.).
Mar 22, 2018. 7 pp.
PhysRevD.97.123001, arXiv:1803.08230
Cited by 27 records

Physics Briefing Book : Input for the European Strategy for Particle Physics Update 2020
Richard Keith Ellis (Durham U., IPPP) *et al.*. Oct 25, 2019. 254 pp.
CERN-ESU-004
e-Print: **arXiv:1910.11775** **[**

9.5.3 Complementarity with direct and indirect detection searches

Radio searches for the conversion of axion/ALP dark matter into photons inside the magnetosphere of neutron stars can have sensitivity [630–632] for ALP masses in the range ~ 0.2–$40\,\mu$eV, and potentially above. The signature is the emission of a narrow radio line from individual neutron stars, with a frequency that corresponds to the mass of the ALP. Several of such searches are now underway, with expected sensitivities to the photon-ALP coupling down to $g_{a\gamma\gamma} \sim 10^{-12}\,\mathrm{GeV}^{-1}$. The future SKA may have the ability to probe significant parts of the QCD axion parameter space [633].

Comments on the radio probe of axion dark DM

1. **Astrophysical uncertainties:the magnetic profile, DM density and distribution, the velocity dispersion, the plasma mass, background including optimized bandwidth**

2. **There are more and more detailed and comprehensive studies after our first rough estimation on the radio signal:**

arXiv:1804.03145 by Anson Hook, Yonatan Kahn, Benjamin R. Safdi, Zhiquan Sun where they consider more details. They also consider extremely high DM density around the neutron star, thus the signal is more stronger.

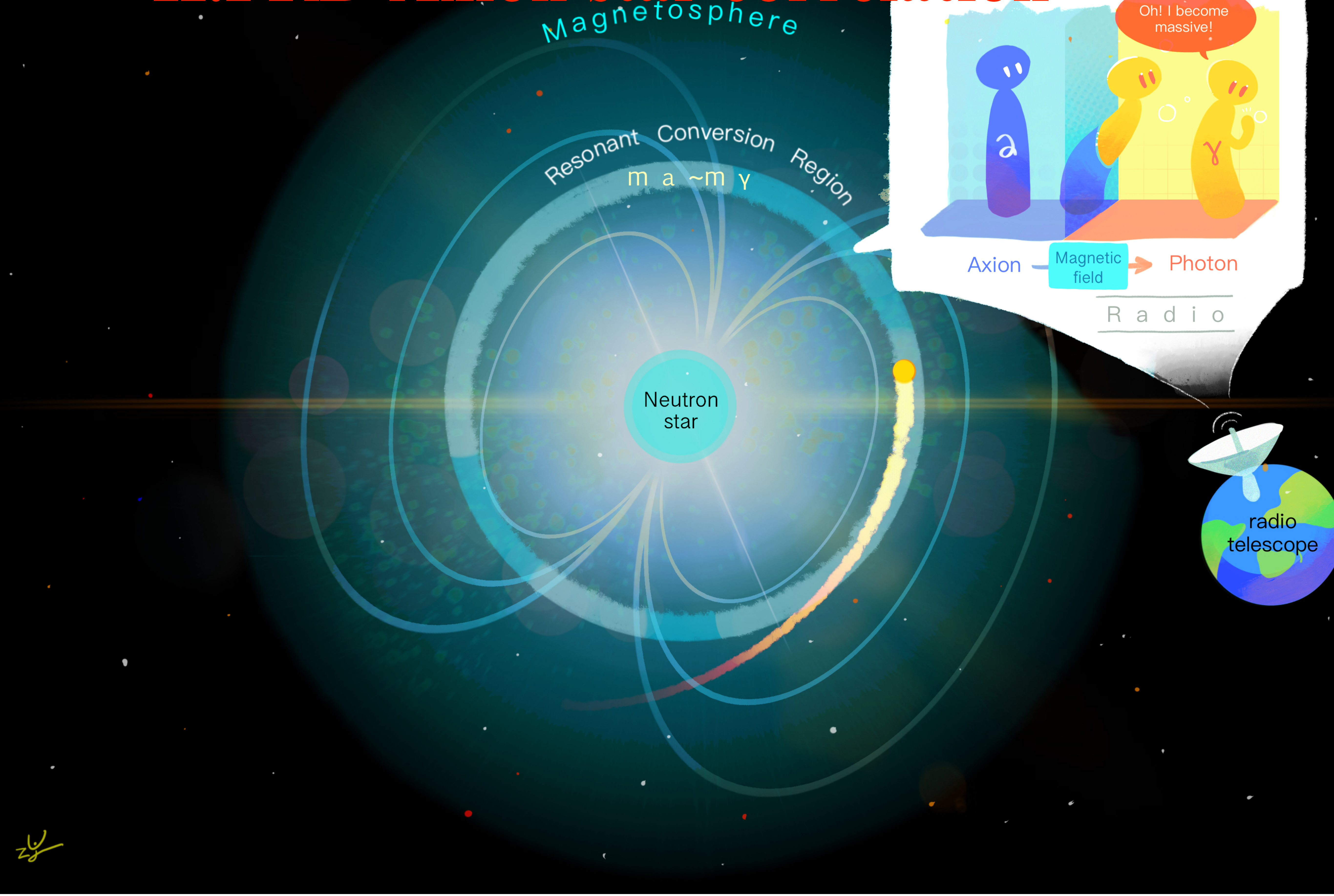
arXiv:1811.01020 by Benjamin R. Safdi, Zhiquan Sun, Alexander Y. Chen

arXiv:1905.04686,Thomas, D.P.Edwards,Marco Chianese, Bradley J. Kavanagh, Samaya M. Nissanke, Christoph Weniger, where they consider multi-messenger of axion DM detection. Namely, using LISA to detect the DM density around the neutron star, which can determine the radio strength detected by SKA.

3. **Recently, GBT already have some data on the observation of neutron star, and Safdi's group is doing the analysis of the data to get some constraints.**

4. **More precise study are needed …**

II.FRB-Axion star correlation



James H. Buckley, P. S. Bhupal Dev, Francesc Ferrer, FPH, arXiv:2004.06486

II.FRB-Axion star correlation

Axion or axion-like particle motivated from strong CP problem or string theory is still one of the most attractive and promising DM candidate.

A collection of axions can condense into a bound Bose-Einstein condensate called an axion star. The typical axion star mass is $10^{-13} M_{\odot}$

The fact that the energy released by FRBs is close to $10^{-13} M_{\odot}$, which is the typical axion star mass, and that their frequency (several hundred MHz to several GHz) coincides with that expected from μeV axion particles, motivates us to further explore whether the axion-FRB connection can be made viable in a pulsar magnetosphere and tested with the future data.

Axion star-Neutron star encounter

Dilute axion star is balanced by kinetic pressure and self-gravity, with the following radius

$$R_a^{\rm dilute} \sim \frac{1}{G_N M_a m_a^2} \cong 270 \left(\frac{10\ \mu{\rm eV}}{m_a}\right)^2 \left(\frac{10^{-12} M_\odot}{M_a}\right)\ {\rm km}$$

In this work, we assume that dense axion stars with a mass around $10^{-13} M_\odot$ can survive to the present, and have a chance to encounter a neutron star. The radius of a dense axion star is

$$R_a^{\rm dense} \sim 0.47 \sqrt{g_{a\gamma\gamma} \times 10^{13}\ {\rm GeV}} \times \sqrt{\frac{10\ \mu{\rm eV}}{m_a}} \left(\frac{M_a}{10^{-13} M_\odot}\right)^{0.3}\ {\rm m}$$

Tidal effects

A gravitationally bound object approaching a star closer than Roche limit will be disrupted by tidal effects. The Roche limit is

$$r_t = R_a \left(\frac{2M_{\rm NS}}{M_a} \right)^{1/3}$$

Tidal disruption may quickly rip apart the dilute axion star, producing a stream of axion debris, long before a dilute axion star enters the magnetosphere of neutron star. For100 km dilute axion, the Roche limit is about 10^6 km.

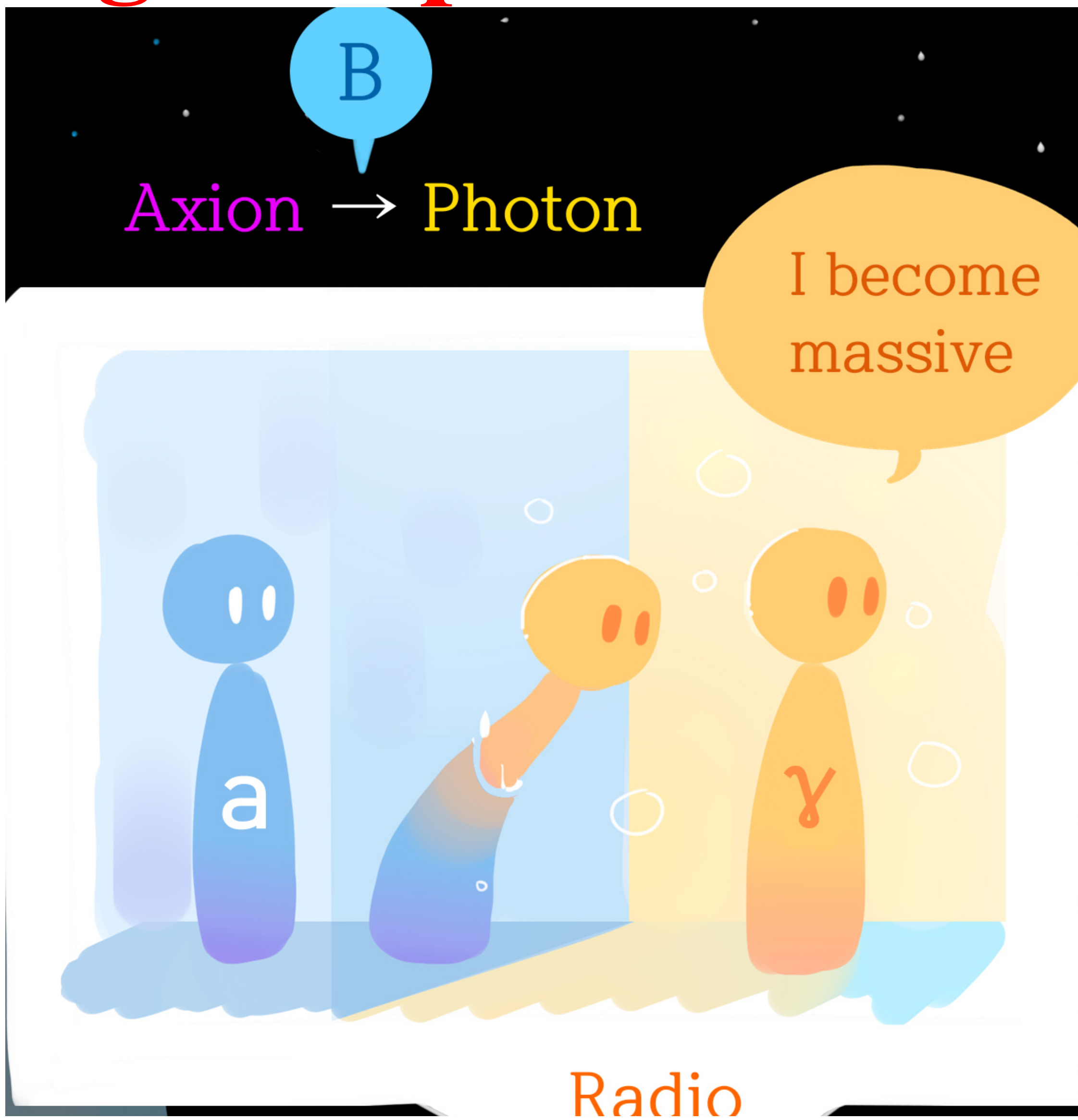
For a dense axion star, the radius is smaller than 1m and the Roche limit is below 10 km. Thus, a dense axion star can reach the resonant conversion region without being tidally ripped.

tidal deformation ratio

$$\frac{\delta R_a}{R_a} = \frac{9M_{\rm NS}}{8\pi\rho_{\rm AS} r^3}$$

Axion-photon conversion in magnetosphere

Massive Photon: **In the magnetosphere of the neutron star, photon obtains the effective mass in the magnetized plasma.**



$$m_\gamma(r) = \omega_p = \sqrt{\frac{e^2 n_e}{m_e}} = \sqrt{\frac{n_e}{7.3\times 10^8\ \mathrm{cm}^{-3}}}\ \mu\mathrm{eV}$$

$$n_e(r) = n_e^{\mathrm{GJ}}(r) = 7\times 10^{-2}\frac{1s}{P}\frac{B(r)}{1\ \mathrm{G}}\frac{1}{\mathrm{cm}^3}$$

$$B(r) = B_0\left(\frac{r_{\mathrm{NS}}}{r}\right)^3$$

Here, we choose the simplest electron density distribution and magnetic field configuration to clearly see the physics process.

Thus, the photon mass is position r dependent, and within some region the photon mass is close to the axion mass.

The Non-adiabatic Resonant Conversion

In the resonant conversion region, the photon effectively has almost the same mass as the axion due to plasma effects:

$$\left(\frac{r_{\mathrm{NS}}}{r_c}\right)^3 \sim \left(\frac{m_a}{\mu\mathrm{eV}}\right)^2 \frac{10^{10}\ \mathrm{G}}{B_0} \frac{P}{1\ \mathrm{s}} \qquad \left.\frac{\mathrm{d}\omega_p^2}{\mathrm{d}r}\right|_{r=r_c} = \left.\frac{3\omega_p^2}{r}\right|_{r=r_c}$$

Landau-Zener probability:

$$P_{a\to\gamma} = 1 - e^{-2\pi\beta}.$$

The non-adiabatic limit corresponds to small β, and we have $P_{a\to\gamma} \approx 2\pi\beta$ with

$$\beta = \left.\frac{\left(g_{a\gamma\gamma}\omega B_0\right)^2 / 2\bar{k}}{\left|\mathrm{d}\omega_p^2/\mathrm{d}r\right|}\right|_{r=r_c}.$$

FRBs

Signal: For resonant conversion the radiated power is

$$\dot{W} \sim \left(\frac{M_a}{10^{-13} M_\odot}\right) \left(10^7 \times P_{a\to\gamma}\right) \left(10^{44}\ \mathrm{GeV}\cdot\mathrm{s}^{-1}\right)$$

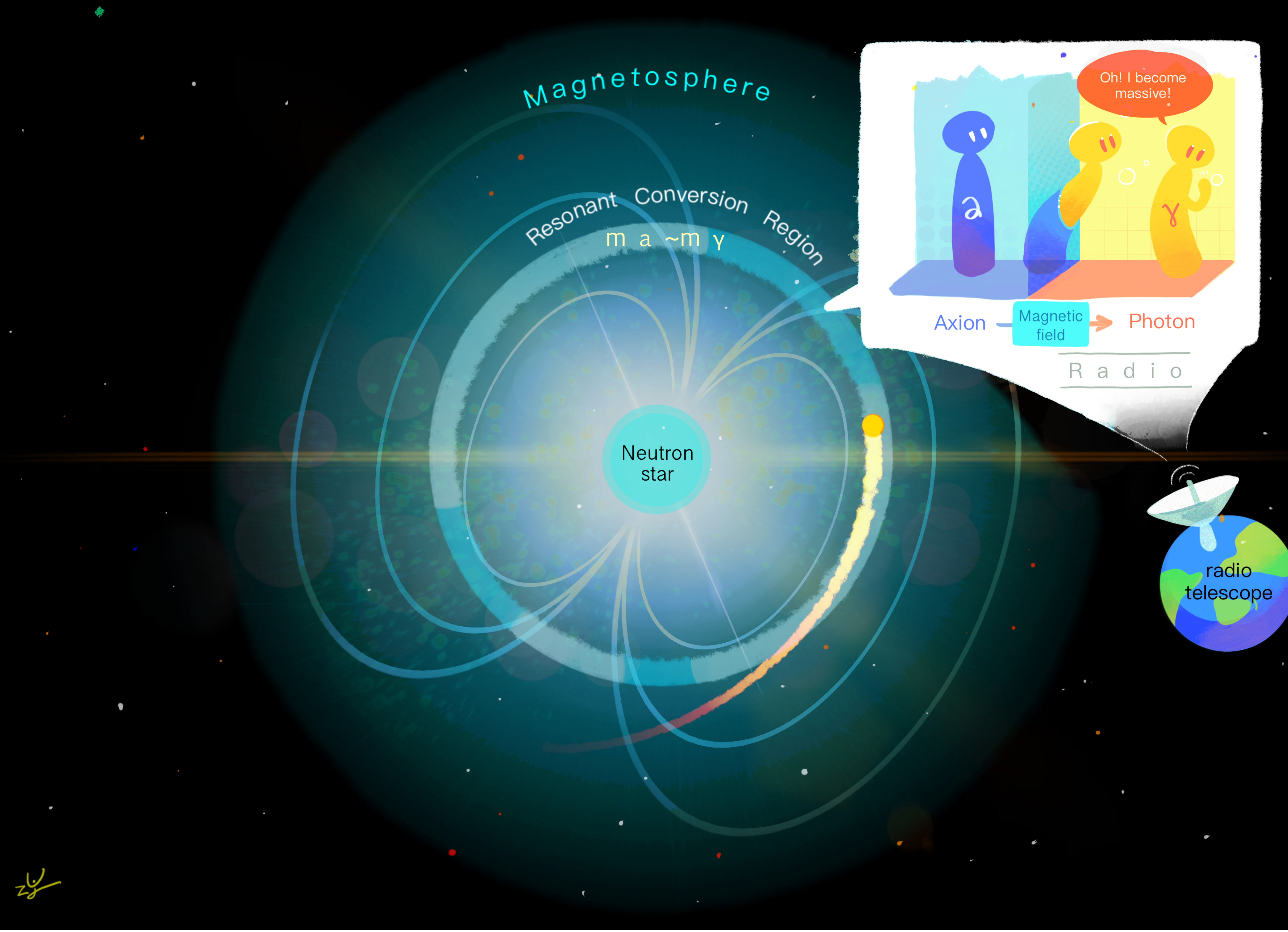
$$\text{FRBs},\ \dot{W} \sim 10^{44}\ \mathrm{GeV}\cdot\mathrm{s}^{-1}$$

$$\mathcal{S} = \frac{\dot{W}}{4\pi d^2 \Delta B} \qquad \frac{E_{\rm FRB}}{\rm J} = \frac{F_{\rm obs}}{\mathrm{Jy}\cdot\mathrm{ms}} \frac{\Delta B}{\rm Hz} \left(\frac{d}{\rm m}\right)^2 \times 10^{-29}(1+z)$$

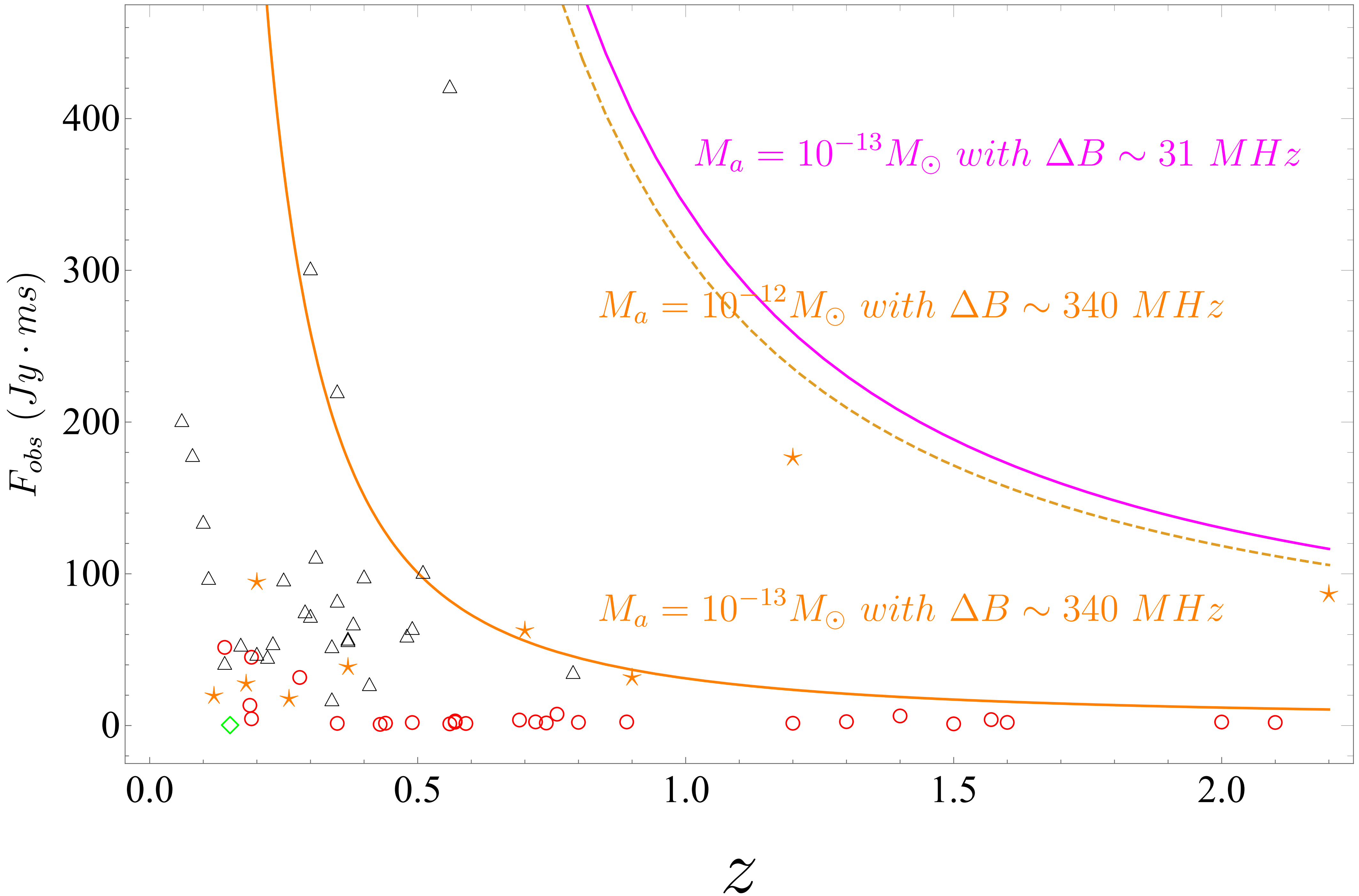
For the benchmark values $m_a = 10\ \mu\mathrm{eV}$, $M_a = 10^{-13} M_\odot$, $g_{a\gamma\gamma} = 10^{-13}\ \mathrm{GeV}^{-1}$ we can naturally explain **FRBs.**

Sensitivity: The smallest detectable flux density of the radio telescope is of order, taking SKA as example

$$S_{\rm min} \approx 0.09\ \mathrm{Jy} \left(\frac{1\ \mathrm{MHz}}{\Delta B}\right)^{1/2} \left(\frac{1\ \mathrm{ms}}{t_{\rm obs}}\right)^{1/2} \left(\frac{10^3 \mathrm{m}^2/\mathrm{K}}{A_{\rm eff}/T_{\rm sys}}\right)$$



James H. Buckley, P. S. Bhupal Dev, Francesc Ferrer, FPH, arXiv:2004.06486



Upper limit on the fluence as a function of redshift z. The solid orange line depicts the upper limit for $M_a = 10^{-13}M_\odot$ with bandwidth $\Delta B \sim 340$ MHz. The dashed orange line represents the upper limit for $M_a = 10^{-12}M_\odot$ and the same bandwidth $\Delta B \sim 340$ MHz. The magenta line corresponds to the upper limit for $M_a = 10^{-13}M_\odot$ and $\Delta B \sim 31$ MHz.

Event rate

$$\frac{N}{\text{year}} = \sigma v_0 n_{\rm AS} n_{\rm NS} f_{\rm NS} V$$

$$\sigma = \pi b^2 = \pi r_c^2 v_c^2 / v_0^2 (1 - 2 G_N M_{\rm NS}/r_c)^{-1}$$

For the whole Universe, the event rate per day is: $10^{13} \kappa_{\rm AS} f_{\rm NS}/365 \sim 1000$

$\kappa_{\rm AS}$ is the fraction of the total DM density in axion stars.

$f_{\rm NS}$ represents the ratio of neutron stars with magnetic fields larger than 10^{13} G on their surface.

the SKA can detect more and more FRB events and provide us with more detailed and accurate information to test our proposed axion-star explanation.

Comments

1. We stress that this paper is aimed at explaining the broad features of FRBs, but there are a number of complicated astrophysical effects that are likely important in describing the detailed emission mechanisms for radiation from these events. Details of the geometry of the magnetosphere (e.g., the position of gaps and the neutral sheet) have a significant impact on the observed signals. Moreover, there are likely to be significant feedback effects in the conversion region. As the axion star moves through the field and plasma comprising the magnetosphere, it may exert radiation pressure on the surrounding plasma, exceeding the relatively small Thomson pressure due to the complicated plasma effects.

2.Work on the explanation of the repeating FRBs will appear on arXiv soon.

Summary

We have proposed a new approach to explore axion cold DM by SKA-like radio telescope in the resonant conversion region of pulsar magnetosphere.

We have proposed a new explanation for the origin of FRBs when a dense axion star moves through the resonant region in pulsar magnetosphere.

SKA can observe many more FRBs and precise radio signals, and allow to pin down the correlation between FRBs, axions cold DM and axion stars.
SKA becomes a powerful new approach.

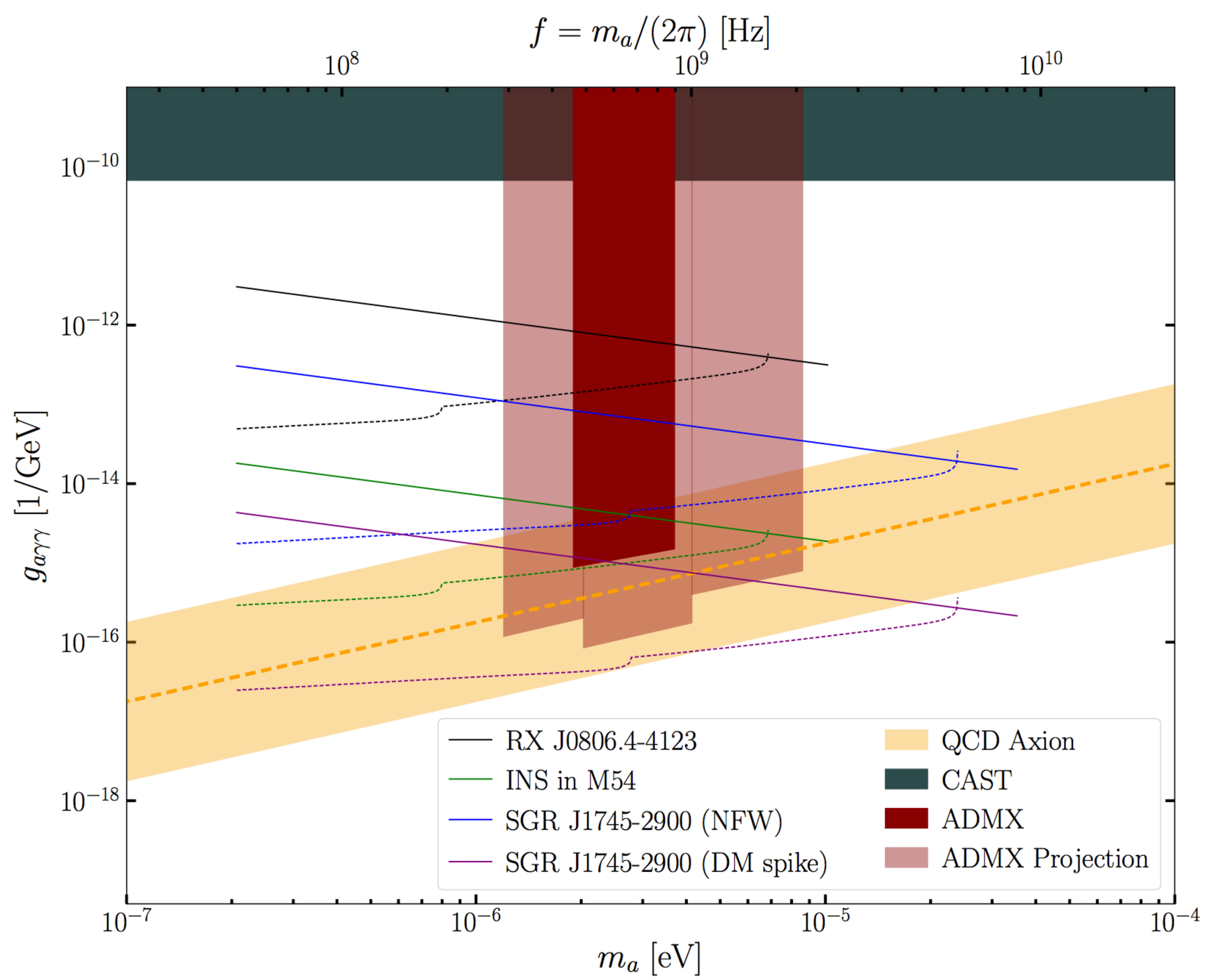
Comments and collaborations are welcome!
Thanks for your attention!

Comments on the radio probe of axion DM

arXiv:1804.03145 by Anson Hook, Yonatan Kahn, Benjamin R. Safdi, Zhiquan Sun where they consider more details.

Besides the normal DM density, they also consider the extremely high DM density around the neutron star, thus the signal is more stronger.

arXiv:1811.01020 by Benjamin R. Safdi, Zhiquan Sun, Alexander Y. Chen



Multi-Messenger Signal of QCD Axion DM

arXiv:1905.04686,Thomas, D.P.Edwards,Marco Chianese, Bradley J. Kavanagh, Samaya M. Nissanke, Christoph Weniger

How can we use next generation gravitational wave and radio telescopes to find DM?

This work is a combination of two classes of well-studied works:

1. **radio signal search of the axion DM by SKA-like experiments**

3. **gravitational wave detection of DM density by LISA-like experiments.**

These two different works are combined as multi-messenger signals through the extremely high DM density surrounded the intermediate massive black hole and neutron star binary.

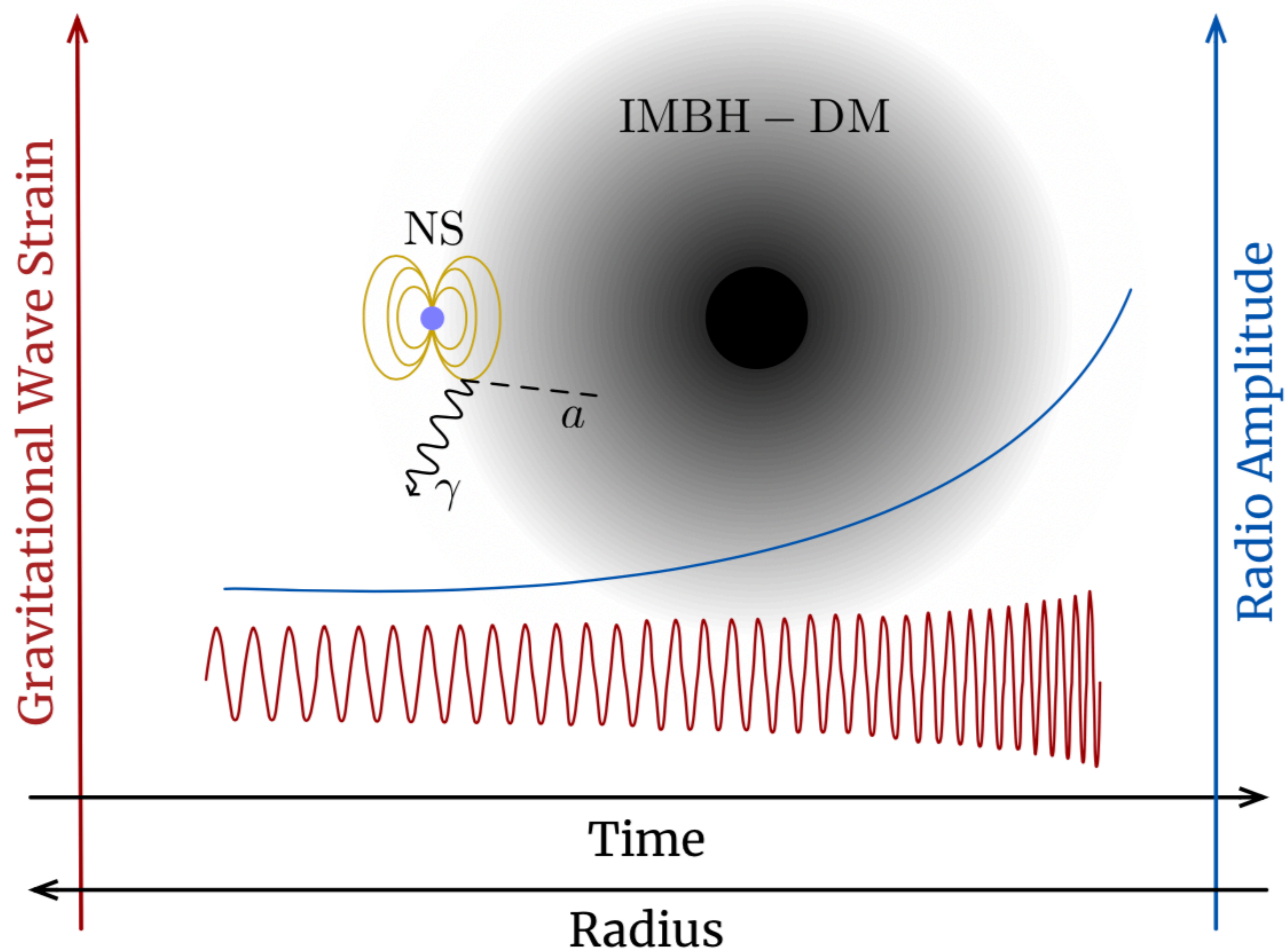


FIG. 1. **Illustration of the IMBH-DM-NS system.** The presence of an axion DM halo around the intermediate mass black hole (IMBH) produces a phase shift in the strain of the GW signal and radio emission due to its conversion into photons in the neutron star (NS) magnetosphere. a and γ represent an axion and radio photon respectively.

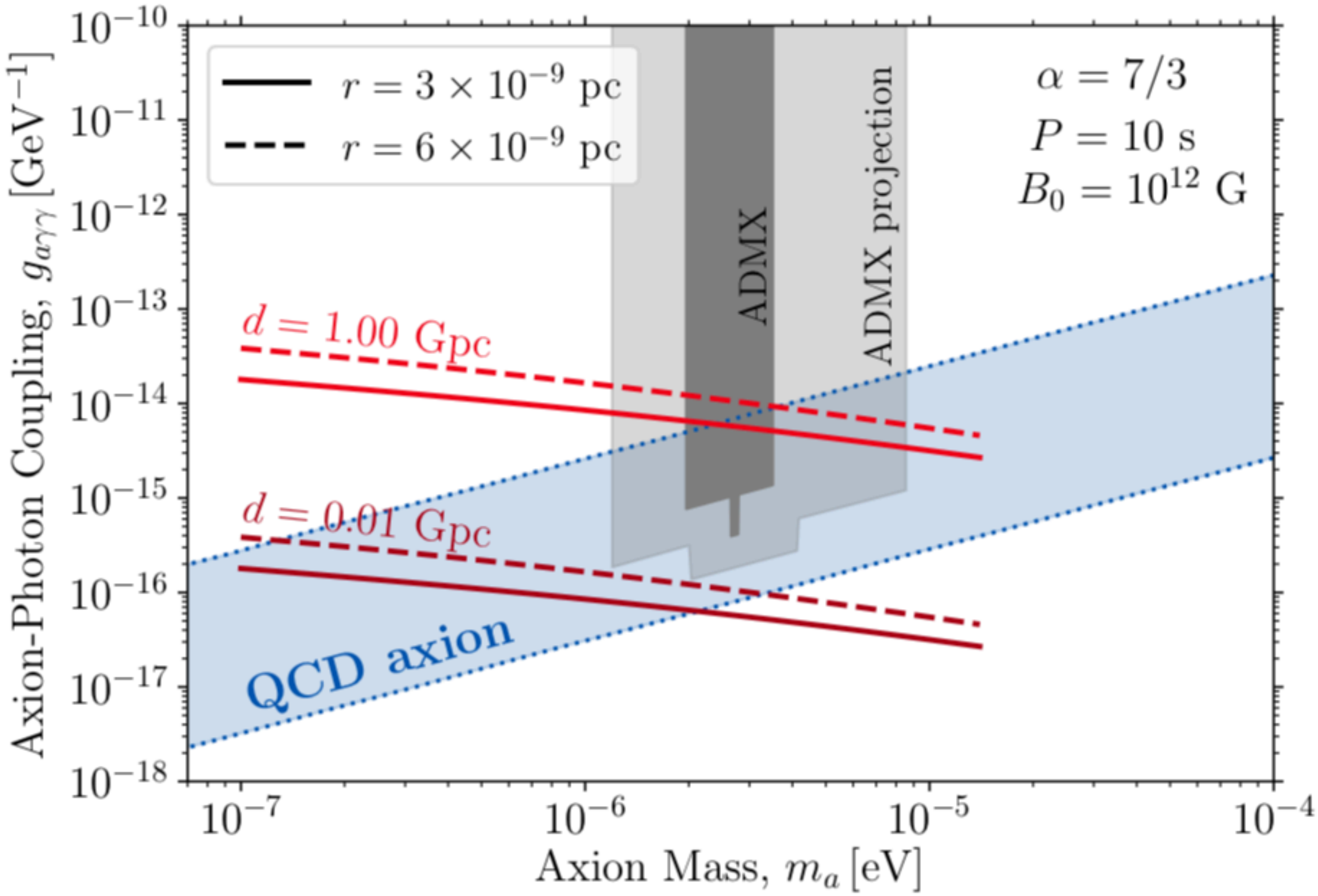


FIG. 3. **Projected sensitivity to the axion-photon coupling from radio observations.** Sensitivity curves of the SKA telescope (100 hours of observation) to the axion-photon coupling as a function of the axion mass for two different inspiral orbits, $r = 6 \times 10^{-9}$ pc (dashed) and $r = 3 \times 10^{-9}$ pc (solid), and two different IMBH-DM-NS system locations, $d = 0.01$ Gpc (dark red) and $d = 1.00$ Gpc (light red). Here, we assume $\alpha = 7/3$ for the slope of the DM spike. The predicted range of parameters for the QCD axion are represented by the blue band, while the vertical gray bands show the current and future ADMX limits [22, 23].