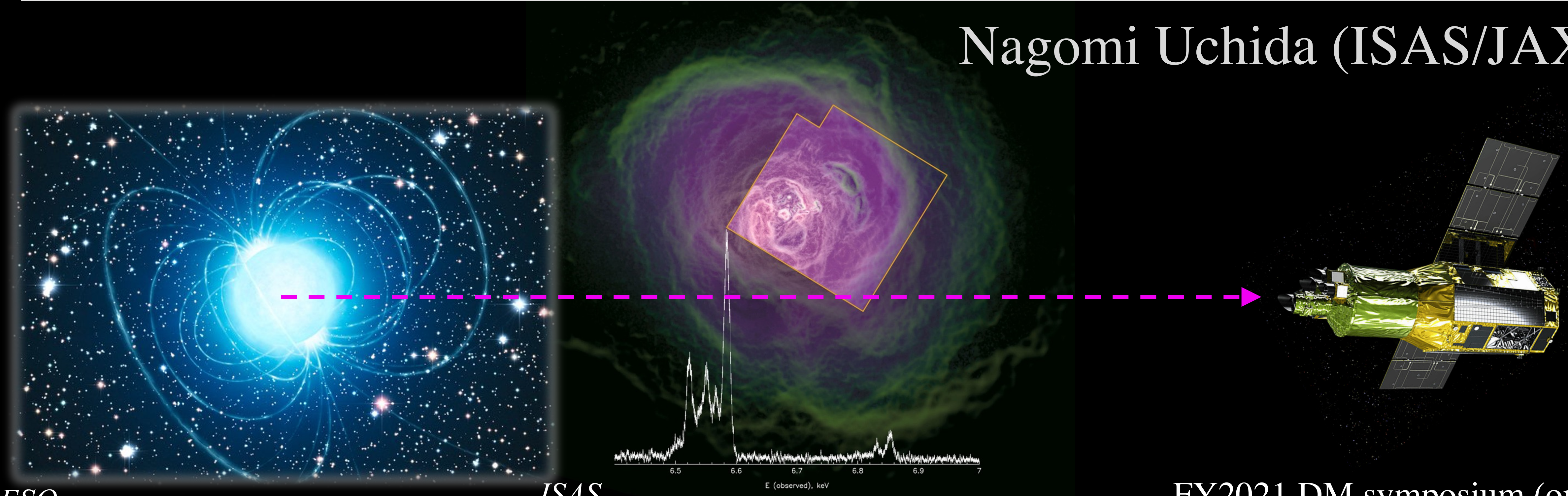
XRISM X-Ray Imaging and Spectroscopy Mission

Dark matter search by astronomical observation in X-ray (B04 report)

Nagomi Uchida (ISAS/JAXA)

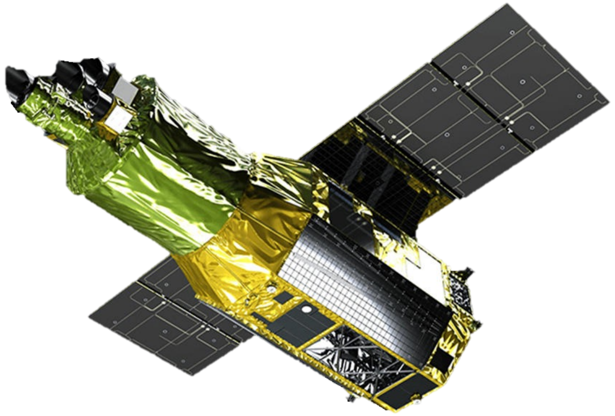


ESO *ISAS*

FY2021 DM symposium (online)

Contents

- Basic strategy
- Sterile neutrino search with cluster of galaxies
- Axion search with magnetars
- Summary



Give me some advices from theoretical/observational side!

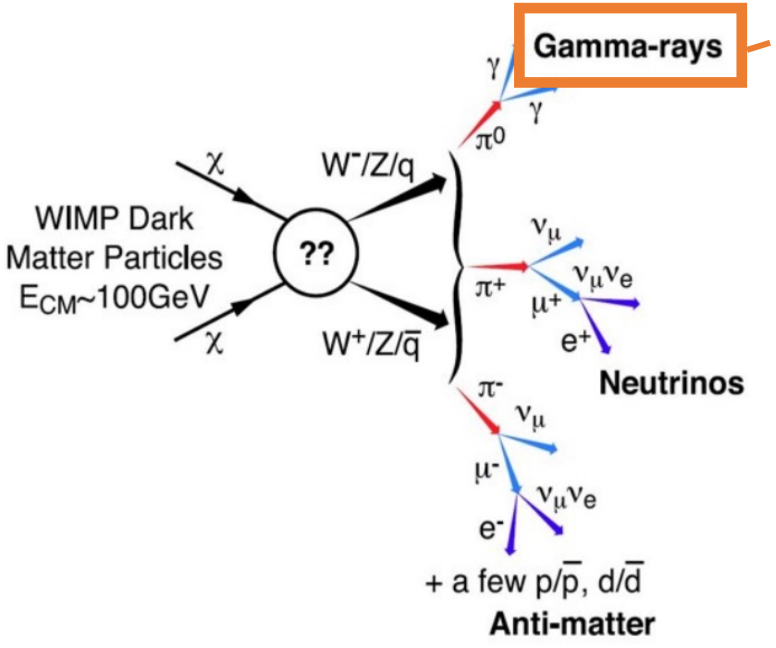
Basic Strategy

Candidates → WIMPs, PBH, Sterile neutrinos, Axions, ...etc.

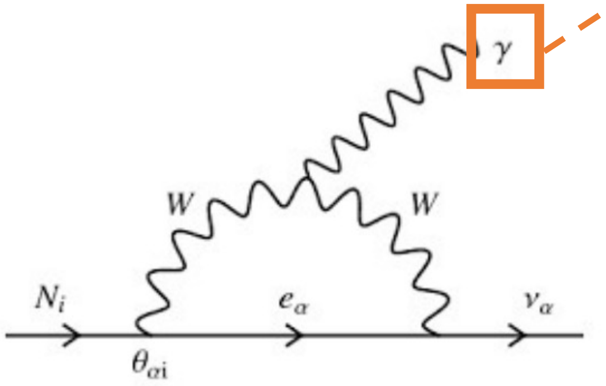
↓

X-ray → Indirect search

1) Self-annihilation
(e.g. WIMPs)

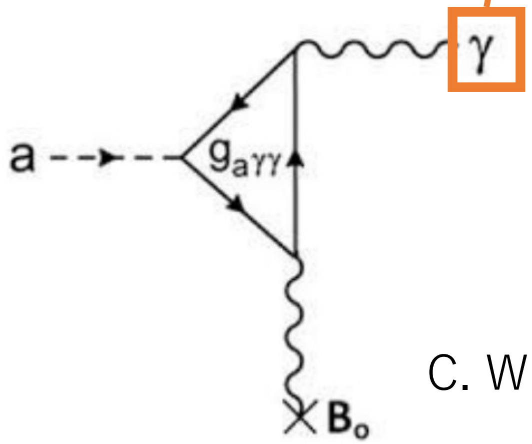


2) Decay
(e.g. sterile neutrinos)



Cluster of galaxies
Dwarf Galaxies

3) Conversion
(e.g. axions)



C. Weniger+19

Galaxy Clusters with their magnetic field,
Earth's magnetic field.

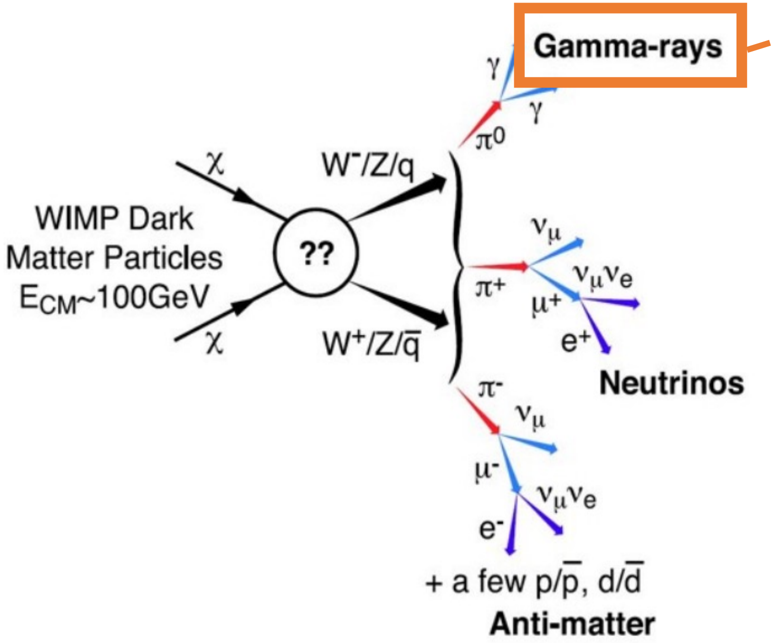
Basic Strategy

Candidates → WIMPs, PBH, Sterile neutrinos, Axions, ...etc.

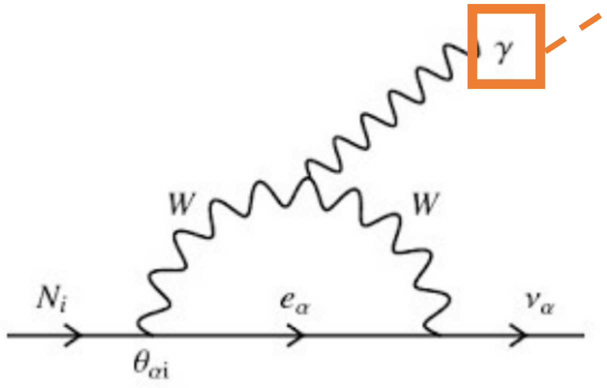
↓

X-ray → Indirect search

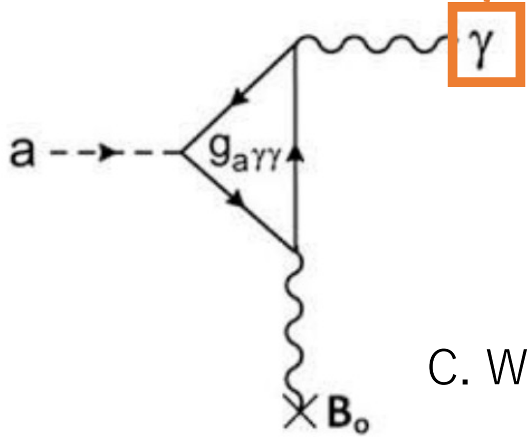
1) Self-annihilation
(e.g. WIMPs)



2) Decay
(e.g. sterile neutrinos)



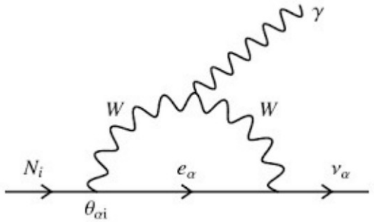
3) Conversion
(e.g. axions)



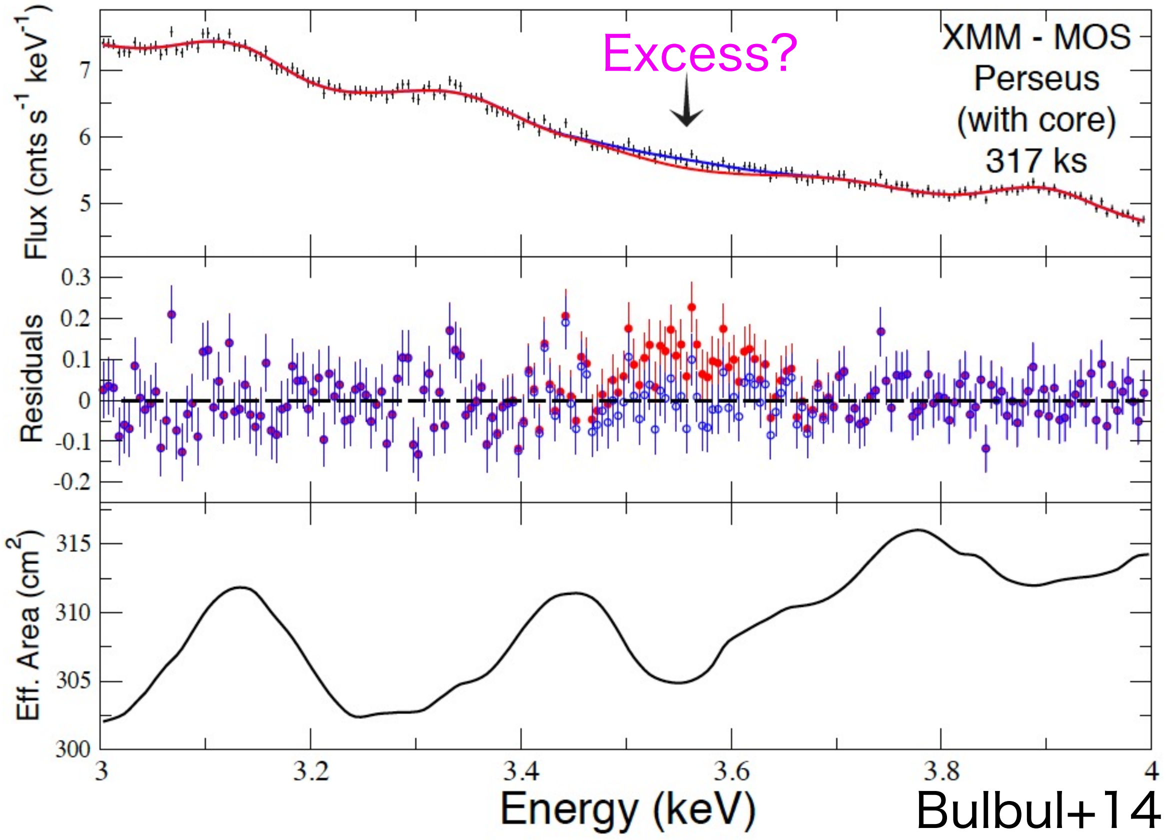
C. Weniger+19

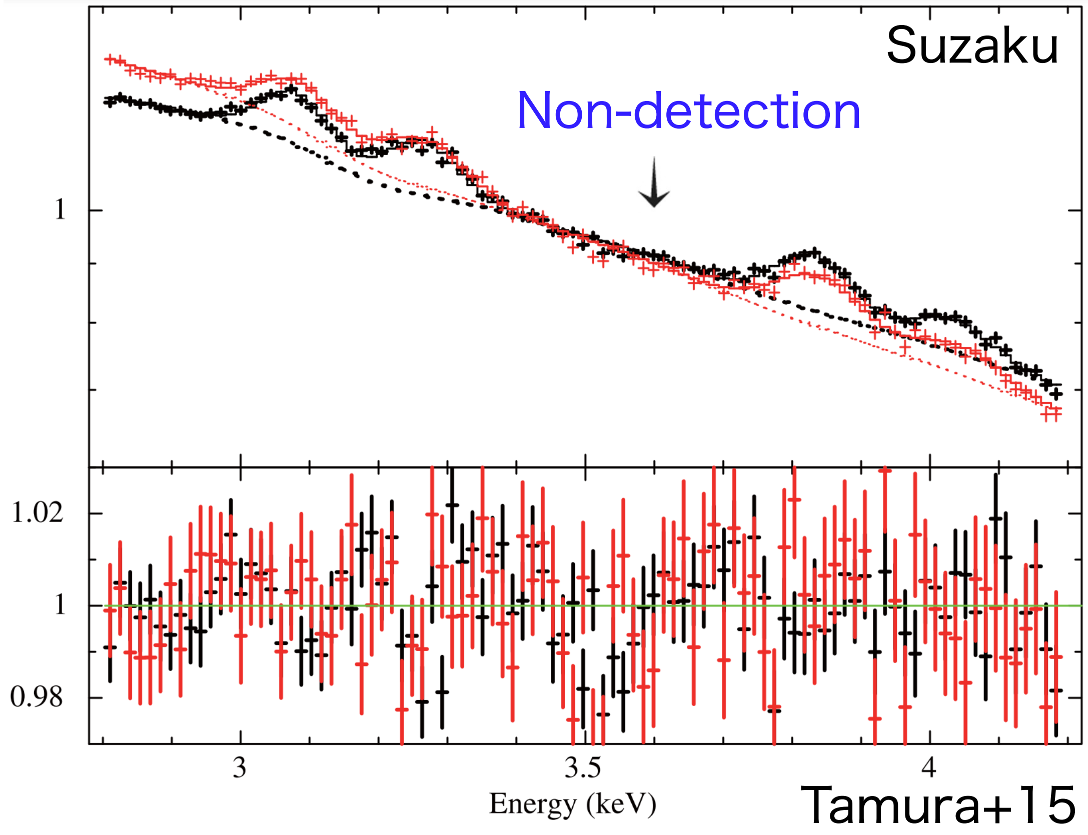
The cluster of galaxies has been mainly focused on as the DM target. → Yamasaki-san's talk

Sterile neutrino × Cluster of Galaxies



In 2014, E. Bulbul reported an undefined line emission from the Perseus cluster around 3.5 keV.
The undefined line was also found from the stacked galaxy spectra.





→ DM?

However, the spectra observed by the Hitomi and Suzaku satellites did not confirm this emission line.

Sterile neutrino × Cluster of Galaxies

Detections
1- Perseus Cluster – too bright
(Bulbul+2014a, Urban+2015, Franse+16)
2- Stacked clusters (Bulbul+14a)
3- Galactic Center
(Boyarsky+2015, Jeltema & Profumo 15)
4- Coma, A2199, and A2319
(Iakubovskyi & Bulbul+15)
5- M31 (Boyarsky+14)
6- NuSTAR Galactic Halo (Neronov+16)
7- NuSTAR Bullet Cluster (Wik+14)
8- Chandra Galactic Halo Observations (Cappelluti+17)

Non-Detection

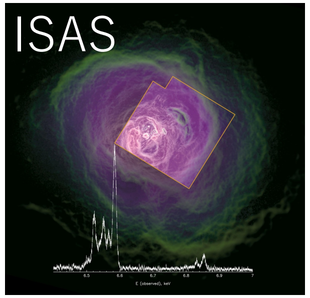
Bulbul+14, Fukuichi+22

1- Virgo Cluster (Bulbul+14a)
2- Coma, Ophiuchus (Suzaku) (Urban+15)
3- Stacked galaxies (Anderson+15)
4- Perseus Cluster (Suzaku Tamura+15)
5- Perseus Cluster
(Hitomi Collaboration 17)
(Tamura+19)
6- Milky Way (XMM Dessert+20)
7- Brank Sky (XMM Foster+21)
8- Galaxy clusters (XMM Bhargava+20)
9- Galactic Halo (Halosat Silich+21)

Still open question!

DM search

→ Distinguishing a Dark Matter line from an astrophysical one.
→ This would require resolving the line, which only a calorimeter can do.
→ The XRISM calorimeter will be the first to resolve and identify or reject those signals.
⭐ This work is executed with Aurora Simionescu(SRON) and Tamura Takayuki(ISAS/JAXA).



FY2022 !

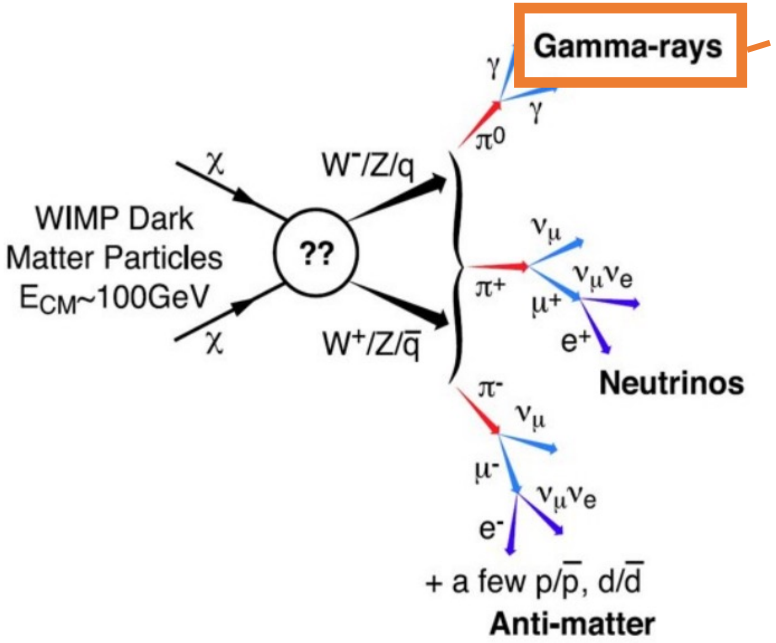
Basic Strategy

Candidates → WIMPs, PBH, Sterile neutrinos, Axions, ...etc.

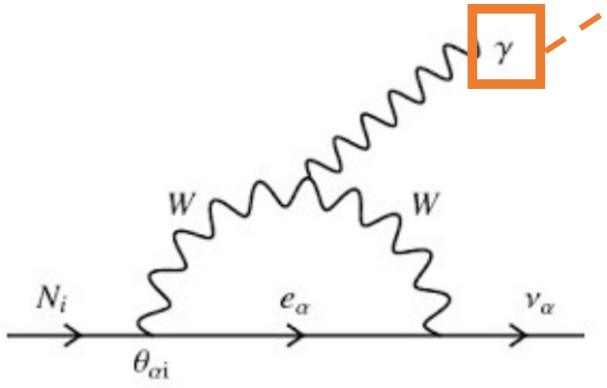
↓

X-ray → Indirect search

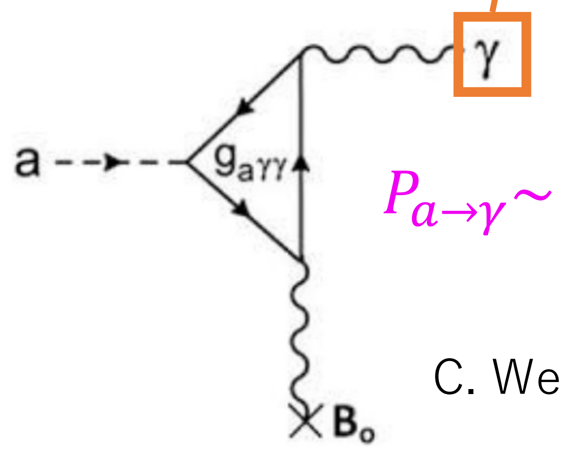
1) Self-annihilation
(e.g. WIMPs)



2) Decay
(e.g. sterile neutrinos)



3) Conversion
(e.g. axions)



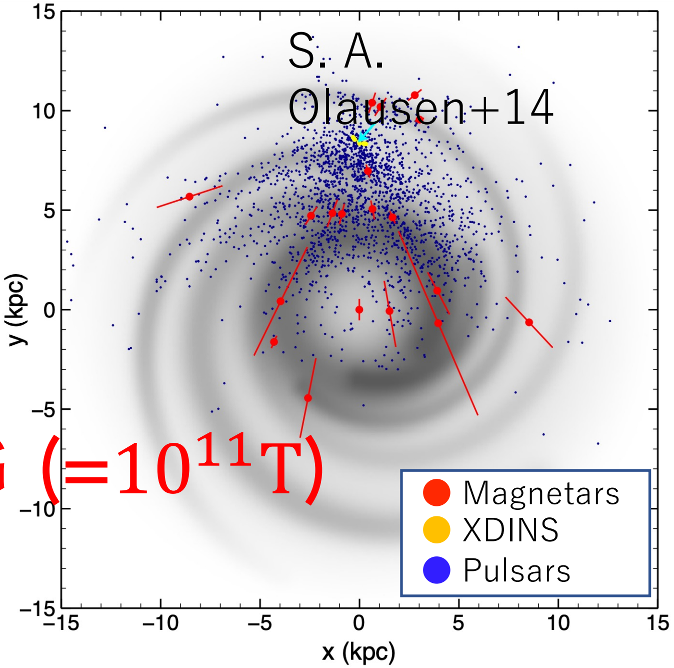
$P_{a \to \gamma} \sim B^2$

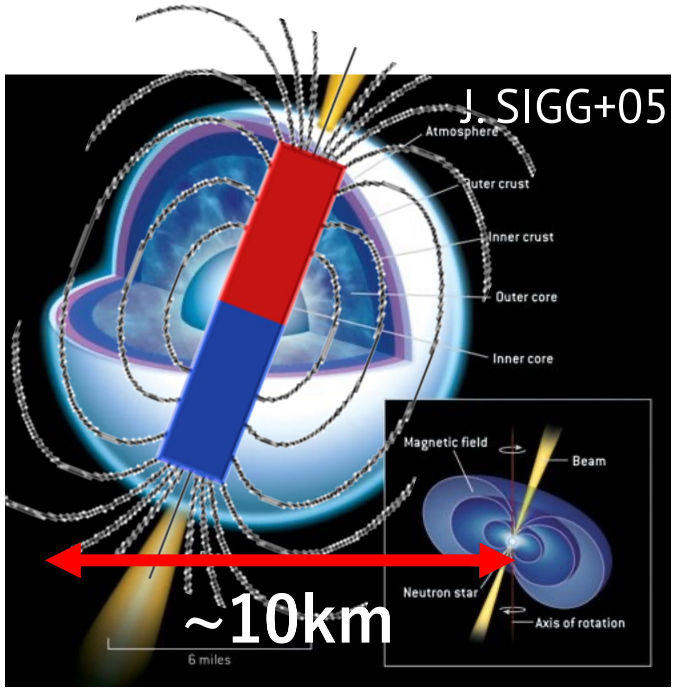
C. Weniger+19

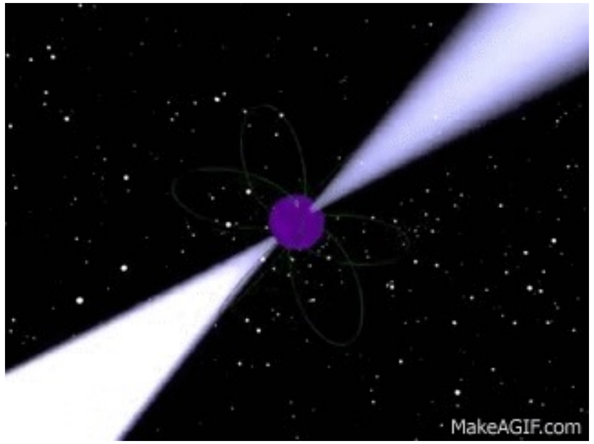
Strongest magnet in the universe → **Magnetar** (∈ **Neutron Star**)

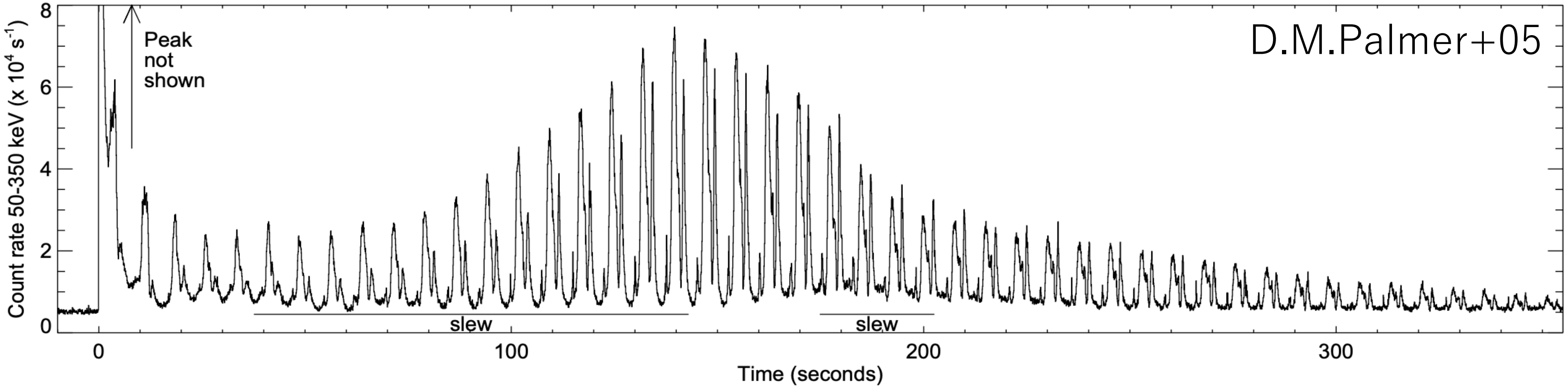
Magnetars – Overview -

- A type of neutron star.
- Habitat: ~ Galactic plane
- Young(τ_c~10^4 yr)
- Size : ~10 km
- Highly magnetized : ~10^{15} G (=10^{11}T)
  → X-ray emission (burst)
- Misalignment of magnetic axis and rotation axis. → Pulsed X-ray





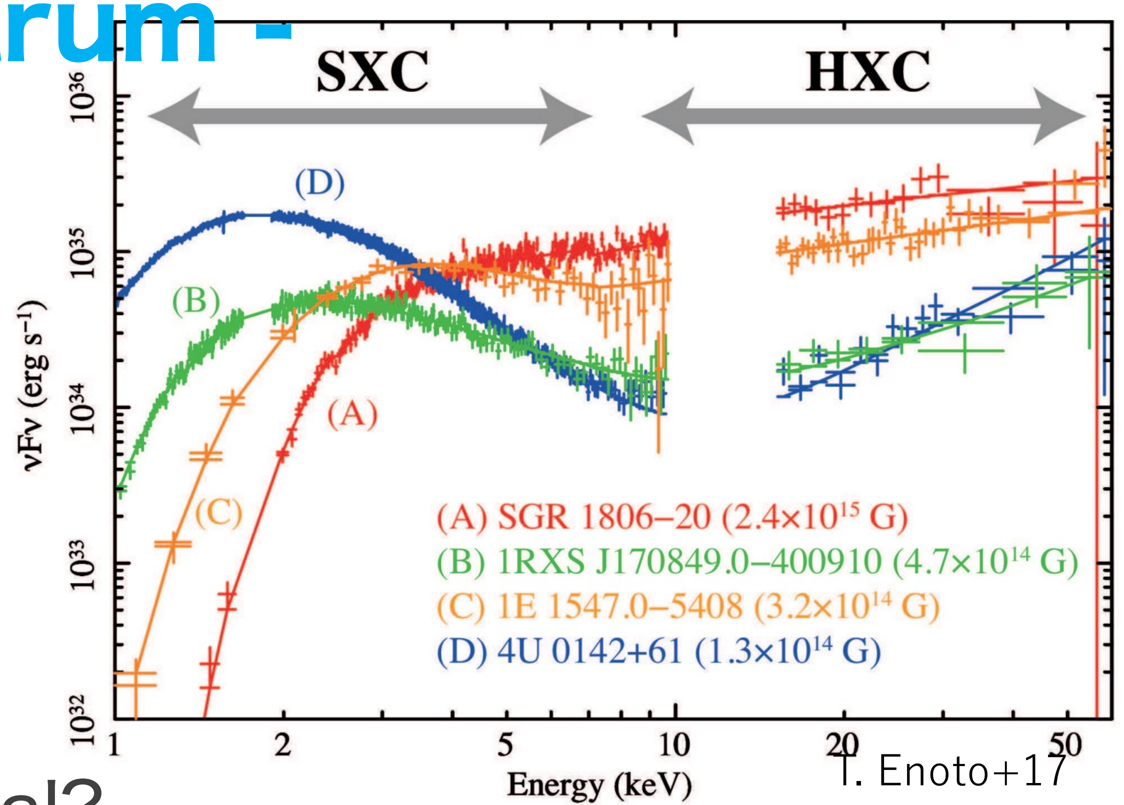




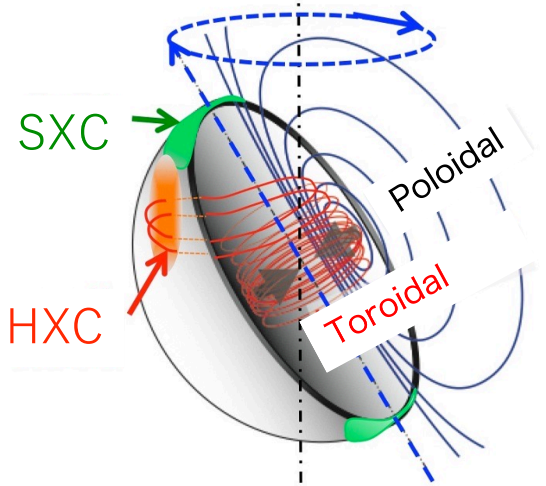
Magnetars – X-ray Spectrum -

- Two component (SXC and HXC)
- 1-10 keV → BB radiation from magnetar surface.
- Younger magnetars
  → Higher surface temperature.
- 10 keV ~ 100 keV: Unknown.
  Photon splitting?
- Outer B: Poloidal, Inner B: Toroidal?
- Inner temperature→ $\sim 10^9$ K (theoretically)
- Magnetars with no non-thermal emission (XDINS, CCO): Magnificent 7.

→ Good targets for detecting/limiting Axion associated continuum X-ray



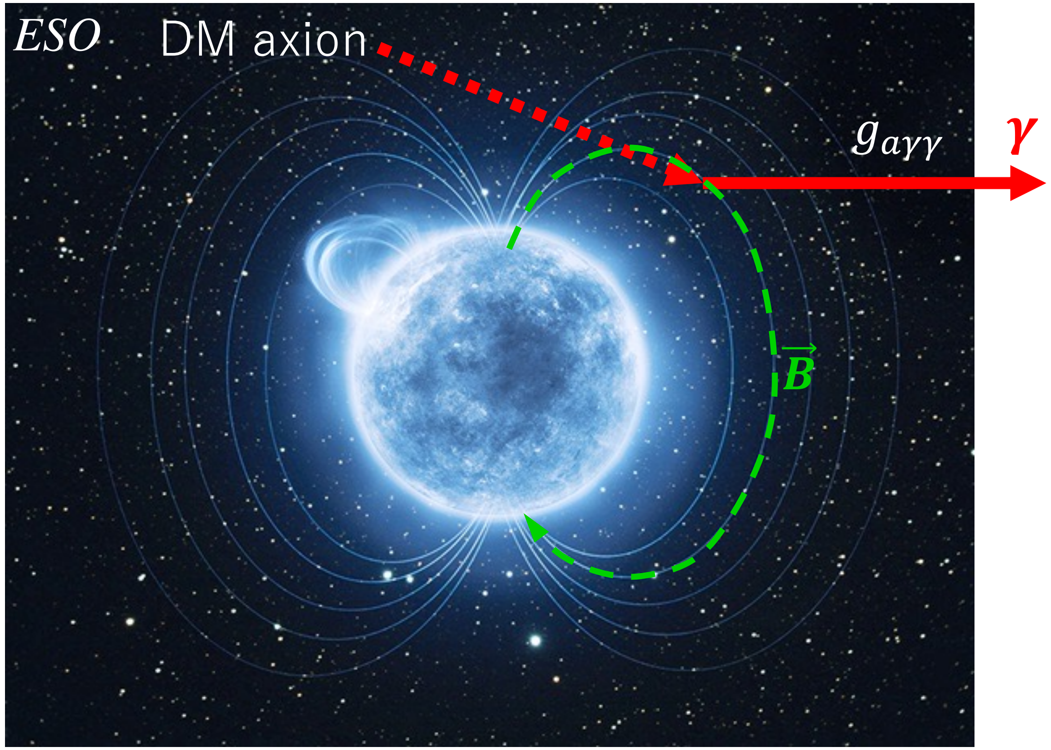
T. Enoto+17



T. Nakano, K. Makishima, 2014

Axion signal from Magnetars

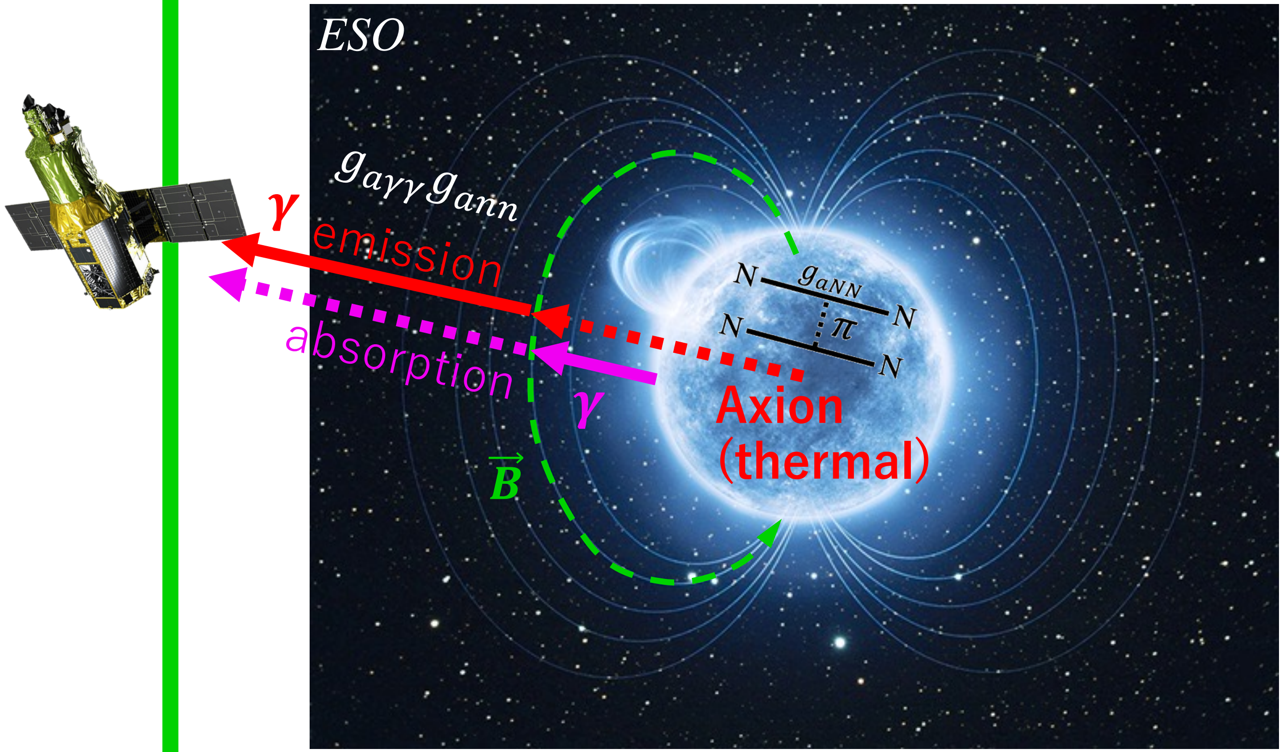
DM(Milky way DM halo) originated



DM axion in the vicinity of the Milky Way can be probed.
Monochromatic line in Radio band← DM mass limit.
Expected axion-induced photon flux $P_{a\gamma} \propto (B \times R)^2$
Strong B (10^15 G) ↔ Small typical R (~10 km)
Cluster of galaxies > Magnetar 😢

J. W. Foster+20

Magnetar originated

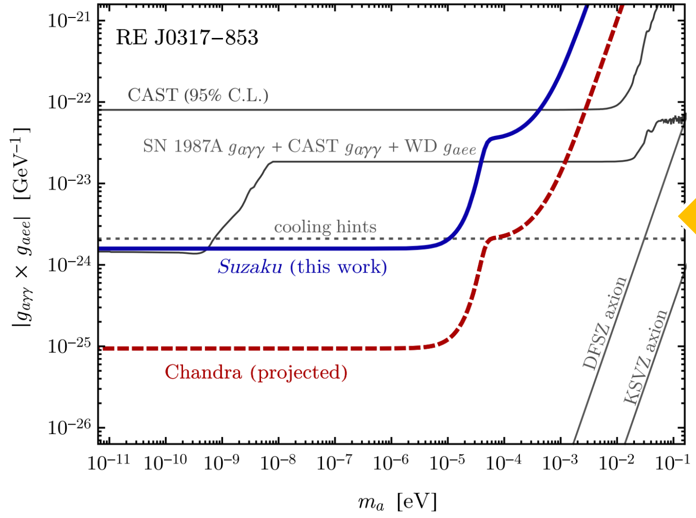


Axion emission from the magnetar cooling process.
(Not DM associated Axion)
Thermal process → Broad spectrum in X-ray.
→ This method seems to be more advantageous.
Need for assuming the EoS for inside.

M. Buschmann+21

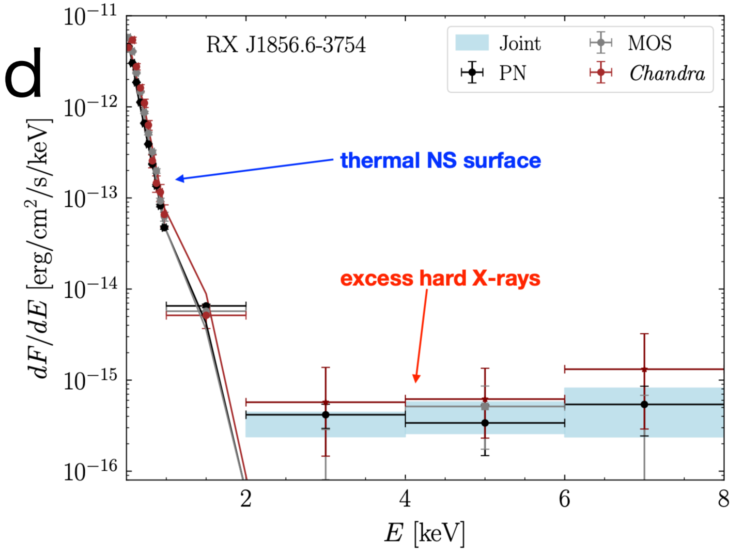
Axion × Magnetars – Previous Research -

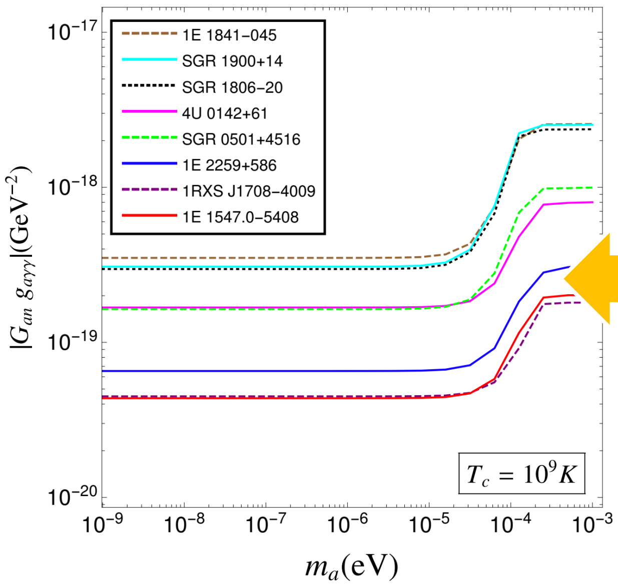
Axion Mass limit from Magnetars (and White Dwarfs)



⭐Original idea is advocated for white dwarfs (G. G. Raffelt+86)
Applied to the observation by C. Dessert+19

⭐Hard X-ray excess was found for Magnificent 7.
(M. Buschmann+21)
→ strong limit for $g_{a\gamma\gamma} g_{ann}$





The Hard X-ray spectrum of eight magnetars are analyzed as the axion source.
(J. F. Fortin+21)

Integrated spectrum → Well Done
Pulse-phase resolved spectrum
should be considered! Because...

Axion × Magnetars – Phase Resolving -

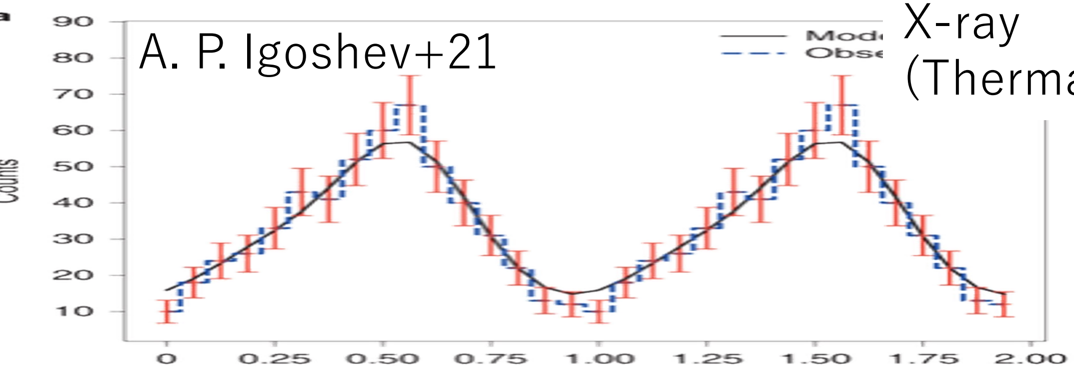
Axion originated X-ray should be modulated by the rotation of magnetars.
→ Pulse phase-resolved spectrum may distinguish the Axion signal.

M. Buschmann+21

$$p_{a\to\gamma} \approx 1.5\times 10^{-4}\left(\frac{g_{a\gamma\gamma}}{10^{-11}\ \mathrm{GeV}^{-1}}\right)^{2}\left(\frac{1\ \mathrm{keV}}{\omega}\right)^{4/5} \times\left(\frac{B_0}{10^{13}\ \mathrm{G}}\right)^{2/5}\left(\frac{R_{\mathrm{NS}}}{10\ \mathrm{km}}\right)^{6/5}\sin^{2/5}\theta,$$

Simple case
Rotation axis
⊥
Magnetic axis

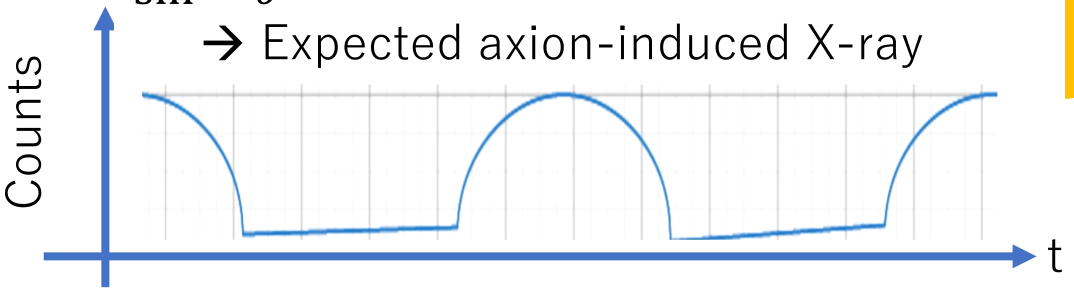
We are here!

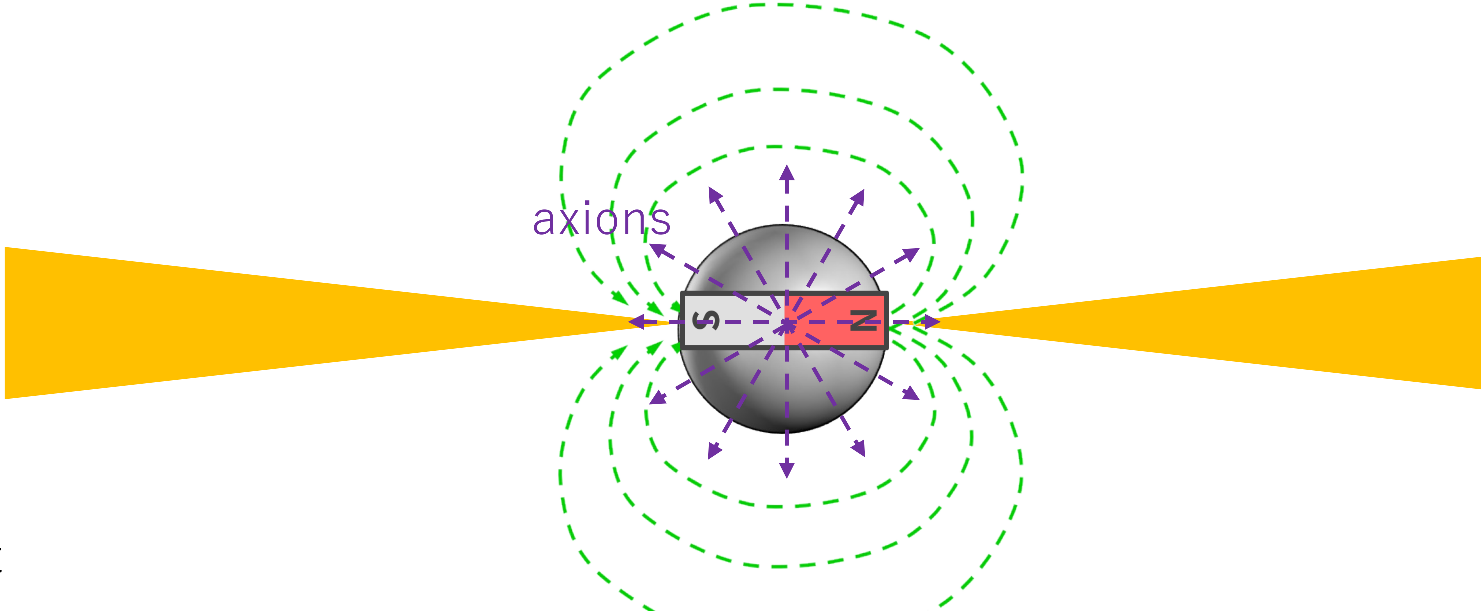


X-ray (Thermal)

$\sin^{2/5}\theta$

→ Expected axion-induced X-ray



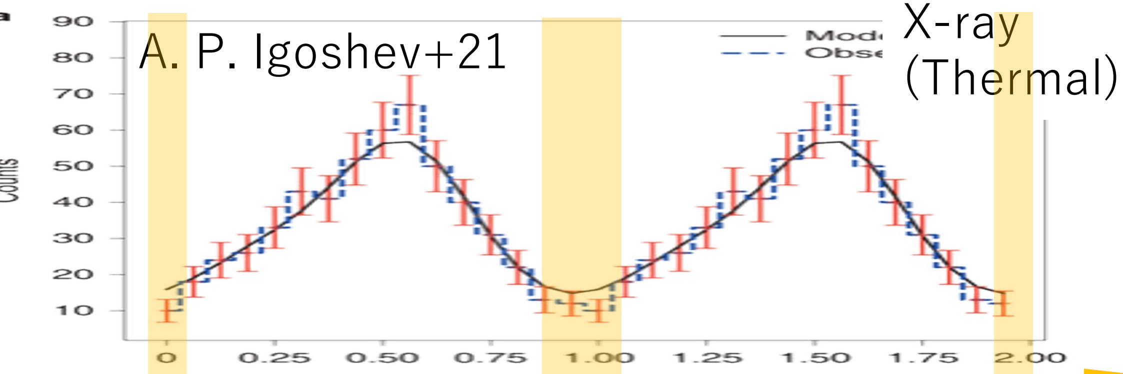


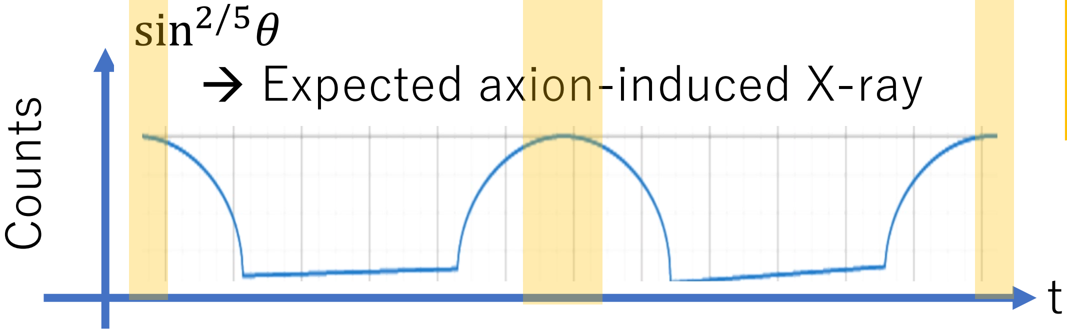
Axion × Magnetars – Phase Resolving -

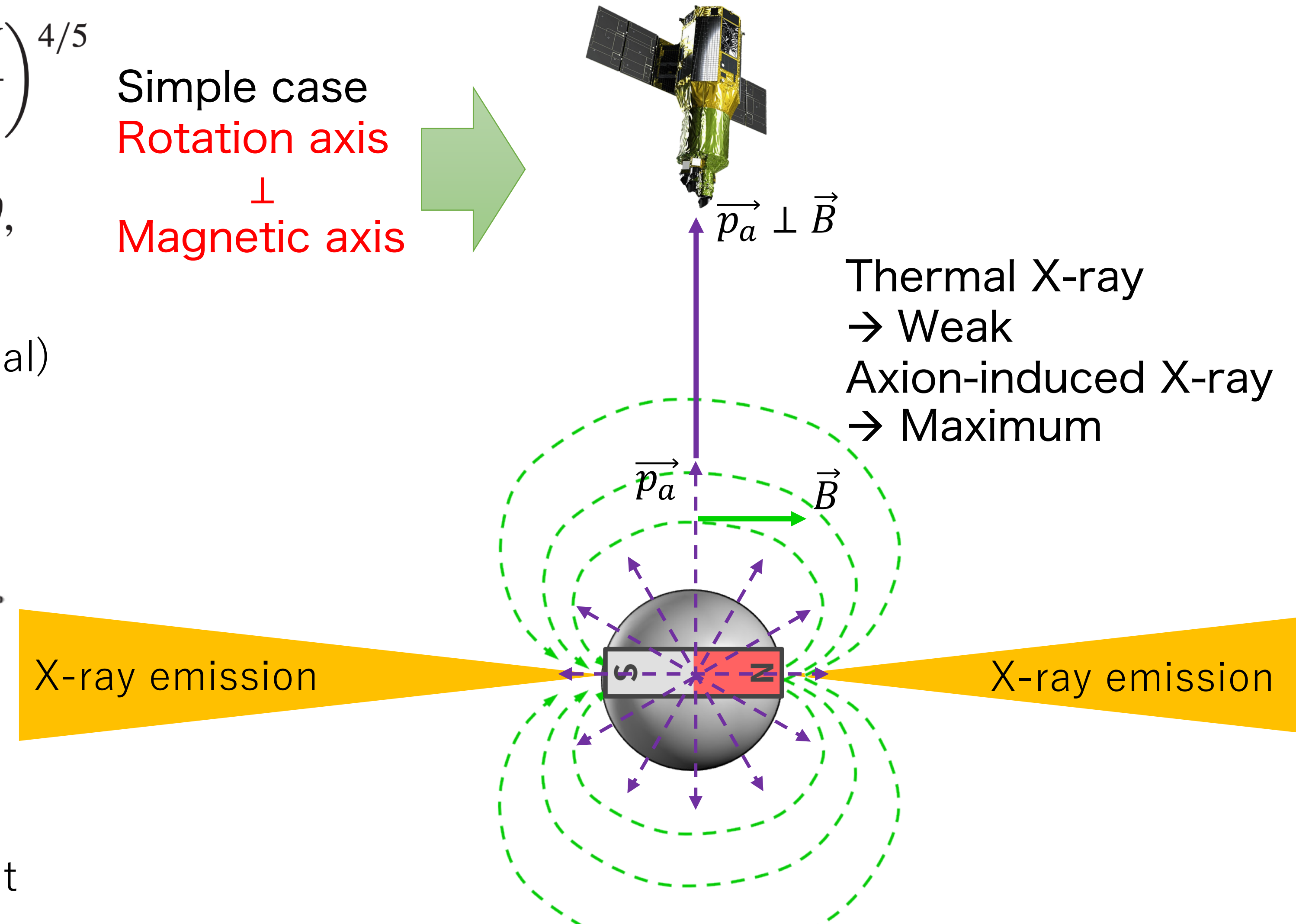
Axion originated X-ray should be modulated by the rotation of magnetars.
→ Pulse phase-resolved spectrum may distinguish the Axion signal.

M. Buschmann+21

$$p_{a\to\gamma} \approx 1.5\times 10^{-4}\left(\frac{g_{a\gamma\gamma}}{10^{-11}\ \mathrm{GeV}^{-1}}\right)^{2}\left(\frac{1\ \mathrm{keV}}{\omega}\right)^{4/5} \times\left(\frac{B_0}{10^{13}\ \mathrm{G}}\right)^{2/5}\left(\frac{R_{\mathrm{NS}}}{10\ \mathrm{km}}\right)^{6/5}\sin^{2/5}\theta,$$







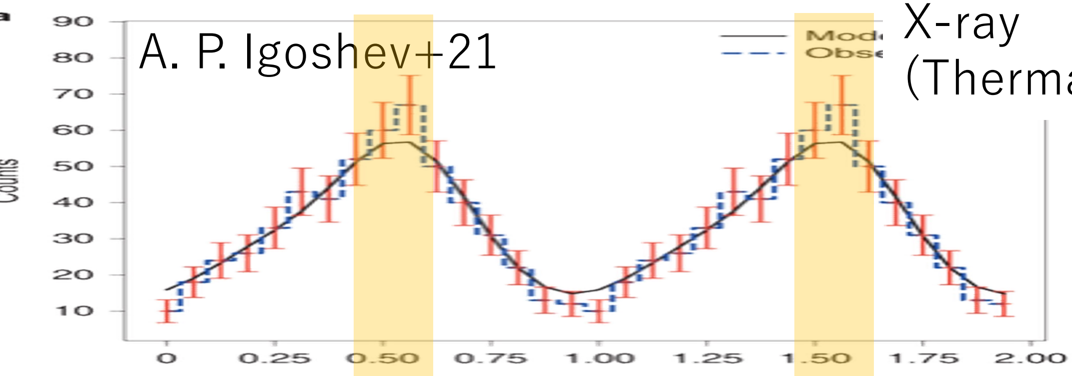
Axion × Magnetars – Phase Resolving -

Axion originated X-ray should be modulated by the rotation of magnetars.
→ Pulse phase-resolved spectrum may distinguish the Axion signal.

M. Buschmann+21

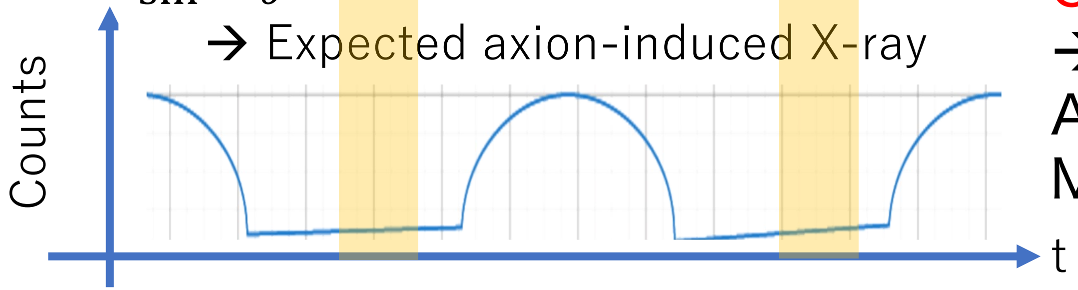
$$p_{a\to\gamma} \approx 1.5 \times 10^{-4} \left(\frac{g_{a\gamma\gamma}}{10^{-11}\ \mathrm{GeV}^{-1}}\right)^2 \left(\frac{1\ \mathrm{keV}}{\omega}\right)^{4/5} \times \left(\frac{B_0}{10^{13}\ \mathrm{G}}\right)^{2/5} \left(\frac{R_{\mathrm{NS}}}{10\ \mathrm{km}}\right)^{6/5} \sin^{2/5}\theta,$$

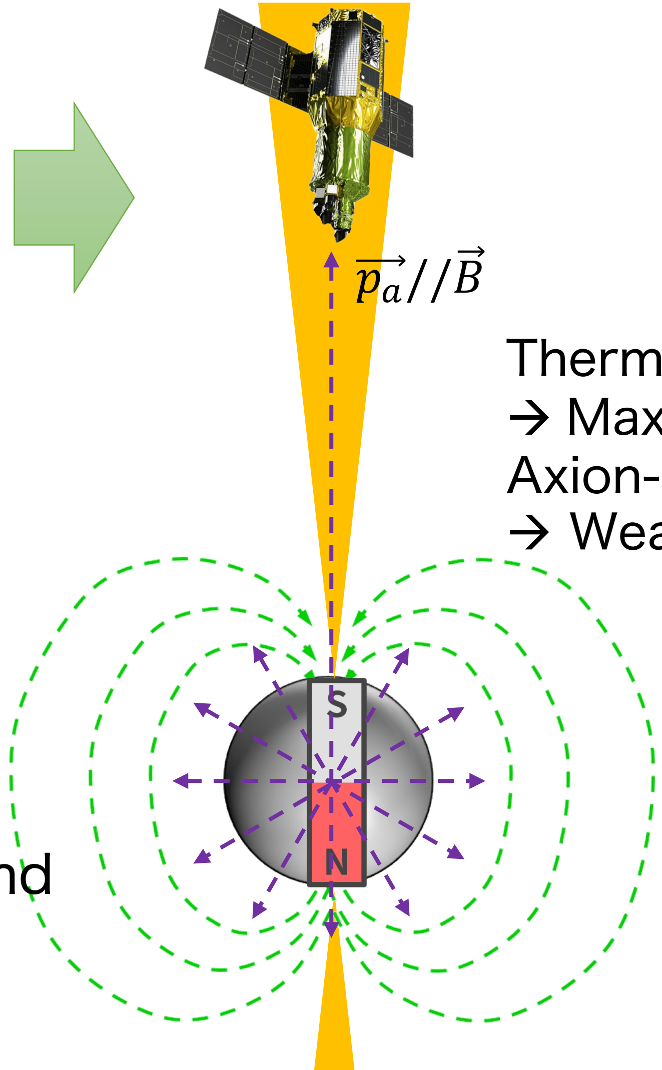
Simple case
Rotation axis
⊥
Magnetic axis



X-ray (Thermal)

$\sin^{2/5}\theta$
→ Expected axion-induced X-ray





Thermal X-ray
→ Maximum
Axion-induced X-ray
→ Weak

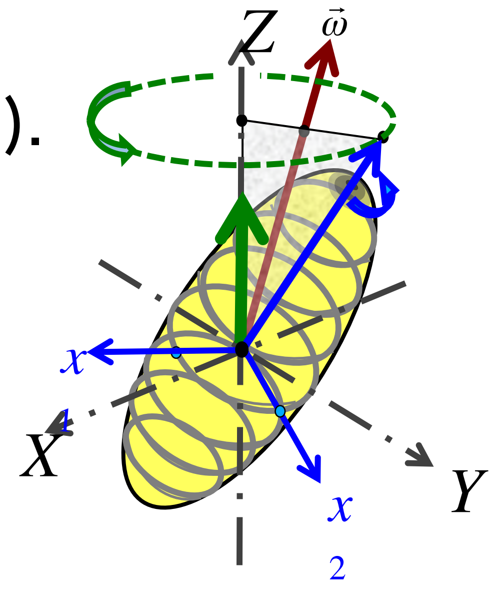
Opposite phase!
→Distinguish a Axion emission and Magnetar one.

Axion × Magnetars – Our Research -

Requirements for the best target:
- Young → High inner temperature.
- Strong $\vec{B}$ field → Large $P_{a\gamma\gamma}$.
- Well known object → Huge observational data.
- NuSTAR observations → Wide energy range.

SGR 1806-20
(“typical” magnetar)

Status:
We found that some magnetars are deformed into a lemon shape by its strong magnetic field(Makishima+14-21).
→The hard X-ray component is phase modulated by the free precession.
→In order to obtain a phase-resolved spectrum, a demodulation analysis must be performed.
→ Ongoing!



Summary

- Astrophysical X-ray observations are unique for various DM and Axion studies.
- Cosmic DM objects (galaxy clusters and dwarf galaxies) have been good targets for hunting DM decays.
  → Ready for high resolution X-ray spectroscopy with the XRISM satellite to be launched in 2022FY.

- Current focus is X-ray study of magnetars and Axion models.

We need helps from the person who familiar with...
- the axion emission model for magnetars(neutron stars),
- the EoS for inside of the neutron stars,
- axion-photon conversion process with magnetic field.

Thank you for listening!