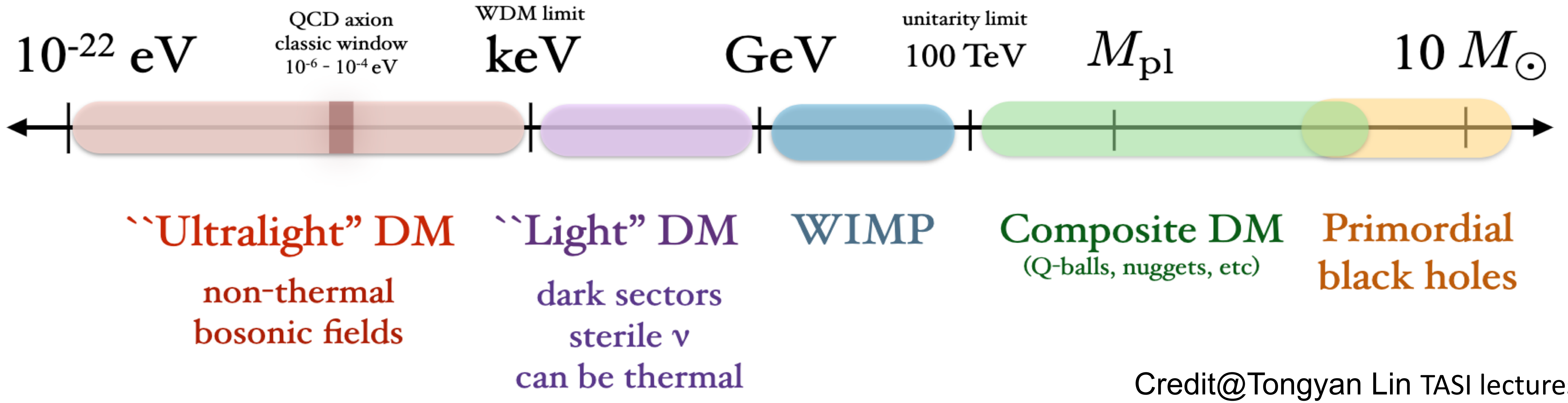
第五届粒子物理前沿研讨会

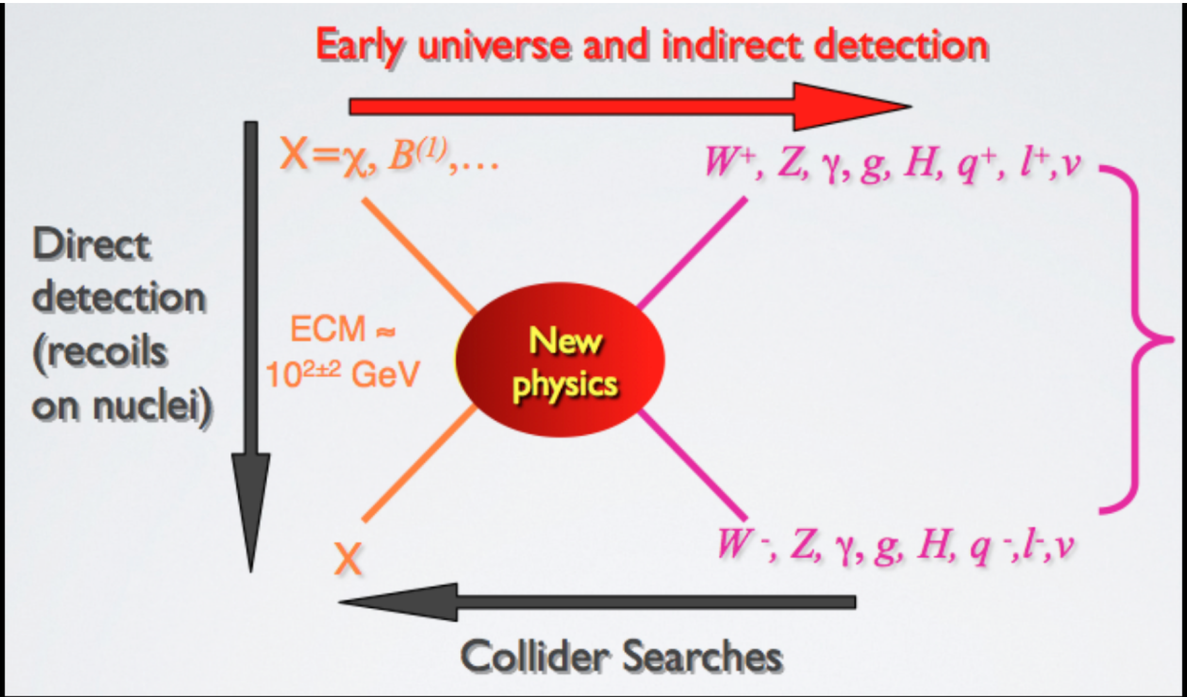
X-ray polarimetric features of Gamma-ray Bursts across varied redshifts and hints for Axion-Like-Particles

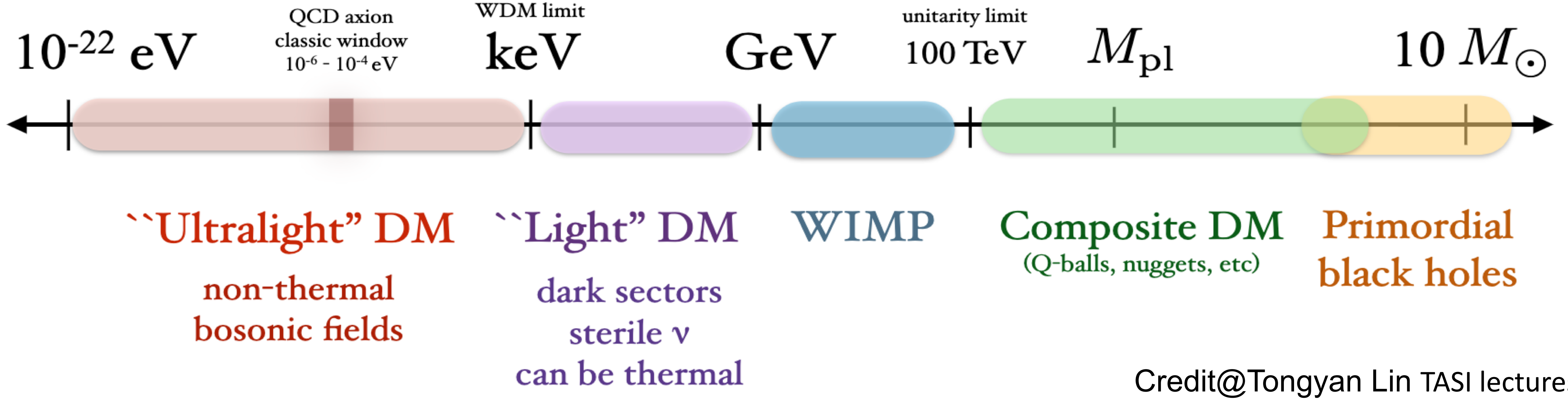
黄 峰（厦门大学）

Based on astro-ph:2404.07555



Credit@Tongyan Lin TASI lectures

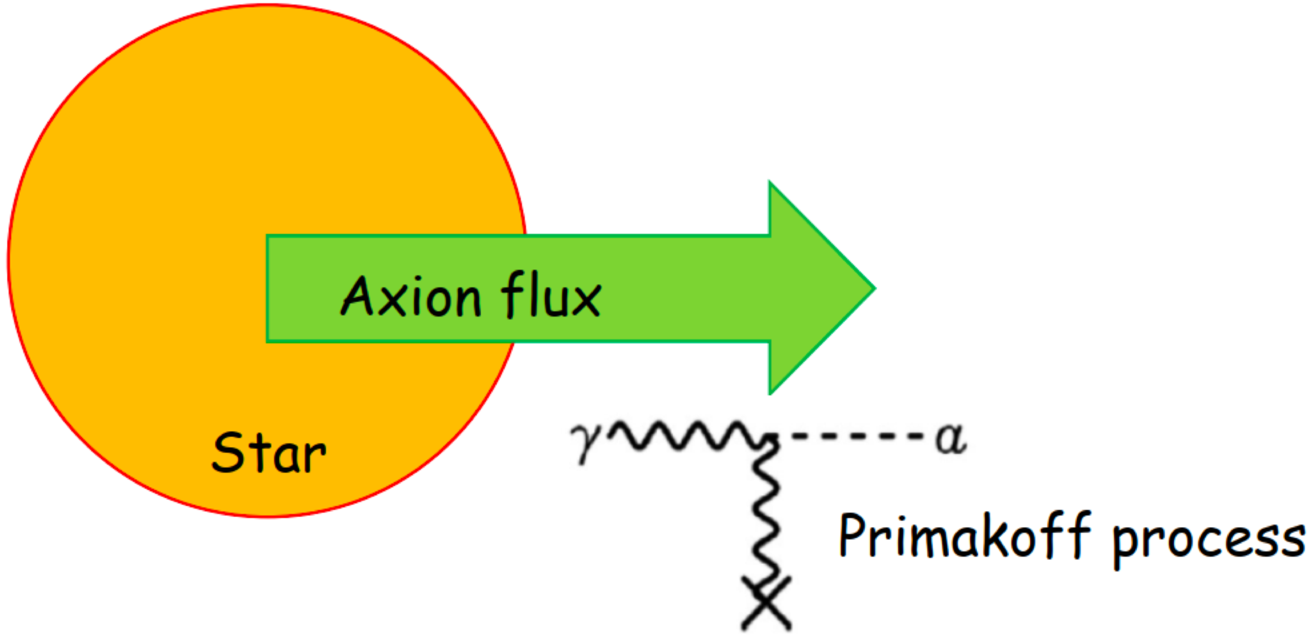




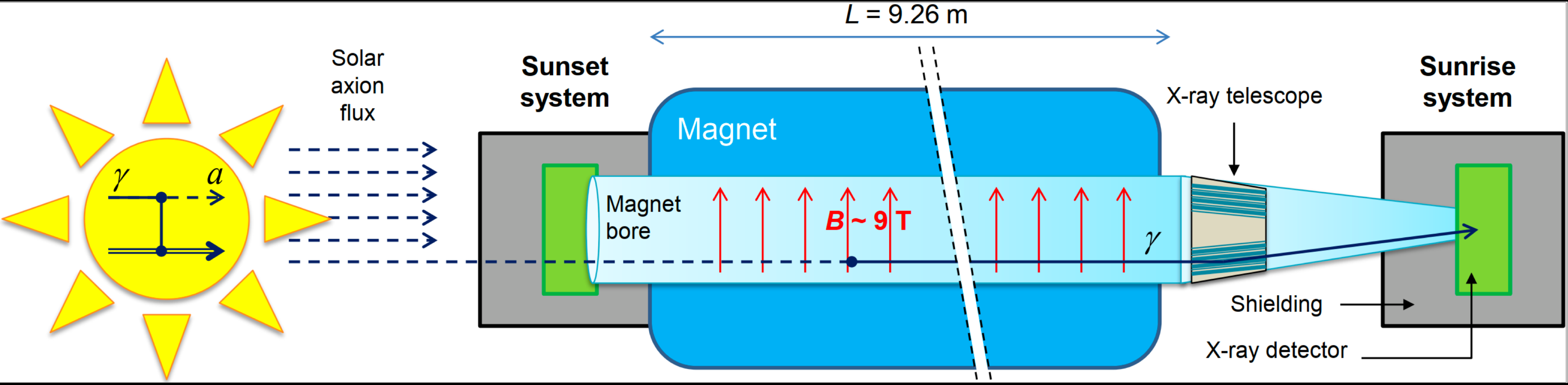
Credit@Tongyan Lin TASI lectures

$$\mathcal{L}_{\rm int} = \sum_{\psi=e,p,n} \frac{g_{a\psi}}{2m_\psi}(\bar{\psi}\gamma_\mu\gamma_5\psi)\partial^\mu a - \frac{1}{4} g_{a\gamma} F_{\mu\nu}\tilde{F}^{\mu\nu} a$$

Axion-Like-Particles:
Production
Propagation



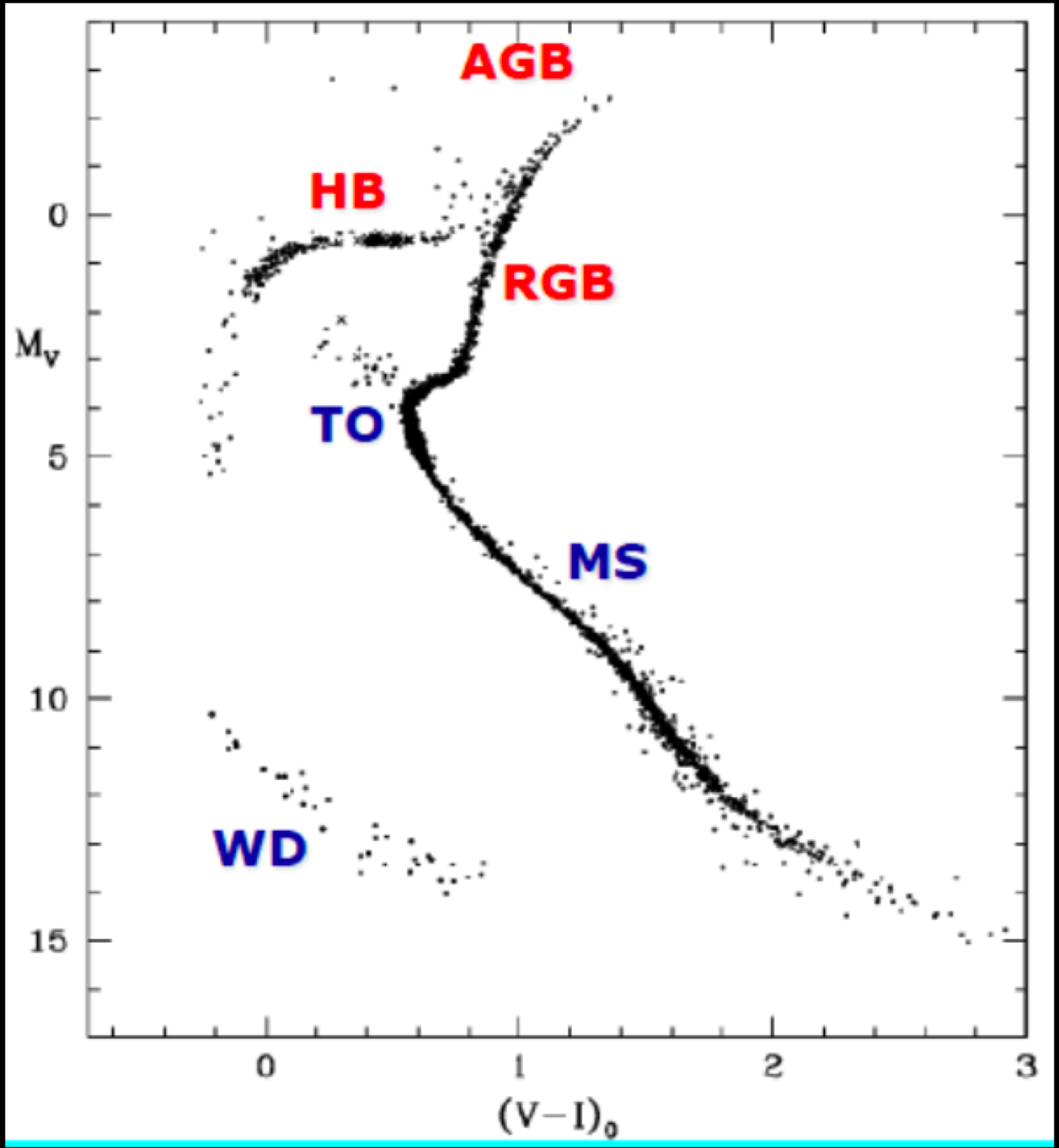
CAST detection of ALPs from the Sun

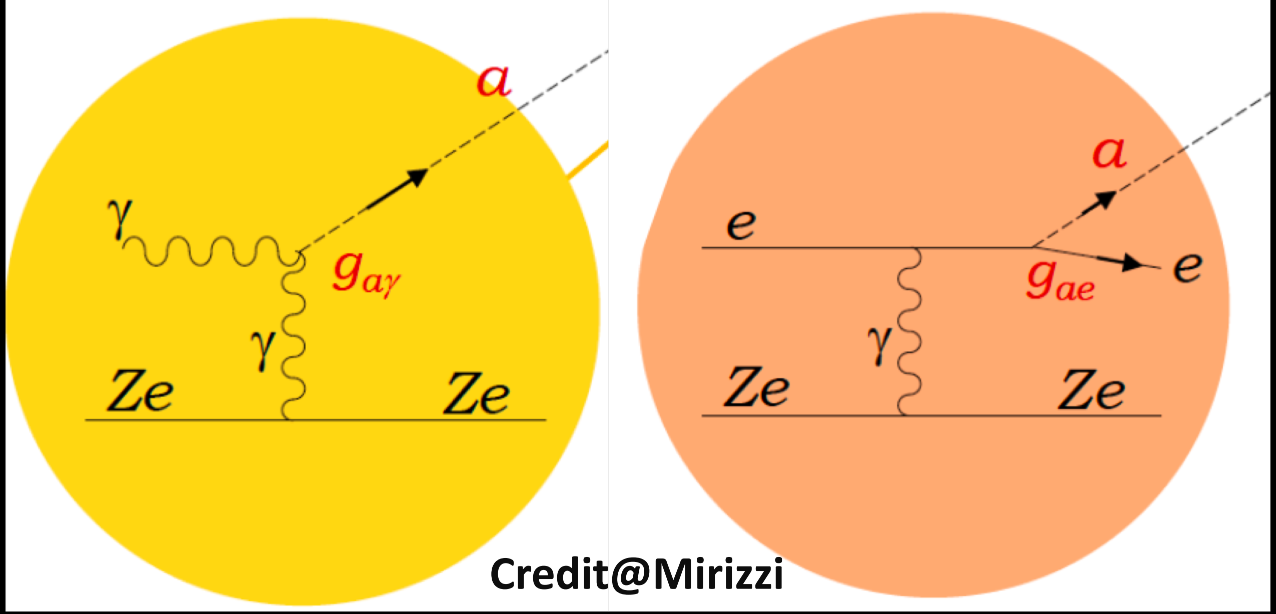


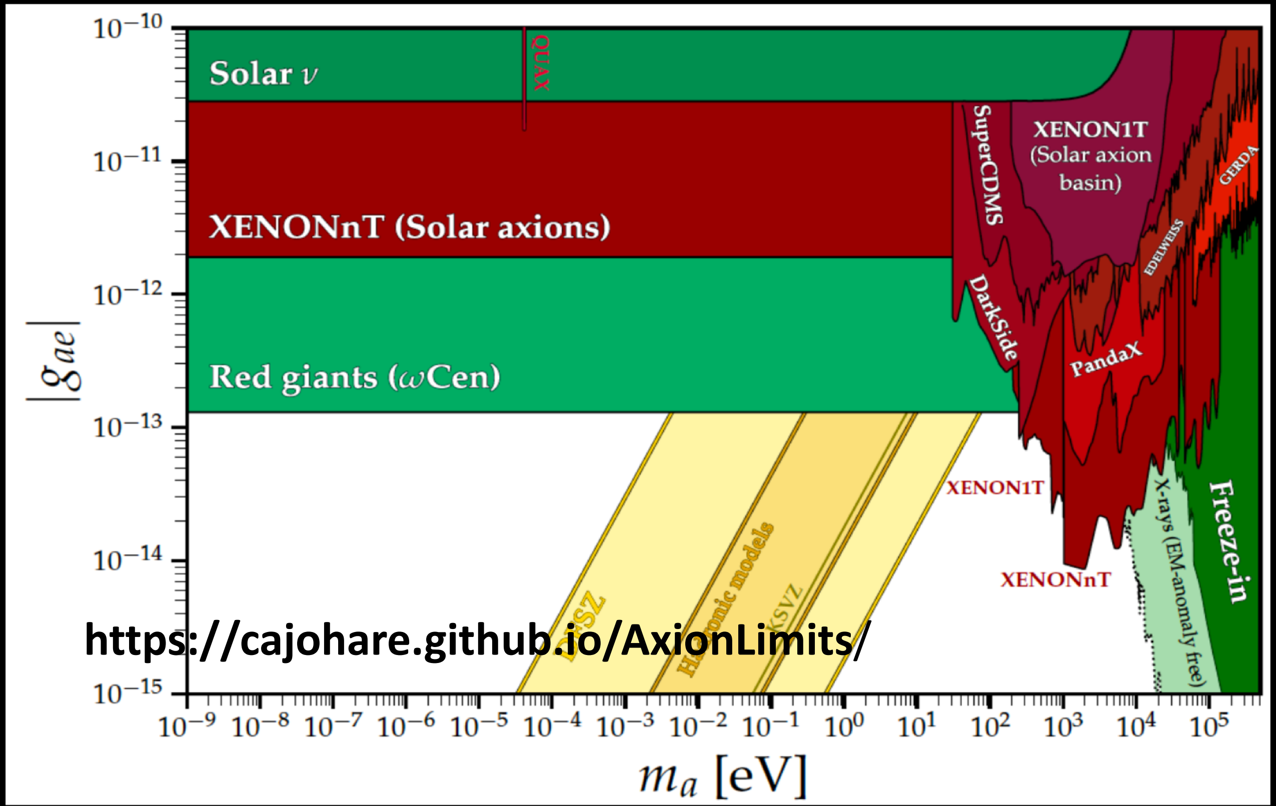
$$g_{a\gamma} \lesssim 6.6 \times 10^{-11} GeV^{-1} \text{ for } m_a \lesssim 0.02 \text{ eV}$$

Limited by the strength and scale of the magnetic field

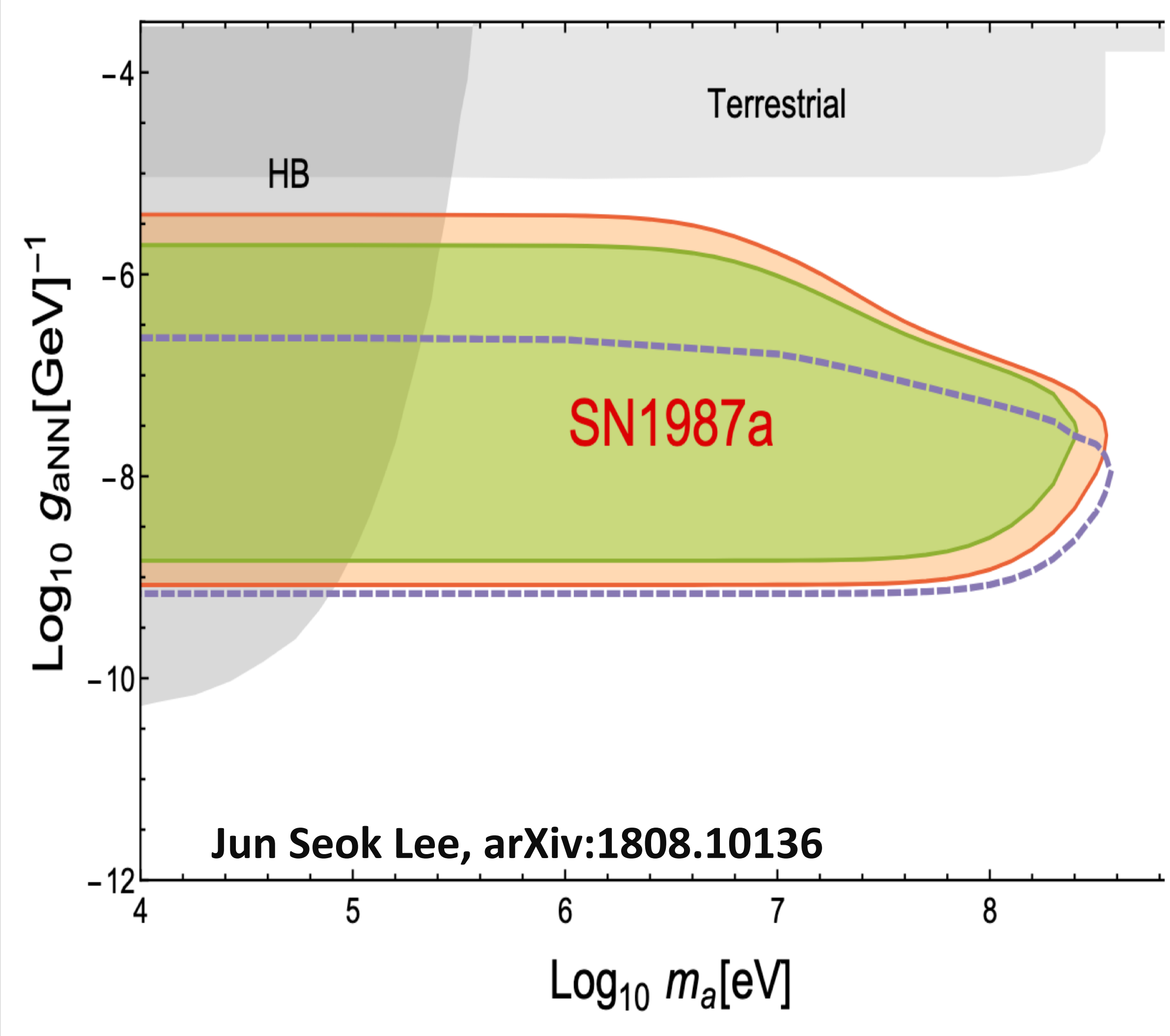
Cooling of Galactic Source







SN1987A/White Dwarfs cooling



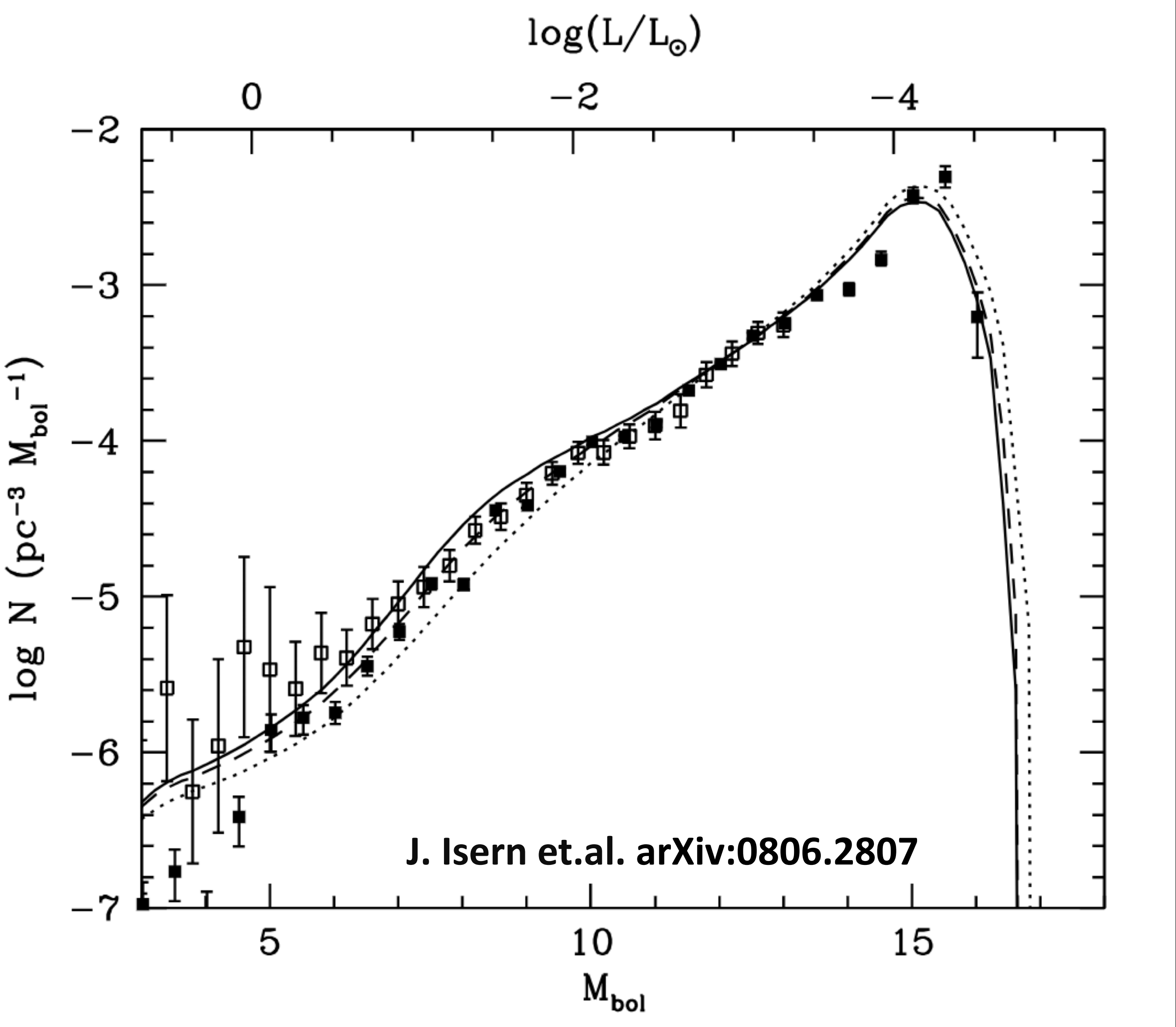
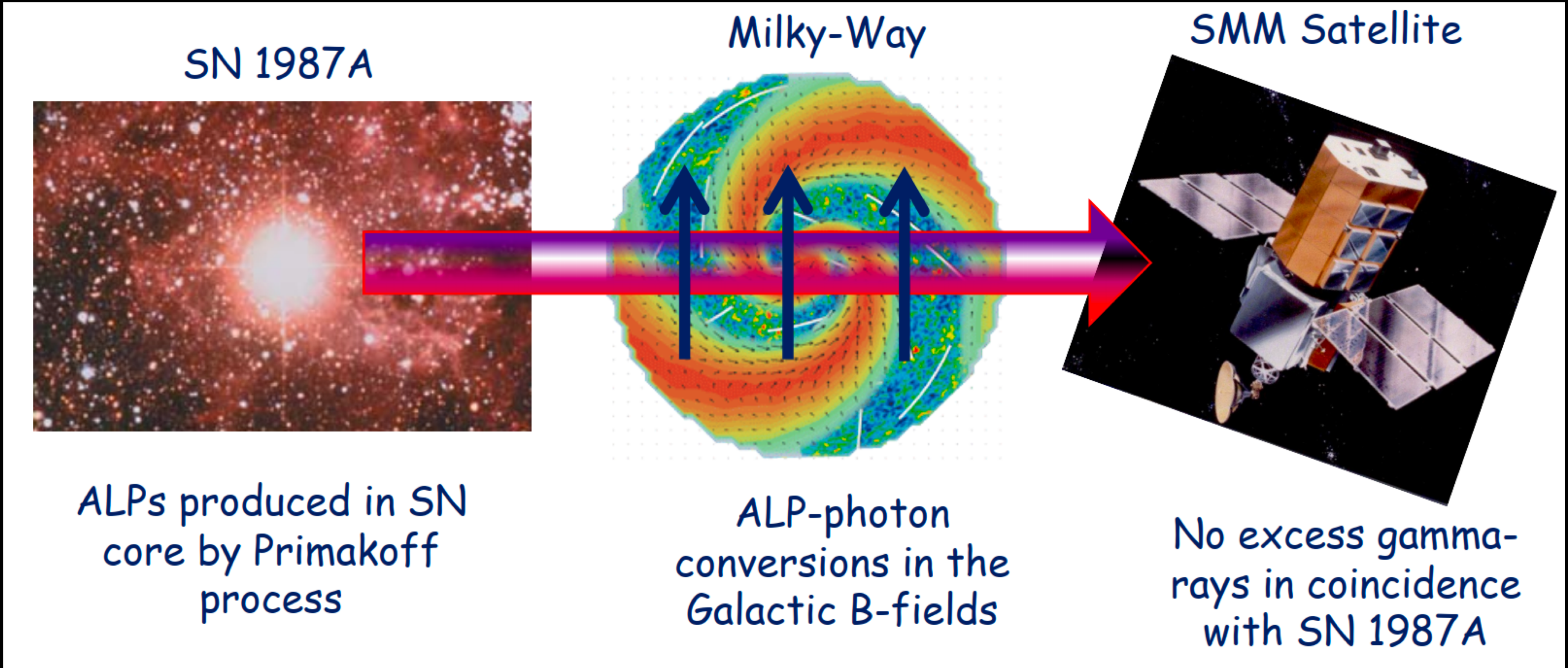
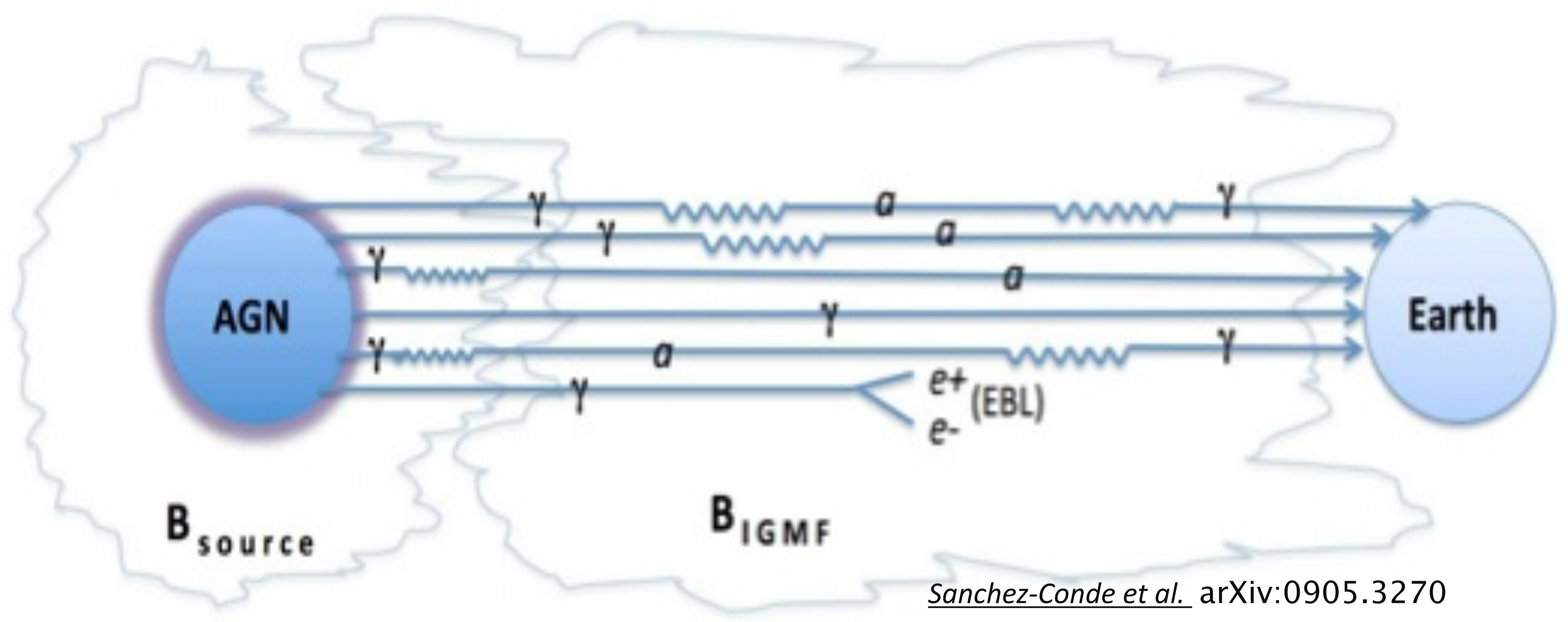


FIG. 3.— White dwarf luminosity functions for different values of the axion mass. The luminosity functions have been computed assuming $m_a \cos^2\beta = 0$ (solid line), 5 (dashed line) and 10 (dotted line) meV.

SN1987A: ALPs propagating in MW's Magnetic Field

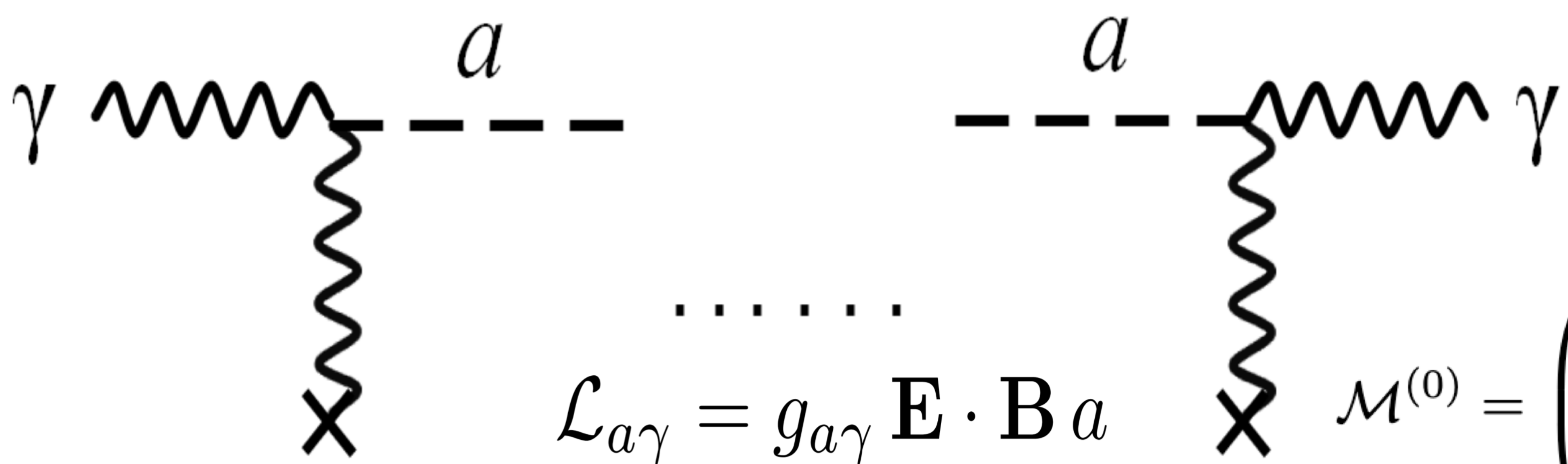


Sources at Cosmological Distance



Sanchez-Conde et al. arXiv:0905.3270

Photon-ALP mixing



$$\mathcal{L}_{a\gamma} = g_{a\gamma}\,\mathbf{E}\cdot\mathbf{B}\,a$$

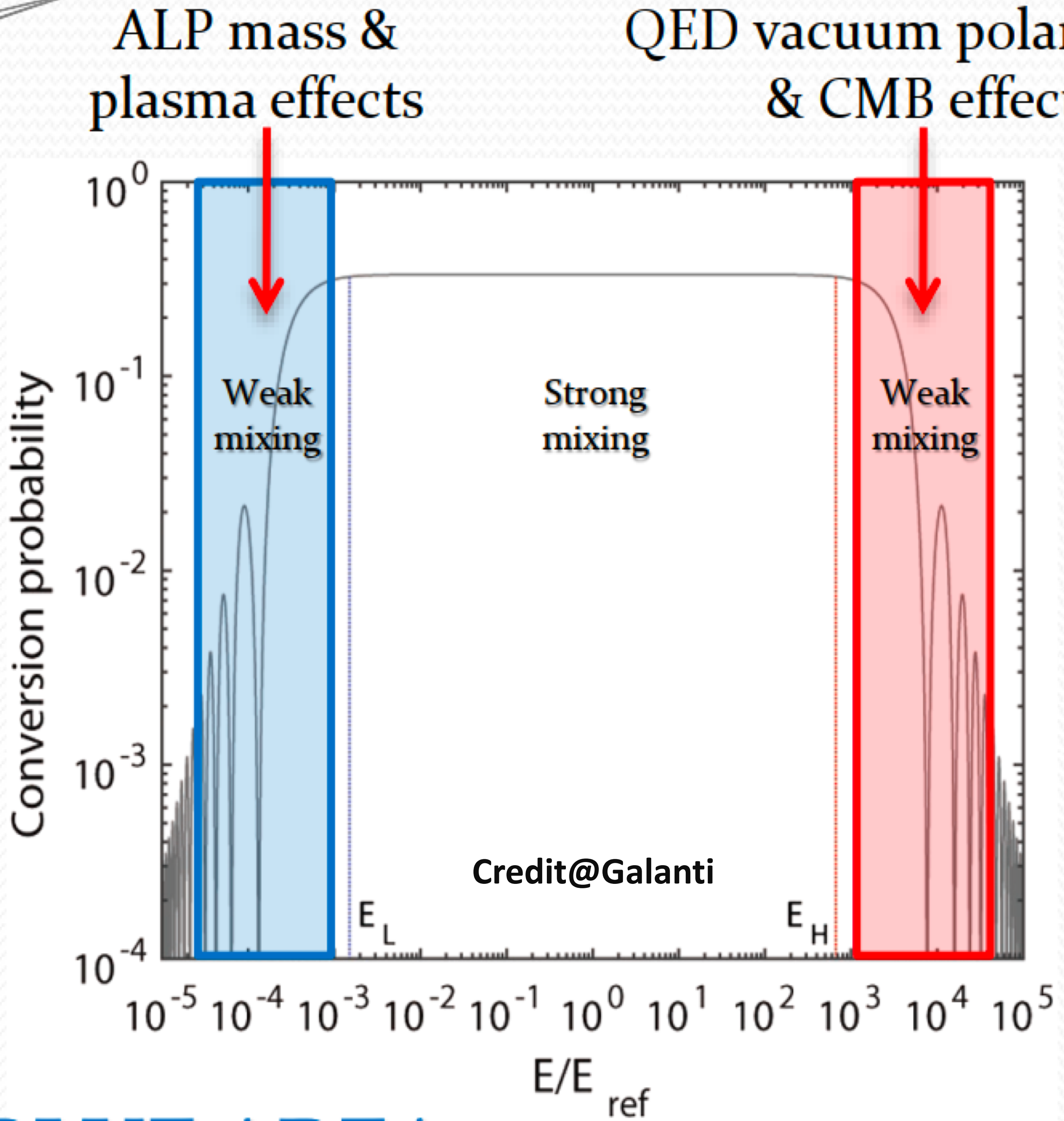
$$\mathcal{M}^{(0)} = \begin{pmatrix} \Delta_\perp & 0 & 0 \\ 0 & \Delta_\parallel & \Delta_{a\gamma} \\ 0 & \Delta_{a\gamma} & \Delta_a \end{pmatrix}$$

Figure 3. Schematic view of a $\gamma \leftrightarrow a$ oscillation in the external magnetic field $\mathbf{B}$.

$$\left(i\,\frac{d}{dx_3} + E + \mathcal{M}\right)\begin{pmatrix} A_{x_1}(x_3) \\ A_{x_2}(x_3) \\ a(x_3) \end{pmatrix} = 0$$

$$\mathrm{I} = \langle A^*_{x_2}(x_3)A_{x_2}(x_3)\rangle + \langle A^*_{x_1}(x_3)A_{x_1}(x_3)\rangle$$
$$\mathrm{Q} = \langle A^*_{x_2}(x_3)A_{x_2}(x_3)\rangle - \langle A^*_{x_1}(x_3)A_{x_1}(x_3)\rangle$$
$$\mathrm{U} = 2Re\,\langle A^*_{x_2}(x_3)A_{x_1}(x_3)\rangle\,,$$
$$\mathrm{V} = 2Im\,\langle A^*_{x_2}(x_3)A_{x_1}(x_3)\rangle\,,$$

$$\Delta_{a\gamma} \equiv \frac{1}{2}g_{a\gamma}B_T \simeq 1.5\times10^{-2}\,\frac{g_{a\gamma}}{10^{-11}\mathrm{GeV}^{-1}}\,\frac{B_T}{\mathrm{nG}}\mathrm{Mpc}^{-1},$$
$$\Delta_a \equiv -\frac{m_a^2}{2E} \simeq -7.8\times10^{-3}\left(\frac{m_a}{10^{-13}\,\mathrm{eV}}\right)^2\left(\frac{E}{10^2\,\mathrm{keV}}\right)^{-1}\mathrm{Mpc}^{-1}\,,$$
$$\Delta_{\mathrm{pl}} \equiv -\frac{\omega_{\mathrm{pl}}^2}{2E} \simeq -1.1\times10^{-4}\left(\frac{E}{10^2\,\mathrm{keV}}\right)^{-1}\frac{n_e}{10^{-7}\,\mathrm{cm}^{-3}}\mathrm{Mpc}^{-1}\,,$$
$$\Delta_{\mathrm{QED}} \equiv \frac{\alpha E}{45\pi}\left(\frac{B_T}{B_{\mathrm{cr}}}\right)^2 \simeq 4.1\times10^{-16}\,\frac{E}{10^2\,\mathrm{keV}}\left(\frac{B_T}{10^{-9}\,\mathrm{G}}\right)^2\mathrm{Mpc}^{-1}$$
$$\Delta_\parallel \equiv \Delta_{\mathrm{pl}} + 3.5\,\Delta_{\mathrm{QED}},\;\; \Delta_\perp \equiv \Delta_{\mathrm{pl}} + 2\,\Delta_{\mathrm{QED}}\,.$$



$$P^{(0)}_{\gamma \to a} = \sin^2 2\theta \, \sin^2\left(\frac{\Delta_{\rm osc}\, d}{2}\right)$$

$$\Delta_{\rm osc} = \left[\left(\Delta_a - \Delta_{\parallel}\right)^2 + 4\Delta^2_{a\gamma}\right]^{1/2}$$

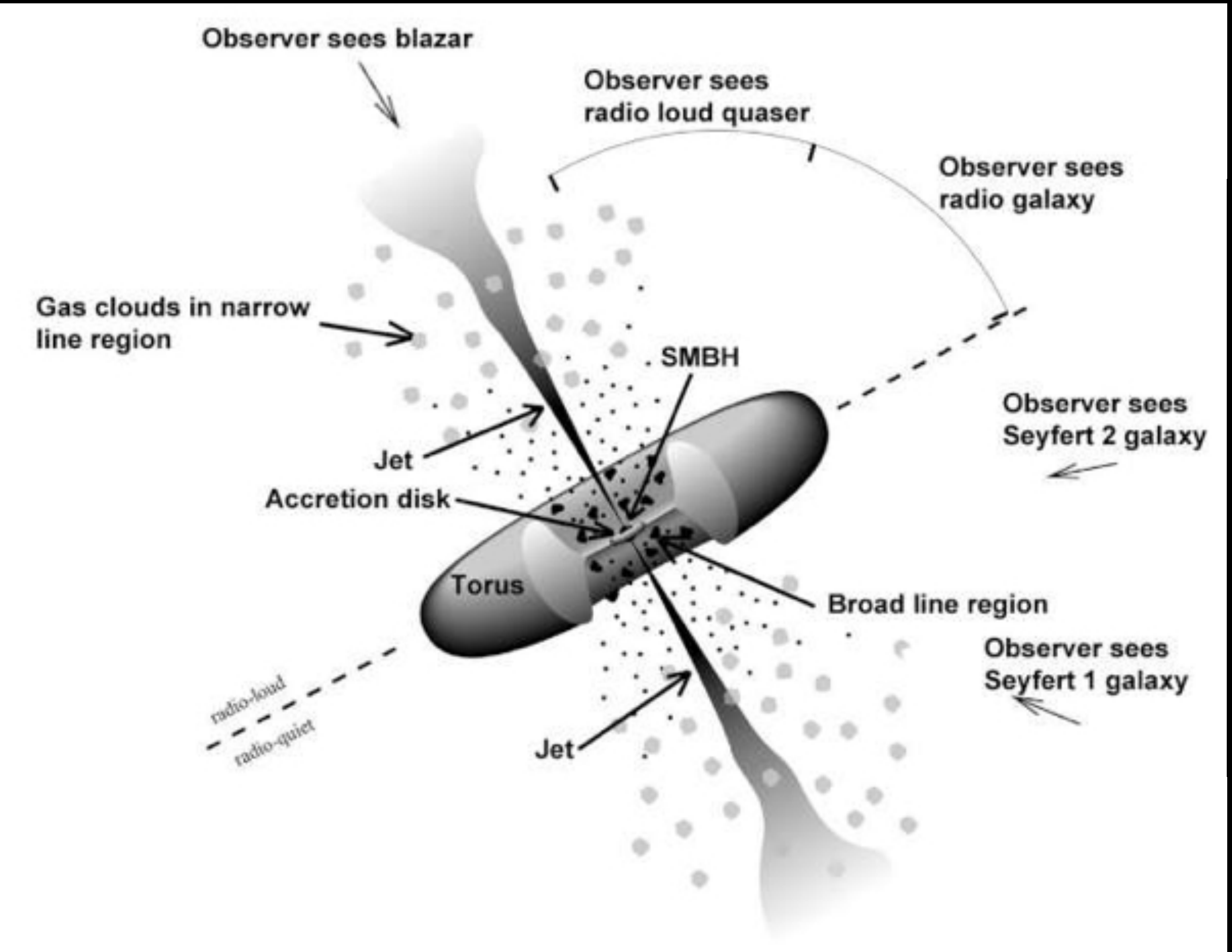
$$\theta = \frac{1}{2}\arctan\left(\frac{2\Delta_{a\gamma}}{\Delta_{\parallel} - \Delta_a}\right)$$

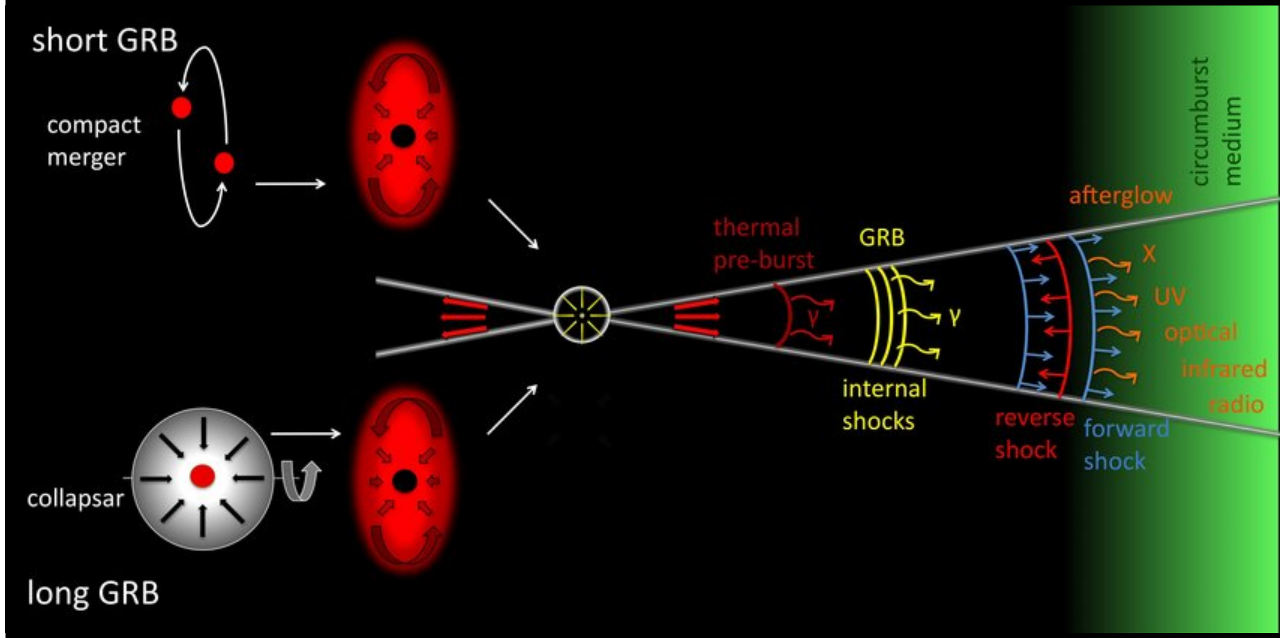
$$\Delta_{a\gamma} \equiv \frac{1}{2} g_{a\gamma} B_T$$

$$E_L \equiv \frac{E\,|\Delta_a - \Delta_{\rm pl}|}{2\,\Delta_{a\gamma}}$$

$$\simeq \frac{25\,|m_a^2 - \omega_{\rm pl}^2|}{(10^{-13}{\rm eV})^2}\left(\frac{\rm nG}{B_T}\right)\left(\frac{10^{-11}{\rm GeV}^{-1}}{g_{a\gamma}}\right){\rm keV}$$

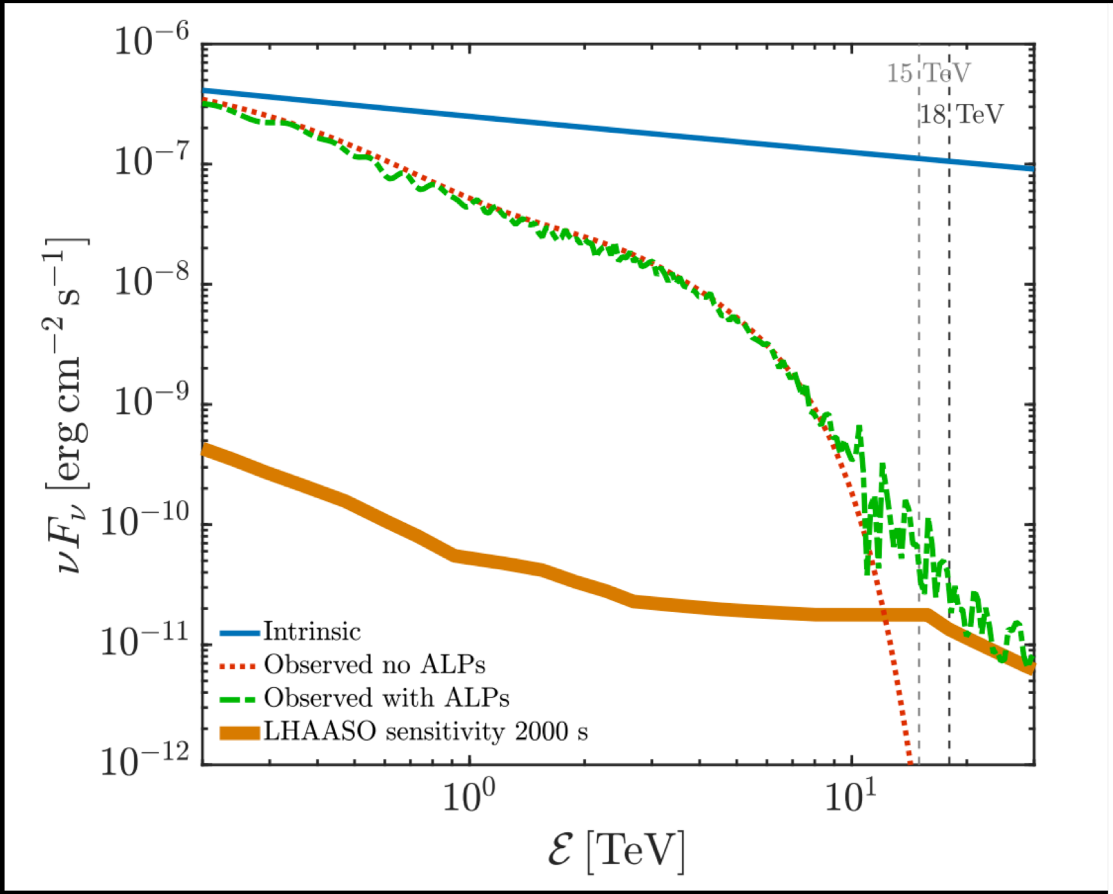
Sources at Cosmological Distance

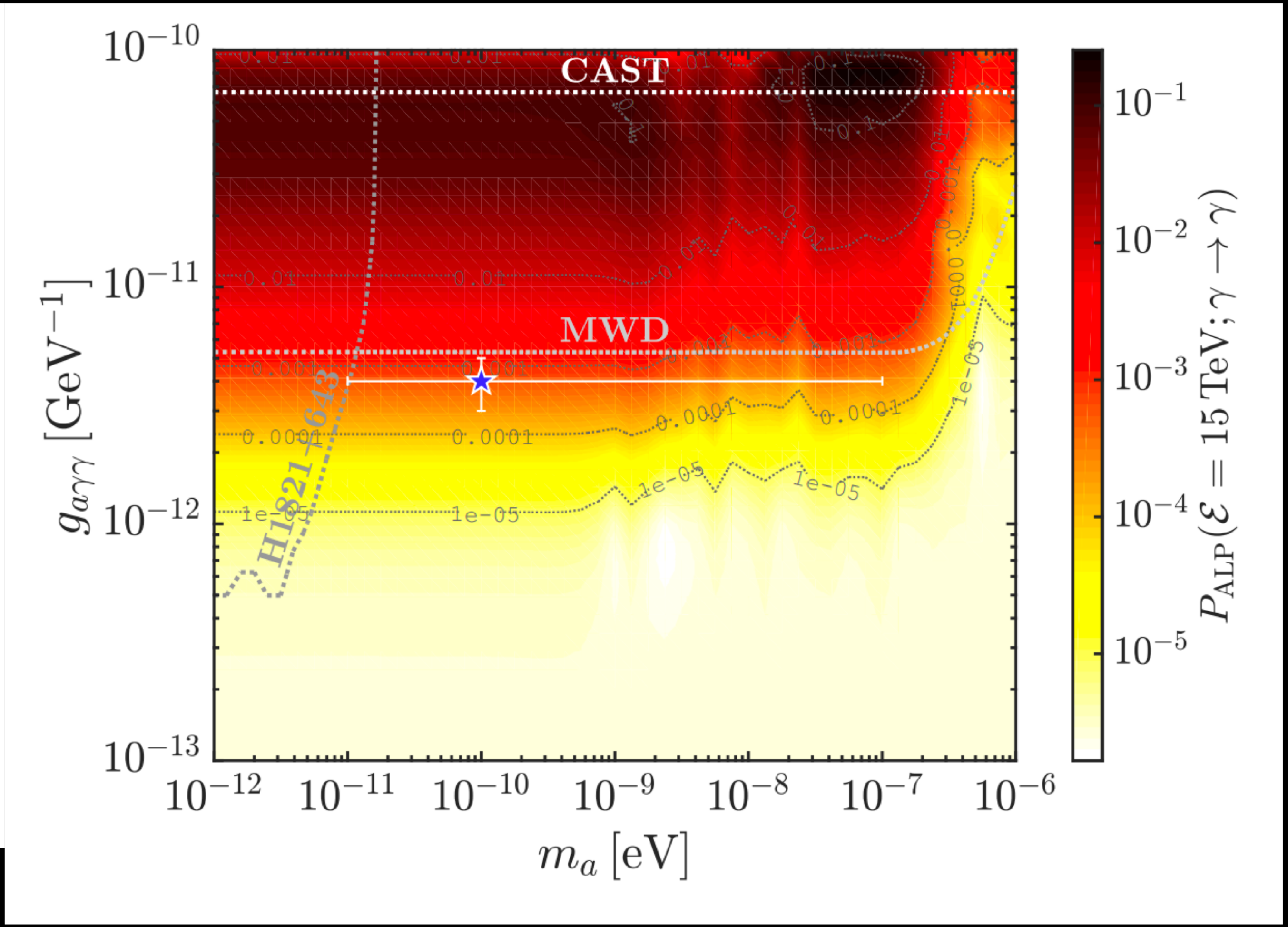




Photon-ALP mixing: Spectral features TeV

Observability of the very-high-energy emission from GRB 221009A (B_IGM)

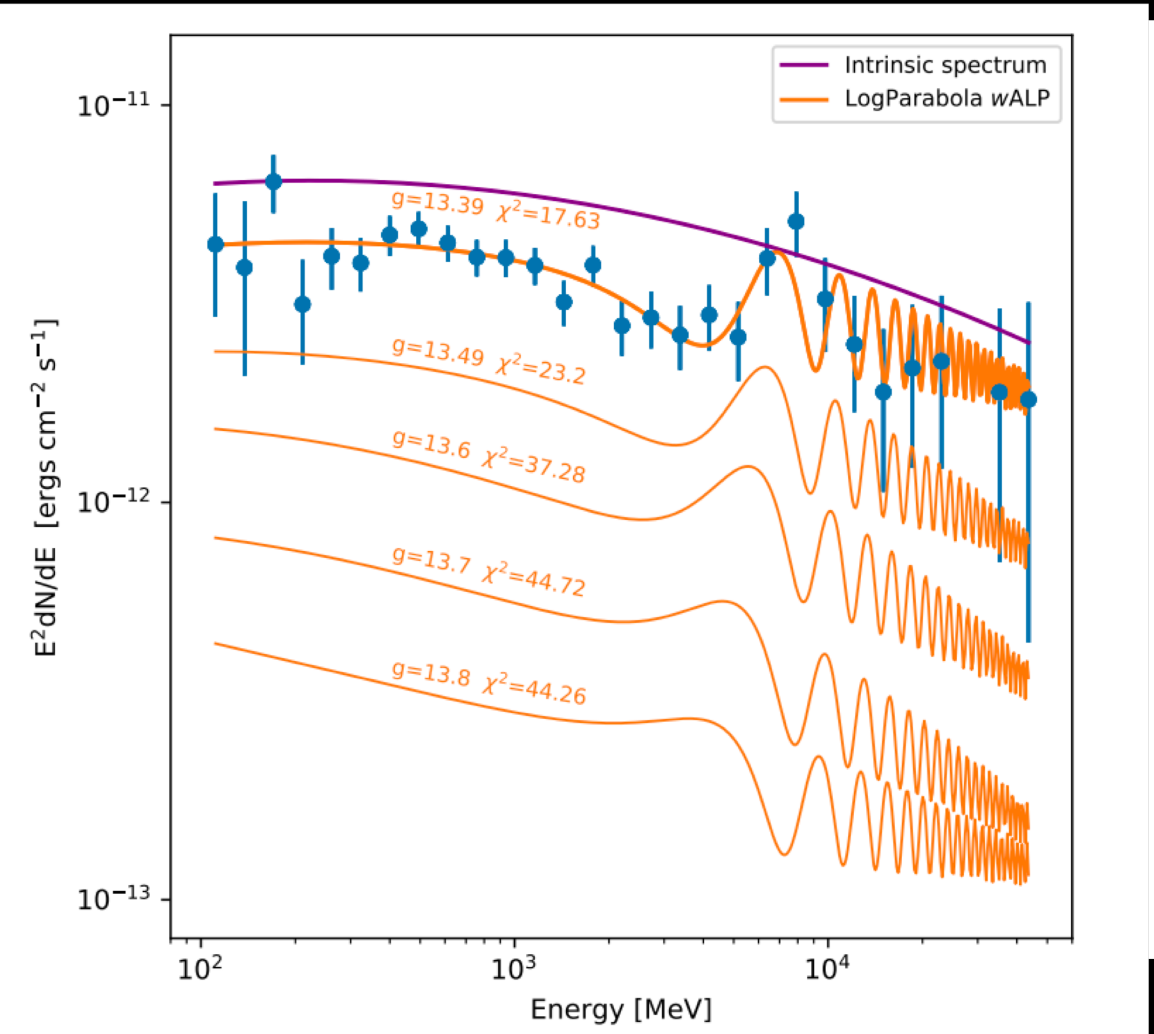


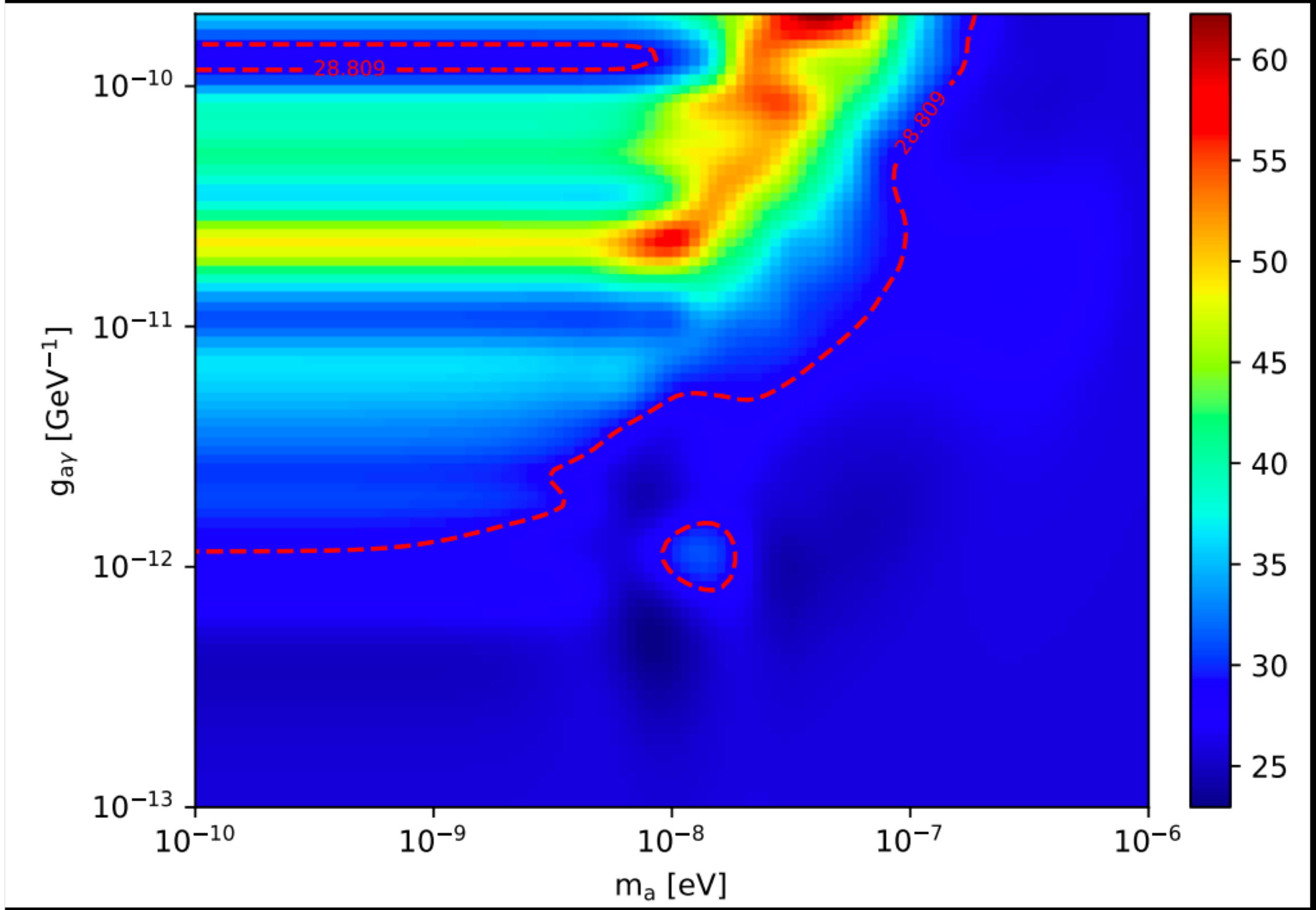


Galanti et al. arXiv:2210.05659

Photon-ALP mixing: Spectral features GeV

Blazar Spectral Irregularity (B_jet)

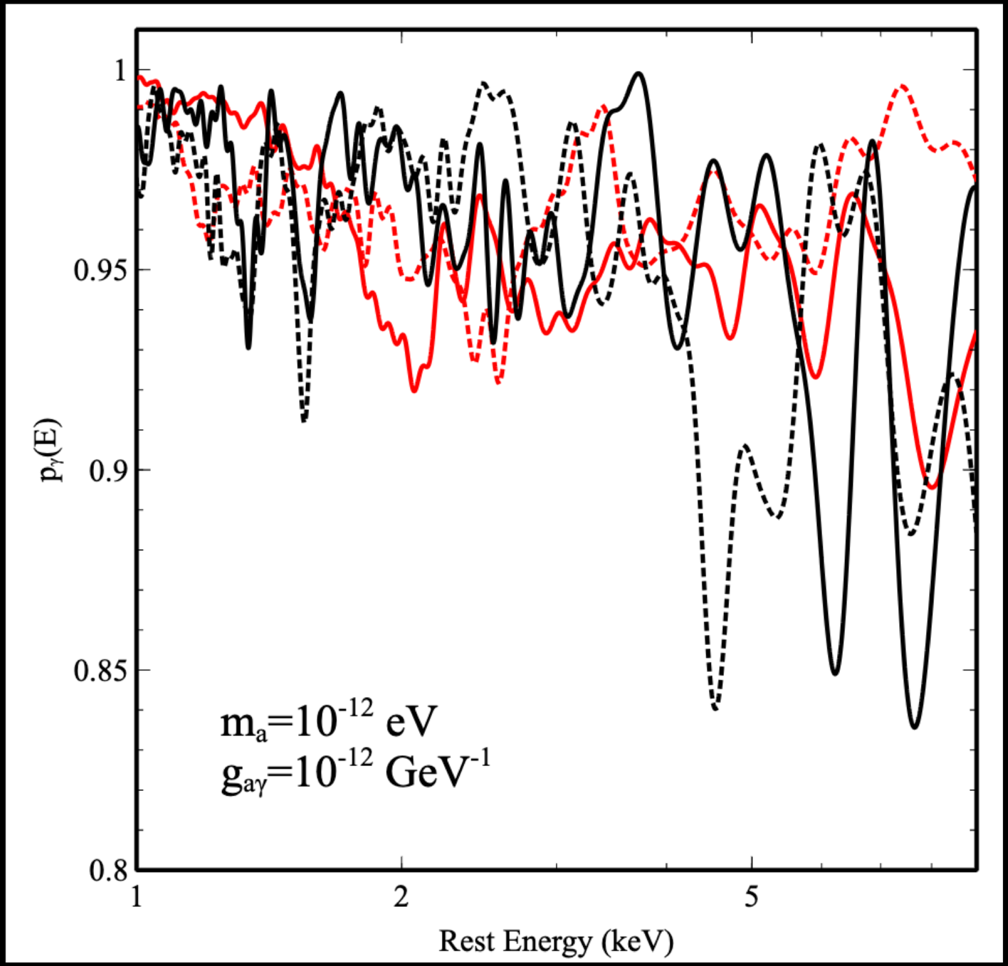


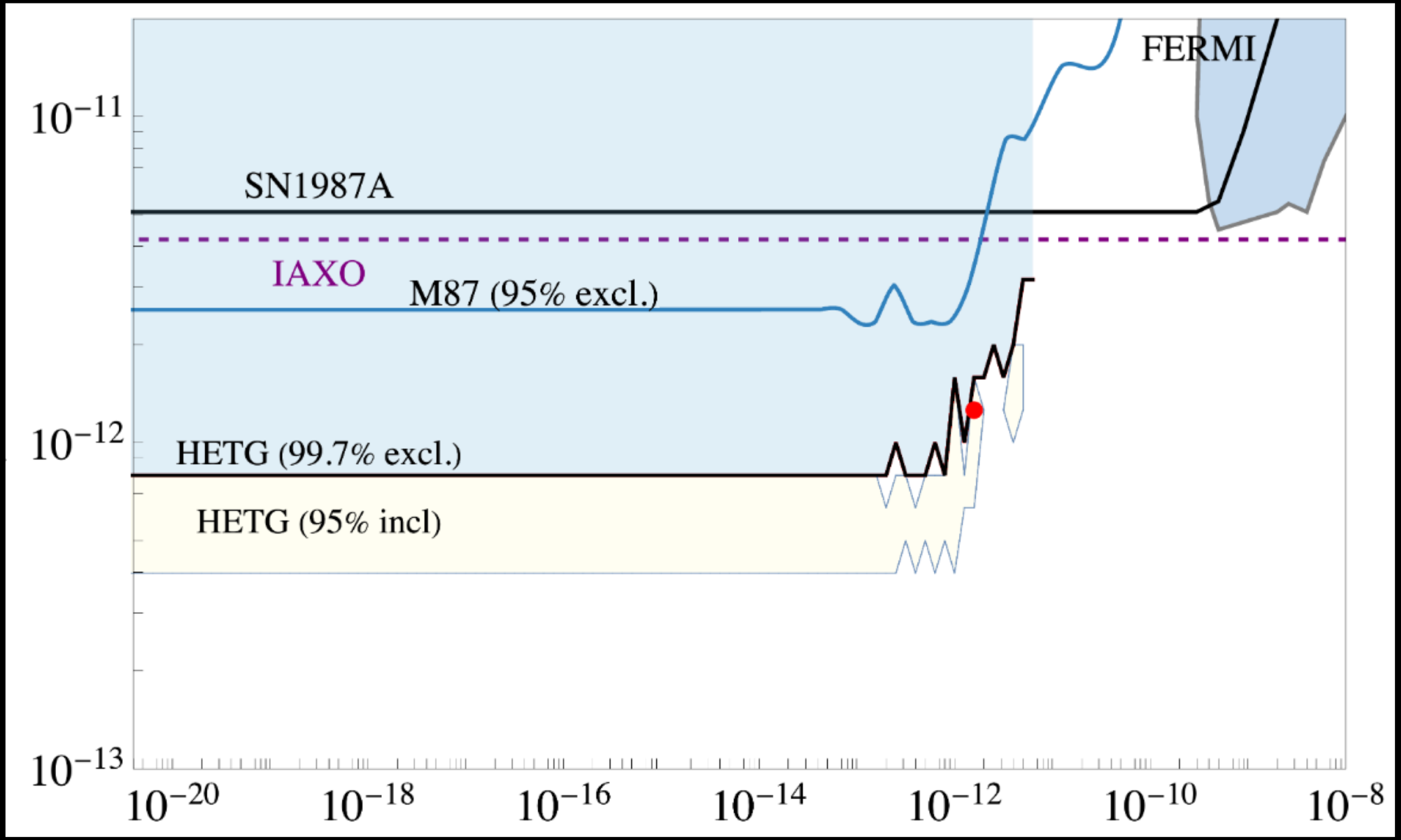


Zhouet al. arXiv:2102.05833

Photon-ALP mixing: Spectral features X-ray

Chandra grating spectroscopy of NGC 1275 (Core AGN in Perseus Cluster, B_ICM)

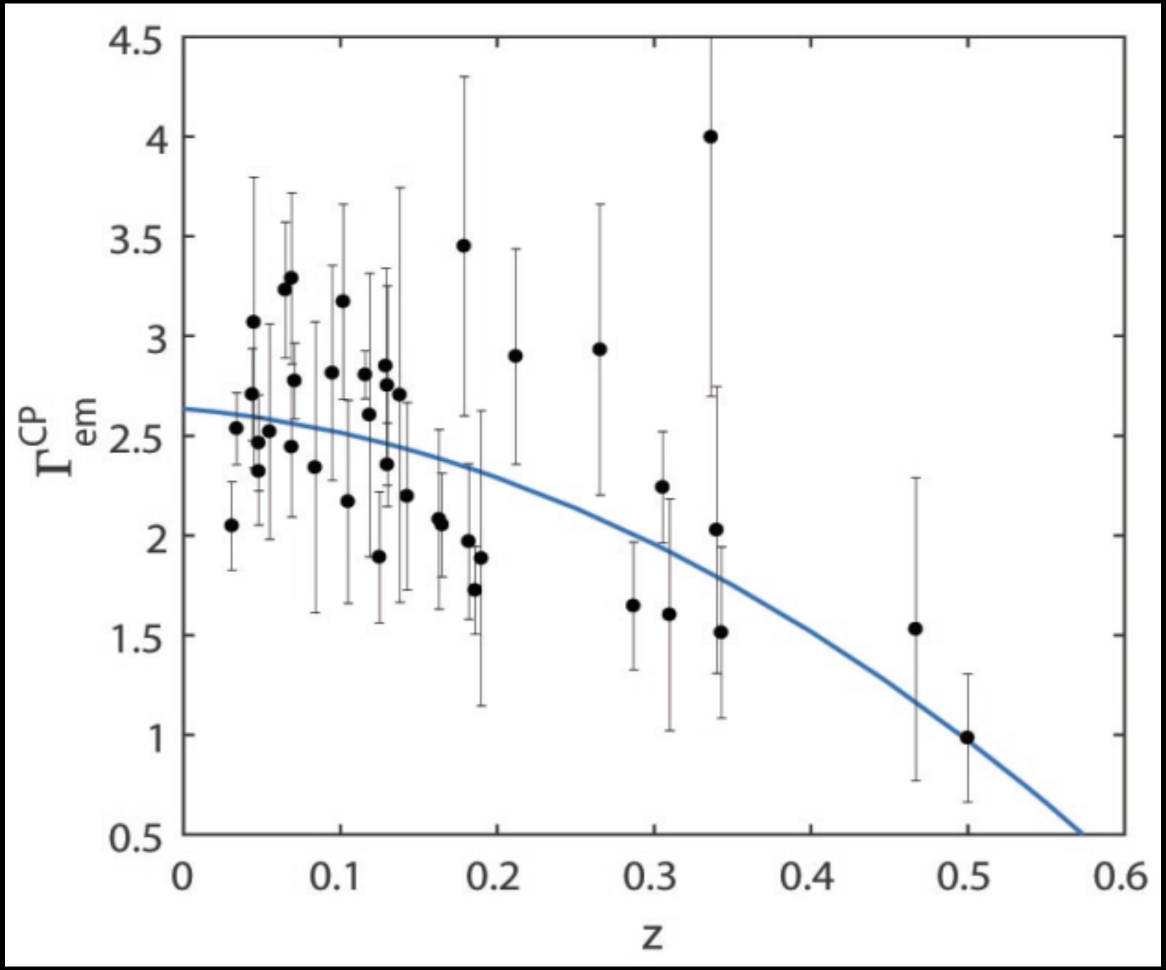


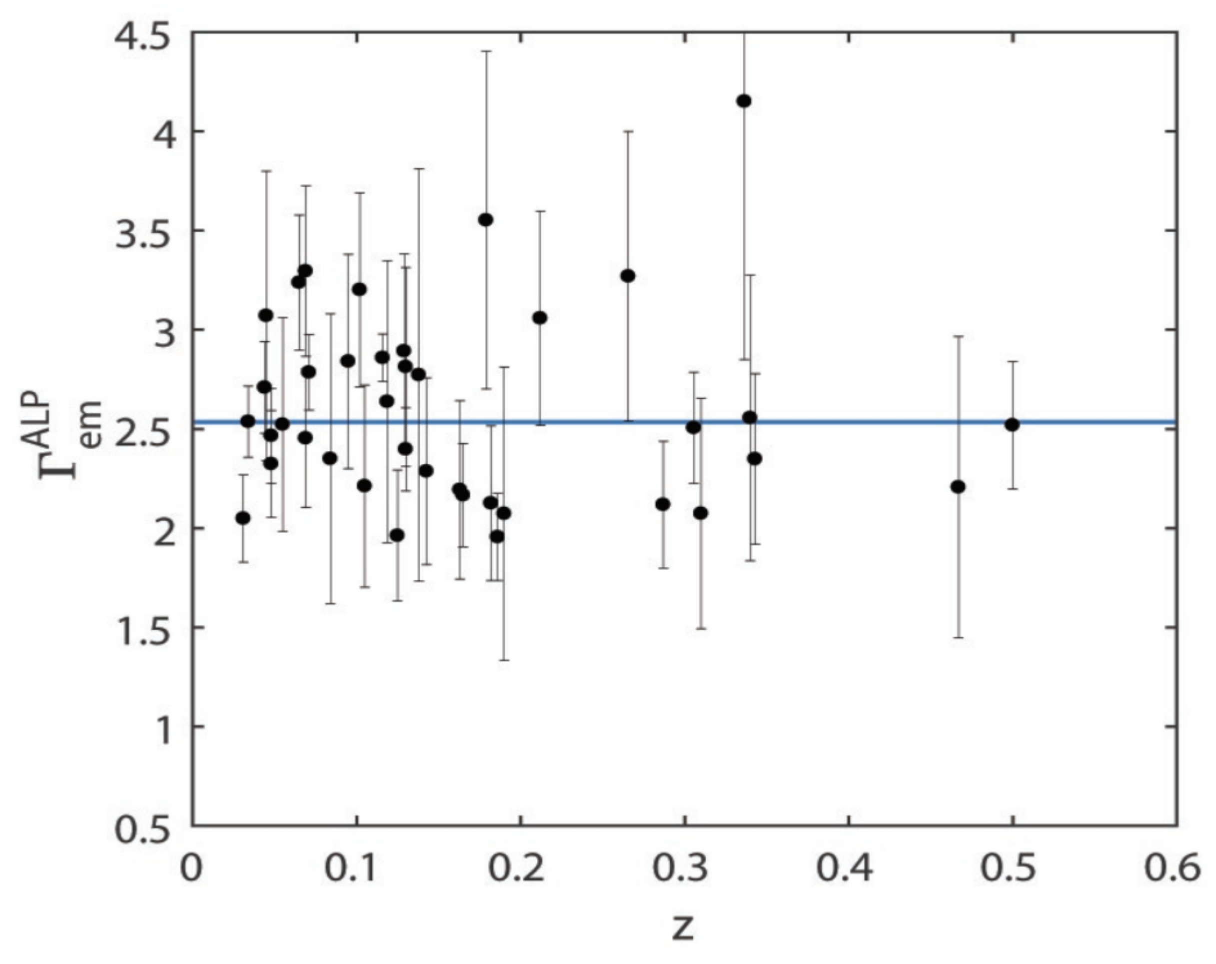


Reynolds, et al. arXiv:190705475

Photon-ALP mixing: Spectral features Large Sample

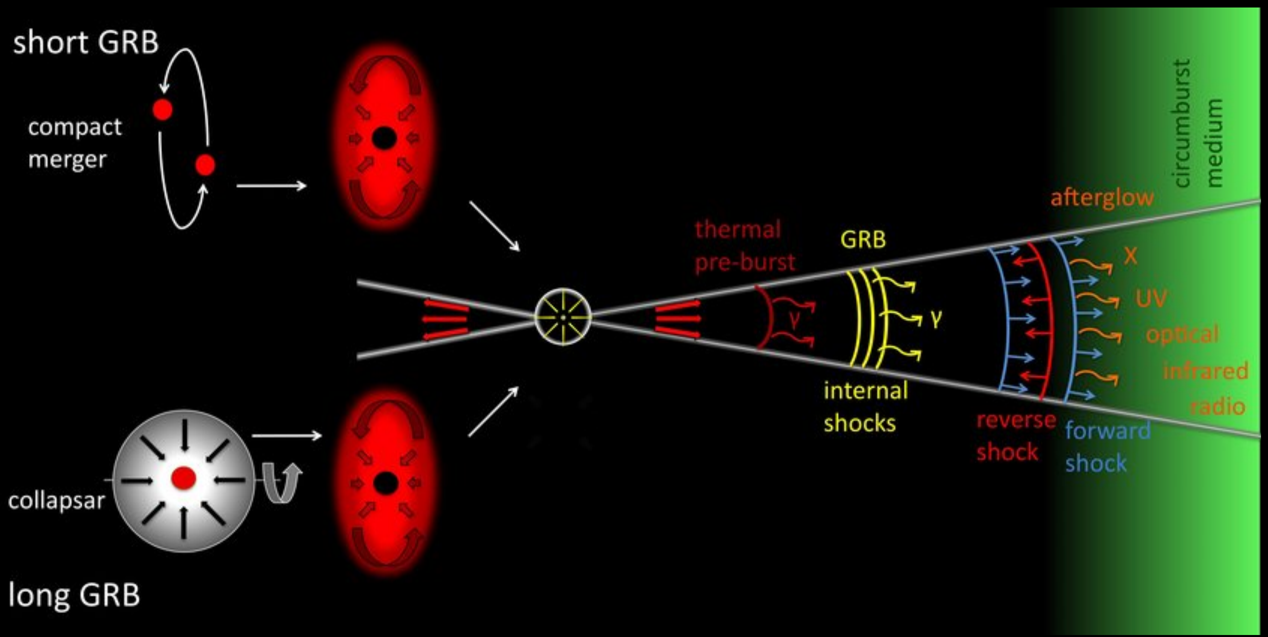
Blazars Spectra index v.s. redshift (B_ICM)



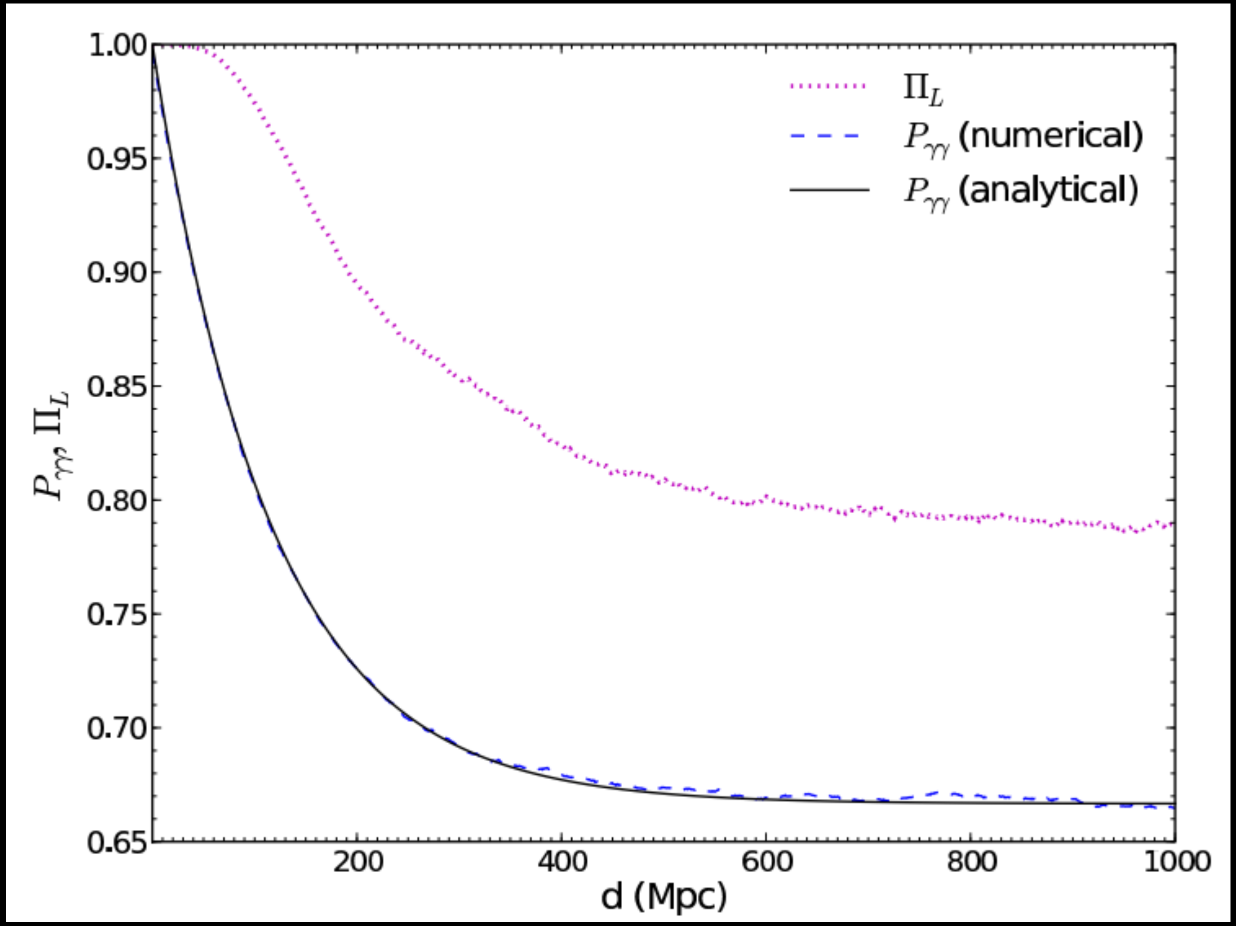


Galanti et al MNRAS 493(2), 1553-1564 (2019)

Photon-ALP mixing: Polarimetric features

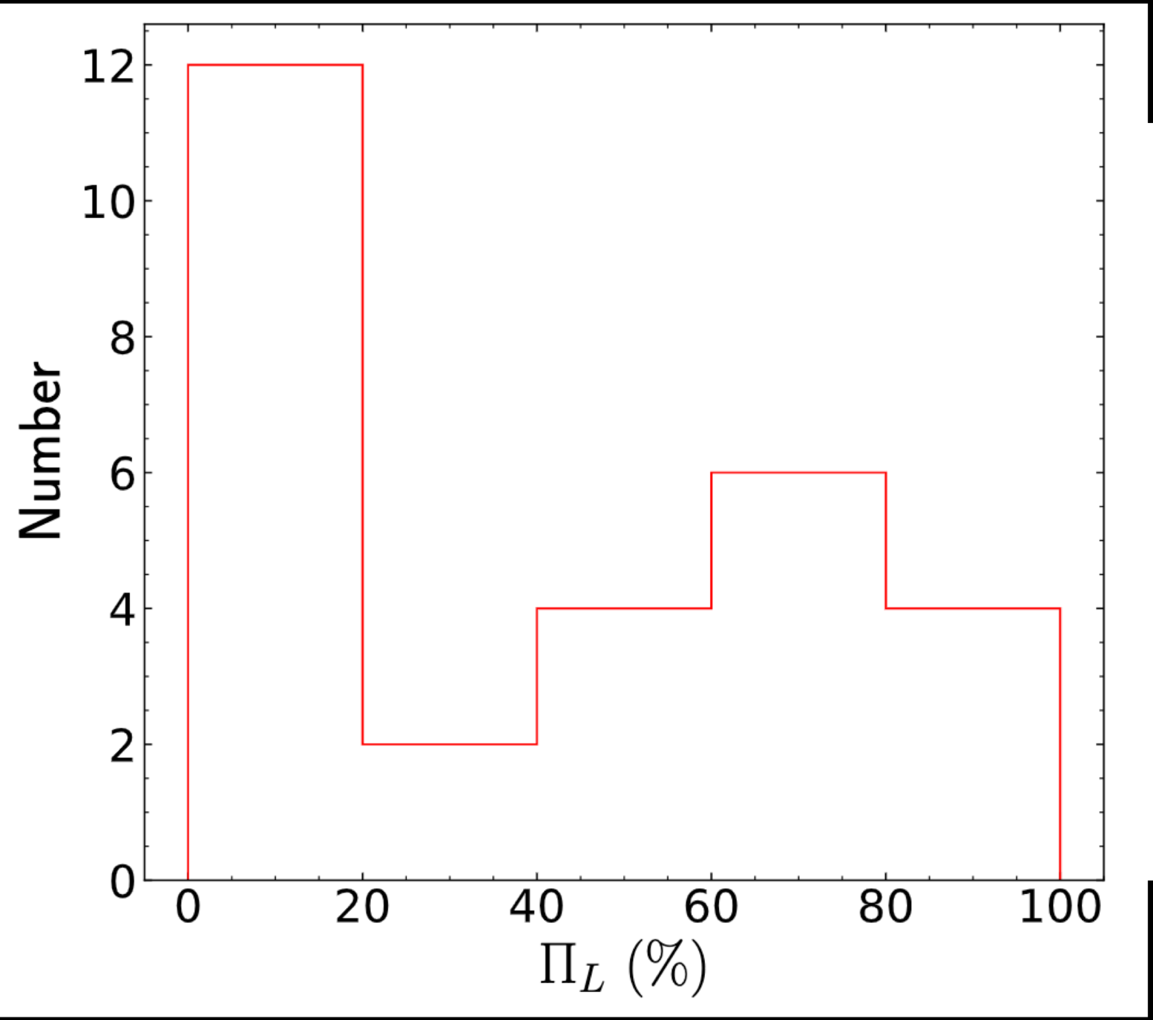


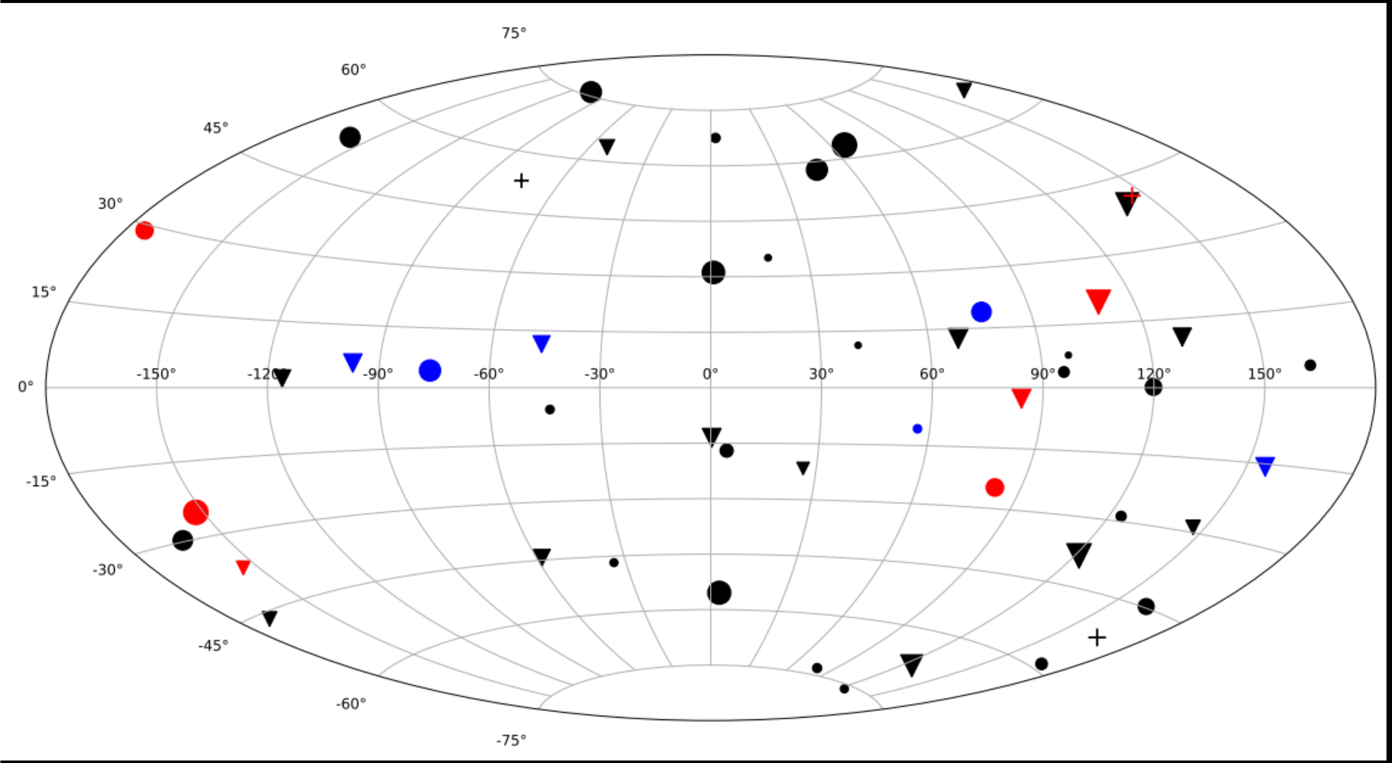
$$\Pi_L = \sqrt{\frac{Q^2 + U^2}{I^2}}$$



Nicola Bassan et al JCAP 05, id.010(2010

X-ray polarimetric features of Gamma-ray Bursts

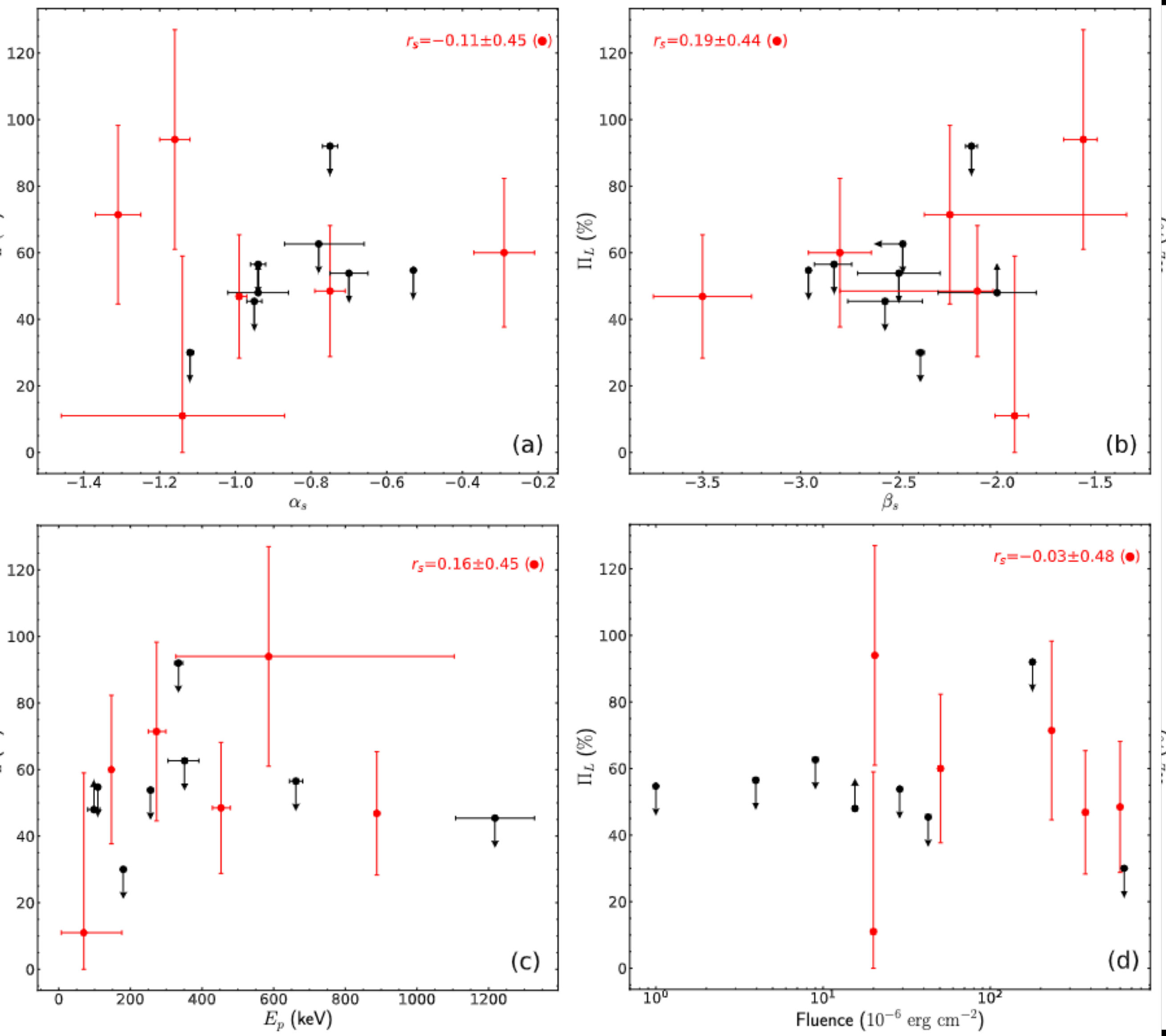


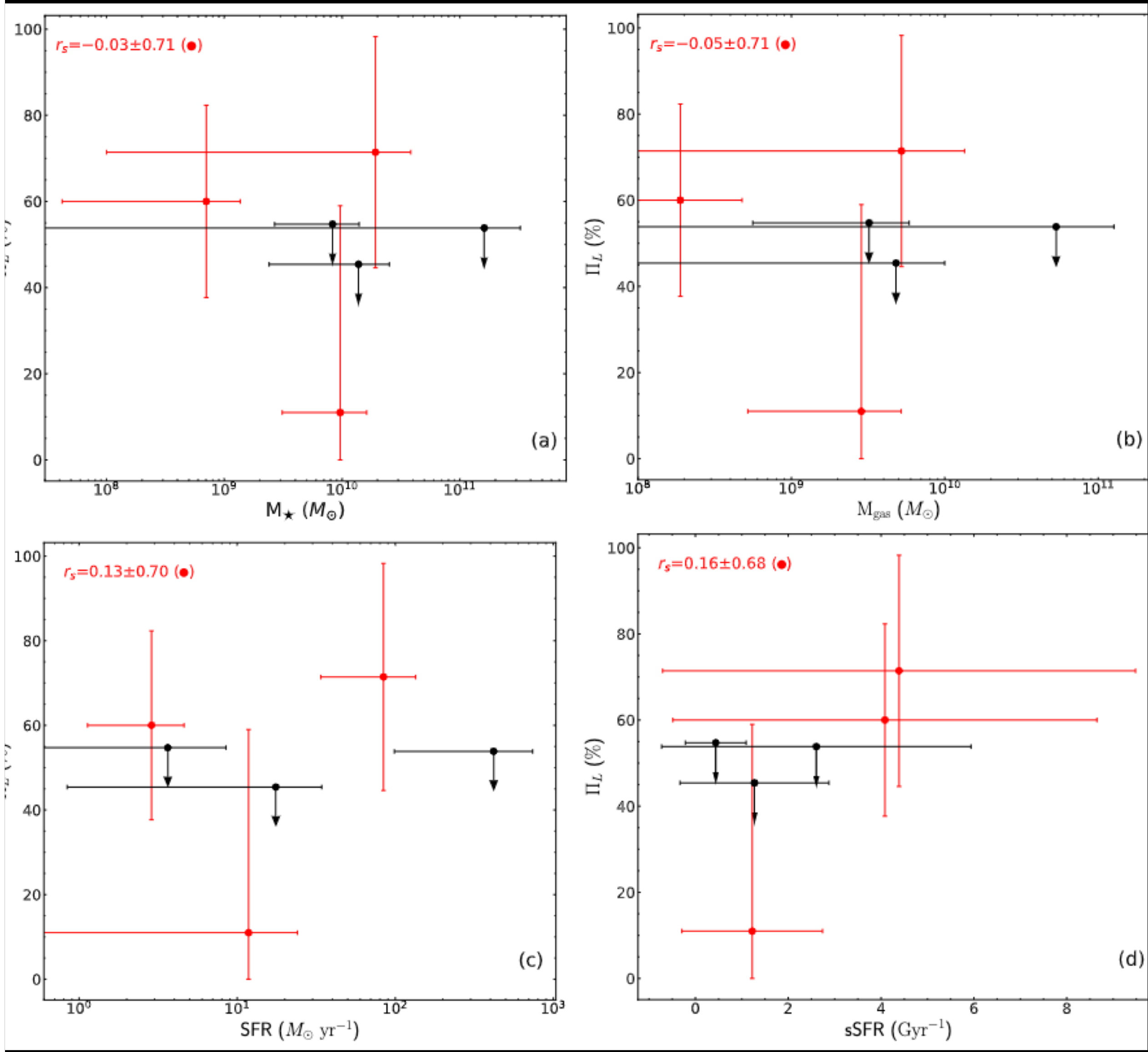


X-ray polarimetric features of GRBs across varied redshifts

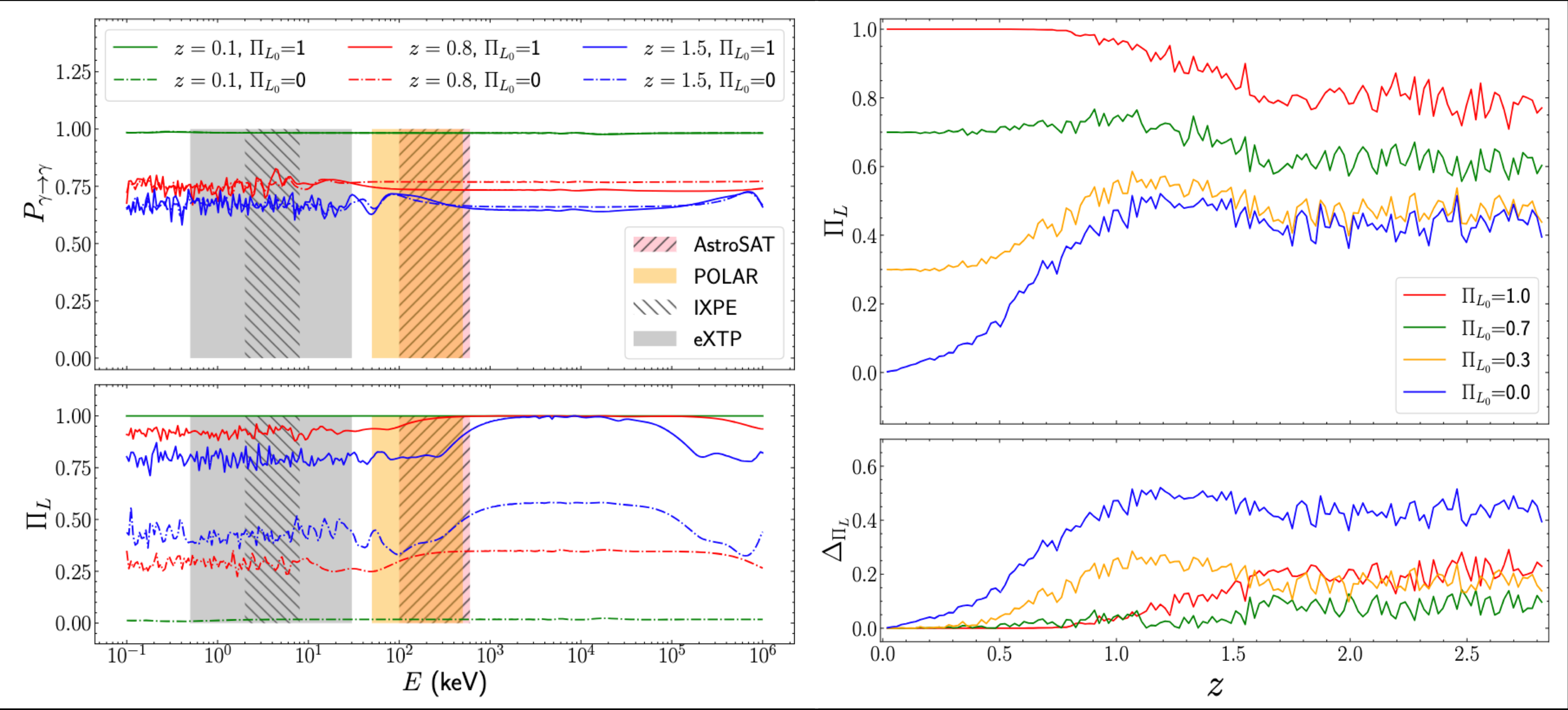
	GRB	$\Pi_L(\%)$	α_s	β_s	E_p (keV)	fluence (10^{-6}erg/cm^2)	Instrument	Redshift*	Offset
1	200311A	< 45.41	$-0.95^{+0.02}_{-0.02}$	$-2.57^{+0.19}_{-0.19}$	1218^{+110}_{-110}	$42.543^{+0.12789}_{-0.12789}$	AstroSAT$^{\mathrm{I}}$	$0.0838^{+0.0349\,a}_{-0.0302}$	0.072′/8.00kpc
2	180103A	$71.43^{+26.84}_{-26.84}$	$-1.31^{+0.06}_{-0.06}$	$-2.24^{+0.90}_{-0.13}$	273^{+26}_{-23}	223	AstroSAT$^{\mathrm{I}}$	$0.037^{+0.0063\,a}_{-0.0015}$	0.184′/8.75kpc
3	180427A	$60.01^{+22.32}_{-22.32}$	$-0.29^{+0.08}_{-0.08}$	$-2.80^{+0.16}_{-0.16}$	147^{+2}_{-2}	$50.455^{+0.12559}_{-0.12559}$	AstroSAT$^{\mathrm{I}}$	$0.0309^{+0.045\,a}_{-0.0309}$	0.273′/10.81kpc
4	200412A	< 53.84	$-0.70^{+0.05}_{-0.05}$	$-2.50^{+0.21}_{-0.21}$	256^{+8}_{-7}	$28.750^{+0.097405}_{-0.097405}$	AstroSAT$^{\mathrm{I}}$	$0.1055^{+0.0192\,a}_{-0.0145}$	0.131′/18.74kpc
5	061122A	11^{+48}_{-11}	$-1.14^{+0.27}_{-0.32}$	$-1.91^{+0.07}_{-0.10}$	70^{+106}_{-63}	20	INTEGRAL$^{\mathrm{II}}$	$1.33^{+0.77\,b}_{-0.76}$	0.435″/20.13kpc
6	200806A	< 54.73	-0.53	-2.96	109.12	1	AstroSAT$^{\mathrm{I}}$	$0.1148^{+0.1749\,a}_{-0.1148}$	0.234′/36.58kpc
7	190530A	$46.85^{+18.53}_{-18.53}$	$-0.99^{+0.02}_{-0.00}$	$-3.50^{+0.25}_{-0.25}$	888^{+8}_{-8}	$370.62^{+0.052475}_{-0.052475}$	AstroSAT$^{\mathrm{I}}$	0.9386^{c}	-
8	180914B	$48.48^{+19.69}_{-19.69}$	$-0.75^{+0.04}_{-0.04}$	$-2.10^{+0.08}_{-0.70}$	453^{+26}_{-24}	598	AstroSAT$^{\mathrm{I}}$	1.096^{d}	-
9	171010A	< 30.02	$-1.12^{+0.01}_{-0.00}$	$-2.39^{+0.02}_{-0.02}$	180^{+3}_{-3}	$632.79^{+0.098525}_{-0.098525}$	AstroSAT$^{\mathrm{I}}$	0.3285^{d}	-
10	160703A	< 62.64	$-0.78^{+0.12}_{-0.09}$	< -2.48	351^{+40}_{-46}	9	AstroSAT$^{\mathrm{I}}$	$< 1.5^{d}$	-
11	160623A	< 56.51	$-0.94^{+0.02}_{-0.02}$	$-2.83^{+0.09}_{-0.10}$	662^{+19}_{-18}	$3.9564^{+0.068702}_{-0.068702}$	AstroSAT$^{\mathrm{I}}$	0.367^{d}	-
12	160509A	< 92	$-0.75^{+0.02}_{-0.02}$	$-2.13^{+0.03}_{-0.03}$	334^{+12}_{-10}	$178.98^{+0.14957}_{-0.14957}$	AstroSAT$^{\mathrm{III}}$	1.17^{d}	-
13	160131A	94^{+33}_{-33}	$-1.16^{+0.04}_{-0.04}$	$-1.56^{+0.07}_{-0.10}$	586^{+518}_{-259}	20.4	AstroSAT$^{\mathrm{III}}$	0.972^{d}	-
14	140206A	> 48	$-0.94^{+0.08}_{-0.08}$	$-2.0^{+0.20}_{-0.30}$	98^{+17}_{-17}	$15.520^{+0.074778}_{-0.074778}$	INTEGRAL$^{\mathrm{IV}}$	$2.739^{+0.001\,e}_{-0.001}$	-

No correlation with spectral parameters or properties of host galaxies

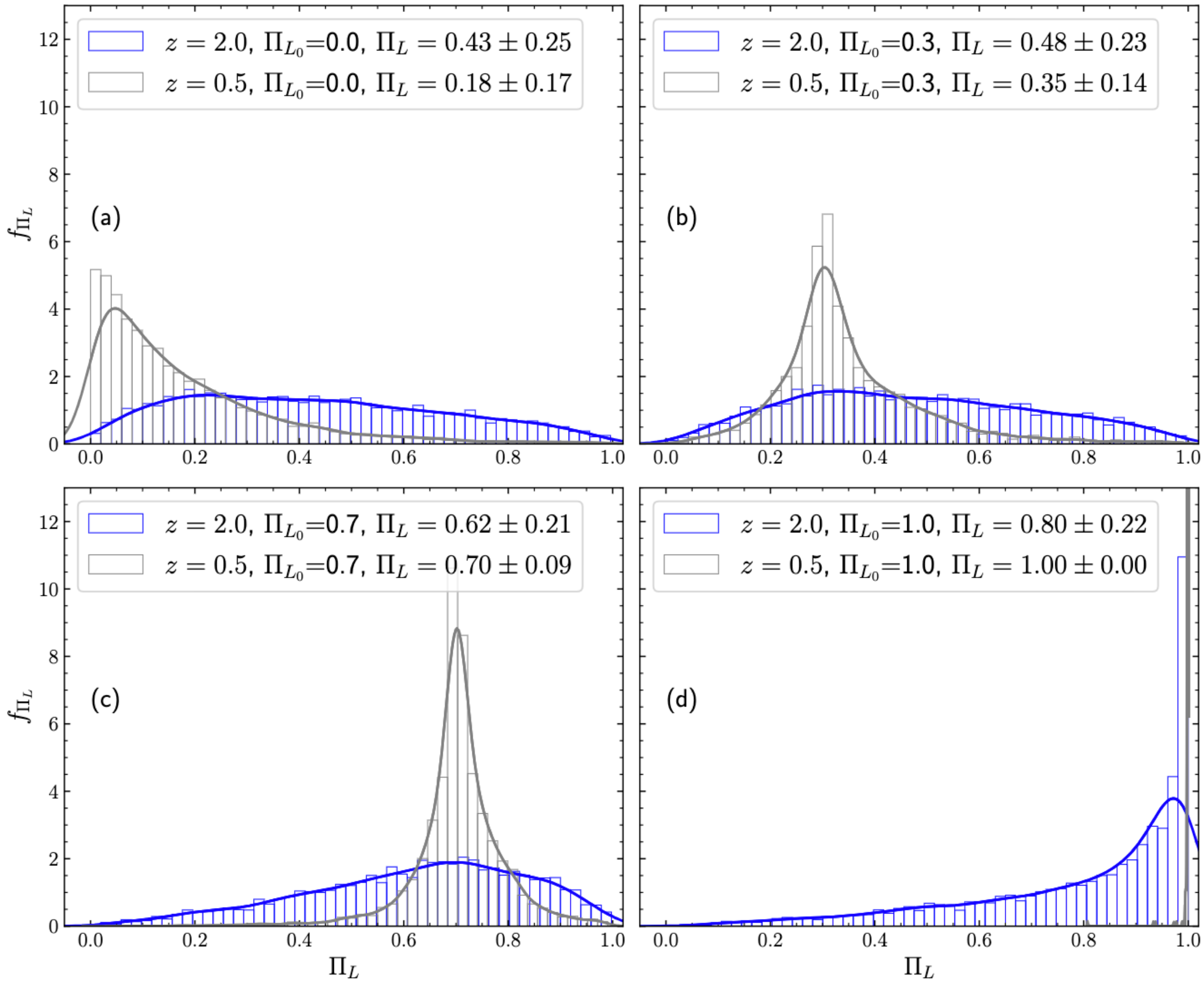


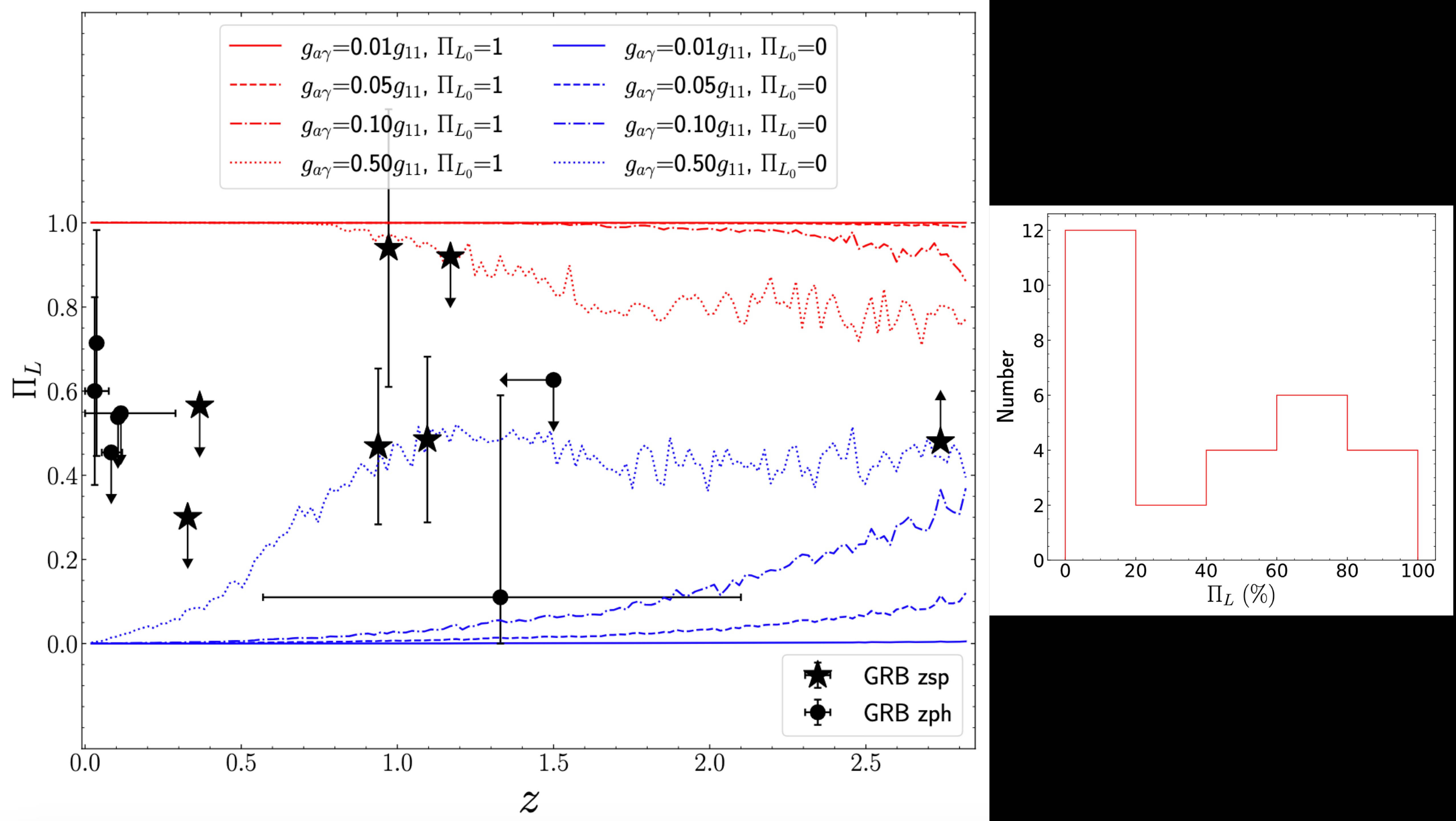


$g_{a\gamma} = 0.5 \times 10^{-11}$ GeV^{-1} for $m_a \leq 10^{-14}$ eV



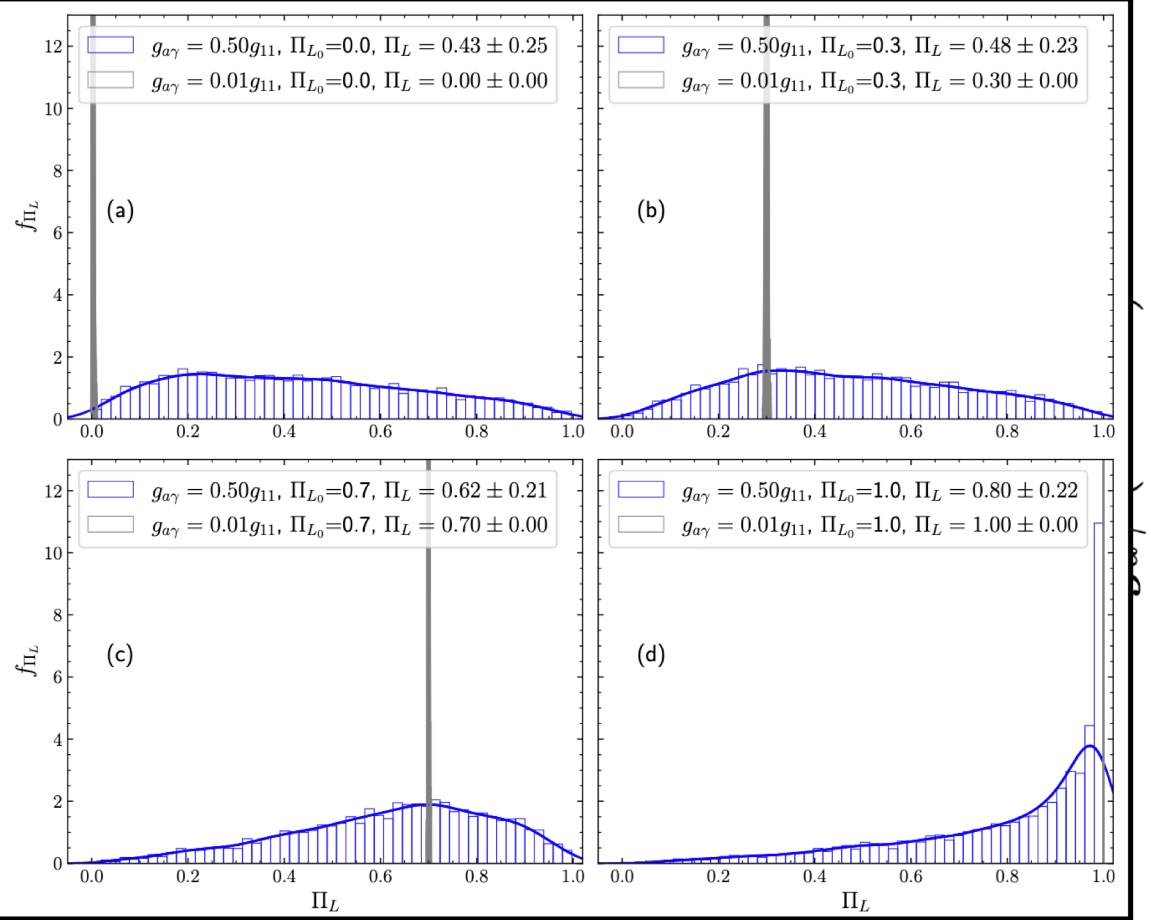
$\mathbf{B}_{\rm IGM} = 1$ nG and coherence length $L_{\rm coh} = 1$ Mpc at z = 0.

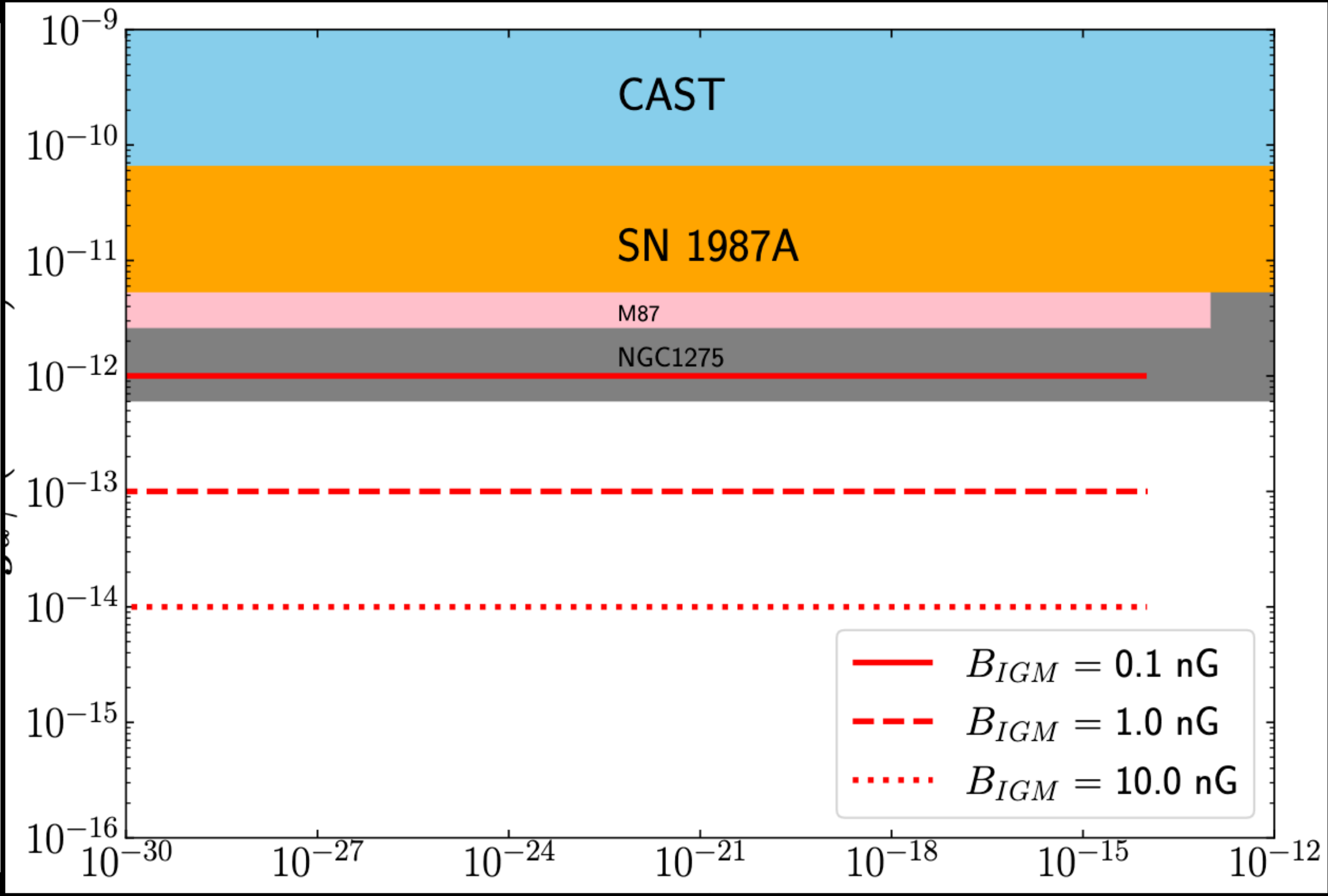

$z = 2.0$, Π_{L_0}=0.0, $\Pi_L = 0.43 \pm 0.25$
$z = 0.5$, Π_{L_0}=0.0, $\Pi_L = 0.18 \pm 0.17$
(a)
$z = 2.0$, Π_{L_0}=0.3, $\Pi_L = 0.48 \pm 0.23$
$z = 0.5$, Π_{L_0}=0.3, $\Pi_L = 0.35 \pm 0.14$
(b)
$z = 2.0$, Π_{L_0}=0.7, $\Pi_L = 0.62 \pm 0.21$
$z = 0.5$, Π_{L_0}=0.7, $\Pi_L = 0.70 \pm 0.09$
(c)
$z = 2.0$, Π_{L_0}=1.0, $\Pi_L = 0.80 \pm 0.22$
$z = 0.5$, Π_{L_0}=1.0, $\Pi_L = 1.00 \pm 0.00$
(d)
f_{Π_L}
Π_L



$g_{a\gamma}$=0.01g_{11}, Π_{L_0}=1
$g_{a\gamma}$=0.05g_{11}, Π_{L_0}=1
$g_{a\gamma}$=0.10g_{11}, Π_{L_0}=1
$g_{a\gamma}$=0.50g_{11}, Π_{L_0}=1
$g_{a\gamma}$=0.01g_{11}, Π_{L_0}=0
$g_{a\gamma}$=0.05g_{11}, Π_{L_0}=0
$g_{a\gamma}$=0.10g_{11}, Π_{L_0}=0
$g_{a\gamma}$=0.50g_{11}, Π_{L_0}=0
GRB zsp
GRB zph
Π_L
z
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
Number
Π_L (%)
0
2
4
6
8
10
12
0
20
40
60
80
100

Constrains on ALP parameters for an extremely case





Summary

1: Astronomical constraints on ALPs independent of dark matter assumption.

2: Photon-ALP mixing produces measurable modifications to final photon polarization of cosmological sources

3: Number of GRBs with both sub-MeV polarization measurement and redshift confirmation remains very limit.

Thank You!