



中国科学院国家天文台

National Astronomical Observatories,
Chinese Academy of Sciences

从多信使出发对暗物质和 致密天体的研究

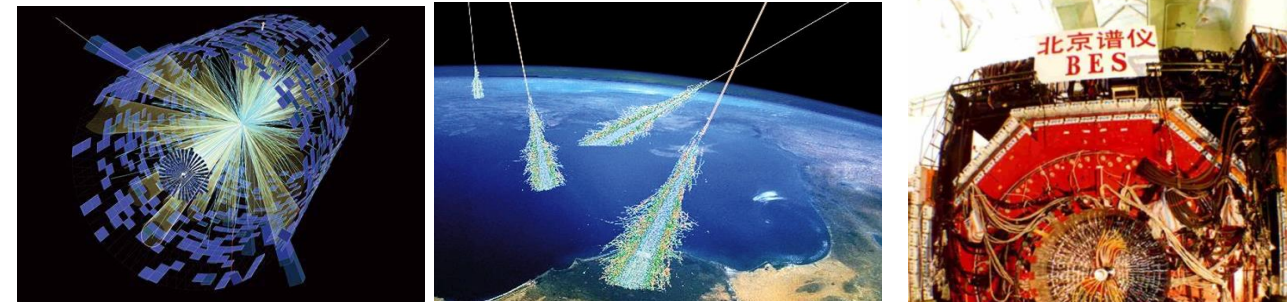
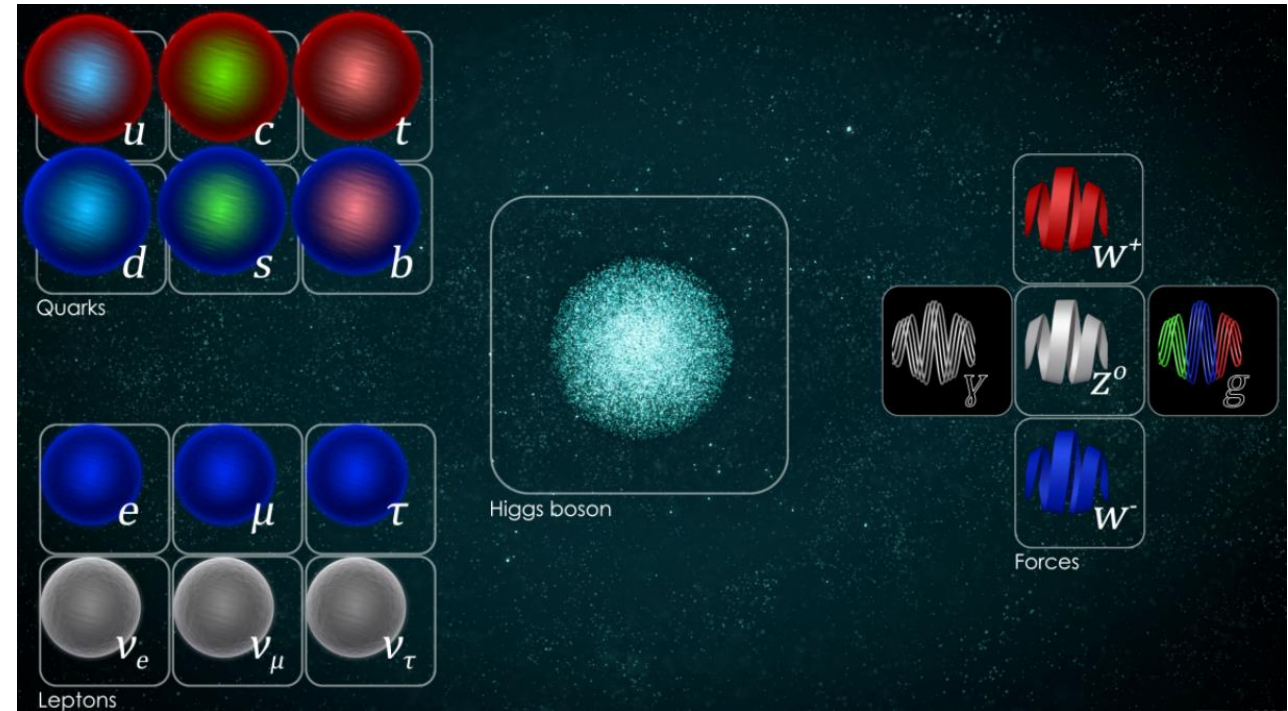
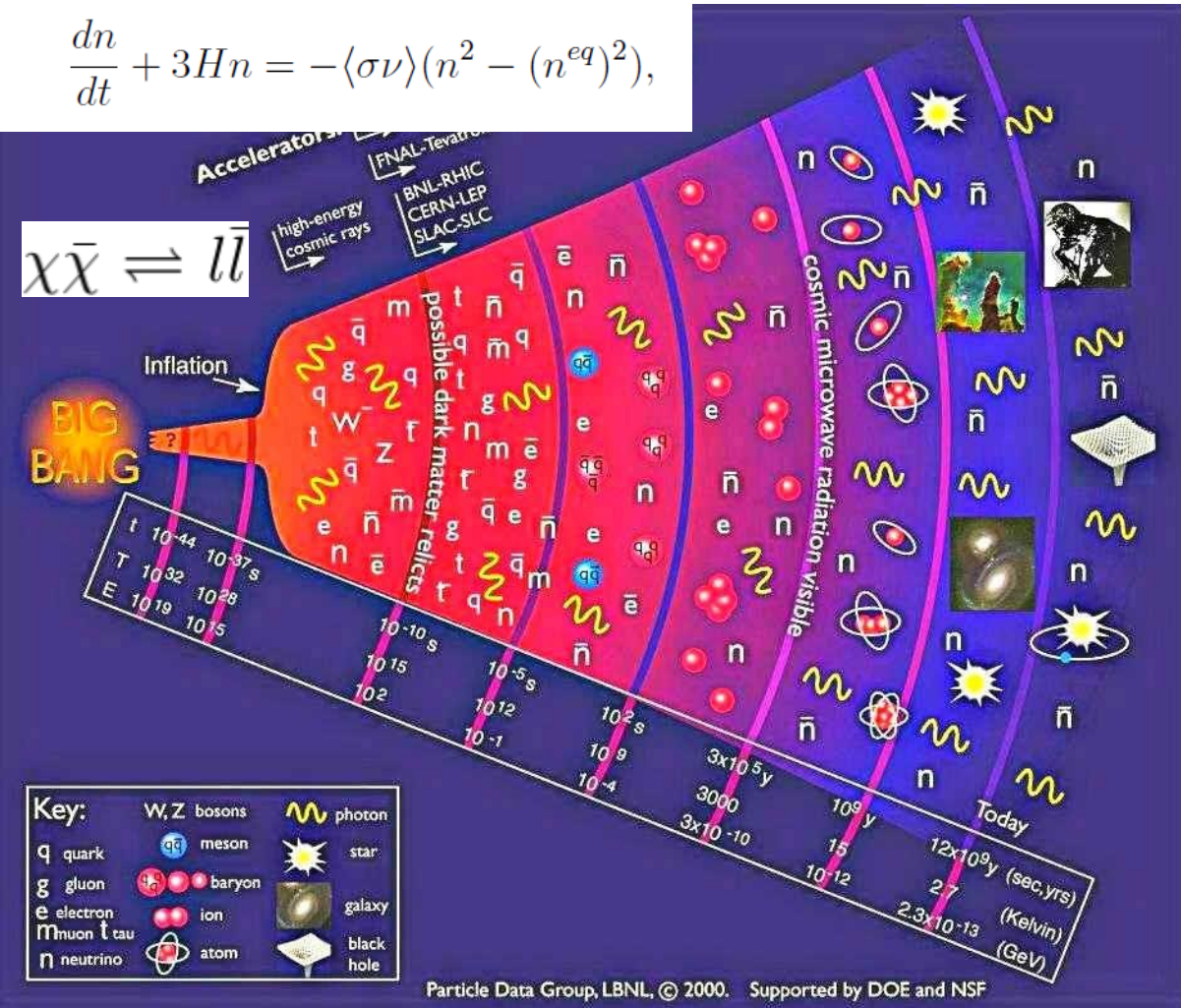
金洪波

2022-11-03

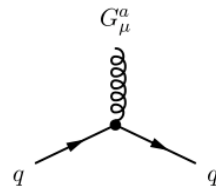
国家天文台青年学者学术交流活动第一期

宇宙学标准模型与粒子物理标准模型-暗物质的存在

$$\frac{dn}{dt} + 3Hn = -\langle\sigma v\rangle(n^2 - (n^{eq})^2),$$



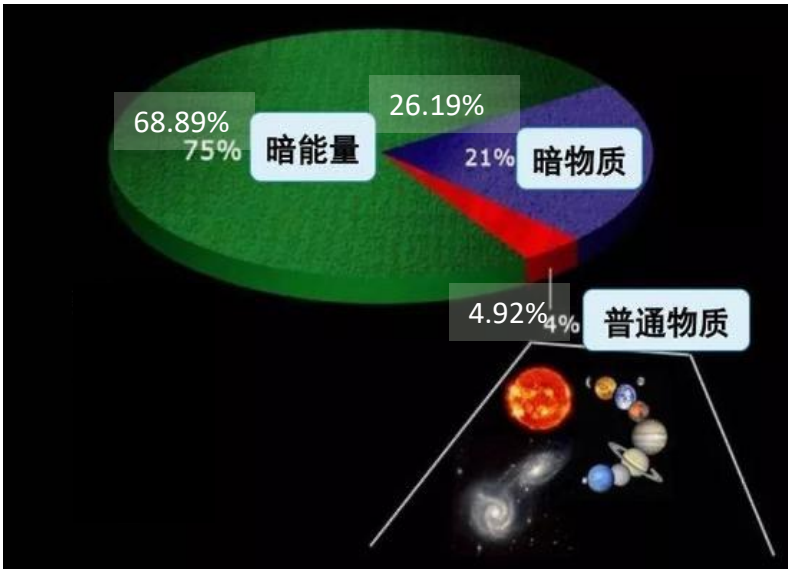
$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu}$$



$$G_{SM} = SU(3)_c \times SU(2)_L \times U(1)_Y$$

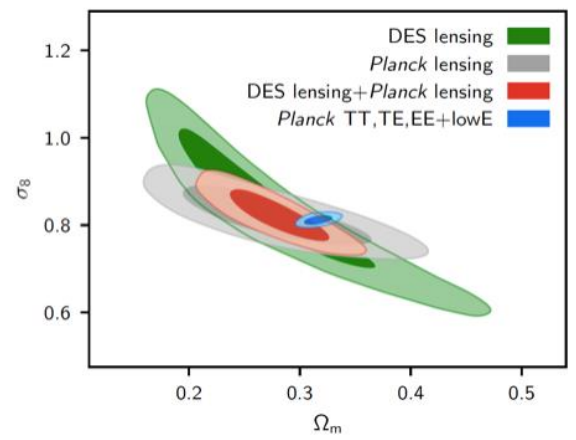
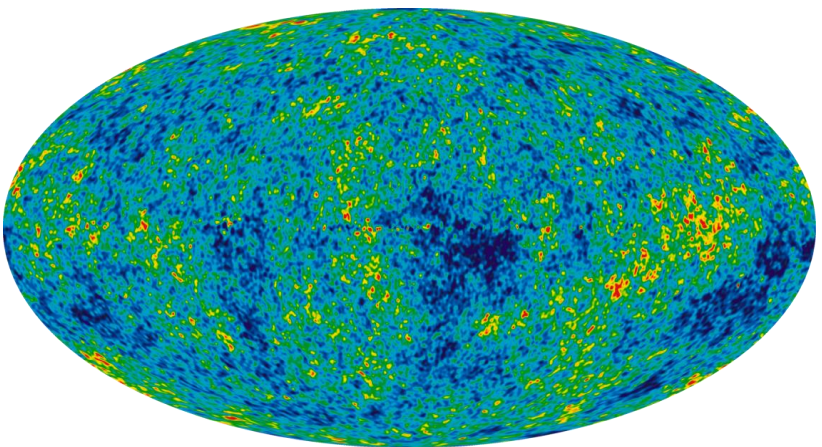
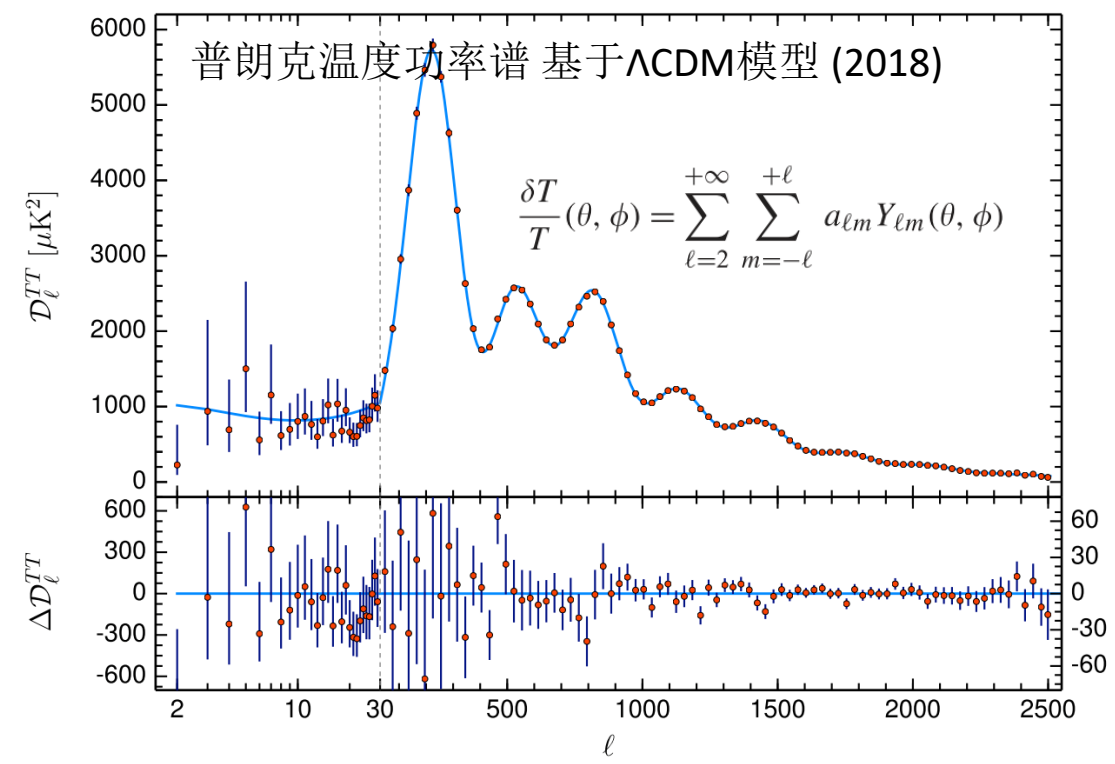
$$\mathcal{L}_{QCD} = \sum_q \bar{q}(i\gamma^\mu D_\mu - m_q)q - \frac{1}{4}G_{\mu\nu}^a G^{\mu\nu a}$$

宇宙物质的构成



$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3} \left(\rho + \frac{3p}{c^2} \right) + \frac{\Lambda c^2}{3}$$

$$\rho_c = \frac{3H_0^2}{8\pi G}, \quad \Omega = \frac{\rho}{\rho_c}$$

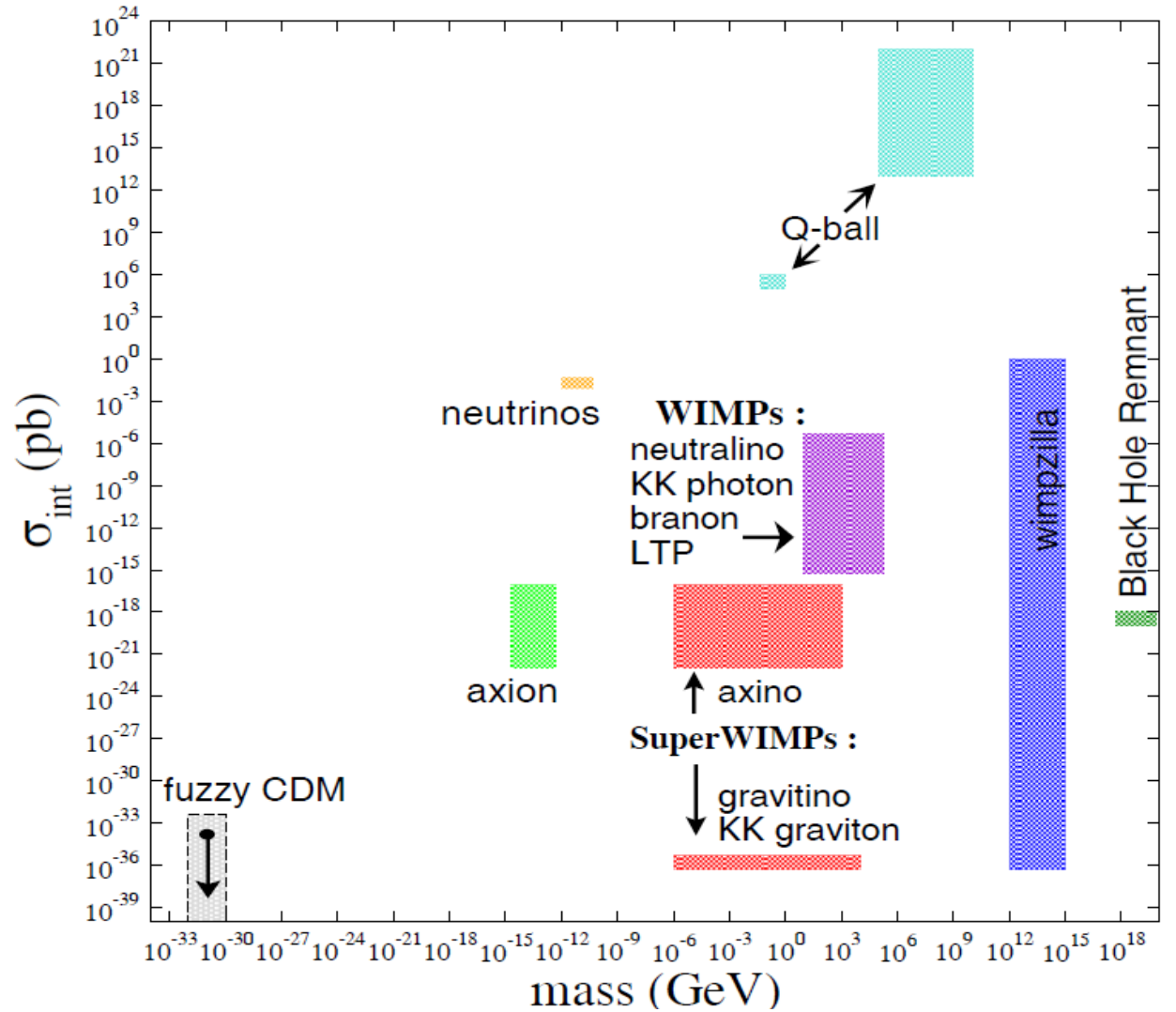
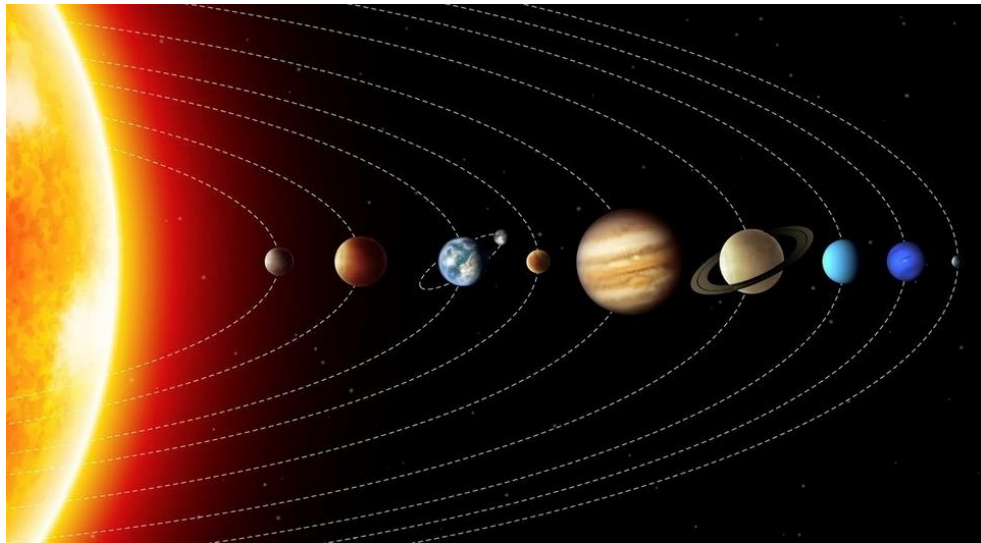
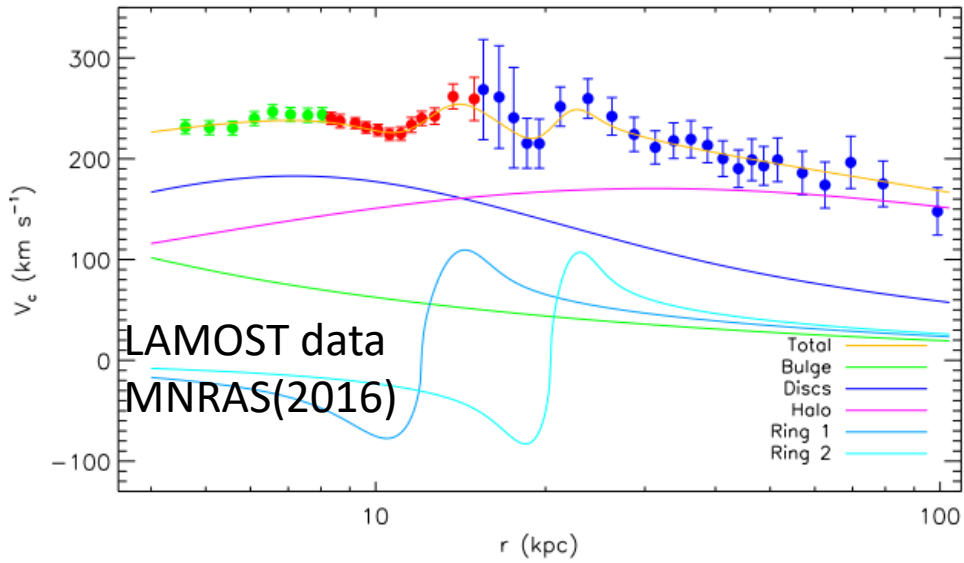


Parameter	TT,TE,EE+lowE+lensing+BAO 68% limits
$\Omega_b h^2$	0.02242 ± 0.00014
$\Omega_c h^2$	0.11933 ± 0.00091
$100\theta_{MC}$	1.04101 ± 0.00029
τ	0.0561 ± 0.0071
$\ln(10^{10} A_s)$	3.047 ± 0.014
n_s	0.9665 ± 0.0038
H_0 [km s ⁻¹ Mpc ⁻¹]	67.66 ± 0.42
Ω_Λ	0.6889 ± 0.0056
Ω_m	0.3111 ± 0.0056

CosmoMC
<http://cosmologist.info/cosmomc/>

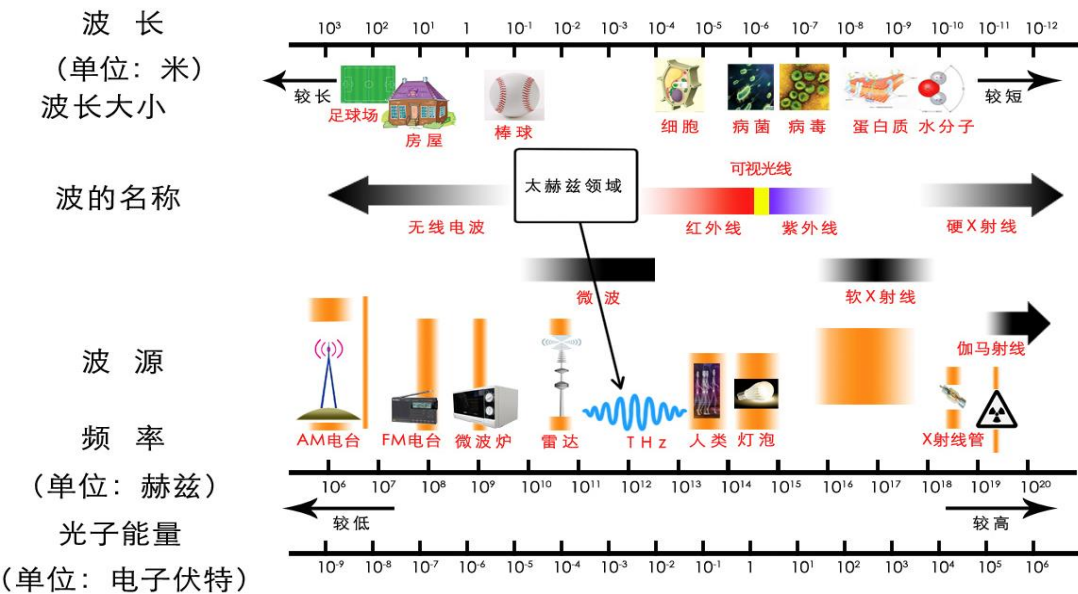
arXiv:1807.06209, 8927 citations

银河系内暗物质和暗物质模型

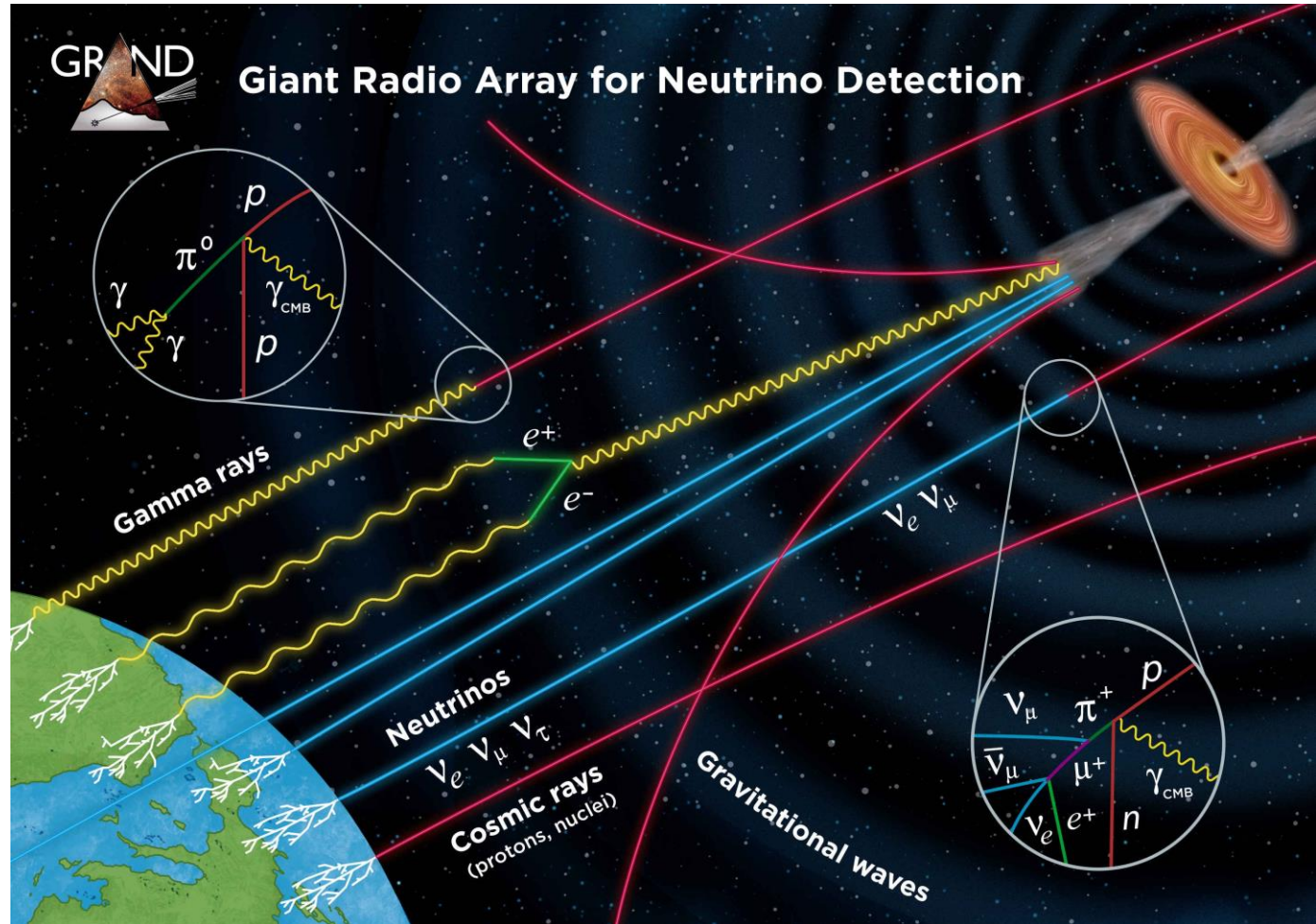
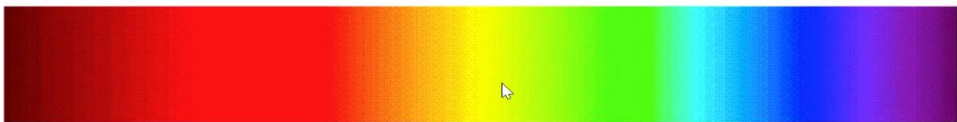
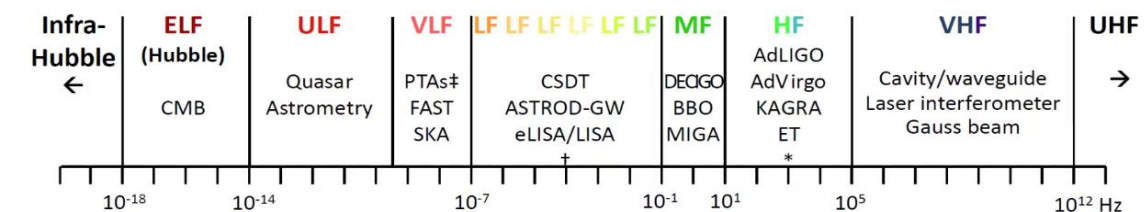


多信使与多波段

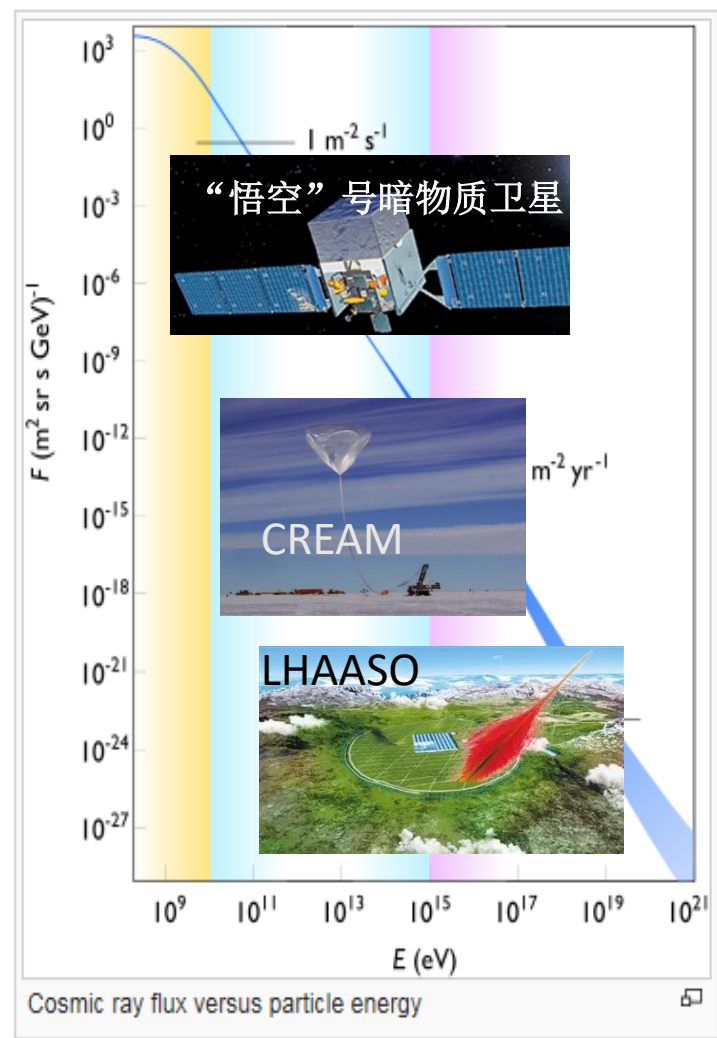
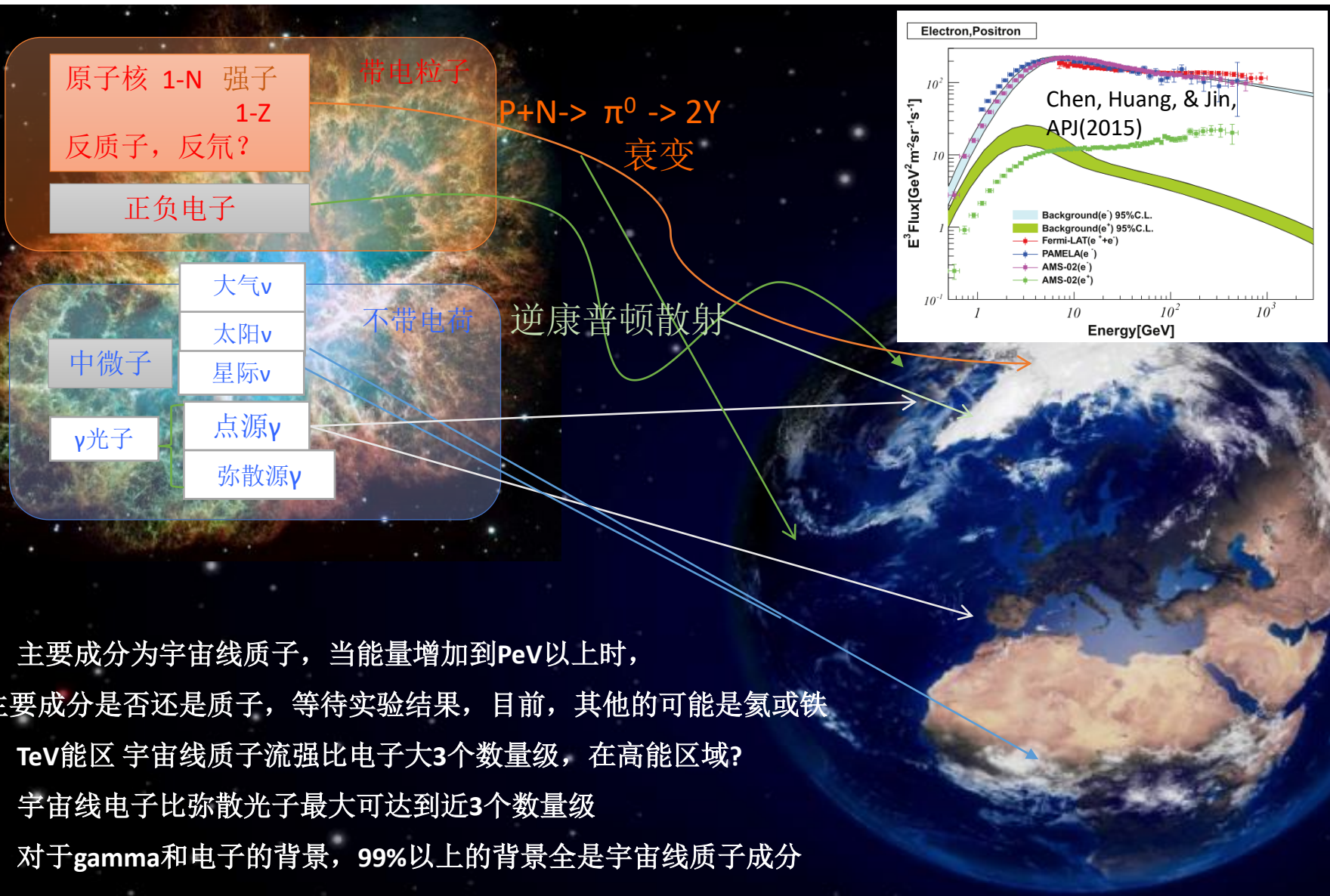
电磁波谱



引力波谱分类 The Gravitation-Wave (GW) Spectrum Classification

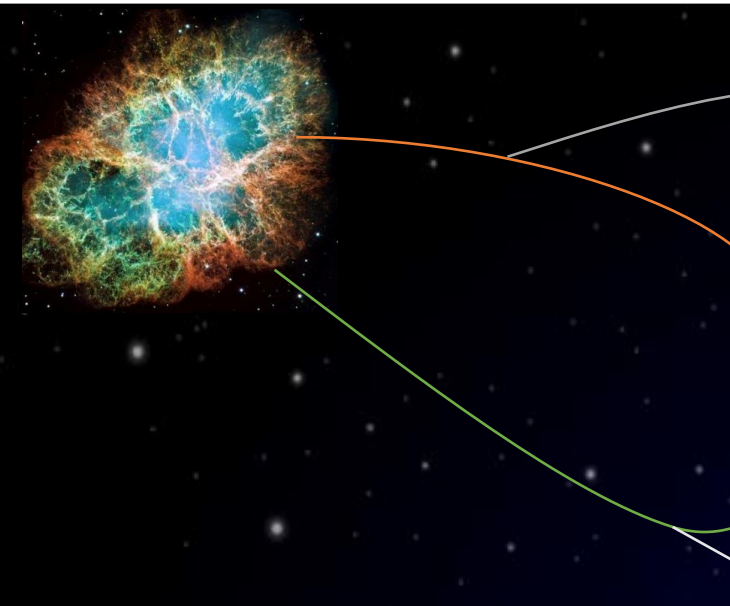


宇宙线成分特征和宇宙线的探测



- 主要成分为宇宙线质子，当能量增加到PeV以上时，主要成分是否还是质子，等待实验结果，目前，其他的可能是氦或铁
- TeV能区 宇宙线质子流强比电子大3个数量级，在 高能区域?
- 宇宙线电子比弥散光子最大可达到近3个数量级
- 对于gamma和电子的背景，99%以上的背景全是宇宙线质子成分

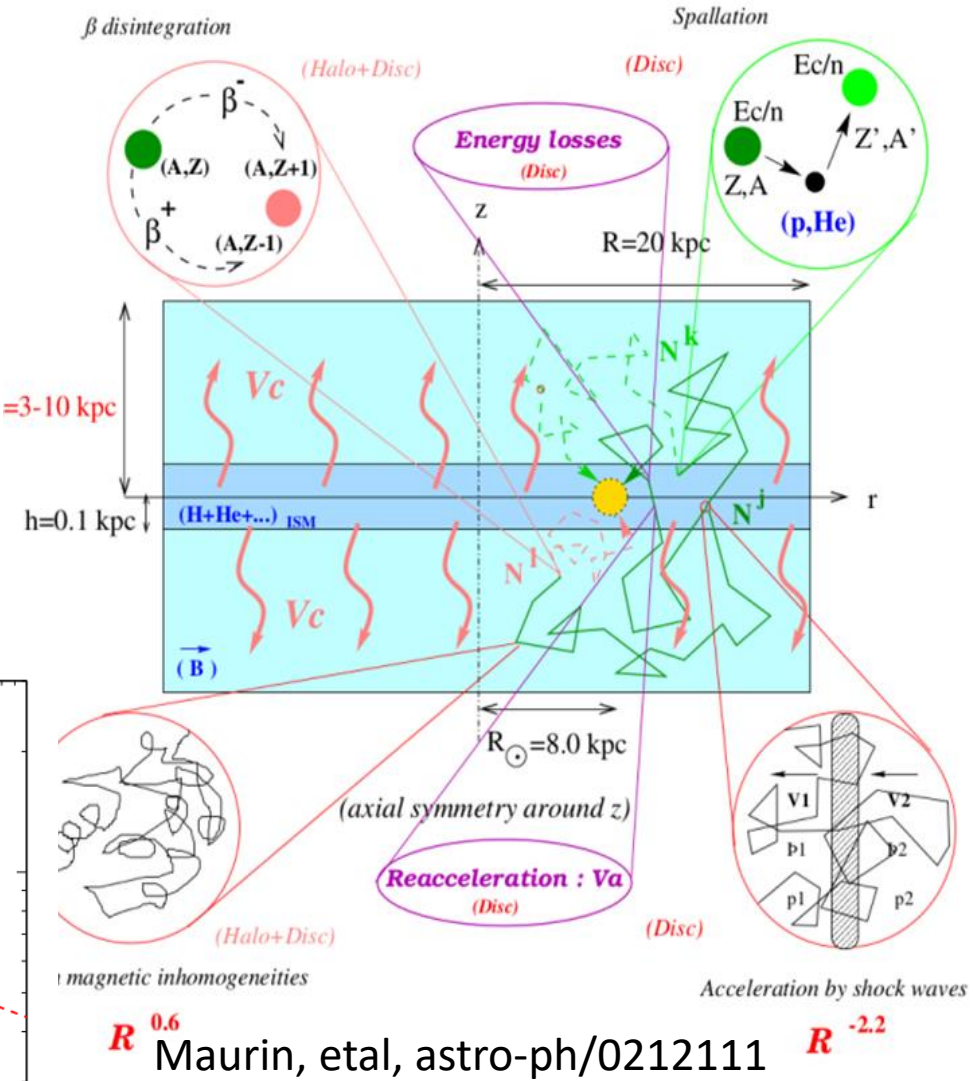
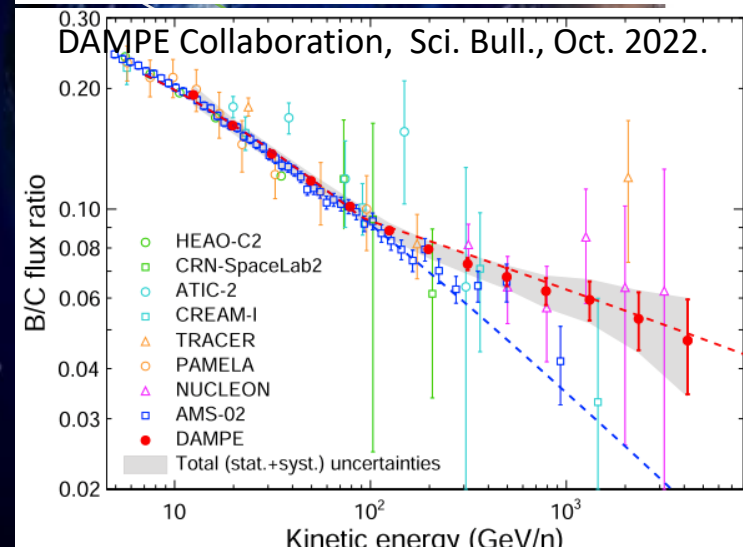
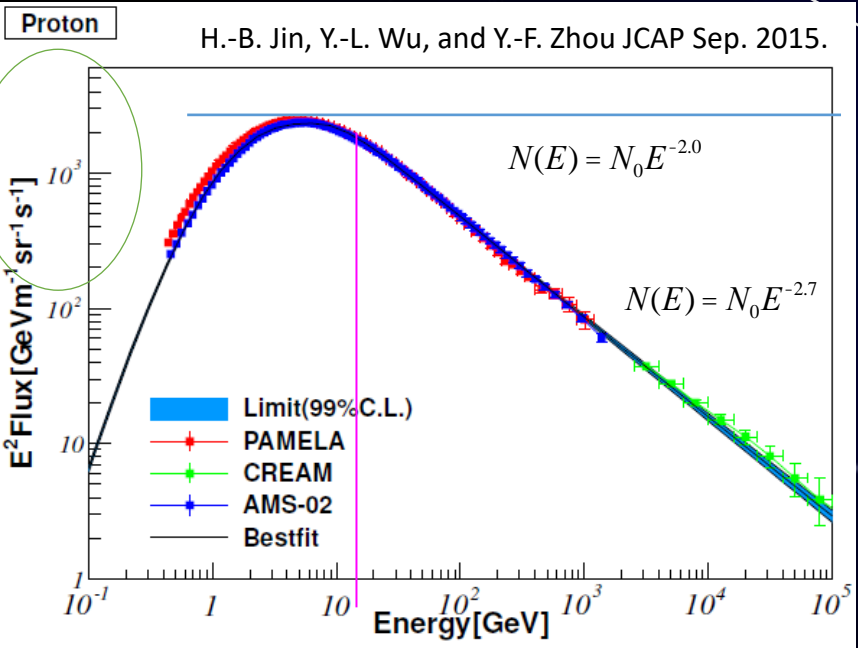
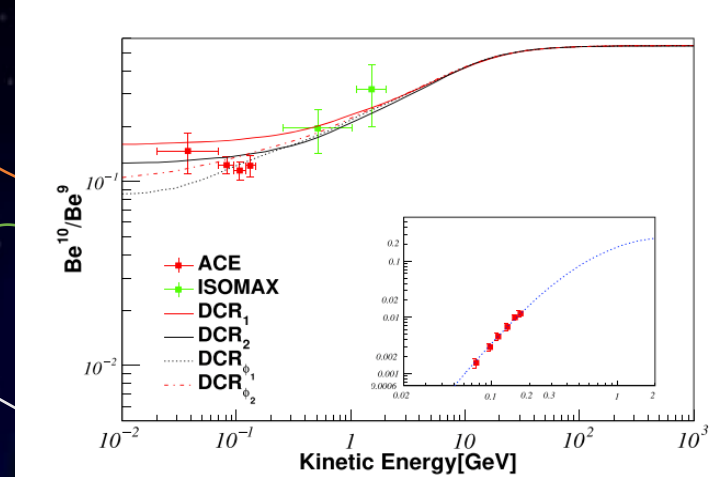
宇宙线的传播--宇宙线谱指数增加



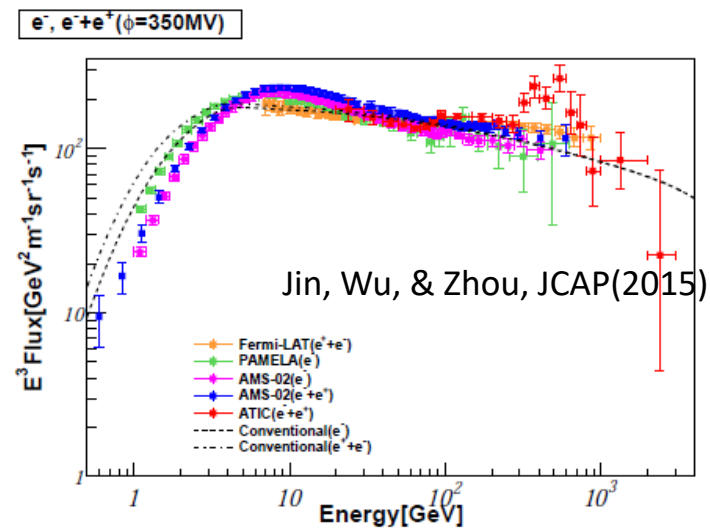
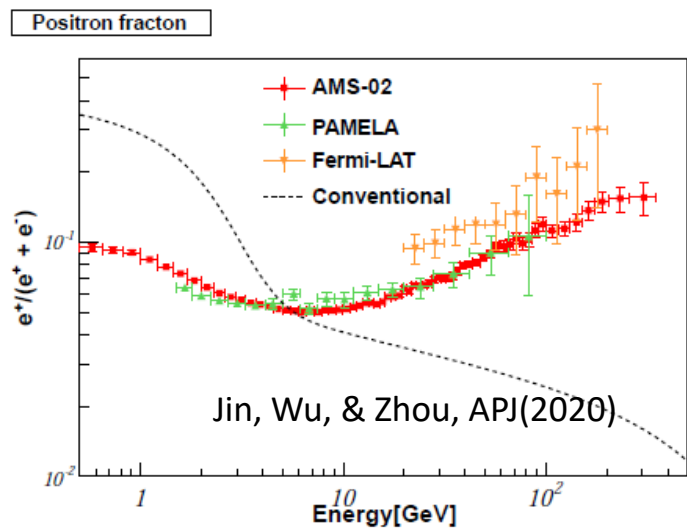
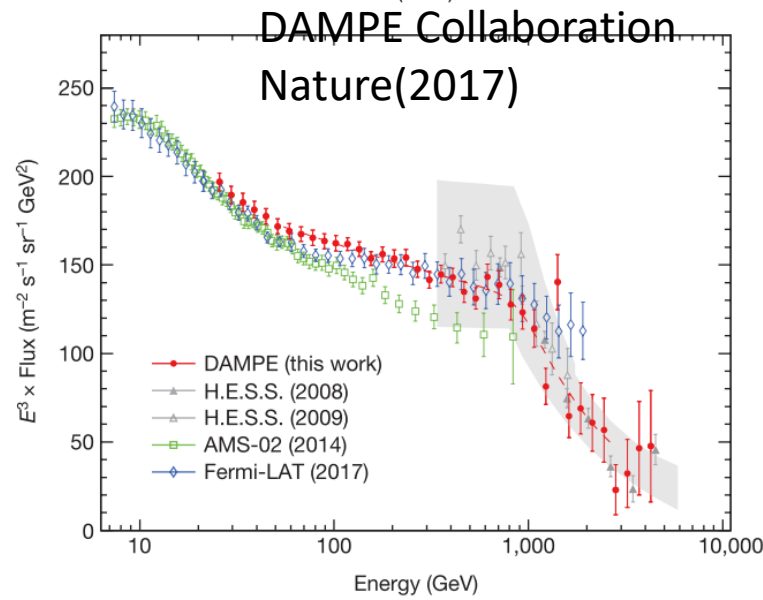
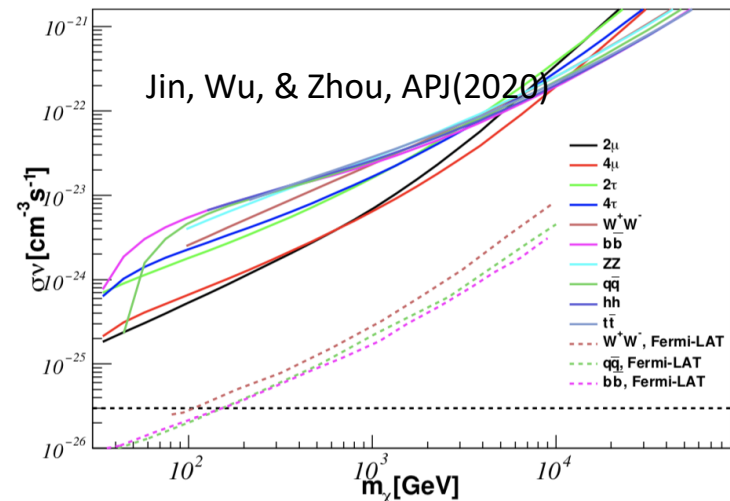
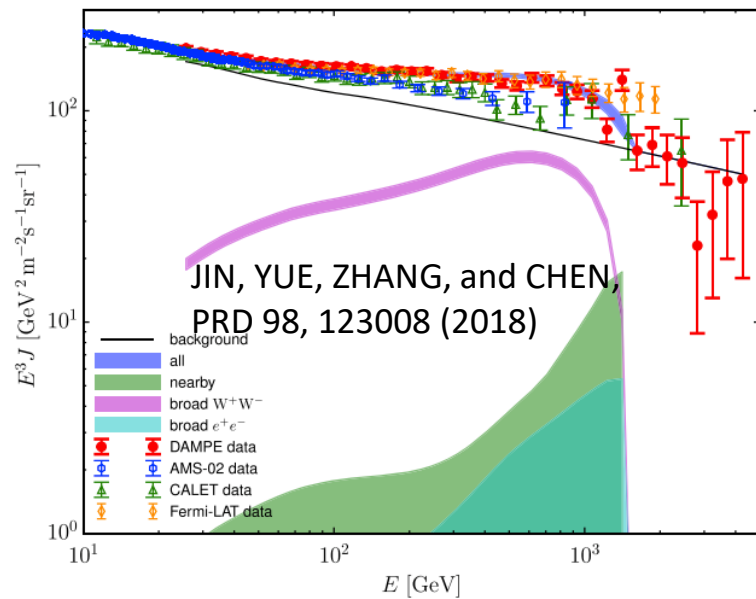
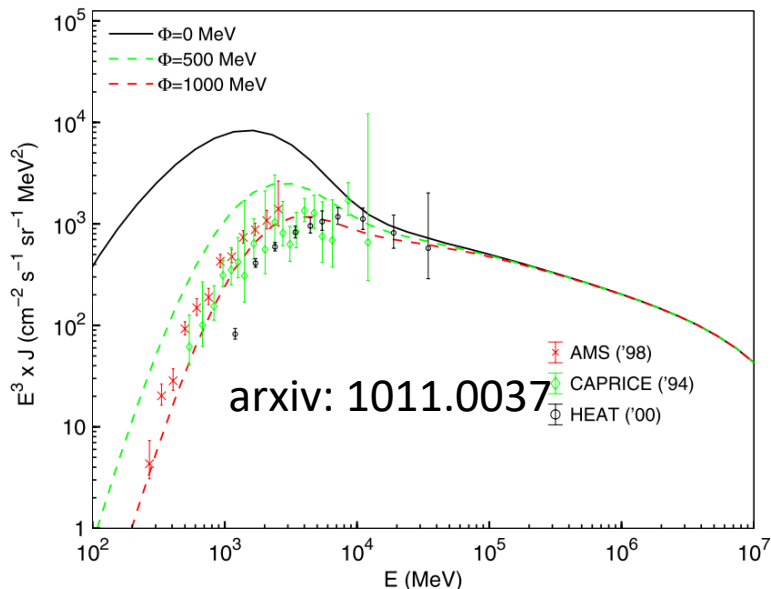
$$d_0 = -2.0$$

$$d = -(d_0 + d_{diffusion} + d_{convection} - d_{re-acceleration})$$

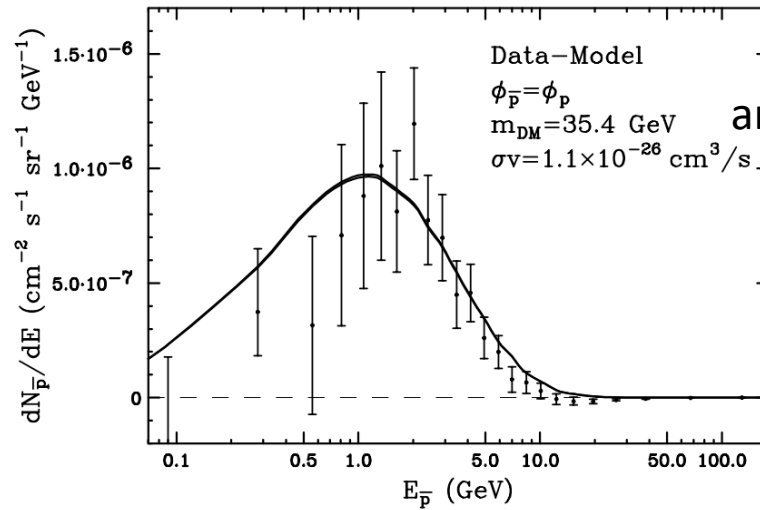
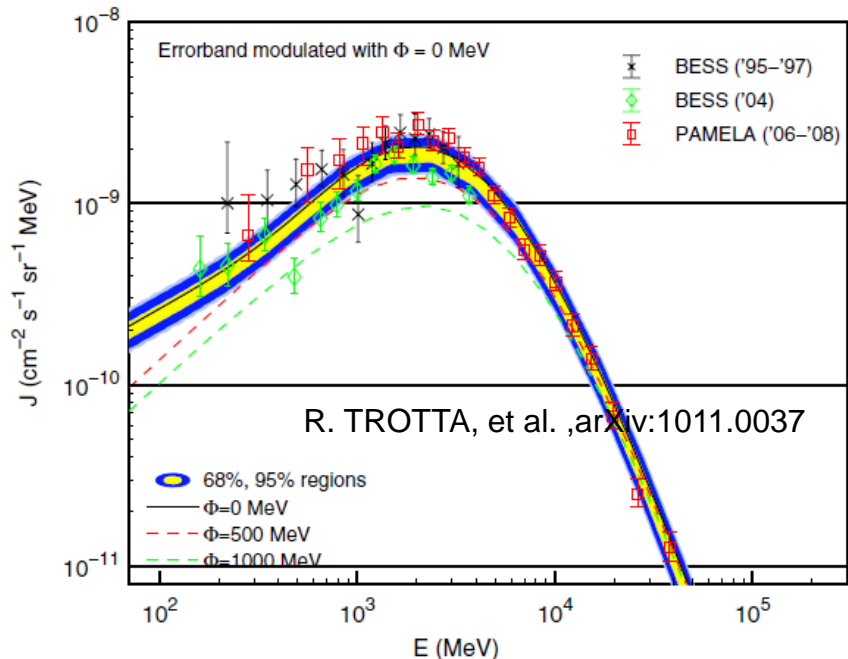
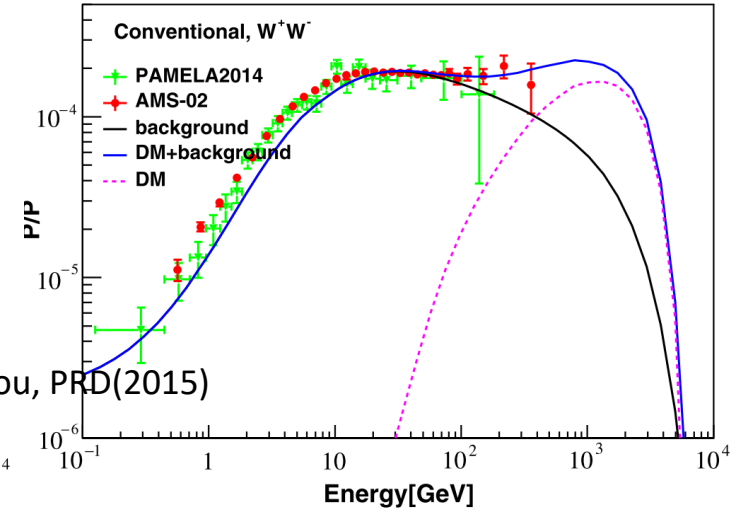
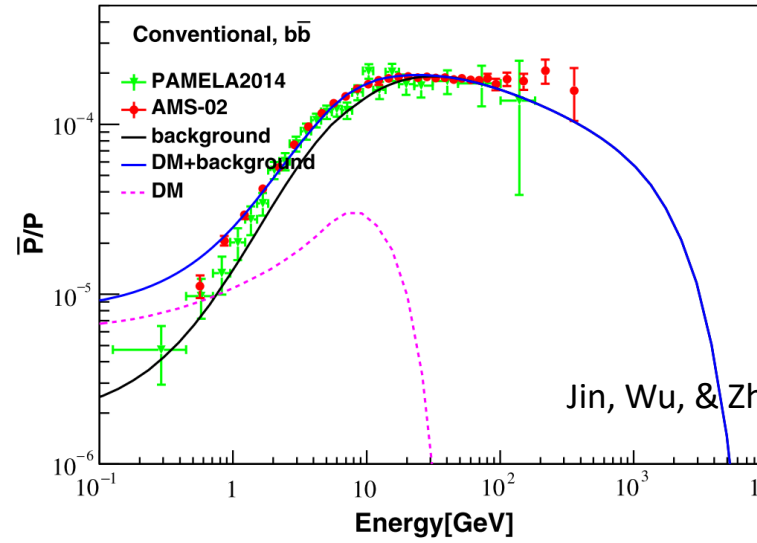
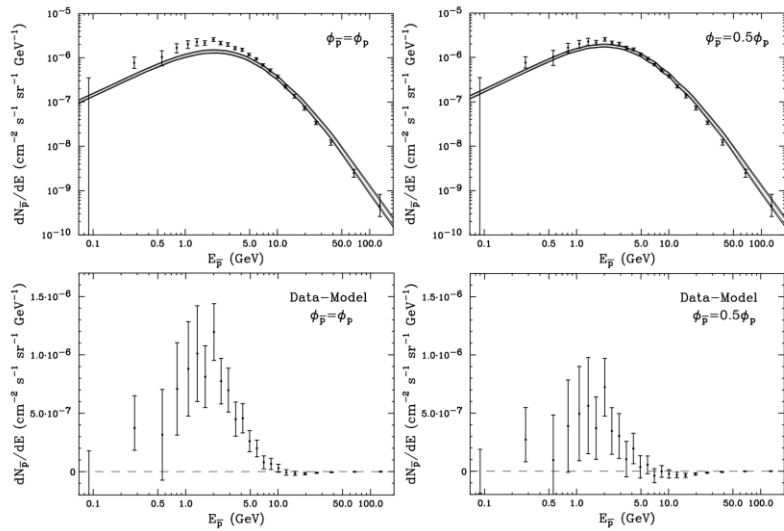
$$d = -2.7$$



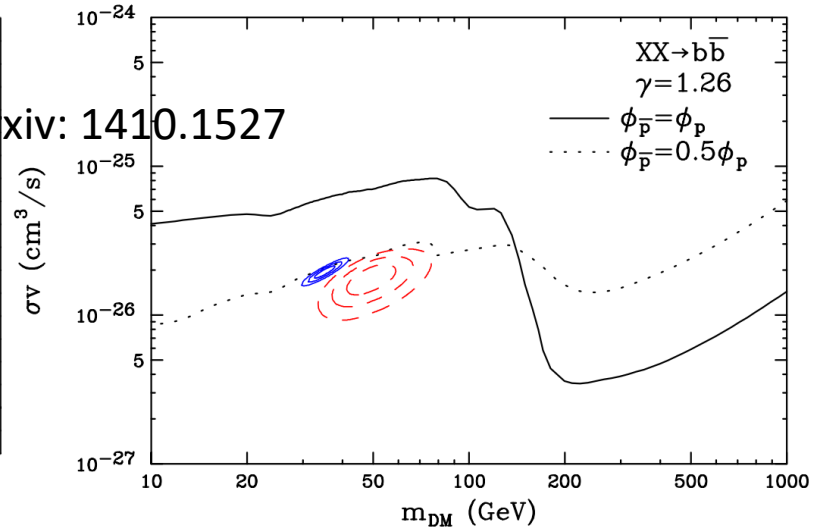
宇宙线研究的方向之一 正电子超出的暗物质解释



宇宙线研究的方向之一 反质子超出的暗物质解释

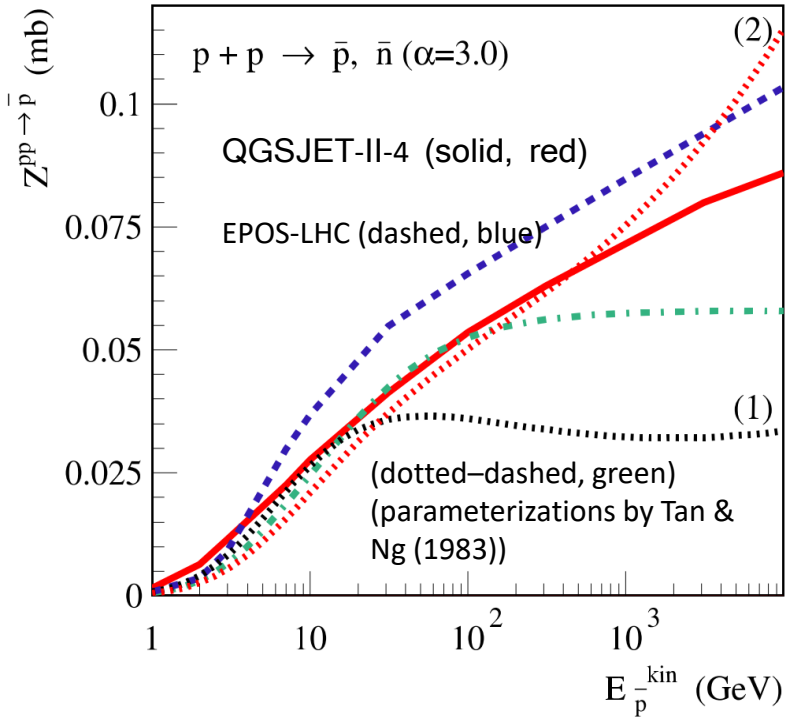


arxiv: 1410.1527

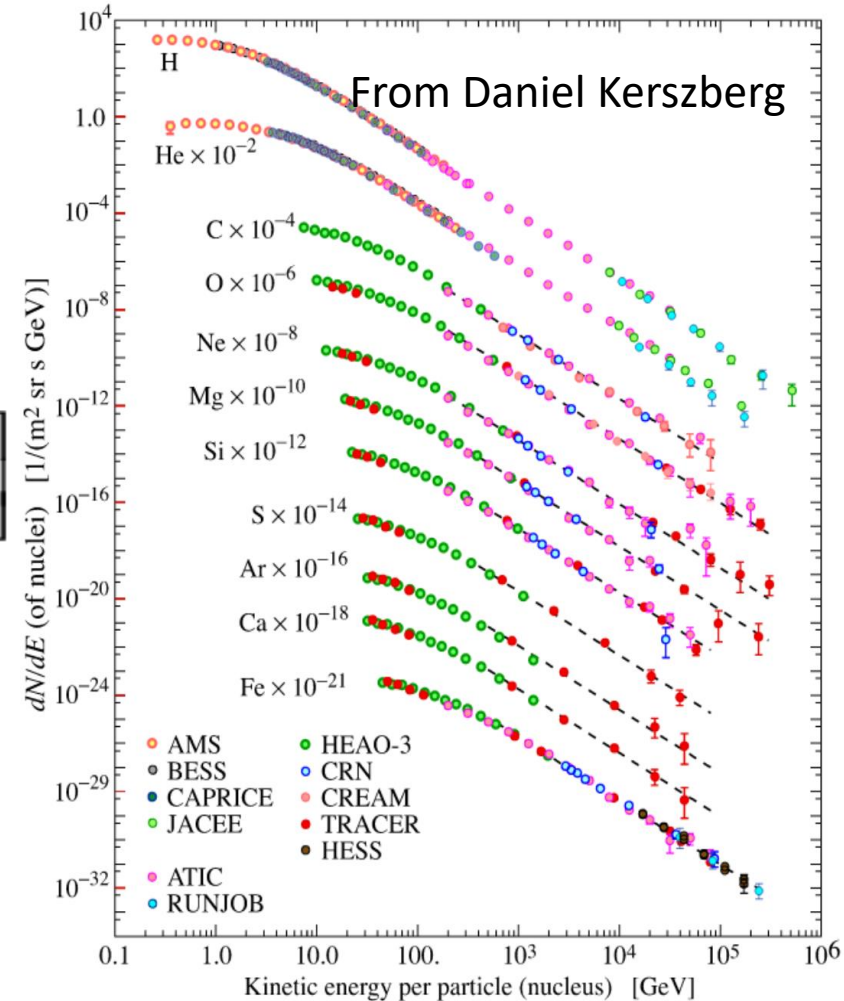


反质子超出的暗物质解释-强相互作用模型

$$q_{\bar{p},e^\pm}(p) = \frac{c}{4\pi} \frac{dn(p)}{dt} = \frac{c}{4\pi} \times \sum_{i=H,He} n_i \sum_j \int dp' \beta n_j(p') \frac{d\sigma_{ij}(E_{\text{tot}}, p')}{dE_{\text{tot}}}$$



$$q_A(R, z) = q_0 c_A \left(\frac{\rho}{\rho_{\text{br}}} \right)^{\gamma_s} \left(\frac{R}{R_\odot} \right)^\eta \times \exp \left[-\xi \frac{R - R_\odot}{R_\odot} - \frac{|z|}{0.2 \text{ kpc}} \right]$$



强相互作用模型-反质子产生的参数化

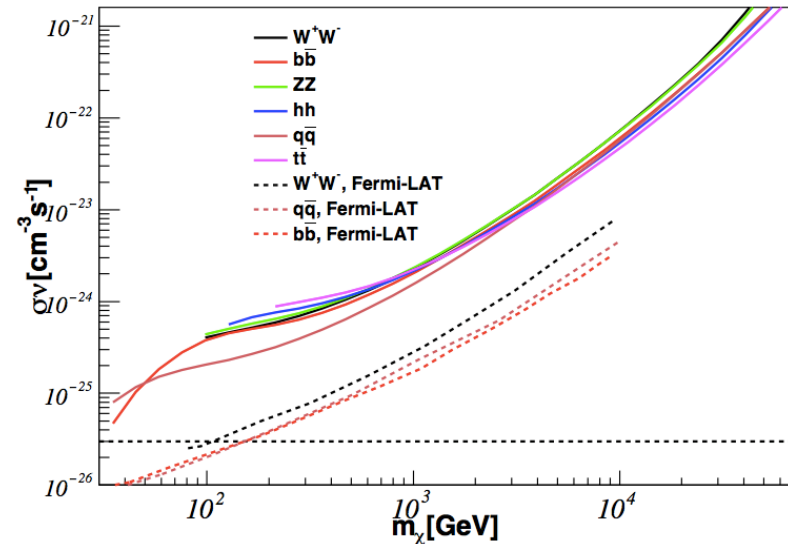
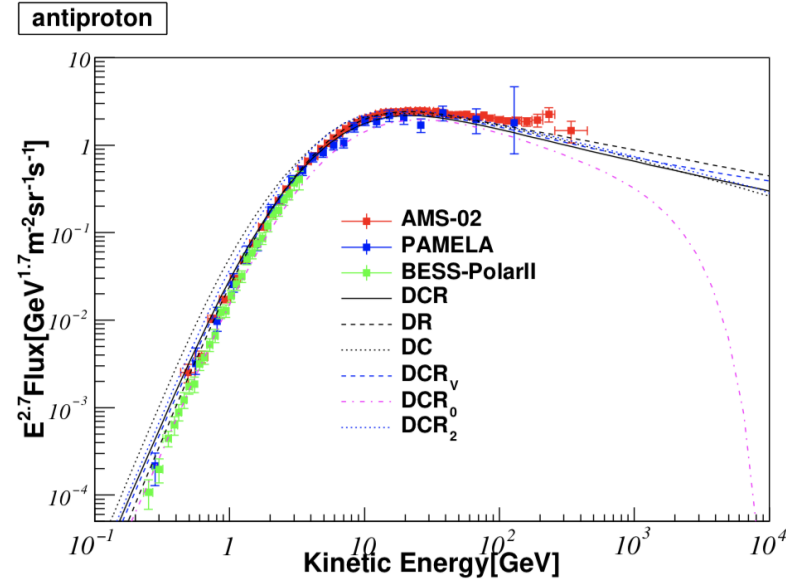
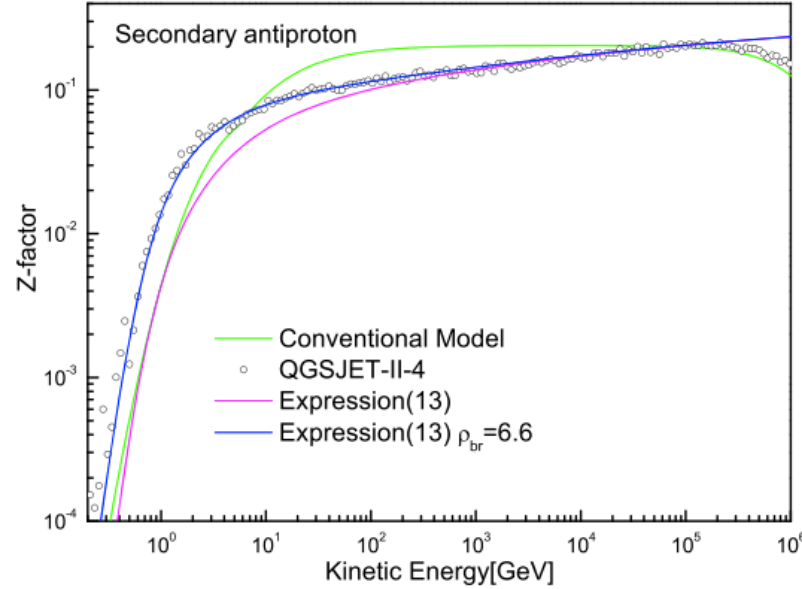
$$\sigma_j(\epsilon_{\bar{p}}, \gamma_j) = \gamma_j^{-6} \ln^{0.8} [0.16 \epsilon_{\bar{p}} (10 - \ln A_j) + 1] \left(1 + \frac{1}{\epsilon_{\bar{p}}} + \frac{a}{\epsilon_{\bar{p}}^3}\right)^{-2},$$

$$\gamma_j = \frac{\gamma_{2,j}}{1 + \frac{1}{12} \left(\frac{\rho_{br}}{E_{\bar{p}}}\right)^{\gamma_{2,j} - \gamma_{1,j}}}.$$

$$Z_{\bar{p}}^{ij}(\epsilon_{\bar{p}}, \gamma_j) = C^{ij} A_{gas}^i A_j \sigma_j(\epsilon_{\bar{p}}).$$

$$C^{ij} = \begin{cases} 9.44, & A_{gas}^i = 1 \\ 8.97, & A_{gas}^i = 4, A_j = 1 \\ 7.08, & A_{gas}^i = 4, A_j > 1 \end{cases}$$

$$q_{\bar{p}}(E_{\bar{p}}) = \sum_{i=H, He} n_i \sum_{j=1}^{A_{max}} I_j(E_{\bar{p}}) Z_{\bar{p}}^{ij}(E_{\bar{p}}, \gamma_j)$$



强相互作用模型-反质子湮灭截面在暗物质直接探测中的限制



暗物质湮灭源项:

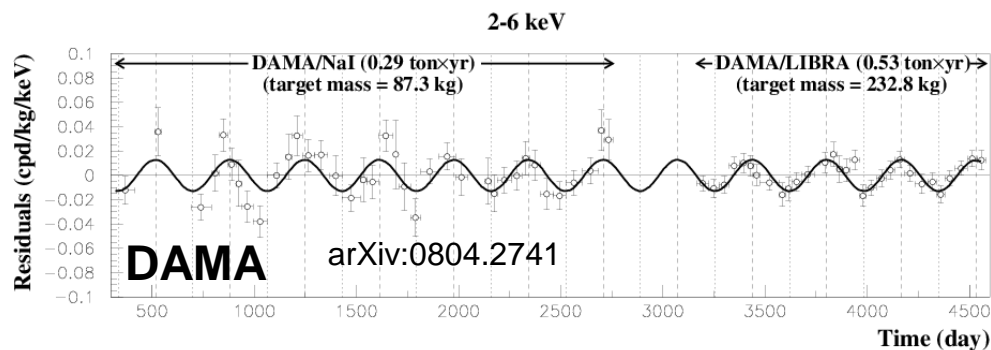
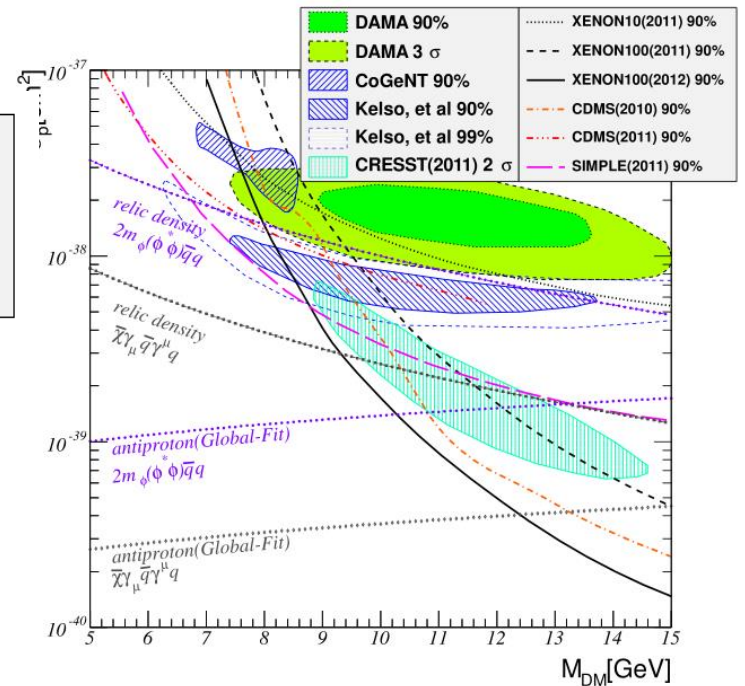
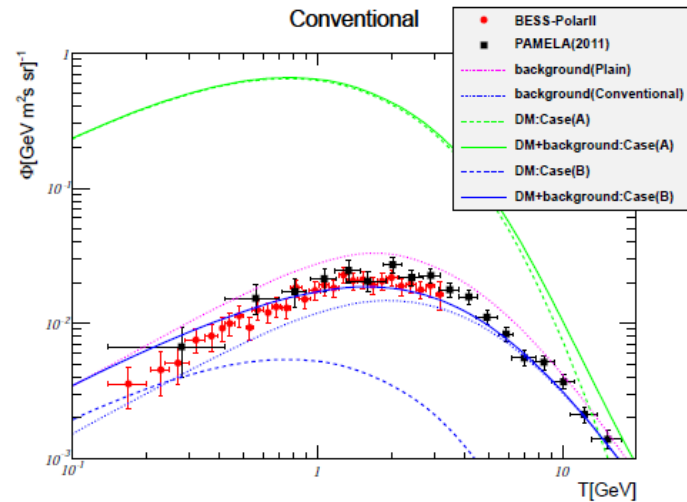
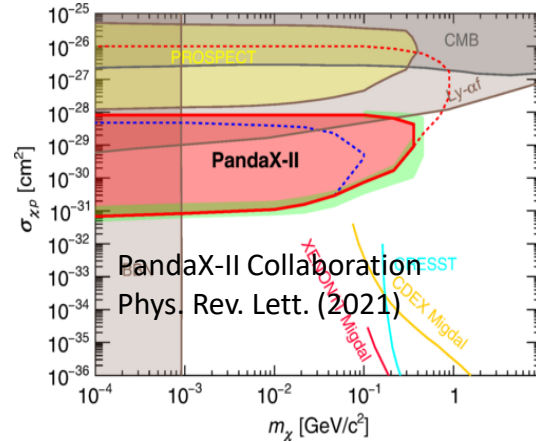
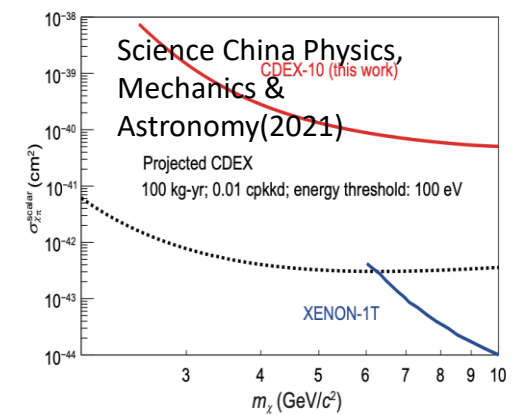
$$q(\mathbf{r}, p) = \frac{\rho(\mathbf{r})^2}{2m_\chi^2} \langle \sigma v \rangle \sum_X \eta_X \frac{dN^{(X)}}{dp}$$

$$\mathcal{L} = \sum_{i,q} a_{iq} \mathcal{O}_{iq}$$

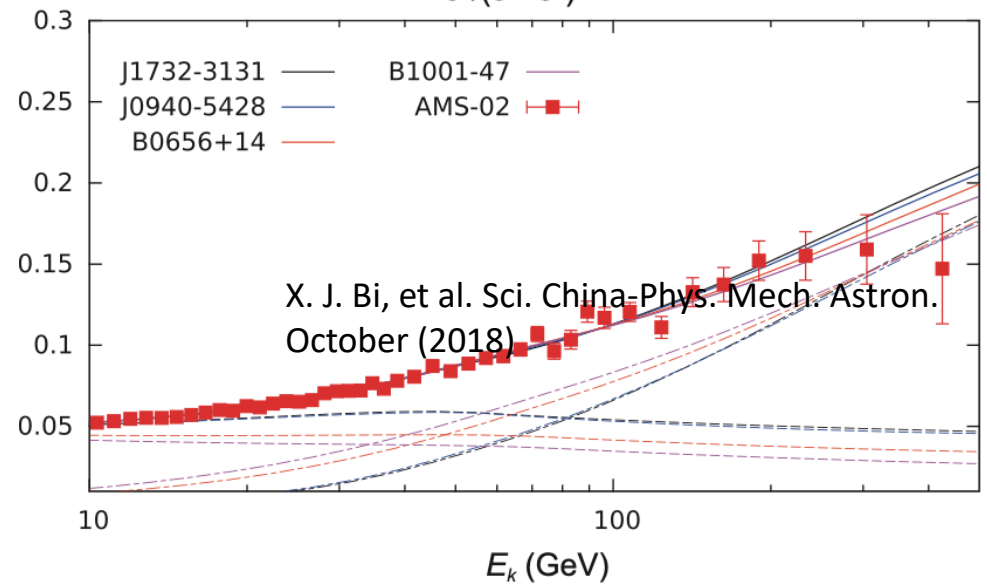
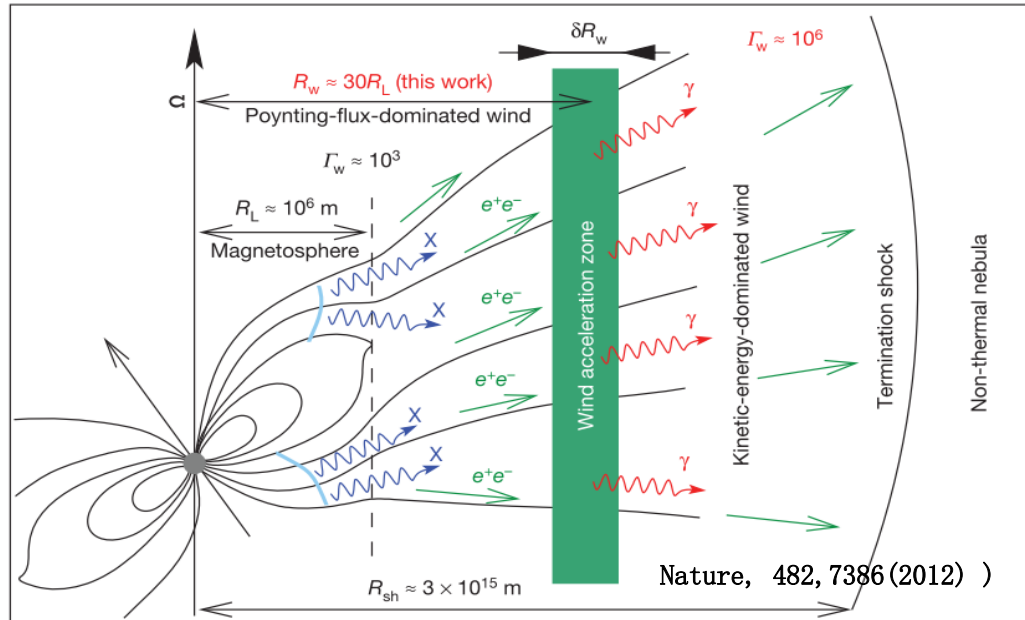
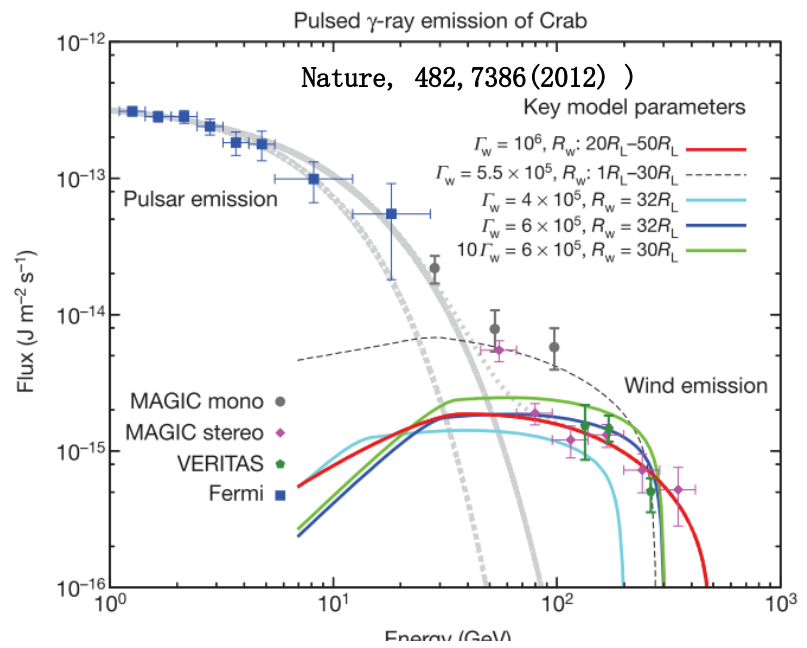
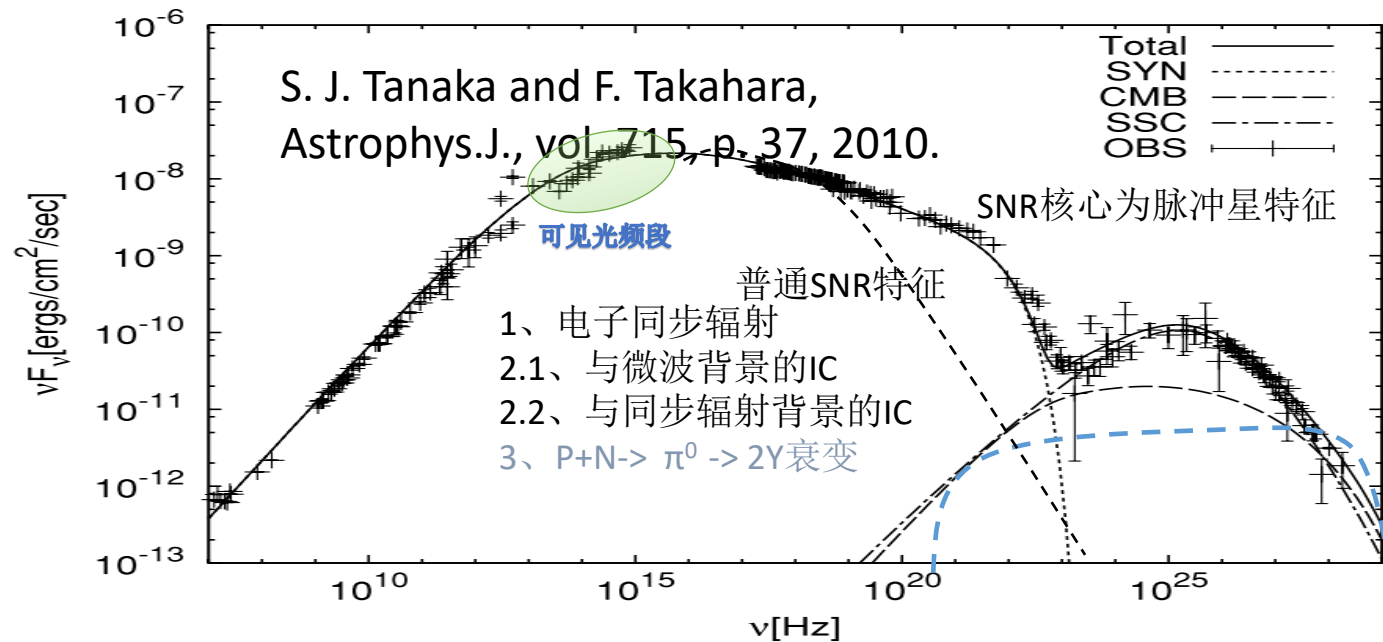
$$\mathcal{O}_{5q} = \bar{\chi} \gamma^\mu \chi \bar{q} \gamma_\mu q$$

$$f_{p(n)} = \sum_q B_{iq}^{p(n)} a_{iq}$$

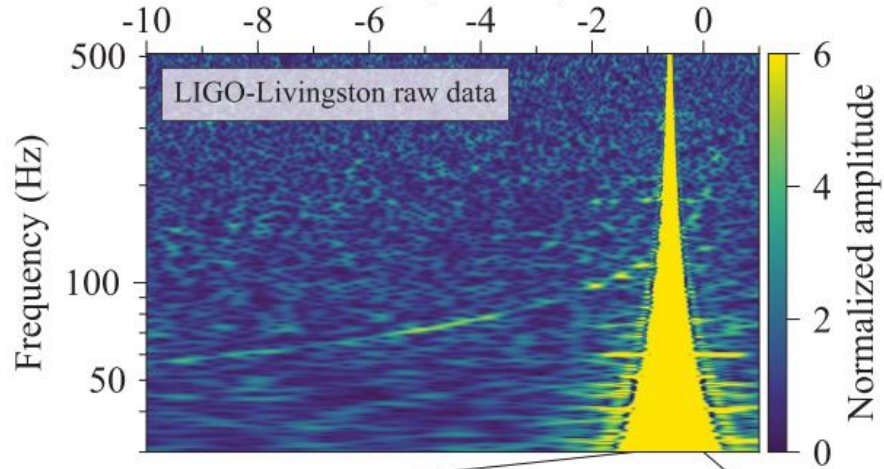
$$\sigma_{5q} v_{\text{rel}} (\bar{\chi} \chi \rightarrow \bar{q} q) = \frac{N_C m_\chi^2}{\pi} a_{5q}^2$$



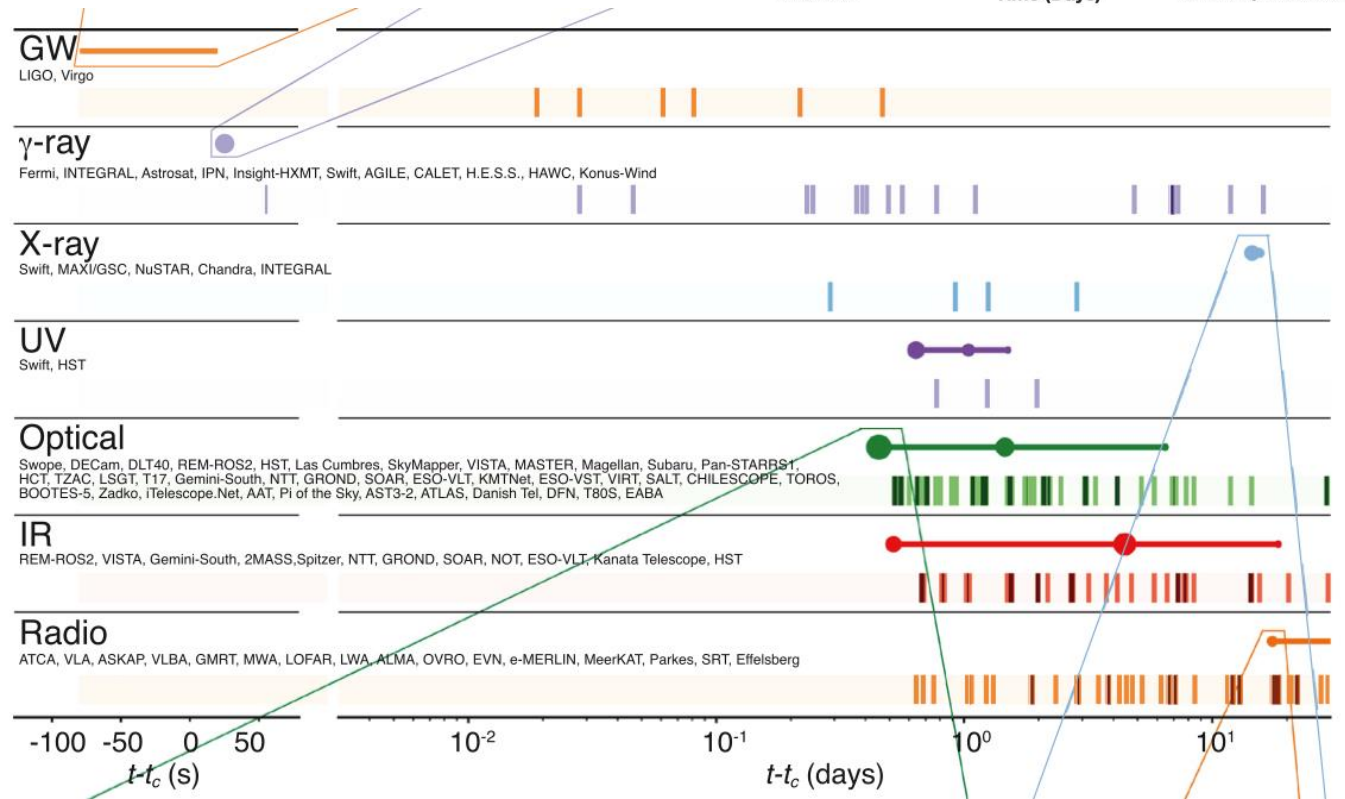
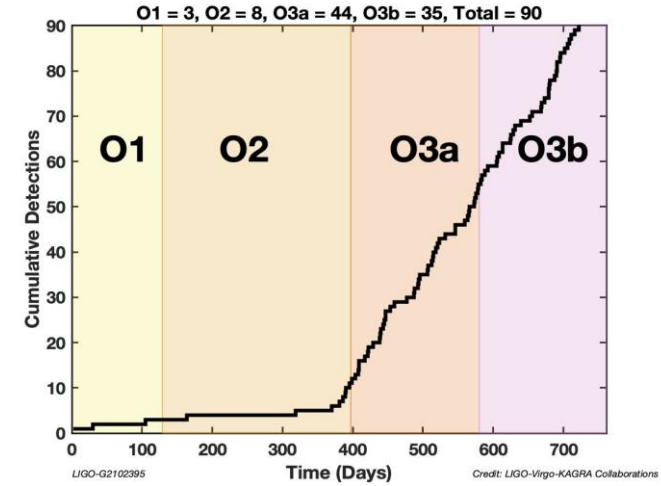
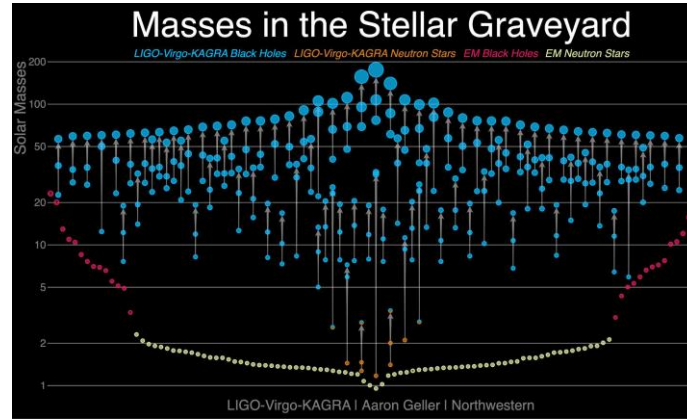
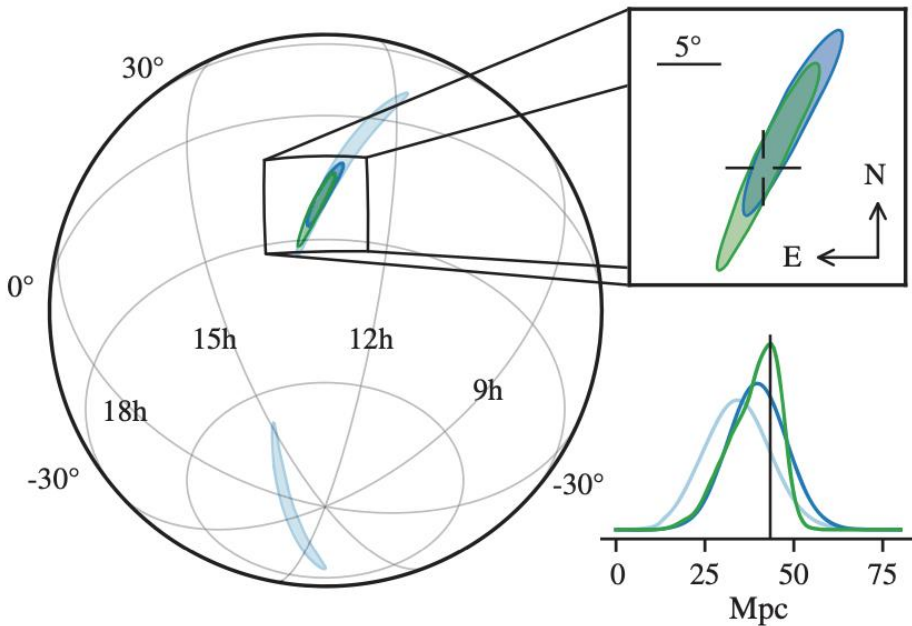
正电子超出的脉冲星解释



引力波发现后的脉冲星多信使研究

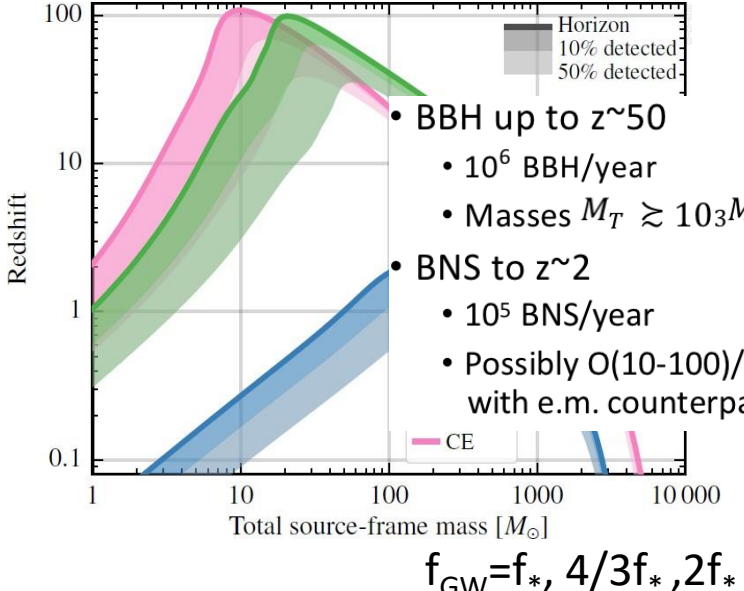
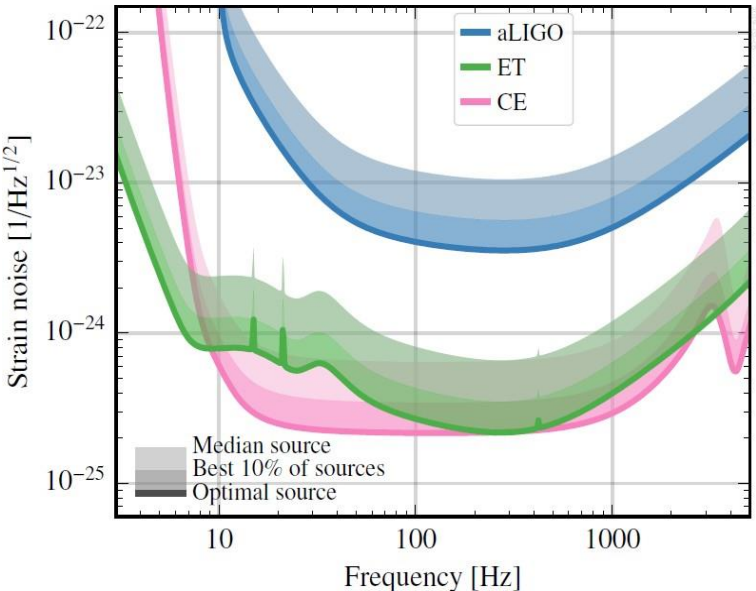


GW170817 PRL 119, 161101 (2017)

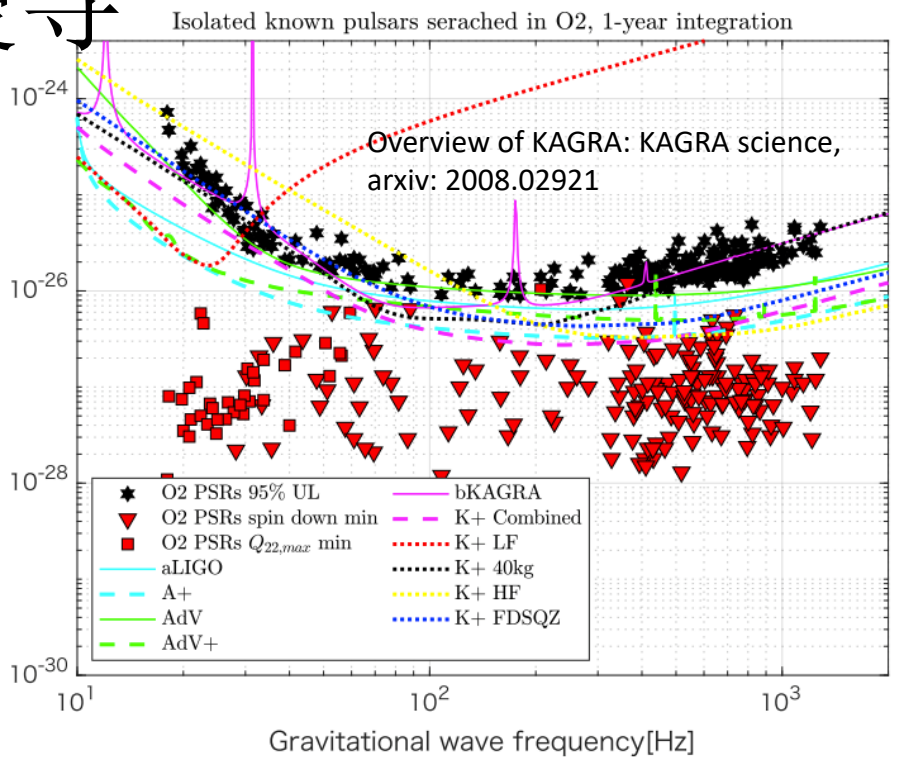


已发现脉冲星对应引力波辐射的搜寻

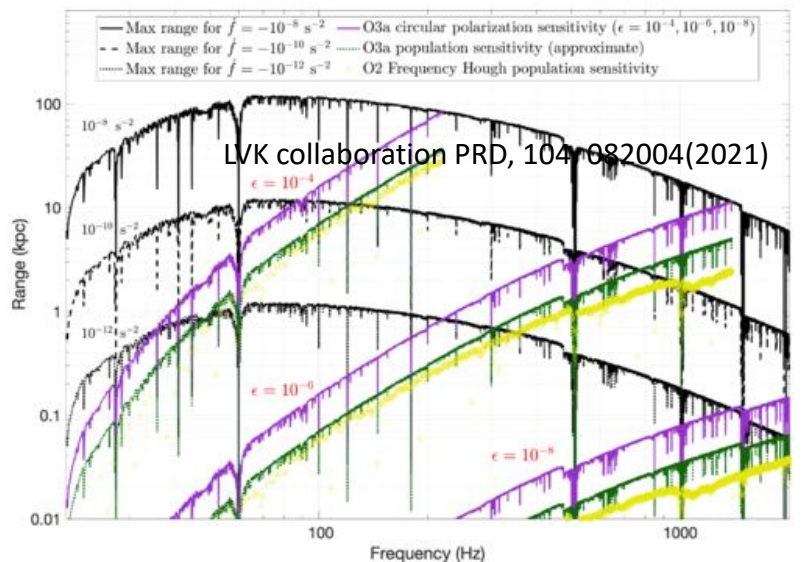
ET status <http://kiw8.org/>



- BBH up to $z \sim 50$
 - 10^6 BBH/year
 - Masses $M_T \gtrsim 10^3 M_\odot$
- BNS to $z \sim 2$
 - 10^5 BNS/year
 - Possibly $O(10-100)$ /year with e.m. counterpart



Pulsar name [J2000]	RA	DEC	Age [kyrs]	Distance Min/Max [kpc]	f_* Spin frequency
J0534 + 2200	05h34m31.973s	+22°00'52.06"	1.26	1.5/2.5	29.946923(1)
J0835 - 4510	08h35m20.61149s	-45°10'34.8751"	11.3	0.26/0.30	11.1946499395(5)
J1016 - 5857	10h16m21.16s	-58°57'12.1"	21	3.16/8.01	9.31216108951(13)
J1357 - 6429	13h57m02.43s	-64°29'30.2"	7.31	2.83/3.88	6.0201677725(5)
J1420 - 6048	14h20m08.237s	-60°48'16.43"	13	5.63	14.667084337(5)
J1513 - 5908	15h13m55.811s	-59°08'09.60"	1.57	3.6/5.7	6.59709182778(19)
J1718 - 3825	17h18m13.565s	-38°25'18.06"	89.5	3.49/3.60	13.39227352093(7)
J1826 - 1334	18h26m13.175s	-13°34'46.8"	21.4	3.61/3.93	9.85349875132(2)
J1831 - 0952	18h31m34.304s	-09°52'01.7"	128	3.68/4.05	14.8661645038(3)
J1849 - 0001	18h49m01.61s	-00°01'17.6"	43.1	7	25.961252072(9)



谢谢！

请各位专家指正！