



Constraints on cosmic-ray boosted DM with CDEX-10 data

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1. 背景简介

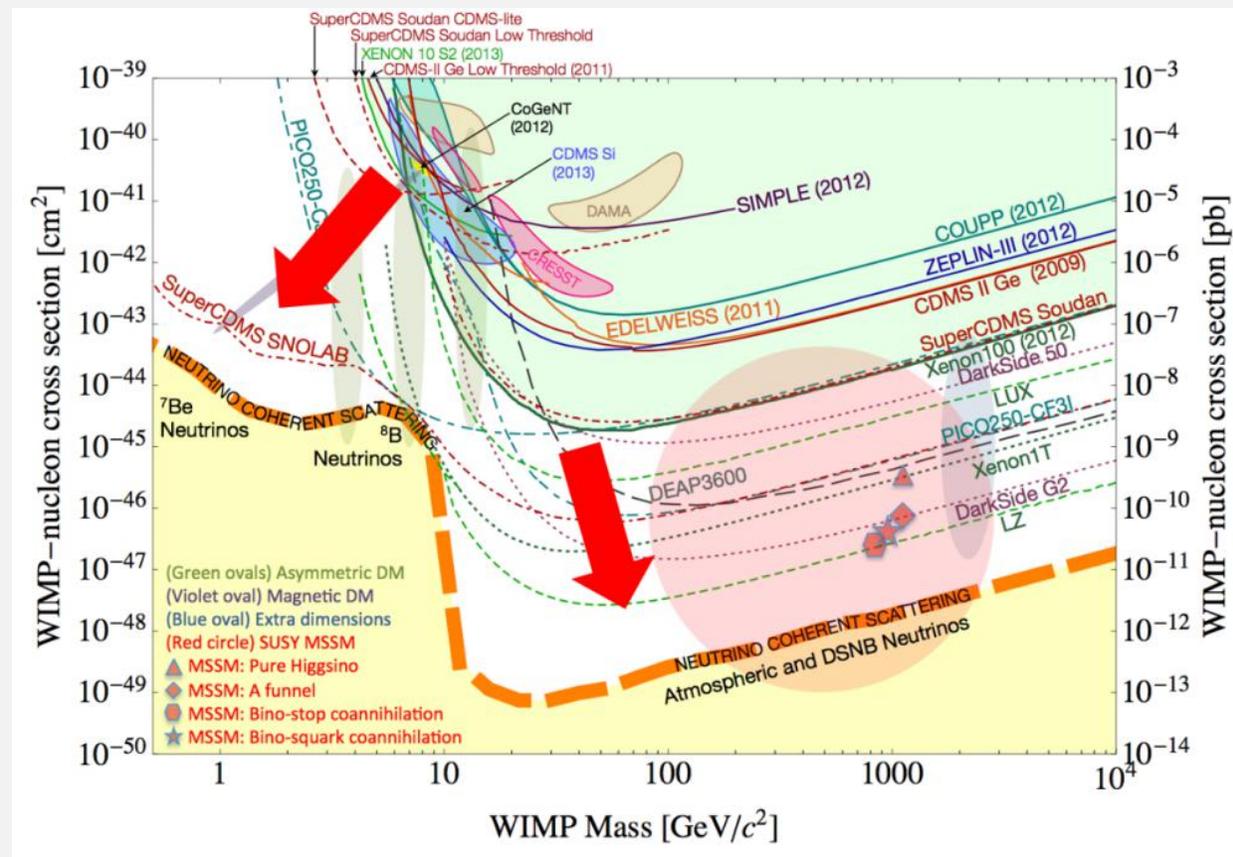
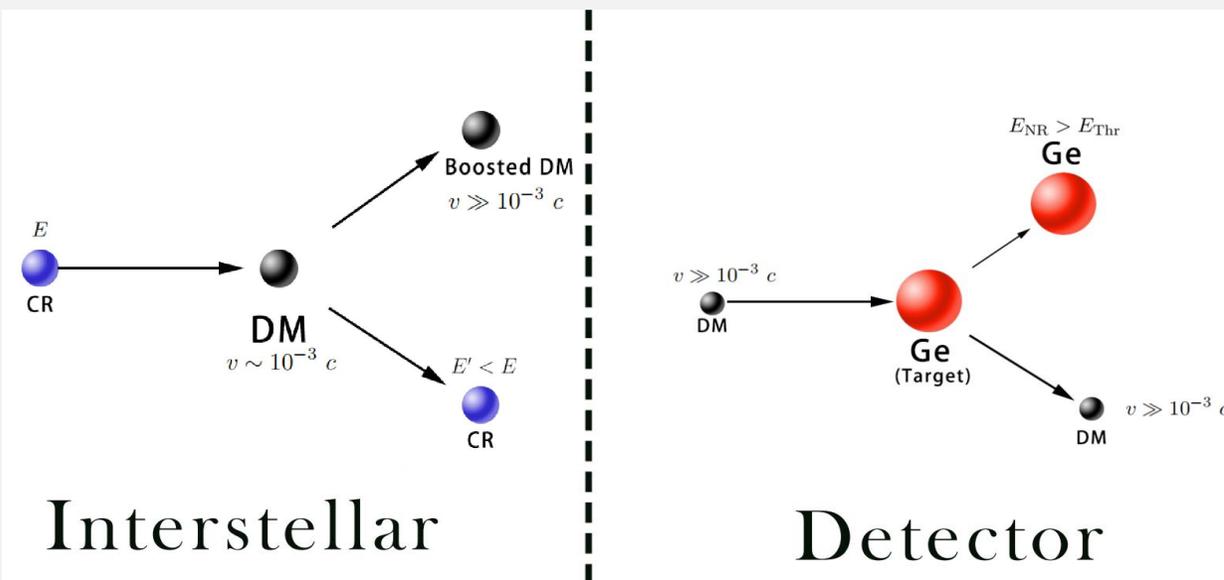


light DM

- $m_\chi \ll m_T$:
$$E_R = \frac{1}{2} m_\chi v^2 \times \frac{4m_\chi m_T}{(m_\chi + m_T)^2} \times \cos^2 \theta_R \propto m_\chi^2$$

- 阈值, 散射过程, 速度

- CRBDM arXiv : 1810.10543

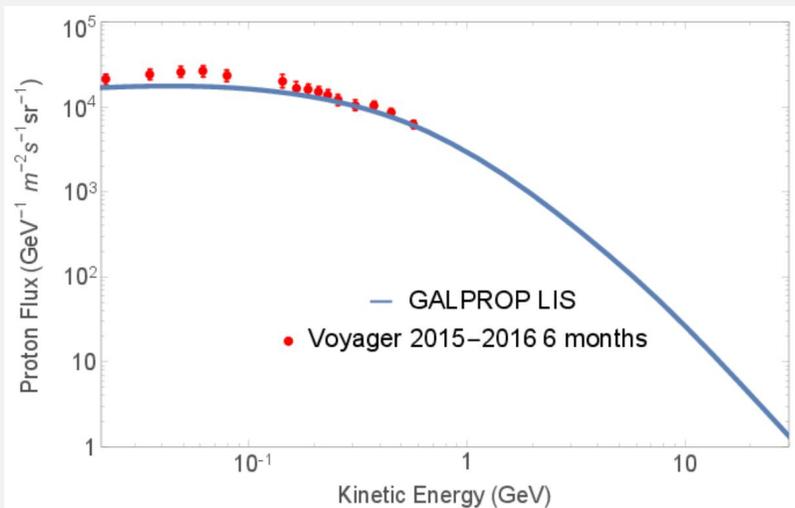




2. CRBDM 模型

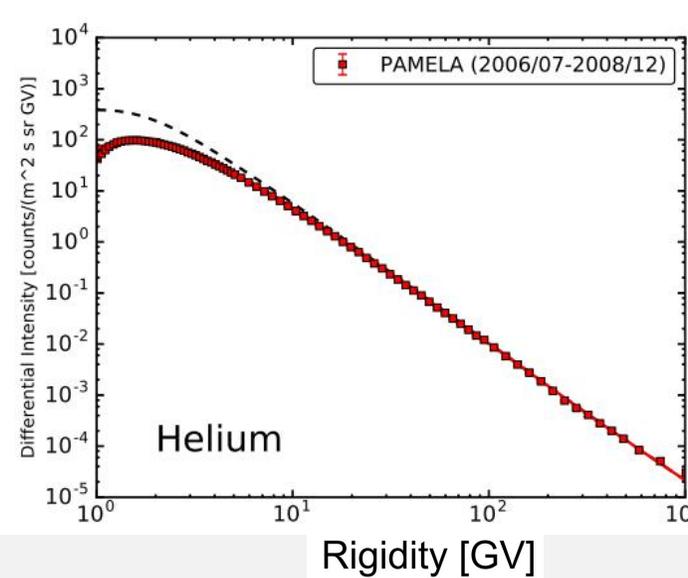
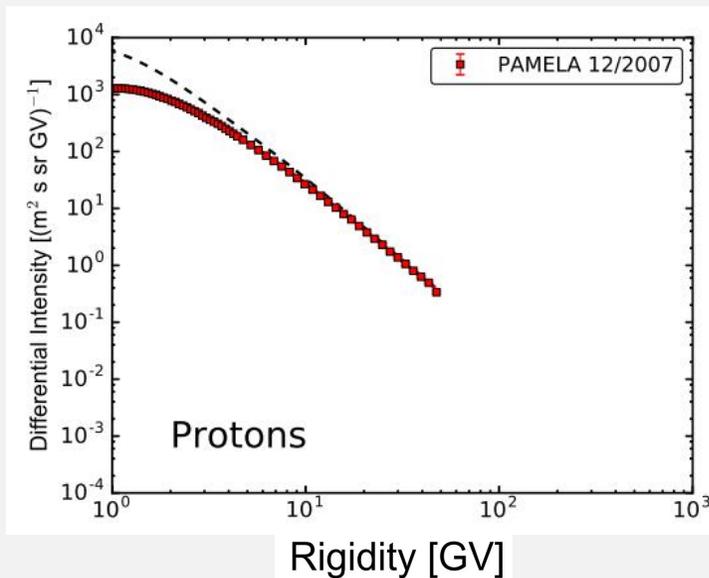


2. Cosmic-ray spectrum



- 一个说法是CR起源于超新星遗迹
- 通过扩散方程描述CR的传播与各向同性
- 能谱数据点来自PAMELA卫星
- 能谱具有幂次律，指数为-2.7

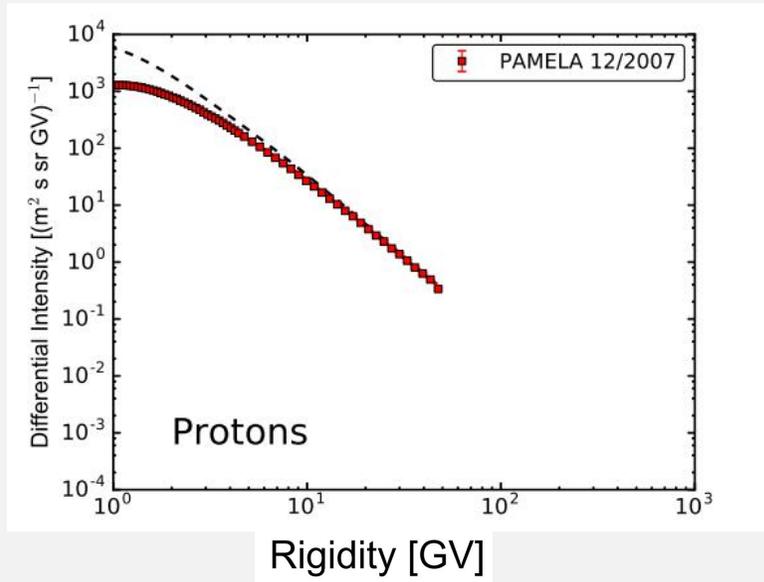
$$\frac{d\Phi_i}{dR} \times R^{2.7} = \begin{cases} \sum_{i=0}^5 a_i R^i & R \leq 1 \text{ GV} \\ b + \frac{c}{R} + \frac{d_1}{d_2 + R} + \frac{e_1}{e_2 + R} + \frac{f_1}{f_2 + R} + gR & R > 1 \text{ GV} \end{cases}$$



arXiv : 1701.02363

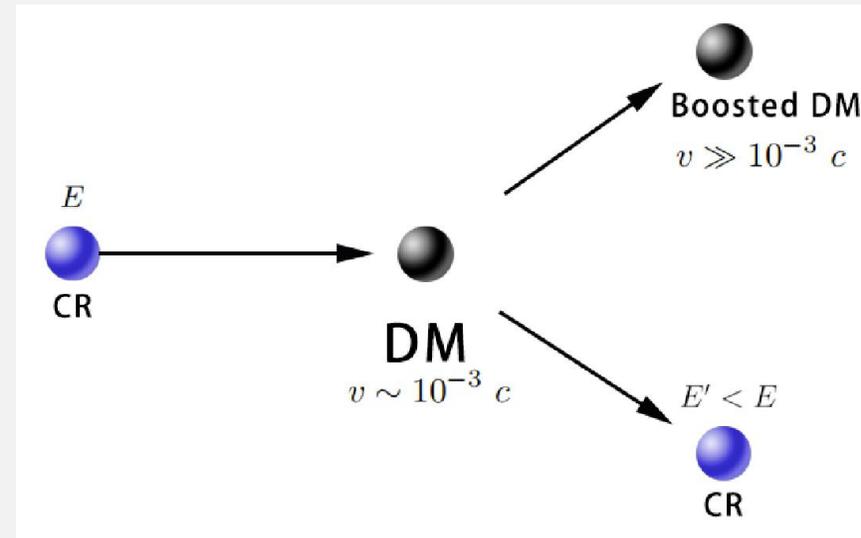
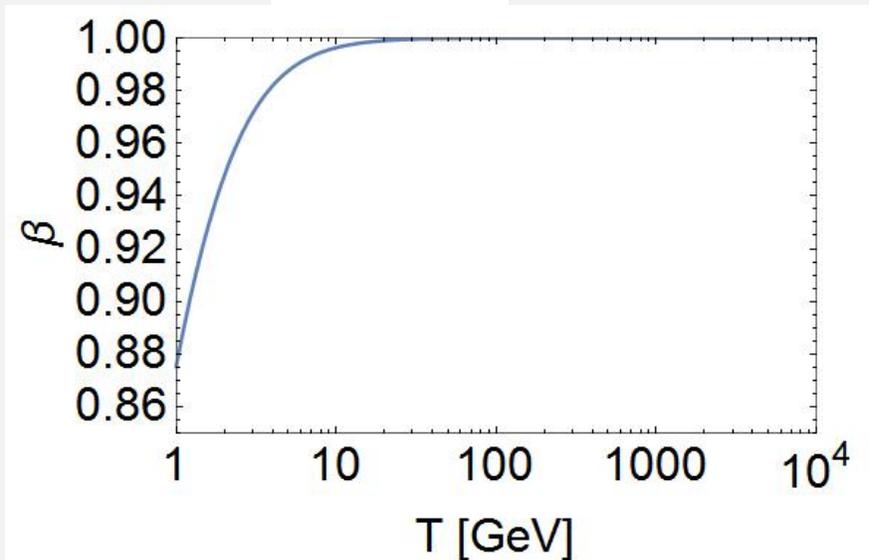


3. Elastic scattering



- 宇宙射线中的高能粒子接近光速，需要考虑相对论修正

$$T_{\chi} = \frac{T_i^2 + 2m_i T_i}{T_i + \frac{(m_i + m_{\chi})^2}{2m_{\chi}}} \frac{1 + \cos \theta}{2}$$

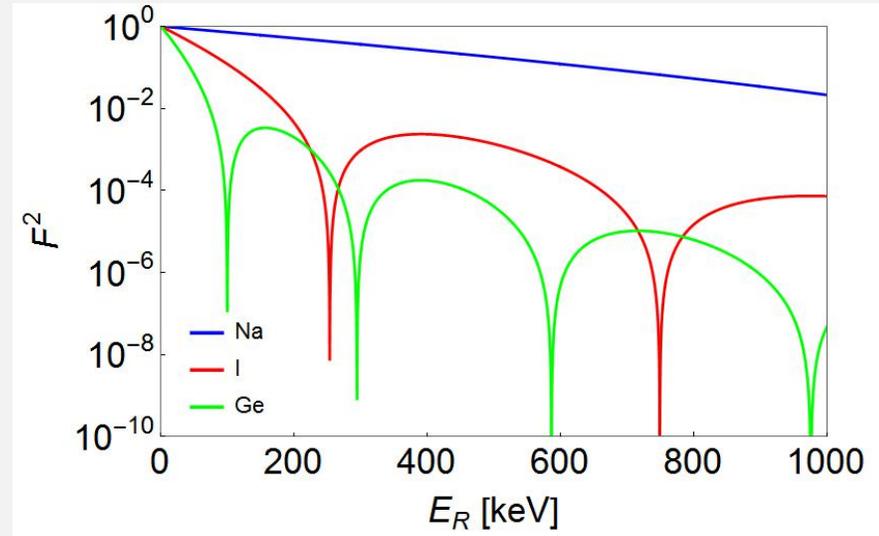




3. Cross section

- 粒子相互碰撞时，若交换的动量越大，也可以理解为两个粒子更加接近导致原子核的形状开始产生影响
- 对于比较小的能动能量交换采用Helm的形式

$$F(qr_n) = 3 \frac{j_1(qr_n)}{qr_n} e^{-(qd)^2/2}$$



- 对于比较大的能动能量交换采用偶极子形式：

$$G_i(2m_\chi T_\chi) = \frac{1}{(1 + 2m_\chi T_\chi / \Lambda_i^2)^2}$$

$$\Lambda_{He} = 410 MeV$$

$$\Lambda_p = 770 MeV$$

- 各向同性散射

$$\frac{d\sigma_{\chi i}}{dT_\chi} = \frac{\sigma_{\chi i}^0}{T_\chi^{max}} G_i^2(2m_\chi T_\chi)$$



3. DM flux

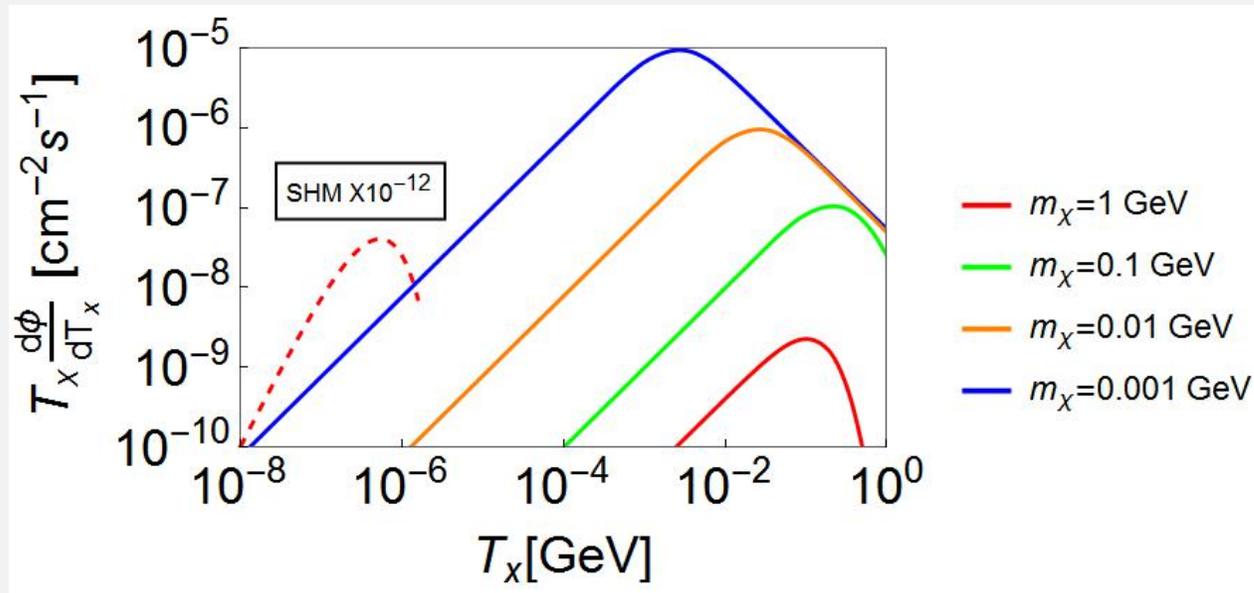
碰撞频率：

$$d\Gamma_{CR \rightarrow \chi} = \sum_i \frac{\rho_\chi}{m_\chi} \times \frac{d\sigma_{\chi i}^0}{dT_\chi} G_i^2(2m_\chi T_\chi) \times \frac{d\Phi_i}{dT_i} dT_i dT_\chi dV$$

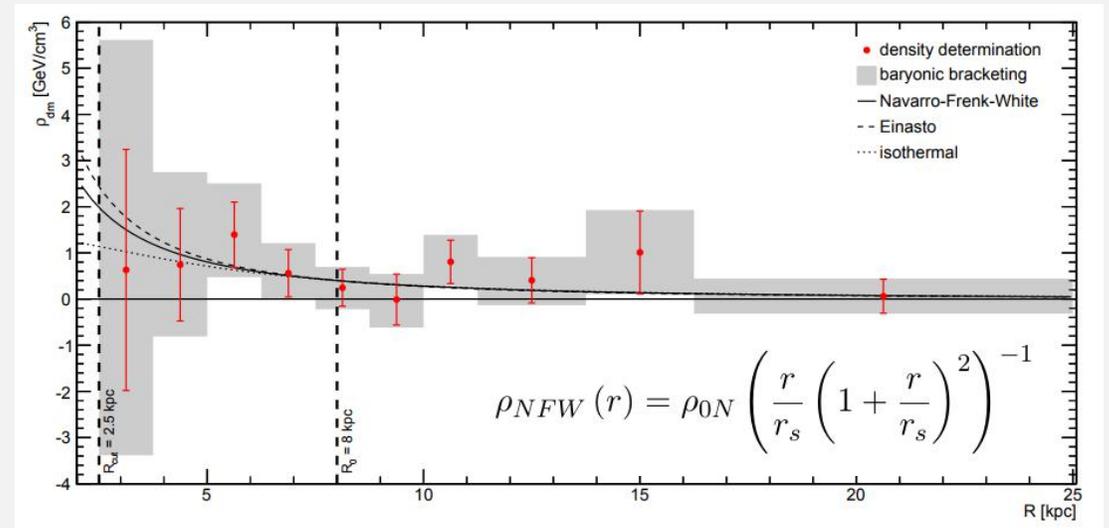
DM 散射 CR

积分：

$$\frac{d\Phi_\chi}{dT_\chi} = D_{\text{eff}} \frac{\rho_{\chi 0}}{m_\chi} \sum_i \sigma_{\chi i} \int_{T_i^{\text{min}}}^{\infty} \frac{d\Phi_i}{dT_i} \frac{1}{T_\chi^{\text{max}}(T_i)} dT_i \quad D_{\text{eff}} = \frac{\int \rho_\chi dl}{\rho_{\chi 0}}$$



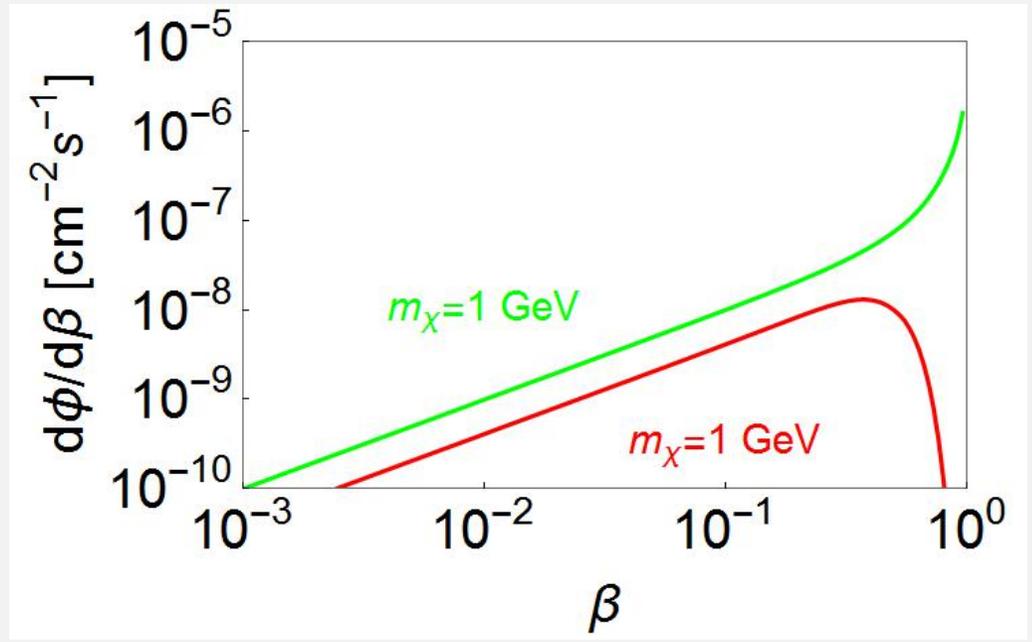
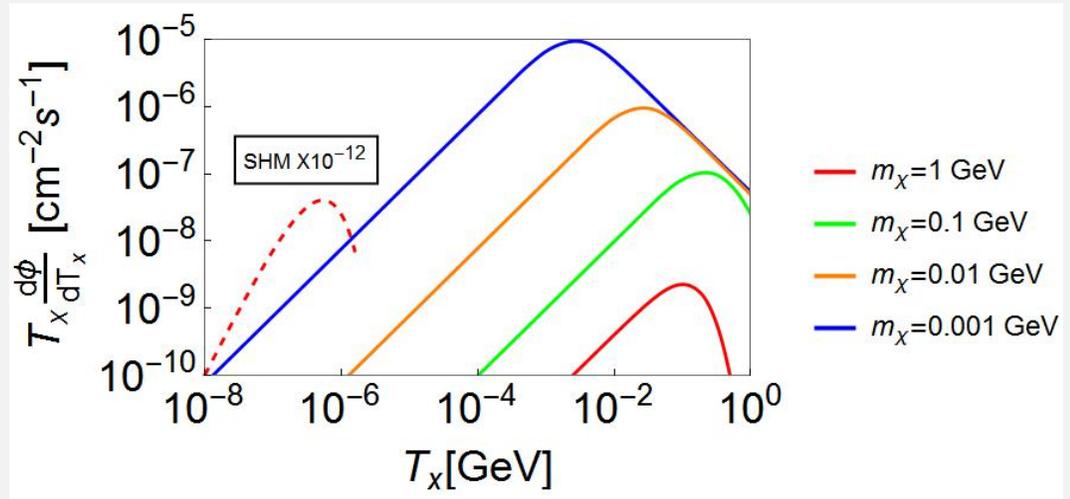
• 暗物质分布采用NFW形式 arXiv : 1504.03317



• CR分布采用均匀形式



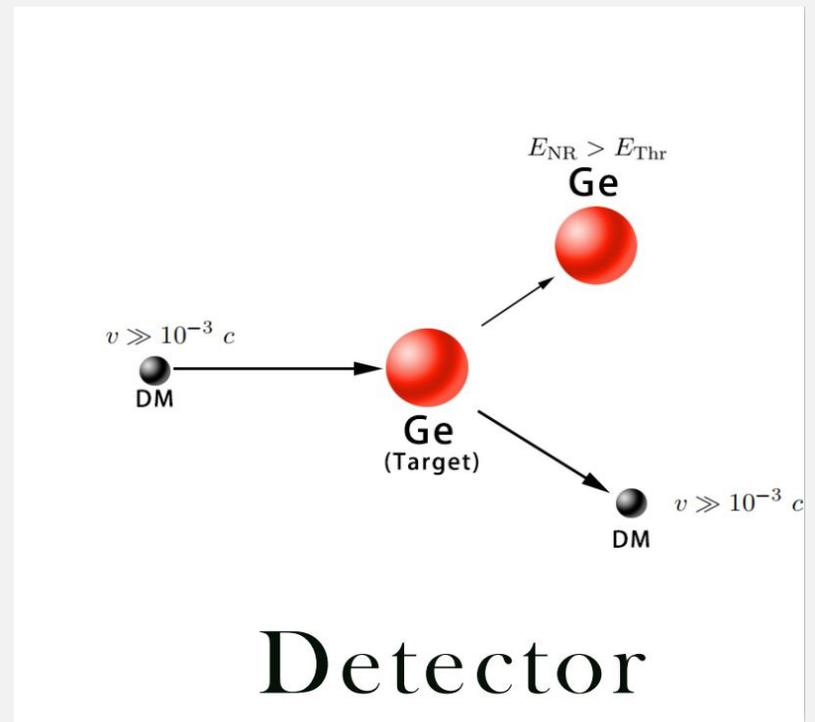
3. DM flux



- DM质量越小，交换能量越小，但数密度加大导致束流强度加大

$$T_\chi = \frac{T_i^2 + 2m_i T_i}{T_i + \frac{(m_i + m_\chi)^2}{2m_\chi}} \frac{1 + \cos \theta}{2} \rightarrow T_\chi / m_\chi \sim \frac{T_i^2 + 2m_i T_i}{m_i^2}$$

- 玻尔兹曼速度分布的束流比较靠近低能区，束流强度大



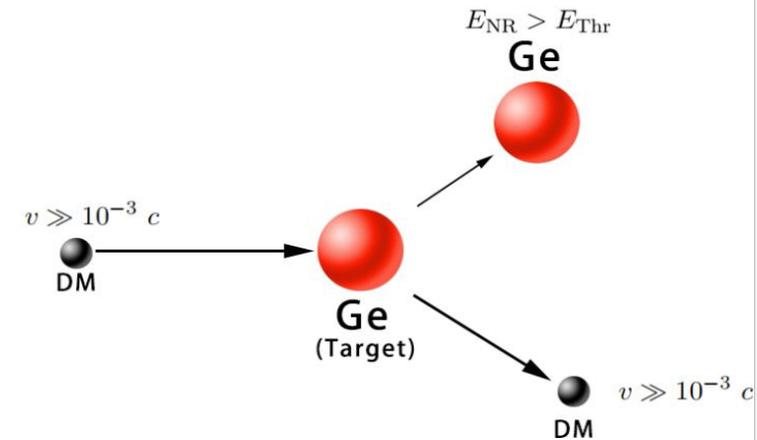
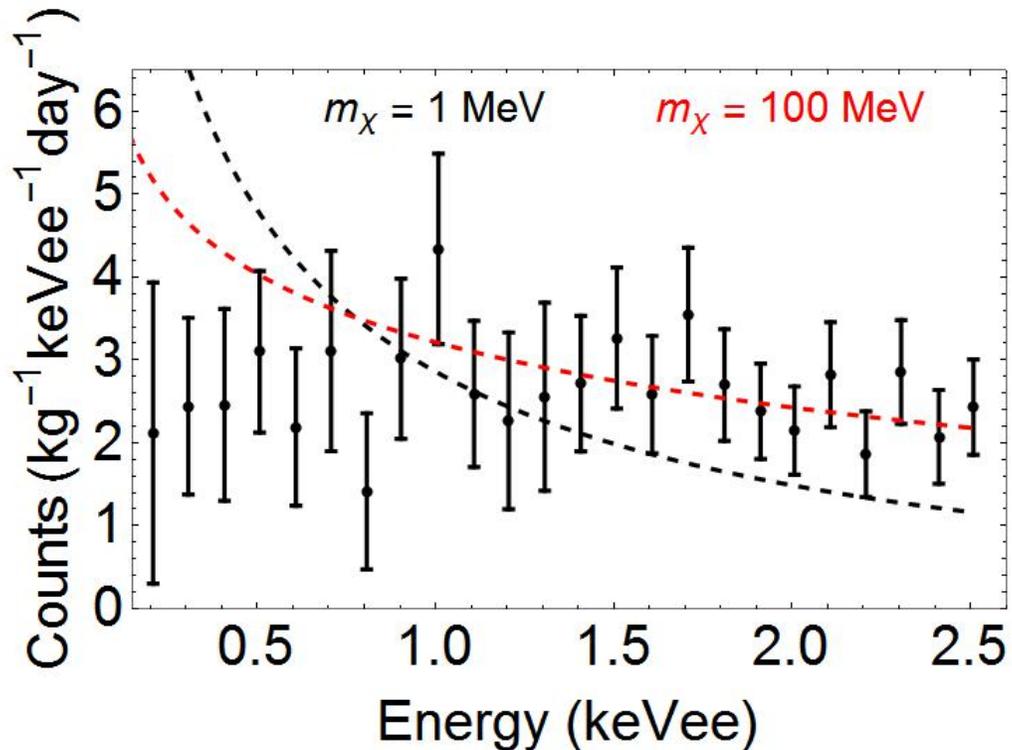


3. Recoil spectrum

$$\frac{dR}{dE_T} = \frac{1}{m_T} \int_{T_\chi^{\min}}^{\infty} \frac{d\Phi_\chi}{dT_\chi} \frac{d\sigma_{\chi T}}{dE_T} dT_\chi$$

- 数据来源于CDEX-10 arXiv : 1802.09016
- Quenching Factor
- 最小卡方

$$\chi^2(m, \sigma) \equiv \sum_k \frac{(S_k - S_k^{Th})^2}{\sigma_k^2}$$



Detector



3. Attenuation

- 暗物质粒子入射大气层、地层会发生能量的衰减

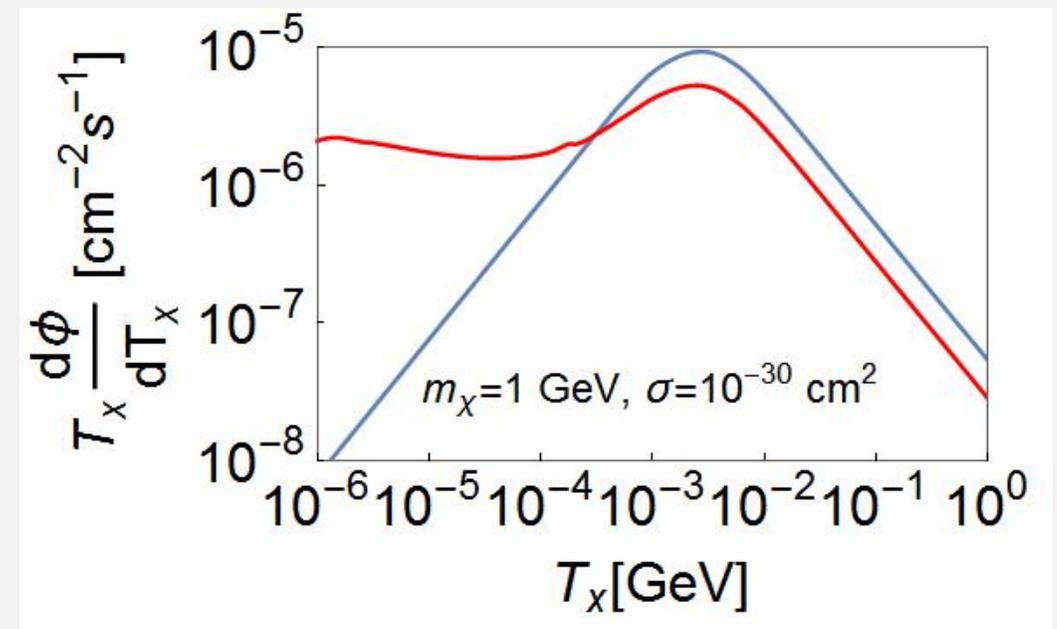
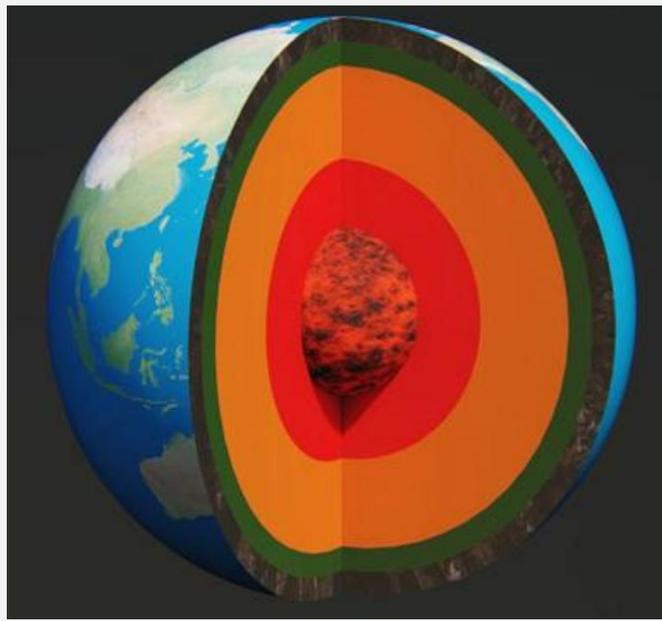
$$\frac{dT_\chi}{dz} = - \sum_N n_N \int_0^{T_r^{\max}} \frac{d\sigma_{\chi N}}{dT_r} T_r dT_r$$

- 自由程估计

$$\lambda = \frac{1}{\sigma_{\chi N} n_N} \sim km$$

- 模型

- 无方向性探测能力

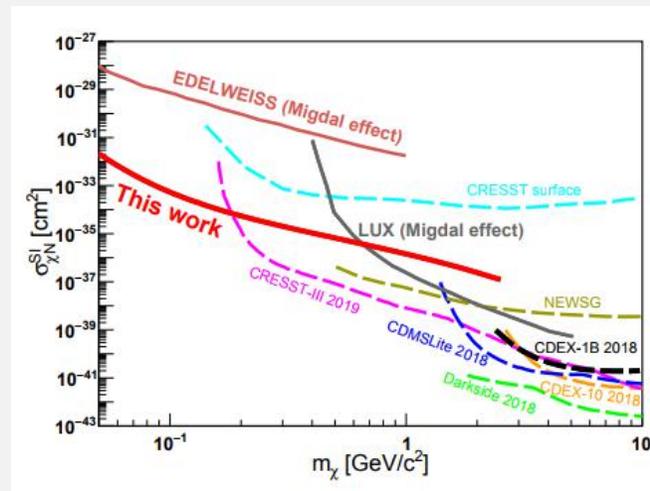
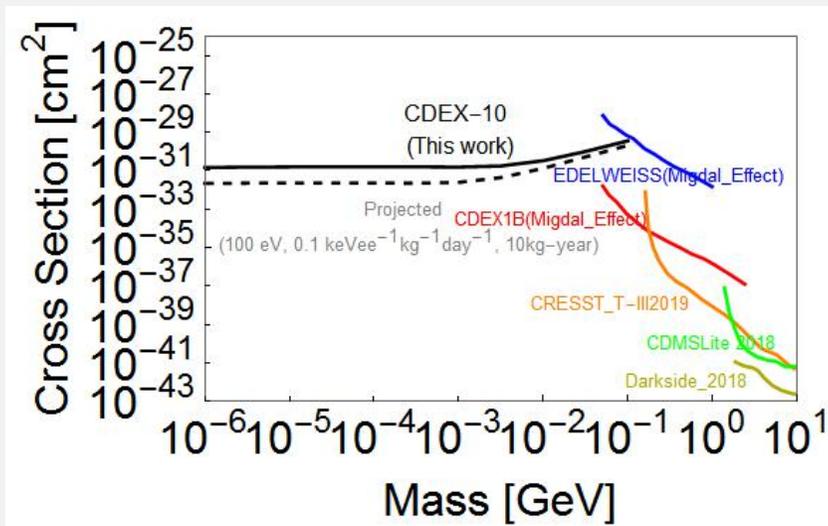




3. 排除曲线

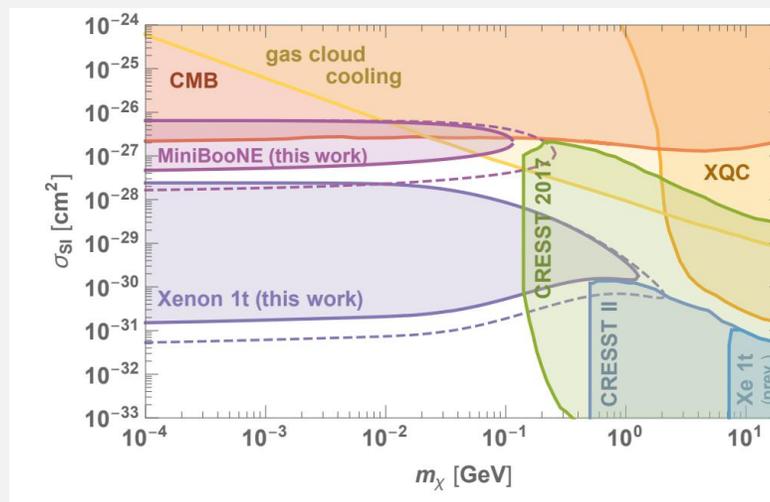
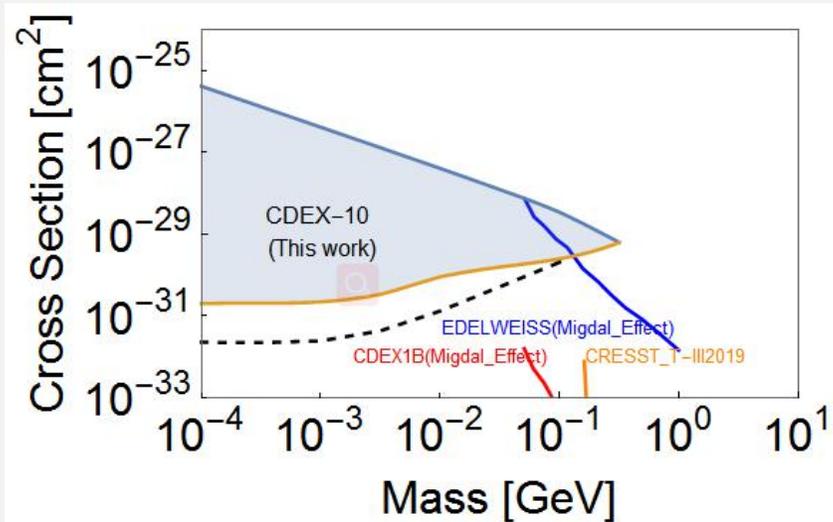


4. Exclusion line



- 提供在低质量区的新限制
- 分区间泊松法
- 比较SHM下与CRBDM模型下的能谱

arXiv : 1905.00354



arXiv : 1810.10543



Conclusion

- 介绍了CRBDM模型
- attenuation模型的研究
- 运用CDEX-10的数据得到排除曲线
- 一些存在的问题：

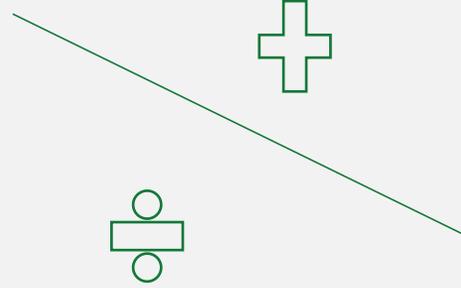
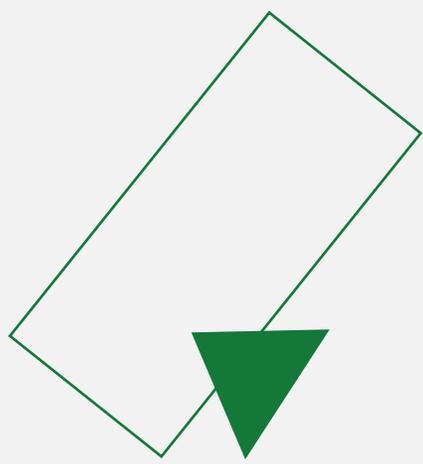
①宇宙学的不确定性：暗物质与CR的分布

②散射截面能量无关

$$\frac{d\sigma_{\chi i}}{dT_{\chi}} = \frac{\sigma_{\chi i}^0}{T_{\chi}^{max}} G_i^2(2m_{\chi}T_{\chi})$$

③attenuation

④...



Thanks

