Dark fluxes from Accreting Black Holes and Direct Detections

（来自吸积黑洞的暗物质喷射与直接探测）

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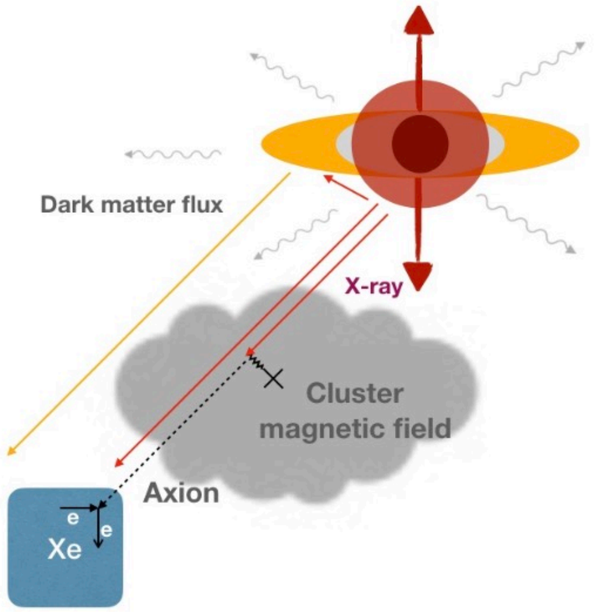
Outline

- **keV dark flux from Black Holes**
    - **KeV environment around the black holes**
    - **Generating keV dark matter**
    - **Possible signals and benchmark parameters**
- **Dark Matter Flux and Black Hole Dynamics**
    - **Dark luminosity and accreting black hole**
    - **Boosting dark matter by black holes**
    - **Dark superradiance of black holes**
- **Summary**

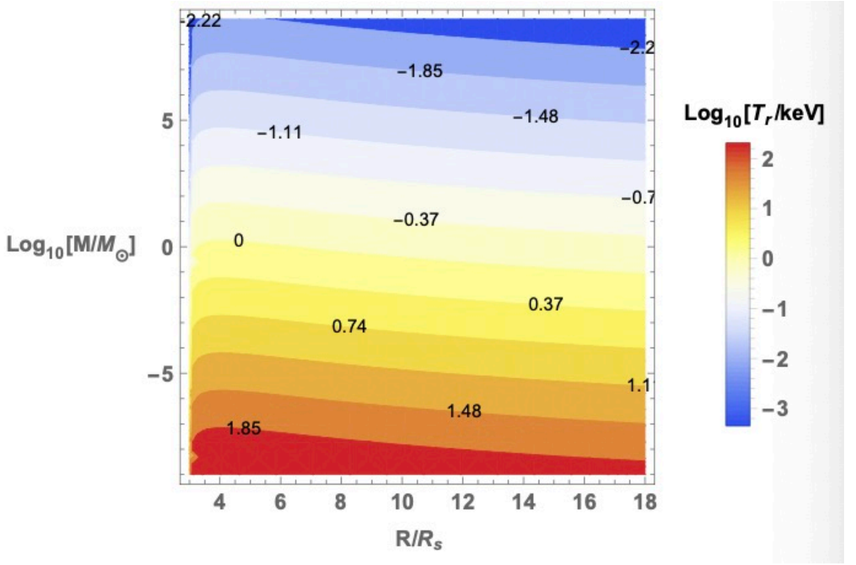
A simple thin disk model

- Shakura-Sunyaev model

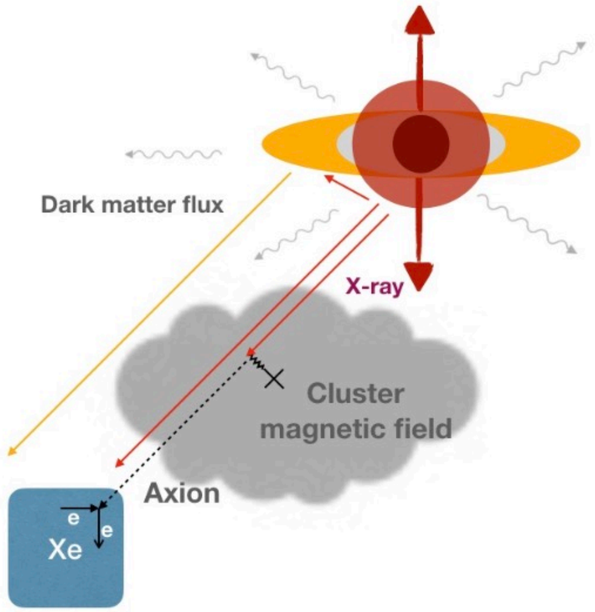
$$T_r = \frac{(1-\sqrt{3/r})^{1/4}}{r^{3/4}} T_0, \quad T_0 \simeq \left(\frac{10}{m_{BH}}\right)^{1/4} \times 3\,\mathrm{keV}.$$



Types of X-ray sources	AGNs	BHBs
Benchmark Masses ($M_\odot$)	$\sim 10^6$	~ 10
Eddington Luminosity L_E(erg/s)	$\sim 10^{44}$	$\sim 10^{39}$
Disk Temperature T_0(keV)	$\sim 10^{-2}$	~ 1



Luminosity



- Eddington luminosity: dominated by the photon scattered onto ions:

$$L_E = 4\pi GMc/\kappa_E,$$

$$\kappa_E \equiv \sigma_i/m_i$$

σ_T ← m_p

- Energy flux then is:

$$\mathcal{E}_E \equiv \frac{L_E}{4\pi R^2} \simeq \left(\frac{M}{M_\odot}\right)\left(\frac{\mathrm{kpc}}{R}\right)^2 \times 10^3 \mathrm{keV}/(\mathrm{cm}^2 \cdot \mathrm{s}).$$

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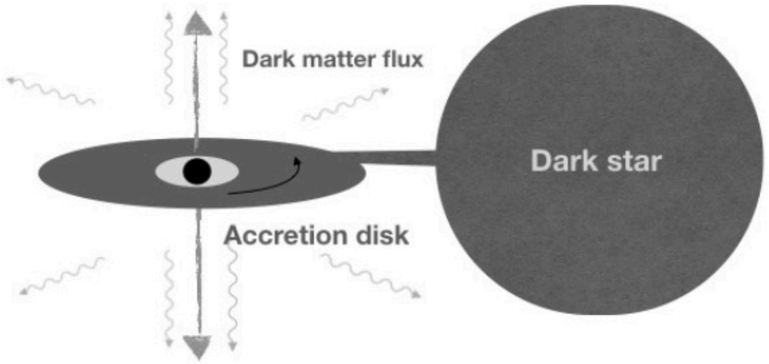
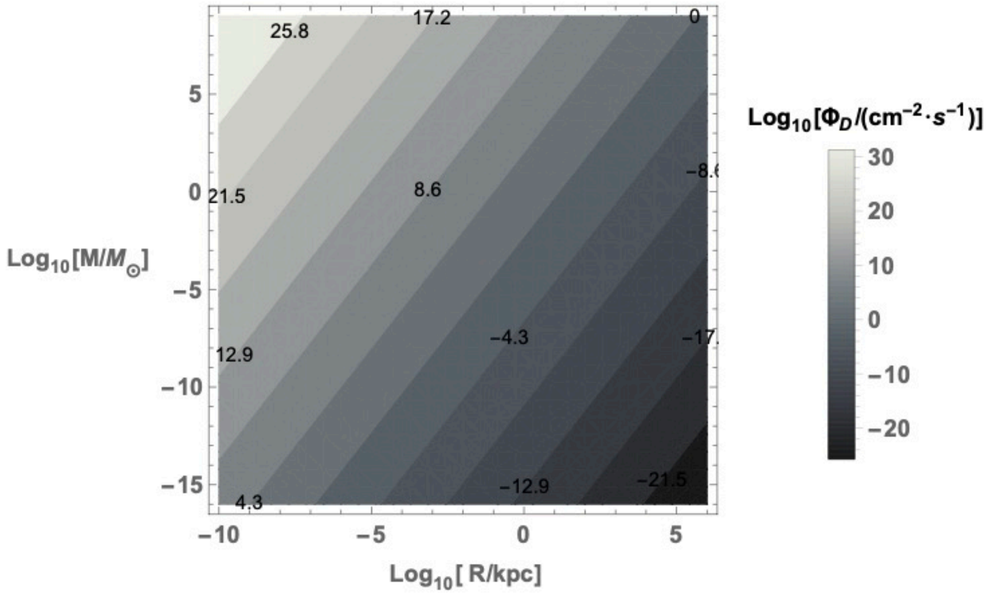
Dark Luminosity



- From multiple arguments:
  - thermal or conversion

$$L_D \sim L_E$$

$$\Phi_D \lesssim \left(\frac{M}{M_\odot}\right)\left(\frac{\mathrm{kpc}}{R}\right)^2\left(\frac{\mathrm{keV}}{E_D}\right) \times 10^3/(\mathrm{cm}^2 \cdot \mathrm{s})$$



Two light dark matter models

- Take Xenon1T as example:
- Axion or ALP

DM Types	Axion or ALP(a)	Dark Photons (γ')
Masse (m/keV)	$< 10^{-3}$	$< 10^{-2}$
Energy(E/keV)	~ 3	~ 3
Flux($\Phi_D/(\mathrm{cm}^{-2}\cdot \mathrm{s}^{-1})$)	$\sim 10^3$	$\sim 10^3$
Couplings	$g_{a\gamma} \sim 10^{-10}\mathrm{GeV}^{-1}$ and $g_{ae} \sim 10^{-12}$	$\epsilon \sim 10^{-14}$

$$\mathcal{L}_a = -\frac{g_{a\gamma}}{4} a\, F_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{ae}}{2}\frac{\partial_\mu a}{m_e}\,\psi_e\gamma^\mu\gamma_5\psi_e.$$

- Dark photon

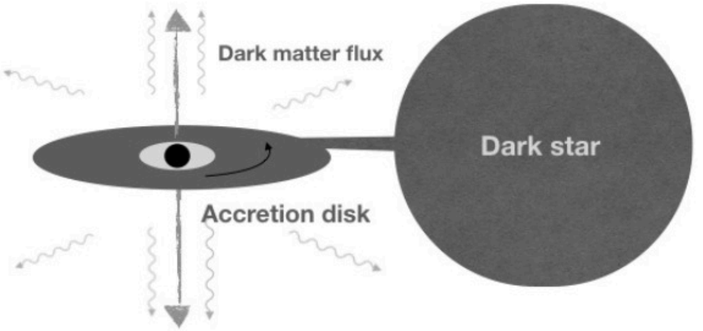
$$\mathcal{L}_{\gamma'} = \bar{\chi}(i\not{D} + m_\chi)\chi - \frac{1}{4}(F'_{\mu\nu})^2 + \frac{m^2_{\gamma'}}{2}A'^2 + \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}.$$

Accreting self-interacting dark matter

- Luminosity with dark photon:

$$L_\chi = \frac{4\pi GMc}{\kappa'_\chi} = L_E \frac{\kappa_E}{\kappa'_\chi},$$

$$\kappa'_\chi \equiv \sigma_{\chi\gamma'}/m_\chi. \qquad \kappa_E = \sigma_{\rm T}/m_{\rm p} \sim 0.3{\rm cm}^2/{\rm g}.$$



- Dark matter luminosity:

$$\frac{\sigma_{\chi\chi}}{m_\chi} \lesssim 1{\rm cm}^2/{\rm g}.$$

$$L_\chi \sim L_E \qquad \kappa'_\chi \sim \kappa_E$$

$$\kappa_{\chi\chi} \equiv \sigma_{\chi\chi}/m_\chi$$

DM Types	Boosted DM(χ)	DPDM(γ')
Masse (m/keV)	$\sim 10^3 - 10^6$	~ 3
Velocity(v/c)	$\sim 10^{-1}$	$\sim 10^{-3}$
Flux($\Phi/({\rm cm}^{-2}\cdot {\rm s}^{-1})$)	$\sim 10^{-6}$	$\sim 10^{12}$
Parameters	$\sigma_{e\chi} \sim 10^{-29}{\rm cm}^2$	$\epsilon \sim 10^{-15}$
Benchmark (R/kpc)	$< 10^1 - 10^3$	–

- For axion flux:

$$\kappa'_a \equiv \frac{\sigma_{a\gamma'}}{m_a}$$

$$\sigma_{a\gamma'} \simeq \sigma_{a\gamma}$$

$$L_a = L_E \frac{\kappa_E}{\kappa'_a}$$

Boosting dark matter in BH orbits:

- Event horizon: $R_s = \frac{2GM}{c^2}$
- photon sphere: $3R_s/2$
- Innermost stable circular orbit: $3R_s$

- DM can be accelerated within those orbits, and escape through collision:

$\chi'\chi' \to \chi\phi$ $\qquad\qquad$ $\chi_A\bar{\chi}_A \to \chi_B\bar{\chi}_B$

BH superradiance

- With order one parameter below, radiate keV rays:

$$\alpha_s \equiv \frac{R_s}{\lambda_\phi} \simeq 0.1 \times \left(\frac{M_{BH}}{10^{-15} M_\odot}\right) \left(\frac{m_\phi}{7\,\mathrm{keV}}\right)$$

$$\phi \rightarrow \gamma'\gamma'$$

- Similar to Hawking radiation, characterized by the quantum wavelength of the black hole size.

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$$T_{BH} = \frac{\hbar}{4\pi k_B} \frac{c}{R_s} \simeq 5.3\mathrm{keV} \left(\frac{10^{-15} M_\odot}{M_{BH}}\right).$$

Summary

- Three different DM mass regions, light kinetic keV, keV mass DPDM, MeV-GeV.

- Different mechanisms: Thermal vs Black hole boosters vs Superradiance

- Rich dark matter phenomena around the black hole.