Nucleosynthesis induced by the Fast Accretion of sMBH in the Disk of AGN

Thesis Defence

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Explanation of the high metallicity of AGN

- Observational evidence shows the exceptional super-solar metallicity in the broad line region (BLR) of AGN[10].

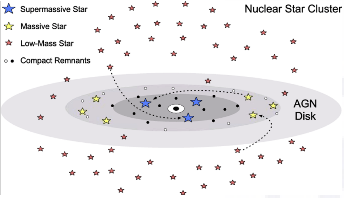

Fig. 1: [1]**Hypo. 1**: Capturing from the nuclear star cluster.

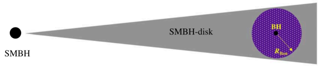

Fig. 2: [9]**Hypo.2** Star formation, evolution result

- Either way, they finally grow to massive BH. High accretion rate($\sim 10^9 L_{\rm Edd}/c^2$), high density($\sim 10^{14}{\rm cm}^{-3}$). AMS may bring a new view to explain the nature of AGN

Our goal

- Modified the model of the fast accretion onto BH.(advection dominated, hot flow)
- Calculated the abundances after the nucleosynthesis in the disk.

Basic equations (After vertically integrated)

- Continuity equation

$$\frac{\partial \Sigma}{\partial r} = -\frac{\Sigma}{r} - \frac{\Sigma}{v}\frac{\partial v}{\partial r}, \tag{1}$$

- Equation of motion (origins from Navier-Stokes Equation)

$$v_r \frac{dv_r}{dr} + \frac{1}{\Sigma}\frac{d\Pi}{dr} = \frac{\ell^2 - \ell_{\rm K}^2}{r^3} - \frac{\Pi}{\Sigma}\frac{d\ln\Omega_{\rm K}}{dr},$$
$$\dot{M}(\ell - \ell_{\rm in}) = -2\pi r^2 T_{r\varphi}, \tag{2}$$
$$\Omega_{\rm K}^2 H^2 = (2N+3)\frac{\Pi}{\Sigma}.$$

- Energy Equation

$$Q^+_{\rm vis} + \boxed{Q^+_{\rm nuc}} = Q^-_{\rm adv} + Q^-_{\rm rad}, \tag{3}$$

- Equation of state

$$p = \text{ideal gas} + \text{radiation} + \text{~~degenerate~~}. \tag{4}$$

Nuclear Reaction[2]: H and He burning

- H burning
  - p-p chain reaction, $T \in [1.5, 1.8] \times 10^7\mathrm{K}$,

$$R_{\mathrm{pp}} \propto \rho X^2 T^4. \tag{5}$$

  - CNO cycle, $T > 1.8 \times 10^7\mathrm{K}$,

$$R_{\mathrm{CNO}} \propto X X_{\mathrm{CNO}} \rho T^{18}. \tag{6}$$

- He burning, $T > 10^8$K.

$$R_{3\alpha} \propto Y^3 \rho^2 T^{40}. \tag{7}$$

The specific expressions are no shown because they are so long.

Method

- Euler's Method

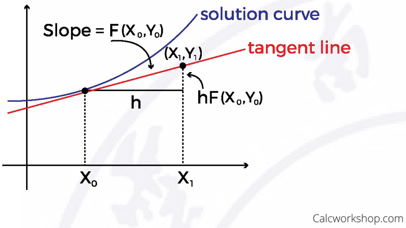

Fig. 3: Euler's Method

- Initial condition
  - adjust the inner angular momentum to show the transonic nature of BH accretion.
  - Keplarian rotation.

Result (1): Thermodynamics

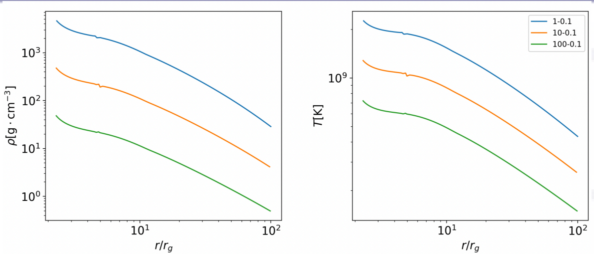

Fig. 4: Fix $\dot{M}/\dot{M}_{\rm edd} = 10^8$, the profile of T and ρ. Higher BH mass gives a low temperature and density.

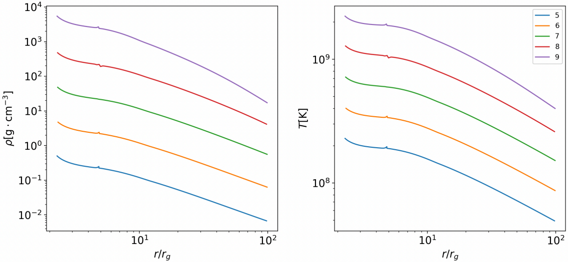

Fig. 5: Fix $M_{BH} = 10M_\odot$, the profile of T and ρ. Higher accretion rate gives a higher temperature and density.

Thermal instability analysis

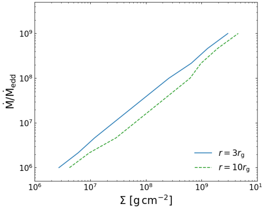

Fig. 6: Phase Diagram on $\dot{M} - \Sigma$. The slope is always positive.

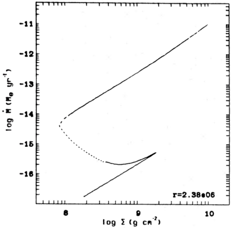

Fig. 7: [7] Phase diagram of a White dwarf

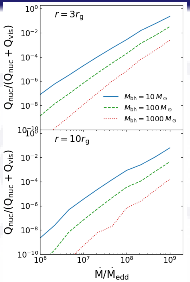

Fig. 8: Ration of the endothermic rate of Nuclear reaction

No thermal instability:

- If the viscosity is normal ($\alpha \sim 10^{-1}$), $Q_{\rm nuc} \ll Q_{\rm vis} \approx Q_{\rm adv}$.
- Even if $Q_{\rm nuc} \geq Q_{\rm vis}$ (by dropping α), the benefit is balanced out by high advection cooling.
  The NS and WD: *a real edge*, a nuclear burst[7][3][6];
  But BH: no *counterpart*.

Reemphasize: advection cooling is one of the two most imoprtant nature of BH accretion (Kato[5]).

Result (2): Nuclear Network

- We calculated the abundances of ^{12}C, ^{14}N, ^{16}O and other species after 1s using an open-source FORTRAN code [8][4].

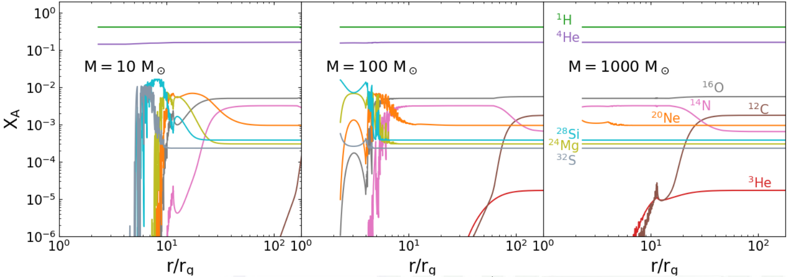

Fig. 9: The profile of mass fraction of Elements after 1s. Carbon and/or Nitrogen was depleted in the inner region, causing the increase of metallicity.

Tab. 1: The metal abundances in the Sun

O	C	Ne	N	Si	Mg	S
7×10^{-3}	2.9×10^{-3}	10^{-3}	9×10^{-4}	7×10^{-4}	5×10^{-4}	4×10^{-4}

Ration of C, N, and O

- We drew N/C and O/C at $5r_g$ and $10r_g$. Indicators of metallicity in observations.

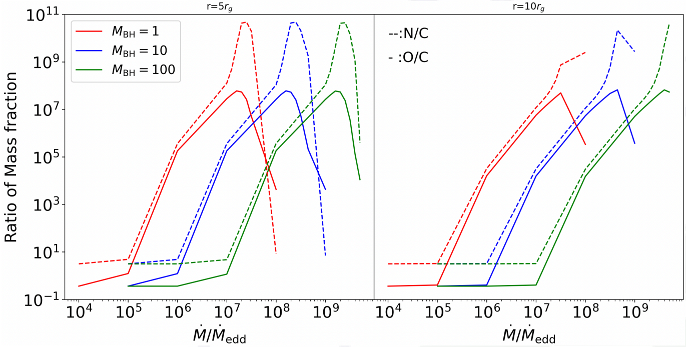

Fig. 10: O/C and N/C with respect to $\dot{M}$ at $5r_g$ and $10r_g$ after 1s. Roughly speaking, higher accretion rate brings higher ratio because of the higher T and ρ. We could not explain the peaks and their shifts til now.

Conclusion

- Disk thermodynamics
  - The structure of the disk of AMSs is modeled and numerically solved.
  - The increase of $\dot{M}$ and the decrease of $M_{\rm BH}$ brings a higher ρ and T. But does not make it thermally unstable or degenerate.
- Nuclear network
  - The nucleosynthesis is examined using an open-source, 19-species nuclear network FORTRAN code.
  - Prominent metal enrichment happened in the disk. ^{12}C was depleted in the inner region of the disk ($\leq 10^1 r_g$), subsequently causing the increase of ^{14}N, $^{20}\mathrm{Ne}$, $^{24}\mathrm{Mg}$, $^{28}\mathrm{Si}$ and $^{20}\mathrm{S}$.
- Outlook
  - The peak and the successive drop cannot be interpreted. (Numerical issue?)
  - Transform the mass ratio to the fluxes of the emission line.

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Thanks!

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