AGN Radiative Feedback: the effective Eddington limit for dusty gas

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AGN Feedback

Accreting black holes release energy and momentum into the host galaxy via Active Galactic Nucleus (AGN) Feedback in both radiative and kinetic forms.

- accretion energy: $E_{BH} \sim \epsilon M_{BH} c^2$, $\epsilon \sim 0.1$
- binding energy: $E_{gal} \sim M_{gal} \sigma^2$, $\sigma \sim 300 \text{km/s}$

$\Rightarrow \frac{E_{BH}}{E_{gal}} \sim 100$

→ AGN feedback plays an important role in the formation and evolution of galaxies.
Radiative feedback: the Eddington limit(s)

Radiation pressure: electron scattering ($\sigma_T$) or dust absorption ($\sigma_d$)

→ AGN feedback via radiation pressure on dust
  (Fabian 1999, Murray et al. 2005, Thompson et al. 2015, Ishibashi & Fabian 2015, ...)

- standard Eddington luminosity:
  $$L_E = \frac{4\pi G c m_p}{\sigma_T} M$$

- “effective” Eddington luminosity:
  $$L'_E = \frac{4\pi G c m_p}{\sigma_d} M$$

$$\sigma_d > \sigma_T \quad \rightarrow \quad L'_E < L_E$$
The “$N_H - \lambda$ plane”

Effective Eddington limit for dusty gas  \cite{Fabian_2006, Fabian_2008, Fabian_2009}

- long-lived obscuration
- “forbidden” region

\[ \log (N_H / \text{cm}^{-2}) \]

\[ \lambda \]
The $N_H - \lambda$ plane: AGN samples

9-month Swift/BAT AGN sample

70-month Swift/BAT AGN catalogue

(Fabian et al. 2009)

(Ricci et al. 2017)

~1% in the forbidden region
AGN radiative feedback with radiation trapping

(Ishibashi, Fabian, Ricci, Celotti 2018)

- Single scattering limit (optically thin to IR, optically thick to UV)
- IR-optically thick regime (optically thick to IR and UV)

\[ F_{\text{rad}} = \frac{L}{c} \left( 1 + \tau_{IR} - e^{-\tau_{UV}} \right) \]
\[ F_{\text{grav}} = 4\pi G m_p M_{BH} N \]

- Effective Eddington luminosity:

\[ L'_E = \frac{4\pi G c m_p M_{BH} N}{1 + \tau_{IR} - e^{-\tau_{UV}}} \]

- Effective Eddington ratio:

\[ \Lambda = \frac{L}{L'_E} = \frac{L(1 + \tau_{IR} - e^{-\tau_{UV}})}{4\pi G c m_p M_{BH} N} \]

\[ \Rightarrow N_E = \frac{(1 + \tau_{IR} - e^{-\tau_{UV}})}{\sigma_T} \lambda \]
The revised $N_H - \lambda$ plane

radiation trapping $\rightarrow$ enhanced forbidden region  

(Ishibashi, Fabian+2018)
Dust-to-gas ratio

\[ f_{dg} = 2f_{dg,MW}, 1f_{dg,MW}, 0.5f_{dg,MW} \]

→ the more dusty gas is preferentially ejected by AGN radiative feedback
Comparison with observations

70-month Swift/BAT AGN sample

lack of AGNs in the forbidden region

“forbidden” region ~ “blowout” region
BH spin, radiation pattern, and outflow geometry

( Ishibashi, Fabian & Reynolds 2019)

Zero spin → “prolate” outflows

Maximum spin → “oblate” outflows

Radiation pattern and outflow geometry: a new probe of BH spin?
Polar dusty outflows and obscuration

\( \alpha = 0, \alpha = 0.5, \alpha = 0.8, \alpha = 0.95, \alpha = 0.998 \)

- IR interferometric observations: polar dust emission in several AGNs (e.g. Asmus+2016, Leftley+2018, ...)
- Polar dusty outflows for intermediate BH spins (0 < \( \alpha < 0.8 \))
- Obscuration geometry set by BH spin?

(Ishibashi, Fabian & Reynolds 2019)
AGN radiative dusty feedback

- Radiation pressure on dusty gas regulates the AGN obscuration & outflow properties

- AGN radiative feedback can adequately reproduce the dynamics and energetics observed in galactic outflows: \( \dot{M}_v \sim 10 \, \text{L/c} \), \( \dot{E}_k/L \sim 5\% \) (Fiore+2017, Fluetsch+2019) if radiation trapping is included (Ishibashi & Fabian 2015, 2016, Ishibashi, Fabian, Maiolino 2018)

- Preferential removal of dusty gas in radiation pressure-driven outflows \( \rightarrow \) populations of “dusty quasars” (Banerji+2015, Zakamska+2016, ...)

- AGN-starburst co-evolutionary sequence: from dust-obscured starbursts to unobscured luminous quasars (e.g. Sanders et al. 1988)

\[\rightarrow \text{AGN radiative dusty feedback: a natural physical interpretation?}\]