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

$$\frac{M_{BH}}{M_{gal}} \sim 10^{-3}$$

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

$\rightarrow$ AGN feedback plays an important role in the formation and evolution of galaxies

Radiative feedback: the Eddington limit(s)

Radiation pressure: electron scattering (σ_T) or dust absorption (σ_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: $$L_E^{'} = \frac{4\pi G c m_p}{\sigma_d} M$$

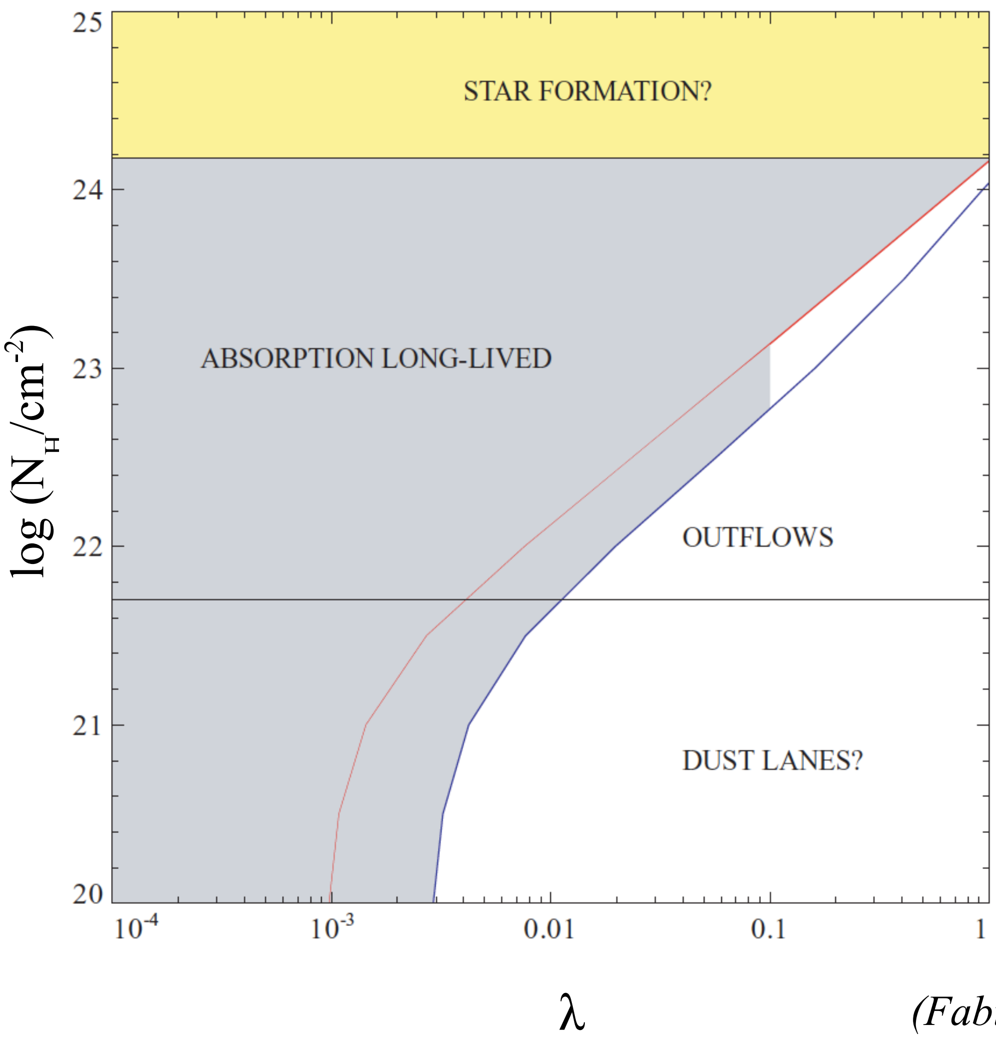
$$\frac{\sigma_d}{\sigma_T} \sim 500$$

$$\sigma_d > \sigma_T \quad \rightarrow \quad L_E^{'} < L_E$$

The “$N_H - \lambda$ plane”

Effective Eddington limit for dusty gas *(Fabian et al. 2006, 2008, 2009)*

- long-lived obscuration

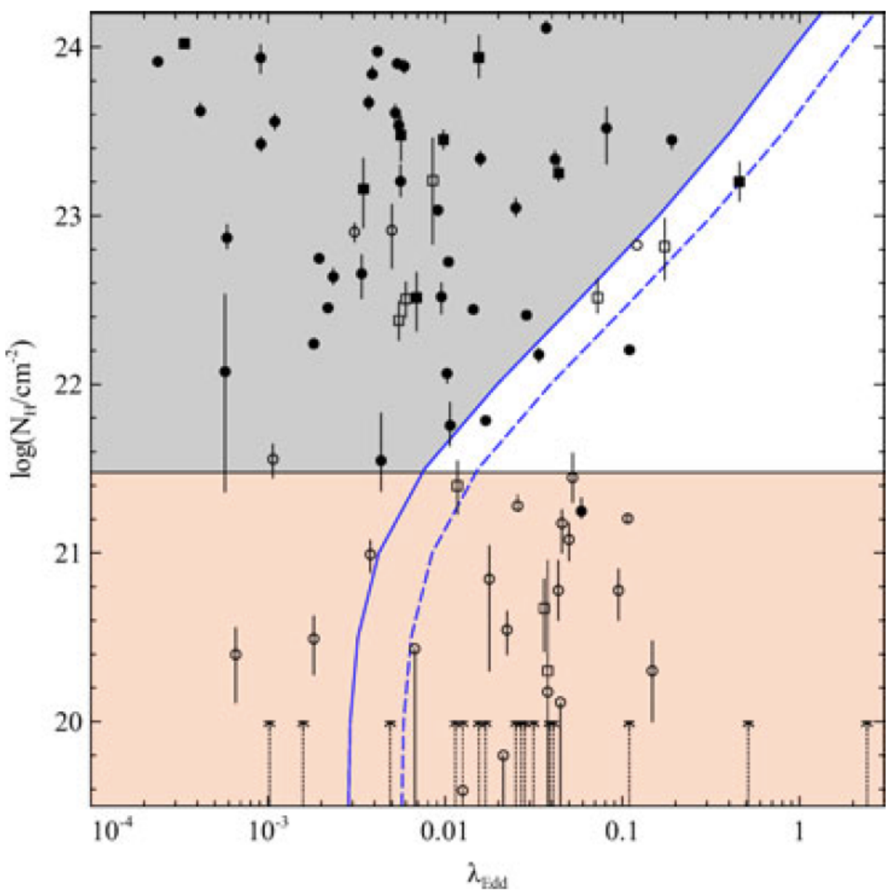


- “forbidden” region

(Fabian et al. 2008)

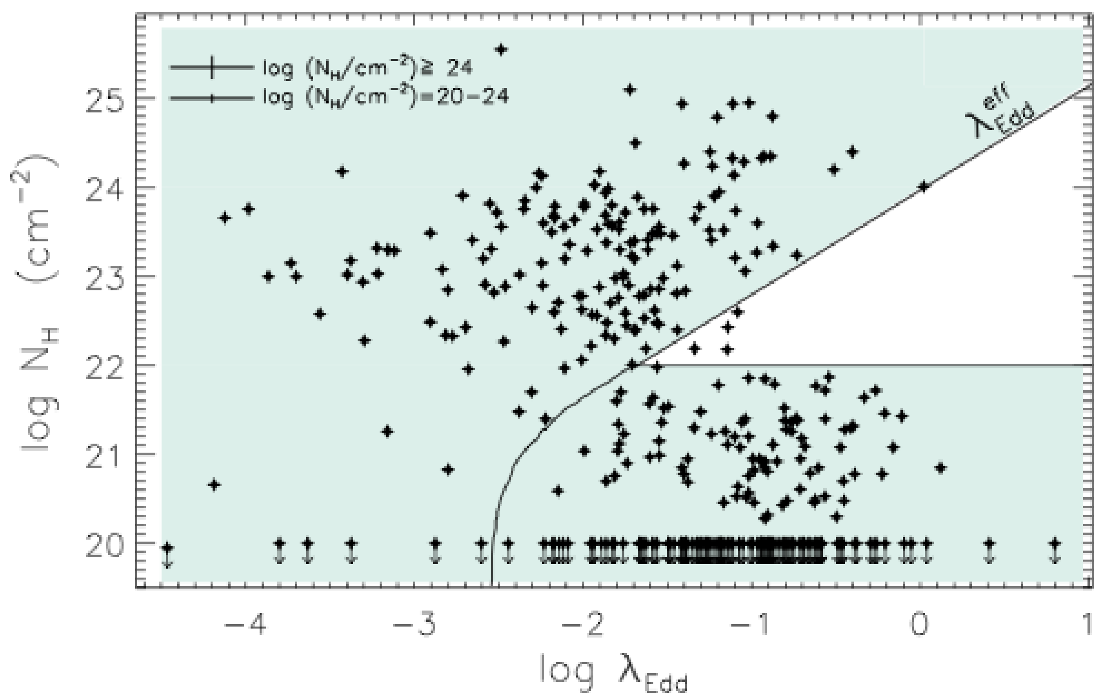
The $N_H - \lambda$ plane: AGN samples

9-month *Swift*/BAT AGN sample



(Fabian et al. 2009)

70-month *Swift*/BAT AGN catalogue



(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)

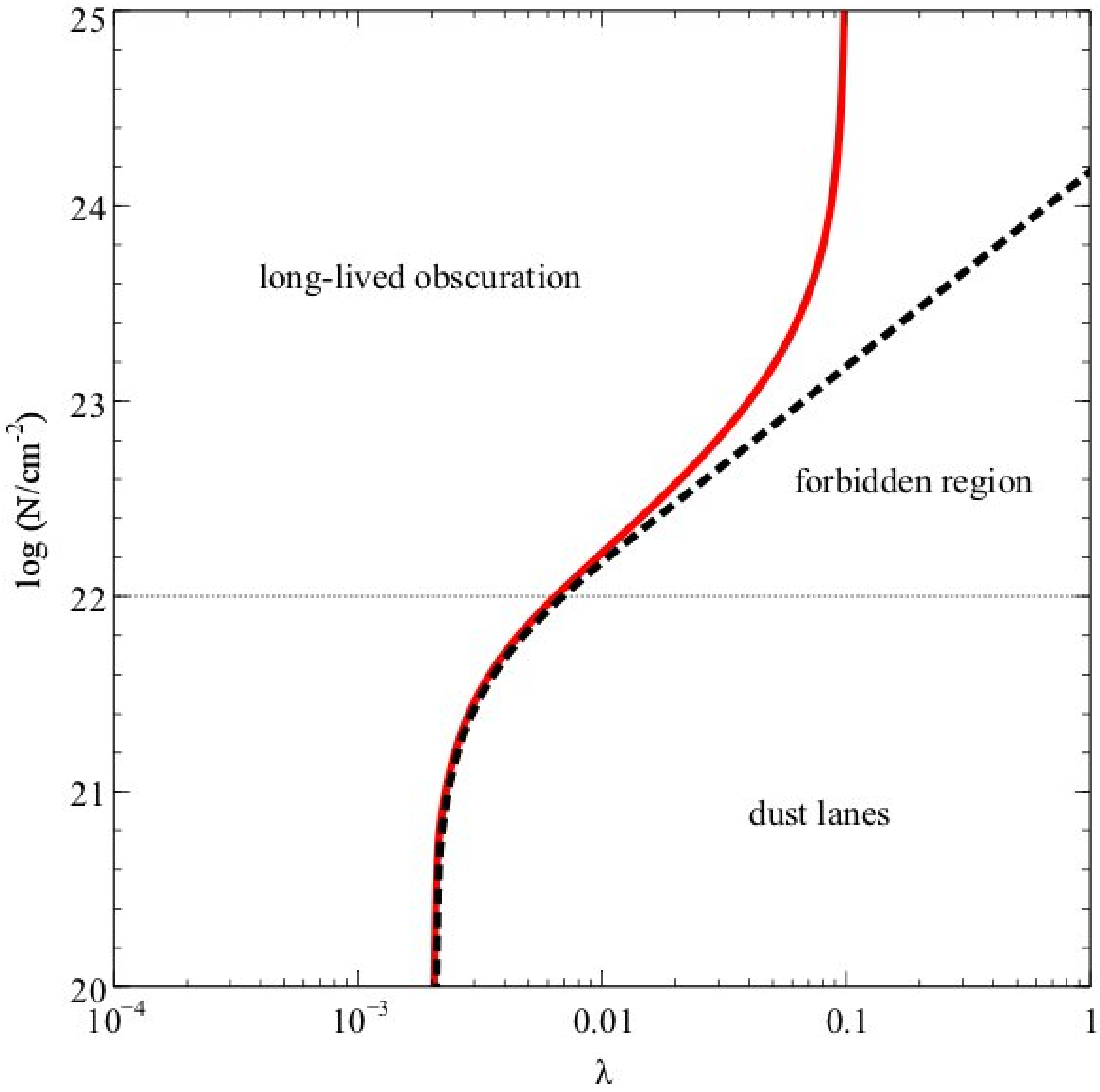
$$F_{rad} = \frac{L}{c}\left(1 + \tau_{IR} - e^{-\tau_{UV}}\right) \qquad F_{grav} = 4\pi G m_p M_{BH} N$$

- 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

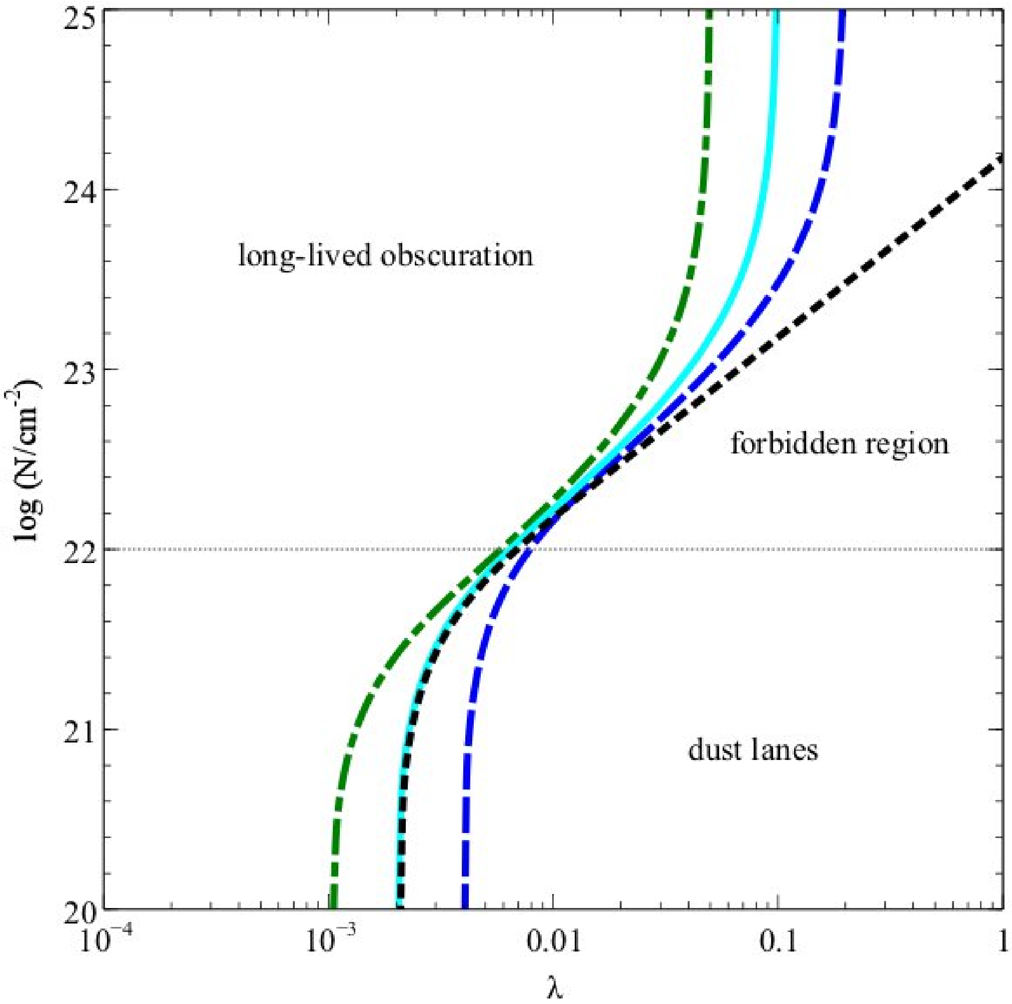


(Ishibashi, Fabian+2018)

radiation trapping → enhanced forbidden region

Dust-to-gas ratio

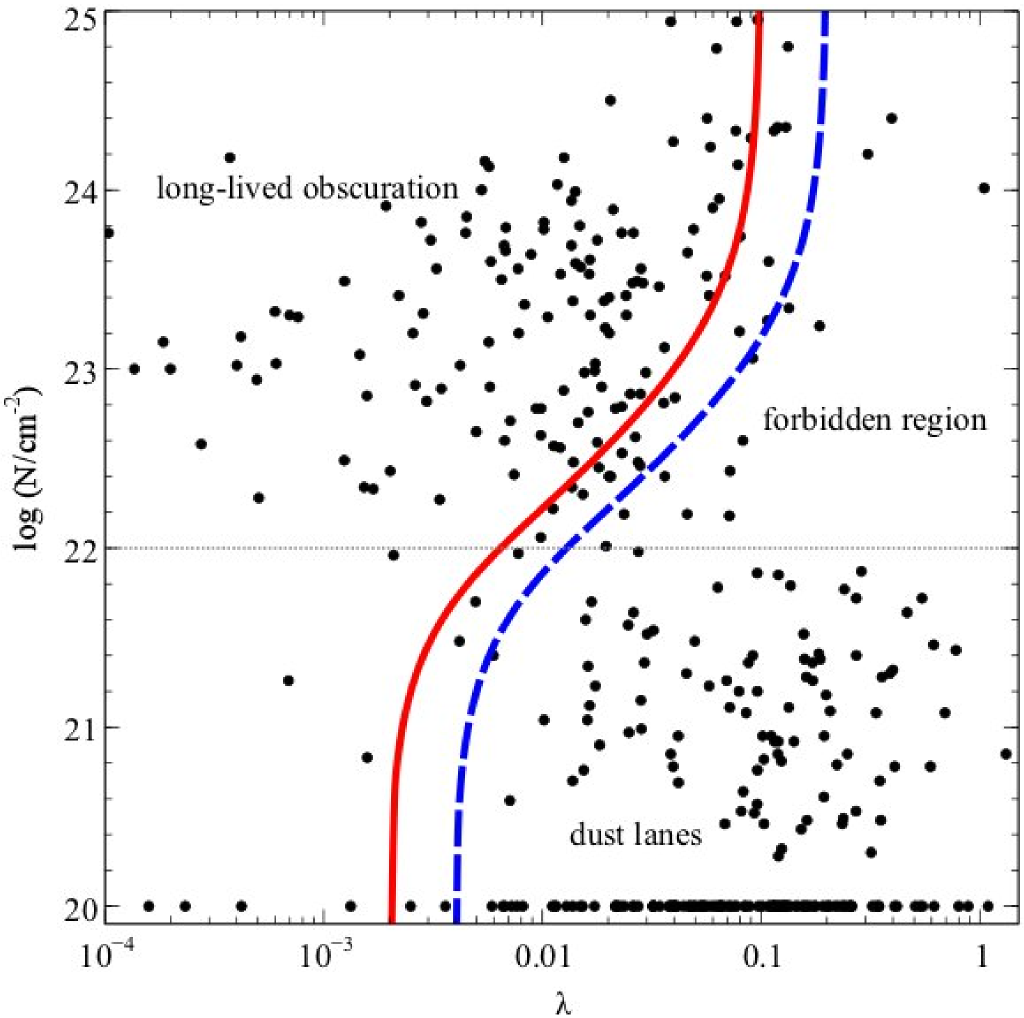
$f_{dg} = 2f_{dg,MW}$, $1f_{dg,MW}$, $0.5f_{dg,MW}$



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

Comparison with observations

70-month *Swift*/BAT AGN sample

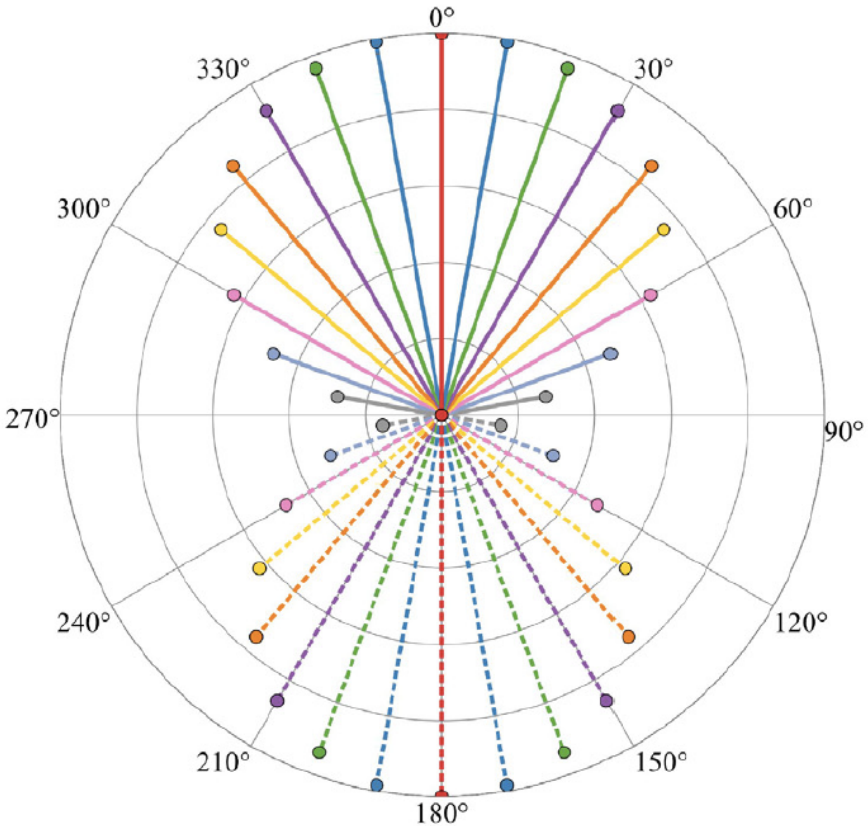


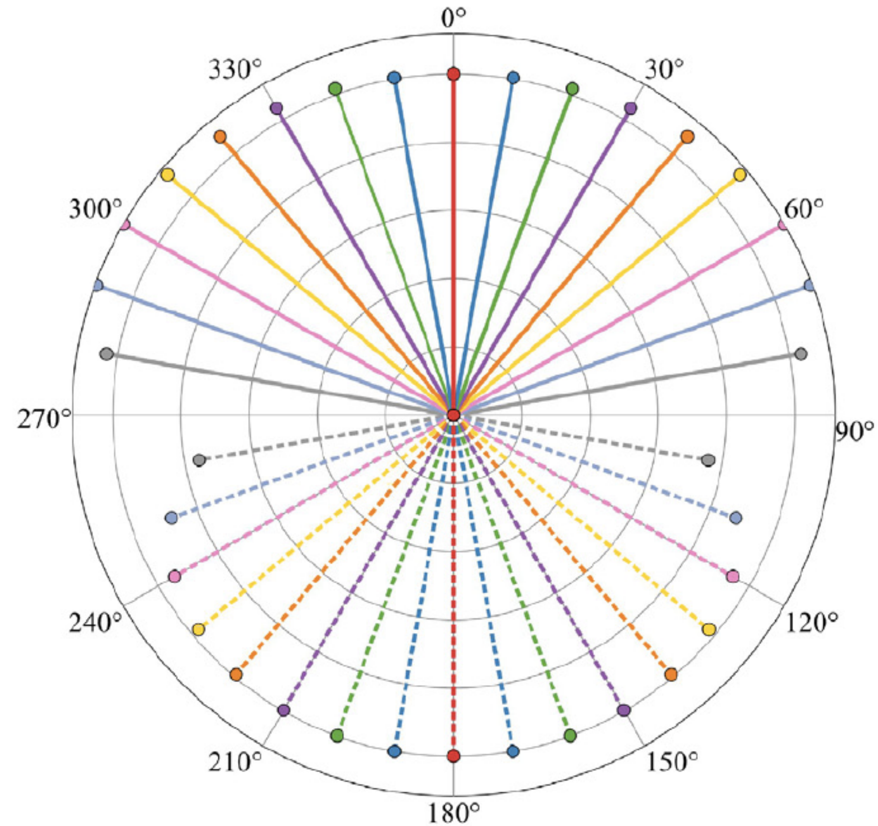
lack of AGNs in the forbidden region

"forbidden" region ~ "blowout" region

BH spin, radiation pattern, and outflow geometry

(Ishibashi, Fabian & Reynolds 2019)





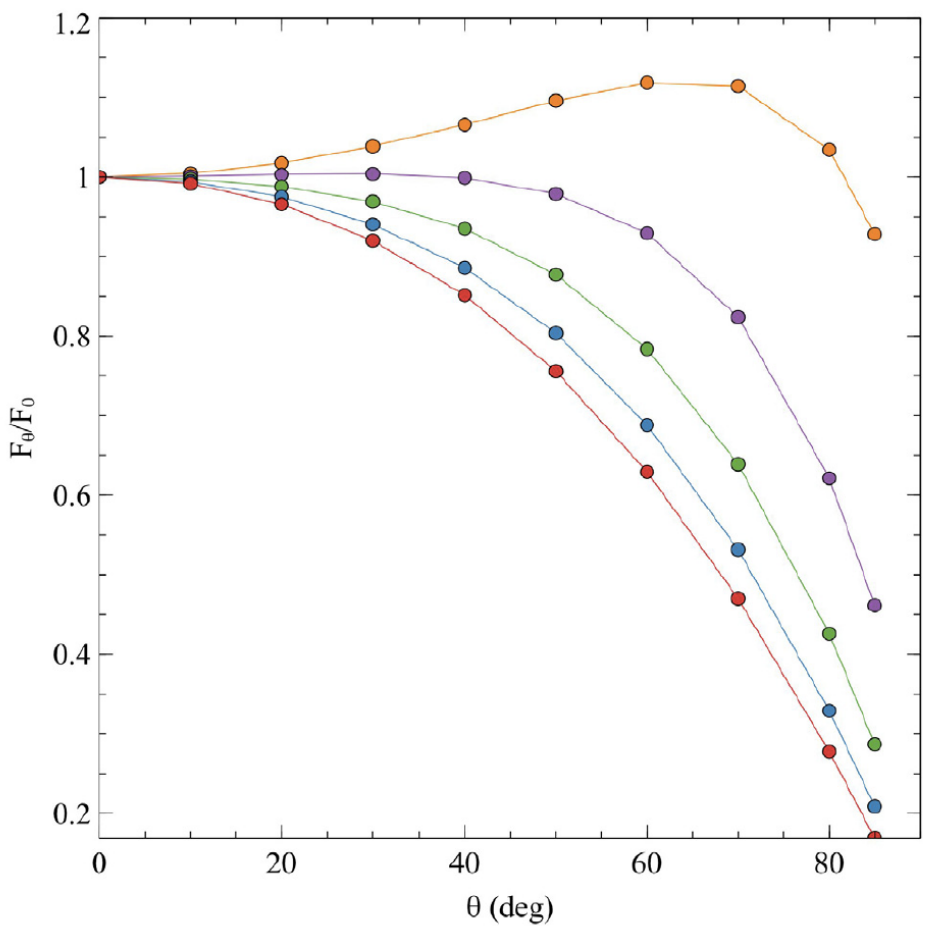
Zero spin → "prolate" outflows

Maximum spin → "oblate" outflows

Radiation pattern and outflow geometry: a new probe of BH spin?

Polar dusty outflows and obscuration

$a = 0$, $a = 0.5$, $a = 0.8$, $a = 0.95$, $a = 0.998$



(Ishibashi, Fabian & Reynolds 2019)

- IR interferometric observations:
  polar dust emission in several AGNs
  (e.g. Asmus+2016, Leftley+2018, ...)

- Polar dusty outflows
  for intermediate BH spins ($0 < a < 0.8$)

- Obscuration geometry set by BH spin?

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: $\dot{M}v \sim 10\ L/c$, $\dot{E}_k/L \sim 5\ \%$ *(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
  → 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)*

→ *AGN radiative dusty feedback: a natural physical interpretation?*