Ultra Fast Outflows from AGN accretion discs

The (limited) role of radiation pressure and the evidence for magnetic driving

Alfredo Luminari, PhD student - *alfredo.luminari@roma2.infn.it*

University of Rome *Tor Vergata* & Astronomical Observatory of Rome (INAF - OAR)

In collaboration with:

M. Laurenti, F. Tombesi, F. Vagnetti (Univ. Tor Vergata), *R. Middei* (ASI-INAF),
E. Piconcelli, F.Nicastro, L. Zappacosta (INAF-OAR), *M. Elvis* (CfA), *F. Fiore* (INAF/OA Trieste)

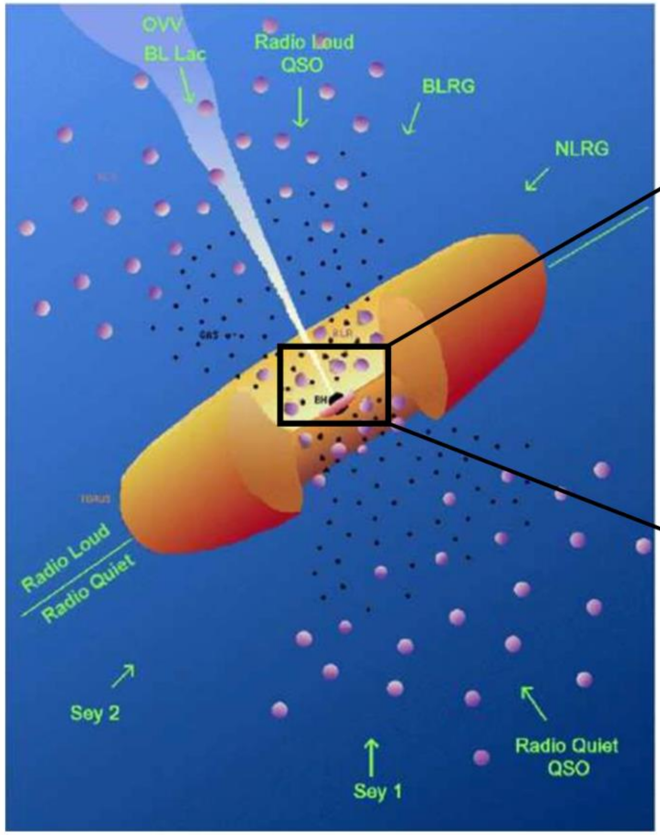
Ultra Fast Outflows from AGN accretion discs

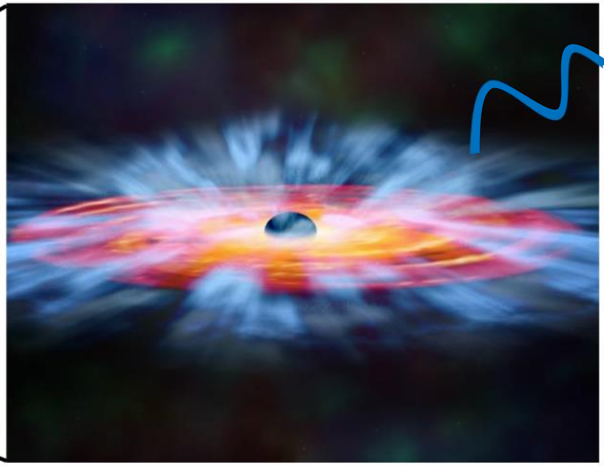
Outline

i. *UFOs from accretion disc: where we stand now*
ii. *The (limited) role of radiative pressure*
iii. *Evidence for Magnetic driving?*
iv. *The UFO-accretion disc interplay*

Ultra Fast Outflows in AGNs: where we stand now

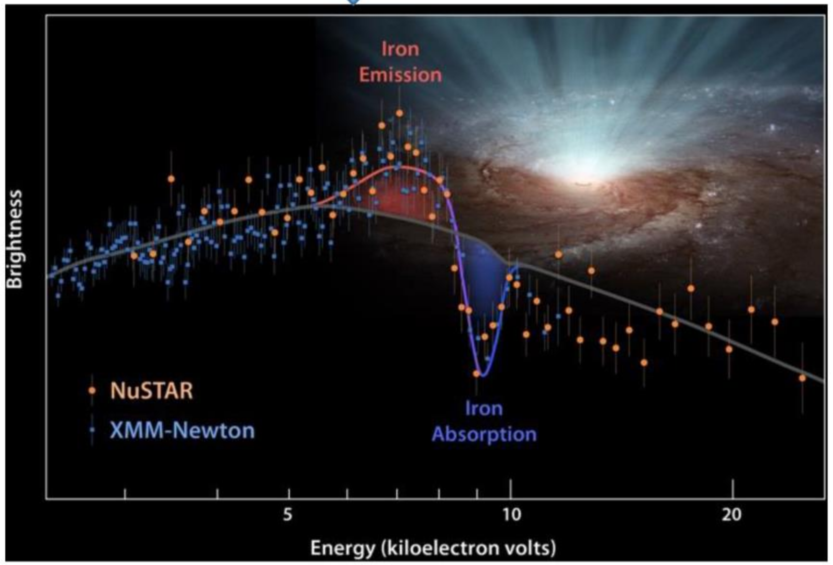
AGN





Accretion disk

X-ray spectrum



P-Cygni profile (PDS456; Nardini+15)

Relativistic winds at accretion disk scales.

Observed through spectroscopy, as blueshifted absorption/emission imprinted on the continuum spectrum of the AGN, mainly at $E \geq 5\ keV$

Ultra Fast Outflows in AGNs: where we stand now

Key properties:

- Outflowing velocity $v_{out} = 0.1 - 0.4\ c$
- Column density $N_H = 10^{22} - 10^{24}\ cm^{-2}$
- Ionisation parameter $\xi = 10^4 - 10^6\ erg\ s^{-1} cm^{-2}$
- Opening angle $\theta = 45 - 60\ deg$

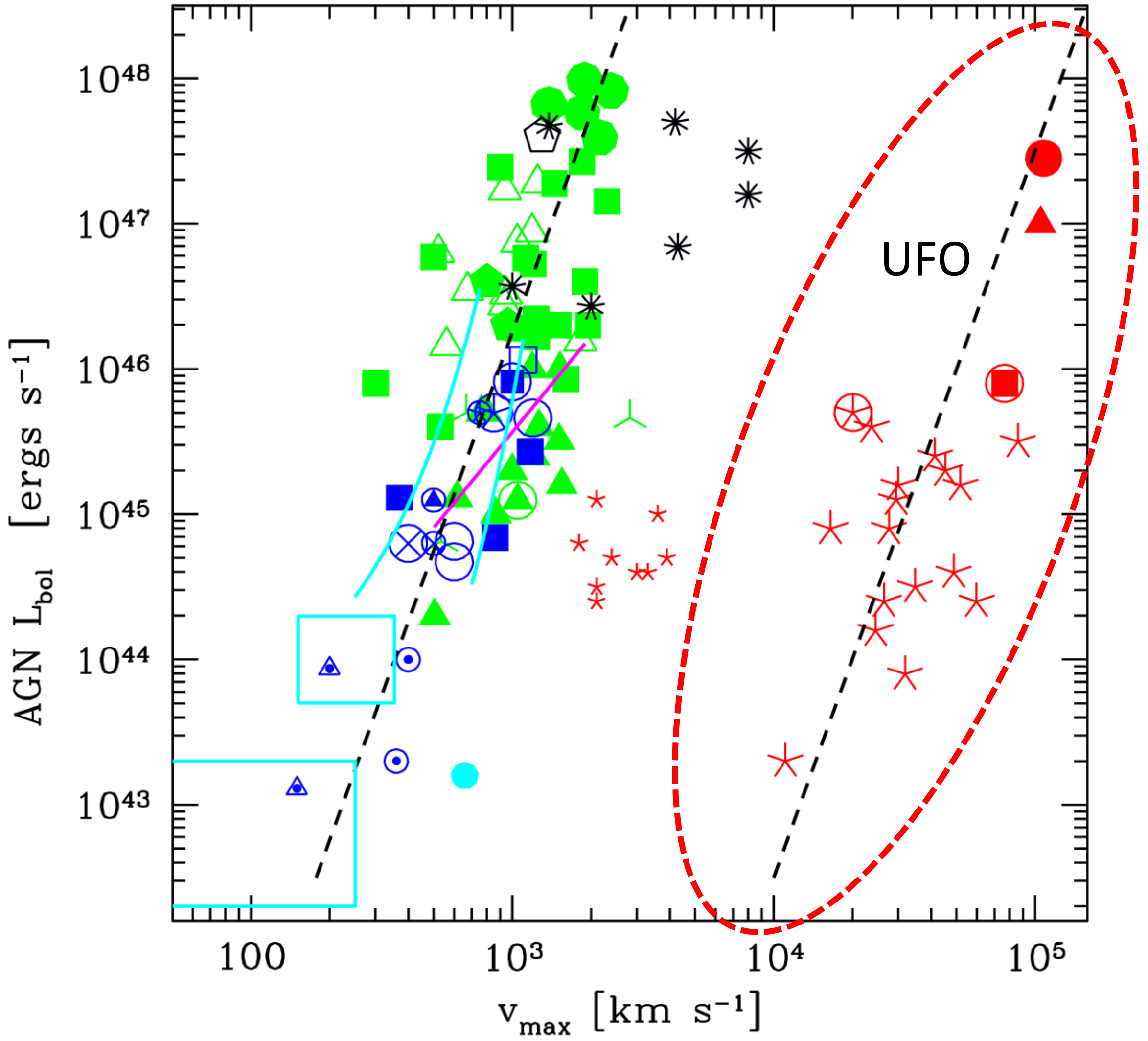
Energy flux $\dot{E}_{out}$ up to $20 - 40\%\ L_{AGN}$:

enough to trigger galactic feedback

Feedback from AGN required to match:

i) $M_{Bh} - \sigma$ relation

ii) Suppressed SFR for high mass galaxies



Fiore+17, King & Pounds 15 , Di Matteo+05, Faucher-Giguère+12, Menci+19, Tombesi+10,+13

How are they accelerated?

Radiation pressure?

The outflow can be accelerated by AGN radiation pressure (scattering, atomic lines, …):

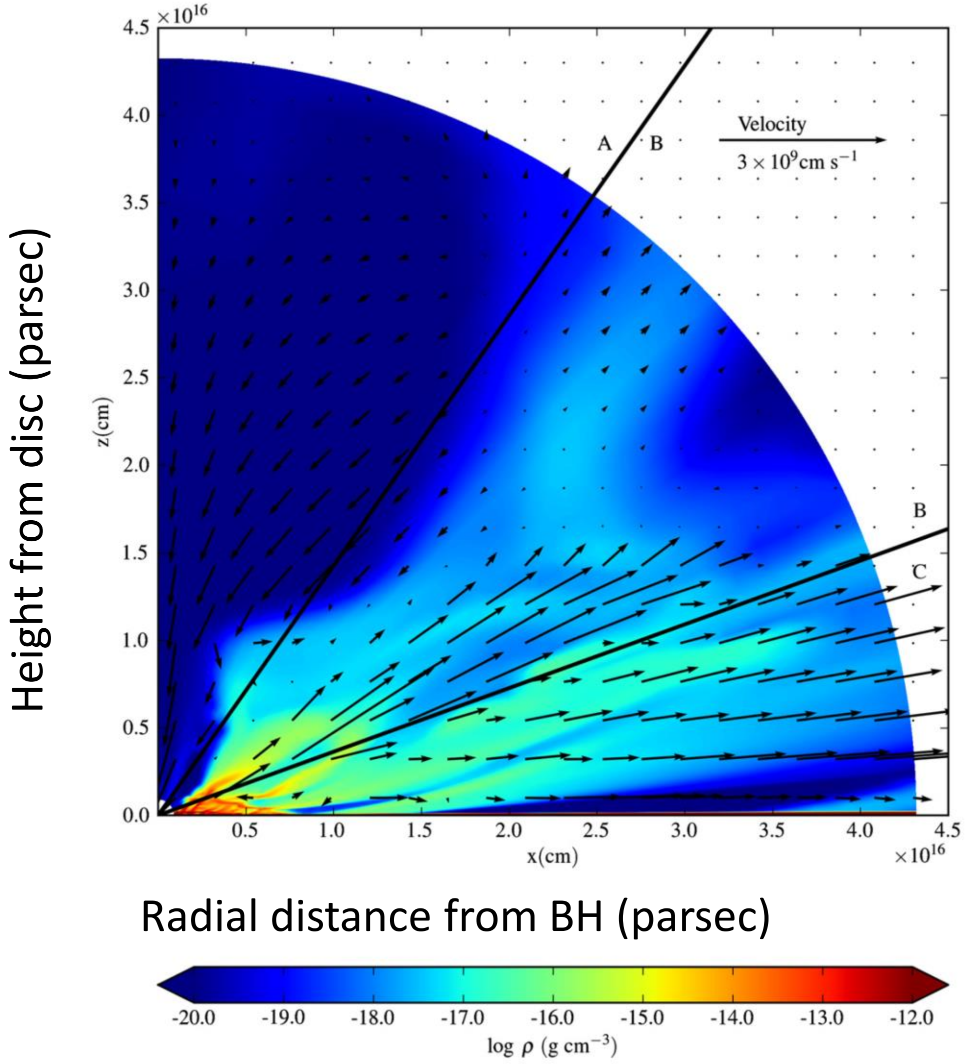
$$\dot{m}_{out} v_{out} \sim \tau \frac{L_{AGN}}{c}$$

Pros:

- ➢ Naturally expected given the high Eddington ratios $(\lambda_{Edd} = 0.1 - 2.0)$
- ➢ Match the observed optical depths $\tau \sim 1$
- ➢ Outflows in the UV show significant absorption

Cons:

- ➢ The outflow easily gets over-ionized:
  - ▪ Insufficient radiation drag
  - ▪ Faint absorption lines



Proga+04, Higginbottom+14

Three dimensional wind model

Initial conditions:

- Thin accretion disc with Keplerian profile
- Wind launched from the disc plane with vertical v_0 and conserving angular momentum

Credit: ESA

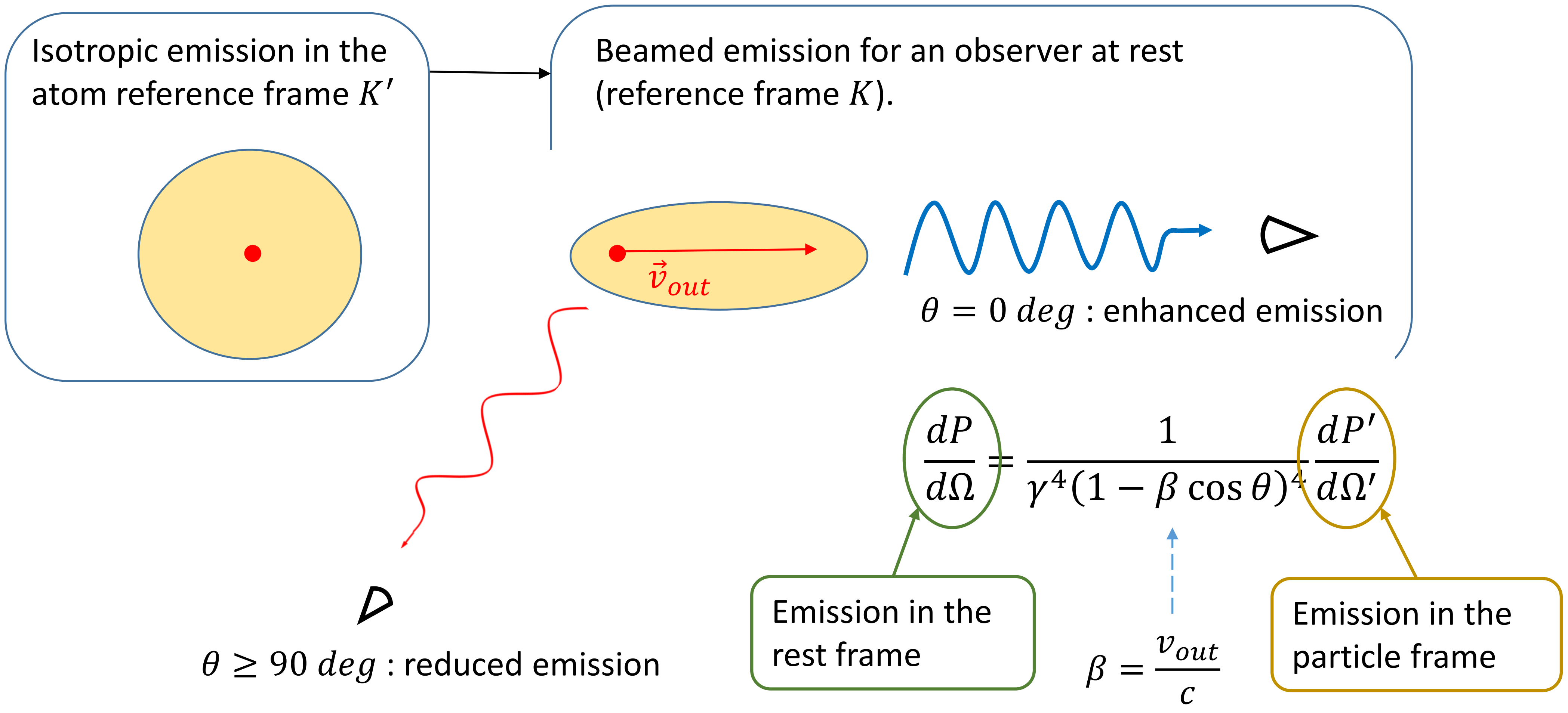
Wind acceleration:

- Gravitational attraction
- Radiation pressure on the wind:
  - Thompson scattering
  - Force multipliers for the line opacity

Special relativistic effects on the wind opacity

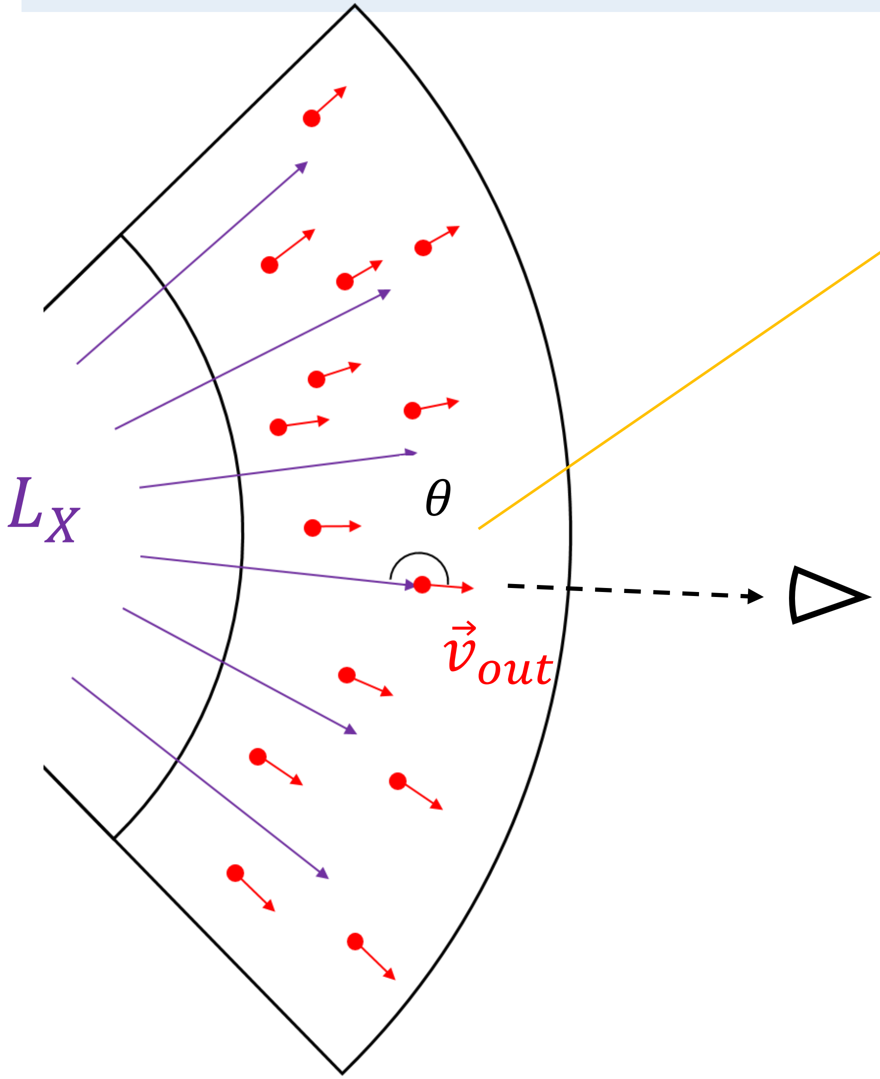
Special relativistic effects on the wind opacity

Emission from a relativistic particle is enhanced frontward ($\theta = 0\ deg$) and reduced backward ($\theta = 180\ deg$):



Special relativistic effects on the wind opacity

In the wind reference frame, the wind is *at rest* and the ionizing continuum is *moving away* from it:
<u>continuum emission is beamed when seen by the outflowing wind</u>



Same formula with $\theta = 0\ deg$:

$$\frac{dP}{d\Omega} = \frac{1}{\gamma^4(1+\beta\cos\theta)^4}\frac{dP'}{d\Omega'}$$

Radiation absorbed by the wind

Emitted radiation L_X

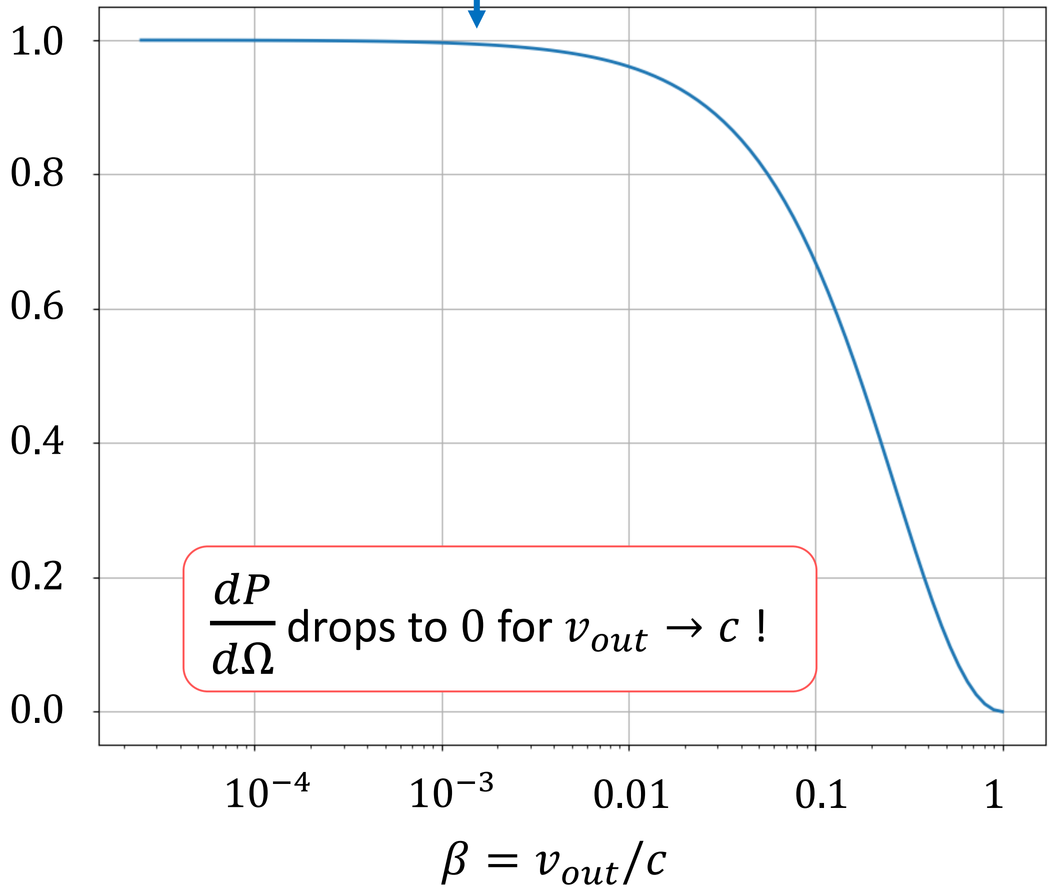
Special relativistic effects on the wind opacity

<u>continuum emission is beamed when seen from the outflowing wind</u>

Radiation absorbed by the wind

$$\frac{dP}{d\Omega} = \frac{1}{\gamma^4(1+\beta\cos\theta)^4}\frac{dP'}{d\Omega'}$$

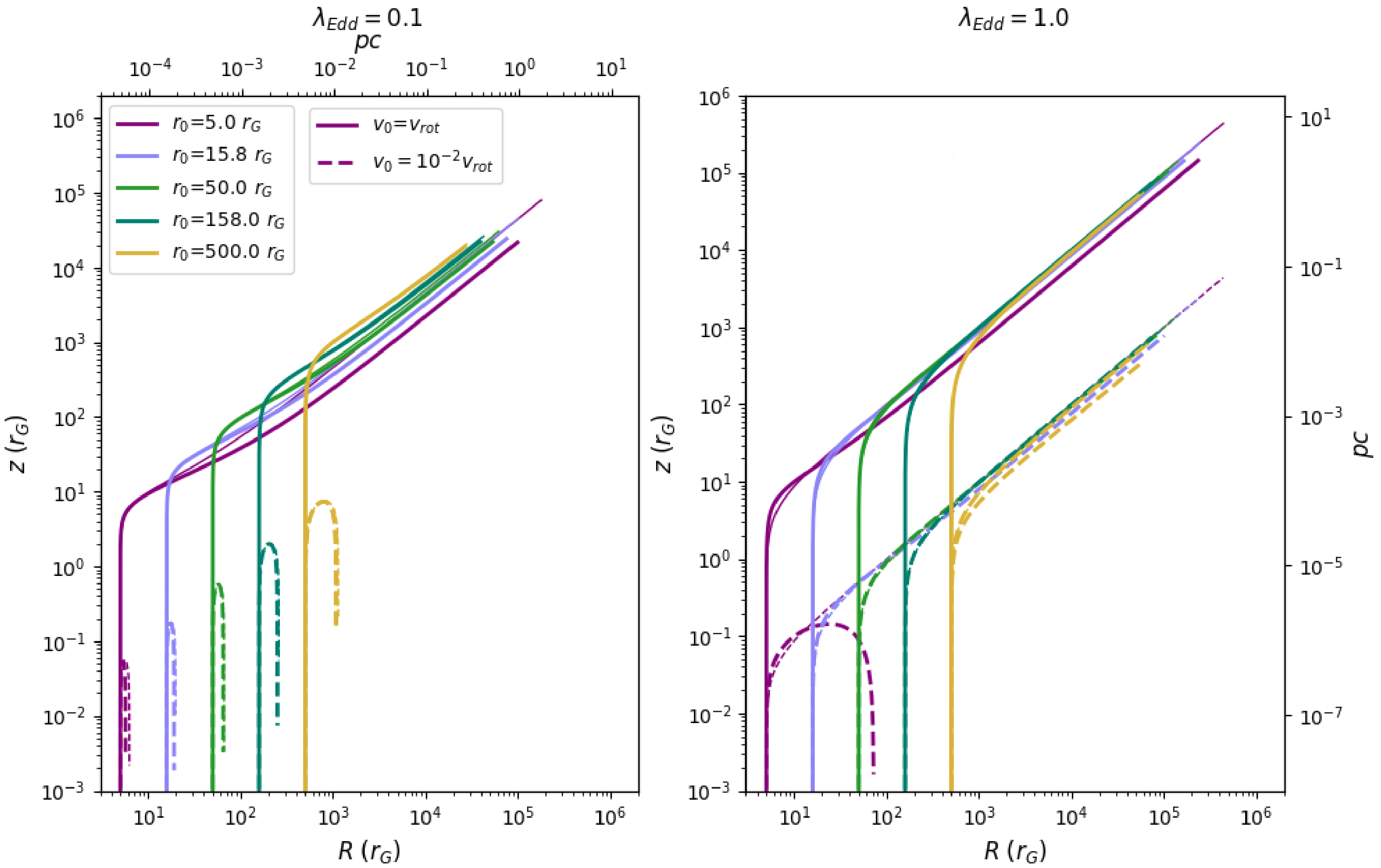
Emitted radiation



Three dimensional wind model

- AGN luminosity: $\lambda_{Edd} \equiv \frac{L_{AGN}}{L_{Edd}} = 0.1 - 1.0$
- Starting radii: $r_0 \in [5.0, 15.8, 50.0, 158.1, 500.0] r_G$
- Launching velocity: $v_0 \in [10^{-2}, 1.0]\ v_{rot}$

Height from disc (parsec)

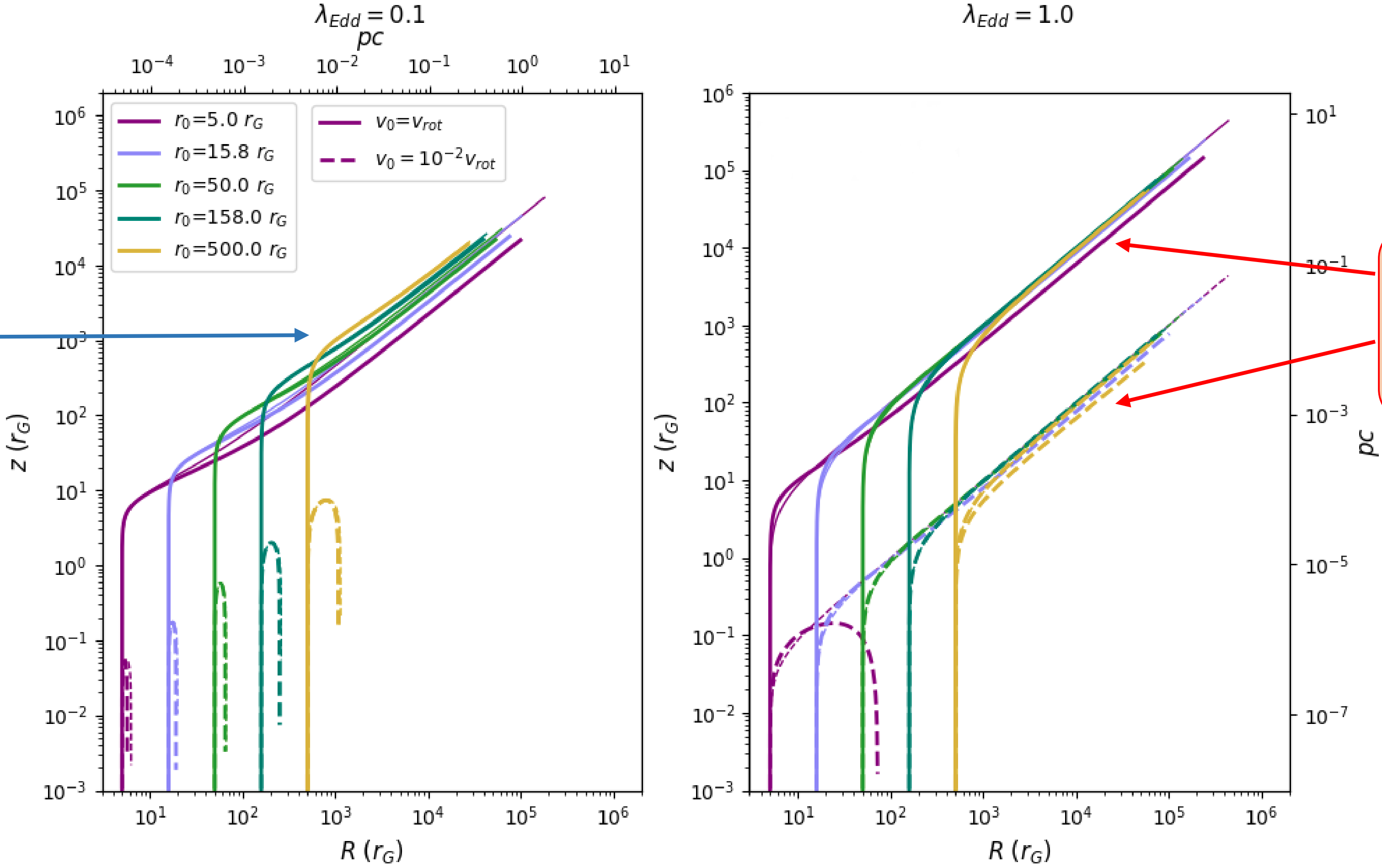


Radial distance from BH (parsec)

Three dimensional wind model

- AGN luminosity: $\lambda_{Edd} \equiv \frac{L_{AGN}}{L_{Edd}} = 0.1 - 1.0$
- Starting radii: $r_0 \in [5.0, 15.8, 50.0, 158.1, 500.0] r_G$
- Launching velocity: $v_0 \in [10^{-2}, 1.0]\ v_{rot}$

Low luminosity: succesfull wind only for $v_0 = v_{rot}$



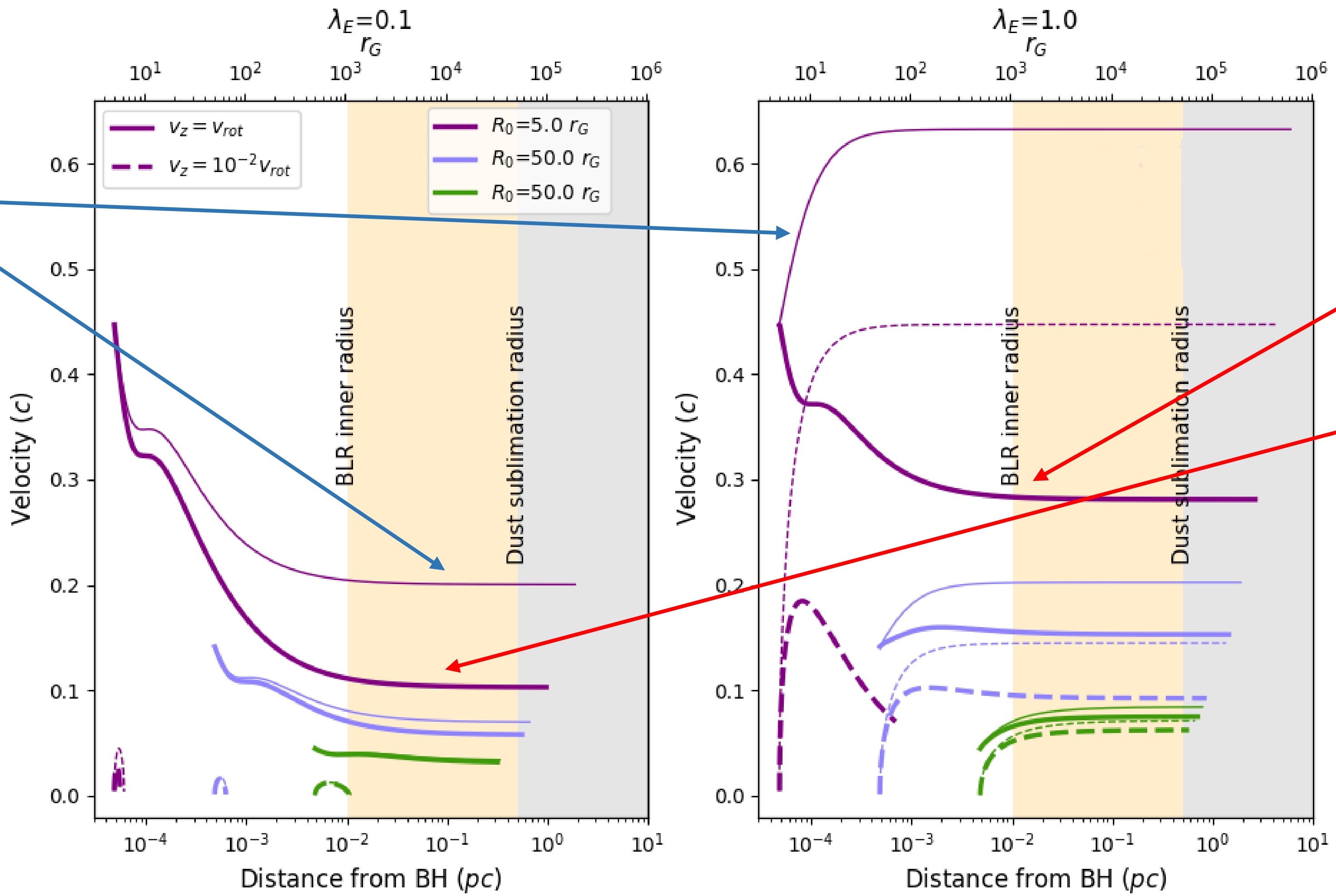
High luminosity: succesfull wind for any v_0

Three dimensional wind model

Impact of relativistic effects:

Classic treatment:

Fast wind, up to 0.2 c (left) and 0.6 c (right) (thin lines)

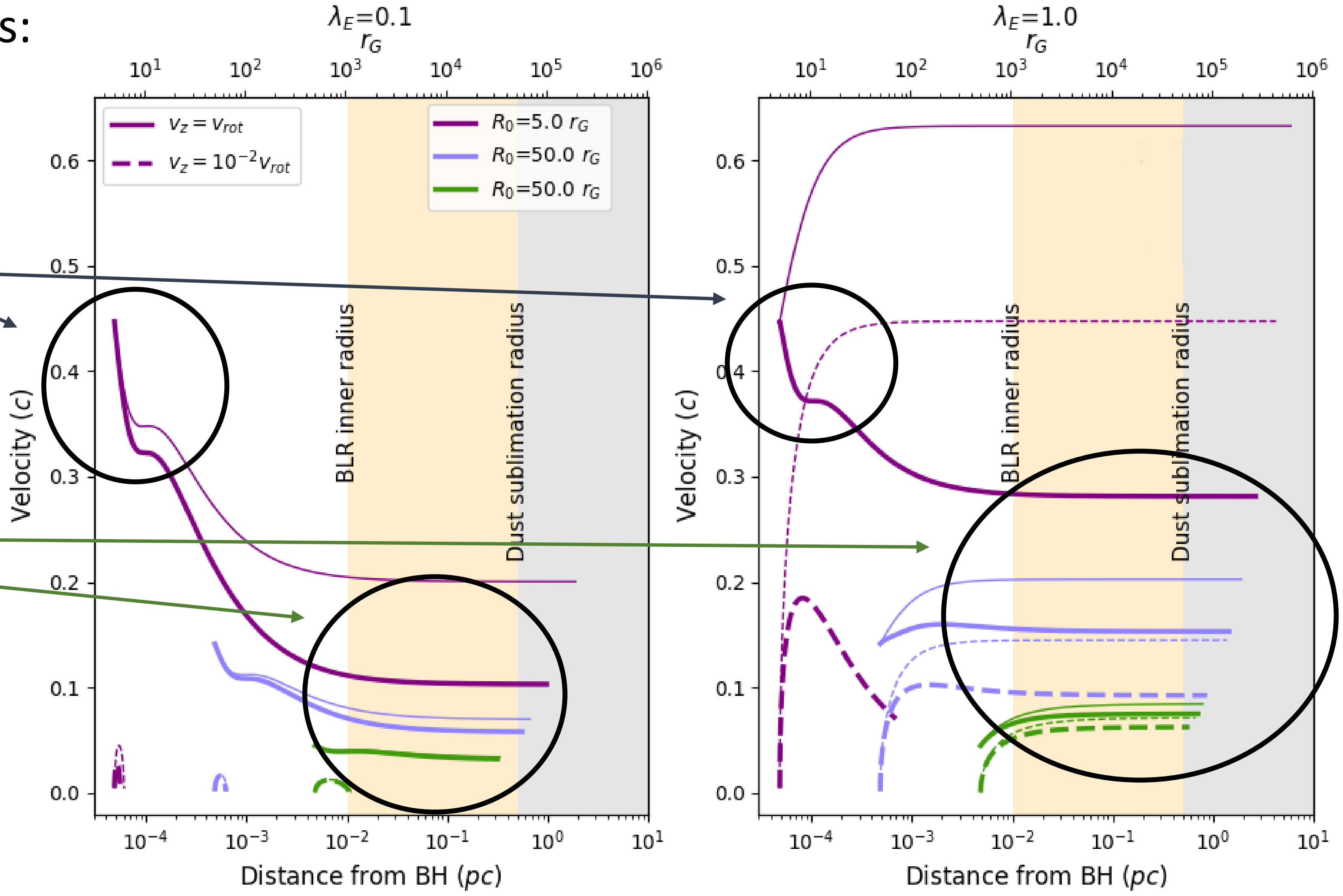


Relativistic treatment:

Slower wind, up to 0.1 c (l) and 0.3 c (r) (thick lines)

Three dimensional wind model

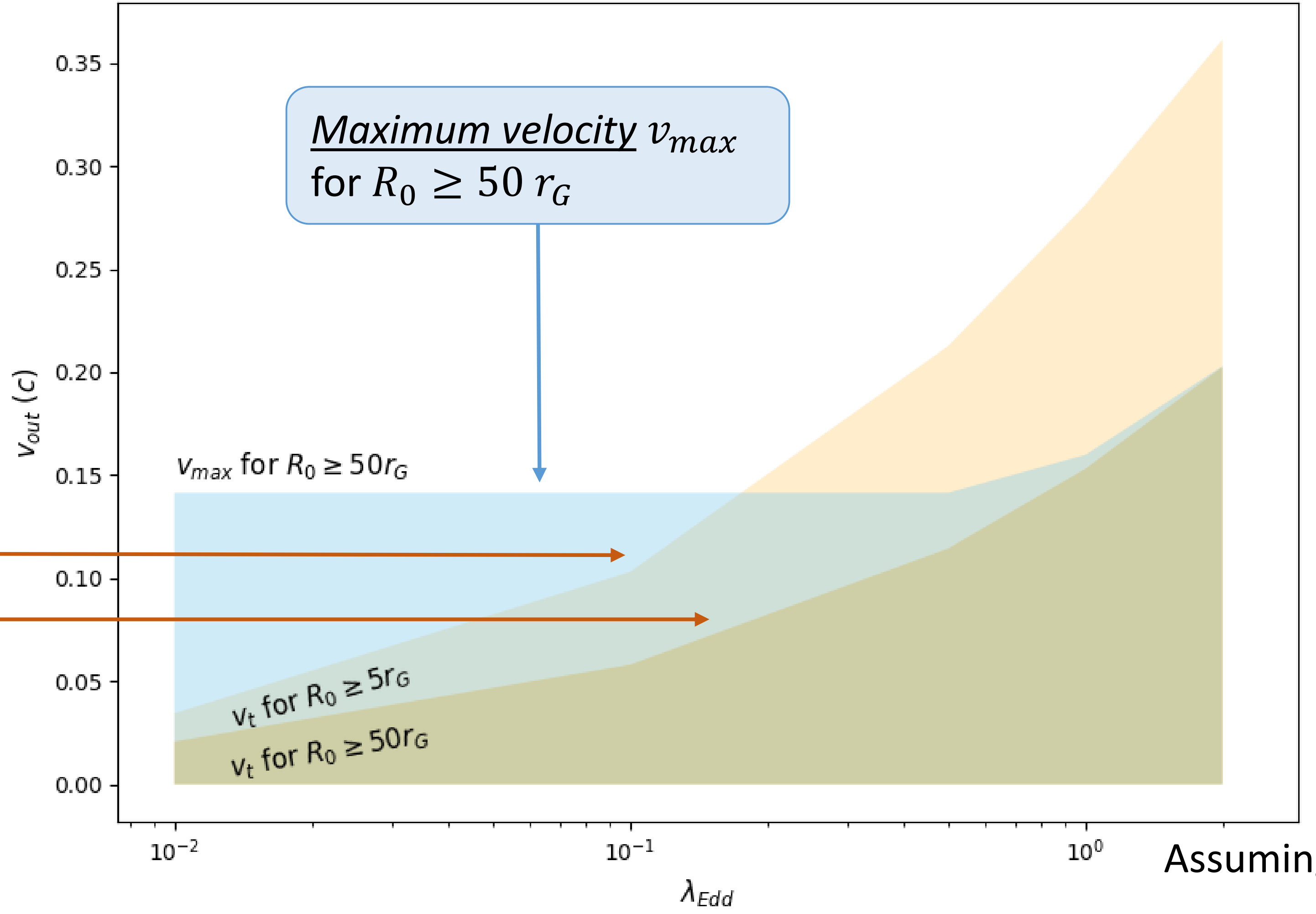
Two velocity regimes:



<u>*Maximum velocity*</u> v_{max}
Temporary, short-living phase (less than 1 day from the launch)

<u>*Terminal velocity*</u> v_t
Long-living, stable phase, lasting up to $1 - 10\ yr$.
Represents the observed velocity.

Limits for v_{out} via radiative driving



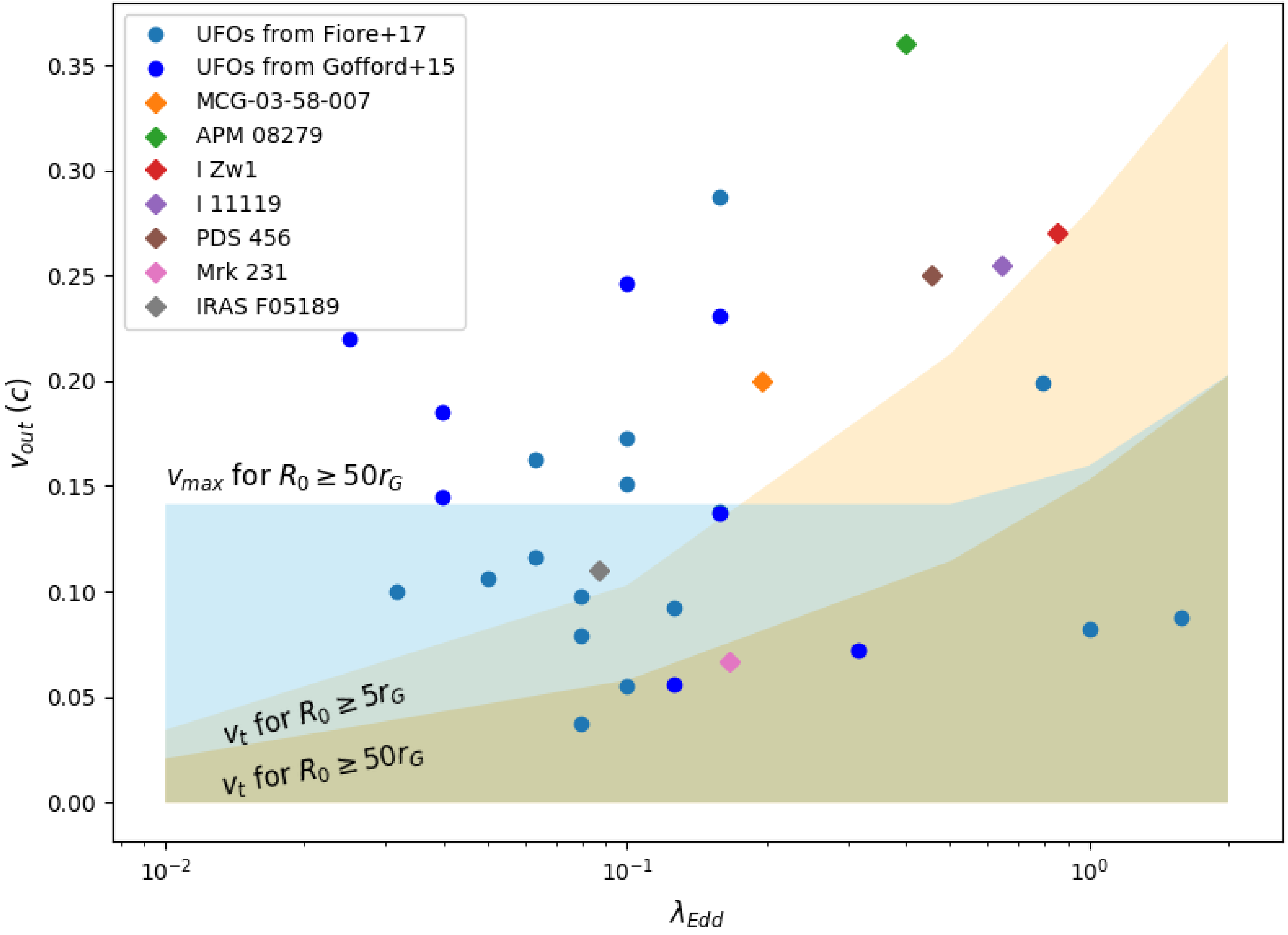
Maximum velocity v_{max}
for $R_0 \geq 50\ r_G$

Terminal velocity v_t
for $R_0 \geq 5\ r_G$:
for $R_0 \geq 50\ r_G$:

Assuming $v_0 = v_{rot}$

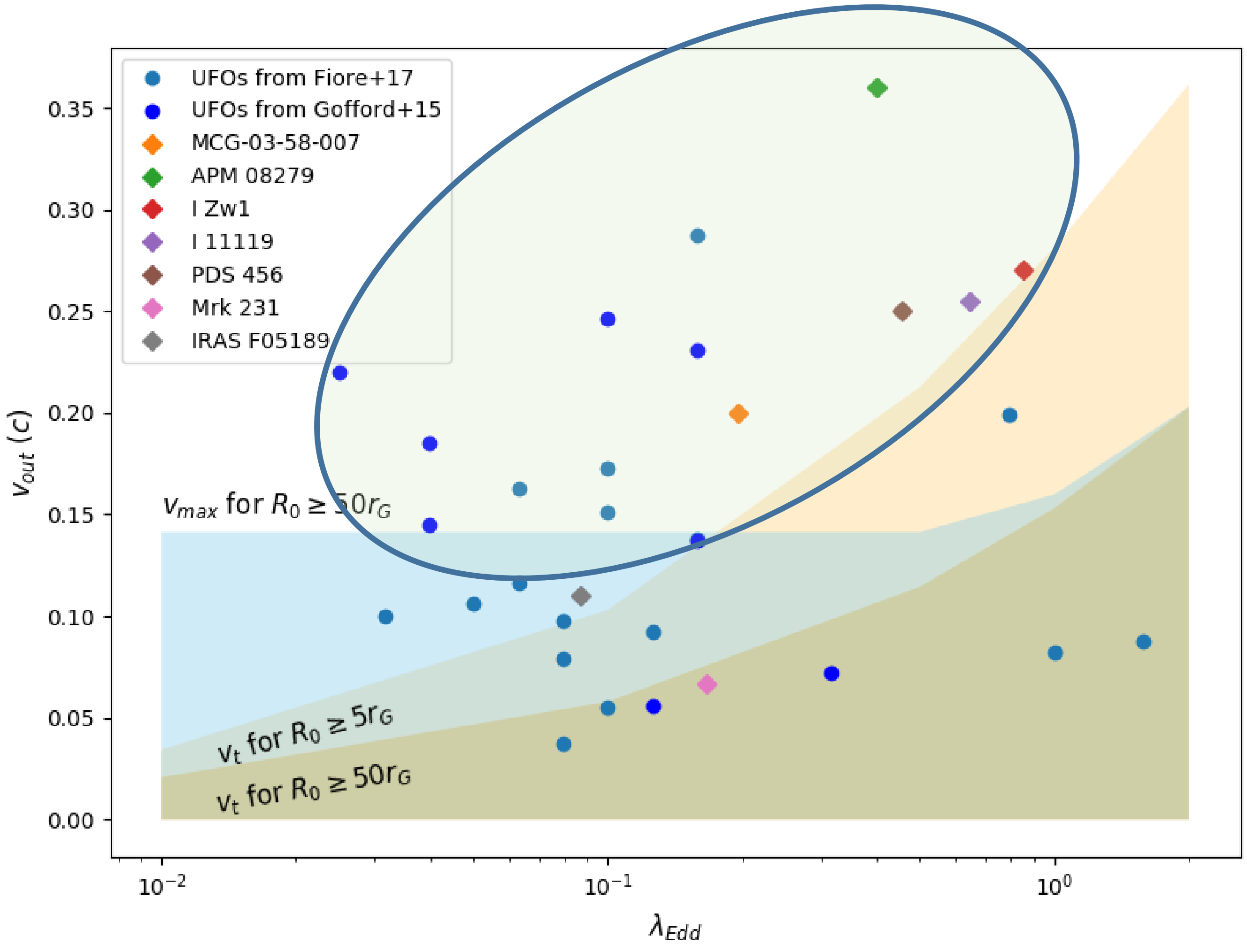
UFOs are typically launched at $r_0 > 50\ r_G$

Limits for v_{out} via radiative driving



Limits for v_{out} : evidence for magnetic driving?

These high velocities cannot be explained via radiative pressure!



<u>Magnetic driving can:</u>

Terminal velocities are $2 - 3 \times \; v_{max}$:

$$v^{\infty} = v_{rot}\mu^{-1/3} \approx v_{rot}\frac{R_A}{R_0}$$

μ is the wind mass loading factor

R_A is the Alfwen radius

$$\frac{R_A}{R_0} = \left[\frac{3}{2}(1 + \mu^{-2/3})\right]^{1/2}$$

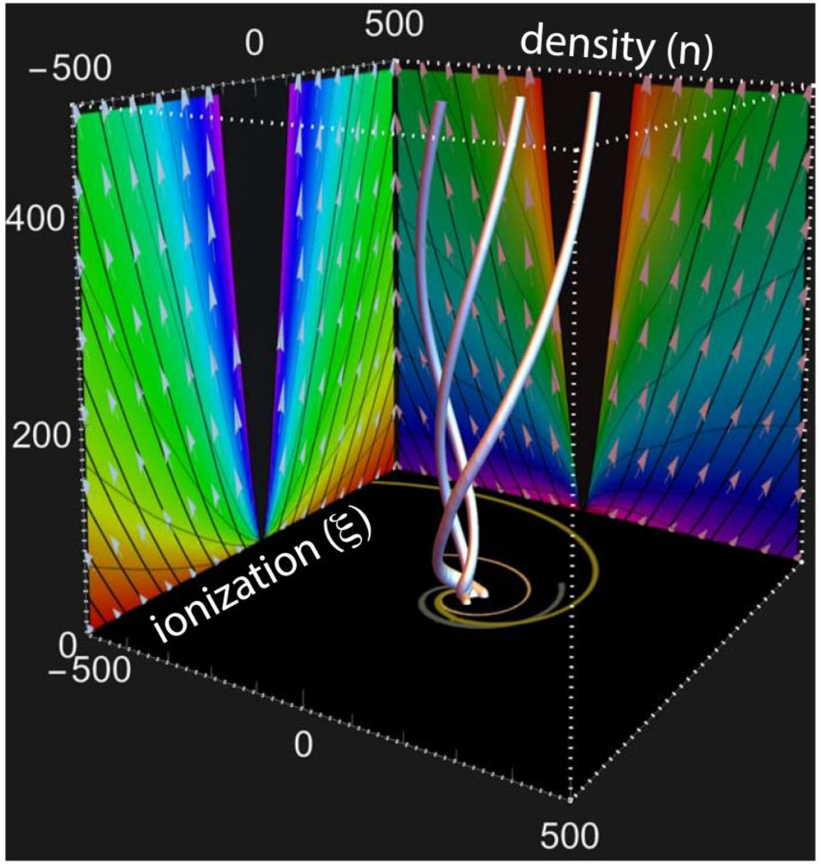
$\mu \rightarrow 0$: light and fast winds, driven by magnetocentrifugal force ($\boldsymbol{B_\rho}$, poloidal component)

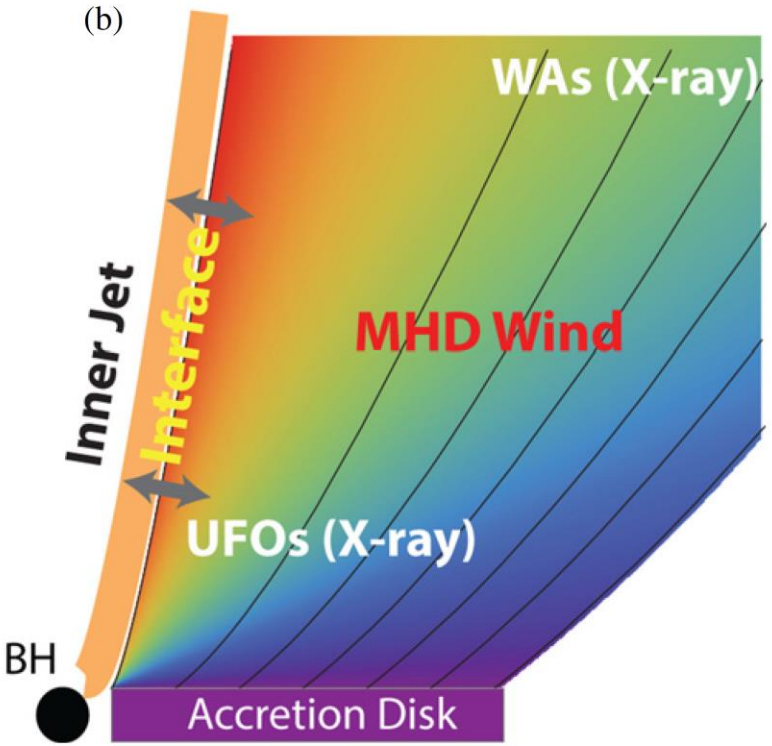
$\mu \rightarrow \infty$: heavily loaded winds, driven by magnetic pressure ($\boldsymbol{B_\phi}$, toroidal component)

Cui+19

Magnetic driving for UFOs

Light and fast wind along the poloidal component $\boldsymbol{B_\rho}$:





Pros:

- Good match with observed UFO properties (v_{out}, N_H, ξ)
- Unification with jets and warm absorbers

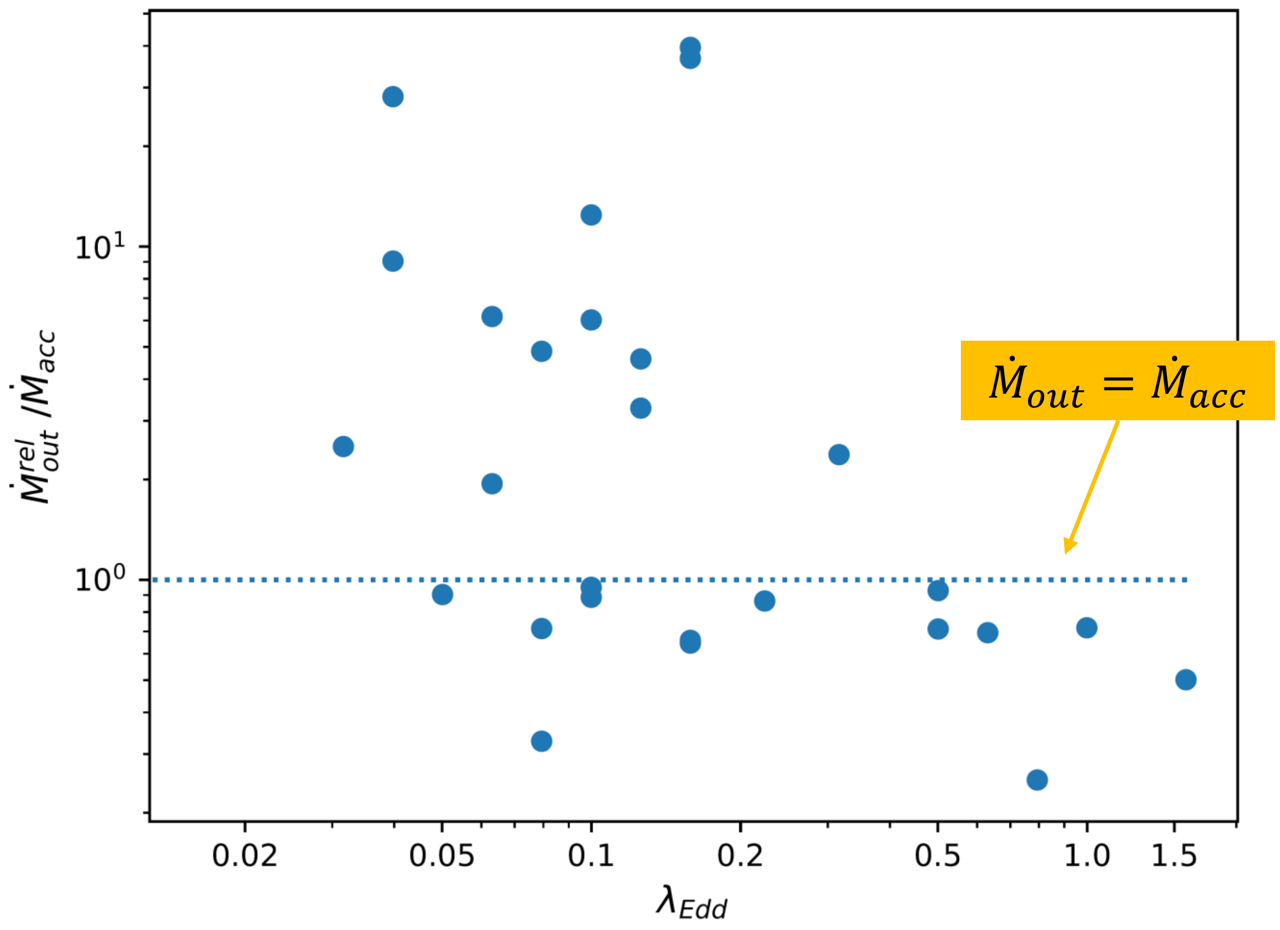
Cons:

- Unknown geometry of B field (self-similarity and time steady assumed)
- Unknown magnetic field strength

Fukumura+14,+18 – see also Blandford+77,+82

The UFO-accretion disc interplay

Mass outflow rate $\dot{M}_{out}$ vs mass accretion rate $\dot{M}_{acc}$:



$\dot{M}_{acc} = \frac{L_{bol}}{\eta c^2}$: mass accretion rate onto the BH

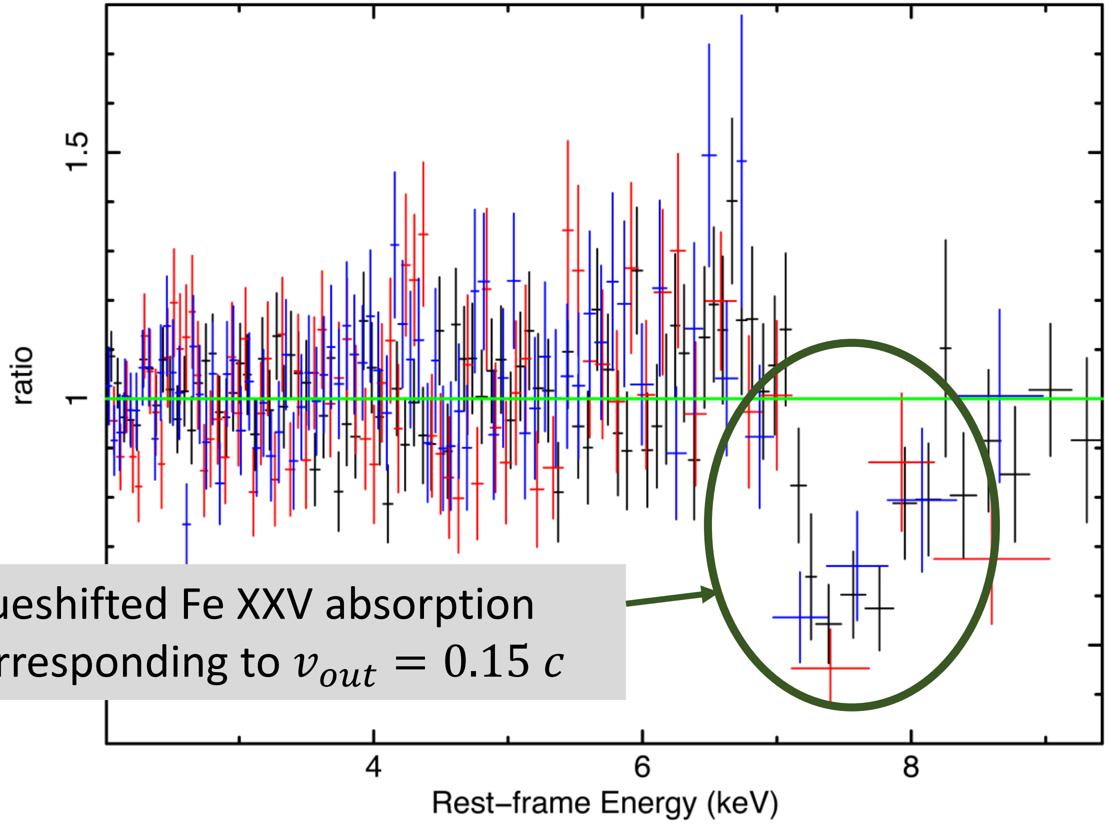
$\dot{M}_{out} \propto R_0 v_{out}\ N_H$: UFO mass outflow rate

Almost half of the sources have $\dot{M}_{out} > \dot{M}_{acc}$: *how can accretion be sustained?*

Luminari+20, see also Belloni+97

The UFO-accretion disc interplay: the case of PG1448+273

A new, powerful UFO from an high-accreting quasar: $L_{bol} = 0.75\ L_{Edd}$



Blueshifted Fe XXV absorption corresponding to $v_{out} = 0.15\ c$

The UFO arises at a small radius from the Black Hole:

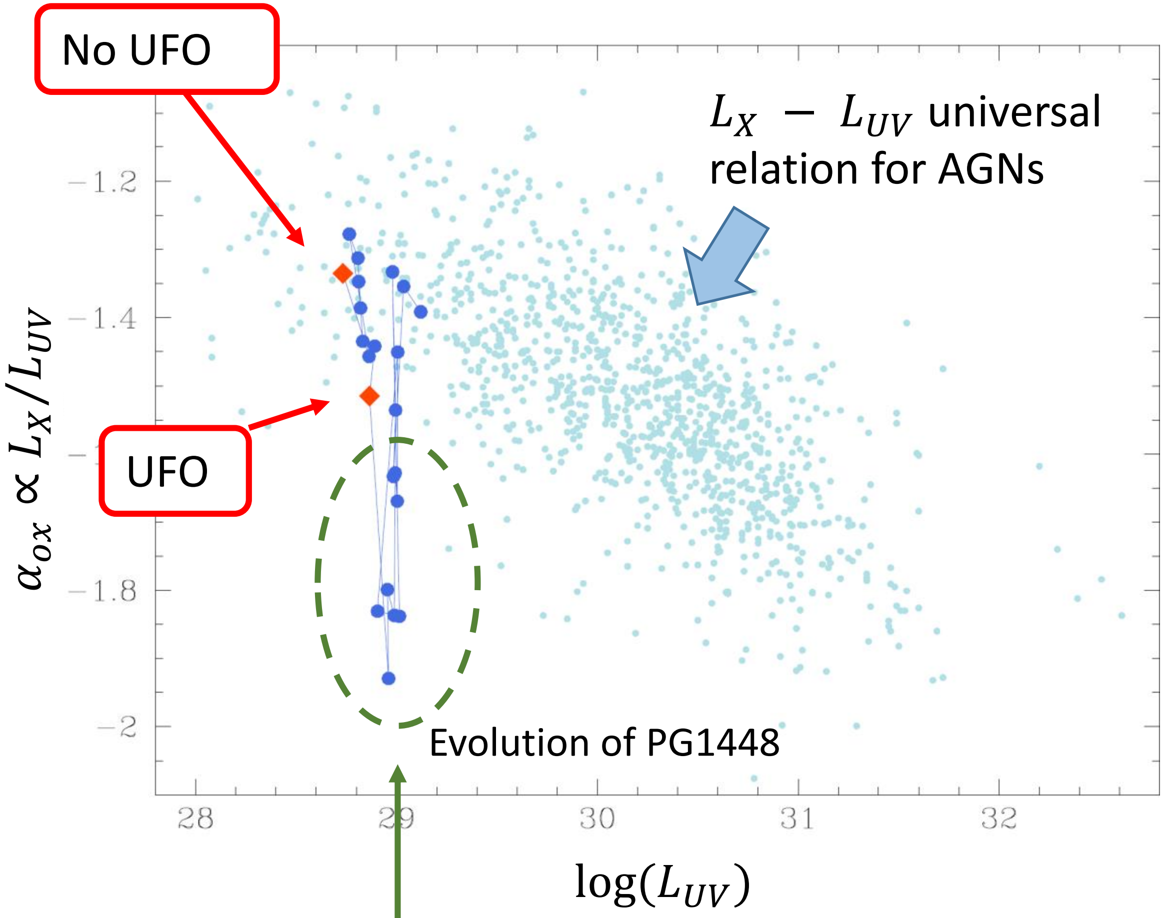
- $R_0 = 77\ r_G$
- $N_H = 4.5 \cdot 10^{23} cm^{-2}$
- $v_{out} = 0.15\ c$

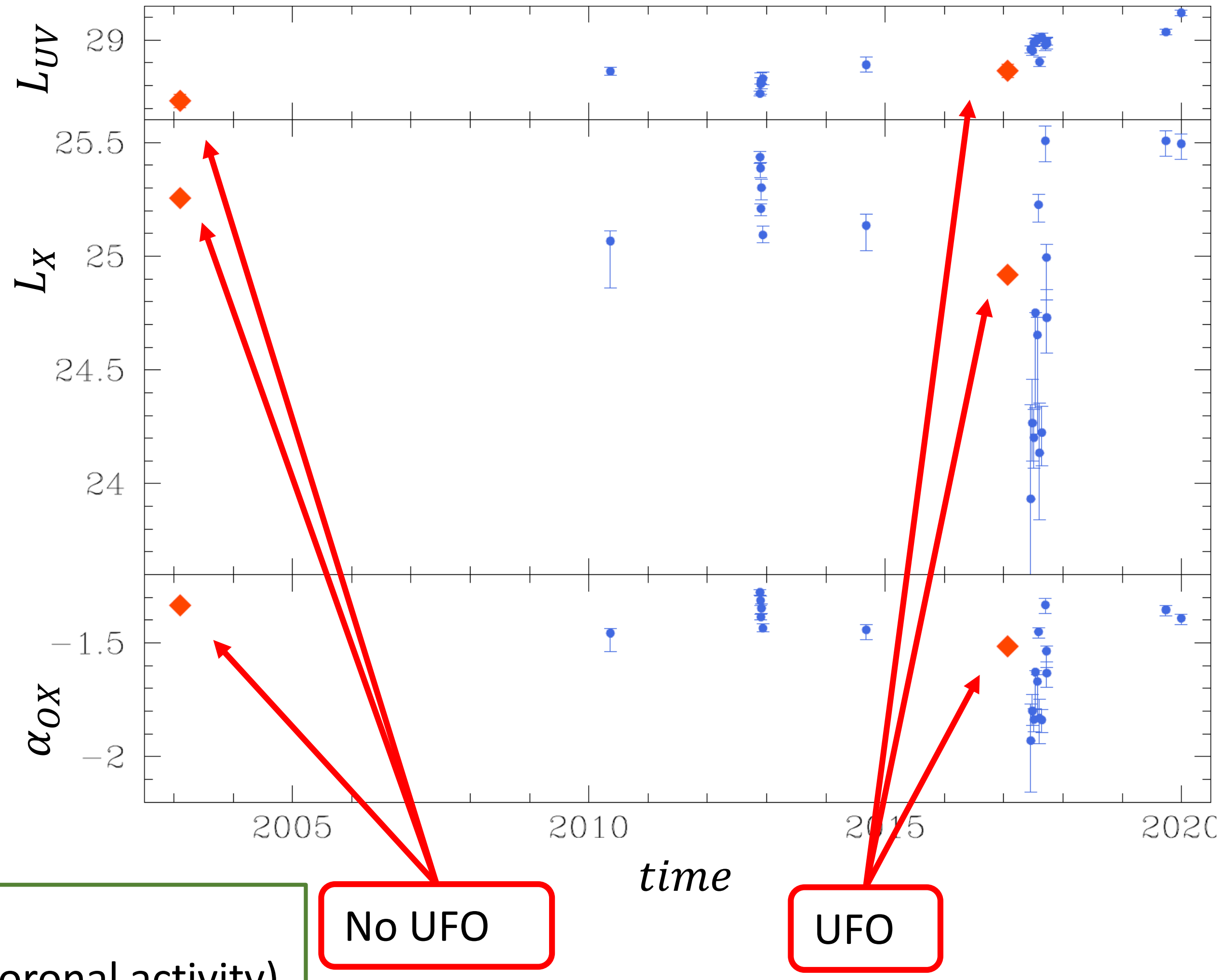
Extreme mass outflow rate:

$$\dot{M}_{out} = 2.0\ \dot{M}_{acc} = 1.5\ \dot{M}_{Edd}$$

Laurenti+20, see also Kosec+20

The UFO-accretion disc interplay: the case of PG1448+273

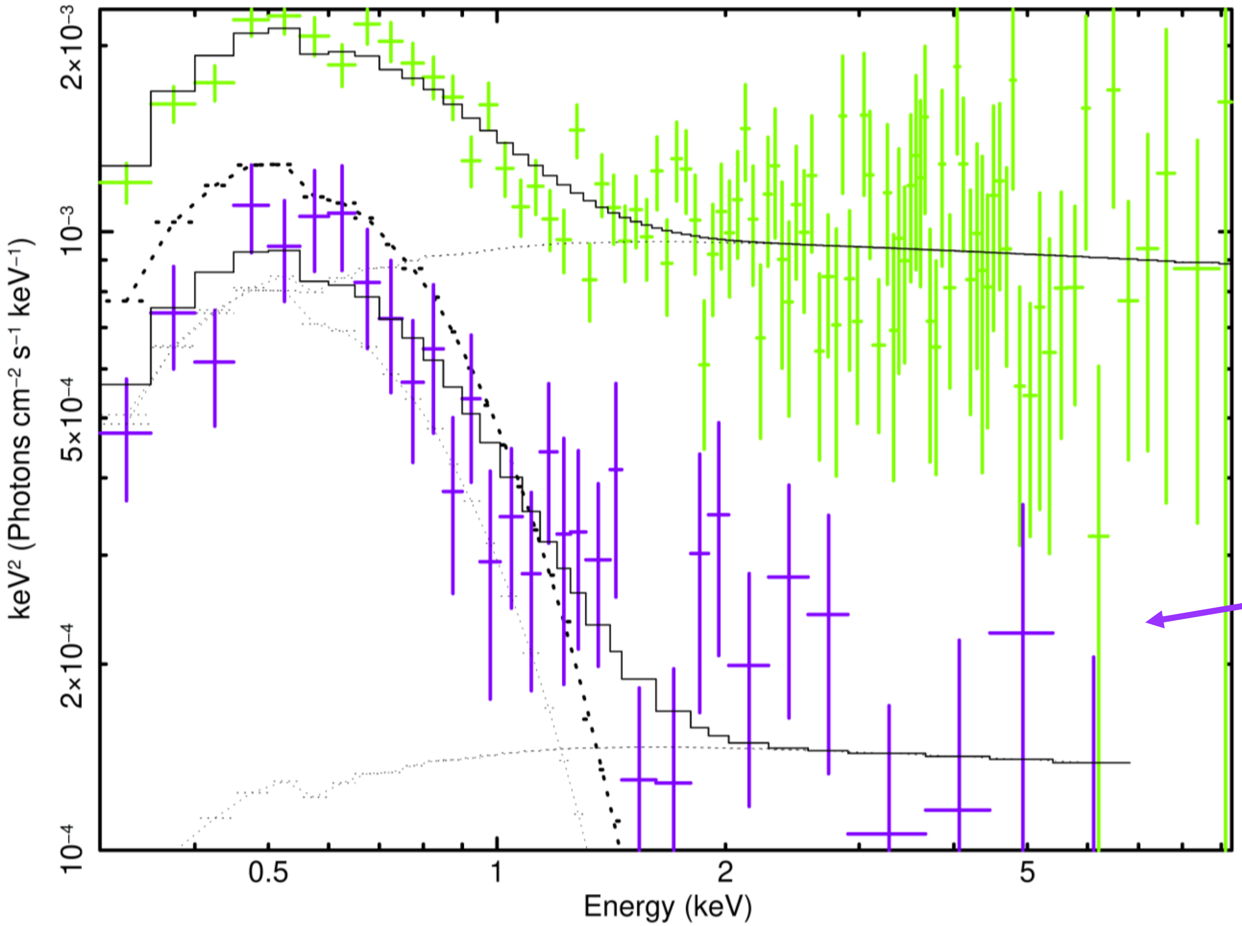


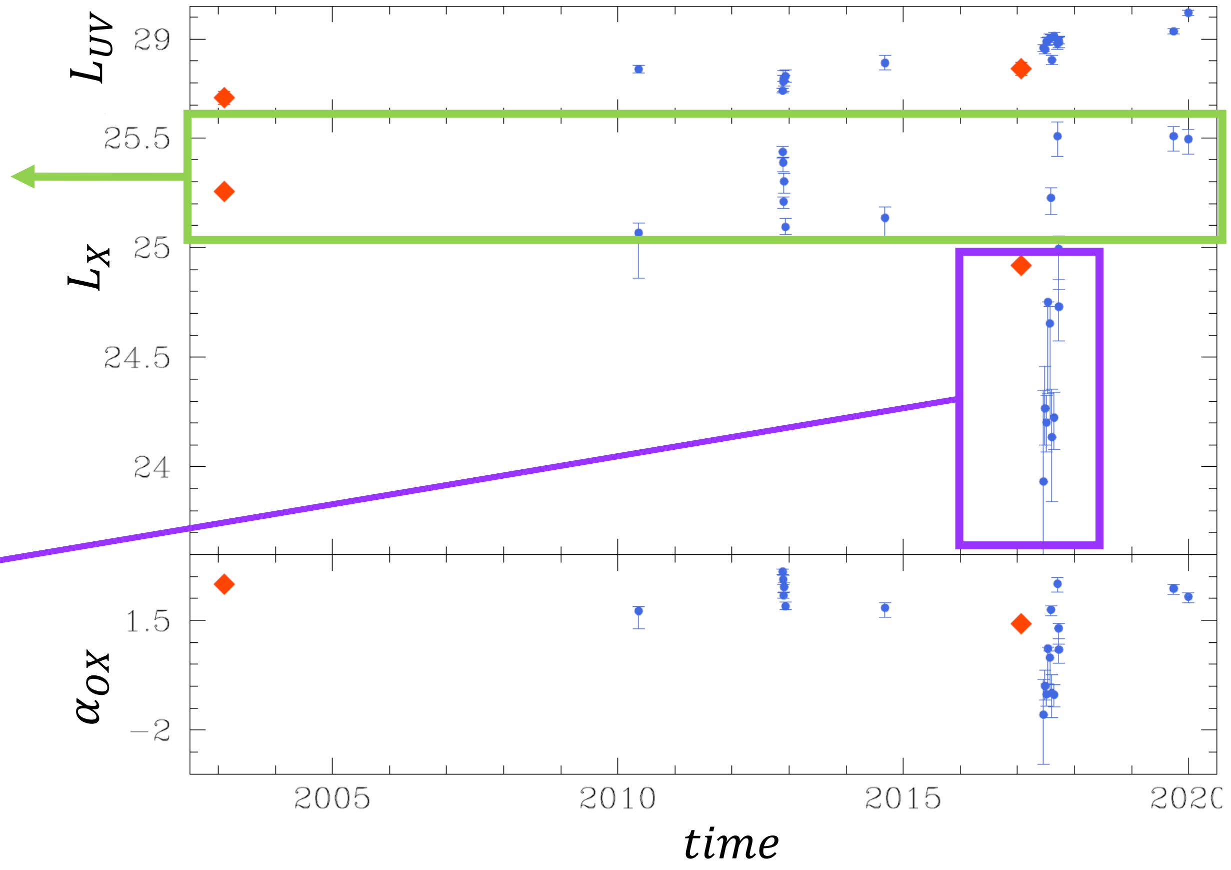


Huge drop in L_X after UFO appearance.
Evidence for a change of the X-ray spectral state (lower coronal activity)

Laurenti+20, sample from Chiaraluce+18. See also Vignali+03, Parker+17, Nardini+19, Zappacosta+20

The UFO-accretion disc interplay: the case of PG1448+273

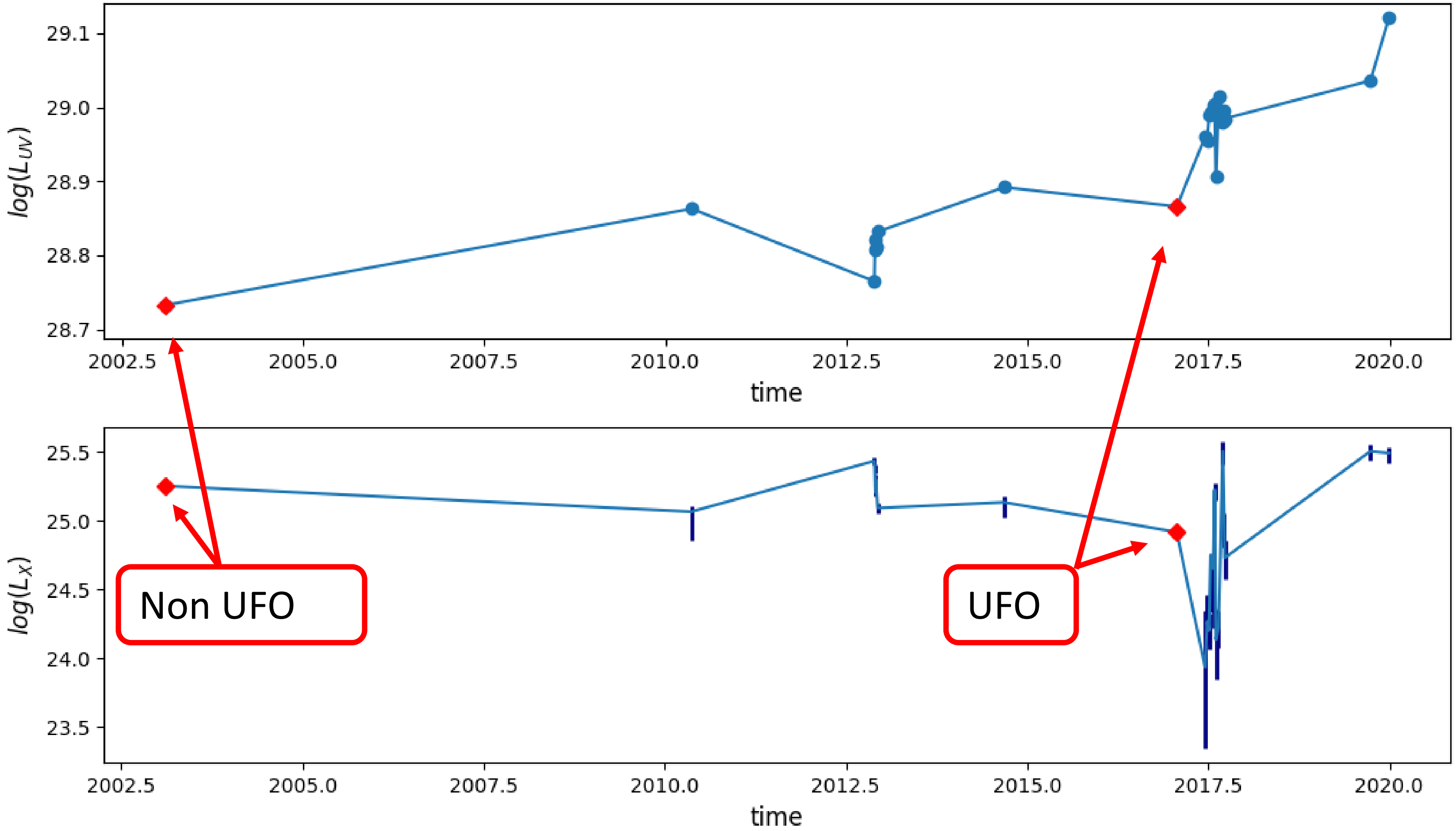




Huge drop in L_X after UFO appearance.
Evidence for a change of the X-ray spectral state (lower coronal activity)

Laurenti+20, sample from Chiaraluce+18. See also Vignali+03, Parker+17, Nardini+19, Zappacosta+20

The UFO-accretion disc interplay: the case of PG1448+273

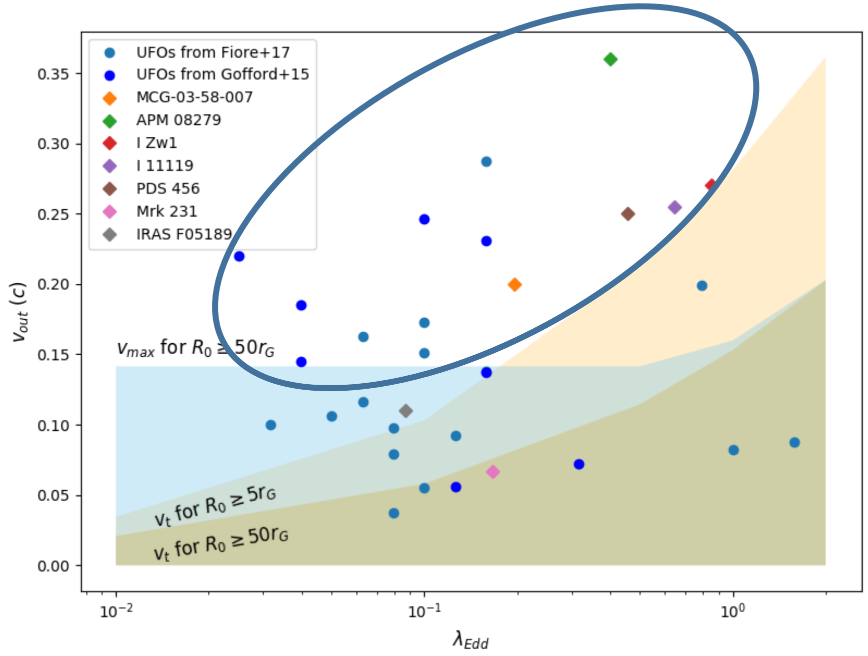


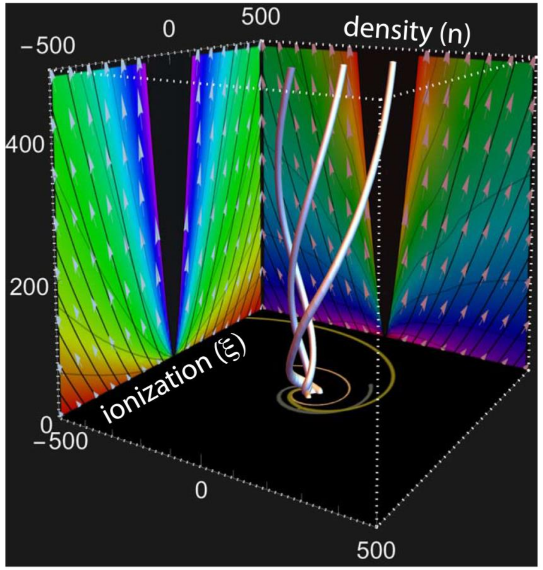
The UFO appears during an increase of L_{UV} : extra removal of angular momentum boosting the accretion?

Laurenti+20, sample from Chiaraluce+18. See also Vignali+03, Parker+17, Nardini+19, Zappacosta+20

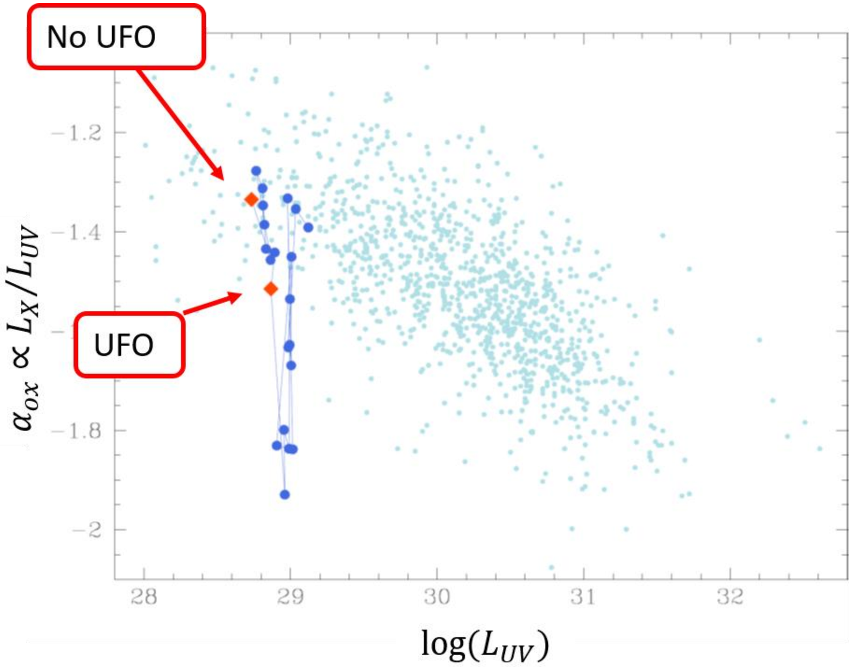
Conclusions

Radiative acceleration is naturally expected, but <u>it is not sufficient to explain the fastest observed UFOs</u>





Magnetic driving could play a major role
Different winds along B_ρ, B_ϕ



UFO may be a <u>systemic component</u> of the accretion process, allowing for <u>*extra removal*</u> of angular momentum from the disc

Ultra Fast Outflows from accretion discs

The (limited) role of radiation pressure and the evidence for magnetic driving

Thank you for the attention!

Università di Roma Tor Vergata

Alfredo Luminari - *alfredo.luminari@roma2.infn.it*

Osservatorio Astronomico di Roma — INAF Istituto Nazionale di Astrofisica