Accreting BH Timescales

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Abstract

A list of Accreting BH timescales, and how they scale with e.g. $M_{\rm BH}$. (See also "General_Physical_terms" and "Xray Terminology).

1 From, Lawrence 2016, ASPC: Accreting BH timescales

All Type I AGN - those where we can see the strong blue continuum and broad emission lines - are variable.[1] This is important because variability can provide indirect information on size scales that are otherwise unmeasurable. Suppose, for illustration, we take an AGN at a distance of 100 Mpc, and we assume that it contains a black hole of mass 10^8 $M_\odot$. The Table below shows the angular scale of well known AGN structures, in units of the Schwarzschild radius $R_S = 2GM/c^2$. The accretion disc, Broad Line Region (BLR) and the geometrically thick obscuring region sometimes known as the "torus" are all unresolvable by direct means, although as we will describe later, may be mappable by microlensing transits.

If the accretion disc is in a stable steady state, we might expect it to evolve gradually on the inward drift timescale set by viscosity, which is of the order 10,000 years (see e.g. **?**). However, instabilities of various kinds could give us much faster changes. The *light crossing timescale* $t_{lt} = R/c$, is the shortest timescale that we could possibly see, if for example one region has variations locked to those of another region by radiation heating or reflection. This is of the order hours, days, and years for disc, BLR, and torus respectively. The *dynamical timescale*, $t_{dyn} = \sqrt{R^3/GM}$, is the shortest timescale on which we are likely to see physical changes in a region, and is of the order of days, years, and thousands of years for disc, BLR, and torus respectively. (Free-fall time is roughly the same and orbital timescale is 2π times longer.) More realistically, perturbations may transmit across a region on the sound crossing timescale $t_{snd} = R/v_{snd}$. This is somewhat model dependent but is of the order of years for the accretion disc. Note what I mean here is the global time to cross the whole region. Local hot spots could grow on the timescale it takes sound to cross the vertical height of the disc, which could be 1–3 orders of magnitude faster. Somewhat related is the "thermal" timescale t_{therm} which is roughly the time it takes for for energy to dissipate within the disc, i.e. it is a kind of response timescale to a spike of energy input. This is model dependent of course, but some standard formulae are given in **?** and **?**. It is of the order of days for the inner disc and years for the optical disc. The analogous "response" timescale for the BLR and for the obscuring region is actually the light-crossing time - the local response time to a change in photo-ionisation or heating is very short, but what we see is smeared out by the range of light travel delays.

Are these timescales relevant to what we actually see? The UV continuum changes on timescales of weeks[2], with an RMS of around $\pm 30\%$, which means trough-to-peak changes of up to a factor of two are not unusual. The variations in the optical continuum, BLR, and IR seem to track these variations with roughly the light-travel time delays suggested in the Table, together with a similar amount of smearing (see recent examples

[1] For simplicity, I am only going to talk about the UVOIR spectral region, ignoring X-rays.

[2] Here I am assuming an Seyfert-like object appropriate to our $10^8 M_\odot$ example.

AGN Structure	physical size	angular size	t_{lt}	t_{dyn}	t_{snd}	t_{therm}
Inner disc	5 R_S	0.1μas	1.4hrs	4.3hrs	1.3 yrs	18.7days
Optical disc	50 R_S	1μas	14hrs	5.7days	23 yrs	1.6yrs
Broad Line Region	1000 R_S	20μas	11days	1.4yrs	800 yrs	–
Obscuring Region	$10^5 R_S$	2mas	3.1yrs	1.4kyrs	350 kyrs	–

Table 1: The Lines

Name	Scaling
Viscous	M^{α}

in **?**, **?**, and **?**). This strongly suggests that almost all the changes we see on the relevant timescales represent reprocessed emission driven by changes in the very central regions. The conventional explanation for many years has been that the driving power is from the X-ray source (e.g **?**), but in many cases this does not work in either energy budget or correlation terms (see **?** and references therein). A good alternative for the driving power is the (unseen) EUV peak of the very inner accretion disc.

The amplitude we see in the optical continuum on these ∼week timescales (around 3% RMS) is much smaller than that seen in the UV variations, which suggests that a very blue variable component mixes with an unchanging, or slower changing, redder component. **?** argues that this variable reprocessor is a system of dense inner clouds surrounding the disc, rather than the disc itself.

The variations seen in the UV, which the optical and BLR emission track, seem to follow a red-noise or random-walk like pattern, increasing in amplitude to longer timescales, flattening at a characteristic timescale of the order tens of days. This timescale depends on the mass of the black hole (Collier and Peterson 2001). This characteristic timescale seems to match the thermal timescale of the inner disc, suggesting that variability is driven by some unknown stochastic process, filtered by the physical response of the disc (**??**).

Note that the changes we see in broad emission lines are also of the order weeks, tracking the changes in the UV photo-ionising source. This is much shorter than the dynamical timescale of the BLR, and means we are not seeing structural changes in this region. In the popular "local optimally emitting cloud (LOC)" models we will be lighting up different pre-existing clouds at different distances as the UV goes up and down (**??**), which is why the amplitude of line variations (the "responsivity") varies with line species - Ly α has a large amplitude and Mg II hardly varies at all (e.g. **?**). However, it is possible that on longer timescales we *will* see BLR structural changes - a point we will return to in section 5.3.

- **Mechanical:**
- **Viscous:**

Croom et al. (2004)

2 Accreting BH timescales and scalings

3 References

References

Croom S. M., Smith R. J., Boyle B. J., Shanks T., Miller L., Outram P. J., Loaring N. S., 2004, MNRAS, 349, 1397