Probing the origin of the two-component structure of BLR by reverberation mapping of an extremely variable quasar

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Context: The physical origins of components in the unified model of quasars such as broad line region (BLR), dust torus, and narrow line region are unresolved. To learn more about them, we focus on studying Changing-State Quasars (also known as Changing-Look Quasars) as they offer the opportunity to observe structural changes associated with state transitions. This can give us insight into the origins of each quasar structure.

Aim: We aimed to understand the central core structure of one of the most variable Changing-State Quasars, SDSS J125809.31+351943.0, and how it changes before and after the state transition.

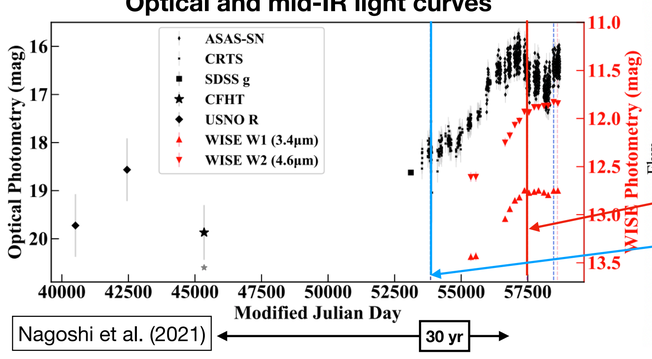
Method & Result 1: We performed optical reverberation mapping to investigate the structure of the BLR and to measure the black hole mass. The results of the reverberation mapping show that the Eddington ratio crossed the value of 0.01 before and after state transition for the black hole mass of $10^{9.46^{+0.15}_{-0.19}}\mathrm{M}_{\odot}$.

Method & Result 2: We compared optical to X-ray spectral indices (α_{ox}) before and after the state transition to investigate the structure difference of the accretion disk. These variations in α_{ox} and the Eddington ratio were found to behave similarly to the state transition seen in X-ray binary systems.

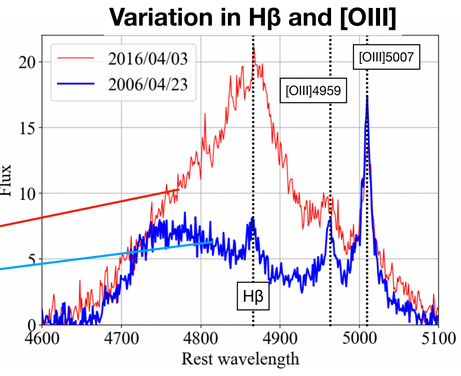
Discussion & Conclusion: From all the acquired information about the BLR and dust torus, we confirmed the existence of two distinct rotating/inflowing BLR components located near the dust torus, probably generated by different processes, which are the origins of the BLRs.

1 Target: CSQ J1258

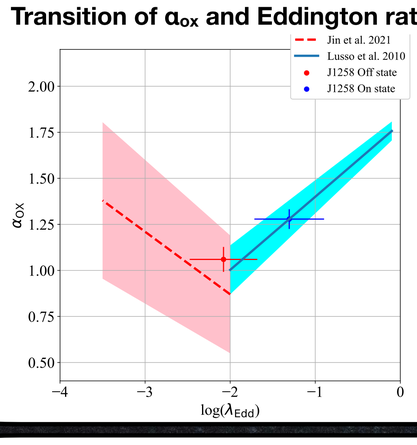
Optical and mid-IR light curves



Variation in Hβ and [OIII]



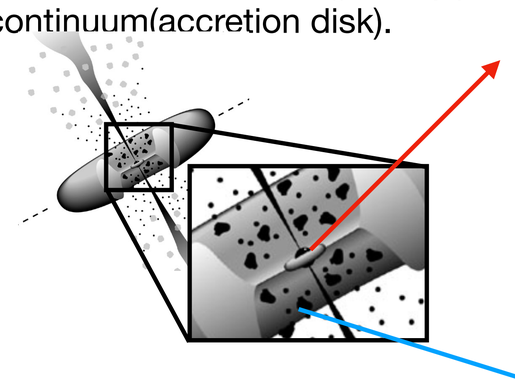
Transition of α_{ox} and Eddington ratio



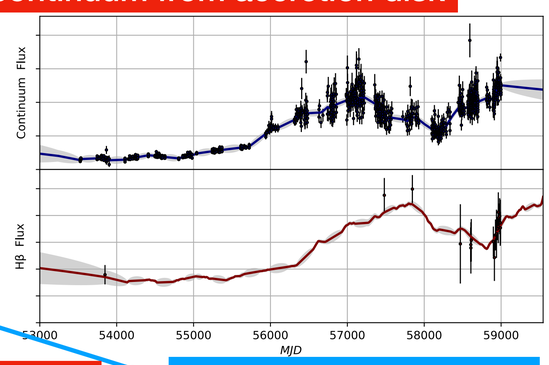
- The most significant variation (4 mags in 30 years)
- Redshift = 0.31
- Radio quiet: $\dfrac{f_\nu(\mathrm{radio})}{f_\nu(\mathrm{optical})} < 10$
- Accretion state transited object

2 Time Lag Measurement

We calculated time lag of Hβ(BLR) and WISE W1/W2(dust torus) to the continuum(accretion disk).



continuum from accretion disk



Line emission (Hβ) from broad line region

- Black Hole Mass: $10^{9.46^{+0.15}_{-0.19}}\mathrm{M}_{\odot}$

We mainly used Kyoto University's 3.8m telescope.

※We welcome collaboration

3 Feature of the variation in the BLR

We found two distinct components in the BLR of J1258. One is variable with the luminosity variation, and the other is less affected. The invariable component has a faster velocity and double-peaked shape.

$$f_{\mathrm{mean}} = \frac{1}{2(t_N - t_1)}\left(f_1(t_2 - t_1) + f_N(t_N - t_{N-1}) + \sum_{i=2}^{N-1} f_i(t_{i+1} - t_{i-1})\right)$$

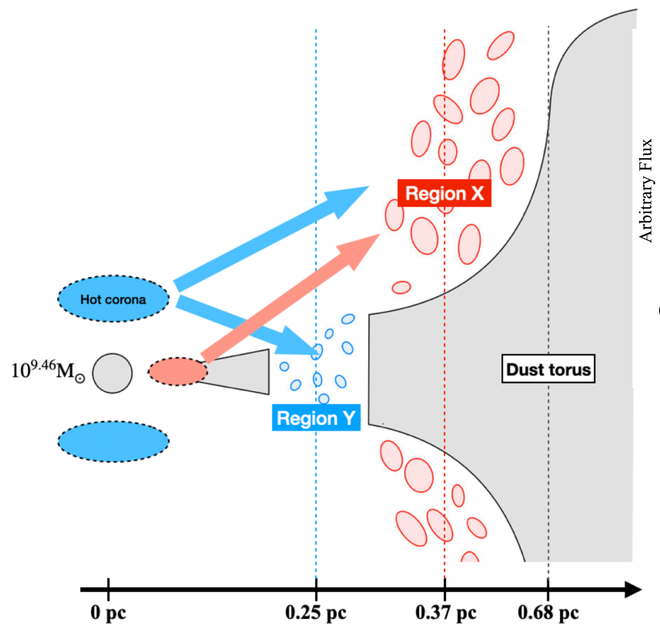
$$f_{\mathrm{rms}} = \left(\frac{1}{2(t_N - t_1)}\left((f_1 - f_{\mathrm{mean}})^2(t_2 - t_1) + (f_N - f_{\mathrm{mean}})^2(t_N - t_{N-1}) + \sum_{i=2}^{N-1} (f_i - f_{\mathrm{mean}})^2(t_{i+1} - t_{i-1})\right)\right)^{(1/2)}$$

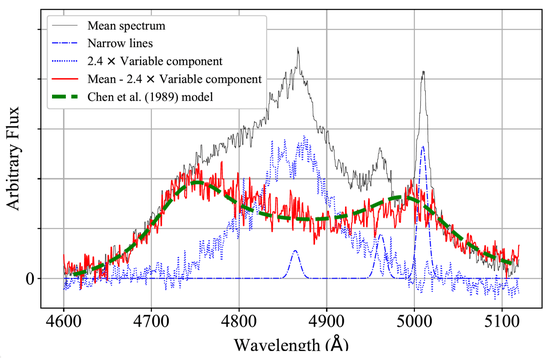
Visualizing invariable component

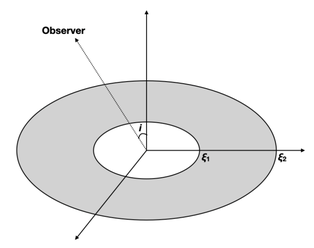
- Region X: Single peaked. Variable with state transition.
- Region Y: Double-peaked shape (disk?). Invariable.

4 Discussion 1: Estimated structure of BLR

We inferred the central structure of J1258 by considering the accretion disc's likely state transition (based on X-ray observations and Eddington ratio changes), the time lag in the dust torus and BLR, and all of the features seen in the BLR variability.





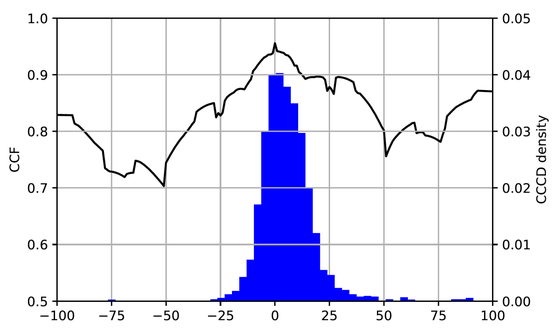


- Only Region X is variable if we consider that the luminosity of the inner part of the accretion disk changes due to state transitions.
- Region Y is not affected by state transitions because it is not radiated by the accretion disk but only by the coronal region.
- Region Y can be reproduced by disk model (right panel).

5 Discussion 2: Origin of BLR

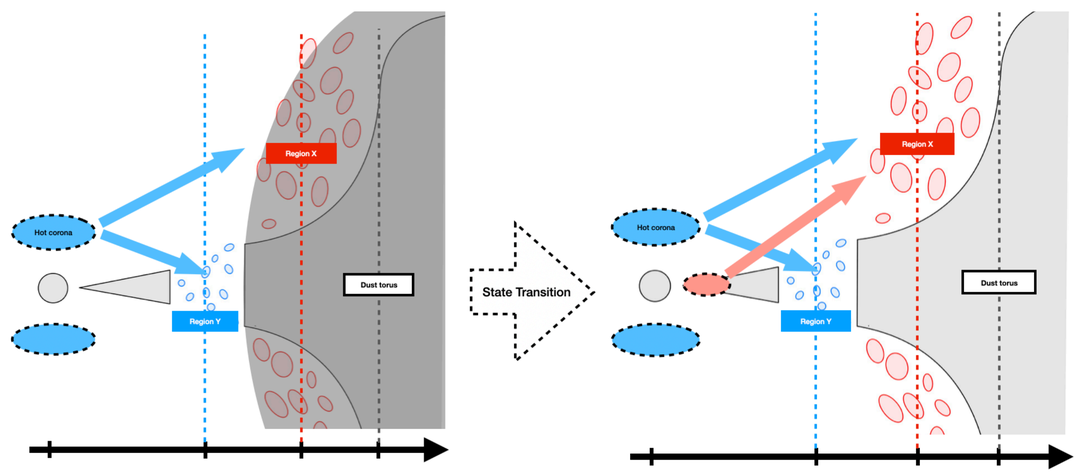
We infer the origin of the gas in the BLR by velocity-resolved RM.

Time lag between red and blue wing of Hβ



No significant lag indicates no significant radial motion

The absence of radial motion in Region X suggests that the gas in the torus ionized to BLR as the state transition of the accretion disk.



- Region X likely originated in the sublimated component of the dust torus by the brightening. <- Time lag was NOT detected between the red and blue wings of Hβ.
- Region Y does not exhibit any variation with the mass accretion rate, implying that the origin of the gas in Region Y is independent of the accretion disk.