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Photoionised Hβ emission in NGC 5548: It Breathes!

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Abstract. Emission line regions in active galactic nuclei and other photoionised nebulae should become larger in size when the ionising luminosity increases. We detect this 'breathing' effect for the Hβ emission in NGC 5548 by using Hβ and optical continuum lightcurves from the 13-year 1989-2001 AGN Watch monitoring campaign. To search for breathing, we use a parameterised model to fit the observed lightcurves in detail. Our model assumes that optical continuum variations track the ionising radiation, and that the Hβ variations respond with time delays, τ, due to light travel time. By fitting the data using a delay map, $\Psi(\tau, C)$, that is allowed to change with continuum flux, C, we find that the strength of the Hβ response decreases and the mean time delay increases with ionising luminosity.

Key words. galaxies: active – galaxies: individual (NGC 5548) – galaxies: nuclei – galaxies: Seyfert

1. Introduction

Rapid variations (on timescales of days) in the ionising luminosity emerging from an active galactic nucleus should cause the photoionised broad emission line region (BLR) to expand and contract, or 'breathe'. Light travel time within the system introduces time delays for any changes in the line emission. A gas cloud 1 light day behind the ionising source will be seen to brighten 2 days after the ionising source flux rises. Thus, we can use light travel time delays to measure the size of the region that is responding to variations in the ionising flux.

The Seyfert 1 galaxy NGC 5548 has been monitored by the AGN Watch group for 13 years from 1989 to 2001 (Peterson et al. 2002,and references therein). This provides optical continuum and Hβ lightcurves over a wide range of luminosity and so is ideal for searching for this 'breathing' effect.

2. 'Breathing' Model

It is generally assumed that the varying Hβ emission is driven by the continuum variability. At each time, t, we see a line flux, $L(t)$, that arises from a range of time delays, τ. In the usual linearised echo model, the line lightcurve driven by continuum variations, $C(t)$, is modelled as

$$L(t) = \bar{L} + \int_0^\infty \Psi(\tau)\left(C(t-\tau) - \bar{C}\right) d\tau$$

where τ is the time delay between the line and continuum variations and $\Psi(\tau)$ is the 'transfer function' or 'delay map' (Blandford & McKee 1982). We adopt a continuum background

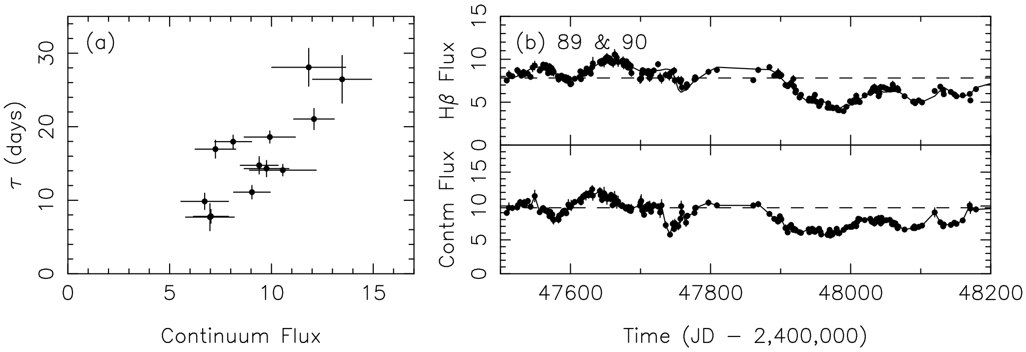

Fig. 1. (a) Time delay, τ, vs. mean continuum flux (at 5100Å, 10^{-15} erg s^{-1} cm^{-2} Å^{-1}) for yearly data from 13 year monitoring campaign of NGC 5548 by AGN Watch. Time delay is determined by a fitting model with a static delay map, and is the mean time delay of the delay map. (b) Continuum lightcurve and Hβ (10^{-13} erg s^{-1} cm^{-2}) lightcurve for the 1989 and 1990 section of the monitoring campaign of NGC 5548. Dashed lines indicate mean continuum and Hβ flux for 13 year lightcurves. Solid lines show the models used. The continuum model is just linearly interpolated between the data points, where as the Hβ model is the result of the 'breathing' model.

level, $\bar{C}$, at the mean of the observed continuum fluxes. $\bar{L}$ is a constant background line flux that would be produced if $C(t)$ were constant at $\bar{C}$.

The linearised echo model is appropriate for responses that are static, i.e. which do not change in time. In principle the delay map $\Psi(\tau)$ may change with time due to motion of gas within the system. Also, higher ionising luminosity changes the efficiency of reprocessing at each place in the region. Gilbert & Peterson (2003) found this for NGC 5548, where the Hβ response to continuum variations is non-linear. A simple analysis of the year-by-year lightcurves for NGC 5548 using cross-correlation also indicates that the time delay increases with increasing continuum flux (Peterson et al. 2002). The same effect is found when fitting a model with a static (i.e. independent of continuum flux and time) delay map that is Gaussian in $\ln\tau$ to the year-by-year lightcurves (Fig. 1(a)) and determining the mean time delay of this Gaussian. To account for these effects, we need to generalise the echo model by allowing the delay map to be luminosity-dependent, $\Psi(\tau, C)$. We model the delay map as a Gaussian in $\ln\tau$, and parameterise it so that $L(t) \propto C(t-\tau)^{\alpha}$ and $\tau \propto C(t)^{\beta}$. Fitting this model to the full 13-year lightcurves for NGC 5548 we find that long-term variations, on timescales of 1-2 years, are not accounted for by this basic breathing model. To improve the fit, we include a spline that follows the long-term variations, interpreting them as changes in the line emitting gas on these timescales. Fitting this model to the data (Fig. 1(b)) gives $\alpha = 0.65 \pm 0.02$ and $\beta = 0.14 \pm 0.03$, showing that the strength of the Hβ response decreases and the mean time delay (and hence mean size of the emitting gas) increases with ionising luminosity.

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References

Blandford, R. D., & McKee, C. F., 1982, ApJ, 255, 419
Gilbert, K. M., & Peterson, B. M., 2003, ApJ, 587, 123
Peterson, B. M., et al. 2002, ApJ, 581, 197