First spatially resolved black hole mass of quasar 3C273 using optical interferometry

S. Rakshit[1], R. Petrov[1], F. Millour[1], M. Vannier[1], A. Meilland[1], A. Marconi[2], G. Weigelt[3]

[1]Laboratoire Lagrange, UMR 7293, Université de Nice-Sophia Antipolis, Observatoire de la Côte d'Azur, BP 4229, 06304 Nice Cedex 4, Nice – France; [2]Department of Physics and Astronomy, University of Florence, Largo Enrico Fermi 2, 50125, Frienze, Italy. [3]Max Planck Institute für Radioastronomie, Auf dem Hügel 69, 53121, Bonn, Germany.

Abstract

We present near-IR spatially and spectrally resolved long baseline interferometric observation of broad line region (BLR) of bight quasar 3C273 using AMBER instrument at vary large telescope interferometer (VLTI). This is the first spatially resolved observation of a BLR of a quasar. Our observation suggests a large BLR extended beyond the dust sublimation radius. A 3D geometrical model and Bayesian model fitting of the data shows Paα emission line size is 2142^{+43}_{-39} lds, 4 times larger than optical reverberation mapping (RM) observation, and clouds are orbiting in Keplerian orbit in the presence of a significant turbulence velocity. The estimated black hole mass is $4.8^{+0.20}_{-0.17}\times10^8$ M_{sun}, which implies a virial factor of about 3. This means BH mass estimated using f=5.5 in RM could be overestimated by a factor of 1.7.

Introduction

The Broad line region (BLR) in quasars provides unique option to study the BH growth and the accretion mechanism. Since spatial resolution needed to observe them was beyond the capability of modern instruments, most of the study of BLRs is based on reverberation mapping (RM) spectro-photometric variability study where one uses time resolution instead of spatial resolution (Blandford & McKee 1982, ApJ, 255, 419). About 60 targets have been successfully observed using RM providing BLR size and luminosity (R-L) and black hole and luminosity (M-L) relations (Bentz et al. 2013, ApJ, 767, 27). However, RM technique is expensive for high luminous object where one needs to observe for several years thus often have large temporal gaps. Moreover, the BH mass estimated in RM uses a virial relation, $M=f\,r\,\Delta V^2/G$, that depends on scale factor f which is highly sensitive to the geometry and kinematics of the BLR (Rakshit et al. 2015, MNRAS, 447, 2420). Thus, one need to resolve the BLR spatially to constrain their geometry and kinematics estimating BH mass independent of f. This will provide an independent R-L and M-L relation as well as correlations between different BLR geometrical and kinematical parameters with luminosity or BH mass.

3C273 is a bright quasar at z=0.158 and K mag=9.9. It has a kilo-parsec Jet as shown in Fig. 1 with position angle 222°. Kaspi et al. (2000, ApJ, 533, 631) monitored 3C273 for 7 years estimating a Hβ BLR size of about 400 lds and a virial BH mass 8.86 ± 1.87 $\times10^8$ M_{sun} (Peterson et al. 2004, ApJ, 613, 682). It has inner rim size of 965 ± 405 lds from Keck interferometric (KI) observation by Kishimoto et al. (2011, A&A, 527, 121).

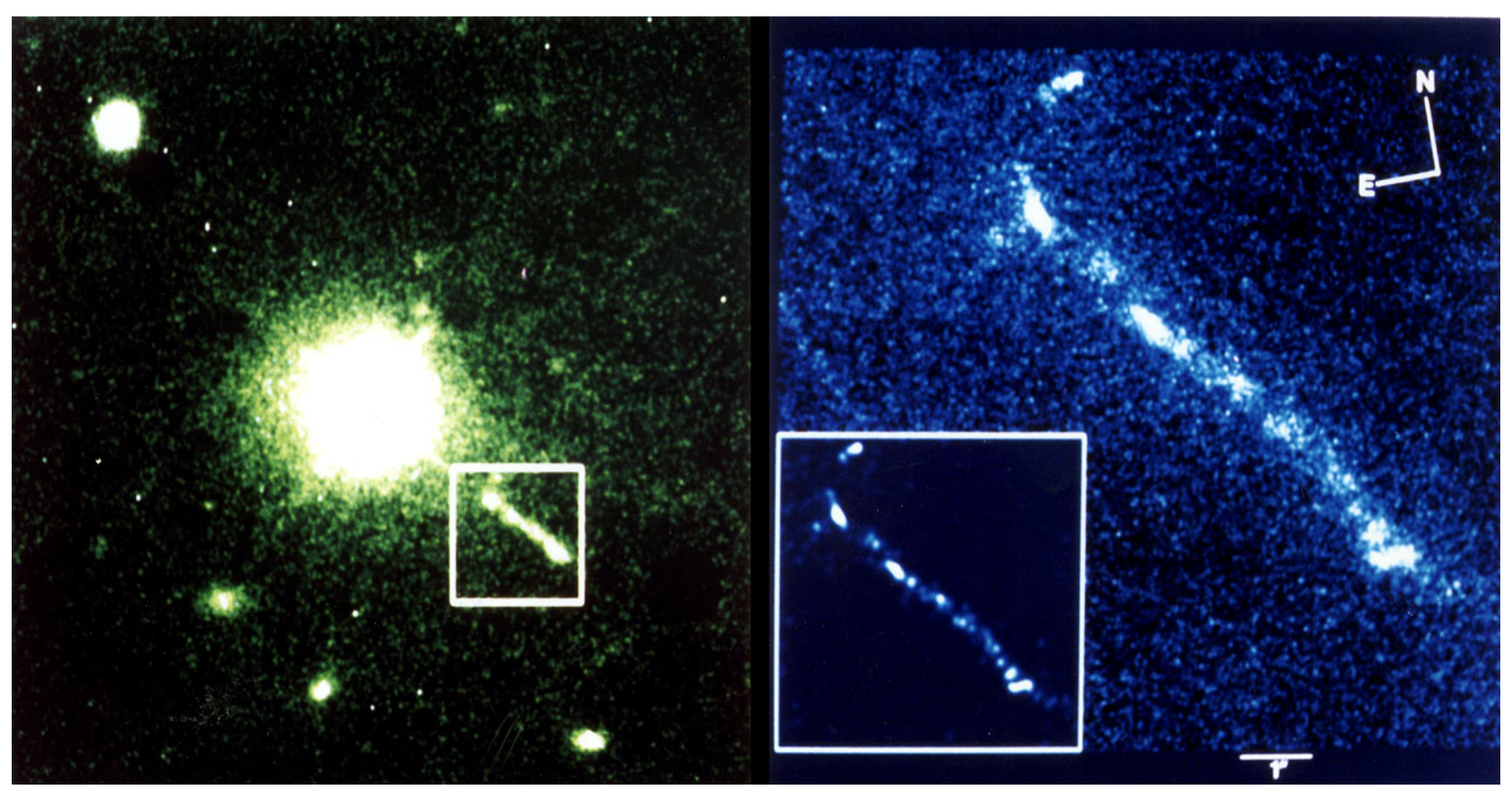

Fig. 1. 3C273 image from HST WFPC2/MERLIN observation (left) and MERLIN 18cm image showing long scale jet (right). Credit: Hubble space telescope (WFPC2)/MERLIN

Spatially resolved VLTI/AMBER observation of 3C273

We observed quasar 3C273 using VLTI spectro-interferometric instrument AMBER combining beams of three 8.2 m telescopes at VLTI (Figure. 2) offering maximum baseline length of 130m (UT1-UT4). It is the only quasar suitable to observe with AMBER/VLTI due to the magnitude limit of the instrument (K=8.5) and presence of strong emission line in K band. The x-λ interferogram, shown in left panel of Fig. 3, does not show any clear fringe pattern since the object is fainter than K=8.5. However, using "Blind mode" observation technique and a 2D-Fourier transform data reduction technique we clearly found the three well separated fringe peaks (right panel Fig. 3).

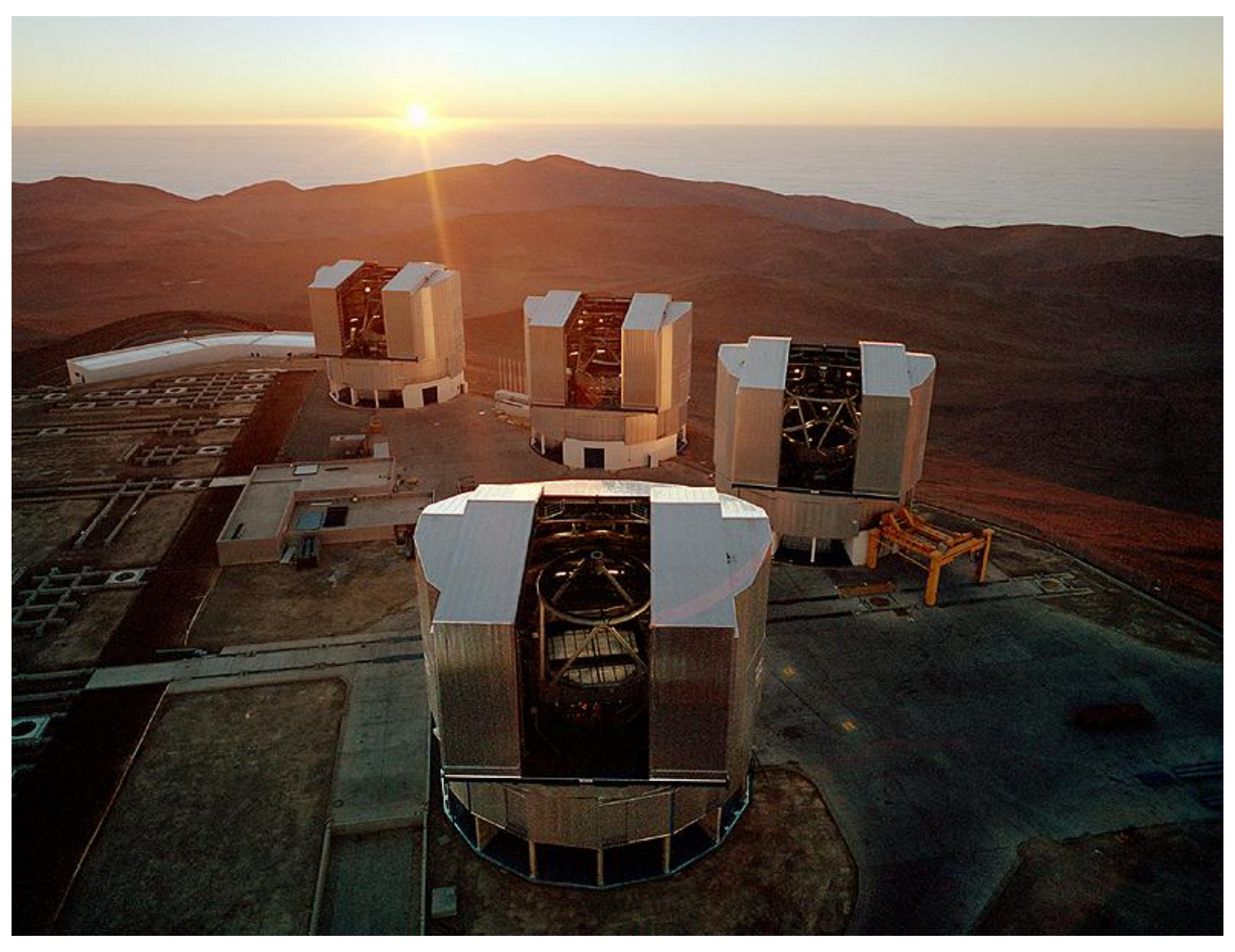

Fig. 2. VLTI four 8.2m (UTs) telescopes are shown. AMBER can combine 3 telescopes with a minimum baseline (UT1-2) length of 50m while maximum baseline (UT1-4) length is 130m.

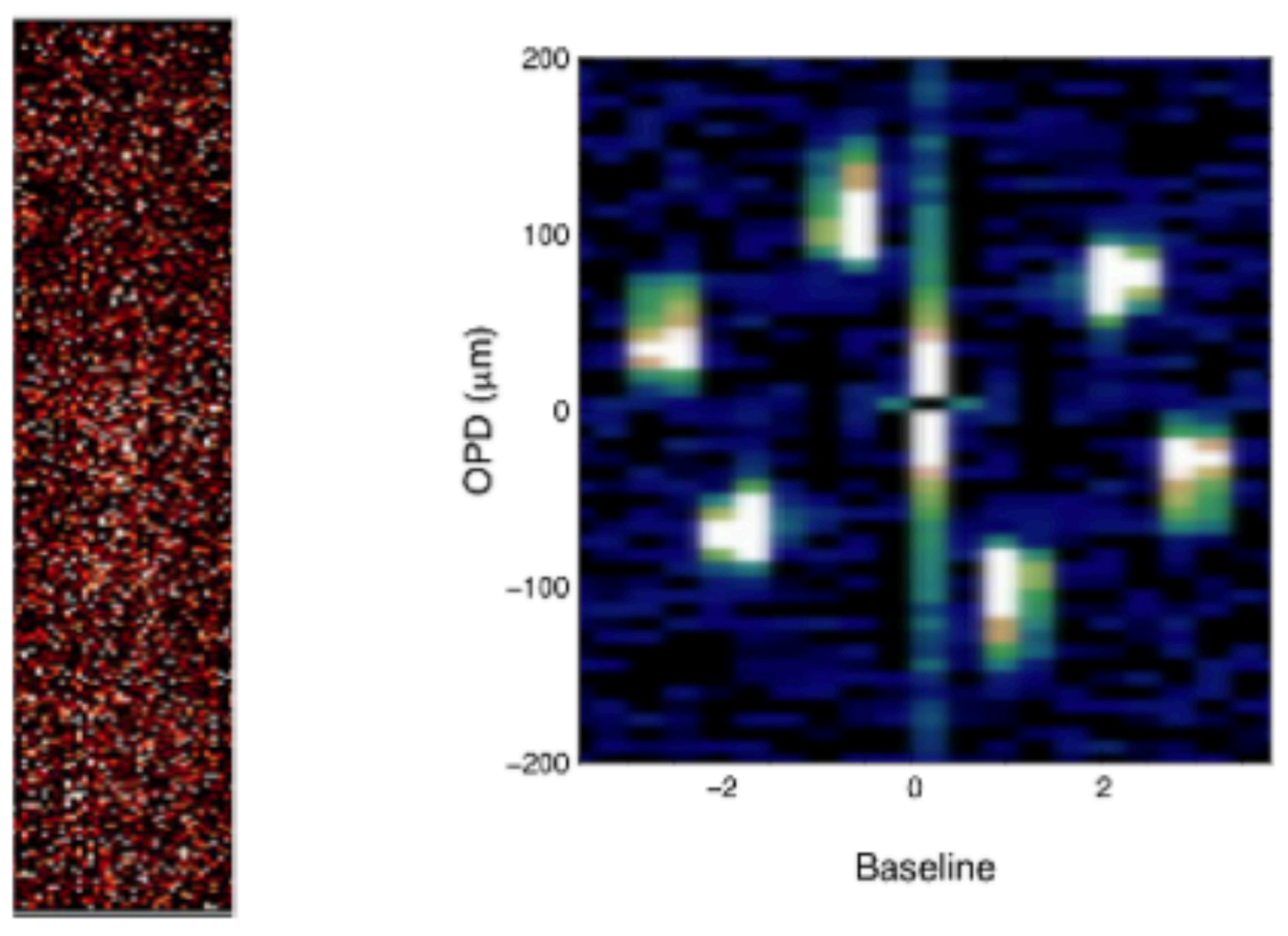

Fig. 3. The x-λ interferogram with fringes dispersed in the vertical direction is shown on the left. A 10' average of 2D Fourier transform is shown on the right panel. Three fringe peaks are clearly visible.

Observation results: spectro-interferometry

Fig. 4 shows observed emission line profile in blue and Fig. 5 shows the observed differential visibility (upper panel) and differential phase (lower panel) signature for 3 VLTI baselines in blue. It shows

- Differential visibility has a drop in the emission line with respect to the continuum and it increases with baseline length. The drops are: $V_{diff}(56m, 26°) = 0.98±0.03$, $V_{diff}(89m, 81°) = 0.94±0.04$ and $V_{diff}(130m, 60°) = 0.92±0.04$
- Differential phase is 0±2° and behavior is flat in all baselines.

Immediate conclusion: A BLR extended than inner rim of dust torus

Question: How to explain the differential phase?

Such a big BLR with Keplerian velocity will produce a strong phase signal.

A detailed modeling of BLR is needed!

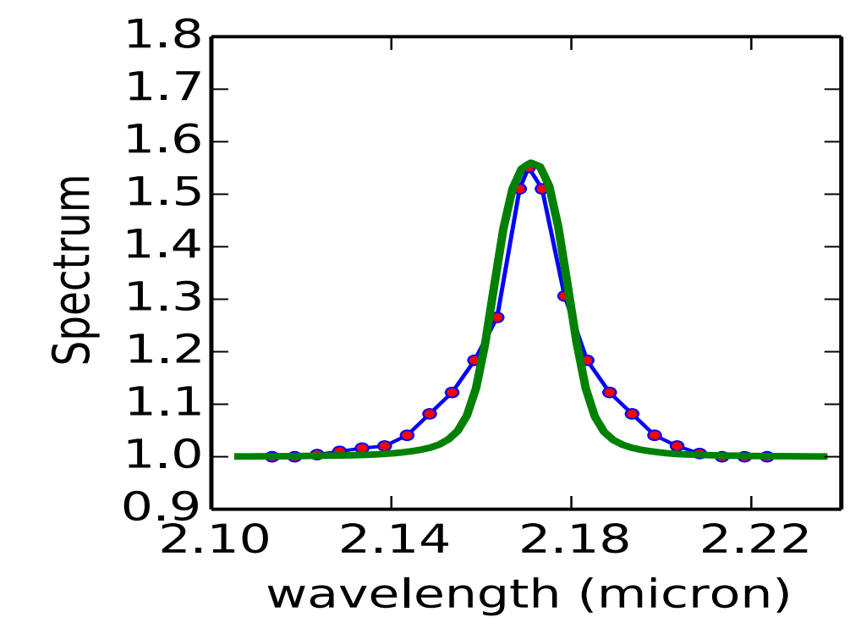

Fig. 4. Emission line profile is shown in blue and green is the model fit (see bellow).

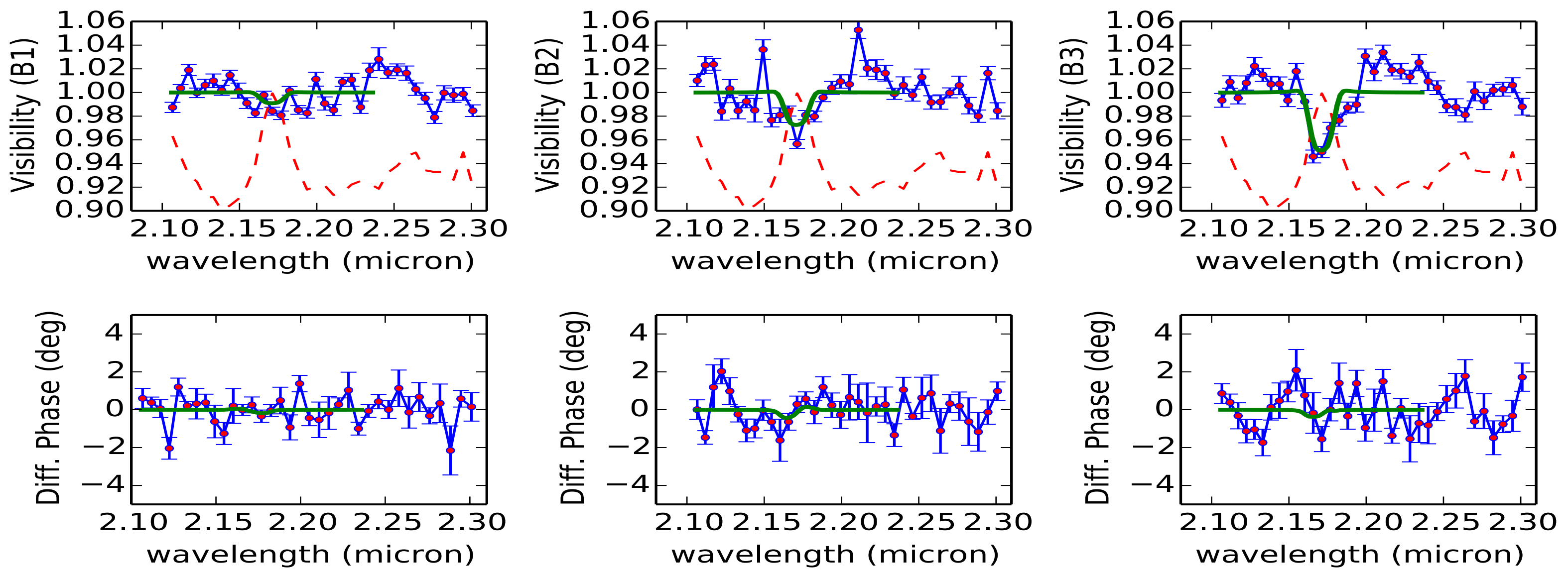

Fig. 5. Differential visibility (upper panel) and differential phase (lower panel) for there different VLTI baselines B1 (50m, 26°), B2 (89m, 81°) and B3 (130m, 60°) in blue color. Differential visibility has a drop with respect to continuum and decreases with wavelength while differential phase is flat in all baselines. The raw emission line profile is over-plotted (in red dashed line) to show the position of the line. The model is shown in green (see bellow for explanation).

A 3D geometrical and kinematical model

A 3D geometrical and kinematical model has been developed to simultaneously predict all interferometric and reverberation mapping signals. BLR is made of large number of line emitting clouds orbiting around a BH of mass M_{bh}:

- Position randomly picked from a Gaussian distribution of width σ_{blr}.
- Opening angle (ω) controls the geometry making it a spherical for 90° and flat disk for 0°.
- Inclination angle of the BLR is zero for face-on and 90° for edge on.
- Velocity is assigned in terms of Keplerian, inflow (or outflow) and random macro-turbulence (P_{turb}).
- A Bayesian model fitting approach using parallel tempered Markov Chain Monte Carlo (PT-MCMC) sampling algorithm is used.

The results of the model fitting is shown in Fig. 6. The 2D scatter plots and 1D histogram of the parameters probability distribution is shown. The corresponding model line profile is shown in Fig. 4. and interferometric signal is shown in Fig. 5 in green. The edge-on (left) and face-on (right) view of the model geometry is shown in Fig. 7. The corresponding 1D RM response function is shown in the left panel of Fig. 8 and RM window problem is shown in the right panel using 3C273 RM data from Kaspi et al. (2000, ApJ, 533, 631). The time window is not sufficient to observe such a long lag of 1514 days.

σ_{blr} (mas)	$\log_{10}(M_{bh}/M_\odot)$	$i(°)$	$\omega(°)$	P_{turb} (fixed)
$0.585^{+0.011}_{-0.012}$	$8.682^{+0.017}_{-0.018}$	$8.4^{+3.7}_{-2.2}$	$88.6^{+1.0}_{-1.5}$	1

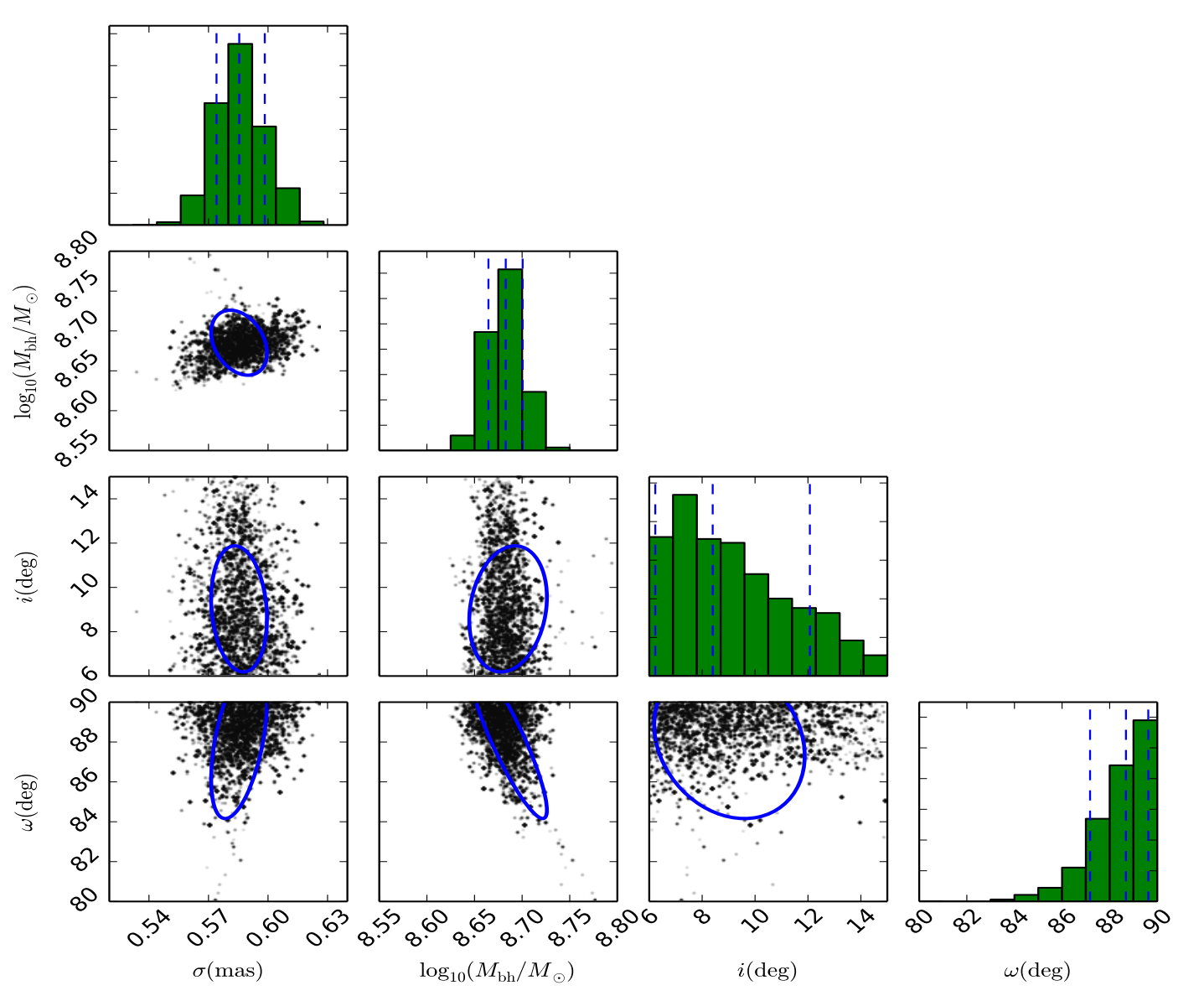

Fig. 6. Parameters probability distribution obtained from MCMC fitting with P_{turb} = 1. The scatter plots show the projected two-dimensional distributions. The histograms show the projected 1D distributions with dotted green lines representing mean and the 1σ uncertainties. From top-to-bottom and left-to-right, the panels show BLR width σ_{blr}, log10 (M_{bh}/M_{sun}), inclination i and opening angle ω.

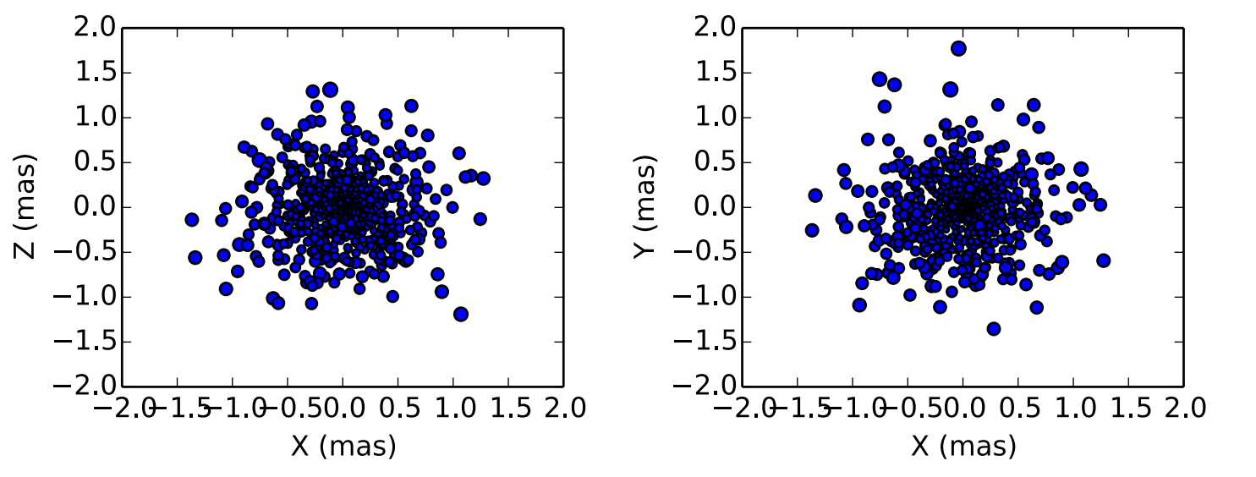

Fig. 7. Geometry of the BLR of 3C273. Left: BLR observed edge-on. Right: BLR observed face-on. In the plots, size of the clouds increases with the time-lag.

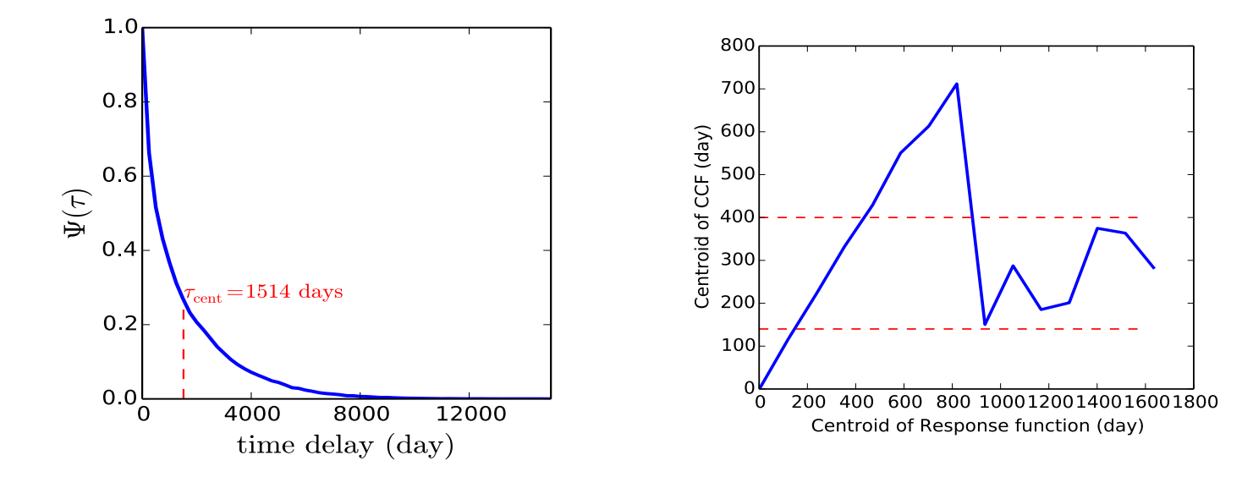

Fig. 8. Left: Model response function of the BLR. The red line shows the centroid of this response function, which is 1514 days. Right: Centroid of the CCF is plotted against the centroid of response function. The time lag can not be measured if the centroid of CCF is greater than 800 days for a 7.5 years observing campaign.

Conclusions

- A large BLR: a Gaussian of HWHM 2142^{+43}_{-39} lds extended beyond the inner rim.
- A response function centroid at 1514 days (4 times of Hβ size)
- Keplerian velocity with significant turbulence motion and a roughly spherical geometry close to face-on
- A SMBH of mass $4.8^{+0.20}_{-0.17}\times10^8$ M_{sun}
- A virial scale factor f=3 comparing our SMBH mass measurement with RM mass measurement from Peterson et al. (2004, ApJ, 613, 682).
- The BH masses estimated in RM technique using virial factor may be overestimated by a factor of 1.8 since f=5.5 is often used in RM
- A handful number of targets will allow to estimate a mean f factor and will provide an independent R-L relation and calibrate M-L relation in RM.

➢ Acknowledgement: SR acknowledge the support of ARIES, Manora peak, Nainital, India for providing local hospitality while writing this poster

➢ Contact: suvenduat@gmail.com