ReverbIR

Towards REVERBeration mapping in the InfraRed

M. L. Martinez[1], C. Kenyon[2], S. Rakshit[3] & K. Yano[4]

1. Universidad Nacional Autónoma de México, Mexico City, Mexico
2. The University of Melbourne, Melbourne, Australia
3. Observatoire de la Côte d'Azur, Nice, France
4. University of Tokyo, Tokyo, Japan

Reverberation mapping

Reverberation mapping techniques (see Figure 1) have been successfully applied to optical AGN spectra to produce radial density profiles and black hole mass estimates (Peterson 1997). Infrared spectra, however, remain a largely untapped resource due to the longer exposure times required for adequate resolution. By using the photoionisation code, Cloudy (last described by Ferland et al. 2013) and by comparison to previous work (see Korista and Goad (2000), hereafter KG00) we demonstrate that these techniques can be successfully applied to IR spectra.

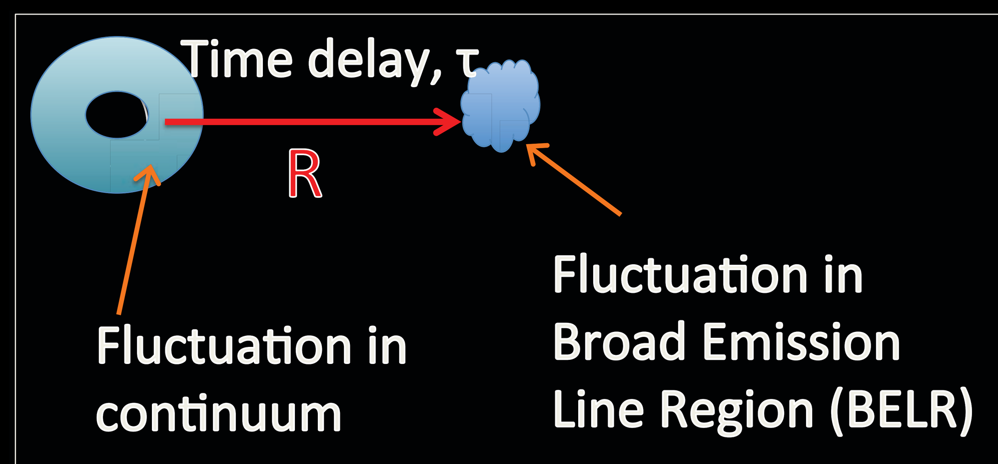


Figure 1: A basic model for reverberation mapping

Modelling with Cloudy

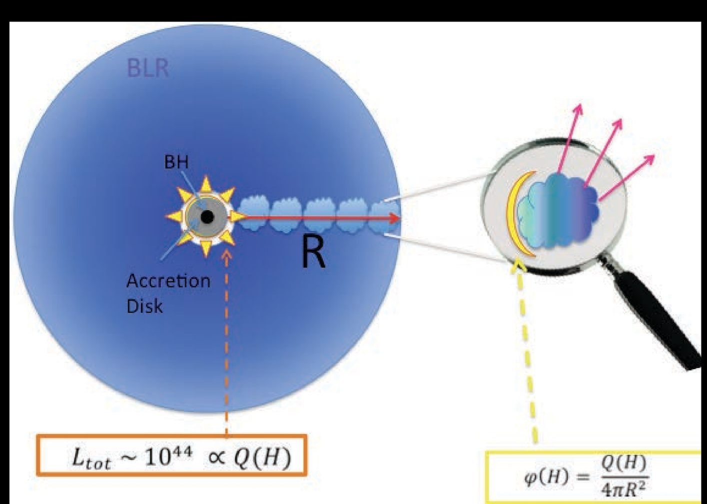


Figure 2: The LOC model and Cloudy

The BELR was modelled as a series of clouds extending radially from the accretion disk. The simulation ran a 15 x 15 grid of number density ($7 \leq \log n \, \mathrm{cm}^{-3} \leq 14$) versus incident ionising flux ($14 \leq \log \phi_H \leq 24 \, \mathrm{cm}^{-2} \, \mathrm{s}^{-1}$), both incremented in 0.5 decade intervals.

We tracked the emission of four spectral lines: Carbon IV (1549 Å), Hydrogen β (6562 Å) and IR lines Paschen α (1.875 μm) and Brackett β (2.624 μm). In current models, hydrogen lines originate in Locally Optimally-emitting Clouds (LOCs) undergoing Keplerian rotation, whilst CIV lines are produced from within an outflow (Korista et al. 1995, Done & Krolik, 1996).

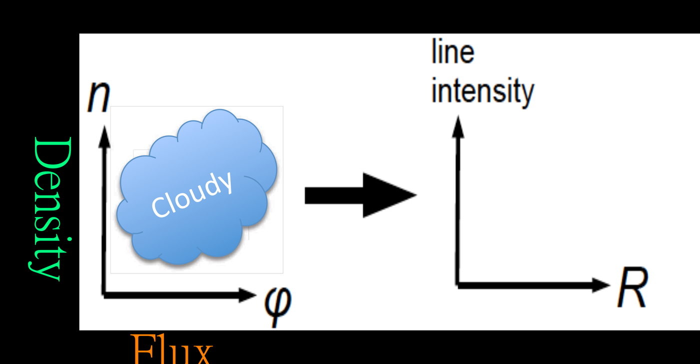


Figure 3: Cloudy input grid and output

Results and analysis

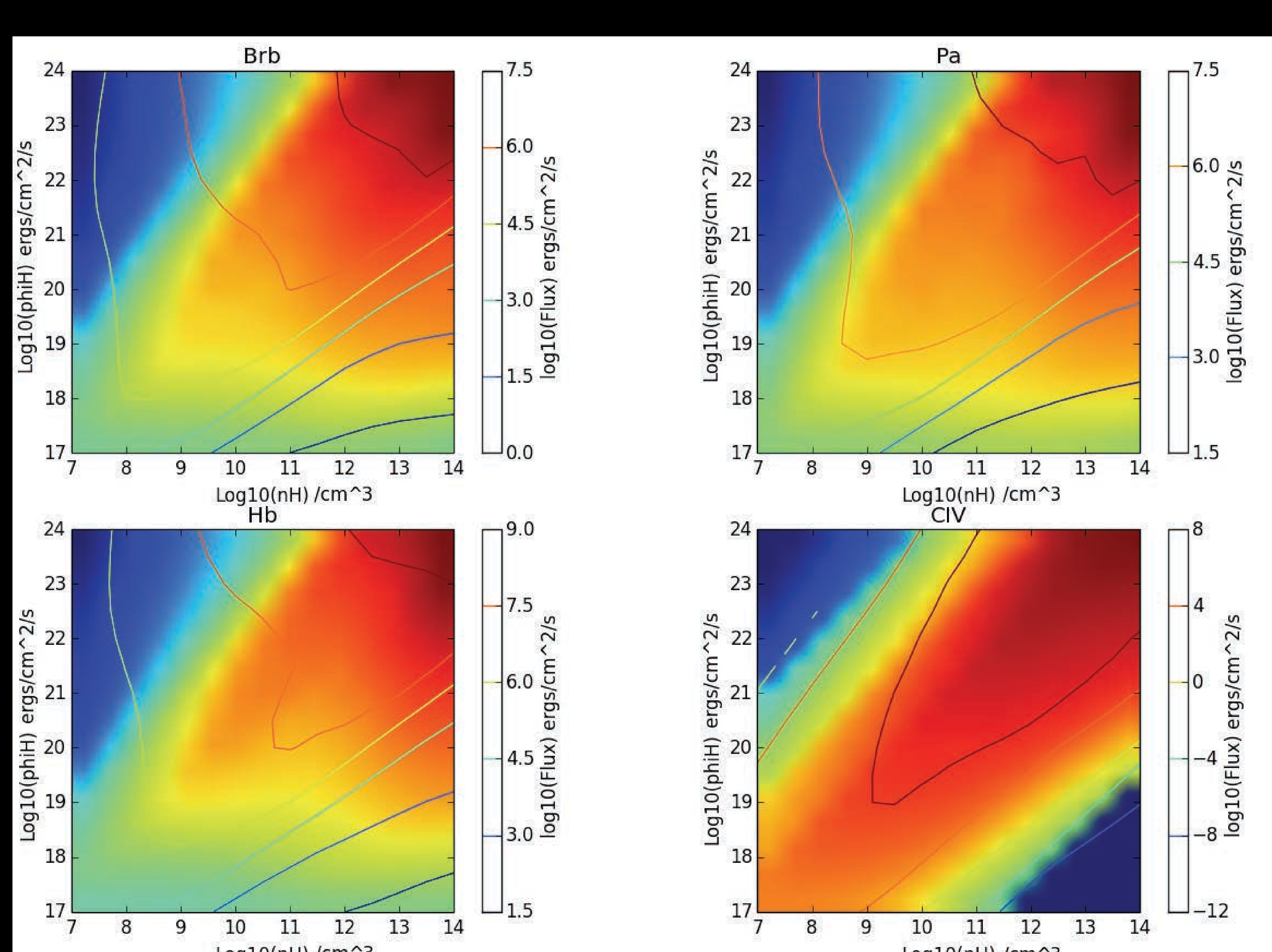
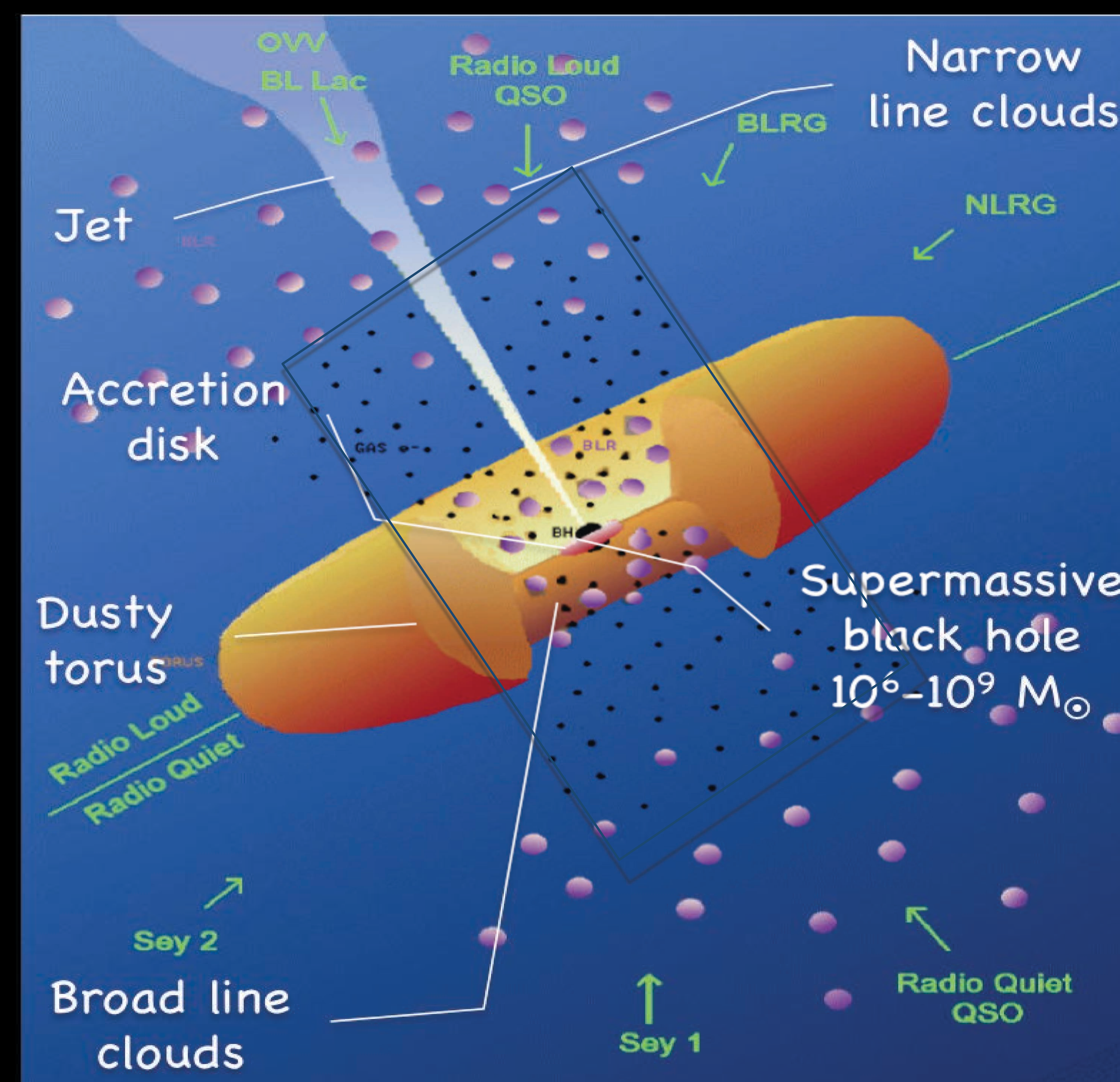


Figure 4: Absolute emissivity for four spectral lines: Hydrogen β (Hb), Carbon IV (CIV), Paschen α (Pa) and Brackett β (Brb)



Adapted from Urry & Padovani (1995)

Equivalent width is a measure of total energy emitted by the spectral line and therefore also of the continuum processing efficiency (KG00). We take the same approach as KG00, assuming a spherically symmetric cloud covering fraction distribution such that the equivalent widths are proportional to the line luminosity distribution - i.e., emissions were not concentrated at larger radii or lower gas densities. A spherically symmetric distribution where $\Phi \propto L/r^2$.

The plots of radial emissivity are very similar to those presented in KG00, particularly for CIV which is expected to represent an AGN outflowing wind. The three hydrogen lines demonstrate similar behaviour to the Lyα line presented in KG00. This is likely due to the similar geometrical space from which they originate - i.e. within small-radius Keplerian rotating clouds rather than from the outflow.

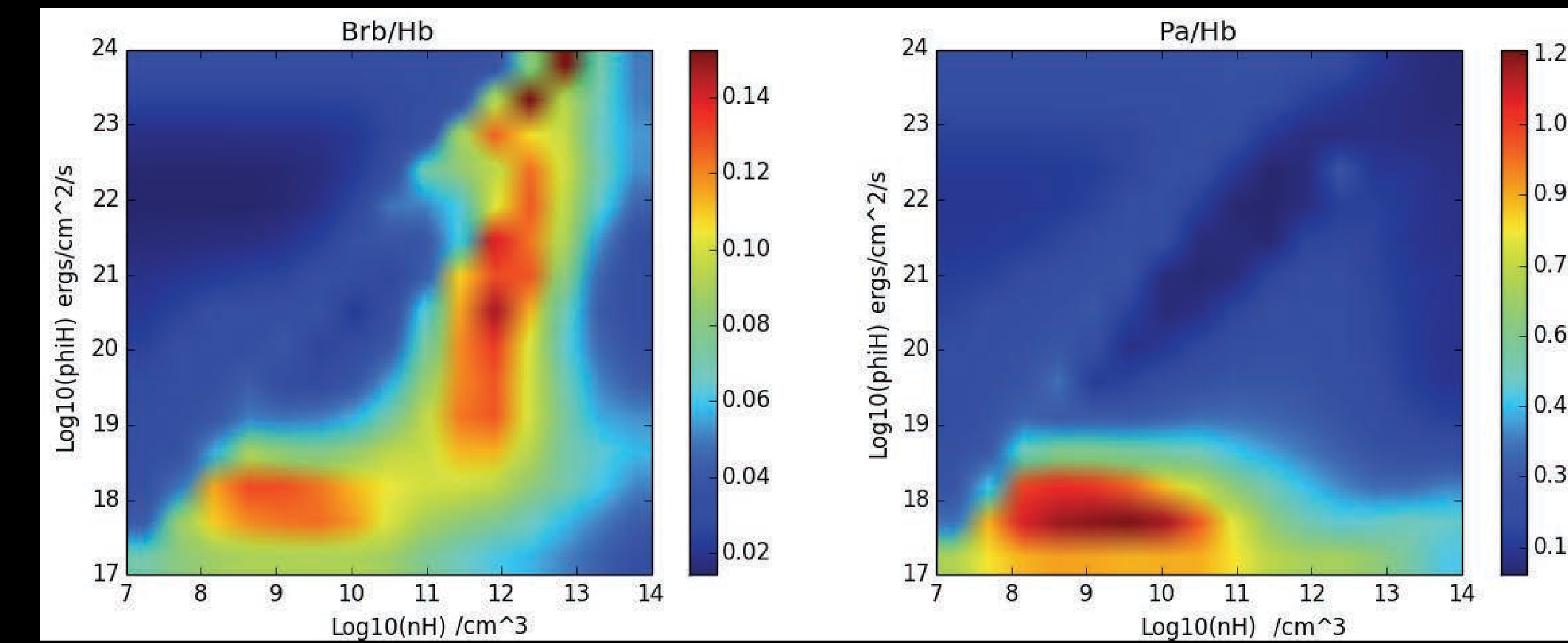


Figure 5: Radial emissivity for Brackett β (Brb) and Paschen α (Pa) with respect to Hydrogen β (Hb).

The three hydrogen lines have similar radial surface flux behaviour (see figure 6). The radial surface fluxes from CIV clouds is higher than for the hydrogen lines and these lines are produced over a smaller range of incident ionising flux (and therefore radial) values than for CIV. Figure 7 demonstrates that the responsivity of both the hydrogen and CIV lines are anti-correlated with incident ionising flux in the outer regions of the BLR.

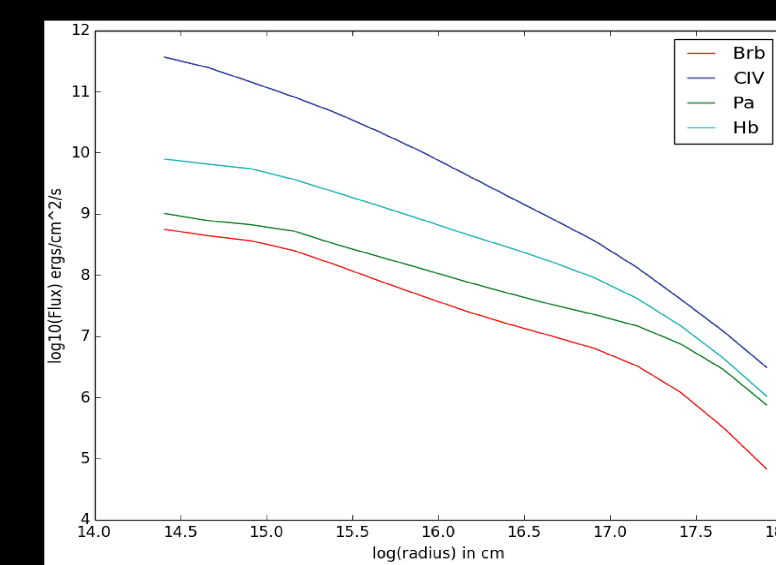


Figure 6: Surface flux

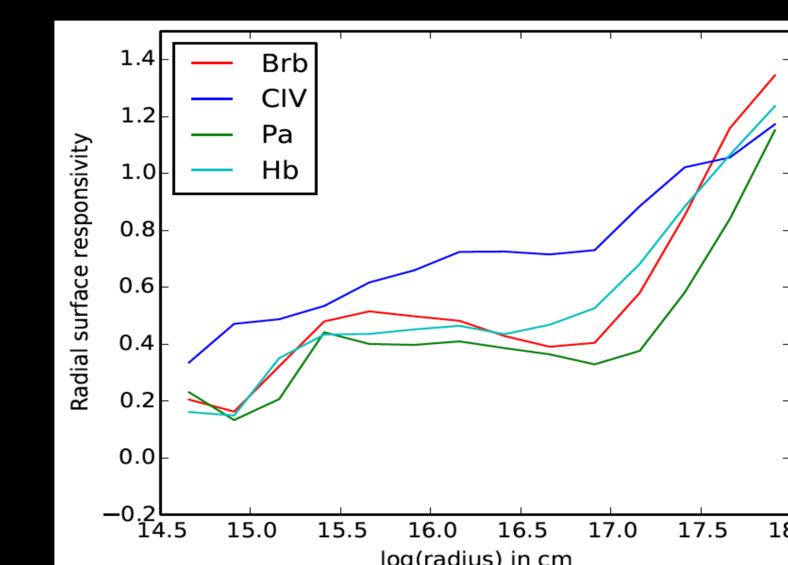


Figure 7: Radial surface responsivity as a function of radius

Conclusions and future work

Our results are generally aligned with those of KG00, although we use the AGN SED within Cloudy rather than the specialised, spectrally harder, SED used by KG00 to match their observational source. We have demonstrated that IR spectral lines are good candidates for investigating the BELR (in terms of density and flux distribution) via reverberation mapping despite the long observation hours required for IR spectra.

Future work includes:

- Increasing the number of emission lines tracked and constructing reverberation mapping light curves for these lines
- Making IR reverberation observations and fitting these to models to obtain physical parameters of BELR – towards a geometrical model of the BELR

References

Done, C. & Krolik, J. 1996, ApJ, 463, 144
Ferland, G. et al. 2013, Revista Mexicana de Astronomia y Astrofisica, 49, 1
Korista, K. & Goad, M. 2000, ApJ, 536, 284
Korista, K. et al. 1995, ApJS, 97, 285
Peterson, B. 1997, An Introduction to Active Galactic Nuclei (New York, Cambridge University Press)
Urry, C. & Padovani, P. 1995, Pub. Astron. Soc. of the Pacific, 107, 803