Shape variations of Broad Emission Lines as probes of the inner structure of AGN*

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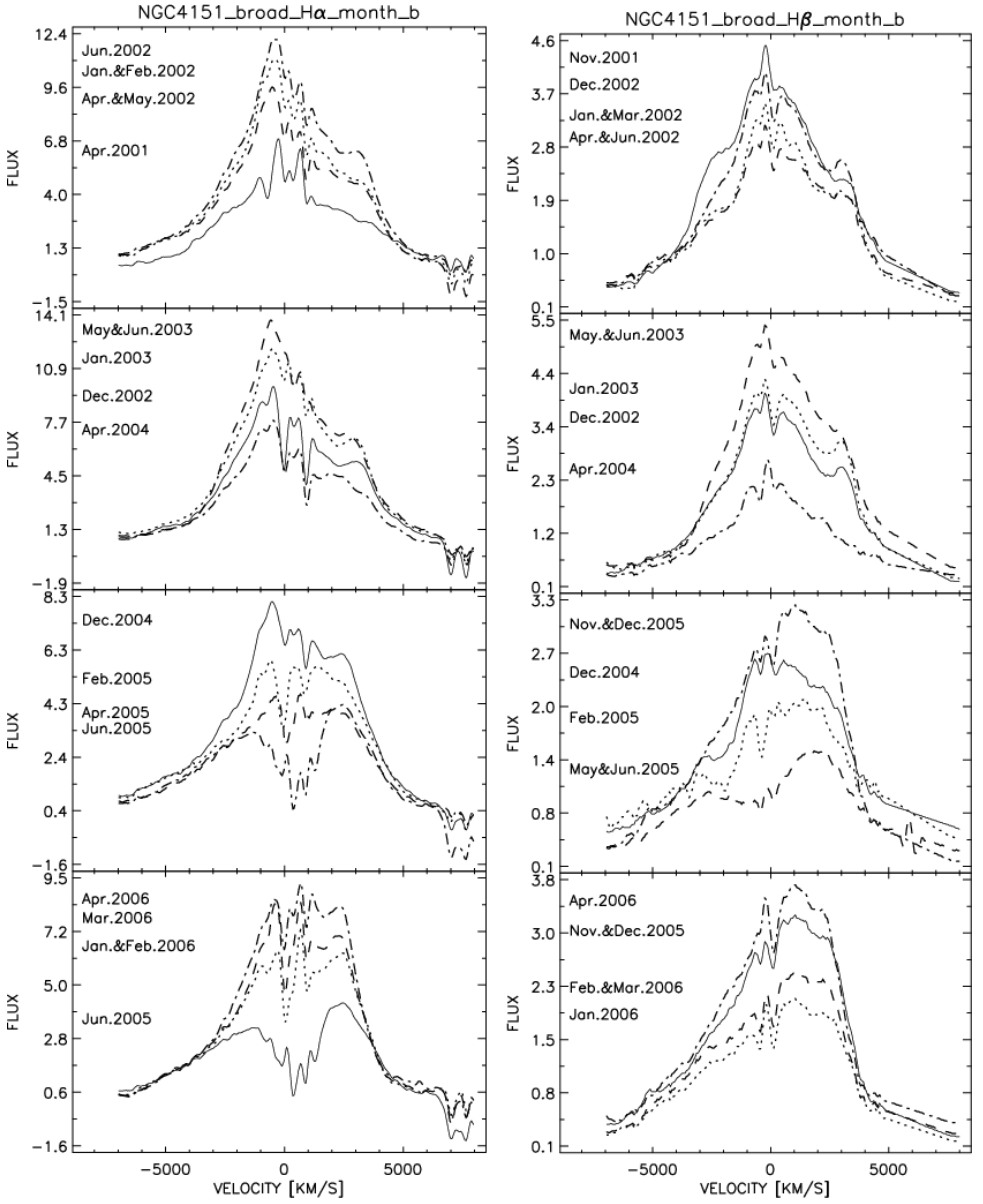
*NGC 4151

Inner structure of AGN

- Inner structure = Hot dust + BLR
- Radial: Reverberation mapping
- Azimuthal: Unless resolved difficult for dust torus
  - Velocity distribution of clouds from BELs
    → Spatial distribution of BEL clouds
- Distribution BLR = distribution dust torus ???

Shape variations

- BEL changes < 10 %
- Often optical Hα + Hβ
- For NGC 4151 largely on red shifted side

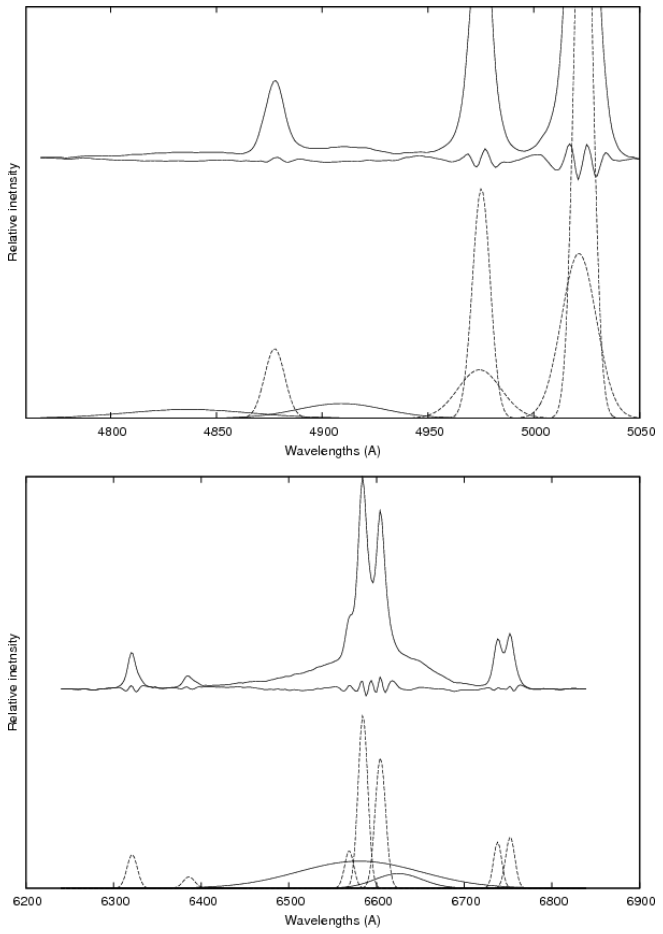


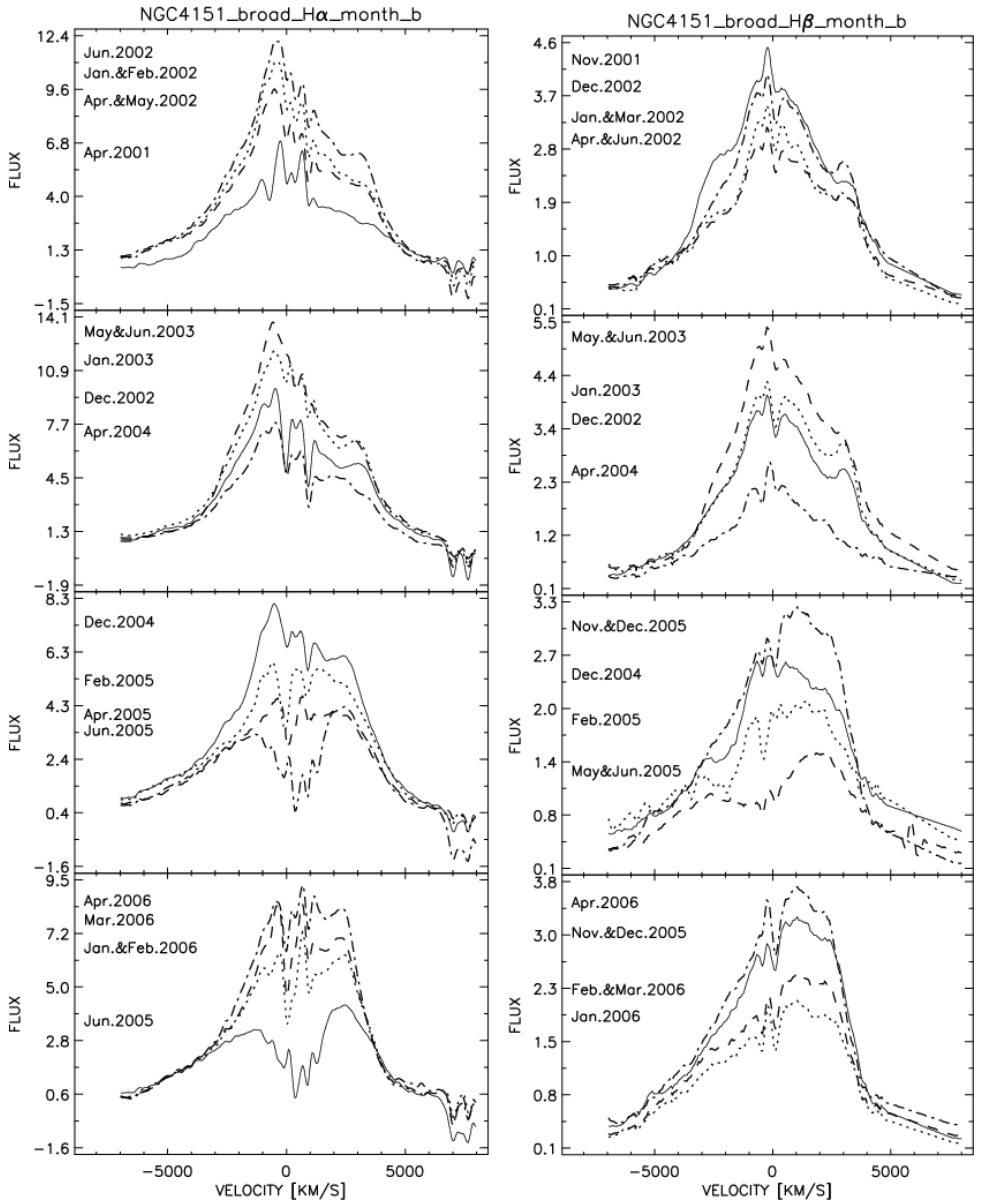
Shapovalova et al. 2010

Shape variations

Hβ

Hα

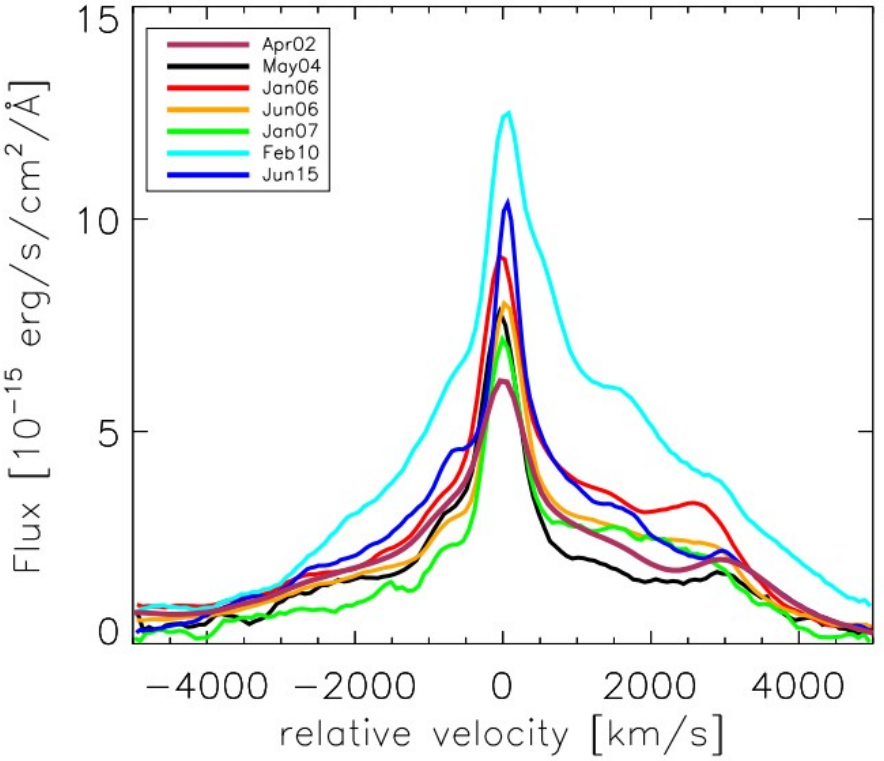




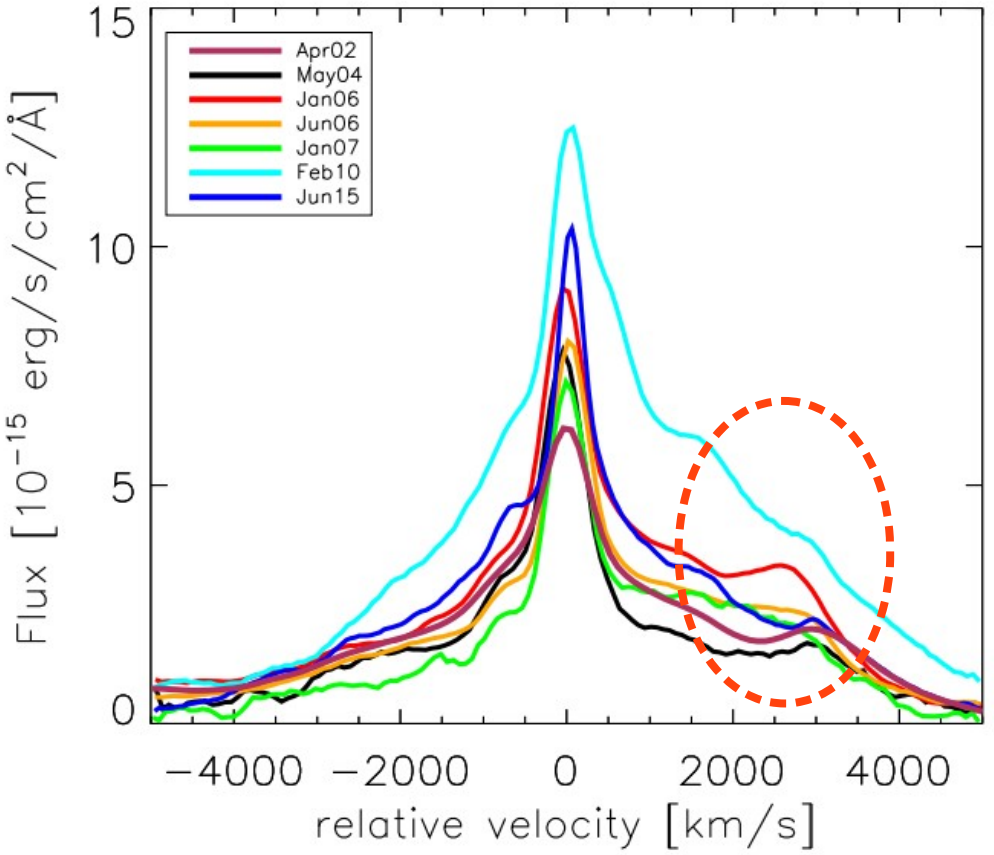
Shapovalova et al. 2010

Shape variations

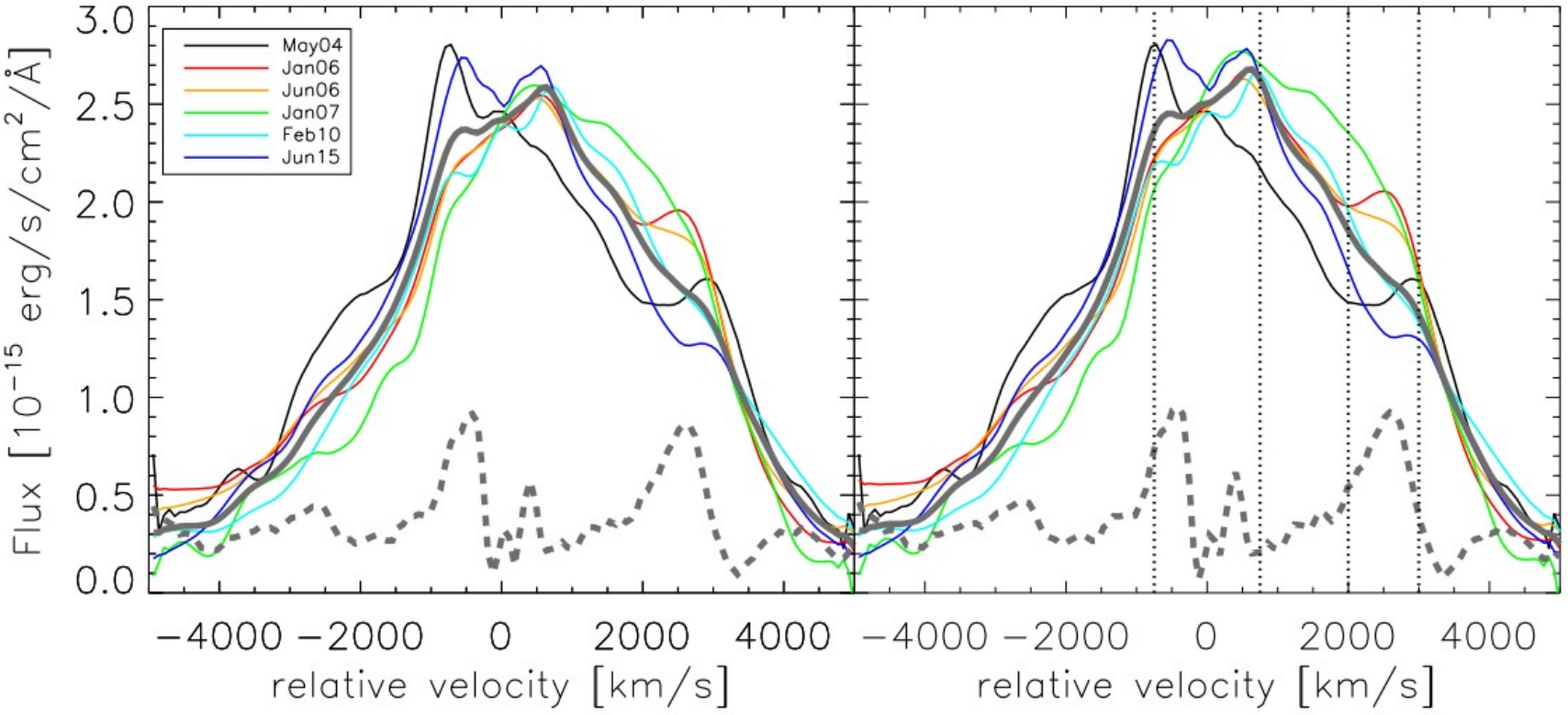
- Move to IR
- No emission line “pollution” for Paβ



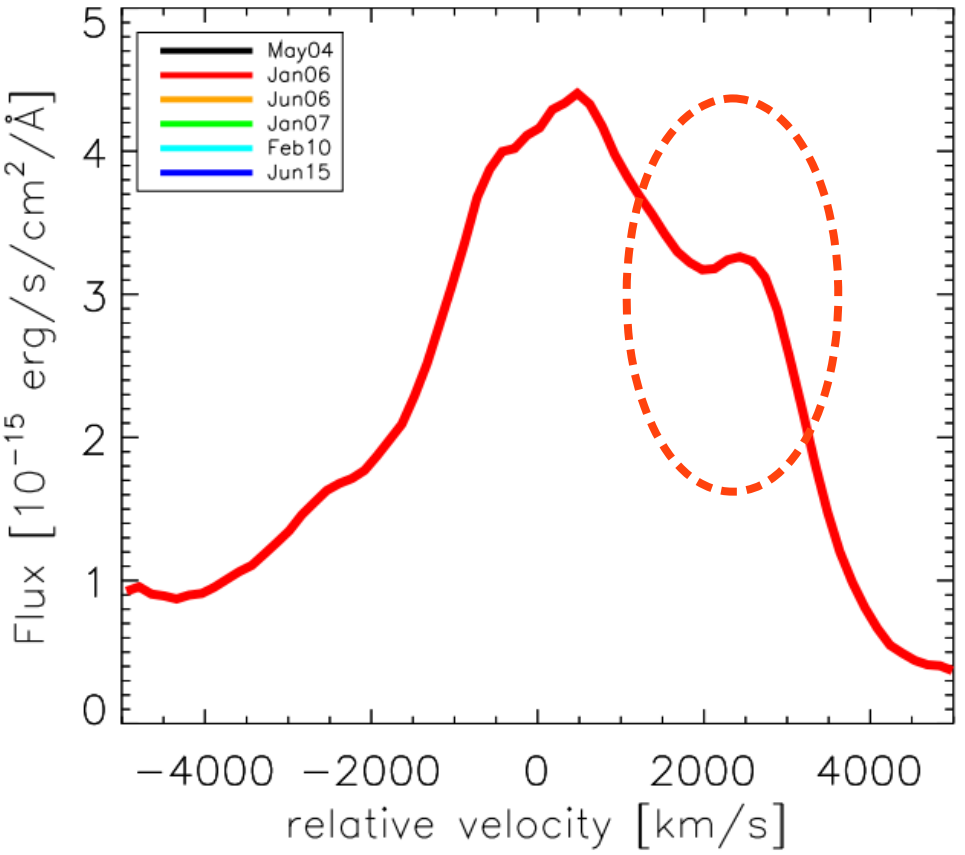
Shape variations



Shape variations



Modeling BLR profile variability



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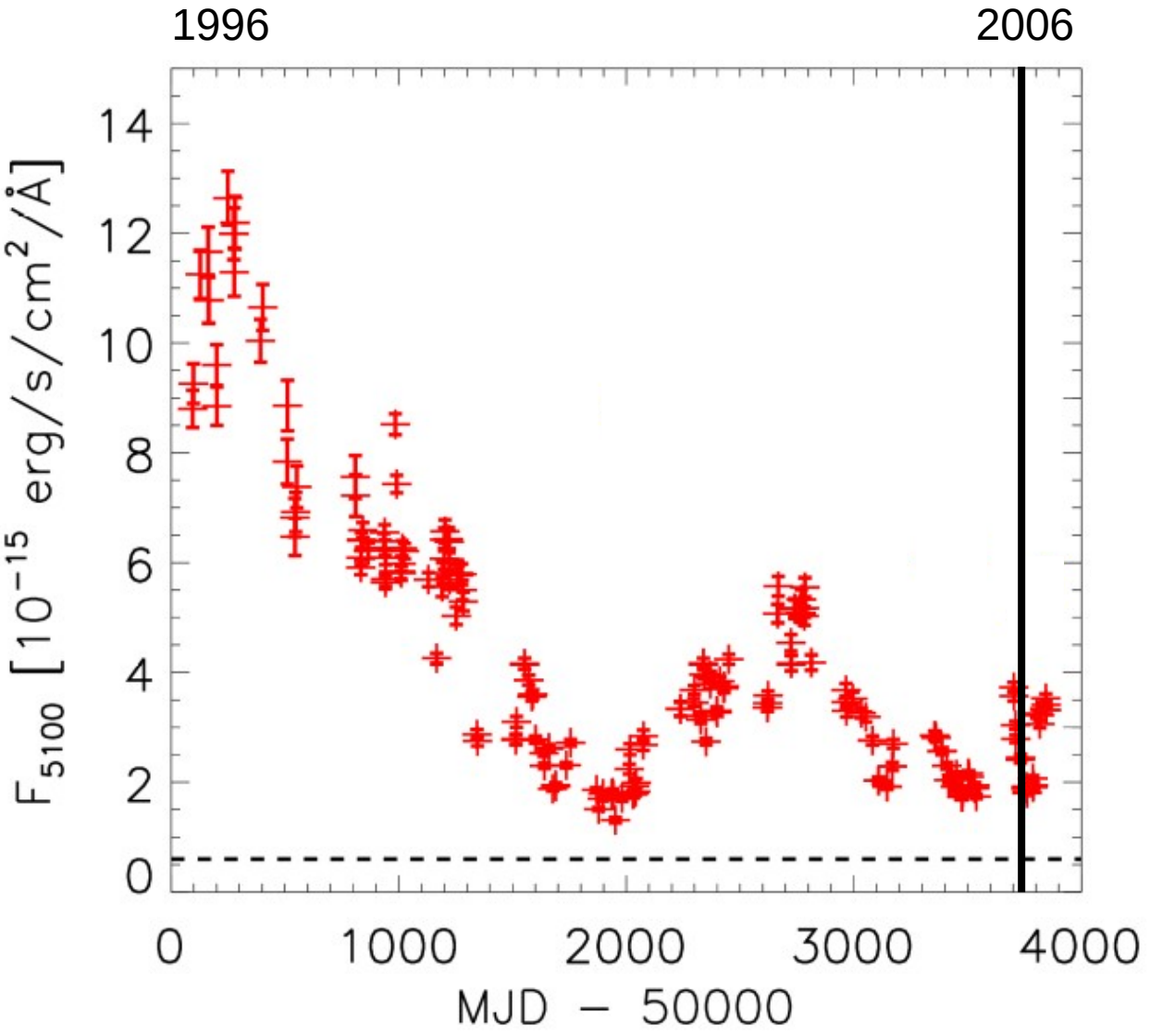
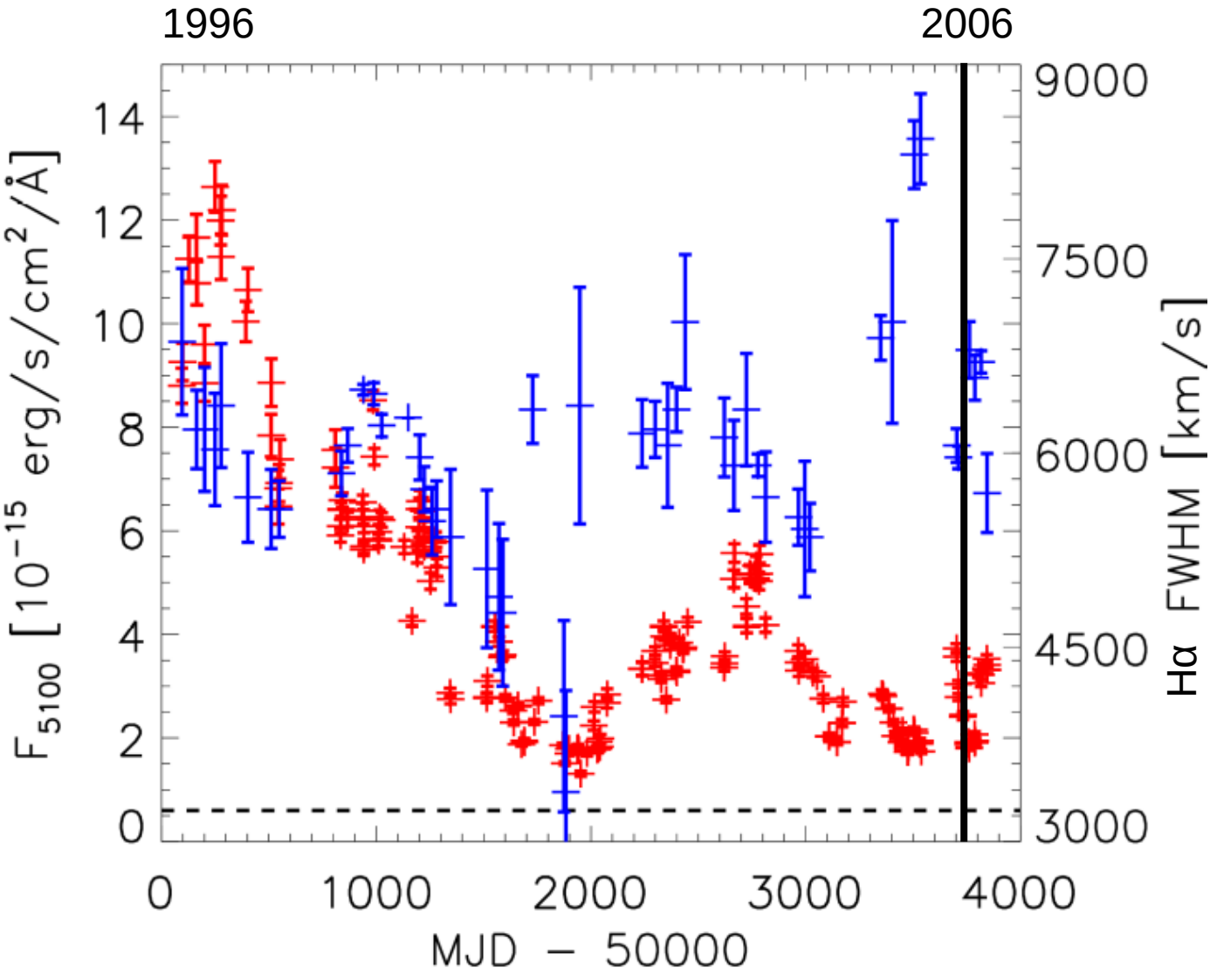


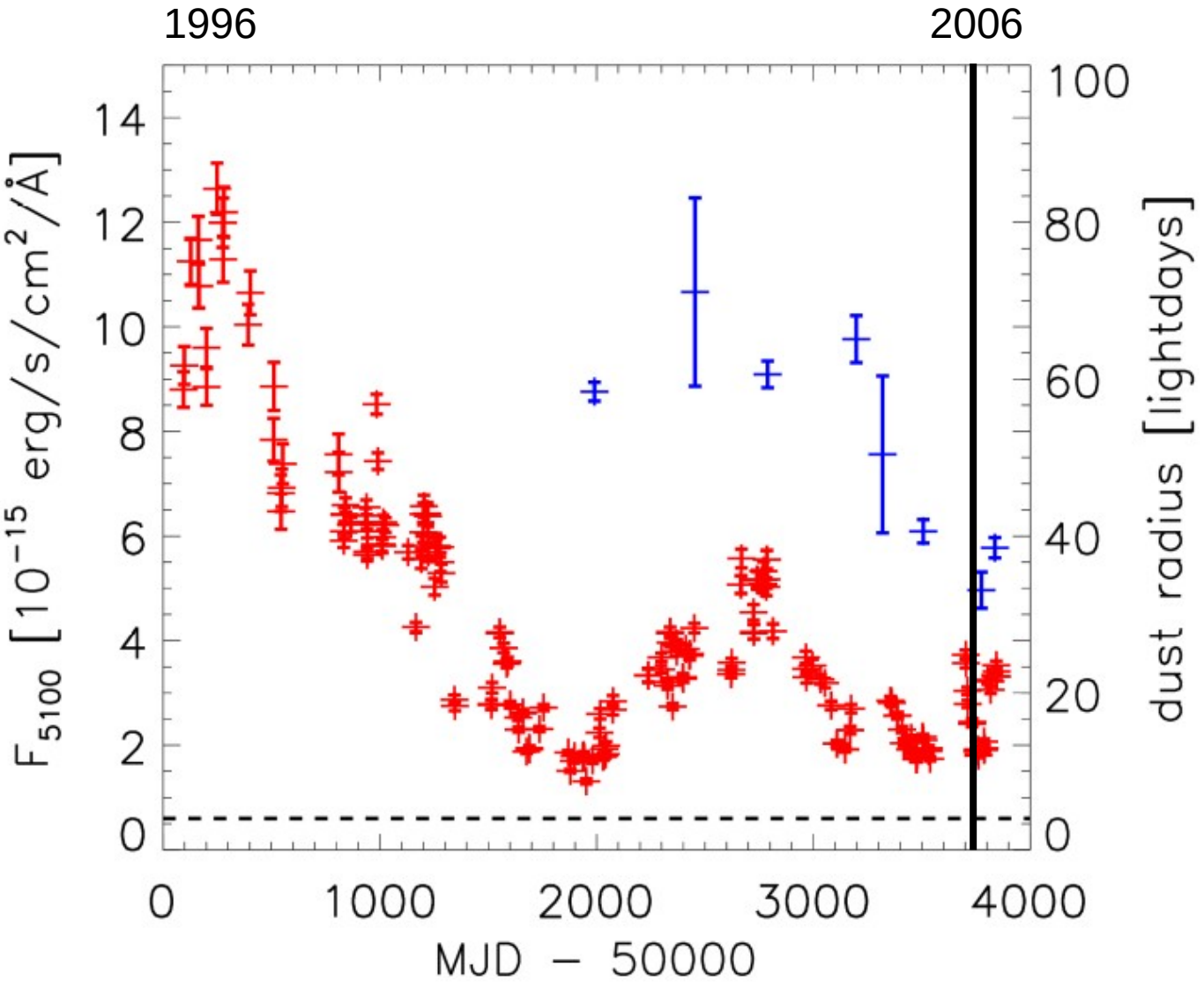
Data from Shapovalova et al. 2008

Modeling BLR profile variability



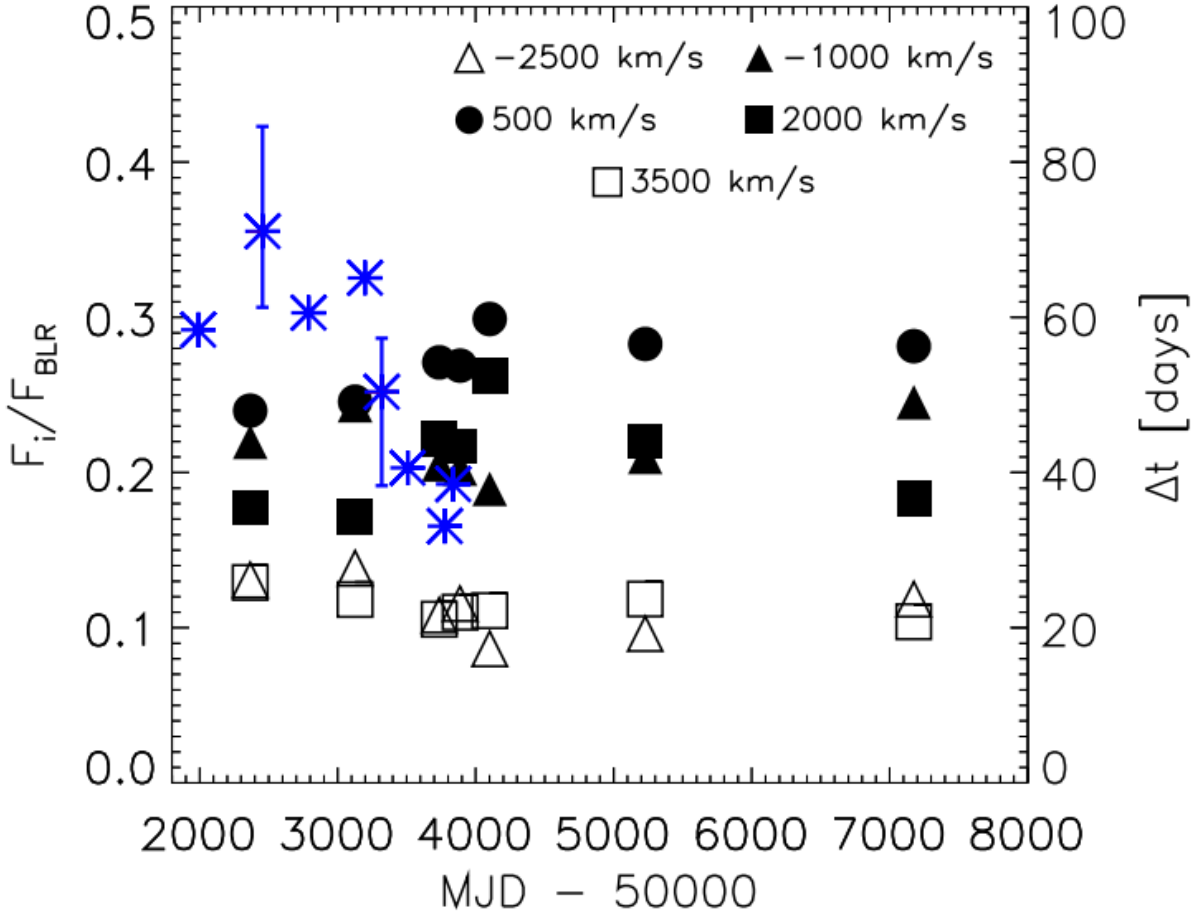
Data from Shapovalova et al. 2008

Modeling BLR profile variability



Data from Shapovalova et al. 2008 and Koshida et al. 2009

Modeling BLR profile variability



Modeling BLR profile variability

- Transfer function from cloud distribution to emission needed:

$$\Phi_v'(r,\phi) = \frac{f(r)}{r} e^{\frac{-(v_{rot}\sin i)^2}{2\sigma^2}\left(\sin\phi - \frac{v}{v_{rot}\sin i}\right)^2}$$

emission

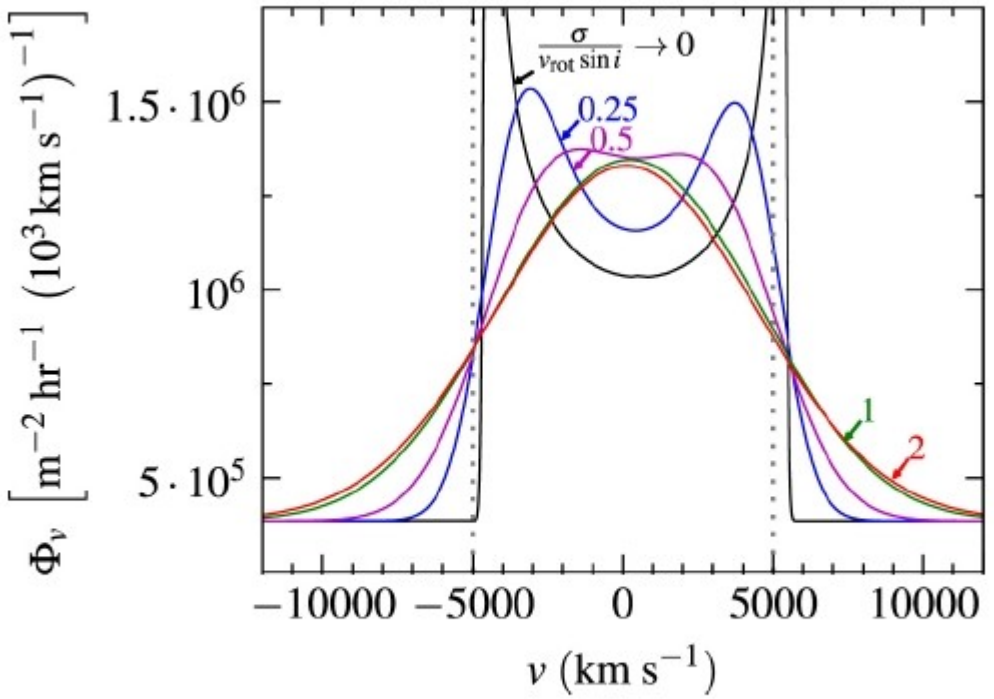
cloud distribution

$$\Phi_v'(r,\phi) = \frac{f(r)}{r} e^{\frac{-(v_{rot}\sin i)^2}{2\sigma^2}\left(\sin\phi - \frac{v}{v_{rot}\sin i}\right)^2}$$

- Projected rotational velocity

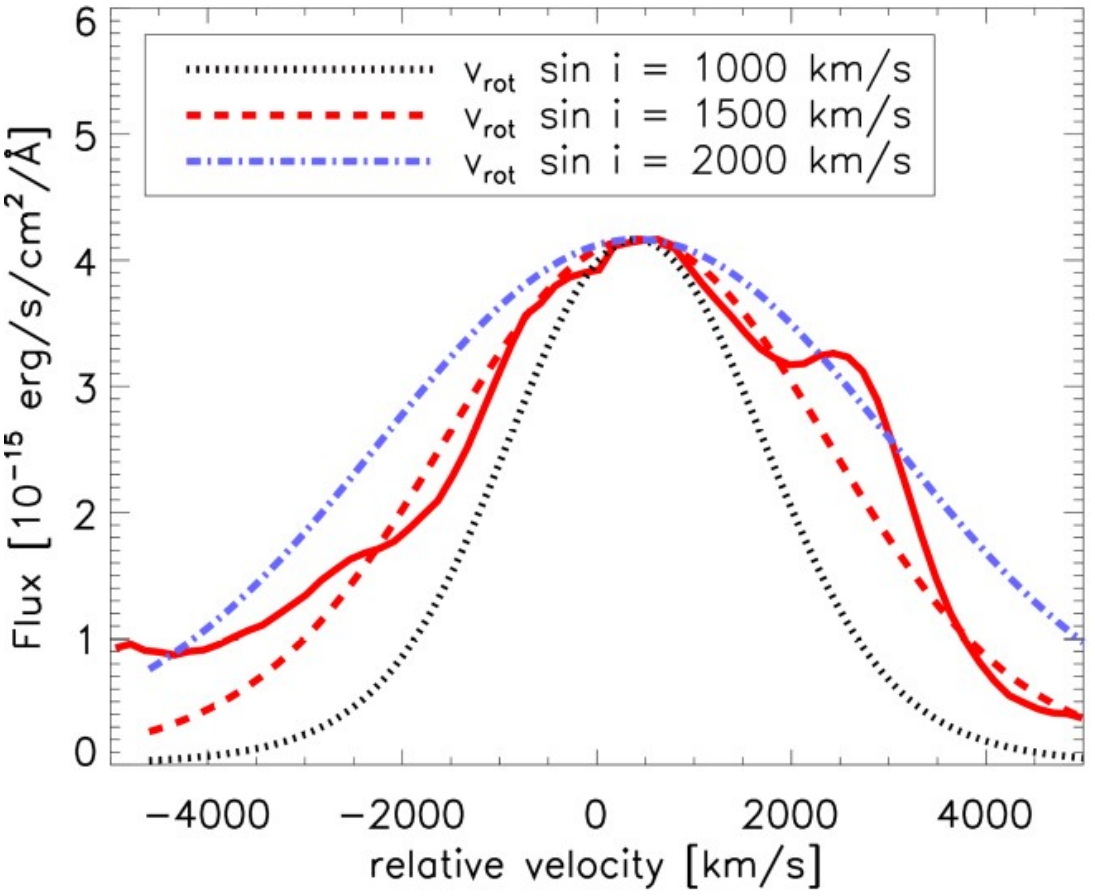
$$\Phi_v'(r,\phi) = \frac{f(r)}{r} e^{\frac{-(v_{rot}\sin i)^2}{2\sigma^2}\left(\sin\phi - \frac{v}{v_{rot}\sin i}\right)^2}$$

- Velocity dispersion due to non rotational velocity components



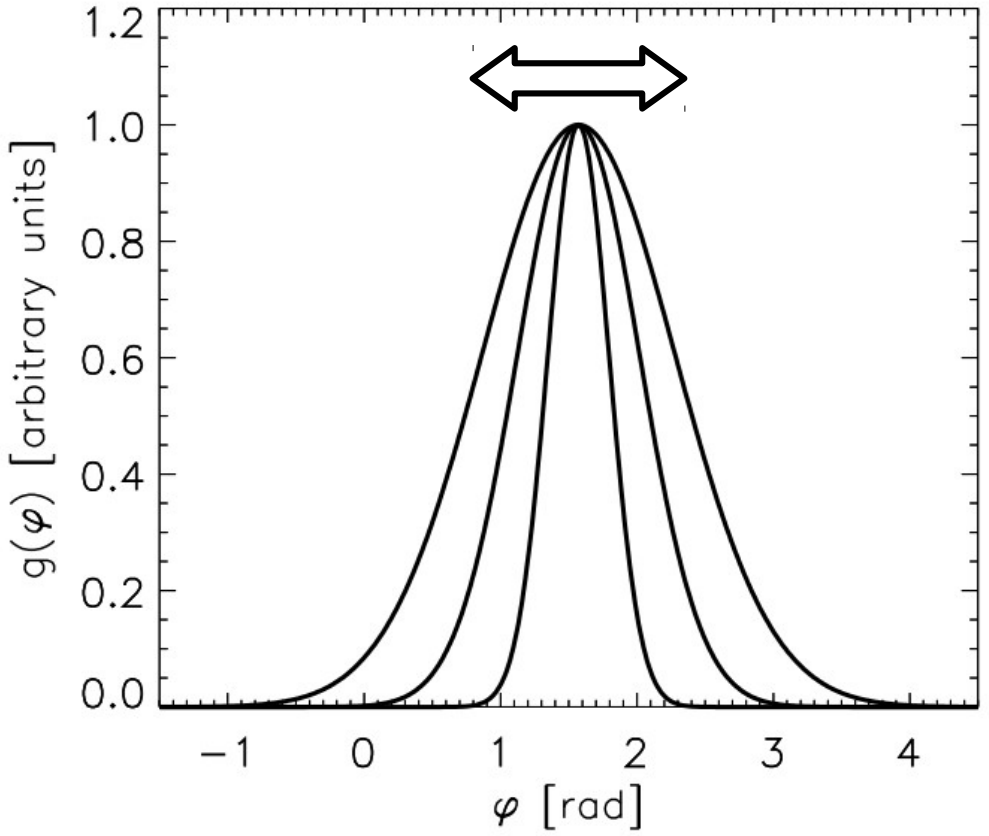
Stern, Hennawi, Pott 2015

$$\Phi_v'(r,\phi) = \frac{f(r)}{r} e^{-\frac{(v_{rot}\sin i)^2}{2\sigma_v^2}\left(\sin\phi - \frac{v}{v_{rot}\sin i}\right)^2}$$



mean velocity of BEL clouds

$$\Phi_v'(r,\phi) = \frac{f(r)}{r}\left(1 + g(\phi)\right) e^{\frac{-(v_{rot}\sin i)^2}{2\sigma_v^2}\left(\sin\phi - \frac{v}{v_{rot}\sin i}\right)^2}$$



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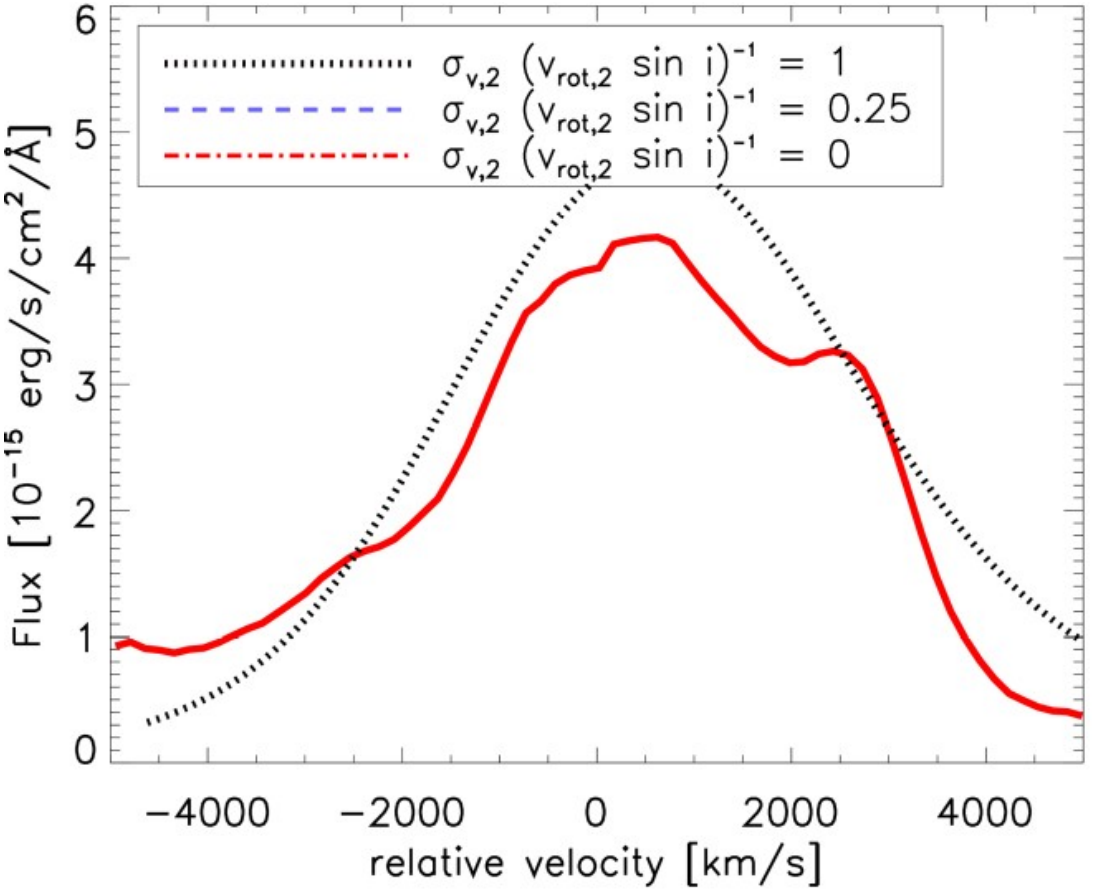
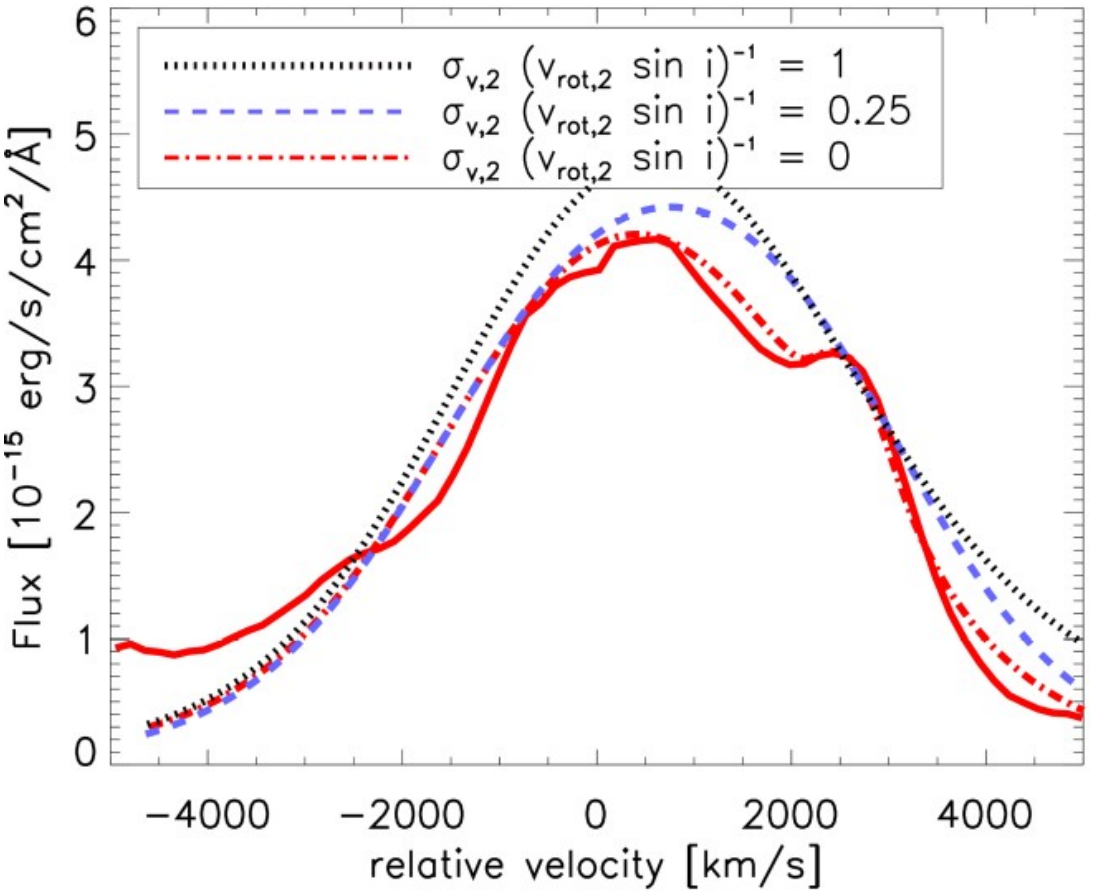


Velocity dispersion of additional clouds

$$\Phi_v'(r,\phi) = BLR_{sym} + \frac{f(r)}{r} g(\phi) e^{\frac{-(v_{rot,2}\sin i)^2}{2\sigma_{v,2}^2}\left(\sin\phi - \frac{v}{v_{rot,2}\sin i}\right)^2}$$



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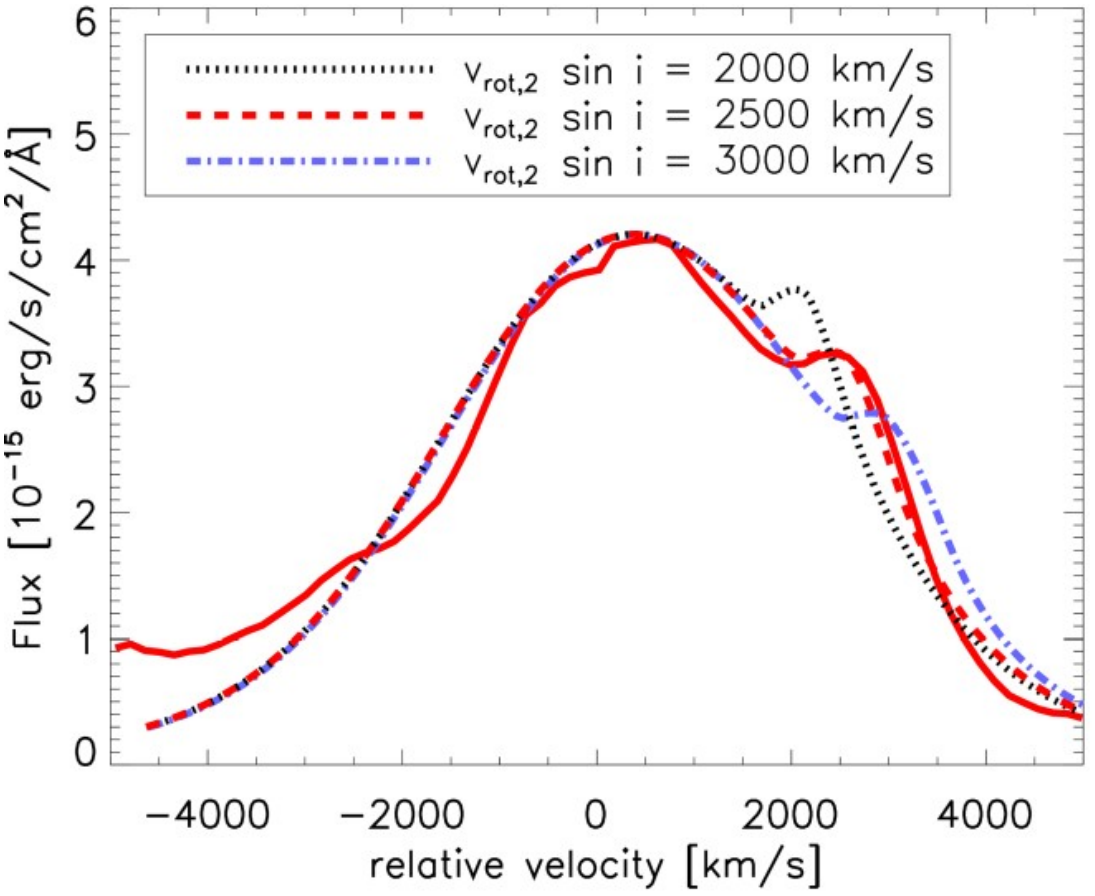
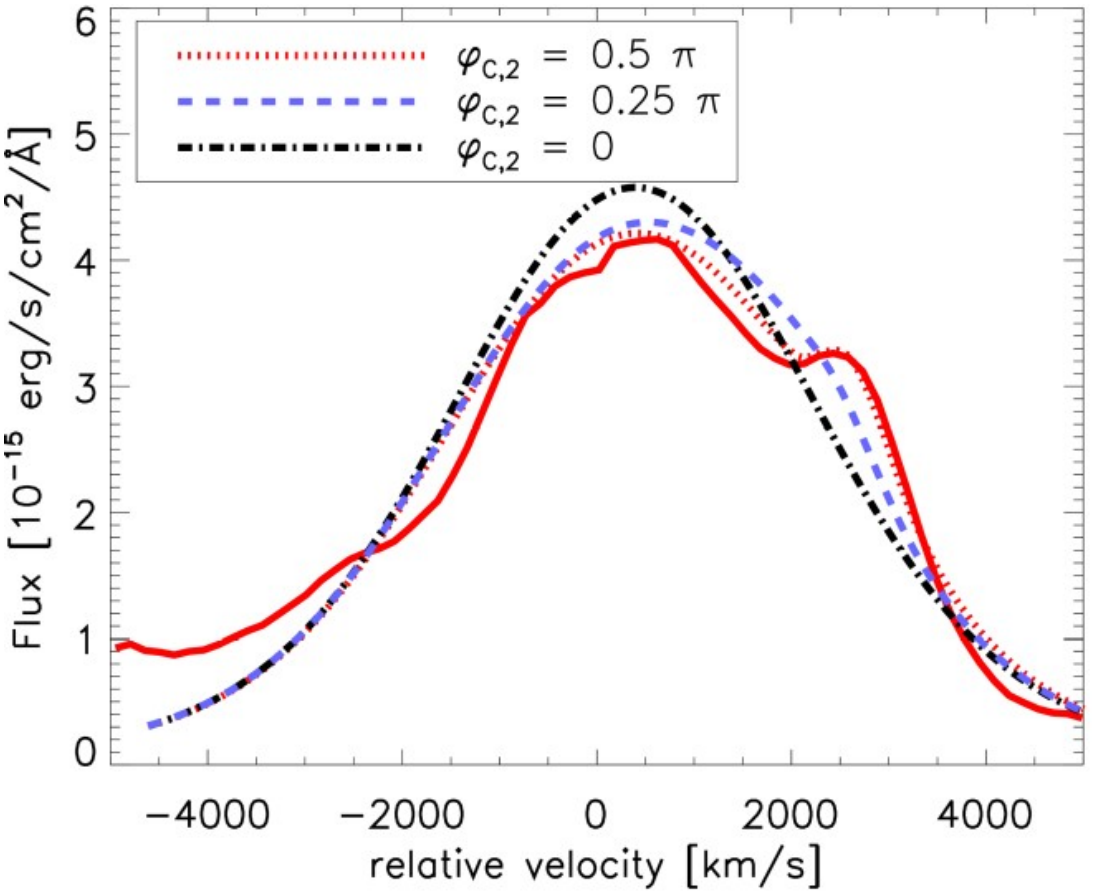


mean velocity of additional clouds

Modeling BLR profile variability

- Population of clouds closer to SMBH
- Change of radius comparable to the dust torus
- Not complete broad line region 'refilled'

$$\Phi_v'(r,\phi) = BLR_{sym} + \frac{f(r)}{r} g(\phi) e^{\frac{-(v_{rot,2}\sin i)^2}{2\sigma_{v,2}^2}\left(\sin\phi - \frac{v}{v_{rot,2}\sin i}\right)^2}$$



center of distribution of additional clouds

BLR profile variability

- Location of peak → lower limit on velocity
- Broadness of the peak → location in azimuthal direction

- No BEL reverberation mapping

  → no direct measurement of BLR radius

Conclusion

Time resolved multi-wavelength data at high cadence needed to probe BLR/torus models

BLR and dust torus seem to be (physically) closely connected (for NGC 4151)

Refill/reformation timescales of the BLR (and dust torus?) can be probed with BLR shape variations