Constraining parameters of a disk-wind model of the BLR

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AGN Reverberation Mapping: the pc Scale Garden of Massive Black Holes

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Outline

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Disk-wind model

- A thin Keplerian disk model with a purely radial wind component (Murray et al. 1995, Chiang & Murray 1996).
- Gas velocity:

$$\boldsymbol{v} = v_r\hat{\boldsymbol{r}} + v_\phi\hat{\phi}$$

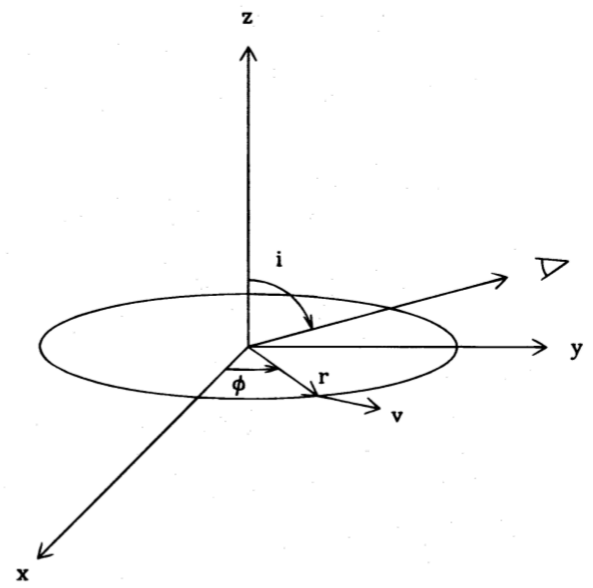
where;

$$v_r \ll v_\phi$$

and

$$\frac{dv_r}{dr} \gtrsim \frac{dv_\phi}{dr}$$

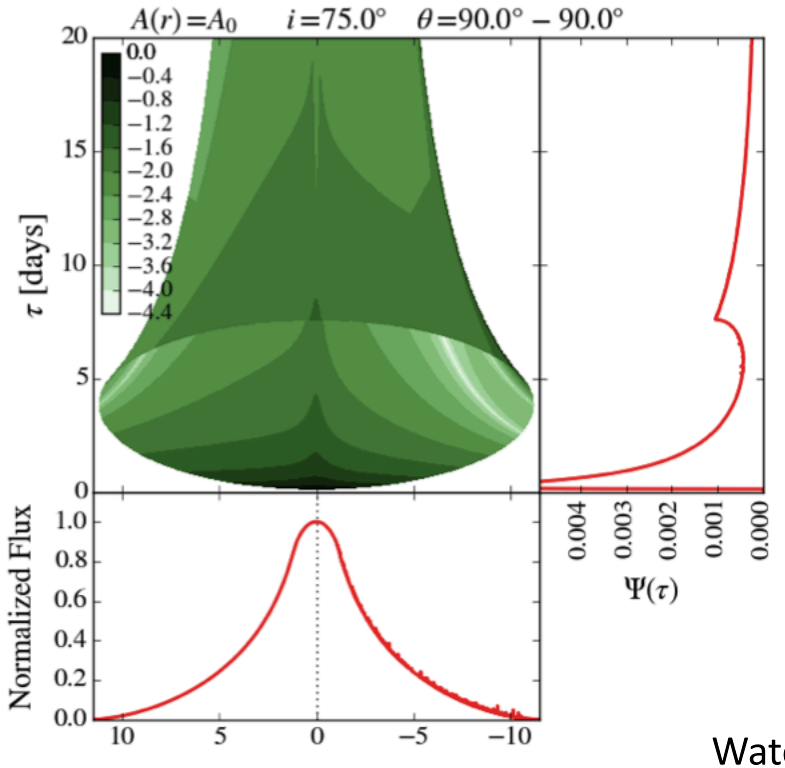
$$v_{proj} = \sin i(\, v_r \sin\phi + v_\phi \cos\phi)$$



Chiang & Murray 1996

- $M_{BH} \sim 10^7 M_\odot$, $v_r \sim 10^7 cms^{-1}$, $v_\phi \sim 10^8 - 10^9\, cms^{-1}$

Echo images



Waters et al. 2016

Light curves

- Continuum light curve $C(t)$:

  A simulated damped random walk (DRW).

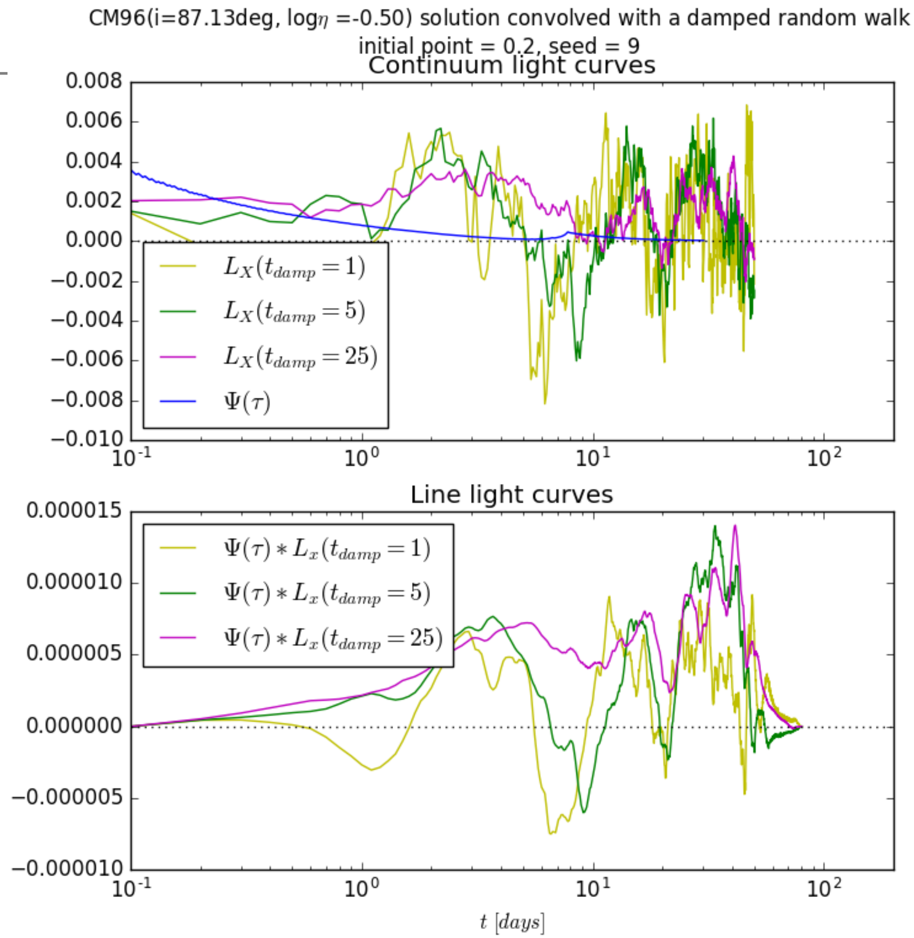
- Line light curve $L(v,t)$:

  Obtained by convolving 2D echo function $\Psi(v,\tau)$ with $C(t)$.

$$L(v,t) = \int_0^\infty \Psi(v,\tau) C(t-\tau) d\tau$$

- Integrated line light curve $L(t)$:

  Obtained by summing over all velocities.



Bayesian Formalism

- From Bayes' theorem,

$$p(\theta|D, I)\ p(D|I) = p(D|\theta, I)\ p(\theta|I)$$

Posterior x Evidence = Likelihood x Prior

$p(\theta|I)$ – prior probability distribution of the model parameters θ, before observational data D.

$p(D|\theta, I)$ – probability of observing data D given the model with parameters θ.

$p(\theta|D, I)$ – posterior probability distribution of model having the parameters θ, given observed evidence D.

$p(D|I)$ – 'model evidence' or the 'marginal likelihood'.

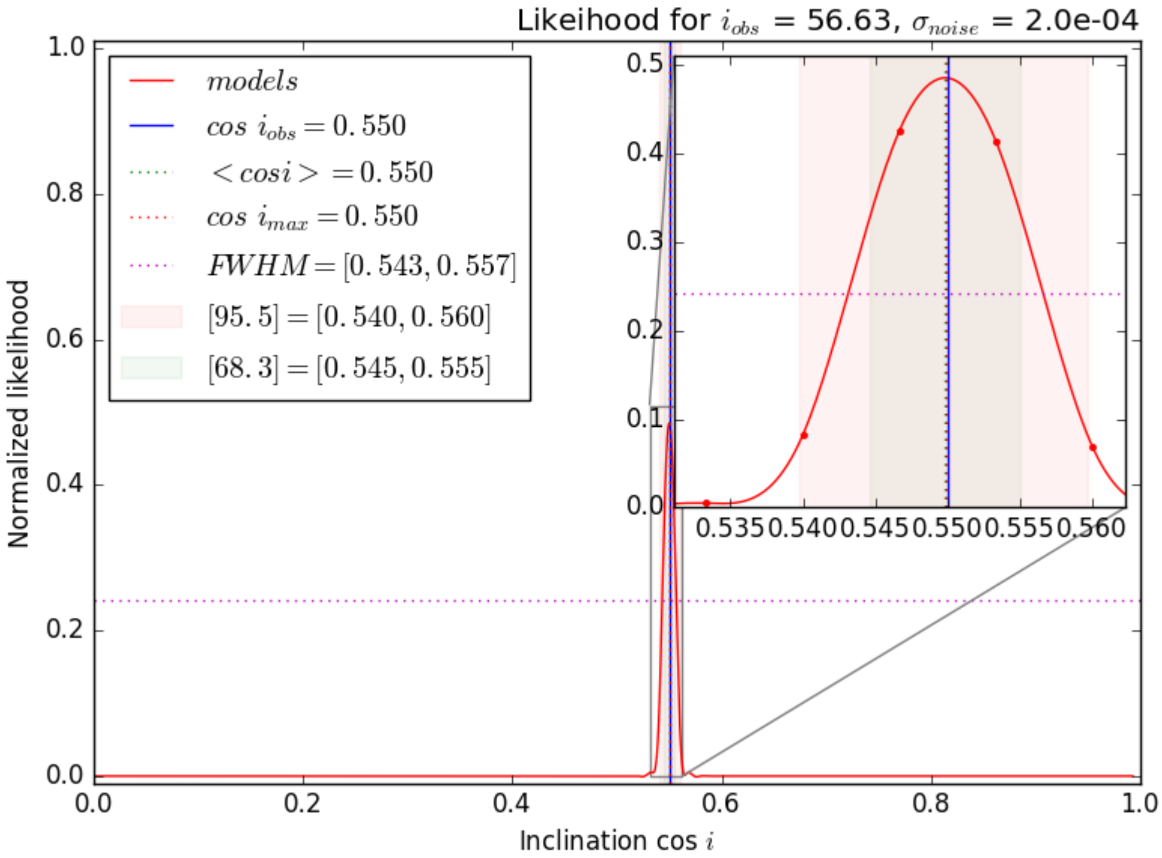
- Likelihood function:

$$p(D|\theta, I) = \prod_i \frac{1}{\sigma\sqrt{2\pi}} e^{\left[-\frac{1}{2\sigma^2}\left(D_i - m_i(\theta)\right)^2\right]}$$

Results: inclination angle i

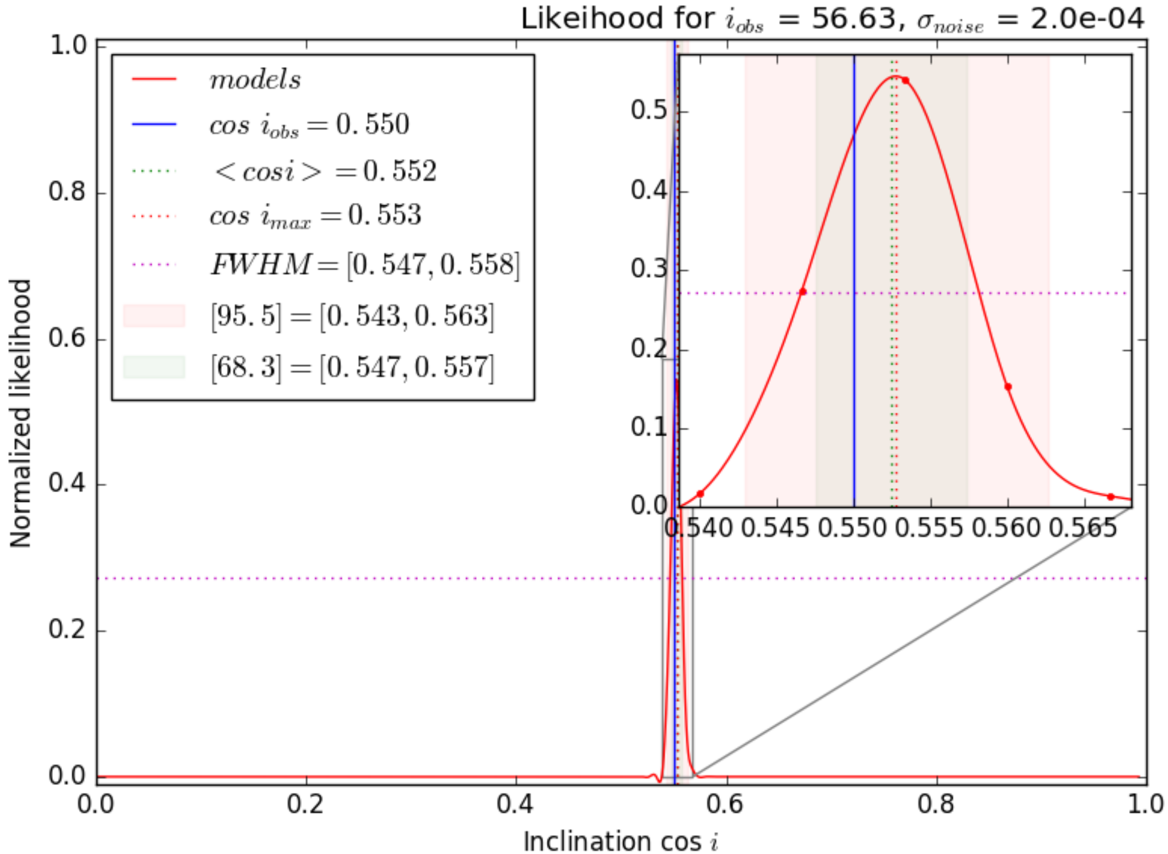
- *cos* i_{obs} : 0.05, 0.15, … , 0.95 (total 10)
- cos i_{mod} : evenly spaced in [0.00, 1.00) (total 150)
- No overlap between i_{obs} and i_{mod}.
- An *observation* i_{obs} compared with a set of 150 *models* (i.e. 150 i_{mod} values).
- Repeated for 10 different i_{obs} values.

Results: inclination angle *i*



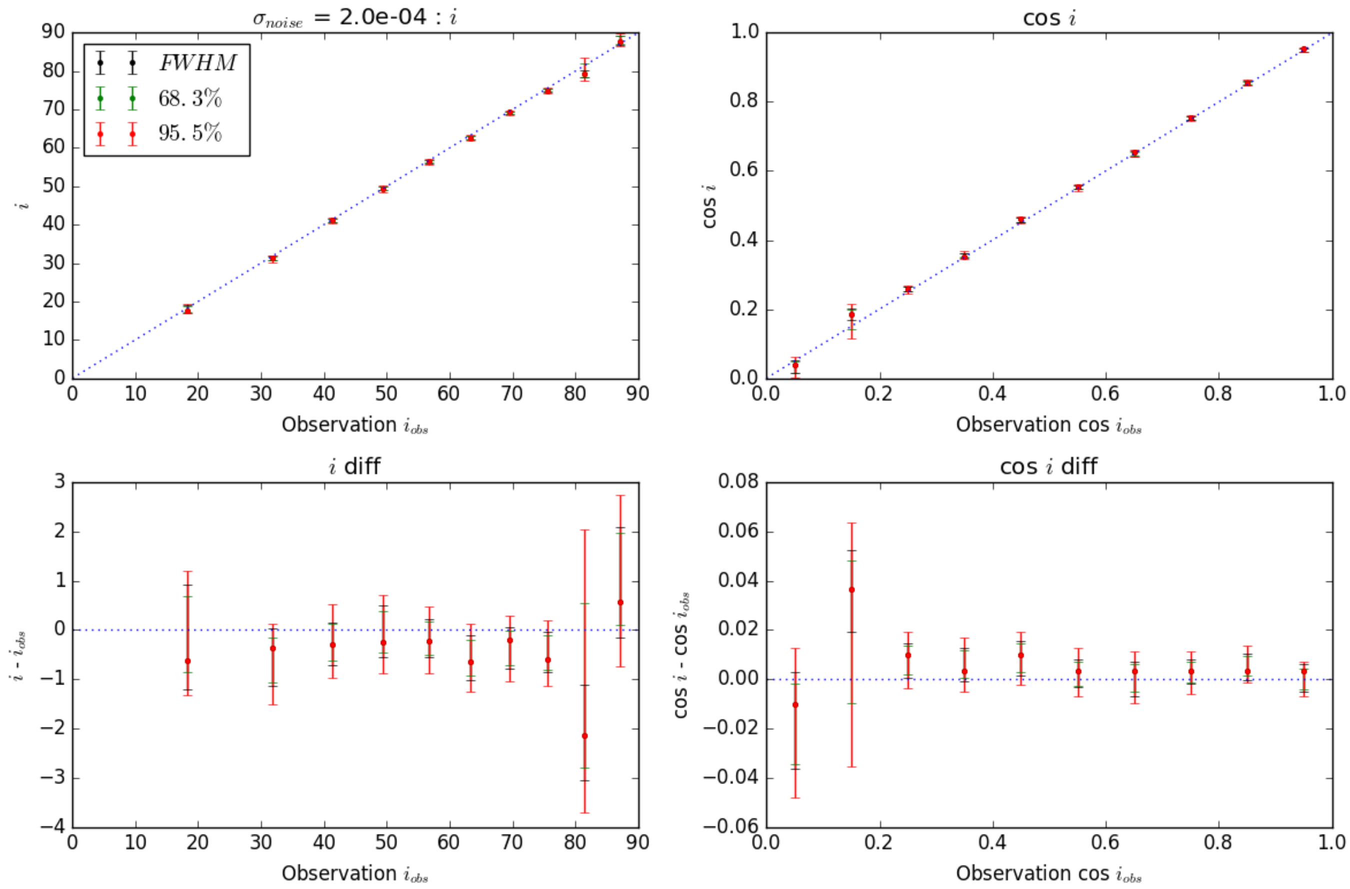
- Without adding error to 'observation'.

Results: inclination angle *i*



- With uncertainty added to the ’observation’.
- σ ~ 50% of the mean value of the *‘observation’*.

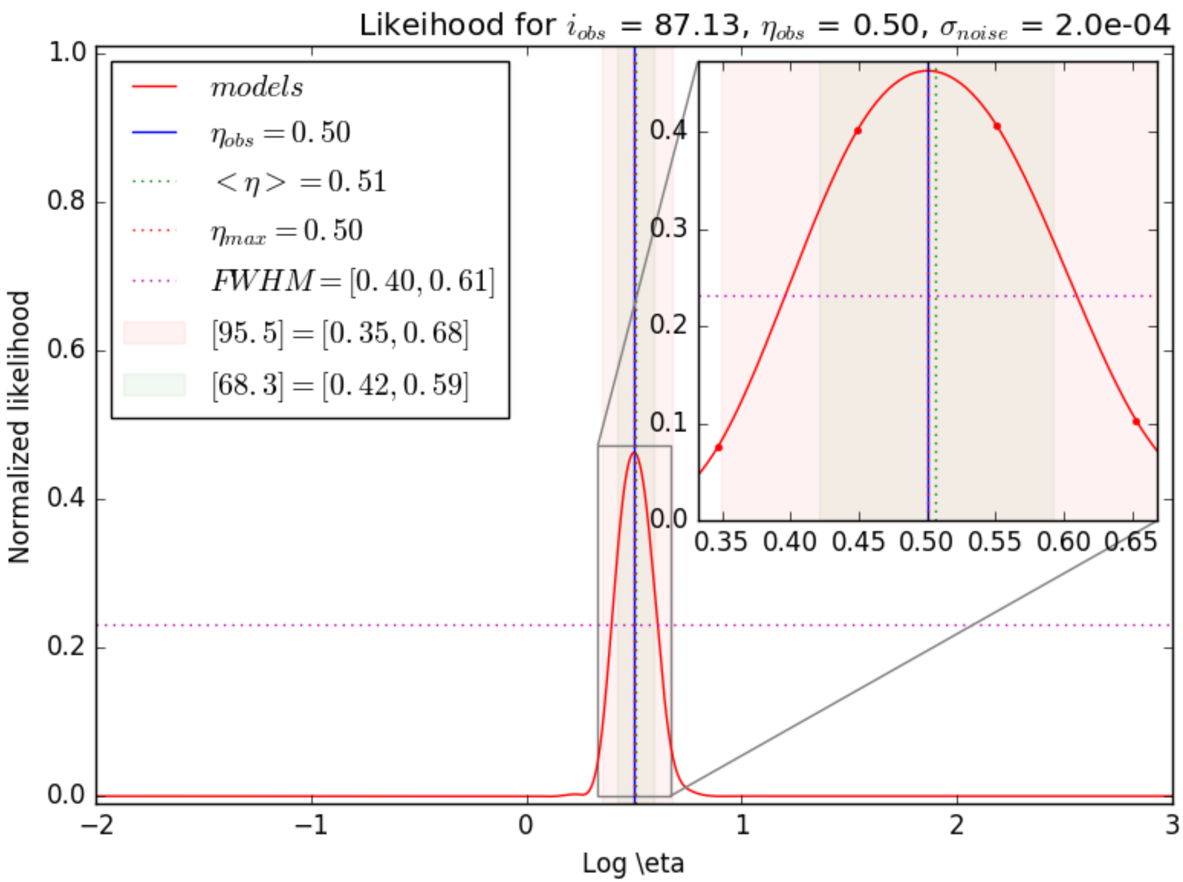
Results: inclination angle *i*



Results: responsivity parameter η

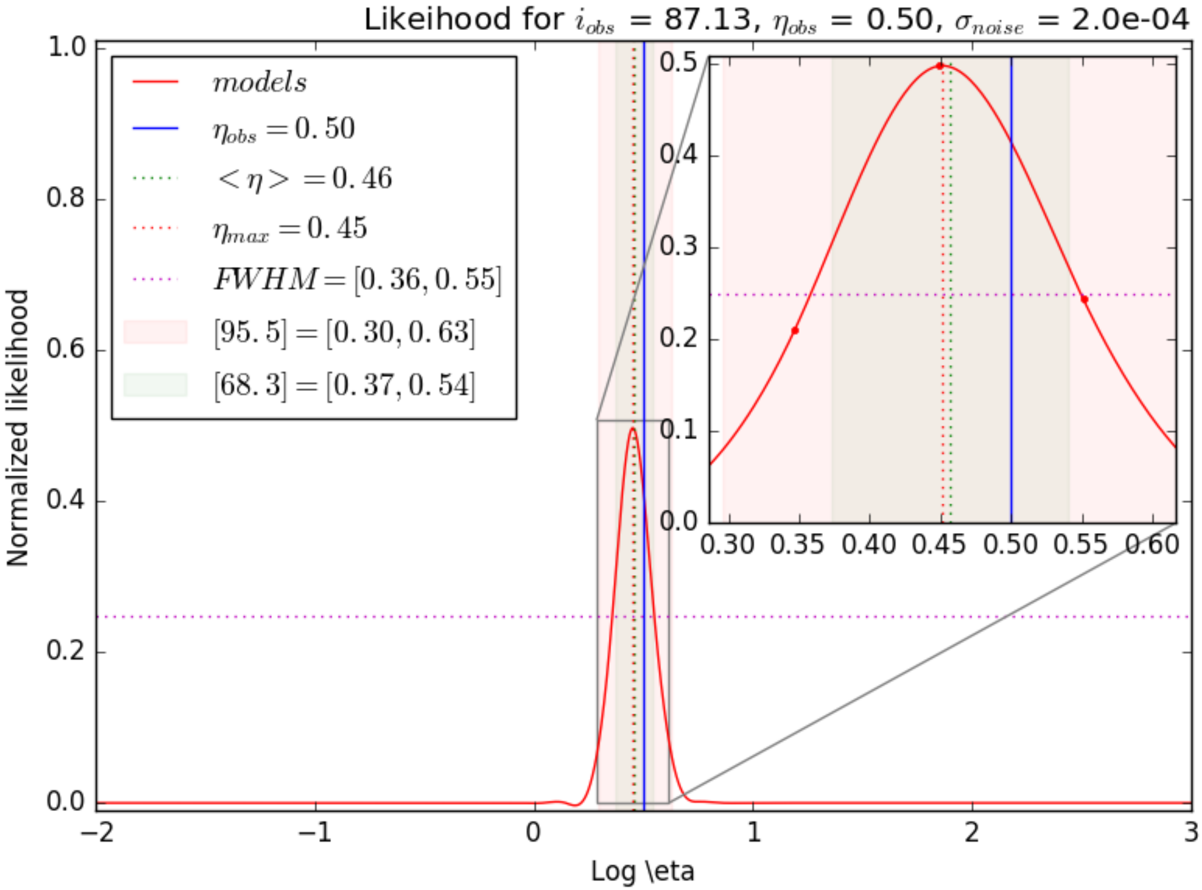
- Responsivity $A(r) \propto r^{\eta}$
- η_{obs} : -1.5, -0.5, 0.0, 0.5, 1.5 (Total 5)
- η_{mod} : evenly spaced in [-2.0, 3.0]. (Total 50)
- An *observation* η_{obs} compared with a set of 50 *models* (i.e. 50 η_{mod} values).
- Repeated for 5 different η_{obs} values.

Results: responsivity parameter η



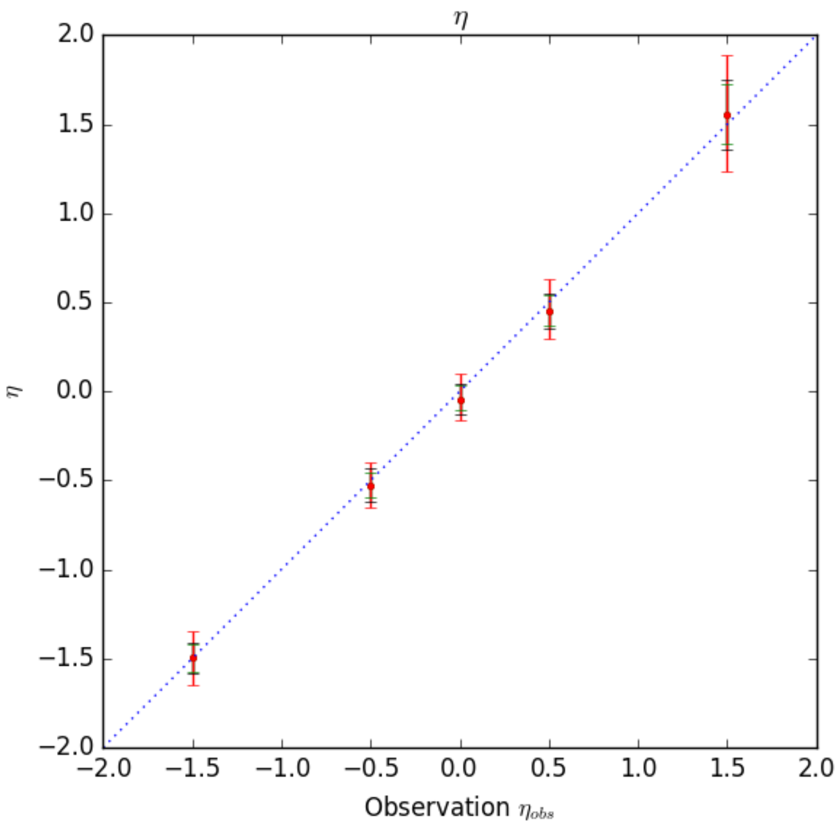
- Without adding error to 'observation'.

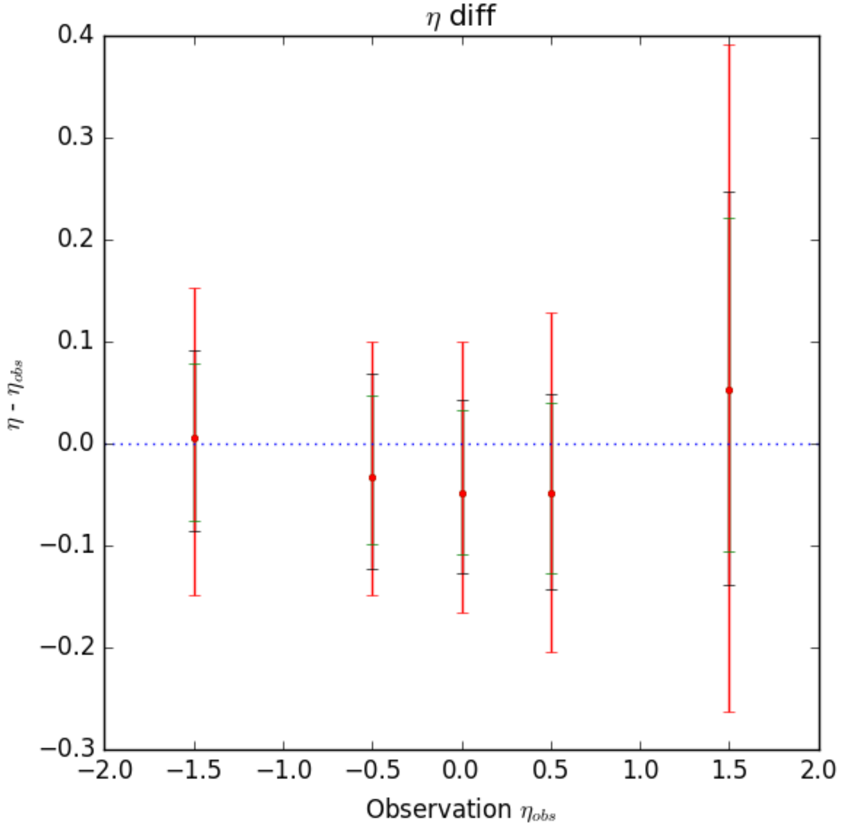
Results: responsivity parameter η



- With uncertainty added to the 'observation'.
- σ ~ 50% of the mean value of the *'observation'*.

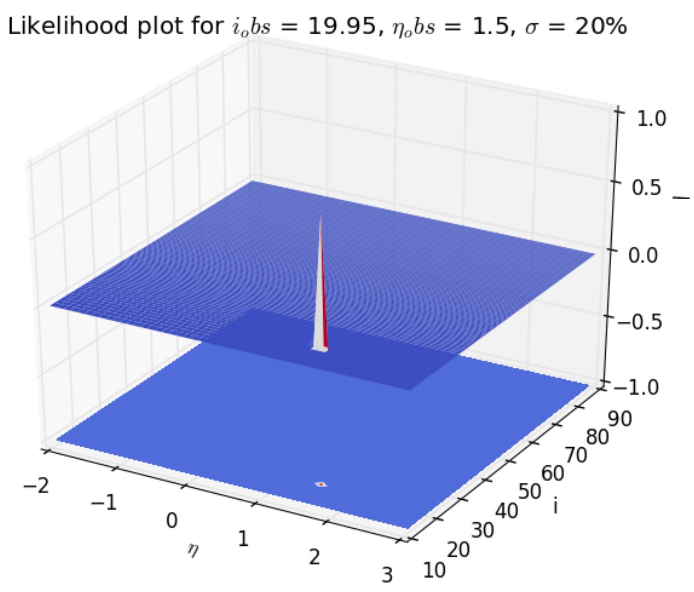
Results: responsivity parameter η

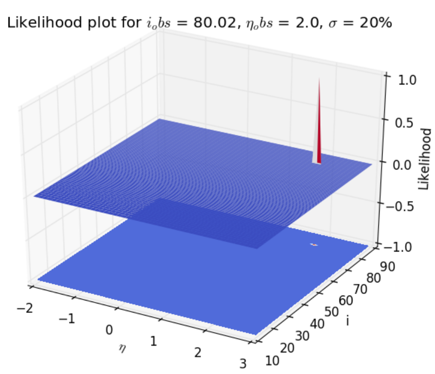


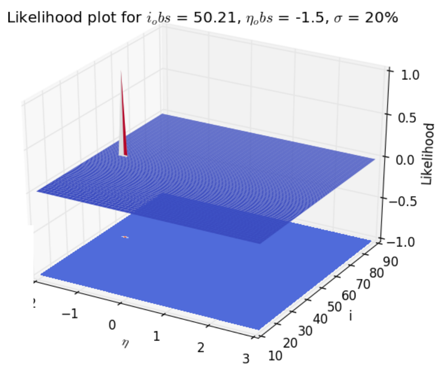


Results: inclination angle *i* & responsivity parameter *η*

- A grid of 143 *i* x 51 *η* models.
- One of the models (with uncertainty added) was selected as *'observation'* and compared with the rest of the models.







Summary & Conclusions

- Explored the feasibility of constraining parameters of a disk-wind model of the BLR using a Bayesian statistical analysis.
- Three different cases:
  - Inclination angle i.
  - Responsivity parameter η.
  - Inclination angle i & responsivity parameter η.
- In all three cases we were able to recover the parameter/s of the 'observation'.

Improvements & Future work

- Increasing the number of parameters explored.
- For higher degree parameter space exploration, a more efficient method will be needed.
  - E.g. Nested sampling
- Applying this method to real observational data.