Research in Astrophysics from Space (E)
Science with AstroSat: from Ultraviolet to Gamma Rays (E1.5)
Consider for oral presentation.

X-RAY SPECTRAL STUDY OF MKN 421 USING ASTROSAT OBSERVATION

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We present a detailed X-ray spectral study of the high energy peaked blazar MKN 421 using the simultaneous broadband observations from the LAXPC and SXT instruments on-board the AstroSat satellite. In order to investigate the spectral properties of the source, we used the method of time resolved spectral analysis by dividing the total observation time into time-segments of 10 ksecs and then by fitting each segment with synchrotron emission of particle density from logparabola model. In each time-segment, we fitted the observed broadband X-ray spectrum. The X-ray spectrum of Mkn 421 showing significant spectral curvature is usually described by log-parabola model, however, the model fails to give the information of underlying physical parameters as the exact relationship of model parameters with the underlying physical quantities is not clear. Therefore in order to obtain the information of underlying physical parameters, we reproduce the X-ray spectrum with a analytical models viz. energy-dependent acceleration(EDA) model. On comparing the goodness of the fit of synchrotron convolved logparabola model with the EDA model, we noted that both the models provided nearly equally good fit to the broadband spectrum, though EDA model is comparatively better. Moreover, we studied the correlation between EDA model parameters (norm, ψ, κ) and the observed quantities using the Spearman rank correlation method. A significant anti-correlation is observed between ψ and κ with $r_s = -0.82 (P_{rs} = 1.69 \times 10^{-9})$ and similar anti correlation is also obtained for the case of κ and norm $r_s = -0.86$ $(P_{rs} = 3.5 \times 10^{-11})$. The above obtained correlation results between fit parameters for the case of EDA model are consistent with the definition. Which refer that the model is more appropriate for reproducing the X-ray spectrum of Mkn 421.

X-ray Analysis of Blazar Mkn 421

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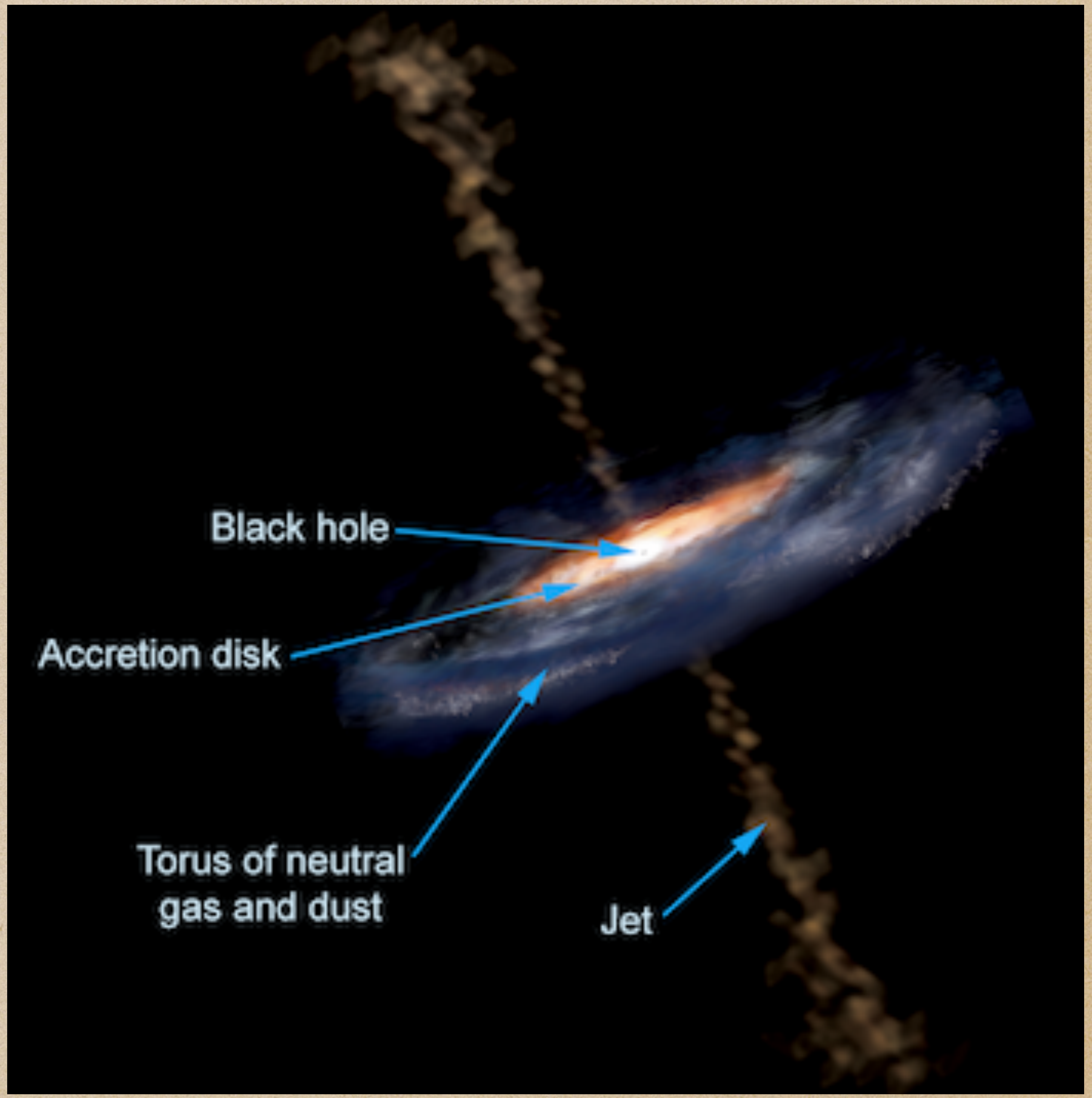
Blazars

- Active galactic nuclei (AGN) with relativistic jets that point very close to the line of sight of the observer
- Variable non thermal emission from radio to γ - rays.
- Spectral energy distribution (SED) Synchrotron process produces low-energy (radio-UV/X-ray) component
- Inverse Compton process giving rise to high-energy (X-ray/γ-ray) spectrum

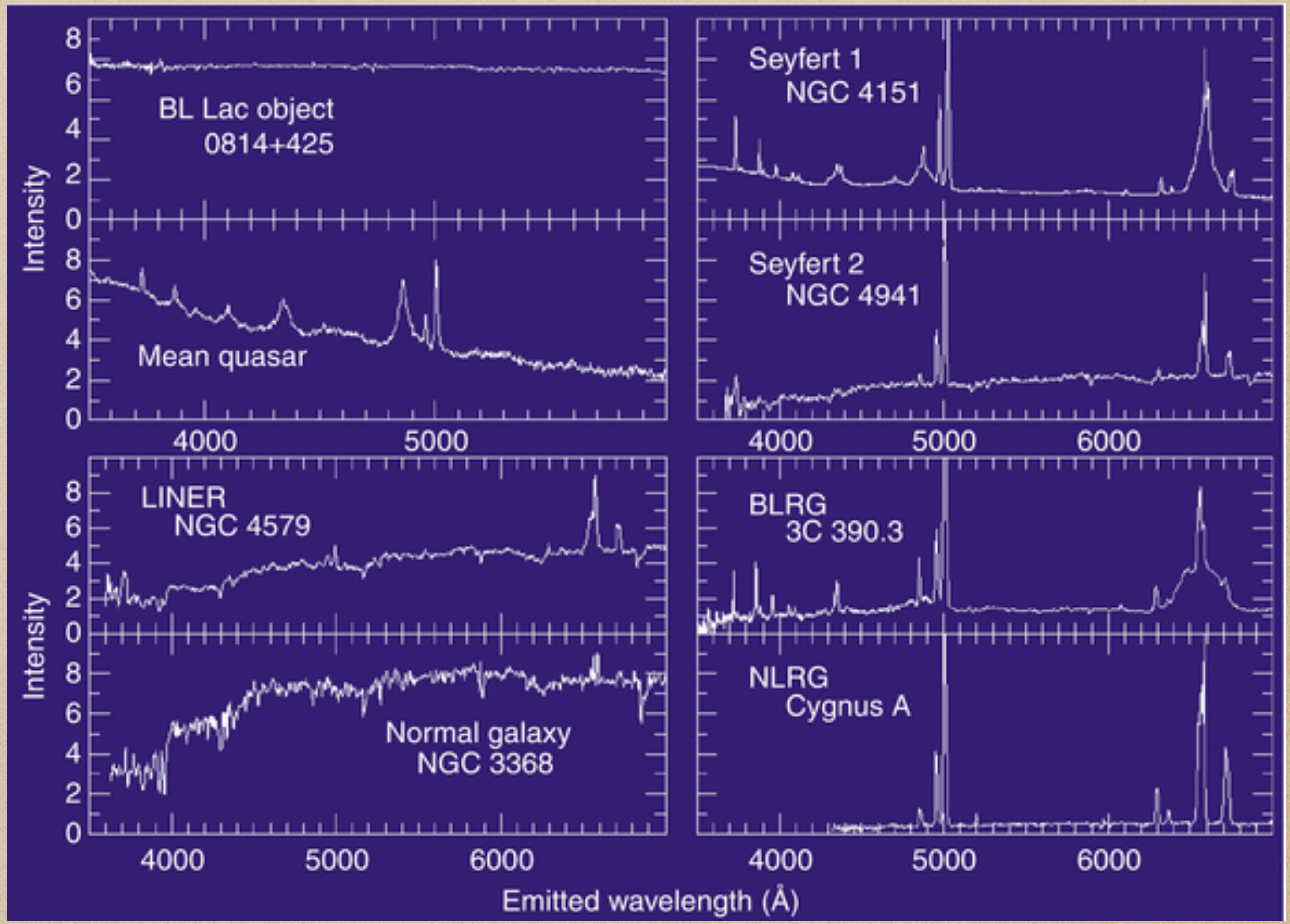


Blazar Classification

Blazar → BL Lacs

Blazar → FSRQ

- Low-energy peaked BL Lacs (LBL)
- Intermediate energy peaked BL Lacs (IBL)
- High-energy peaked BL Lacs (HBL)



Markarian 421(Mkn 421)

- Mkn 421 is a nearest and an extremely bright source and display a strong variability across electromagnetic spectrum.
- During 2017 January 3-8, AstroSat carried a ToO observation of the flaring activity of Mkn 421 for a total observation time of 409 ksec.
- We carried a time resolved spectral study by dividing the observation time into time segments of 10 ksec.

Spectral analysis

- The combined X-ray spectrum in each segment is fitted by synchrotron emission from different particle energy distribution e.g log parabola (lp), and particle model such as energy-dependent diffusion (EDD), energy dependent acceleration (EDA), Power-law with a maximum energy (ξ_{max}) model.

- The motivation of our work was to obtain a more consistent physical scenario responsible for emission.

- The synchrotron flux emission arises from a spherical region of radius (R) filled with tangled magnetic field (B) and relativistic isotropic electro distribution ($n(\gamma)$) received by the observer at energy ϵ is given by $F_{syn}(\epsilon) = \dfrac{\delta^3(1+Z)}{d_L^2} V \mathbb{A} \displaystyle\int_{\xi_{min}}^{\xi_{max}} f(\epsilon/\xi^2) n(\xi) d\xi$

- This equation is solved numerically and included it as local convolution model, $synconv \otimes n(\xi)$ in XSPEC.

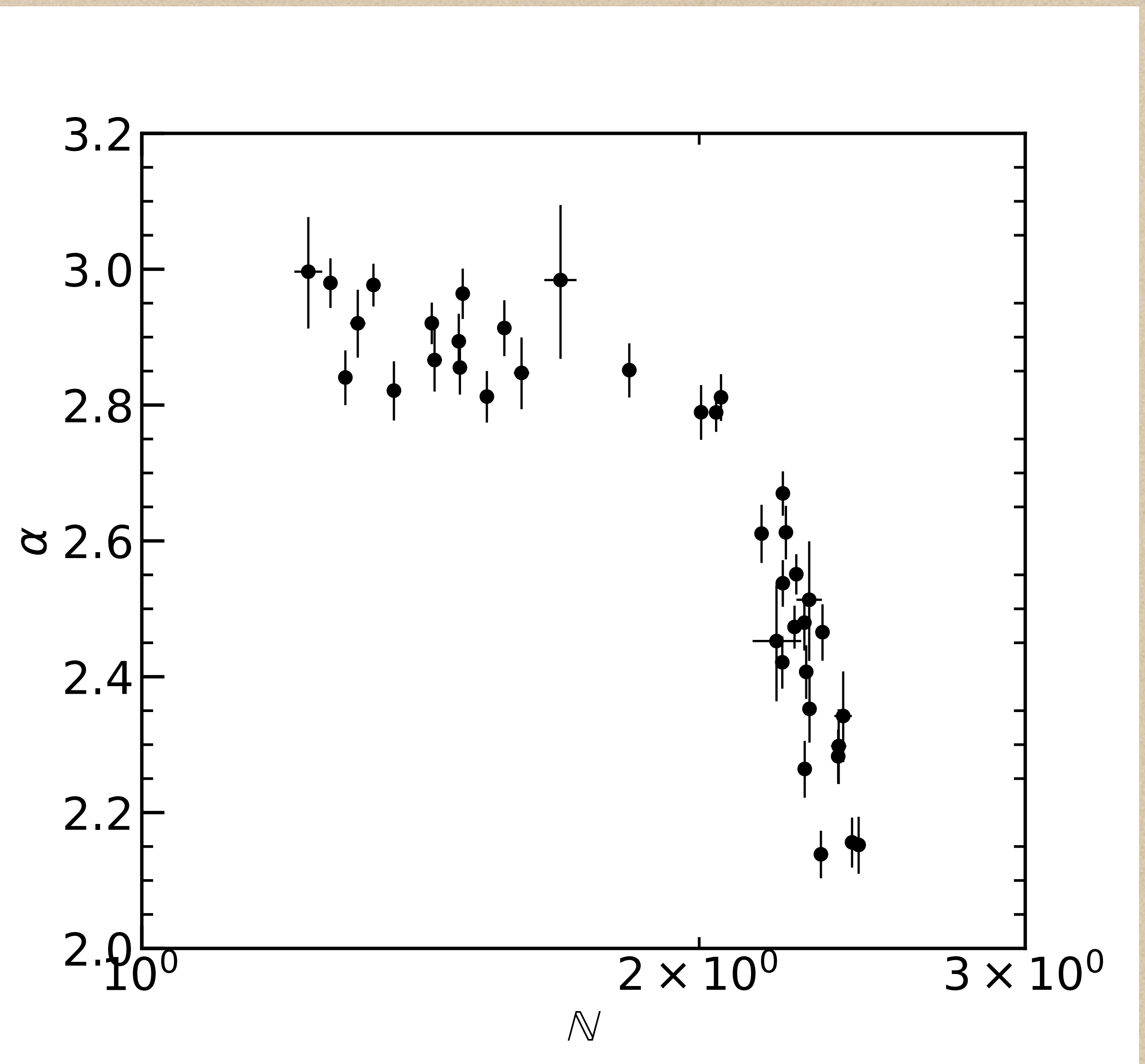
Log-parabola model

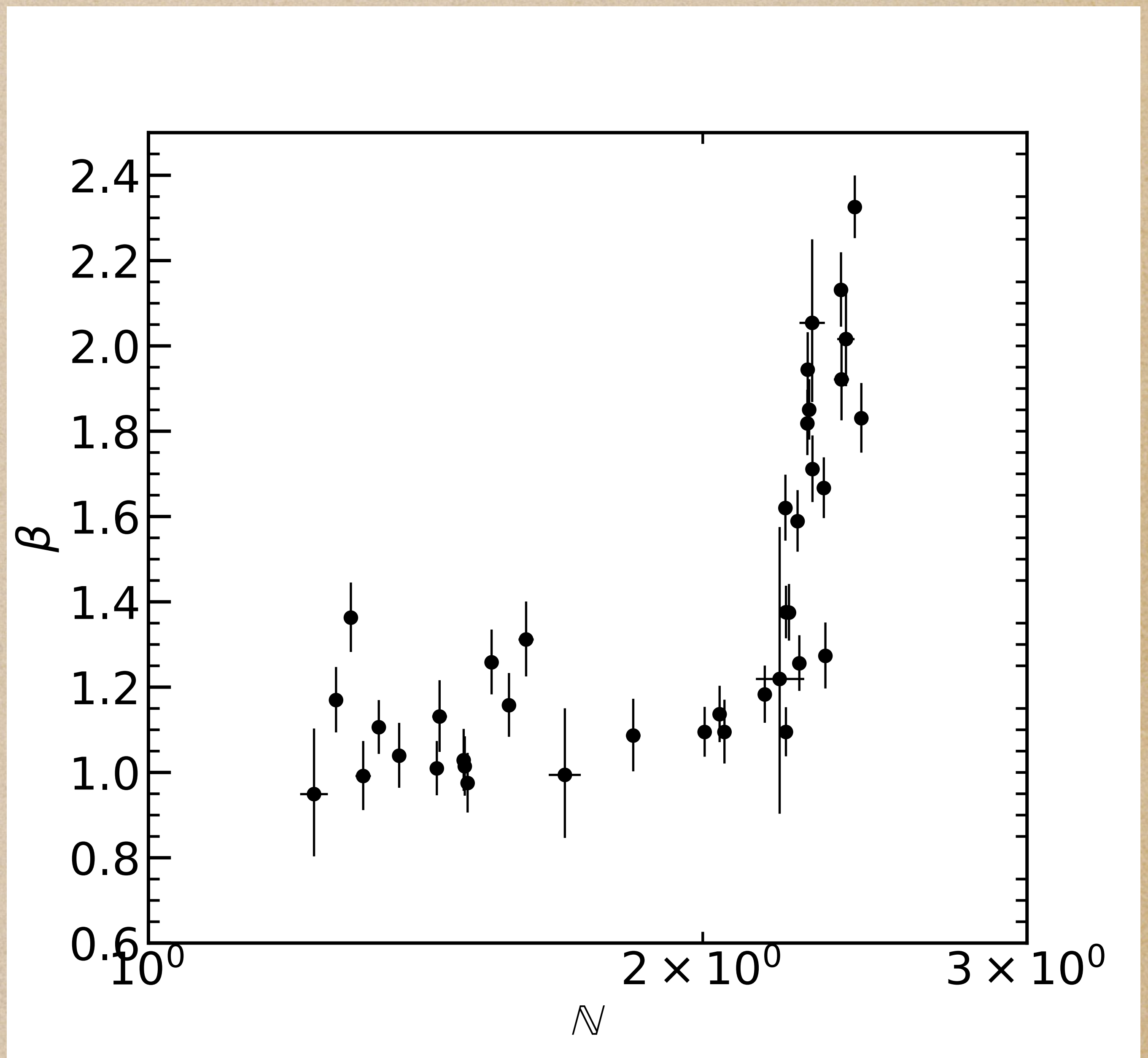
- Shape of Input particle density as $n(\xi) = K(\xi/\xi_r)^{-\alpha-\beta\log(\xi/\xi_r)}$
- We perform the combined spectral fit in each time bin with $synconv \otimes n(\xi)$ model

$$\mathbb{N} = \frac{\delta^3(1+z)}{d_L^2} V \mathbb{A} K$$

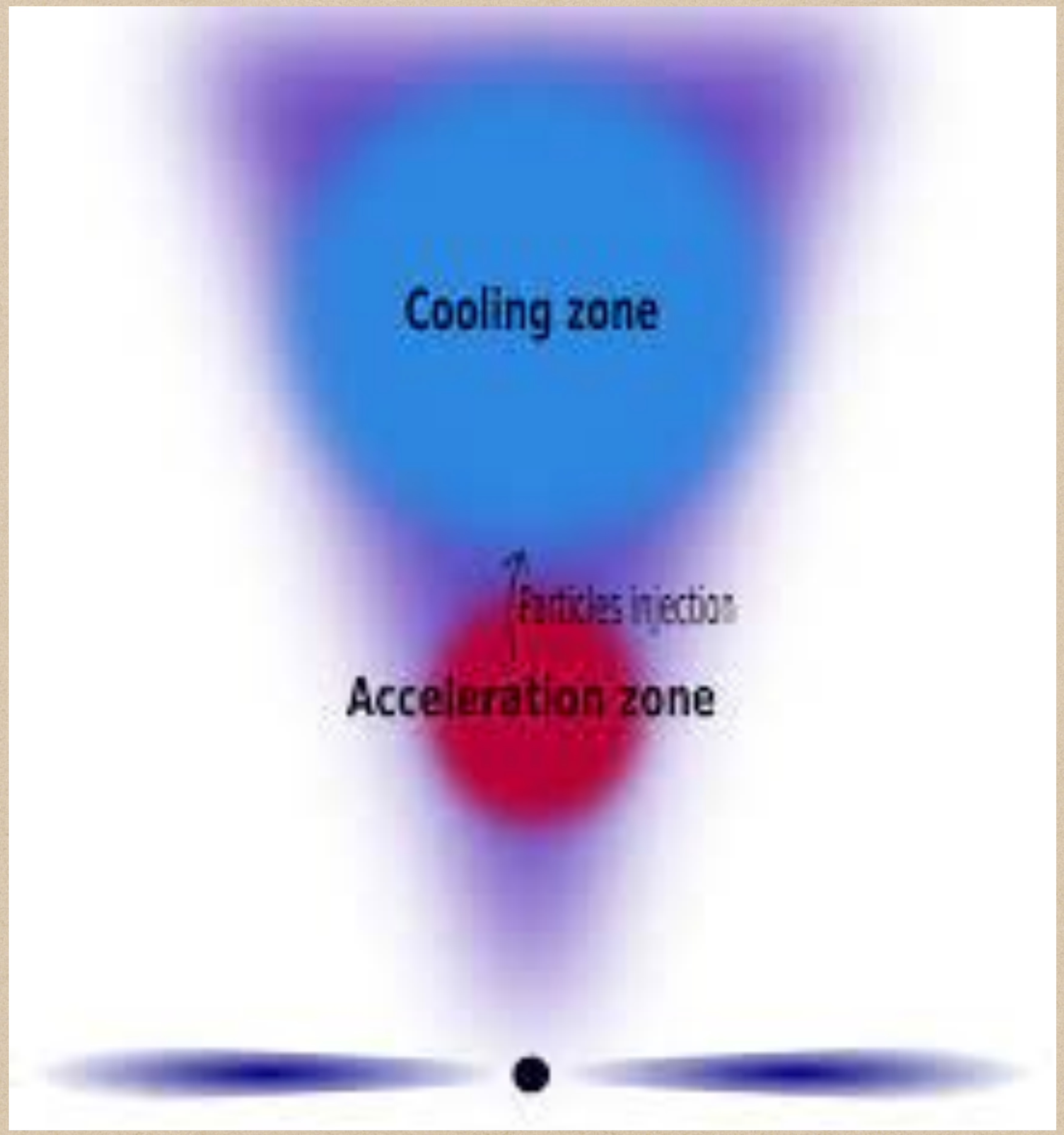
Issue:

- The exact relationship of model parameters with physical parameters is not clear.





Jet emission modelling



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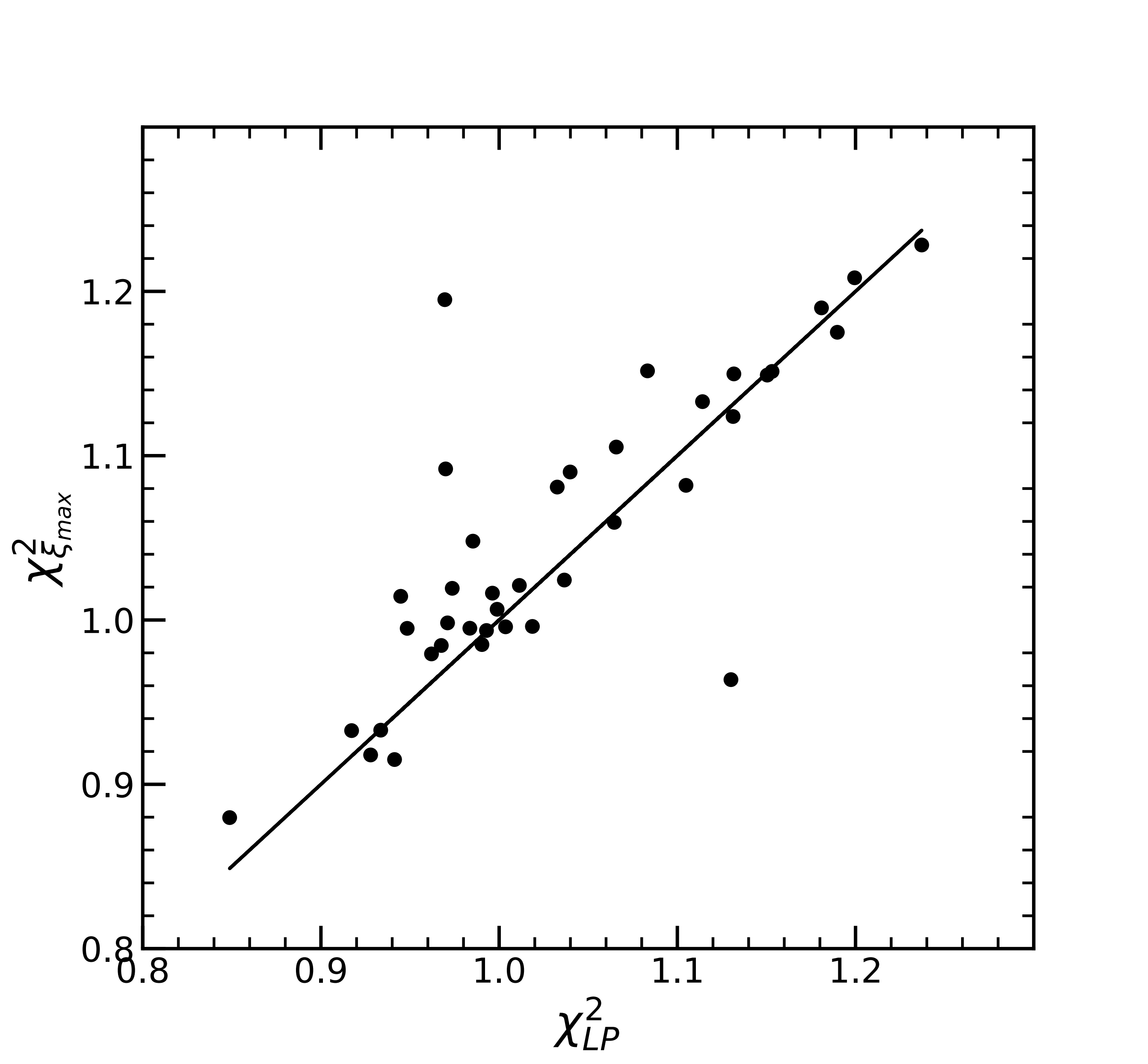
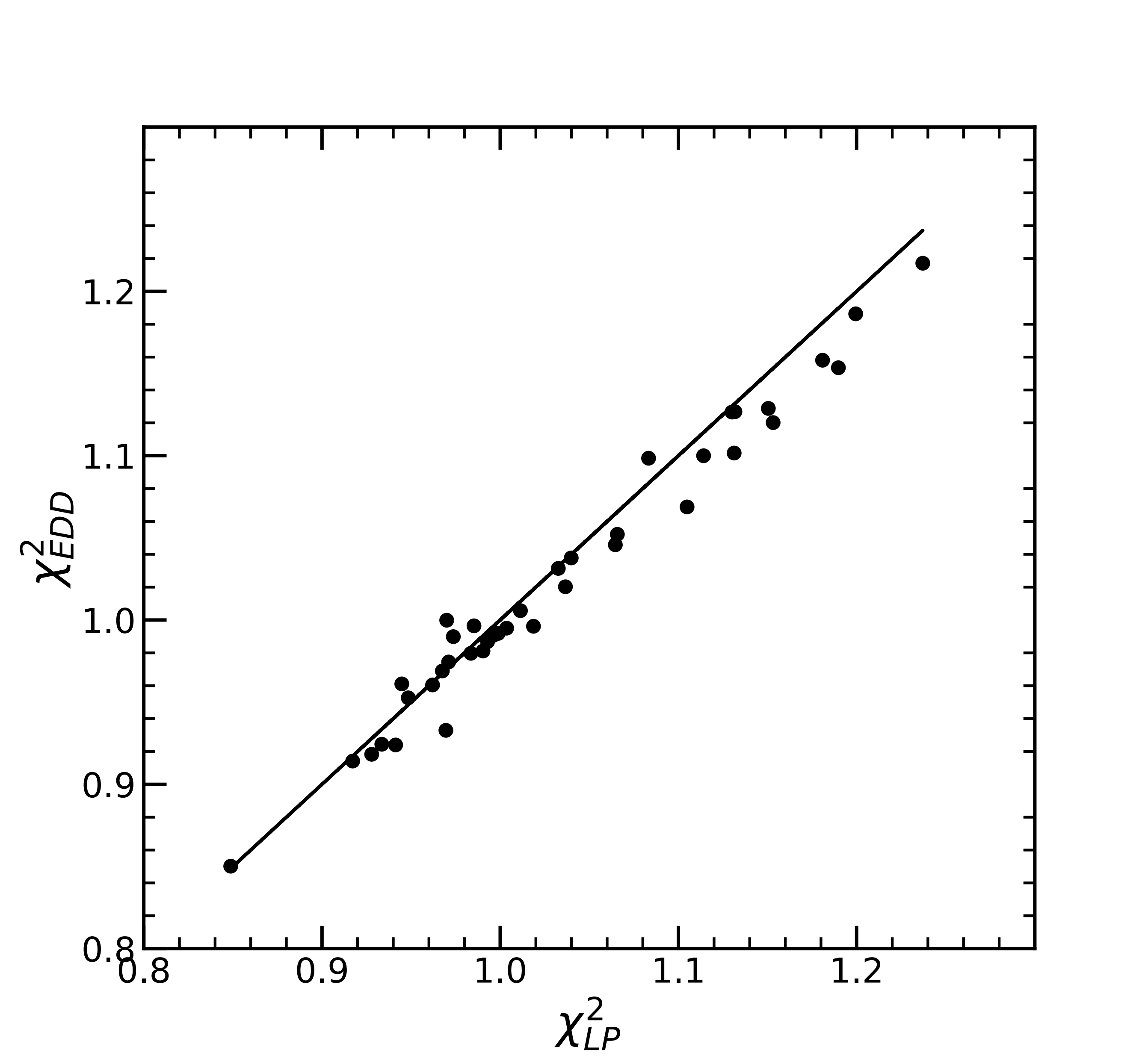
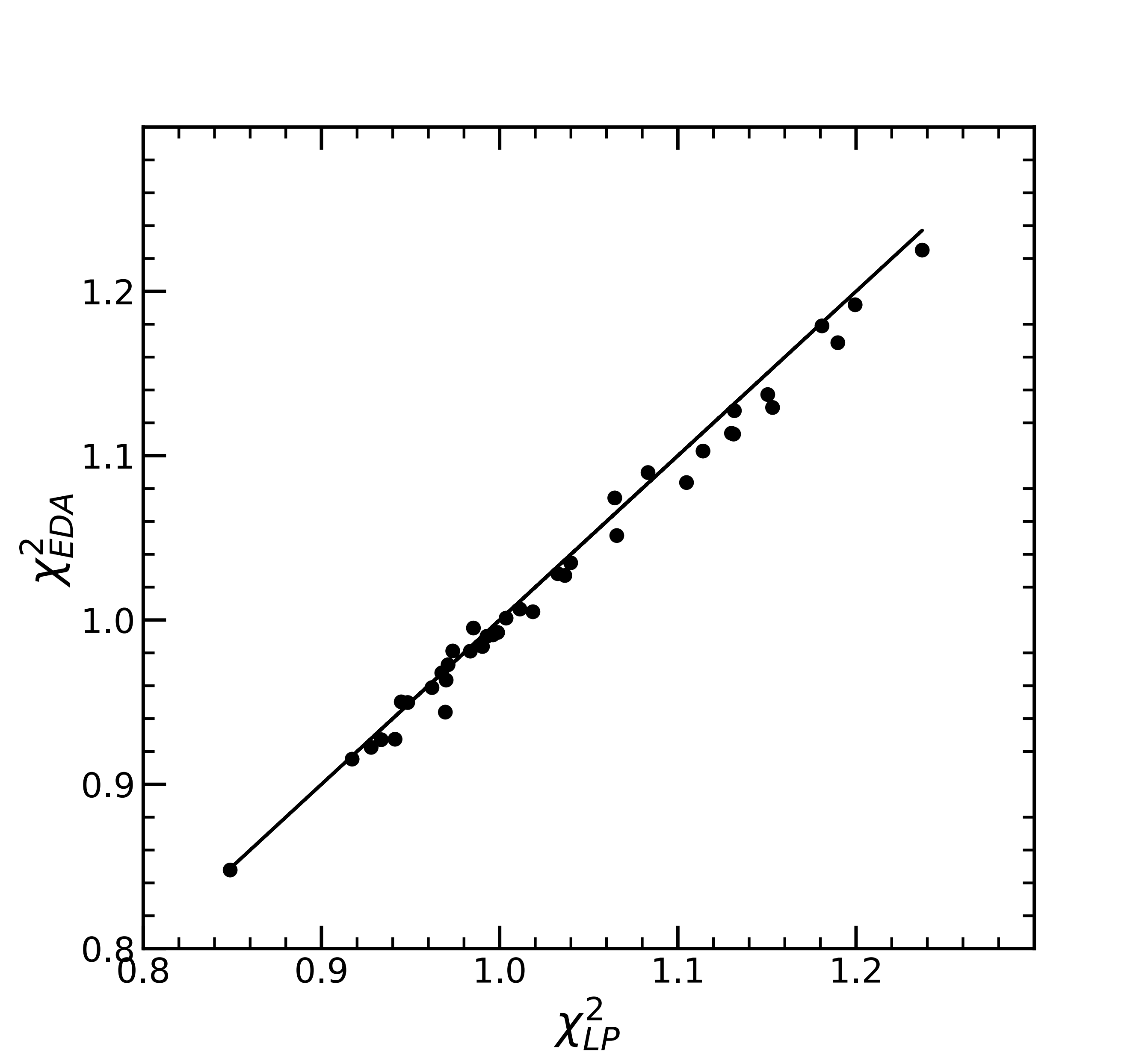
Analytical model

- The steady state particle distribution
- $$\frac{\partial}{\partial \gamma}\left[\left(\frac{\gamma}{\tau_{acc}} - \beta_s \gamma^2\right) n_a]\right] + \frac{n_a}{\tau_{esc}} = Q\delta(\gamma - \gamma_0)$$
- Power-law with a maximum energy due to radiative cooling (ξ_{max}) model (τ_{acc} and τ_{esc} energy independent)
- Energy dependent diffusion (EDD) model (τ_{esc} energy dependent)
- Energy dependent acceleration (EDA) model (τ_{acc} energy dependent)

Comparisons of different models

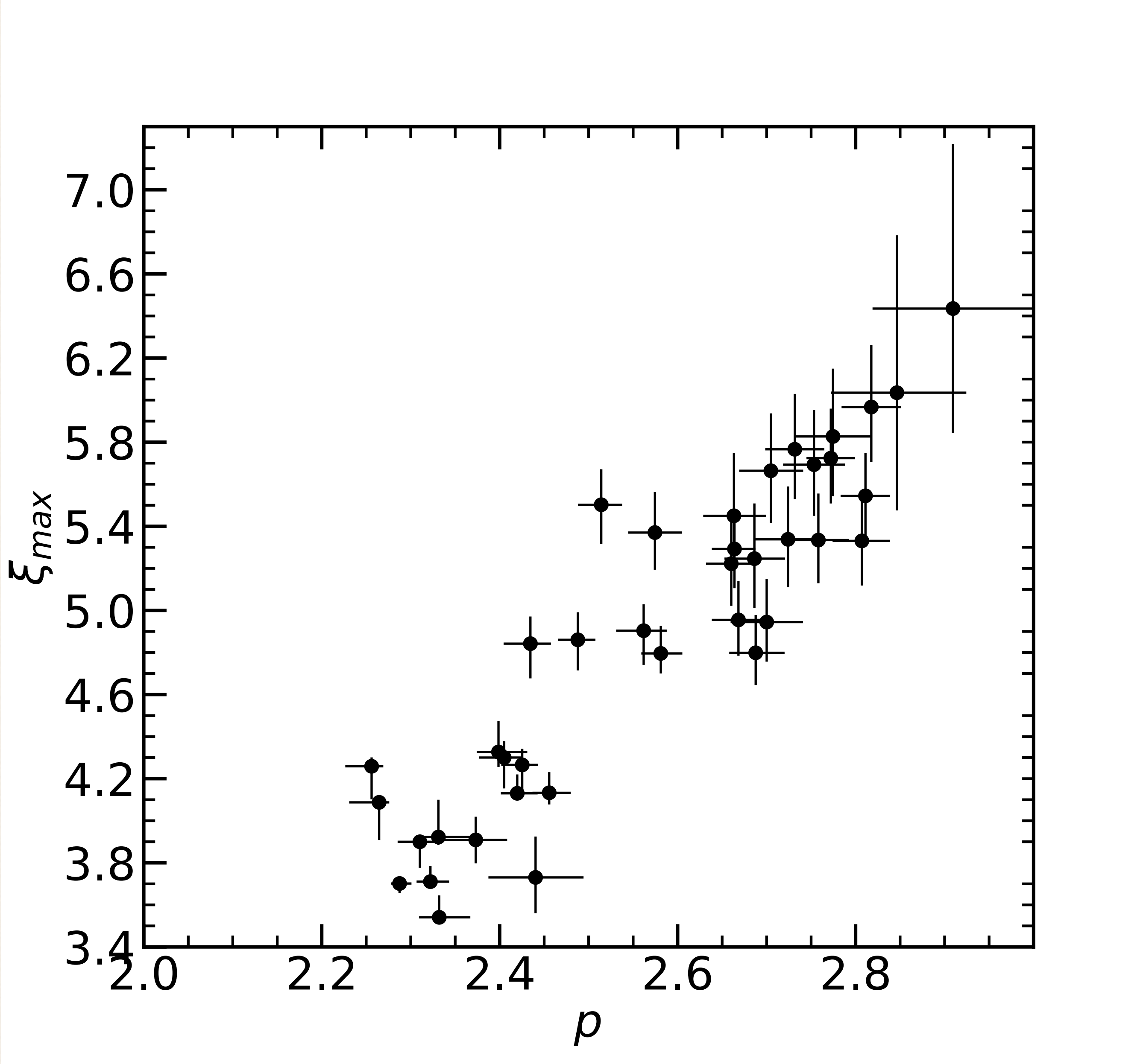


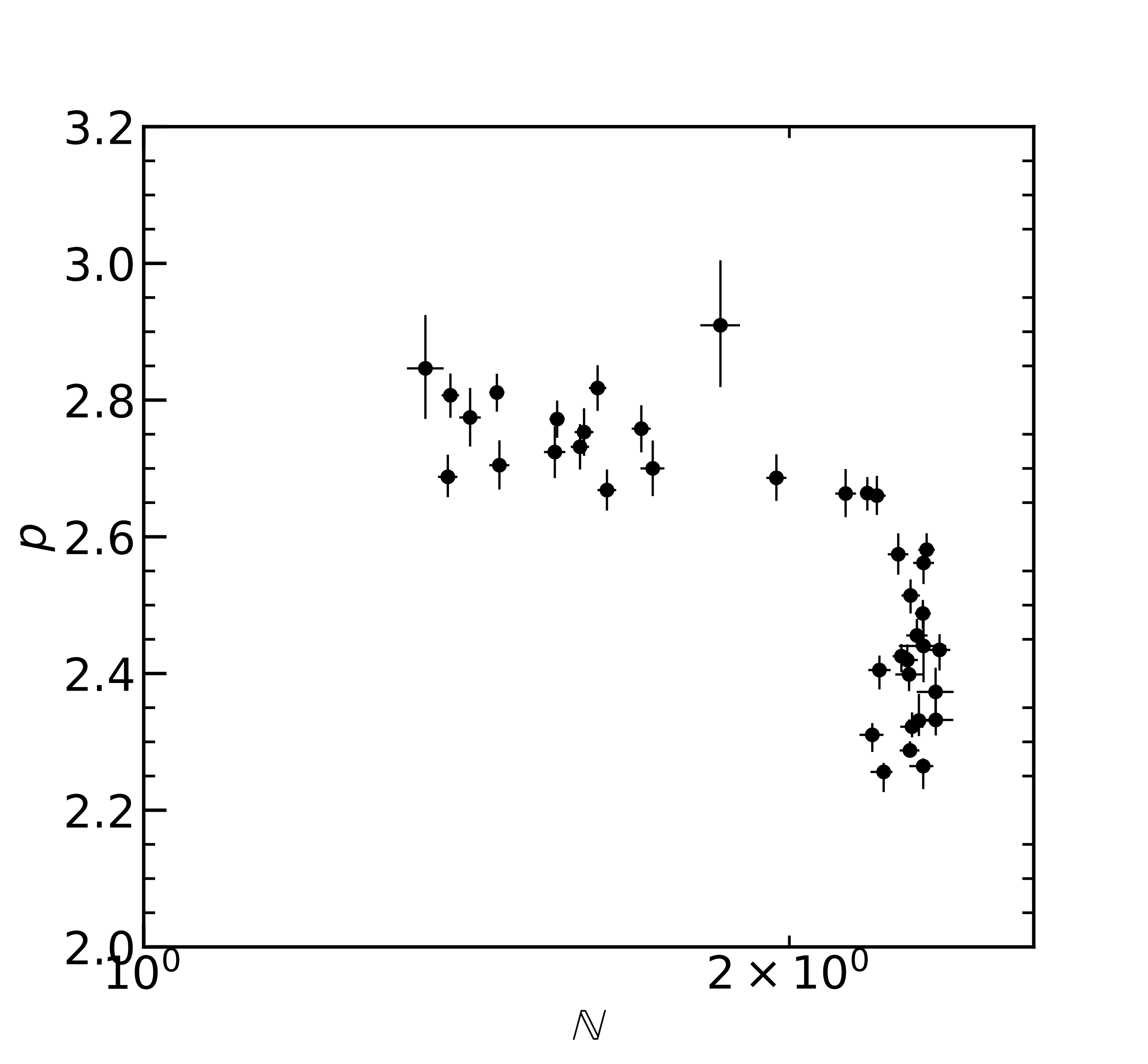




Particle distribution with a maximum energy (ξ_{max})

- Particle energy $n(\xi) = K\xi^{-p}\left(1 - \frac{\xi}{\xi_{max}}\right)^{(p-2)}$
- The combined spectral fit with $synconv \otimes n(\xi)$model, with free parameter as N, p and ξ_{max}
- $\mathbb{N} = \frac{\delta^3(1+z)}{d_L^2} V \mathbb{A} Q_0 \tau_{acc} \gamma_0^{p-1} \mathbb{C}^{p/2}$





Issue

- The correlation between p and ξ_{max}
- Variation of index p should result in $\Delta/N = log(\xi_0^2)\Delta p/2$, change in index p should result in a significant change in normalisation.

The correlation between model parameters are inconsistent with the prediction of model.

EDD model:

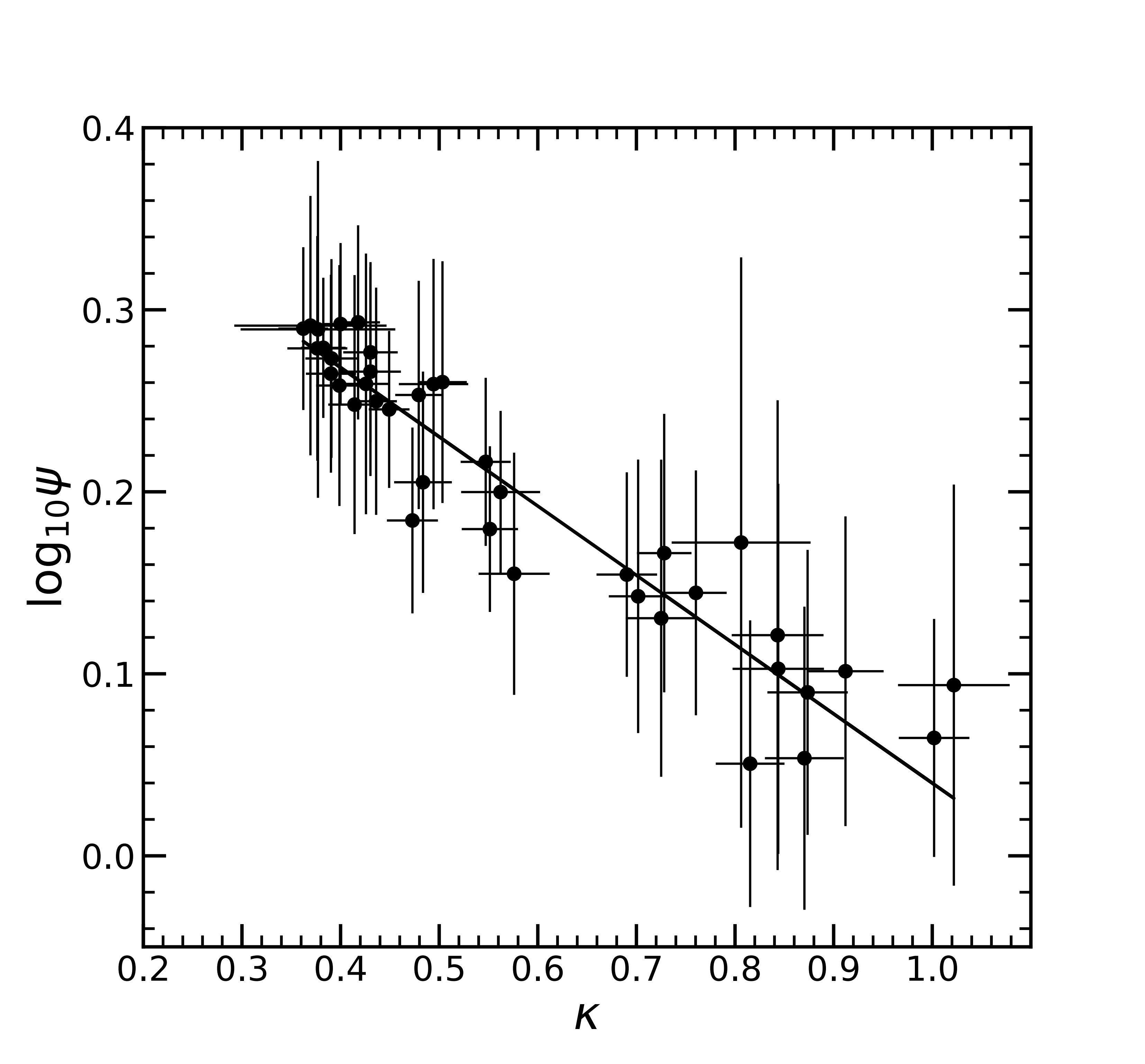
- Energy dependent of escape time scale $\tau_{esc}(\gamma)$ $\tau_{esc} = \tau_{esc,R}\left(\frac{\gamma}{\gamma_R})\right)^{-\kappa}$
- The particle energy distribution $n(\xi) = K'\xi^{-1}\exp\left[-\frac{\psi}{\kappa}\xi^{\kappa}\right]$ where $\psi = \eta_R\left(\mathbb{C}\gamma_R^2\right)^{-\kappa/2} = \eta_R\xi_R^{-\kappa}$

$K' = Q_0\tau_{acc}\sqrt{\mathbb{C}}\exp\left[\frac{\eta_{\mathrm{R}}}{\kappa}\left(\frac{\gamma_0}{\gamma_{\mathrm{R}}}\right)^{\kappa}\right]$

- The free parameters for the model are ψ, κ and $\mathbb{N}$ given by $\mathbb{N} = \frac{\delta^3(1+z)}{d_L^2}V\mathbb{A}K'$

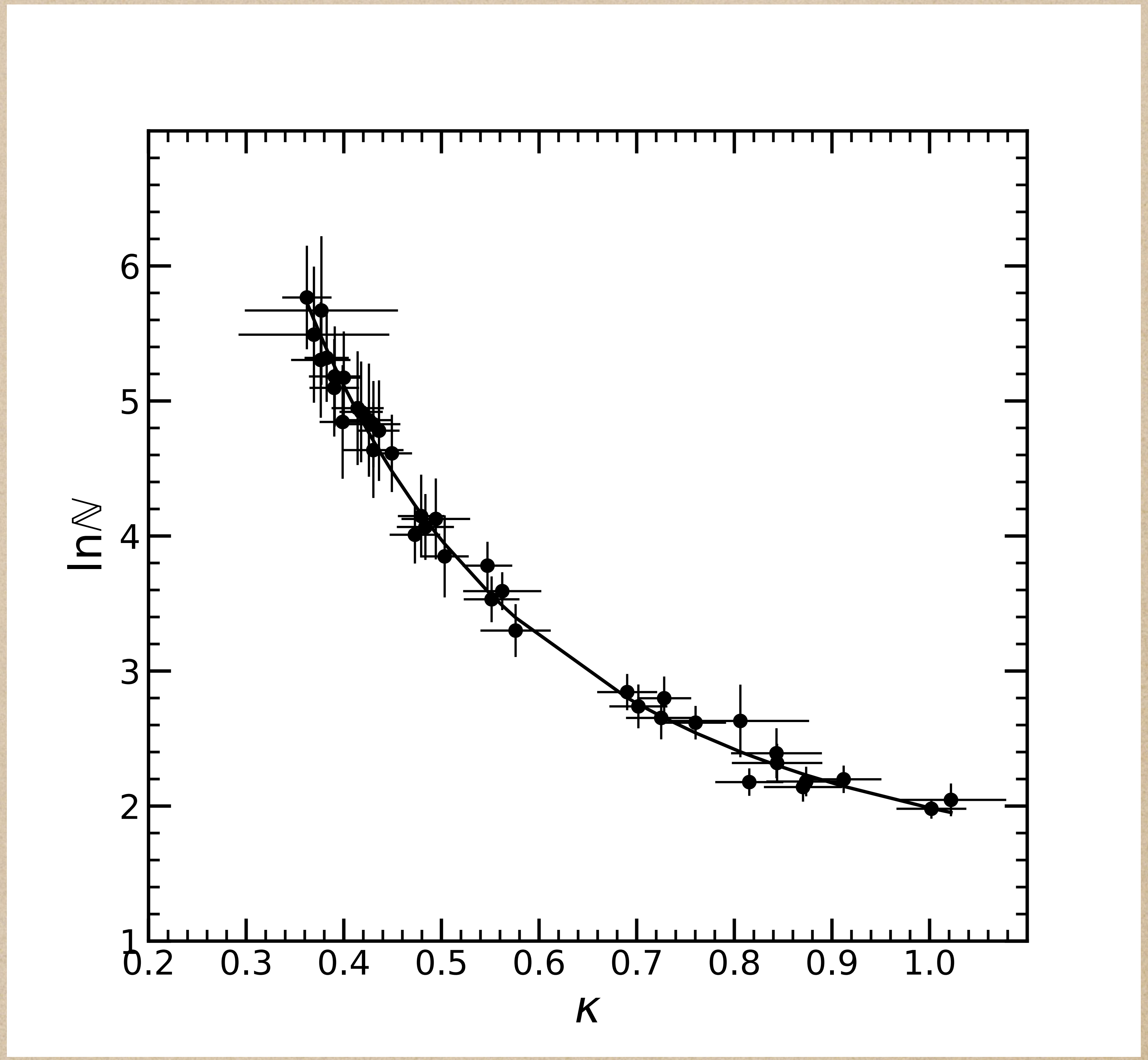
EDD model:

- $\psi = \eta_R \psi_R^{-\kappa}$, $log_{10}\psi = -0.38\kappa + 0.42$
- $\eta_R \approx 2.6$ and $\xi_R \approx 2.4$ keV
- The observed photon energy corresponding to γ_R , $\xi_R \approx$ 2.4 keV



EDD model:

- $ln\mathbb{N} = \frac{\eta_R}{\kappa} A^{\kappa} - \kappa \log \xi_R + B$
- From the fit, A= 0.26, B= 1.3 and $\eta_R = 2.6$
- The injection energy of the acceleration region, as $\gamma_0 \approx 0.26\gamma_R$



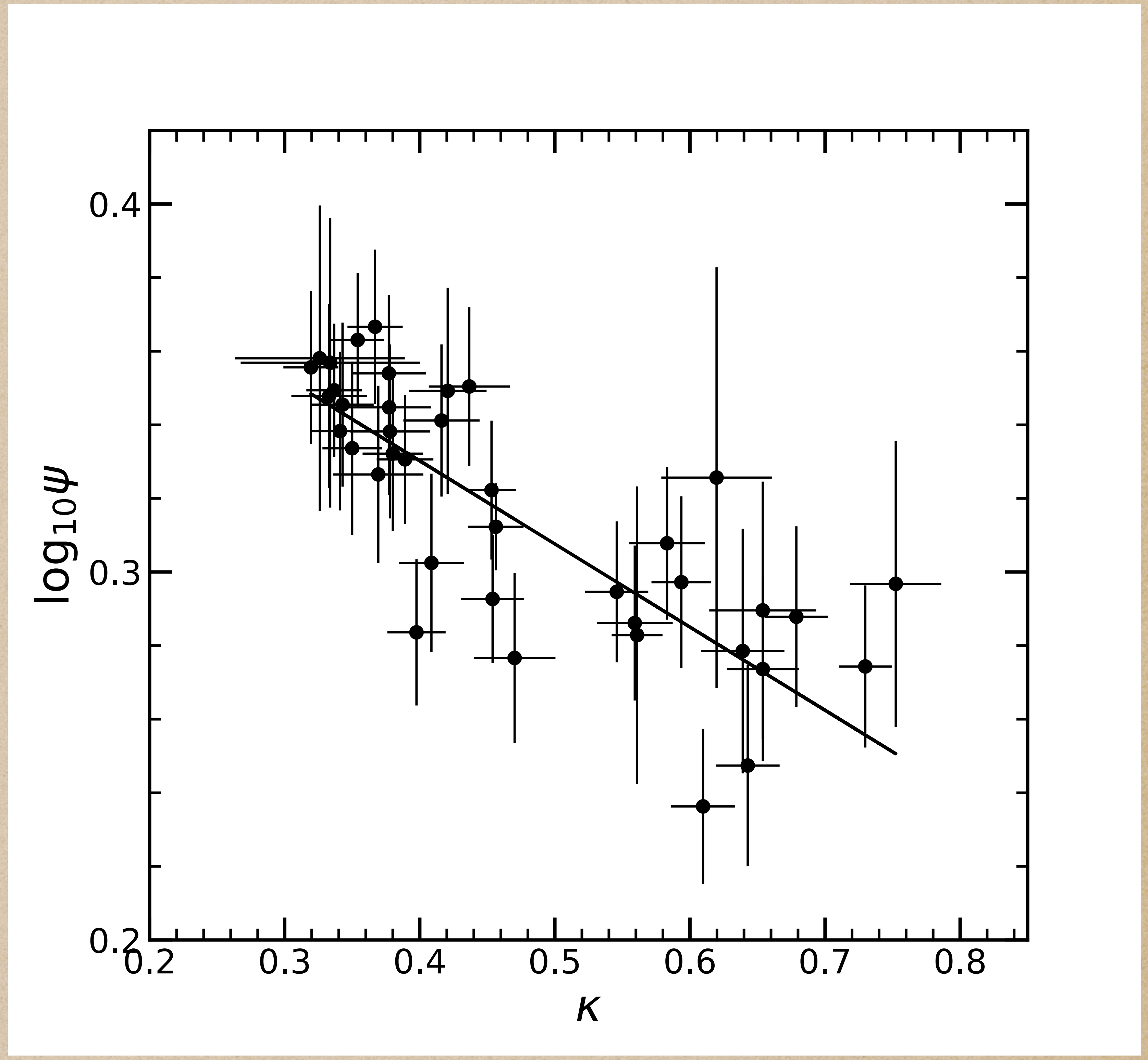
EDA model:

- Energy dependence of acceleration time-scale $\tau_{acc}(\gamma)$ $\quad \tau_{acc} = \tau_{acc,R}\left(\frac{\gamma\,)}{\gamma_R}\right)^{\kappa}$
- The particle energy distribution $n(\xi) = K'\xi^{\kappa-1}\exp\left[-\frac{\psi}{\kappa}\,\xi^{\kappa}\right]\psi = \eta_R\left(\mathbb{C}\gamma_R^2\right)^{-\kappa/2} = \eta_R\xi_R^{-\kappa}$

  $K' = Q_0\tau_{acc,R}\sqrt{\mathbb{C}}\,\xi_R^{-\kappa}\exp\left[\frac{\eta_\mathrm{R}}{\kappa}\left(\frac{\xi_0}{\xi_\mathrm{R}}\right)^{\kappa}\right]$
- The free parameters for the model are ψ, κ and $\mathbb{N}$ given by. $\quad \mathbb{N} = \frac{\delta^3(1+z)}{d_L^2}V\mathbb{A}K'$

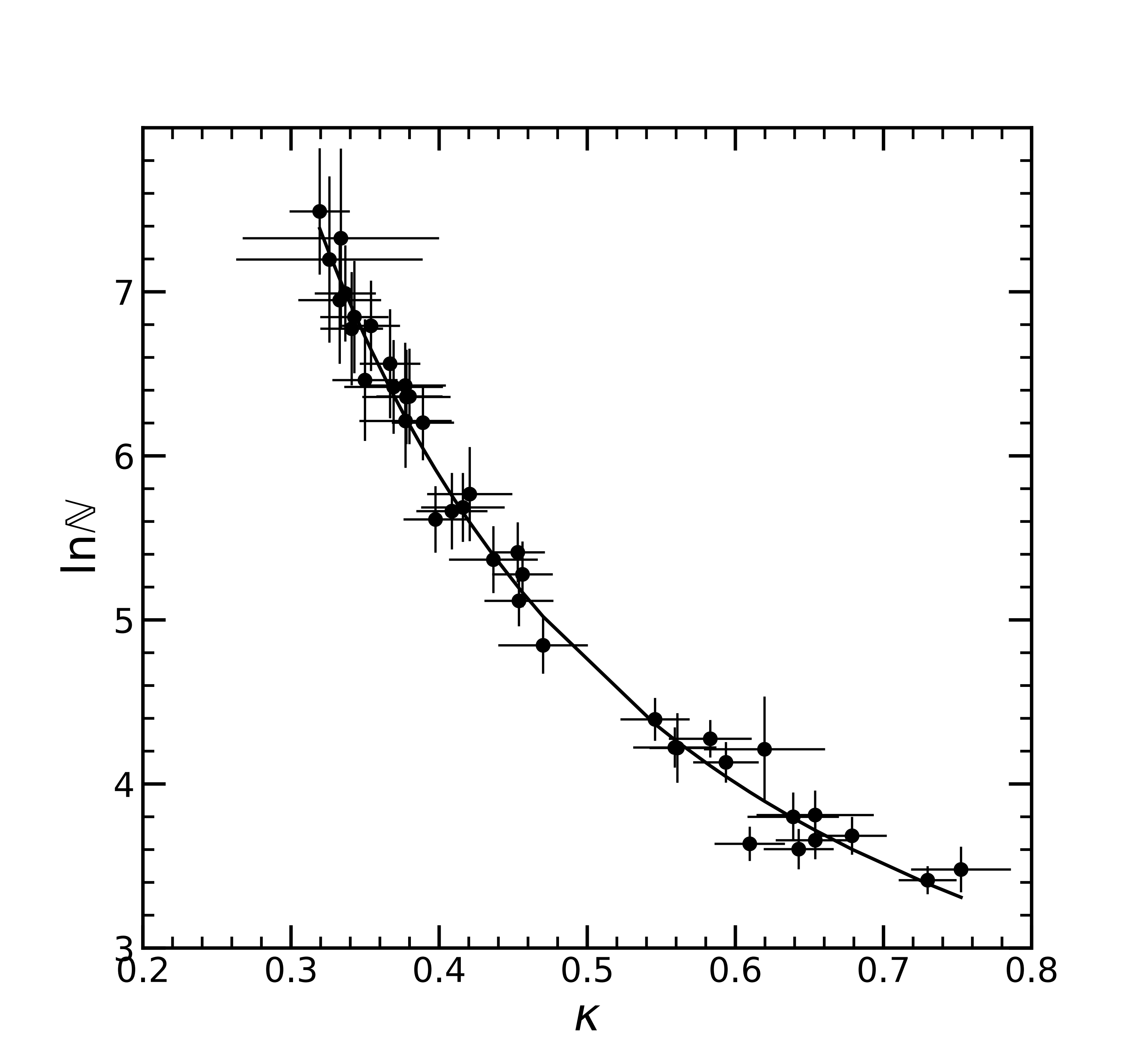
EDA model:

- $\psi = \eta_R \psi_R^{-\kappa}$, $log_{10}\psi = -0.23\kappa + 0.42$
- $\eta_R \approx 2.63$ and $\xi_R \approx 1.70$ keV
- The observed photon energy corresponding to γ_R , $\xi_R \approx 1.70$ keV



EDA model:

- $ln\mathbb{N} = \frac{\eta_R}{\kappa} A^{\kappa} - \kappa \log \xi_R + B$
- From the fit, A≈ 0.19, B≈ 2.70 and $\eta_R = 2.6$
- The injection energy of the acceleration region, as $\gamma_0 \approx 0.19\gamma_R$



Conclusion and Future work

- We have shown that Time-resolved spectral analysis is powerful toll to check the consistency the models.
- The correlation between spectral parameters and the inferred estimates of physical values can be used to constraint the models.
- The model contains in this work are simple ones which have analytical solution, but in reality the physical situation may be more complex.
- We will develop more sophisticate model by considering both diffusion and acceleration process to be energy dependent.

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