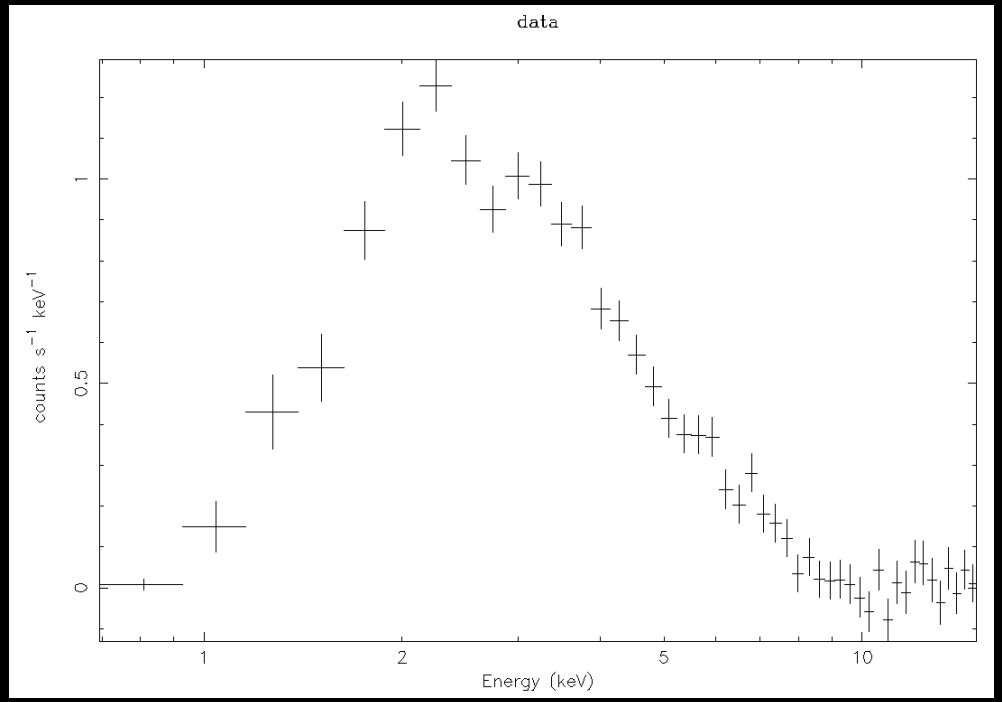
Pitfalls and solutions to model miss-specification in X-ray spectral modelling

Matteo Lucchini

X-ray data has changed

Legacy data: low S/N, spectra only



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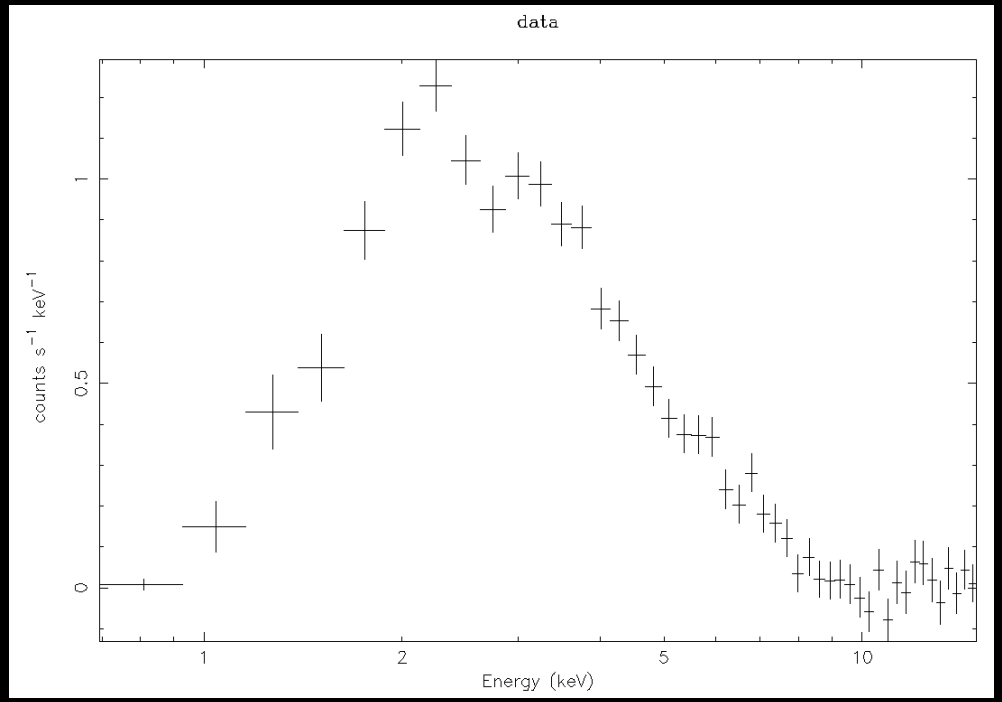
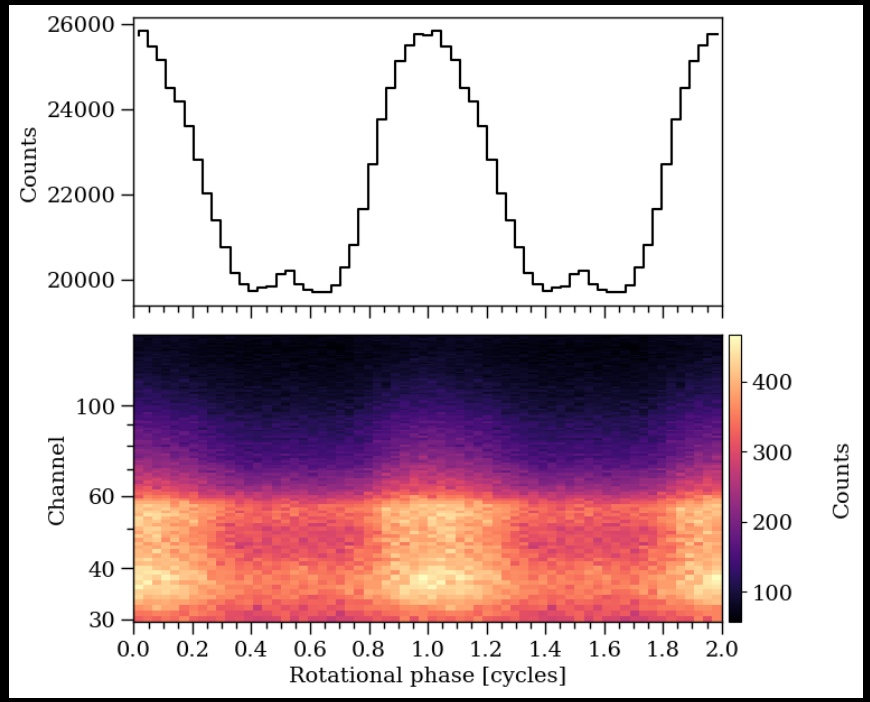
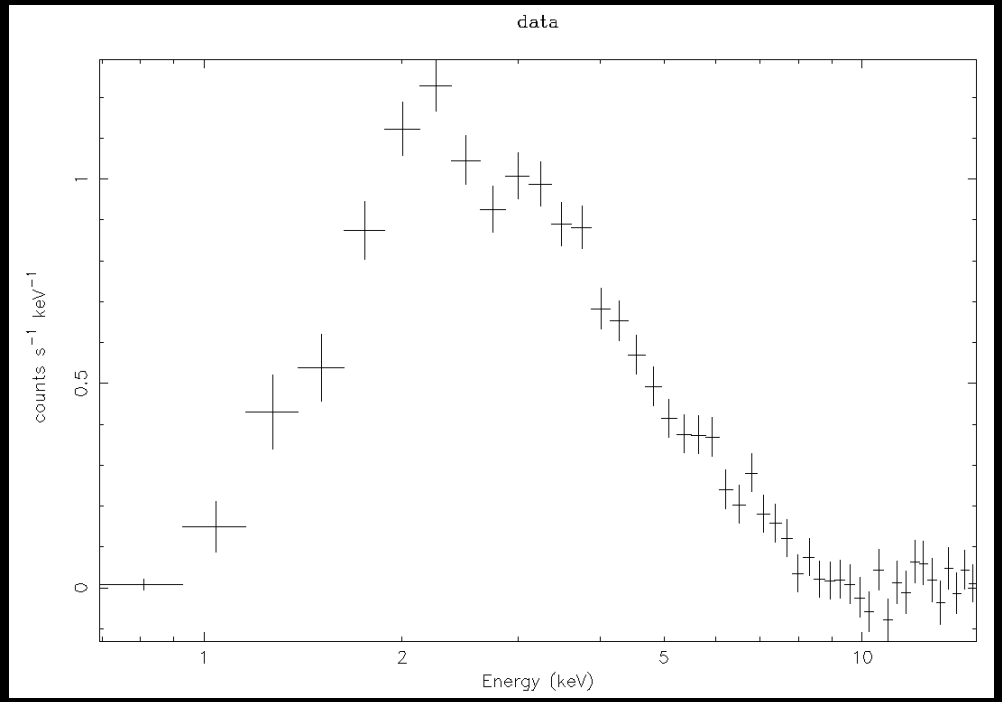


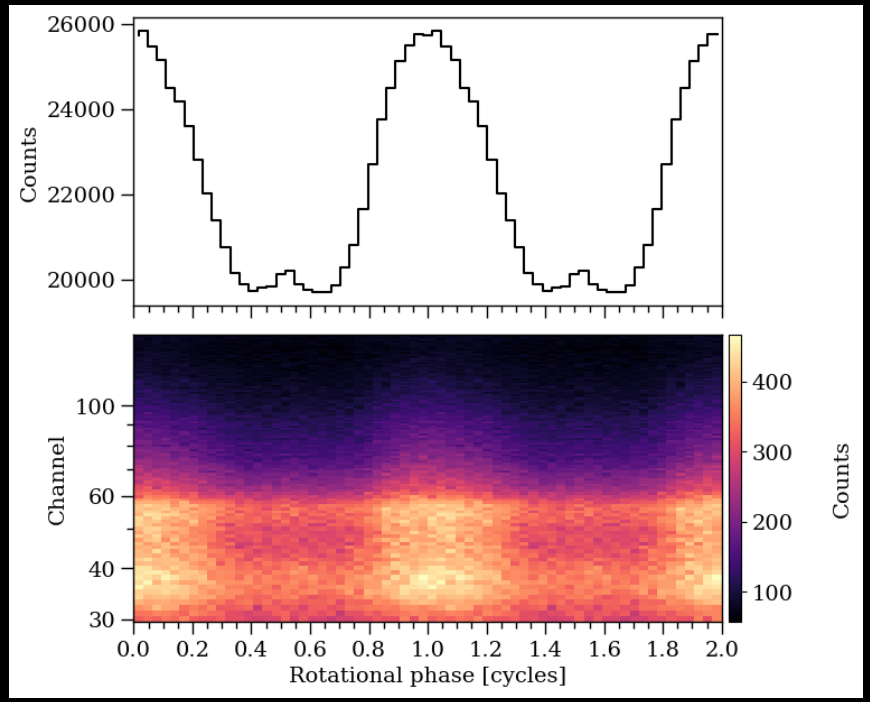
Modern data: high S/N, two+ d



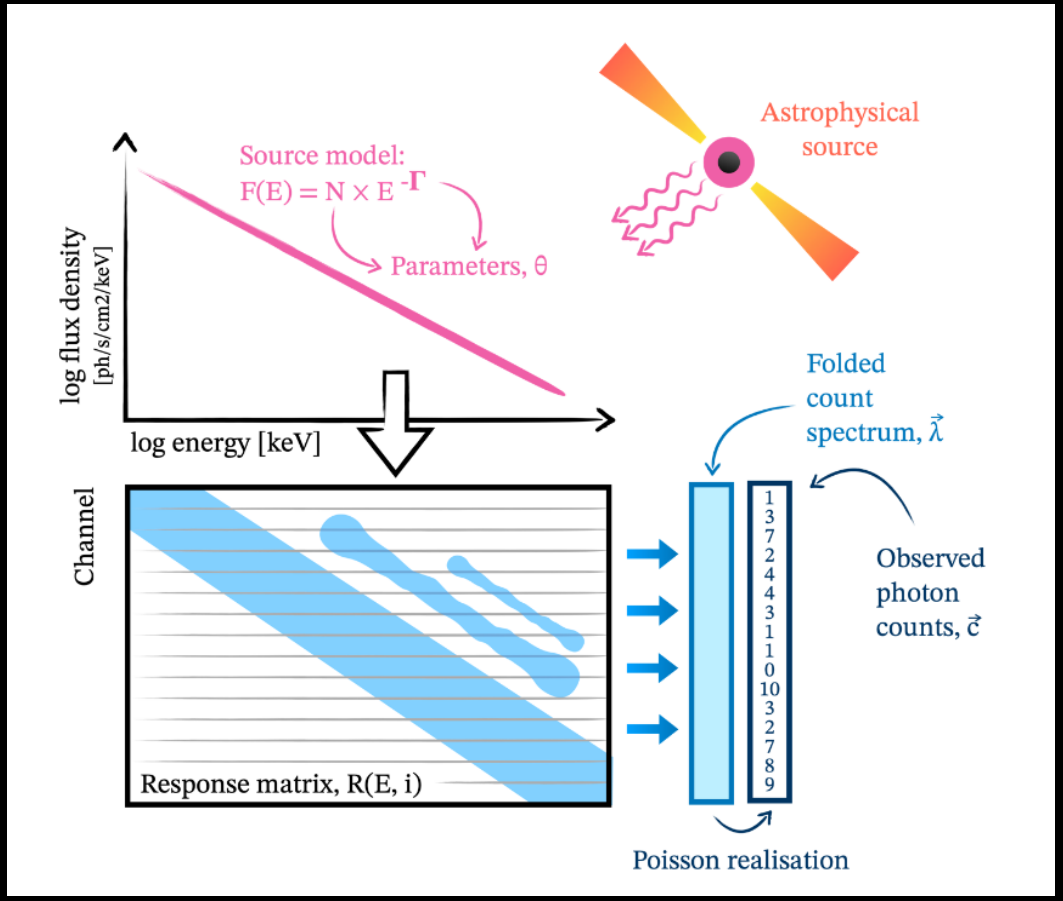
X-ray data has changed

Our software has not changed, our data (and models) have





Current software: 1D data+models



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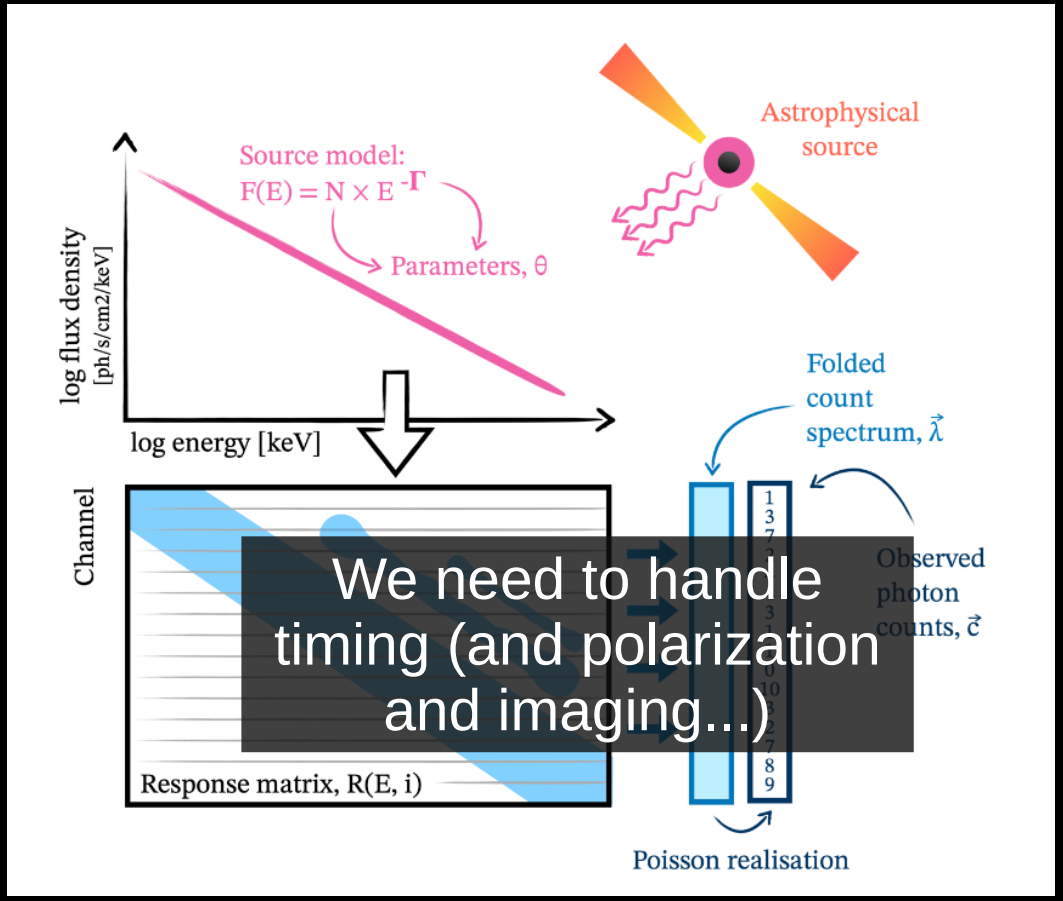
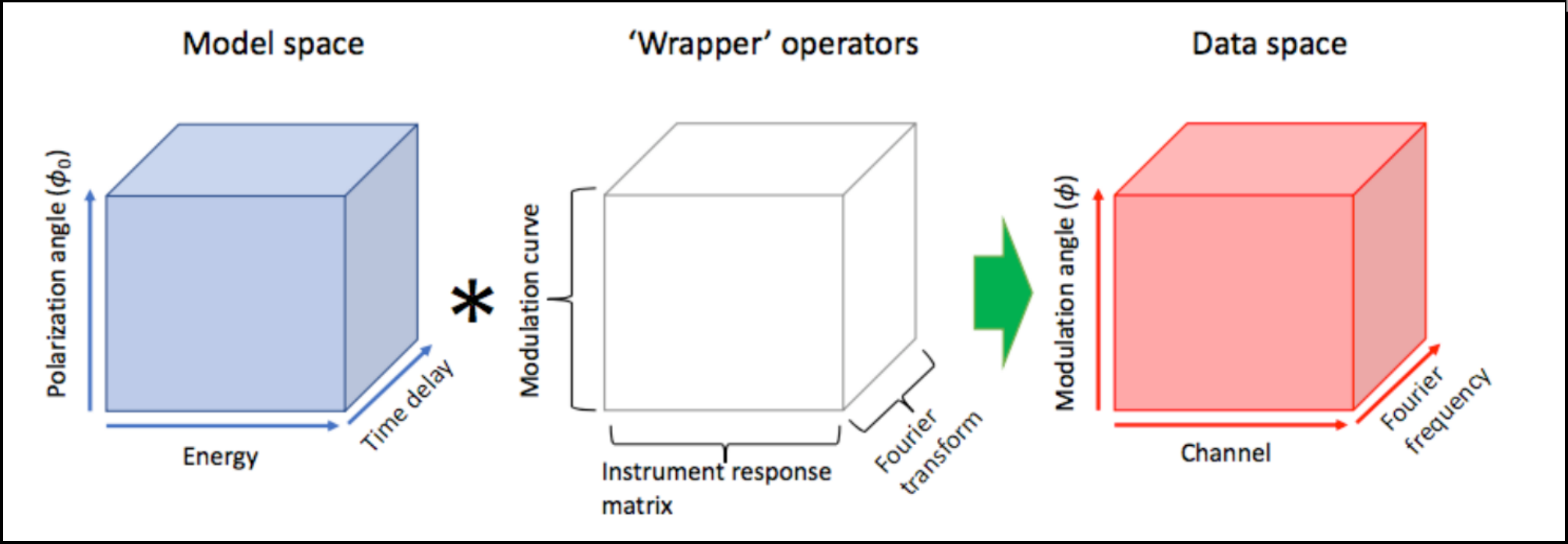
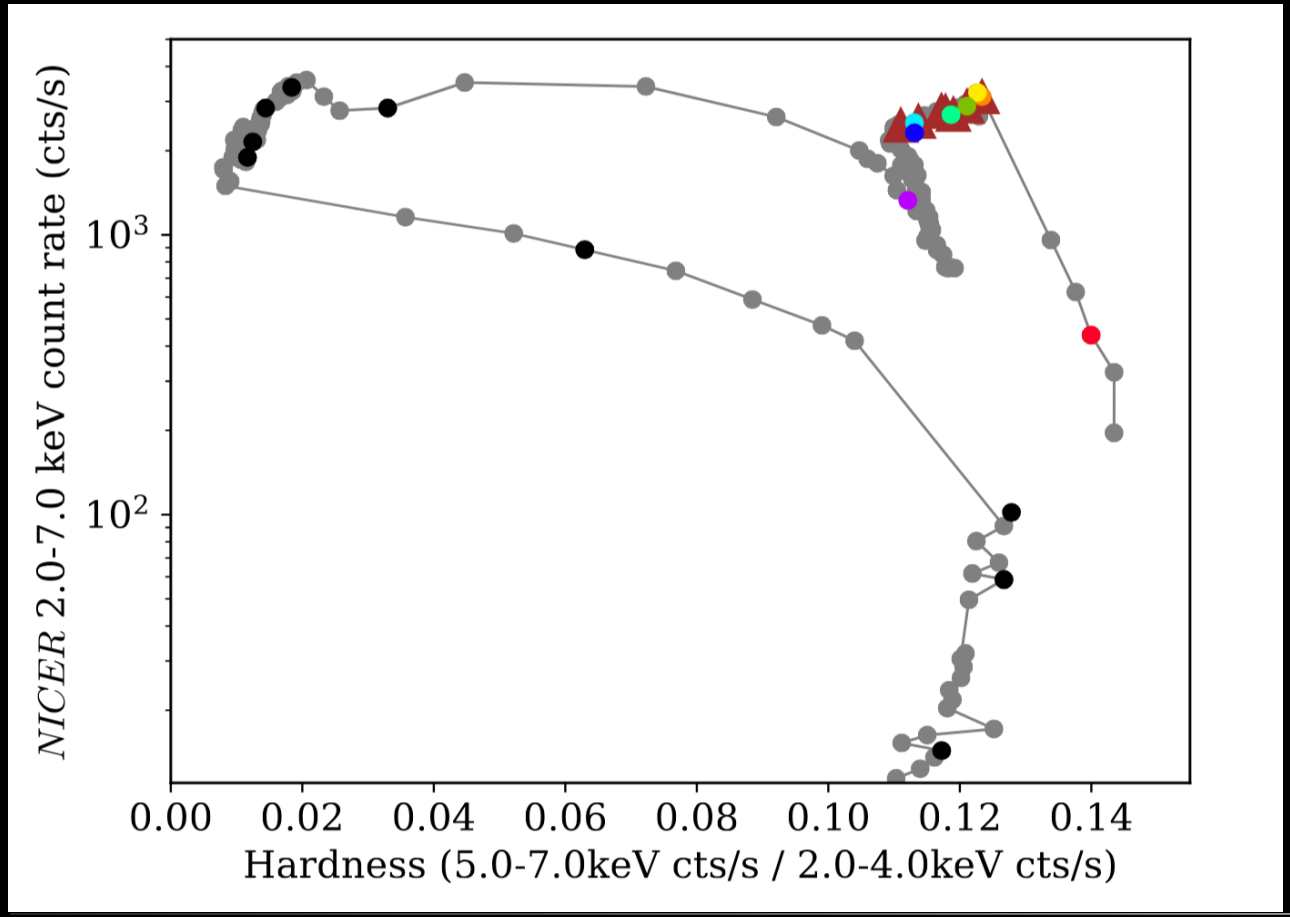


nDspec: nD data+models

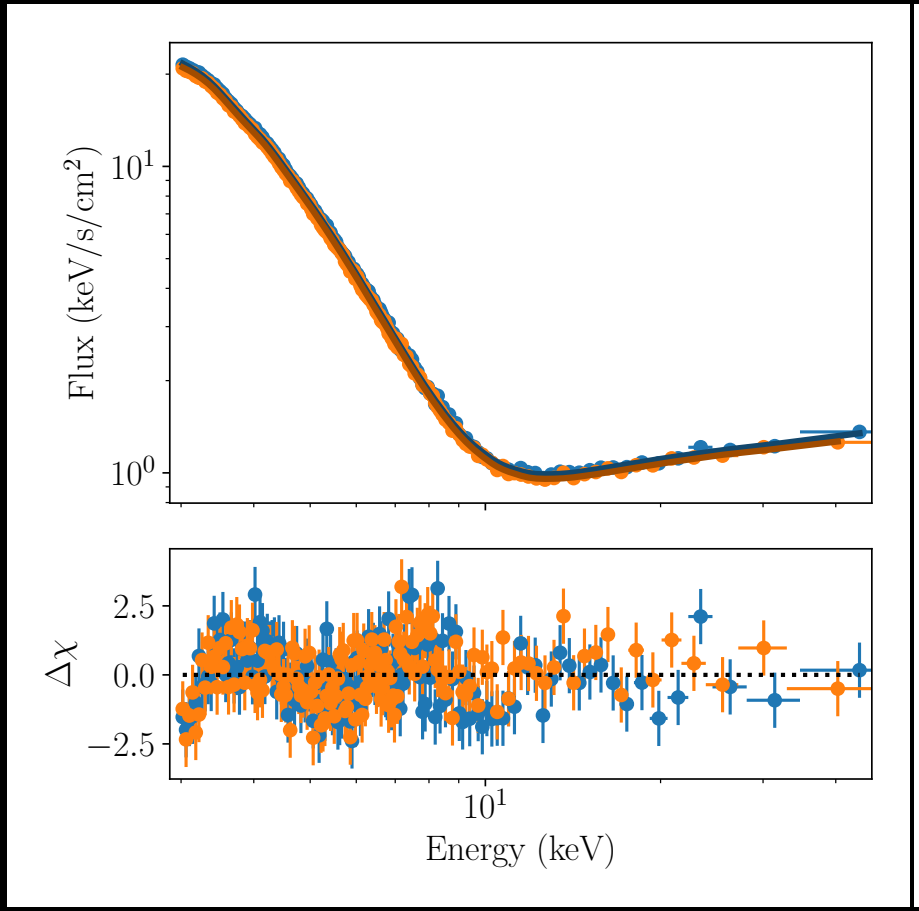


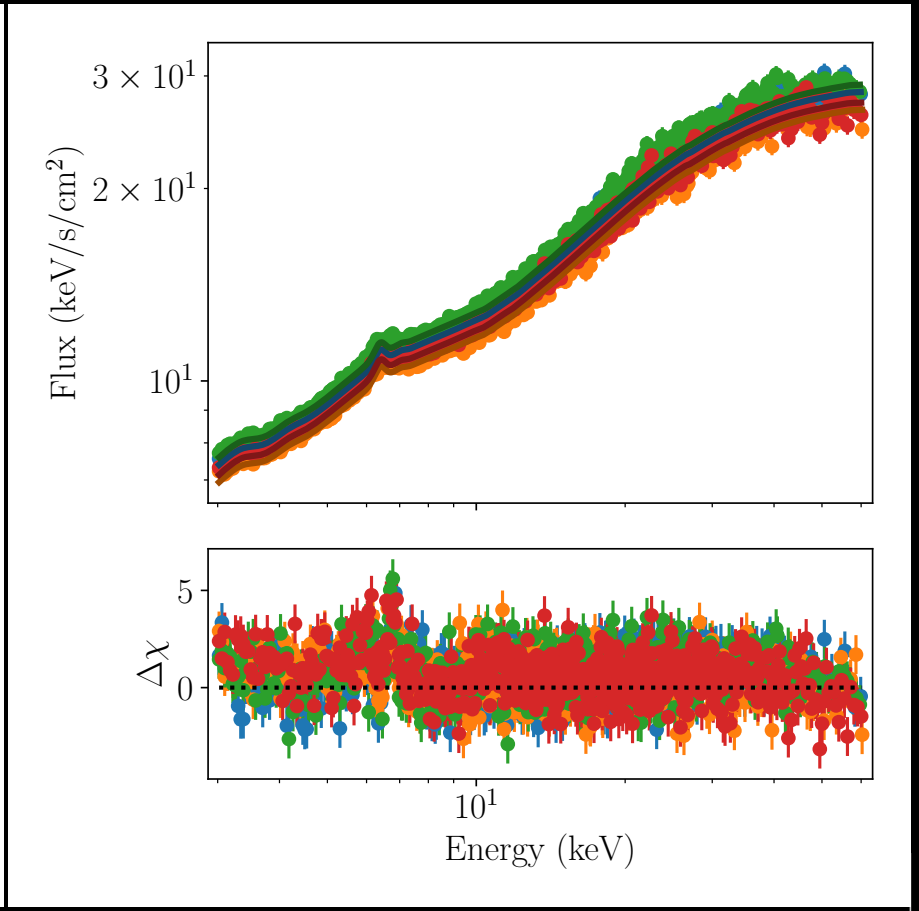
- Generalize handling instrument responses to “Operators” in all dimensions
- With data complexity we also need better sampling ability!
- 25% of the funding from NewAthena

A standard case: relativistic modelling



Found a decent fit...now what?





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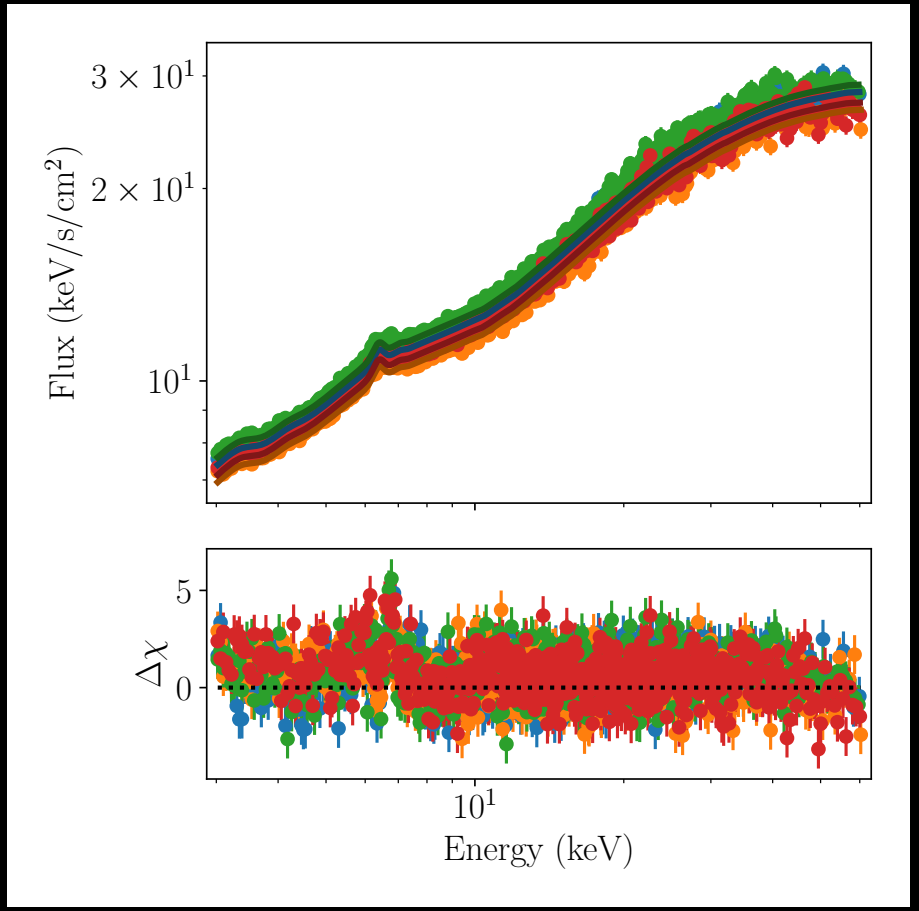
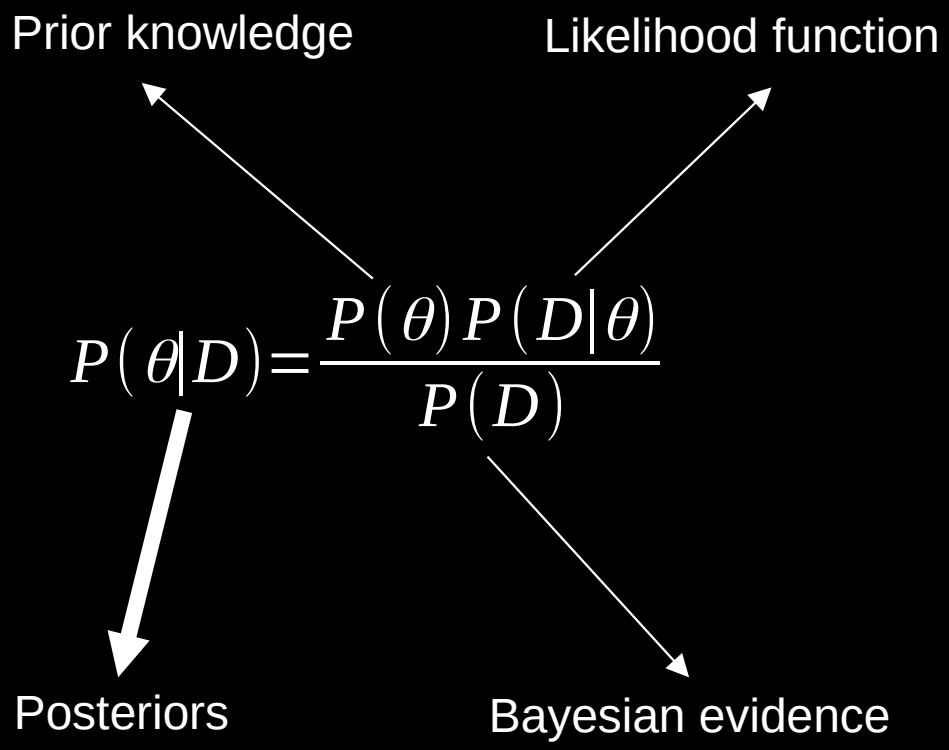


How well constrained are my parameters?
Can I measure spin here?

Time for Bayesian sampling!

A recap of Bayesian inference



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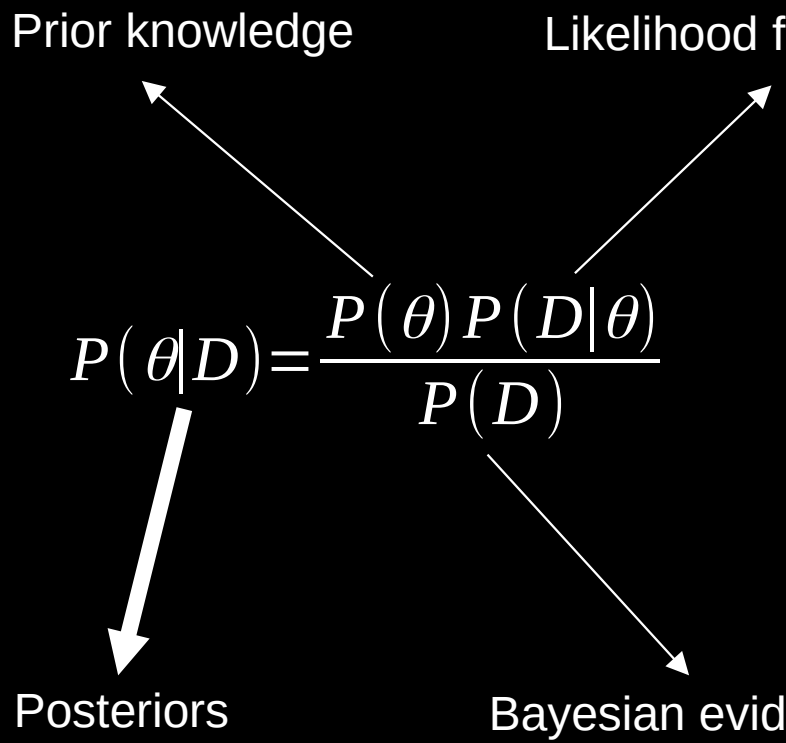

We need to find clever ways to find the ``right'' θ, then calculate P(θ) and P(D|θ)

P(D) is for model comparison (and a bit difficult to calculate)

A recap of Bayesian inference

$$P(\theta_i|D) = \frac{\int_{i!=j} P(\theta_j) P(D|\theta_j) d\theta_j}{P(D)}$$

Marginalization

Inference is just one giant Monte Carlo integration problem!

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Two main approaches in the field:
1) MCMC: draw samples in some clever way to estimate the integrals more easily

2) Nested sampling: reduce the problem to a 1D problem

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Regardless of method, convergence is key! Need to minimize Monte Carlo errors!

Convergence issues

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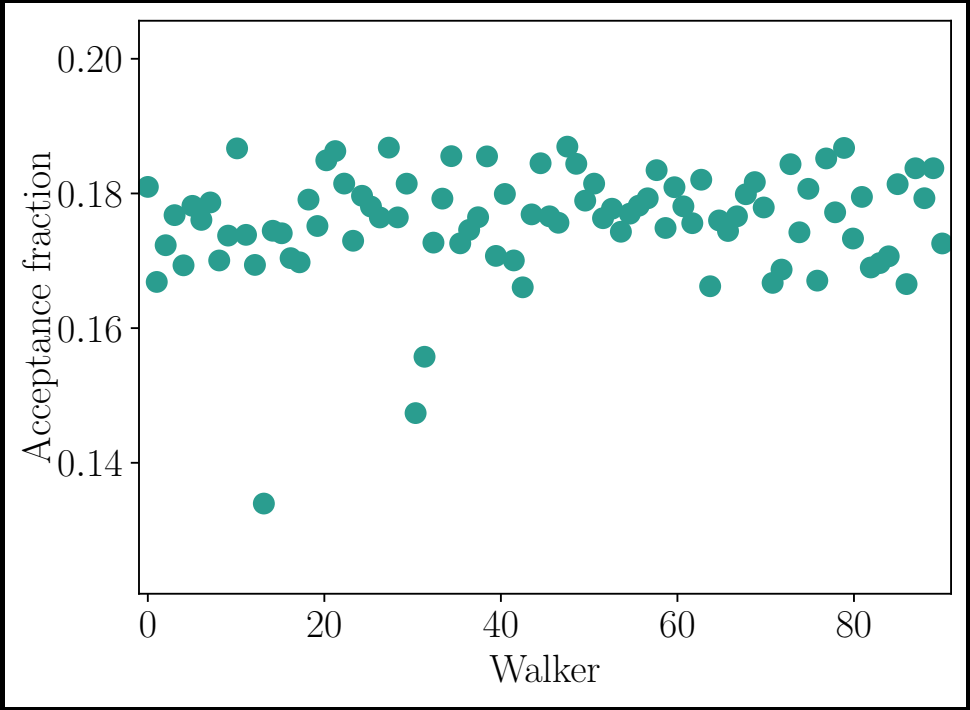
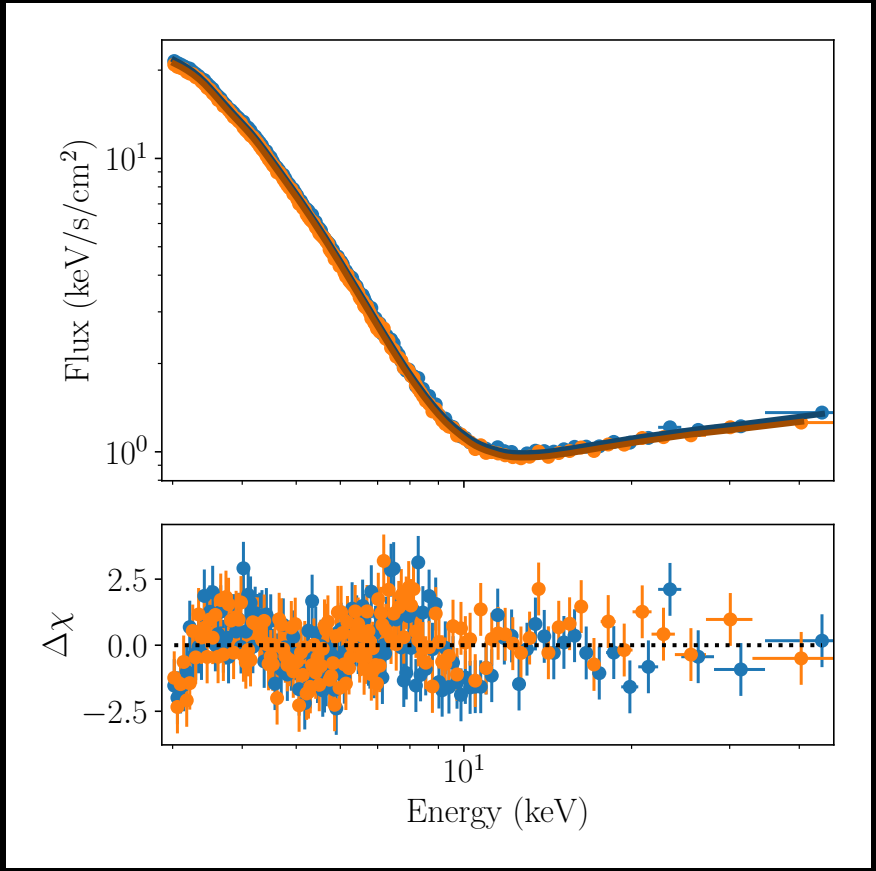


Fixed spin: reasonable behavior



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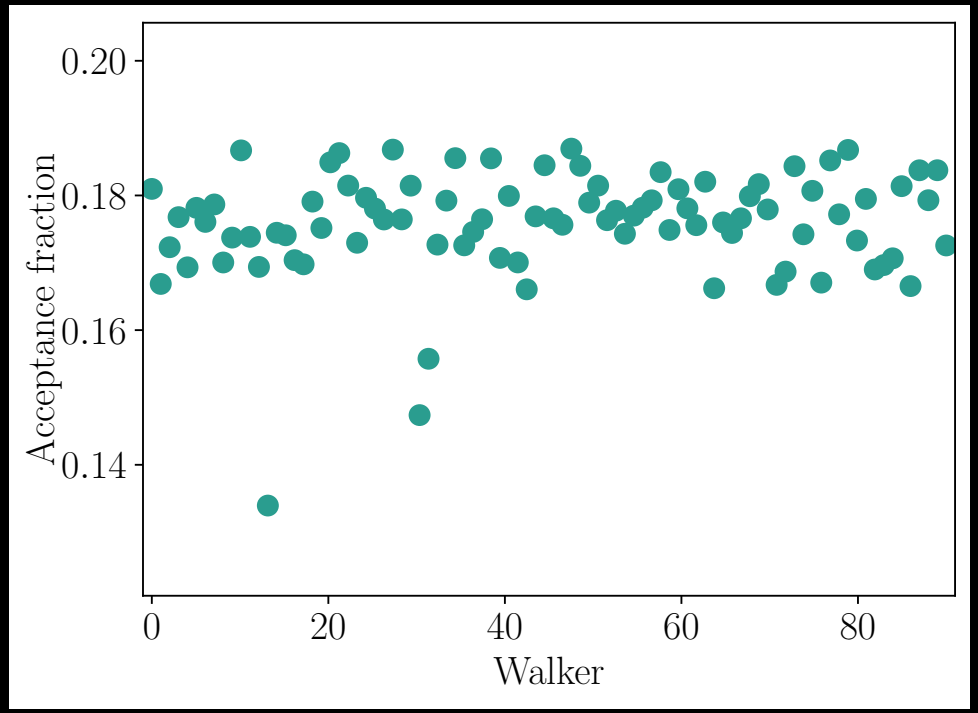
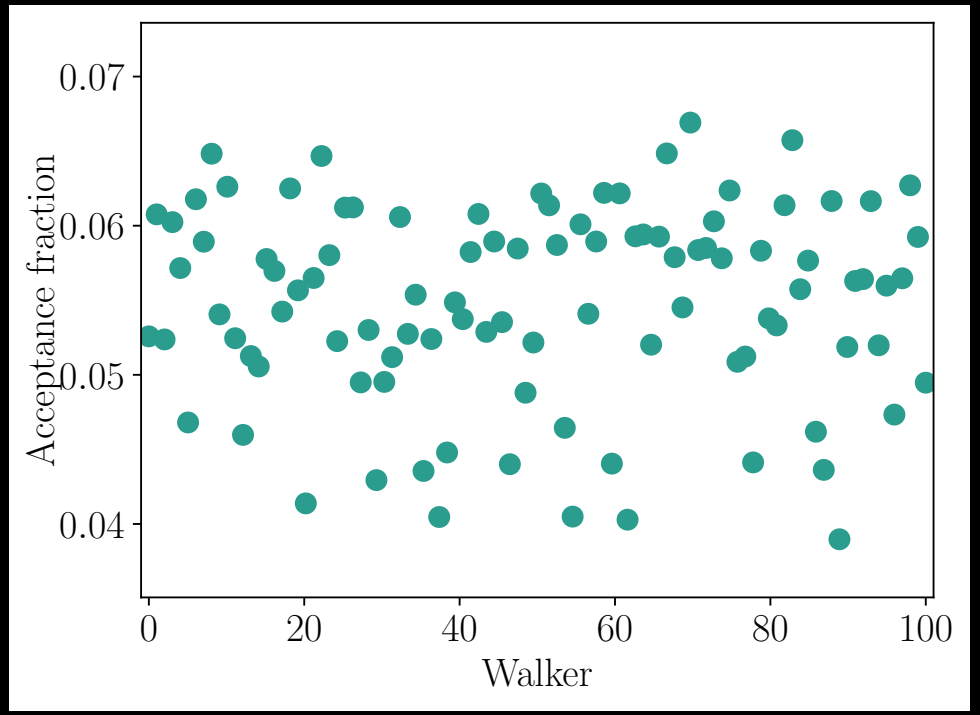


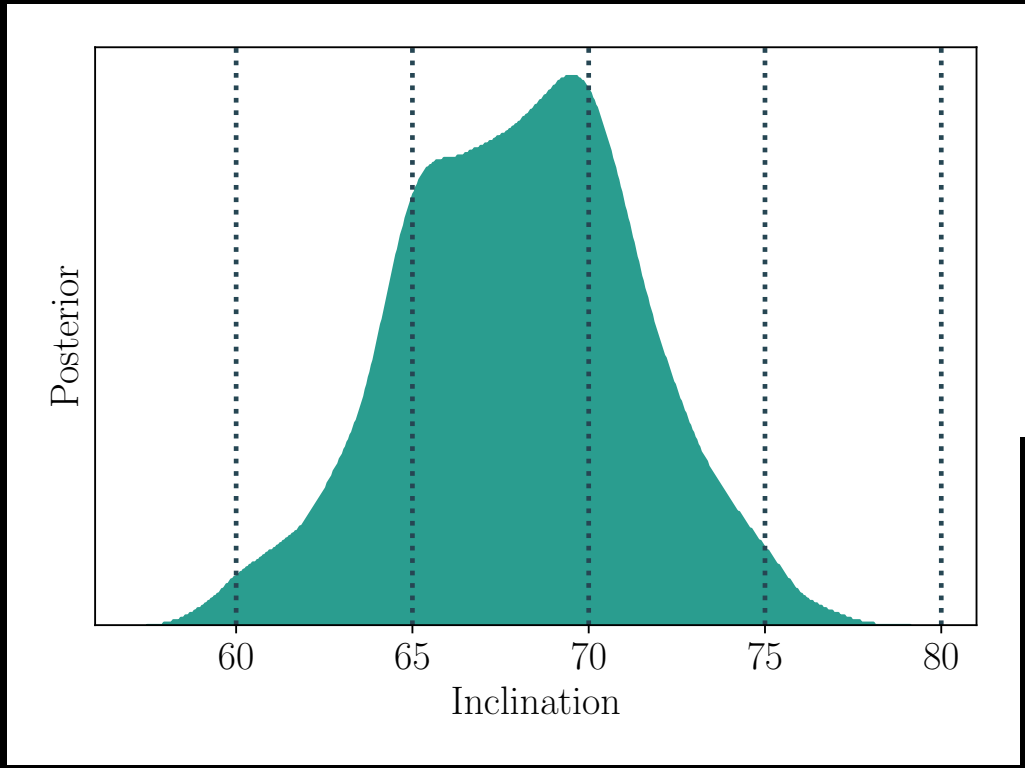


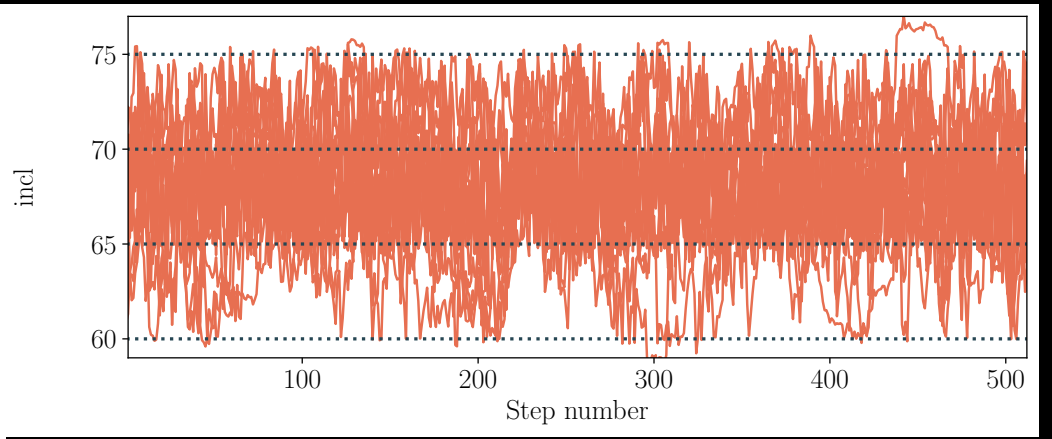
Fixed spin: reasonable behavior

Free spin: uuuuuuuh….

“If the acceptance fraction is getting very low, something is going very wrong.”

Problematic results: kerrbb





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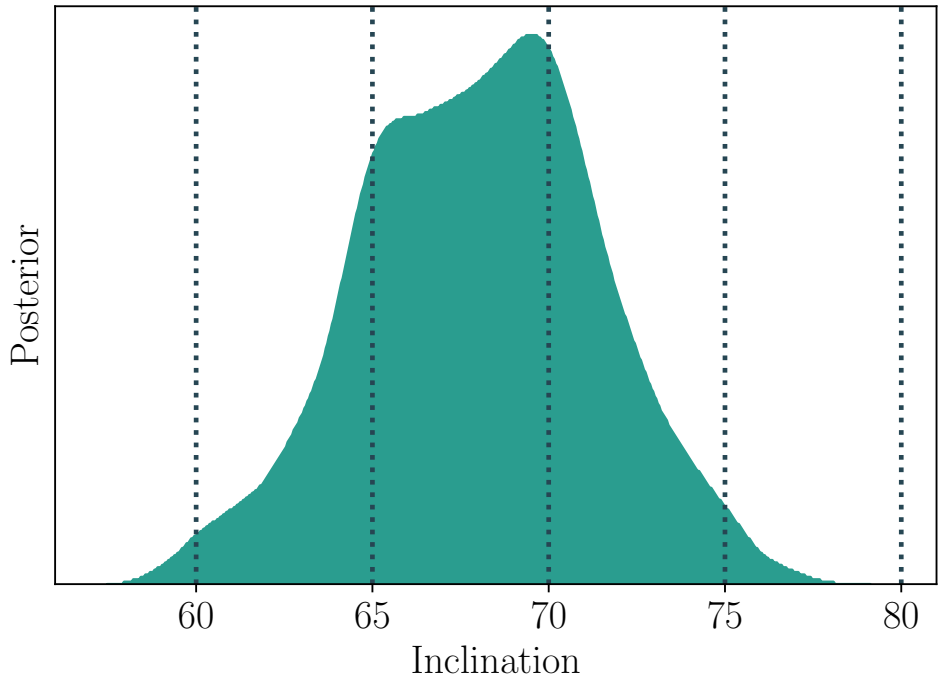

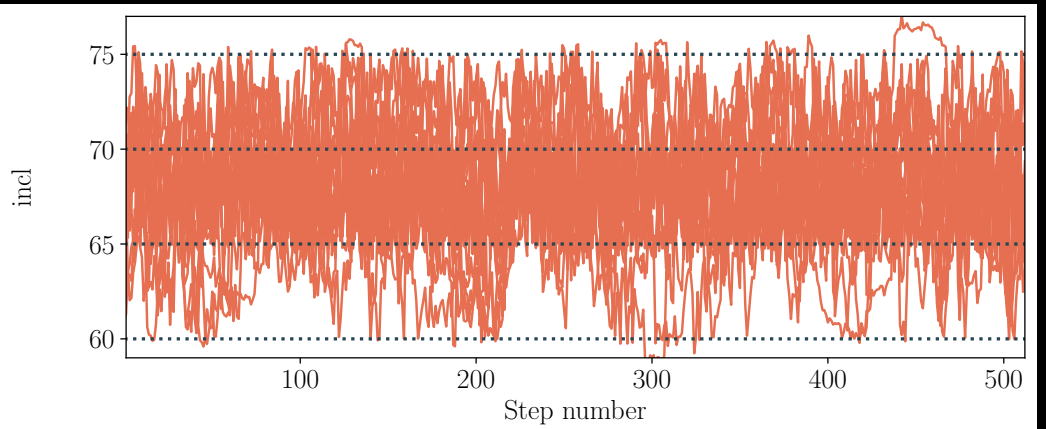

The dotted lines are grid points in kerrbb

The walkers cluster artificially around them!

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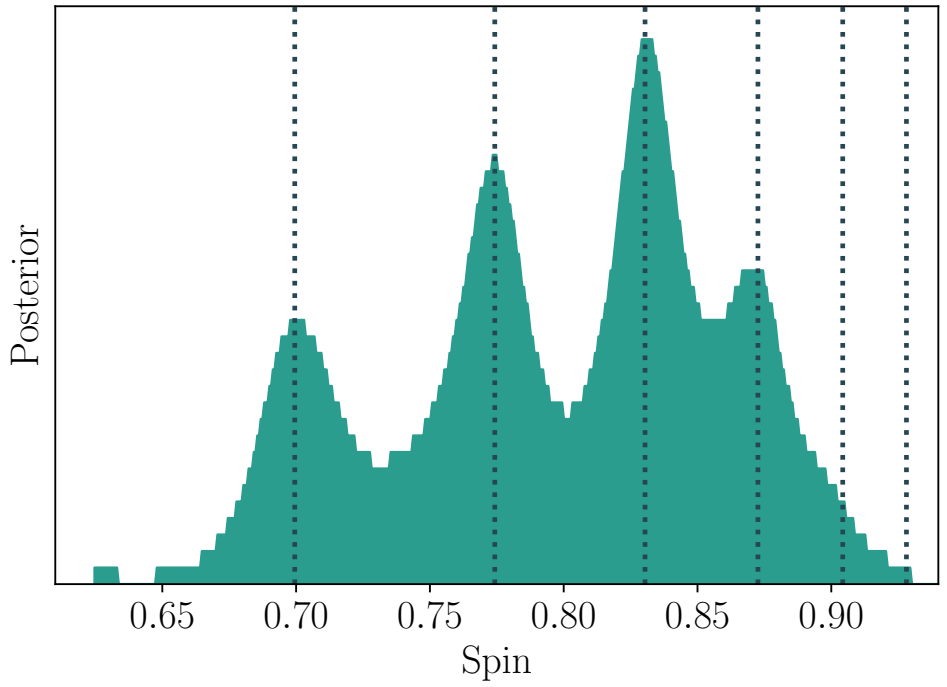

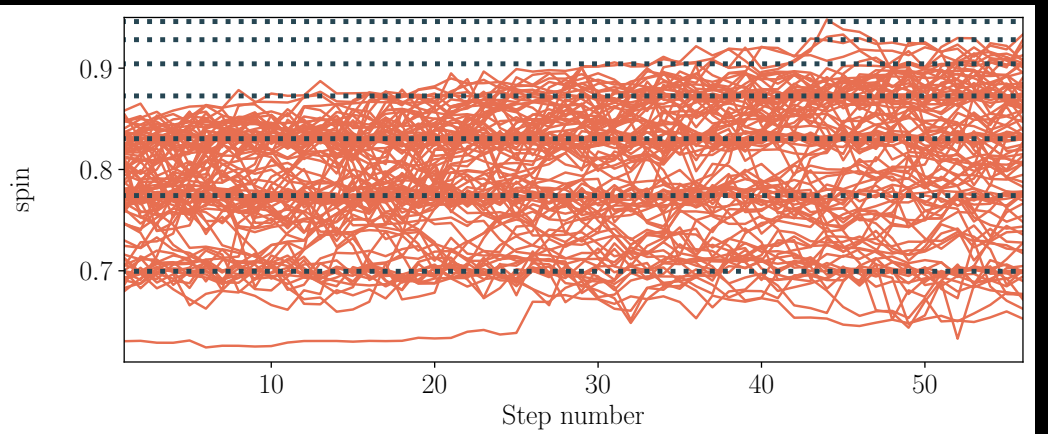

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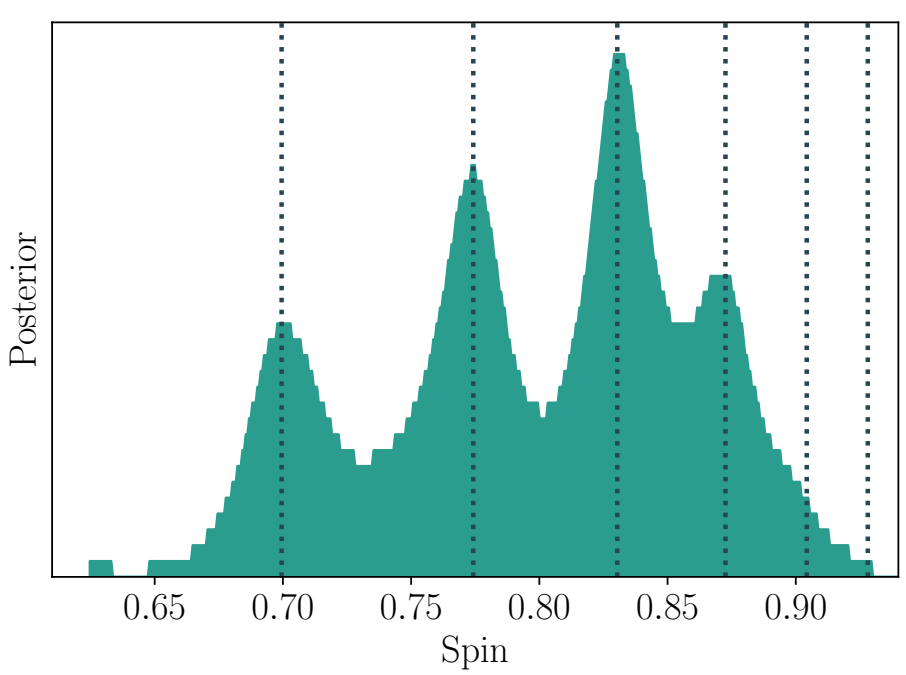
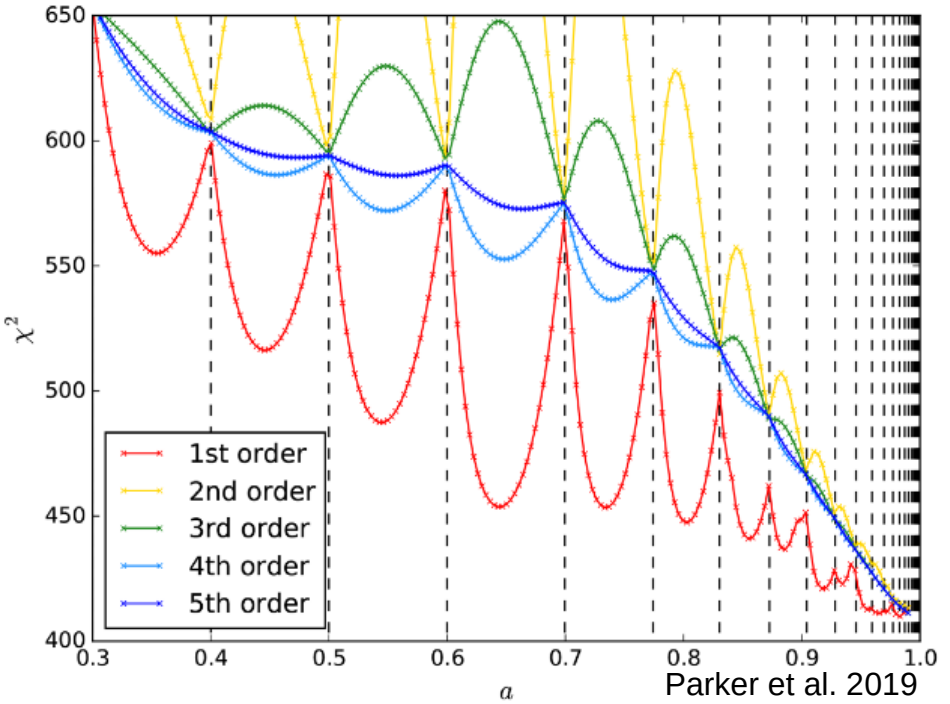
The walkers cluster artificially around them!

We MUST solve this to measure spin reliably!

Problematic results: kerrbb

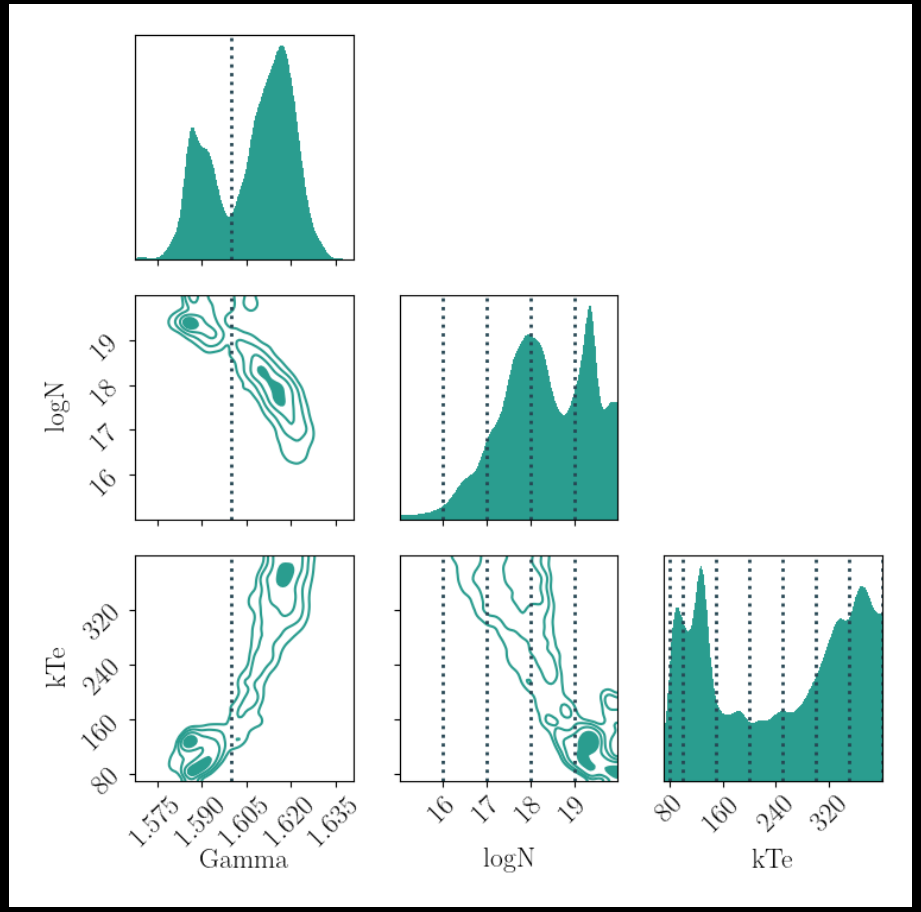




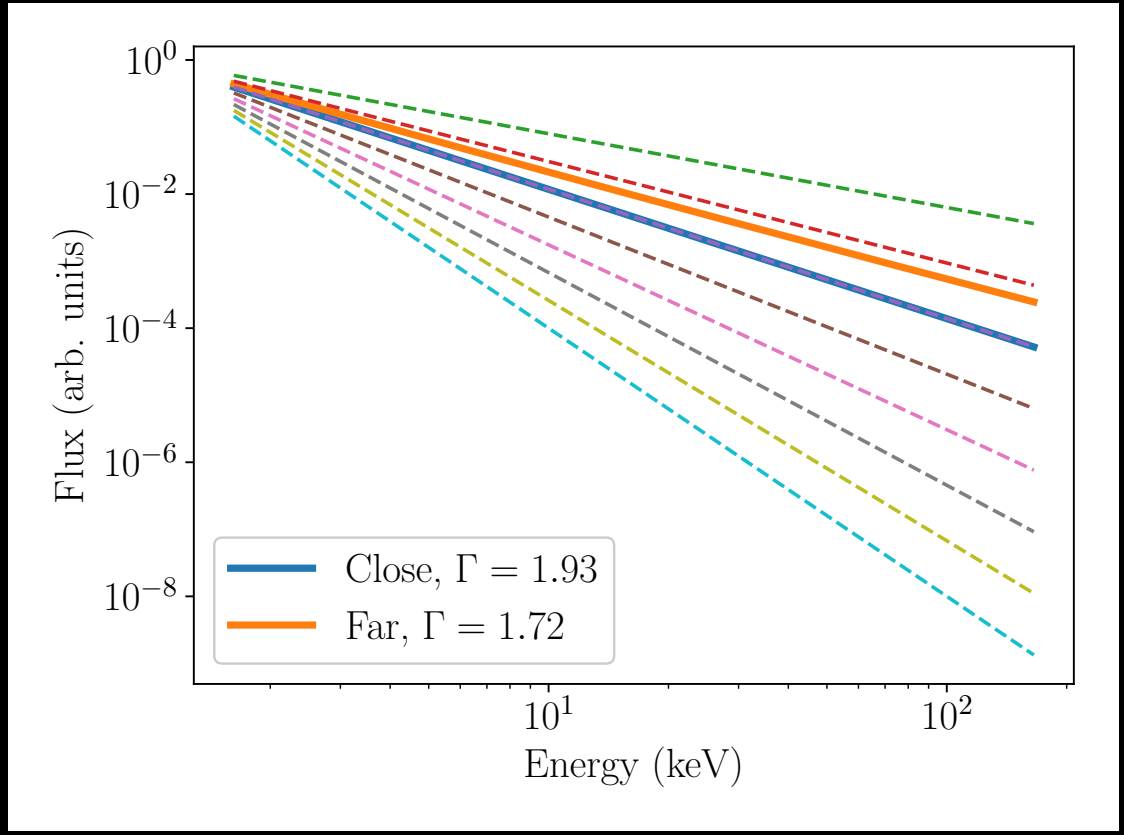
Parker et al. 2019

1) Samplers and fitters can't find or explore the correct solution
2) Model comparison becomes impossible

It is not just kerrbb!

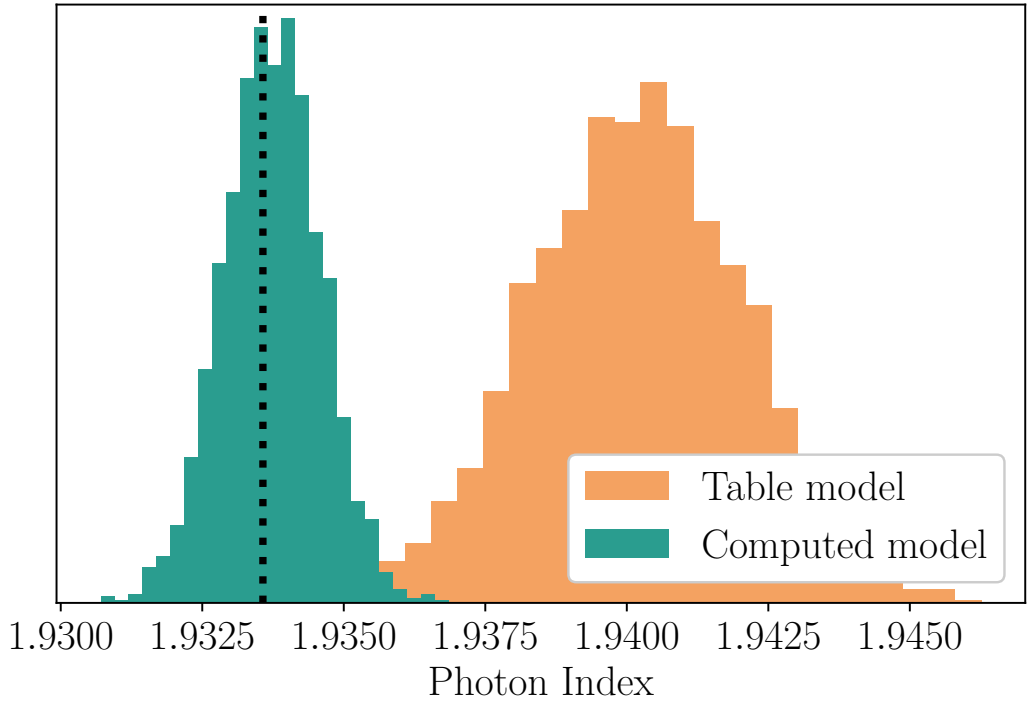


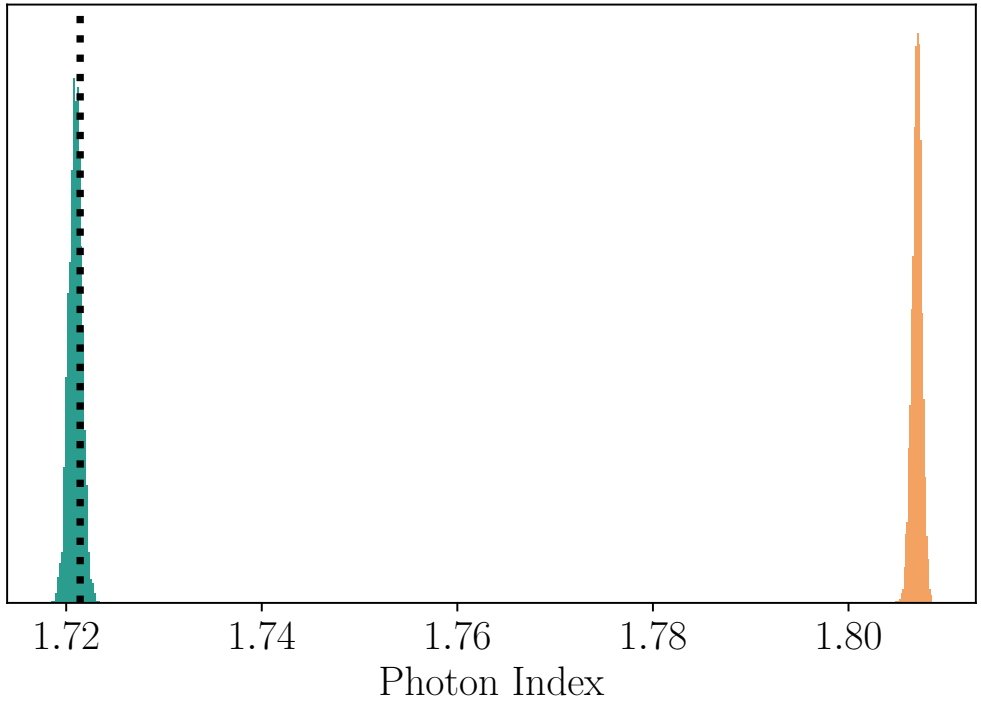
Additional biases



What happens if I just tabulate a power-law model?

Additional biases

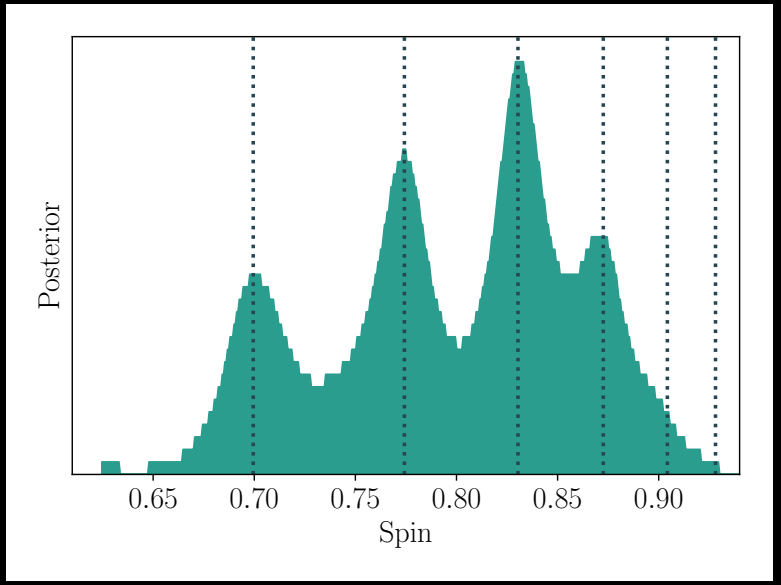




What happens if I just tabulate a power-law model? Oh no….

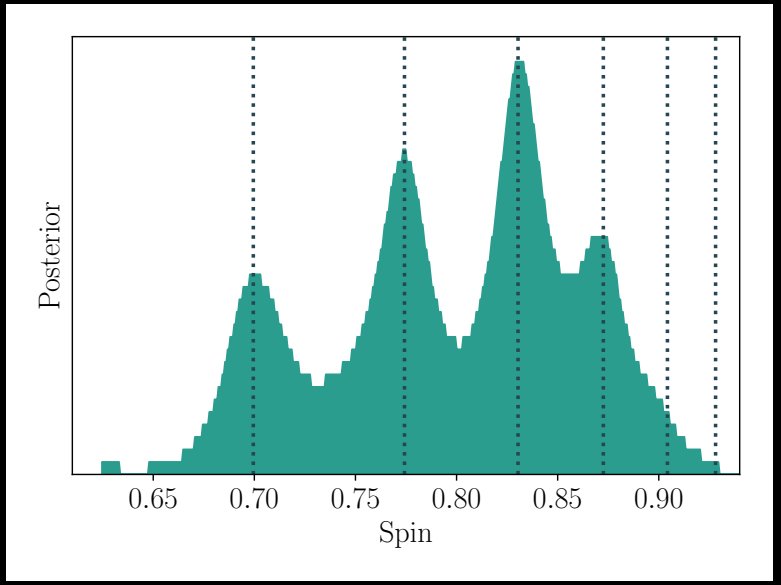
Conclusions

- X-ray spectroscopy has very fundamental issues with table models! We are making our lives harder than they need to be
- Linear interpolation of table models introduces multi-modality! Modern data demands a new approach

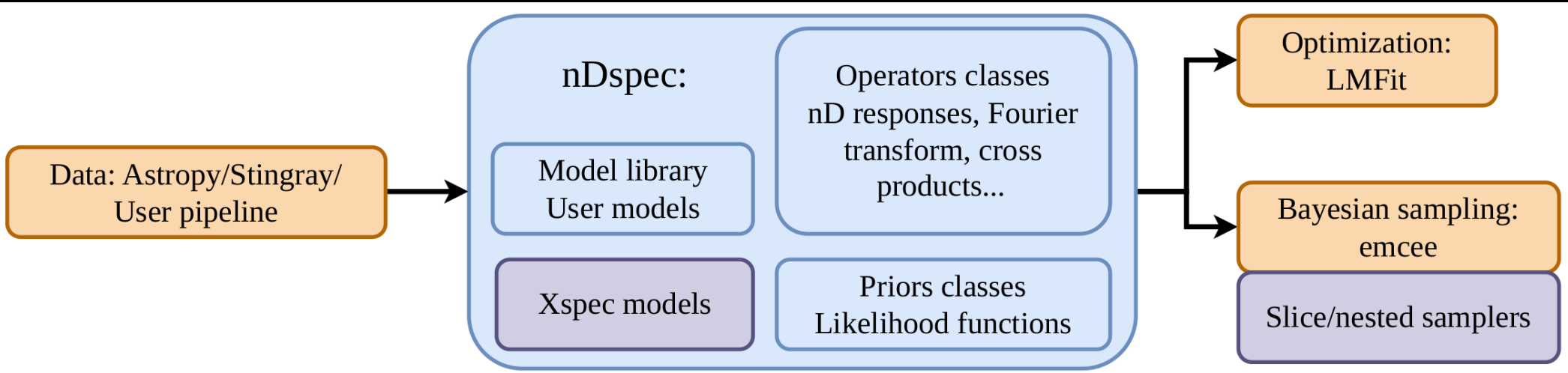


Conclusions

- X-ray spectroscopy has very fundamental issues with table models! We are making our lives harder than they need to be
- Linear interpolation of table models introduces multi-modality! Modern data demands a new approach
- New instruments require new methods and tools! Exciting to see so much open source software discussed here!
- Where do we go next? See next talk!

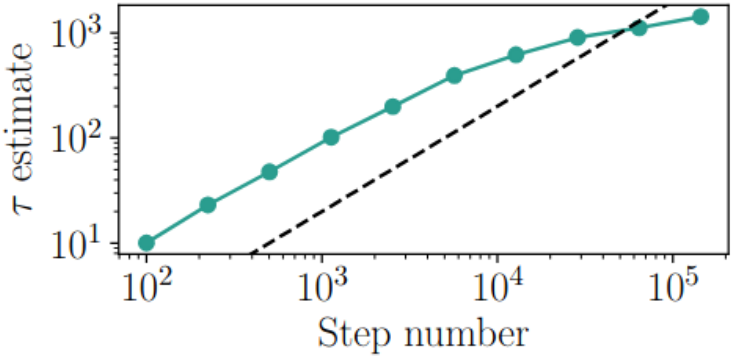


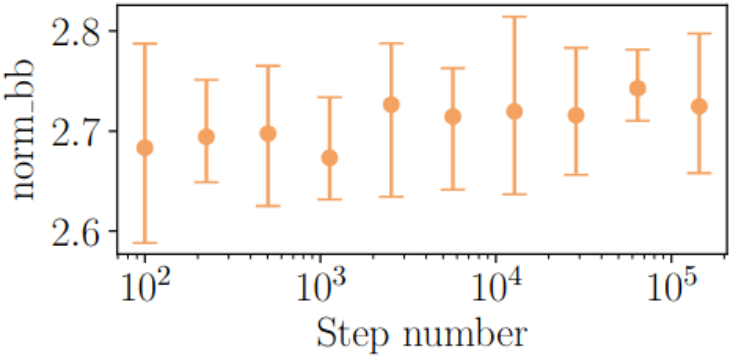
nDspec structure

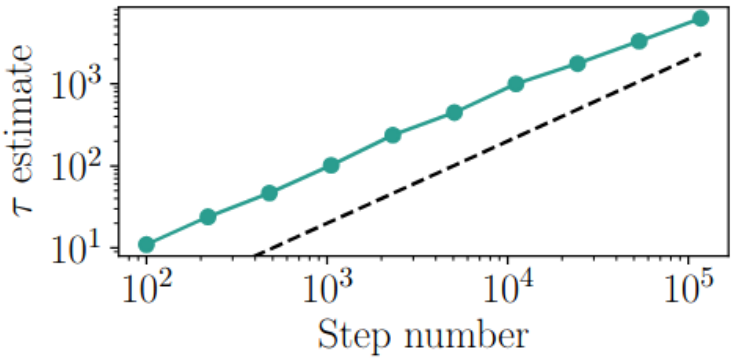


Tie existing libraries with native functionality
Open architecture allows straightforward extensions to additional codes
After 2.5 yrs, nDspec has (minimum) feature parity with existing software

Convergence examples







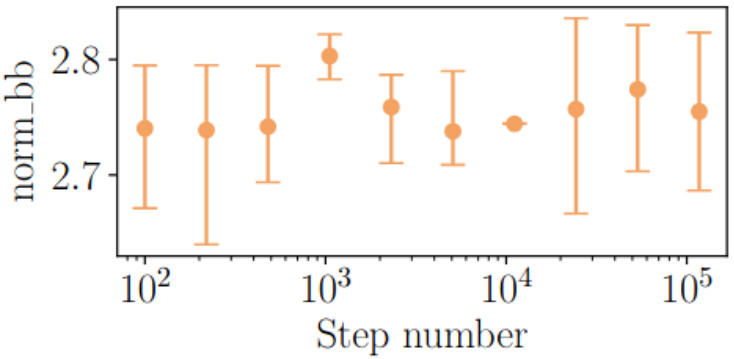


Table models and fit statistics