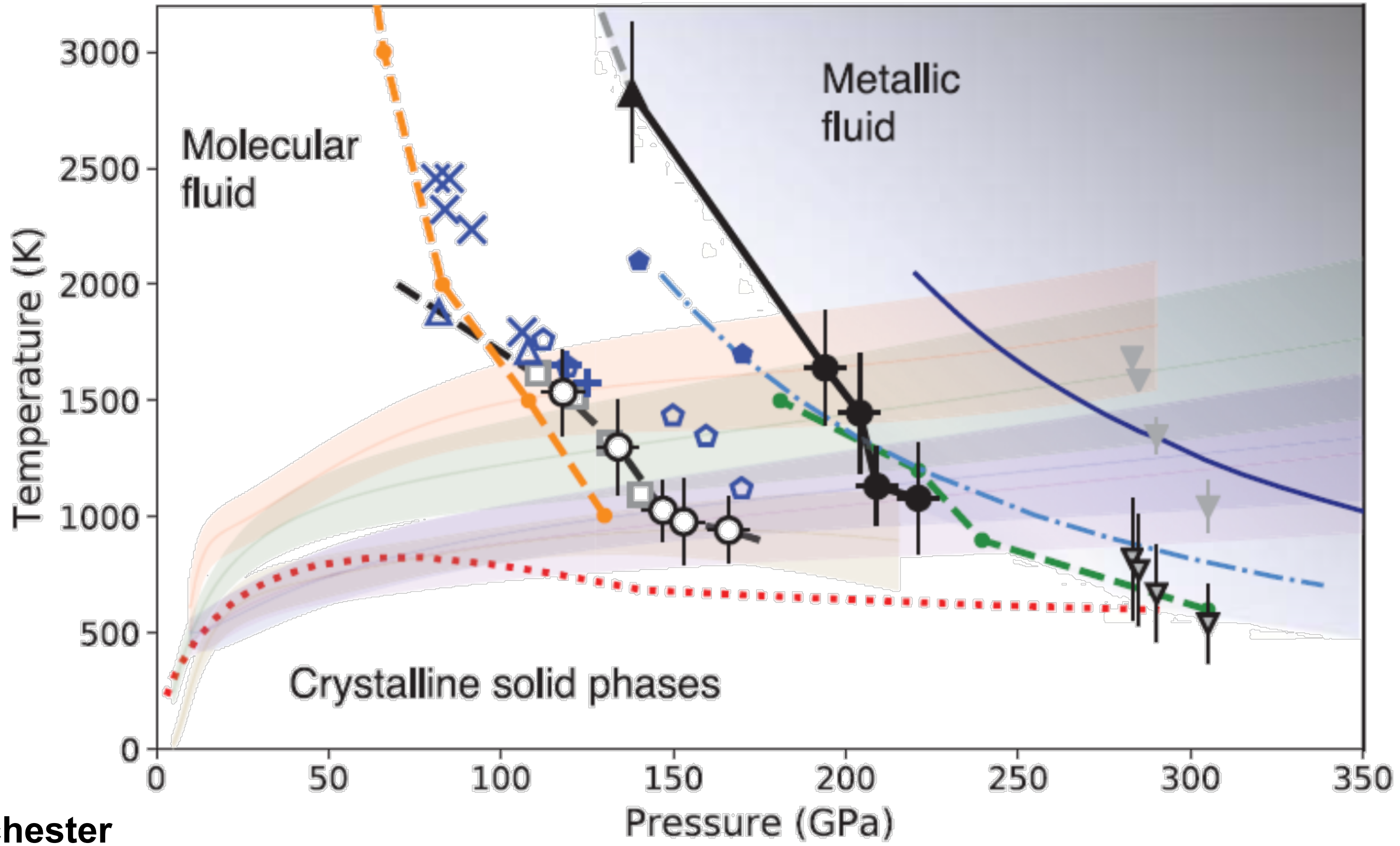
Extending Optical Pyrometry Temperature Measurements to below 5000 K



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A statistical model is being developed to infer temperature from low signal-to-noise ratio (SNR) Streaked Optical Pyrometer (SOP) data.

- **Measuring temperature of dynamically compressed materials over nanosecond timescale, especially ramp compressed materials, is a grand challenge in High Energy Density Physics (HEDP).**

- **SOP is often used to infer sample temperature from self-emission of optical photons.**

- **Samples below 5000 K have low SNR data, because so few photons are emitted over nanosecond timescales.**

- **We are developing a statistical method to infer temperature from low SNR data, extending temperature measurements to the few thousand Kelvin regime.**

Collaborators

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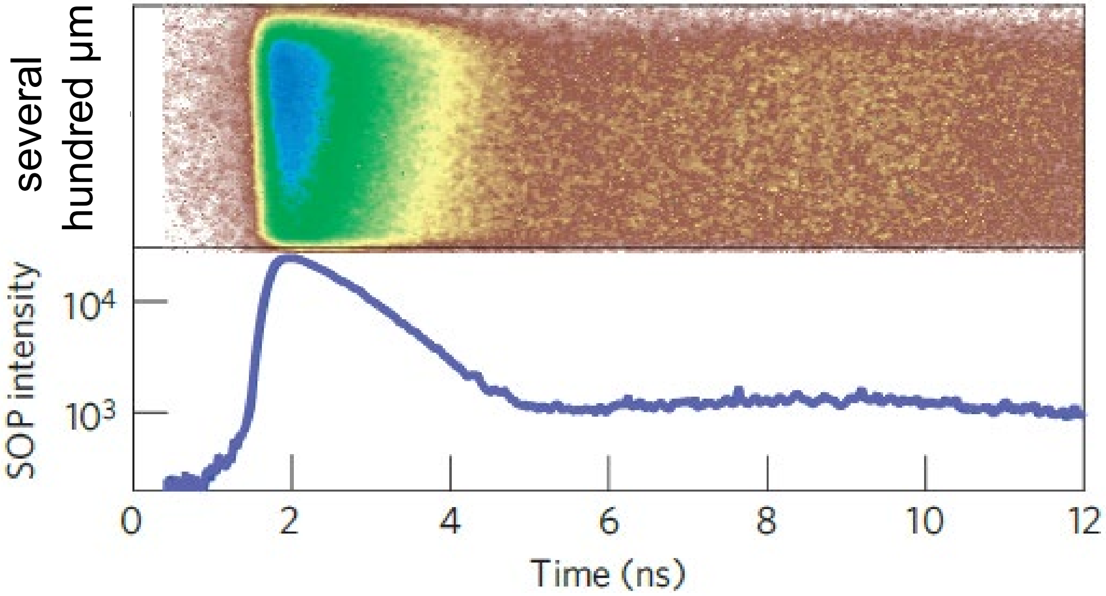
SOP is often used to measure brightness temperature of an emitting surface for T>5000 K with nanosecond resolution.

Temperature of a decaying shock front in diamond



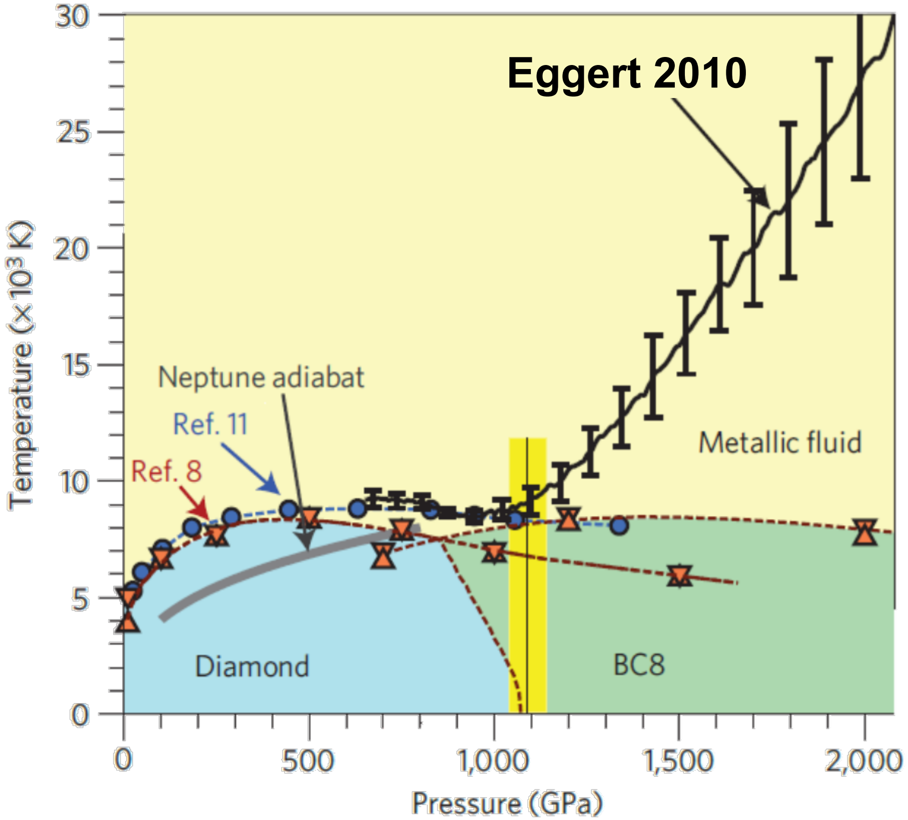
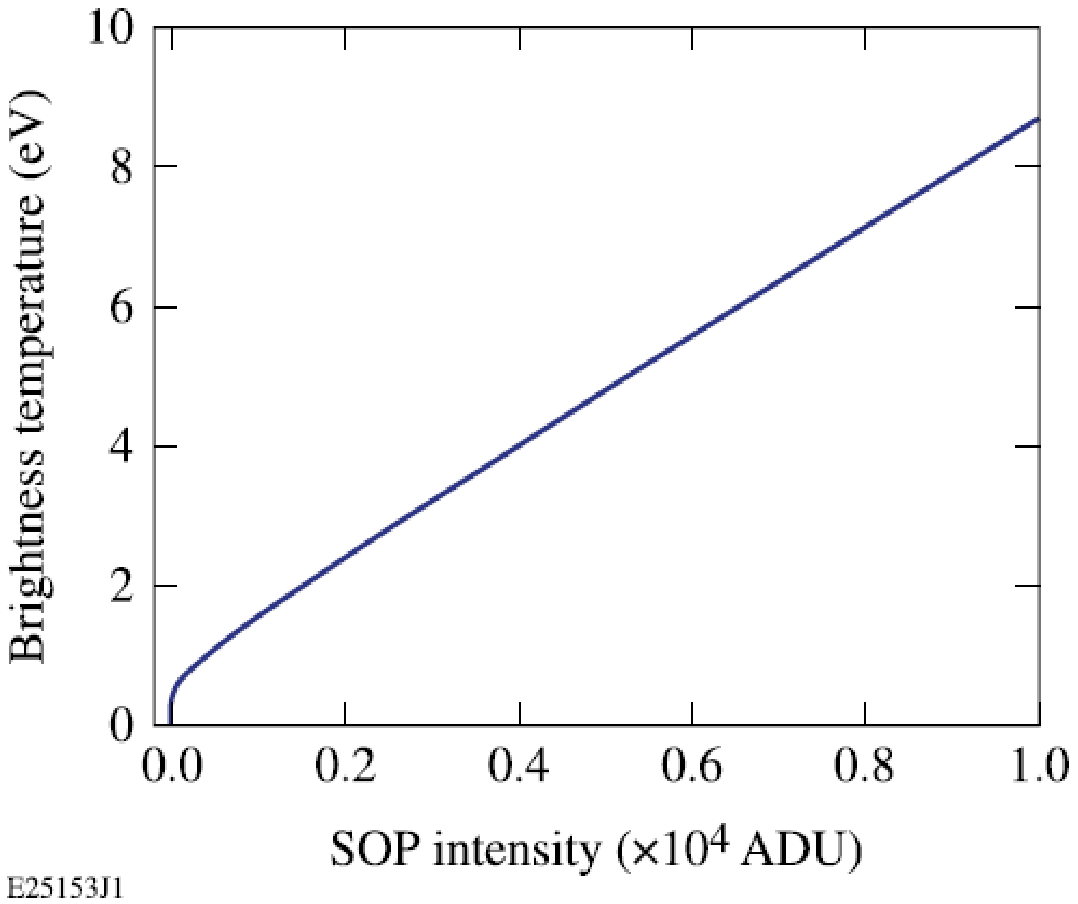


Figure adapted from J. H. Eggert, et al., Nature Phys 6 (1), 40-43 (2010).

There is a simple relation between brightness temperature and SOP intensity.



$$T = \frac{T_0}{\ln\left(1 + \frac{(1-R)A_0 X}{\eta I}\right)}$$

Derived from Planck's radiation law

R is the target reflectance;

T_0, A_0, X, η depend on diagnostic design and setup.

I is "background subtracted" SOP intensity.

ADU is a unit converting CCD electrons to analog signals.

1 eV ~ 11600 K

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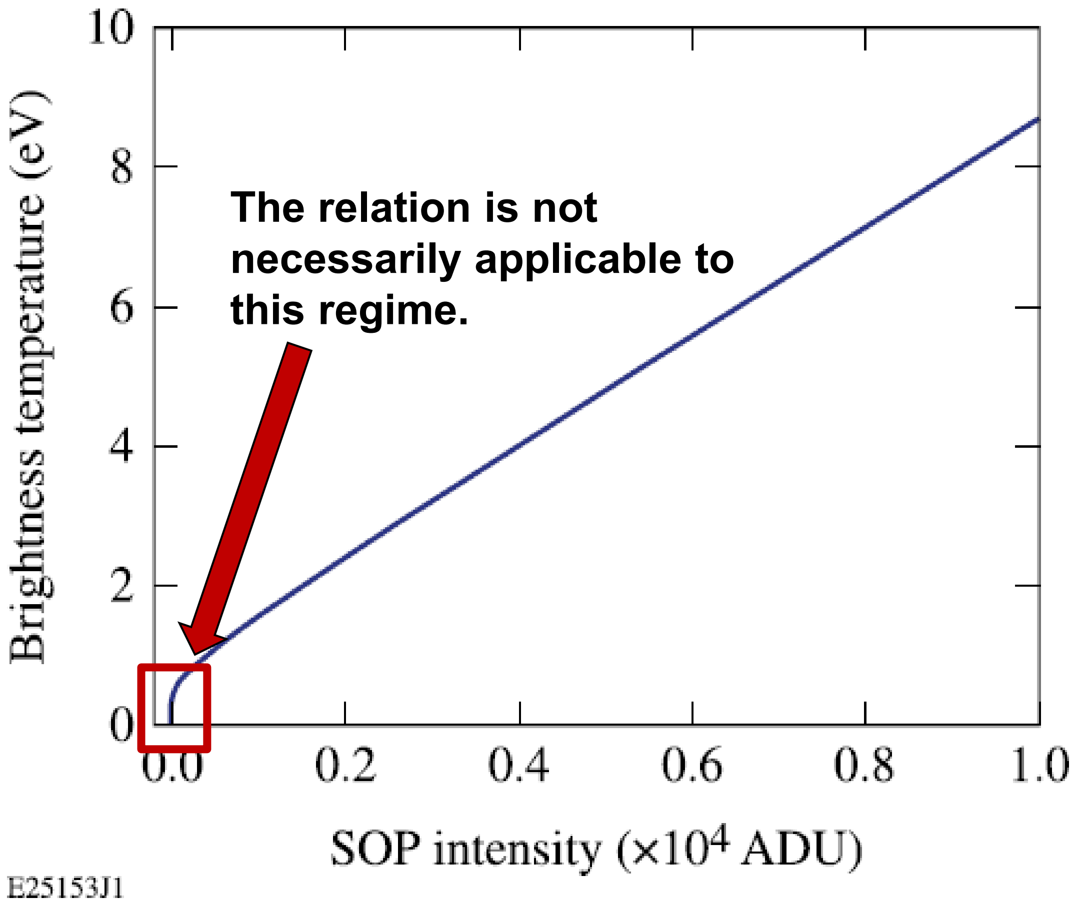

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Current SOP model works for high temperatures (T>~5000 K). At low temperatures, the histogram deviates from Gaussian, and a new model is necessary.

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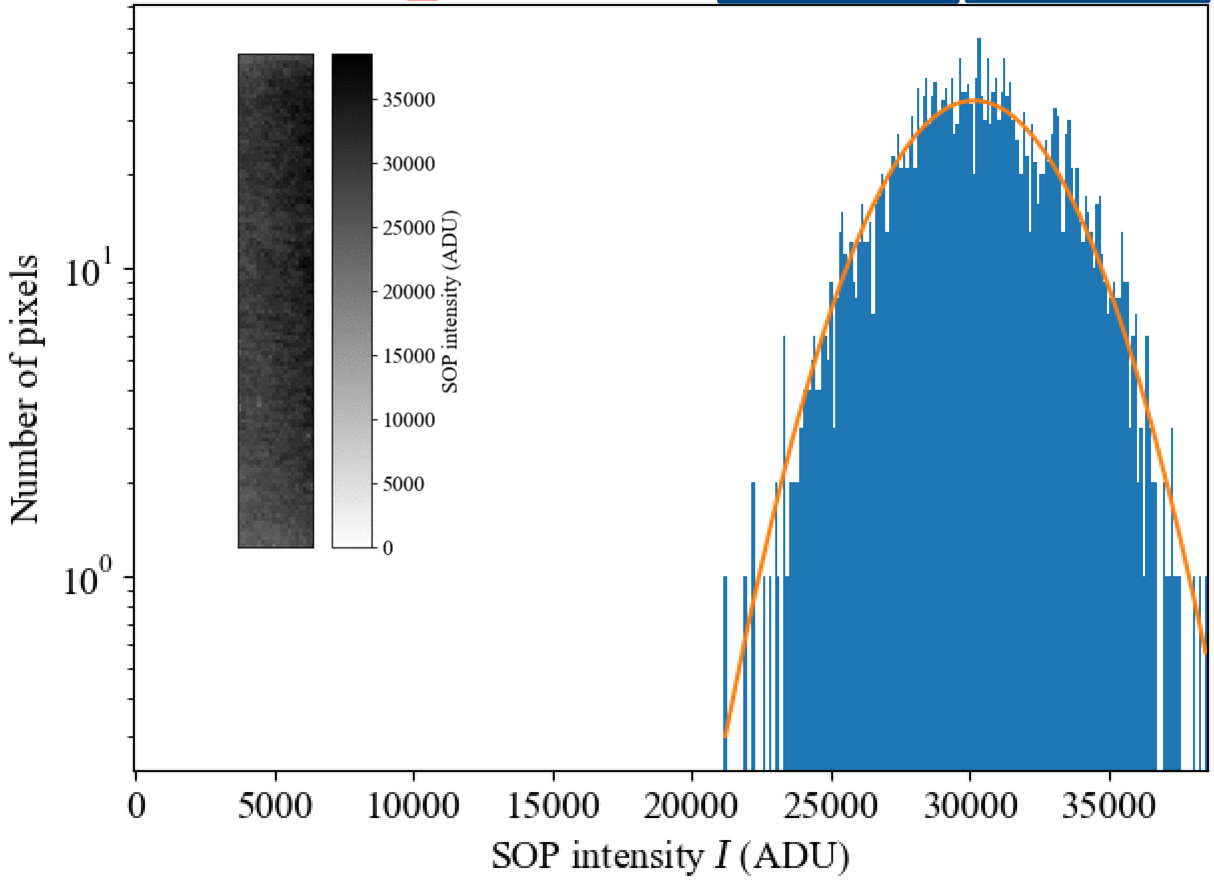
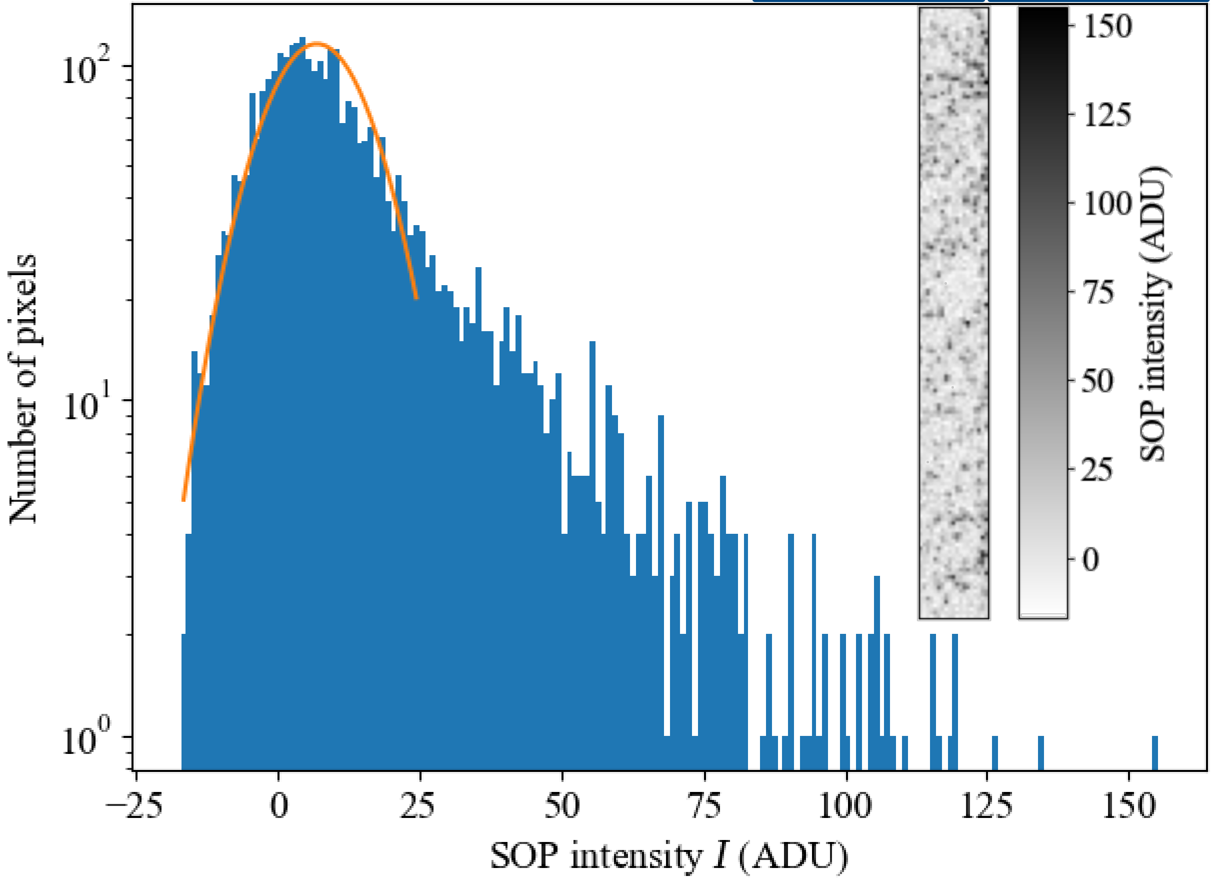
High SNR T~30000K



Low SNR T~3000K



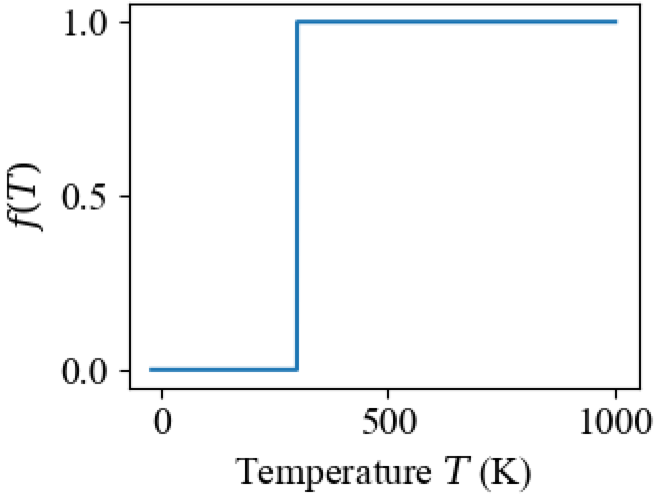
We use the maximum likelihood estimation to infer T from SOP image

$$f(T|\{N\}) = \frac{f(\{N\}|T)f(T)}{f(N)} \propto f(\{N\}|T)f(T)$$

Having obtained data $\{N\}$, how likely is T?

Given T, how likely to obtain data $\{N\}$?

Prior knowledge of temperature (must be higher than 300 K)



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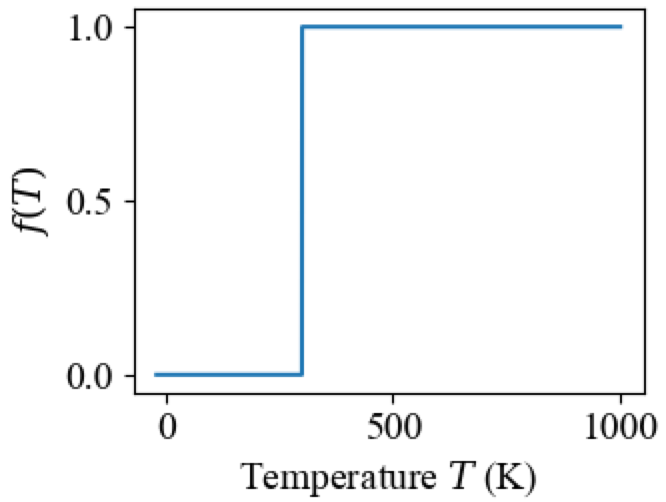


Two challenges:

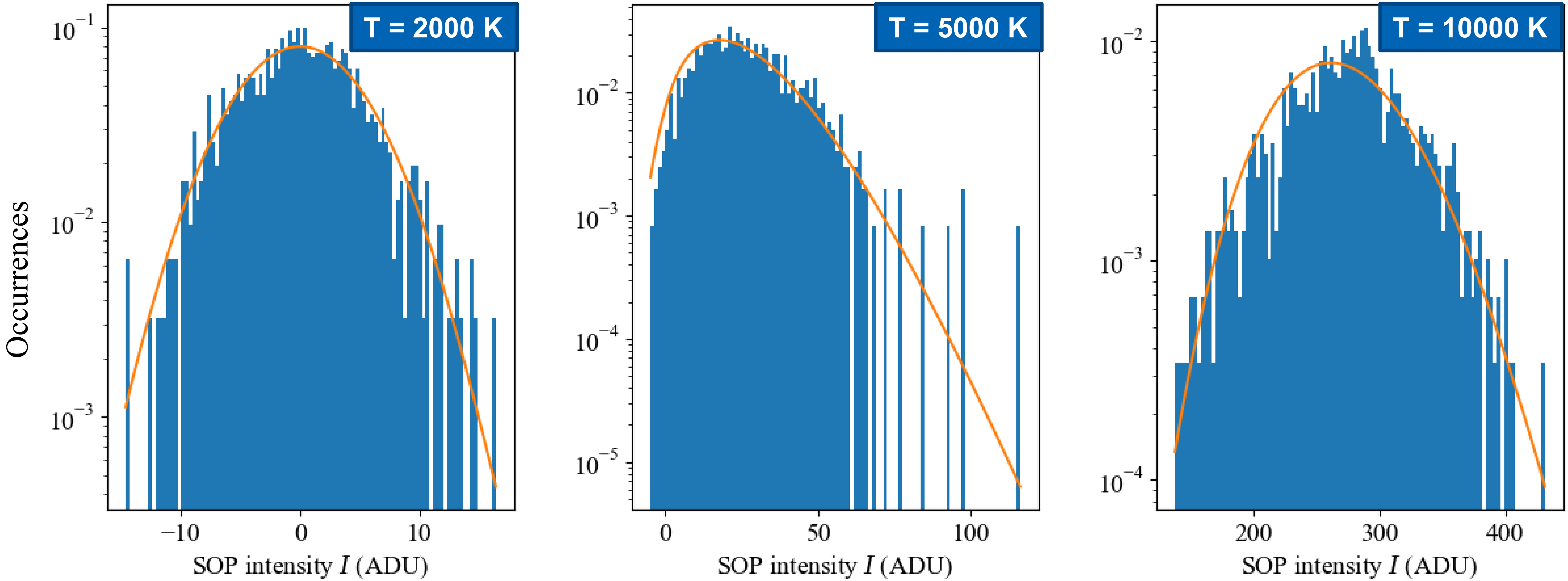
1) The histogram is not Gaussian.

2) There are correlations between neighboring pixels.

Address these one at a time (but not simultaneously).

1) The histogram is not Gaussian.

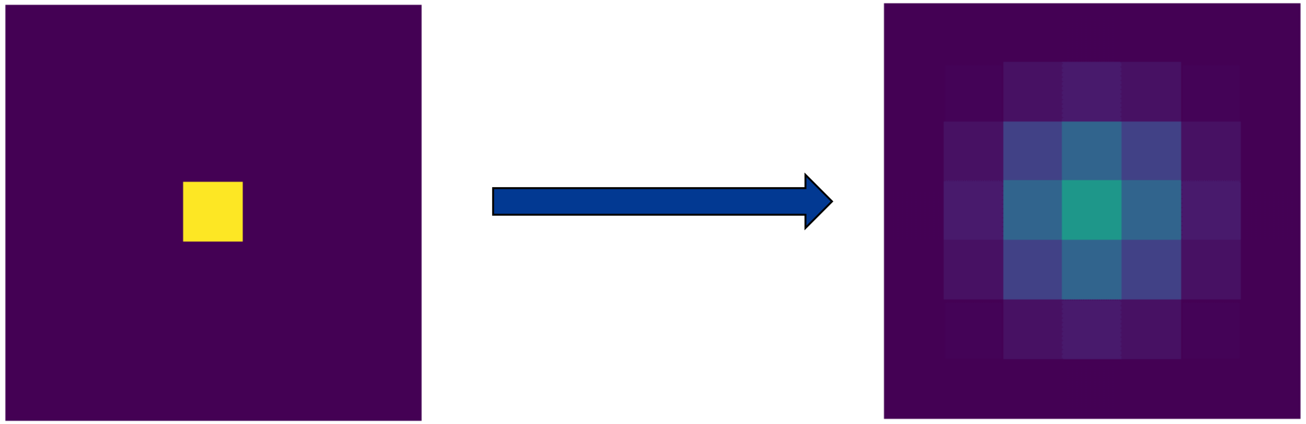
We developed a model to describe how the non-Gaussian histogram depends on temperature.



simulated sample over 100x10 pixels

2) There are correlations between neighboring pixels.

In the streak camera, when a single photoelectron deposit itself on phosphor screen to generate photons, energy spreads its energy among neighboring pixels.



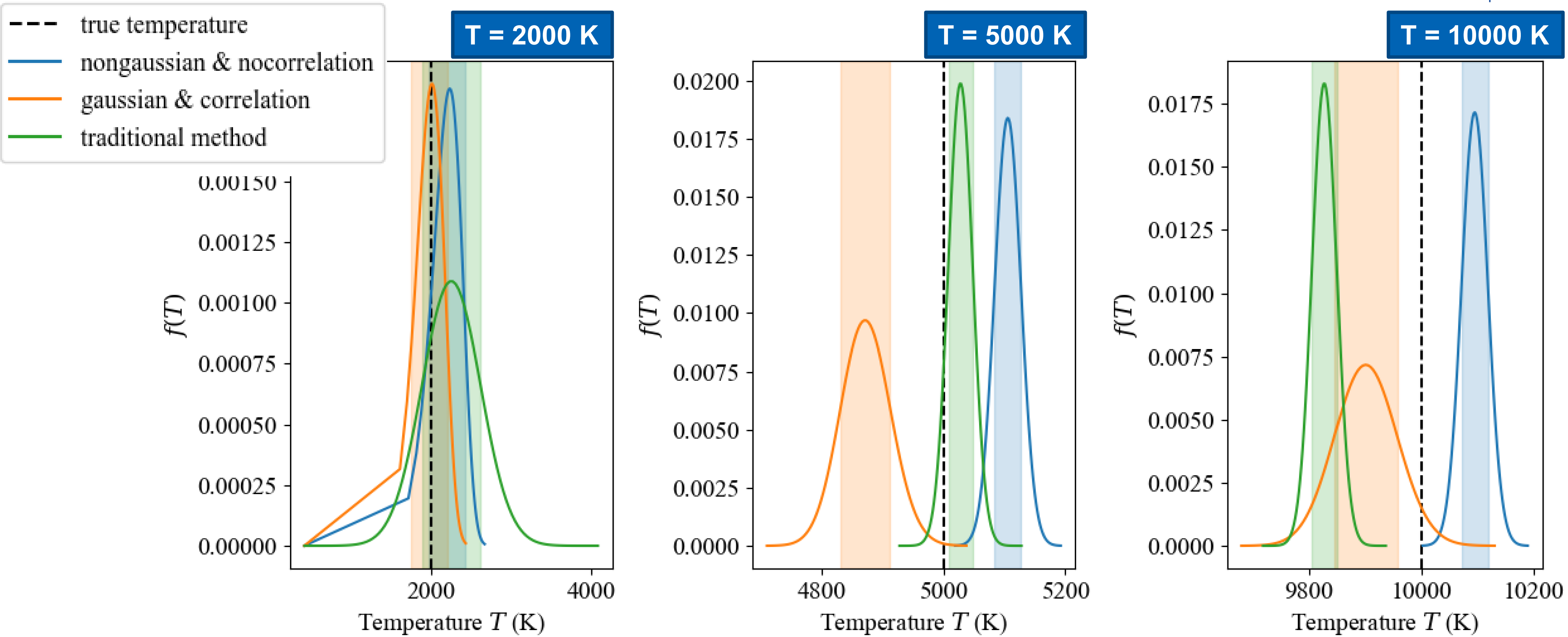
Uncorrelated assumption

Real energy deposition

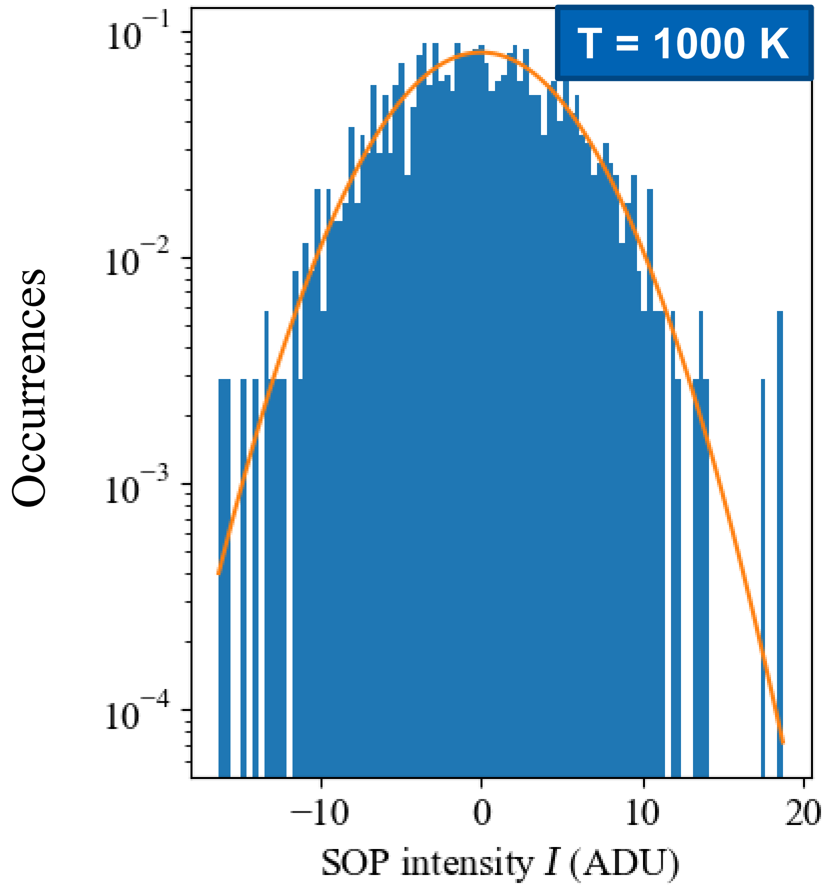
The neighboring pixels are therefore spatially correlated.

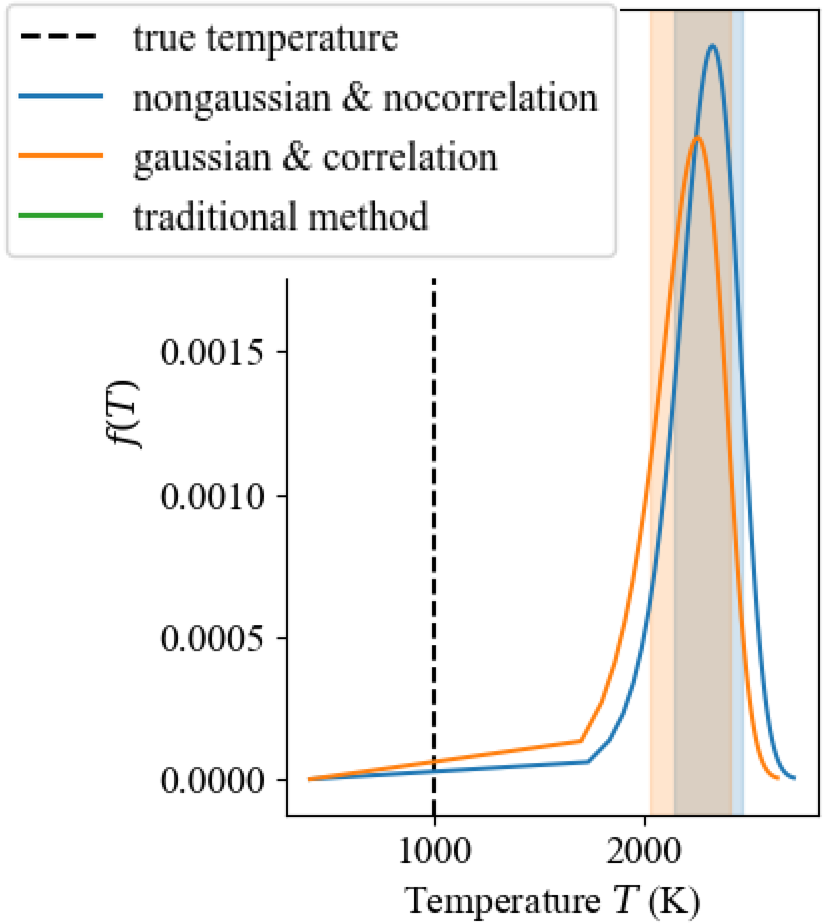
Start with the simpler case of Gaussian distribution.
The likelihood function is therefore a multivariate Gaussian distribution.

The temperature is given in the form of posterior distribution.



At extremely low temperatures, the traditional method run into numerical errors, while the new model at least gives us an upper bound for temperature.





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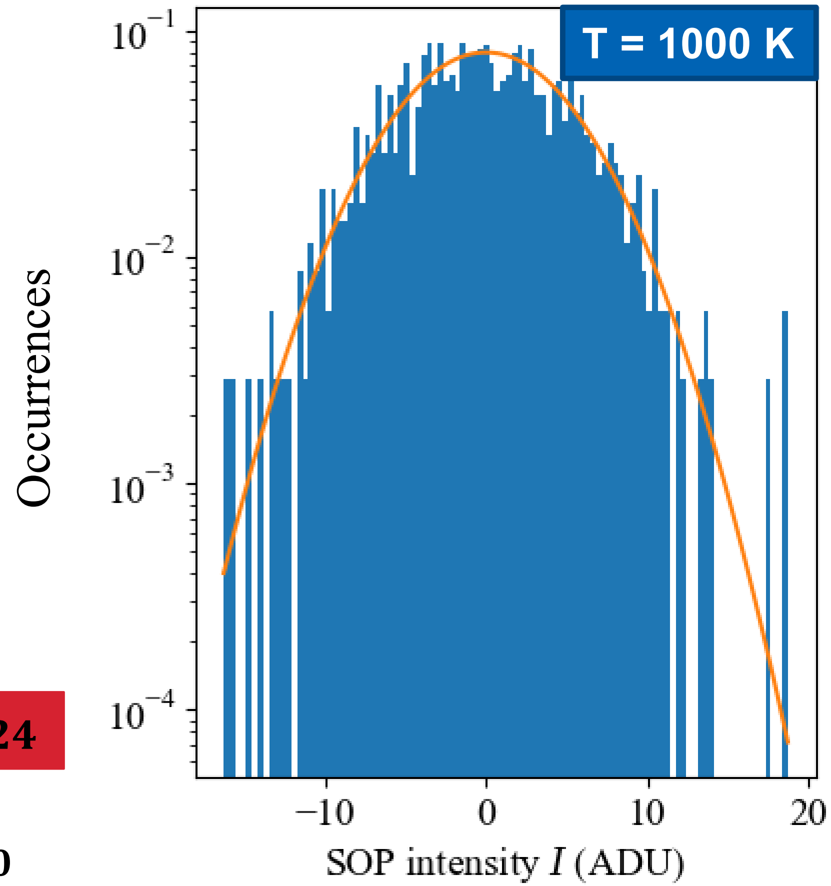

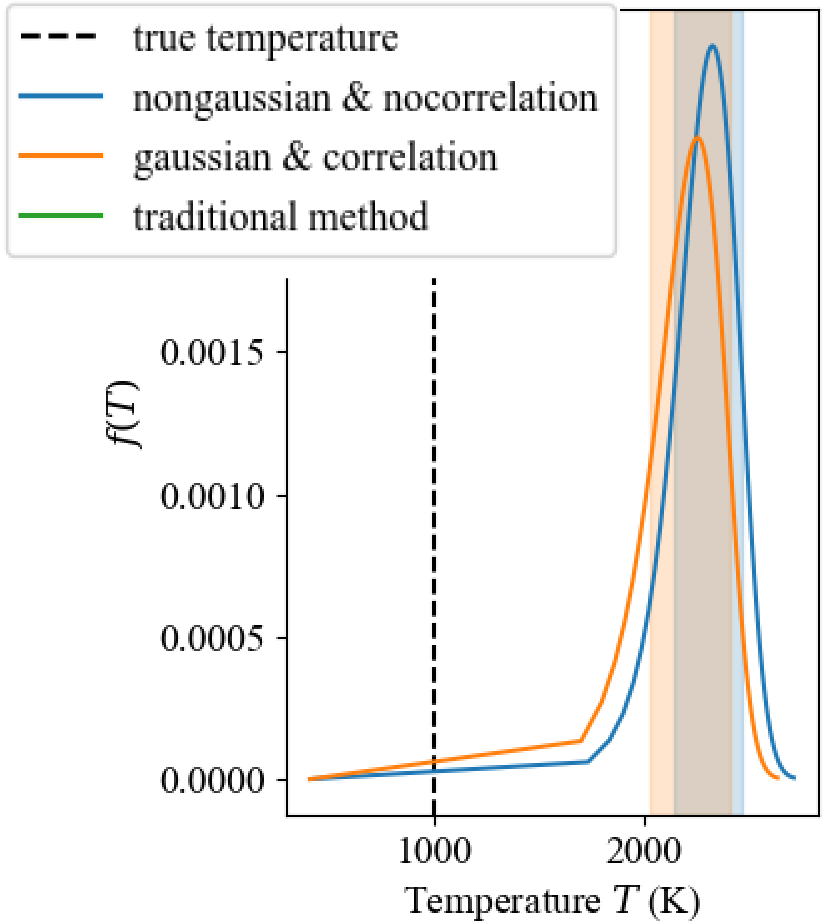

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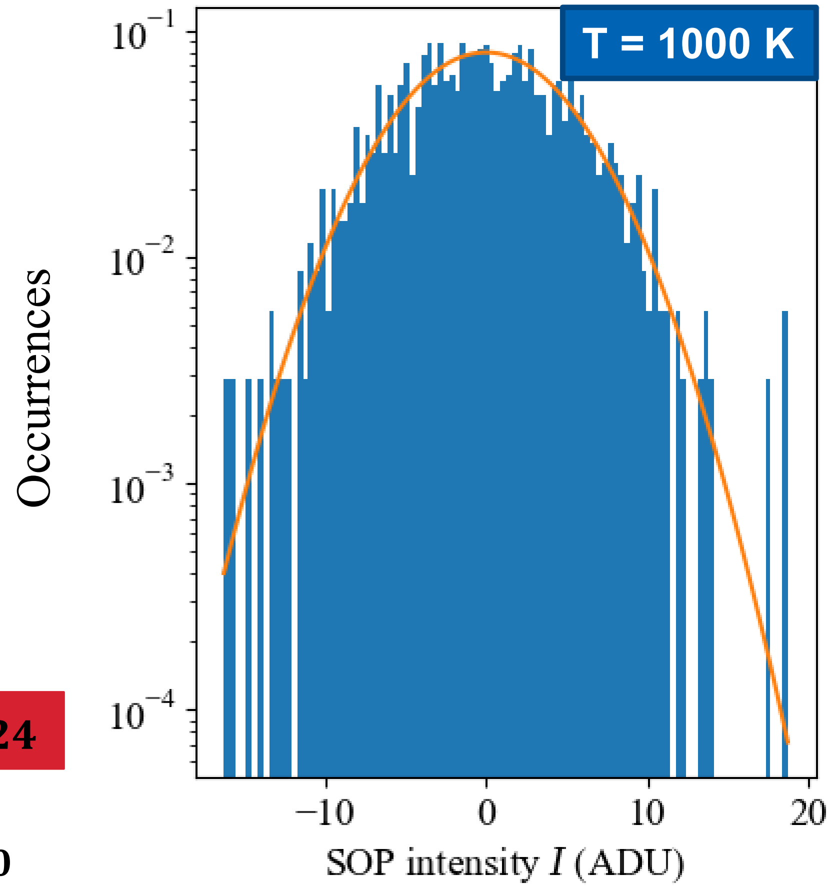

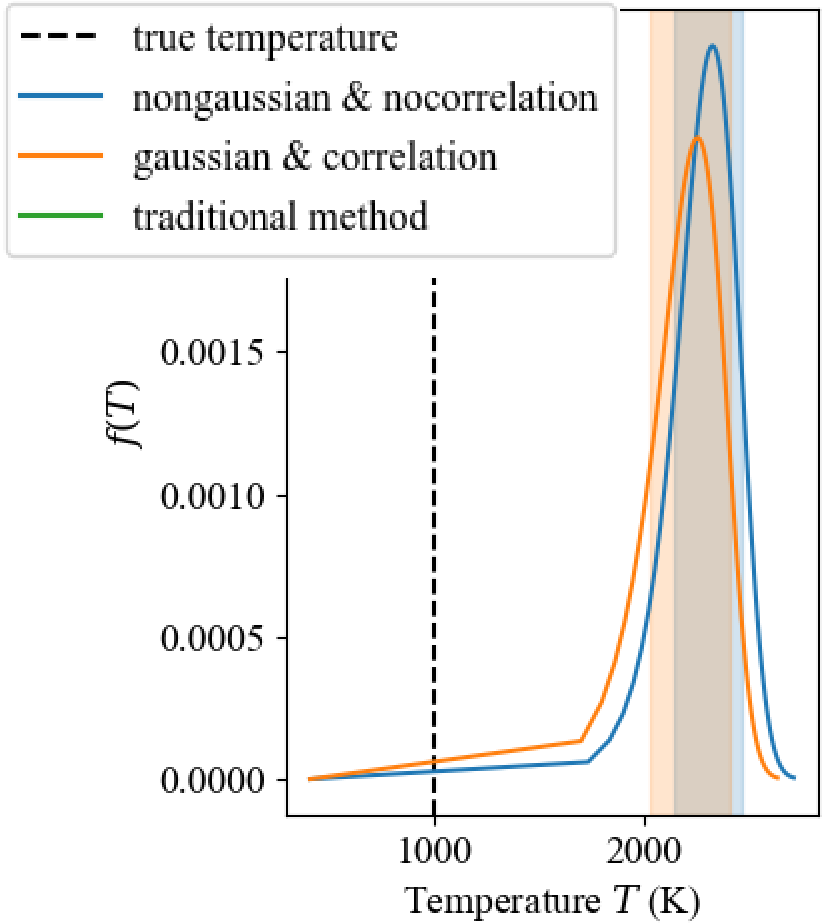

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Still working on the formalism to make the credible interval one-sided.

Future work

- **Measure streak camera parameters of the OMEGA EP SOP (already collected data);**

- **Incorporate systematic uncertainties of streak camera parameters, SOP parameters, etc., possibly in a full Bayesian scheme.**

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Thanks for your attention.

Any questions are welcome.