Improving astrophysical $\gamma$-ray modeling with Gaussian processes and variational inference

Siddharth Mishra-Sharma and Kyle Cranmer, New York University

**Motivation**
- Signals of dark matter (DM) may be hiding in $\gamma$-ray observations of the Galactic Center
- Galactic backgrounds of astrophysical origin make up a large fraction (> 80%) of the data in this region
- The poorly-understood spatial morphology of these backgrounds makes it difficult to characterize DM signals [1-2]
- Motivates analysis techniques that can account for uncertainty in knowledge of Galactic background contribution (e.g., Refs. [3,5])

**Traditional template fitting**
- Spatially-binned (pixelized) data $d^p$ is modeled as a Poisson realization of sum of templates $T^p$
- Spatial profile of each template is rigidly fixed
- Normalizations $A_i$ of templates are floated as free parameters of the model

**Proof-of-principle analysis on simulated data**
- Create simulated data using one Galactic background model (Model 1), analyze using other model (Model 2) (templates from Refs. [5-6])
- GP used for variational posterior defined using GPyTorch [7] and Pyro [8]
- Variational distributions of non-GP parameters (template normalizations) $q(A_i | GP)$ defined using inverse autoregressive flows conditioned on GP summary statistics in order to capture correlations between GP and non-GP parameters

**Summary**
- Traditional $\gamma$-ray analyses model data as a sum of rigid spatial templates, each corresponding to a specific astrophysical component [9]
- We modulate the poorly-understood Galactic background templates by a Gaussian process (GP) in order to give them more freedom and account for uncertainty in their spatial variation
- The GP is included as part of a larger probabilistic model that includes parameters describing other modeled components, including a dark matter signal. Variational inference is used for tractable analysis.

**Augmenting Galactic background template with a GP**
- Modulate Galactic background template with GP
- Exponential link function to ensure positivity

**References**
[1] Leane & Slatyer [2004.08430]
[3] Storm et al. [1705.04065]
[4] Lee et al. [1506.05124]
[7] Gardner et al. [1809.11165]
[8] Bingham et al. [1810.09583]

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https://github.com/smsharma/gamma-po