Physical machine learning for astrophysics

Differentiable spherical harmonics
Harmonic Bayesian evidence
Spherical scattering networks

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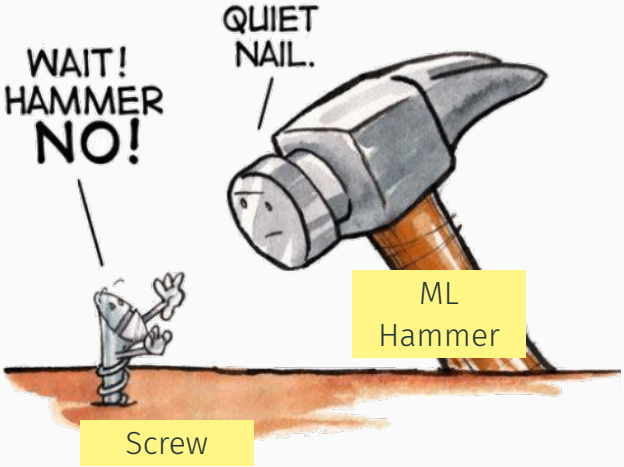
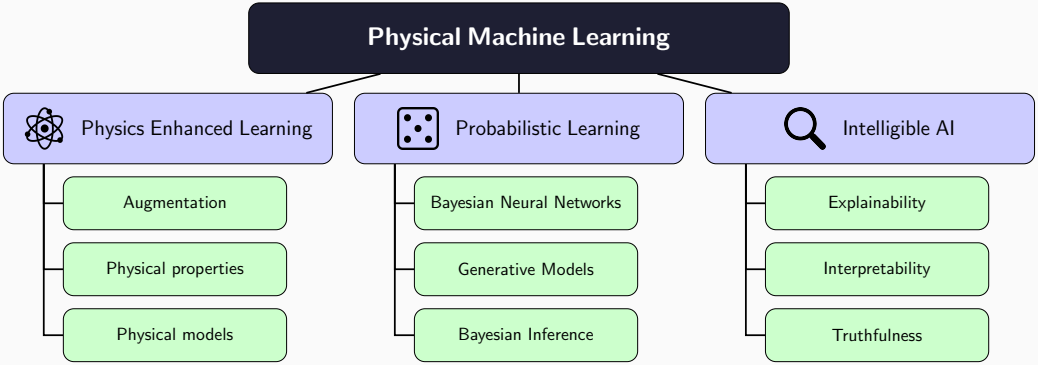
Potential of Machine Learning in Astronomical Surveys, IAP, November 2023

The machine learning hammer



The machine learning cog

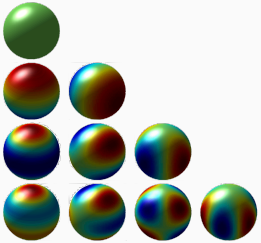
Physical machine learning for astrophysics



Accelerated and differentiable spherical harmonic transforms

Accelerated and differentiable spherical harmonic and Wigner transforms

(Price & McEwen 2023)



- Parallelisable Wigner d-function computation
  - ⇝ Stable to very high harmonic degree ($\ell_{\text{max}} \sim 10,000+$)
  - ⇝ Extremely parallelisable
- Efficient gradients
  - ⇝ Hyrbid manual and automatic differentiation
- Runs on hardware accelerators, e.g. GPUs, TPUs
  - ⇝ Up to 400-fold acceleration compared to C code
  - ⇝ Linear scaling with GPUs
- Largely agnostic to sampling
  - ⇝ HEALPix (approximate transforms)
  - ⇝ Equiangular (exact transforms)
  - ⇝ Others can be added easily

Code: https://github.com/astro-informatics/s2fft

Webpage & Docs: https://astro-informatics.github.io/s2fft

Learned harmonic mean estimator for Bayesian model selection

Enhanced Bayesian model selection with **learned harmonic mean**

(McEwen *et al.* 2021, Spurio Mancini *et al.* 2022, Polanska *et al.* 2023, +2 papers in prep.)

- ▷ Requires **posterior samples only**
  - ⇝ Evidence almost for free
- ▷ **Agnostic to sampling** technique
  - ⇝ Leverage efficient samplers
  - ⇝ Simulation-based inference
  - ⇝ Variational inference
- ▷ Scale to **high-dimensions**
  - ⇝ Normalizing flows

Accelerated Bayesian inference (preliminary)

37 parameter cosmic shear analysis of LCDM vs $w_0 w_a$CDM

- ▷ CAMB + PolyChord
  - ⇝ $\Delta \log Z = 0.89 \pm 0.61$
  - ⇝ Compute: 4 months on 48 CPU cores
- ▷ CosmoPower-JAX + NumPyro/NUTS + **Harmonic**

  (see CosmoPower-JAX poster)
  - ⇝ $\Delta \log Z = 1.42 \pm 0.32$
  - ⇝ Compute: 1 day on 3 GPUs

Code: https://github.com/astro-informatics/harmonic

Webpage & Docs: https://astro-informatics.github.io/harmonic

Full-sky emulation with scattering networks

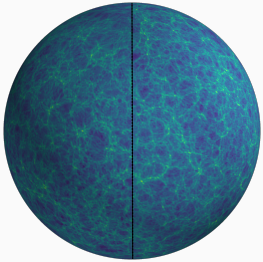
Emulation of cosmic string signatures in the CMB

(`stringgen` code; Price *et al.* 2023, +1 paper in prep.)

Scattering covariance networks on the sphere

(Mousset, Price, Allys, McEwen, in prep.)

- Build on **suite of differentiable spherical transforms**
  - ⇝ Differentiable spherical harmonic transforms (`s2fft`)
  - ⇝ Differentiable Wigner transforms (`s2fft`)
  - ⇝ Differentiable wavelet transforms on the sphere (`s2wav`)
- **Emulation on the sphere**
  - ⇝ Rapid emulation of full-sky cosmological observations
  - ⇝ Accurately capture non-Gaussian information



Spherical scattering code coming soon!