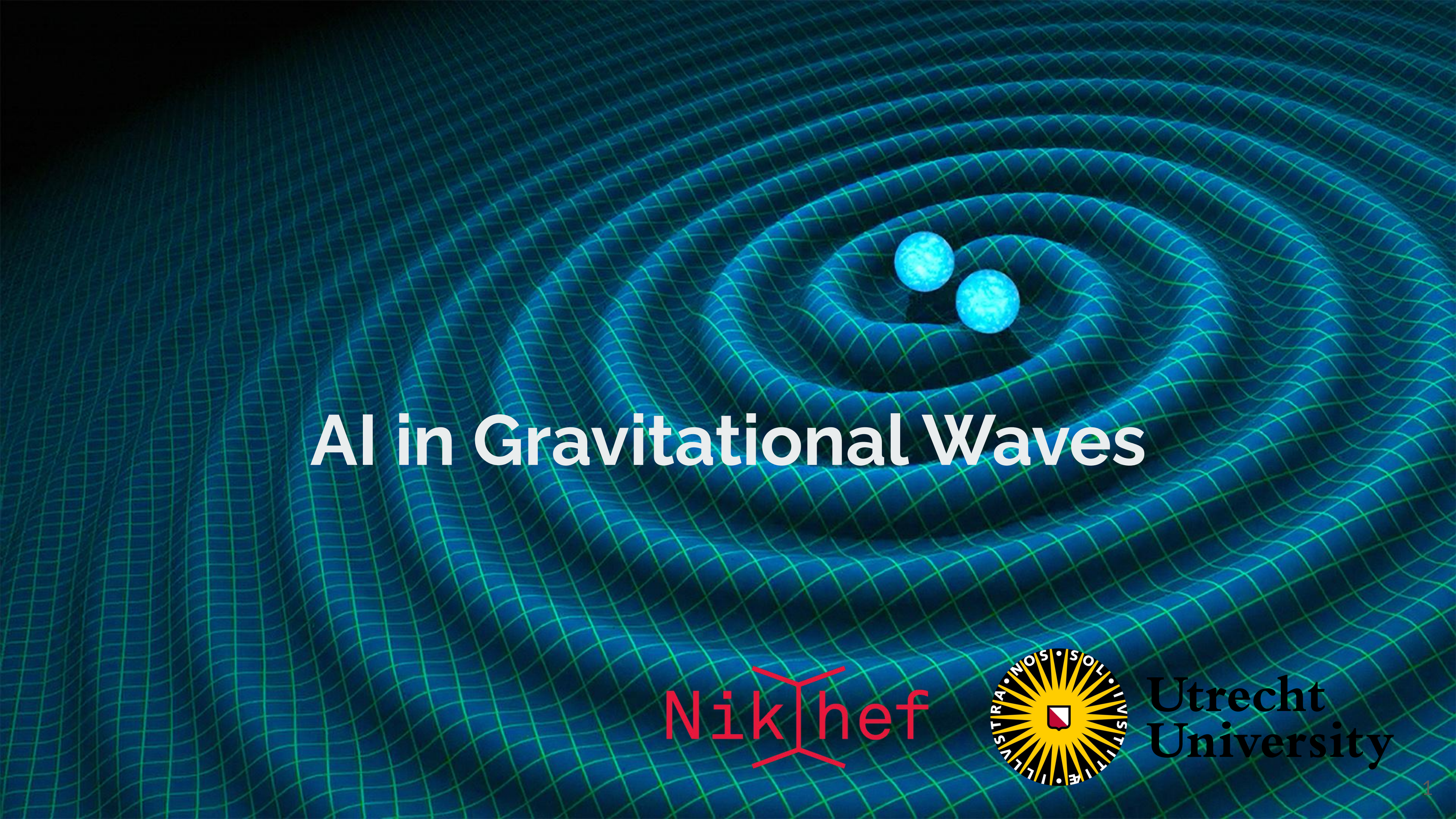
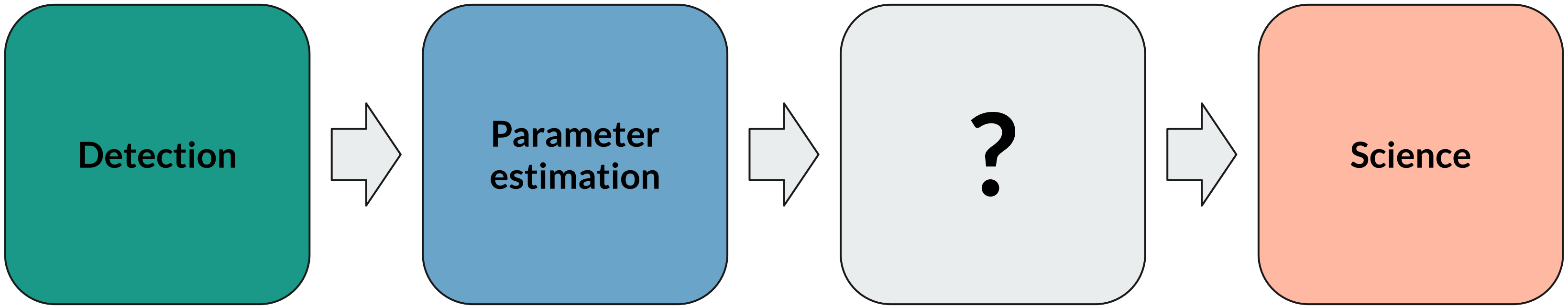
AI in Gravitational Waves

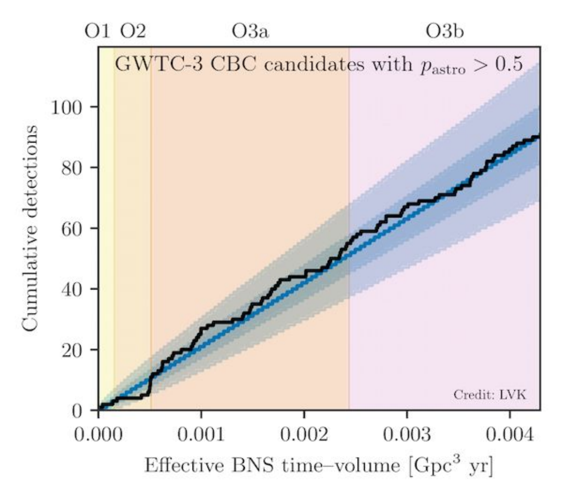


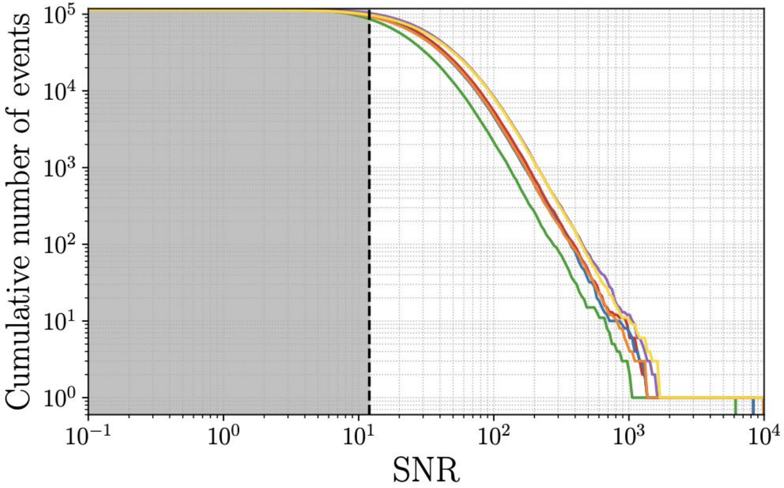
Gravitational-wave astrophysics



Challenges

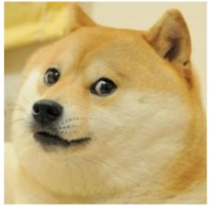
- Detection
    - More robust
    - Find more and find new stuff
- Parameter estimation
    - Currently close to the limit
    - O(1000) more events in 3G



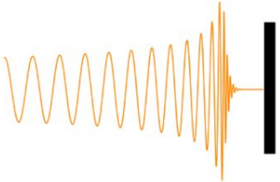


Detection of transient GW signals

Melissa Lopez

P( | ), P( | )

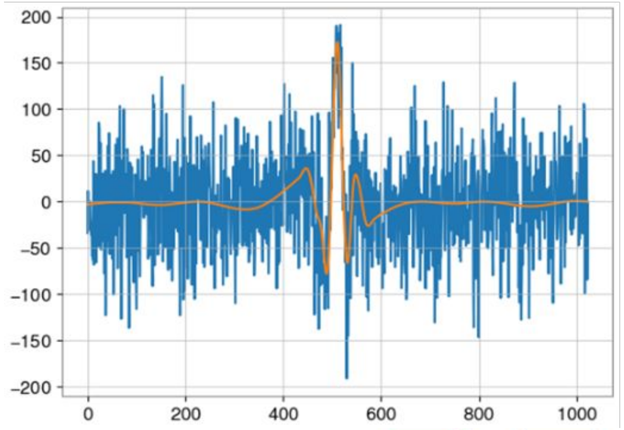
or equivalently

P( | ), P(0 | )

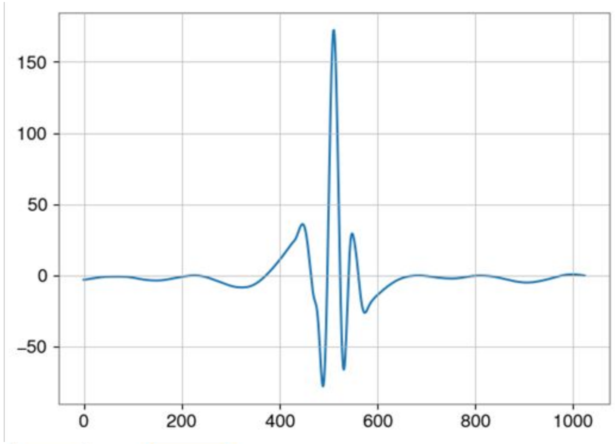
Detection of compact binary coalescence and supernovae, with background mitigation
(ResNet-based, WaveNet, autoencoder, GAN)

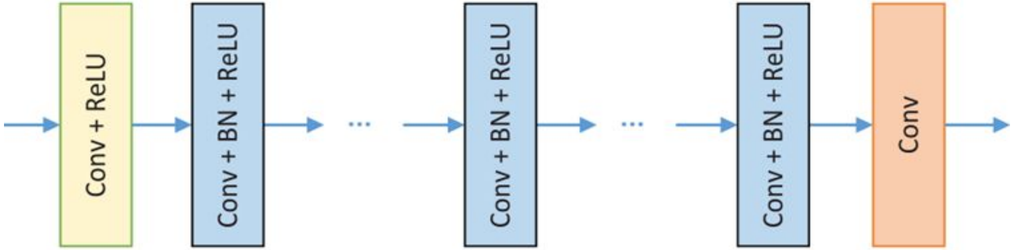
Extracting the glitch

Tom Dooney



Learn mapping from noisy glitch to clean glitch



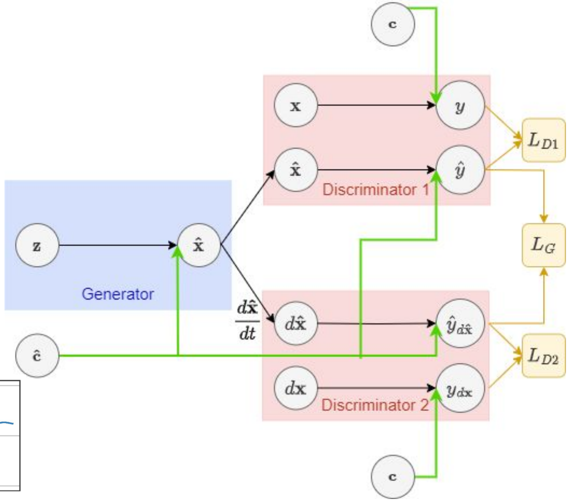


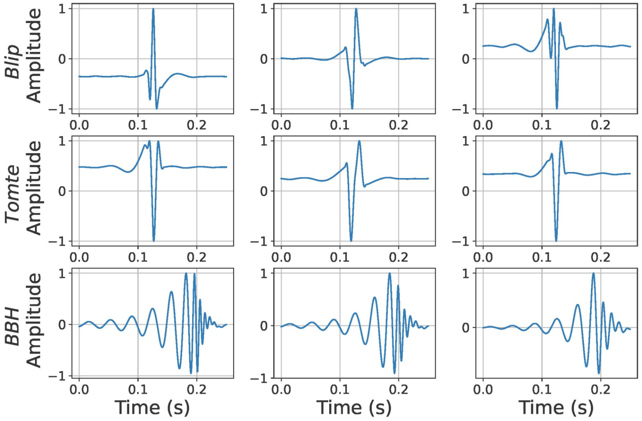
Modelling glitches in a generative model (cDVGAN)

Tom Dooney

Model different glitch/signal classes in a conditional GAN

Novel architecture - derivative discriminator, helps GAN learn realistic glitches





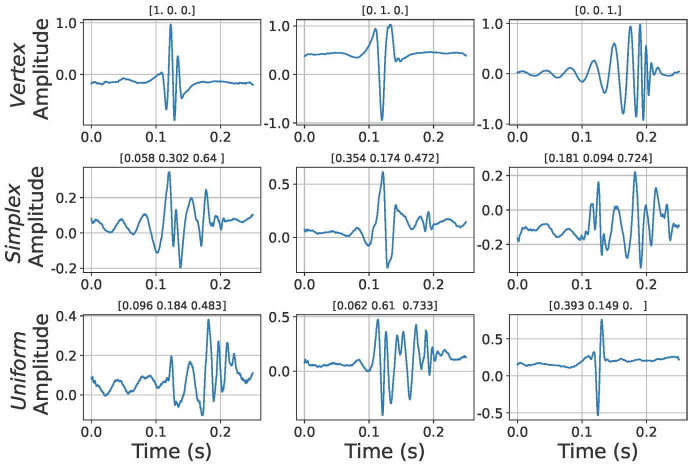
Training data

Gengli 2.0: Next-gen glitch generator

Easy-to-use tool for the collaboration

We can generate specific classes (top), or hybrid samples.

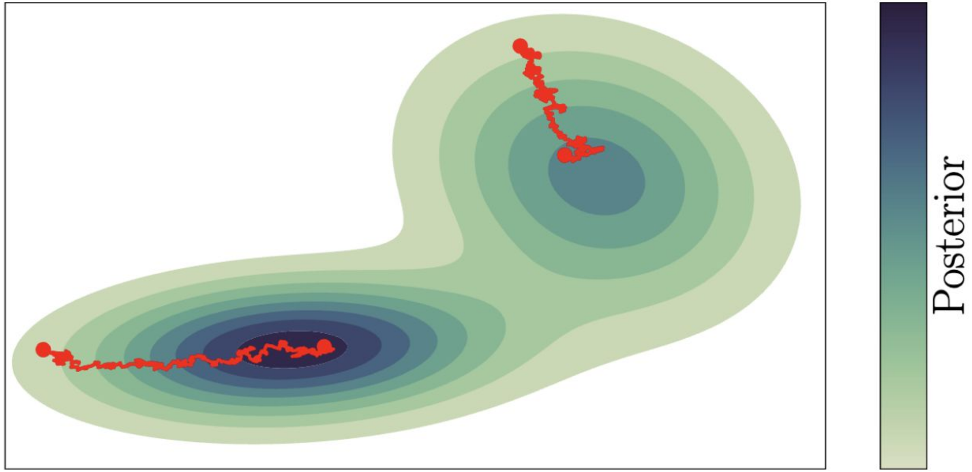
Can be useful for testing pipelines



GAN-generated data

Parameter estimation (PE)

$$p(\vec{\theta}|d) = \frac{p(d|\vec{\theta})p(\vec{\theta})}{p(d)}$$
$$= \frac{\text{likelihood} \times \text{prior}}{\text{evidence}}$$



Traditionally slow: ~1 - 2 months on a single CPU core for binary neutron star signal

Parameter estimation (PE)

- Accelerate with:
  - Machine learning: Use normalizing flows to enhance the robustness and speed of MCMC
  - JAX: Python with auto-differentiation, JIT-compilation and hardware acceleration (GPU/TPU)
- Results
  - PE on BNS in **< 30 minutes** [paper], O(1000) speed-up
  - Speed up waveform evaluation with deep learning [paper, Github]
- On-going work
  - Bridging theoretical gap between nuclear physics and astrophysics [Github]
  - Combining telescopes' data: accelerated multi-messenger astrophysics [Github]

Thibeau Wouters

Peter Pang

Stefano Schmidt

Conclusion

- A lot more effort for AI in GW within NL not covered
  - Simulation-based inference
  - Detections on early inspiral
  - And more…
- Various tools used
  - JAX
  - Normalizing flows
  - “Vanilla” deep learning
- Dream
  - More GPU resources
  - More cross-group collaboration