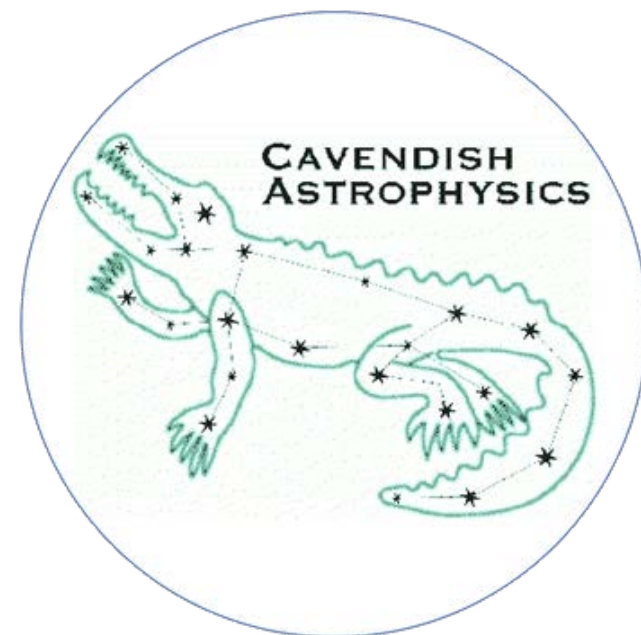
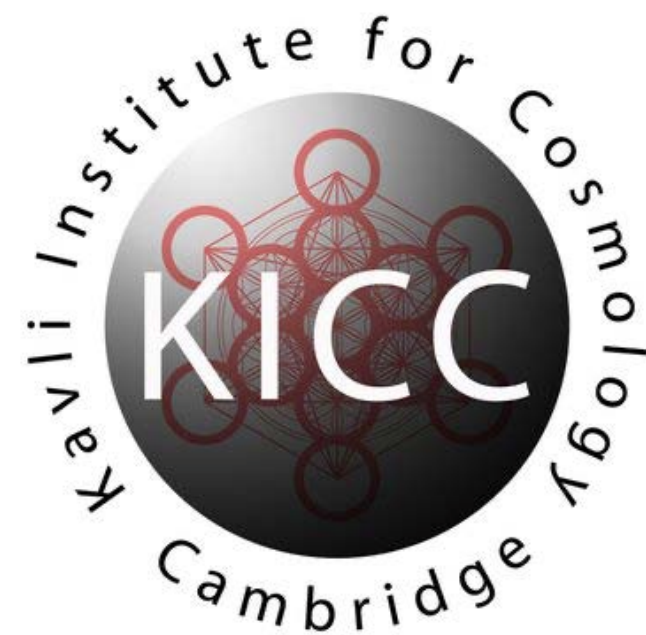


# Novel Statistical Methods and 21-cm Cosmology

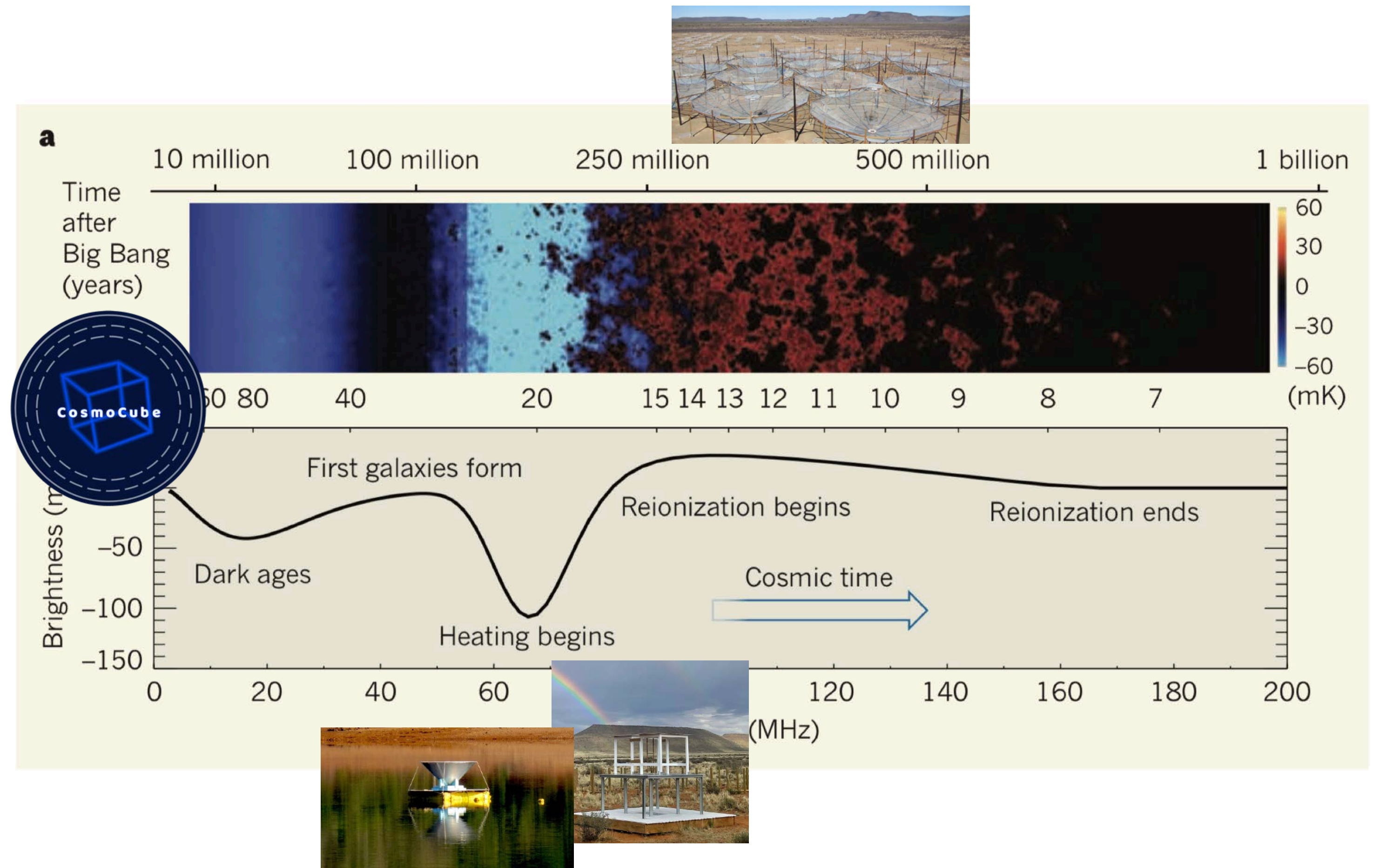
Harry Bevins  
Kavli Junior Fellow - K07





# 21-cm Cosmology

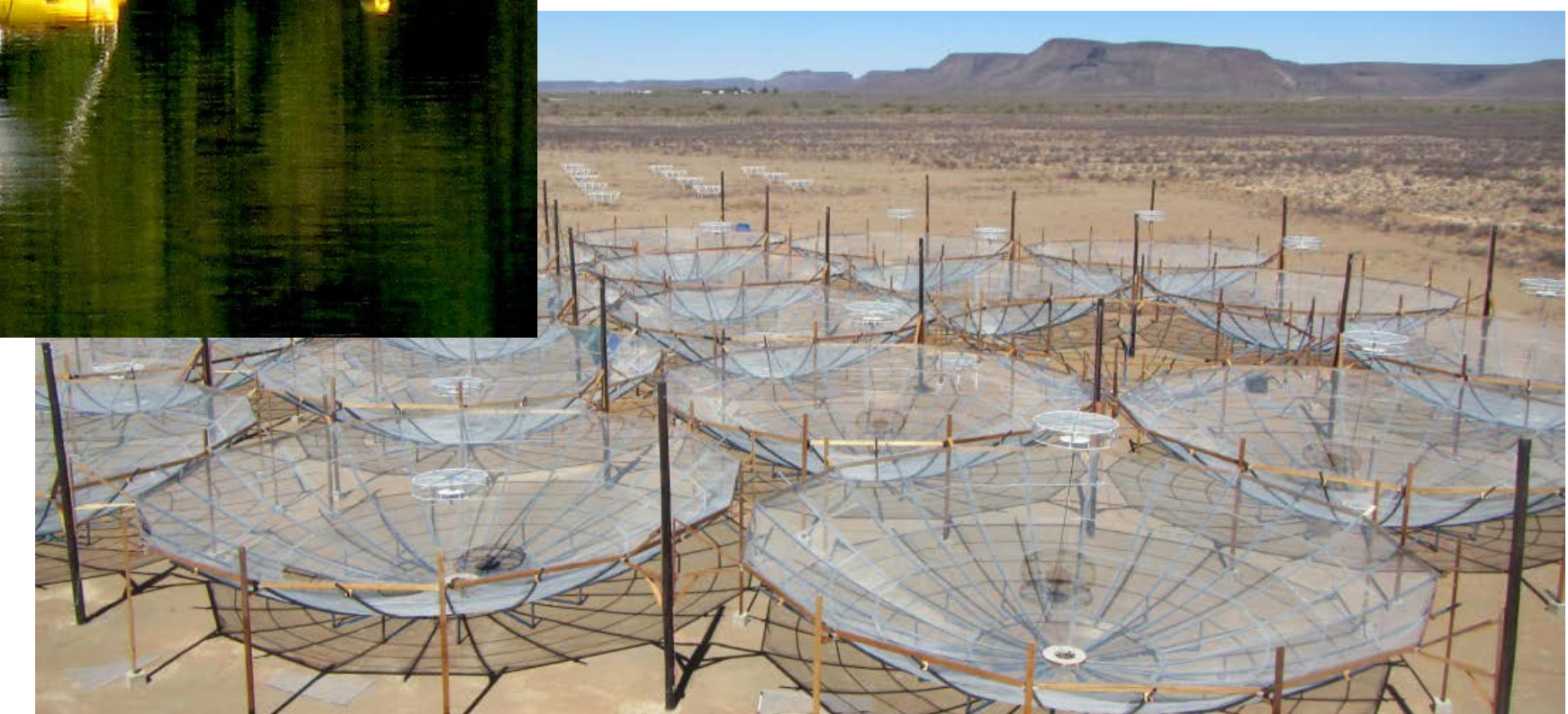
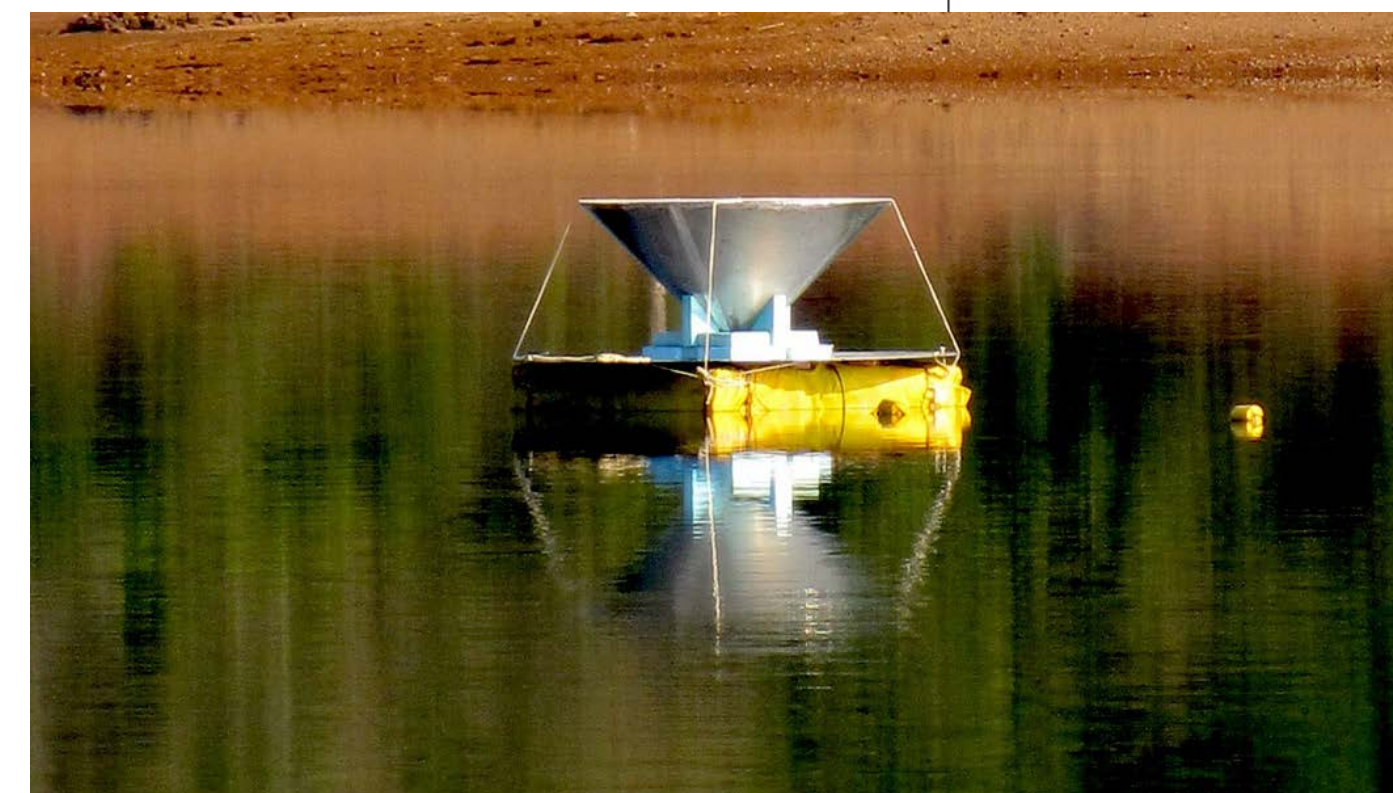
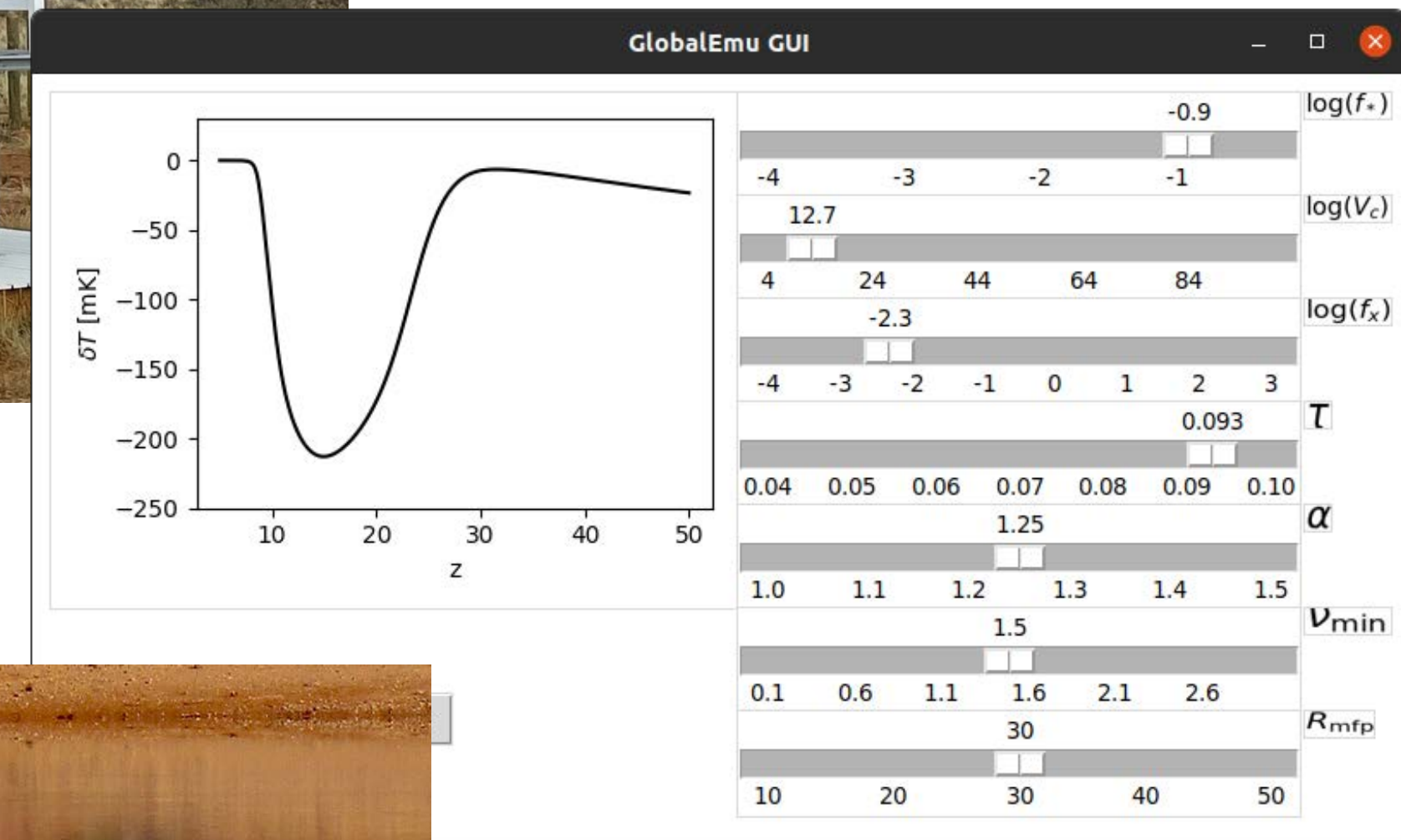
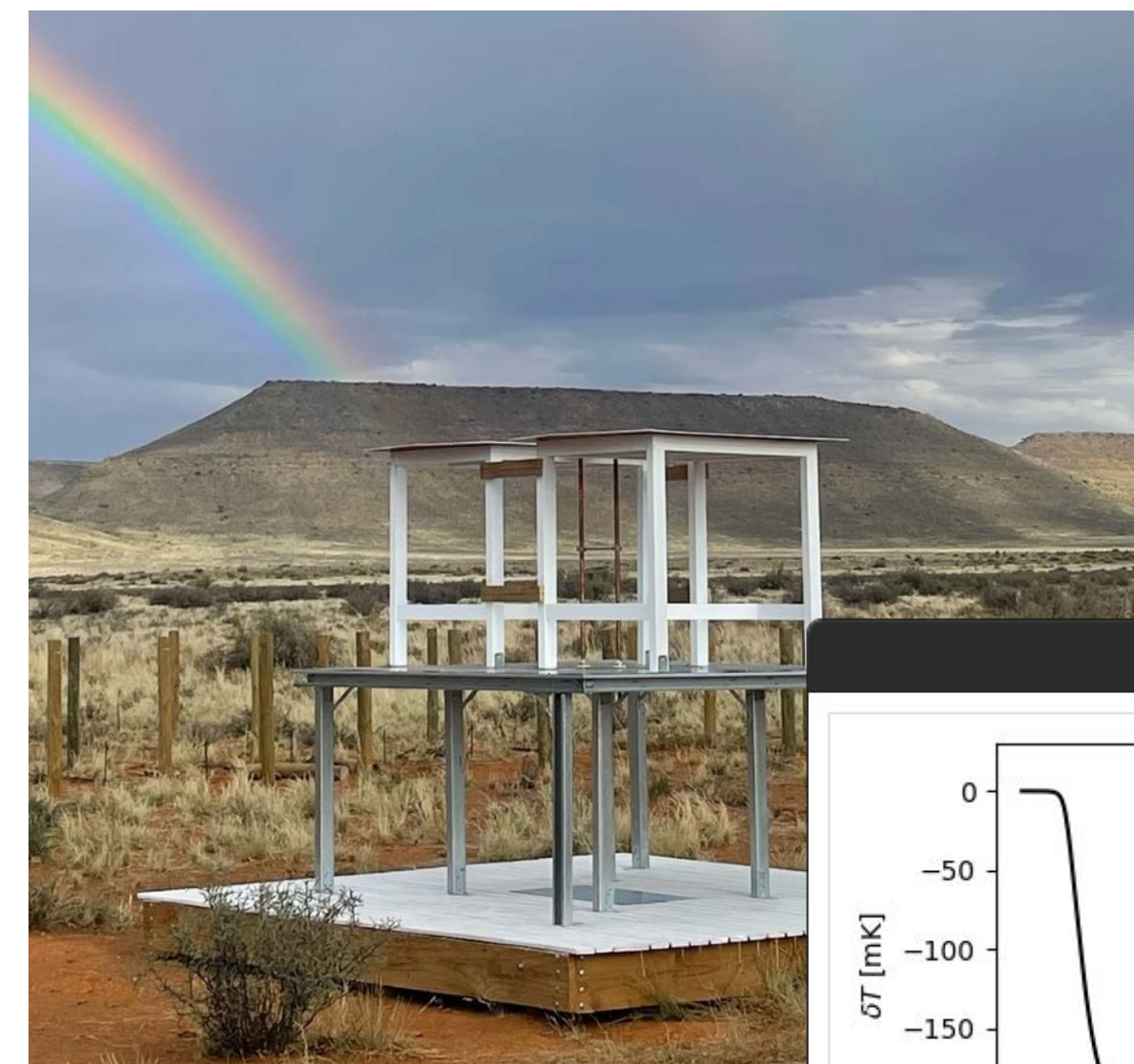
- Redshifted 21-cm emission from neutral hydrogen
- Differential measurement with radio background
- Measure sky-averaged signal and fluctuations with power spectrum
- Informs us about cosmology in Dark Ages
- And astrophysics at cosmic dawn and EoR





# My research...

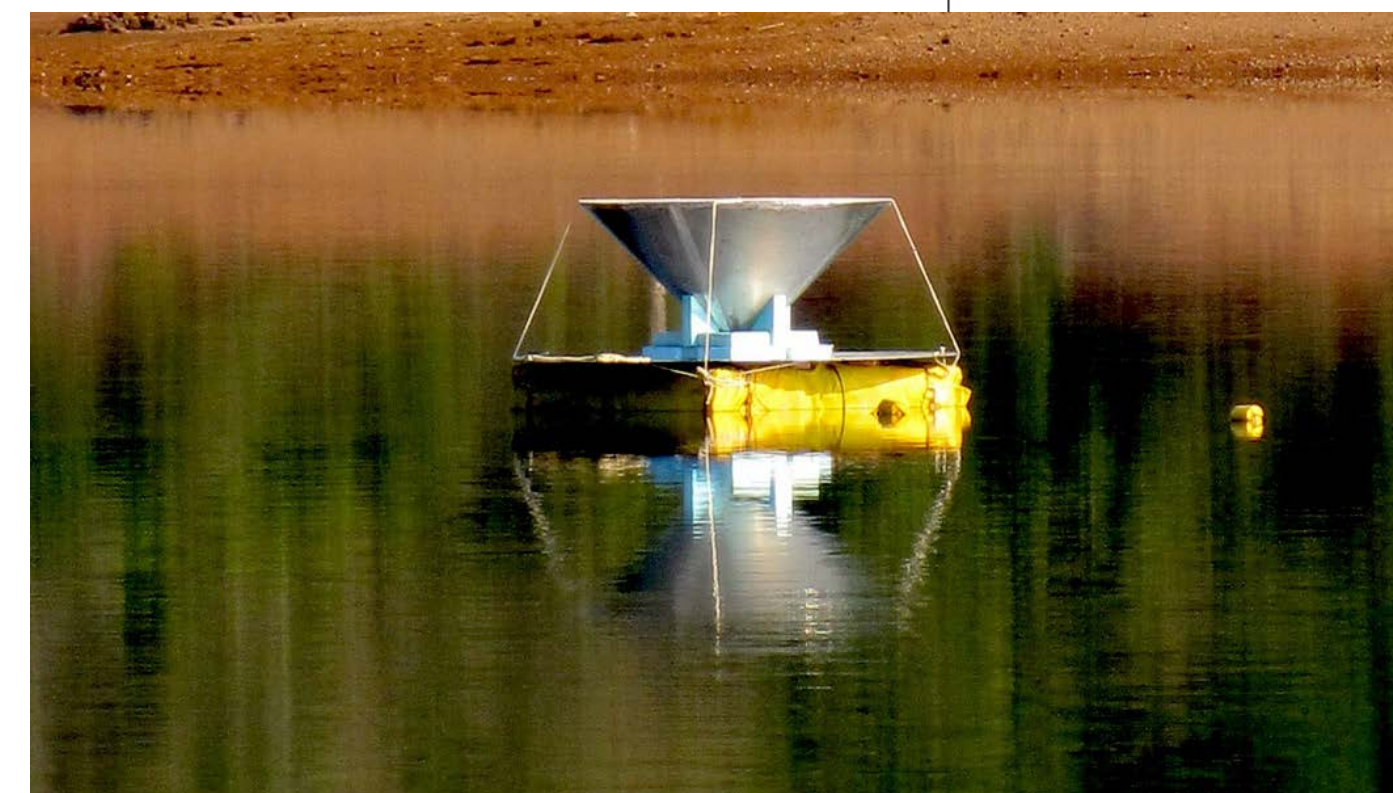
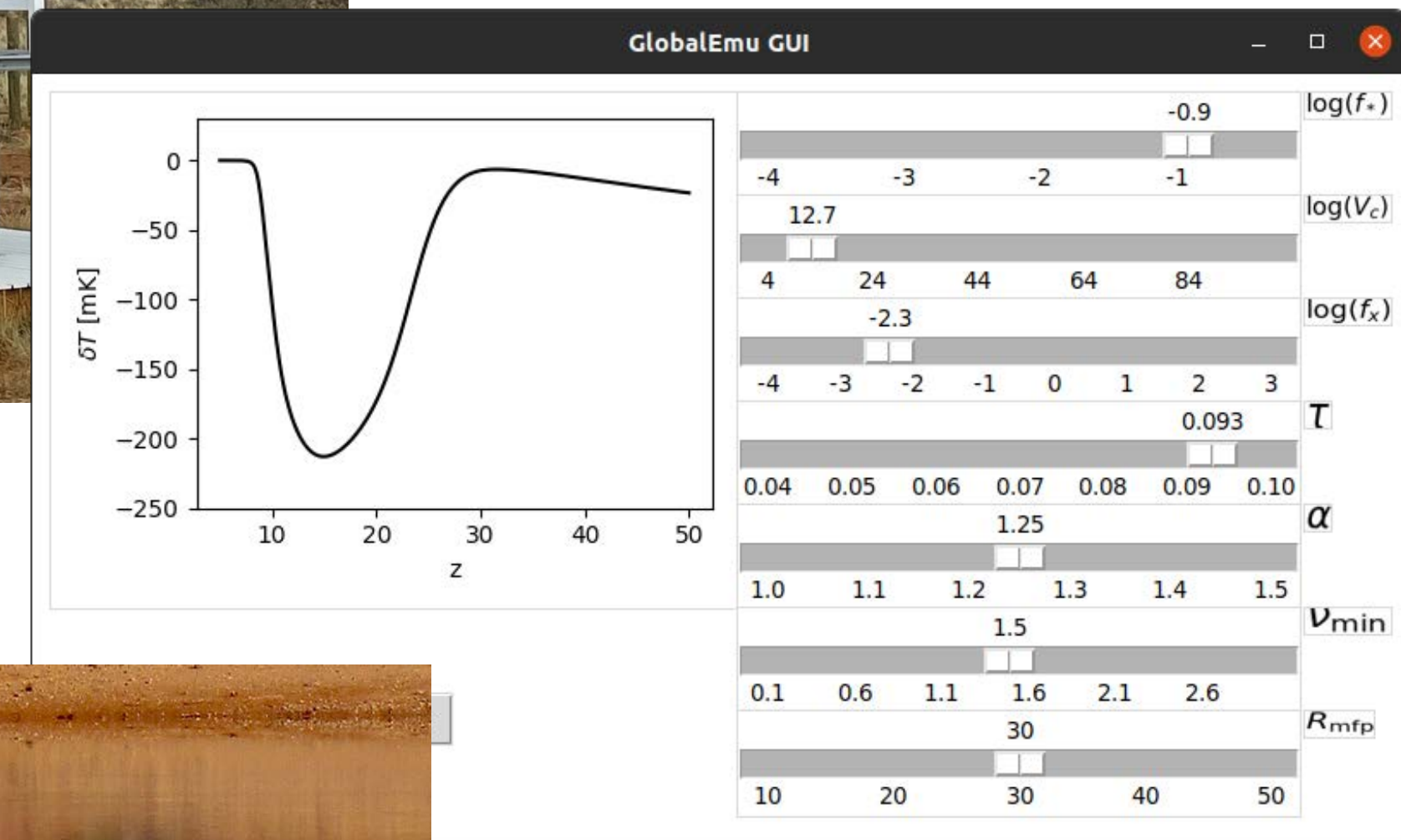
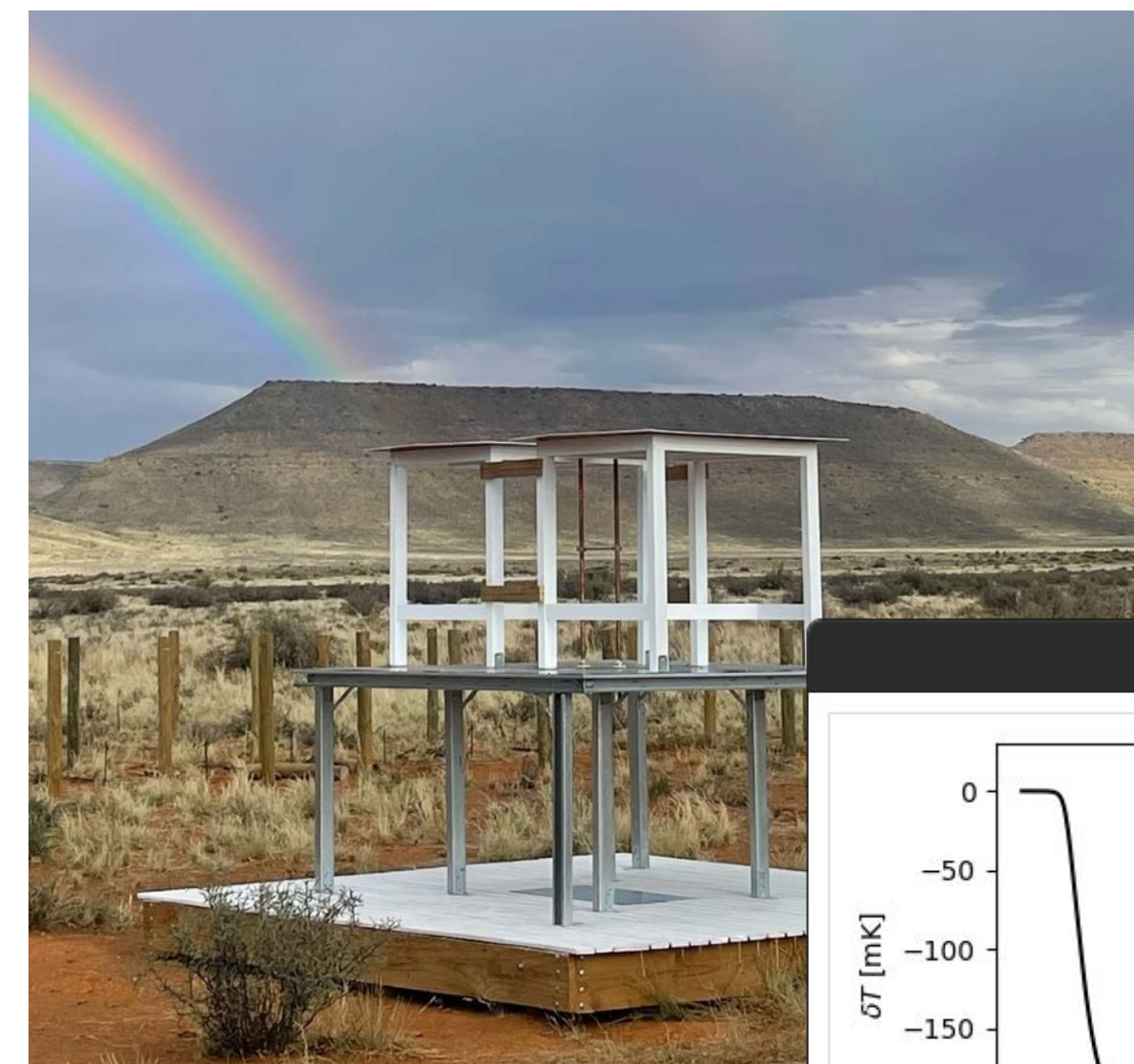
- Novel analysis techniques for 21-cm cosmology
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  - Signal emulators (2104.04336)
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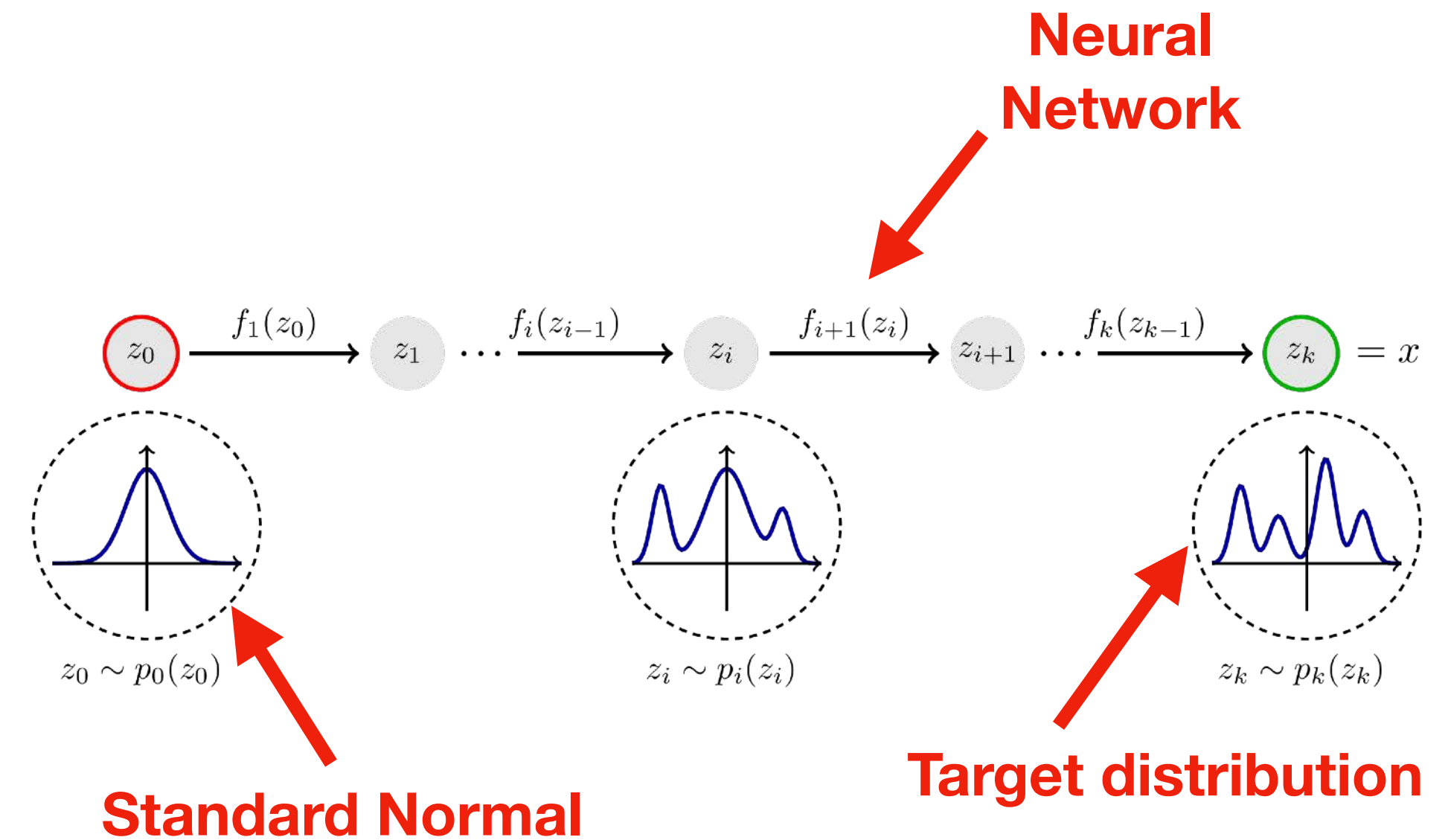
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# margarine and Normalizing Flows?

- NFs perform density estimation and can be used
  - As marginal prior and likelihood emulators ( Alsing and Handley 2021, 2102.12478, Bevins et al. 2023, 2301.03298)



## margarine: Posterior Sampling and Marginal Bayesian Statistics [↗](#)

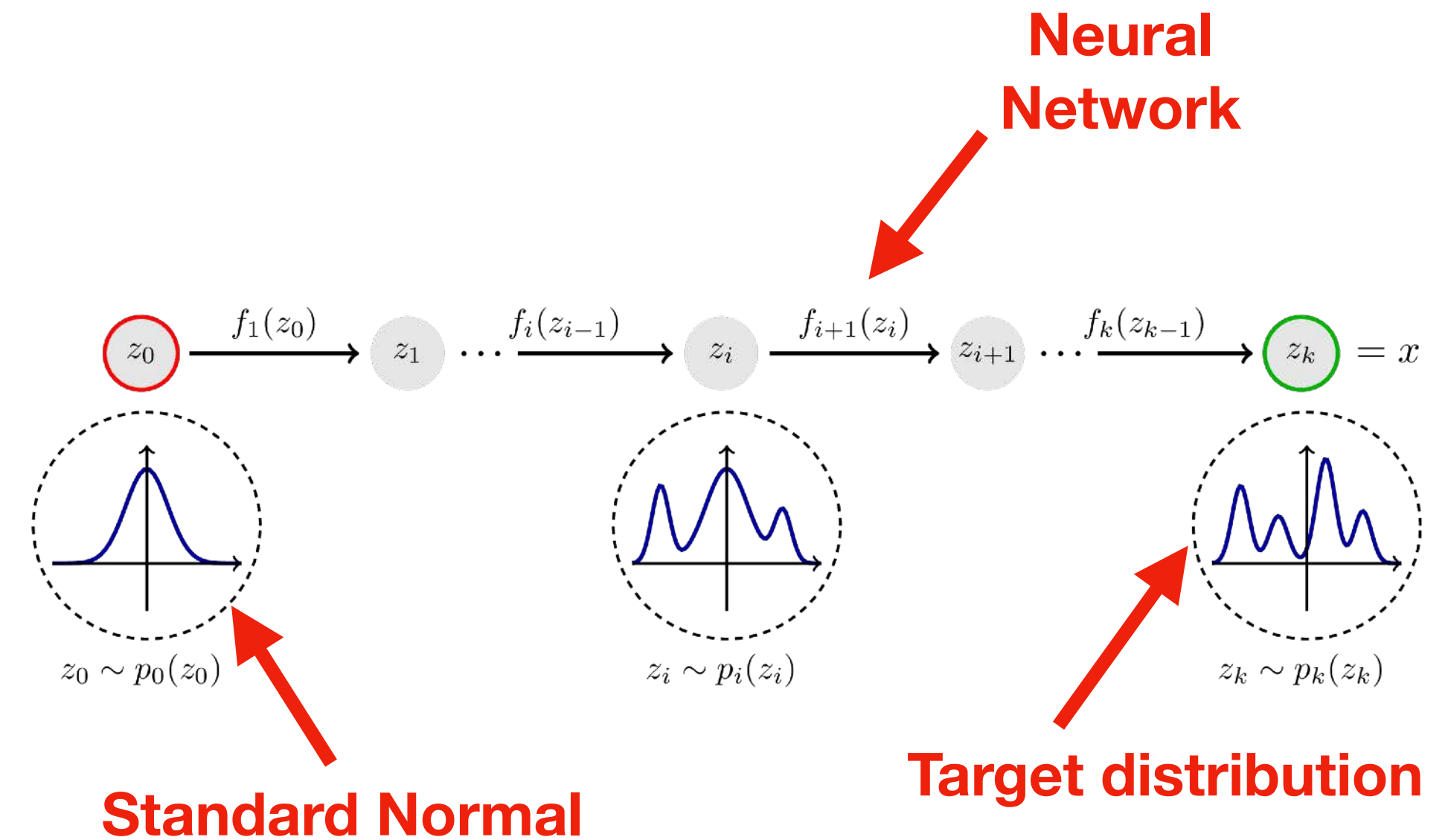
### Introduction [↗](#)

<b>margarine:</b>	Marginal Bayesian Statistics
<b>Authors:</b>	Harry T.J. Bevins
<b>Version:</b>	1.1.2
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docs [passing](#) [launch](#) [binder](#) [astro.IM](#) [arXiv:2205.12841](#)

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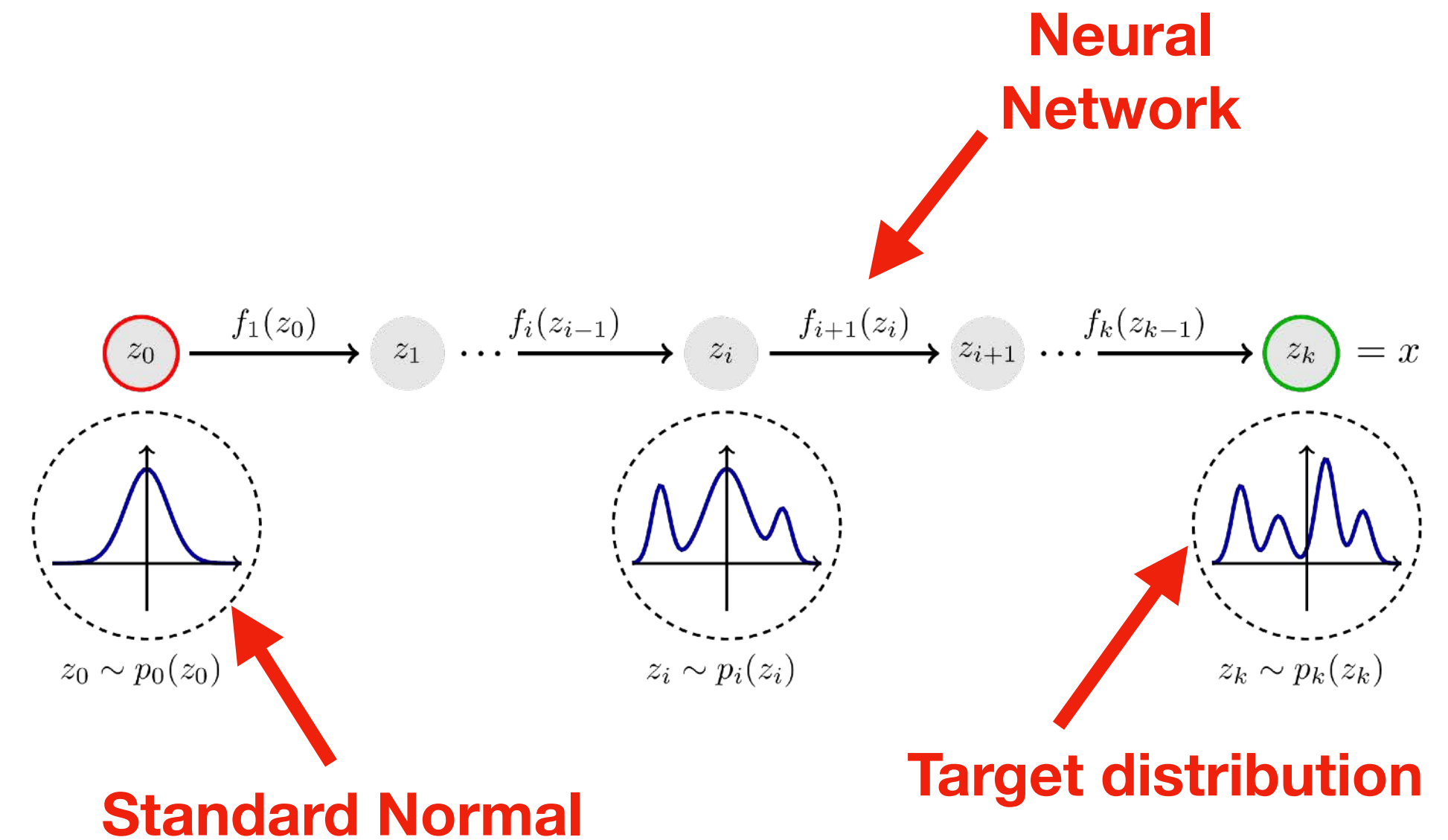
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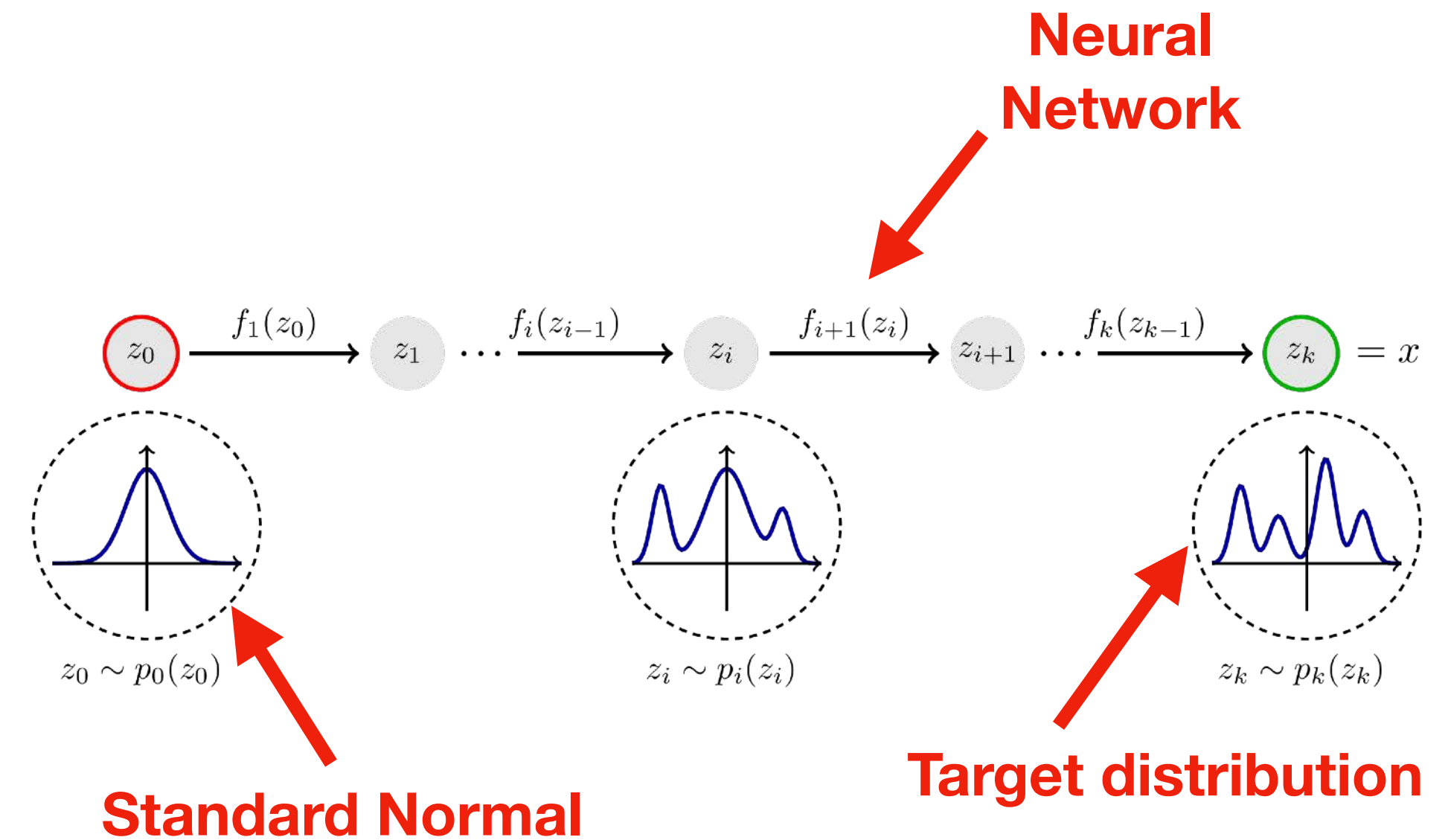
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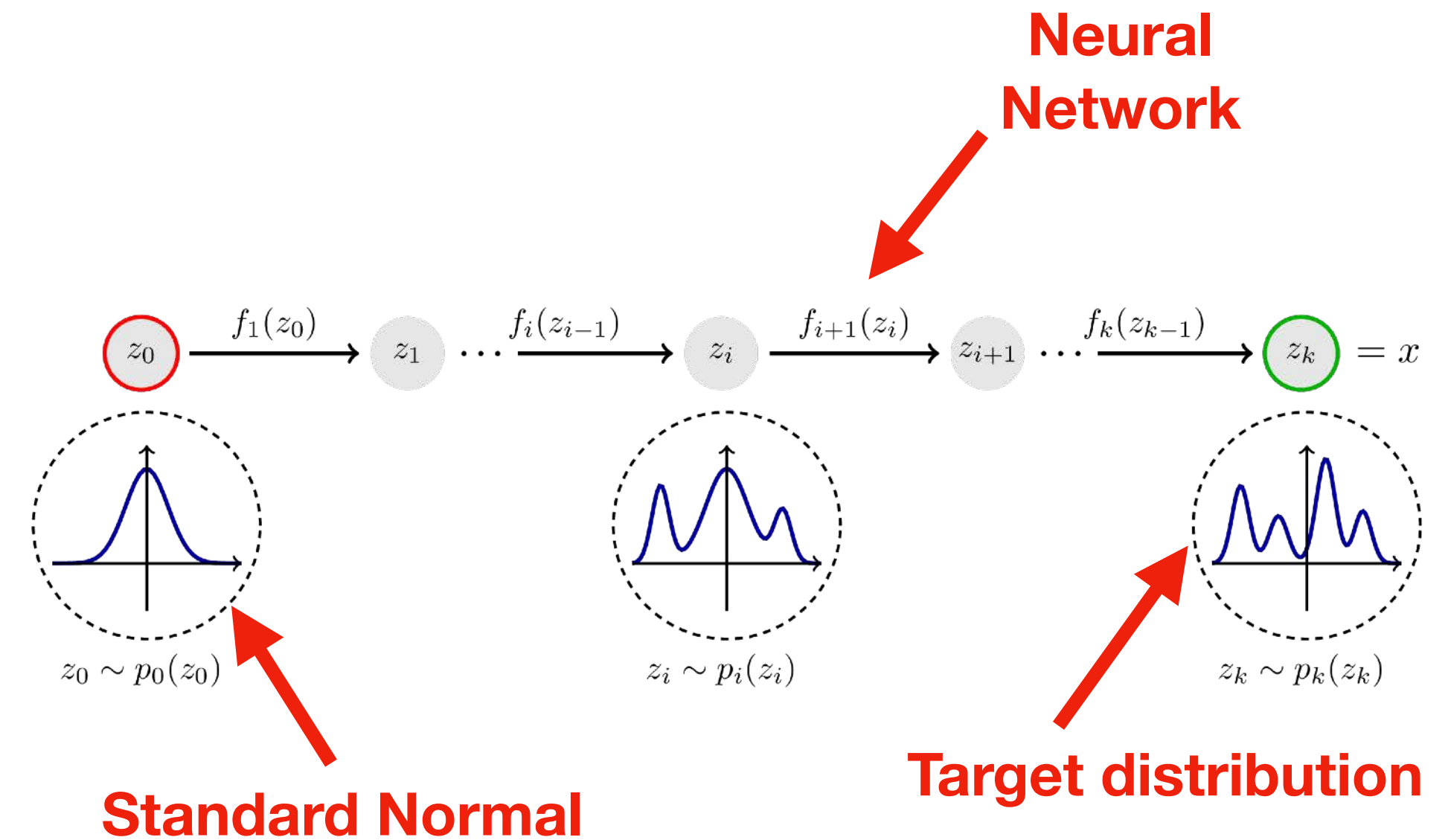
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  - Many others...



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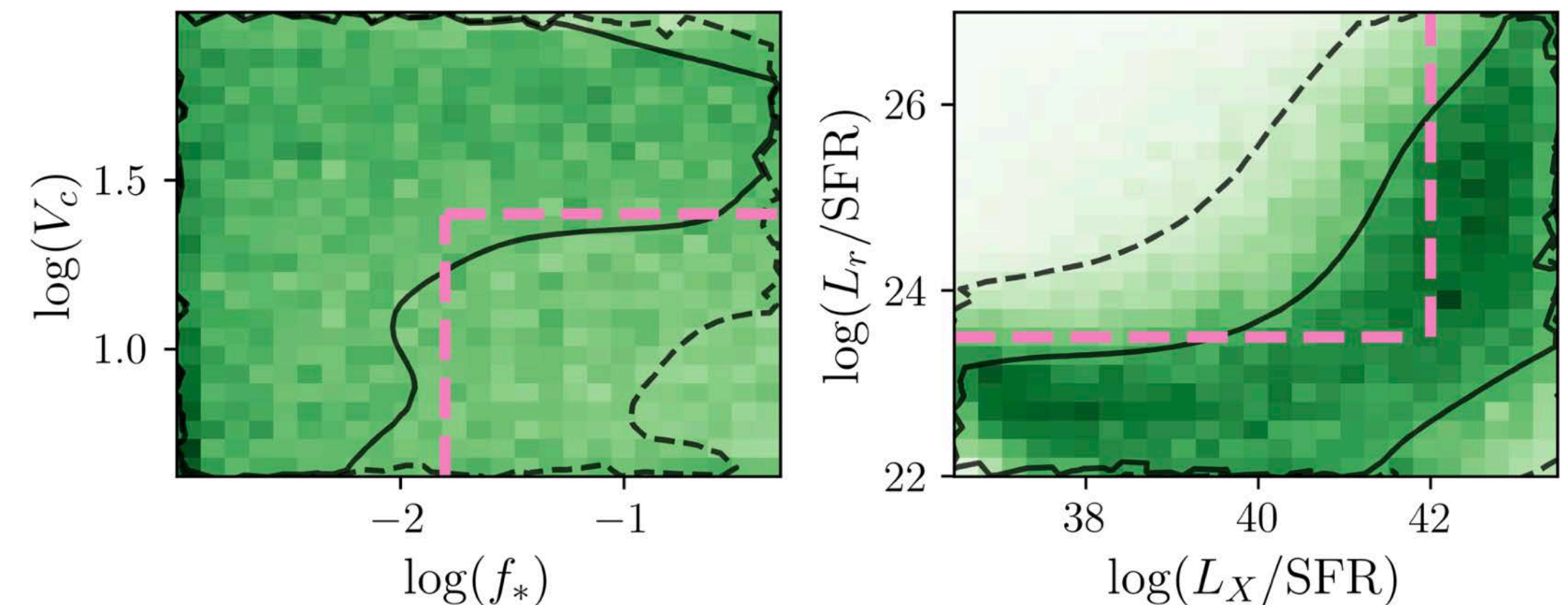
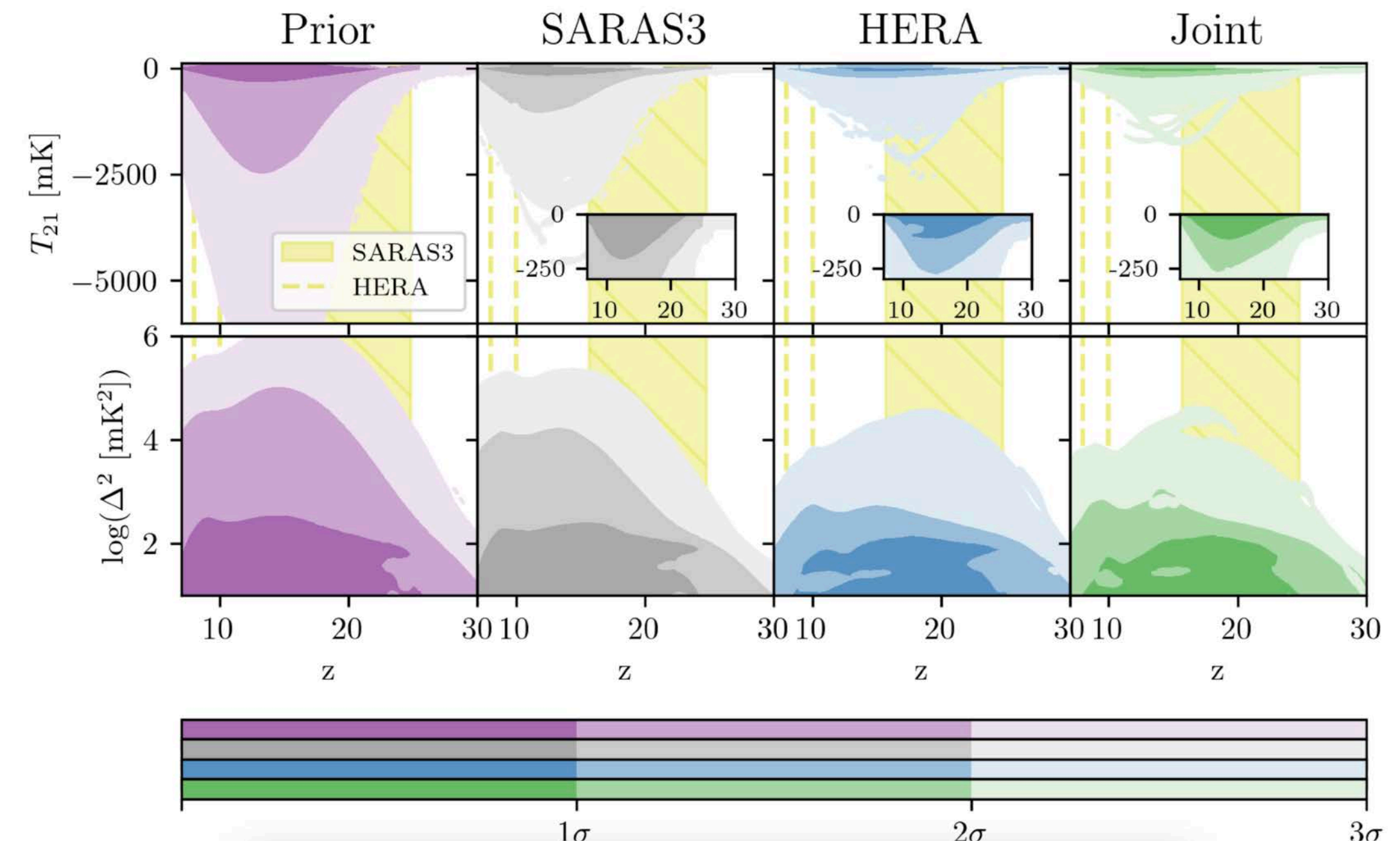
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# First (model dependent) constraints on the first stars?

- Joint analysis of HERA and SARAS3 with Normalizing Flows
- Constraining the magnitude of the sky-averaged 21-cm signal and power spectrum
- Weak constraints on X-ray and radio luminosities of early galaxies
- Weak constraints on star formation properties
- Further development by Simon Pochinda, Thomas Gessey-Jones and Peter Sims



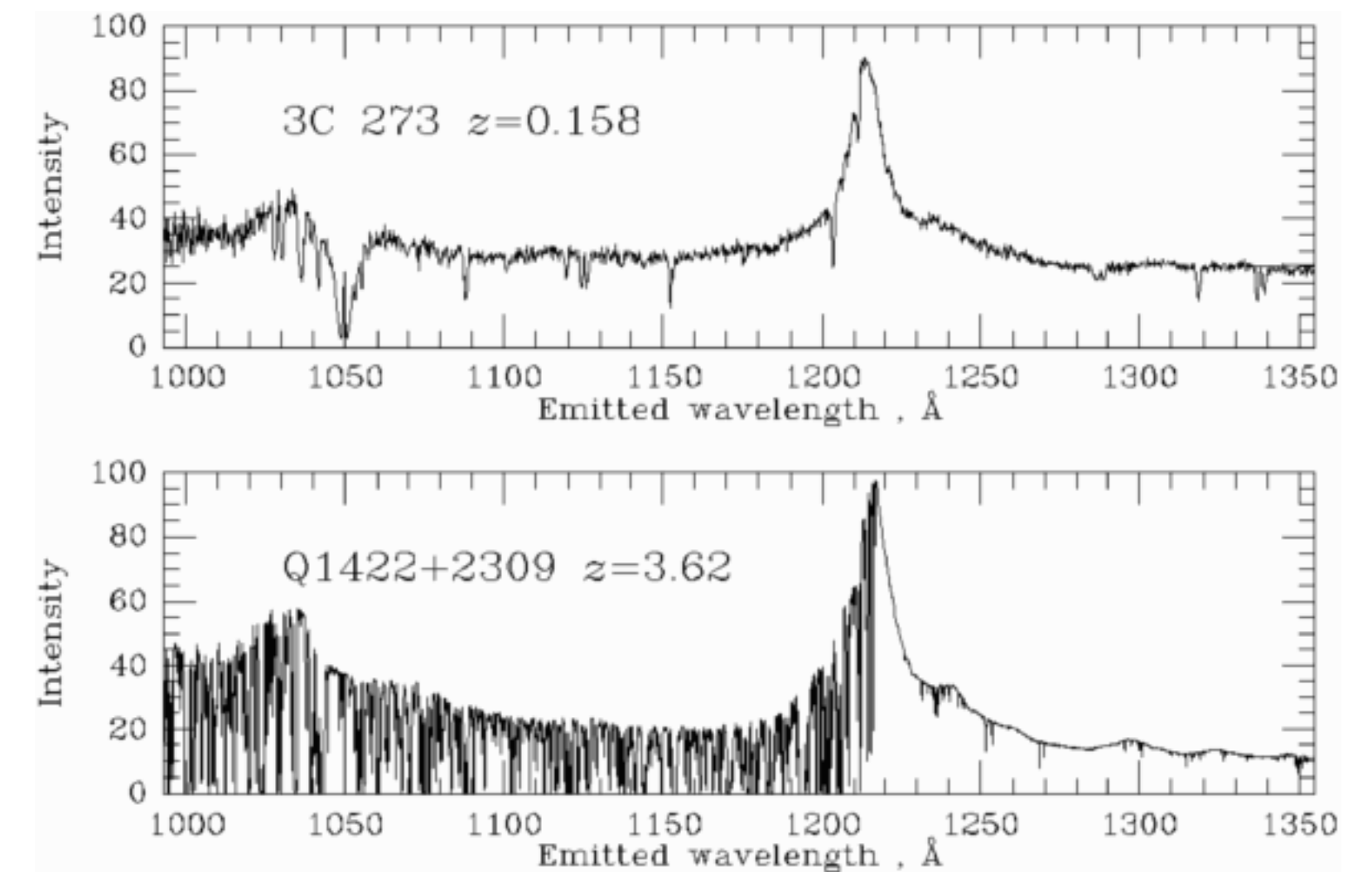


# Where next - Applications of NFs and the future of *margarine*?

- 21-cm observations plus JWST (Jiten Dhandha and Anastasia Fialkov) and Lyman- $\alpha$  forest

$$\log \mathcal{L}(\theta) = \log \mathcal{L}_{21\text{cm}}^{NF}(\theta) + \log \mathcal{L}_{\text{JWST-UV}}^{NF}(\theta) + \log \mathcal{L}_{\text{Ly}\alpha\text{-X}_{\text{HI}}}^{NF}(\theta)$$

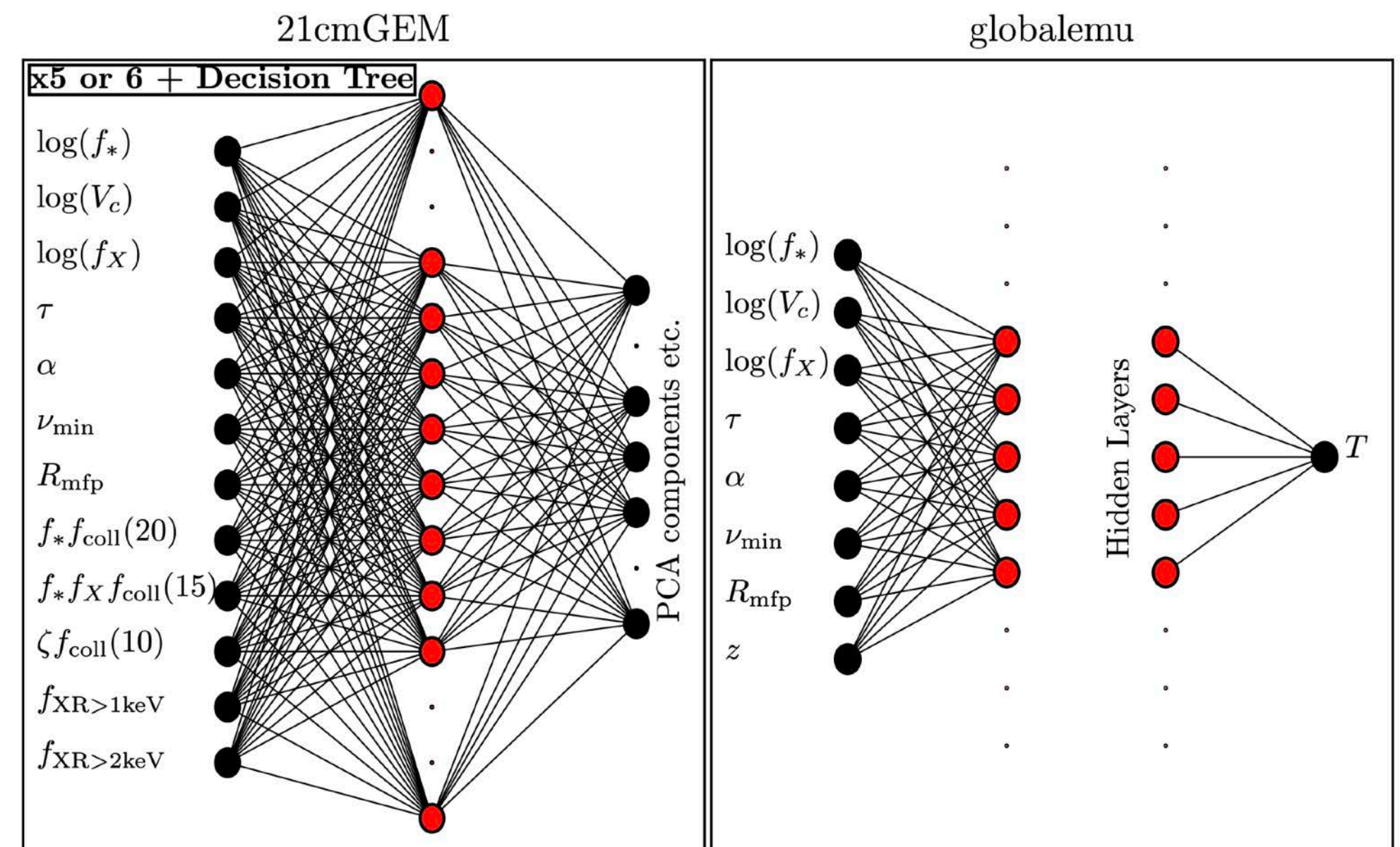
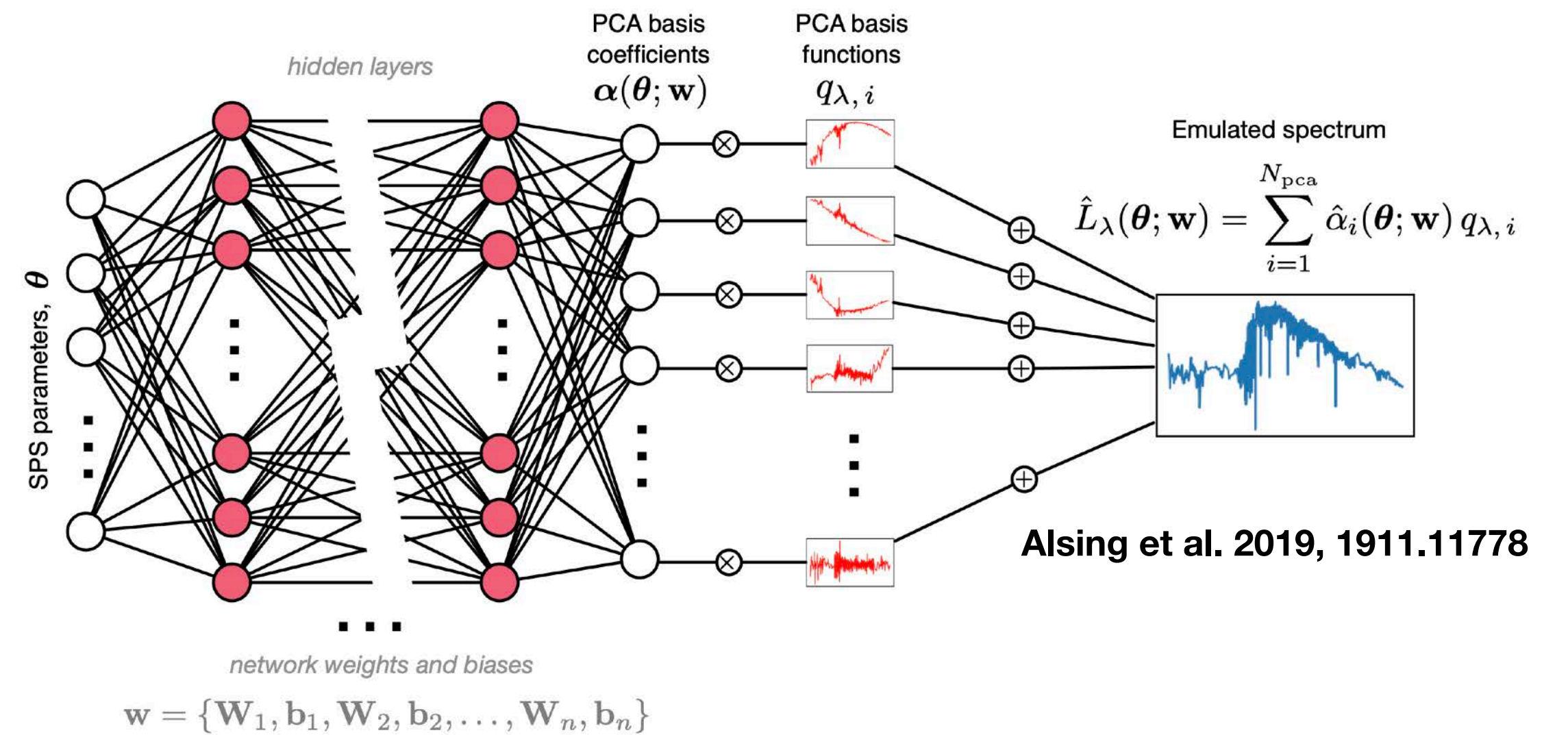
- $\beta$ -flows and Piecewise Normalizing Flows
- NF accelerated Nested Sampling (with David Yallup and Will Handley)
- Applications of NFs to Gravitational Wave studies (Metha Prathaban and Will Handley)
- *unimpeded* library of cosmological likelihood emulators (Dily Ong and Will Handley)





# Where next - Emulators and SED Emulators?

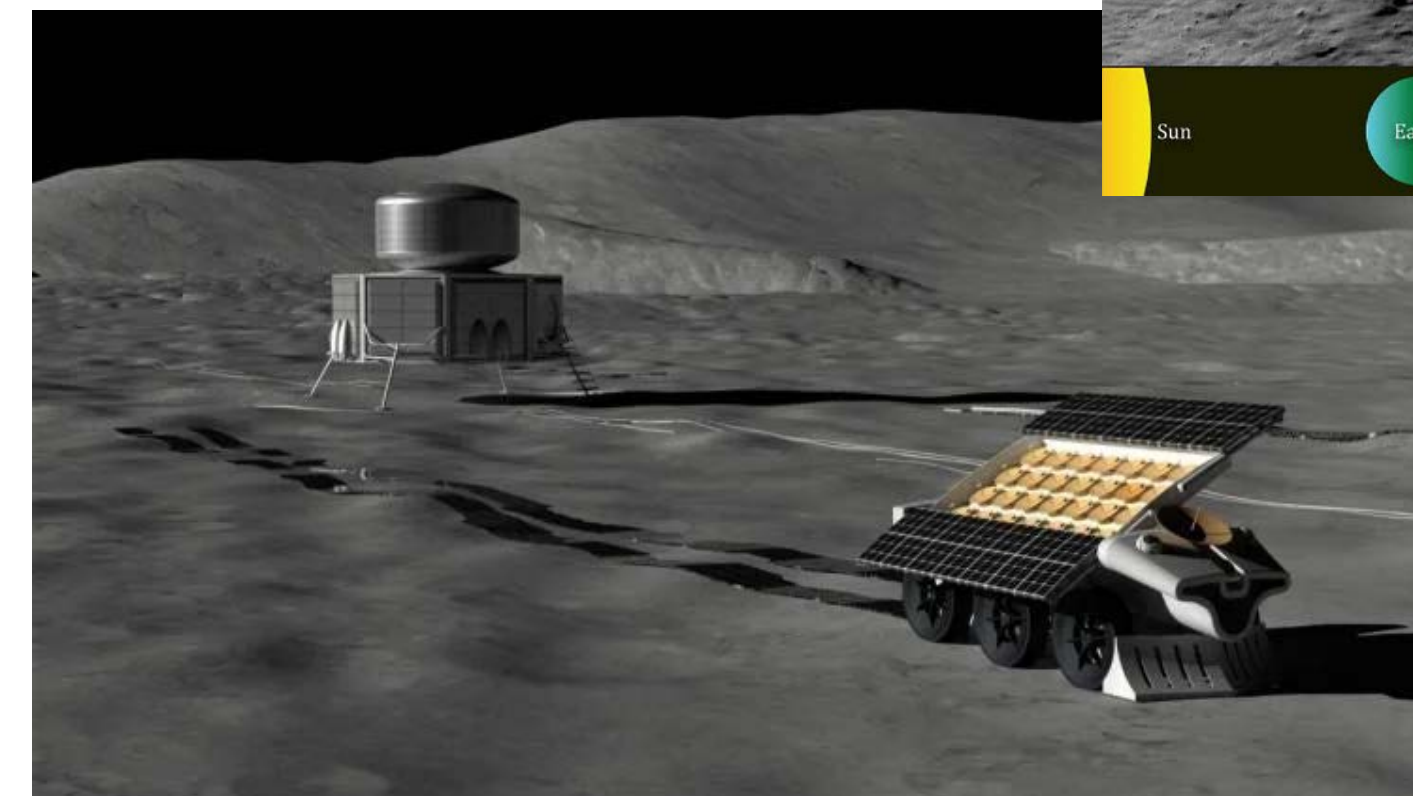
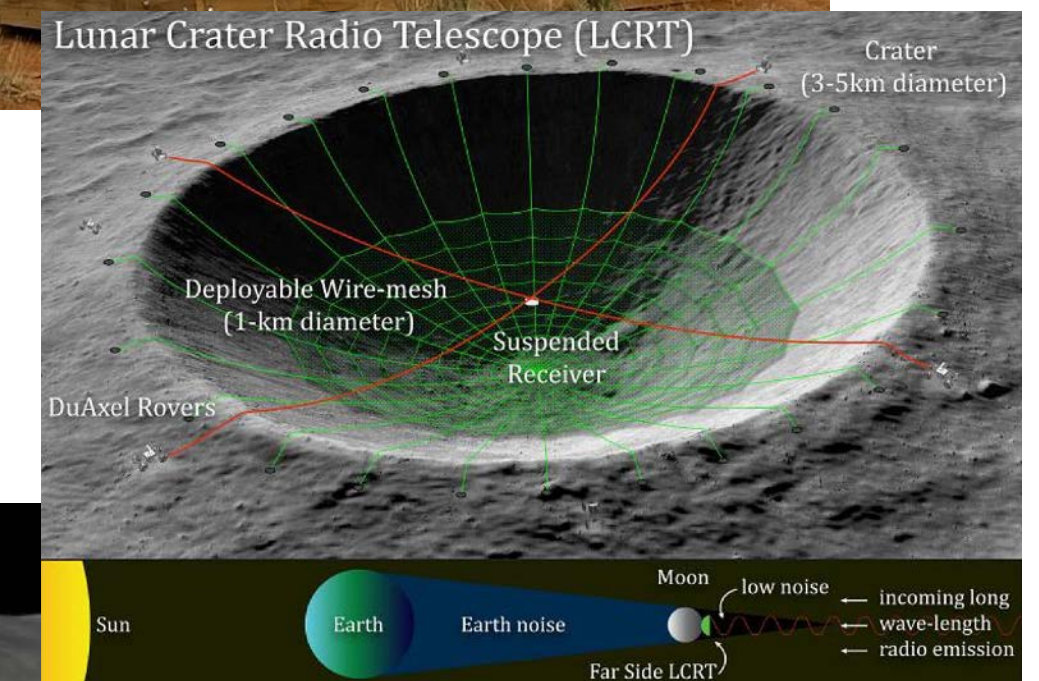
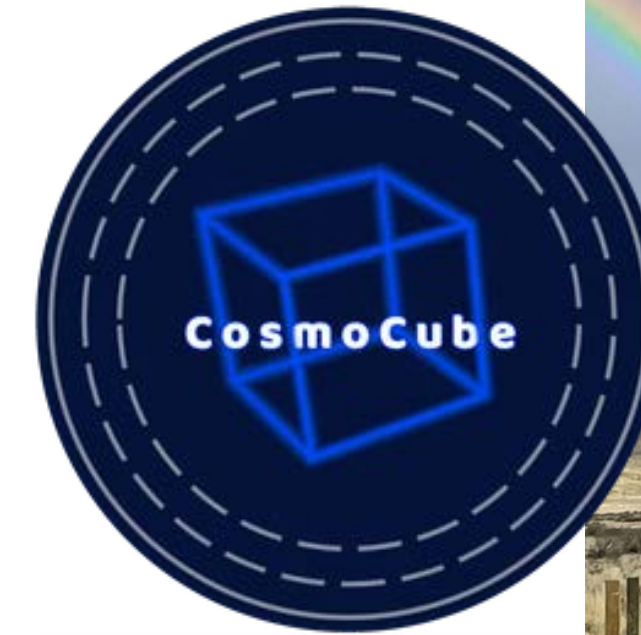
- Take novel techniques developed for 21-cm signal emulators and apply to SED emulation
- Relying on FSPS for SED modelling which is expensive
- Need lightweight and compact emulator that is easy to retain





# Where next - the dark ages and the future of 21-cm?

- REACH observations in the near future
- 21-cm Cosmology from the moon?
- Theoretical modelling of the dark ages 21-cm signal (with Nora Gavrea and Anastasia Fialkov)
- Machine learning based calibration techniques (with Sam Leeney, Eloy de Lera Acedo and Will Handley)





# Conclusions

- Expecting new 21-cm data in the coming years
- Explore combined constraints from JWST, Ly- $\alpha$  forest, 21-cm and CMB probes
- Detailed modelling of the dark ages 21-cm signal
- SED emulators, CMB power spectrum emulators etc
- Further development of marginal bayesian inference framework
- **Come and chat to me in K07**

