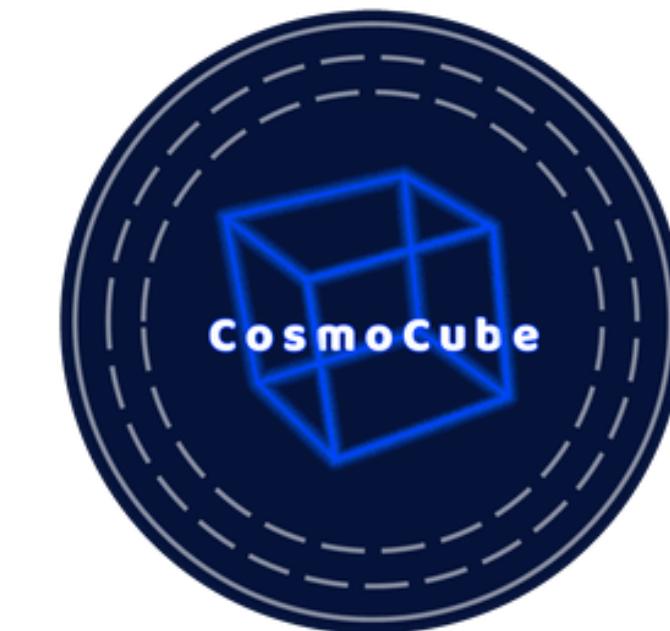
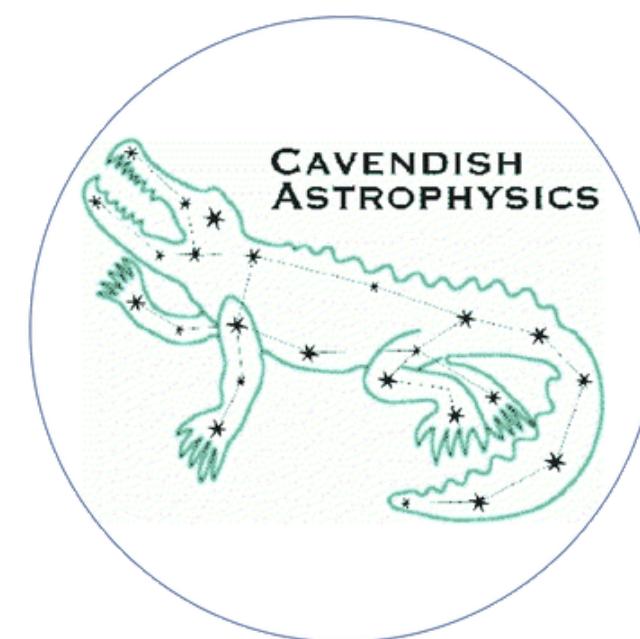
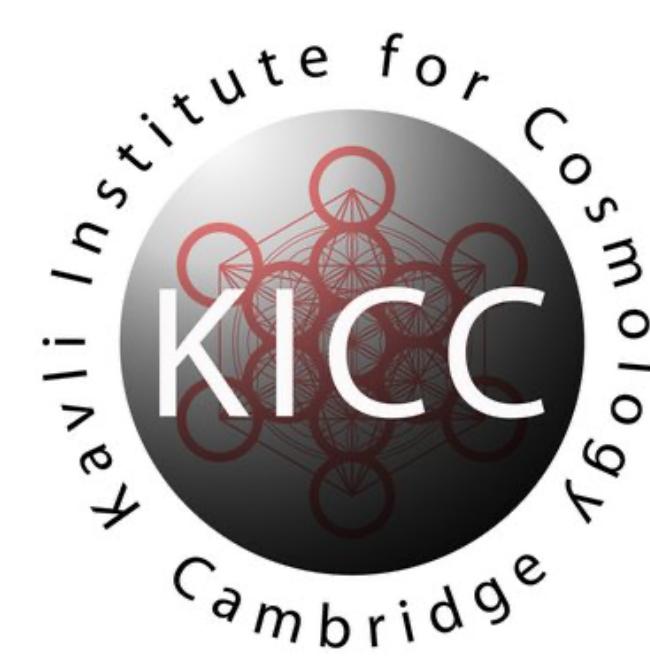


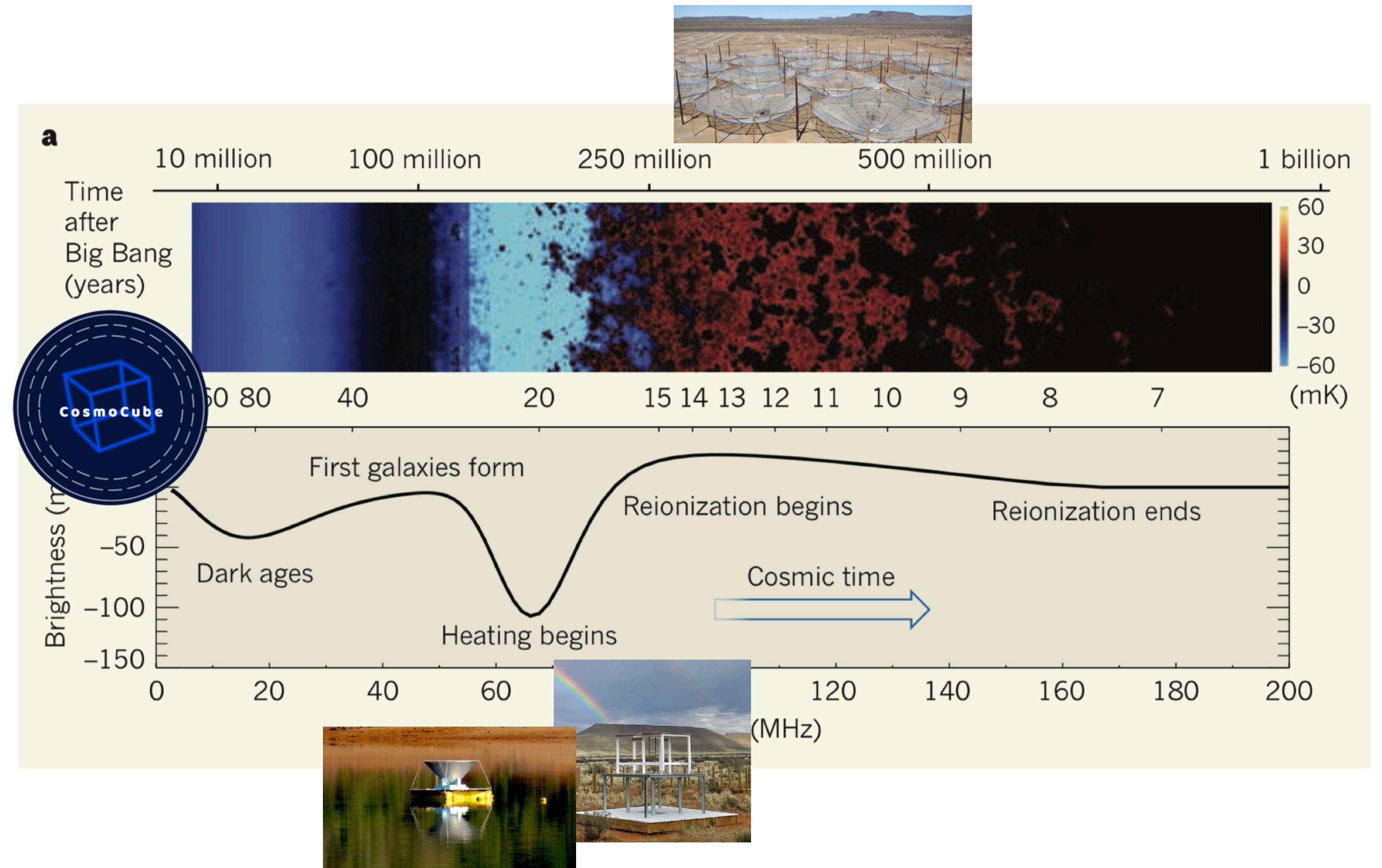
Novel Statistical Methods and 21-cm Cosmology

Harry Bevins
Kavli Junior Fellow - K07



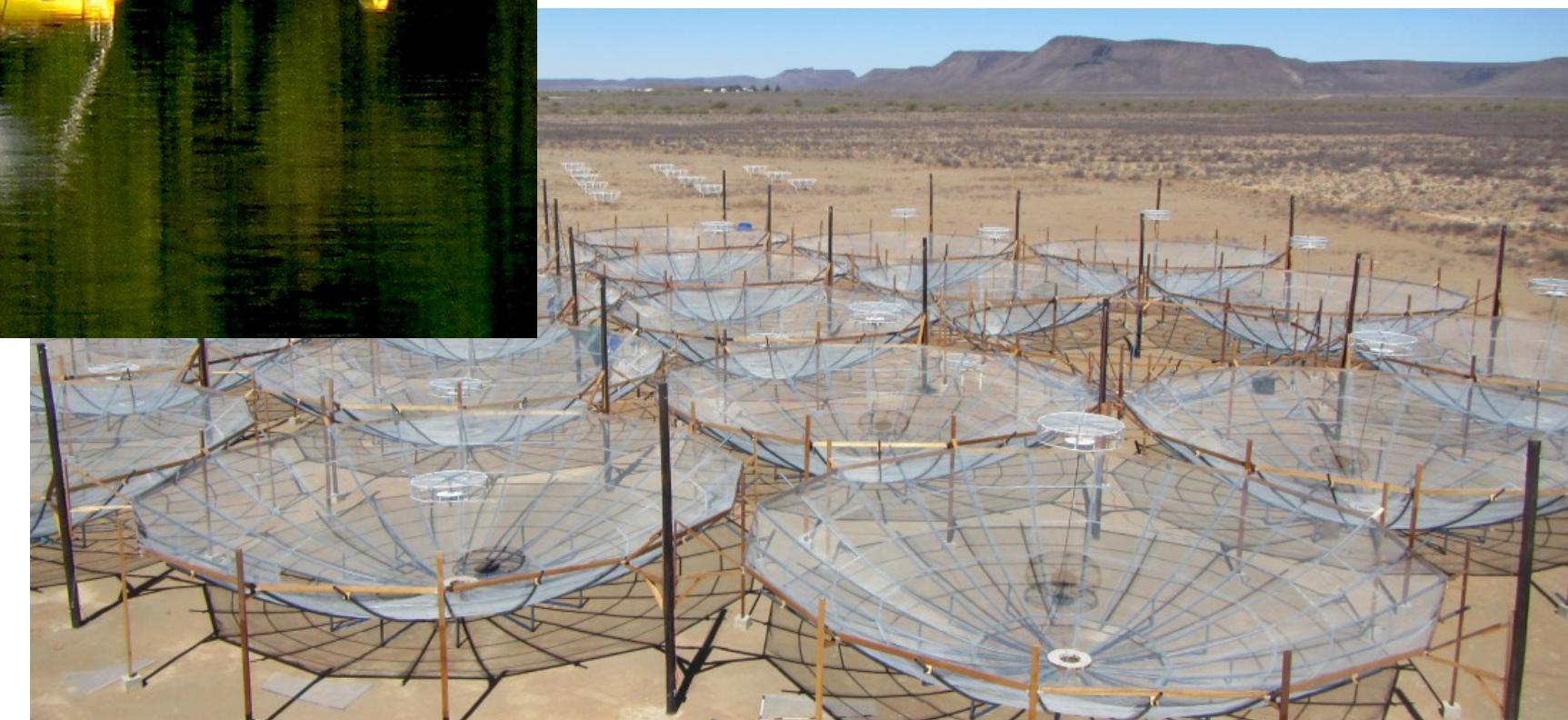
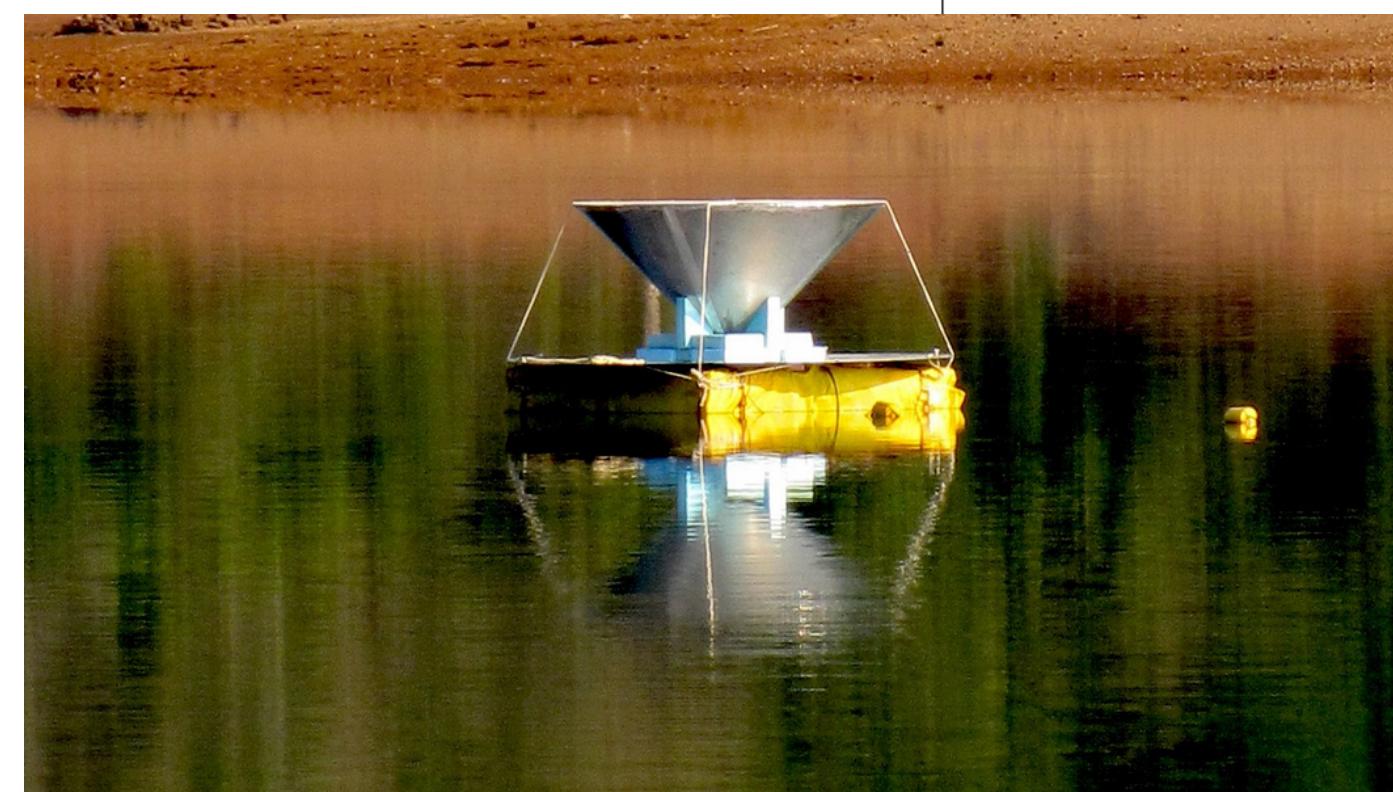
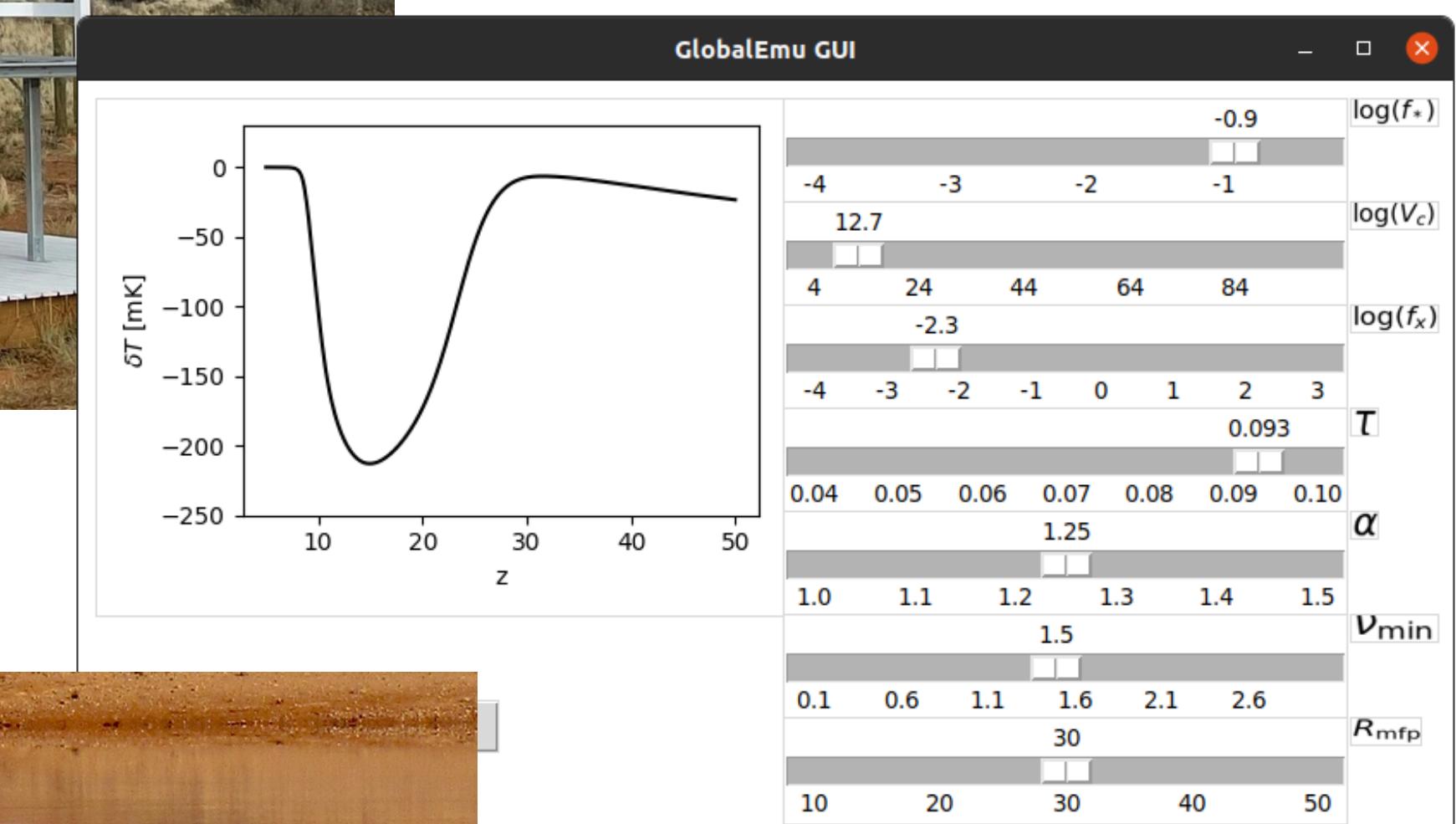
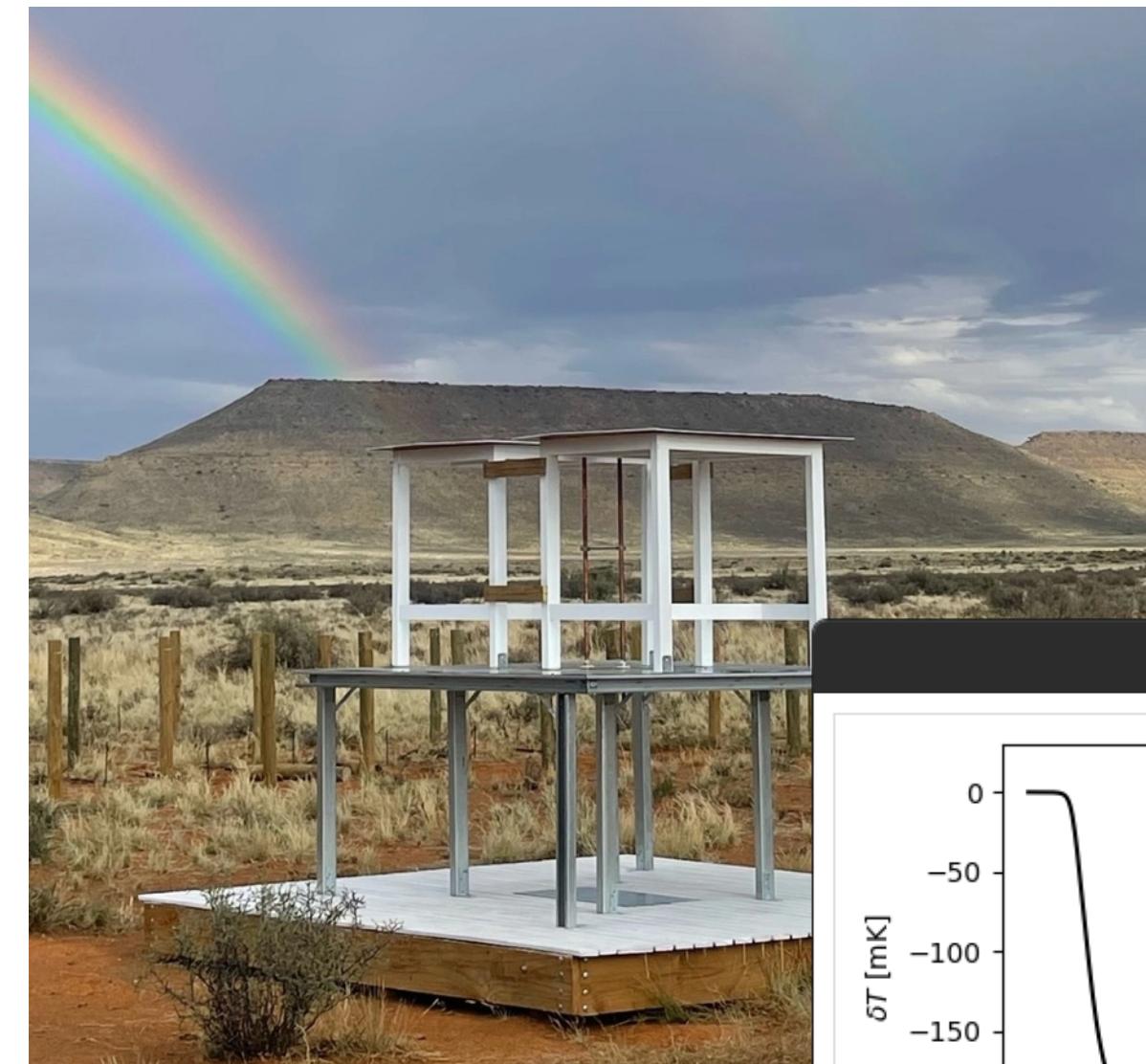
21-cm Cosmology

- 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



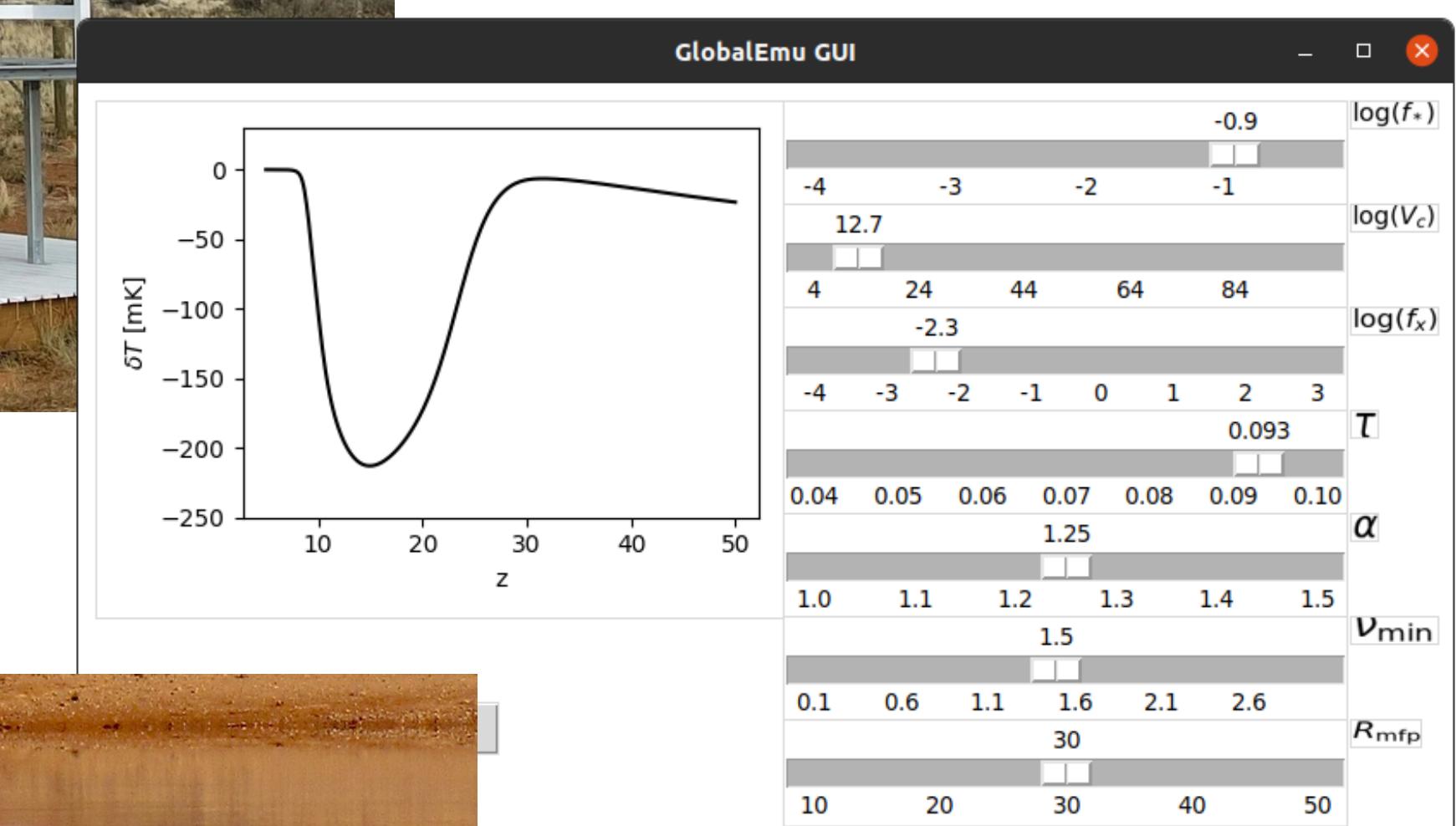
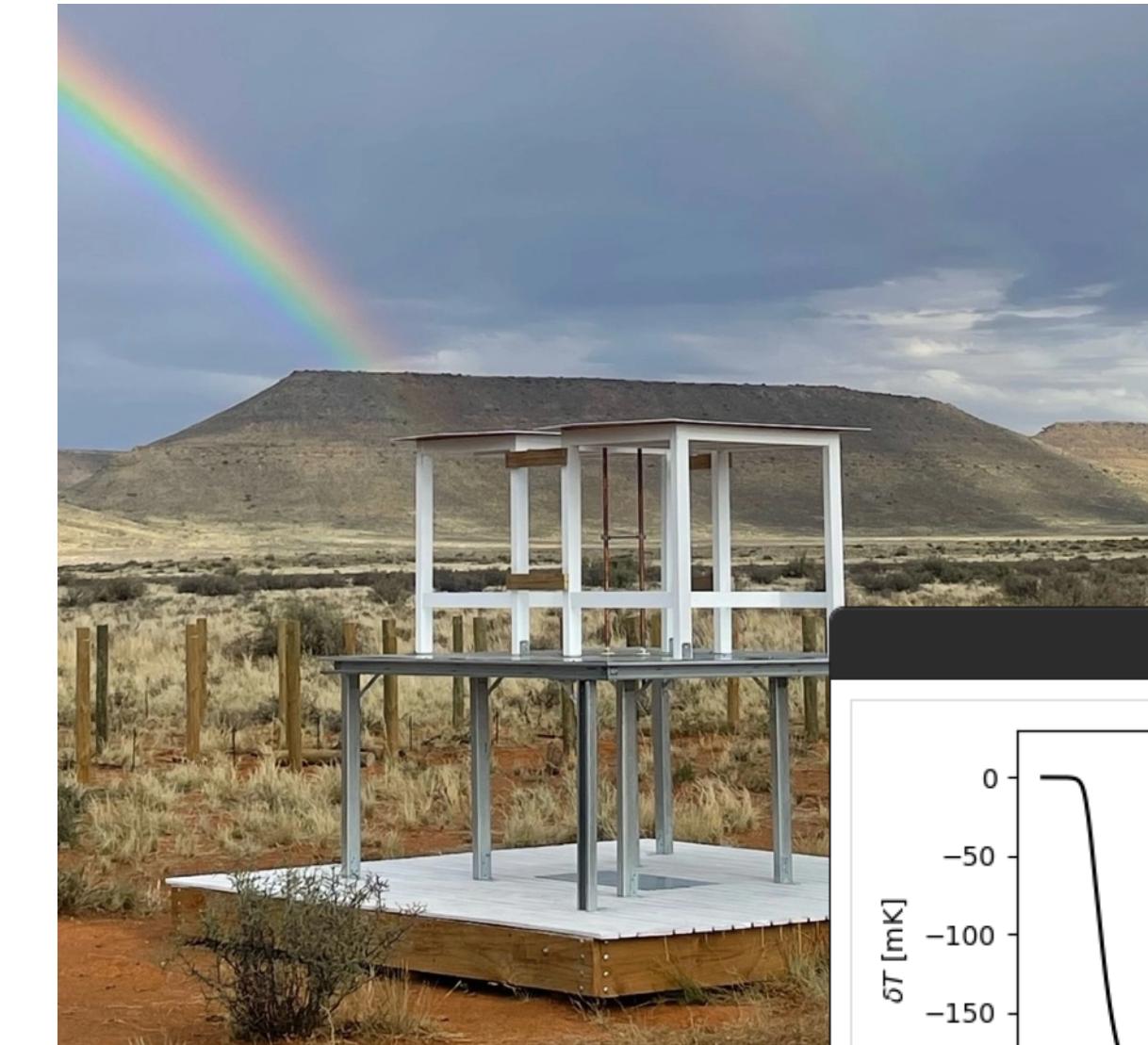
My research...

- Novel analysis techniques for 21-cm cosmology
 - Foreground modelling (2007.14970)
 - Signal emulators (2104.04336)
 - Marginal Bayesian analysis with Normalizing Flows (2207.11457, 2205.12841, 2305.02930)
- Applications of these tools to real data from EDGES and LEDA (2007.14970), SARAS2 (2201.11531), SARAS3 (2212.00464) and HERA (2301.03298)



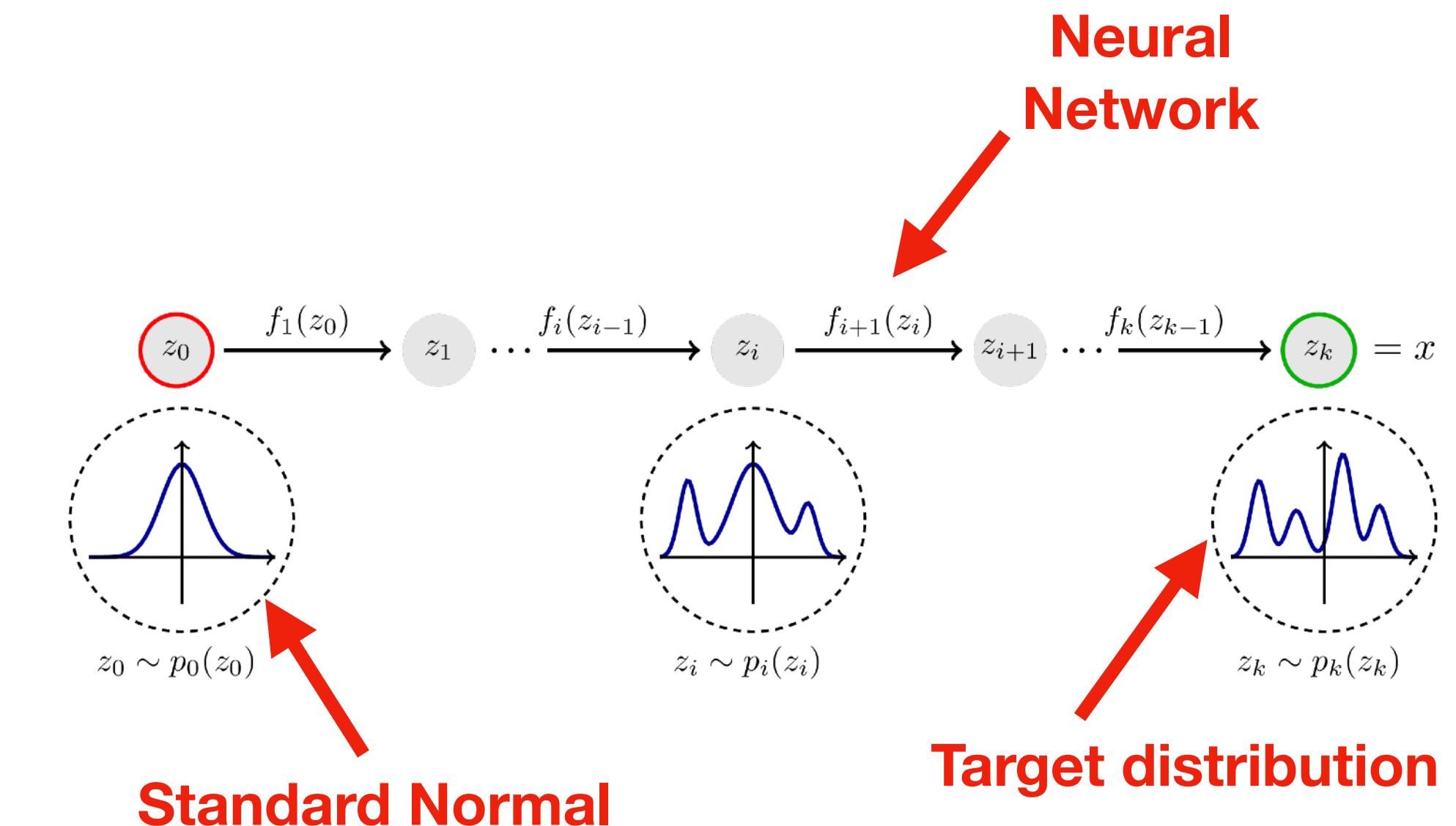
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margarine and Normalizing Flows?

- 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](#)

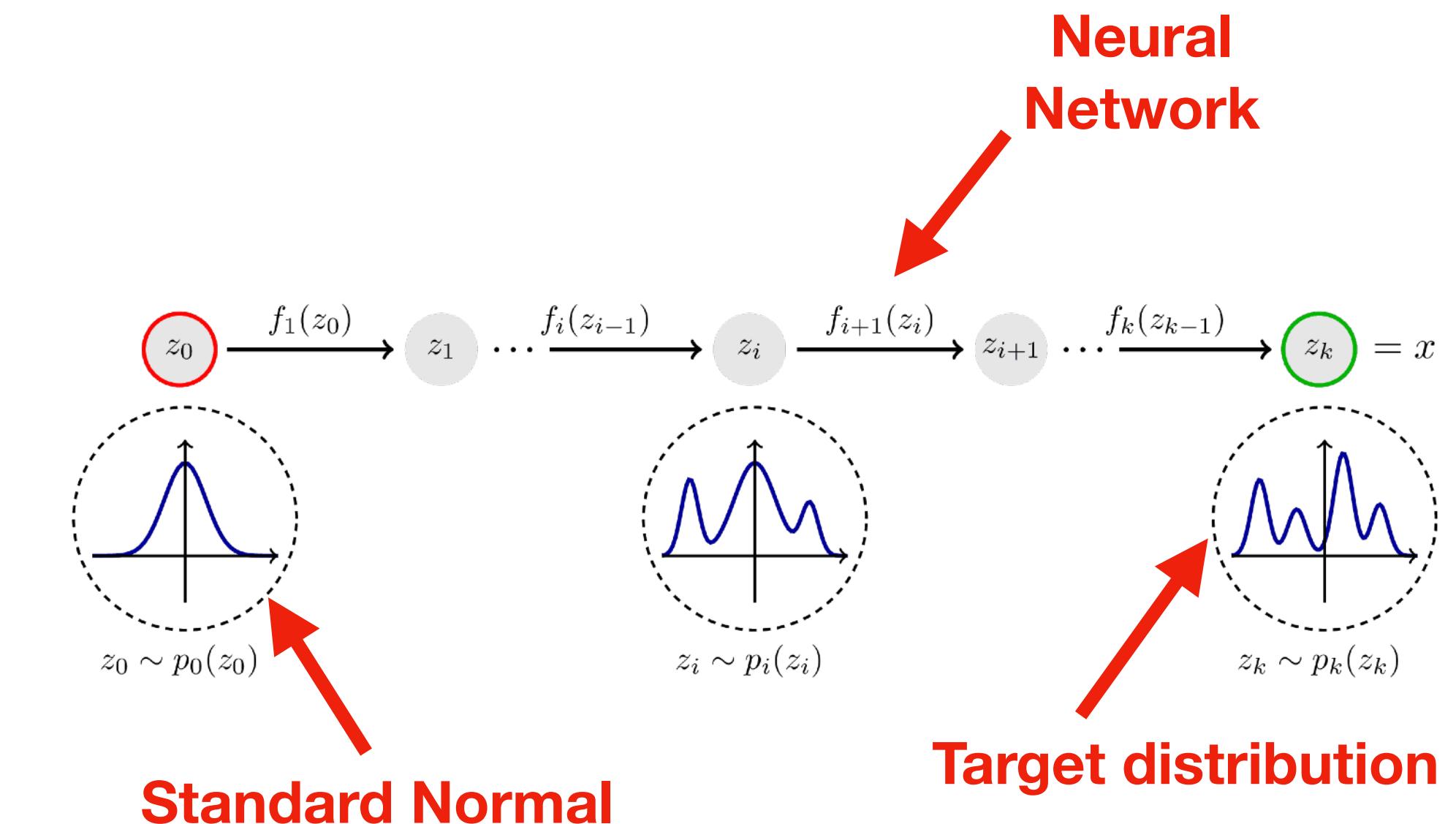
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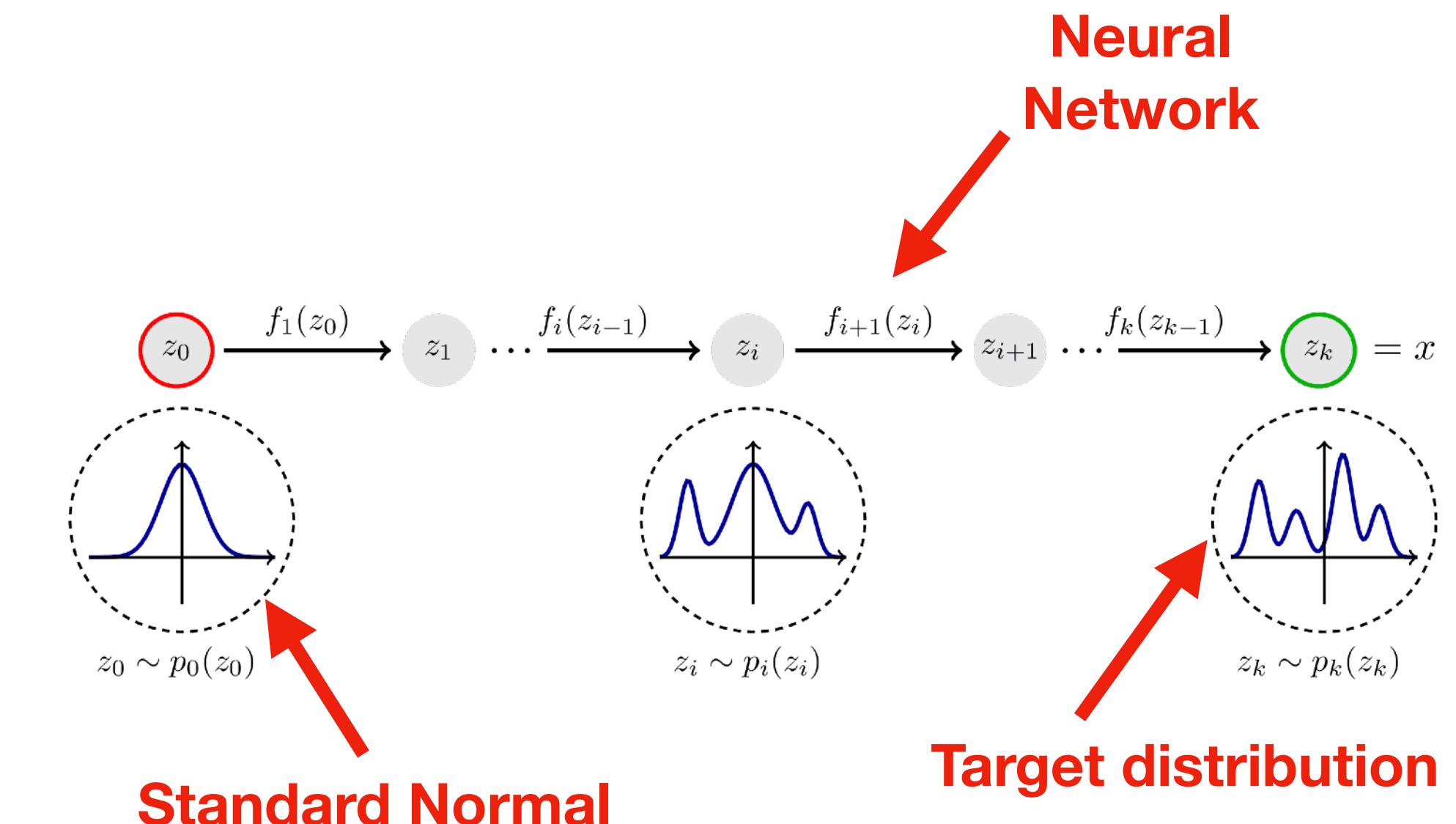
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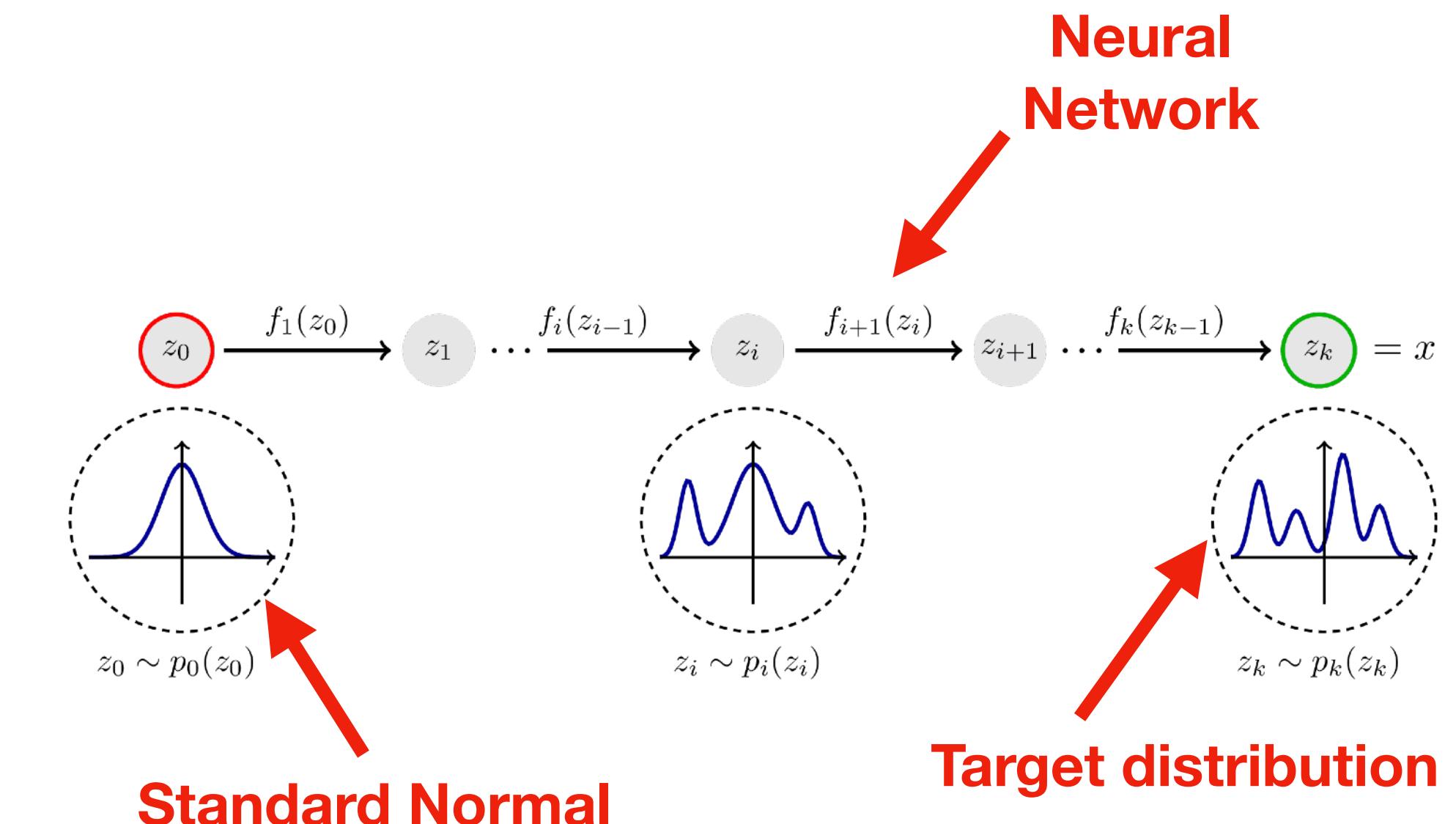
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[margarine: Posterior Sampling and Marginal Bayesian Statistics](#) ↗

Introduction ↗

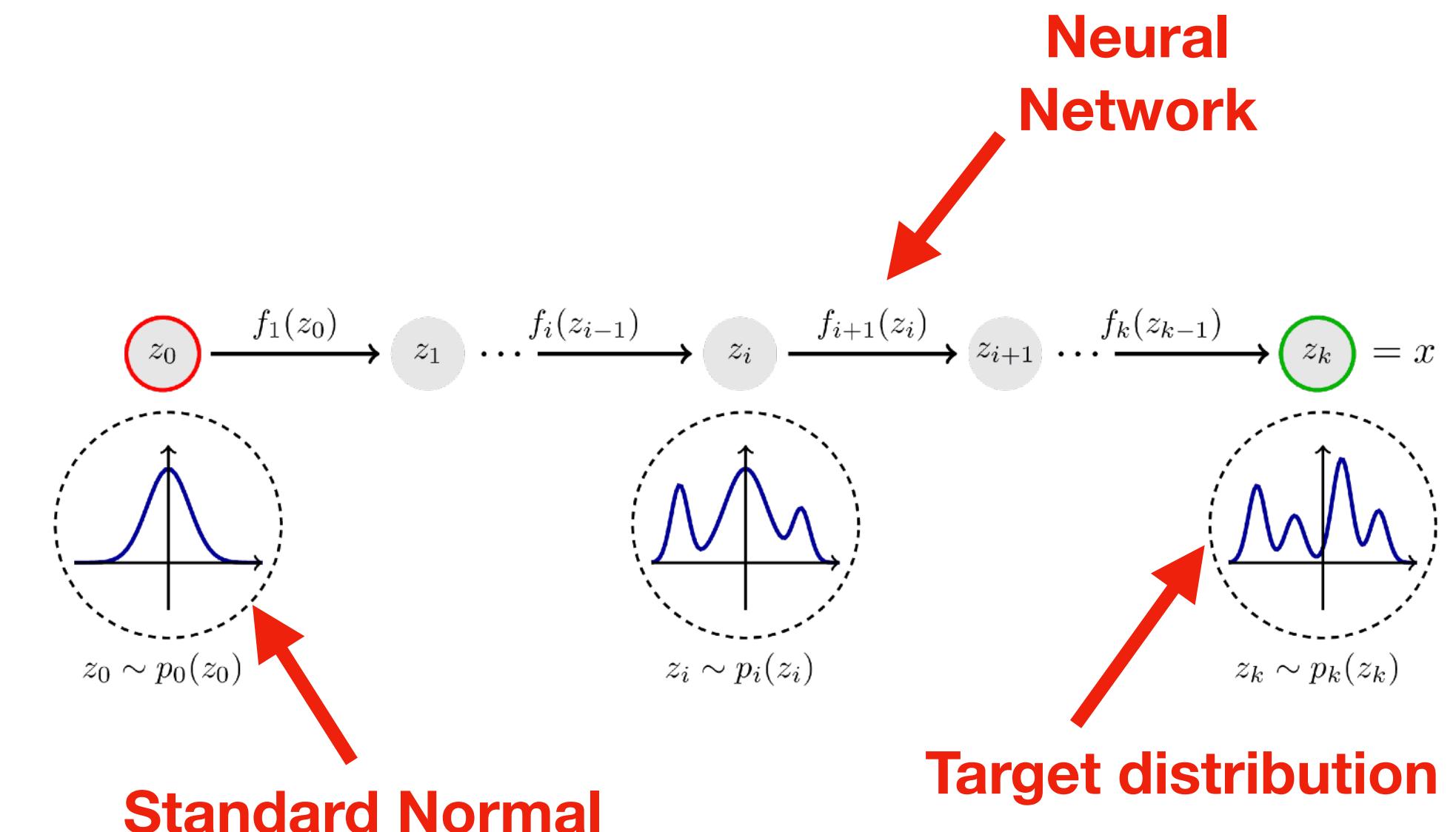
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- Many others...



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

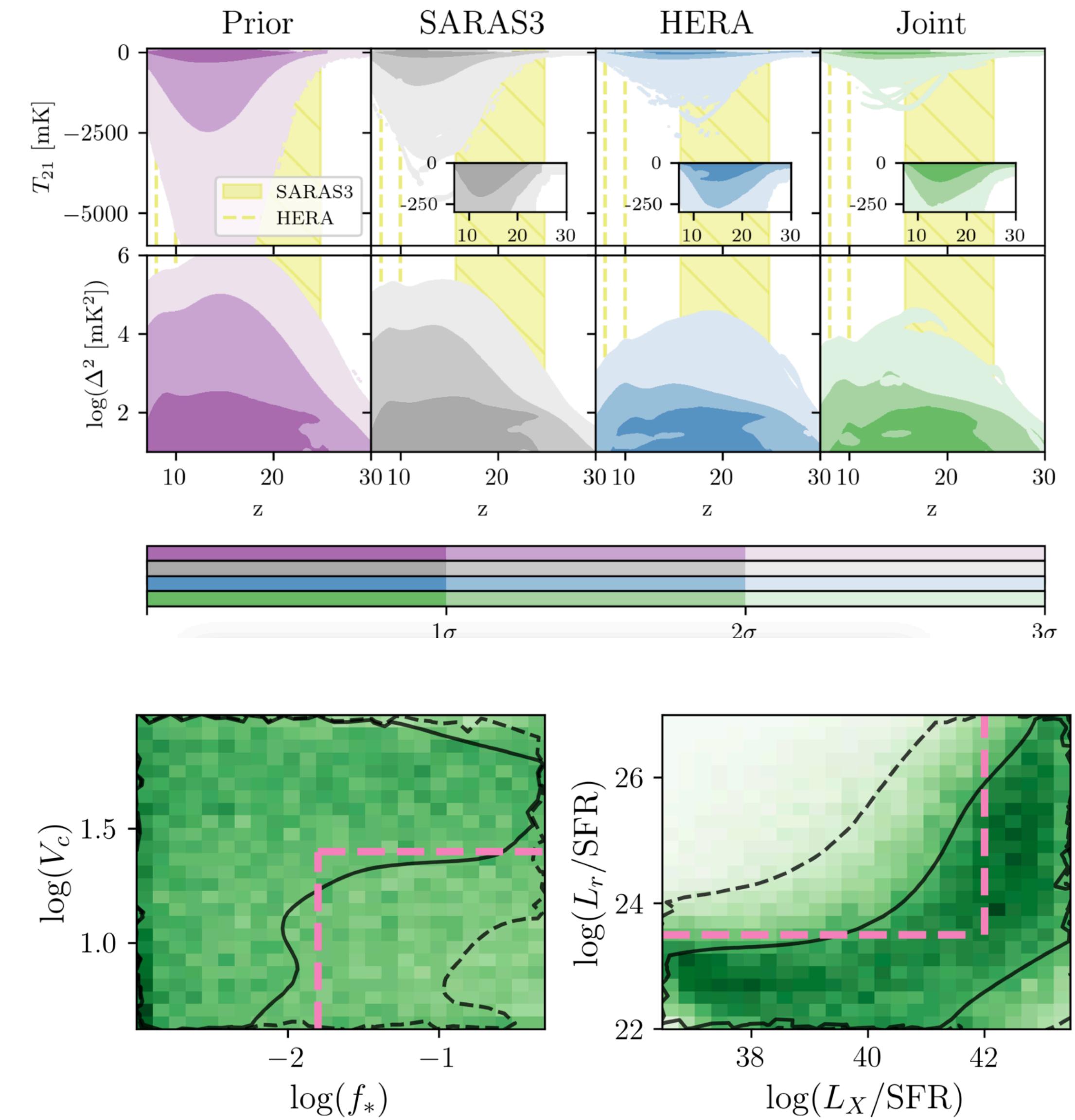
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First (model dependent) constraints on the first stars?

- 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

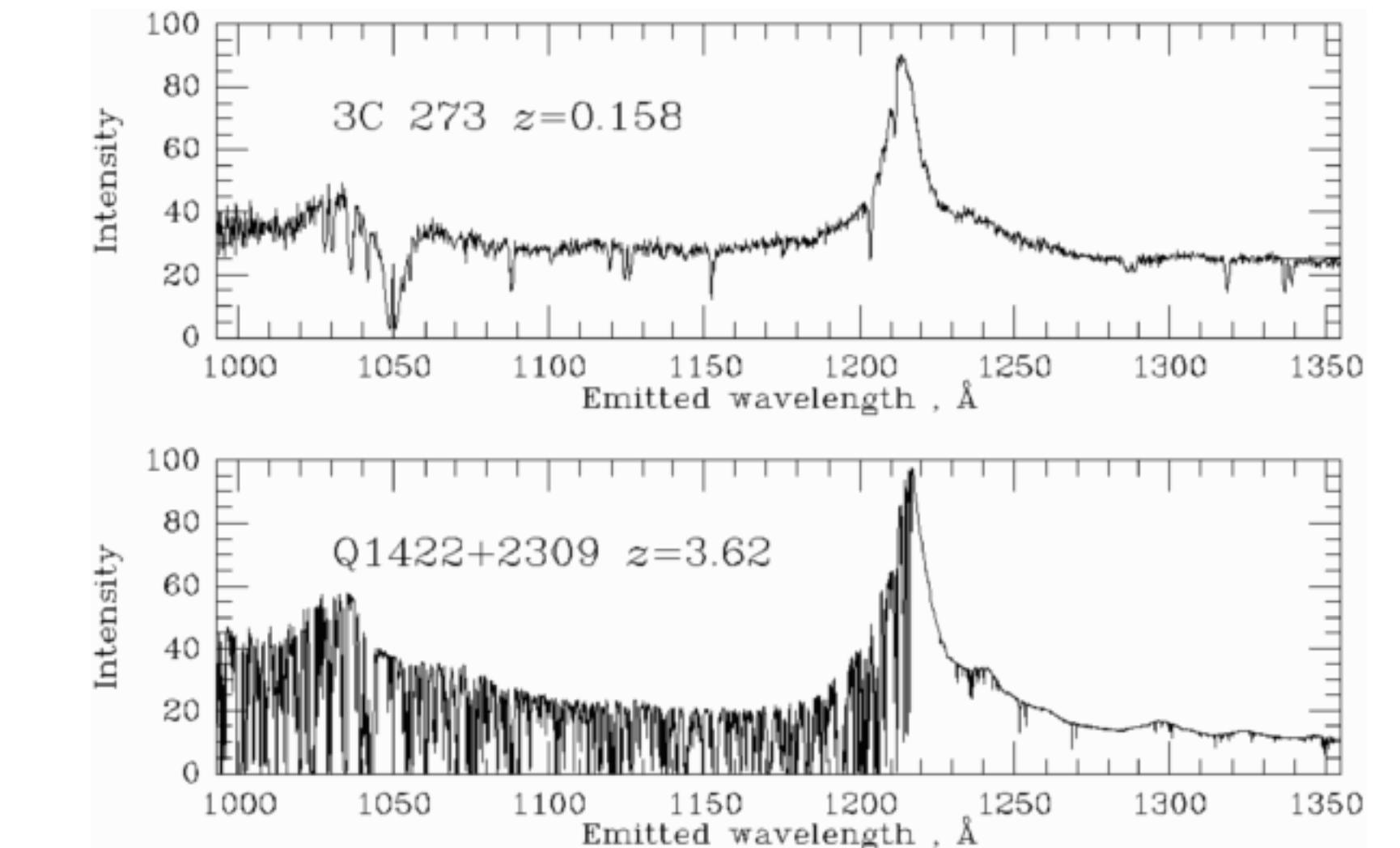


Where next - Applications of NFs and the future of *margarine*?

- 21-cm observations plus JWST (Jiten Dhandha and Anastasia Fialkov) and Lyman- α forest

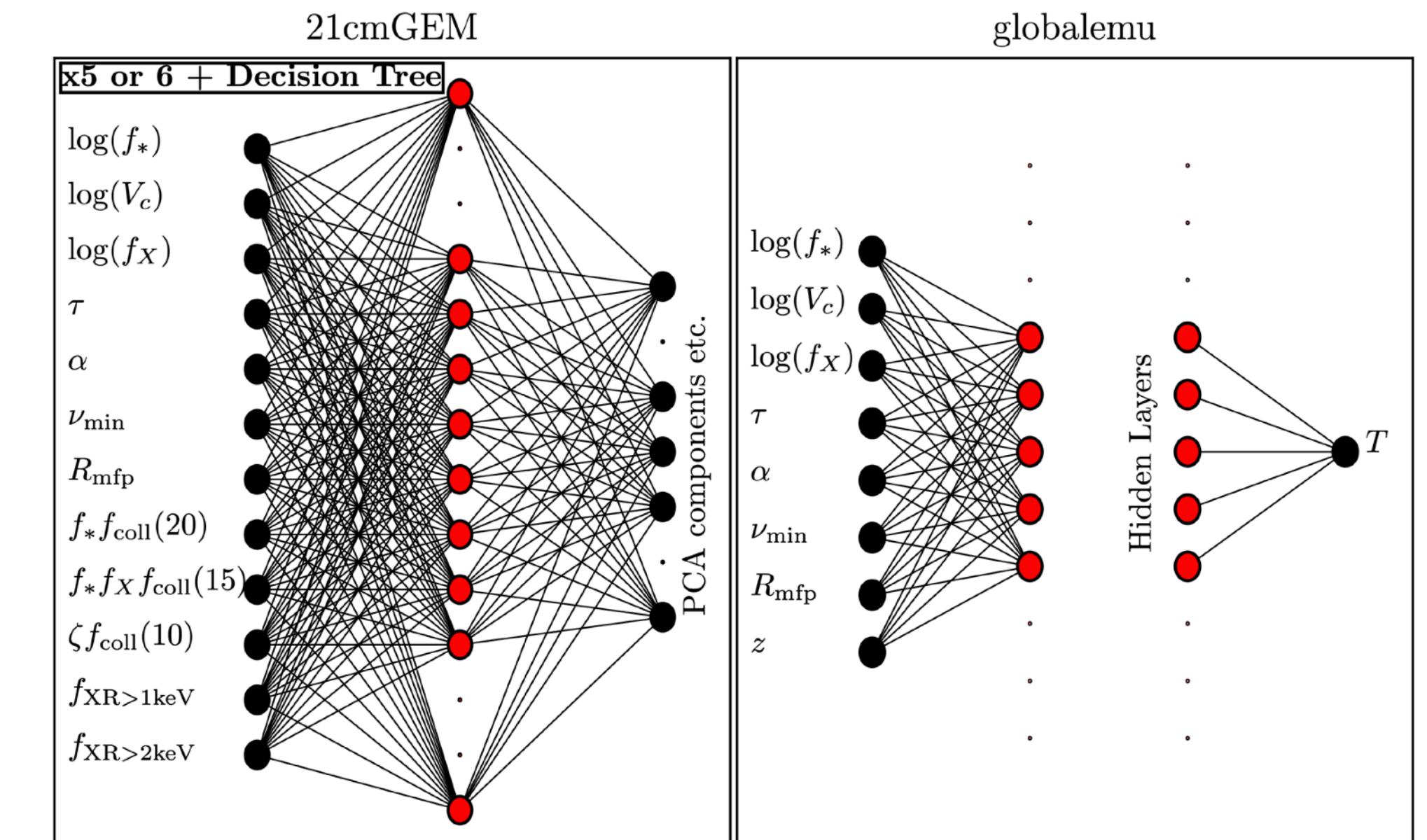
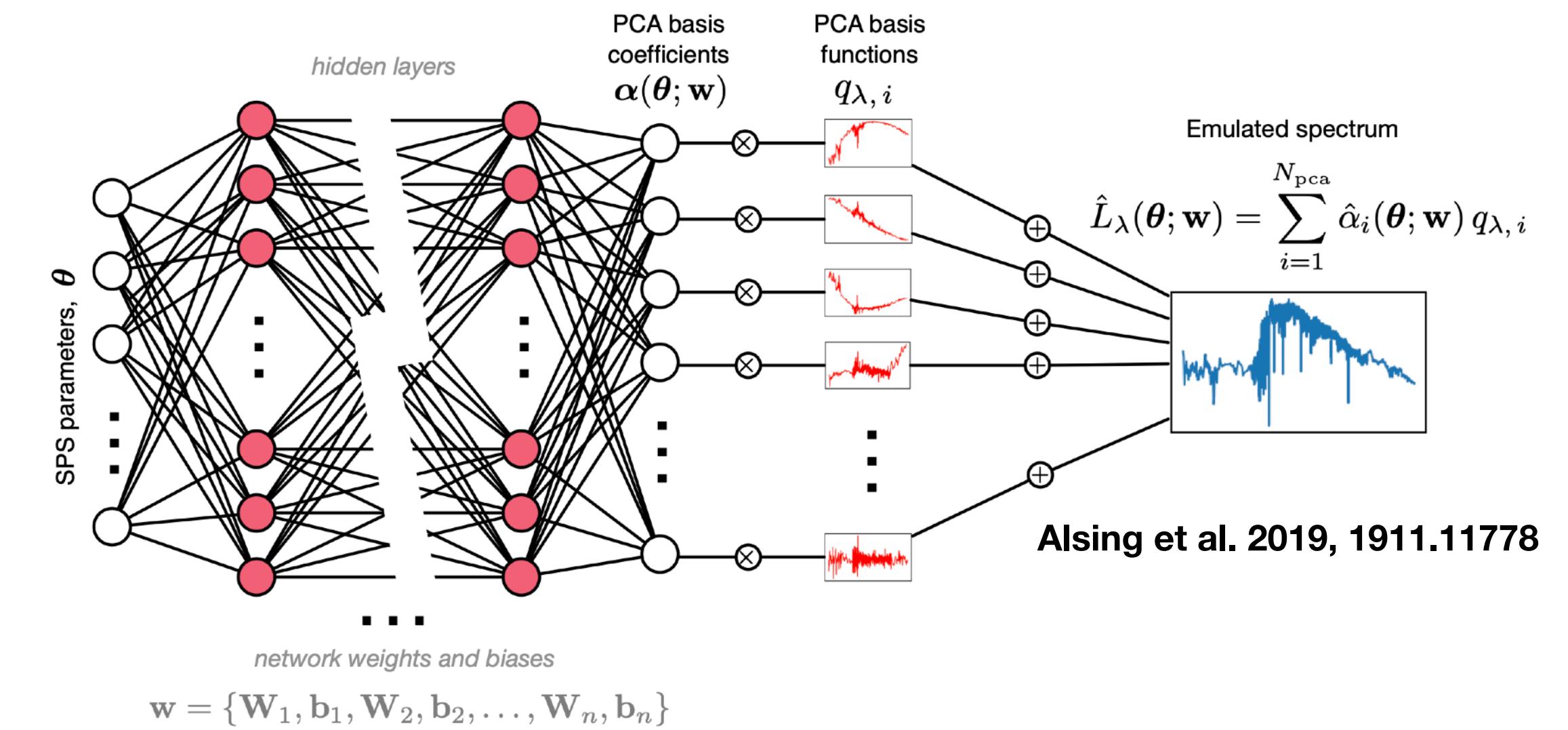
$$\log \mathcal{L}(\theta) = \log \mathcal{L}_{21cm}^{NF}(\theta) + \log \mathcal{L}_{JWST-UV}^{NF}(\theta) + \log \mathcal{L}_{Ly\alpha-X_{HI}}^{NF}(\theta)$$

- β -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)



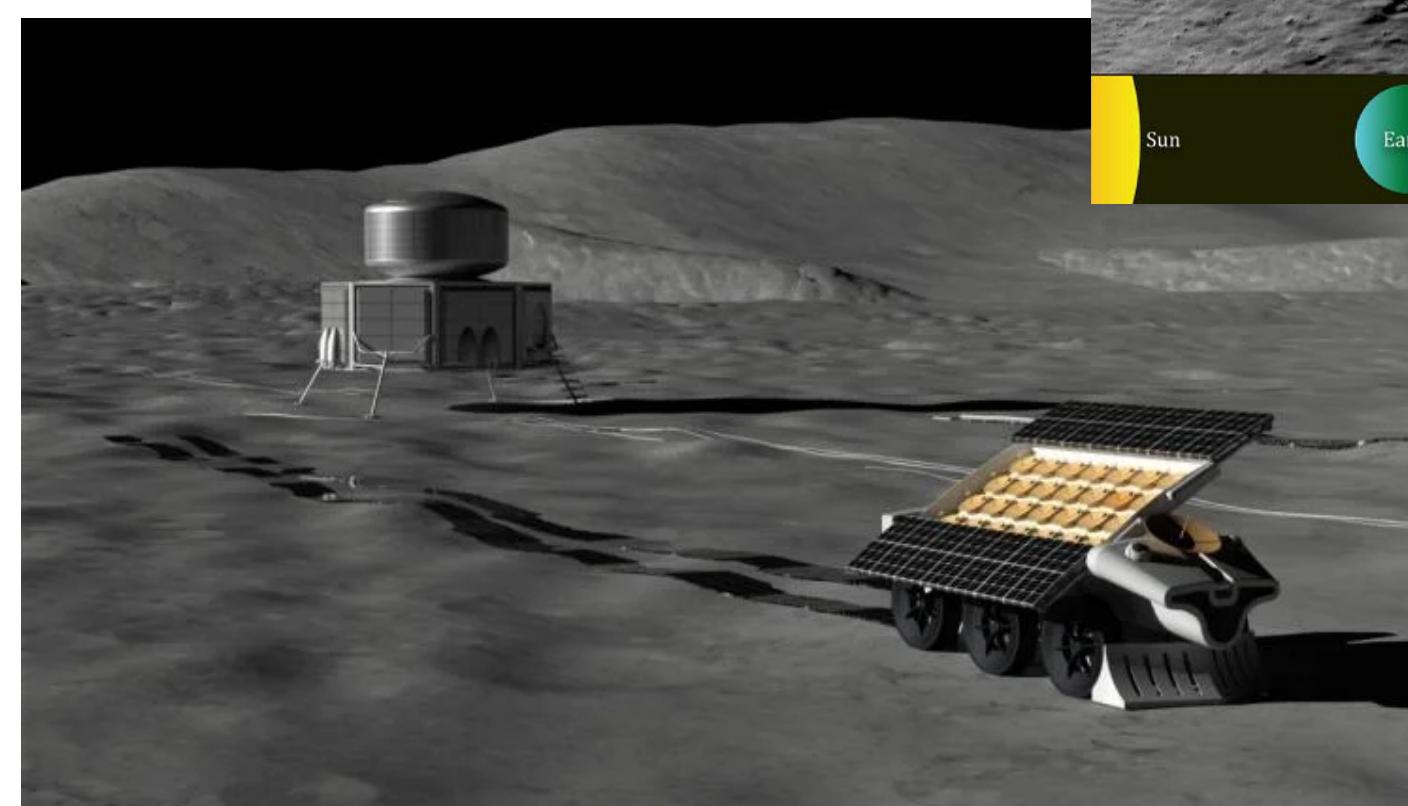
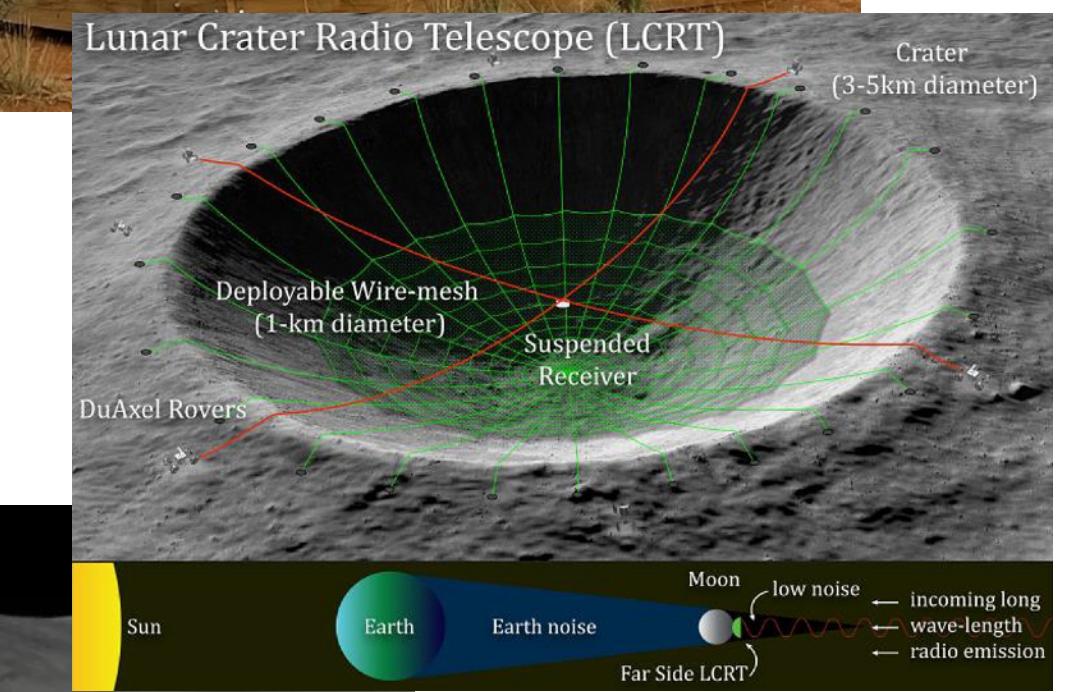
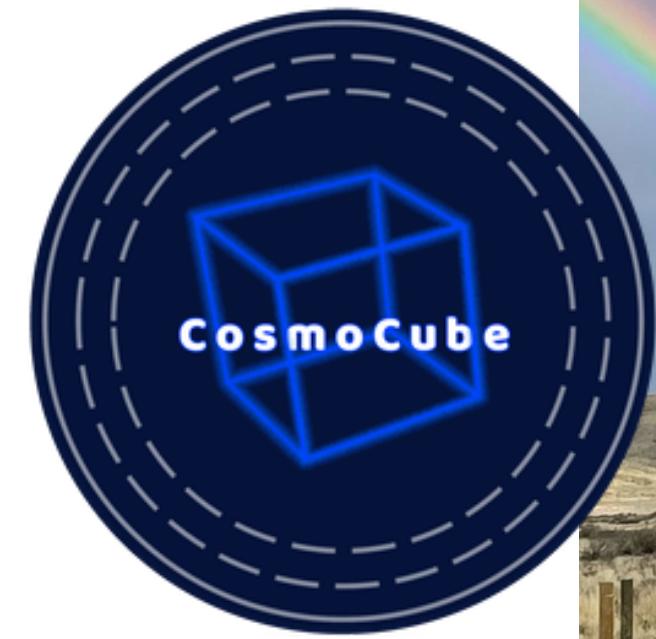
Where next - Emulators and SED Emulators?

- 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- α 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

