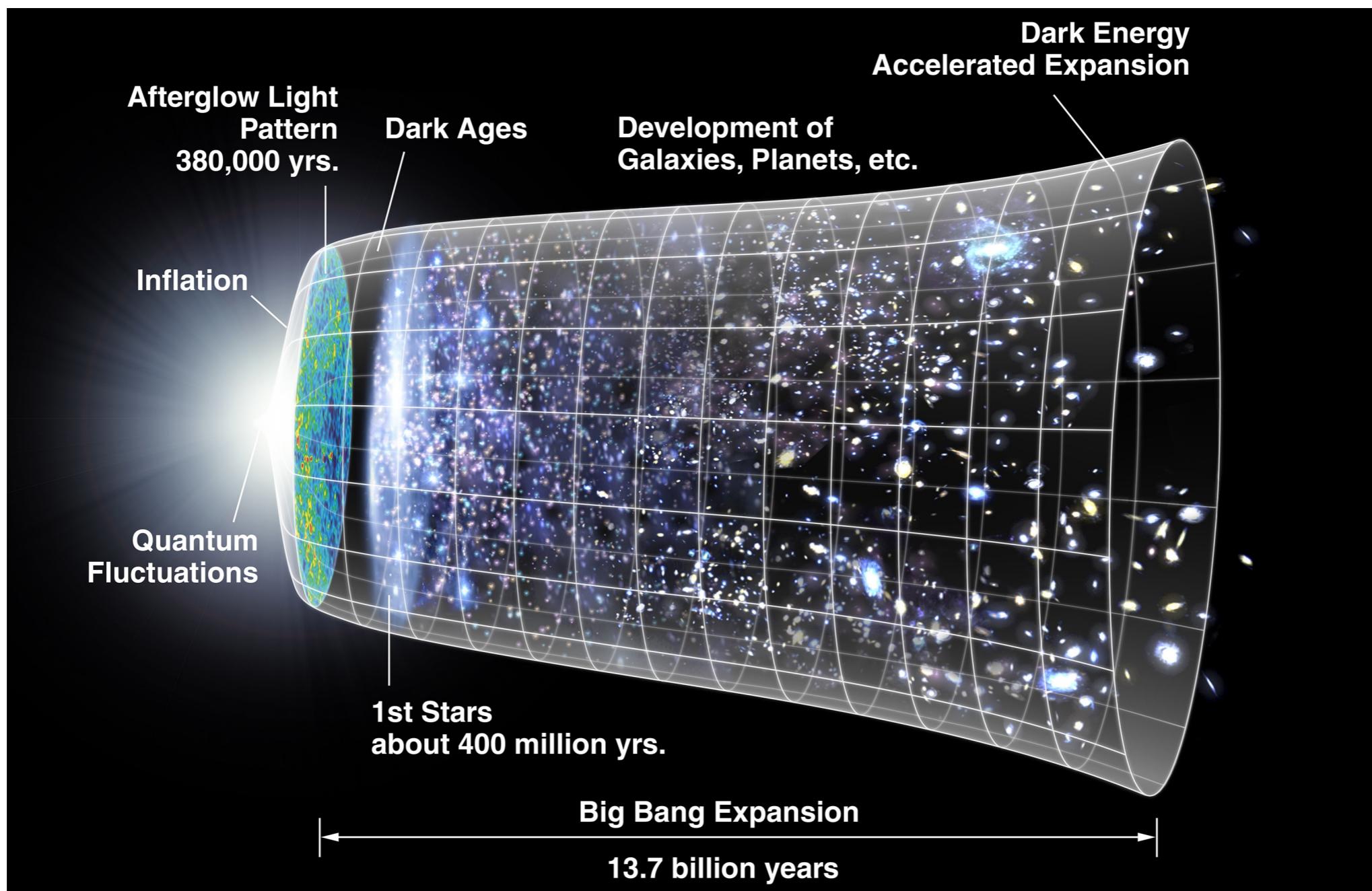


Python in Cosmology: Approximate Bayesian Inference

Jörg Herbel
Cosmology Research Group

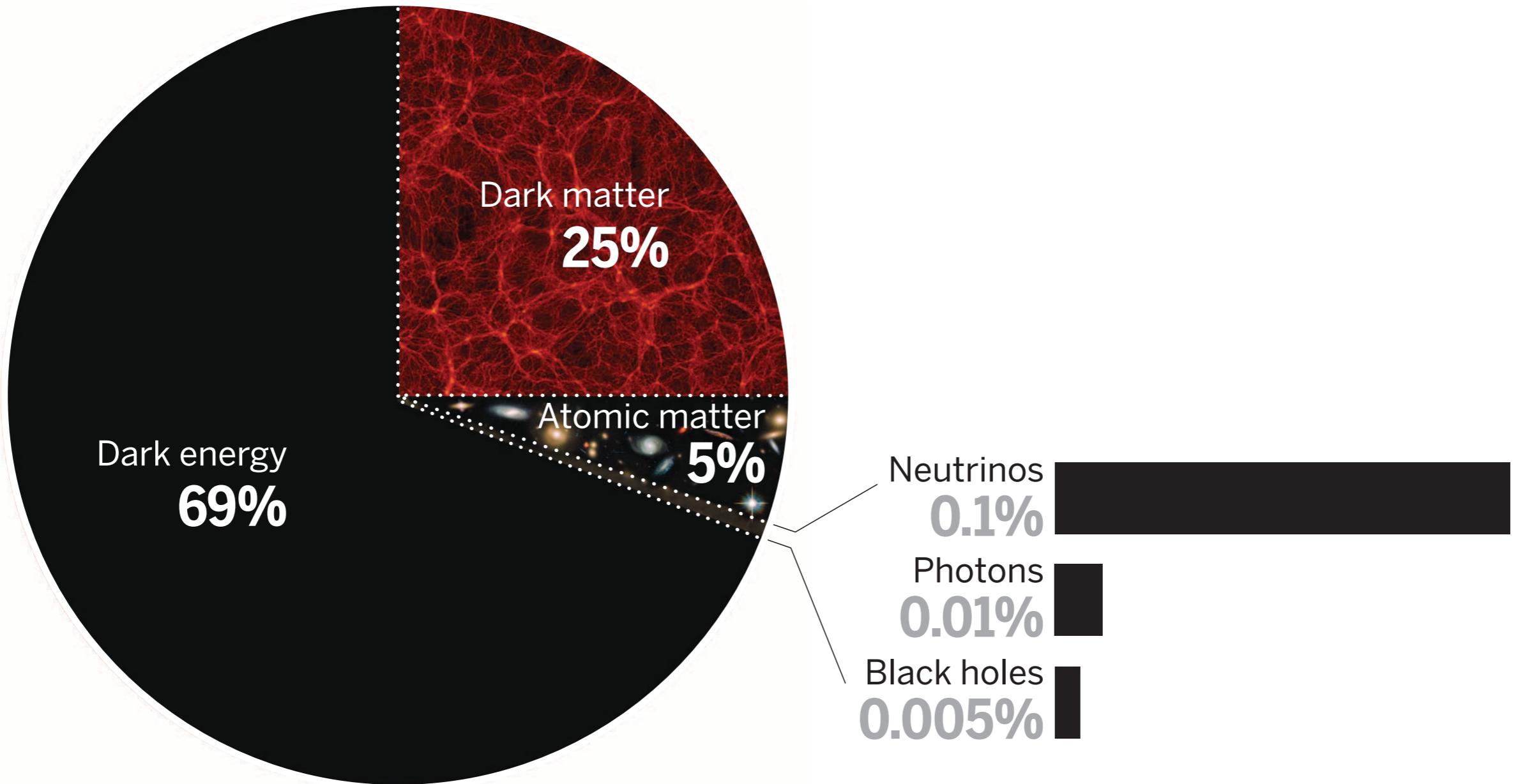


Cosmology



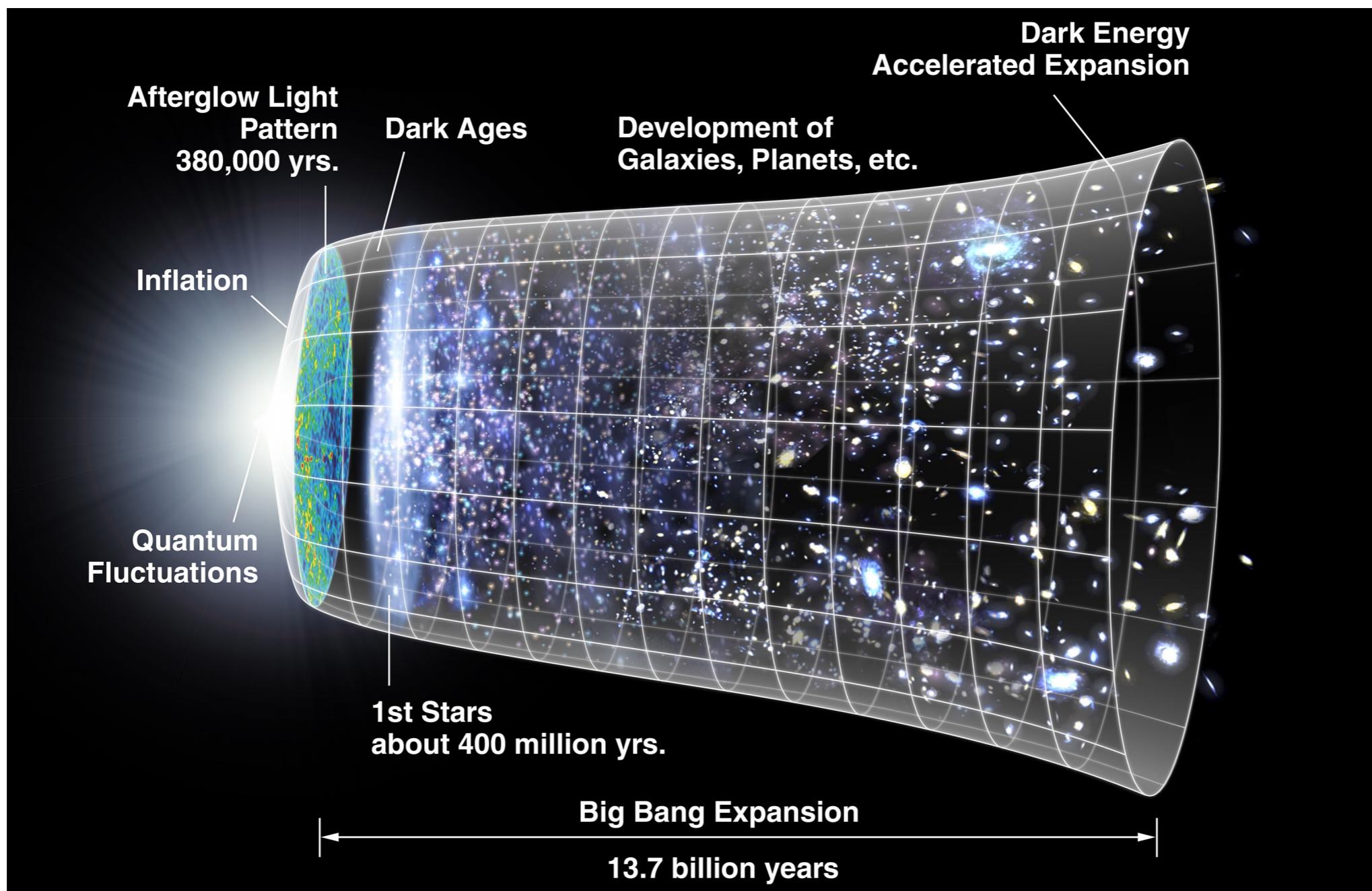
NASA / WMAP Science Team

Cosmology



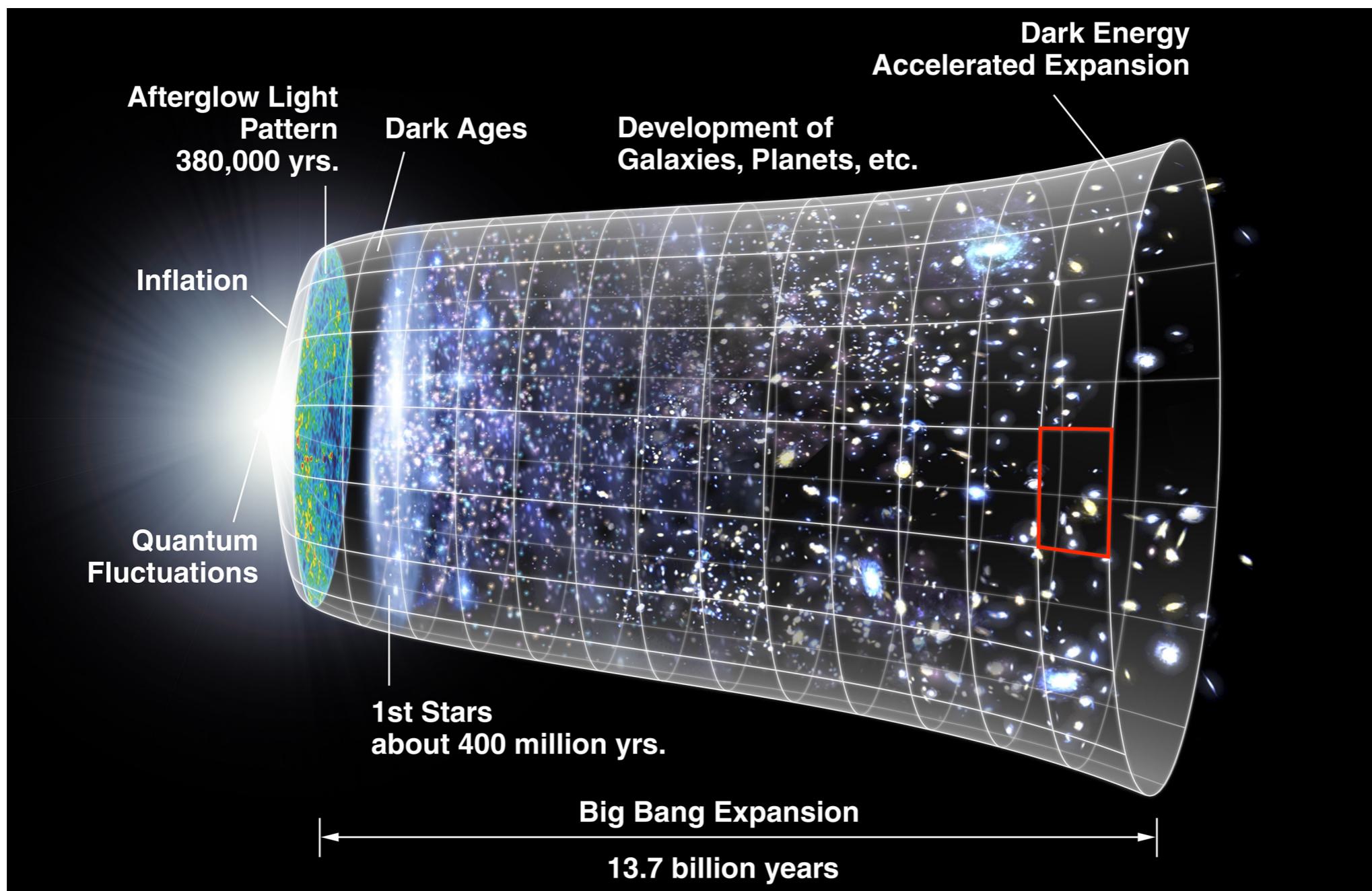
Spergel et al. 2015

Cosmology



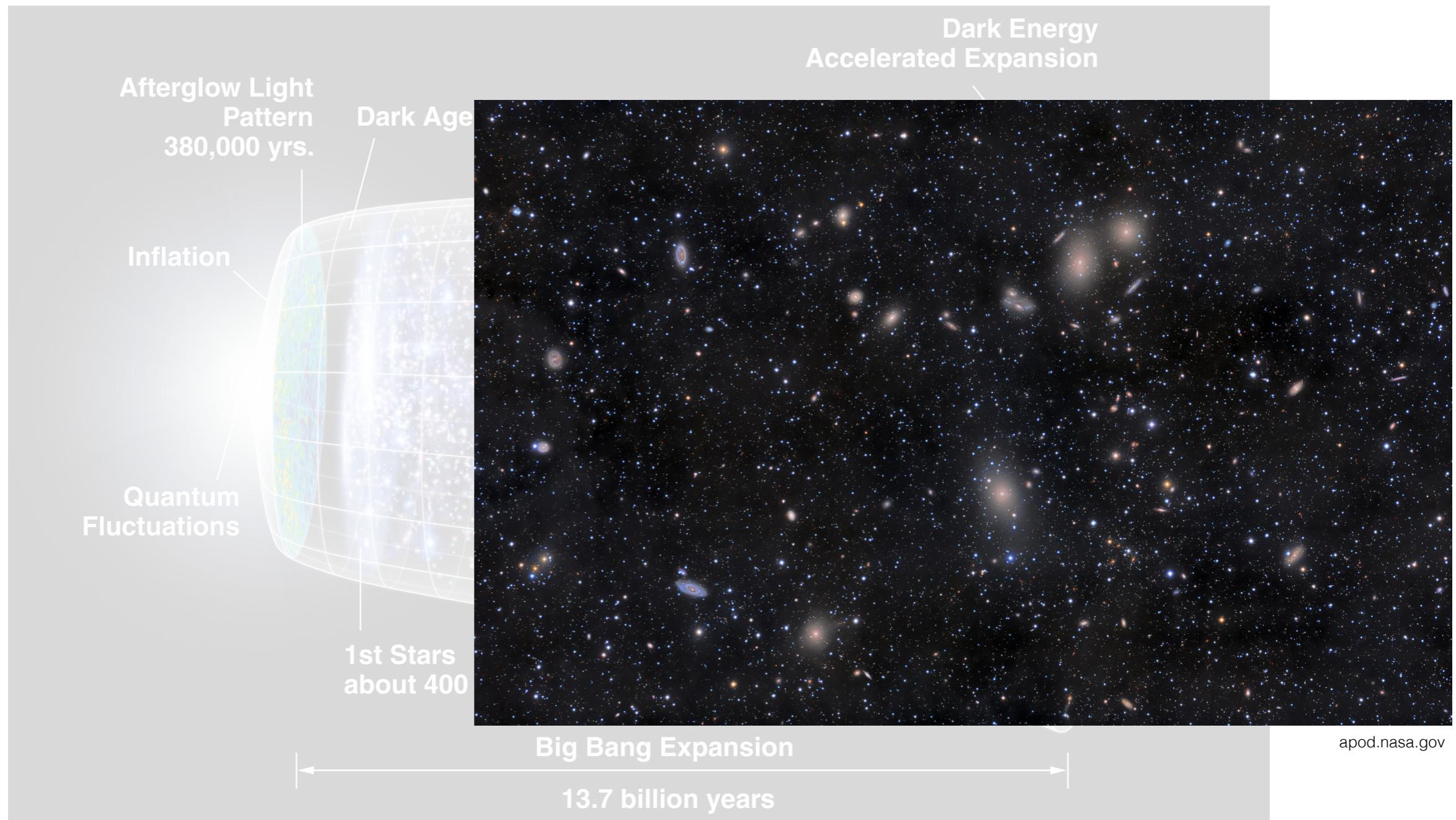
NASA / WMAP Science Team

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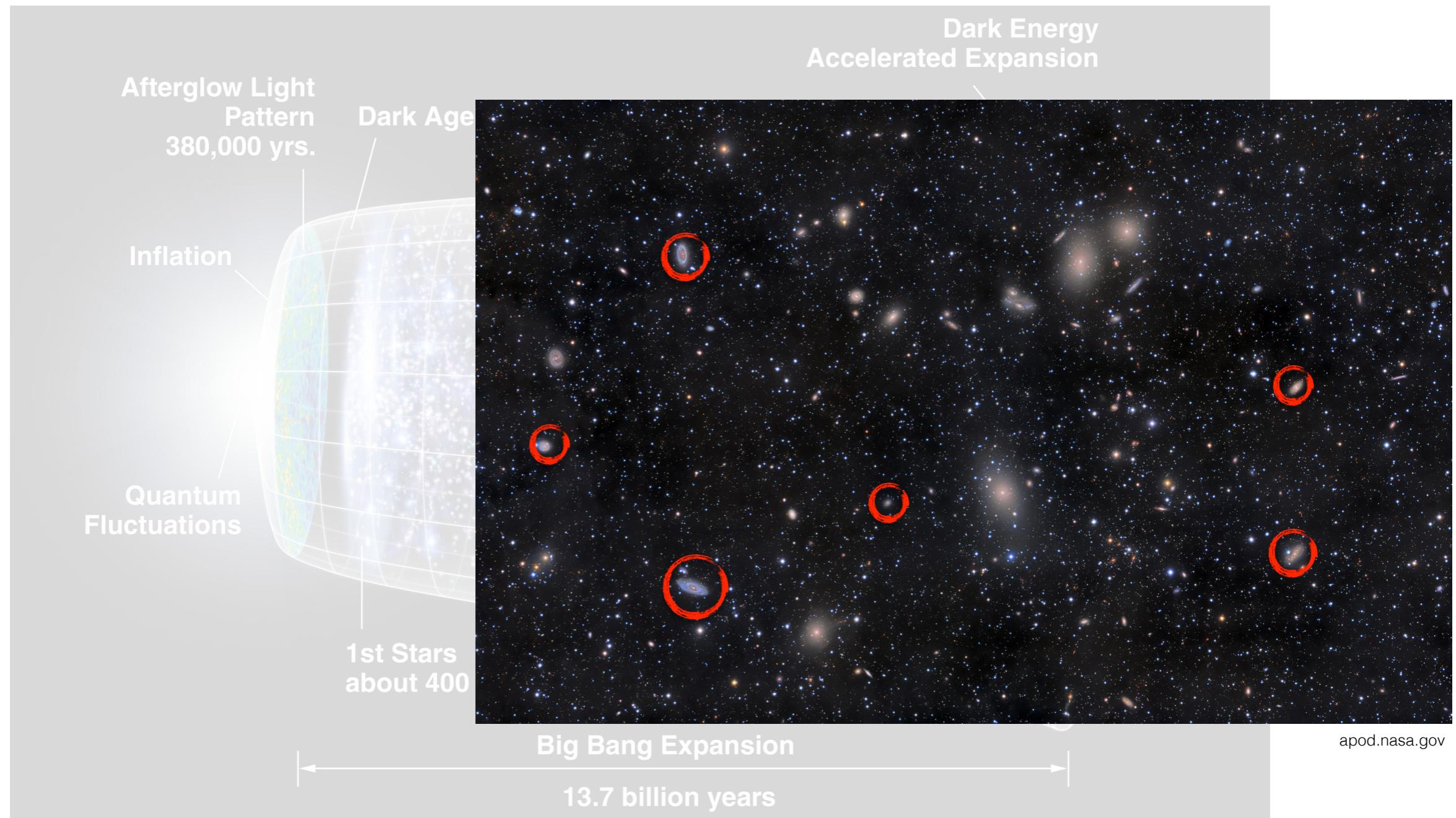
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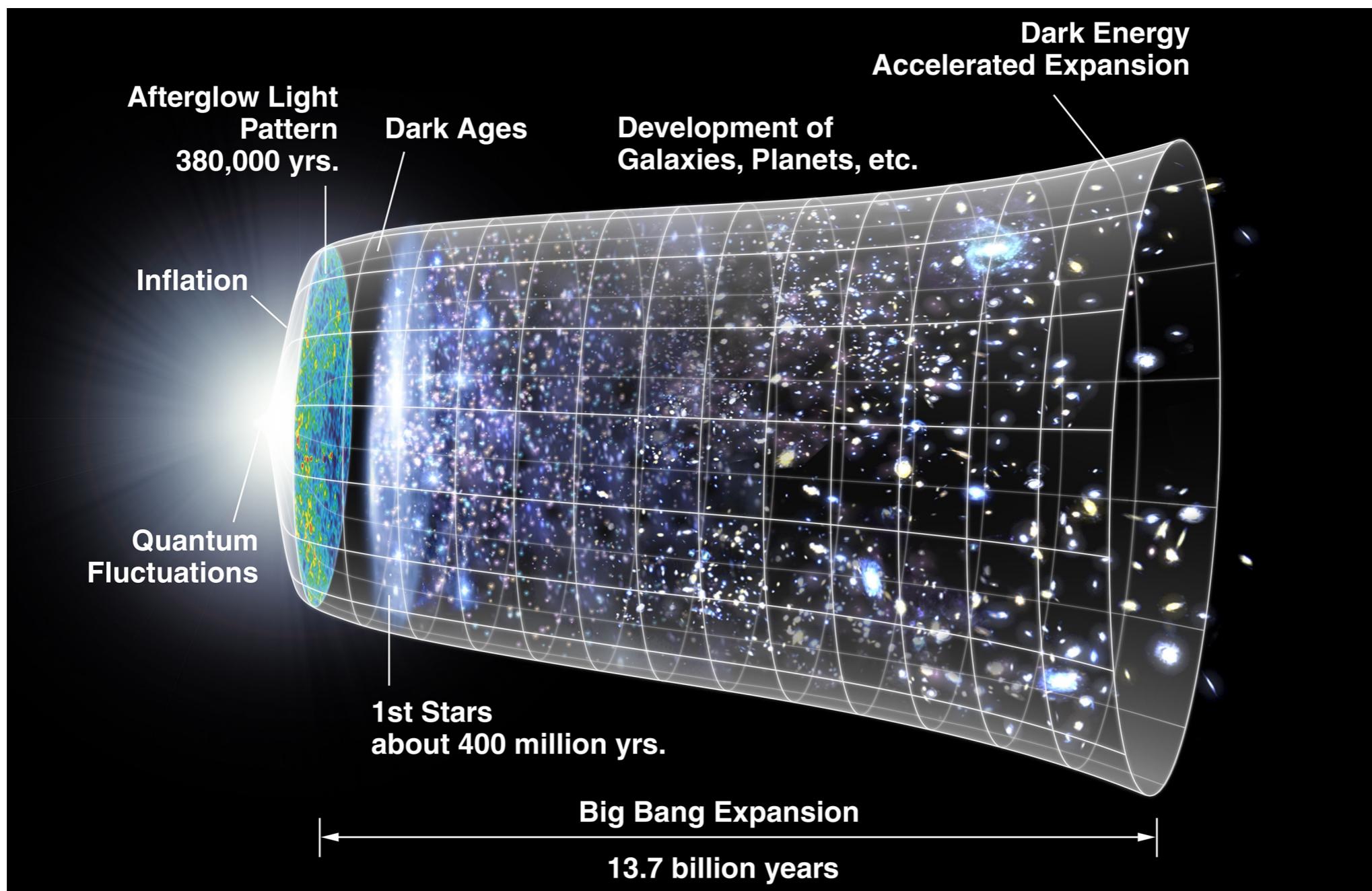
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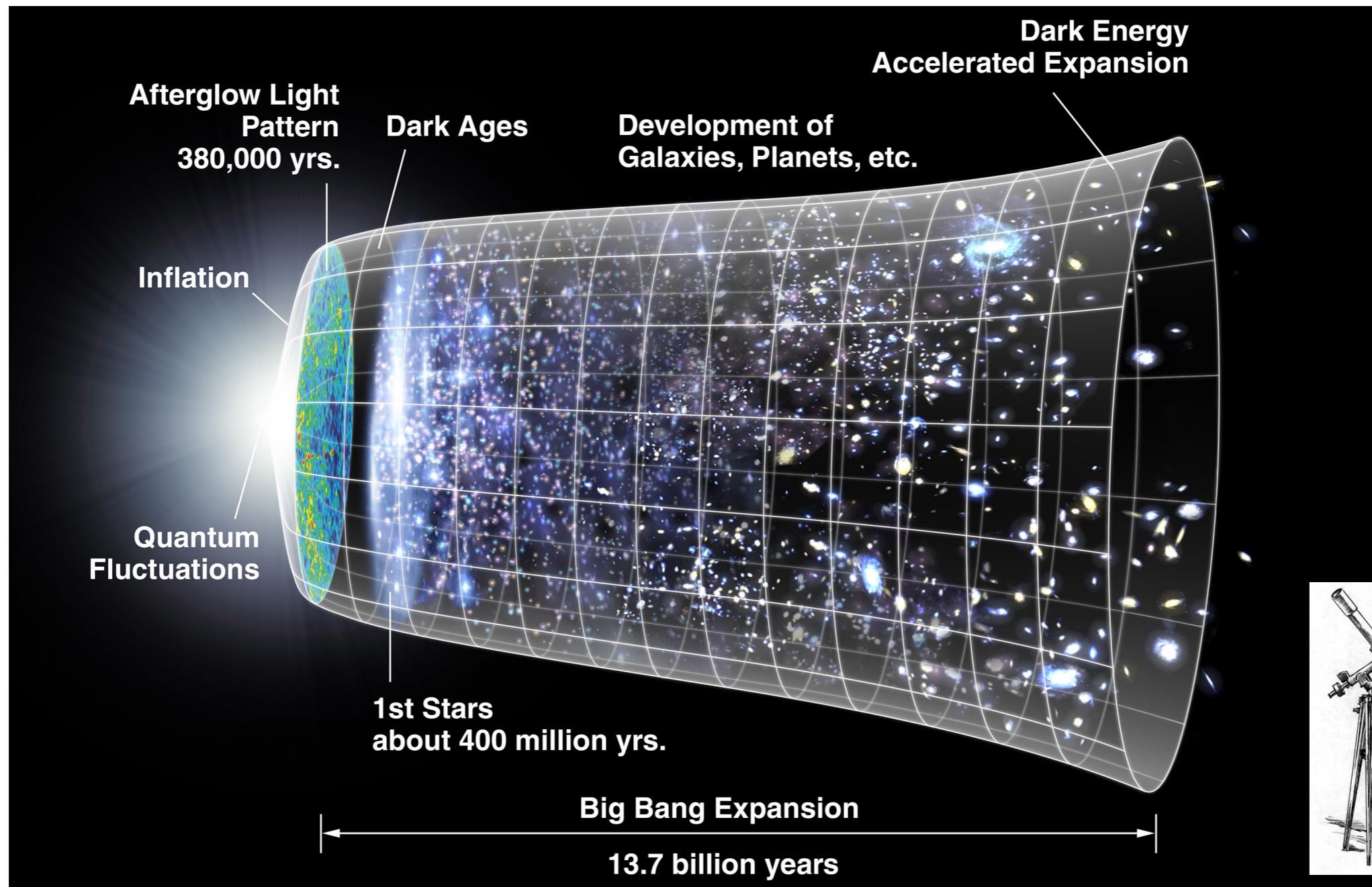
NASA / WMAP Science Team

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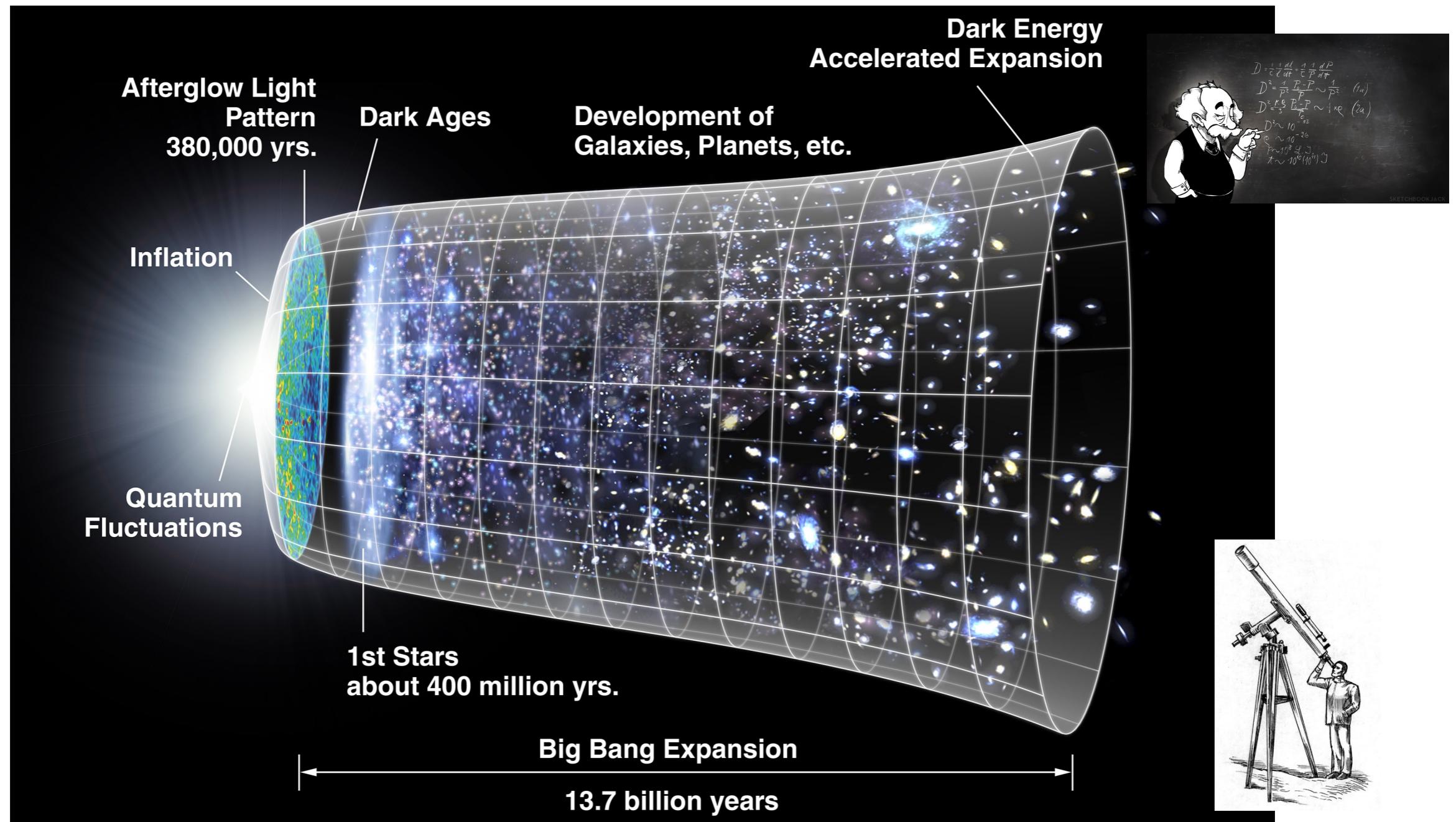
NASA / WMAP Science Team

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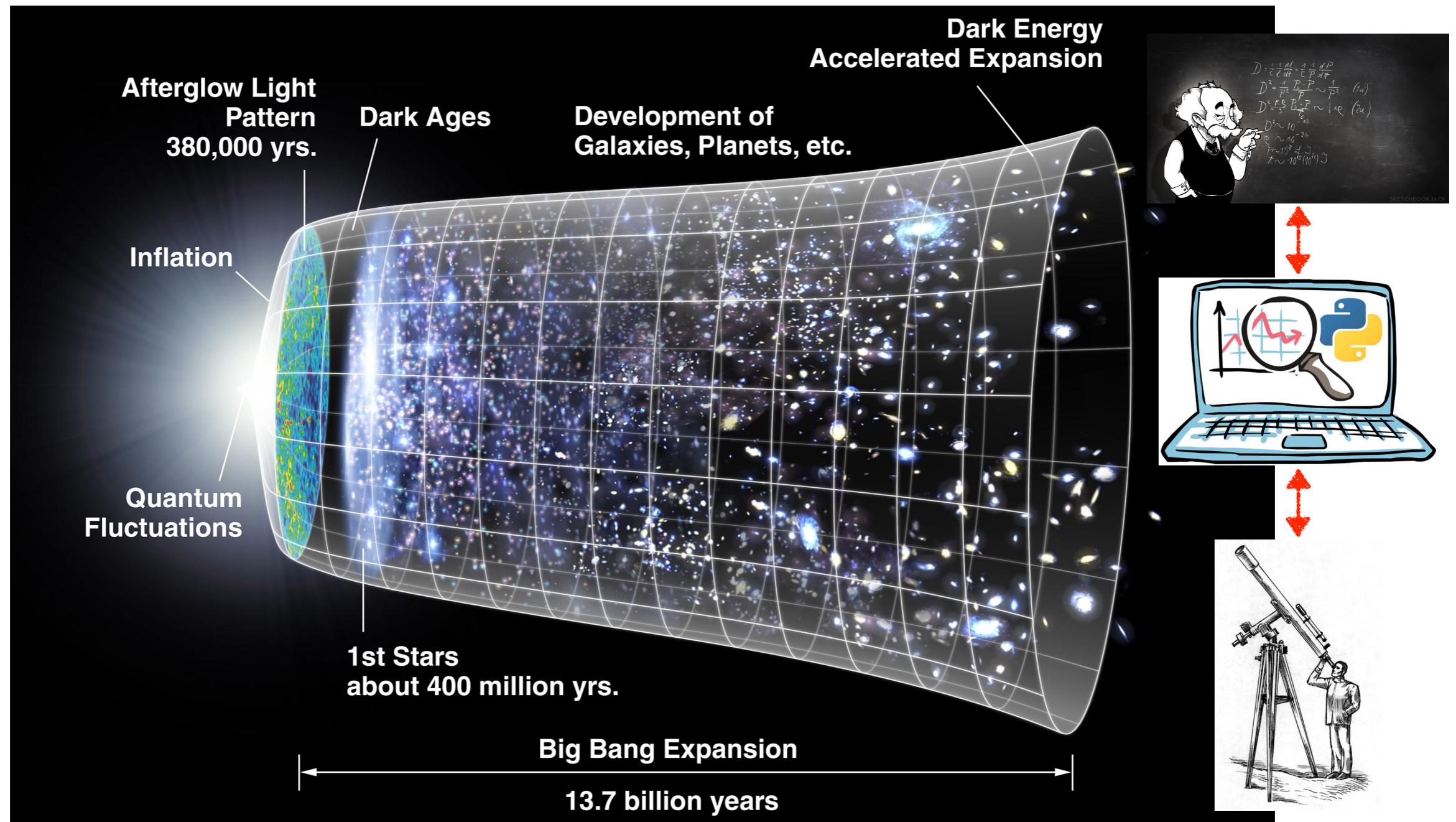
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Cosmology



NASA / WMAP Science Team

Cosmology



NASA / WMAP Science Team



Dark Energy Survey

- Wide-field imaging survey
- 12% of the sky (5000 sq. deg.), 5 years
- Images of millions of galaxies, TBs of data
- Goal: constrain cosmology (accelerated expansion of the universe, dark matter, ...)



Dark Energy Survey



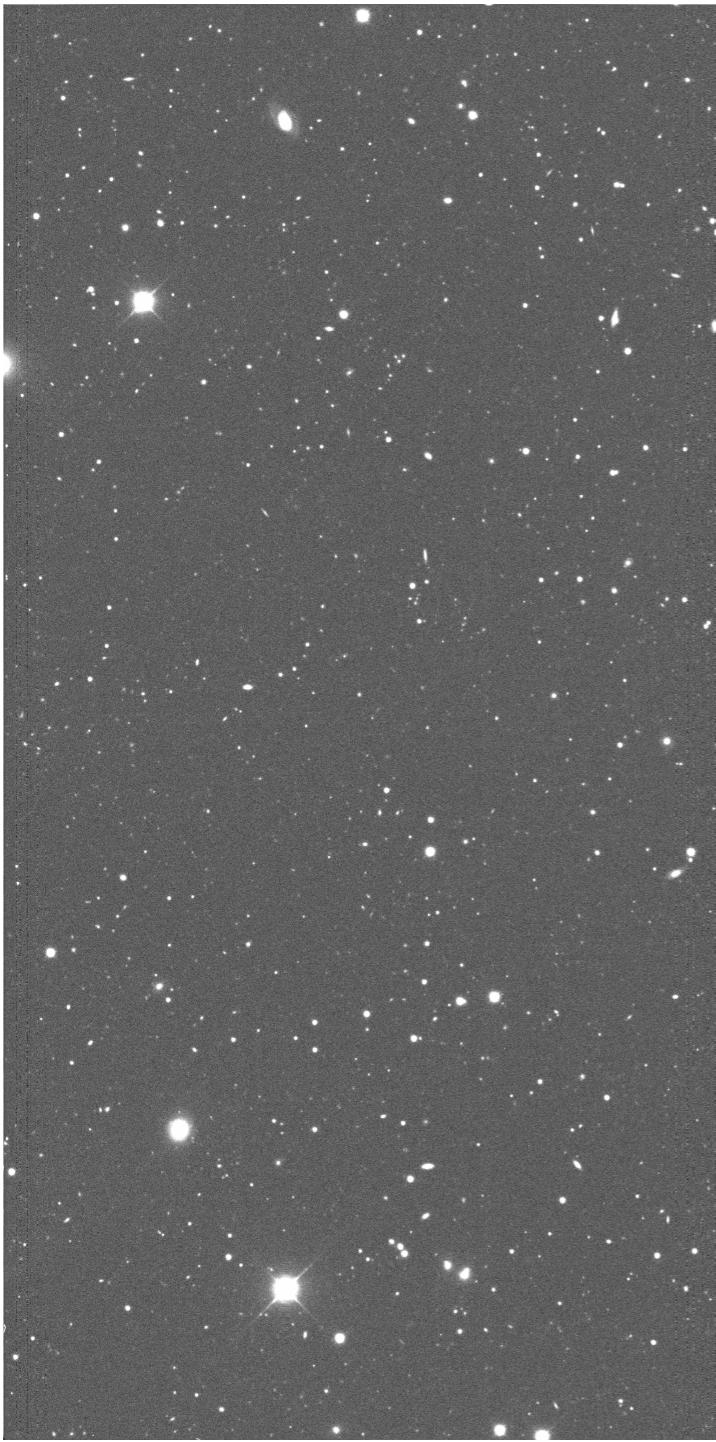


Dark Energy Survey





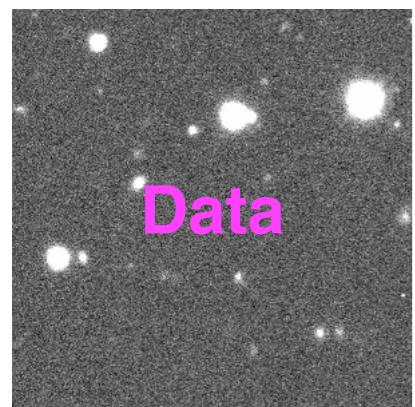
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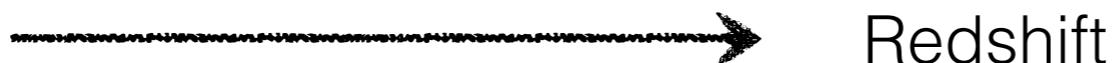
Data analysis

Data analysis

“Backwards”: From image to redshift



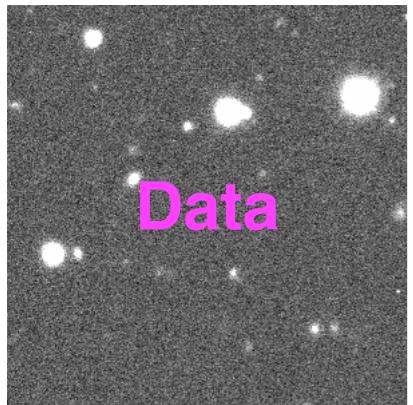
Direct measurement



Redshift

Data analysis

“Backwards”: From image to redshift



Direct measurement

Biases

Uncertainty?



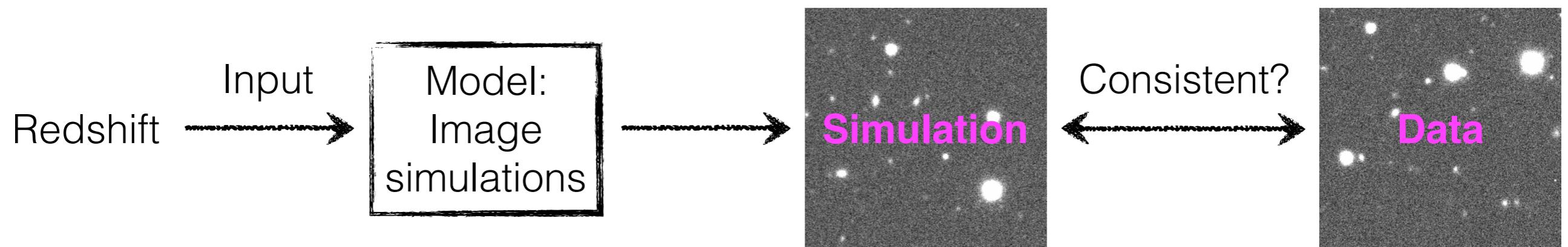
Redshift

Data analysis

“Backwards”: From image to redshift



Forward: From redshift to image



Ultra-Fast Image Generator (UFIG)

- Simulation of wide-field images
- Completely implemented in Python
- Render galaxies photon by photon
- Ca. 30 μ s per galaxy, 1 - 3 min. for $10k \times 10k$ image
- NumPy, SciPy, Astropy, ...



HOPE

- Just-in-time compiler implemented in Python

- Translates Python source code to C++

```
from hope import jit  
@jit  
def sum(x, y):  
    return x + y
```

- Caching

	Python (NumPy)	Numba	Cython	Nuitka (NumPy)	PyPy (NumPy)	numexpr (8 cores)	HOPE	C++
Fibonacci	57.4	65.7 ^a	1.1	26.7	21.1	-	1.1	1.0
Quicksort	79.4	_ ^b	4.6	61.0	45.8	-	1.1	1.0
Pi sum	27.2	1.0	1.1	13.0	1.0	-	1.0	1.0
10th order	2.6	2.2	2.1	1.2	12.1	1.4	1.1	1.0
Simplify	1.4	1.5 ^{a,b}	1.8	1.4	23.2	0.6	0.015	1.0
Pairwise distance	1357.8 (8.7)	1.8	1.0	1247.7 (9.5)	277.8 (60.4)	-	1.7	1.0
Star PSF	265.4	250.4 ^a	46.2	234.6	339.5	-	2.2	1.0

HOPE

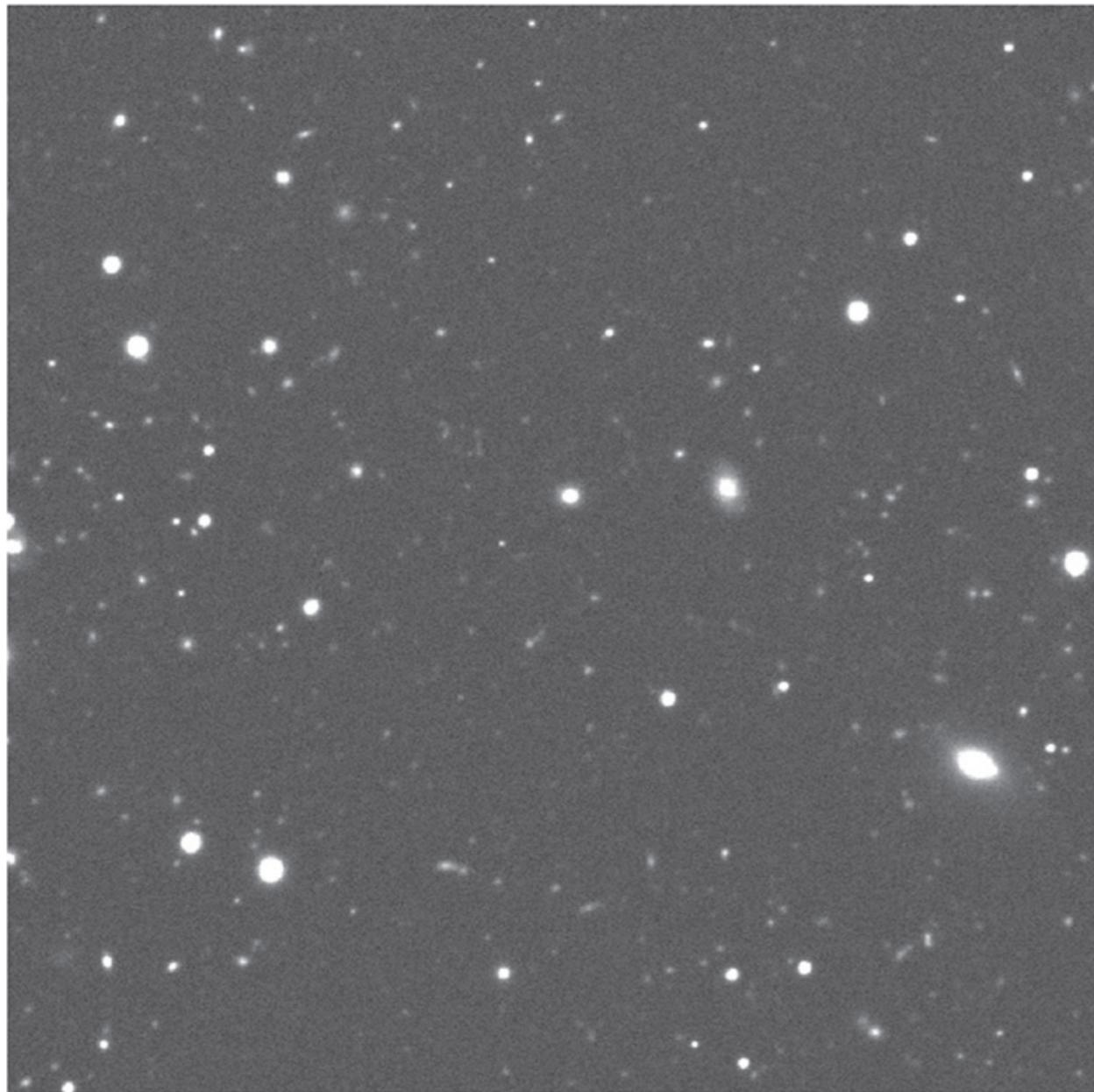
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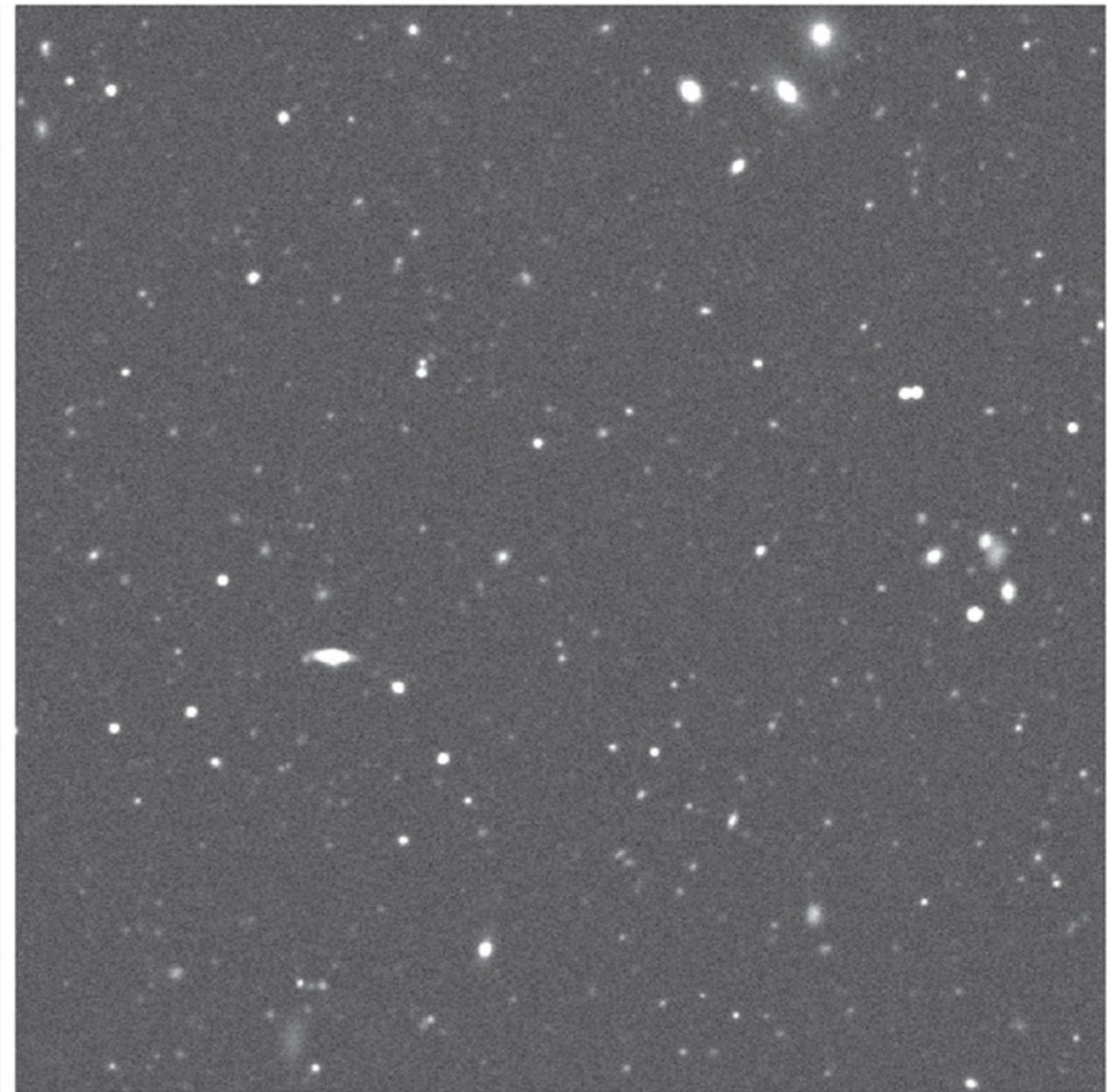
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Simulations vs. real data

DES

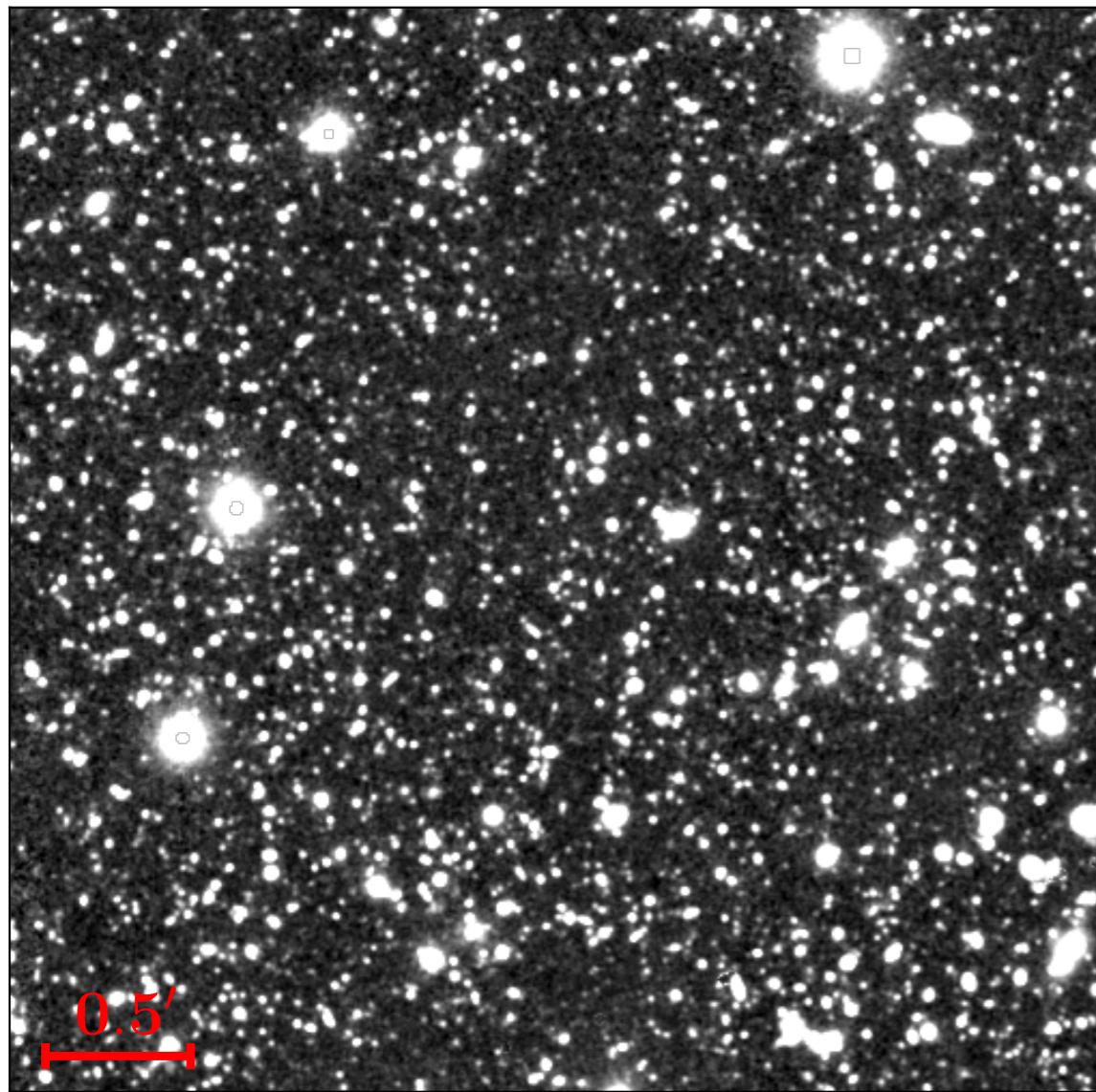


UFIG

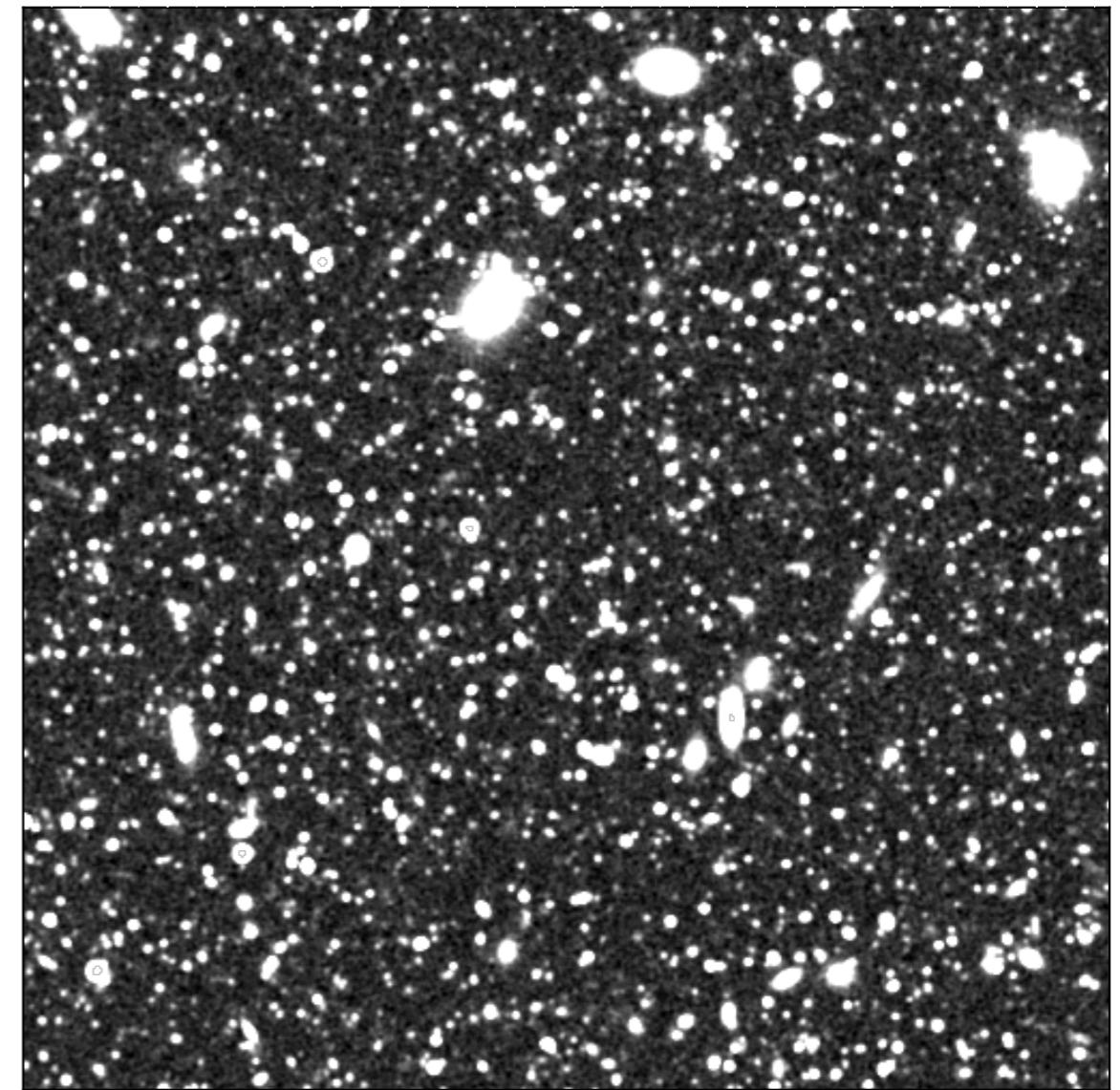


Simulations vs. real data

Subaru

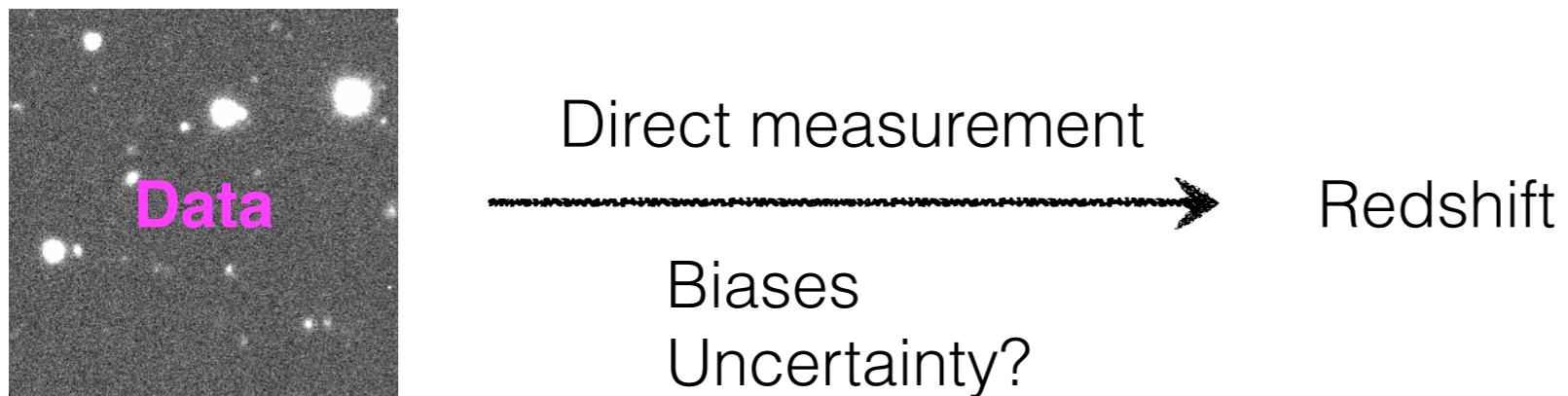


UFIG

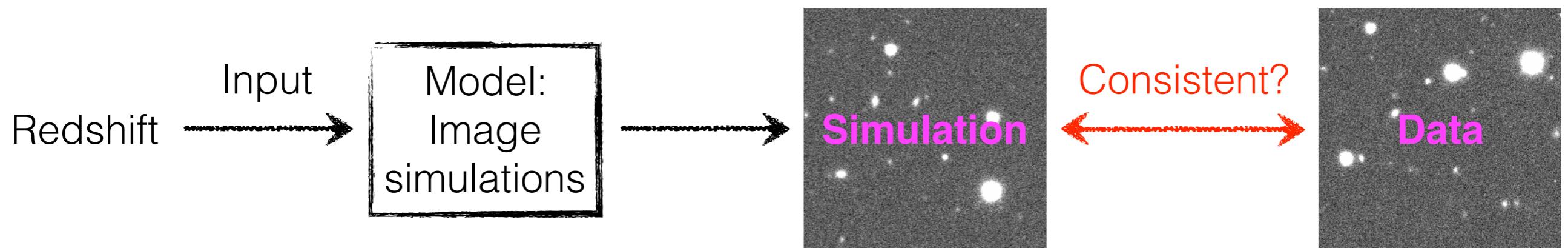


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Forward: From redshift to image



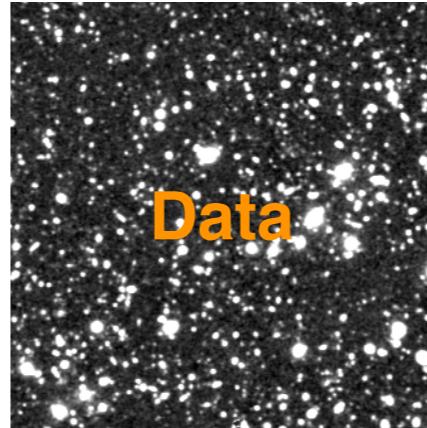
Approximate Bayesian Computation

Approximate Bayesian Computation

- Likelihood-free Bayesian inference
- Approximate posterior built from simulations statistically similar to data
- Robust estimate of uncertainties

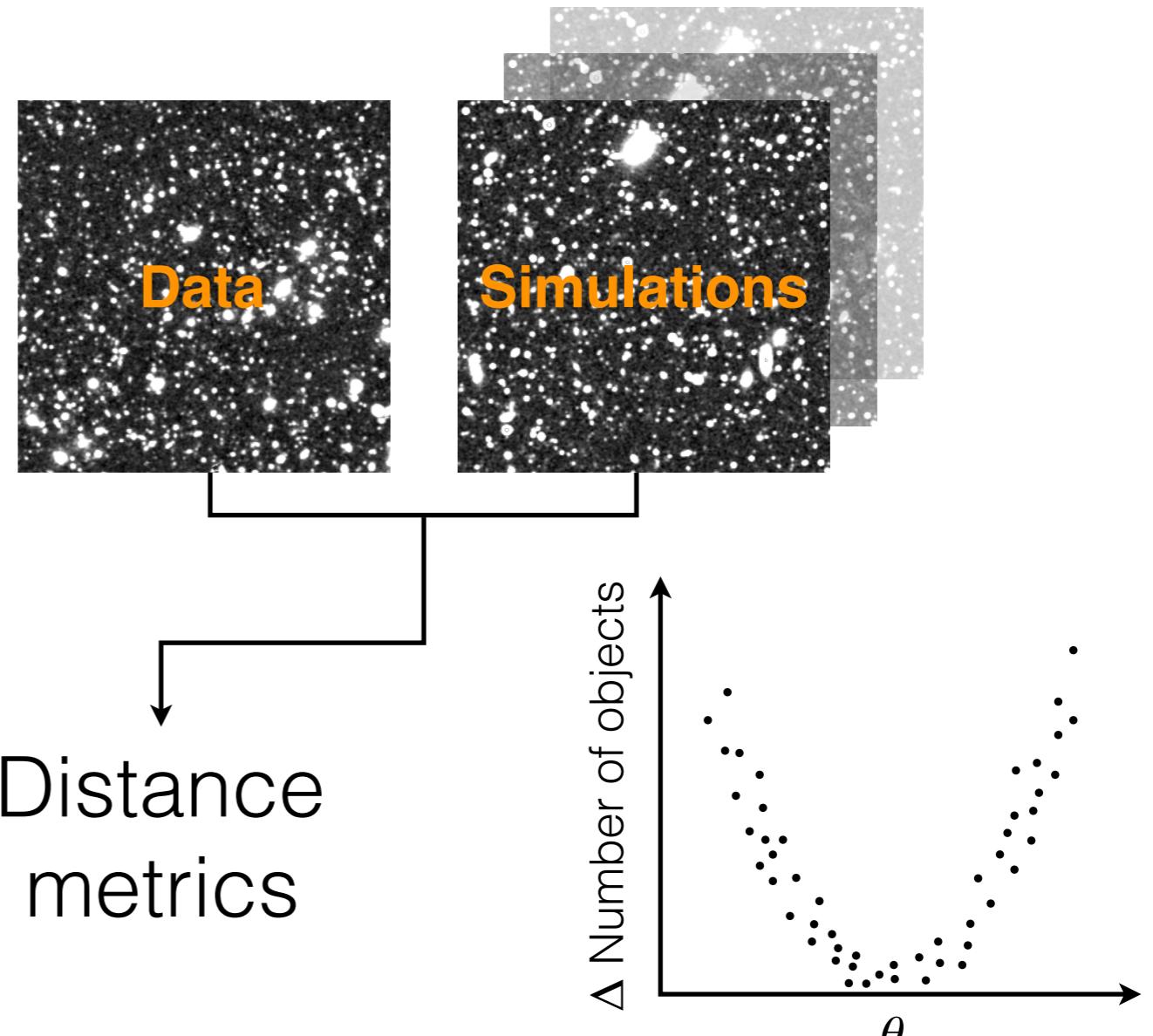
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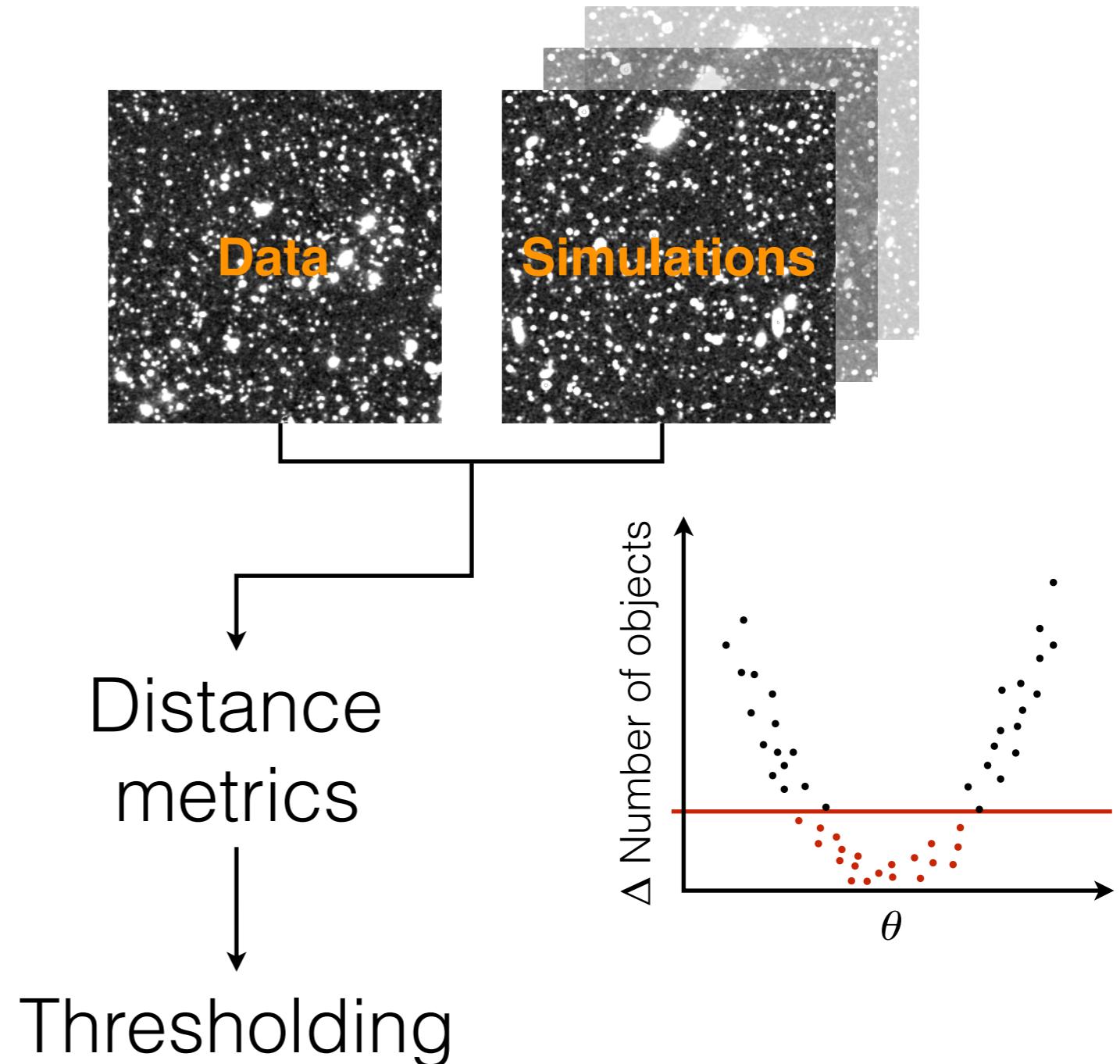
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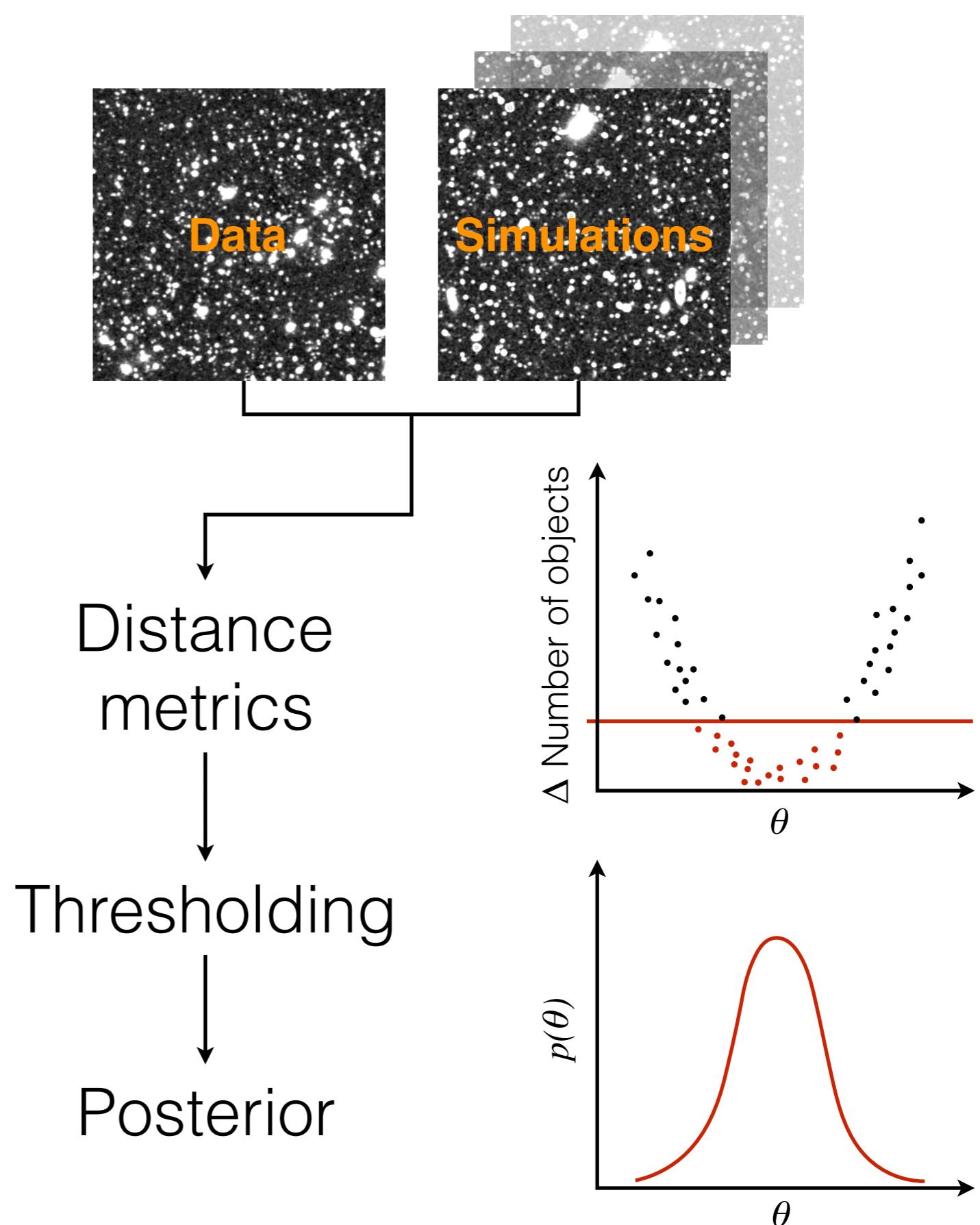
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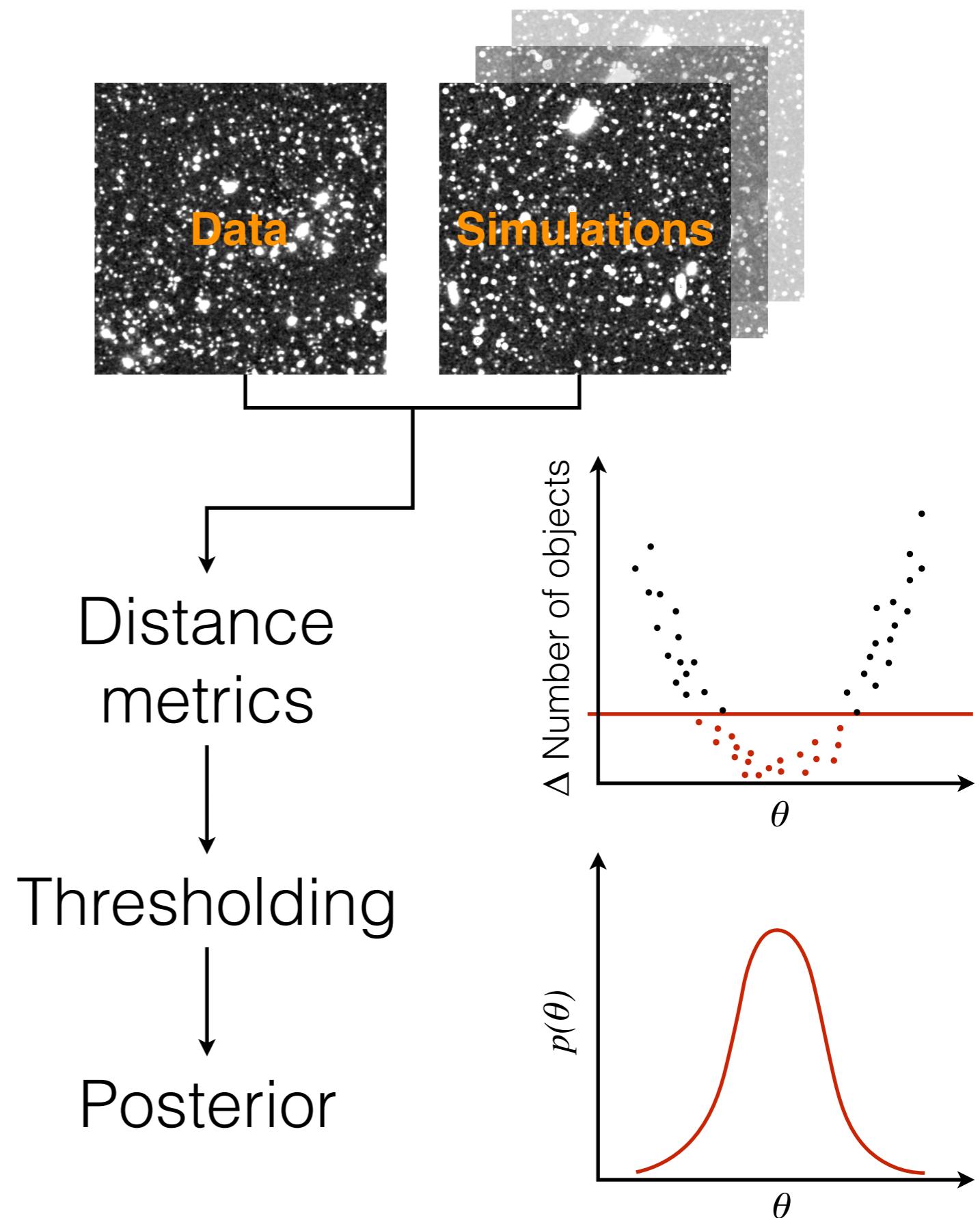
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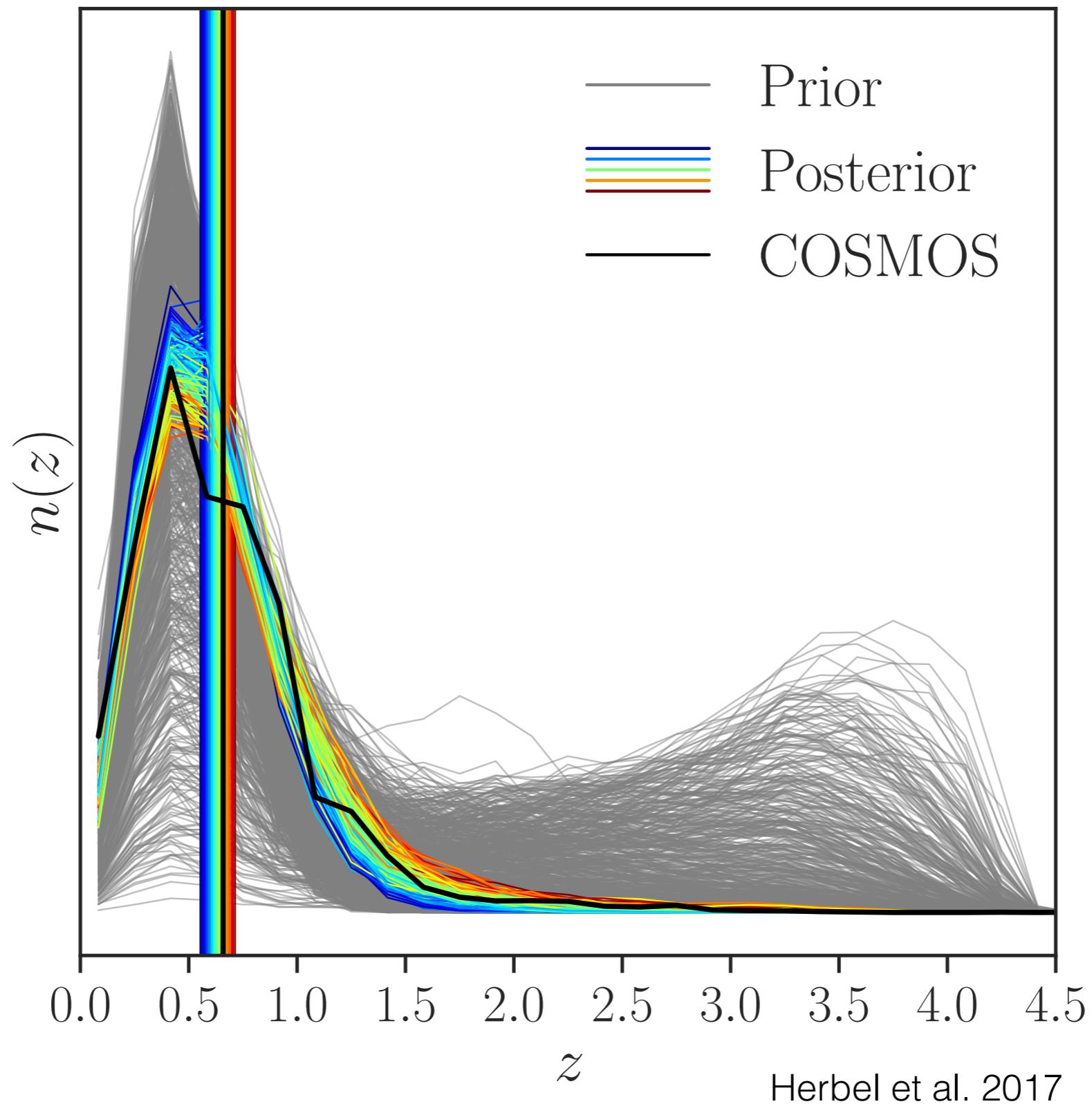
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ABC & UFIG @ CSCS

- UFIG on several hundred cores in parallel
- Enables exploration of high-dim. parameter spaces
- Result: Image simulations which are statistically consistent with real data
- Allows to perform measurements via novel forward-modeling approach
- Everything in Python 😊

First result



Summary & Conclusions

- Cosmology heavily relies on Python
- Inference of cosmological parameters from data is not straightforward
- Image simulations in Python (UFIG)
- ABC in Python, parallelized on cluster
- Many more applications (DES data processing pipeline, PynPoint, CosmoHammer, ...)