Supersymmetry, Non-thermal Dark Matter and Precision Cosmology

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Syracuse University

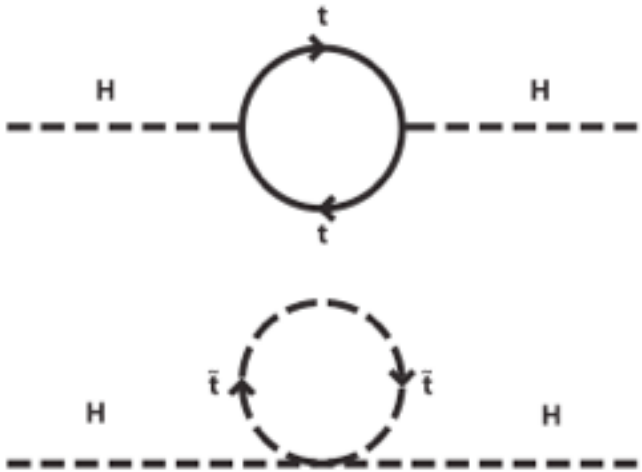
ArXiv:1307.2453
with R. Easther (Auckland), R. Galvez, and O. Ozsoy (Syracuse)

Summary of this talk

If SUSY exists in nature, it appears we must revisit our assumptions about the history of the post-inflationary universe prior to BBN.

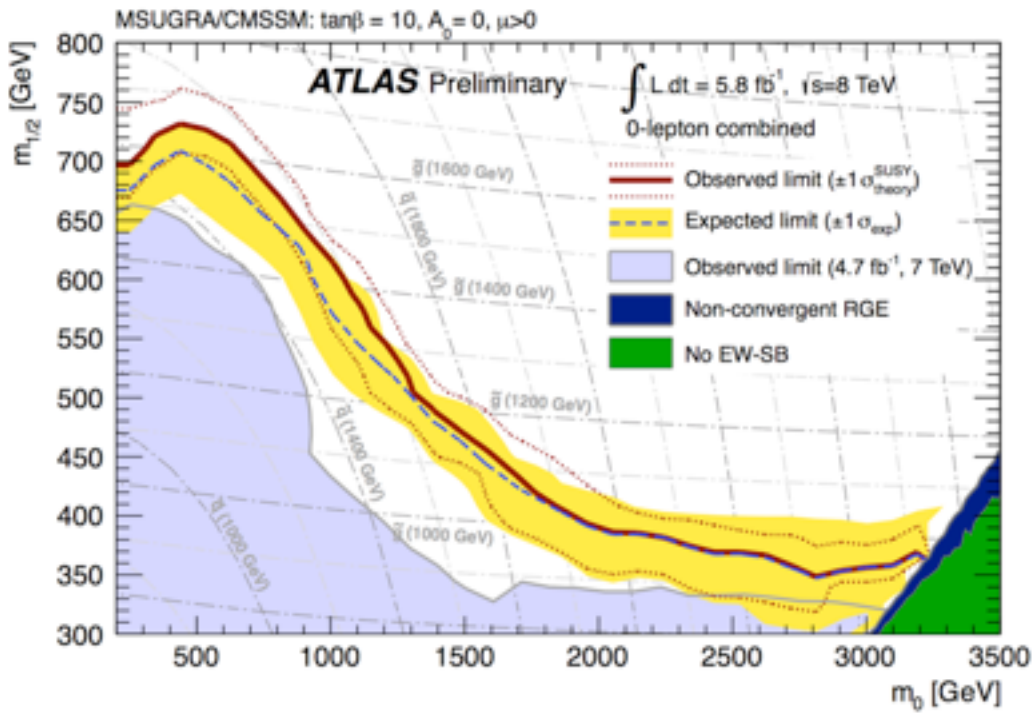
This has direct consequences for testing models of inflation and requires a new approach to confronting inflationary theories with data.

SUSY and Hierarchies after LHC



SUSY can stabilize the Electroweak Hierarchy

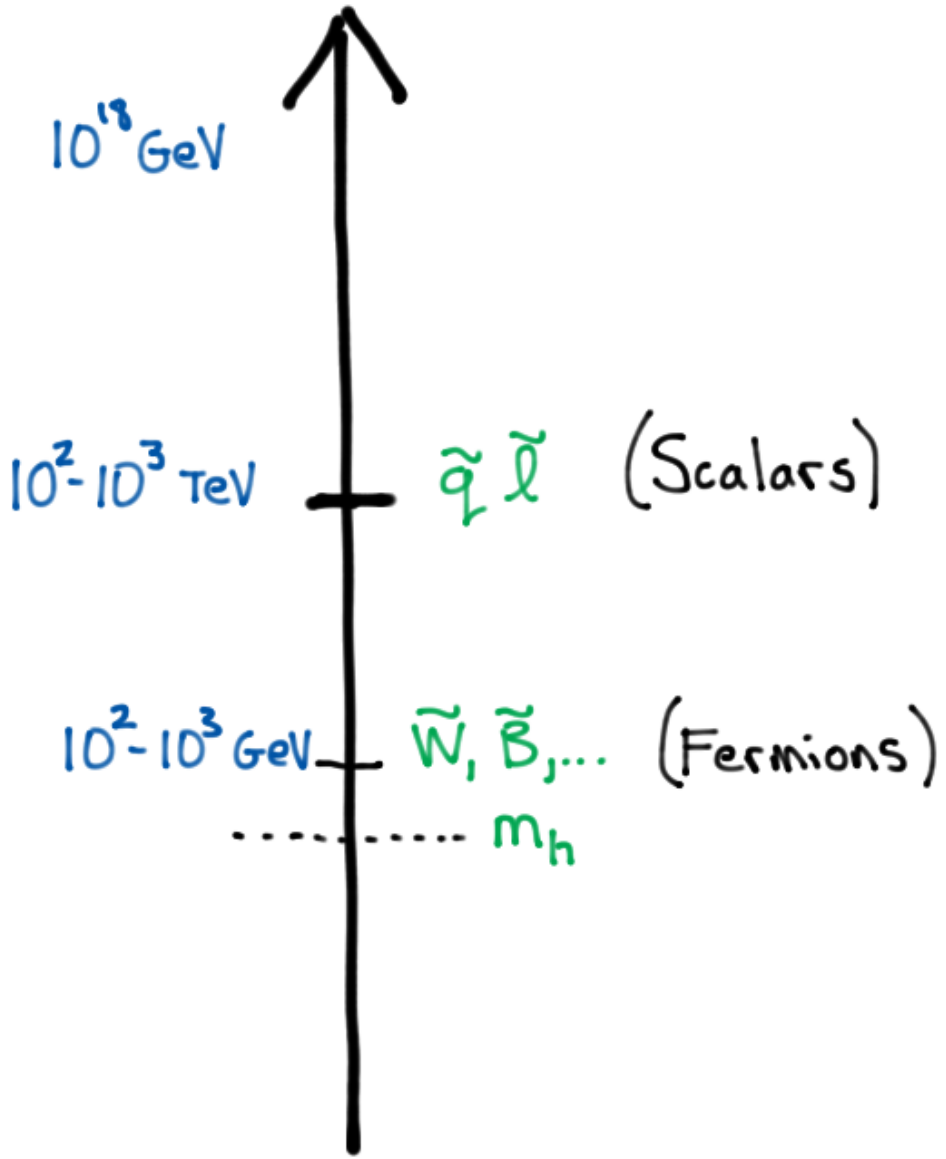
No sign of SUSY yet.



Split SUSY

J. Wells (hep-ph/0306127) N. Arkani-Hamed and S. Dimopoulos (hep-th/0405159)

- ✓ Gauge Coupling Unification
- ✓ Dark Matter
- ✓ No Flavor, CP problems



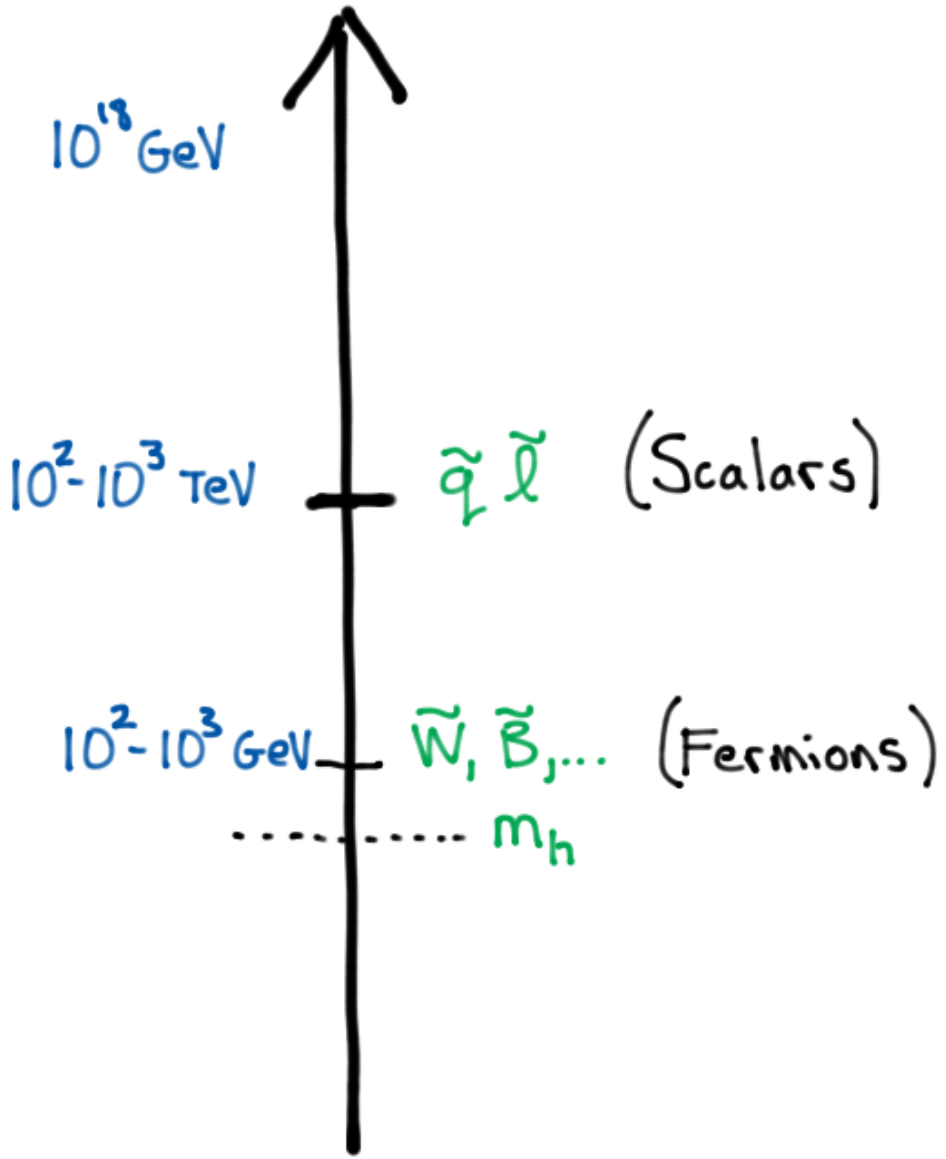
Scalars heavy, Fermions light

(Fermions carry R-symmetry, scalars do not.)

UV Completions of SUSY (a.k.a. String Theory)

S. Watson (Arxiv:0912.3003)
with B. Acharya, G. Kane, P. Kumar (Arxiv:0908.2430)

- ✓ Unification
- ✓ Dark Matter
- ✓ No Flavor, CP problems
- ✓ **No moduli problems**



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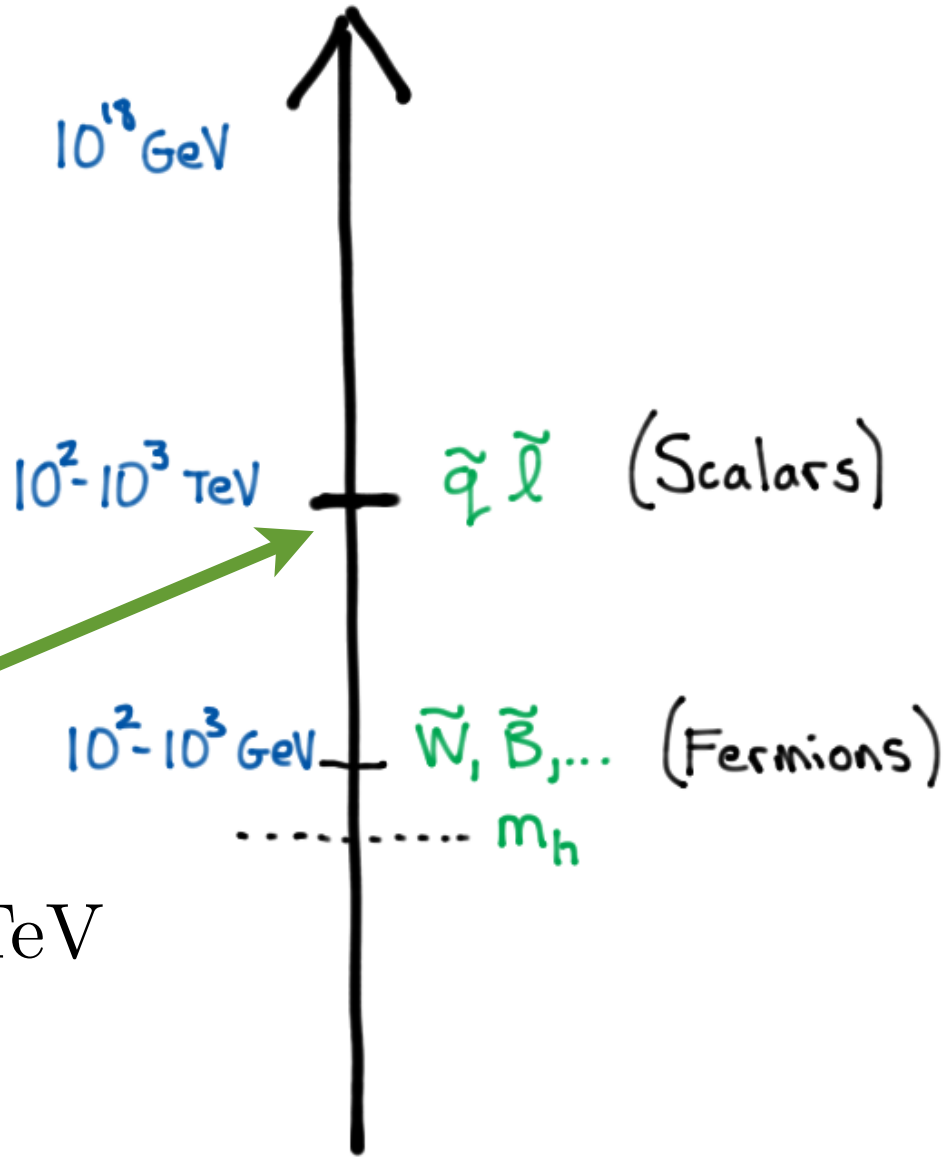

Moduli get masses:

$$m_\phi \simeq m_{3/2} \simeq 100 - 1000 \text{ TeV}$$

$$m_{3/2} = \frac{\Lambda_{SUSY}^2}{m_p}$$

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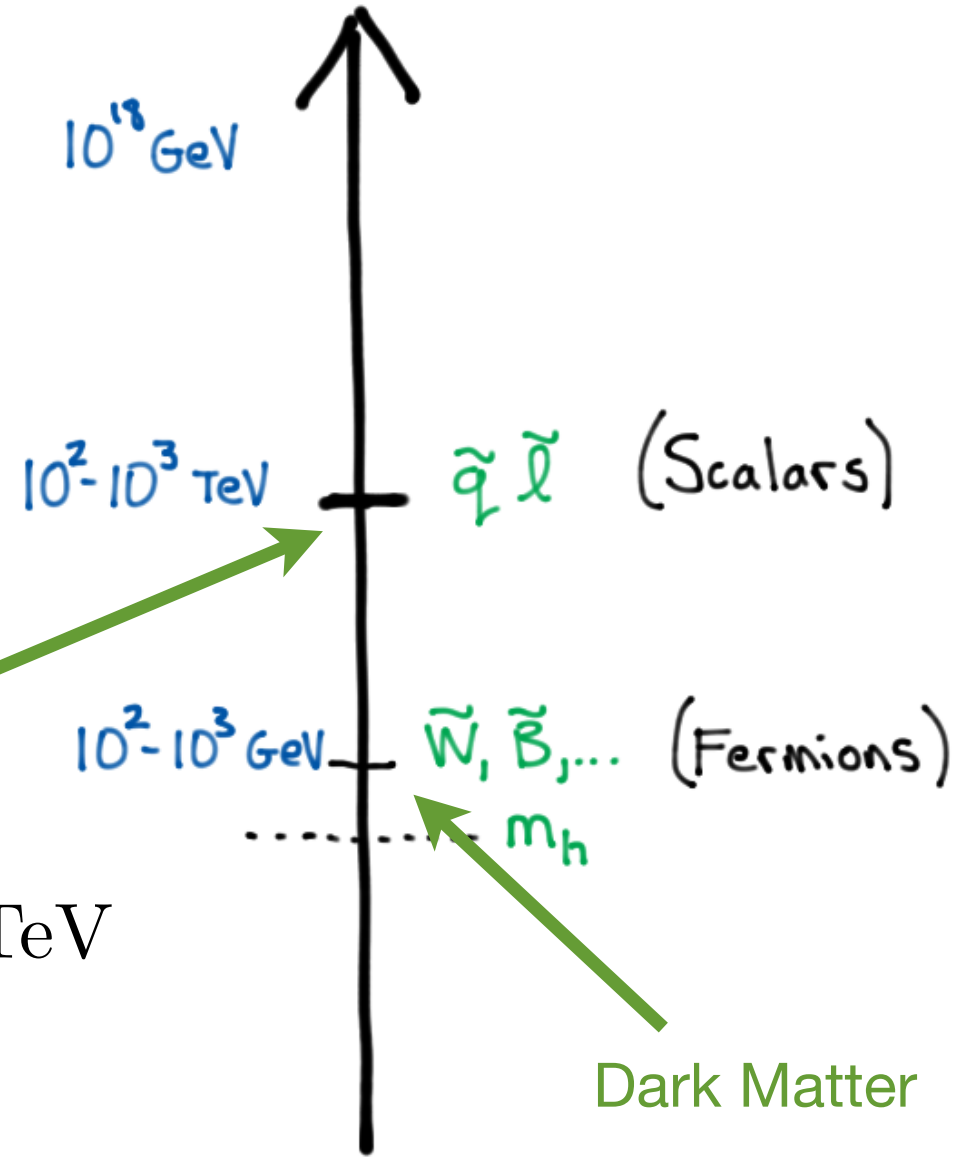

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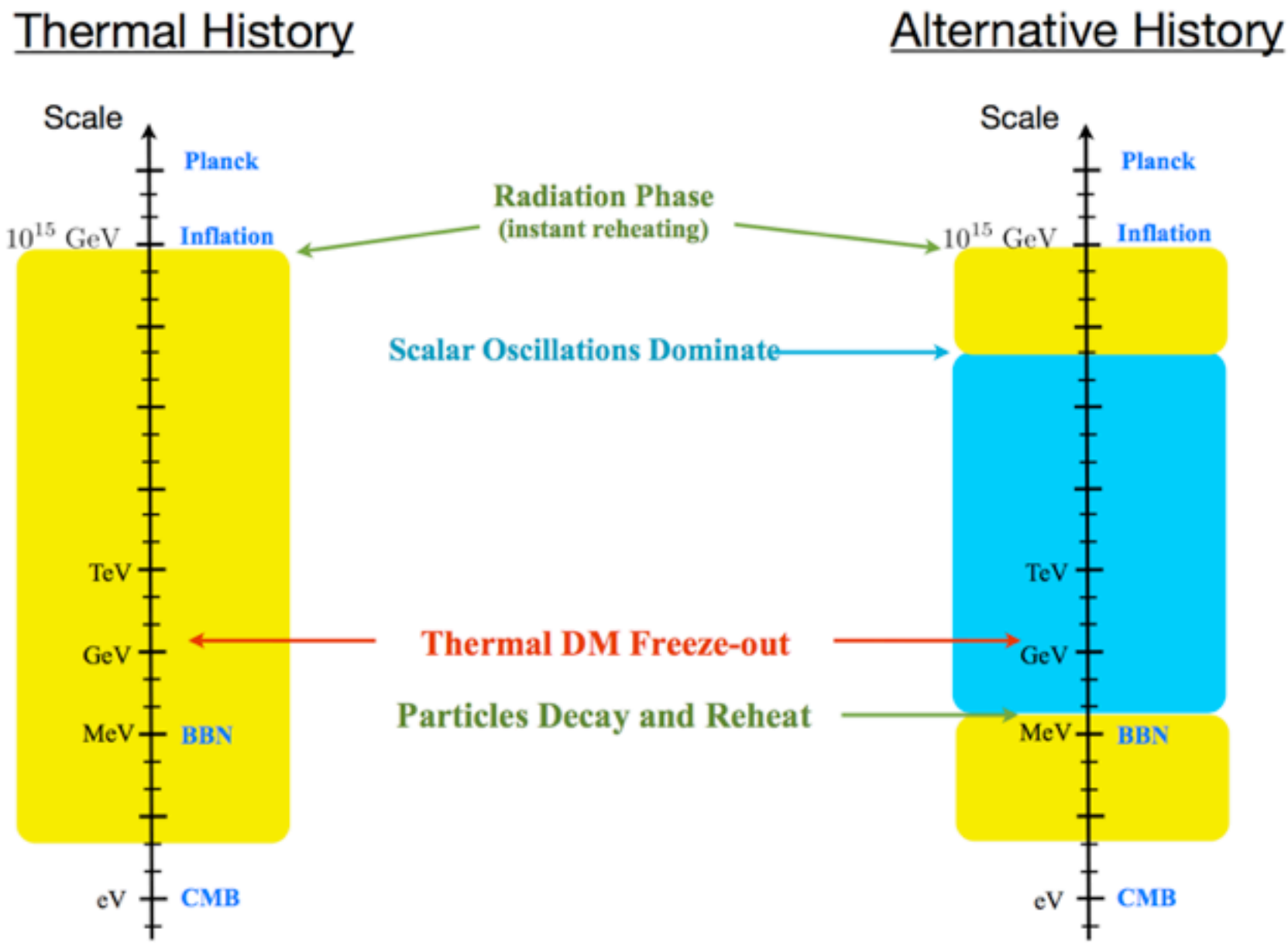
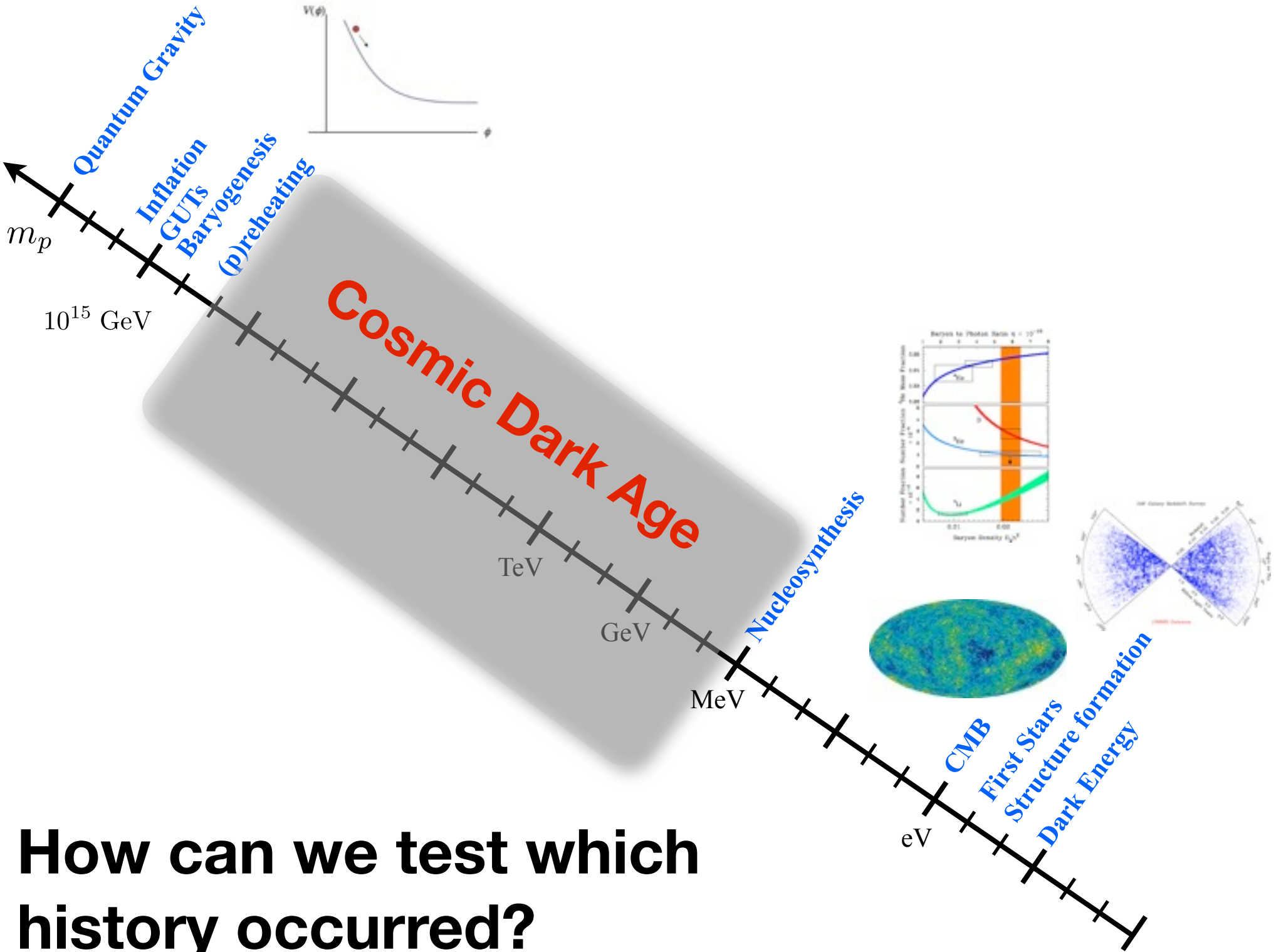
Which cosmological history results from this framework?

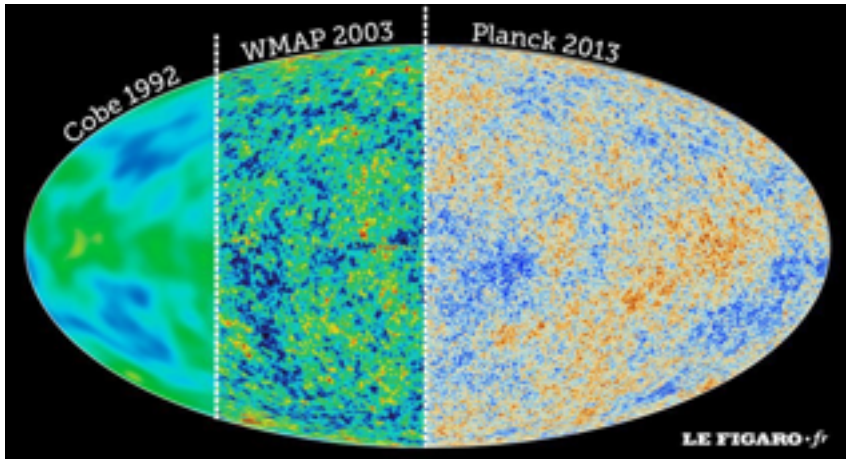


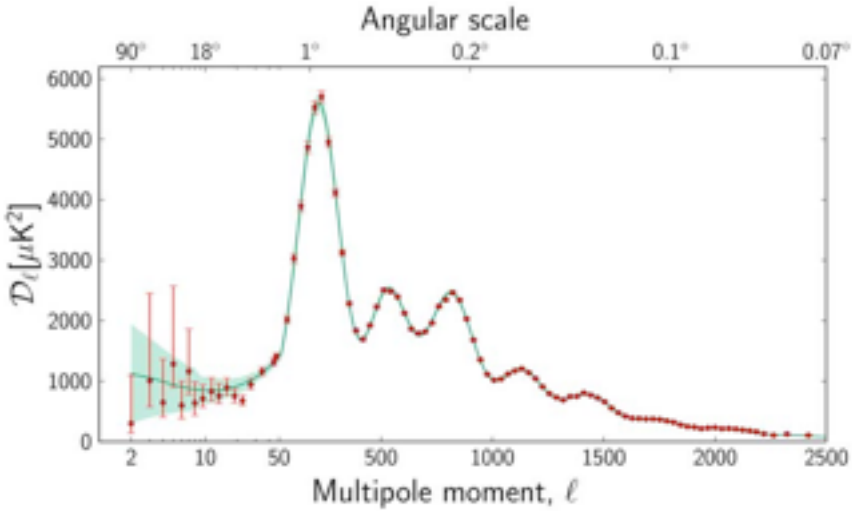
Split SUSY and String motivated approaches
both seem to favor a Non-thermal History for Dark Matter

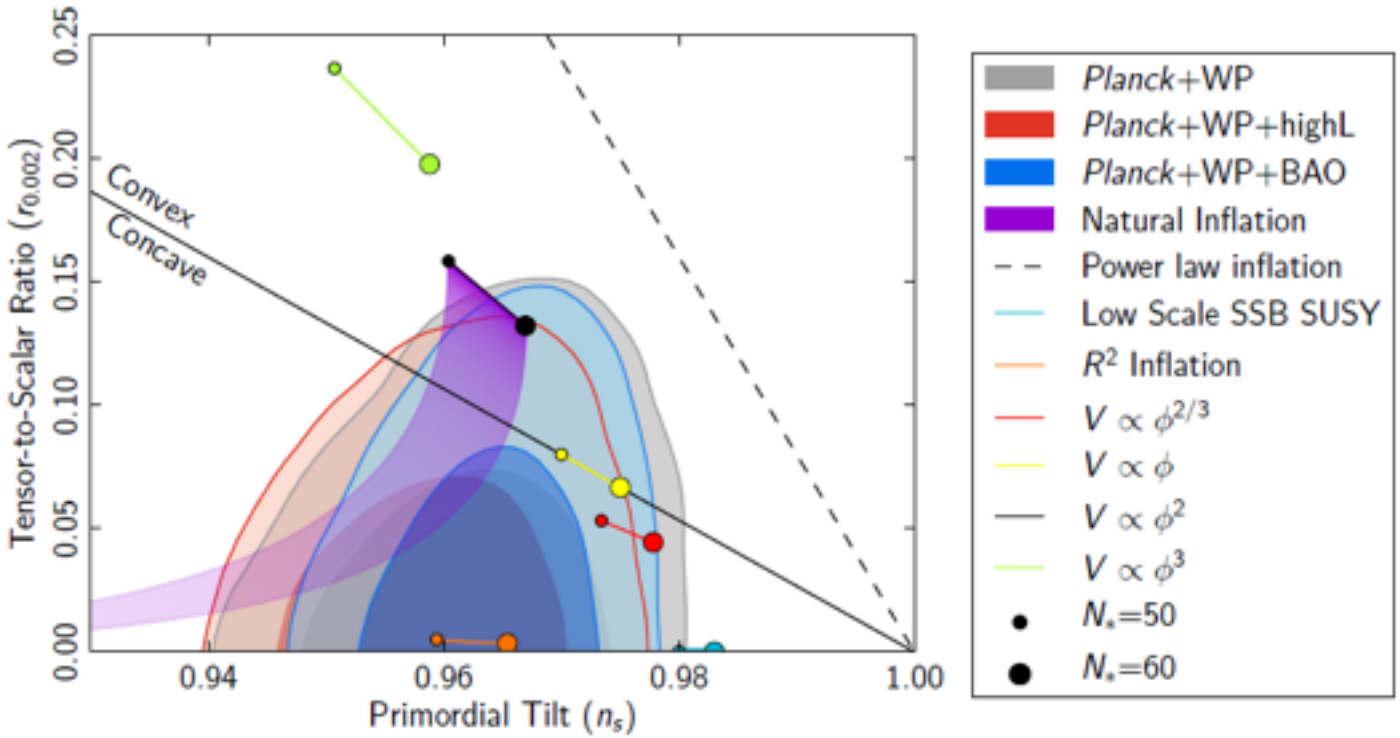


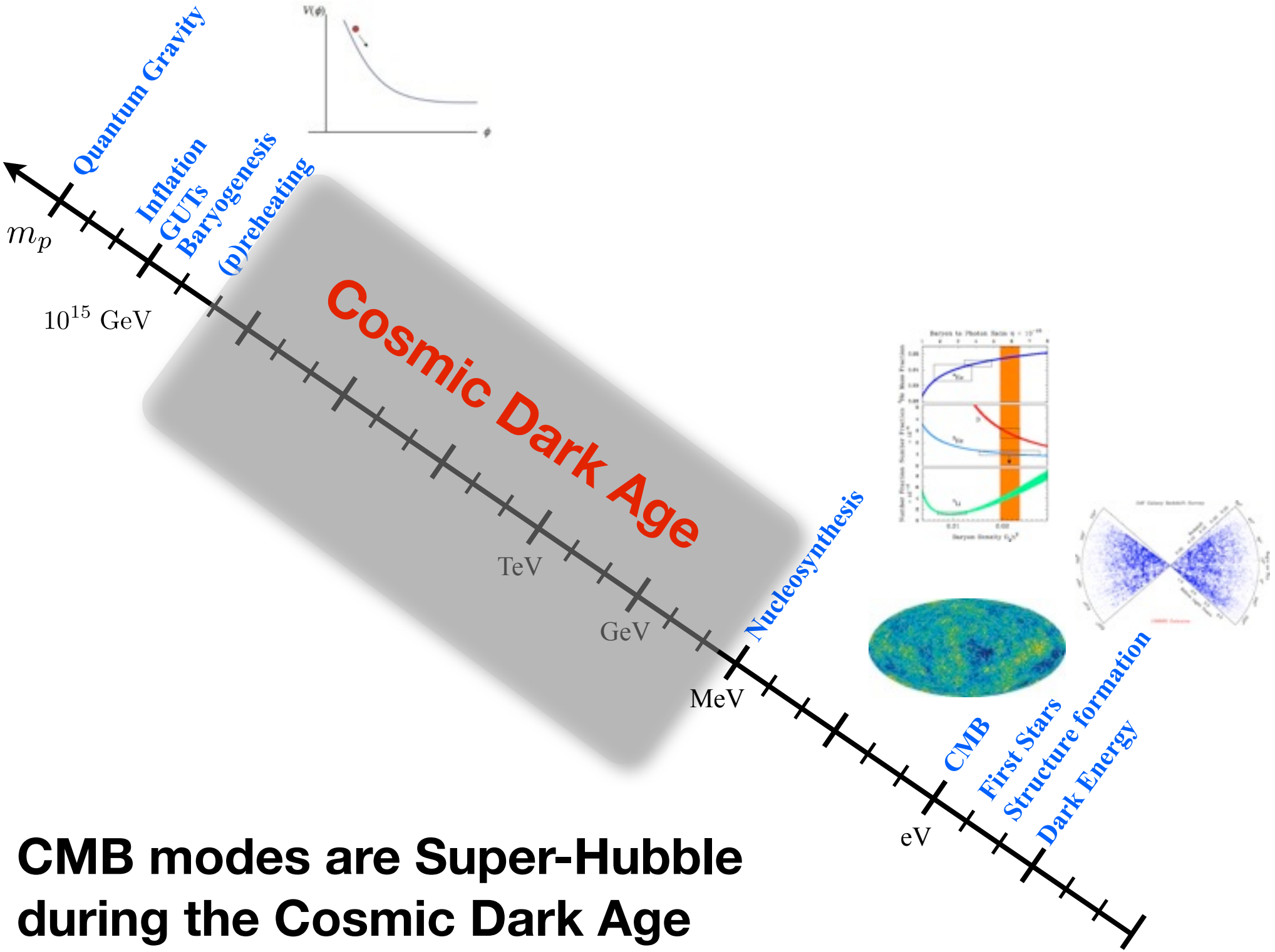
How can we test which history occurred?

Planck has constrained models of inflation to an impressive level of accuracy

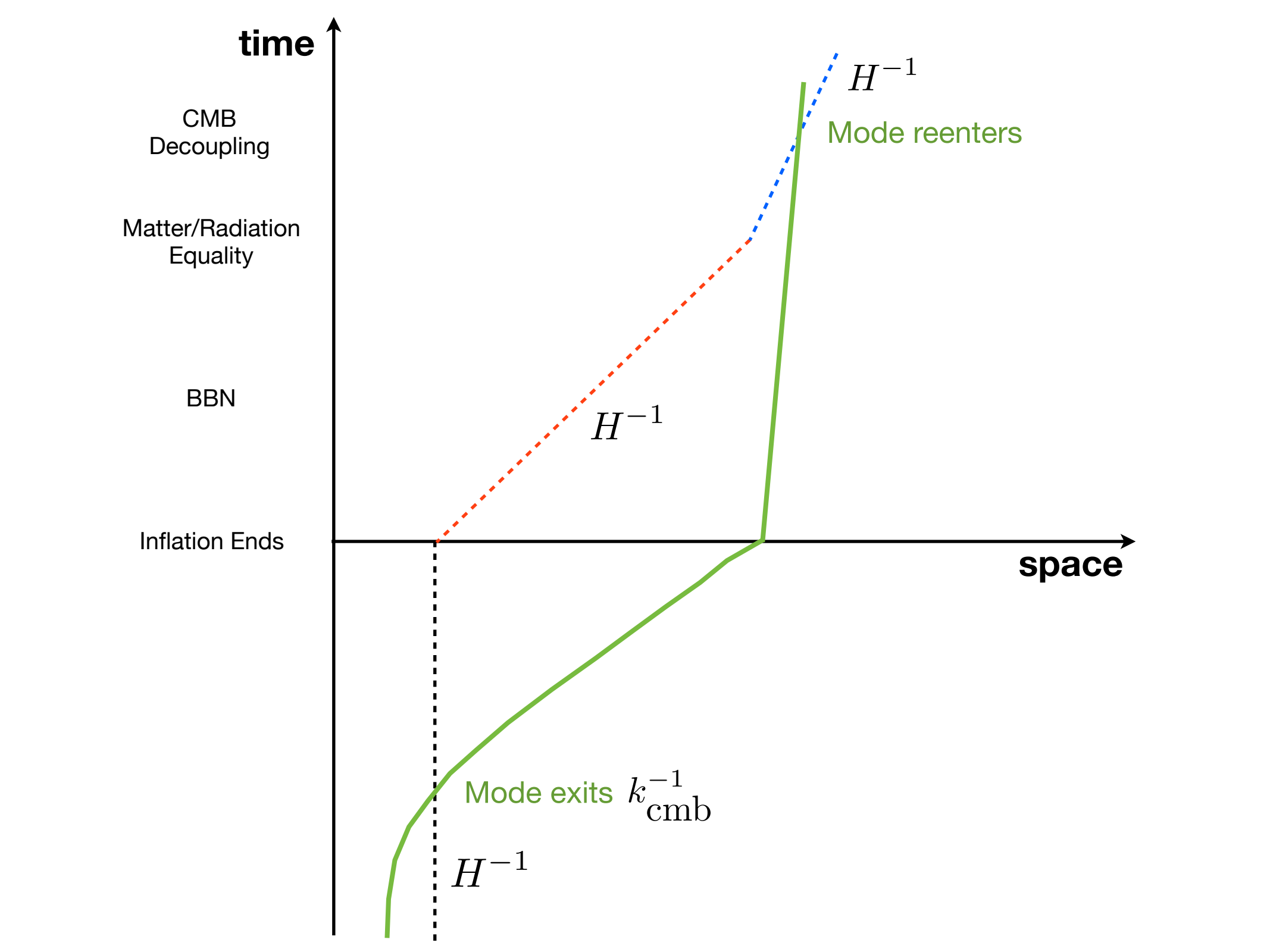




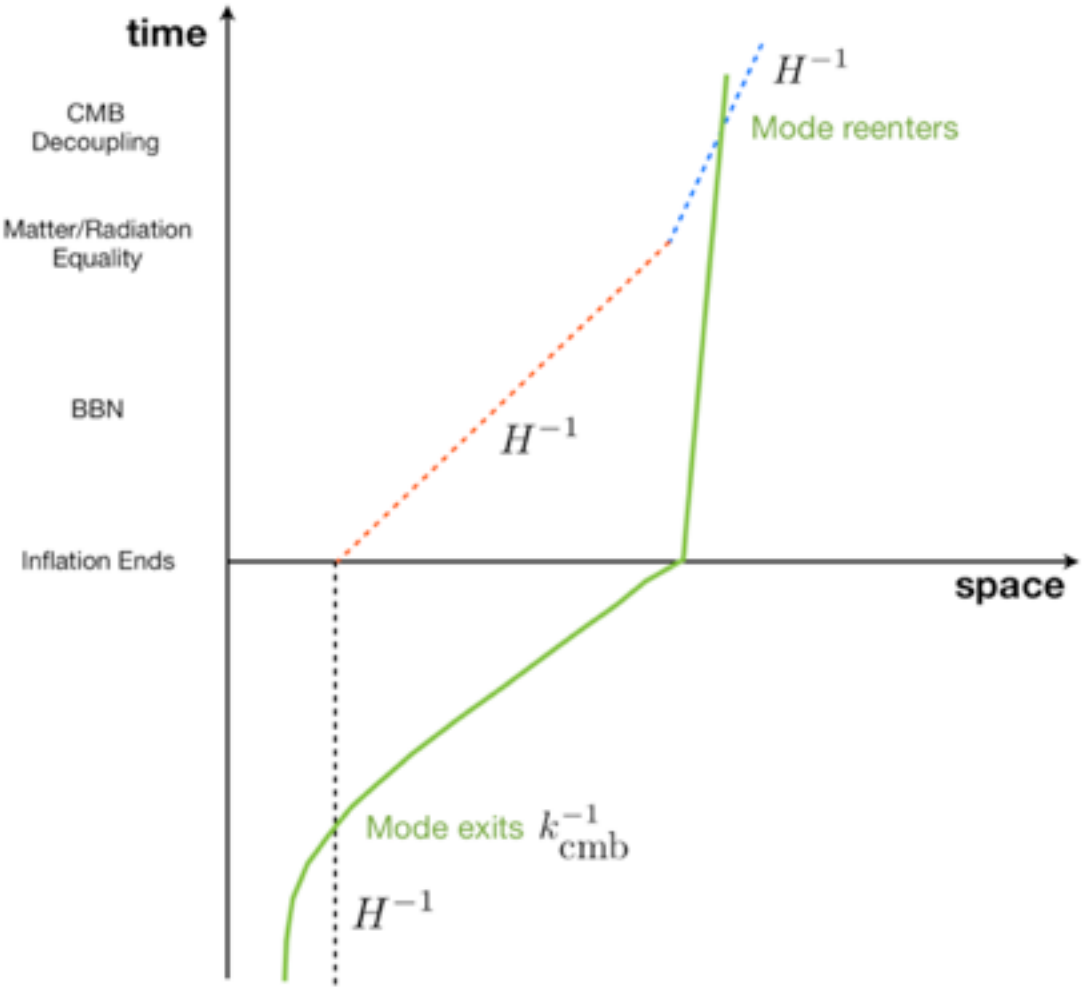




CMB modes are Super-Hubble during the Cosmic Dark Age


time
CMB
Decoupling
Matter/Radiation
Equality
BBN
Inflation Ends
H^{-1}
Mode reenters
H^{-1}
space
Mode exits $k_{\rm cmb}^{-1}$
H^{-1}

There is an uncertainty in matching observable modes today with a particular inflationary model during inflation
(related to scale of inflation and how it ends)



Matching Equation

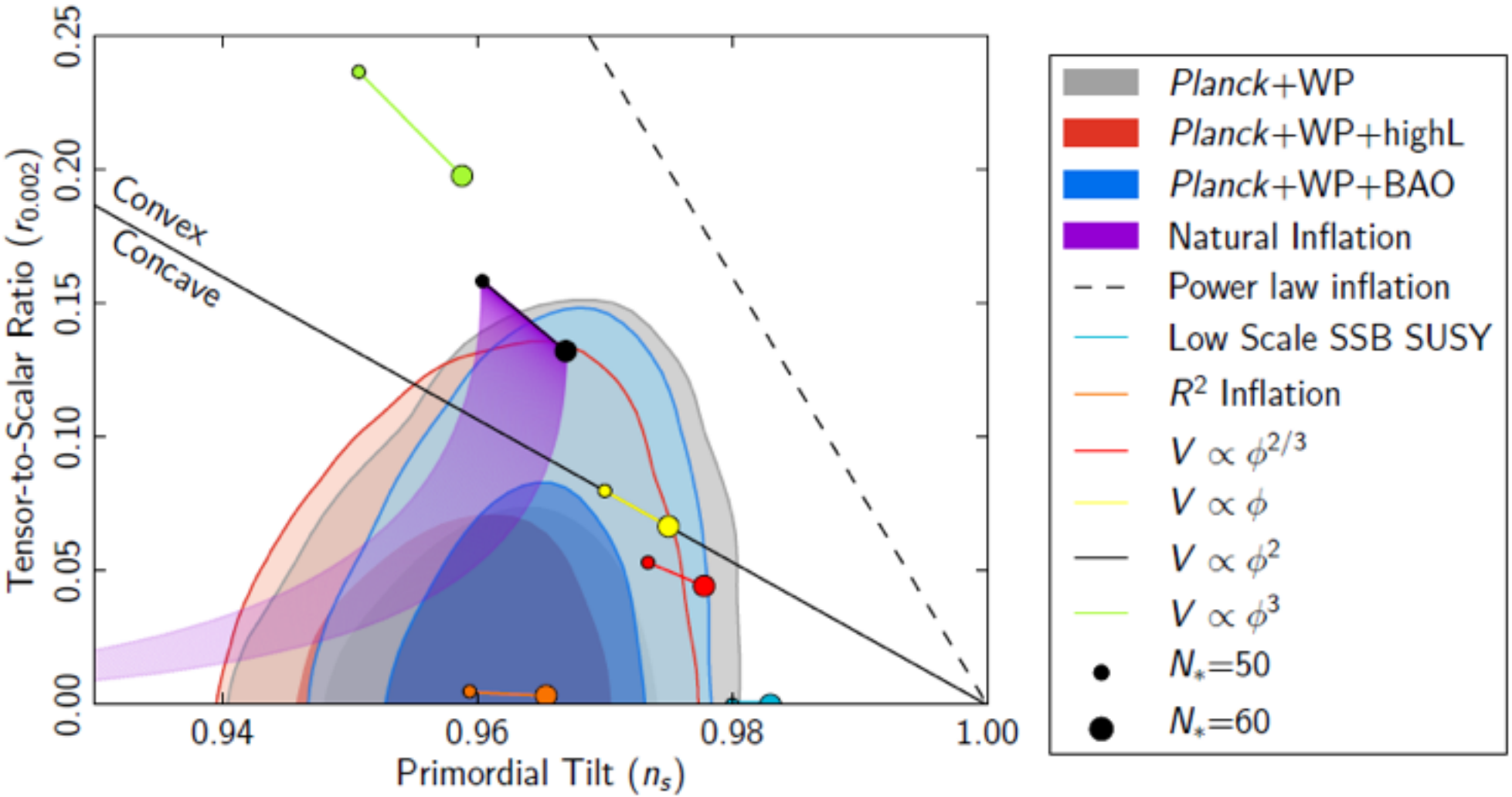
$$N(k,w) \simeq 71.21 - \ln\left(\frac{k}{a_0 H_0}\right) + \frac{1}{4}\ln\left(\frac{V_k}{m_p^4}\right) + \frac{1}{4}\ln\left(\frac{V_k}{\rho_{end}}\right)$$

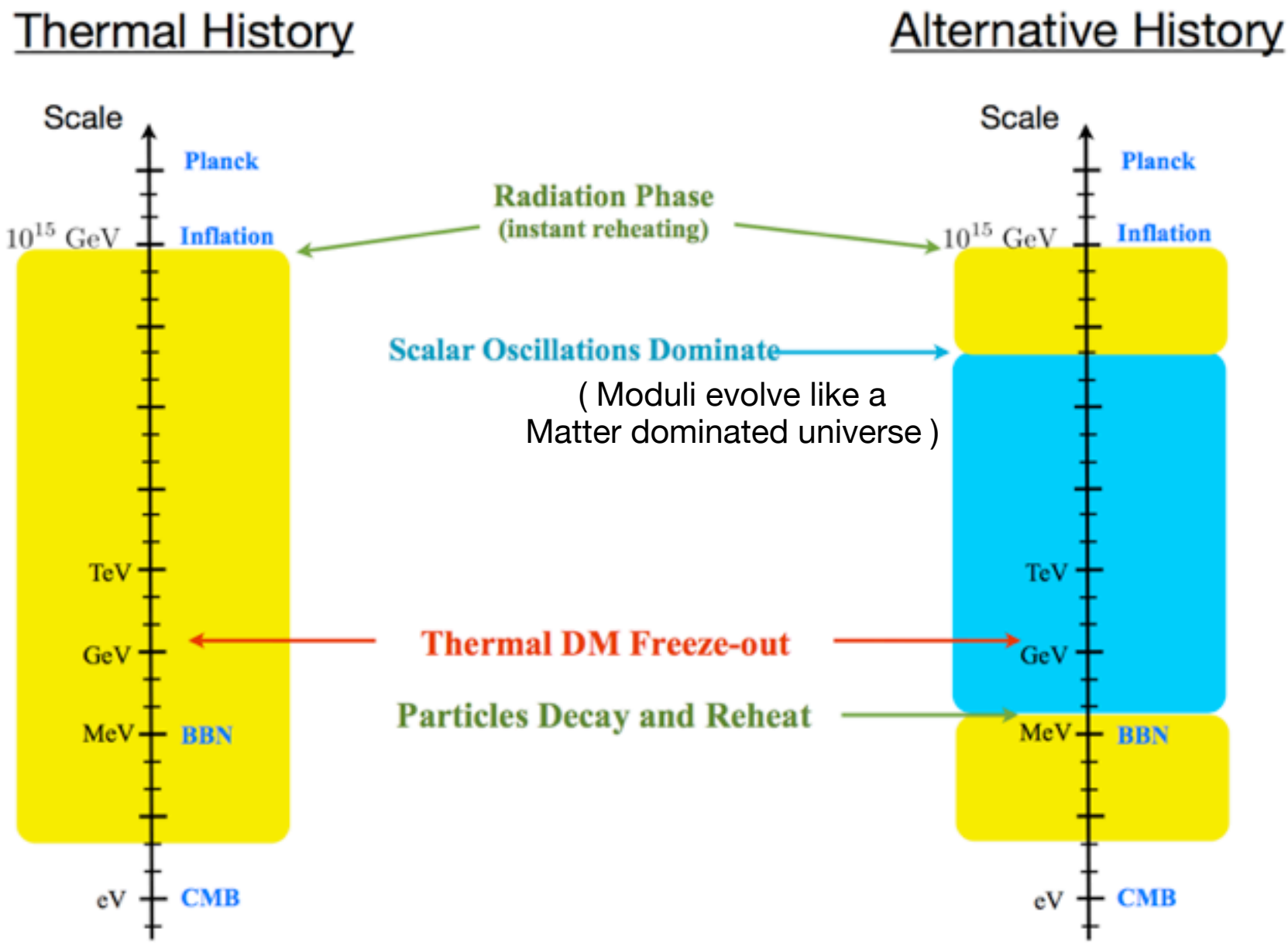
This leads to some (well known) freedom in Model Constraints

$$\Delta n_s = (n_s - 1)\left[-\frac{5}{16}r - \frac{3}{64}\frac{r^2}{n_s - 1}\right]\Big|\Delta N,$$

$$\Delta r = r\left[(n_s - 1) + \frac{r}{8}\right]\Big|\Delta N.$$

$$\Delta N \simeq 10$$





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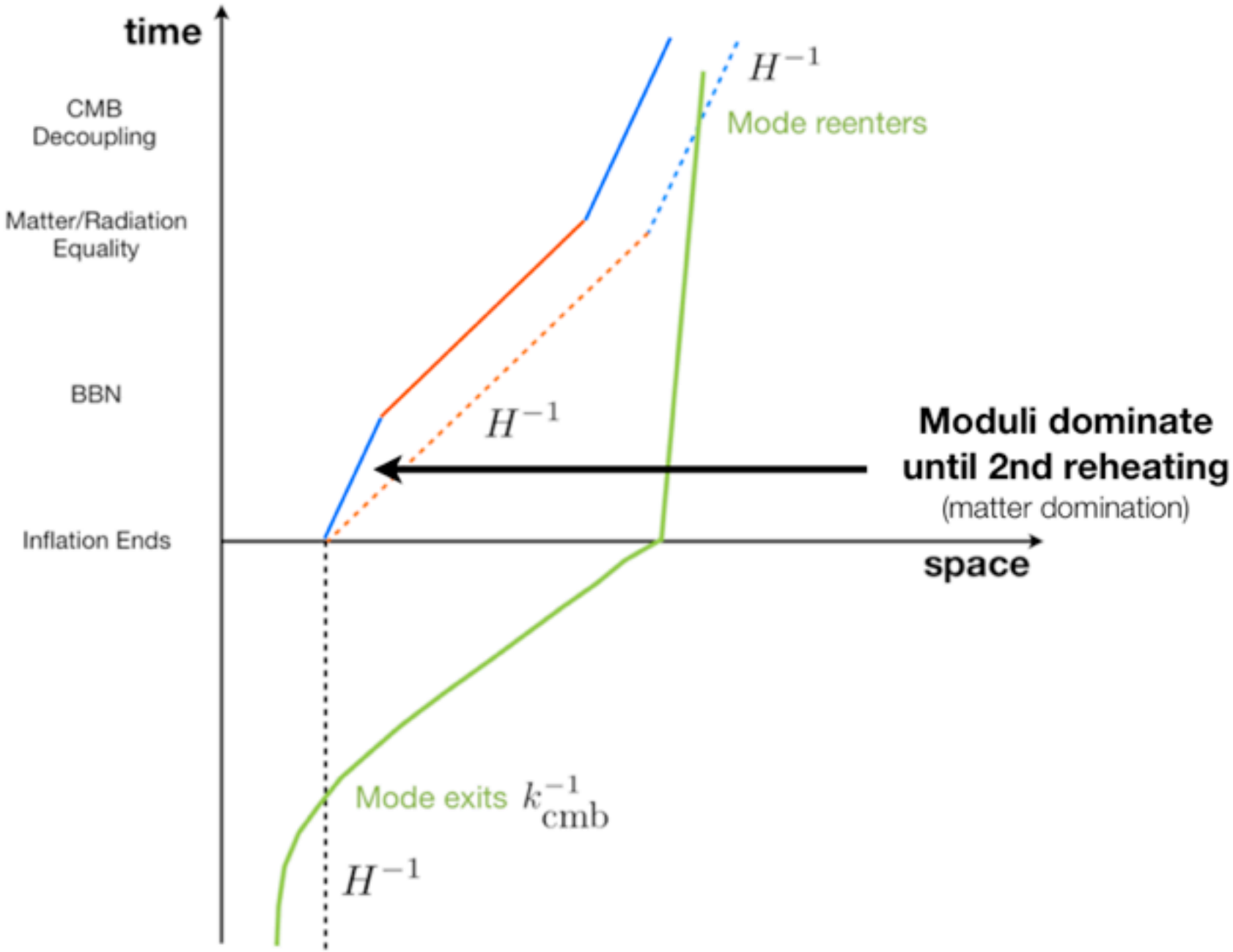
Changing the post-inflationary history introduces additional priors (2nd reheat temperature)



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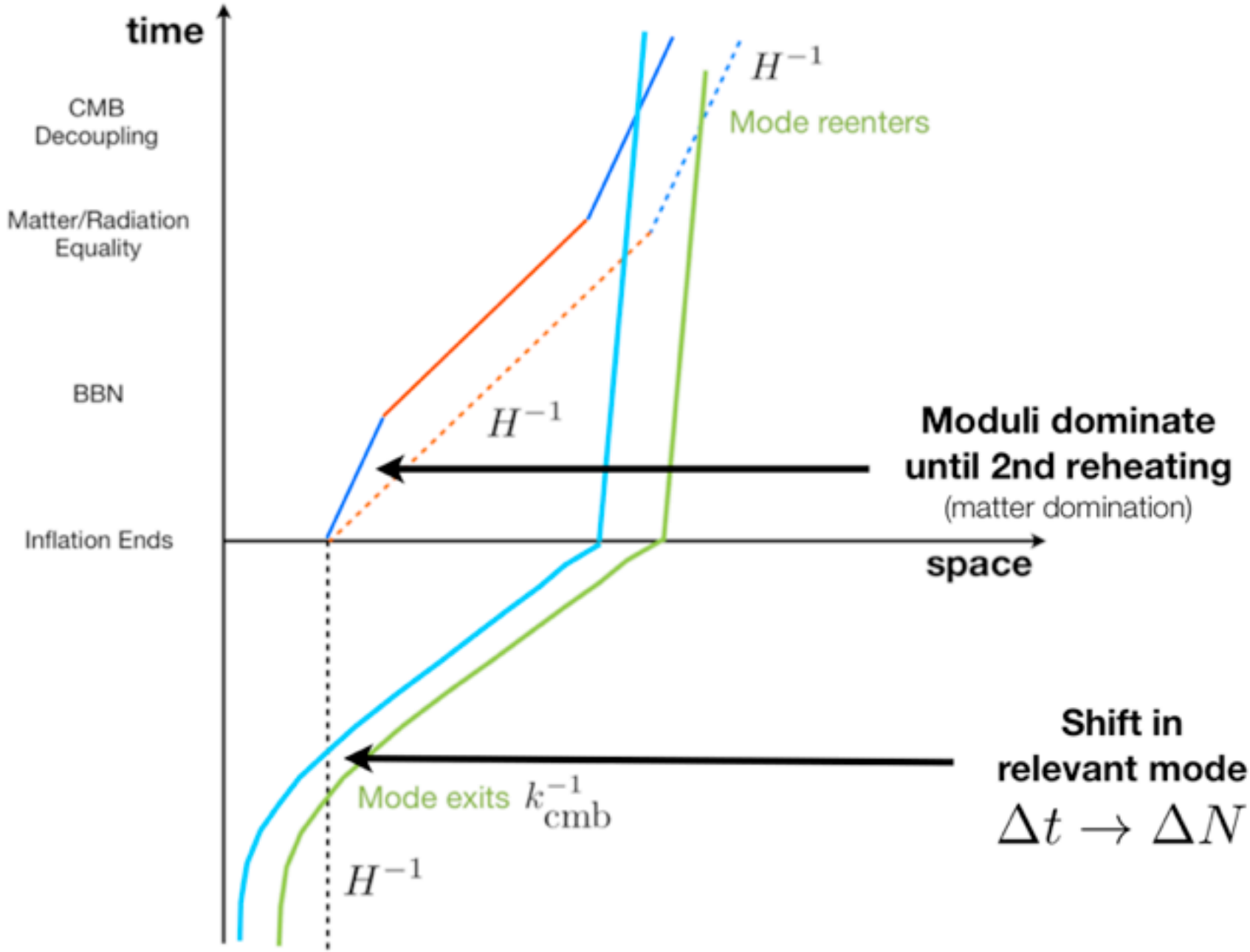
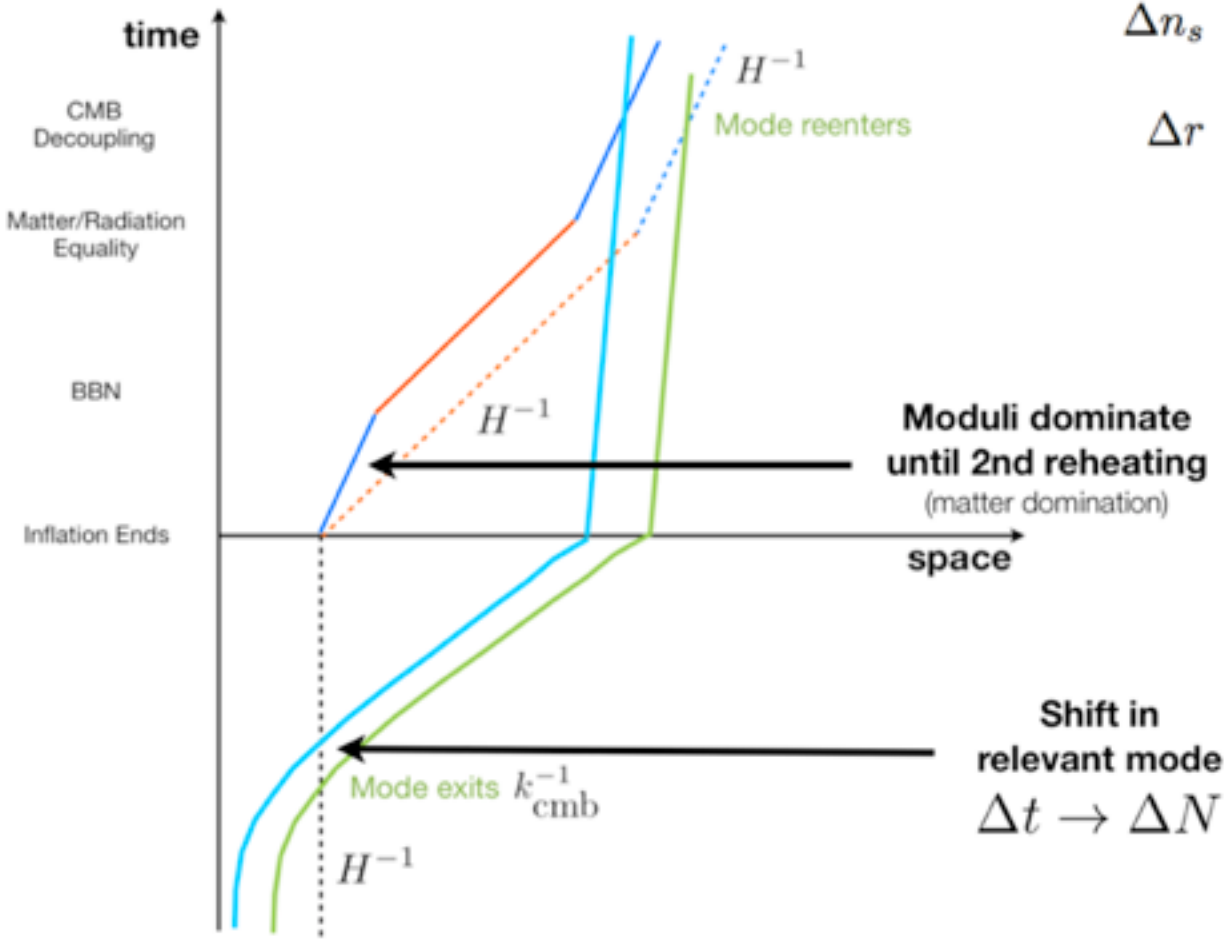


Additional freedom in constraining models

(similar to papers where people considered prolonged inflationary reheating)

$$\Delta N = -10.68 + \frac{1}{18} \ln \left[\left(\frac{g_*(T_r^\sigma)}{10.75} \right) \left(\frac{T_r}{3\ \mathrm{MeV}} \right)^4 \left(\frac{m_p}{\Delta\sigma} \right)^3 \right]$$



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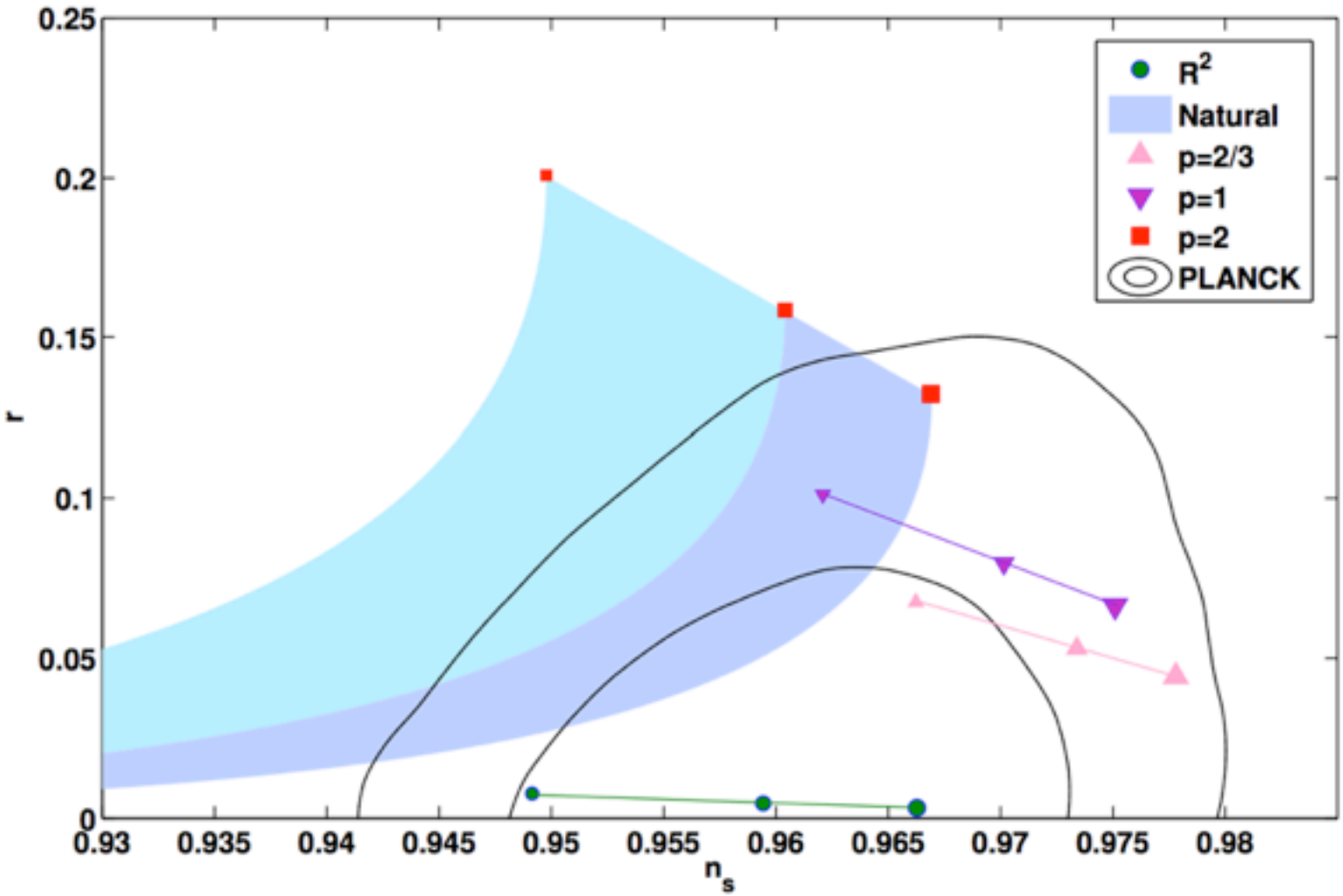
Weaker constraints for inflation in a universe with SUSY

ArXiv:1307.2453
with R. Easther (Auckland), R. Galvez, and O. Ozsoy (Syracuse)



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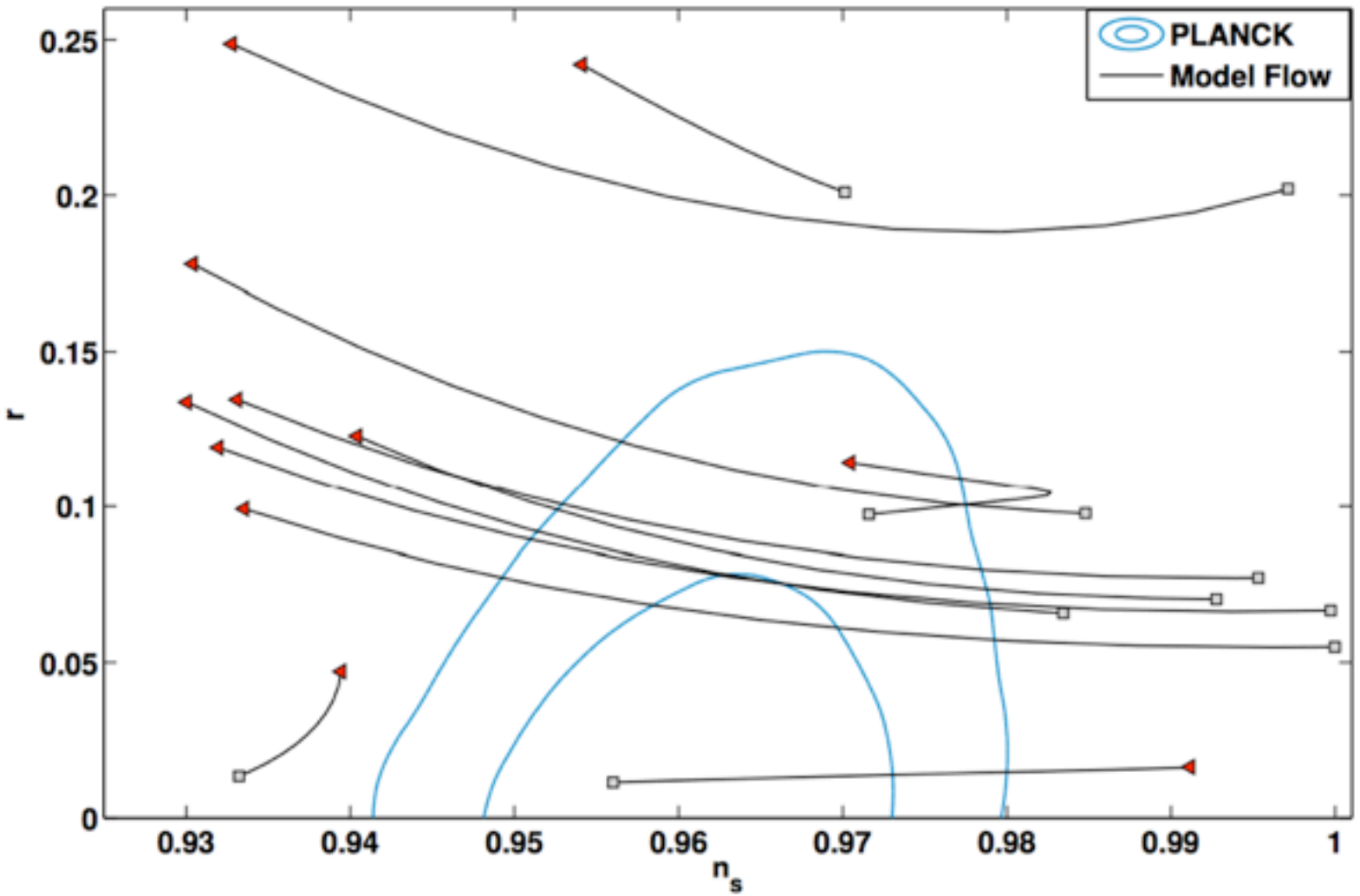
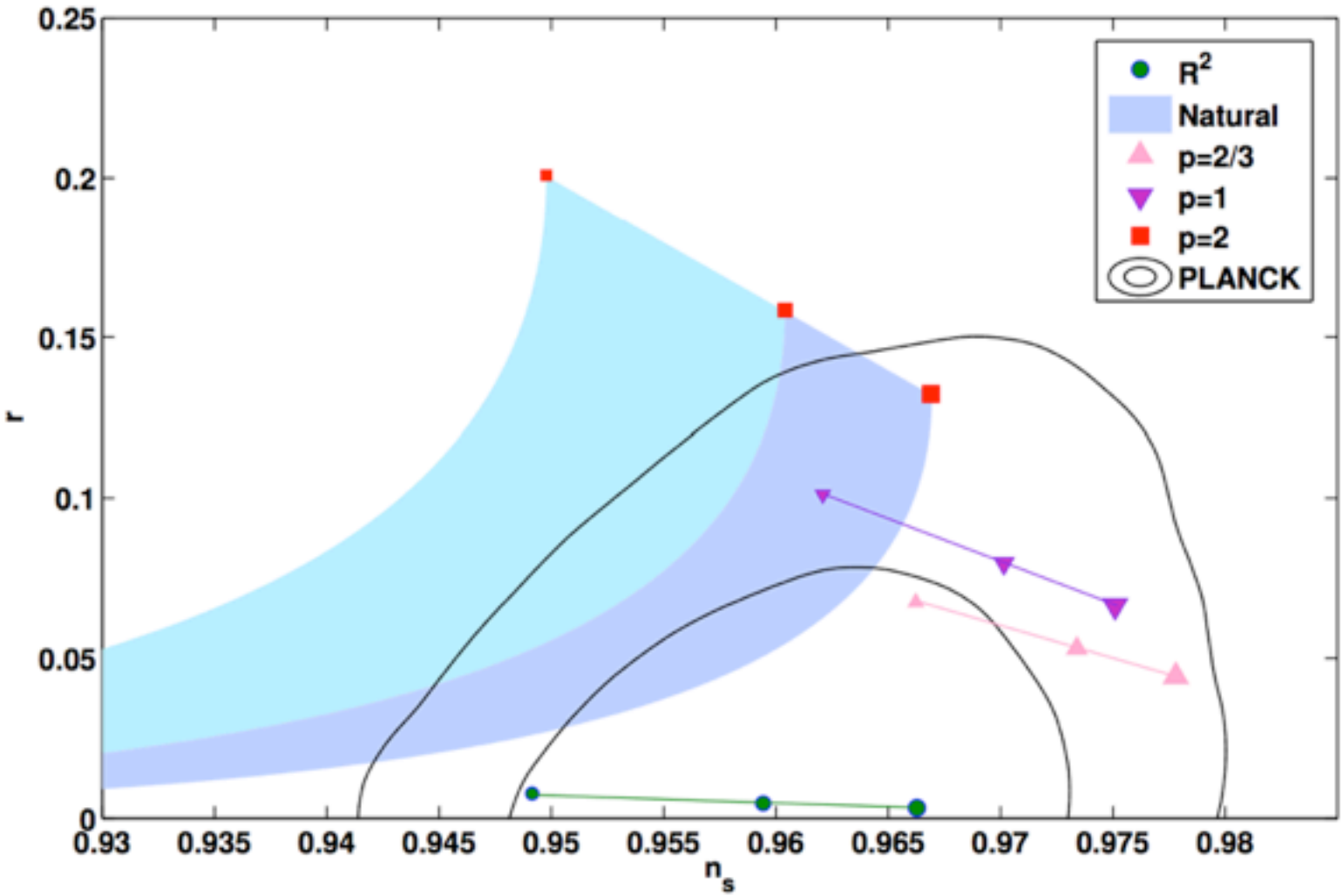
Inflation without scalars (using W. Kinney's Flow Code 1.0)



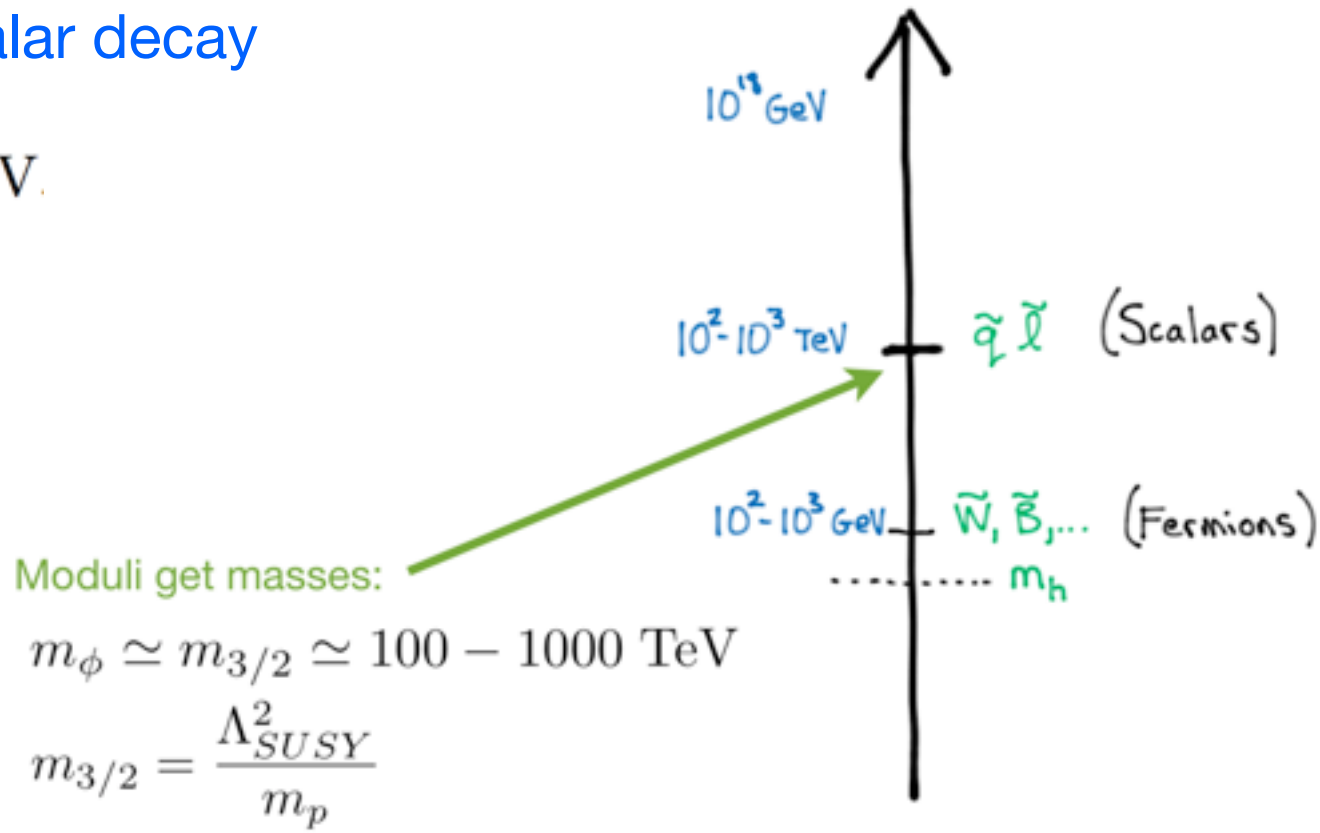
Is a universe with SUSY less constrained?



SUSY Wimps in Non-thermal Histories

2nd Reheating from Scalar decay

$$T_r \simeq \left(\frac{m_\sigma}{10\ \text{TeV}}\right)^{3/2}\ \text{MeV}$$



$$m_\phi \simeq m_{3/2} \simeq 100 - 1000\ \text{TeV}$$

$$m_{3/2} = \frac{\Lambda_{SUSY}^2}{m_p}$$

Dark matter will be dominantly non-thermal:

$$\Omega_{dm}^{NT} h^2 \simeq 0.10 \left(\frac{m_X}{100\ \text{GeV}}\right)\left(\frac{10.75}{g_*}\right)^{1/2}\left(\frac{3\times 10^{-23}\,\text{cm}^3/\text{s}}{\langle\sigma v\rangle}\right)\left(\frac{10\ \text{MeV}}{T_r}\right)$$

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Cross-section and reheat temperature related by WMAP / Planck Constraint

$$\Omega_{\mathrm{obs}} h^2 \simeq 0.12$$

Cross-section constrained by (in)direct detection of dark matter experiments!

Indirect Detection Constraints from FERMI

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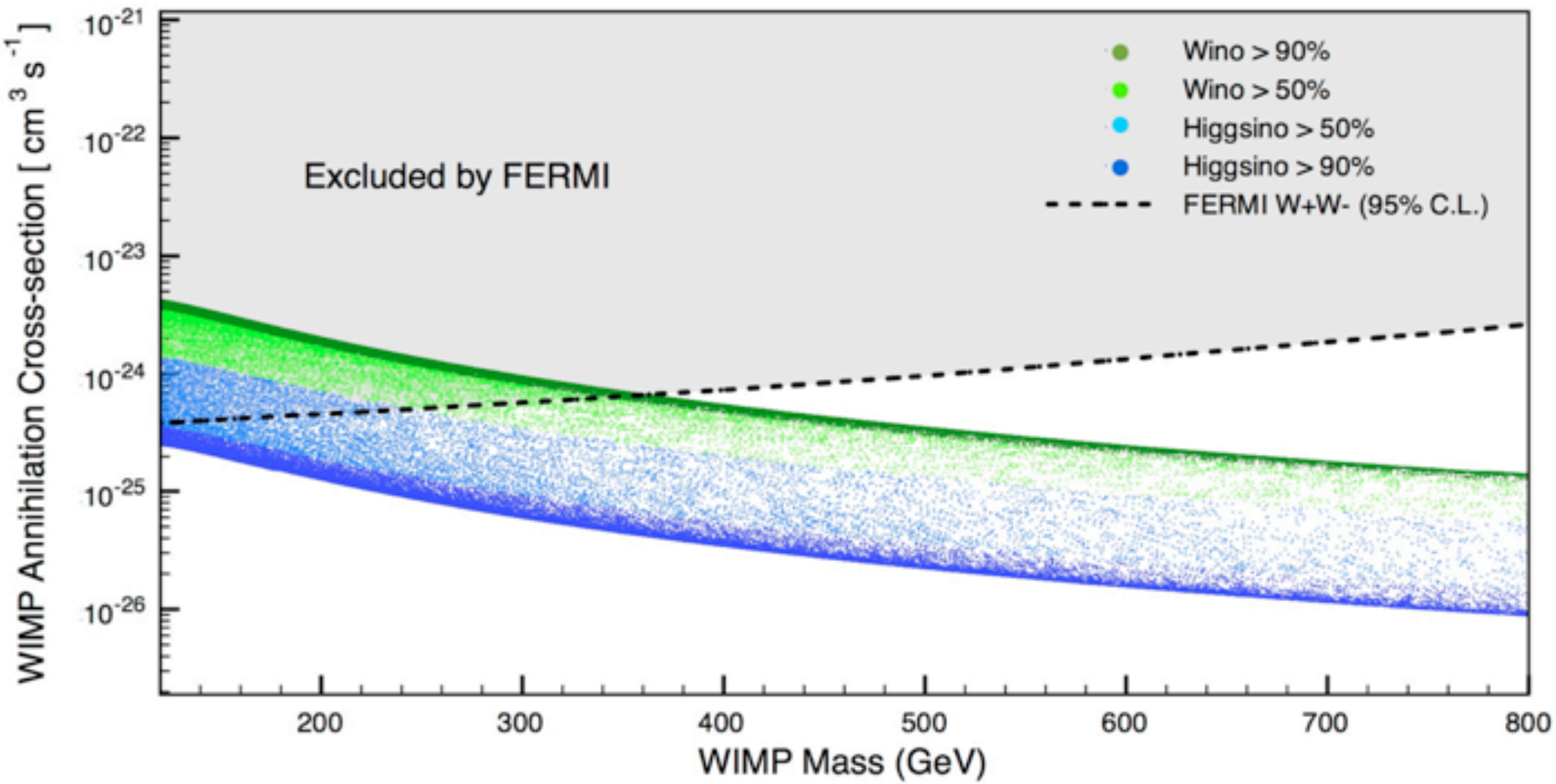

Current and Future Constraints from Xenon

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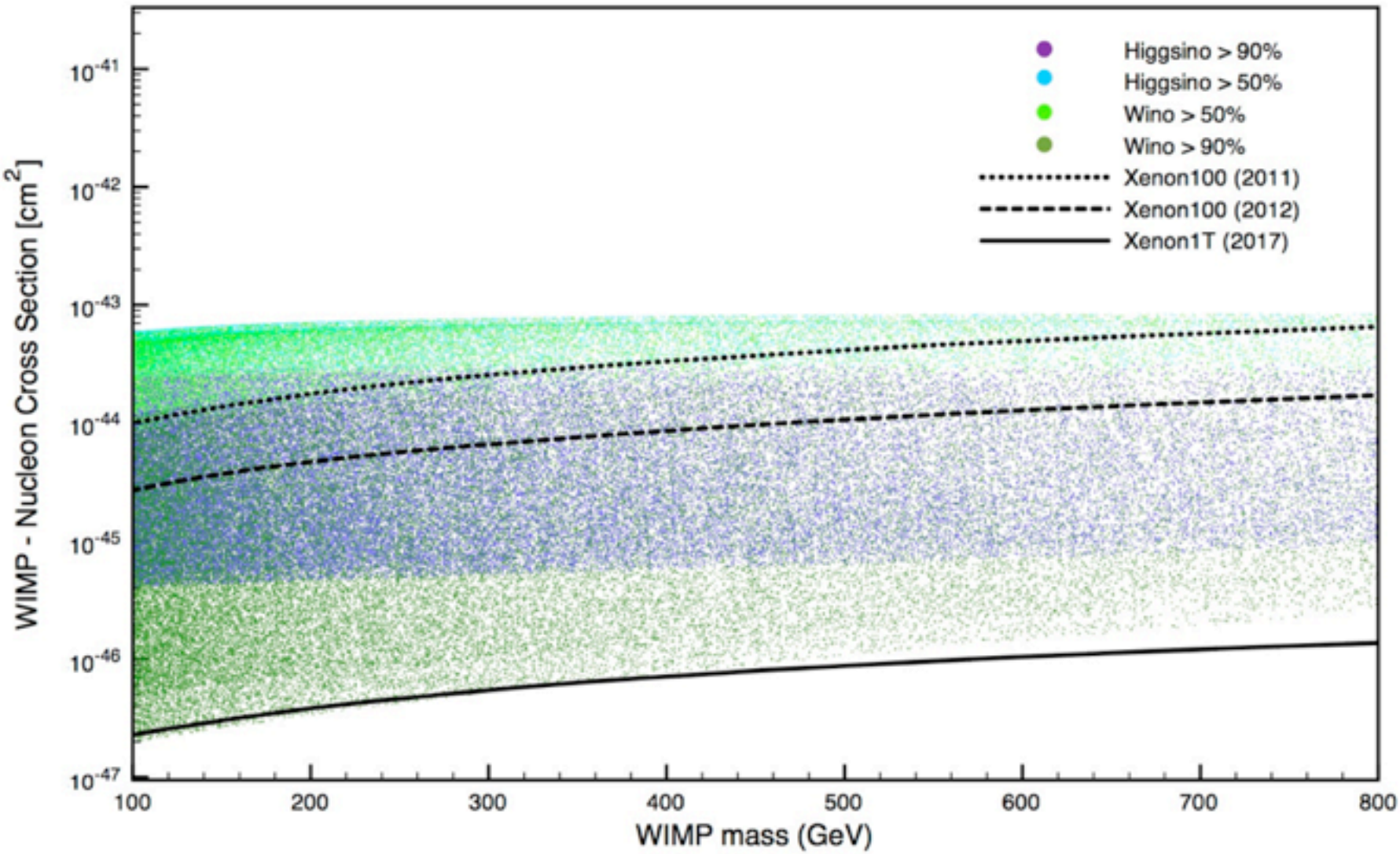


Summary of our Results

ArXiv:1307.2453
with R. Easther (Auckland), R. Galvez, and O. Ozsoy (Syracuse)

- For the pure wino we find a lower bound on the reheat temperature of around 700 MeV, substantially reducing the theoretical prior.

- More general SUSY WIMPs are also constrained, but a little more model dependence must be considered (e.g. tan beta, etc..)

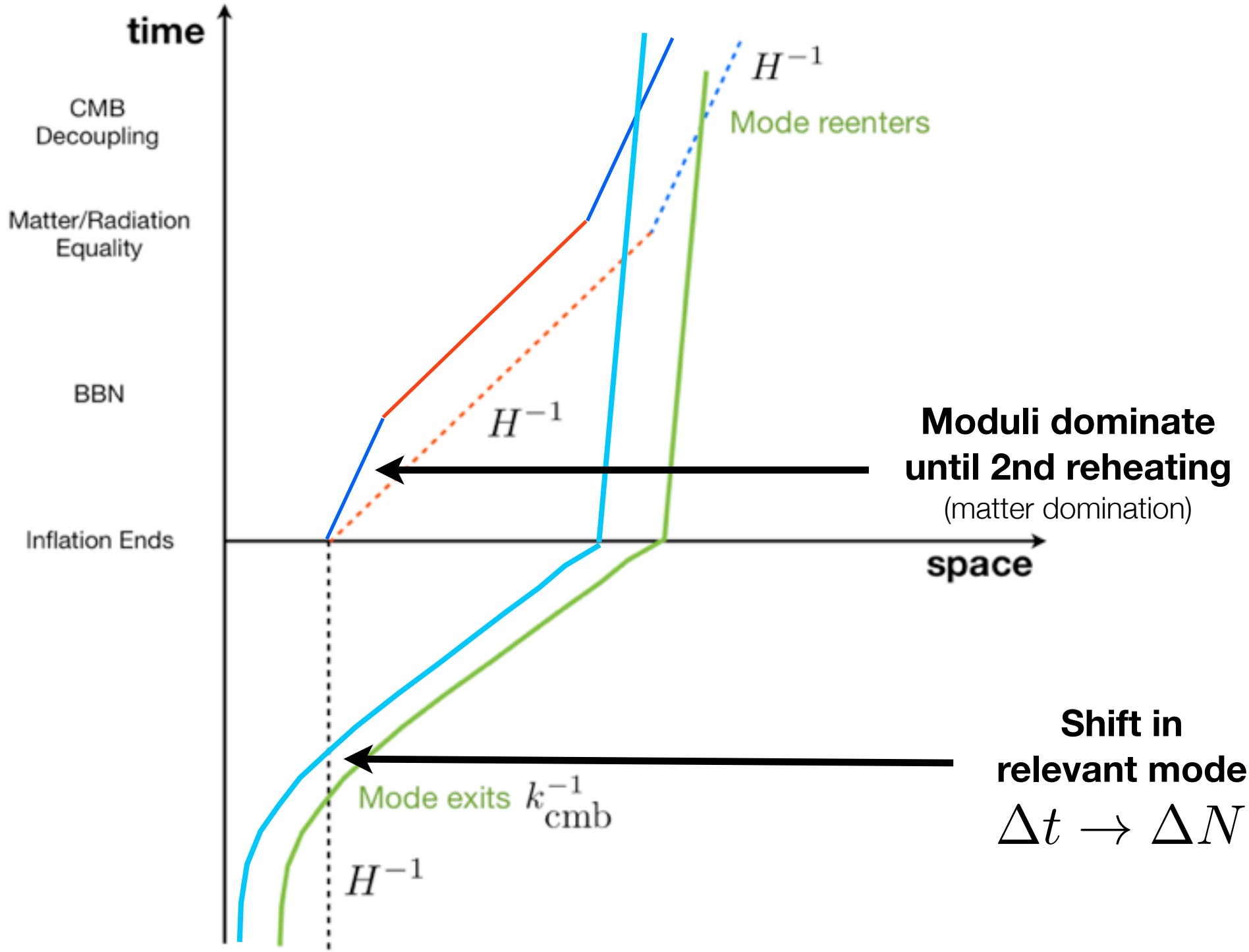
- Lesson learned: Theory Priors (SUSY / Inflation), Cosmological constraints (Planck) + Dark Matter Detection, allow us to begin to probe the “Dark Ages”.

- Including line data from HESS, Fan/Reece and Cohen, et. al. find stronger constraints on SUSY WIMPs, which will improve our bounds on the reheat temperature of all SUSY Dark Matter.

Partial list of many things I did not mention

- Gravitino Problem (model dependent)
- BBN / Lithium fit
- Baryogenesis?
  Affleck-Dine + moduli decay can address this: **Arxiv:1108.5178 with Kane, Shao, and Yu**
- Dark Radiation / N_{eff}
- Gravity Waves?
- Consequences for Matter Power Spectrum / mini-halos / Non-gaussianity
  (work in progress with O. Ozsoy)
- Effect on CMB last scattering and reionization (many authors have considered)
- Bayesian approach to post-inflation history
  work of Easther, Martin, Peiris, Ringeval and others “ModeCode”
  Include dark matter data into analysis?
  Work in progress with R. Easther and R. Galvez
- Behavior of moduli during inflation (work in progress with K. Sinha)

Thank you for your attention.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Shift in
relevant mode
$\Delta t \to \Delta N$