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Topological defects after Planck

XXV. Searches for cosmic strings and other topological defects

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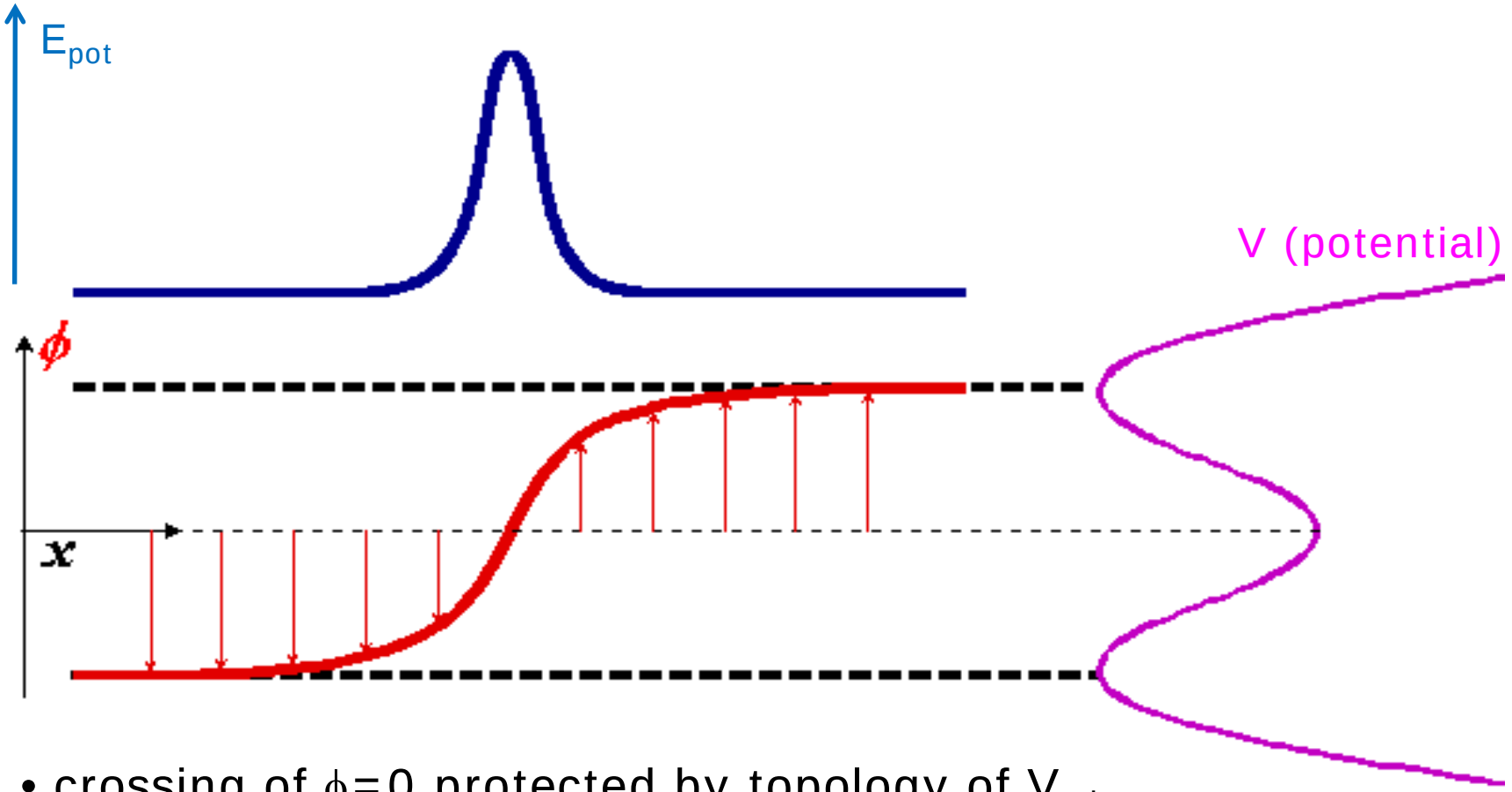
on behalf of the Planck Collaboration

what are topological defects?



- crossing of $\phi=0$ protected by topology of V_{min}
- field has to balance potential and gradient energy

why cosmic strings / defects?

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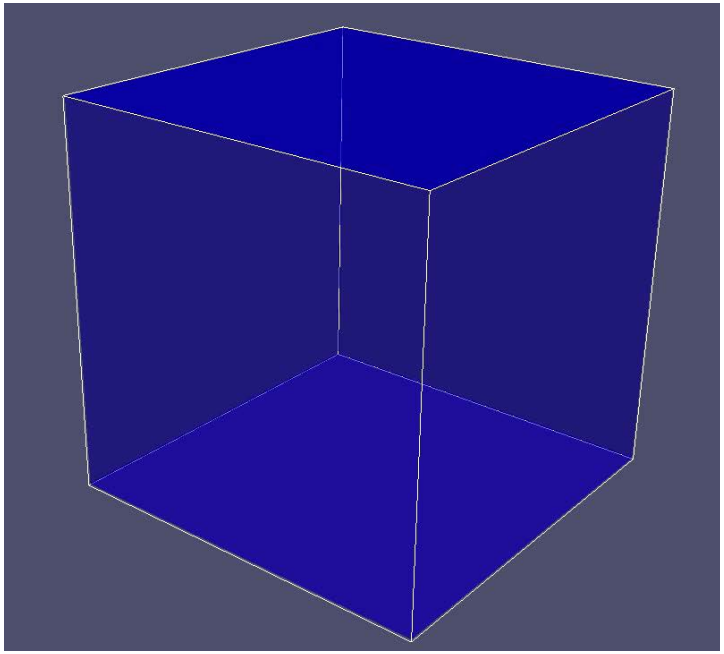
1. Realistic inflation models embedded in particle physics models generically produce phase transition remnants.
2. These topological defects create additional perturbations (+B modes +nG), visible in the CMB for GUT-scale models!
3. Defects typical for hybrid inflation models with small r



(movie: David Daverio)

(defects also emit gravitational waves and cosmic rays – really multi-messenger!)

that for e.g. $3_C\ 2_L\ 2_R\ 1_{B-L}$ stands for $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$.

$$
E_6 \xrightarrow{1} SO(10)\ 1_{V'} \begin{cases}
\xrightarrow{2} SO(10) & \longrightarrow \text{Eq. (23)} \\
\xrightarrow{1} 5\ 1_V\ 1_{V'} & \longrightarrow \text{Eq. (24)} \\
\xrightarrow{1} 5_F\ 1_V\ 1_{V'} & \longrightarrow \text{Eq. (25)} \\
\xrightarrow{1} 5_E\ 1_V\ 1_{V'} & \xrightarrow{2',2} G_{SM}\ Z_2 \\
\xrightarrow{2} 5\ 1_{V'}\ Z_2 & \longrightarrow \text{Eq. (24a)} \\
\xrightarrow{1,2} 5\ 1_V & \longrightarrow \text{Eq. (23a)} \\
\xrightarrow{1} 5_F\ 1_V & \xrightarrow{2',2} G_{SM}\ Z_2 \\
\xrightarrow{1} G_{SM}\ 1_V & \xrightarrow{2} G_{SM}\ Z_2 \\
\xrightarrow{1,2} G_{SM}\ 1_{V'}\ Z_2 & \xrightarrow{2} G_{SM}\ Z_2 \\
\xrightarrow{1,2} 4_C\ 2_L\ 2_R\ 1_{V'} & \longrightarrow \text{Eq. (26)} \\
\xrightarrow{1} 4_C\ 2_L\ 2_R & \longrightarrow \text{Eq. (27)} \\
\xrightarrow{1} 3_C\ 2_L\ 2_R\ 1_{B-L}\ 1_{V'} & \longrightarrow \text{Eq. (26c)} \\
\xrightarrow{1} 3_C\ 2_L\ 1_R\ 1_{B-L}\ 1_{V'} & \longrightarrow \text{Eq. (26b)}
\end{cases} \tag{22}
$$

Sakellariadou, hep-th/0702003

levels of approximations

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String/M-theory

Energy << M_p

Quantum Field Theory

Large occupation number

Classical Field Theory

Bevis, Hindmarsh, Urrestilla, MK et al, astro-ph:0605018
arXiv:0704.3800, arXiv:1005.2663

Low curvature string configurations

Classical Nambu-Goto Strings

Allen (1997)
Contaldi et al (1998)
Landriau et al (2004)
Olum et al (2005)
Ringeval et al (2005)
Martins & Shellard (2006)

Phenomenological

Unconnected segment model

Perivolaropoulos (1995)
Albrecht et al (1997)
Wyman et al (2005,2006)
Pogosian et al (1999, 2006)

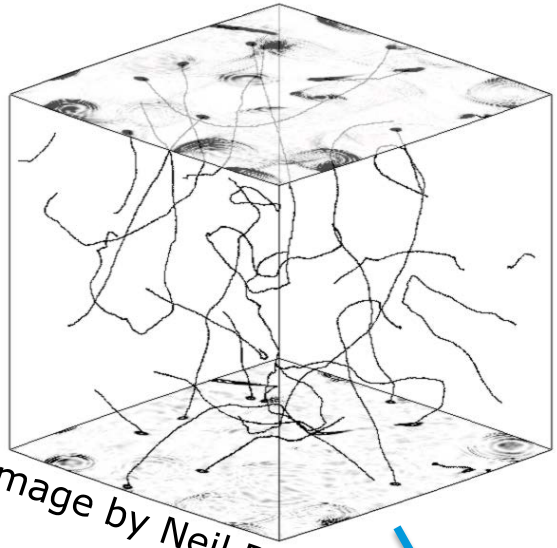
(can fit both field theory & NG)

increasing dynamic range / speed

esa

European Space Agency

string simulations



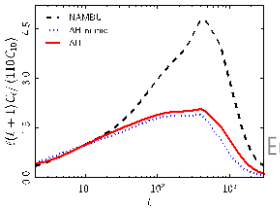
(image by Neil Bevis)

measure USM parameters

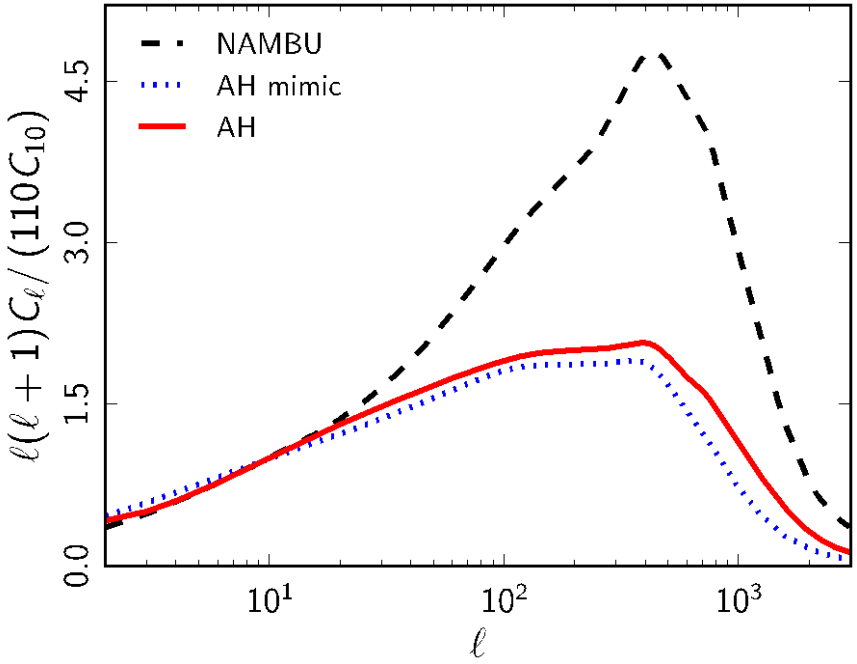
create realizations and measure EMT

feed through Boltzmann code

measure correlation fct of energy-moment tensor



string spectra



cosmic strings

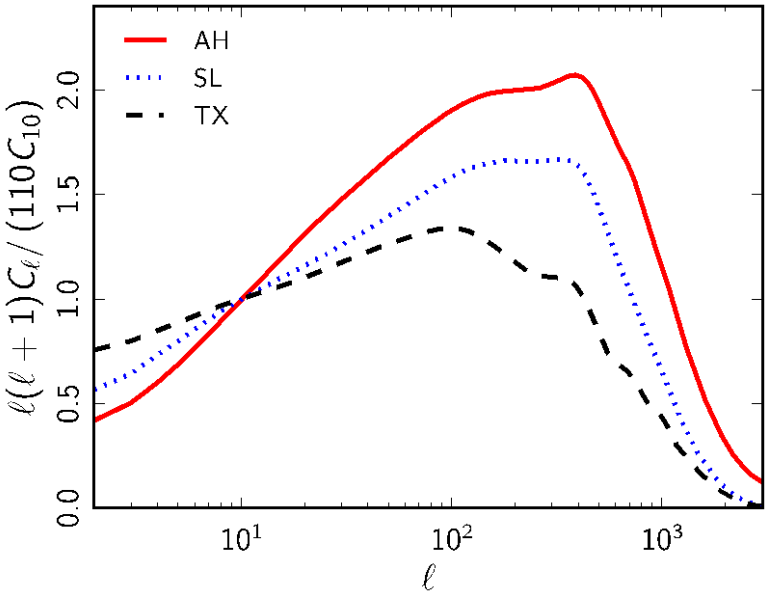
NAMBU: USM fitted to Nambu-Goto

AH: Abelian-Higgs field theory sim
AH mimic: USM fitted to AH

NAMBU has more and heavier strings, especially during radiation era

other defects

TX: global O(4) texture (no gauge fields, `unwinding events')
SL: semilocal strings (additional scalar making strings unstable)



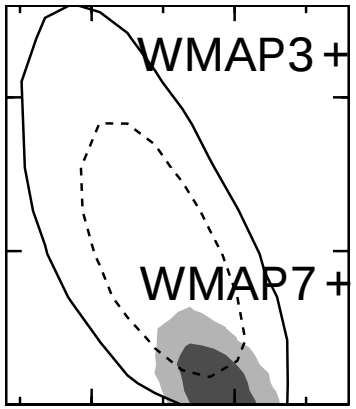
cosmic strings before Planck

Model	Data set	$10^6\,G\mu$ (95%)	f_{10} (95%)
AH [25]	WMAP3+BOOMERANG+CBI+ACBAR+VSA	0.7	0.11
AH (this work)	WMAP7	0.57	0.095
AH (this work)	WMAP7 + ACBAR + QUAD + ACT	0.42	0.048
USM-AH [35]	(Battye & Moss) WMAP5	0.68	0.11
USM-NG [35]	(Battye & Moss) WMAP5	0.28	0.054
USM-NG [5]	WMAP7+ACT	0.16	(0.018)

Gμ: string scale (1 = Planck scale)

f_{10}: ratio of C_l from inflation and defects at l = 10

$n_s = 1$



gravitational waves:
10^6 Gμ < 0.53
(Sanidas et al, arXiv:1201.2419)

Hybrid SUSY inflation predicts strings, wants typically n_s close to 1

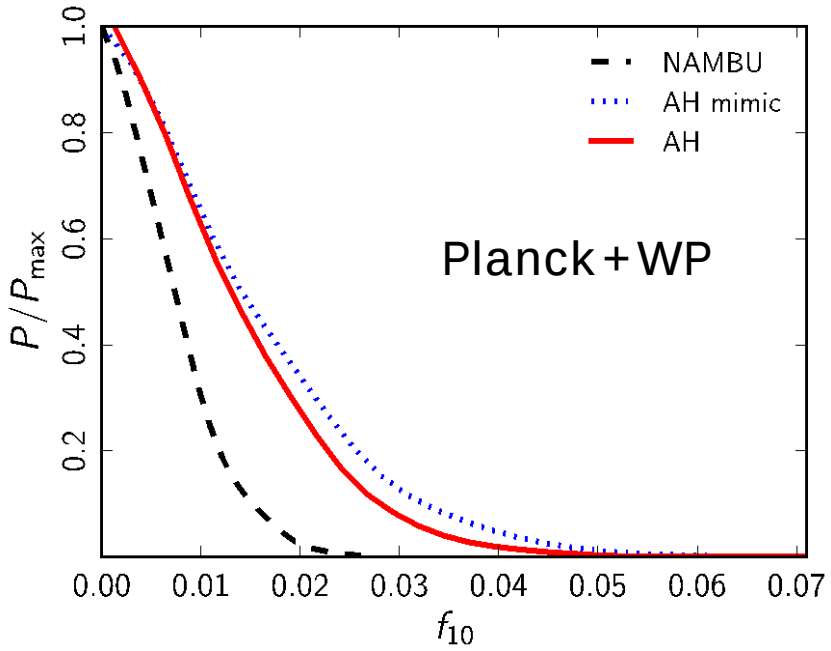
Urrestilla et al, arXiv:1108.2730, see also Battye & Moss, arXiv:1005.0479

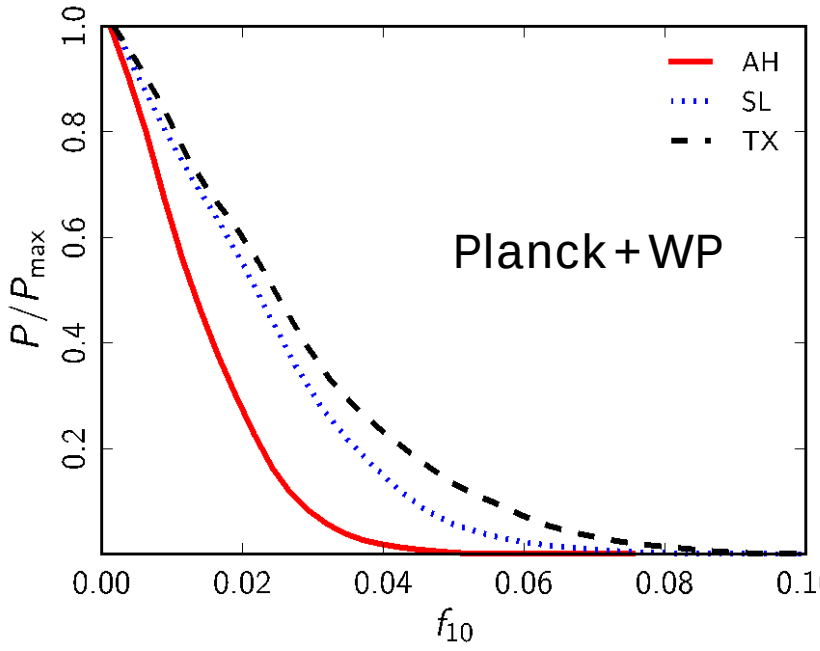
Planck constraints on defects

Defect type	*Planck*+WP		*Planck*+WP+highL	
	f_{10}	$G\mu/c^2$	f_{10}	$G\mu/c^2$
NAMBU	0.015	1.5×10^{-7}	0.010	1.3×10^{-7}
AH-mimic	0.033	3.6×10^{-7}	0.034	3.7×10^{-7}
AH	0.028	3.2×10^{-7}	0.024	3.0×10^{-7}
SL	0.043	11.0×10^{-7}	0.041	10.7×10^{-7}
TX	0.055	10.6×10^{-7}	0.054	10.5×10^{-7}

Planck + WP:

~ factor 2 improvement in f_{10}!





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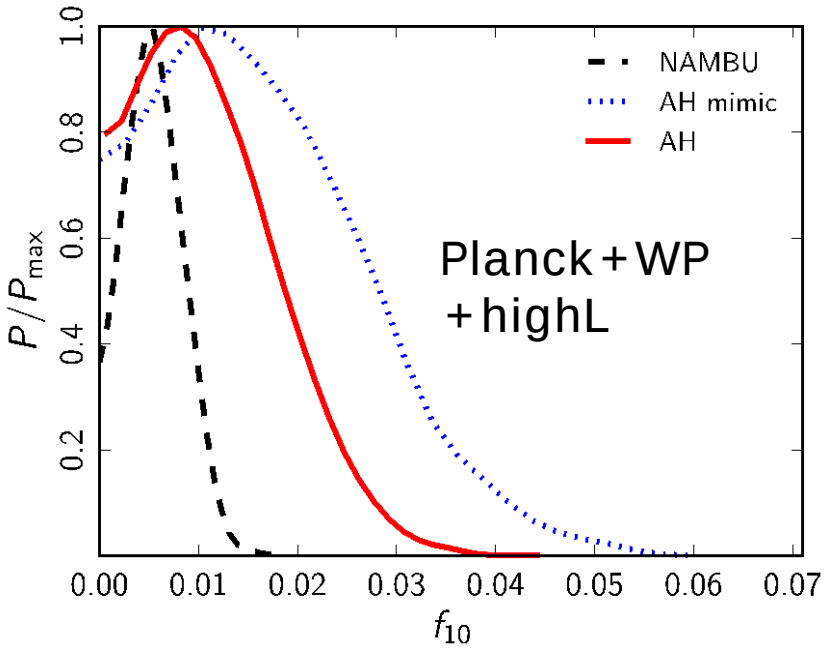
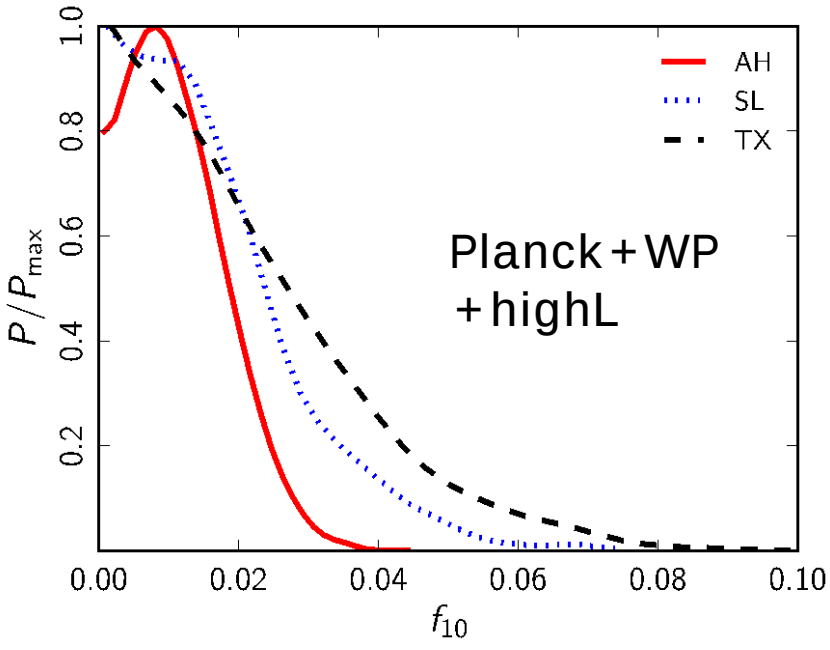
adding ACT+SPT:

constraints not strongly improved because peak moves!





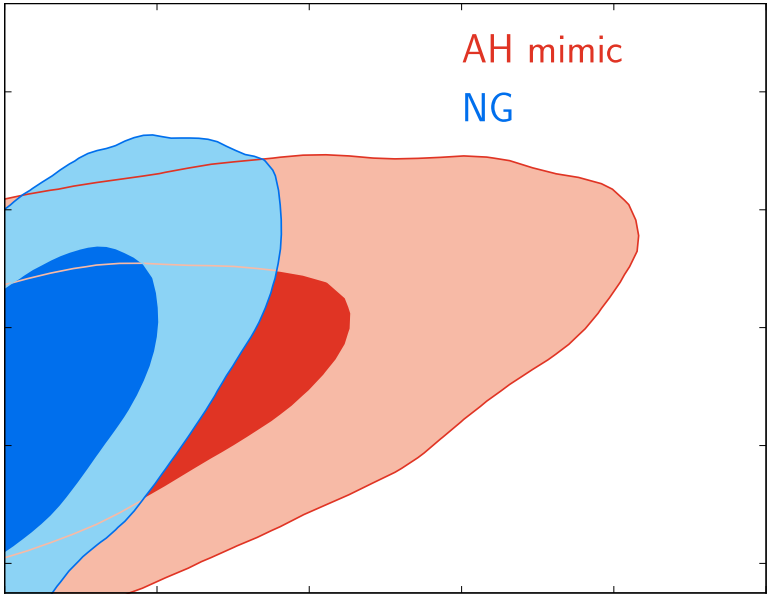
degeneracies

Parameter	NAMBU	AH *mimic*	AH	SL	TX
$\Omega_b h^2$	0.0223 ± 0.0003	0.0223 ± 0.0003	0.0223 ± 0.0003	0.0223 ± 0.0003	0.0223 ± 0.0003
$\Omega_c h^2$	0.119 ± 0.003	0.119 ± 0.003	0.119 ± 0.003	0.119 ± 0.003	0.119 ± 0.003
θ_{MC}	1.0415 ± 0.0006	1.0415 ± 0.0006	1.0415 ± 0.0006	1.0415 ± 0.0006	1.0415 ± 0.0006
τ	0.089 ± 0.013	0.090 ± 0.013	0.090 ± 0.013	0.090 ± 0.013	0.088 ± 0.014
$\log(10^{10} A_s)$	3.080 ± 0.027	3.080 ± 0.026	3.081 ± 0.025	3.081 ± 0.025	3.078 ± 0.028
n_s	0.961 ± 0.007	0.963 ± 0.008	0.963 ± 0.008	0.964 ± 0.007	0.965 ± 0.008
H_0	68.4 ± 1.3	68.3 ± 1.2	68.3 ± 1.3	68.2 ± 1.2	68.3 ± 1.2
$G\mu/c^2$	$< 1.5 \times 10^{-7}$	$< 3.6 \times 10^{-7}$	$< 3.2 \times 10^{-7}$	$< 1.10 \times 10^{-6}$	$< 1.06 \times 10^{-6}$
f_{10}	< 0.015	< 0.033	< 0.028	< 0.043	< 0.055

No significant degeneracies with the standard parameters left!

$n_s = 1$ strongly ruled out

(But some extended model parameters are degenerate with strings, e.g. N_{eff} or Y_p)

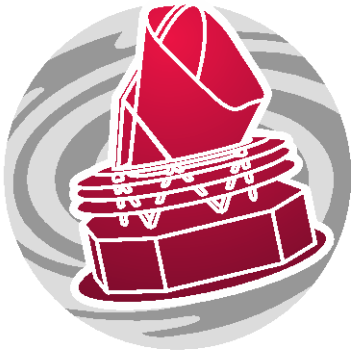


after Planck is before Planck!

- Cosmic string constraints at **$G\mu = 1.3\times10^{-7}$ / 3×10^{-7}**
- Contributing no more than **1% to 2.4%** to CMB at l=10 (up to ~ 5% for other defect models)
- **No degeneracy** with standard parameters, $n_s<1$
- Problematic for D-/F-term hybrid inflation models (cf Battye et al, arXiv:1001.0769)

- **Full mission + polarization data will improve constraints even further**
- More models will start to be in trouble (or confirmed!) (e.g. Higgs inflation MSSM with $G\mu\approx1\times10^{-7}$ and $n_s\approx0.976$, Hindmarsh & Jones arXiv:1301.4890)

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada



Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.