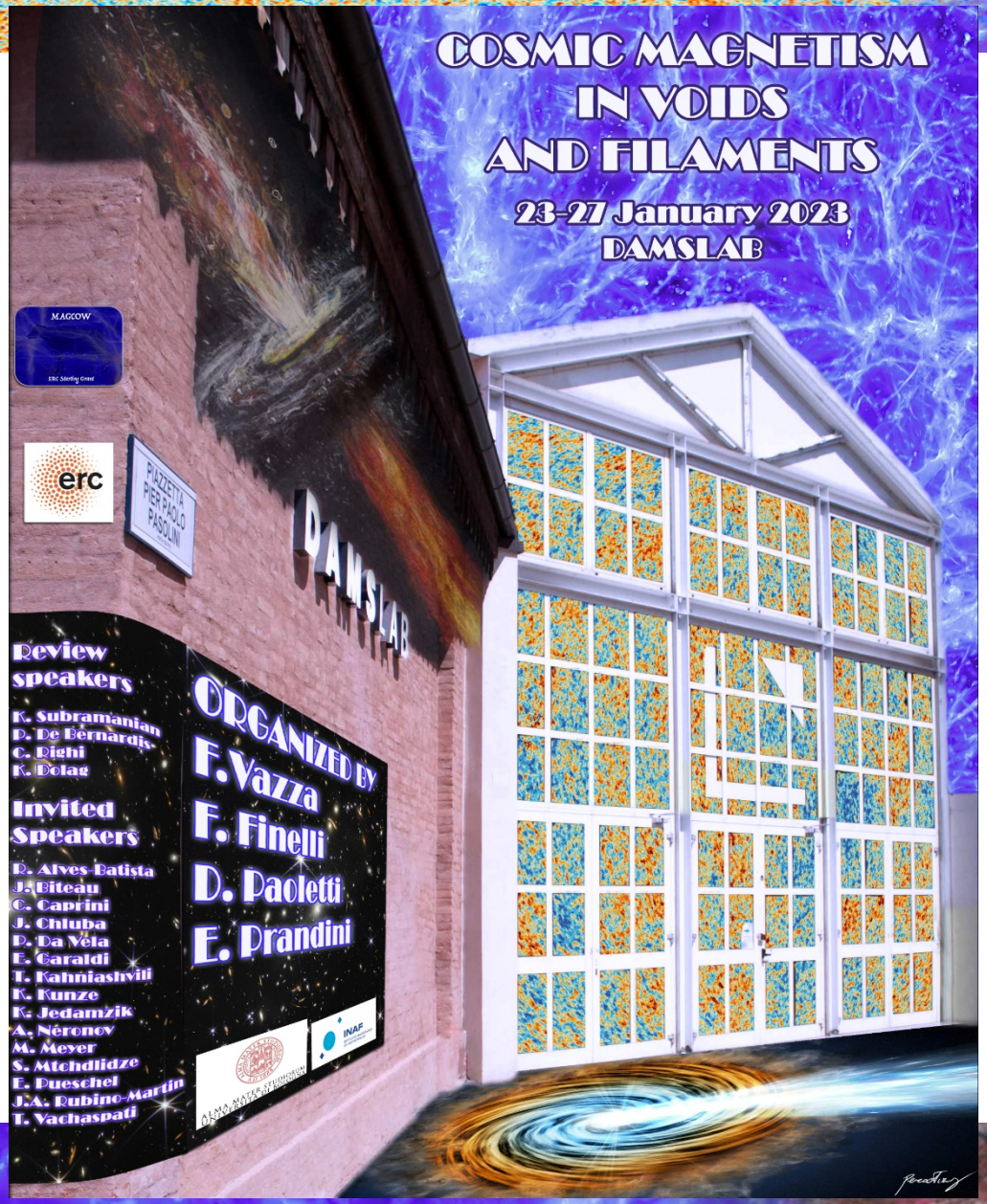


Discussion on the future probes for primordial magnetism

A little Fairytale

A long time ago , in a Galaxy far far away

Well ok actually it was Monte Verità in Ascona 2009

A little group of brave scientists met to gather strenght to convince the world that PMF are important

With very little success….

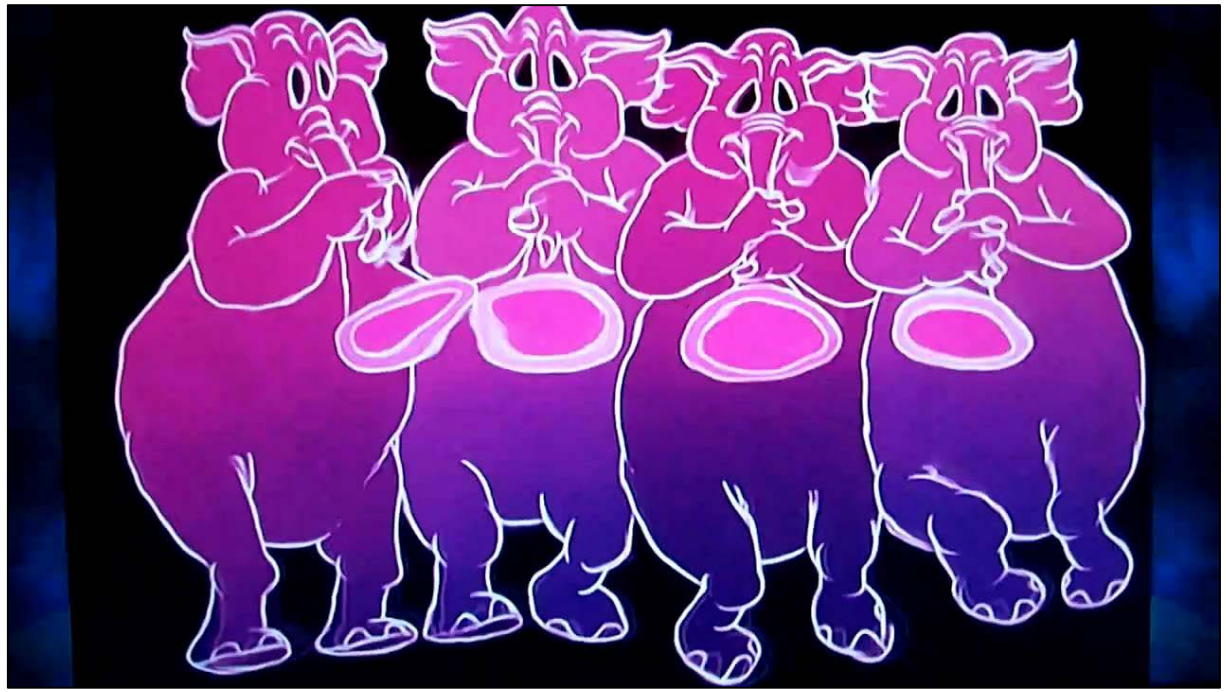
But in 2010 Neronov and Vovk came to the rescue, with a very unexpected evidence (not for Klaus who knew all along)

It took some time…

But now PMF are considered as one of the main science target for future experiments and the brave scientists are here filling an entire theatre discussing about such amazing science

And they discussed about PMF effects and limits happily ever after

We probably need to change our talks intros, Cosmic Magnetism is still the big giant pink dancing elephant in the cosmology room but now the world does not ignore it anymore but dances with it!
We have spent a week discussing the connection between PMF and Cosmic Magnetism but the importance of PMF does not stop here

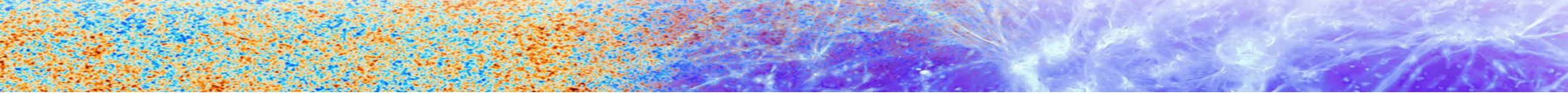


Disclaimer: if you really see pink dancing elephant in the room, either you are still drunk from the social dinner or please inform the SOC since maybe the combo of slaughterhouse, warfield ghosts and swamplands is becoming dangerous

From the characteristics of primordial magnetism we can infer important information on the fundamental physics in the early Universe.
Causal PMF imply first order phase transitions, currently disfavoured…this would open an entire world for theoretical physicists with implications for example for supersymmetry
Inflationary PMF imply a whole bunch of non standard physics…additional fields..breaking fo conformal invariance…ways to overcome the back reaction or the strong coupling problem

This means that PMF can provide a unique unconventional and amazing insight on the fundamental physics in the early Universe!

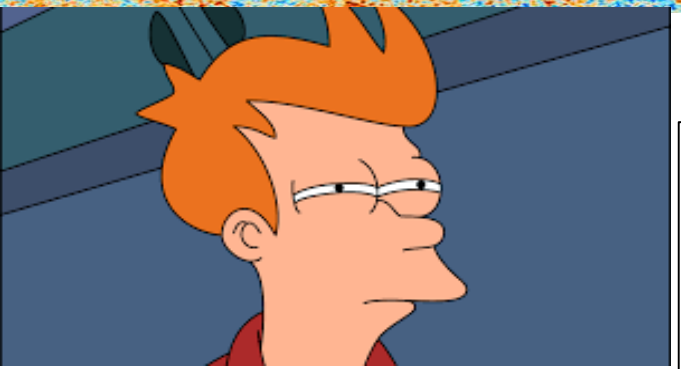
Cesare's insight

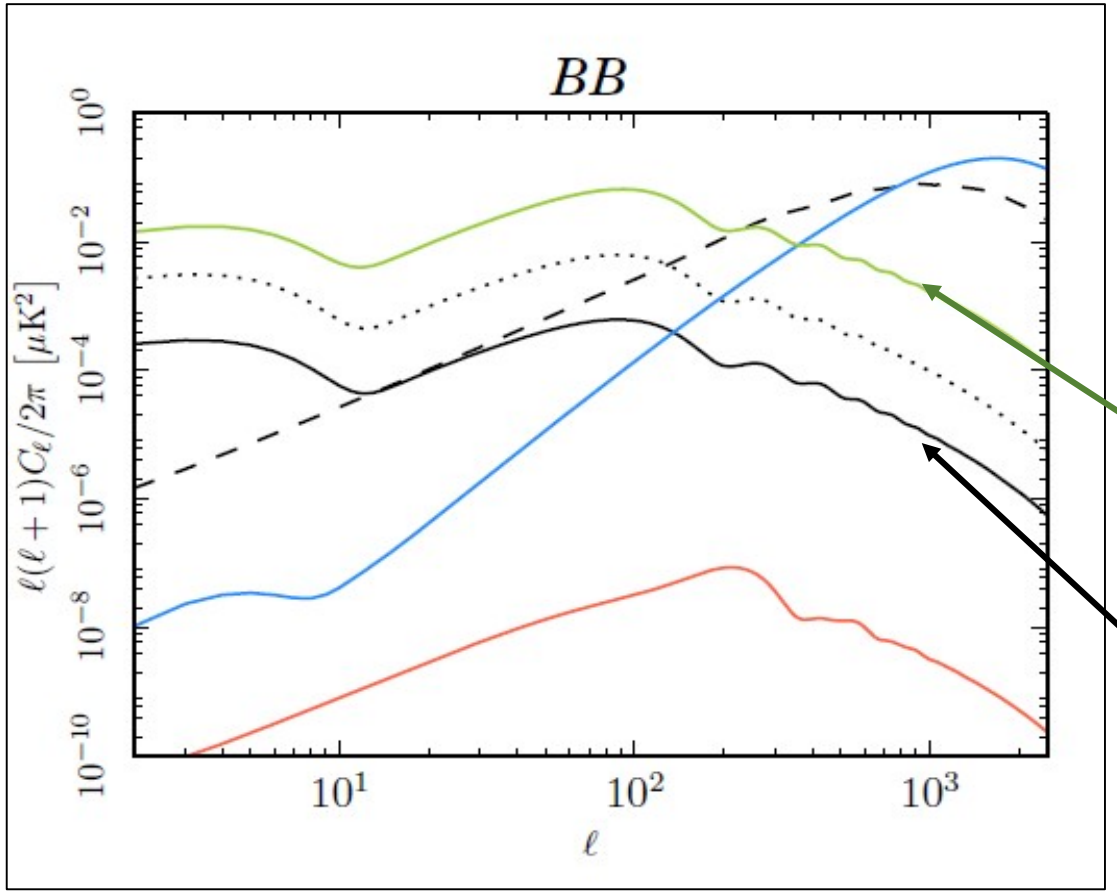


Future of the CMB is mainly two words:
B-MODES
INFLATION
And there's a good reason for this….it is called Nobel Prize…

Suppose that thanks to the wonderful work of Carlo and collaborators we detect B-modes beyond any reasonable foreground and systematics

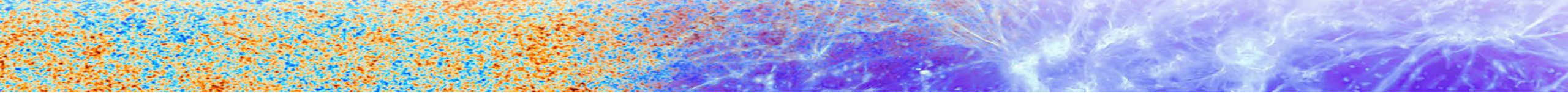
Are you really sure you have detected primordial gravitational waves from inflation?





This are PMFs

This is inflation

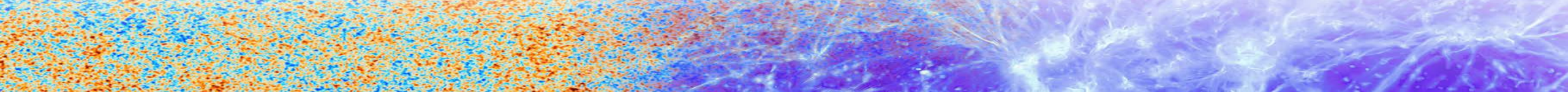


Primordial Magnetic Fields

...or...

How I learned to sometimes stop worrying about inflation and love exotic cosmological models*

*Freely inspired by Kubrick's Dr Strangelove

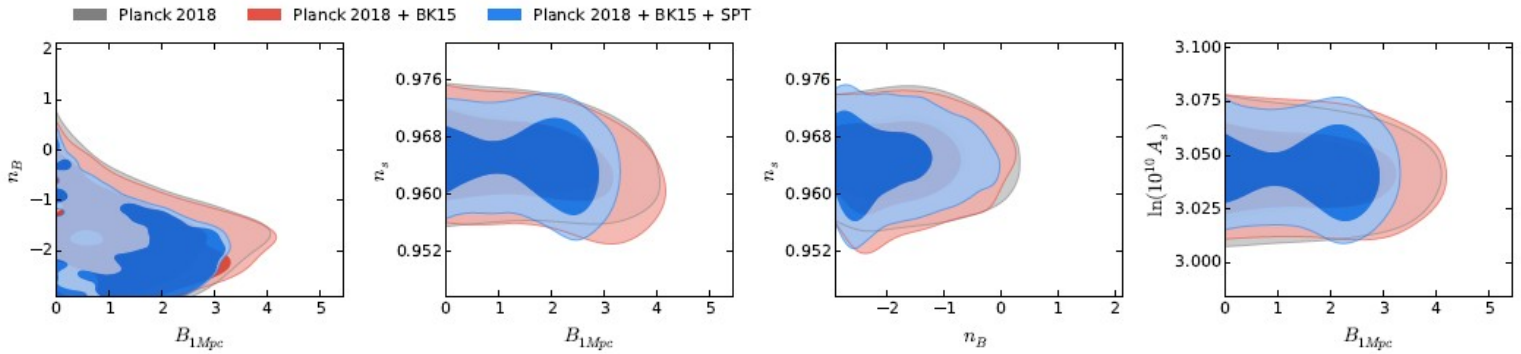


PMF effects in future cosmological observables

- **CMB-gravitational –** ***Alex talk***
- **CMB-non-Gaussianities**
- **CMB-heating from dissipation -** ***Jens talk***
- **CMB-Baryon overdensities -** ***Karsten, Pranjal T., Pranjal R. and Alex talks***
- **CMB-Faraday rotation –** ***Alberto Talk***
- **CMB-spectral distortions -** ***Kerstin and Jens talks***
- **Matter power spectrum** ***- Kerstin talk***
- **21 cm –** ***Kerstin talk***
- **Direct detection of Gravitational waves -** ***Axel ,Chiara and Tina talks***
- **Pulsar timing arrays** ***- Chiara and Tina talks***

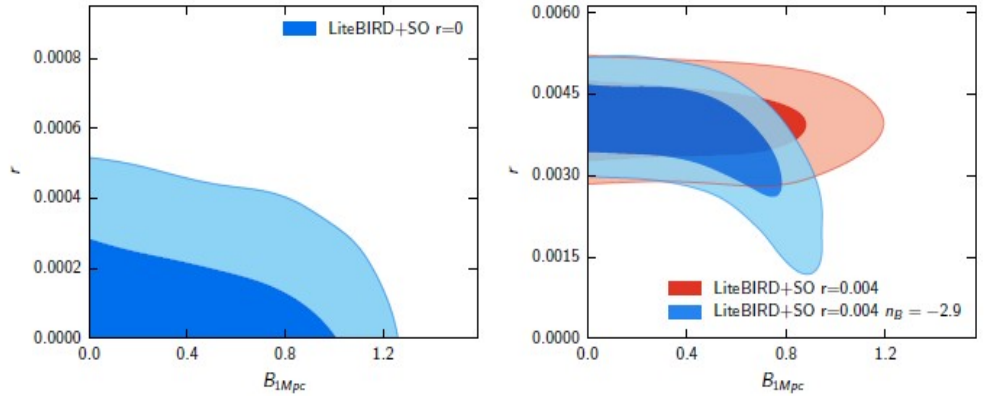
CMB-GRAVITATIONAL

Based on mostly analytical calculations applied to numerical einstein Boltzmann codes.
Current results in the few nGauss range on 1 Mpc scale when marginalized on the spectral index. Stronger constraints are provided for fixed configurations with causal fields constrained to few picoGauss and almost scale invariant to the nGauss.



Paoletti and Finelli 2019

The room of improvements relies mainly on B-modes polarization since Planck exhausted the power of Temperature. Strong constraints on blue spectrum from current forecasts on LiteBIRD breaking the picoGauss treshold. But the almost scale invariant can be a problem for primordial gravitational waves from inflation

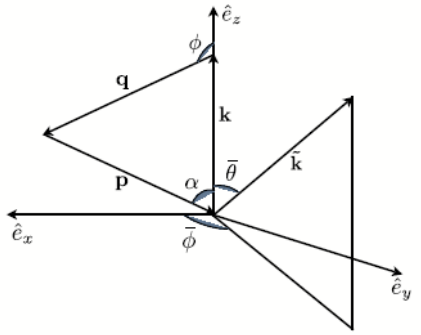


CMB-NG

Stochastic background of PMF has a fully non-Gaussian impact with non zero bispectra and trispectra. From both compensated and passive modes. Current constraints from Planck at the level of few nGauss.

$$\langle \rho_B(\mathbf{k})\rho_B(\mathbf{q})\rho_B(\mathbf{p})\rangle = \frac{1}{(8\pi)^3}\int \frac{d^3\tilde{k}\, d^3\tilde{q}\, d^3\tilde{p}}{(2\pi)^9}\langle B_i(\tilde{\mathbf{k}})B_i(\mathbf{k}-\tilde{\mathbf{k}})B_j(\tilde{\mathbf{q}})B_j(\mathbf{q}-\tilde{\mathbf{q}})B_l(\tilde{\mathbf{p}})B_l(\mathbf{p}-\tilde{\mathbf{p}})\rangle\,.$$

$$A_{\rm bis} \equiv \left(\frac{B_{1\,\rm Mpc}}{3\,\rm nG}\right)^6 \left[\frac{\ln(\tau_\nu/\tau_B)}{\ln(10^{17})}\right]^3$$



Room of improvement is limited by two factors: most non-Gaussian signals saturate rapidly, only large angular scales can improve it and this mean SPACE. The signal scales as the PMF to the sixth power.

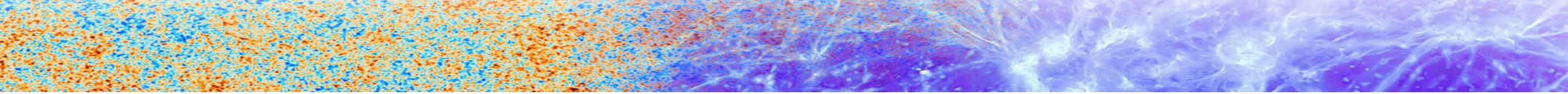
But there is B-mode polarization! Intermediate scale window outside cosmic variance limit and before lensing domination can with future experiment as LiteBIRD provide a detectable signal in BBB

OBSERVATIONAL SIDE I

- **CMB-gravitational**
  - ***relying on B-modes on large and small angular scales -LiteBIRD+ground based- ENEMY: FG Contamination***
- **CMB-non-Gaussianities:**
  - ***B-modes Large Scales – LiteBIRD- ENEMY: LENSING Contamination***
- **CMB-heating from dissipation :**
  - ***Temperature and E-modes on large and intermediate scales – LiteBIRD with some advantage from ground based-***
- **CMB-Baryon overdensities:**
  - ***Small scale temperature and E modes – Ground based – ENEMY: FG Contamination+ beams***
- **CMB-Faraday rotation :**
  - **B-modes on large and intermediate angular scales – LiteBIRD-** ***ENEMY: FG Contamination***
- **CMB-spectral distortions:**
  - **Spectral measurements –** ***ENEMY: FG and Obtuseness of funding agencies***

OBSERVATIONAL SIDE II

- **Matter power spectrum**
  - **Next generation of Galaxy surveys will provide amazing data on the smallest scales where it would be possible to prove PMFs – Euclid (almost literally on the launch pad), Vera Rubin etc.**
- **21 cm**
  - ***SKA just to mention a small one***
- **Direct detection of Gravitational waves and PTA**
  - **LISA, what about ground based?, timescale?**



The bets are open!

Choose you favourite champion in the next generation of cosmological probes for primordial magnetism

But since you are actually in the center of the Motor Valley
Let's enjoy
(Ducati, Ferrari, Lamborghini, Maserati, MV, +2 main circuits+some of the best motoGP pilots, all in 100 Km radius…)

FORMULA COSMO 2020-2030 CHAMPIONSHIP

- **CMB Gravitational : reliable, little assumptions, not the most powerful**

- **CMB Heating: Very powerful but sometimes it suffers from the assumptions**

- **CMB-non-Gaussianities:** **Transversal constraint, can provide very good performances but requires support from complex data analysis**

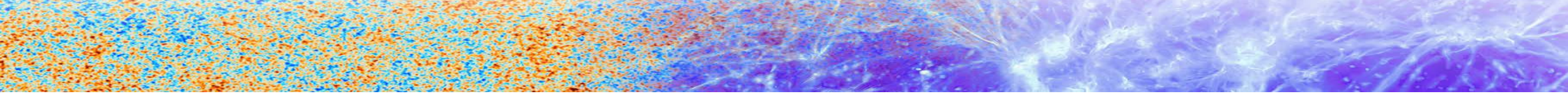
- **Baryon overdensities:** **Very good potential, some development ongoing**

- **CMB-Faraday rotation : Solid theory a lot of space of improvement with future data**

- **CMB-spectral distortions: JUST GIVE THEM A GOOD CAR!!!!**

- **Matter power spectrum:** **lot lot lot of potential but handling the non linear treatment in a likelihood approach is not easy**

- **21 cm:** **as the matter power spectrum they are very promising also with tomography but again require non-linear account**



As in F1 we need both a good car which means good data and good pilots which means good theoretical treatments

And apart from the winner also in F1 good part of the show are the continuous improvements stimulated by new challenges.

Having different probes with different characteristics which continuosly interact and exchange is the best way to improve in all directions and one of the reason we are here today!

The open question is, which are the crucial points of improvement we have in the next few years on these different probes?