Summary Talk
(i.e. What I learned this week listening to 102 talks)

Moriond, La Thuile 24 March 2018
BOSS and eBOSS: LRG, Quasars, $\text{Ly}\alpha$

(Pieri, Gil Marin, Zarrouk, Bautista)

Quasars now used as tracers of density field
Entering Stage IV era
DESI, JPAS, LSST

(Vargas, Abramo, Doux)

DESI: 1 million → 35 million objects. $10^9$ in LSST/Euclid

1280/sq. degree
$0.6 < z < 1.6$
17.9 M
>90% completeness

LRG, ELG, QSO, Ly$\alpha$

56 filters

100 deg$^2$/month
(mag$_{AB} \sim 22.5$)
CMB

(Pagano, Bender, Racine, Manzotti, Wu, Beck)

Temperature is dead
Planck is dying (waiting for final polarisation)

BICEP-Keck / Planck joint analysis

2014 BICEP/Keck analysis adds deep 95 GHz

BICEP Array + SPT3G

\[ \sigma(r) = 0.034 \quad \text{arXiv:1502.00612} \]

\[ \sigma(r) = 0.025 \quad \text{arXiv:1510.09217} \]

forecast \[ \sigma(r) \sim 0.003 \]
BICEP/Keck: Drilling and drilling

See Kimmy Wu's talk
We have not used the WMAP polarization maps in this work. The WMAP Q and U maps have a small number of poorly constrained modes at low \( \ell \) that introduce large scale gradients and offsets into the maps and as such \( P \) can not be directly calculated (Jarosik et al., 2011; Bennett et al., 2013).

### 6.1.2 Checking the calibration of the C-BASS \( P \) map

The astronomical calibration subroutine in the pipeline calculates the amplitude of the noise diode signal in \( I_{TOD} \) from observations of the total intensity emission of TauA, which is well known. This calibration is applied to the polarization data via the internal temperature-stabilised load. This is the first attempt at the calibration and to verify that it has worked we extract the polarization fraction of TauA from the C-BASS maps. In this section we also briefly discuss future and ongoing work to check and improve on the calibration of C-BASS North using C-BASS South data.

**Figure 6.9**: Maps of the estimates of (top) and (bottom) between the real C-BASS and \( \text{Planck} \) 30 GHz \( P \) maps.

**Smoking gun for GWs**

- Homogeneity
- Angular dependence
- Gaussianity
Gravitational waves for early universe
(Figueroa)

Good probe since they decouple early, but weak...

1) GWs from Inflation (Extra sources)
2) GWs from Preheating
3) GWs from Phase Transitions
4) GWs from Cosmic Defects

Exciting possibility, but we need some luck
Dark Energy after GW170817 (Battye, Ezquiaga, Leloup, Mota Yamaguchi)

Both the GWs and the sGRB arrived almost simultaneously

$$\Delta t = 1.74 \pm 0.05 \text{ s}$$

after traveling approx. 100 million light years ($40^{+8}_{-14} \text{ Mpc}$).

$$-3 \cdot 10^{-15} \leq \frac{c_g}{c} - 1 \leq 7 \cdot 10^{-16}$$
Luminosity distance in the future

\[ h''_{ij} + (2 + \nu) \mathcal{H} h'_{ij} + (c_g^2 k^2 + a^2 m^2) h_{ij} = 0 \]

For example (Maggiore):

\[
\Gamma_{RR} = \frac{m_{Pl}^2}{2} \int d^4x \sqrt{-g} \left[ R - \frac{1}{6} m^2 R \frac{1}{\Box^2} R \right]
\]

\[ c_g = 1 \quad \text{but} \quad \text{effect on amplitude} \]
Voids as cosmological probes?

VOIDS IN REDSHIFT SPACE

(Hawken, Nadathur, Hamaus)

- Complementary search
- AP test
- Screening should be absent in voids
Dark Matter Theory

• No talk on WIMPS, paradigm shift? (Arbey, Sloth)
• Fuzzy DM and tension with Lyα (Urban, Armengaud)
• Sterile neutrino: 3.5 keV line, Lyα constraints (Boyarsky)
• Fluidy DM (Khoury, Tutusaus, Vikman, Ramazanov, Kopp)
• Axions (Notari, Ringwald)

\[ 10^{-22} \text{ eV} \rightarrow 10^{67} \text{ eV} : \sim 90 \text{ orders of magnitude} \]
Dark Matter and Baryons

(Khoury)

\[ g_{\text{obs}} \simeq \sqrt{a_0 g_{\text{bar}}} \]

Very small scatter: can standard DM explain this?
\begin{align*}
\rho_{\text{NFW}} &= \frac{\rho_c}{\frac{r}{r_s} \left(1 + \frac{r}{r_s}\right)^2} \\
\rho_s &\approx \text{const.}
\end{align*}

\begin{align*}
\mathcal{L}_{\text{MOND}} &= -\frac{2M_{\text{Pl}}^2}{3a_0} \left((\partial \phi)^2\right)^{3/2} + \frac{\phi}{M_{\text{Pl}}} \rho_b
\end{align*}
The beginning of 21cm era?

EDGES

(D’Amico, Wang, Harper, Hill)

Forget about the factor of 2: is it real?
Example history and signal

Lyα start recoupling

T \text{gas} and T \text{S} \text{X-rays} start heating the gas

From absorption to emission

Reionization kills the signal

Taylor et al. 2012 (1206.6733)

21cm Cosmology

The observable Universe in comoving scale

Figure inspired by Yi Mao & Max Tegmark

Rich physics

Potentially huge volume
Indirect detection DM

(Mijakowski, Behlmann, Manconi)

Electron Spectrum

Positron Spectrum

AMS measurements of the Electron and Positron spectra

1,080,000 Positrons

16,500,000 Electrons

Electron and positron spectra are significantly different in their magnitudes and energy dependences. This is a clear indication of distinct origins for these two cosmic ray species.

Preliminary results. Please refer to the forthcoming AMS publication in PRL.

20 March 2018

Published flux ratio:

\[ \frac{\Phi(\bar{p})}{\Phi(p)} \]


The AMS measurement is still statistically limited.

AMS-02 PAMELA

Cross-correlation with cosmo data (Camera)

AMS: over 2000 $\bar{p}$ above 100 GV (compared with 4 before AMS)

$|\text{Rigidity}| [\text{GV}]$

AMS: over 2000 $\bar{p}$ above 100 GV (compared with 4 before AMS)

AMS: over 2000 $\bar{p}$ above 100 GV (compared with 4 before AMS)
Direct detection DM

(Manfredini, Lehnert, Davini, Settimo, Bolognino, Gentile)

• Noble competition: Xenon VS Argon (DEAP 3600, Darkside)
• SABRE will finally check DAMA
• Already looking beyond neutrino floor (directional detection)
Vector Mediator, Dirac DM,
\( g_{\text{DM}} = 1 \)
\( g_q = 0.1 \)
\( g_l = 0.01 \)
Agujeros negros primordiales y materia oscura
(Primordial black holes as dark matter)
(Garcia-Bellido, Zumalacarregui, Quartin)

Clustered, with broad mass distribution

Clustered, with broad mass distribution
spectral distortions bounds at the time [23], since then the dark matter, as was implied by the stringent CMB
the case where PBHs are a very subdominant fraction of
ized it to an arbitrary PBH abundance. They focused on
updated this calculation to 30
detection of a binary-black-hole merger [5], Sasaki
merger rate at the present time. Following the first de-
the chance proximity of PBH pairs, and estimated their
form binaries in the early Universe, as a consequence of
bounds in that mass range.

We see that LIGO O1 may limit show the result in Fig. 7, alongside other existing bounds
not linear in
low the LIGO upper limits. Note, that the merger rate is
maximum PBH fraction for which the merger rate is be-
abundance.

ter component, and set stringent upper limits to their
magnitude, depending on the mass. This indicates that
exceeds the estimated upper limits, by 3 to 4 orders of
formation and merger. We see that the latter
if PBH binaries are not significantly perturbed between
("\sum\tau\text{LIGO} = \tau_{\text{ET}}\) and the ET + LIGO bounds need to be confirmed by numerical simulations. For

arXiv:1709.06576

Living dangerously: LIGO MACHO ?

Excluded halo fraction if no event found

produced by A. Mirhosseini

Bump in production due to QCD phase transition

(Moniez, Ali-Haimoud, Byrnes)
Baldauf, Mercolli, Zaldarriaga 2015, see also Foreman, Perrier, Senatore 2015

Including counter-terms (a single free parameter at two loops)

PT approach to LSS

Let us define Zel’dovich power spectrum as the result of

\[ \xi(z) = \frac{\Delta^2}{\sigma^2} \]

In the Zel’dovich approximation, the relative displacement function can be related to the correlation function of the

BAO as success story

We have to live with counterterms!

BAO as success story

Parameter-free modeling of the BAO peak (including bias, RSD…)

Various theoretical approximations to the acoustic

LSS analytic

(Simonovic, Lazanu, Fasiello, Lewandowski)
Efficient evaluation of cosmological statistics
A different point of view on FFTLog

In order to simplify and speed up loop calculations we require new ideas, new strategies, to approach the problem. One inspiring idea, developed in [9] and [10], is to use Fast Fourier Transform (FFT) for efficient evaluation of the one-loop power spectrum. After first "deconvolving" the lowest order PT solutions, and performing all angular integrals, the one-loop expressions reduce to a set of simple one-dimensional integrals that can be efficiently evaluated using FFT.

Unfortunately, deconvolving higher order perturbative solutions and extending this approach to the one-loop bispectrum or the two-loop power spectrum proves to be challenging [11].

In this paper we build on ideas of [9, 10] but choose a slightly different strategy which allows us to go beyond the one-loop power spectrum. Let us briefly sketch the main idea behind our proposal. Prior to doing any integrals, the linear power spectrum is expanded as a superposition of ideal self-similar power-law cosmologies. This is naturally accomplished using FFT in log $k$.

Given some range of wavenumbers of interest, from $k_{\text{min}}$ to $k_{\text{max}}$, the approximation for the linear power spectrum with $N$ sampling points is

$$\bar{P}_{\text{lin}}(k_n) = \sum_{m=-N/2}^{m=N/2} c_m k_n^{\nu + i \eta_m},$$

(1.2)

where the coefficients $c_m$ and the frequencies $\eta_m$ are given by

$$c_m = \frac{1}{N} \sum_{l=0}^{N/2} P_{\text{lin}}(k_l) k_l^{\nu} e^{2\pi i m l / N},$$

$$\eta_m = \frac{2\pi m \log(k_{\text{max}}/k_{\text{min}})}{\log(k_{\text{max}}/k_{\text{min}})}.$$

(1.1)

Notice that the we denote the approximation for the linear power spectrum with $\bar{P}_{\text{lin}}(k_n)$, while eq. (1.2) uses the exact linear power spectrum $P_{\text{lin}}(k_n)$ to calculate the coefficients $c_m$. We will keep using the same notation throughout the paper. The parameter $\nu$ is an arbitrary real number. As we will see, the simplest choice $\nu = 0$ is sufficient in some applications, so we will use the more general form of the Fourier transform. In the terminology of [9] we call this $\nu$ parameter bias.

Note that the powers in the power-law expansion are complex numbers. In practice, even a small number of power-laws, $O(100)$, is enough to capture all features of the linear power spectrum including the BAO wiggles. One important thing to keep in mind is that the Fourier transform produces the power spectrum that is periodic in log $k$. Therefore, we will take care to choose $k_{\text{min}}$ and $k_{\text{max}}$ such that we cover the range of scales where we actually care about the value of the power spectrum. In other words we are choosing the momentum range where the loop integrals have the most of the support. However, one always has to be careful about possible contributions particularly from high $k$ modes or short scales.

Is this a limitation? Absolutely not. At the heart of the EFT understanding is the simple recognition that the PT idealized description of satisfying fluid-like equations of motion can only be valid at certain scales. This is much the same as the hydrodynamic description of liquid water is only valid at certain scales. Attempting to integrate this approximation over scales outside of its validity introduces non-parametrically controlled errors. Instead the information in the power spectrum is used to constrain the errors.

Any cosmology can be written as a sum of power-law universes
All cosmology dependence is just in $c_m$

Relation with amplitude calculations in QFT
The QCD phase transition also represents a puzzle with regard to dark energy.

Naively, one expects that the vacuum energy changes by an amount of order $\Lambda_{QCD}^4$ after the phase transition.

This is obviously much larger than the observed dark energy, and is another take on the CC fine tuning problem.

It suggests that in extreme environments such as the interior of a neutron star, where the QCD enters a different phase, there may be a non-negligible contribution to the equation of state from vacuum energy.

Figure 1: Sketch of the evolution of vacuum energy (dotted-red) and the total pressure (solid-purple) dominated by radiation (dashed-blue) during the expansion of the Universe. Left: standard model evolution where the vacuum energy jumps at every PT (the ones pictured here correspond to the GUT, EW and QCD PTs). Right: the evolution assuming some form of adjustment mechanism for vacuum energy.

$\Lambda_{vac}^{QCD} + \Lambda_{bare} = (10^{-3} \text{ eV})^4$

$\Lambda_{other}^{QCD} + \Lambda_{bare} \sim \Lambda_{QCD}$
CMB spectral distortions

(Chluba, Dimastrogiovanni)

A lot of possible signals

The future is foreground dominated!

Attempts from the ground
The biggest problem facing current large area galaxy surveys: Validating redshifts for samples of galaxies.

We extract 1-d spectra from simulations (known redshift), added realistic noise. Ask OzDES observers to redshift the spectra, using their common analysis tools.

We cannot validate photo-z performance on data which is biased w.r.t the truth.

Dark Energy Survey Y1

- Too large bias for future!
- Self-consistent method
- Clustering red-shifts
# DES Supernovae

(Moller, Saunders)

## Survey

<table>
<thead>
<tr>
<th>SURVEY</th>
<th>SN e Ia</th>
<th>wErr (stat + sys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JLA (2014)</td>
<td>740</td>
<td>0.054</td>
</tr>
<tr>
<td>Pantheon (2018)</td>
<td>1049</td>
<td>0.040</td>
</tr>
<tr>
<td>DES 3YR (2018) spec</td>
<td>334</td>
<td>0.057</td>
</tr>
<tr>
<td>DES 5YR spec</td>
<td>~500</td>
<td>?</td>
</tr>
<tr>
<td>DES 5YR photo</td>
<td>~2000</td>
<td>?</td>
</tr>
</tbody>
</table>

Data coming. Need to understand scatter.

Dispersion indicates unmodeled processes in the supernovae, which can lead to bias.

Data coming. Need to understand scatter.

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Dispersion ~ 0.16 mags

Data coming. Need to understand scatter.
The Simons Observatory science goals:

1. Large aperture telescope (6m) on a "large" sky patch: $N_{\text{eff}}, \Sigma m_\nu, w(z)$, cluster science.
2. Small aperture telescopes (0.5m) on a "deep" sky patch: primordial B-modes.
Axions in Inflation and as Hot Relics

QCD Axion via $N_{\text{eff}}$

Inflation with Axial coupling

Thermalization

Axion-mediated scatterings

SM scatterings

Thermal Perturbations

QCD Axion through $N_{\text{eff}}$

$g^\leftrightarrow$, DEC is smaller at 1 GeV.

$T_{100}$ GeV

Prediction: larger $N_{\text{eff}}$ (*Not just upper bound!*)

$t_b (T_F = 0.5 \text{ GeV})$

$b (T_F = 0.4 \text{ GeV})$

$b (T_F = 0.3 \text{ GeV})$

$c (T_F = 0.5 \text{ GeV})$

$c (T_F = 0.4 \text{ GeV})$

$c (T_F = 0.3 \text{ GeV})$

$c (T_F = 0.2 \text{ GeV})$

$1 \times 10^6$

$5 \times 10^8$

$1 \times 10^9$

$0.00$

$0.01$

$0.02$

$0.03$

$0.04$

$0.05$

$0.06$

$0.07$

$f/c_i \text{ [GeV]}$

$\Delta N_{\text{eff}}$

$1 \sigma$, CMB-S4

$2 \sigma$, CMB-S4

$1 \sigma$, futuristic

Figure: (R.Ferreira & A.N., 2017).

Stage 2

1000 detectors

$\approx 10^{-5}$ 0.035 0.14 0.15eV 180

Stage 3

10,000 detectors

$10^{-6}$ 0.006 0.06 0.06eV ~300-600

Stage 4

CMB-S4

~500,000 detectors

$10^{-8}$ 0.0005 0.027 0.015eV 1250

Target

Sensitivity ($\mu K^2$) $\sigma(r)$ $\sigma(N_{\text{eff}})$ $\sigma(\Sigma m_\nu)$ Dark Energy F.O.M

Boss BAO prior

DES+BOSS SPT clusters

DES + DESI SZ Clusters

DES + BOSS + SPT clusters

DESI + LSST S4 Clusters

(Notari, Ringwald, Rossi)
Future CMB: space missions

(Banerji, Remaizelles)

ESA
- COrE -> 2010
- PRISM -> 2013
- COrE+ -> 2015
- CORE -> 2017

NASA
- EPIC/CMBpol -> 2009
- PIXIE -> 2017
  Spectroscopic study over several decades of frequency
- CMB Probe/PICO -> 2020

ISRO
- CMBBharat
  Announcement of opportunity out. Due mid-April

JAXA
- LiteBIRD -> 2008
  Has not yet been selected. Currently undergoing a Phase A study

Optimal CMB delensing

(Millea, Fabbian)

Broad frequency coverage essential to control unknown foregrounds
Clusters, tSZ, kSZ

(Salvati, Blanchard, Sakr, Bollet, Perotto, Hill)

Cluster tension:
due to mass-observable relation?
NIKA2

AdvACT: 1300 clusters
Stage IV: $10^5$ clusters
Can Casimir energy violate NEC and give reliable bounces?

Bouncing Cosmology:

\[ \mathcal{L} \supset (-M^2 - \kappa \sigma^2 + g\phi)|h|^2 + gM^2\phi + \cdots + 4\pi f_y y_u \langle h \rangle F(\phi/f) \]
Inflation

(Holman, Notari, Godunov, Vieira, Karciauskas)

Very few talks about inflation and primordial universe

Understand Starobinsky

\[
\frac{\partial P[\phi(\cdot); t]}{\partial t} = \left( \frac{H^3}{8\pi^2} \right) \frac{\partial^2 P}{\partial \phi^2} + \frac{\partial}{\partial \phi} \left( \frac{V'(\phi)}{3H} P \right)
\]

prob. dist. noise term drift term
Too much focus on Dark Energy?

• Figure of merit is always $w, w'$, growth rate... We should not forget it is very likely a cosmological constant.

• Maybe there should be more focus on early universe observables: tilt, non-Gaussianity...

• How many modes can we use? Can we go to short scales? More on standard physics: bias, baryons...
Thanks to the organizers!
Summary of the summary

• GWs, 21cm brand new probes!

• Standard probes (BAO, SNs, B-modes, LSS, shear, clusters, indirect DM detect...) are doing great, with clear road ahead.

    Cosmology VS Gastrophysics

• $\Lambda$ is doing great

• DM: exploration in all directions