USING EXTREME DIGITISATION TO COMBAT DATA CHALLENGES IN CMB OBSERVATIONS

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EXTREME DIGITISATION

➤ Lossy few-bit compression

![Diagram showing 64 Bits and 1 Bit comparison](image)
COSMIC MICROWAVE BACKGROUND

➤ Earliest light to travel freely through universe
➤ Wealth of Information in Temperature and Polarisation

Planck (2013)
CMB SCIENCE AREAS

➤ Inflation (primordial gravitational waves)
➤ Neutrinos and light relics
➤ Dark matter
➤ Dark energy
➤ CMB lensing
1.3 From science goals to CMB-S4 design

1.3.1 Conceptual design of CMB-S4

The science goals discussed above lead to a rough conceptual design of CMB-S4.

1.3.1.1 Sensitivity and detector count

The sensitivity of CMB measurements has increased enormously since Penzias and Wilson's discovery in 1965, following a Moore's Law like scaling, doubling every roughly 2.3 years. Fig. 1 shows the sensitivity of recent experiments as well as expectations for upcoming Stage 3 experiments, characterized by order 10,000 detectors on the sky, as well as the projection for a Stage 4 experiment with order 100,000 detectors. To obtain many of the CMB-S4 science goals requires of order 1 \( \mu K \) arcminute sensitivity over roughly 70% of the sky, which for a four year survey requires of order 500,000 CMB-sensitive detectors. To maintain the Moore's Law-like scaling requires a major leap forward, it requires a phase change in the mode of operation of the ground based CMB program. Two constraints drive the change: 1) CMB detectors

**Takeaway:**
Data volumes are growing quickly!
DATA CHALLENGES

➤ Best observation locations have limited transmission

➤ Stage 4 style experiment at the South Pole will produce ~O(10)Tb/d
  ➤ Transmission will likely be ~O(100)Gb/d

➤ Space-based missions (PIXIE, COrE, LiteBIRD) face transmission hurdles
  ➤ Planck-style compression must be reviewed
DATA CHALLENGES

➤ Mission Planning
  ➤ Cannot simulate full time-stream data over entire parameter space

➤ Analysis
  ➤ Calculations become increasingly expensive
SUCCESSFUL EXTREME DIGITISATION

- Search for continuous gravitational wave sources with LIGO
  - Clearwater et al. in preparation
- Pulsar timing observations
  - Jenet & Anderson 1998
CMB OBSERVATION STRATEGY

Observe True Sky

Record Time-ordered Data

Reconstruct Map

Calculate Powerspectrum
DIGITISING OBSERVATIONS

➤ Simulate observations for a fixed detector noise level

➤ Using 1, 2 and 3 bit optimal digitisation schemes

➤ Compare resulting power spectra

➤ Analyse induced noise
POWERSPECTRUM OVERVIEW

CMB Power Spectrum for $\sim 10^8 h^{-1}$

$C_l [\mu K^2]$ vs. Multipole Moment $l$
VARIATION WITH NUMBER OF BITS

CMB Power Spectrum for $8 \times 10^6 h_{\text{pp}}$

- 1 Bit
- 2 Bit
- 3 Bit
- Regular
VARIATION WITH HITS PER PIXEL

Induced Map Noise Level through Digitisation

\[ \frac{\Delta \sigma_{MAP}}{\sigma_{MAP}} \]

- 1bit: 25.3%
- 2bit: 6.1%
- 3bit: 1.8%

Hits per pixel

\[ 10^2 \rightarrow 10^8 \]
FUTURE WORK

➤ Investigate polarisation
➤ Explore cluster finding algorithms
➤ Use different noise profiles
CONCLUSION

➤ Extreme Digitisation saves an order of magnitude in data volume

➤ Additional percentage to map noise is independent of the number of hits per pixel

➤ Optimal 3-bit digitisation adds ≲2% to the map noise level

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