Long wavelength astrophysics

by

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A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy
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Abstract

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2016

Acknowledgements

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Chapter 1

The Canadian Hydrogen Intensity Mapping Experiment

1.1 Chapter Overview

In this chapter we will introduce in detail the Canadian Hydrogen Intensity Mapping Experiment (CHIME).

1.2 Introduction

CHIME is a Canadian collaboration between the University of British Columbia (UBC), the University of Toronto (UofT), McGill University, and the Dominion Radio Astrophysical Observatory (DRAO). Located at DRAO near Penticton, BC, it is Canada's national radio observatory, and consists of two stages: A pathfinder instrument, known hereon as the CHIME Pathfinder, which is two 20x37 m cylinders; and the final instrument, called either full CHIME or just CHIME, and is four 20x100 m cylinders. The Pathfinder was first "on sky" in November 2013, however it has only been observing in full capacity, i.e., with all of its feeds mounted and drawing power, since XX 2015. As of late spring 2016, Full CHIME's structure exists and is meant to be instrumented before the end of 2016.

CHIME's primary science goal is to measure the Universe's neutral hydrogen, mapping out the large-scale structure (LSS) and constraining dark energy's equation of state. However, it was noticed early on that CHIME could be a powerful tool for studying several different facets of the time-variable sky. Digital radio telescopes like CHIME can run multiple experiments in parallel, since data can be siphoned off and split between different backends. In light of this an effort was made, successfully, to acquire funding

Figure 1.1: Photograph of the CHIME Pathfinder, constructed in 2013. The Pathfinder was built as a testbed for analysis and instrument design, largely because CHIME is attempting a very difficult measurement that requires an unprecedented understanding of our telescope. In attempting a new technique with an unorthodox telescope design we were guaranteed to not get it perfect the first time, hence the smaller precursor instrument to "find the path". After two years of taking data in multiple configurations, we have learned a number of lessons about calibration, cross talk, our beams, and the correlator. We also ran into unforeseen obstacles, including a mis-pointing caused by the ambiguous definition of "north", the pervasive effects of a standing wave betweem the reflector's vertex and our focal line, and the impact of surface perturbations in the cylinders' mesh.

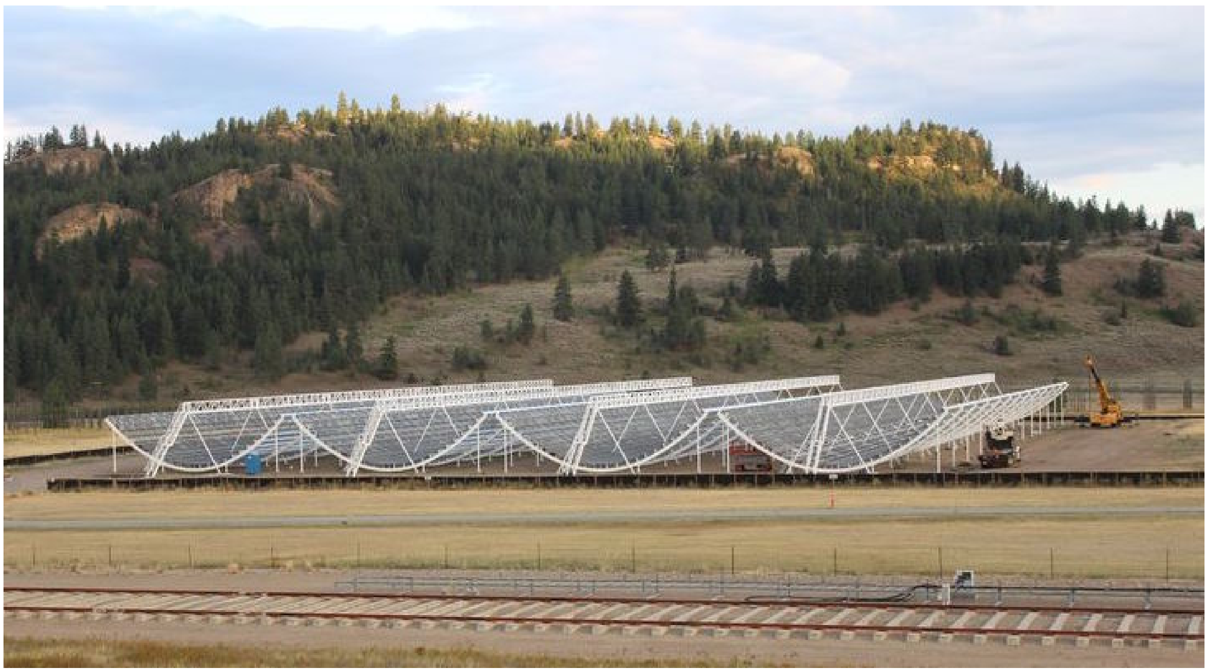

Figure 1.2: Full CHIME shortly after the construction of the fourth and final parabolic cylinder in fall 2015. Each dish is 20 m in the east-west direction and 100 m long. Unlike the Pathfinder, the cylinders are aligned with the *celestial* North Pole and should have true declination beams. There was also great care taken creating a smooth surface, since the Pathfinder's relatively large surface RMS lead to issues with its beams.

	Pathfinder	**Full CHIME**
Geometric area	1480 m^2	8000 m^2
Freq	400-800 MHz	400-800 MHz
Redshift	2.5-0.8	2.5-0.8
Beamsize	2.5°-1.3°	0.43°-0.22°
No. dual-pol antennas	128	1024
No. tracking beams	1	10
No. FFT beams	?	1024
E-W FoV	2.5°-1.3°	2.5°-1.3°
N-S FoV	$\sim$100°	$\sim$100°
Receiver Temperature	50 K	50 K

Table 1.1: CHIME Parameters

for two new experiments to piggy-back on CHIME. One is a pulsar backend that will monitor large numbers of sources, observing up to 10 pulsars at a time, 24/7. Another is an FRB backend that will search 1024 FFT-formed beams for dispersed transients.

1.3 CHIME Science

1.3.1 21 cm Cosmology

Historically, constraining the nature of dark energy has been expensive in time and resources. Traditional spectroscopic galaxy surveys require resolving scales (galaxies, $\sim$10s of kpc) that are much smaller than the LSS, specifically the BAOs ($\sim$100 Mpc). A far more economic, albeit uncharted, approach is to map out 21 cm emission from Hydrogen that traces the underlying dark matter distribution. This technique was proposed by **?** as a cheaper and more efficient alternative to galaxy surveys. Since one is concerned only with $\sim$degree angular scales, the collective emission from thousands of galaxies can be used as a proxy for the Universe's LSS.

1.3.2 Pulsar

1.3.3 FRB Survey

1.4 Instrument

CHIME is a novel telescope that carefully pairs its signal processing and analysis pipeline with its instrumental specifications. It is a cylindrical radio interferometer aligned in the north-south direction, and has no moving parts. As a transit telescope, it looks at the meridian as the earth rotates and the sky passes overhead, and has an on-sky duty-cycle of 100%. Since its reflectors are parabolic cylinders, light is focused only in the east-west direction, with a transverse beamwidth given by $\frac{\lambda}{D} \approx$ 1-2°. In the north-south direction the dish effectively acts as a mirror. This results in a very large declination beam that can see nearly the whole north-south sky, barring the feed's beam and cosine projection at low-elevation. To gain north-south spatial resolution, CHIME's focal line is populated with broad-band, dual-polarization antennas that we call "clover" feeds due to their four pedals. The signals from these feeds can then be interfered either in beamforming or by traditional interferometric correlation.

The clover feeds are separated by $\sim$30 cm, constrained by their physical size and the requirements of a 400-800 MHz feed. This is problematic for the top of our band. Since we observe at 37.5-75 cm, wavelengths shorter than twice the physical separation of our feeds will not be properly Nyquist sampled. Therefore below $\sim$60 cm (above $\sim$500 MHz) we do not uniquely measure the electric field in the north-south direction and our signal will be aliased. In other words, without external information, a point source's declination will be ambiguous at high frequencies.

1.4.1 Beams

1.5 Pathfinder analysis

1.6 Conclusion

Acknowledgements

Bibliography

????, IEEE Milestone award, http://ethw.org/Milestones:List_of_IEEE_Milestones, accessed: 2016-06-13

Broten, N. W., Locke, J. L., Legg, T. H., McLeish, C. W., & Richards, R. S. 1967, Nature, 215, 38

Klages, P., Bandura, K., Denman, N., et al. 2015, ArXiv e-prints, arXiv:1503.06203

Lange, C., Kramer, M., Wielebinski, R., & Jessner, A. 1998, A&A, 332, 111

Lyne, A. G., & Graham-Smith, F. 1998, Pulsar astronomy