Cosmic Microwave Background: 13.7 billion years ago

- Afterglow Light Pattern 400,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Quantum Fluctuations
- Big Bang Expansion 13.7 billion years

1st Stars about 400 million yrs.

7 billion years ago

Today

(slide adapted from NASA publicity figure)
Cosmic Microwave Background: 13.7 billion years ago

Afterglow Light Pattern
400,000 yrs.

Dark Ages

Development of Galaxies, Planets, etc.

Inflation

Dark Energy
Accelerated Expansion

7 billion years ago

13.7 BILLION YEARS AGO
(Universe 380,000 years old)

Neutrinos
10%

Dark Matter
63%

Photons
15%

Atoms
12%

Atoms
4.6%

Dark Energy
72%

Dark Matter
23%

(slide adapted from NASA publicity figure)
At $z=1-3$ for 21cm line, need 100m telescope to resolve BAO clearly. Unresolved galaxies, resolved BAO.

Galaxy Surveys
- ~1% ($2\ Gpc^3/h^3$) of the universe has been mapped with optical light from galaxies.
- Galaxy surveys are expensive
- Rely on (non-linear) galaxies as tracers for BAO

Blanton et al. (2003)
21 cm Hydrogen Line

Rate $3 \times 10^{-15}/s$

Frequency gives redshift:

$$\nu = \frac{1420 \text{MHz}}{1+z}$$

Oort et al. 1958

HI map of the Milky Way

(Parkes Telescope)

Matt.Dobbs@McGill.ca, CHIME Overview 2013-04
3-D Intensity Mapping

1. The telescope gathers radio waves from a swath of sky directly above the observatory near Penticton, B.C.

2. As Earth turns the telescope will sweep through a vast volume of space, mapping out the location of clouds of hydrogen gas that emit radio waves.

3. The distribution of the clouds, ranging from 7 to 20 billion light years away, will reveal how space has expanded over time, allowing astronomers to measure the influence of 'dark energy,' thought to be causing the expansion to speed up.
Cosmic Sound
Start: $z=0.01$
End: $z=0.62$

Simulation Video: Nick Gnedin & Dave McGinnis (Fermilab),
Matt.Dobbs@McGill.ca, CHIME Overview 2013-04
Mapping the Observable Universe

CHIME will:
- survey BAO
- measure the growth of space
  - from $0.8 < z < 2.5$
- over a volume of $\sim 400$ co-moving Gpc$^3$
Illinois 1937: Grote Reber, 9m
First parabolic dish radio telescope
Sky survey

Green Bank Telescope, 100m

Illinois 400’ (120x180m) 1959
- 610 MHz
- BW ~ 5 MHz
Cylinder Telescope

Hybrid: 1D Dish + 1D Interferometry

N “Formed Beams”

N feeds

Correlator
The Canadian Hydrogen Intensity Mapping Experiment

UBC
- Mandana Amiri
- Greg Davis
- Meiling Deng
- Mark Halpern
- Gary Hinshaw
- Kris Sigurdson
- Mike Sitwell

McGill U
- Kevin Bandura
- Jean-Francois Cliche
- Matt Dobbs
- Adam Gilbert
- David Hanna
- Juan Mena Parra

U Toronto / CITA
- Dick Bond
- Ue-li Pen
- Richard Shaw
- Keith Vanderlinde
- Ivan Padilla

HIA, DRAO
- Tom Landecker

View poster!
The Canadian Hydrogen Intensity Mapping Experiment

- a transit telescope
- no moving parts
- one scan strategy
- 24/7 observations
- no TAC (time allocation committee)
### Full CHIME Specs

#### Full CHIME Layout

<table>
<thead>
<tr>
<th>Structure</th>
<th>5 cylinders, 100m x 20m each</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>400-800 MHz</td>
</tr>
<tr>
<td>Number Feeds/cylinder</td>
<td>256 dual pol feeds per cylinder (2560 digitizers total)</td>
</tr>
<tr>
<td>Frequency Channels</td>
<td>512 frequency channels, 781 kHz wide (1.28 µs) (for cosmology, you can channelize further!)</td>
</tr>
<tr>
<td>Digitize 8bits at 800 MSPS</td>
<td></td>
</tr>
<tr>
<td>~31cm spacing</td>
<td></td>
</tr>
<tr>
<td>Data Rate</td>
<td>$2N_{FEEDS} \times 3.2 \text{ Gbit/s} = 8 \text{ TeraBit/s}$ (assumes 4bit truncation)</td>
</tr>
</tbody>
</table>

#### Observing Frequency

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>400 MHz</th>
<th>to</th>
<th>800 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>21cm Redshift</td>
<td>$z=2.5$ (11 Gyr ago)</td>
<td>$z=0.8$ (7 Gyr ago)</td>
<td></td>
</tr>
<tr>
<td>Beam Size</td>
<td>$0.52^\circ$</td>
<td>$0.26^\circ$</td>
<td></td>
</tr>
<tr>
<td>E-W FoV</td>
<td>$2.5^\circ$</td>
<td>$1.3^\circ$</td>
<td></td>
</tr>
<tr>
<td>N-S FoV</td>
<td>$-45^\circ \text{ to } +135^\circ$ (max possible)</td>
<td>$0^\circ \text{ to } +90^\circ$ (more likely)</td>
<td></td>
</tr>
<tr>
<td>Time/pixel/day</td>
<td>10min, 14min, 24hrs equator, 45deg, ncp</td>
<td>5min, 7min, 24hrs equator, 45deg, ncp</td>
<td></td>
</tr>
<tr>
<td>Receiver Noise Temperature</td>
<td>50k</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flux Conversion</td>
<td>$\sim 2K / \text{ Jy}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily Sensitivity</td>
<td>$\sim 50 \mu \text{Jy} / \text{ pixel}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Survey</td>
<td>$\sim 1.5 \mu \text{Jy/pixel}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Approximate – for planning purposes only)
Five 20m x 100m reflectors

512 digitized signals per cylinder

One transform for each frequency channel and polarization to form beams.
System Overview

LNA
20 dB
35 K

LNA2
21 dB
65 K

Filter + Amp Block
40 dB 300 K

Coax/RFOF
60 m

ADC

Filter + Amp Block
40 dB 300 K

FFT

Shuffle

Correlator GPU Cluster
System Overview

LNA 20 dB 35 K 60 m
LNA2 21 dB 65 K
Filter + Amp Block 40 dB 300 K

Coax/RFoF

Correlator GPU Cluster
Two FMC Mezzanines (analog signals come in the front)

FPGA

Digital signals come in the back

Custom Backplane
Power, clock, timestamp
Board inter-connect

ARM processor
DDR RAM
Ethernet

Two Gbit Ethernet

Shuffle

Correlator GPU Cluster
1 TB/s = 86 PB/day
System Overview

LNA
20 dB
35 K
LNA2
21 dB
65 K
AD
FFT
Shuffle
1280 x 10 Gbe
Correlator GPU Cluster

Matt.Dobbs@McGill.ca, CHIME Overview 2013-04
Prototype, two 8m Dishes
• 4 channels
• running since March 2011

Pathfinder, two 20m x 40m Cylinders
• 256 channels
• under construction

Full CHIME, five 20m x 100m Cylinders
• 2560 channels
• FUNDED by CFI. Operating in 2016.

Matt.Dobbs@McGill.ca, CHIME Overview 2013-04
Jan 2013: Construction of CHIME Pathfinder
Pathfinder construction, April 14, 2013
Beyond Cosmology

- **Chime will map the polarization and intensity of 40% of the sky with great sensitivity in a poorly explored frequency band.**

- **Pulsar monitoring**
  - Nightly all-sky monitoring for Pulsar Timing Arrays
  - Monitor “space weather”, to correct observations at higher frequency.

- **Pulsar search**
  - Detect new pulsars, then monitor them daily.

- **Radio transient phenomena**
  - New ground.
  - Surprisingly bright and distant radio events have been reported recently. CHIME is an ideal all-sky monitor.

- **Galactic Magnetic Fields**
Summary

- Intensity mapping—a new tool to map the expansion history of the universe.
  - $z=1-3$ key for Dark Energy
- FFT Telescope will come of Age with CHIME—seeing the whole overhead sky at once.
- CHIME will map the largest volume of the universe to date.
- CHIME will measure the expansion of space in a large chunk of the observable universe, to $z \sim 2.5$.
- Hydrogen mapping can (in theory) probe anything to $z \sim >50$. 

Matt.Dobbs@McGill.ca, CHIME Overview 2013-04