

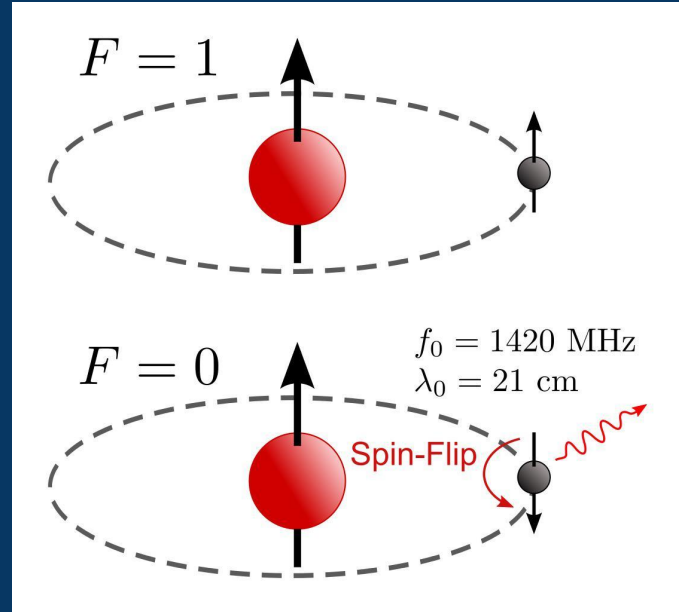


21-cm Astronomy through the Ages

By Katherine Elder
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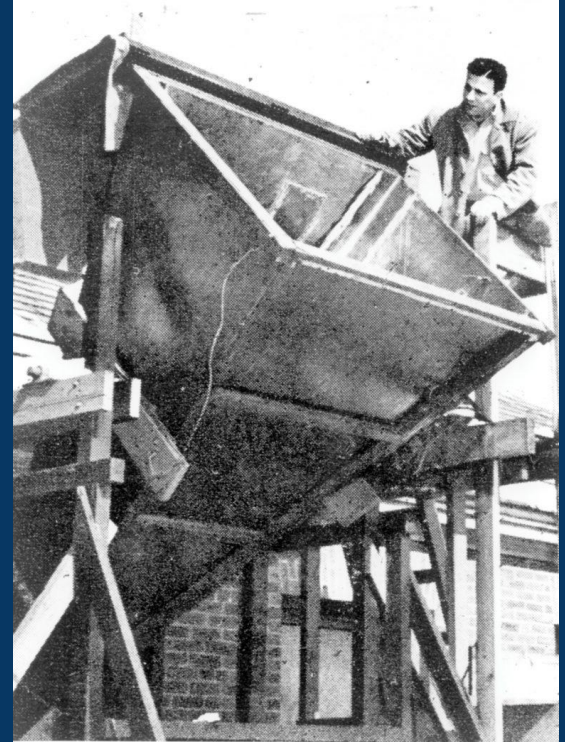
What is the 21-cm line?

- Hydrogen in the ground state
- Hyperfine transition caused by electron and nuclear spin states
- Parallel spin is higher energy
- “Forbidden” transition to lower energy state



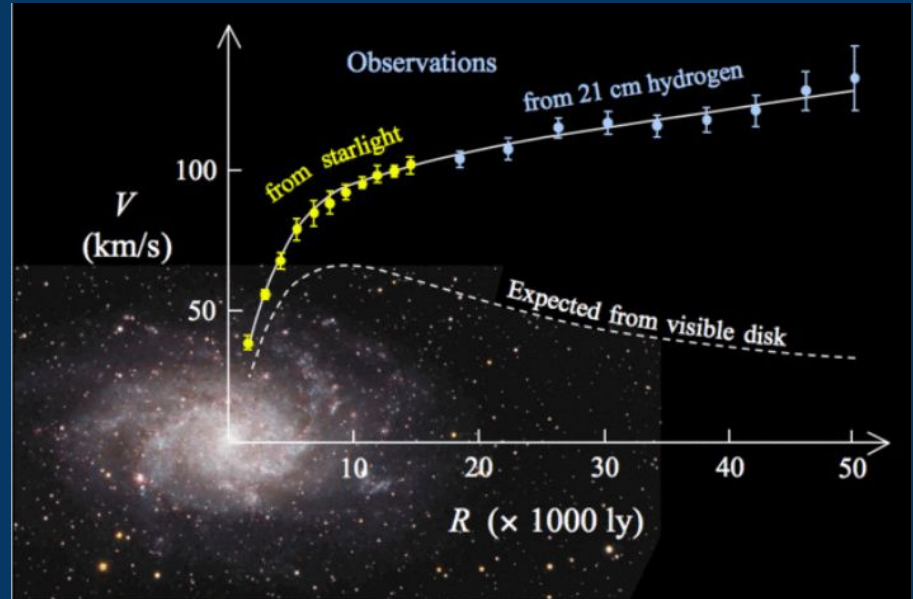
First detection

- Theorized in 1944 by Hendrik van de Hulst
- Detected in 1951 by H. Ewen and E. Purcell at Harvard
 - Clouds near the galactic plane
- First maps of the galaxy were made in 1952
 - Revealed the spiral structure of the Milky Way



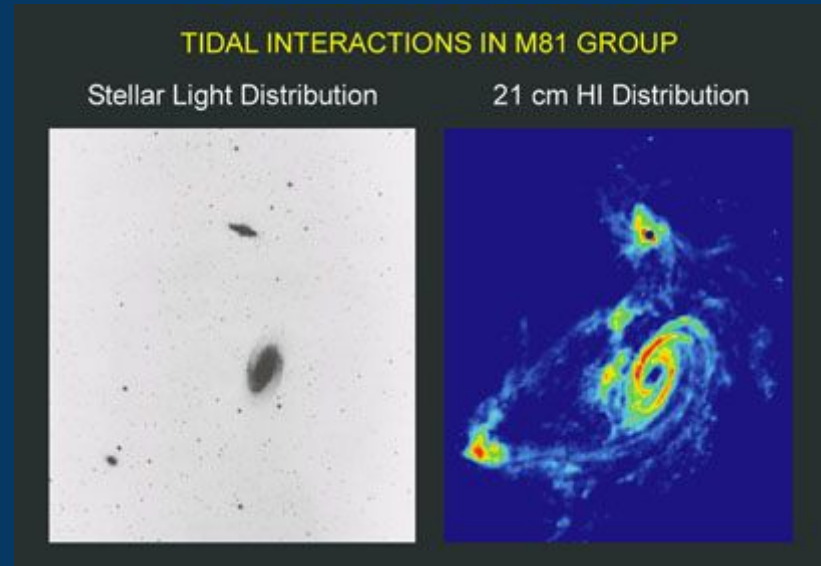
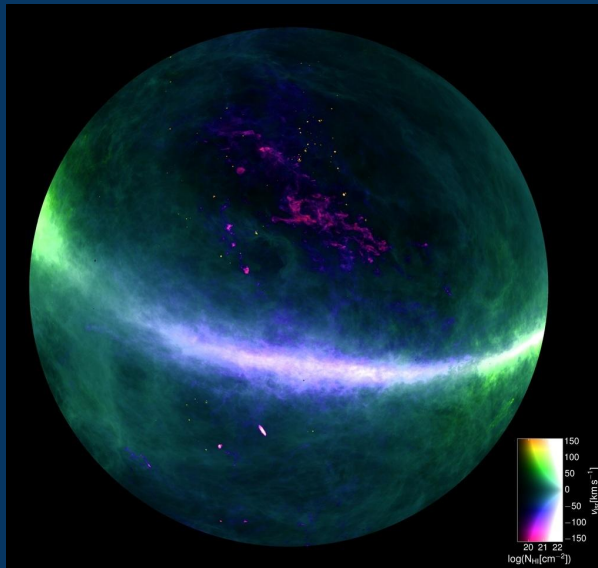
Rotation Curves

- Calculate relative speed of Galaxy spiral arms
 - Doppler shift of HI line
- Plot rotation curve for a galaxy
- Vera Rubin and Kent Ford used rotation curves to show evidence of dark matter

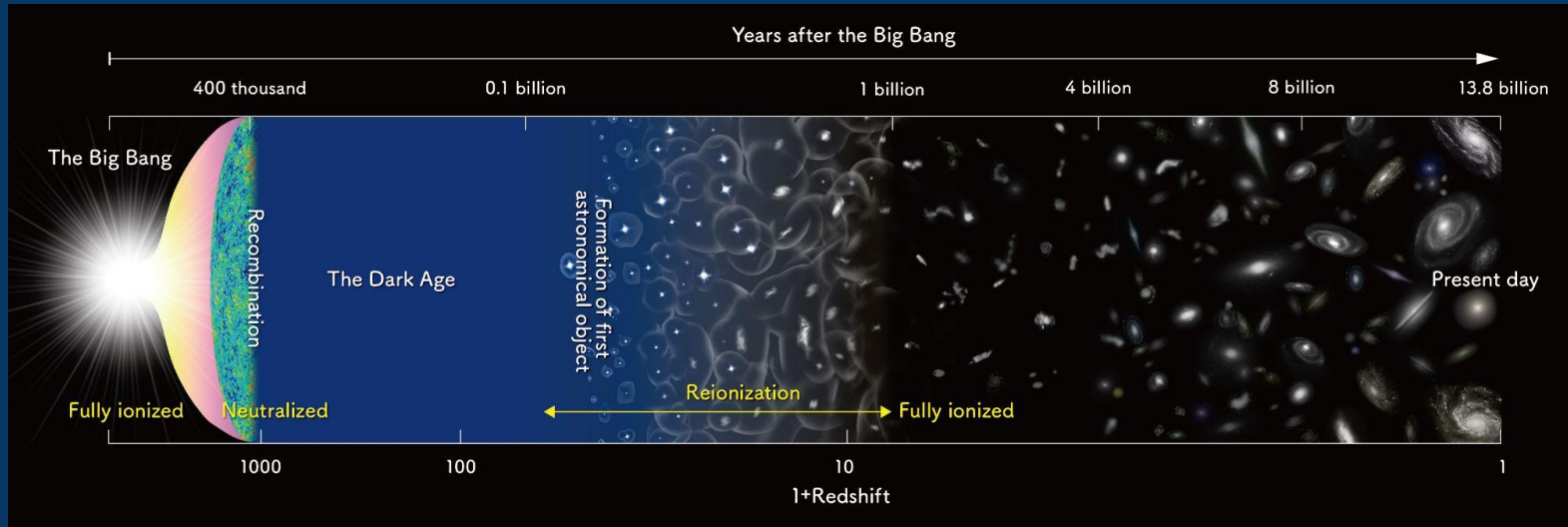


Other Local Universe uses

- Distance to pulsars in the galactic plane
- Mapping shape and structure of galaxies



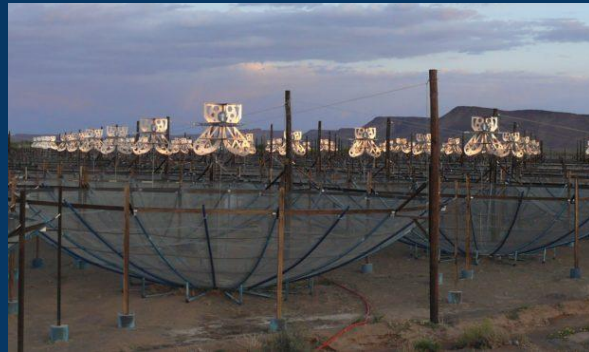
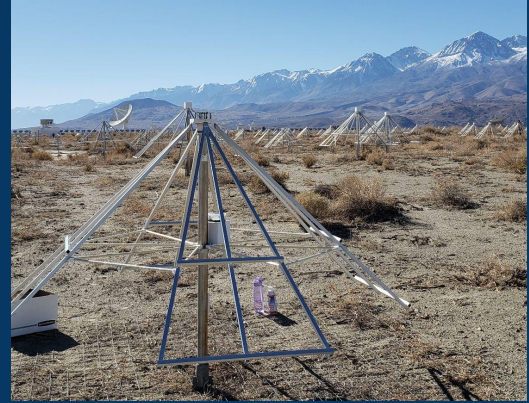
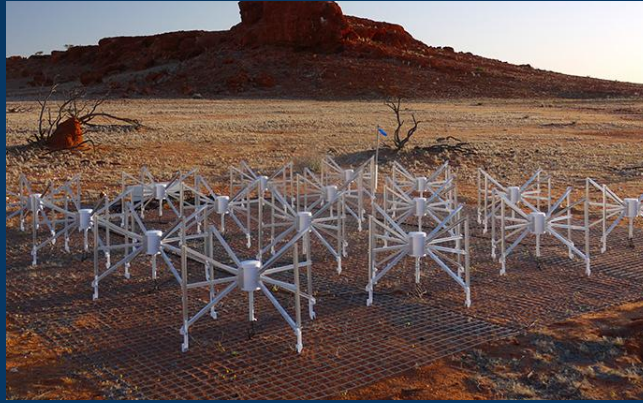
Dark Ages, Cosmic Dawn, Reionization



- Mapping ionization bubbles
- Finding first stars and galaxies in the Cosmic Dawn
 - Intensity mapping

Current 21-cm Experiments and Telescopes

- MWA
- LWA
- VLA
- HERA
- LOFAR





Suggested Reading

Review article: [21 cm cosmology in the 21st century, Jonathan R Pritchard and Abraham Loeb, 2012](#)

In-depth: [Cosmology at Low Frequencies: The 21 cm Transition and the High-Redshift Universe, Steven R. Furlanetto, S. Peng Oh, and Frank H. Briggs, 2006](#)

Data Analysis and instrumentation: [Data Analysis for Precision 21 cm Cosmology, Adrian Liu and J. Richard Shaw, 2019](#)