Results from the Allen Telescope Array: Real Time Imaging

Garrett K. Keating[1] and Jeanette B. Barott[2] for the ATA Team
[1]University of California, Berkeley Berkeley, CA 94720
[2]Embry Riddle Aeronautical University Daytona Beach, FL 32114

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ABSTRACT

We present current results from the Automated Real-Time Imaging System (ARTIS), a software system that allows for rapid reduction of interferometer data at the Allen Telescope Array (ATA). ARTIS supports automated processing for both continuum and spectral line observations, and is capable of supporting wide-field surveys. Motivation for this system arises from both the volume of data produced at the ATA and the need for timely results from observations. The ATA is capable of producing hundreds of gigabytes of data, and covering thousands of square degrees of the sky in a single day. The ATA has also embarked upon several surveys searching for transient events, making quick and reliable automated analysis essential for scientific work. ARTIS (and its affiliated software) has been used for a number of large-scale observations, including transient, HI and maser surveys. ARTIS is also producing real-time data quality measurements for observations, allowing for more robust observing.

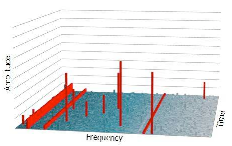
System Overview

The Automated Real Time Imaging System (ARTIS) is divided into three primary sections – RFI excision, calibration and imaging. In order for ARTIS to function properly, each system much meet three requirements. Processing in each section cannot require more time than the length of the observation, each section must be robust enough that bad results from one section can either be corrected for or thrown out, and each section must be able to function with limited or no a-priori information about the sky and system. ARTIS and its sister software project RAPID (Rapid Automated Processing and Imaging of Data, an offline reduction software package) are now utilized for several different projects at the ATA.

ARTIS

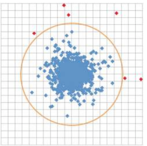
RAPID

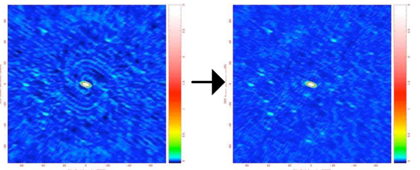
Flag, Calibrate, Image, Repeat.



RFI Excision currently has two primary modes of operation: amplitude and spectral occupancy. Amplitude-based excision removes spectral channels with amplitudes greater than 4σ above the mean amplitude of each spectrum. Spectral-occupancy based excision counts the number of times each channel exceeds 4σ of an individual spectrum for all baselines within a specified time window. Channels that exhibit a high occupancy rate (5σ above the median occupancy rate) are excised across all baselines. With both modes employed, standard RFI excision will remove approximately 98% of all RFI pollution. Later stages of processing are designed to identity and excise the remaining 2% of RF pollution.

During the first calibration observations, ARTIS uses a point source model to try and determine the best solutions for phase, amplitude and bandpass corrections for each antenna. ARTIS then uses this information as a basis for additional data excision, removing any data that exceeds RMS scatter or closure limits for both amplitude and phase. Solutions are derived again, and the flagging cycle repeated until no further data exceed RMS scatter or closure limits. Those baselines which retain fewer than 20% of their data are removed entirely. Similarly, those antennas which retain fewer than 20% of their baselines are also removed entirely. Once the point source model generates satisfactory solutions, ARTIS will then image the calibrator data, building a more complex model for the calibrator field and self-calibrating to that model. This model is used (and refined) during future calibrator reduction cycles.





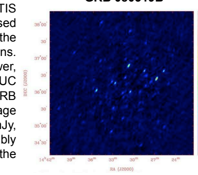
During the imaging cycle, ARTIS will use the calibrated data to find a flagging, deconvolution and self-calibration solution. ARTIS maximizes image quality by evaluating dynamic range and/or image fidelity. During the deconvolution cycle, ARTIS utilizes CLEAN to derive a preliminary deconvolution model. Once the a preliminary model has been derived, ARTIS will calculate which deconvolution method (CLEAN or MEM) along with the number of iterations to use, testing the deconvolution solution by looking for point sources and noise statistics in the residual map. ARTIS will then establish upper and lower amplitude limits for visibilities, removing visibilities that exceed these limits. ARTIS will finally self-calibrate on the image, and will repeat the imaging cycle until either the dynamic range or image fidelity has reached a maximum threshold.

Continuum Projects

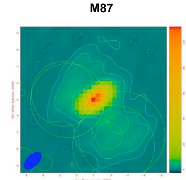
Due to the additional processing requirements with spectral line imaging, ARTIS and RAPID were first tested and deployed for continuum observations. The continuum mode of ARTIS was first successfully tested on March 15th, 2008 and was deployed for scientific observations just days later.

First scientific observations utilizing ARTIS were of GRB 080319B. ARTIS was used primarily because of its ability to produce the quick results desired in GRB observations. Observations were conducted by Geoff Bower, JR Forster, JS Bloom and Garrett Keating (UC Berkeley), with the goal of detecting the GRB afterglow at 1.43 GHz. The final image contained an RMS residual noise of 2.17 mJy, with point sources above 12 mJy reliably matching up with those sources listed in the NVSS catalog.

GRB 080319B



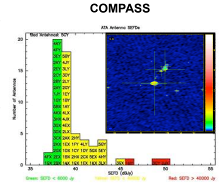
M87



Observations of M87 were taken over during November 2008 at several different frequencies. Observations were conducted by JR Forster and Garrett Keating (UC Berkeley), with the goal of producing spectral profiles of the outer halo surrounding M87's core. A total of six observations were taken: 1.43 GHz, 2.75 GHz, 4.5 GHz, 6.5 GHz, 7.5 GHz and 8.5 GHz. The 1.43 GHz observation was imaged using ARTIS, with the final image containing an RMS residual noise of 49 mJy, with a dynamic range of approximately 2600.

In February 2009, the RAPID toolset was used to create COMPASS (Calibrator Observing and Measurement Processing for Array Statistics and Status), a diagnostic tool to produce real-time information about hardware health and observation/data quality. COMPASS uses the real-time results of calibrator observations to diagnose potential hardware problems with the array, and give observers a measure of quality control for observations.

COMPASS

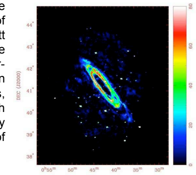


Spectral Line Projects

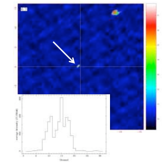
ARTIS and RAPID both feature spectral line imaging components, capable of handling projects as diverse as large-scale HI imaging to methanol maser detection. Spectral line imaging is capable in working "blind" (i.e. without knowledge of what frequency channels contain spectral line data).

One of the first spectral line projects that the RAPID toolset was used for was a series of observations on M31, conducted by Garrett Keating and Leo Blitz (UC Berkeley). The observation was designed to search for inter-galactic HI in the M31 region. The observation consisted of a total of seven different pointings, centered on M31. The final HI map (a zeroth moment map over 30 104 kHz frequency channels) contains an RMS residual noise of 18.9 mJy.

M31



W3



The RAPID toolset have also been used in a series of observations on the W3 GMC. The observations – conducted by Samantha Blair (SETI), JR Forster and WJ Welch (UC Berkeley) – were conducted using two correlators, observing the region at both 4.8 GHz and 6.7 GHz to image formaldehyde and methanol masers respectively. RAPID was used to image the 6.7 GHz data, the final image produced an image with a residual noise of 87 mJy and produced a spectrum of the methanol maser.

The RAPID toolset was also used in a series of observations, conducted by Katherine Alatalo and Leo Blitz (UC Berkeley), designed to detect HI in NGC 1266. Each frequency channel was mapped independently (roughly 800 channels), with the final series of maps containing a median RMS residual noise of 11.9 mJy.

NGC 1266