Summer Research Fellowship (SRF) 2020 for Science Students
Poster No.: D1
Name: CHEUNG So Yee
University No.: 3035570303
Major: Chemistry
Minor: Astronomy

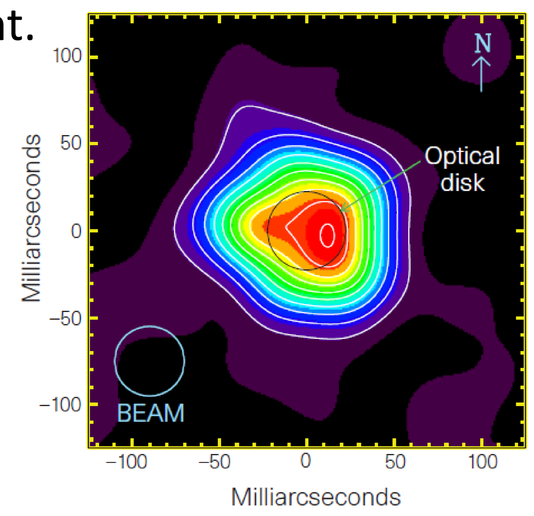
EVLA Observations of Betelgeuse

So Yee (Jasmine) Cheung, supervised by Dr. Jeremy J. L. Lim
Department of Physics, The University of Hong Kong

Fast-switching as a means to construct high-fidelity images

Betelgeuse is the closest red supergiant star. To observe the atmosphere and investigate the mass loss mechanism of red supergiant stars like Betelgeuse, high-fidelity images are necessary.

Very Large Array (VLA) observations by Lim et al. (1998) showed that the atmosphere of Betelgeuse was highly asymmetric and cool, leading to the interpretation that the atmosphere is elevated by giant convection cells that occur randomly. If Betelgeuse is observed at different times, it will look different.



Lim et al. 1998

The "fast-switching" observing mode (Carilli, Holdaway & Sowinski 1996) was implemented in this study and previous observations, to correct for tropospheric phase variations mainly due to temporal changes in the water vapor content.

However, VLA is not designed for fast-switching at shorter wavelengths (e.g. 7 mm).

Objectives:

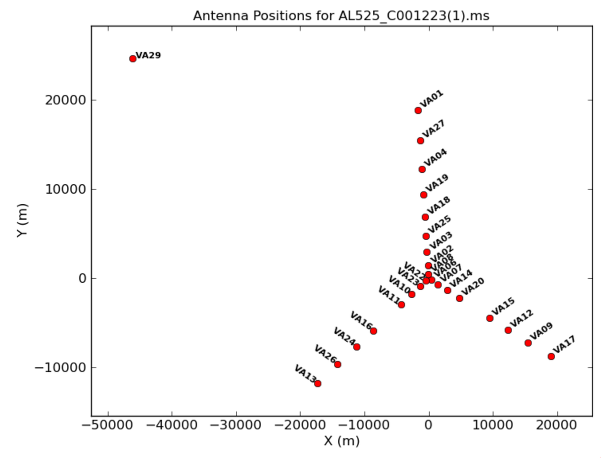
1. To investigate atmospheric structure in more detail by observing with longer exposure time and higher sensitivity
2. To identify problems and finding solutions for VLA Betelgeuse observations in fast-switching mode at 7 mm.

The 8-hour VLA observation of Betelgeuse was conducted in 23 Dec 2000 in "fast-switching" mode at 42.6 GHz and 42.7 GHz (each 50 MHz wide) with cycle time of 2 minutes.

We switched rapidly between the target source and a secondary calibrator. The secondary calibrator was used to interpolate the phases of Betelgeuse. CASA was used for data processing.

To check the effectiveness of phase corrections, an unresolved test calibrator (5.6° away from Betelgeuse) was used. The phases of the test calibrator were interpolated by the secondary calibrator. If the resultant image of the test calibrator is unresolved, the phase interpolation by secondary calibrator is accurate.

The Pie Town antenna from VLBA was linked to VLA. The 105-km fiber link allowed VLA to observe in more detail.



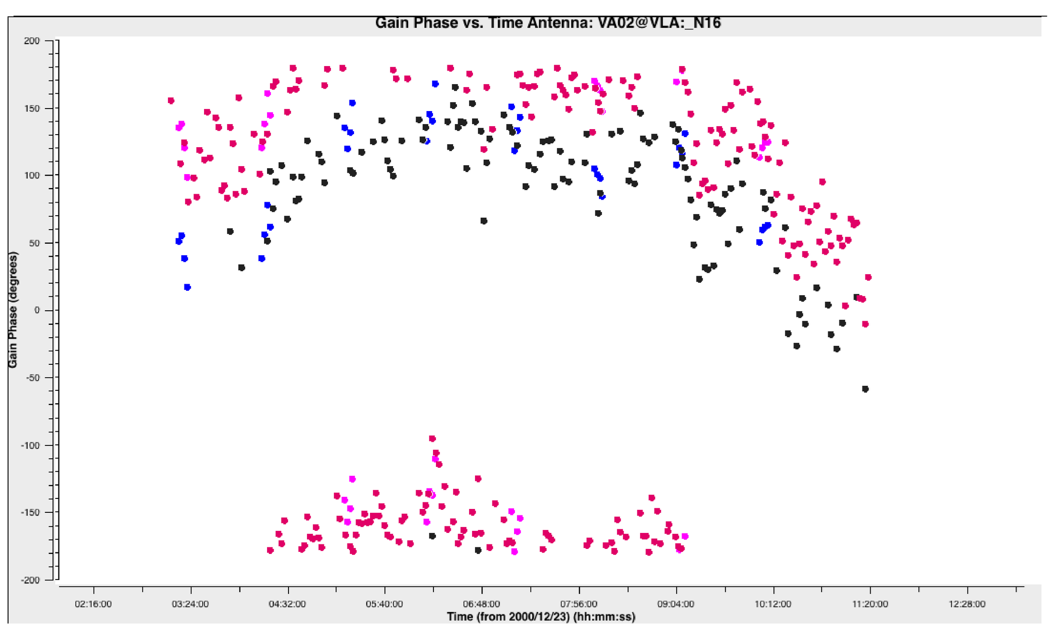
Problems with VLA observations and solutions

Opacity corrections:

At frequencies >15 GHz water vapor in the troposphere absorbs radio waves, so we applied opacity corrections using seasonal model.

Checking that phases of secondary calibrator matches that of test calibrator:

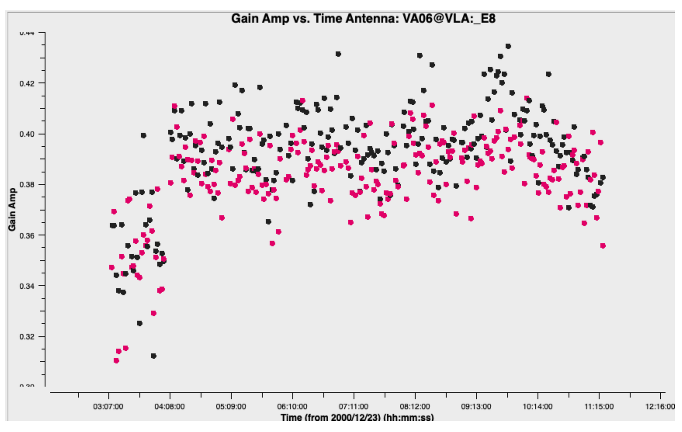
Antenna may have slightly incorrect measurement of position of sources, leading to mismatch in test and secondary calibrator phases, and hence incorrect interpolation. The solution was to pick a reference antenna where the phases of secondary and test calibrator match each other.



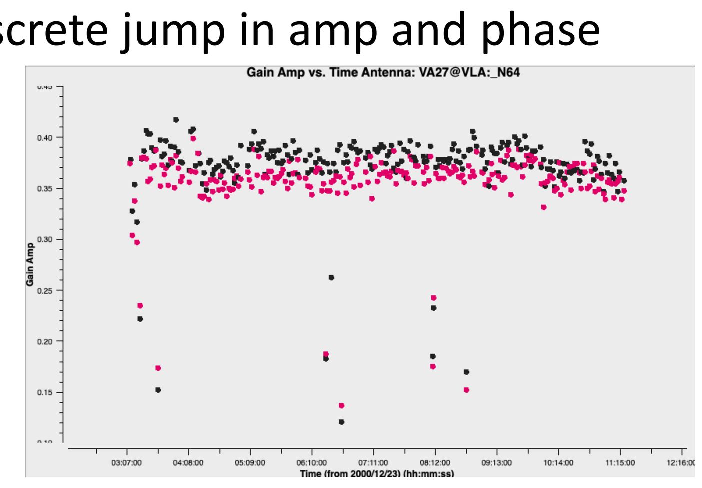
- Secondary calibrator, 42.6 GHz spectral window
- Test calibrator, 42.6 GHz spectral window
- Secondary calibrator, 42.7 GHz spectral window
- Test calibrator, 42.7 GHz spectral window

Flagging deviant data in gain solutions of secondary calibrator manually:

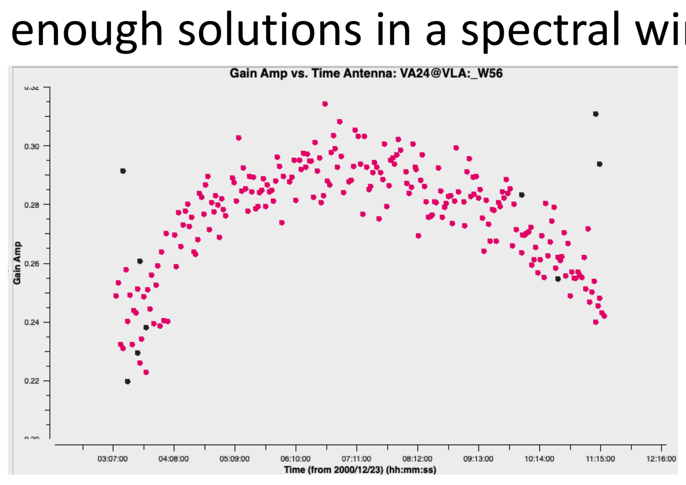
1. Discrepant amplitudes accompanied by noisy phases



2. Discrete jump in amp and phase



3. Not enough solutions in a spectral window

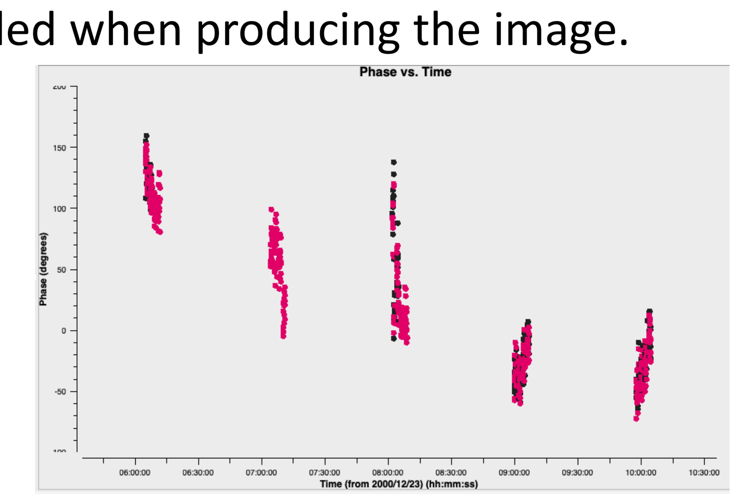


Development of a program to further remove deviant data in secondary calibrator:

After flagging, some deviant data might still exist, e.g. large phase jumps that are difficult to judge by eye. Hence, we wrote a program to perform flagging for these phase jumps. For each spectral window and correlation, the absolute difference between consecutive phases is determined, and the time range where phase jumps in secondary calibrator exceeds certain threshold (e.g. twice the median absolute difference) is flagged. There are no interpolated solutions for Betelgeuse where phase jumps in secondary calibrator exceeds the threshold.

Test calibrator phase error of unknown cause in Pie Town antenna:

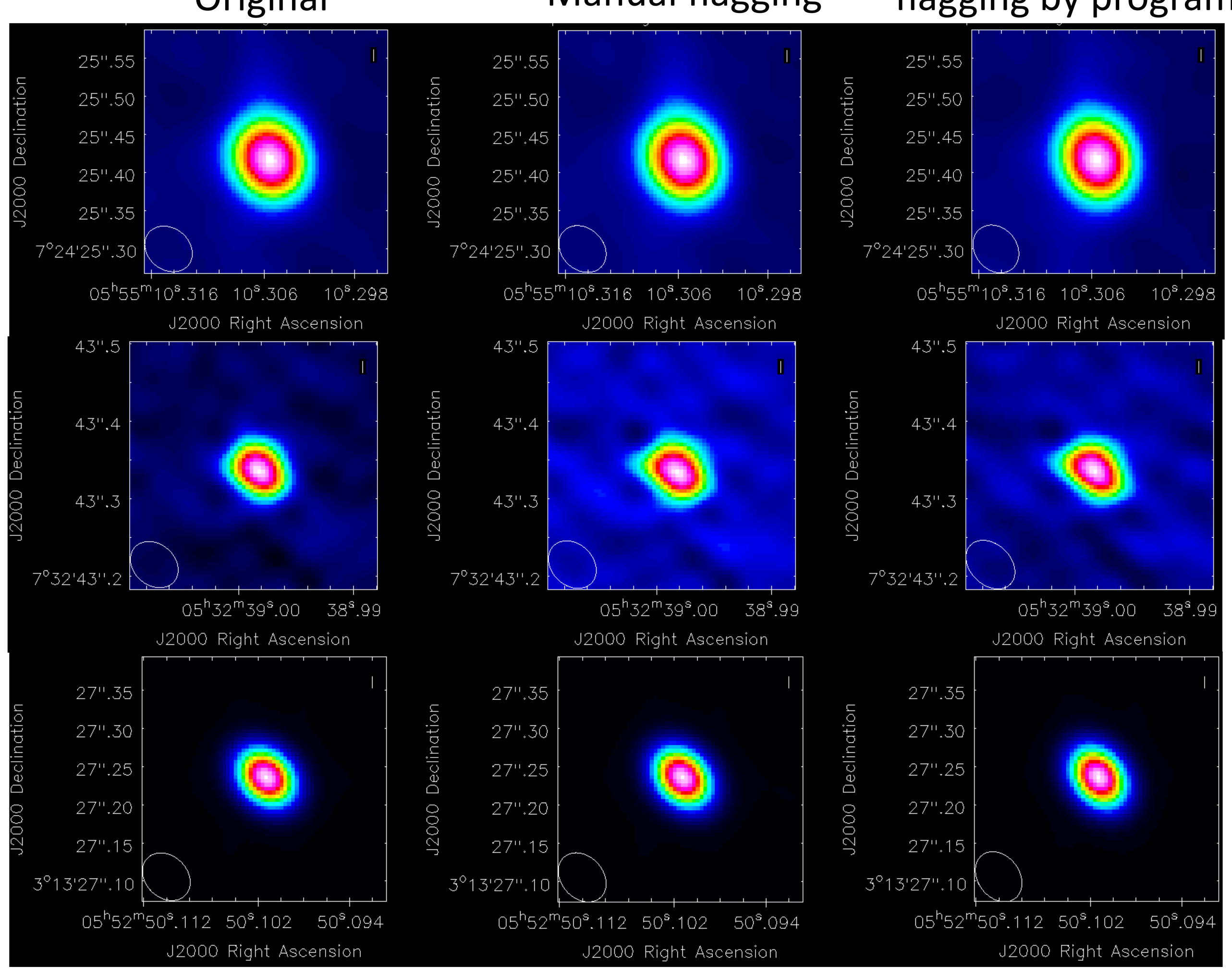
The phase error is possibly due to baseline error. To tackle this issue, Pie Town antenna was excluded when producing the image.



Final results and future prospects

Final images

	Original	Manual flagging	Manual flagging + flagging by program
Betelgeuse			
Test calibrator			
Secondary calibrator			



Discussion of resultant images

- Discarded quite a lot of data:
  1. First three scans of test calibrator discarded due to inaccurate matching of phases with secondary calibrator
  2. Data of baselines involving VA26 antenna discarded due to deviant phases of test calibrator
  3. 4th scan of baselines involving VA27 antenna discarded due to deviant phases of test calibrator
- **Extended structure of Betelgeuse as expected**
- **However, the test calibrator did not match the beam**, implying there were still faulty data
- Can try baseline correction for Pie Town antenna

Acknowledgement

So Yee Cheung is supported by the Faculty of Science of the University of Hong Kong and Dr. Jeremy Lim.

Alternative solutions:

Closure-only imaging (closure amplitudes and closure phases) using `eht-imaging` software library (Chael et al. 2018) can eliminate station-based gain errors, but it comes with issues, e.g. loss of some image information such as total image flux density and image centroid.

References:

Carilli, C. L., Holdaway, M. A. & Sowinski, K. P. Fast Switching at the VLA (VLA ScientificMemo. no. 169, National Radio Astronomical Observatory, Socorro, NM, 1996).

Chael, A., Bouman, K., Johnson, M., Blackburn, L., & Shiokawa, H. 2018, Eht-imaging: Tools for Imaging and Simulating VLBI Data, 1.0, Zenodo, doi:https://doi.org/10.5281/zenodo.1173414

Lim, J., Carilli, C.L., White, S.M., Beasley, A.J., & Marson, R.G. 1998, Nat, 392, 575