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AU MIC

1. OBSERVATIONS

AU Mic was observed on three dates with ALMA: 26 March 2014, 18 August 2014, and 24 June 2015. All observations were configured with four spectral windows, and employed ALMA's 12 m antennas and Band 7 receivers. One spectral window was centered around the CO $J = (2-1)$ transition at a frequency of 230.538001 Ghz, while the remainging three were configured to detect continuum emission with maximum bandwidths of 2 Ghz and channel spacing of 15.6 Mhz. Central frequencies for the continuum bands are 228.5, 213.5, and 216.0 Ghz.

The 26 March data were obtained with 32 antennas and baselines ranging between 14 and 437 m; weather conditions were excellent (∼0.6 mm of precipitable water vapor (PWV)). The quasar J1924-2914 was used as a bandpass calibrator, and Titan was used to calibrate absolute flux. After these initial calibrations, observations cycled every seven minutes between AU Mic and the quasar J2101-2933, which was used for phase calibration. In total, 35 minutes were spent on source.

The 18 August utilized 35 antennas in a more extended antenna configuration (baselines between 20 and 1268 m) to probe the small scale structure of the disk. Weather conditions were poor, with ∼1.6 mm PWV. The quasars J2056-4714 (bandpass calibration) and J2056-472 (absolute flux calibration) were observed at the beginning of the observation window. For the remainder of the time block antennas cycled between seven-minute observations of AU Mic and brief observations of the quasars J2101-2933, for phase calibration, and J2057-3734, to test the quality of the gain transfer. AU Mic was observed for 35 minutes altogether.

The 24 June observation was taken to supplement the August observation, which was of poor quality due to weather conditions. 37 antennas covered baselines between 30 and 1431 m, and weather conditions were good: ∼0.7 mm PWV. Bandpass and absolute flux calibrations, making use of J1924-2914 and Titan respectively, were conducted at the beginning of the scheduled time block. Short observations of the quasars J2056-3208 for phase calibration and J2101-2933 to assess gain transfer quality were interspersed among seven-minute observations of the source, which was observed for 33 minutes. The host star flared during the last observation of AU Mic, from 04:23:38-04:29:58 UT.

Table 1. Subtracted point source fluxes

Time (UTC)	Point source flux (μJy)
03:45:0-04:20:00 (no flare)	410 ± 20
4:23:38-4:24:00	920 ± 170
4:23:38-4:24:00	$11,460 \pm 100$
4:25:00-4:26:00	3590 ± 100
4:26:00-4:27:00	1580 ± 100
4:27:00-4:28:00	450 ± 100
4:28:00-4:29:00	460 ± 100
4:29:00-4:29:58	520 ± 100

Calibration, reduction, and imaging were carried out using the `CASA` and `MIRIAD` software packages. Standard ALMA reduction scripts were applied to the datasets: phase calibration was accomplished via water vapor radiometry tables, and system temperature calibrations were performed to account for variations in instrument and weather conditions. Flux and bandpass calibrations were subsequently applied.

The authors travelled to the NRAO facility in Charlottesville, VA in October 2015 to further process the data; in particular the trip was intended to allow on-site correction of the 24 June flare. Tasks used to reduce the data at the NRAO facility were all part of the CASA package. An elliptical gaussian was fit to a small region around the star in the image plane of each dataset using the task `imfit`; the equatorial coordinates of the the model gaussian centroid were used to define the star position. Each observation was then phase shifted using the task `fixvis` so that the the pointing center was the same as the star position fit. The peak flux of the model gaussian was also subtracted from the location of the star in the visibility domain so that only the disk remained.

The 24 June dataset required additional reduction due to the flare. While for the other dates we were able to fit a single point source to account for the stellar component over the entire observation, the flare required that the dataset be split into one minute bins between 04:23:38 and 04:29:58 in order to account for the variable flux of the host star. For each of these bins, we used the task `uvmodelfit` to fit a point source to the long baseline visibilities, which we subsequently subtracted from each bin in the visibility domain. Subtracted point fluxes can be found in Table 1.

The June date pointing center, defined by the centroid of the elliptical gaussian fit to the star, was visibly offset from the surrounding disk; this could be explained if the flare referenced above were not symmetric with respect to the star. The offset was remedied by redefining the pointing center as follows. Because the star is known to be located at the center of the disk, we can use information provided by the brightness distribution of the disk to infer the star position. We do so by selecting the brightest pixel on each side of the disk from the clean component map (the `.model` file produced by `tclean`), and redefining the star/pointing center as the mean of the two pixel positions. This yields offsets of $(0.01'', -0.05'')$ for the March observation, $(0.01'', 0.00'')$ for the August observation, and $(0.00'', 0.09'')$ for the June observation. Given the good agreement between the calculated star position and the image center for the two non-flare dates (March and August), we conclude that the 'pixel' method represents a viable way to accurately determine star position. We apply this correction and redefine the image center via `fixvis`. For consistency, we apply the phase shift to all three dates.

Due to the high proper motion of AU Mic, the pointing centers of the three dates differ by a not-insignificant amount. When datasets with different pointing centers are cleaned together with `tclean`, the pointing center of the first dataset is taken as the new pointing center, and the data are combined in in the *uv* plane with each subsequent dataset offset from the first as given by their relative pointing centers. In the case of AU Mic, this leads to an image of the disk composed of three observations offset with respect to each other. To remedy this, we use the task `concat`, which combines datasets with their pointing centers aligned so long as the pointing centers do not differ by more than the value of `dirtol`. We set `dirtol` to $2''$, a value larger than AU Mic's proper motion over ALMA's ~ 1 year observation baselines.