Imaging Mira's Masers

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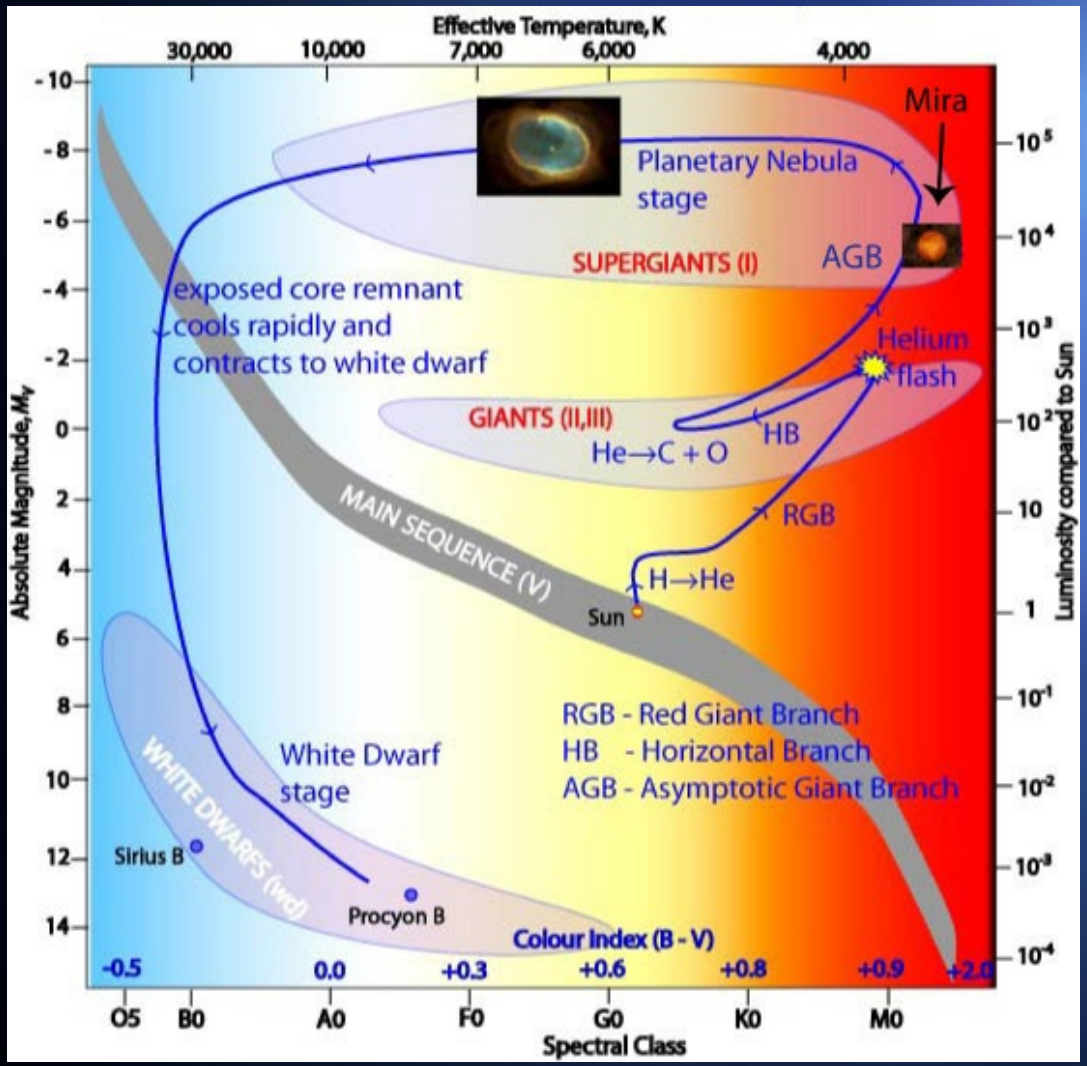
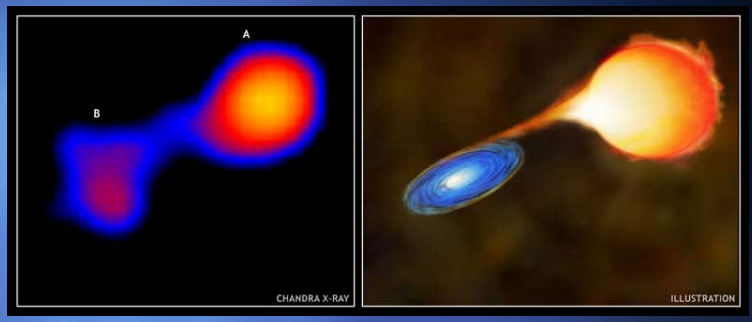
MIT Haystack REU 2012

Mira AB



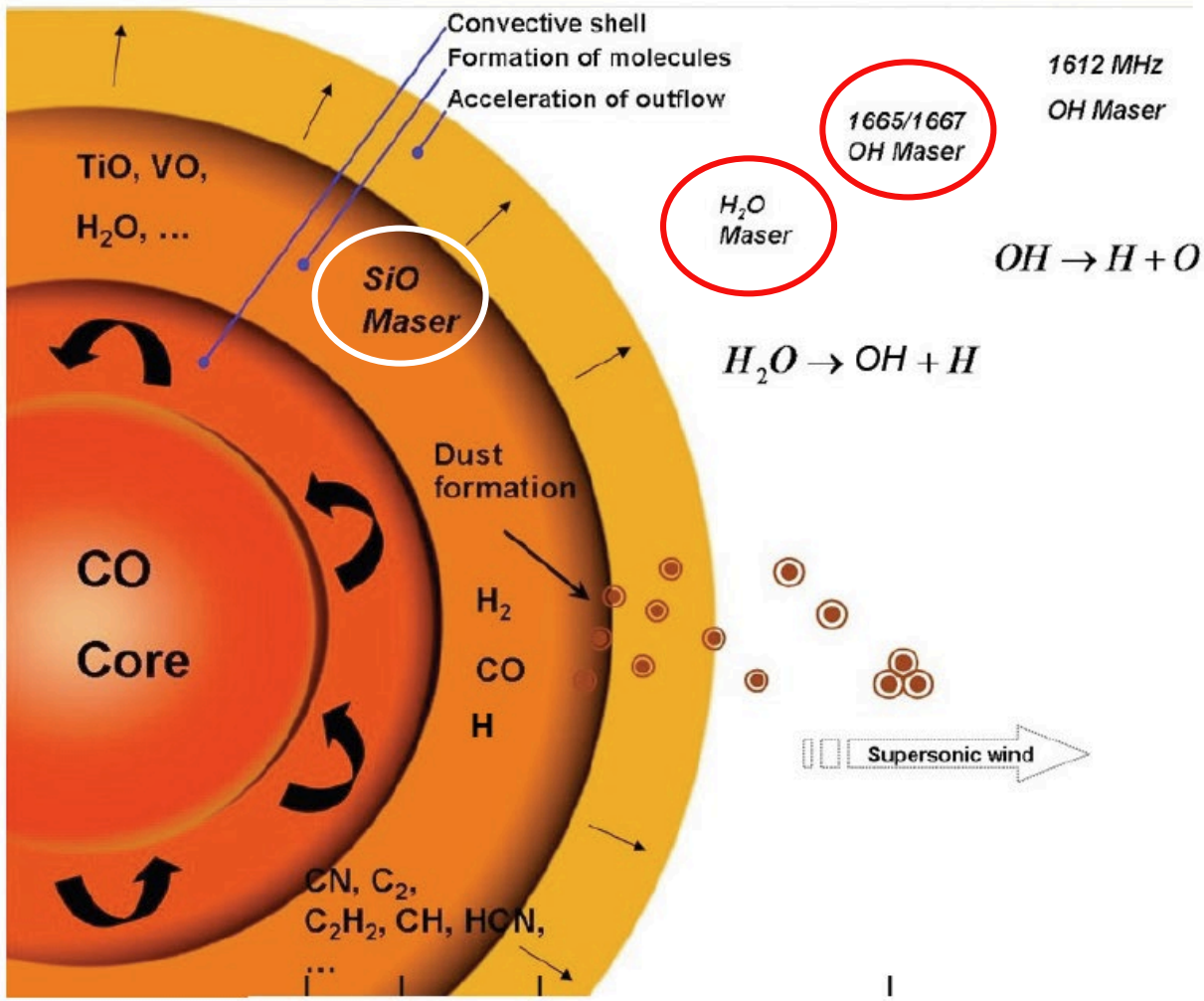
x-ray

illustration



- Mira A is an AGB star
- 107 parsecs from Earth
- 1.7 $M_\odot$ but 600x the size of the sun
- has a pulsation period of ~332 days
- undergoes mass loss
- binary star system
- Mira B is a white dwarf
- A and B separated by ~65 AU

Masing Regions



The Masers of Mira A

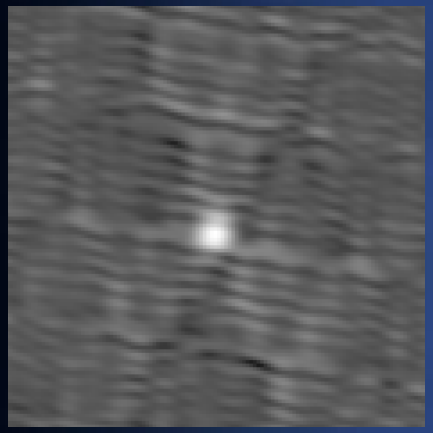
- Motivation for this project was an unprecedented x-ray burst from Mira A detected in 2003 by Karovska et al. It is the first time x-rays have been observed coming from an AGB star.

- Data were taken by the VLA in three frequency bands for the detection of SiO (43 GHz), H2O (22 GHz), and OH (1665 MHz) masers. Observations were made during six epochs, and in multiple VLA configurations.

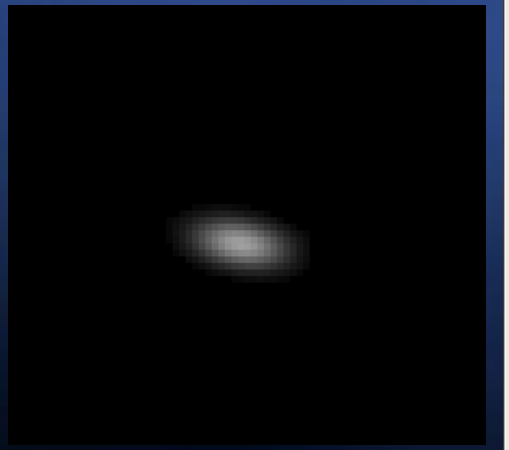
- Masers are the radio-wavelength equivalent to lasers, naturally occurring in the circumstellar envelope surrounding Mira.

AIPS and Calibration

- Two calibrator sources were used to set the absolute flux scale and complex gains of the maser emission, correcting for amplitude and phase inaccuracies caused by atmospheric and instrumental effects.
- Self-calibration on the maser emission was used to further improve the amplitude and phase of the image.



before self-calibration



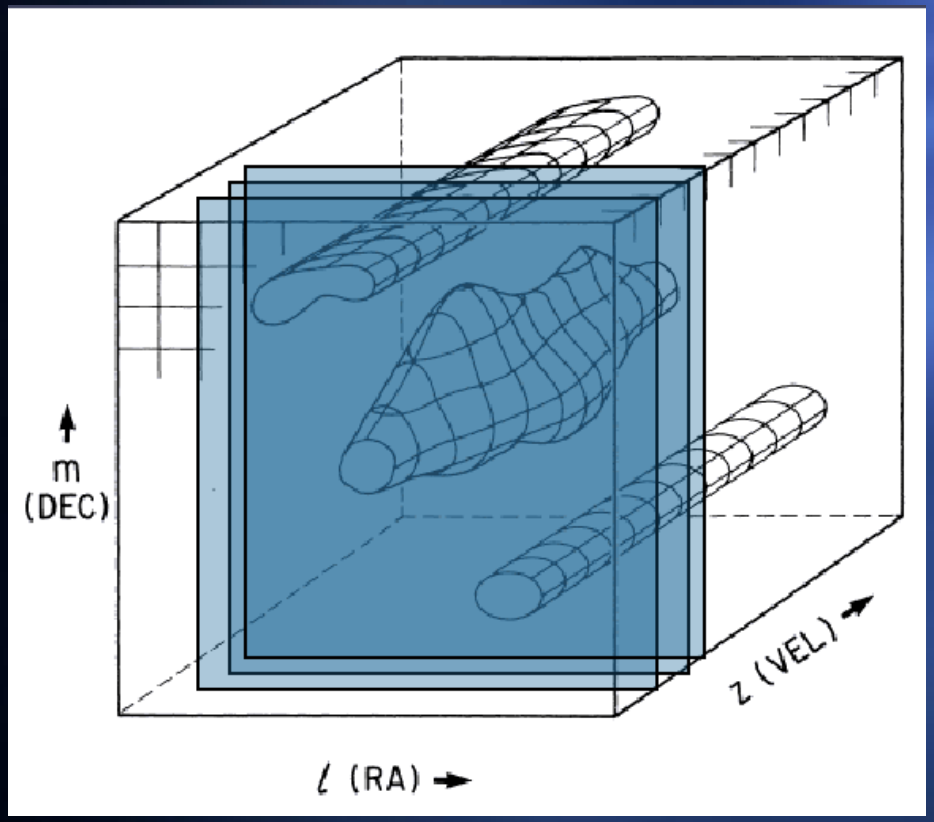
after self-calibration

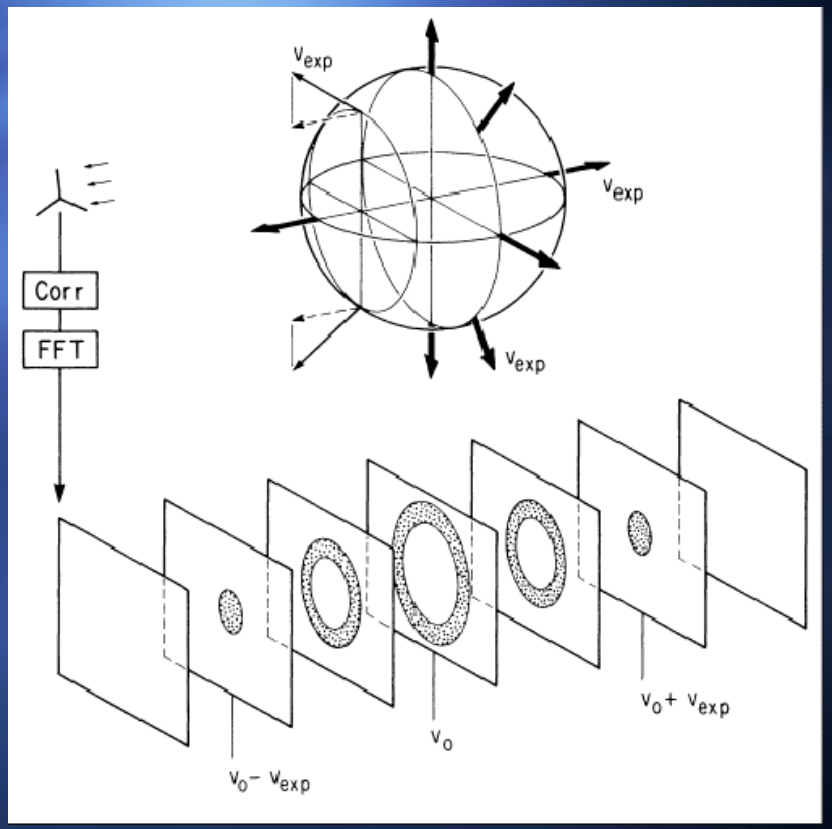
rzizza@reu1:/home/aips

File Edit View Terminal Tabs Help

```
>inp
AIPS 1: CALIB:  Task to determine calibration for data.
AIPS 1: Adverbs     Values                  Comments
AIPS 1: ------------------------------------------------------------------
AIPS 1:                                     Input uv data.
AIPS 1: INNAME     'CH 64 K'                   UV file name (name)
AIPS 1: INCLASS    'CH64KP'                    UV file name (class)
AIPS 1: INSEQ         1                        UV file name (seq. #)
AIPS 1: INDISK        6                        UV file disk drive #
AIPS 1:                                     Data selection (multisource):
AIPS 1: CALSOUR    'MIRA-H2O'               Calibrator sources
AIPS 1:            *rest ' '
AIPS 1: QUAL          -1                    Calibrator qualifier -1=>all
AIPS 1: CALCODE    ' '                      Calibrator code '    '=>all
AIPS 1: SELBAND       -1                    Bandwidth to select (kHz)
AIPS 1: SELFREQ       -1                    Frequency to select (MHz)
AIPS 1: FREQID        -1                    Freq. ID to select.
AIPS 1: TIMERANG   *all 0                   Time range to use.
AIPS 1: ICHANSEL   *all 0                   Array of start and stop chn
AIPS 1:                                     numbers, plus a channel
AIPS 1:                                     increment and IF to be used
AIPS 1:                                     for channel selection in the
AIPS 1:                                     averaging. See HELP ICHANSEL.
AIPS 1:                                     Default = center 75% of band.
AIPS 1: ANTENNAS   *all 0                   Antennas to select. 0=all
AIPS 1: DOFIT      *all 0                   Subset of ANTENNAS list for
AIPS 1:                                     which solns are desired.
AIPS 1: ANTUSE     *all 0                   Mean gain is calculated
AIPS 1:                                     (CPARM(2)>0) using only the
AIPS 1:                                     listed antennas. See explain.
AIPS 1: SUBARRAY      0                     Subarray, 0=>all
AIPS 1: UVRANGE       0           0         Range of uv distance for full
AIPS 1:                                     weight
AIPS 1: WTUV          0                     Weight outside UVRANGE 0=0.
AIPS 1: WEIGHTIT      0                     Modify data weights function
AIPS 1:                                     Cal. info for input:
AIPS 1: DOCALIB      -1                     > 0 calibrate data & weights
AIPS 1: ** press RETURN for more, enter Q or next line to quit print **
#
```

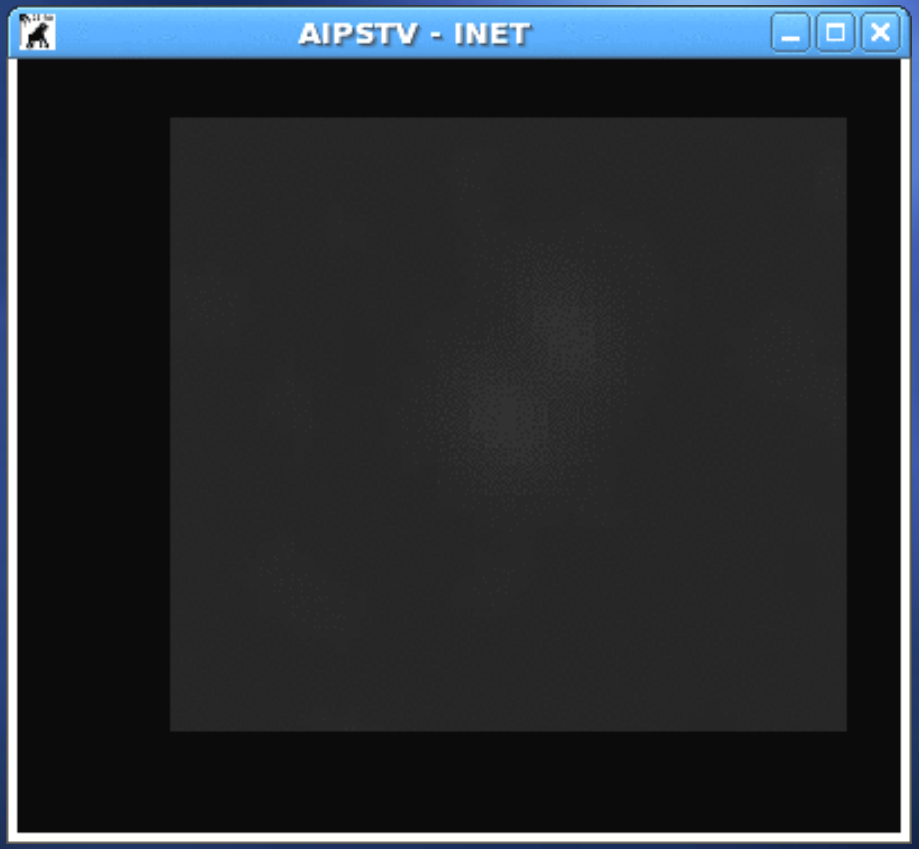
The Data Cube





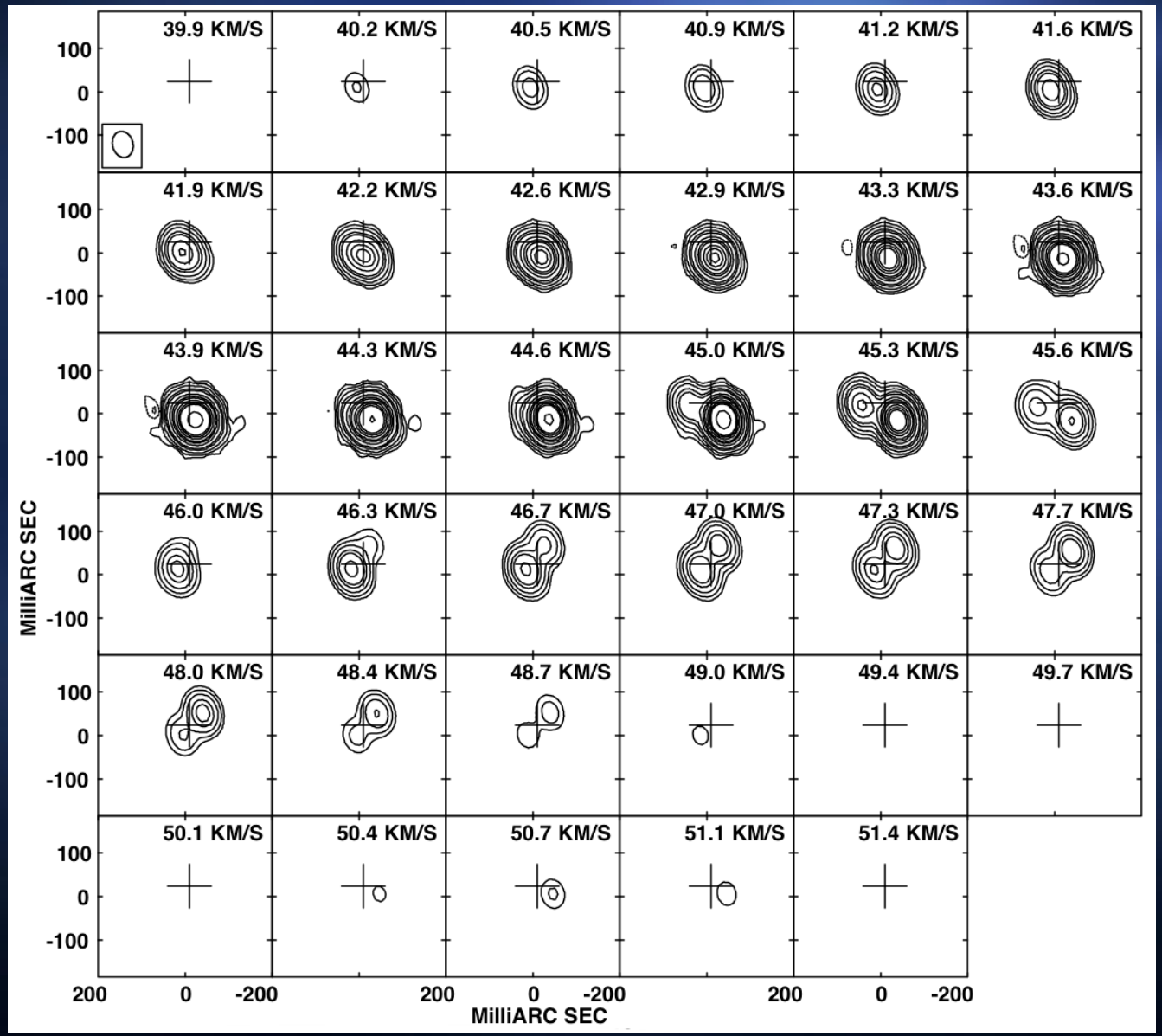
SiO 12/08/04

200 mas
= 21.4 AU

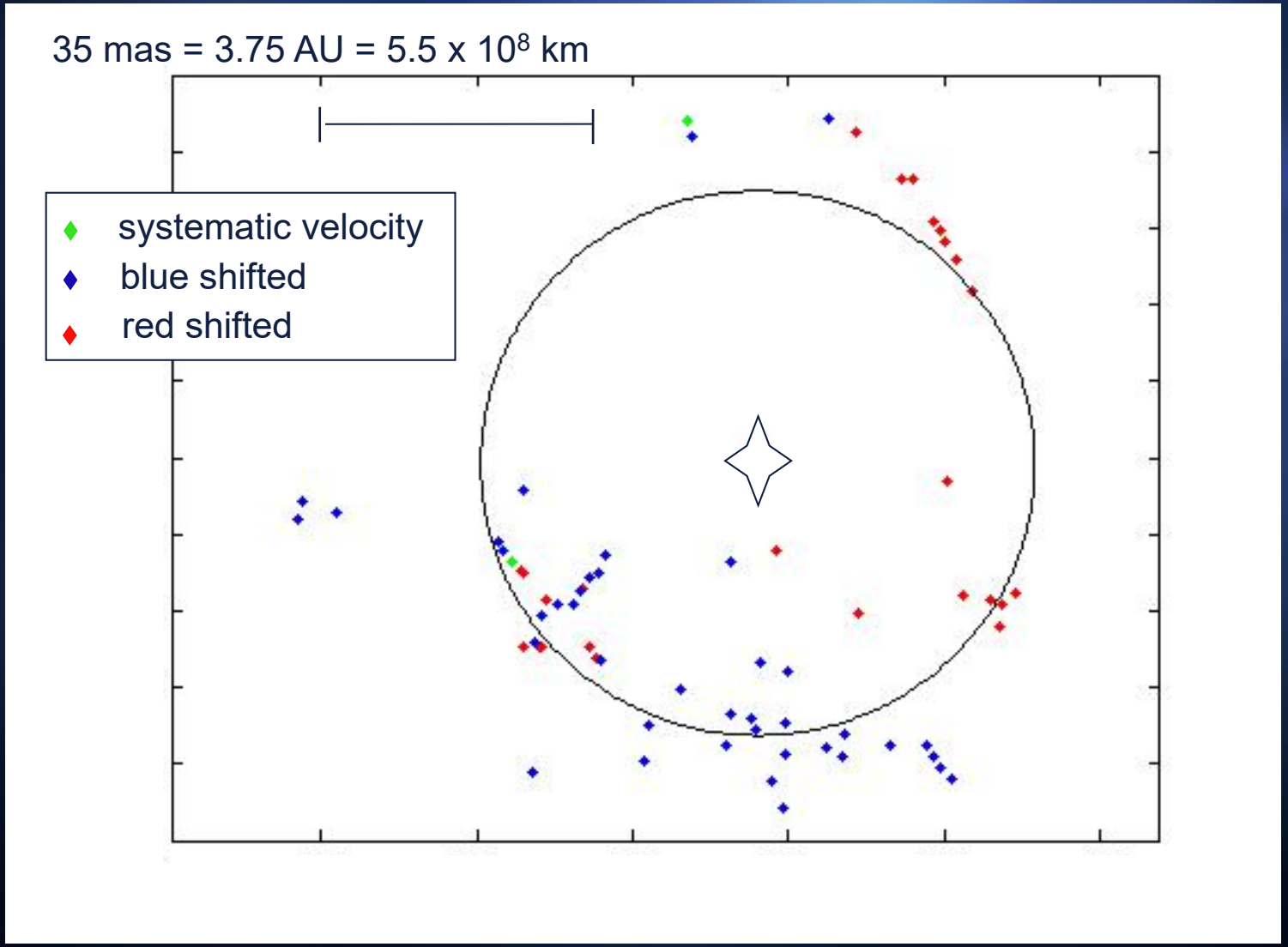


Channel Maps and Contour Plots

SiO 10/19/04

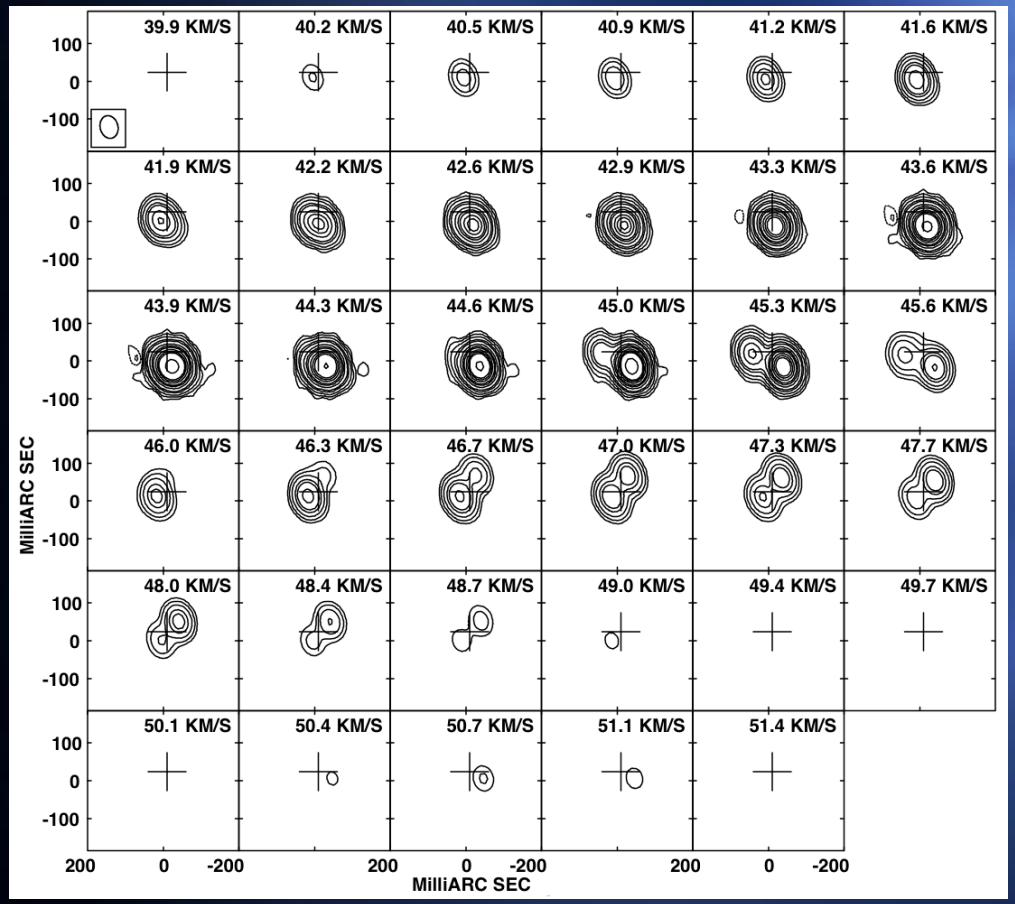


SiO 10/19/04 Spot Map

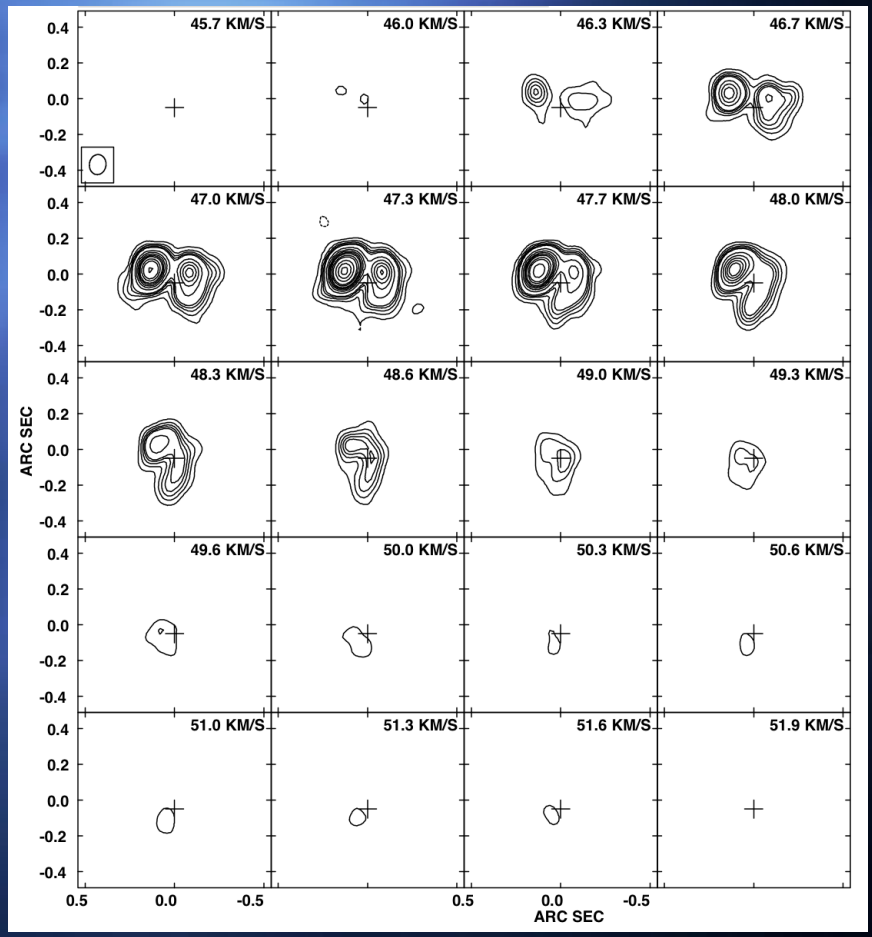


Epoch 10/19/04

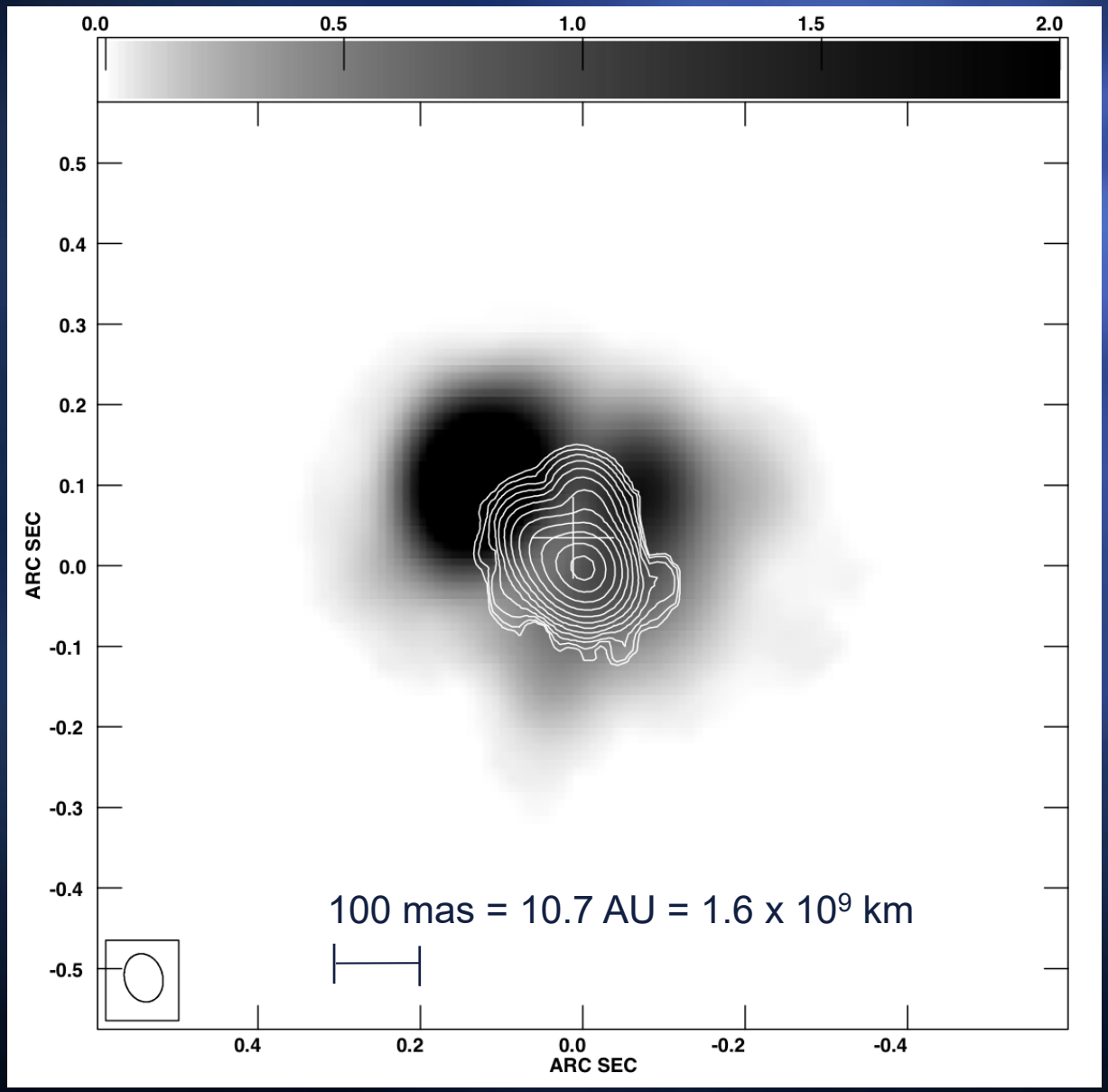
SiO



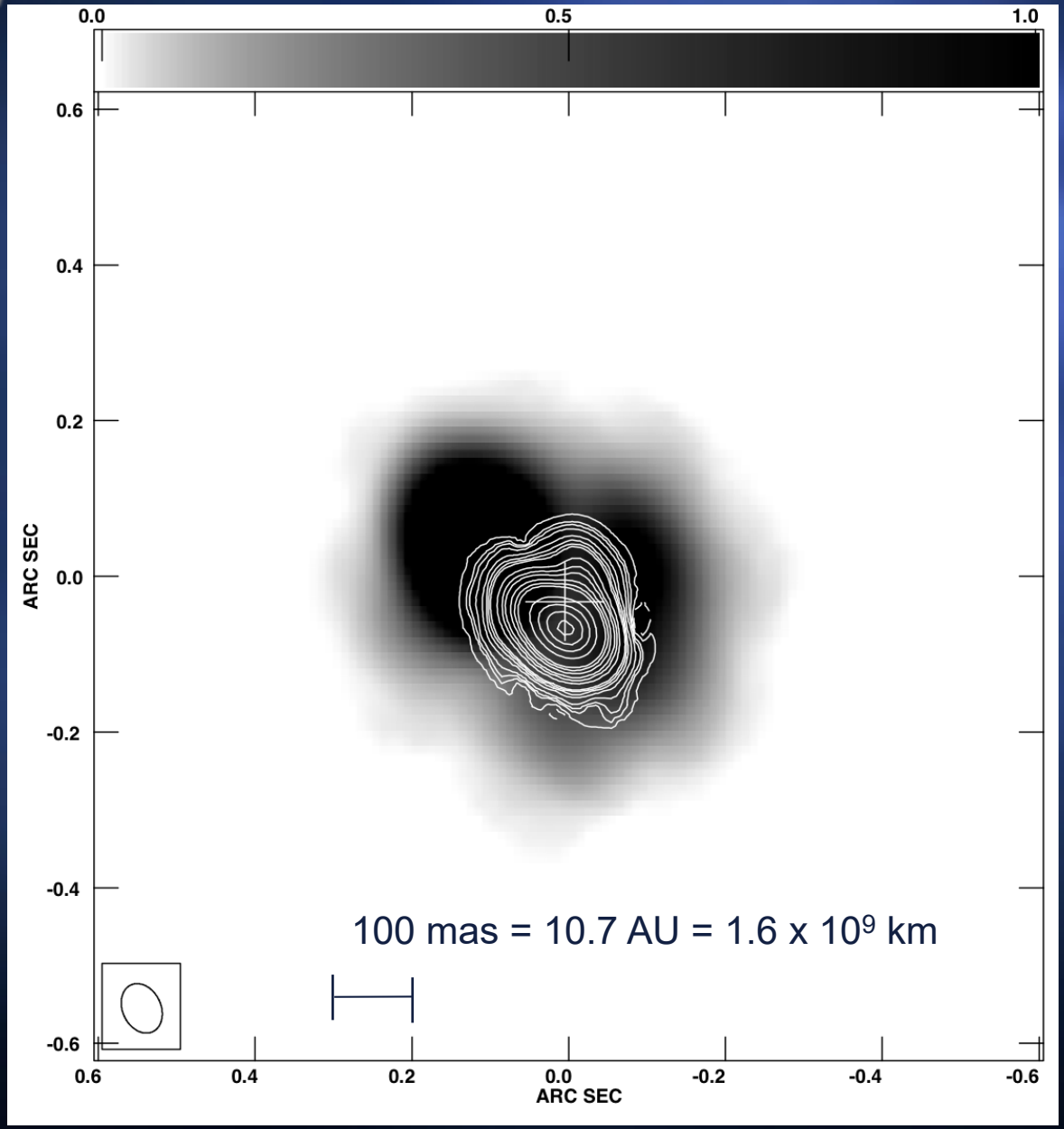
H2O



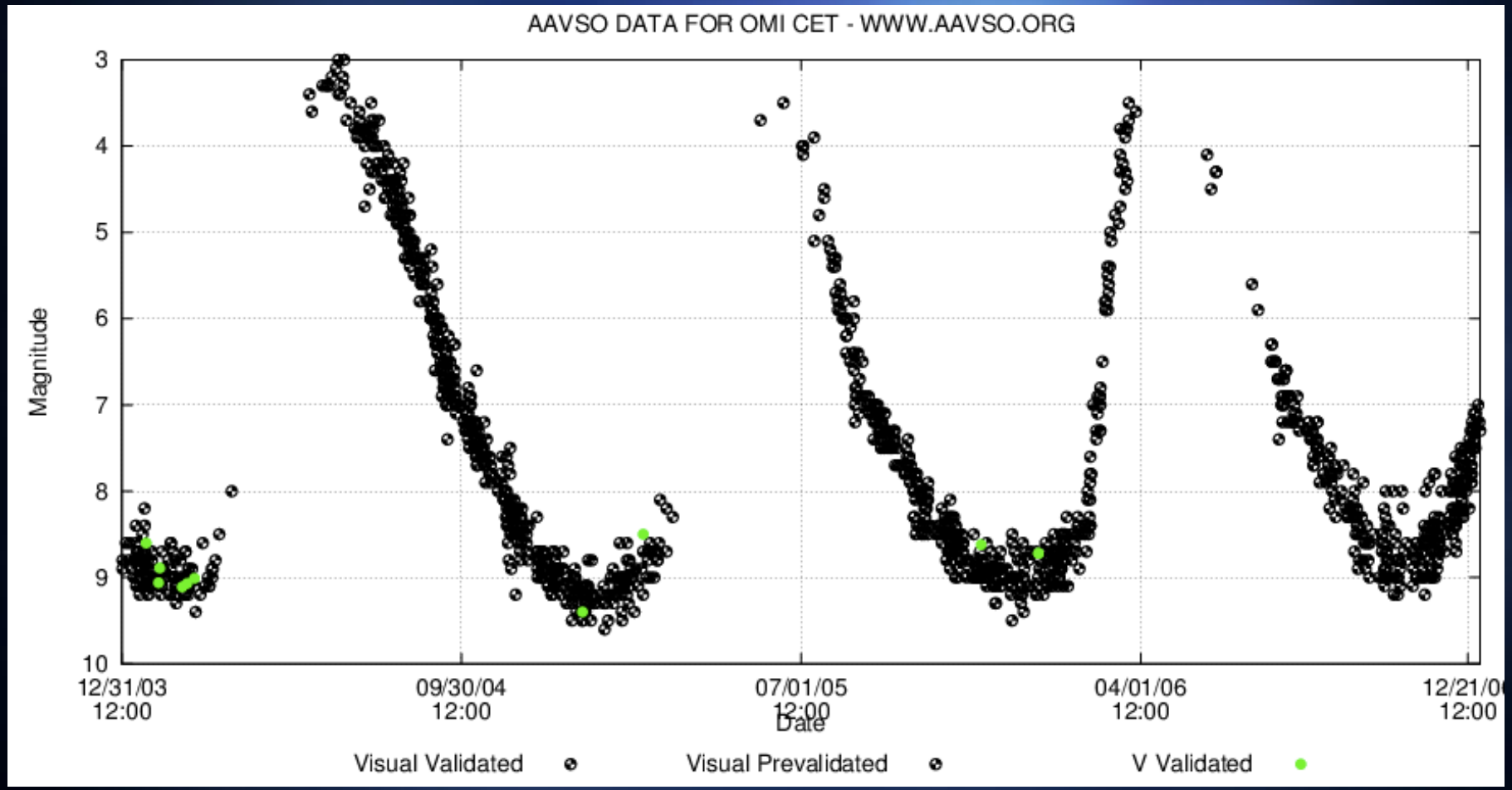
10/19/04 - H2O and SiO



12/08/04 - H2O and SiO

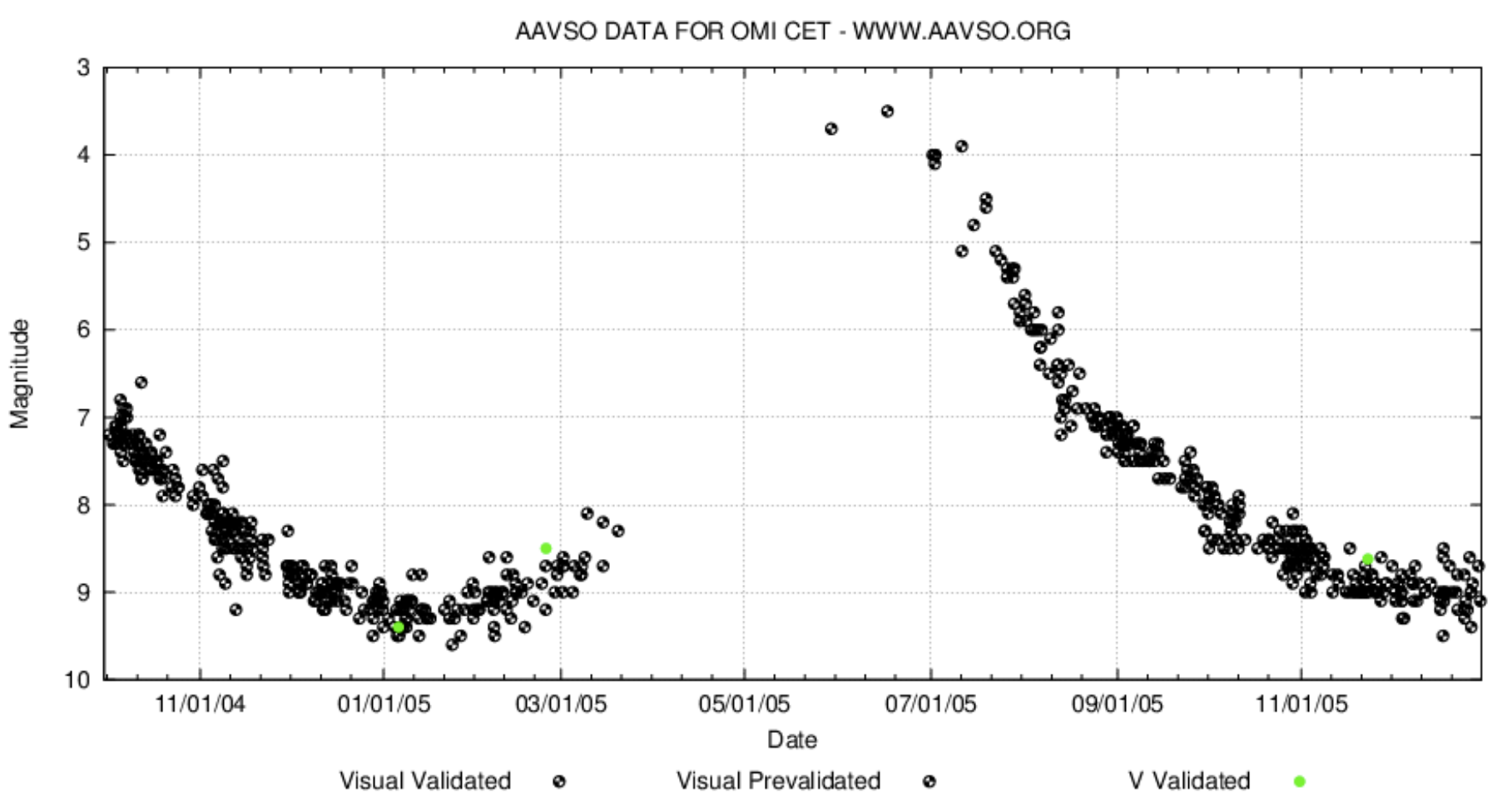


Mira's Light Curve



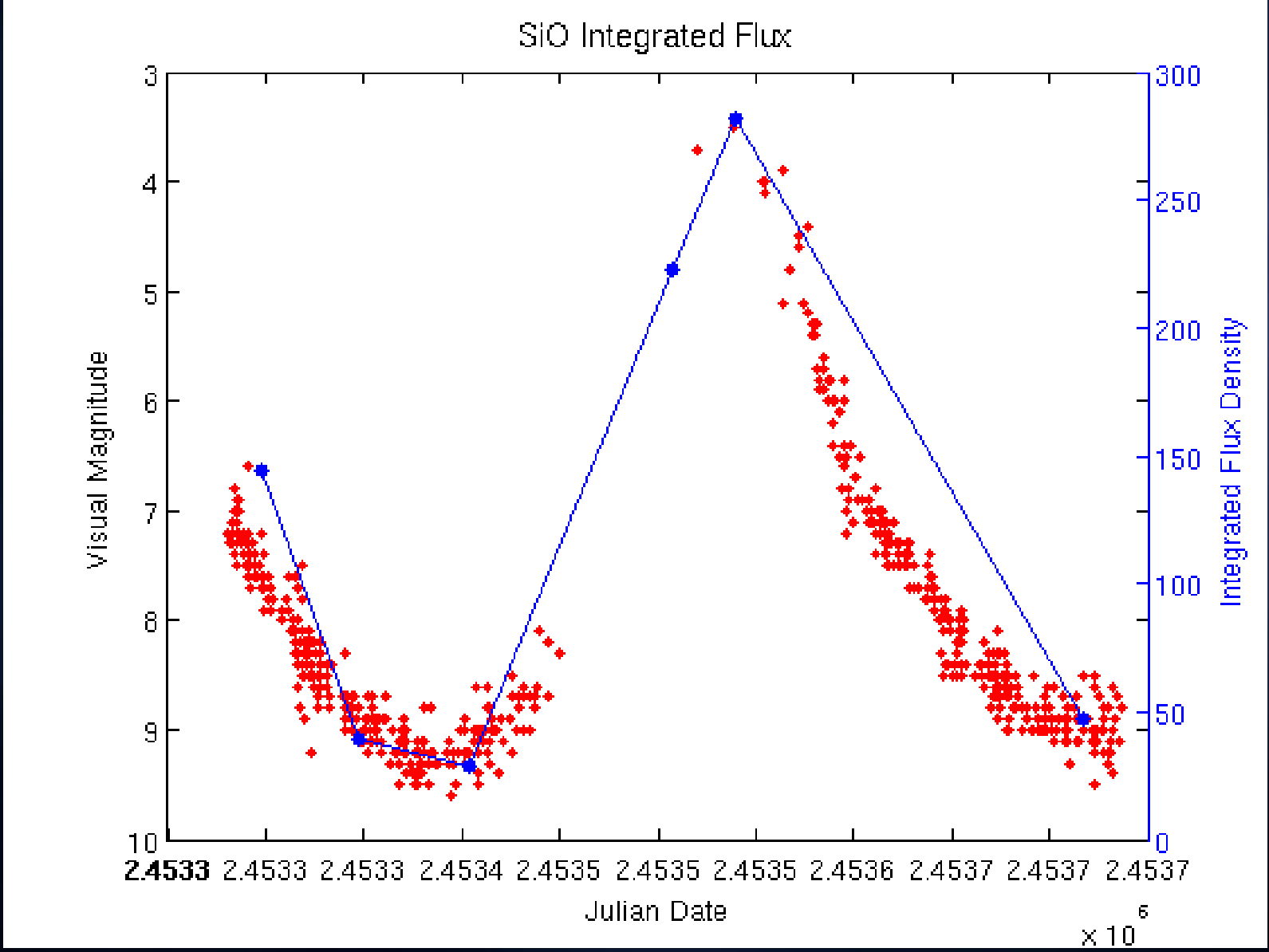
Visual magnitude

Mira's Light Curve

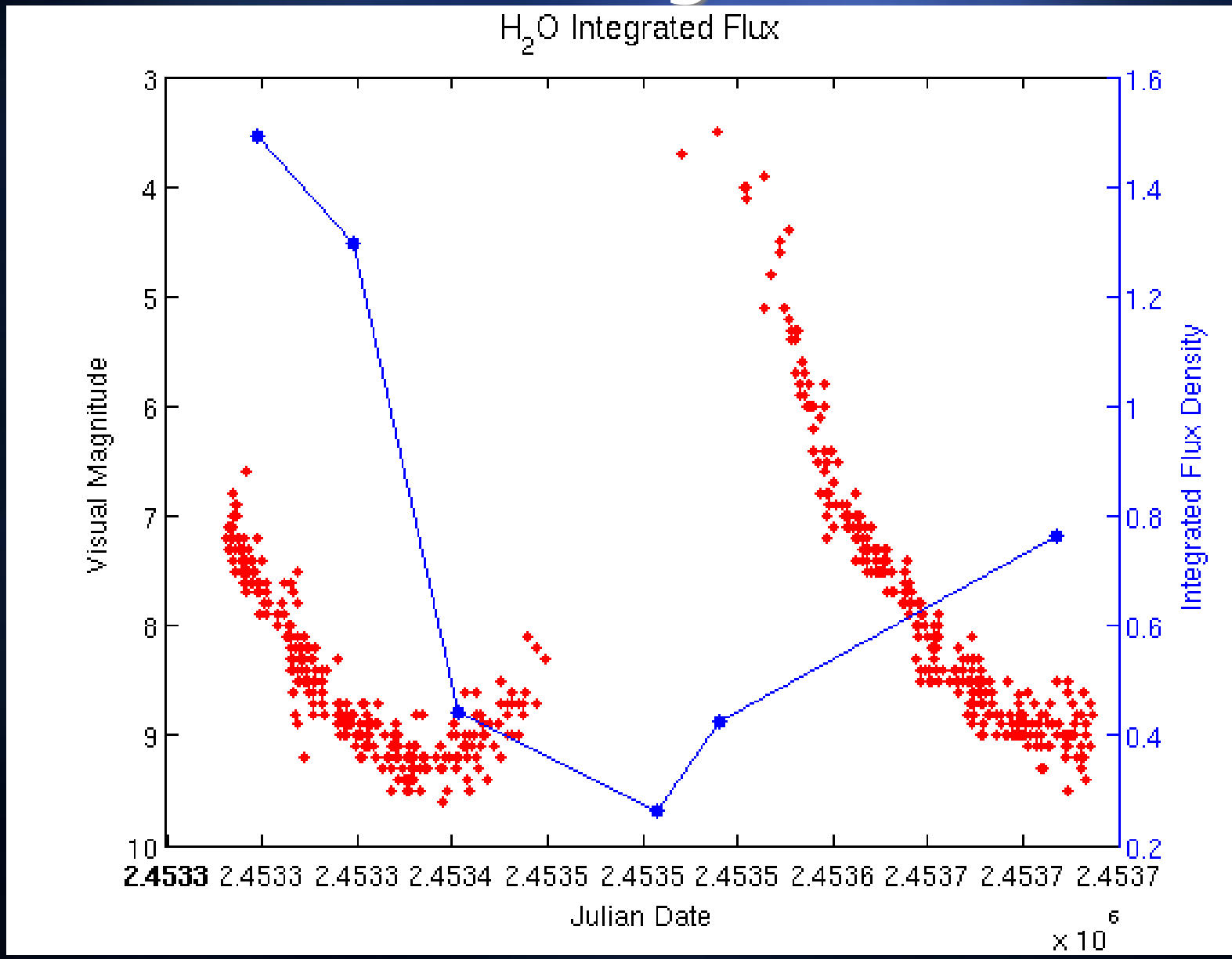


Visual magnitude

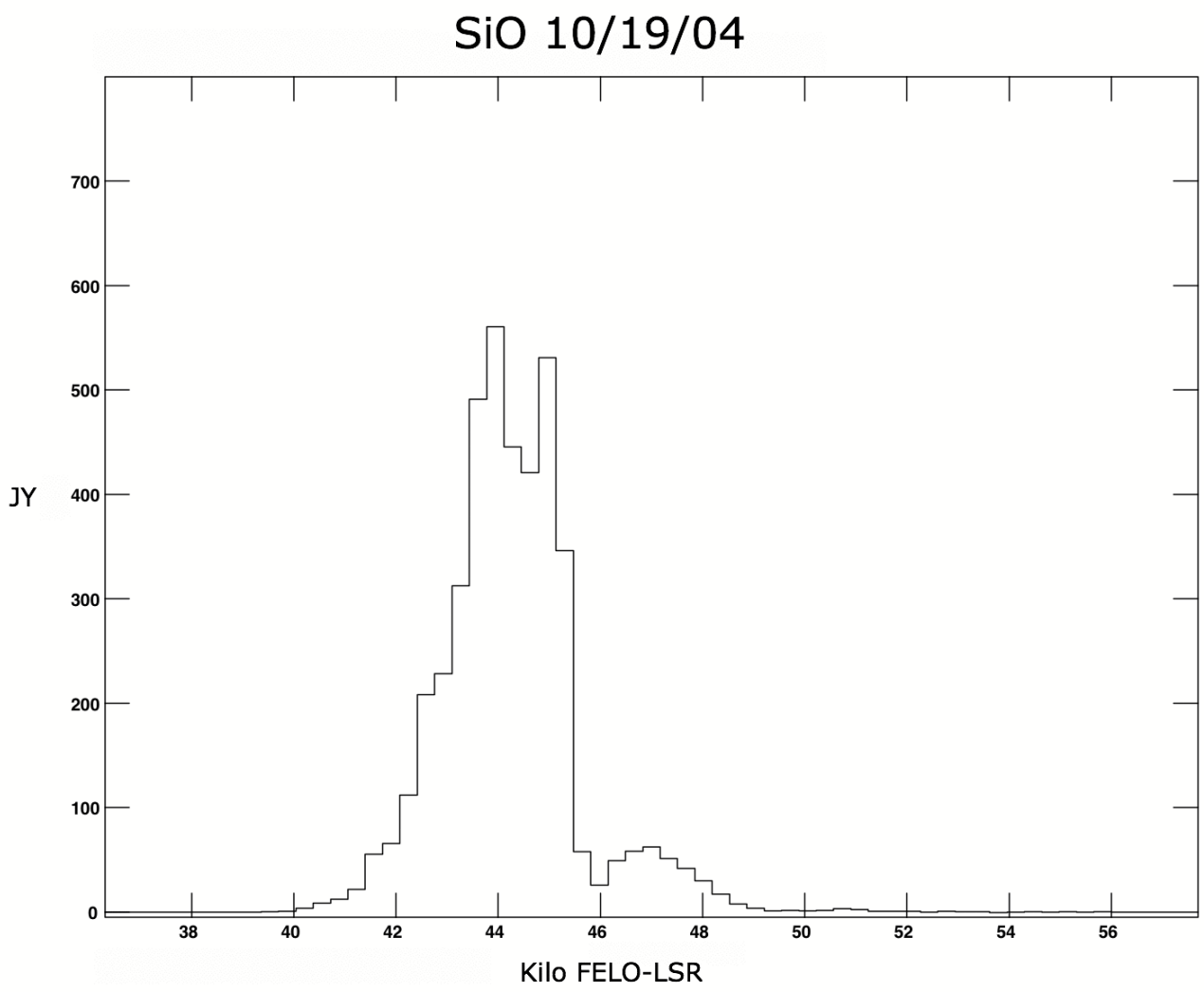
Masers and the Light Curve



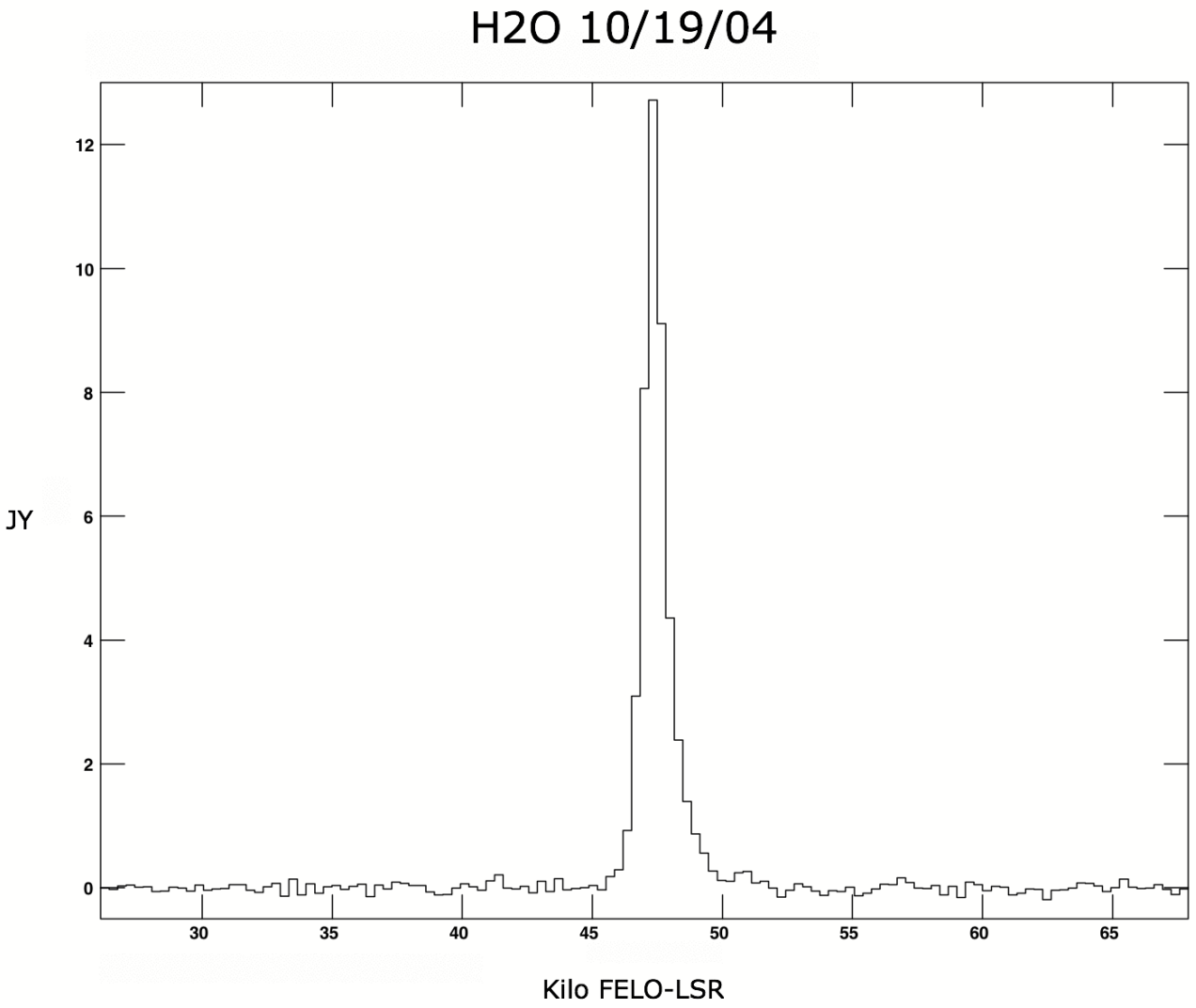
Masers and the Light Curve



SiO Spectral Data



H2O Spectral Data



What about the OH maser?

- The OH maser was not seen in any of the observing epochs.

- This is consistent with other independent observations- the OH maser was absent during a roughly 10 year period that included our observing time.

- Since OH masers are in the outer part of the circumstellar envelope, they may be affected by Mira B.

- Mira's OH masers were detected by Etoka et al. in 2009, and emission was seen at about 3 Jy.

(Etoka et al. 2010)

Conclusions

- SiO and H_2O masers were detected at every observing epoch. H_2O masers were not always previously detected in Mira.

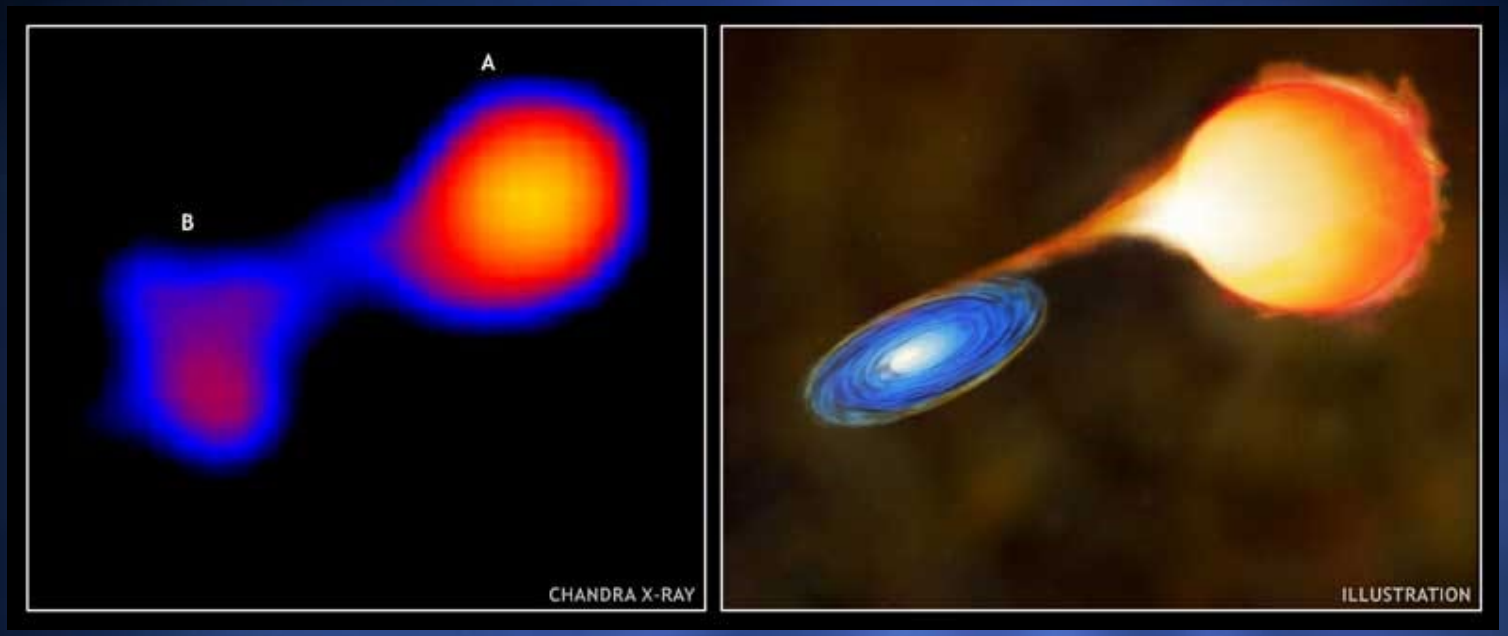
- H_2O peak maser emission consistently occurs at about 0.4 the period of Mira's light curve.

- For the first time, the diameters of the SiO and H_2O maser emitting regions were simultaneously measured. SiO region diameter was found to be 7.5 AU, and the H_2O region diameter was 21.4 AU.

- H_2O maser emission was found to be the strongest yet recorded in the literature- 12.5 Jy as opposed the average peaks of 5 Jy.

- A high proper motion feature in the SiO maser region could be the result of outflow from Mira

- It cannot really be determined if any of our maser activity was correlated to the x-ray burst in 2003, but the simultaneous measurements of SiO and H_2O masers can be used to test and constrain theoretical models of maser emission.



Special thanks to my mentor, Lynn Matthews
and to MIT Haystack Observatory

Thank you!