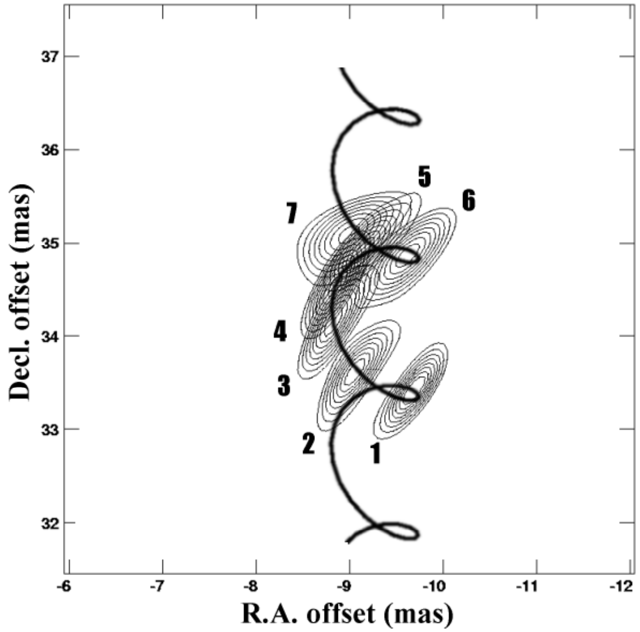
Distance of W3(OH) by VLBI parallax measurement



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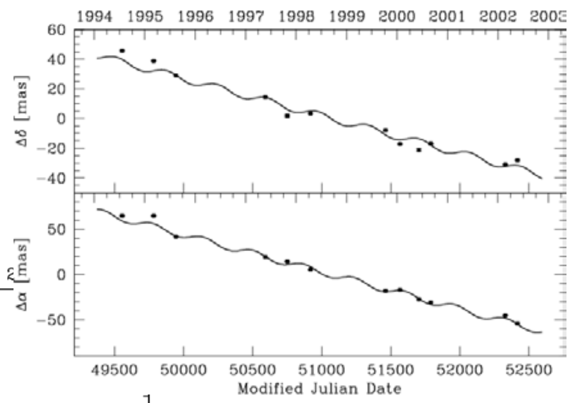
Annual Parallax

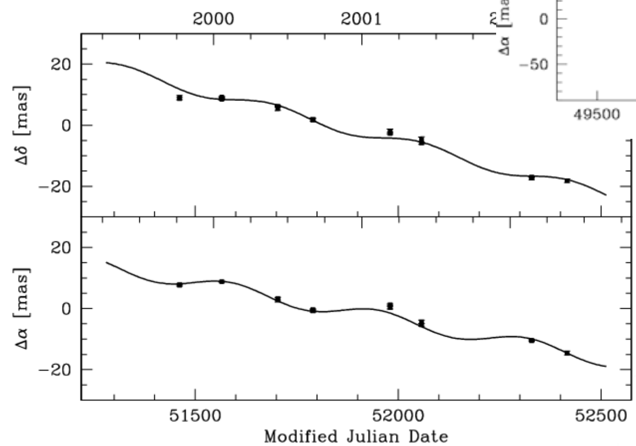
- The most powerful tool for the determination of distances to objects in the Galaxy
  - HIPPARCOS, VLBI, others
- Phase-referencing VLBI
  - The highest resolution for the astrometry
  - can be measured an absolute position and proper motion of Galactic target objects relative to an adjacent extragalactic source
    - Masers
    - Pulsars
    - Others (X-ray binaries, stars, etc)
  - an absolute proper motion includes annual parallax which can be estimated the distance from the sun
    - absolute astronomical parameters (luminosity, size, etc)
    - Galactic structure and dynamics

OH maser in U Her

(Vlemmings et al. 2003)

π= 3.61±1.04 mas
(d=0.370 $^{+0.092}_{-0.045}$ kpc)

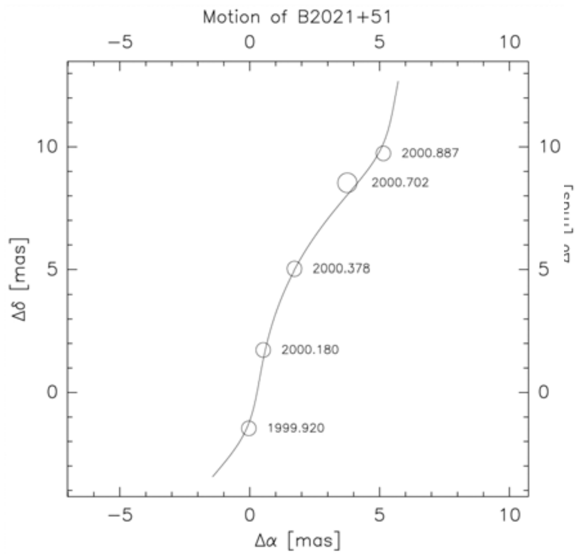




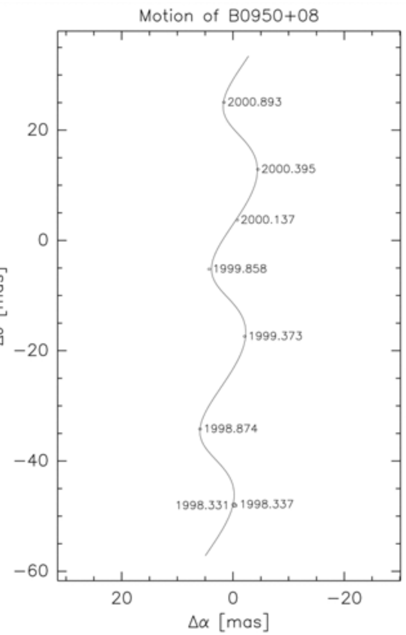
OH maser in S Crb

(Vlemmings et al. 2003)

π= 2.31±0.33 mas
(d=0.433 $^{+0.032}_{-0.054}$ kpc)



π= 0.50±0.07 mas
(d=1.9 $^{+0.3}_{-0.2}$ kpc)



π= 3.82±0.07 mas
(d=0.262 $^{+0.005}_{-0.005}$ kpc)

Pulsars (Brisken et al. 2002)

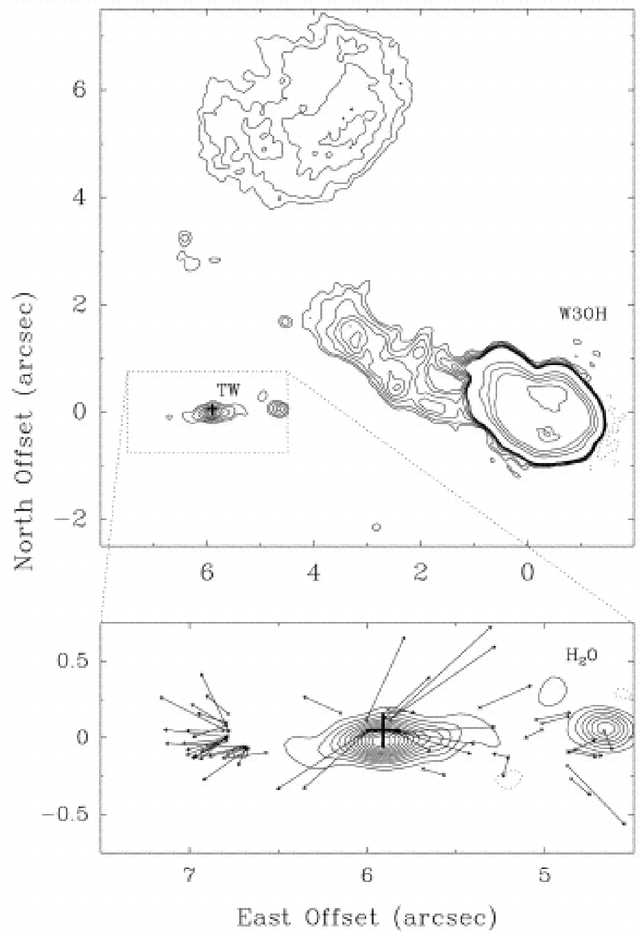
Astrometry of H_2O masers with the phase-referencing VLBI

- H_2O masers
  - associate with the star forming region and the late type star
  - many maser features (≥ 1) are detectable in the each maser source
  - highly time variability
    - flux, structure
  - have a lifetime
    - We can not know it exactly before a observation
  - exist whole the Galaxy
    - we can perform the astrometry for many H_2O maser sources
    - we can understand structure and dynamics of the Galaxy

- Astrometry of H_2O masers
  - need a long monitor
    - we should complete the observation within the lifetime of H_2O masers
    - we should trace a same maser carefully
  - achieve a high accuracy
    - we can get many data sets from ONE source
  - Absolute proper motions include
    - annual parallax
    - Galactic rotation
    - solar motion
    - inner motion
    - etc.

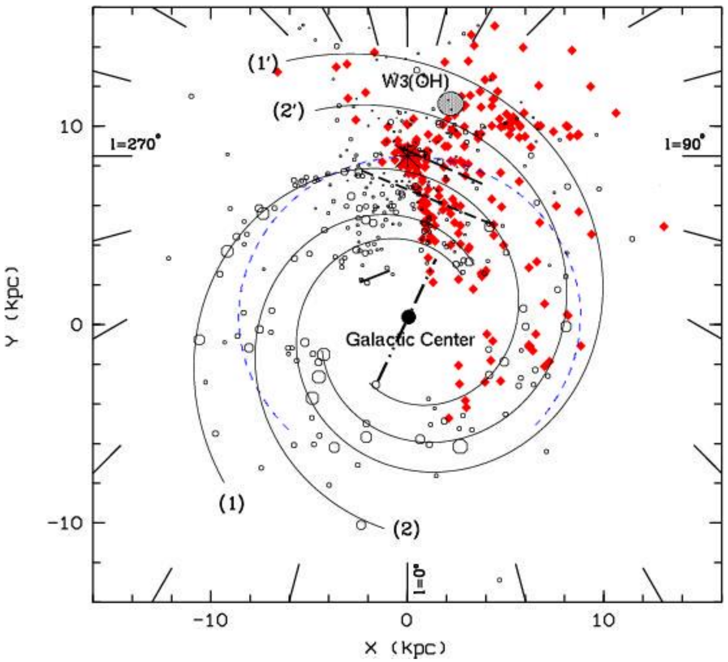
Galactic H_2O maser source W3(OH)

- High/intermediate-mass protostar (Reid et al. 1995; Wyrowski et al. 1999)
- H_2O masers move in a bipolar outflow (Alcolea et al. 1992)
  - origin TW (Turner Welch) object



(Wilner et al. 1999)

W3(OH) is located at the Perseus arm.
The distance is ~2.2 kpc from the sun.

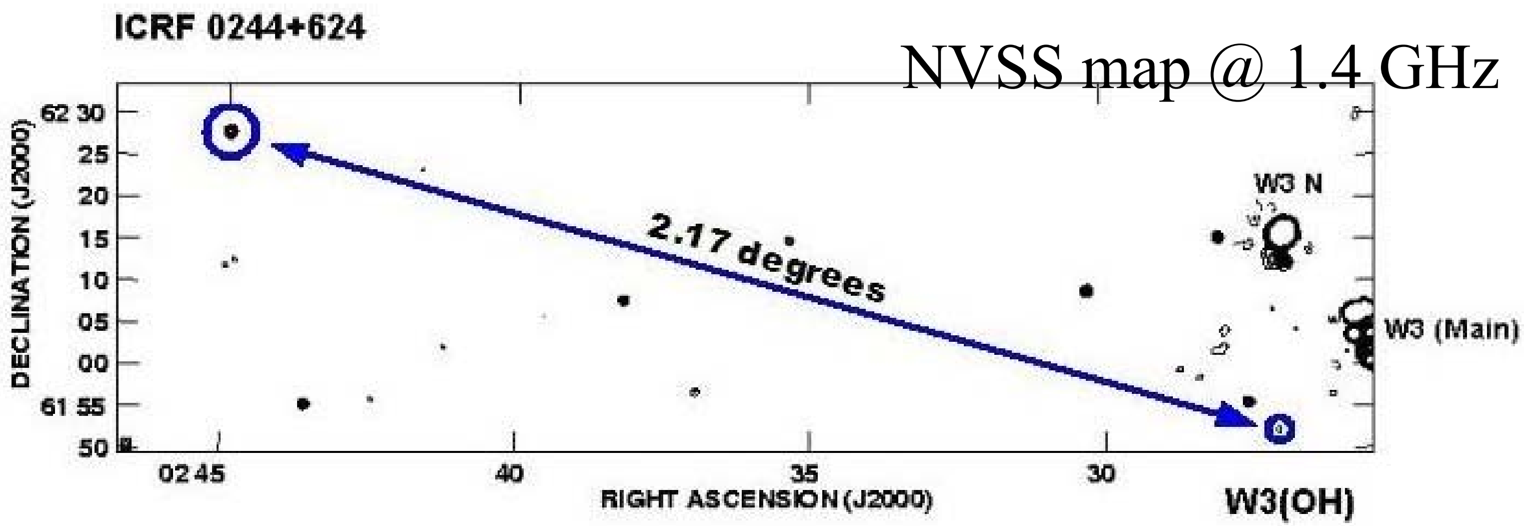


The distribution of the Galactic H_2O maser sources (red) is overlaid on the four-arm model of the Galaxy (Russeil 2003).

Phase-referencing VLBI observation

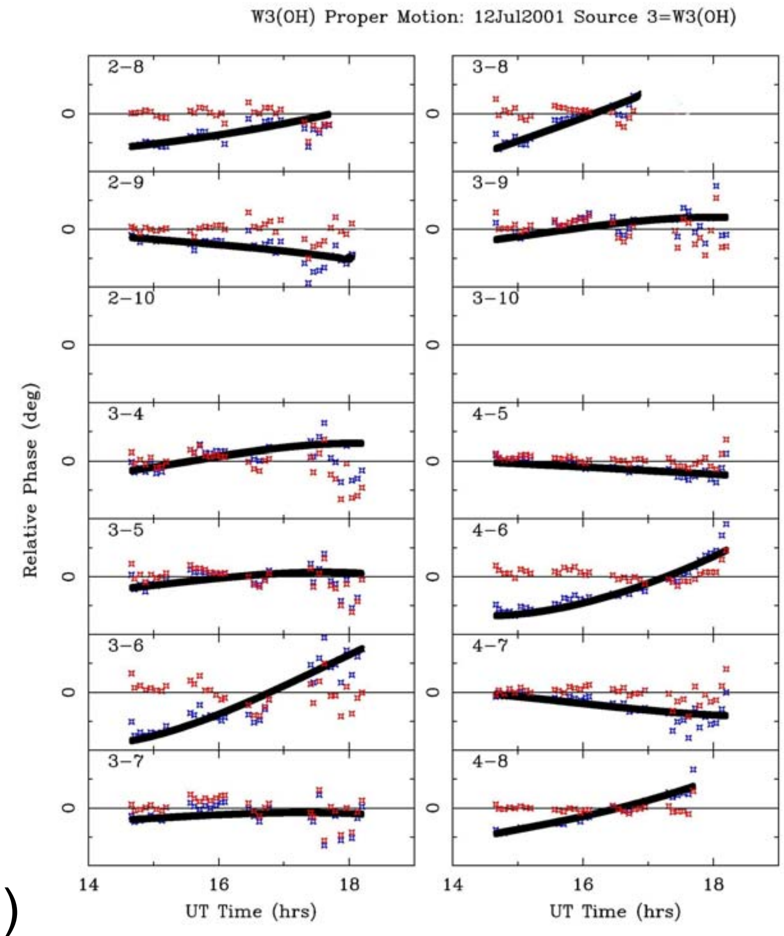
- Observation
  - VLBA (all stations)
  - Fast-switching (40 sec. cycle)
  - 22GHz
  - 7 times during 16 months
    - typically separated 2 months
  - Integration time: 2 sec.
  - Velocity resolution: 0.224 km/s
- Observed sources
  - Target: H_2O maser in W3(OH)
  - Positional reference: ICRF 0244+624
    - z = 0.0438 (Margon&Kwitter 1978)
  - Calibrator: NRAO150

NVSS map @ 1.4 GHz



Data reduction

- use NRAO AIPS
- tropospheric zenith delay error correction (e.g. Brunthaler et al. 2003)
  - AIPS task “CLCAL”
    - `opcode ='ATMO'`
    - flagged MK station at 7th epoch
- Determination of
  - the reference position
    - perform fringe fit and self-calibration for only reference source ICRF 0244+624, and then applied these solutions to W3(OH)
  - the positions of H_2O masers
    - AIPS task “JMFIT”

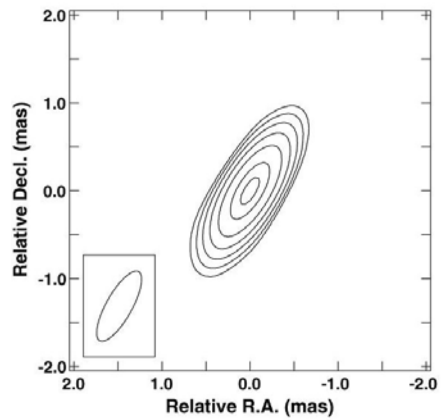


The zenith delay error estimation
Blue: fringe phase of maser

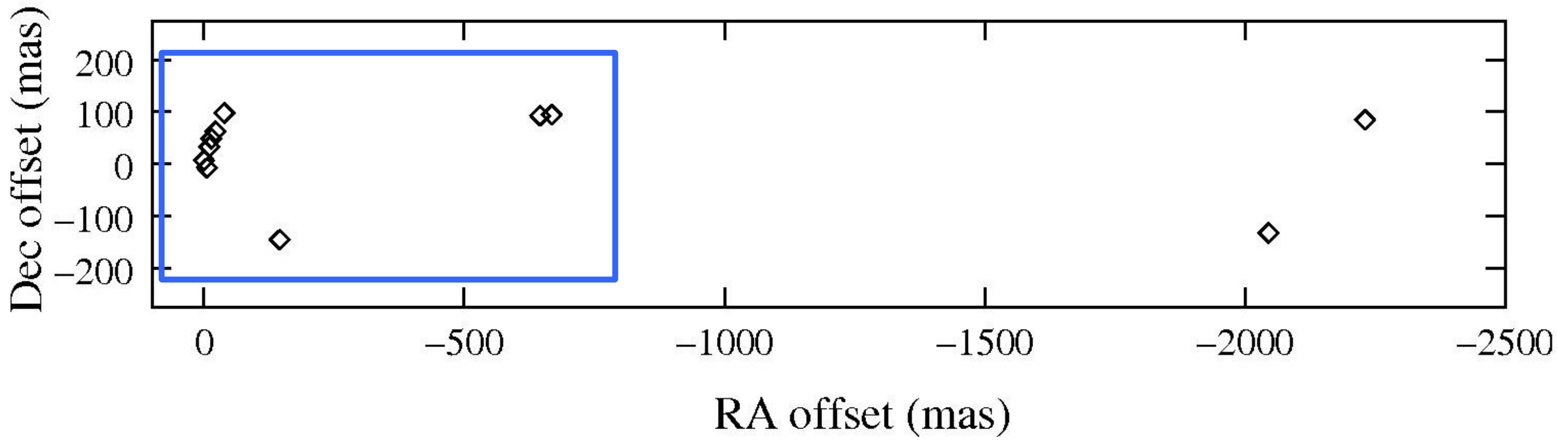
Red: residual from the fit (solid line)

Results

- the reference source ICRF 0244+624 has a strong flux and a very compact structure.
- H_2O masers
  - over 20 maser features were detected for every epoch (but some masers are not same).
  - flux densities: from a few hundred mJy to 1 kJy
  - the distribution of masers is consistent with previous VLBI observation (Alcolea et al. 1992).



The image of ICRF 0244+624.
Peak flux density is ~1.0 Jy/beam.



The distribution of long lived (≥ 5 epochs) H_2O masers in W3(OH).
The origin is the phase tracking center (R.A.=$02^h27^m04^s.8362$, Decl.=$+61^d52^m24^s.607$ (J2000)).

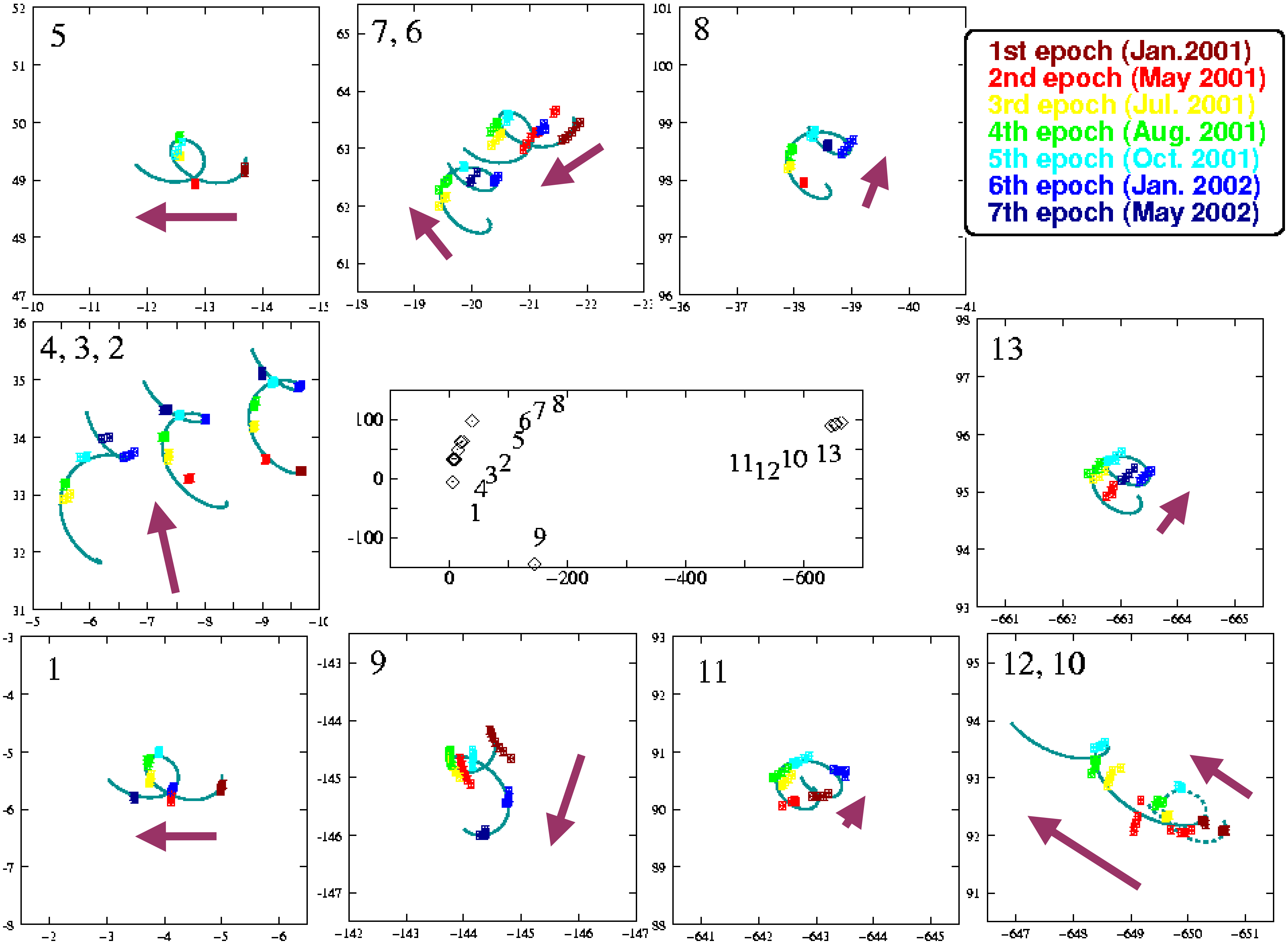
Astrometric model fit

1. search and traced same maser feature
   - ✓ we also estimated **RELATIVE** proper motions
     - ✓ we assumed the relative proper motions are linear
2. select **13 maser features** with several velocity channels **(=45 data sets)** which are detected more than 5 epochs
   - ✓ do not use the masers at 2 arc-seconds away from the phase center.
3. determine 5 parameters from **ABSOLUTE** proper motions

$$\Delta\alpha\cos\delta = \Pi f_\alpha(\alpha,\delta,t) + \mu_\alpha t + \alpha_0$$

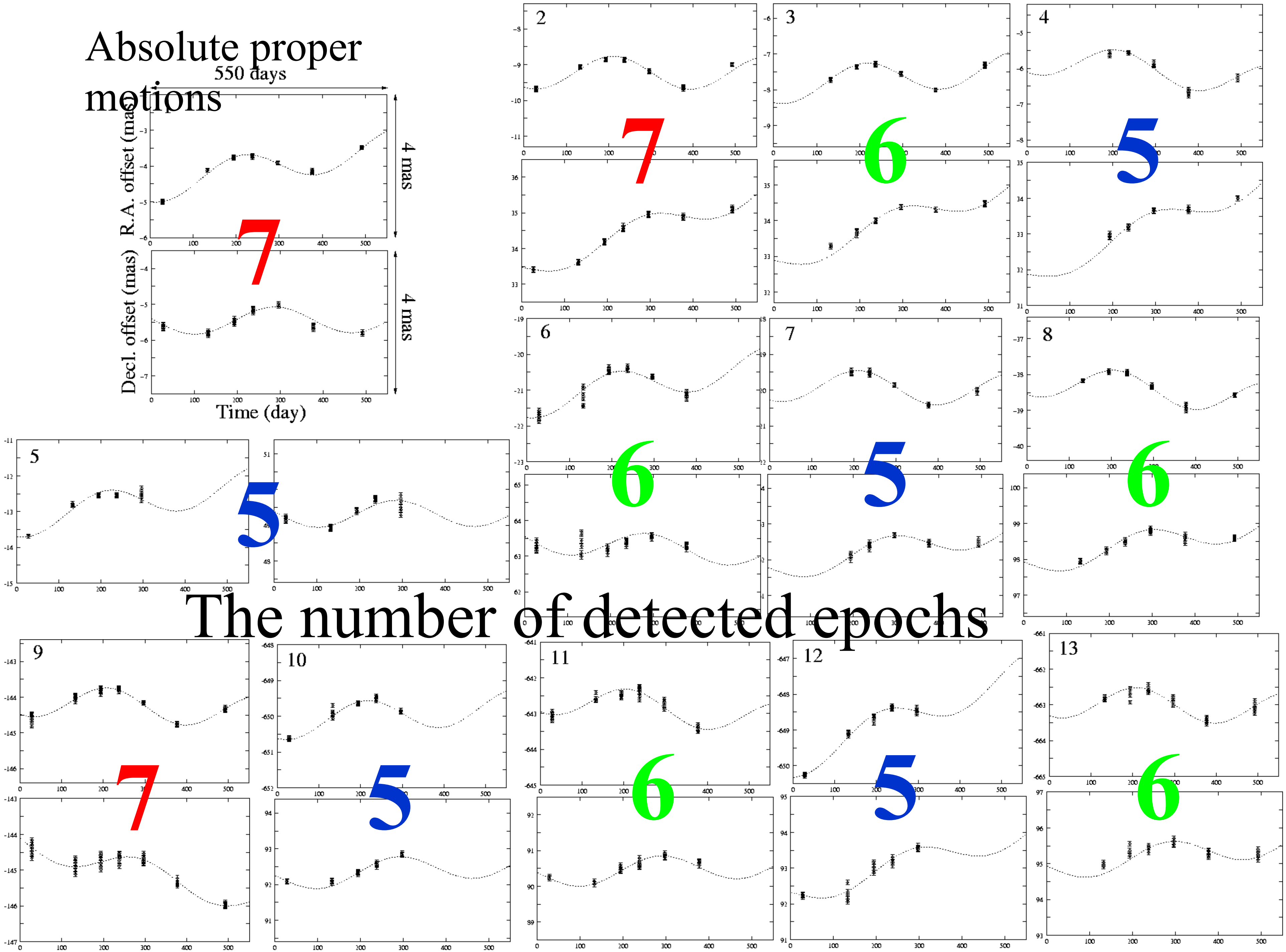
$$\Delta\delta = \Pi f_\delta(\alpha,\delta,t) + \mu_\delta t + \delta_0$$

1. We assum
   a. non-linear motion is caused by only annual parallax
   b. ignore acceleration/deceleration of the proper motions of masers
   c. ignore variations of LSR velocities of masers
2. estimate **ONE** parallax for all data sets, **Π= 0.484±0.004 mas**
   - ✓ linear proper motions were estimated for each data set.



1st epoch (Jan.2001)
2nd epoch (May 2001)
3rd epoch (Jul. 2001)
4th epoch (Aug. 2001)
5th epoch (Oct. 2001)
6th epoch (Jan. 2002)
7th epoch (May 2002)
5
7, 6
8
4, 3, 2
13
1
9
11
12, 10

Absolute proper motions



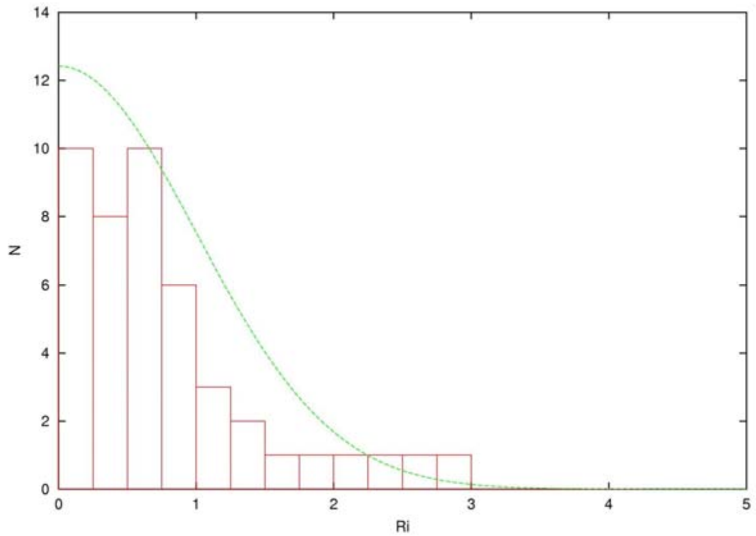
The number of detected epochs

Annual parallax of H2O masers in W3(OH)

- fit one annual parallax: 0.484±0.004 mas
  - use 13 maser features (45 data sets)
- fit an annual parallax to each of 45 data sets individually
  - parallaxes are from ~0.3 mas to ~ 0.6 mas.
  - parallax errors are from ~ 0.01 mas to ~ 0.1 mas.
  - parameter *Ri* is in good agreement with a Gaussian distribution.

$$R_i = \frac{|\pi_i - \bar{\pi}|}{\Delta\pi_i},$$

where π_i and $\Delta\pi_i$ are the parallax and its error from fit i and $\bar{\pi}$ is the parallax from the combined fit.

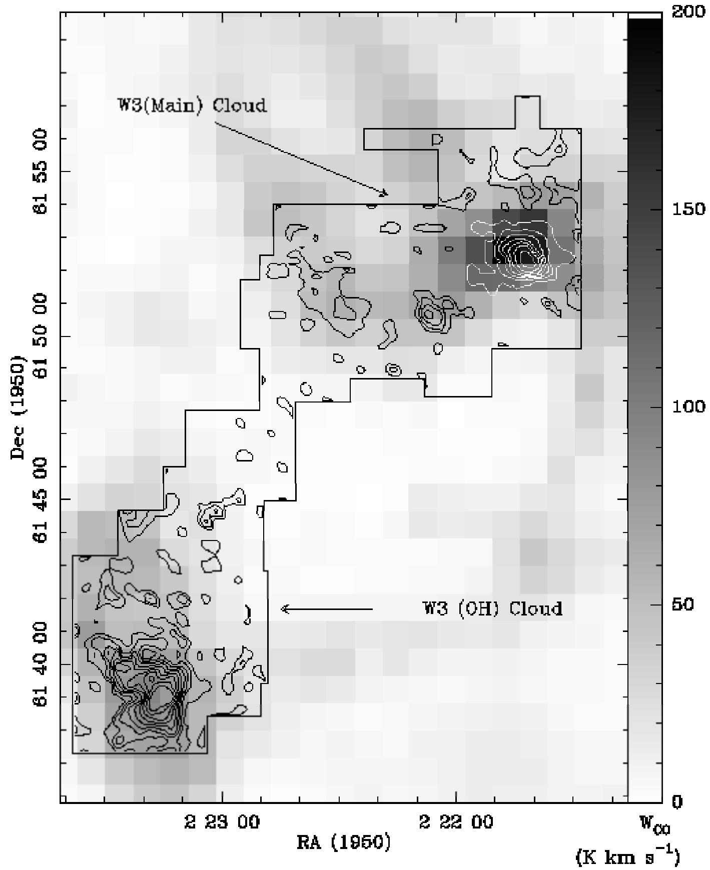


Histogram of parameter *Ri*

  - the fitting results are dominated by statistical and not by systematic.

Distance of W3(OH)

- Annual parallax distance
  - 2.07 $^{+0.01}_{-0.02}$ kpc (this work)
- Previous distance measurements
  - Kinematic distance
    - 2.3 kpc (Georgelin & Georgelin 1976)
  - Photometric distance
    - 2.2 kpc (Humpherys 1978)
  - Model fit using relative proper motions of H_2O masers in W3 IRS 5 (which is located in W3 Main)
    - 1.83 ± 0.14 kpc (Imai et al. 2000)



Location of W3 Main and W3(OH)
Contour: NH_3 map
Gray-scale: $^{12}CO(1\text{-}0)$ map
(Tiefrunk et al. 1998)

Conclusion

- We estimated the annual parallax of H_2O masers in W3(OH) using their absolute proper motions
  - The corresponding distance is consistent with previous observations (kinematic/photometric distance).
- Further works
  - use proper motions of other maser features which are detected less than 5 epochs
    - can we get a higher accuracy ?
  - have to estimate the systematic error
  - estimate the linear proper motions
    - estimate Galactic rotation speed of the W3(OH) region
    - 3D structure and dynamics of H_2O masers in W3(OH)