The Golden Age of VLBI Astrometry

P. Charlot
Laboratoire d'Astrophysique de Bordeaux

Outline

1. Global VLBI astrometry/Reference frames
   - International Celestial Reference Frame (ICRF)
   - VLBI Calibrator Survey (VCS)
   - ICRF-2
   - Extension of ICRF to higher frequencies

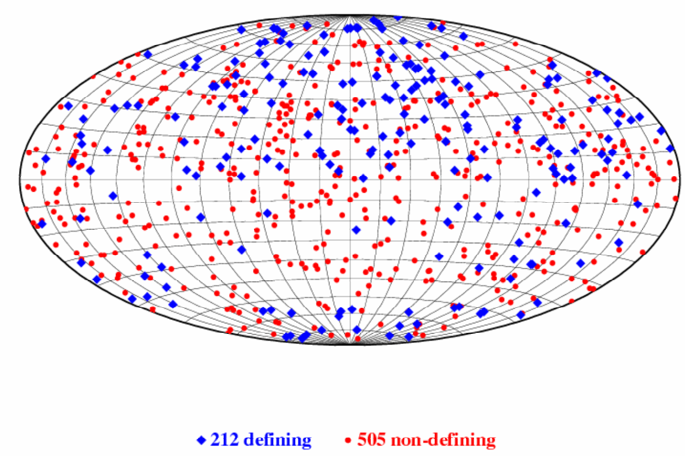
2. Differential VLBI astrometry
   - Extragalactic work
   - Galactic work
     - proper motions
     - parallax measurements

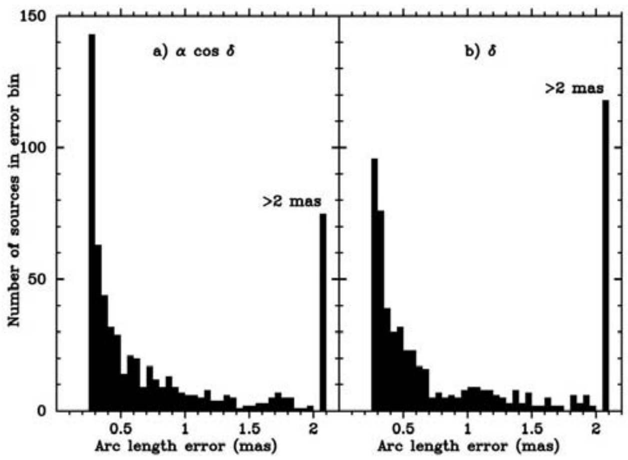
Global VLBI Astrometry

- Based in group delays and phase-delay rates
- Dual-frequency observations (2.3/8.4 GHz) to remove ionospheric contribution
- 24-hour sessions
- ~100 sources observed per session
- Schedules optimize sky coverage above antennas (for troposphere estimation)
- Requires mm astronomical and geophysical modeling

International Celestial Reference Frame (ICRF)

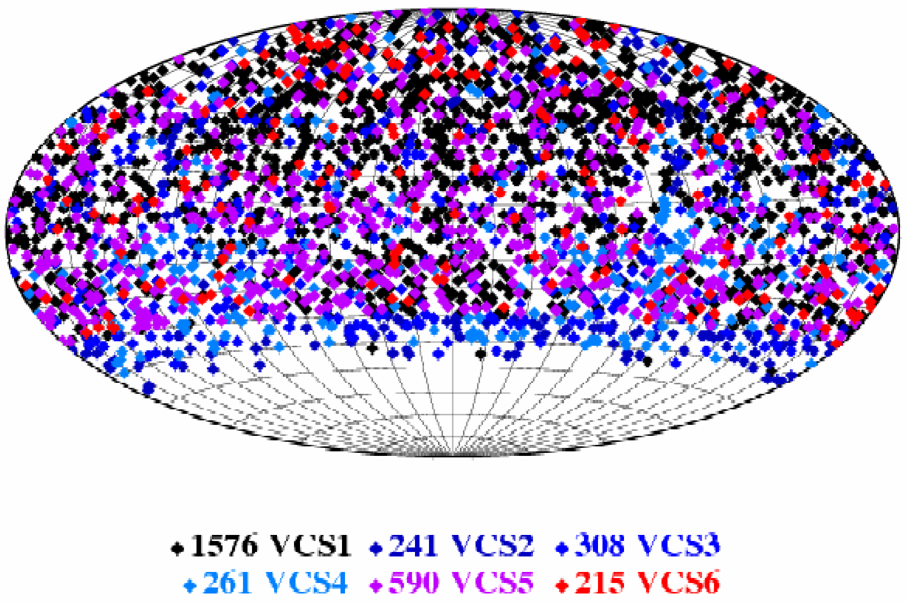
- Based on all astrometric/geodetic data acquired between 1979 and 1995
- Original ICRF has 608 sources:
  - 212 defining sources
  - 396 non-defining sources
- Source position accuracy: ≥ 250 μas
- Multi-epoch observations
- Orientation of the frame know to 20 μas
- ICRF Ext.1 (1999) and Ext. 2 (2004) add another 109 sources: 717 sources today
- References:
  - Ma et al. (1998)
  - Fey et al. (2004)





VLBA Calibrator Survey

- Another 3200 sources observed in a series of VLBA experiments conducted since 1994
- Mostly single-epoch observations
- Declination > -45 deg.
- Milliarcsecond position accuracy
- Includes VLBI images as well
- Provides a dense grid of VLBI calibrators for phase-referencing



- References:

  Beasley et al. 2002; Fomalont et al. 2003; Petrov et al. 2005, Petrov et al. 2006, Kovalev et al. 2007, Petrov et al. 2008

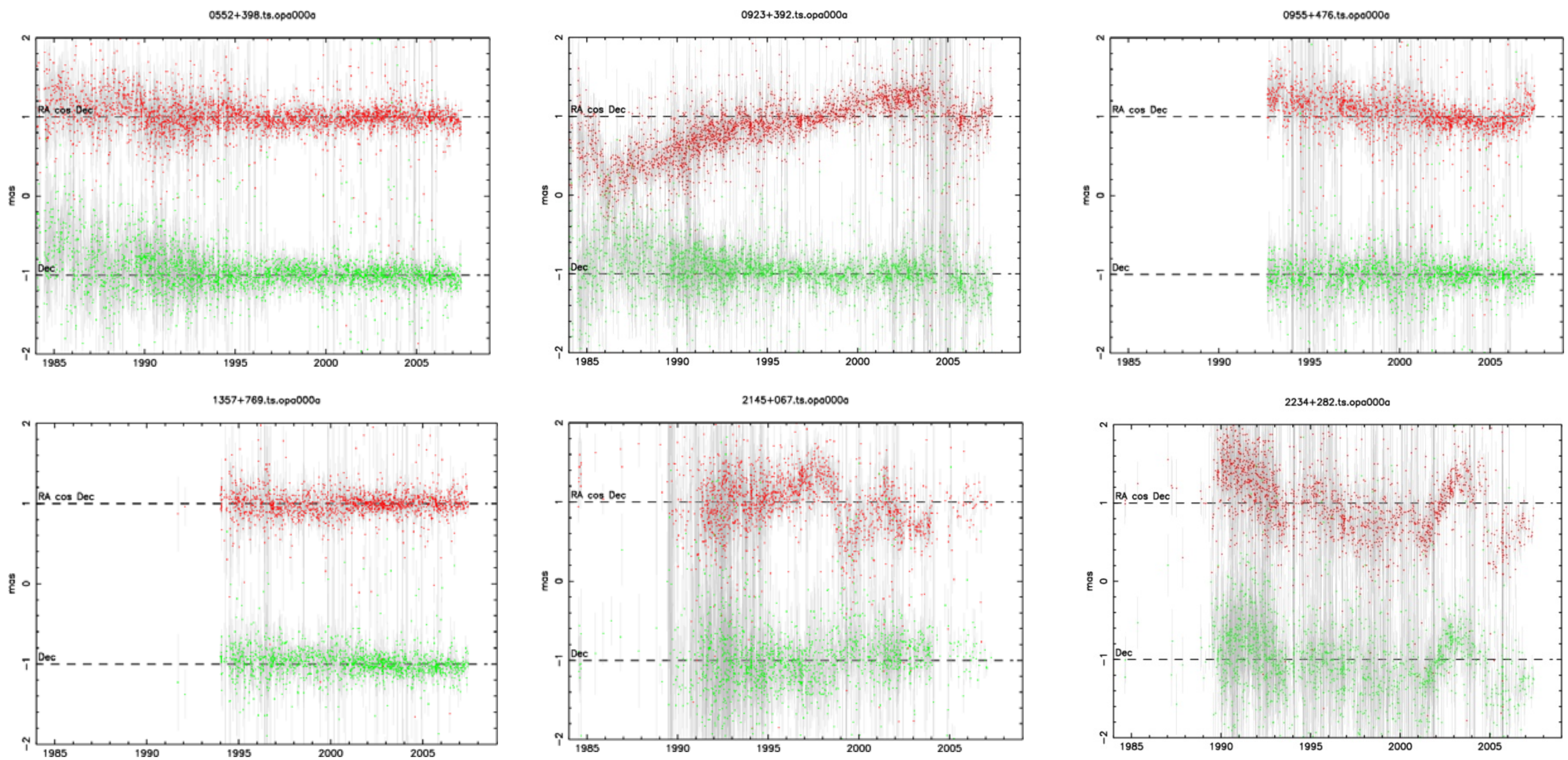
ICRF-2 construction

- Joint IVS/IERS/IAU Working Group in charge of the construction of the next ICRF (to be presented at IAU 2009 General Assembly)
- Will add all geodetic/astrometric acquired since 1995
- Improved geophysical and astronomical modeling

Issues

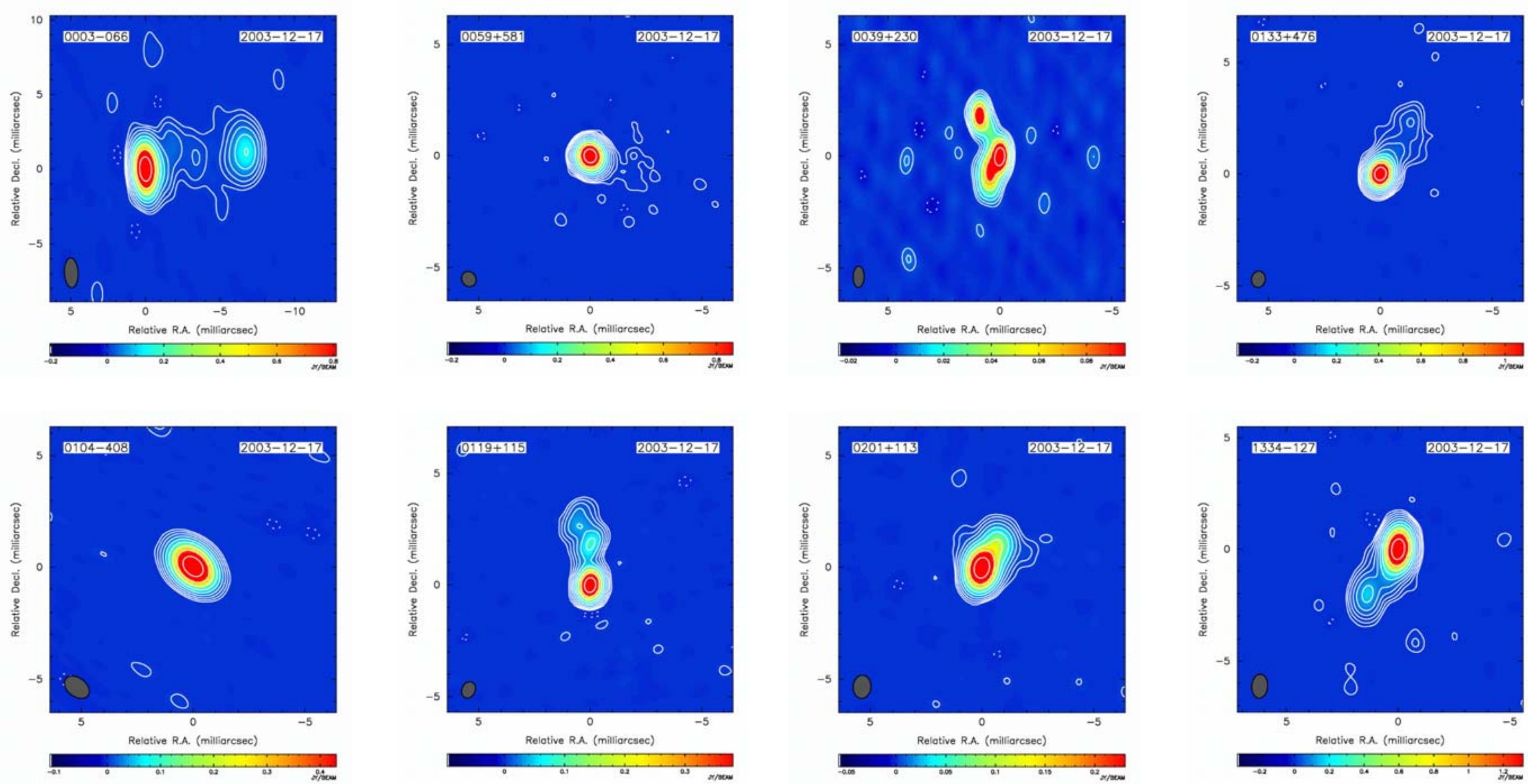
- Selection of defining sources
- Treatment of source position variations
- Incorporation of information about source structure
- Selection of data (keep pre-1990 data?)

Source position variations



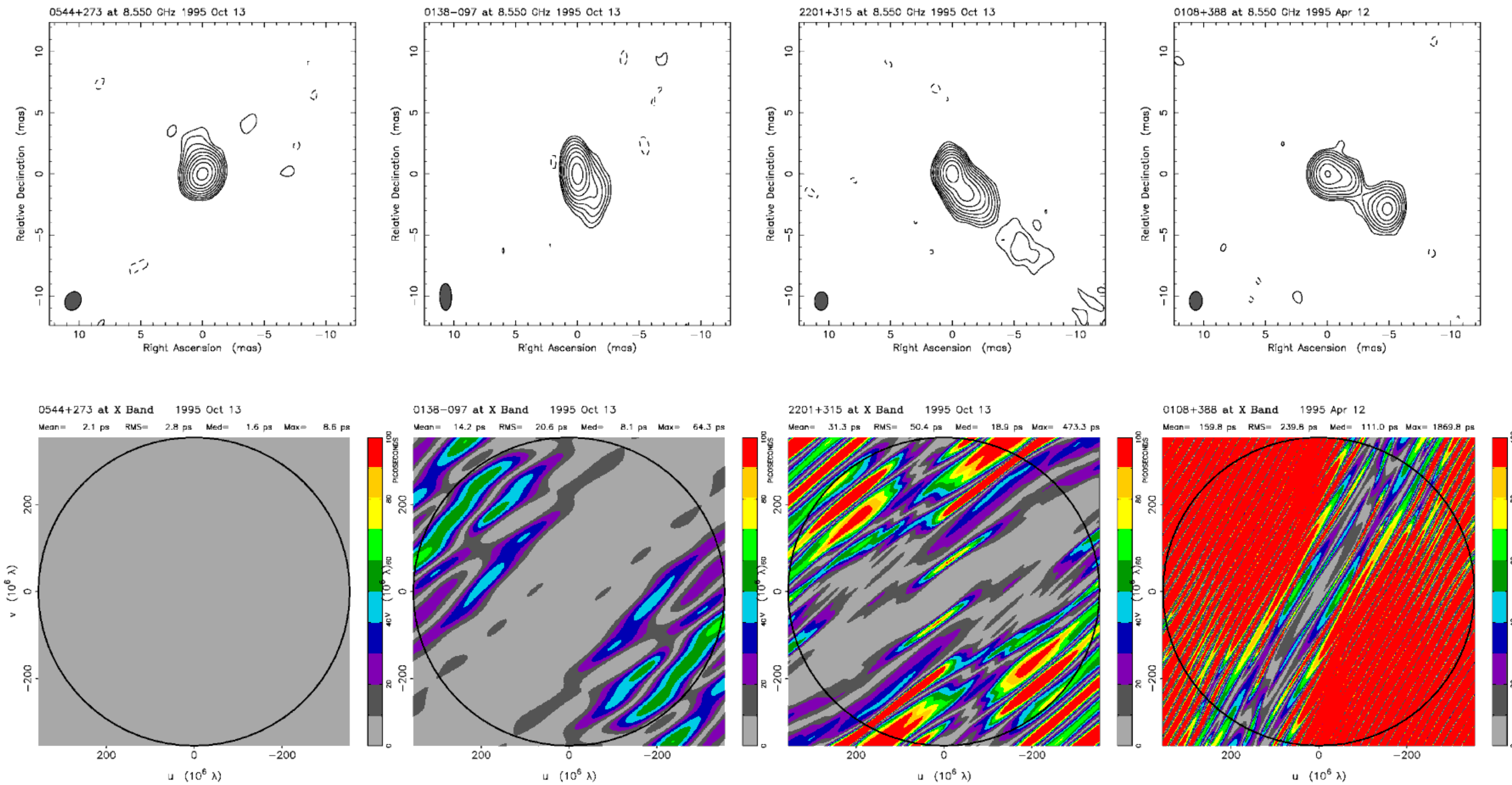
Figures from Lambert (2007)

Source structure



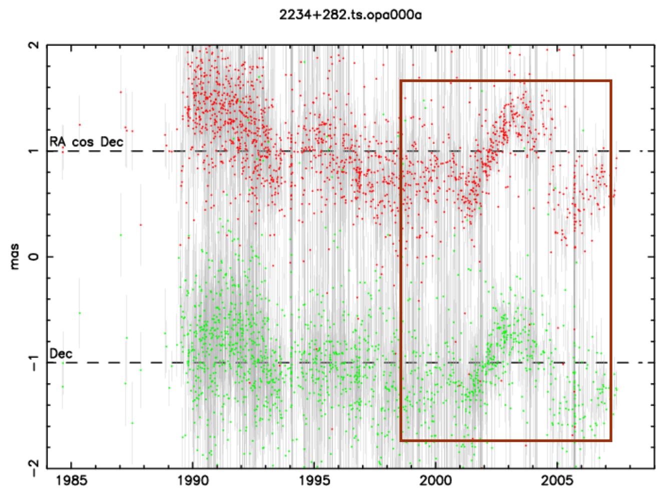
A sample of 8 GHz VLBI images from ICRF sources

Source classification



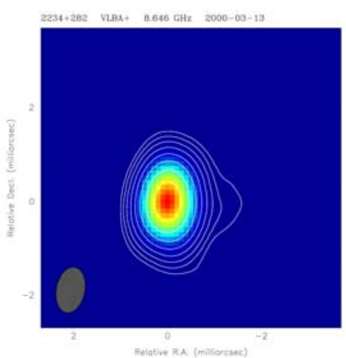
Four « structure index » categories defined according to their compactness

Source structure evolution

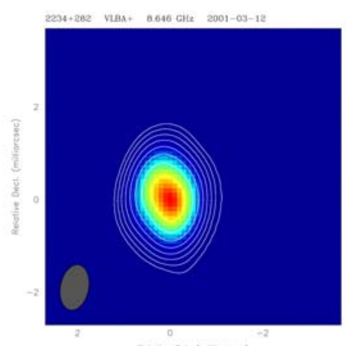


Correlation between source position instabilities and source structure evolution

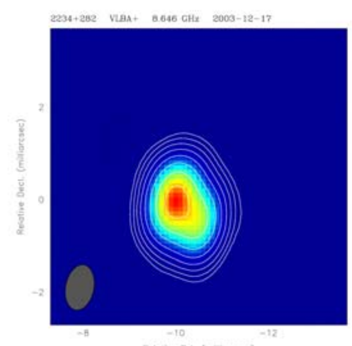
2000



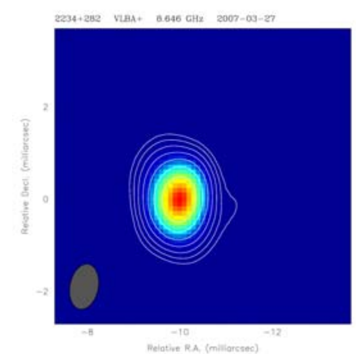
2001



2003



2007



Extension of ICRF at 24 and 43 GHz

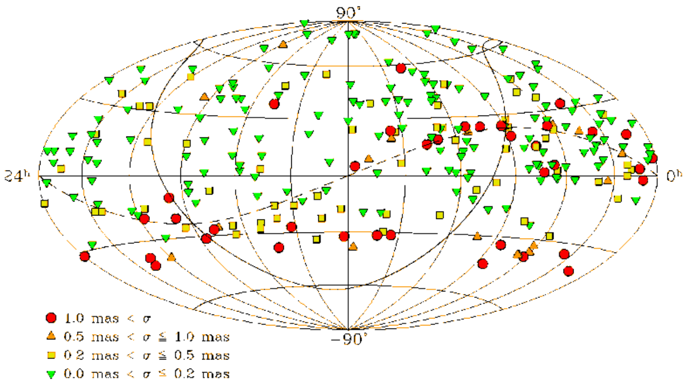
- 10 VLBA sessions conducted at K band (22 GHz) since 2002 → 268 sources detected
- 4 sessions also included Q band observing (43 GHz) → 131 sources detected

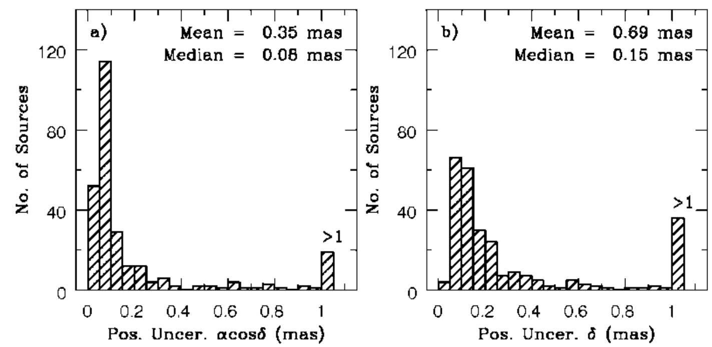
Objectives

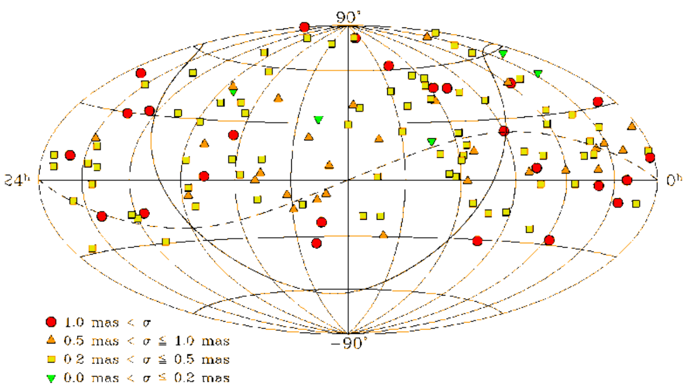
- Spacecraft navigation (tracking to be conducted at Ka band = 32 GHz in the future)
- Improve ICRF (sources more compact at higher frequencies)
- Identify calibrators for high-frequency phase-referencing

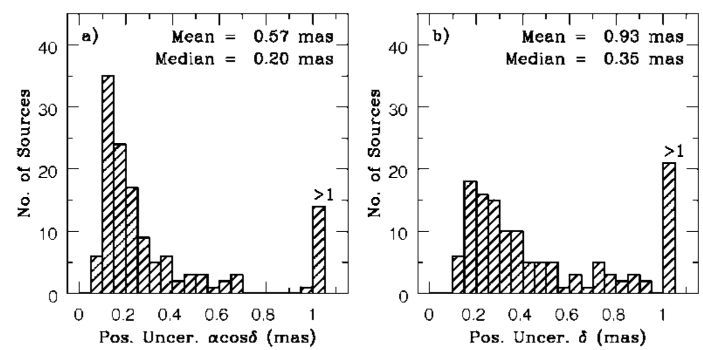
Collaboration: JPL, NRAO, USNO, NASA, Bordeaux

Astrometric results









(Lanyi et al. 2008)

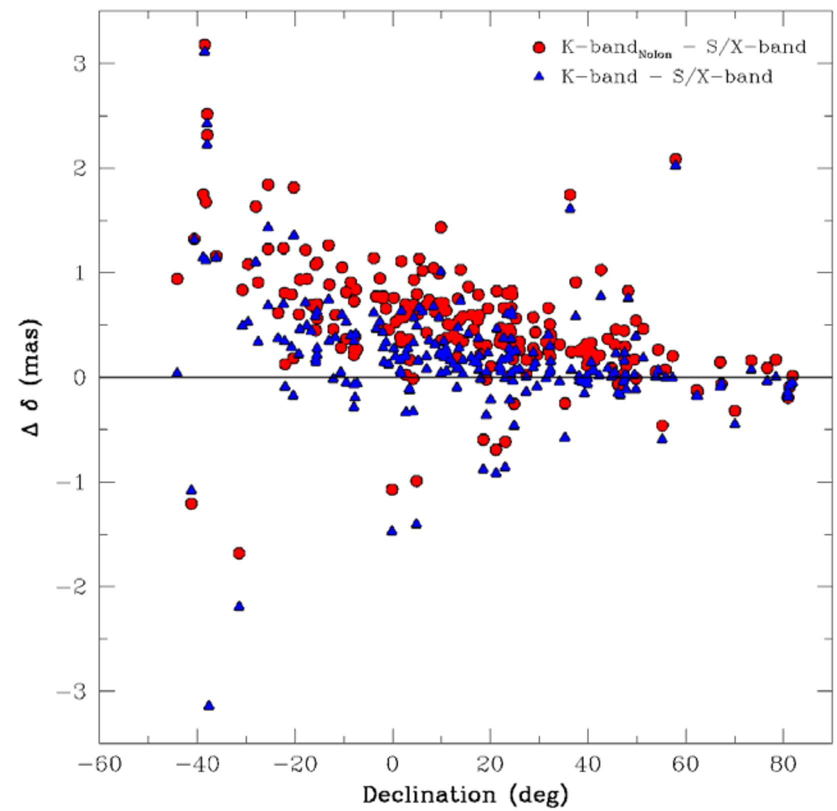
Positions at 24 & 43 GHz consistent with ICRF at ≤ 0.3 mas level

Ionospheric issues

Declination differences K-band – S/X band

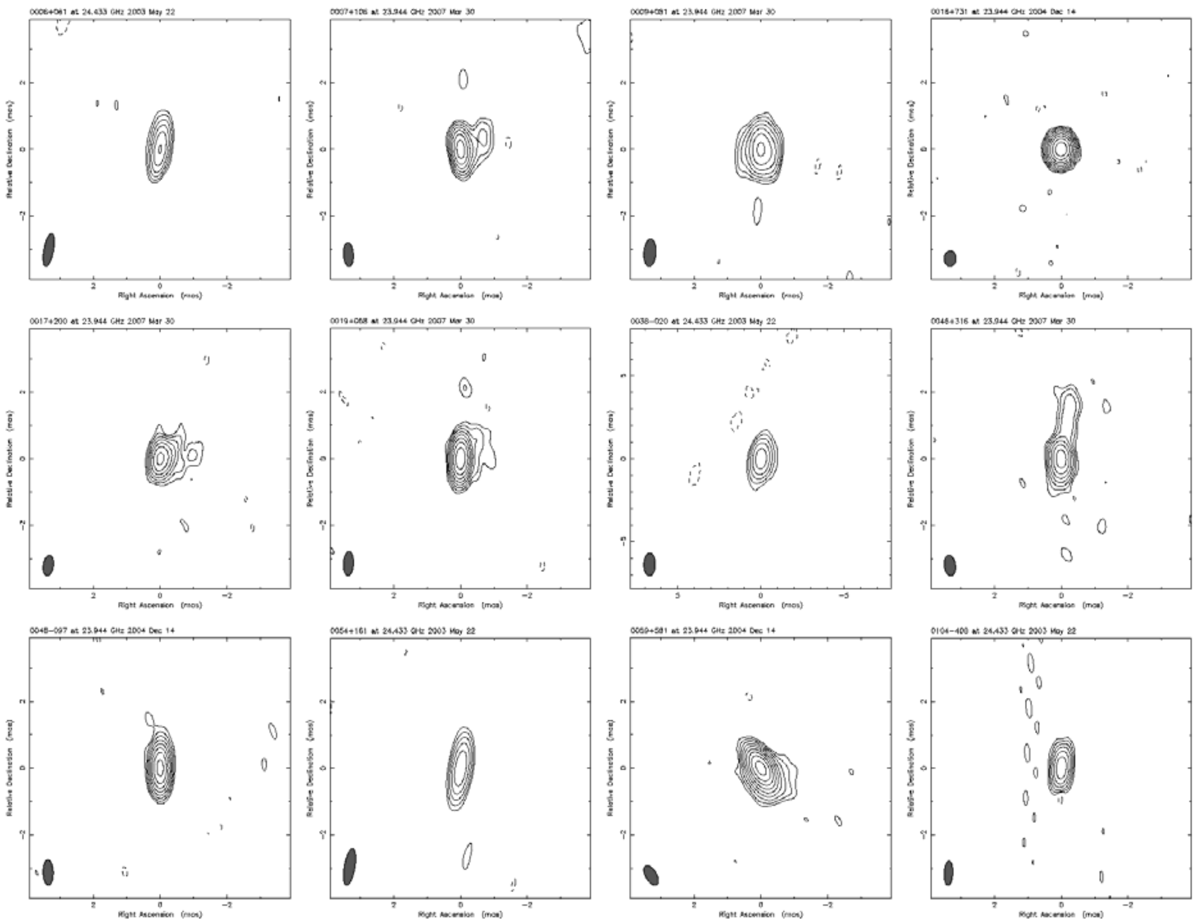
- Two cases:
  - External GPS ionospheric corrections applied
  - No GPS corrections

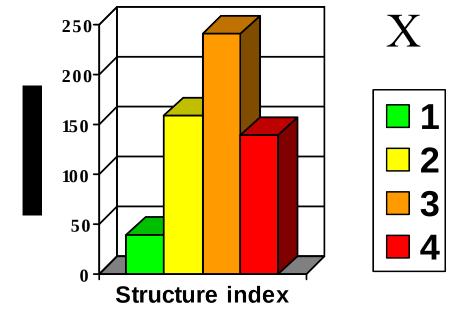
- Application of GPS-derived ionospheric corrections only partially removes systematic declination effects.

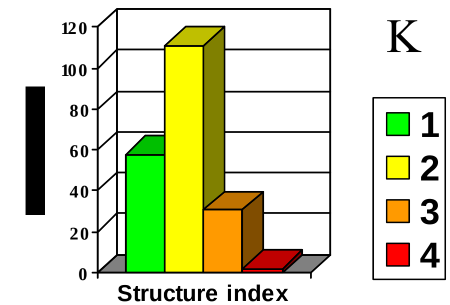


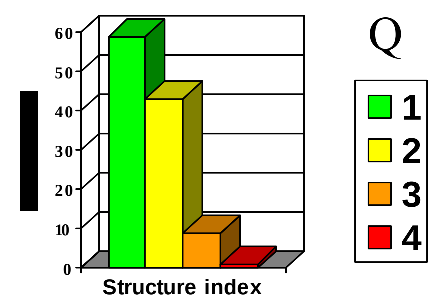
Images – astrometric suitability

K band images



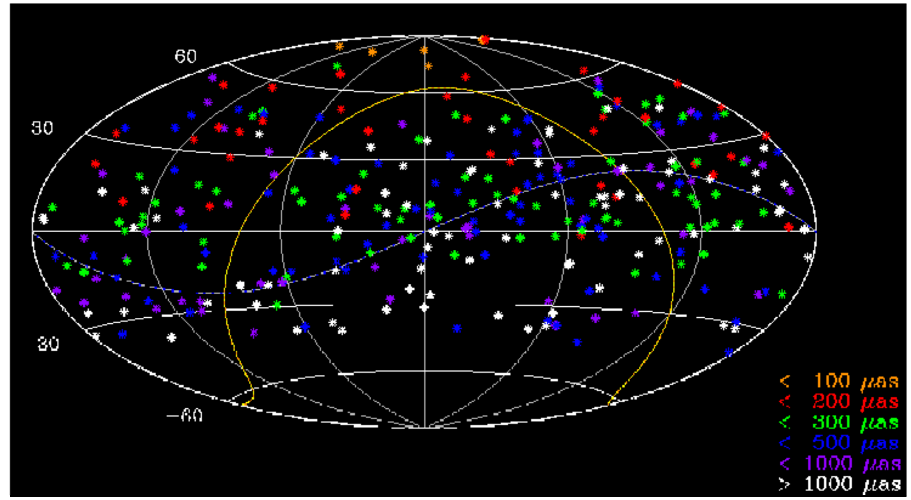


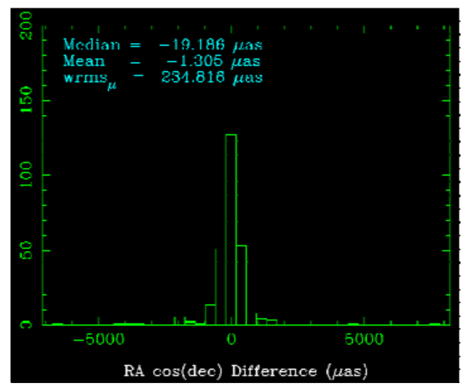


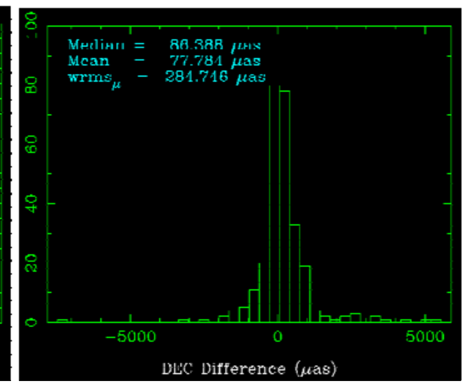


X/Ka (8.4/32 GHz) observations

- 34 DSN sessions with two baselines:
  - Goldstone – Madrid
  - Goldstone – Tidbinbilla
- 321 sources detected
- Agrees with S/X results at 250 µas level
- Future: add more antennas, higher bit rates







Jacobs (2008)

Future prospects

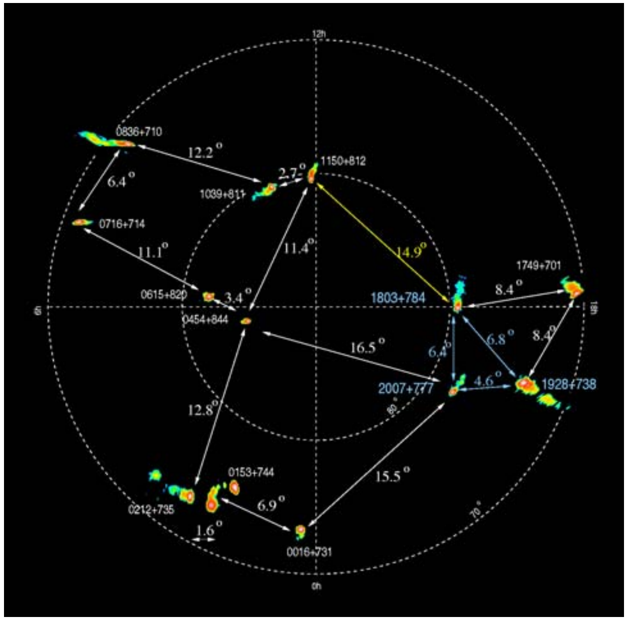
- Densify the southern hemisphere (decl. < -45deg)
- Complete a high-frequency reference frame (24/32/43 GHz)
- Incorporate source structure models in the analysis
- Core shift studies
- GAIA link
  - See next talk by Bourda et al.
- VLBI2010 prospects: re-observe the whole ICRF everyday

Differential astrometry

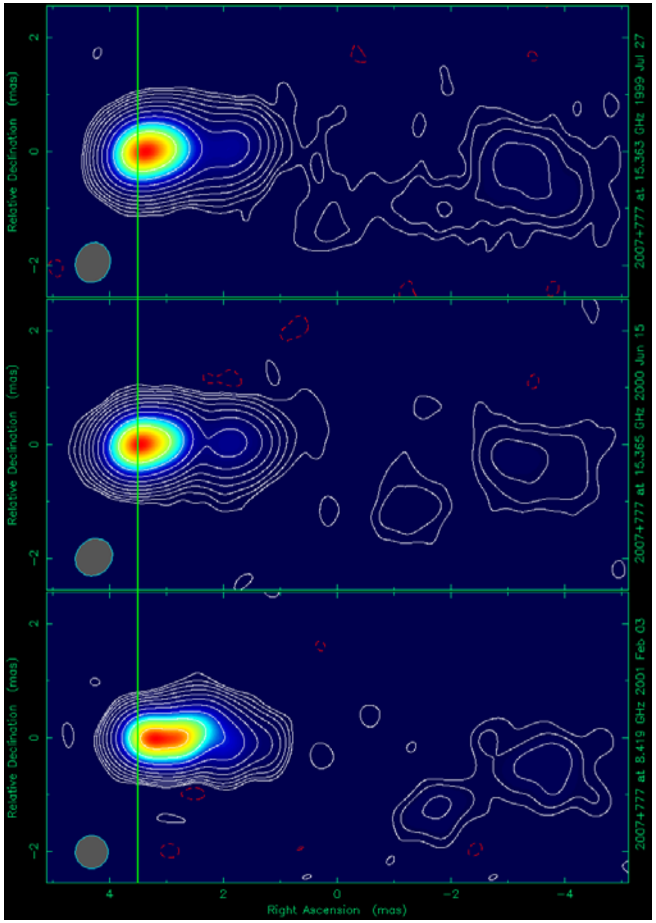
- Based on phase delays
- Observations switch between calibrator and target
- Relies on accurate calibrator position
- Geodetic-style observations interleaved to estimate the atmospheric component
- Precision scales with target-calibrator separation
- Can reach ~10 μas for closeby calibrators (< 1 deg.)

Extragalactic astrometry

S5 Polar cap sample



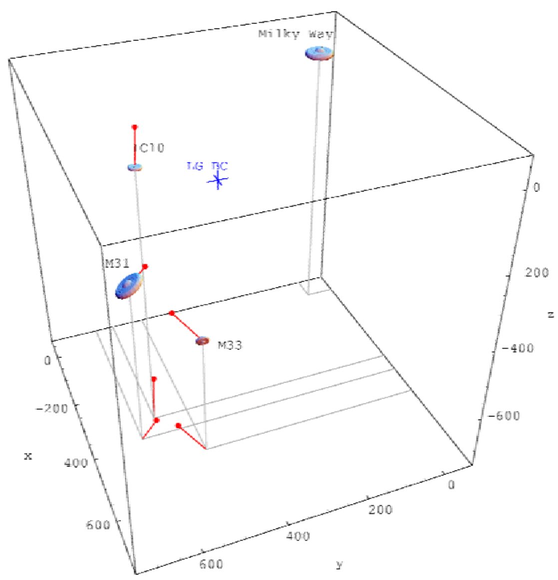
- Automatic phase connection algorithm
- Alignment of maps over time/frequency



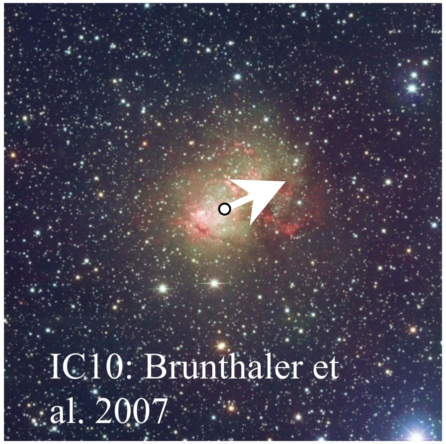
Marti-Vidal et al. (2008)

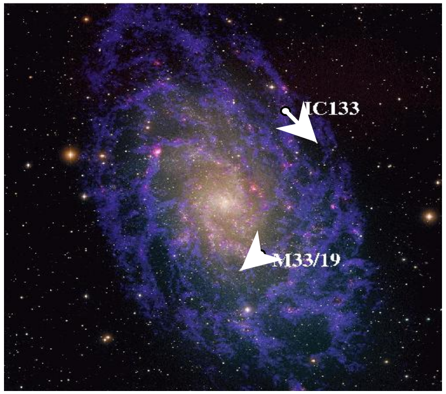
Local Group dynamics

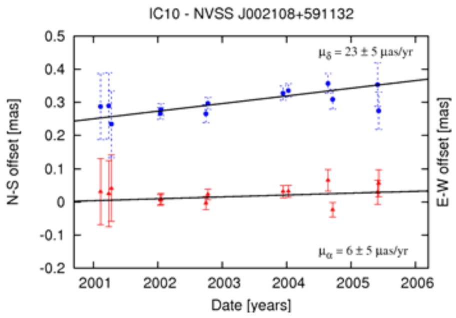
3-D motions of Local Group galaxies M33 and IC10

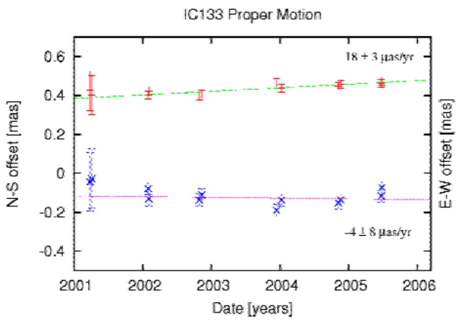


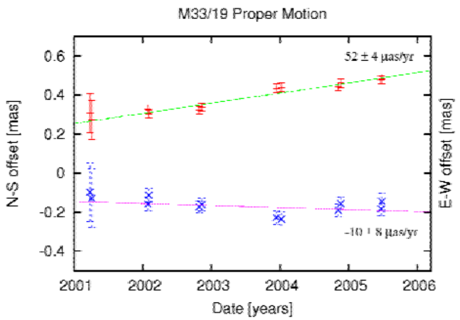
lower limit for the mass of M31 of 7.5×10^{11} M_{sol}



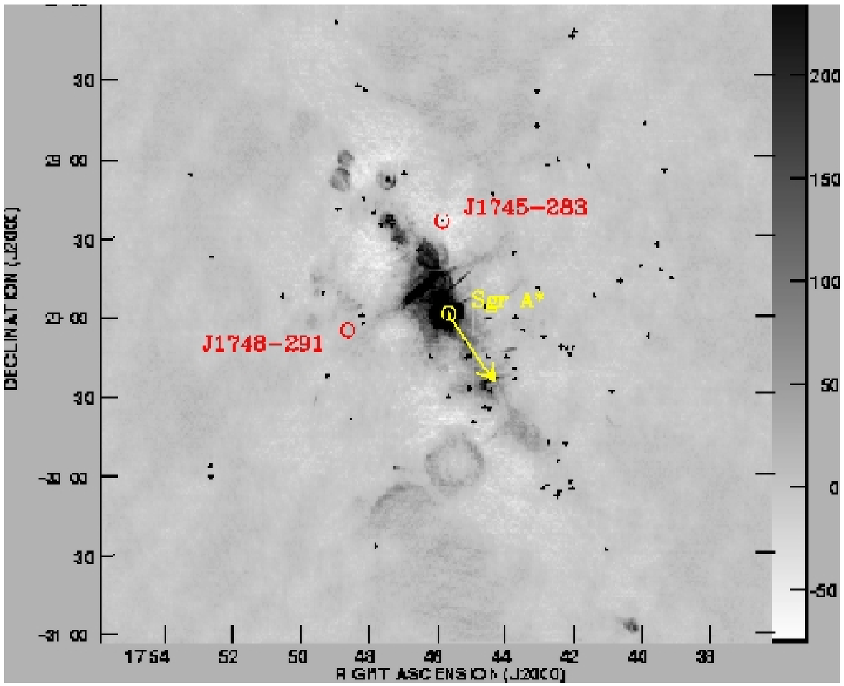


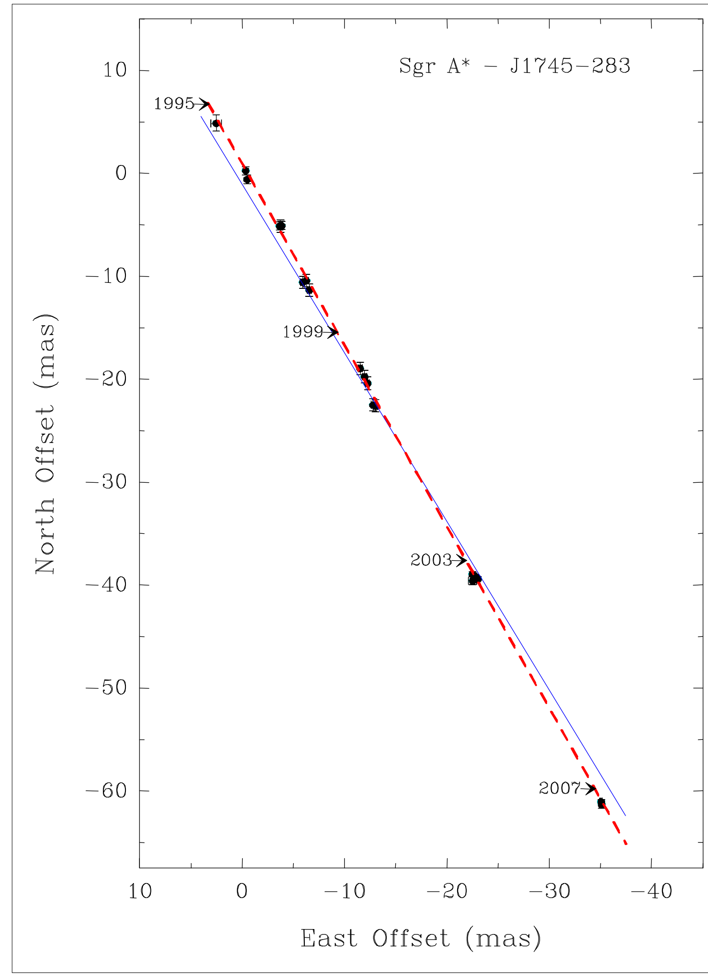






Sgr A* proper motion



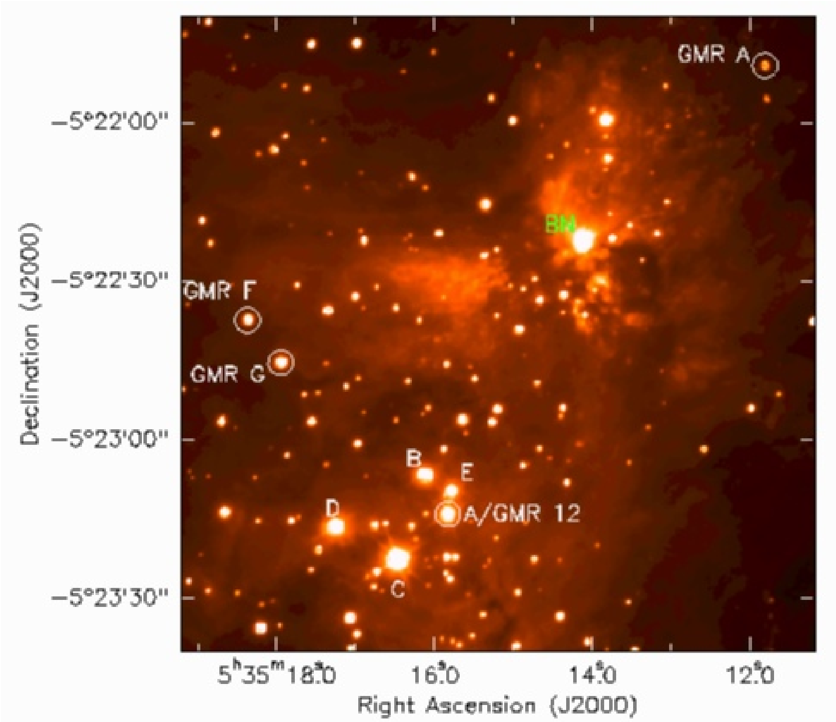


Proper motion: 6.379 +/- 0.024 mas/yr

Reid & Brunthaler (2004)
Reid (2008)

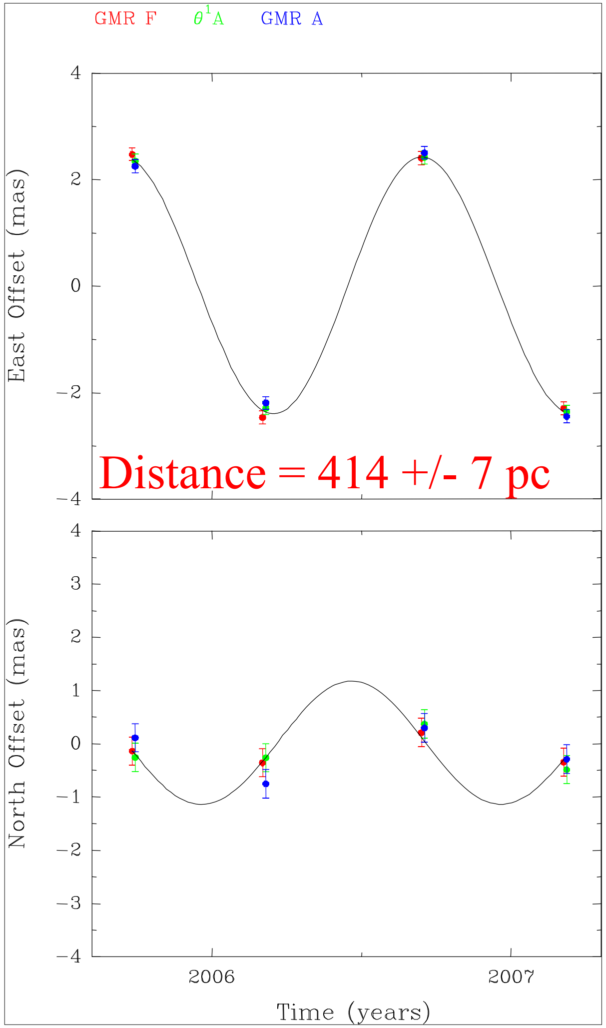
Distance to star forming regions

Orion Nebular Cluster Parallax



Menten, Reid, Forbrich & Brunthaler (2007)

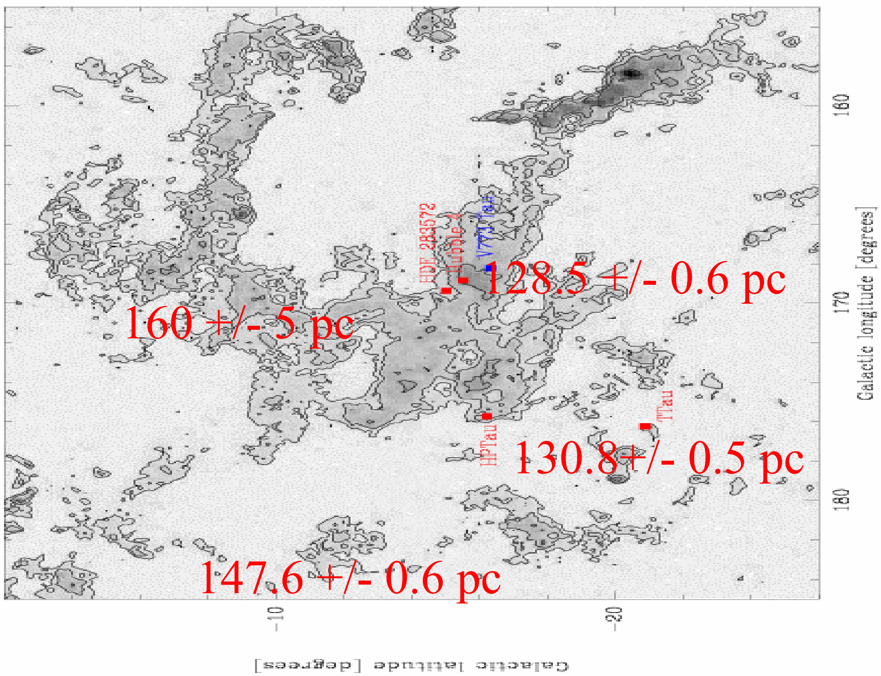
VERA result: 418 +/- 7 pc (Kim et al. 2008)



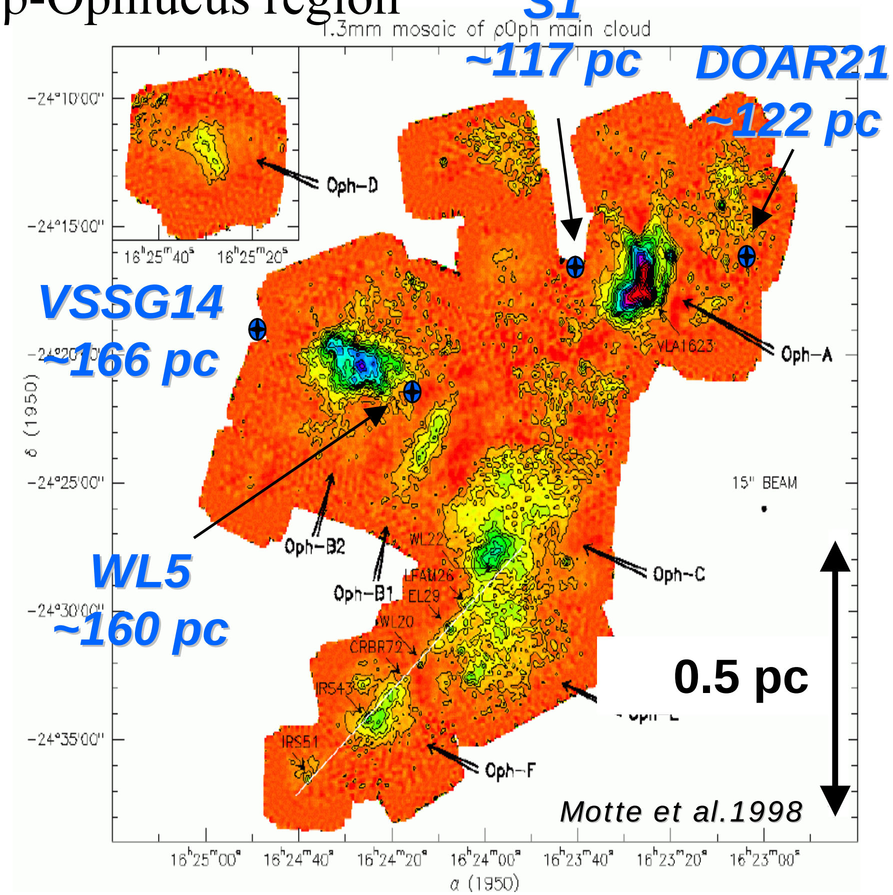
Distance = 414 +/- 7 pc

Distance to star forming regions

Taurus region



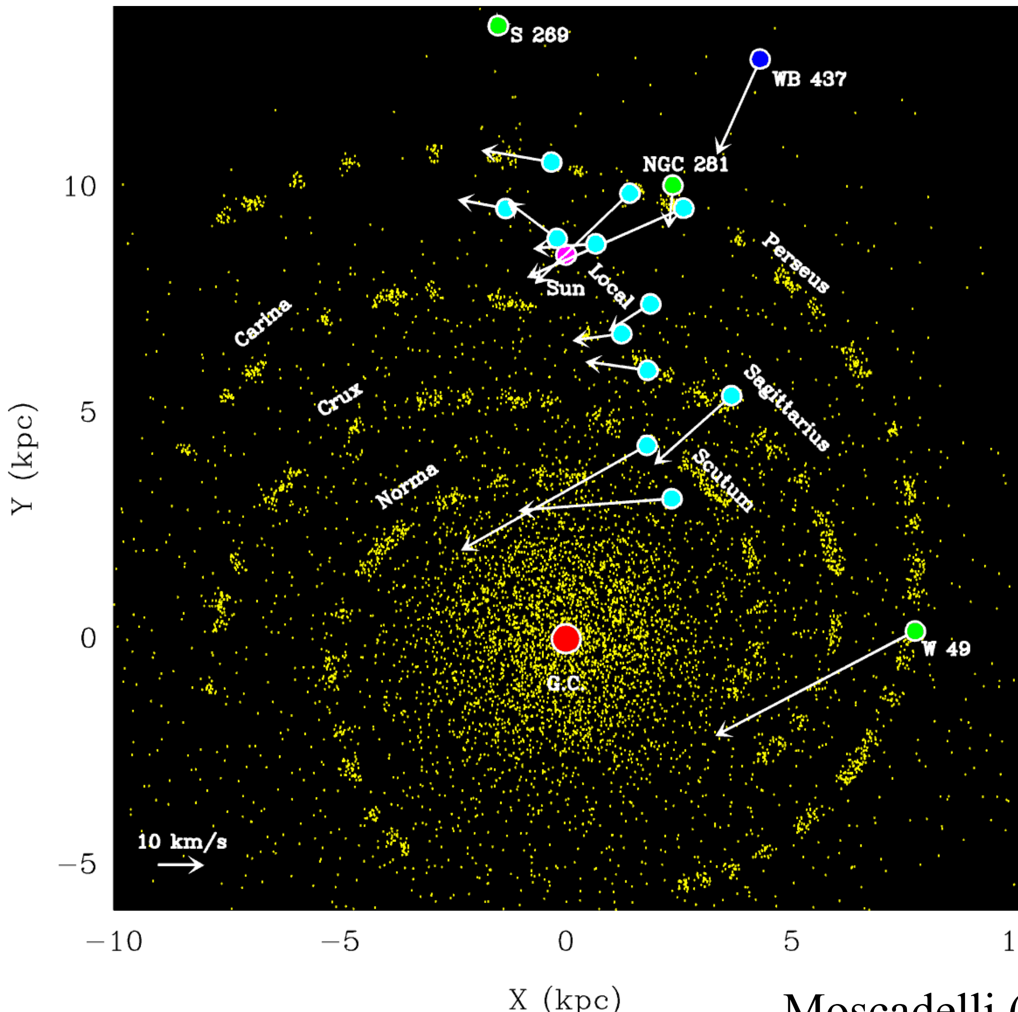
ρ-Ophiucus region



Mean distance d=142 pc

Loinard et al. (2008)

Mapping the Milky way



Moscadelli (2008)

Peculiar motions

Flat MW Rotation:

$R_0 = 8.5$ kpc

$\Theta_0 = 220$ km s^{-1}

HIPP. Solar Motion:

$U_0 = 10.0$ km s^{-1}

$V_0 = 5.25$ km s^{-1}

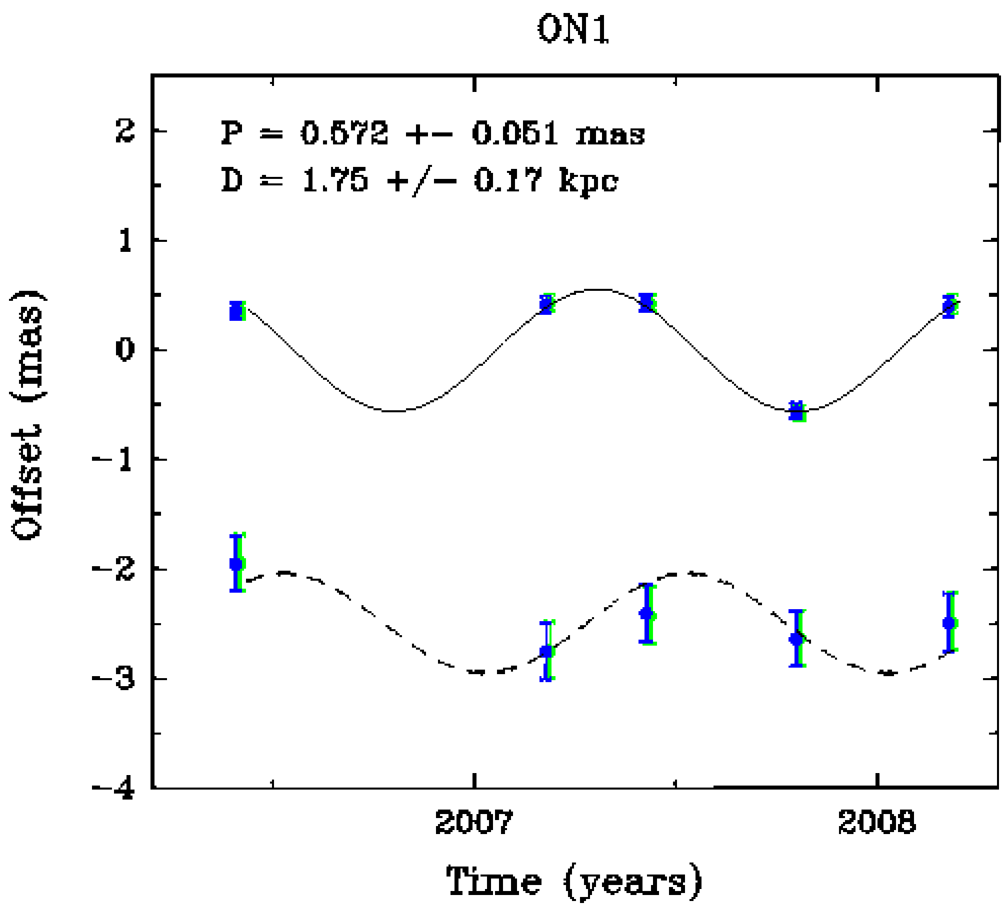
$W_0 = 7.16$ km s^{-1}

Methanol/H2O masers

- : 12 GHz VLBA
- : 22 GHz VERA
- : 22 GHz VLBA

Parallax measurements with EVN

- Use 6.7 GHz methanol masers



- ON1
- P = 0.572 ± 0.051 mas
- D = 1.75 ± 0.017 kpc

See Kazi Rygl talk