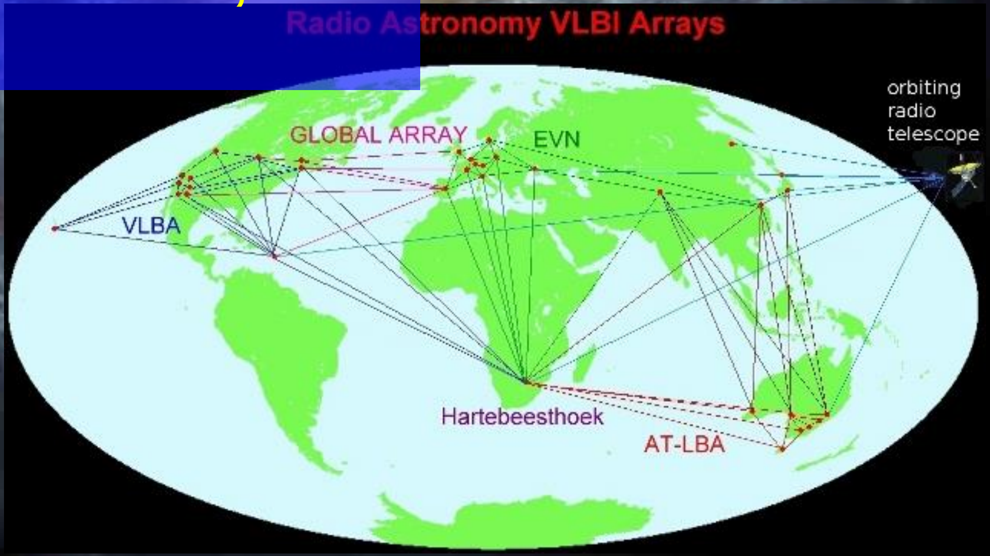
VLBI Today – Science and Technical Issues

Karl M. Menten

Max-Planck-Institut für Radioastronomie, Bonn



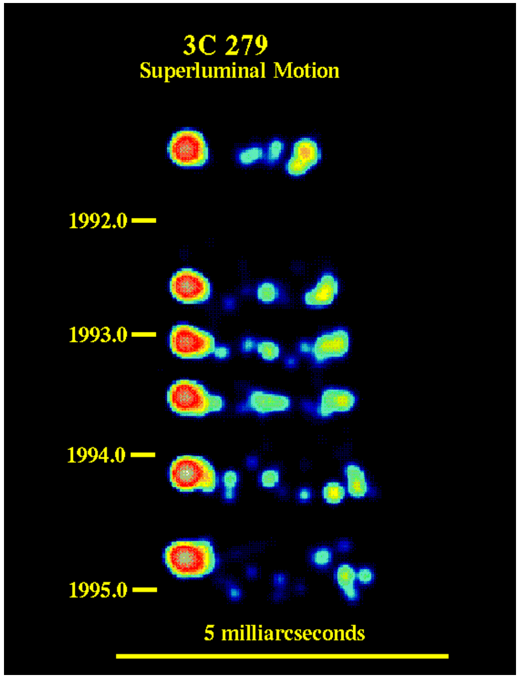
AERAP Workshop

Brussels, 6 March 2013

VLBI Sources must have non-thermal radio emission

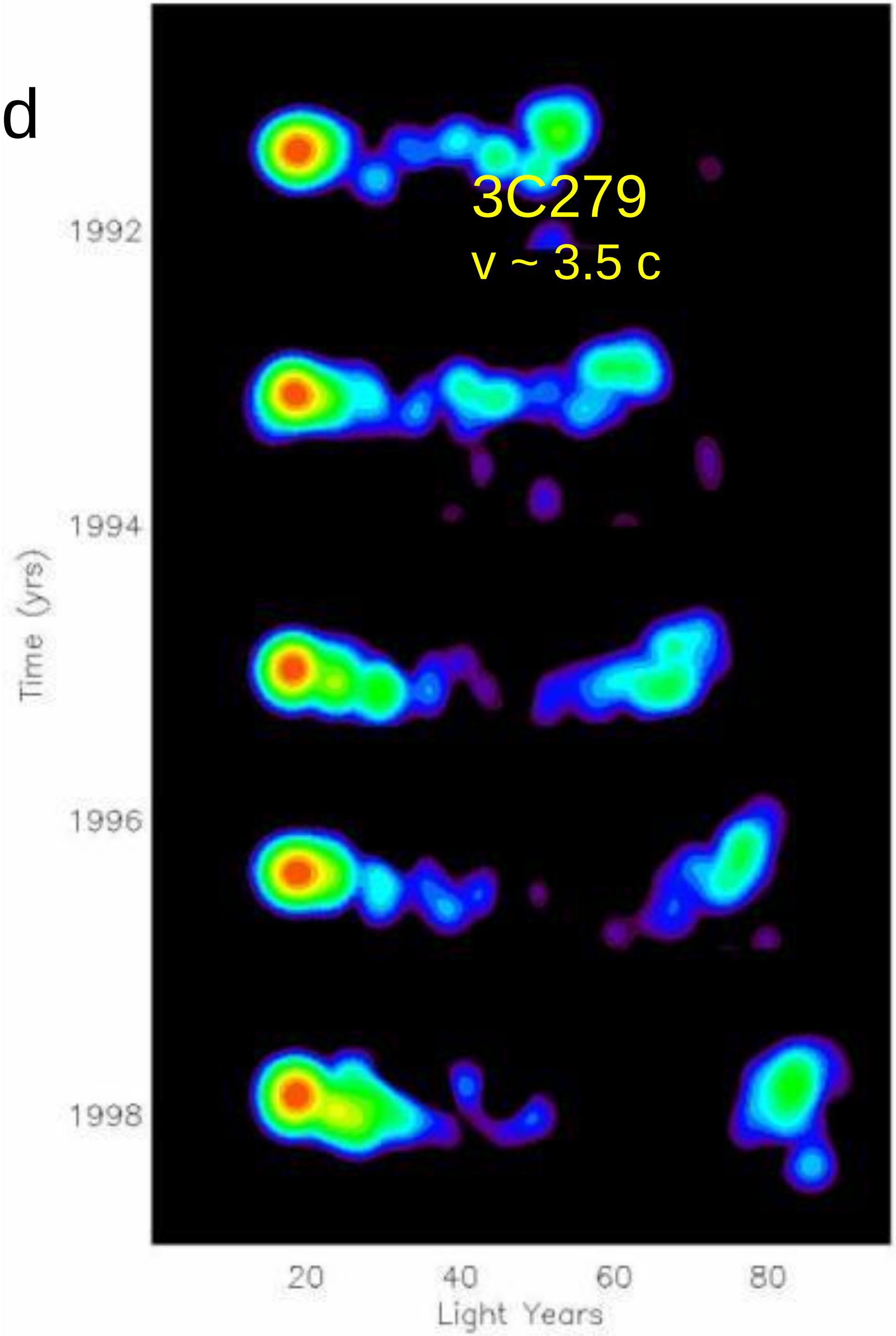
- Active Galactic Nuclei
- Radio "active" stars
- Cosmic masers

Microwave
Amplification by
Stimulated
Emission of
Radiation



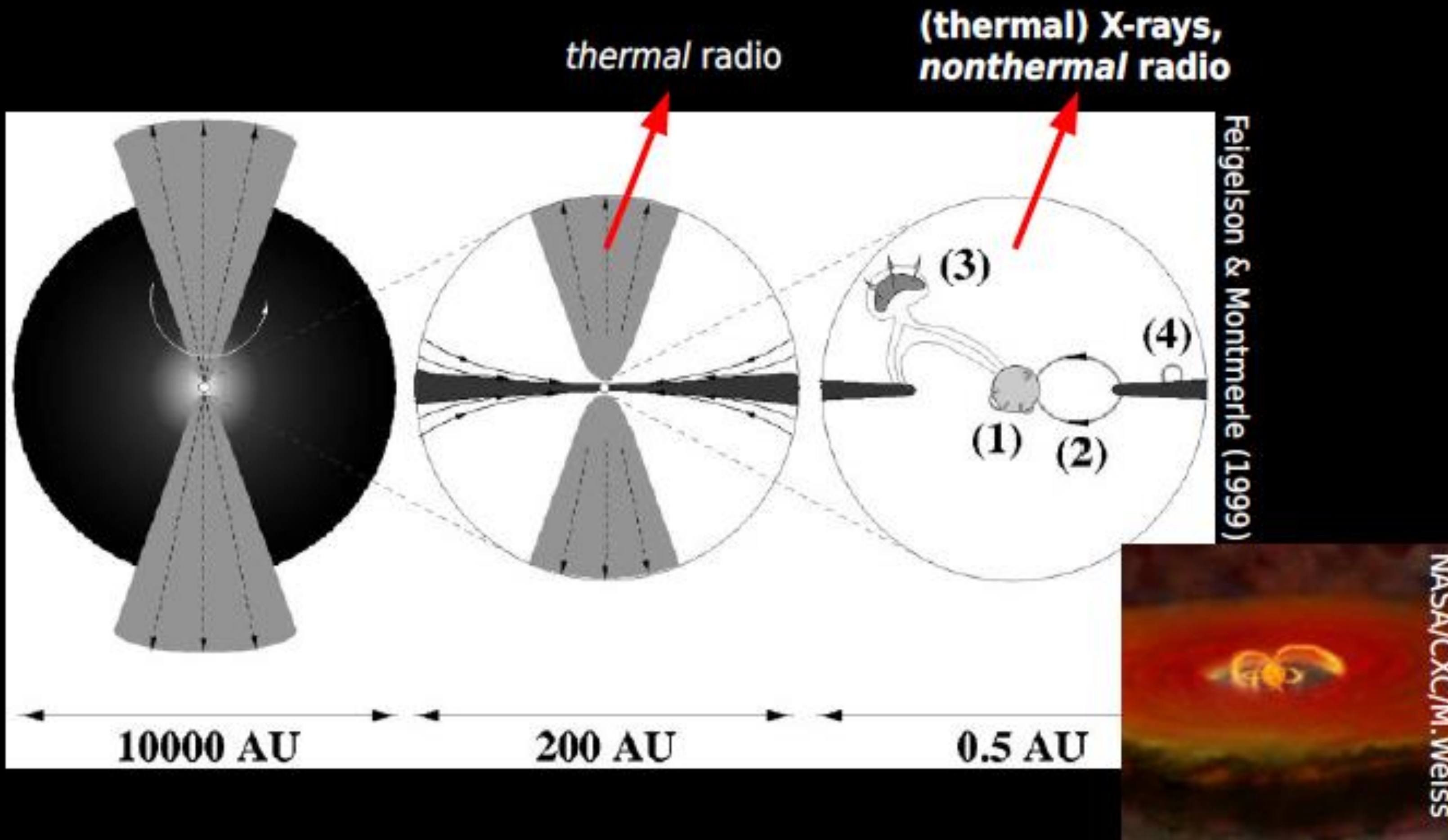
Wehrle et al. 1998

VLBI from the mid 1960s on: Active Galactic Nuclei and their jets

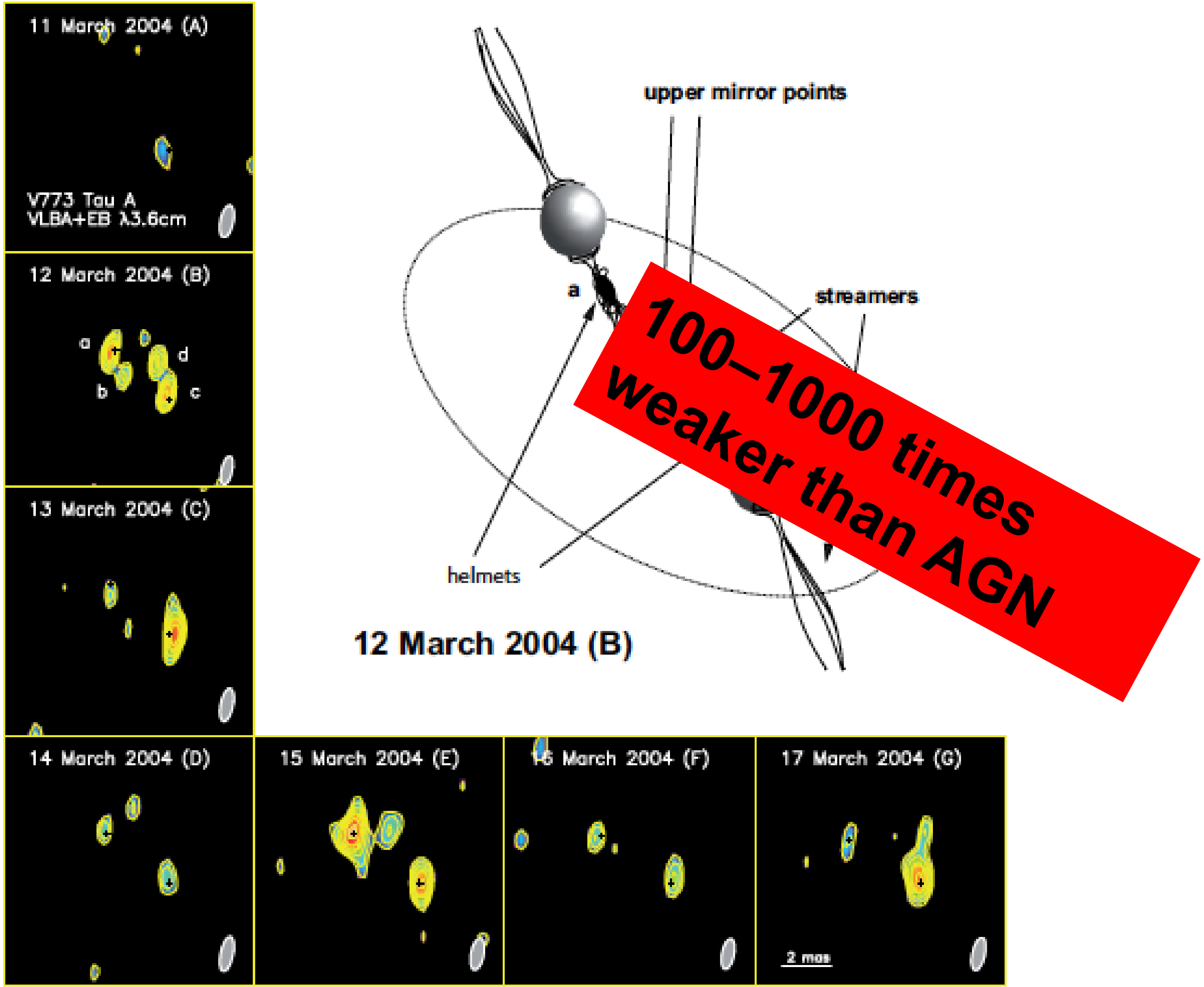


A. Wehrle

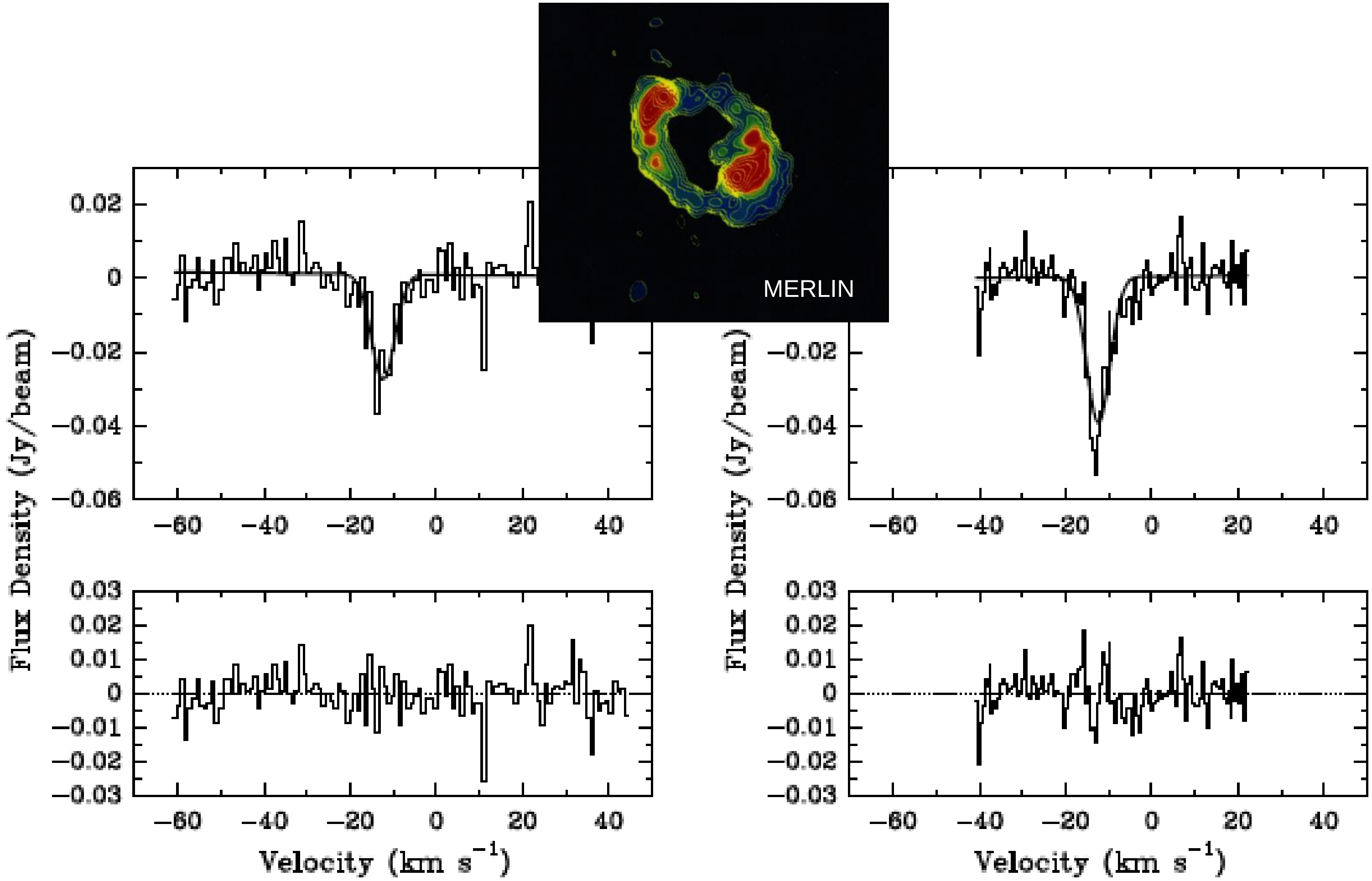
Radio emission from protostars



M. Massi et al.: Observational evidence for solar-like helmet streamers



Massi et al. 2008

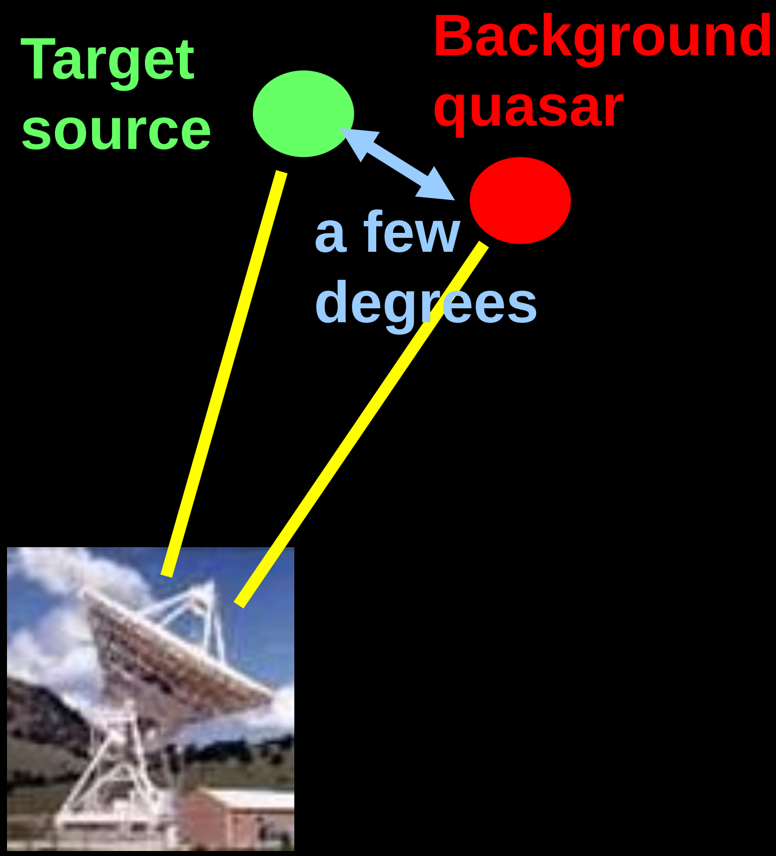


Redshift 0.88582 absorption in the HC_3N J = 3-2 and 5-4 lines toward the PKS 1830-211 gravitational lens system

Sato, Reid, Menten, & Carilli 2013

$$\sigma_S = \frac{2kT_{\rm sys}}{A_{\rm eff}[N(N-1)\Delta\nu_{\rm RF}\tau]^{1/2}}$$

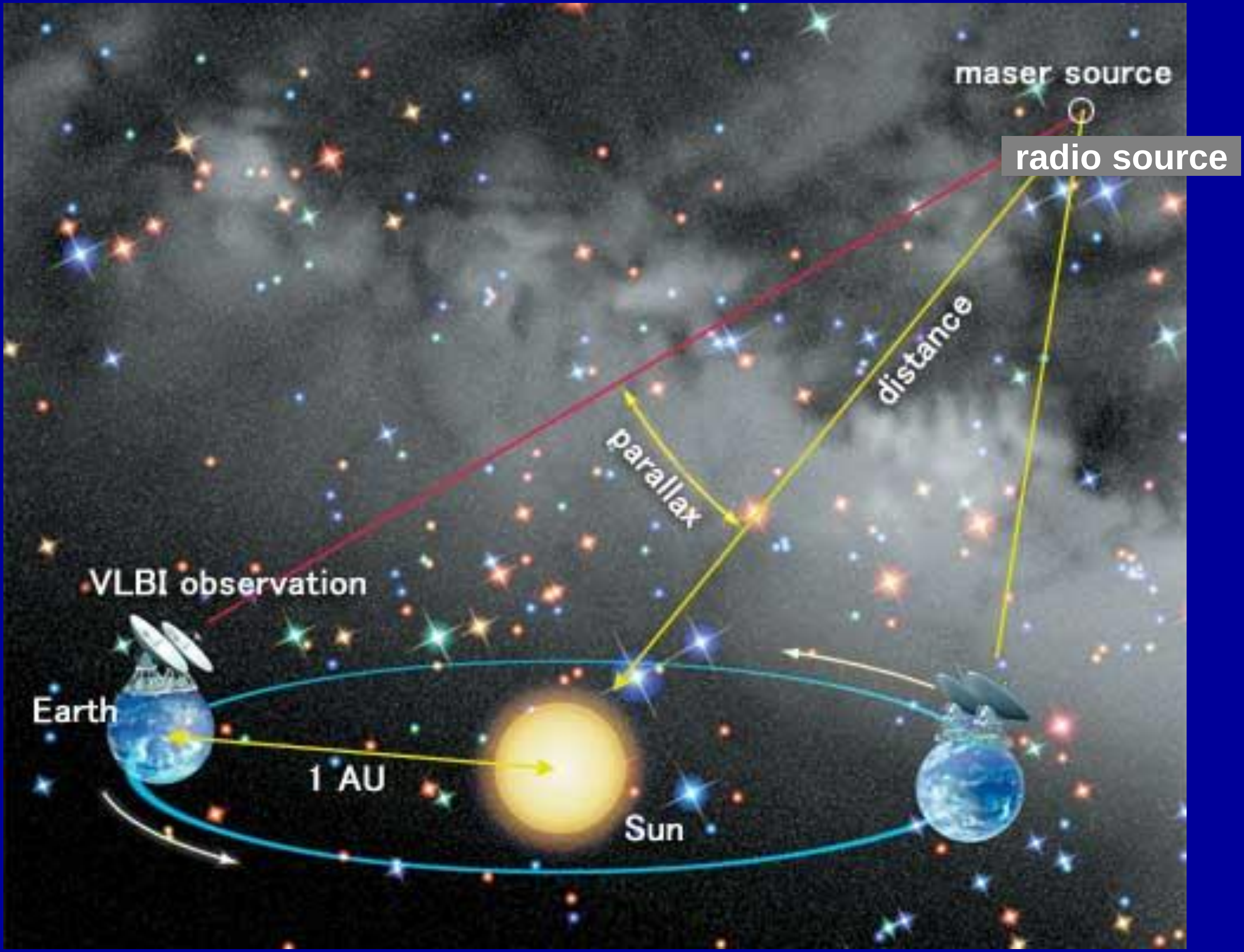
Phase referencing



VLBA: Switch every 15 second between maser and quasar. 50% duty cycle

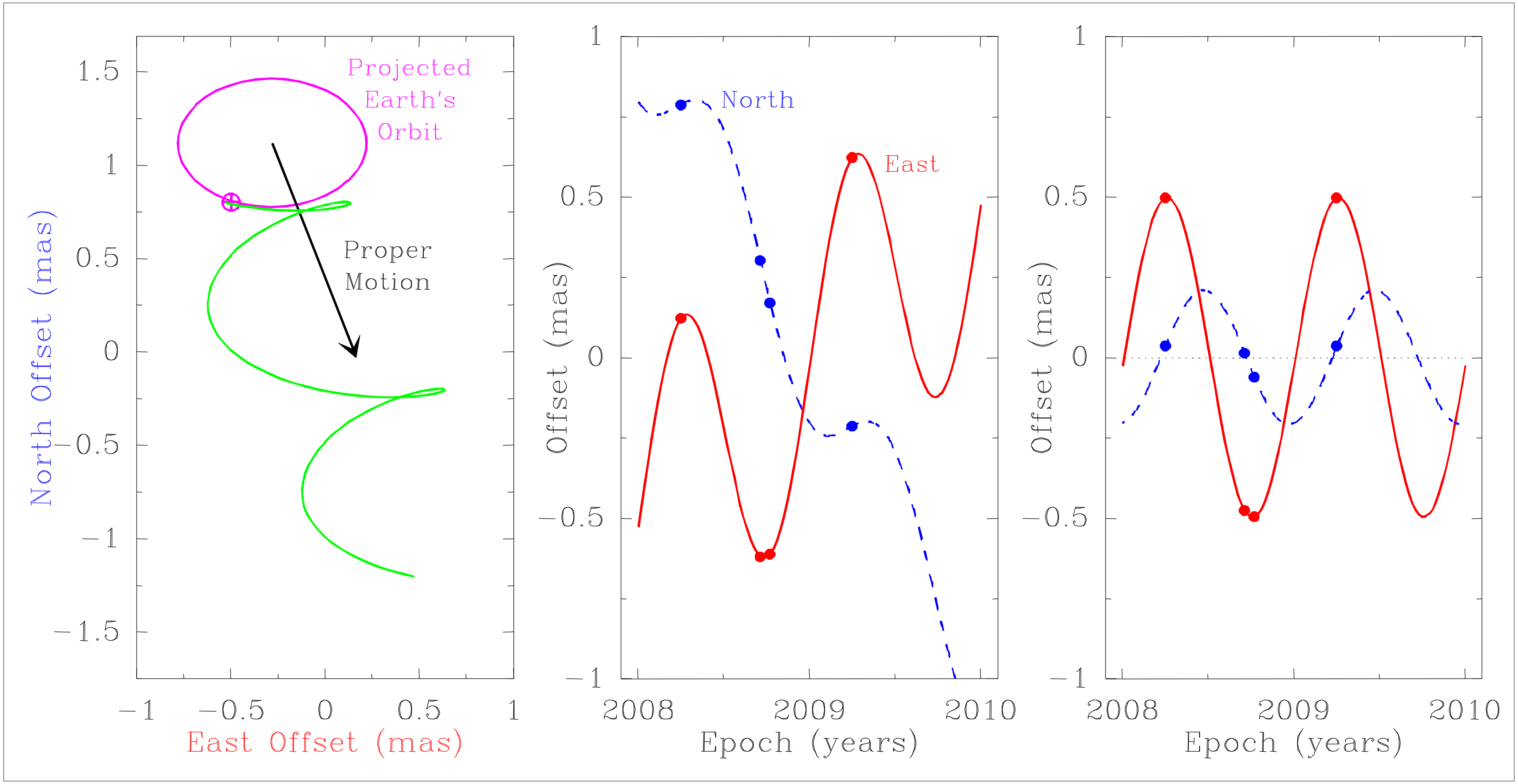
- Allows imaging of weak sources
- Provides excellent astrometric accuracy (down to 10 μarcsec)

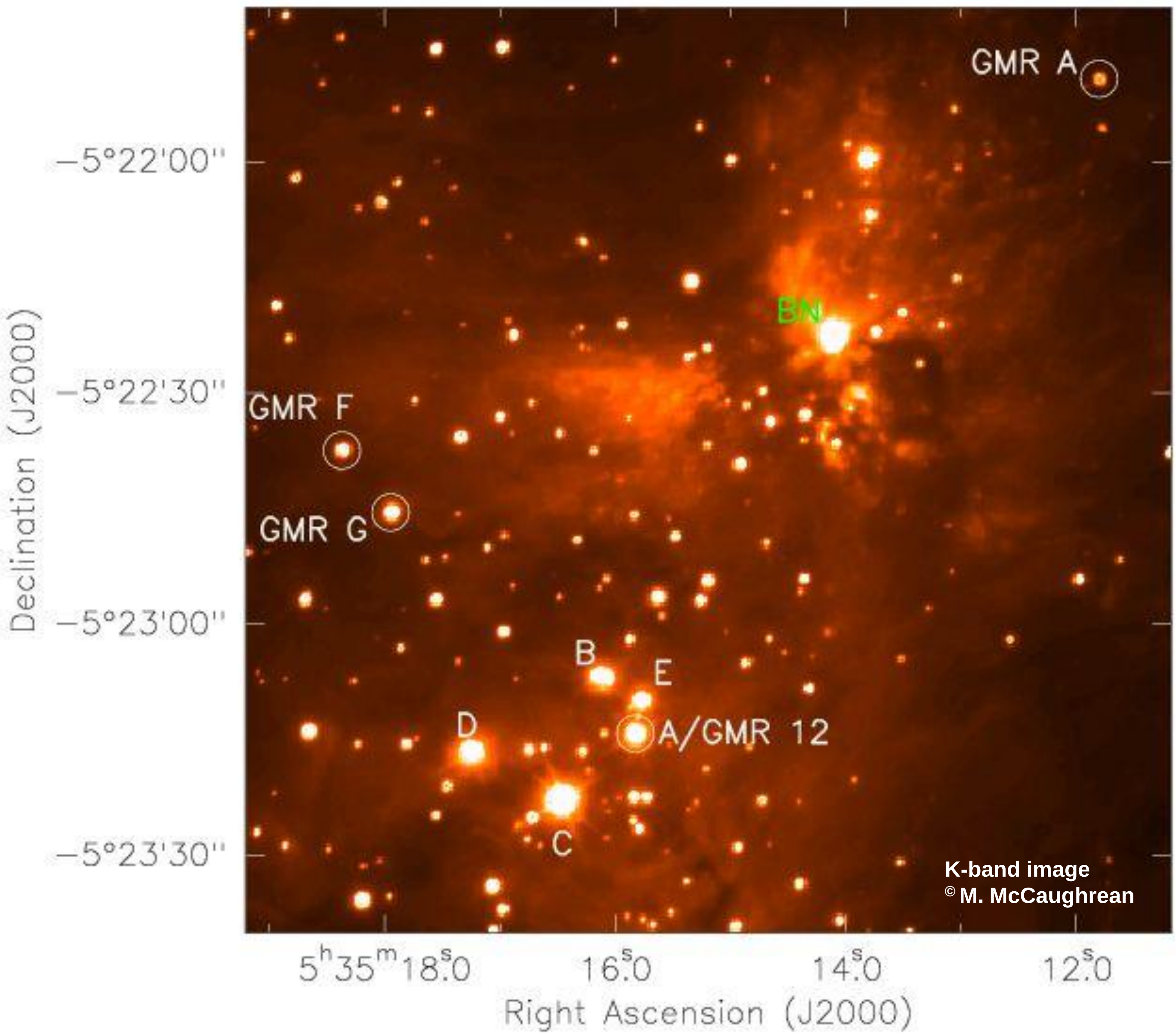
VLBI Trigonometric Parallaxes

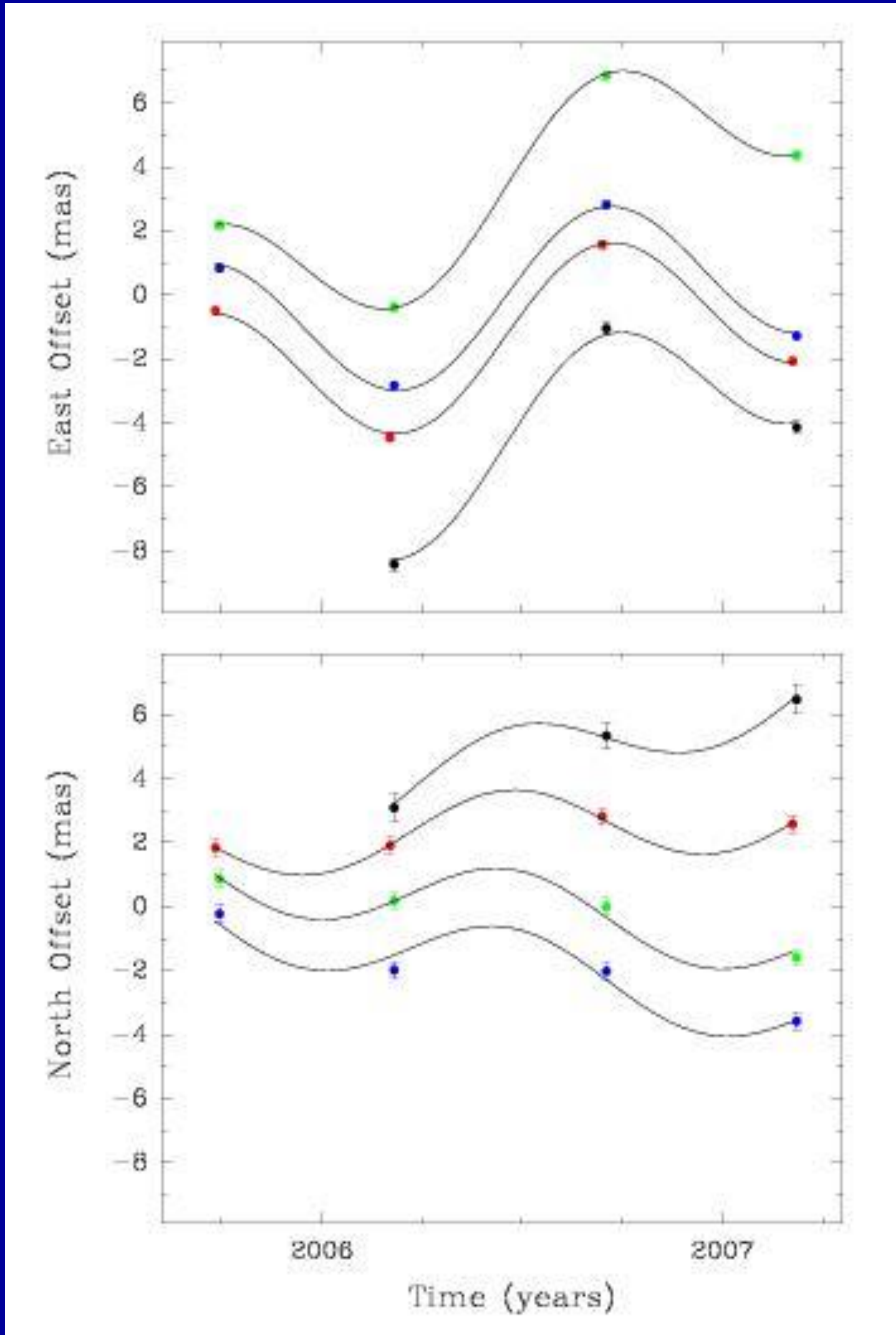


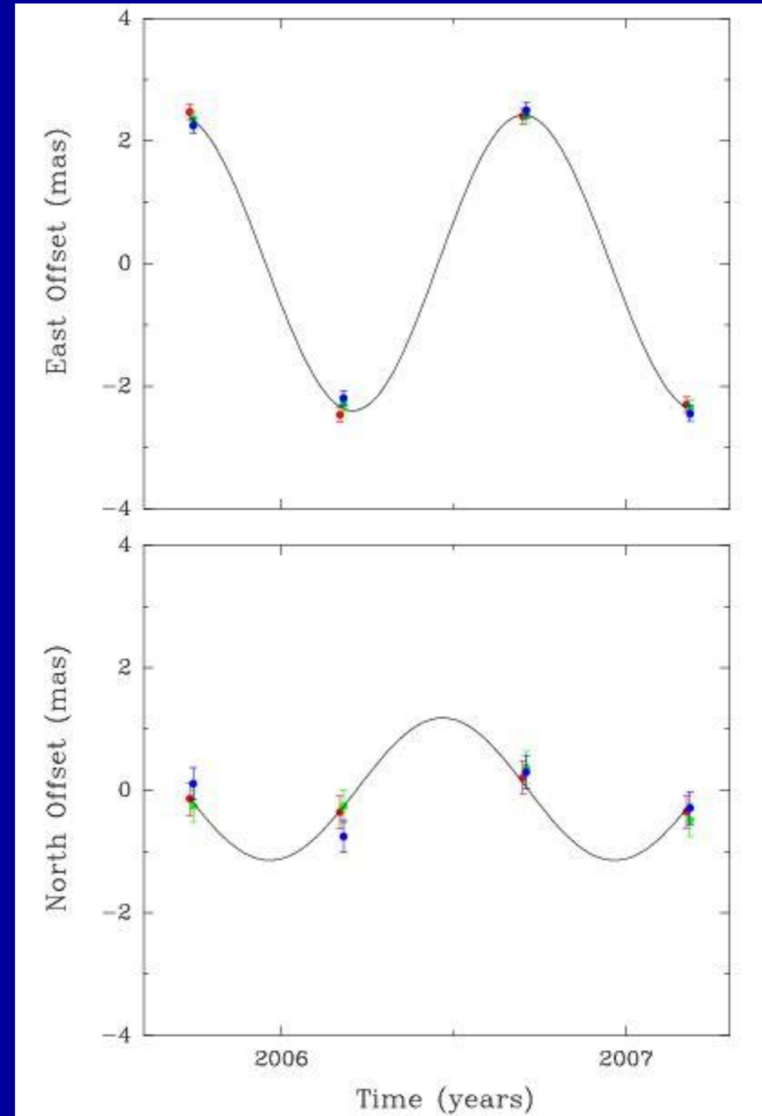
http://veraserver.mtk.nao.ac.jp/outline/vera2-e.html

Parallax Signatures




GMR A
BN
GMR F
GMR G
B
E
D
A/GMR 12
C
−5°22'00''
−5°22'30''
−5°23'00''
−5°23'30''
Declination (J2000)
5h35m18.0s
16.0s
14.0s
12.0s
Right Ascension (J2000)
K-band image
© M. McCaughrean


East Offset (mas)
North Offset (mas)
Time (years)
2006
2007


East Offset (mas)
North Offset (mas)
Time (years)
2006
2007

Source	π (mas^{-1})	D (pc)	μ_x (mas y^{-1})	μ_y (mas y^{-1})
GMR A	2.390(0.104)	418.4(18.2)	+1.82(0.09)	−2.05(0.18)
GMR 12	2.393(0.053)	417.9(9.2)	+4.82(0.09)	−1.54(0.18)
GMR G	–	–	+4.29(0.17)	+3.33(0.37)
GMR F	2.462(0.051)	406.1(8.4)	+2.24(0.09)	+0.66(0.18)
Mean	2.425(0.035)	412.4(6.0)		
Joint	2.415(0.040)	414.0(6.8)		

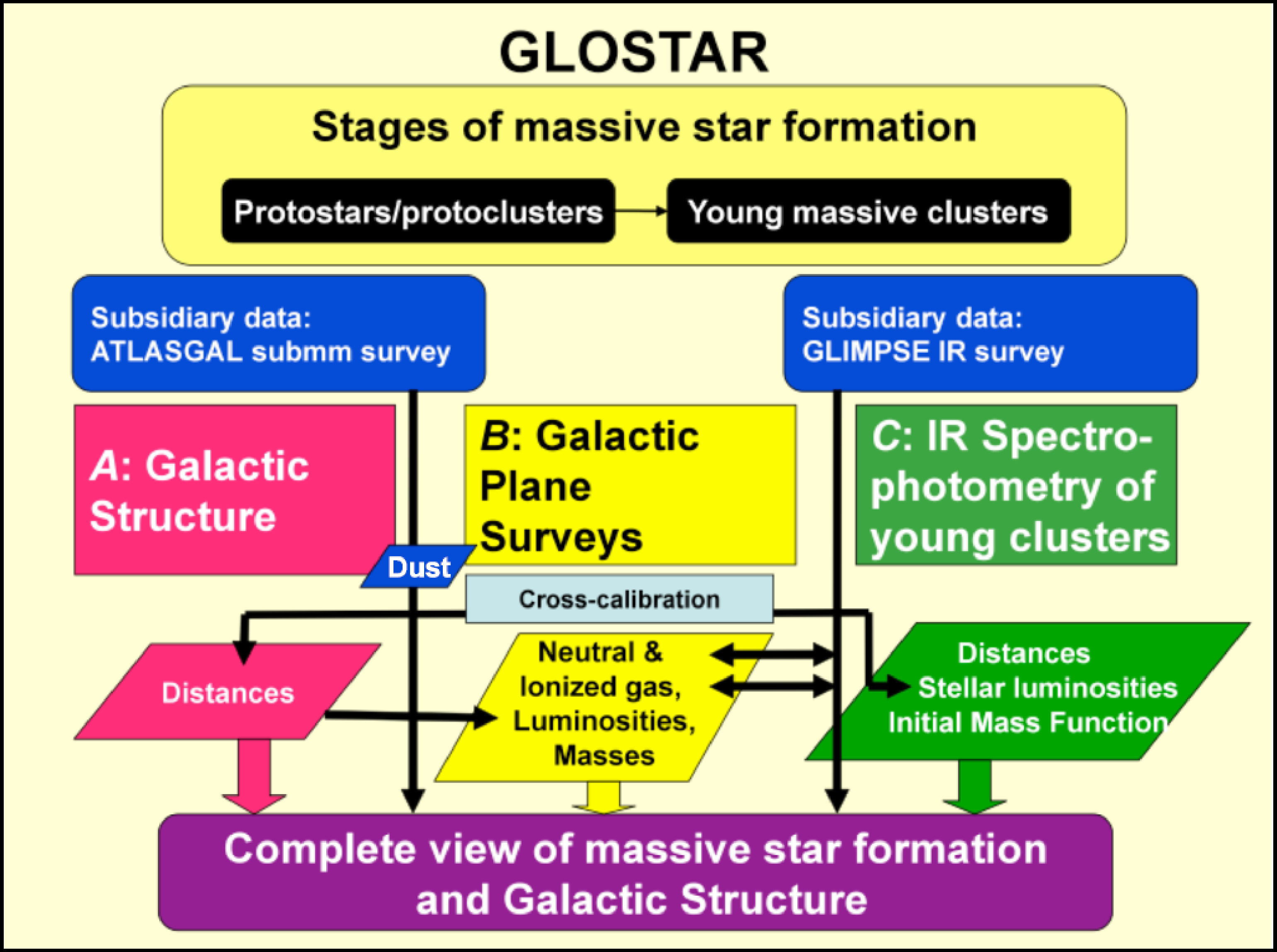
Menten et al. 2007

Bar and Spiral Structure Legacy Survey,
a VLBA Key Science Project

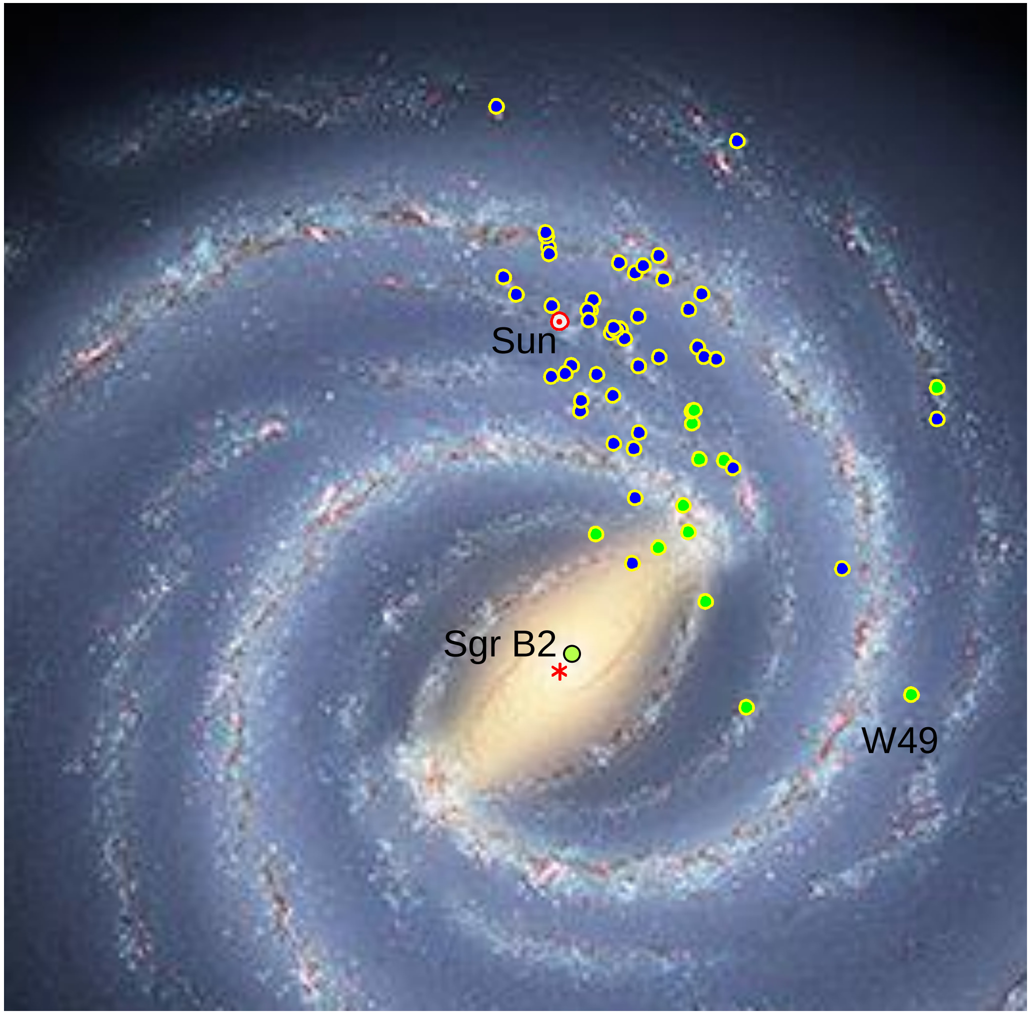
The BeSSel Team:

Mark Reid (PI), Tom Dame, Mayumi Sato	Harvard-Smithsonian Center for Astrophysics, USA
Karl Menten, Andreas Brunthaler, Yoon Kyung Choi, Bo Zhang, Kazi Rygl, Katharina Immer, Alberto Sanna, Yuanwei Wu	Max-Planck-Institut für Radioastronomie, Germany
Xing-Wu Zheng	Nanjing University, China
Ye Xu	Purple Mountain Observatory, Nanjing, China
Kazuya Hachisuka	Shanghai Astronomical Observatory, China
Luca Moscadelli	Osservatorio di Arcetri Observatory, Florence, Italy
George Moellenbrock	National Radio Observatory, USA
Anna Bartkiewicz	Torun Centre for Astronomy, Poland
Huib van Langevelde	JIVE

GLOSTAR: A Global View of Star Formation in the Milky Way
European Research Council Advanced Investigator Grant

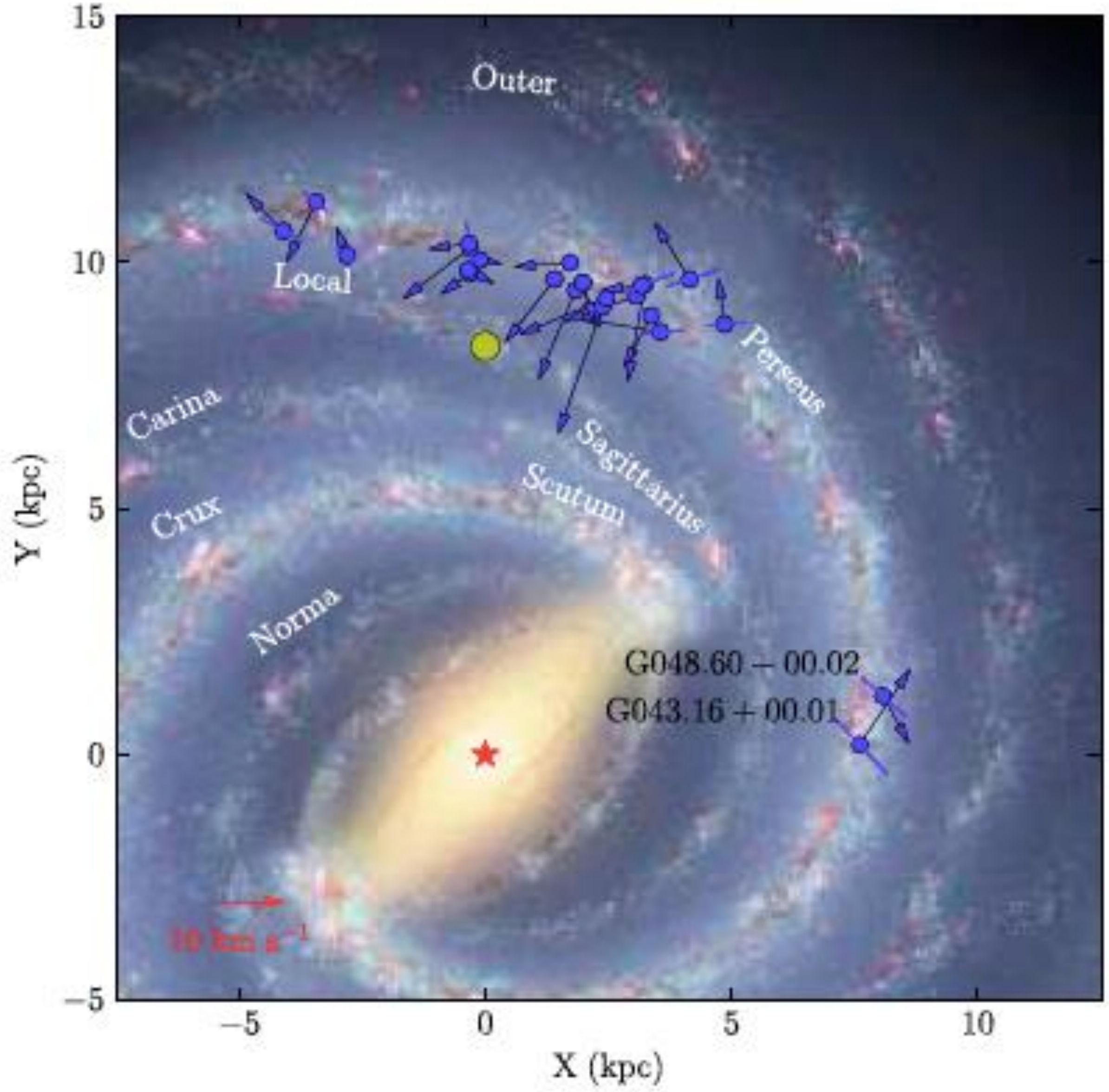


Mapping the Milky Way



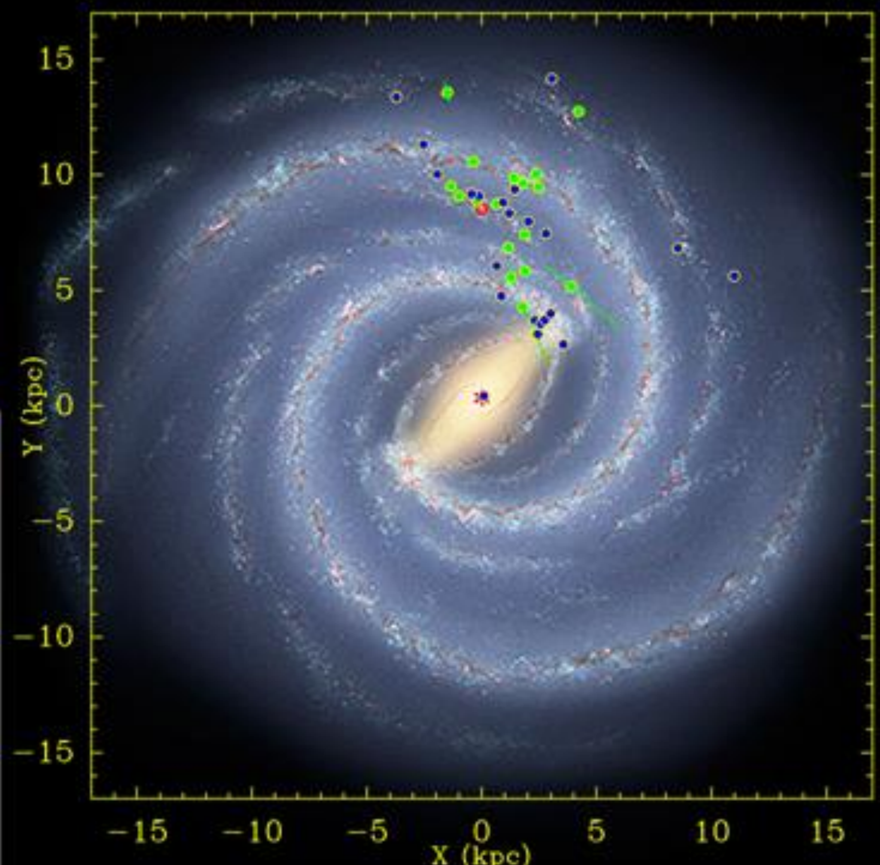
Artist conception: Robert Hurt (NASA:SSC)

- Preliminary results for 62 parallaxes from VERA, EVN & VLBA:
  blue ($\sigma_d < 0.5$ kpc)
  green ($\sigma_d > 0.5$ kpc)
- Tracing outer spiral arms
- Inner, bar-region is messy

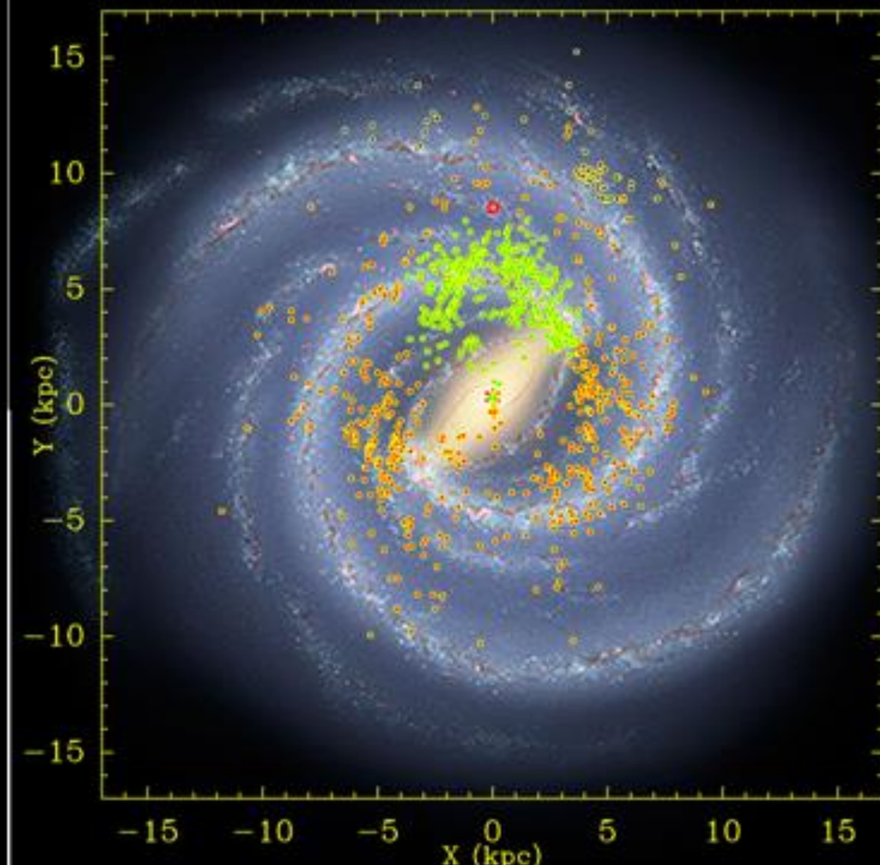


Inner Perseus Arm (Zhang et al. 2013)

Masers with parallaxes



Catalogued 6.7 GHz CH_3OH Masers



- near kinematic distance
- far kinematic distance

Niger
Mali
Mauretanien
Senegal
Burkina Faso
Sudan
Tschad
Rotes Meer
Golf von Aden
Nigeria
Guinea
Elfen-bein-küste
Sierra Leone
Liberia
Ghana
Togo
Benin
Äthiopien
Zentralafrika-nische Republik
Kamerun
Somalia
Uganda
Kenia
Gabun
Republik Kongo
Ruanda
Burundi
Demokratische Republik Kongo
Tansania
Atlantischer Ozean
Angola
Sambia
Malawi
Zimbabwe
Namibia
Botswana
Mosambik
Mauritius
Madagaskar
Südafrika
Indischer Ozean
0
1000
2000
3000 km


Cape Verdean Islands
Mauritius
9700 km
Portugal
Morocco
Tunisia
Mediterranean Sea
Syria
Iraq
Iran
Algeria
Libya
Egypt
Western Sahara
Saudi Arabia
Oman
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Gulf of Aden
Burkina Faso
Guinea
Nigeria
Ghana
South Sudan
Ethiopia
Gulf of Guinea
Somalia
Kenya
Gabon
DR Congo
Tanzania
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Madagascar
Botswana
South Atlantic Ocean
South Africa

HIPPARCOS

(HIgh Precision PARallax COllecting Satellite)

(Perryman et al 1997 A&A 323 49)

118,000 stellar parallaxes

σ_π ~ 0.001 arcseconds (1 mas)

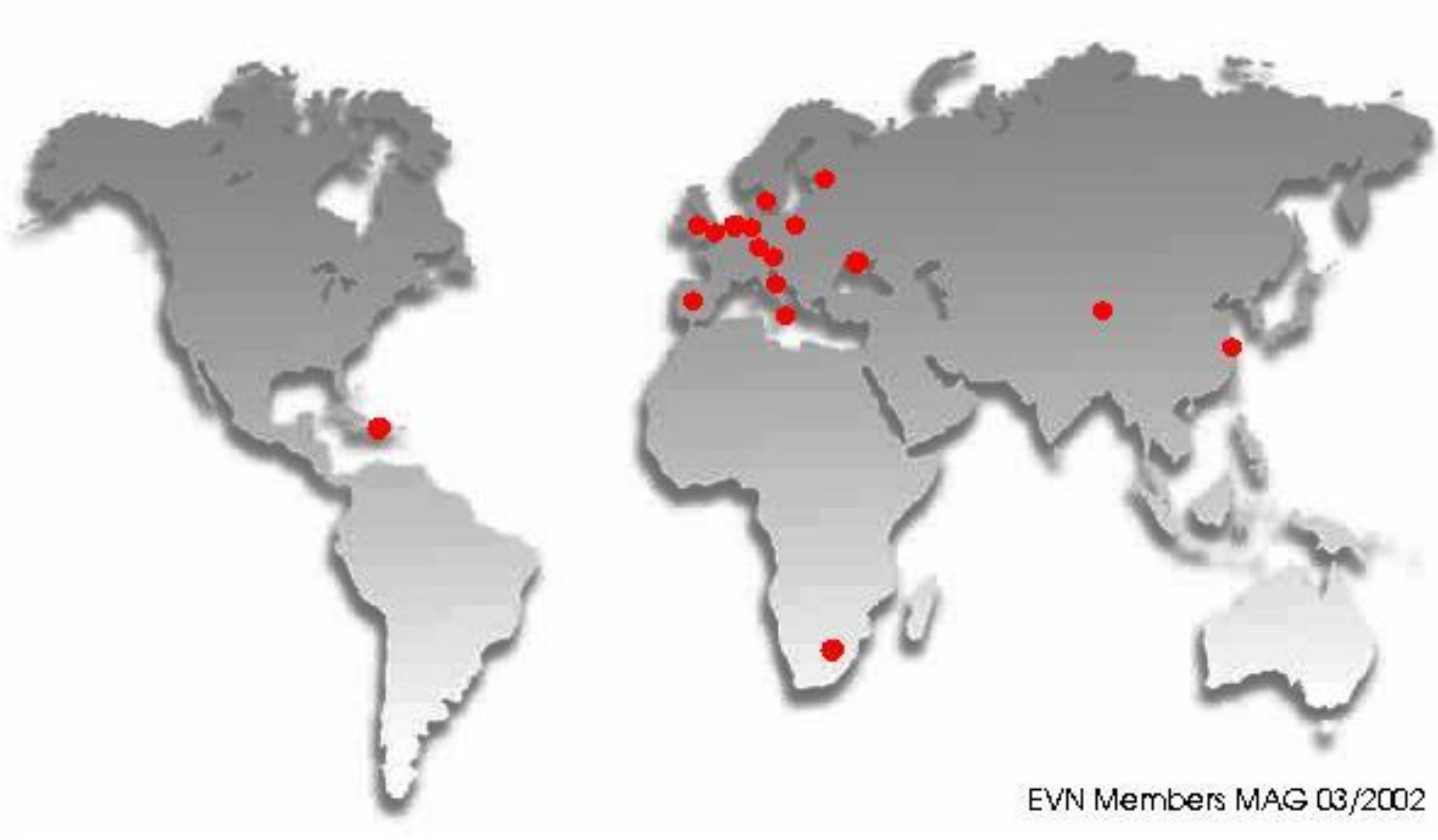
10% accuracy at 100 pc…

mapped solar neighborhood

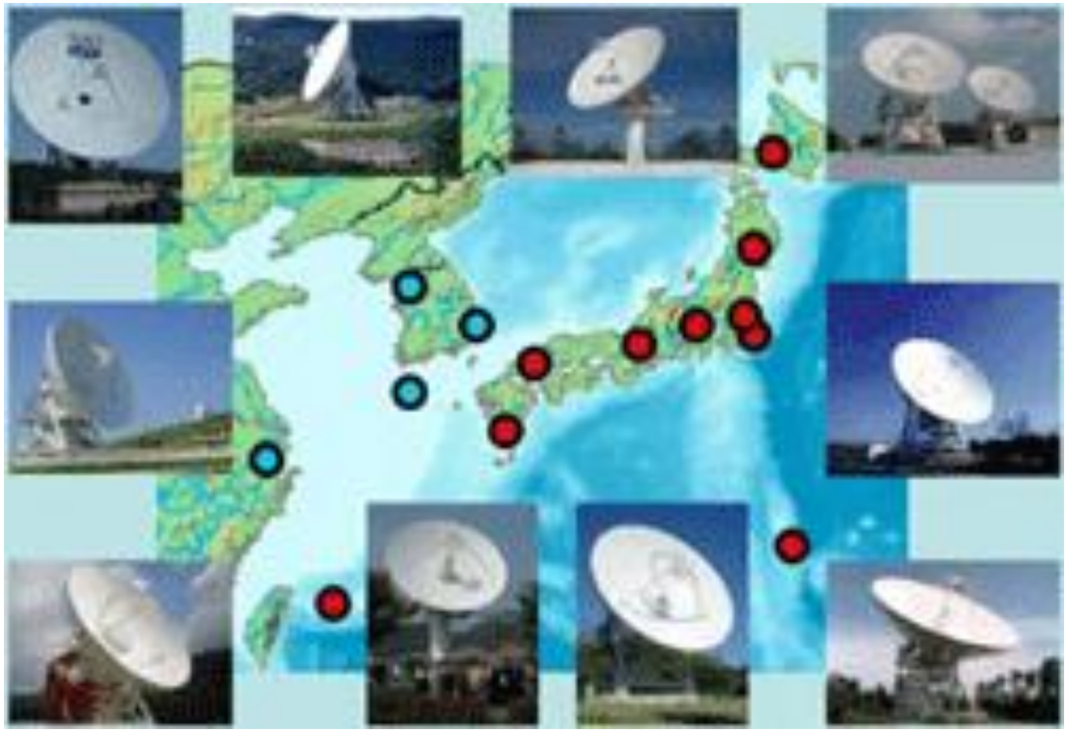
Next great space missions:

GAIA & SIM: ~10 μas

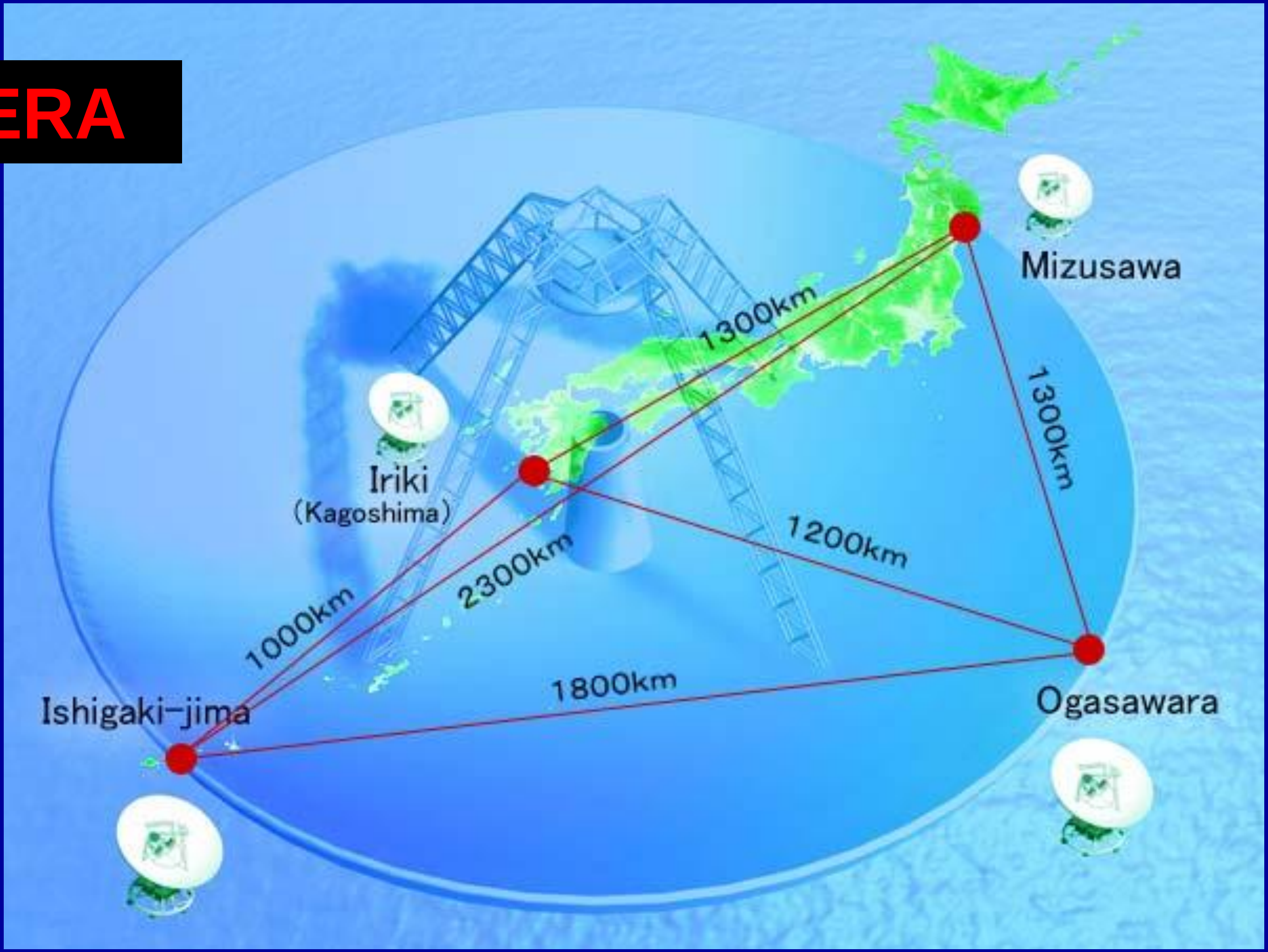
European VLBI Network



East Asia VLBI Network

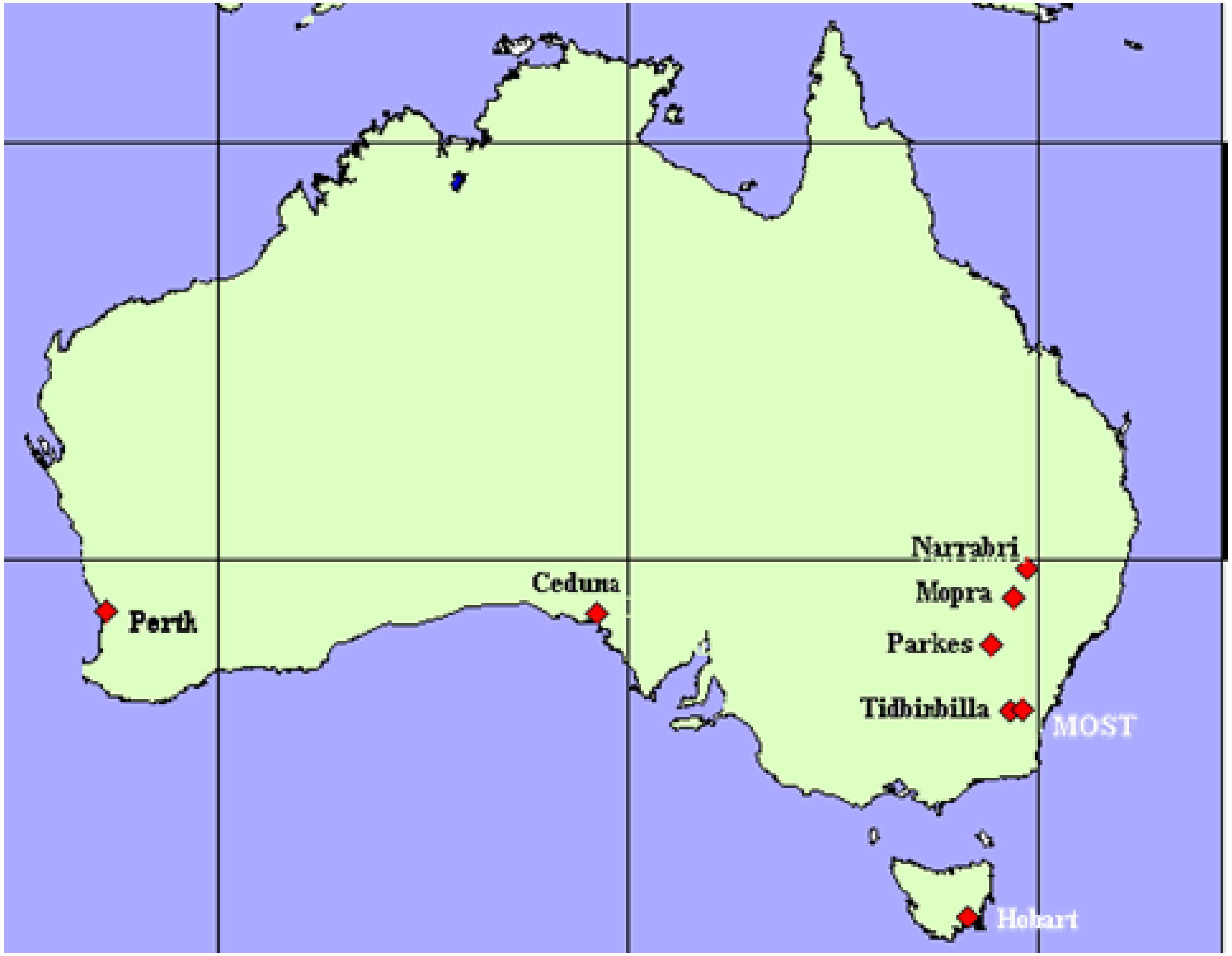


VERA

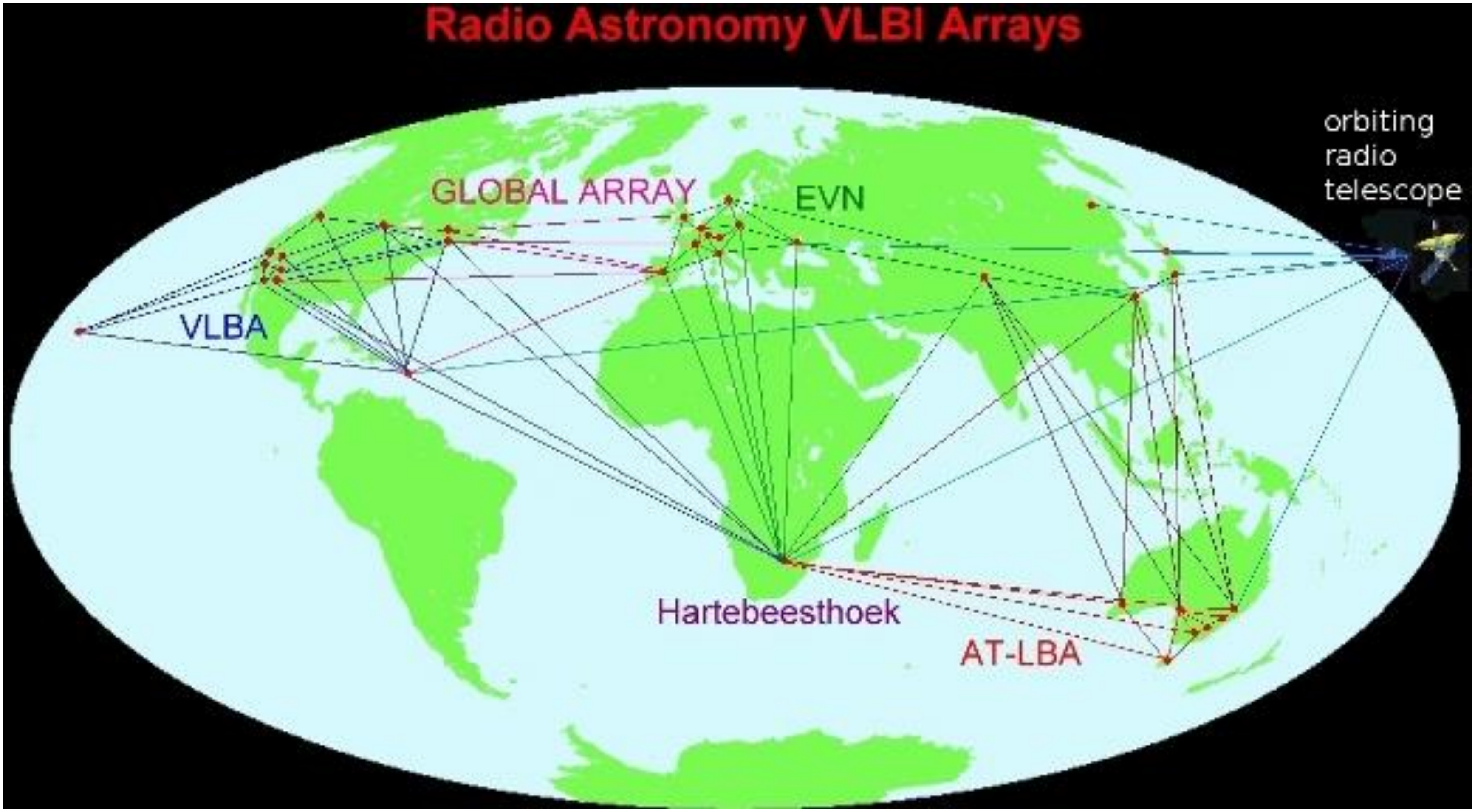


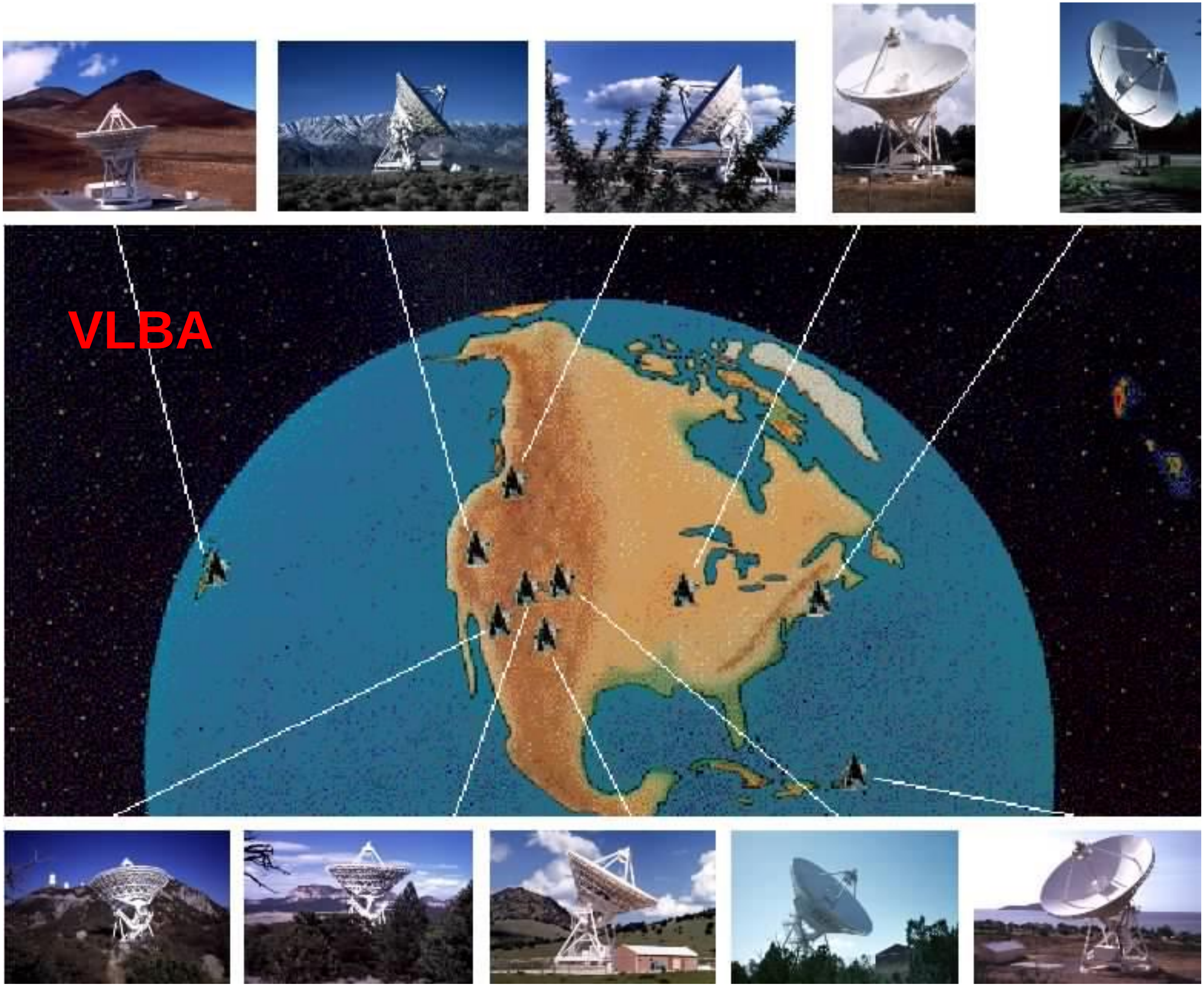
http://veraserver.mtk.nao.ac.jp/outline/vera2-e.html

The Long Baseline Array (Australia)



Global VLBI Network




VLBA

The Very Long Baseline Array (VLBA)

- Radio waves "see" through galaxy
- Can "synthesize" telescope the size of the Earth

Angular resolution:

$\theta_f \sim \lambda/D \sim 1$ cm / 8000 km = 250 μas

Centroid Precision:

$0.5\ \theta_f$ / SNR ~ 10 μas

Systematics:

path length errors ~ 2 cm (~2 λ)

shift position by ~ $2\theta_f$ ~ 500 μas

Relative positions (to QSOs):

$\Delta\Theta$ ~ 1 deg (0.02 rad)

cancel systematics: $\Delta\Theta * 2\theta_f$ ~ 10 μas


VLBA
NSF Portfolio Review

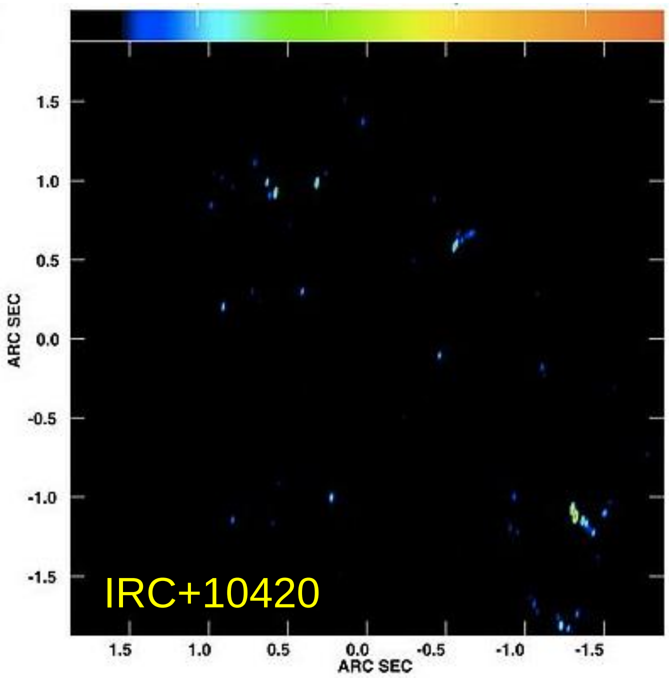
J.L. Casse / New Astronomy Reviews 43 (1999) 503–508

The JIVE Data Processor control room. The row of 16 DPUs

Today: Cheap, flexible software correlators + e-VLBI

e-VLBI

- connects VLBI radio telescopes in real-time, while still employing the local time references of the VLBI technique.
- Gigabit per second links via
  - their National Research Networks and
  - the Pan-European research network GEANT2



Modern VLBI requires:

- Broad receiver bandwidths. Gives:
  - Good continuum sensitivity
  - Frequency agility (e.g, for redshifted spectral line)
- Fast switching
- A dedicated network, allowing repeated observations
- Broad bandwidth connectivity
- Appreciable collecting area
- **A really good science case!**