Astrometric Detection of Extrasolar Planets

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Overview

- Capabilities of astrometry
- Capabilities of radio astrometry - SKA
- Technique cooperation: the case for AB Dor

Planet Detection Score

Radial Velocity	*Astrometry*
120	2 ?

- Radial velocity is a very efficient technique
- Astrometry is the technique of the past…

  …and the technique of the future

Astrometry

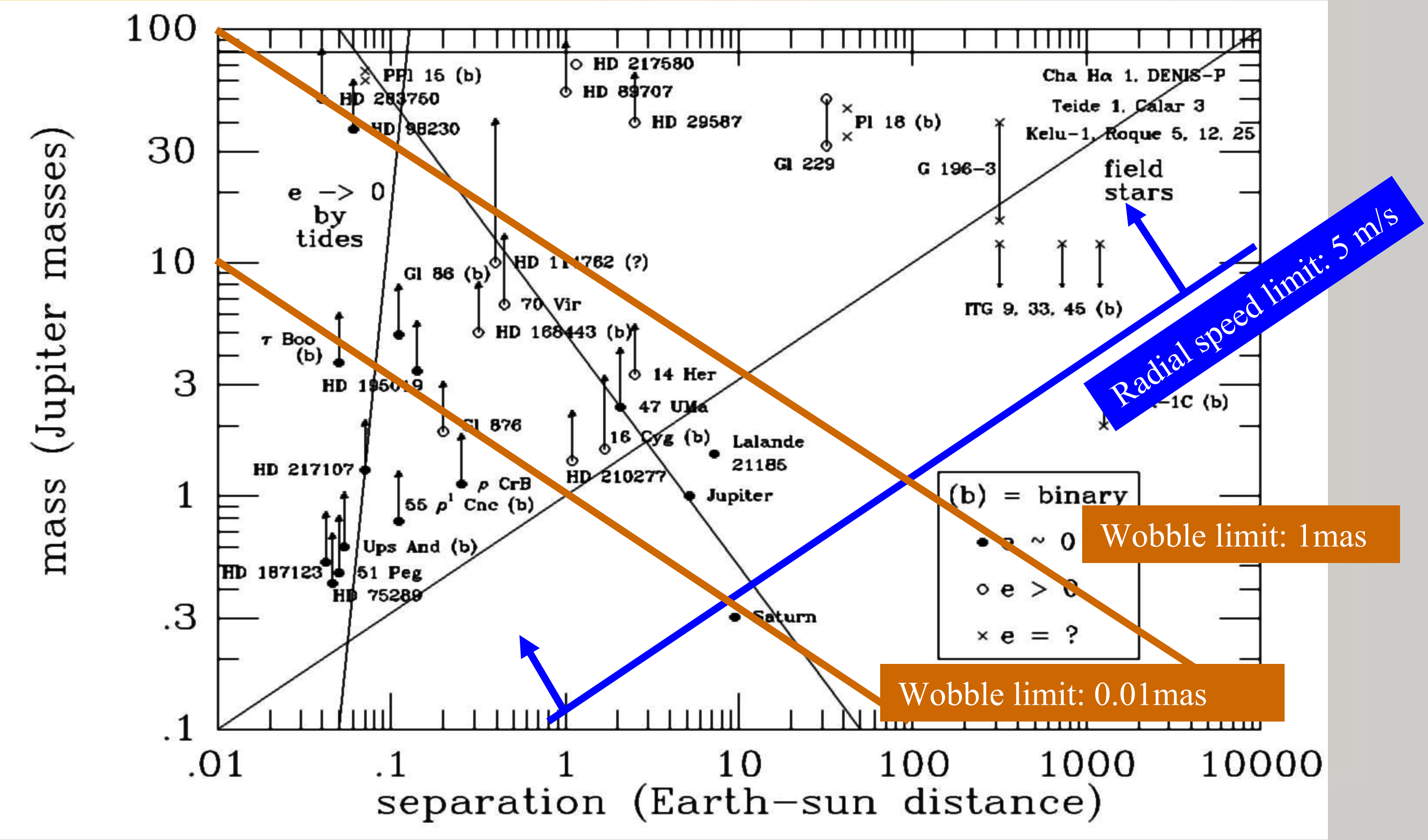
- Determination of 3D orbit. Unambiguous mass determination.

  (masses determined by Doppler techniques are coupled with orbit inclination)
- Young and active stars may be studied
- Sensitivity to longer periods (larger a's):

$$\theta = \frac{m_p}{M_s} \frac{a_p}{d}$$

- Expected very high-precision:
  - SIM (4μas) & GAIA (1μas)

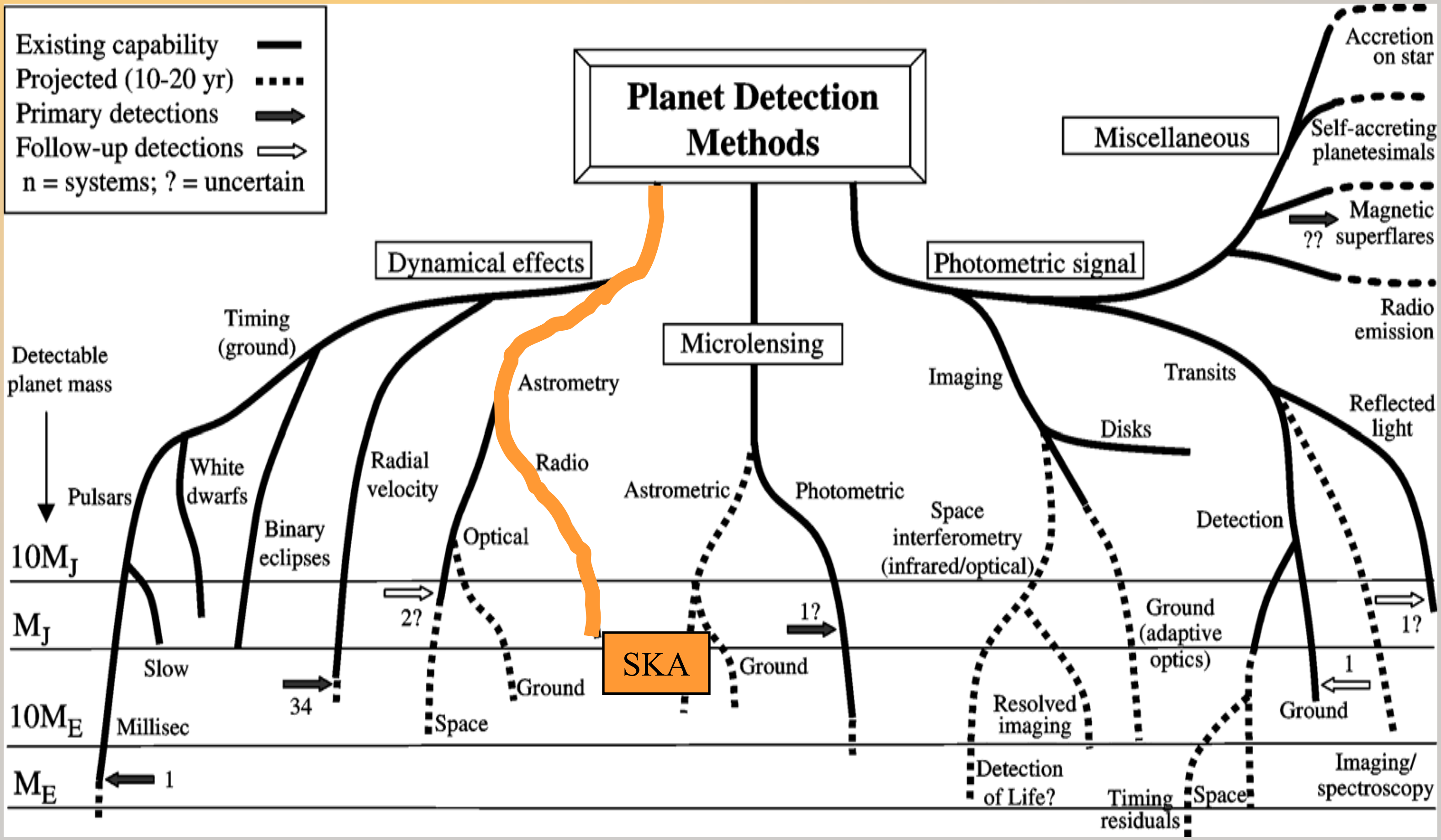
Mass vs. Separation



J. Liebert (2000)

Radio Astrometry

M. Perryman (2000)



Radio Astrometry

- Space-based expected (2010) very high-precision in the optical:
  - SIM (4μas) & GAIA (1μas)

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1983

HIGH PRECISION ASTROMETRY VIA VERY-LONG-BASELINE RADIO INTERFEROMETRY: ESTIMATE OF THE ANGULAR SEPARATION BETWEEN THE QUASARS 1038+528A AND B

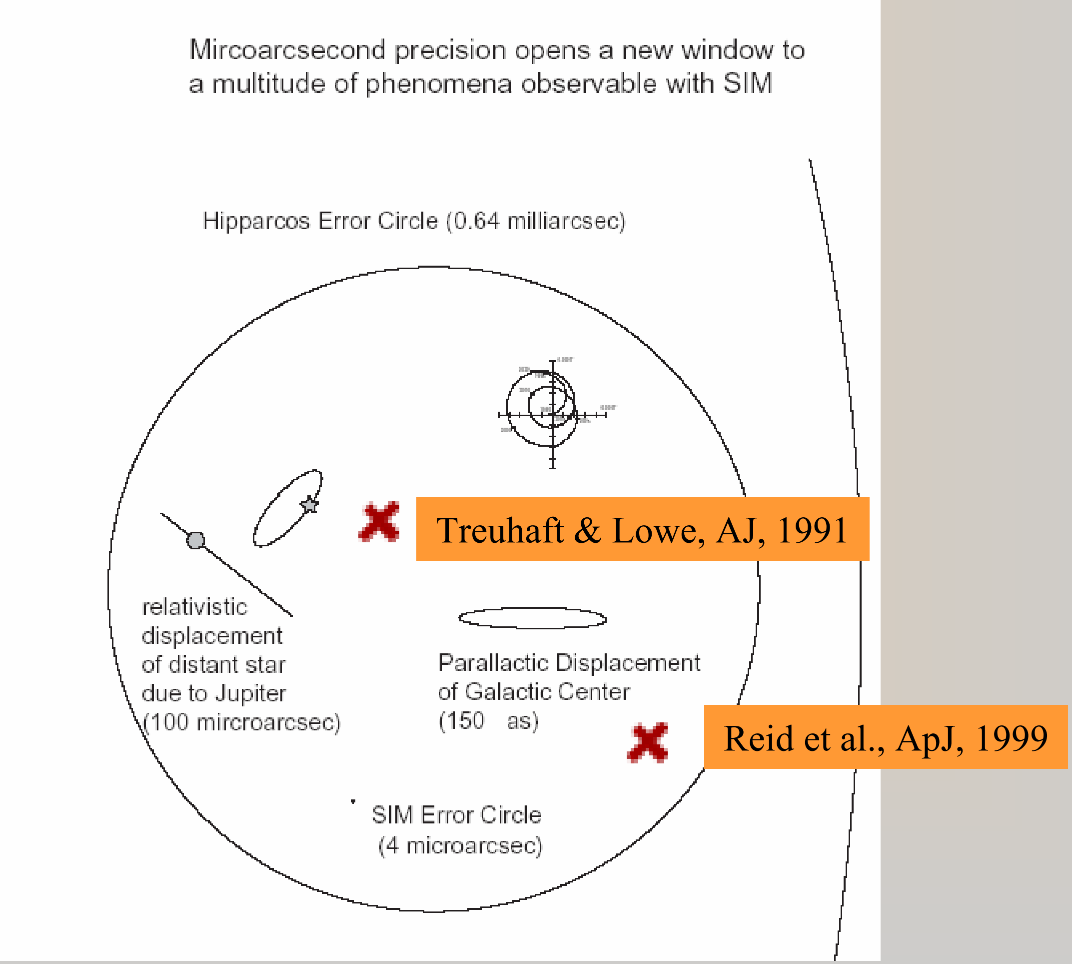
J. M. MARCAIDE[a] AND I. I. SHAPIRO[b]
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
Received 14 December 1982

TABLE II. Relative position of 1038 + 528A and B.

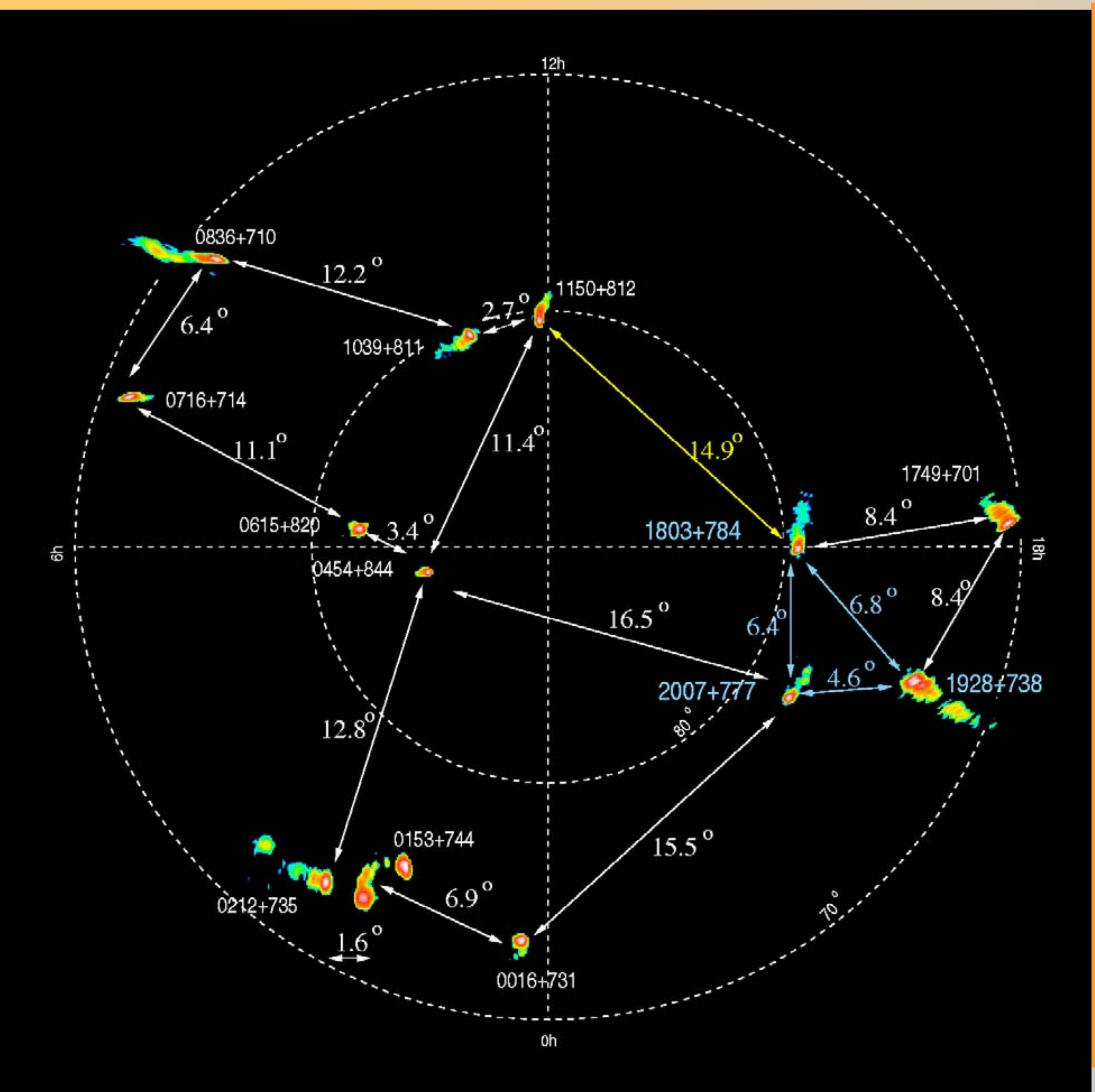
Radio wavelength	Epoch of measurement	Position of $B-A$ (1950.0)[a] Right ascension (s)	Declination (arcsec)
3.6 cm	23–24 Nov 1979	2.120500[illegible] ± 0.0000007	27.4292[illegible]46 ± 0.000005
	17–18 Mar 1981	2.120500[illegible] ± 0.0000002	27.4292[illegible]8 ± 0.000003

~ 5 μas

Radio Astrometry



The S5 Polar Cap sample



- Flat spectrum radio sources:
  - 8 QSOs
  - 5 BL-Lac objects
- Long-term astrometric program
- λ= 3.6, 2, 0.7 cm
- Bootstrapping techniques

Ros et al 2000

Pérez-Torres et al 2004

The technique

$$\tau(t) = \tau_{GEO}(t) + \tau_{STR}(E(t)) + \tau_{ION}(\nu, E(t)) + \tau_{tropo}(\nu, t) + \tau_{INSTRUM}(t)$$

$$\tau_{geo} = \frac{\vec{D} \cdot \hat{s}}{c}$$

$$\phi^{\mathrm{res}}_{\mathrm{A\text{-}B}} = \underbrace{\phi^{\mathrm{res,GEO}}_{\mathrm{A\text{-}B}} + \phi^{\mathrm{res,STR}}_{\mathrm{A\text{-}B}}} + \overset{\nearrow 0}{\phi^{\mathrm{res,ION}}_{\mathrm{A\text{-}B}}} + \overset{\nearrow 0}{\phi^{\mathrm{res,TROPO}}_{\mathrm{A\text{-}B}}} + \overset{\nearrow 0}{\phi^{\mathrm{res,INSTRUM}}_{\mathrm{A\text{-}B}}}$$

- Phase-delay astrometry
- Phase-reference mapping

High resolution and astrometric precision

- Theoretical precision for an interferometer:

$$\sigma_{\alpha,\delta} = \frac{1}{2\pi} \times \frac{1}{SNR} \times \frac{\lambda}{D}$$

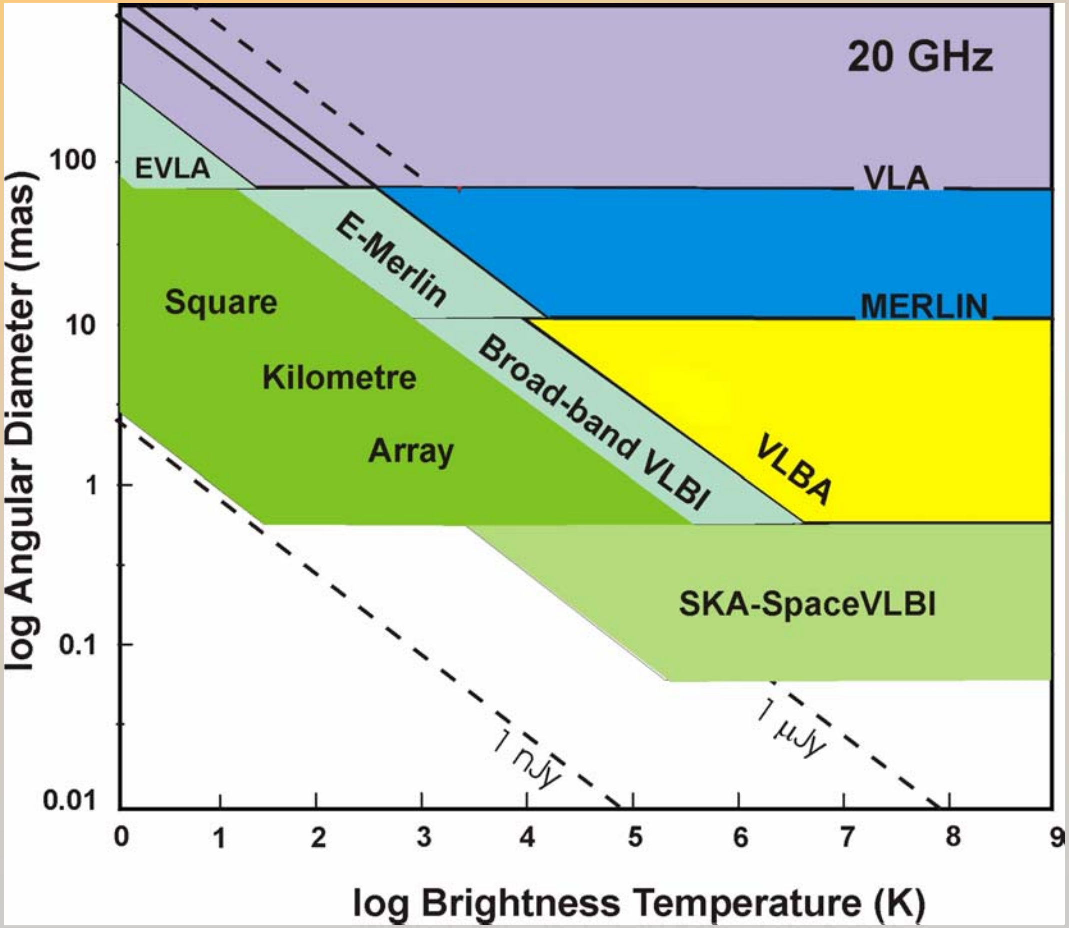
D	**λ**	**$\sigma_{SNR>15}$**
300 km	6cm	440 μas
3000km	6cm	44 μas
300km	1.3cm	90 μas
3000km	1.3cm	9 μas

- Sources of error:
  - Φ-extrapolation
  - Differential contribution from atmosphere and ionosphere
  - Structures of reference and target source

Sources of Error in Astrometry: Solutions for new instruments

- Multi-beam System:
  - Φ-extrapolation problem solved – simultaneous observation from target and reference
  - Different lines of sight: tomography of the atmosphere/ionosphere - removal of propagation medium biases
- On-the-fly mapping:
  - Removal of structure contribution of reference (and target)

Sensitivity



A.R. Taylor (2000)

SKA: Sensitivity and High Resolution

- Baselines of thousands of kilometers will match the progress in sensitivity with the present VLBI resolution
- Sensitivities expected: far below μJy/beam
- The Φ-referencing increases the integration time from minutes to hours → detection of weaker sources

Search for Planets and Star Companions: VLBI Program

- Antennas at Effelsberg/Robledo/ Goldstone
- Single baseline: ~1 mas astrometric resolution
- Search for companions in
  - stars nearby the sun (10pc)
  - small mass
  - single (or wide separation binaries)
  - with (some) radio emission

- dMe stars look the most suitable targets

Search for Planets and Star Companions: VLBI Program

- dMe stars look the most suitable targets

Star	Distance (pc)	Flux Density (mJy)	Comments
Wolf 47	9.3	0.3 – 4.0	Refs: 3, 9
YZ CMi	6.1	0.5 – 1.5	Refs: 7
AD Leo	4.9	0.2 – 2.1	Refs: 7
V1054 Oph	5.7	1.2	Refs: 8
EV Lac	5.1	0.3 – 4.0	Refs: 8, 9
UV Cet	2.6	1.0 – 2.0	Binary (2"); Refs: 6
Wolf 630 A	6.2	0.2 – 2.0	Binary (0.2"); Refs: 2, 4
DO Cep	5.1	0.4 – 5.5	Binary (3"); Refs: 1
EQ PegB	6.6	1.1 – 5.5	Binary (5"); Refs: 5, 9

Refs: (1) White et al (1989), (2) Phillips et al (1989), (3) Hewitt et al (1989), (4) Fomalont & Sanders (1989), (5) Benz et al (1995), (6) Benz et al (1998), (7) Pestalozzi et al (2000), (8) Leto et al (2000), (9) This work

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Astrometric Precision

The star's astrometric reference point may change from epoch to epoch due to instabilities of the star's surface. This will limit te astrometric precision. However:

- The size of the photospheres ranges from 0.2 to 0.8 mas.
- Motion of the hot-spots should be averaged out after several epochs.
- The quiescent flux is easier to detect at 8.4 GHz. Flaring is more common at smaller frequencies.

Our goal is to measure orbital motions of ~1 mas amplitude.

Technique cooperation: the case of AB Dor

- Very well known southern-hemisphere PMS star ($m_V = 6.9$)
- Importat feature: FAST ROTATOR (0.5 days):
  - Broadening of the spectral lines, limiting precision of Doppler techniques to 5km/s
  - Present radio emission via dynamo effect

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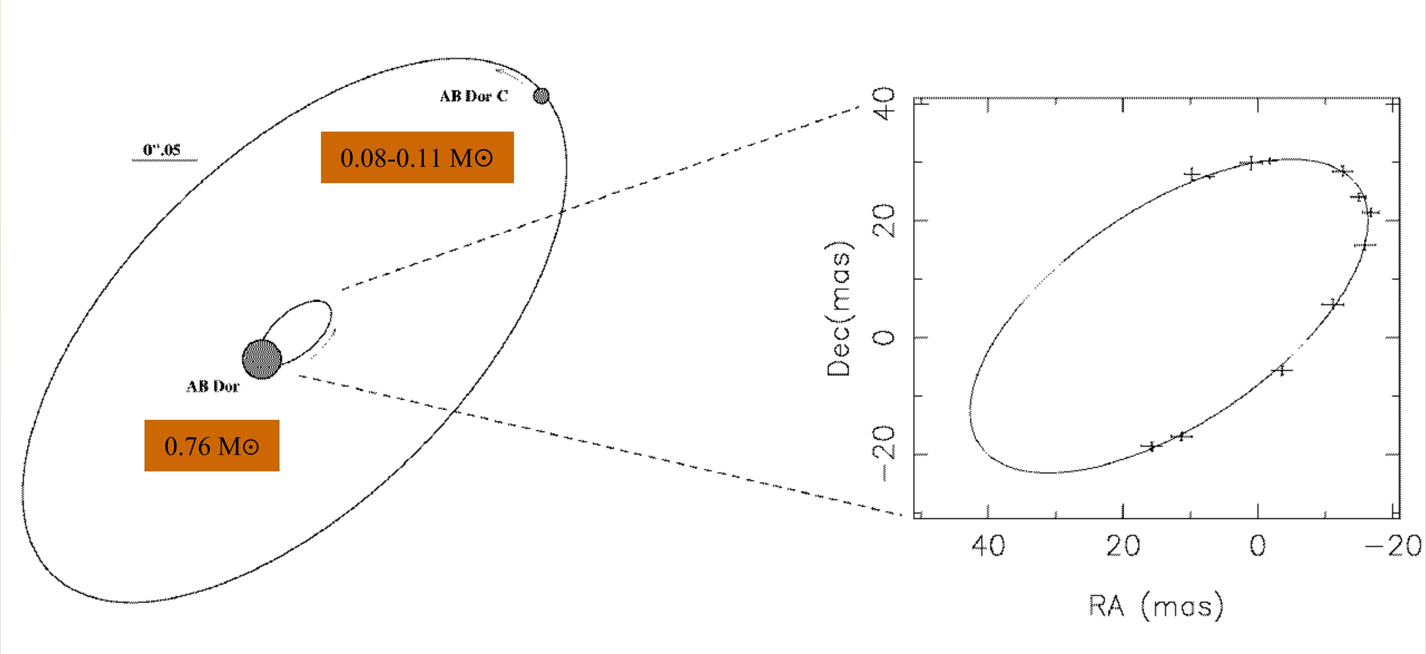
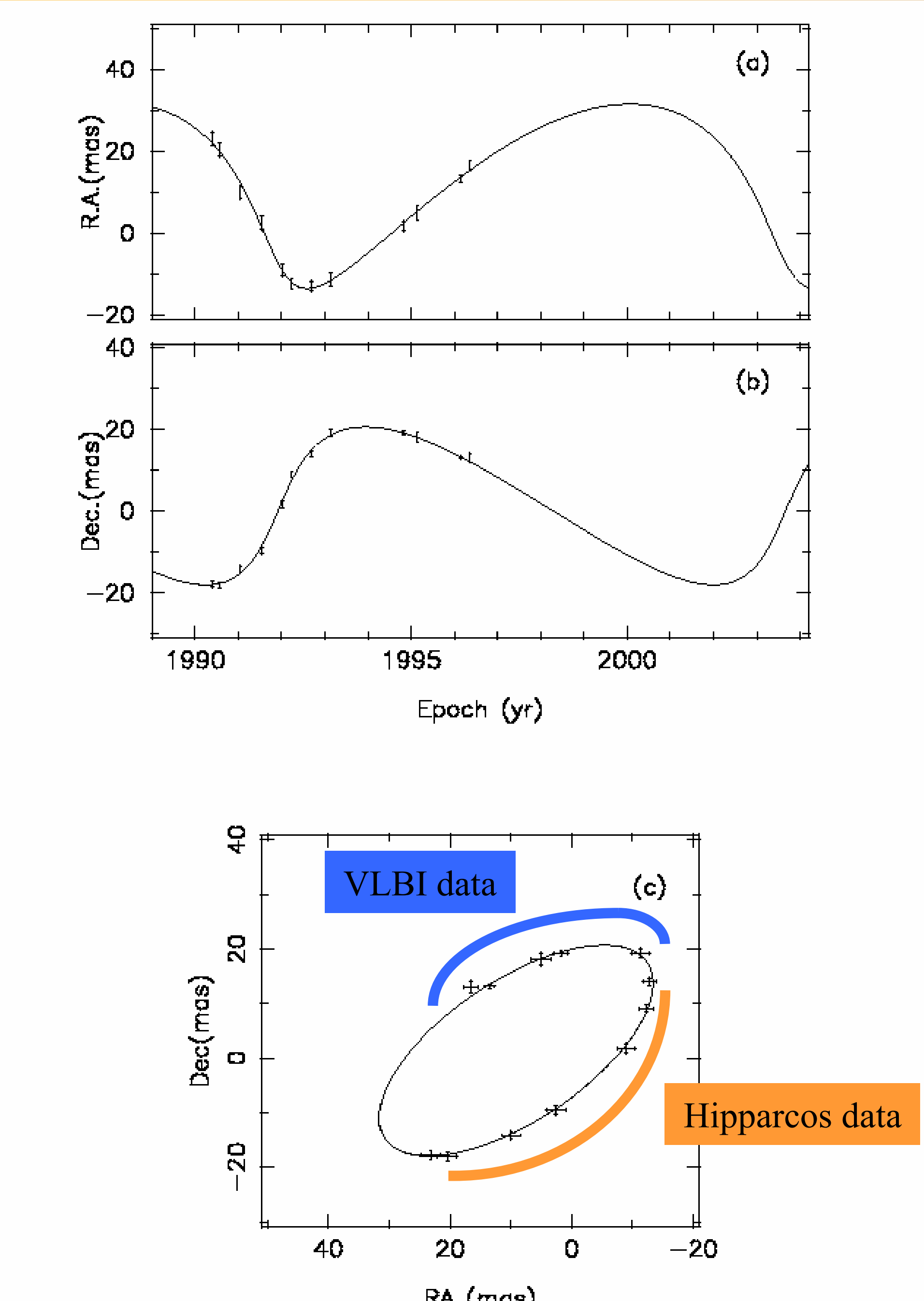


Guirado et al. (1997, ApJ, 490, 835)



Orbit Determination

- Weighted-least-squares fit of the VLBI+HIPPARCOS positions to estimate simultaneously

- 5 astrometric parameters

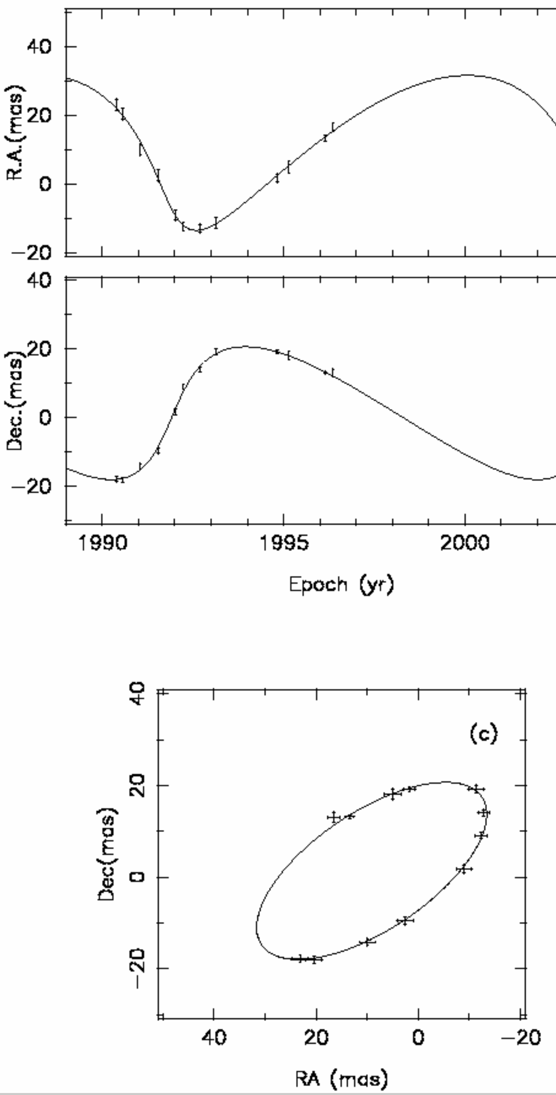
$$\alpha,\ \delta,\ \mu_\alpha,\ \mu_\delta,\ \pi$$

- 7 orbital parameters (Thieles-Innes method)

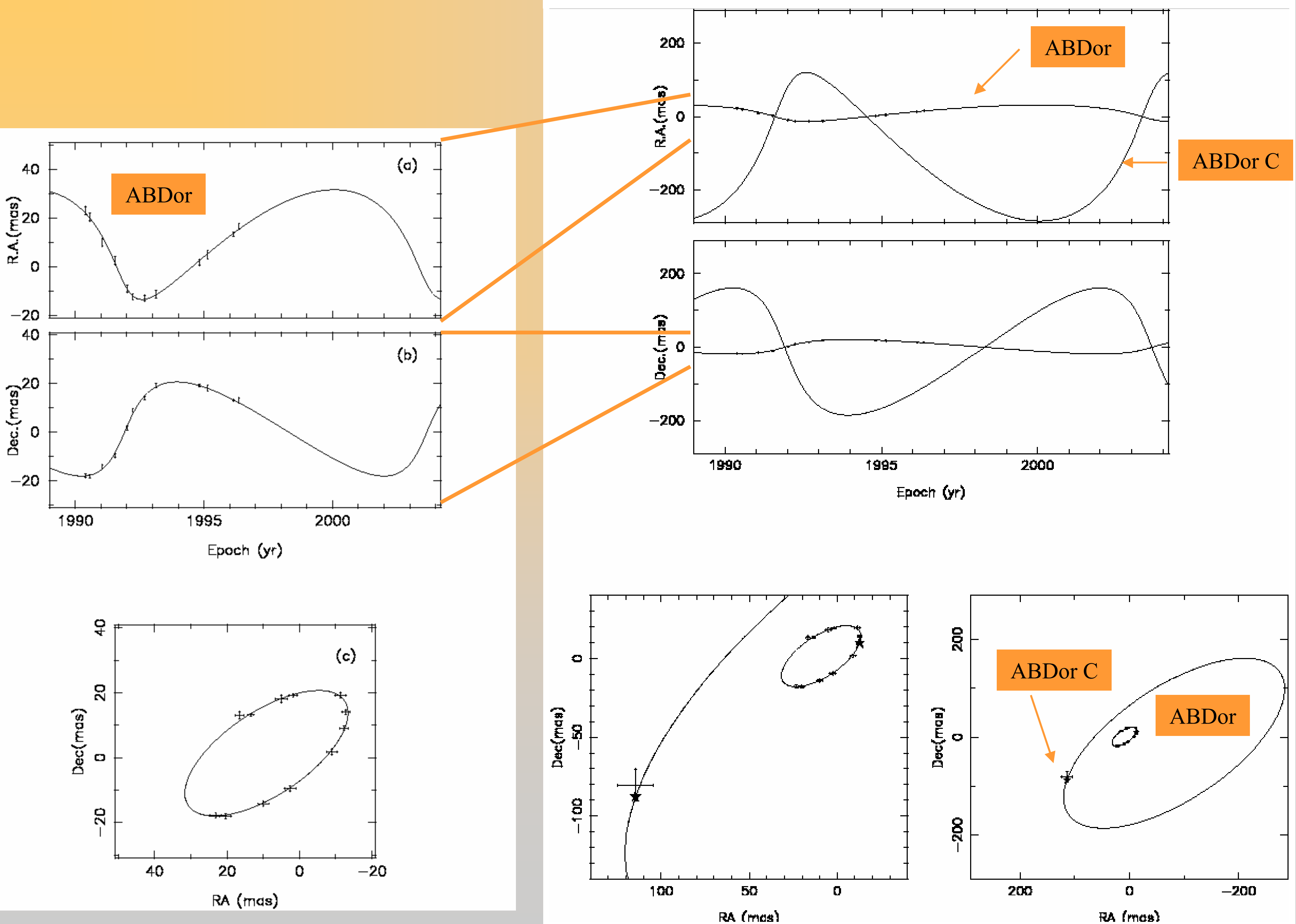
$$P,\ a_1,\ e,\ i,\ \omega,\ \Omega,\ T_o$$

- Mass estimate (ABDor C):

  0.08 – 0.11 $M_\odot$



(a)
R.A.(mas)
40
20
0
−20
(b)
Dec.(mas)
40
20
0
−20
1990
1995
2000
Epoch (yr)
(c)
Dec(mas)
40
20
0
−20
40
20
0
−20
RA (mas)


ABDor
(a)
R.A.(mas)
(b)
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1990
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RA (mas)
ABDor
ABDor C
R.A.(mas)
Dec.(mas)
Epoch (yr)
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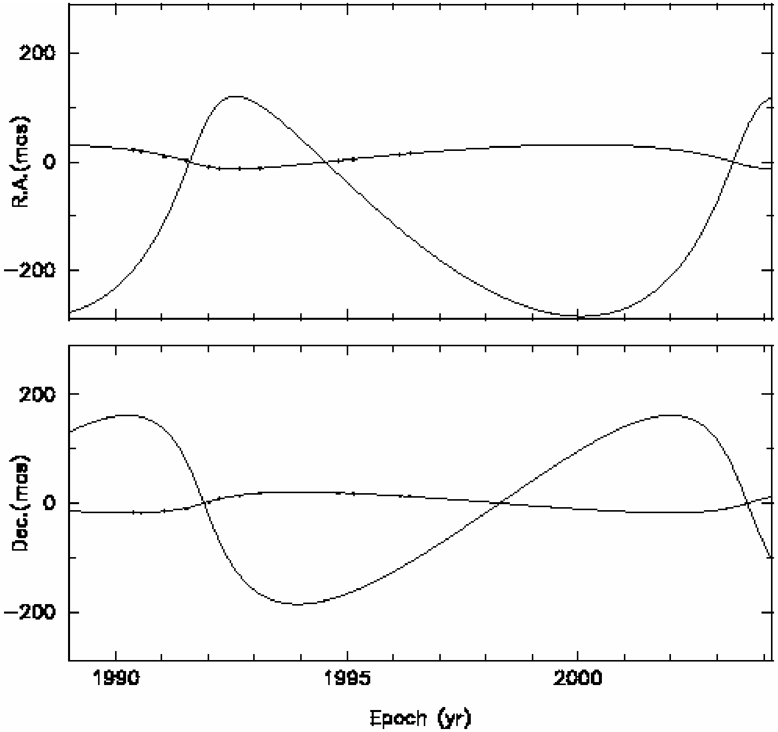
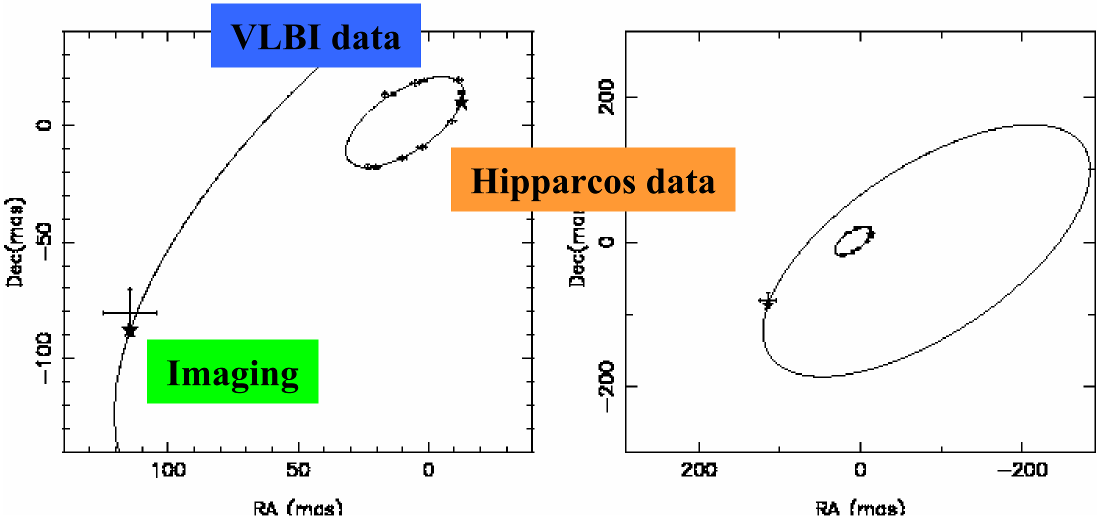
RA (mas)
ABDor C
ABDor
Dec(mas)
RA (mas)





(New) Orbit Determination

- Mass estimate (ABDor C):
  0.08 – 0.11 $M_\odot$
- Mass estimate (three techniques):
  0.084 +/- 0.004 $M_\odot$
- Even a modest detection of the position of ABDorC would lead to very precise determination of its mass.

Summary

- The SKA will increase the observed radio stars from hundreds to millions of objects
- SKA in astrometric mode:
  - Link with the optical astrometric satellites (SIM, GAIA)
  - Discovery of low-mass objects and exoplanets
- High resolution is needed to reach the highest astrometric precision
- Cooperation with other techniques is needed to confirm or improve the detections.