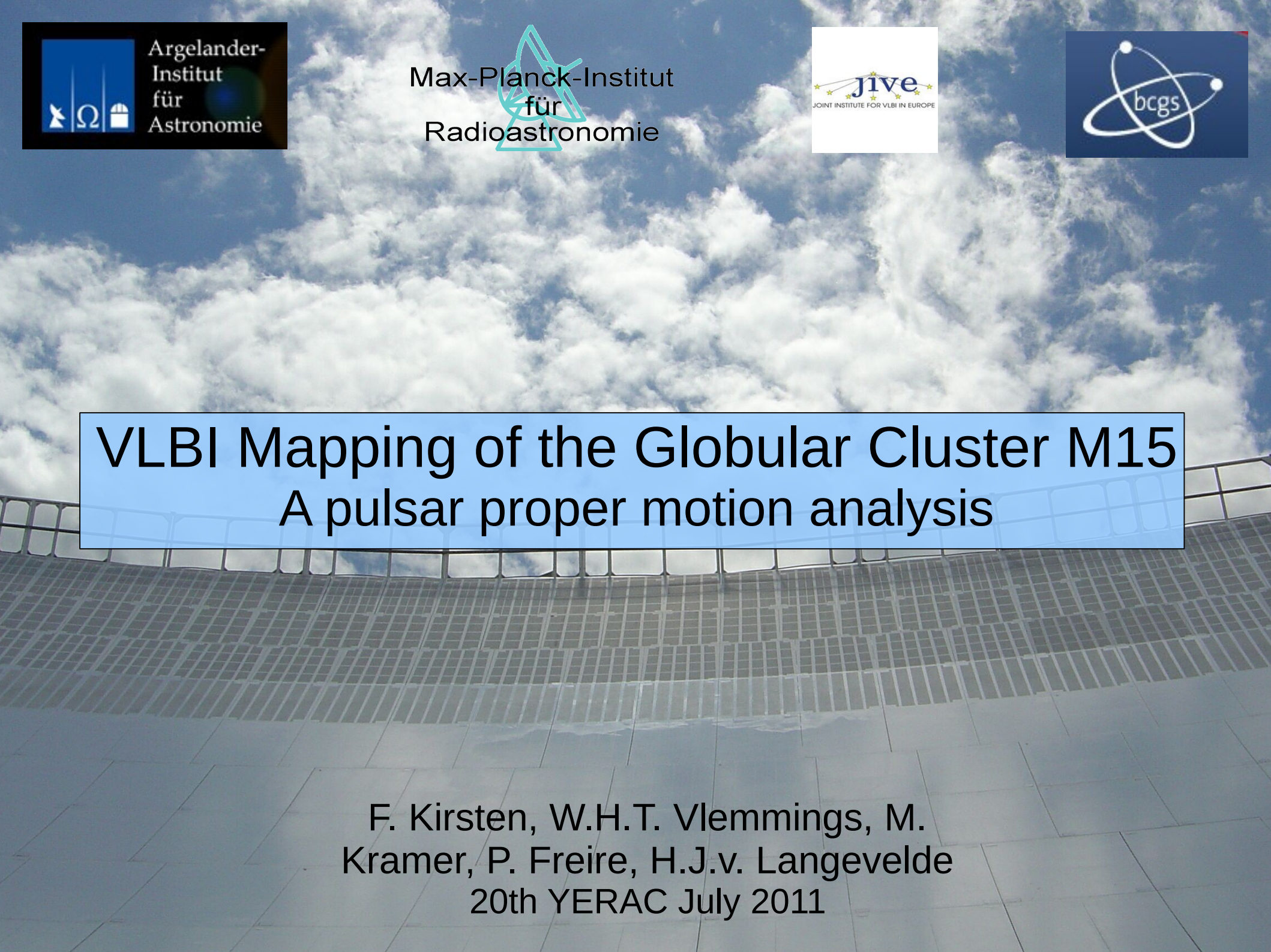
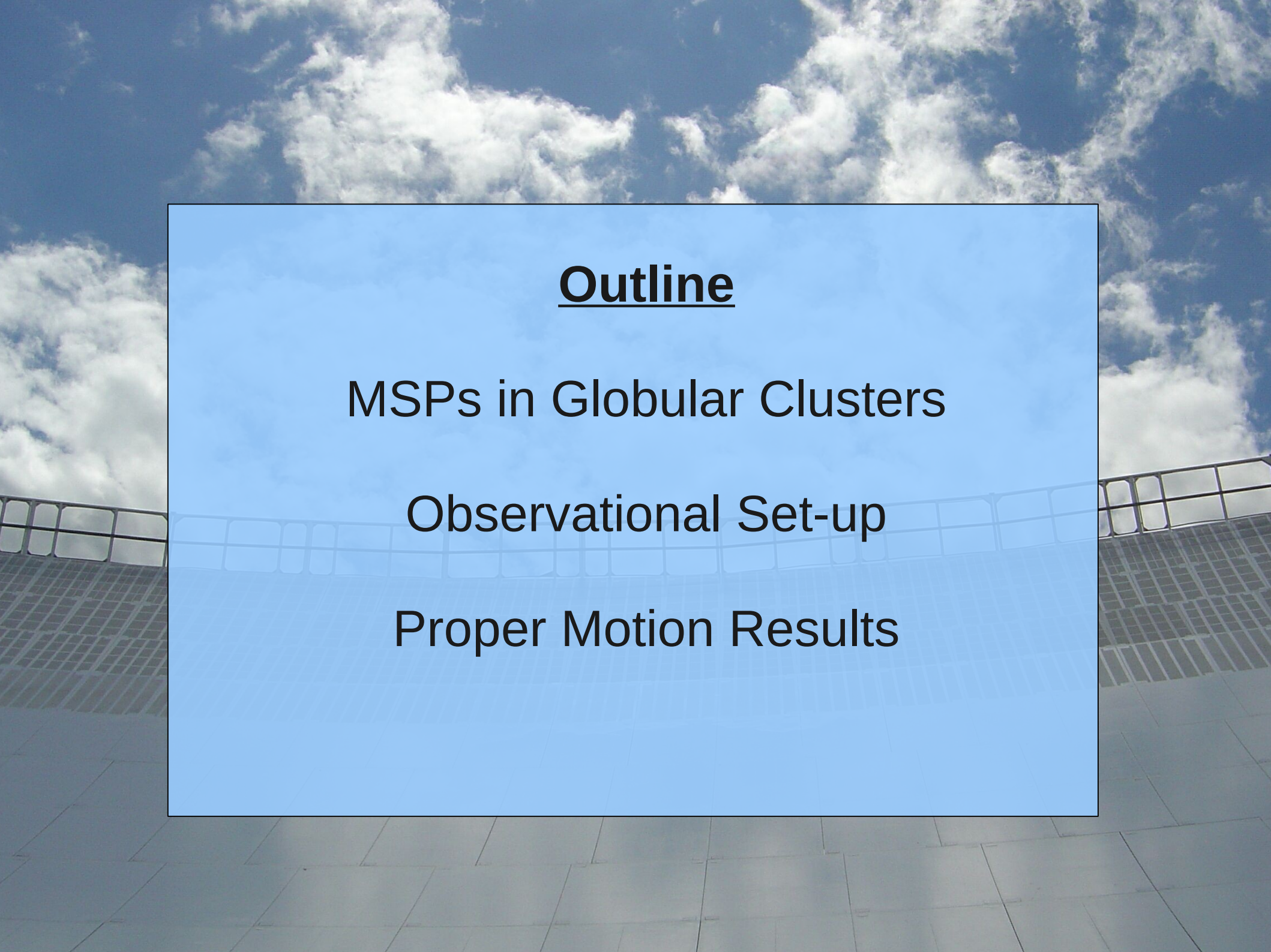


VLBI Mapping of the Globular Cluster M15
A pulsar proper motion analysis

F. Kirsten, W.H.T. Vlemmings, M. Kramer, P. Freire, H.J.v. Langevelde

20th YERAC July 2011



Outline

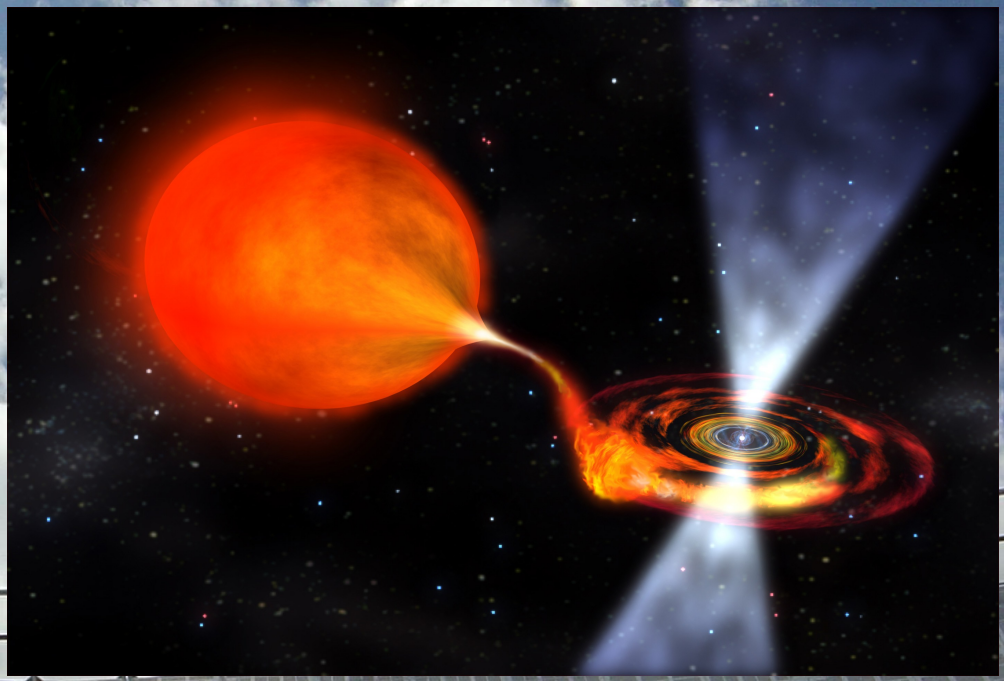
MSPs in Globular Clusters

Observational Set-up

Proper Motion Results

MSPs and Globular Clusters

- most pulsars are born as solitary objects
- majority of MSPs in binary systems
- need to capture/ be captured by secondary
- highest probability for capture in dense stellar environment



www.nikhef.nl

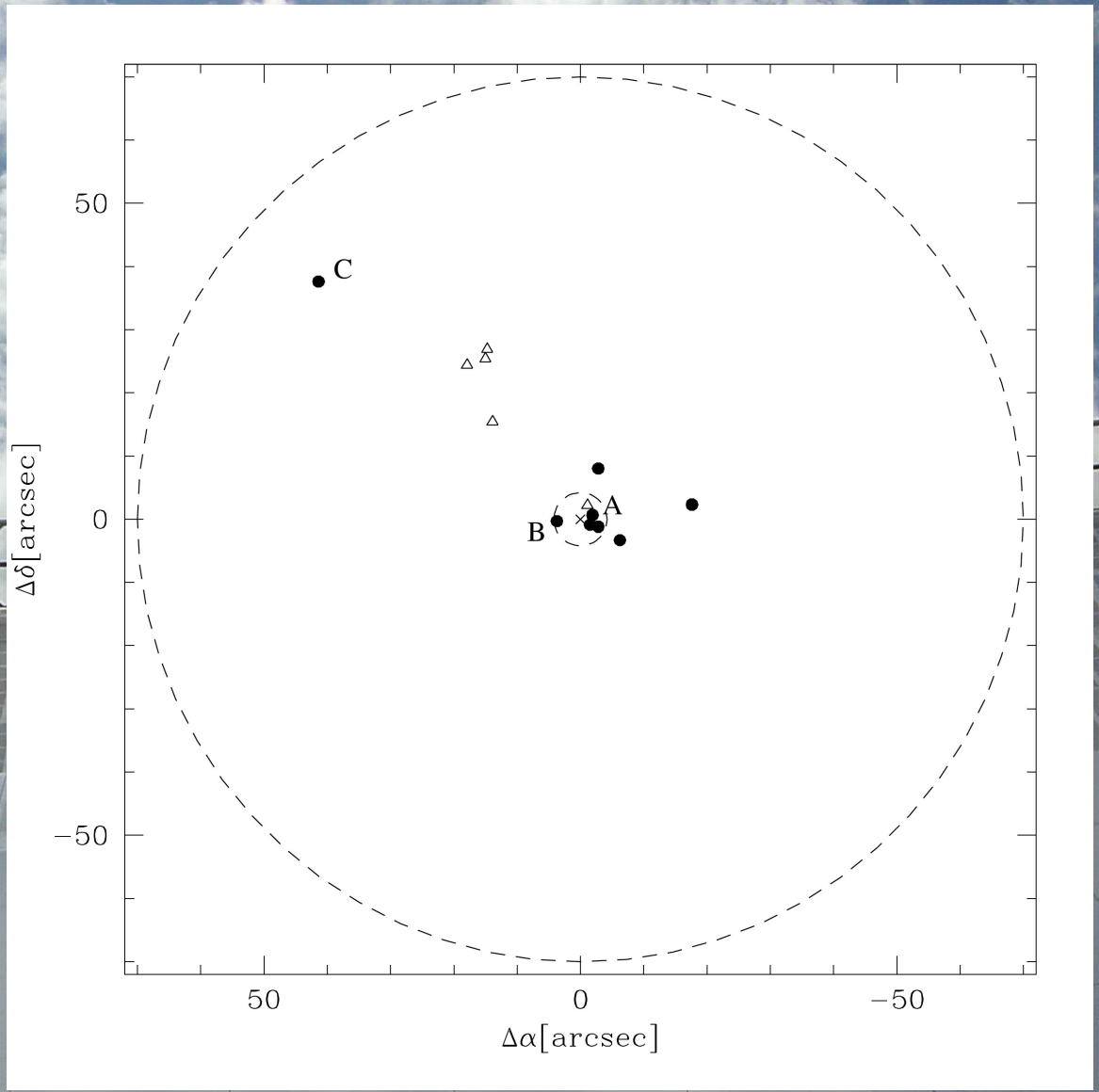
- Terzan 5, 33 MSPs (Ransom et al. 2005)
- 47 Tucanae, 23 MSPs (Camilo et al. 2000)
- M15 (NGC7078), 8 MSPs, 1 LMXB close to center

Globular Clusters, M15

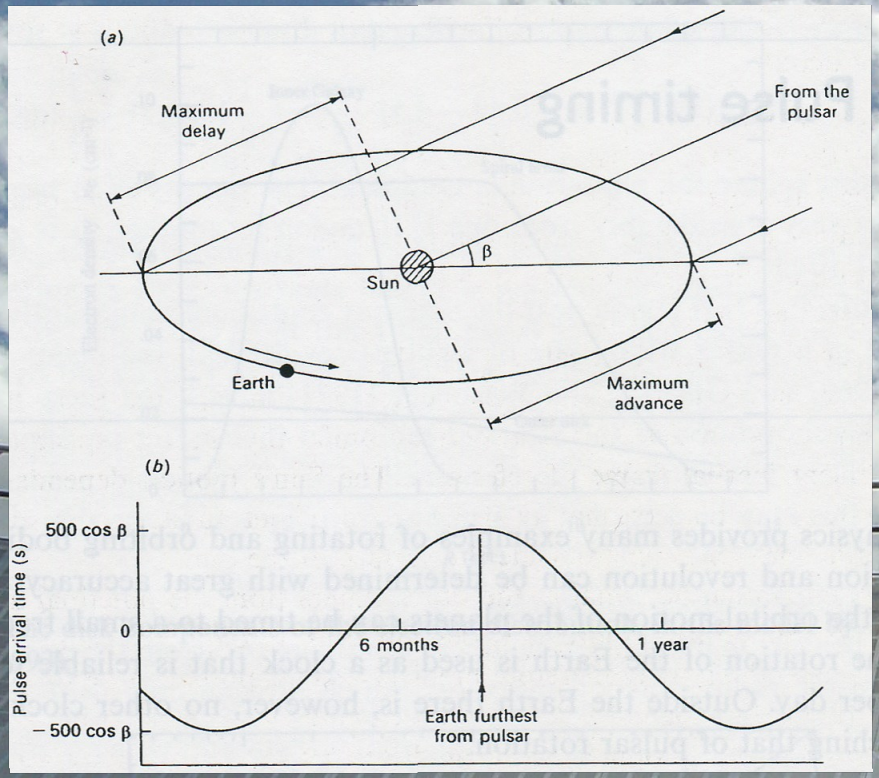
- spherical, gravitationally bound systems
- host ~ 10 000 stars
- on average 0.4 stars/pc^3 in core 100-1000 stars/pc^3
- among the oldest objects

M15

- D ~ 10.5 ± 0.4 kpc
- 4 MSPs and 1 LMXB within 4.5 arcsec (~0.25 pc) of center
- 1 double Neutron Star system with 14 years of timing data
- shows evidence to host an IMBH (Gerssen et al. 2002)



Timing



from Lyne, A.G. 1998

Model Parameters

- Ephemeris
- Barycenter
- Earth rotation (Doppler Effect)
- Ellipticity of orbit
- Shapiro Delay of Sun

- Parallax
- Proper Motion
- possible Binary Orbit of Star
- Spin down rate
- Shapiro Delay
- Acceleration in Grav. Potential

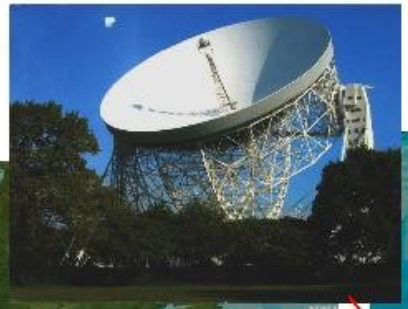
Degeneracy of parameters is inevitable!

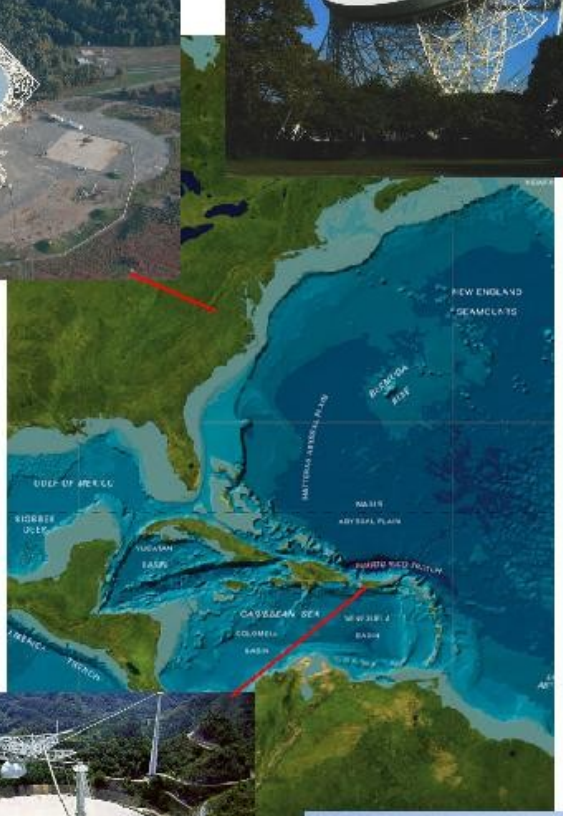
→ Need model independent measurements to fix, e.g., π, PM

→ VLBI astrometry

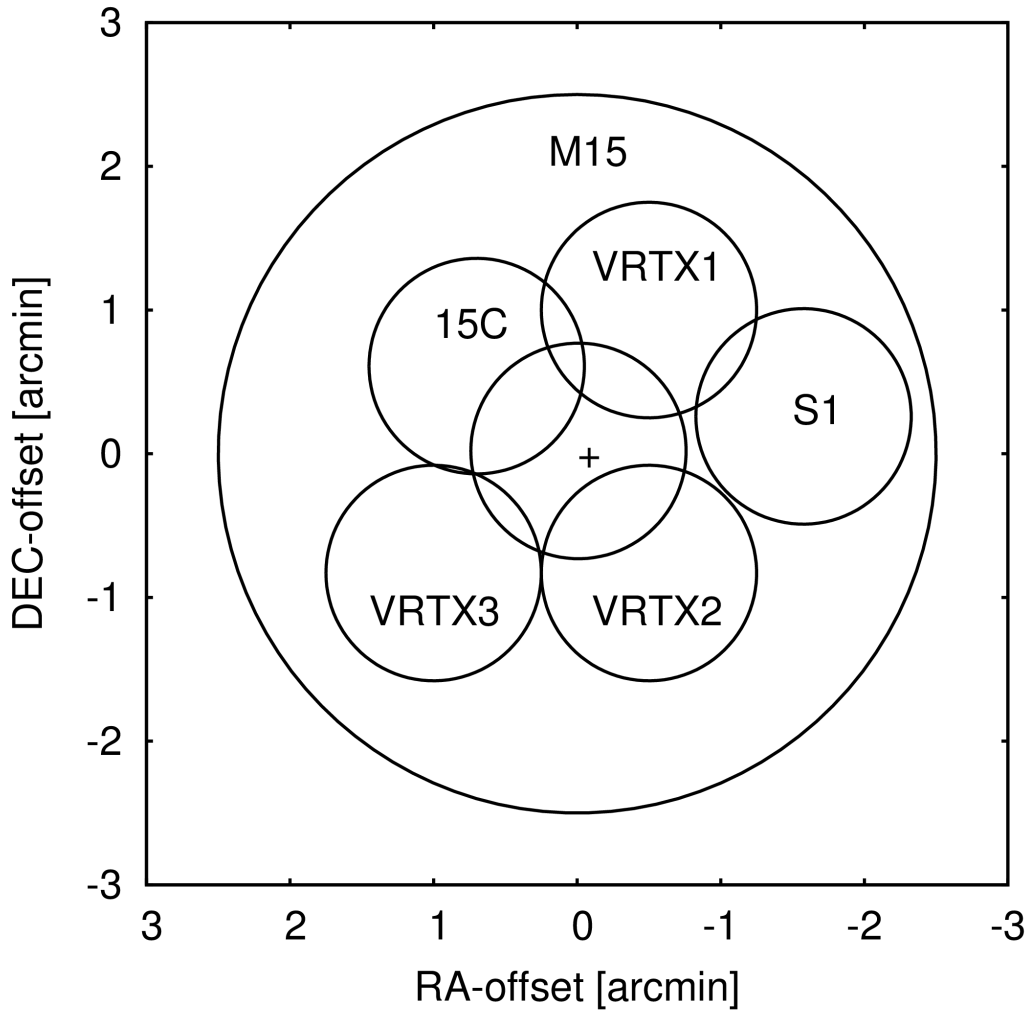
Goals

1. Measure proper motion of pulsars
2. Constrain central mass distribution from orbits
3. Search for signature of central IMBH
4. Search for new compact objects
5. Improve timing model of double neutron star 15C



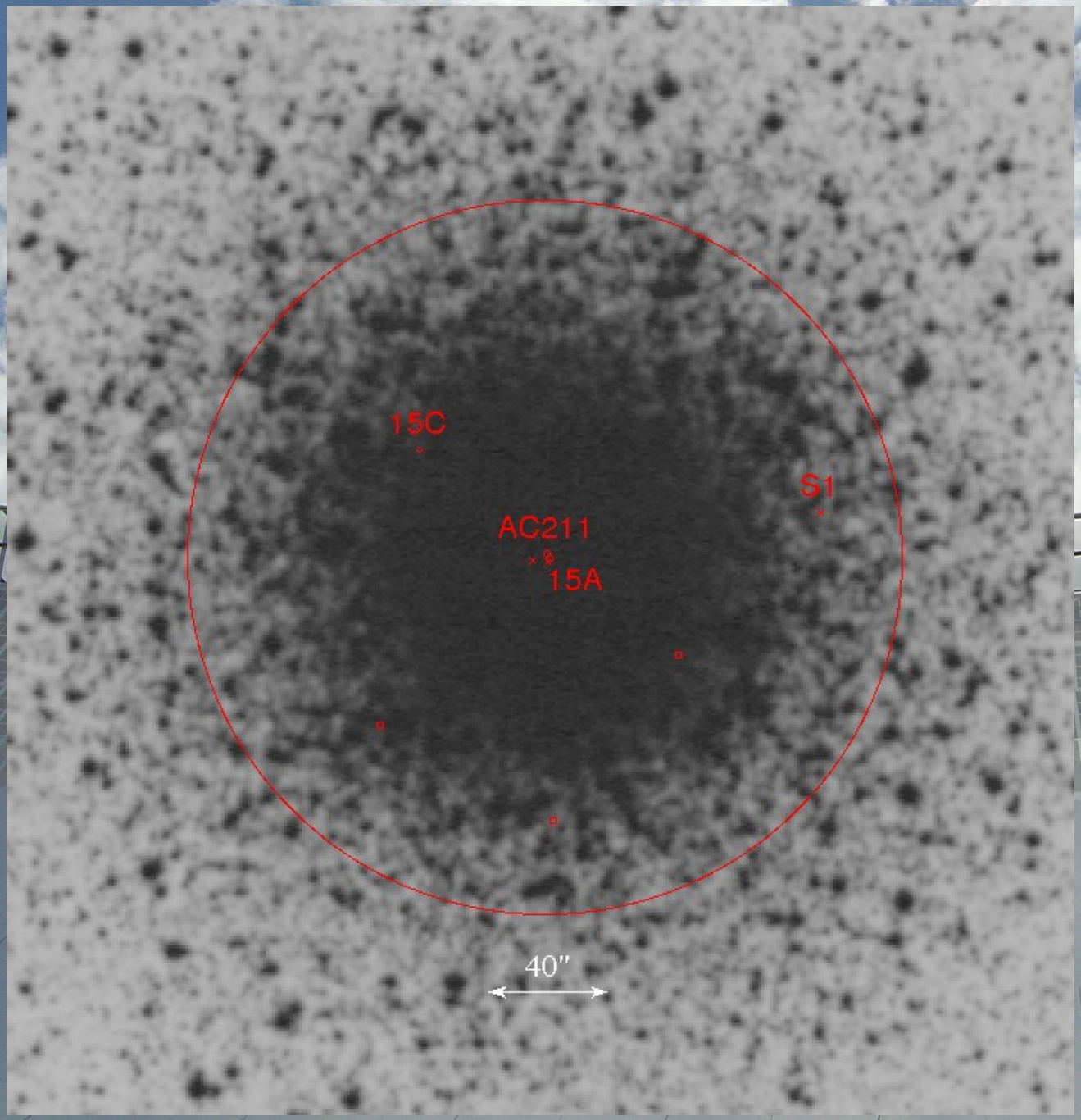


Observational Setup



- Observations at 1.6 GHz (ensure for high sensitivity **and** astrometric precision)
- Bandwidth ~200 MHz (8 IFs, 128 channels, 0.5 sec) (512 ch, 0.25 sec in epoch 1)
- FOV ~2 arcmin
- Beam size 4x7 mas
- rms ~3 μJy

Observational Setup



Observations

November 2009

March 2010

June 2010

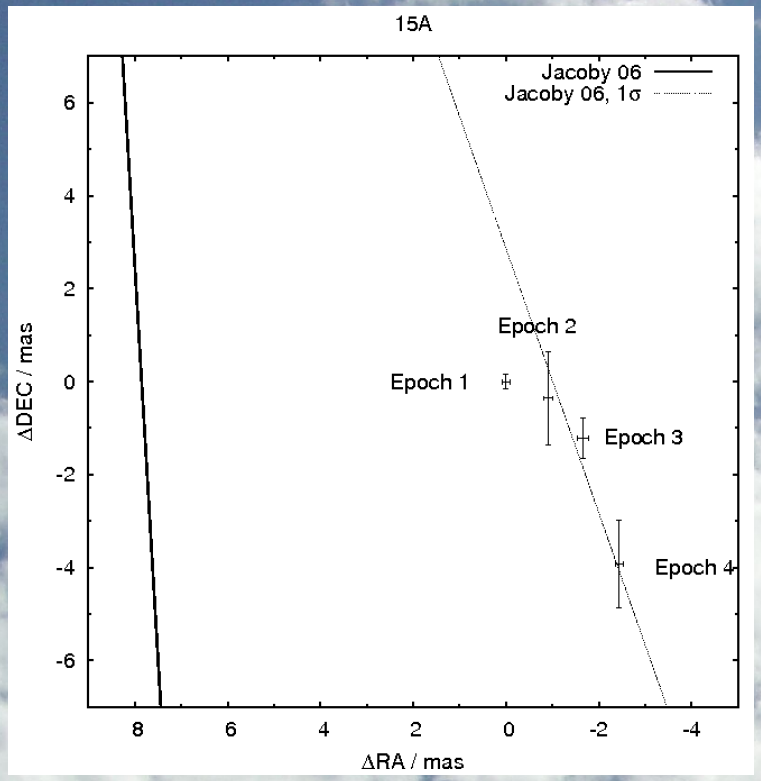
November 2010

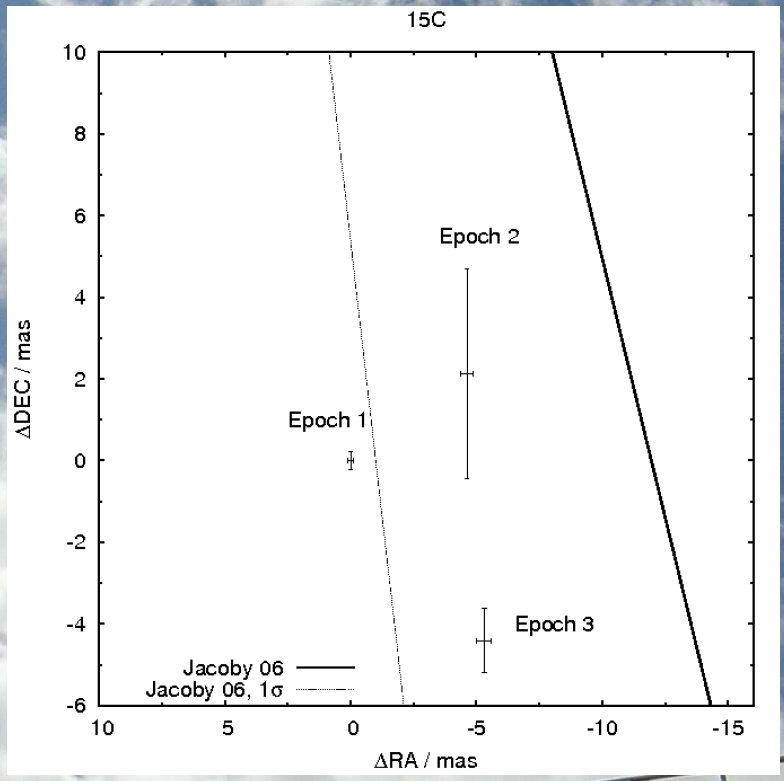
Feb 2011

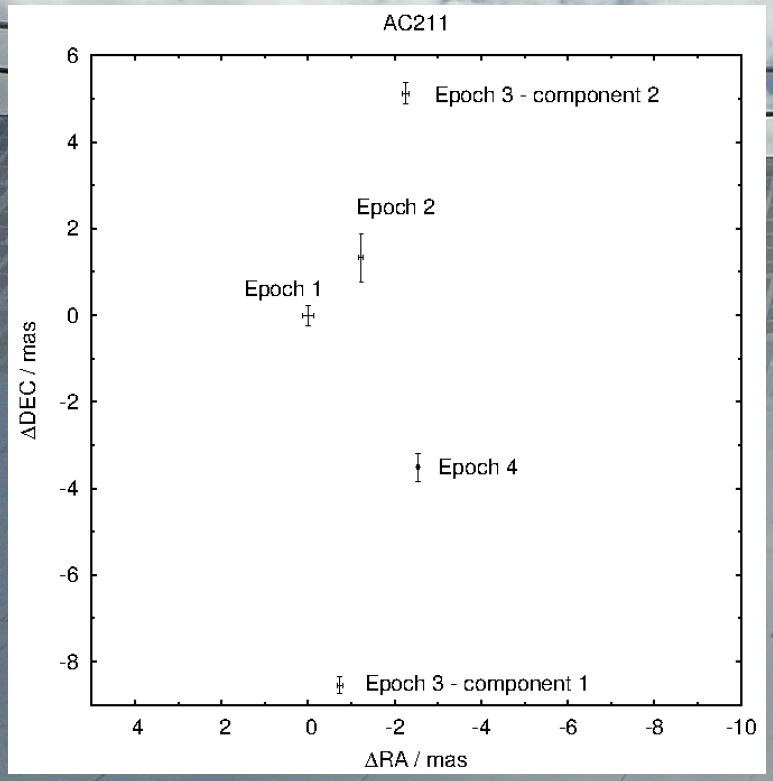
June 2011

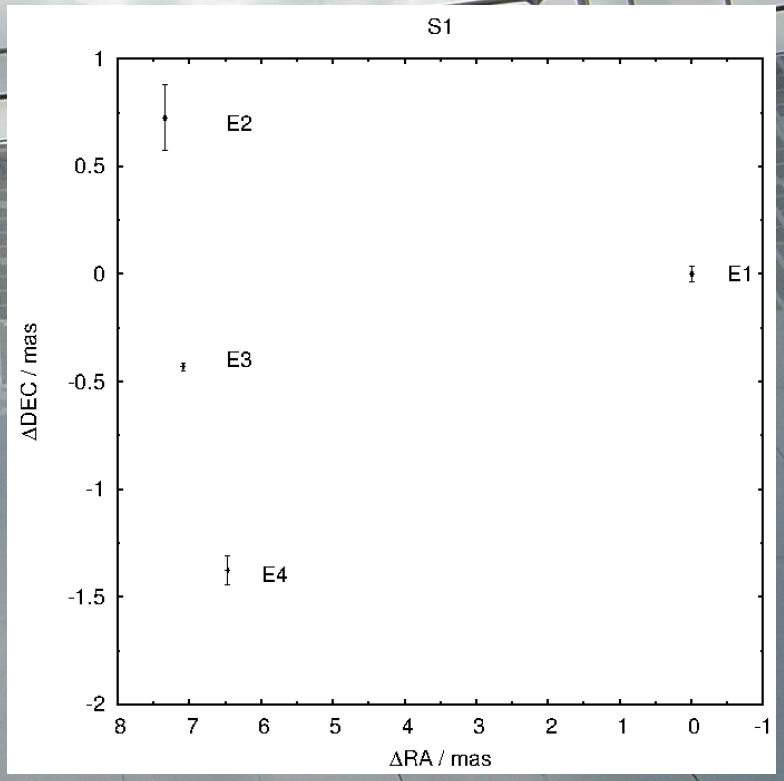
November (?) 2011

Results

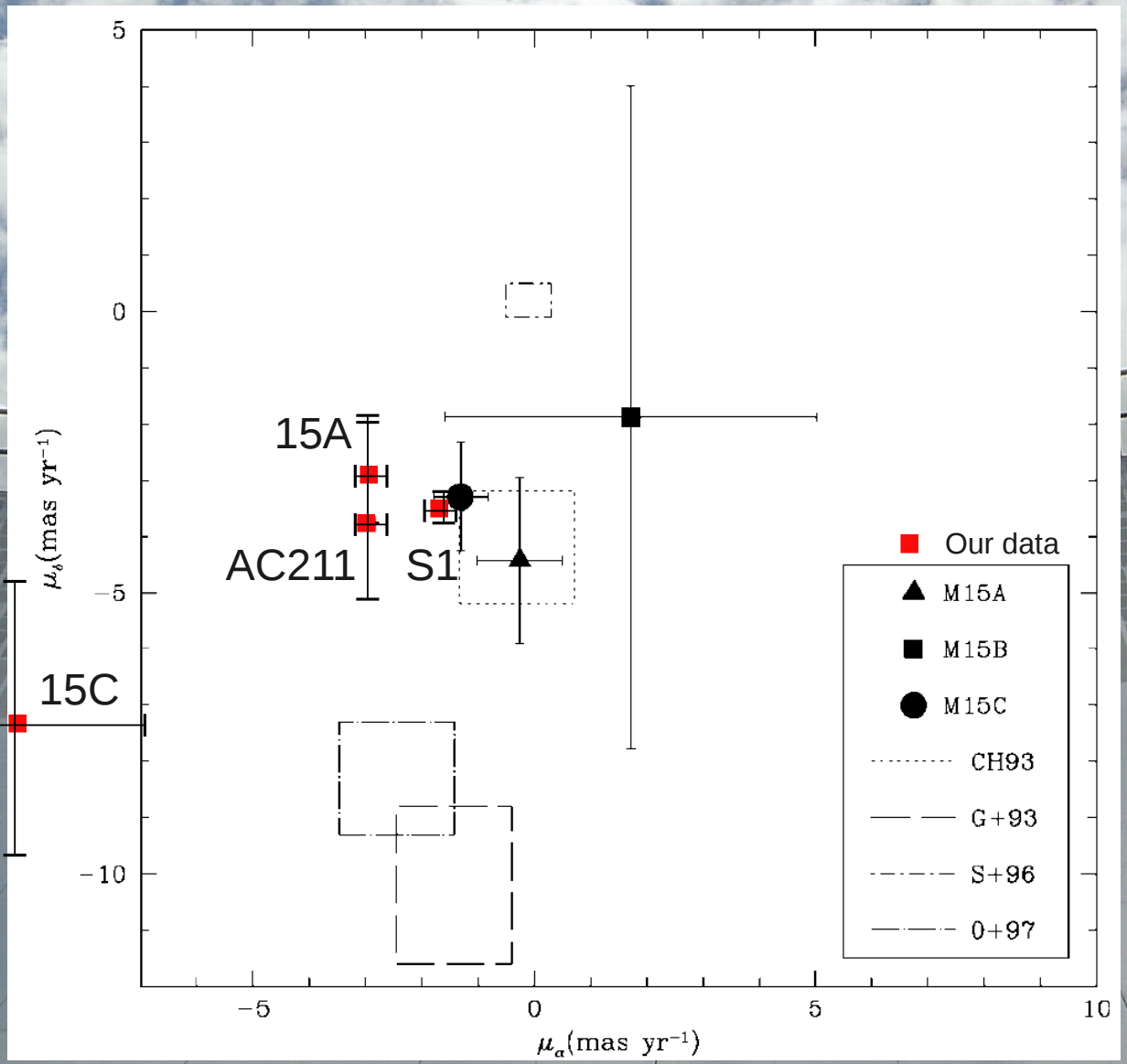

15A
Jacoby 06
Jacoby 06, 1σ
Epoch 1
Epoch 2
Epoch 3
Epoch 4
ΔDEC / mas
ΔRA / mas


15C
Epoch 1
Epoch 2
Epoch 3
Jacoby 06
Jacoby 06, 1σ
ΔDEC / mas
ΔRA / mas


AC211
Epoch 3 - component 2
Epoch 2
Epoch 1
Epoch 4
Epoch 3 - component 1
ΔDEC / mas
ΔRA / mas


S1
E2
E1
E3
E4
ΔDEC / mas
ΔRA / mas

	μ_α [mas/yr]	μ_δ [mas/yr]
15A	-2.90 ± 0.01	-2.89 ± 0.86
15C	-10.8 ± 2.3	-7.3 ± 2.4
AC211	-3.0 ± 0.2	-3.8 ± 1.7
S1	-1.9 ± 0.4	-3.6 ± 0.4



adapted from Jacoby et al. 2006

Conclusions

- It is feasible to determine PM of pulsars with high precision within a two-year campaign.
- If M15 hosts an IMBH its maximal flux at 1.6 GHz is ~3 μJy.
- S1 follows the global motion of M15 – it is very likely that it is part of the cluster
- Astrometric accuracy degrades dramatically at large distances from the phase tracking center

Outlook

- Use data from all epochs to improve PM (implement more accurate shifting algorithm)
- Model cluster potential
- Follow-up observations at 350 MHz (June 2011)
- Keep raw data from epoch 5 to determine pulse frequency via folding
- Continue with other GCs


Thank you for your attention