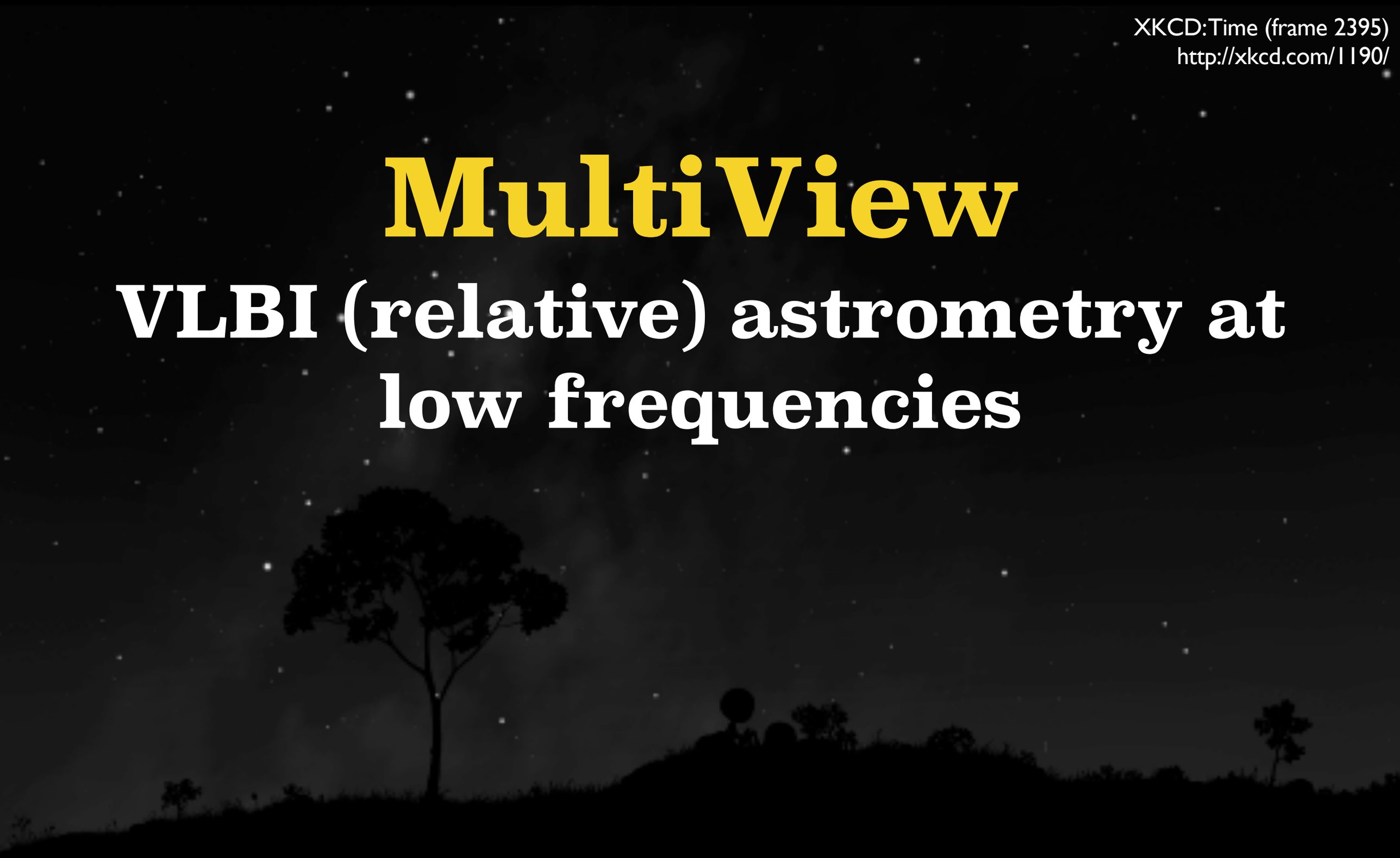
XKCD: Time (frame 2395)
http://xkcd.com/1190/

MultiView

VLBI (relative) astrometry at low frequencies

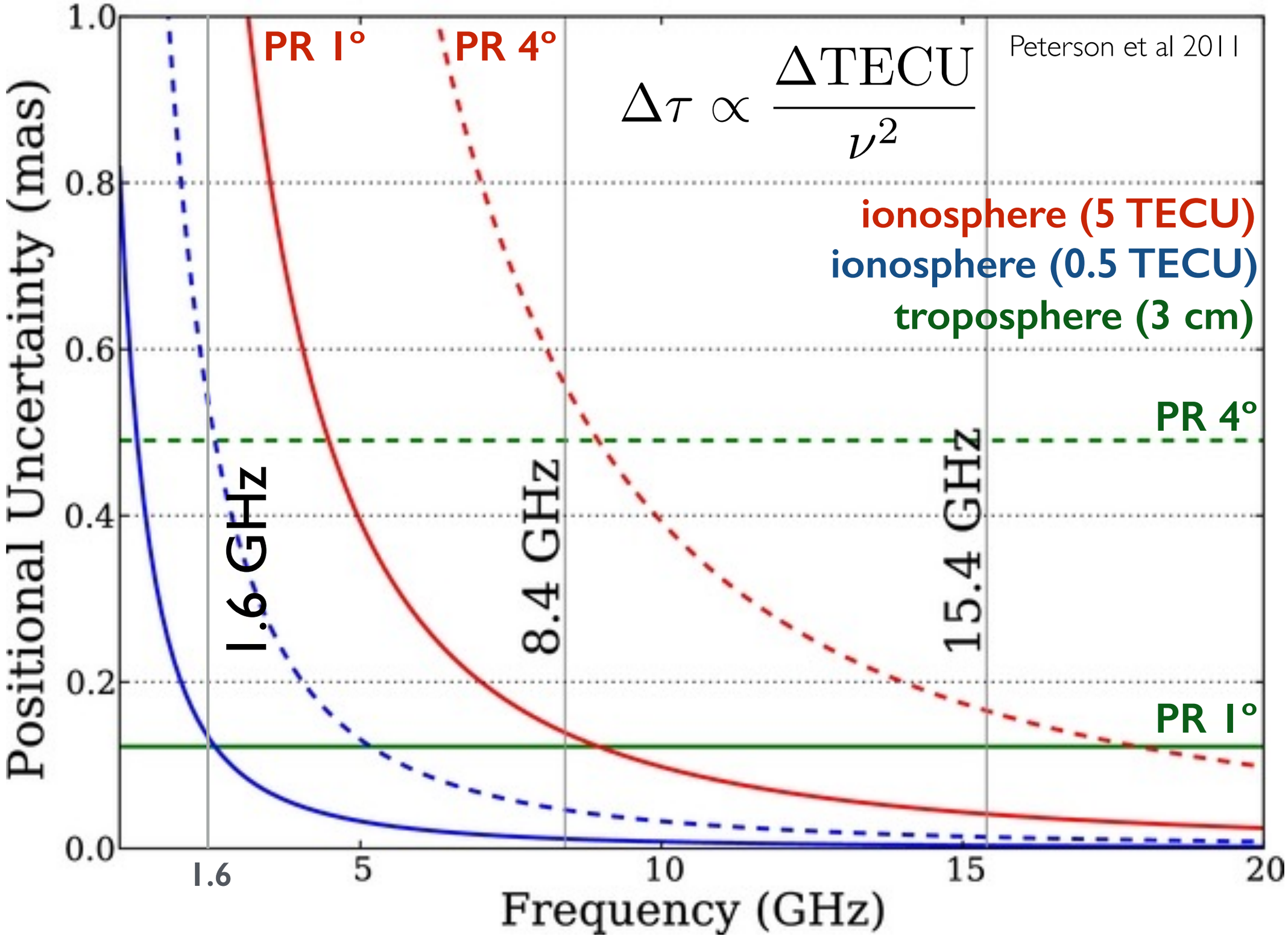


Gabor Orosz
University of Tasmania

2018.11.10
3rd AOV Meeting

The challenge of low frequency phase referencing

The dispersive ionosphere!



The challenge of low frequency phase-referencing

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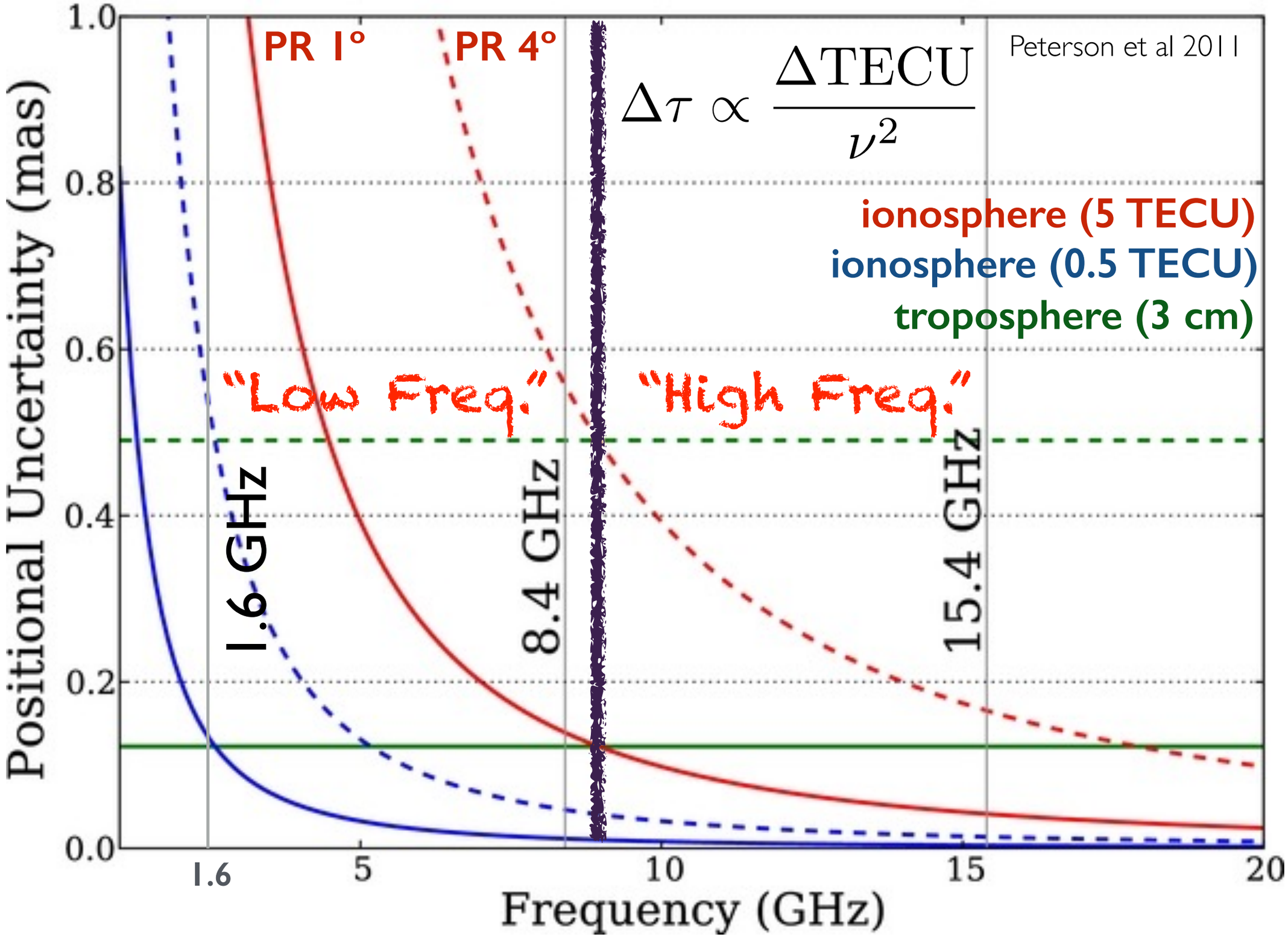

The challenge of low frequency phase-referencing

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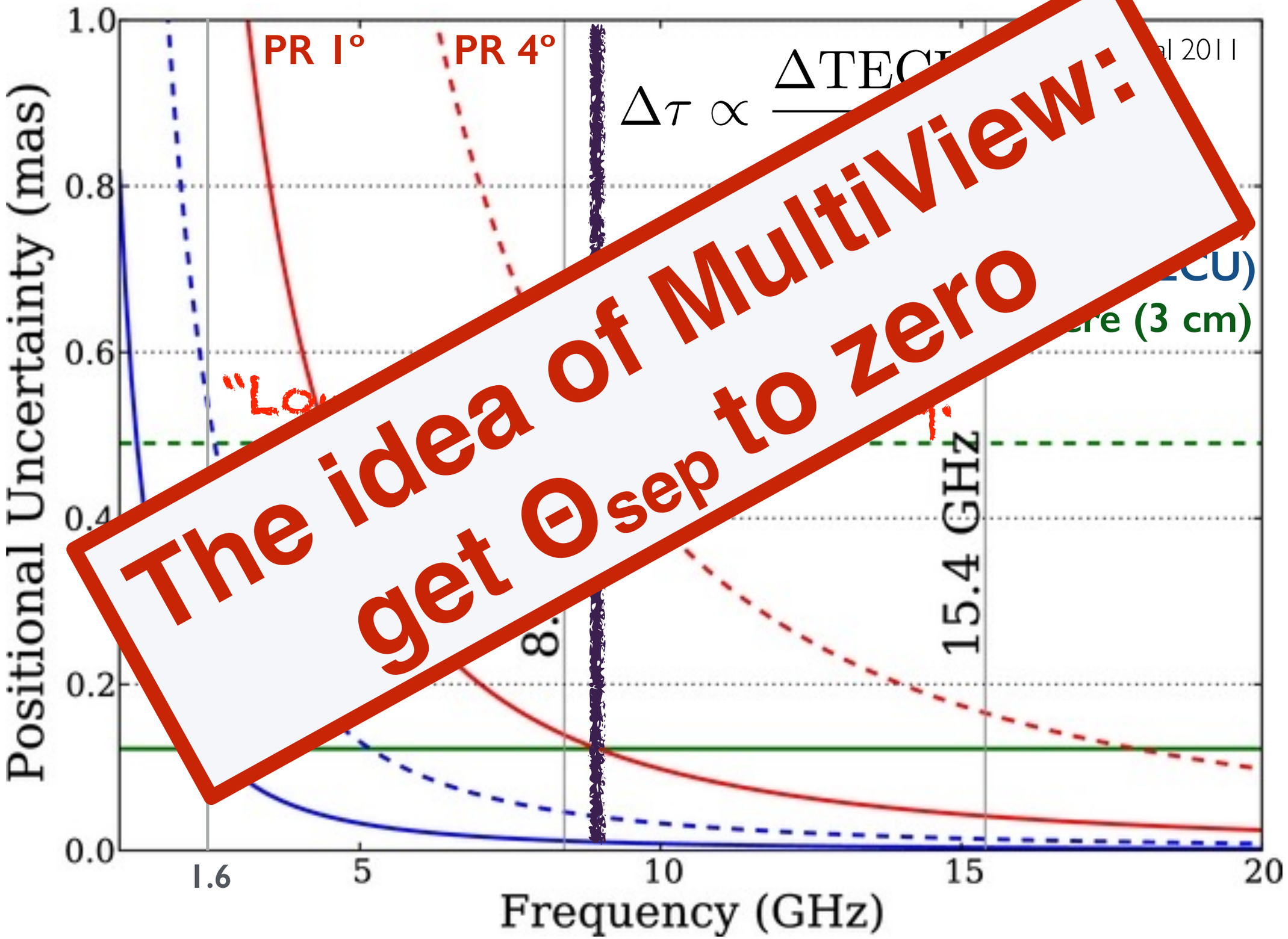
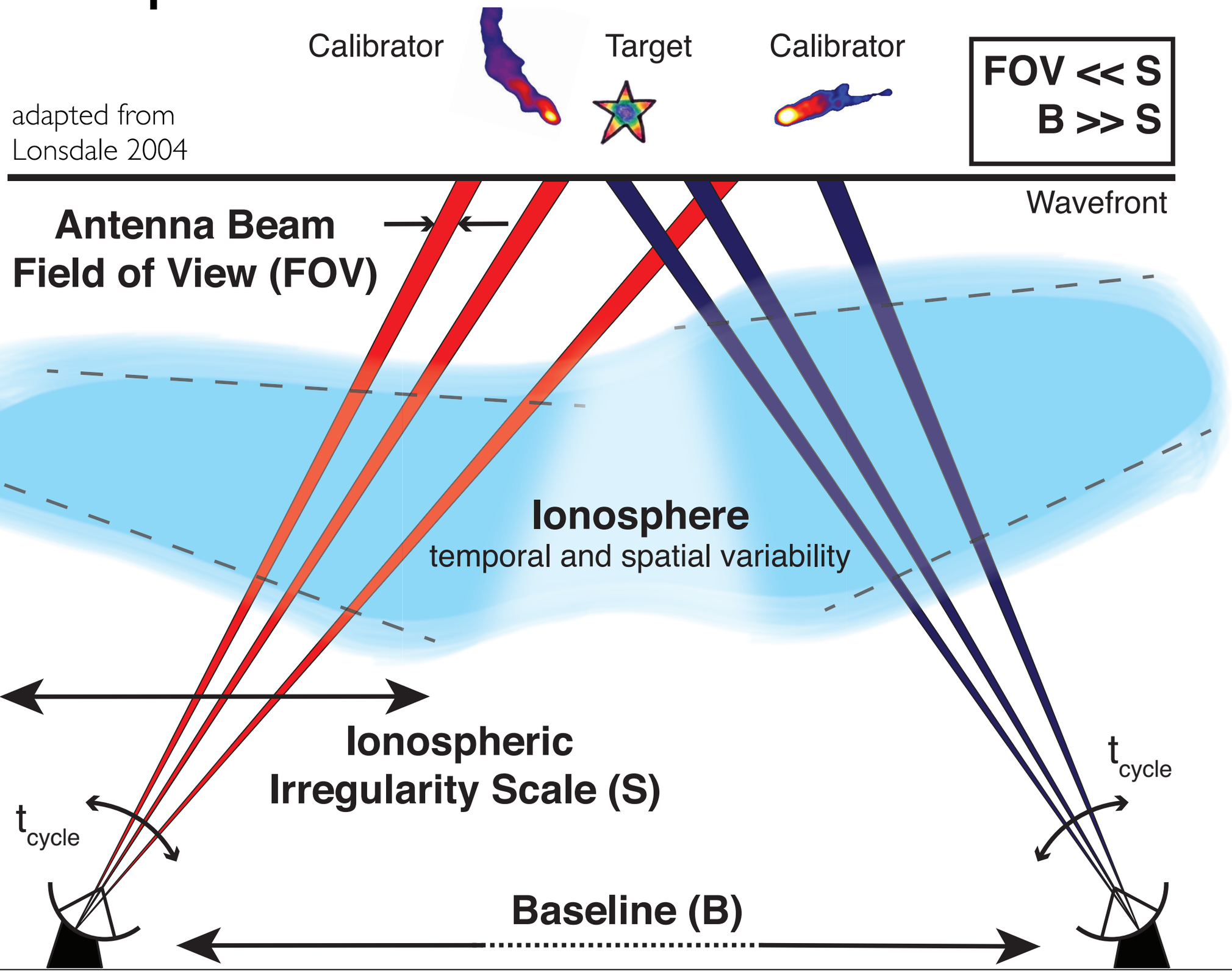


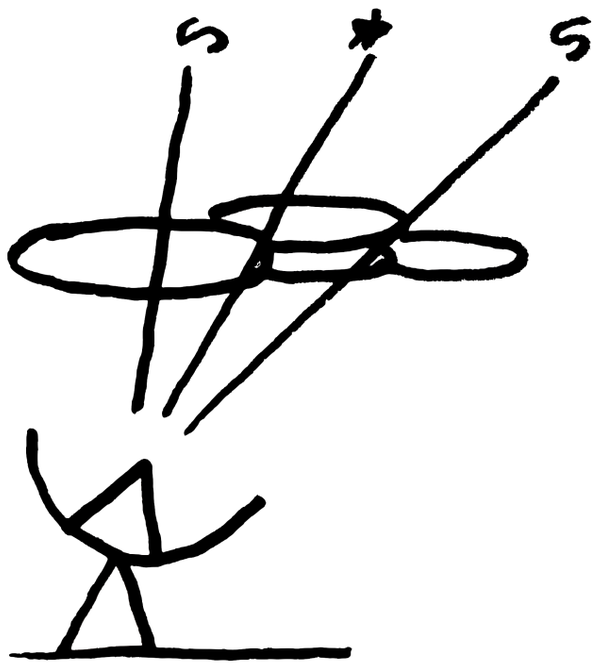
The idea of MultiView: get Θ_{sep} to zero

Concept of multi-calibrator PR: **MultiView**

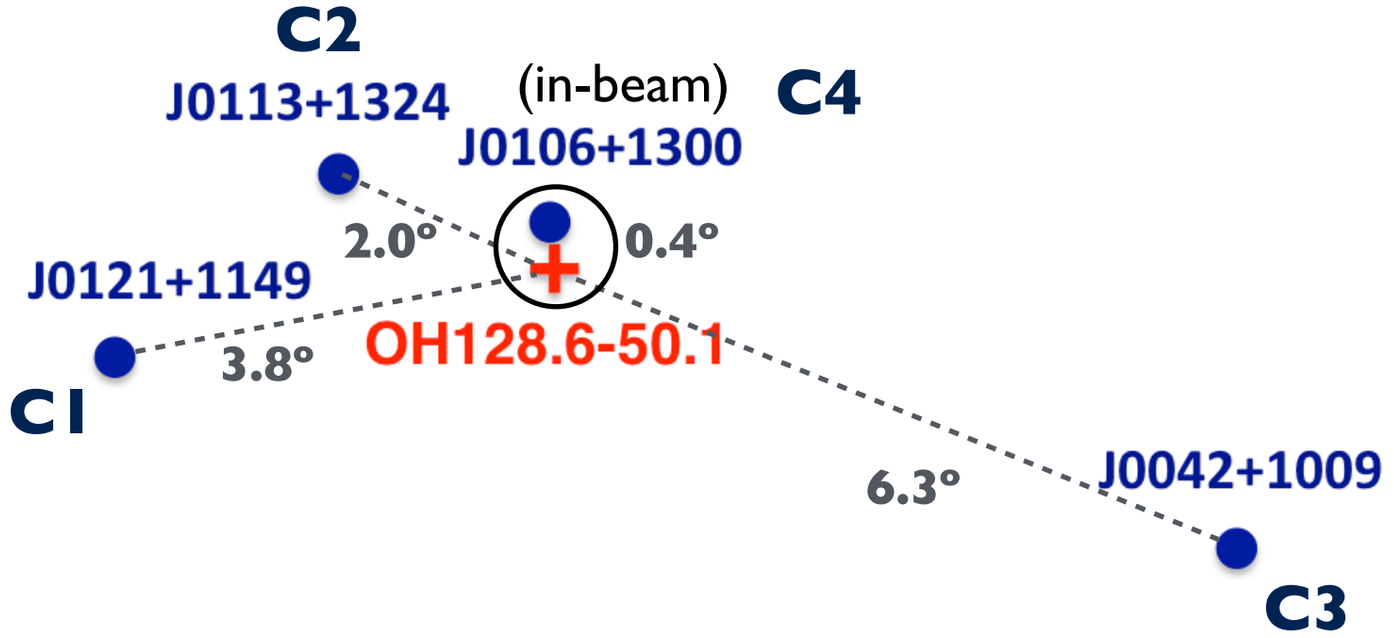


"IONOSPHERIC WEDGE" → Spatial structure (frequency/weather/direction)

MultiView models the phase-screen around the target: direction dependent calibration



Observational demonstration of MultiView



Very Long Baseline Array (VLBA)

Frequencies: 1.4 – 1.7 GHz (L-band AGN and OH masers)

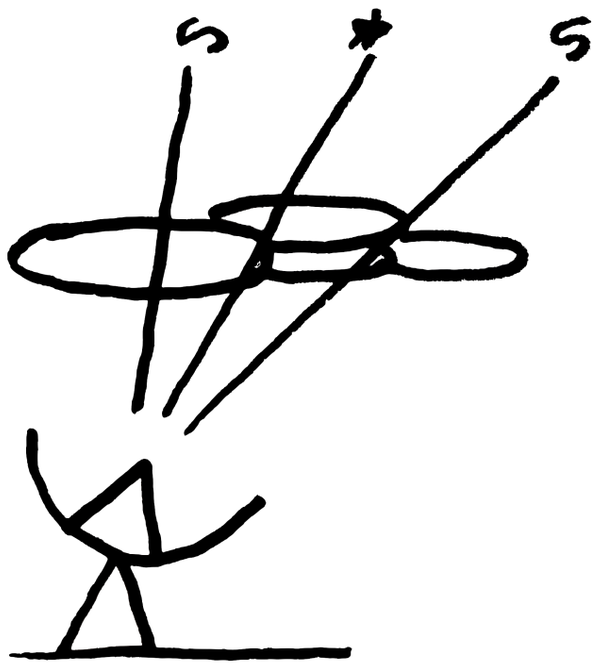
Switching cycle: 5 min

2 epochs, 4 hours/epoch (time on source: 40%), 1 month apart

June 8, 2015
July 7, 2015

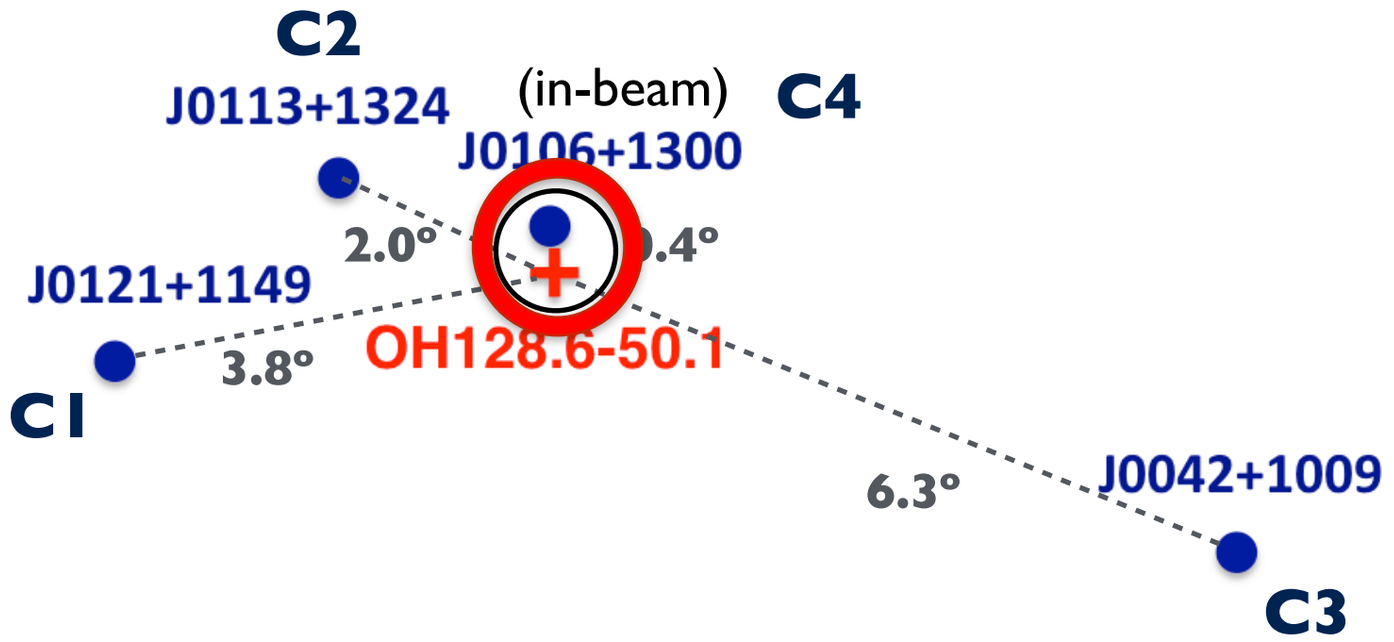
RA (deg)

Dec (deg)



Observational demonstration of MultiView

cycle around in 5 min



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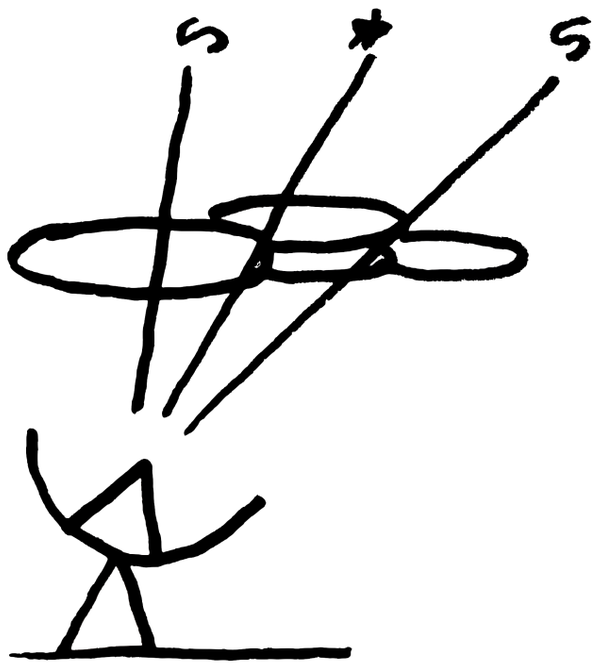

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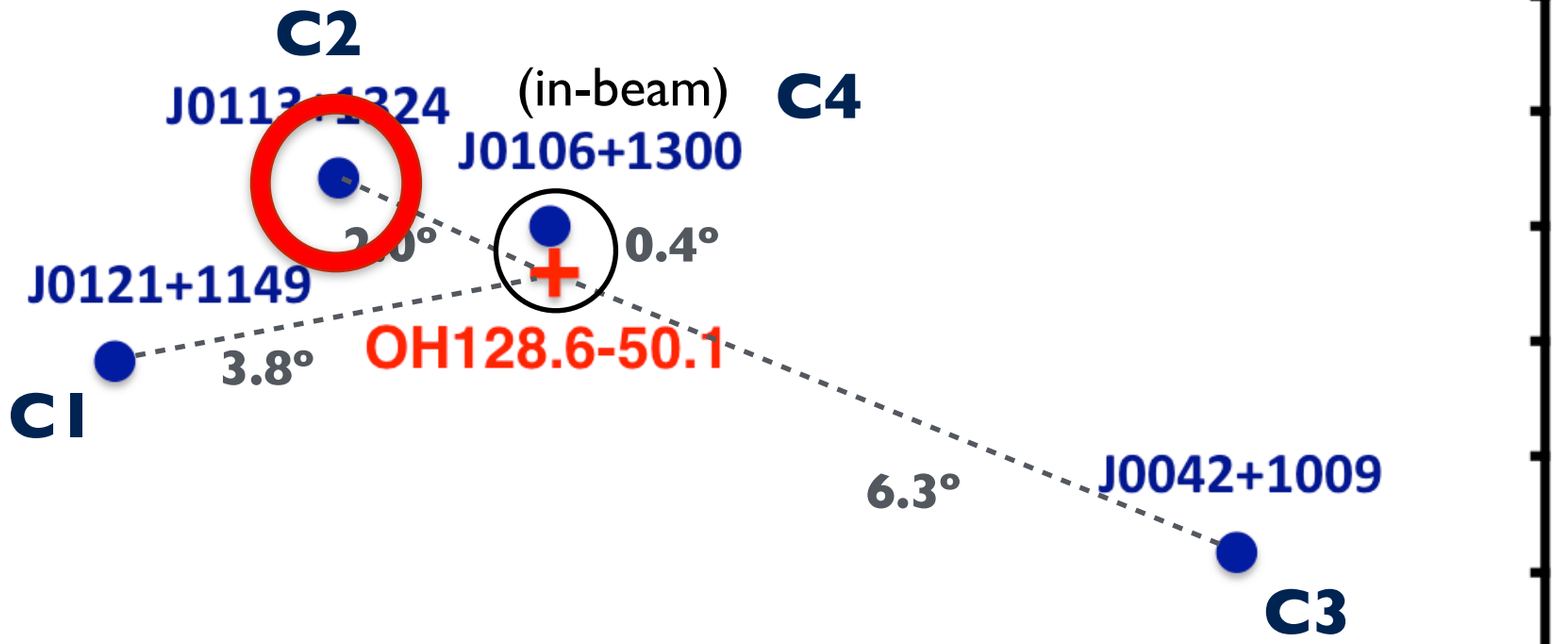

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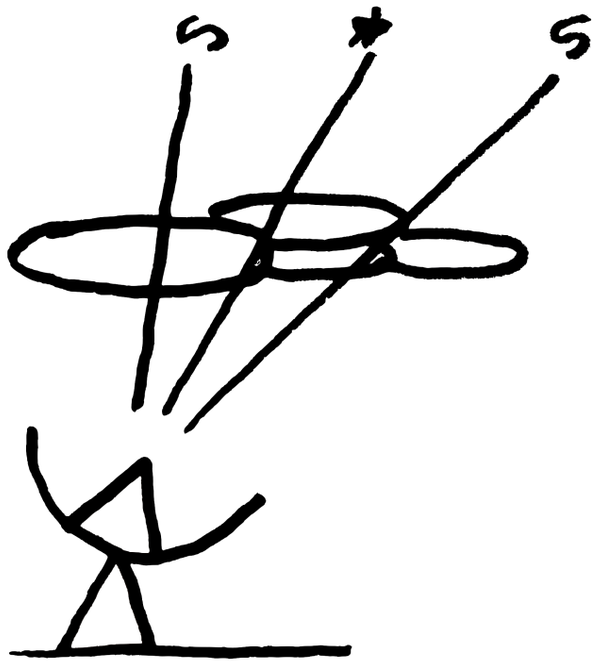

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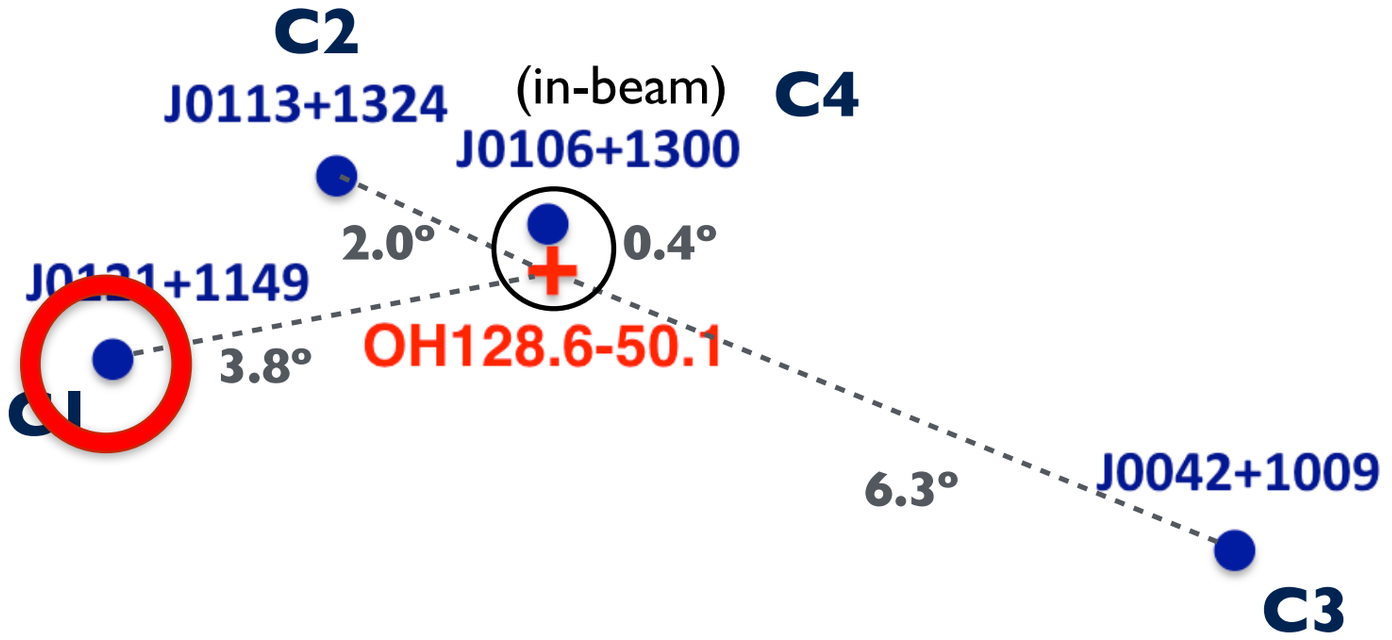

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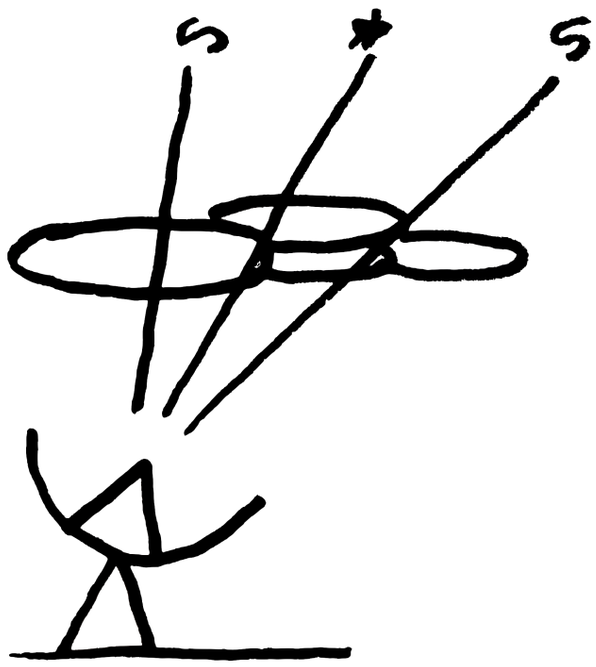

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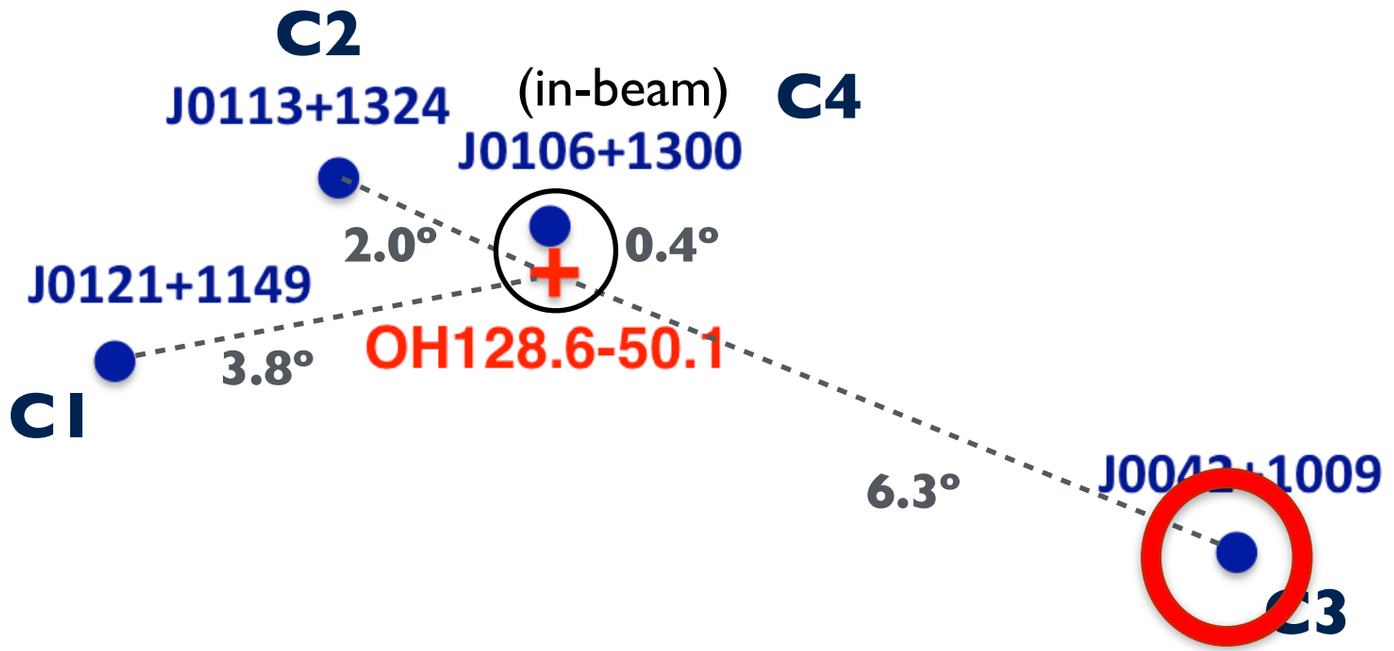

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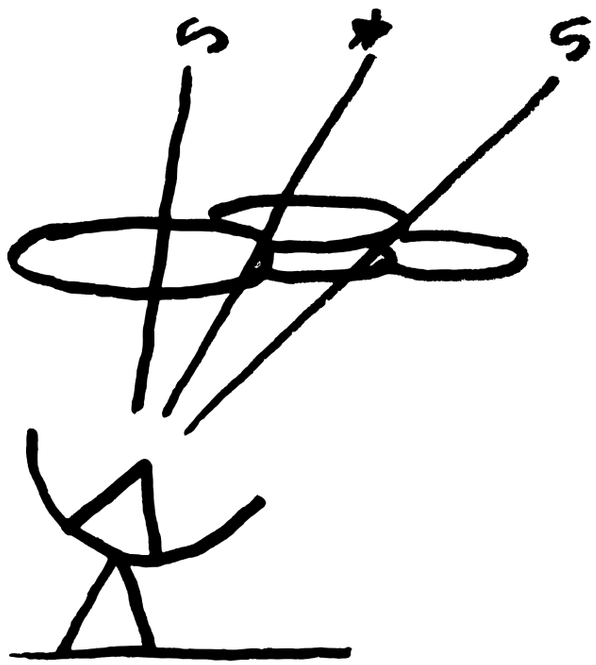
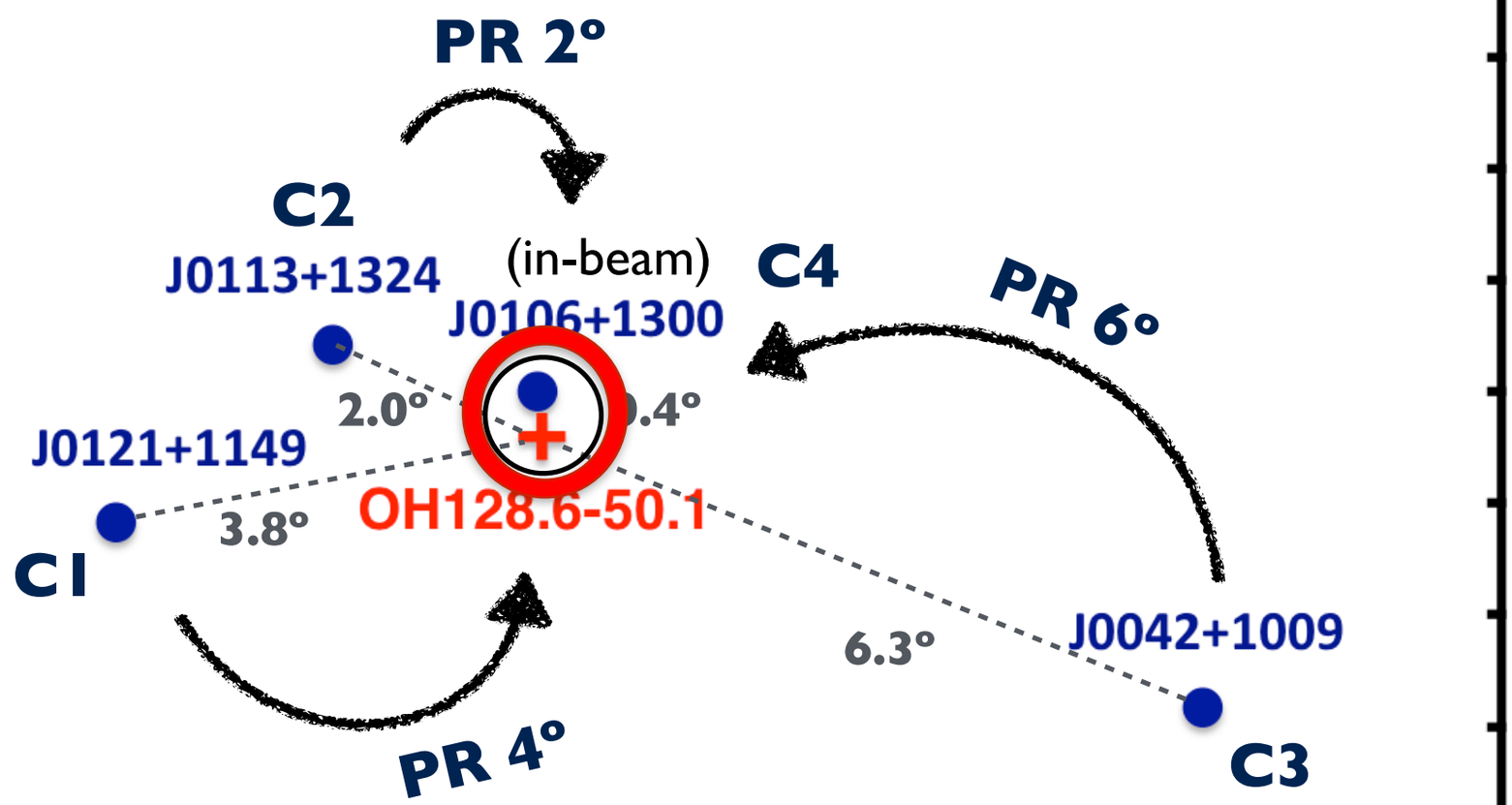




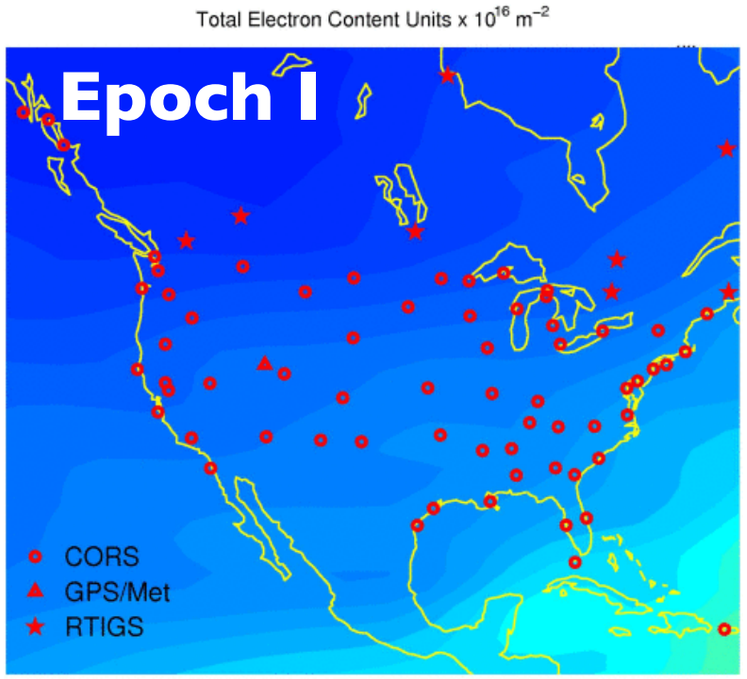
Test #1: on AGN (PR vs MV)

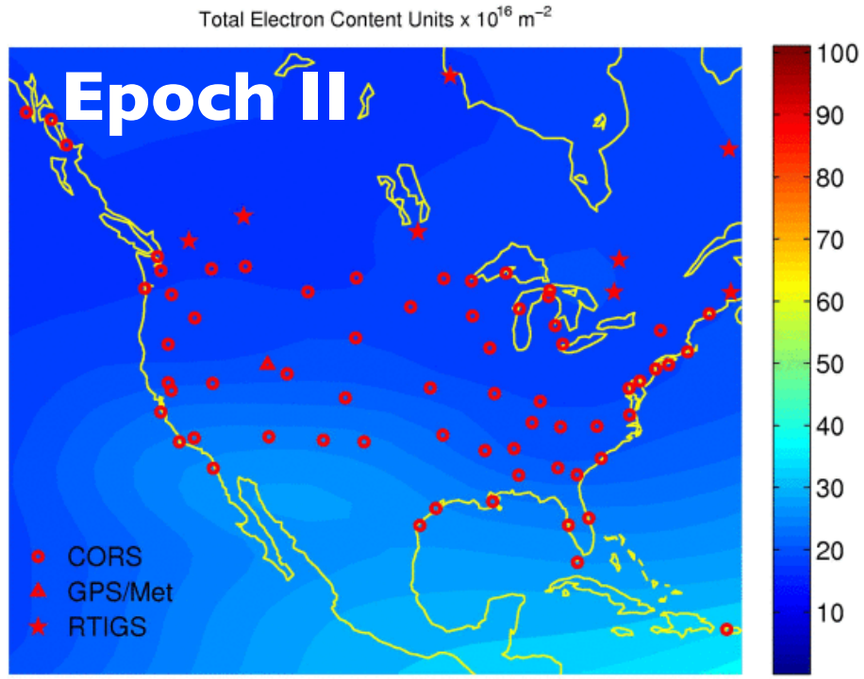
Phase referencing (PR): single calibrator, no spatial interpolation

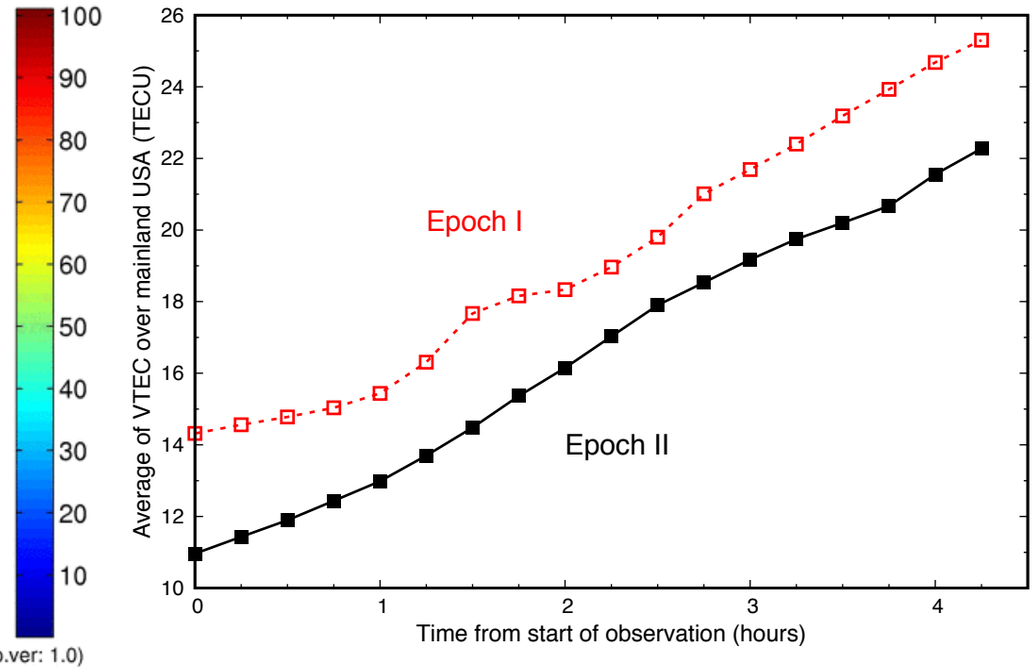
MultiView (MV): three calibrators together + 2D interpolation to target l.o.s.

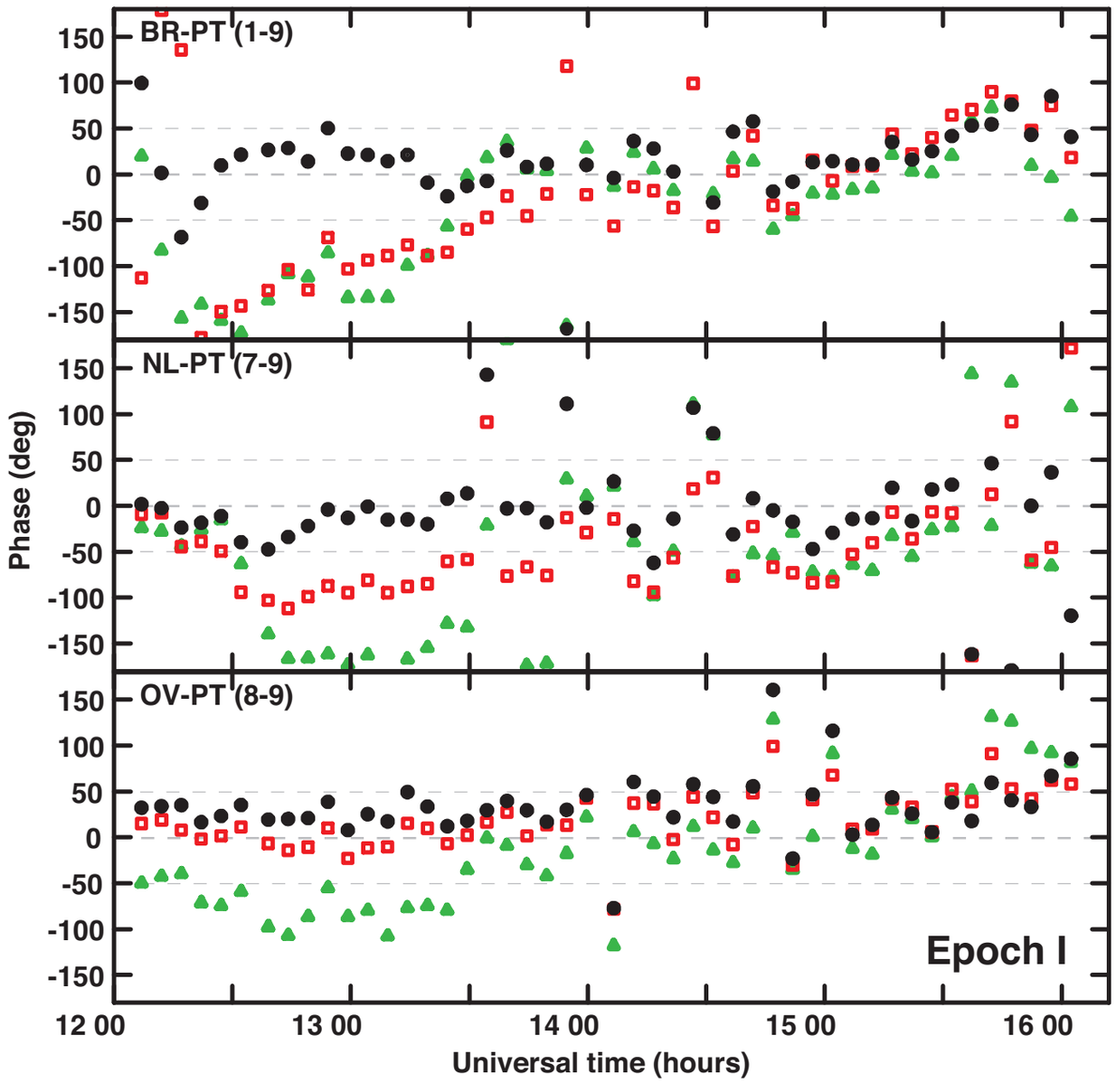
$$\varphi_{MV} = [\varphi_{C3}\, w_1 + \varphi_{C2}\,(1-w_1)]\, w_2 + \varphi_{C1}\,(1-w_2) + n2\pi$$

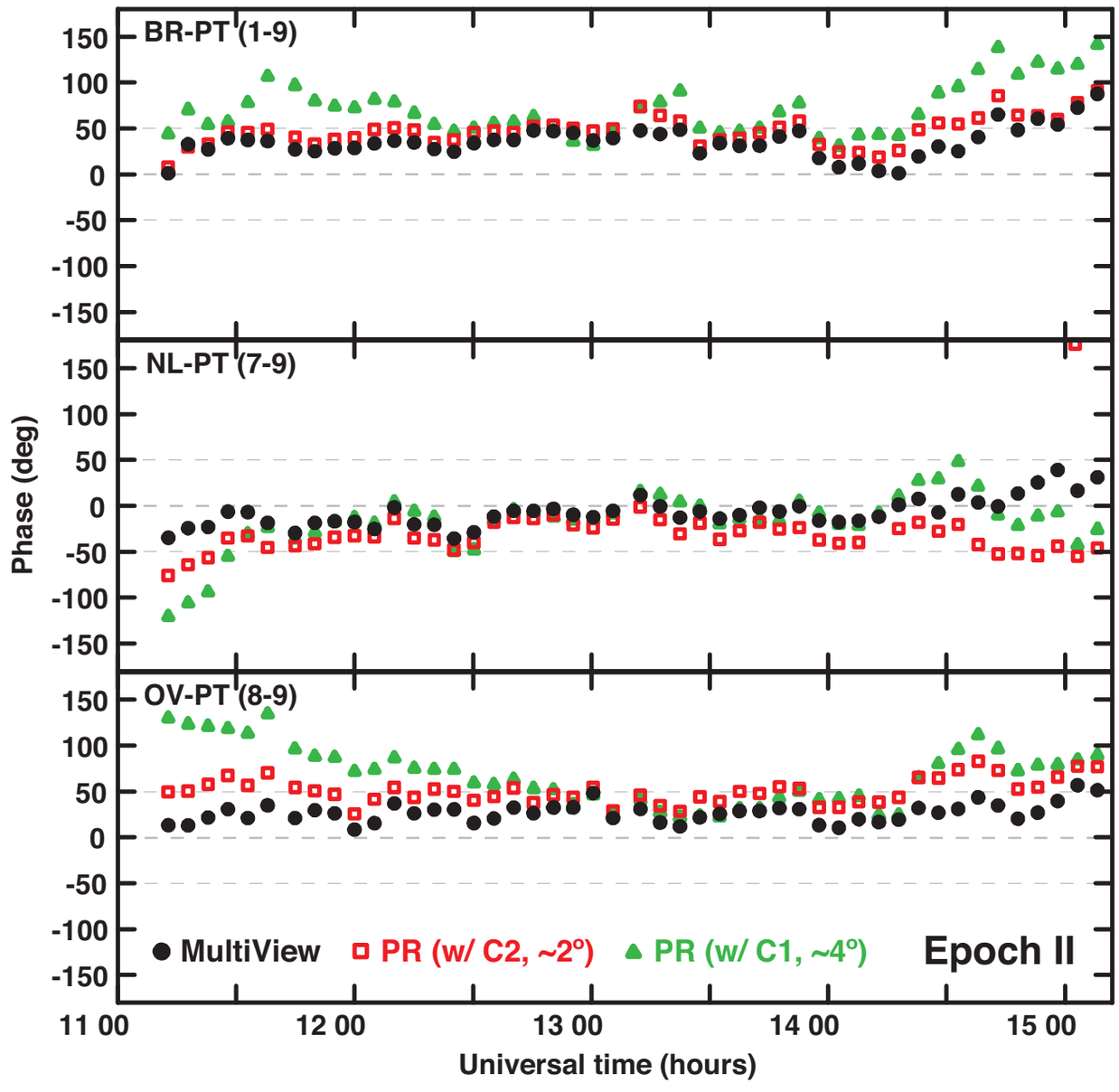
Dec (deg)


Total Electron Content Units x 10^{16} m^{-2}
Epoch I
CORS
GPS/Met
RTIGS
08–Jun–2015 from 16:00 to 16:15 UT
NOAA/SWPC Boulder, CO USA (


Total Electron Content Units x 10^{16} m^{-2}
Epoch II
CORS
GPS/Met
RTIGS
07–Jul–2015 from 15:00 to 15:15 UT
NOAA/SWPC Boulder, CO USA (op.ver: 1.0)

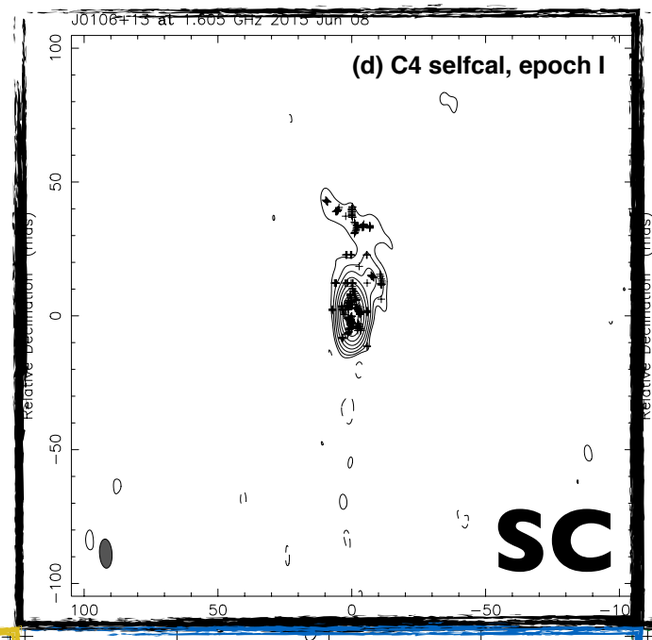

Average of VTEC over mainland USA (TECU)
Time from start of observation (hours)
Epoch I
Epoch II

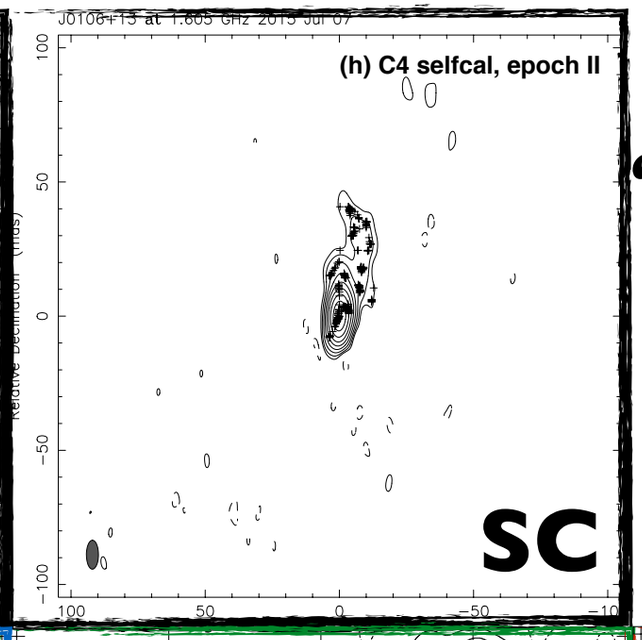

BR-PT (1-9)
NL-PT (7-9)
OV-PT (8-9)
Phase (deg)
Universal time (hours)
Epoch I


BR-PT (1-9)
NL-PT (7-9)
OV-PT (8-9)
Phase (deg)
Universal time (hours)
MultiView
PR (w/ C2, ~2°)
PR (w/ C1, ~4°)
Epoch II

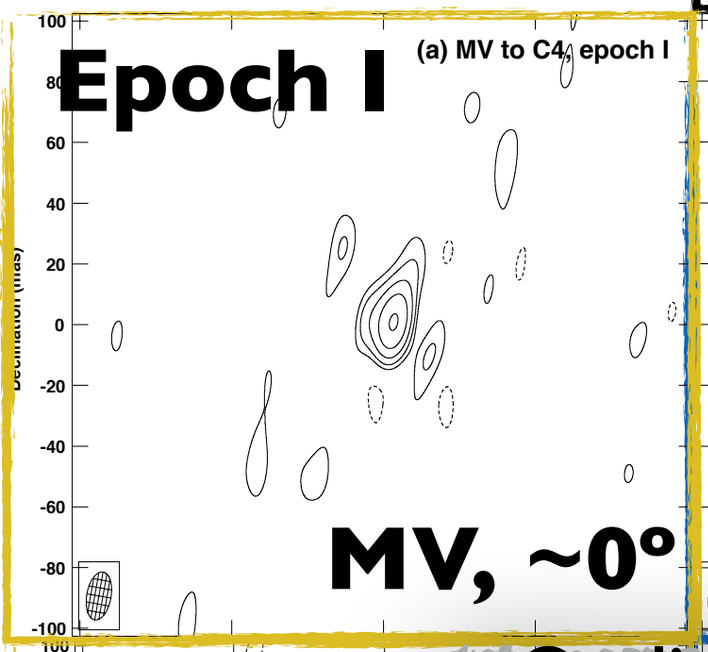
Epoch I
"bad" weather
2015 June

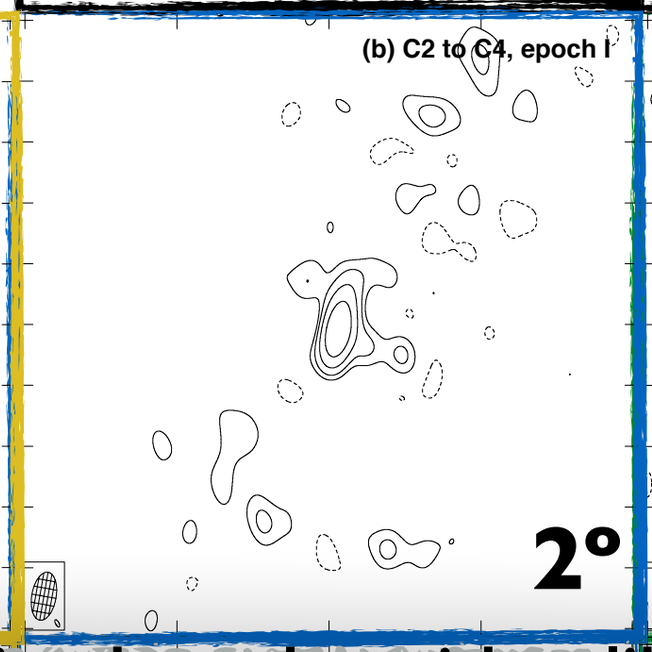
Epoch II
"good" weather
2015 July

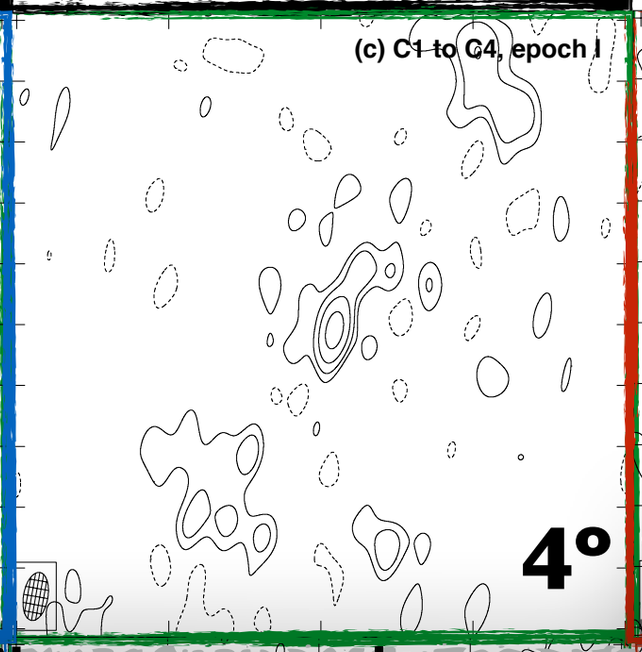


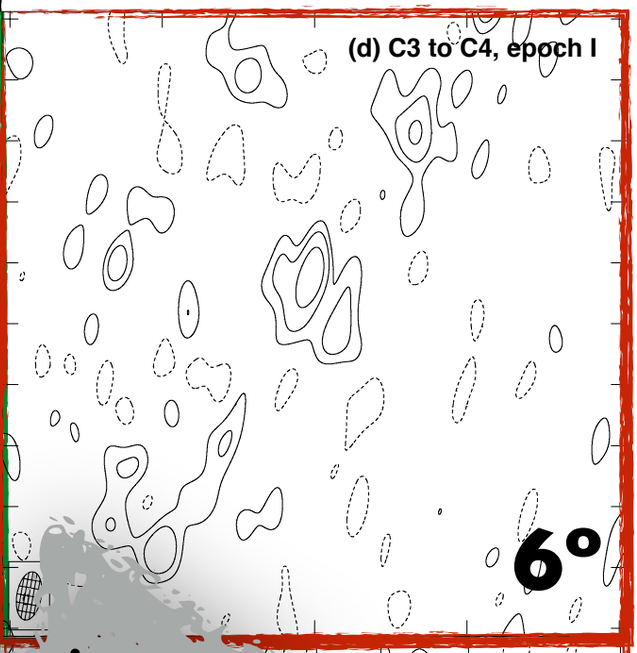


Epoch I

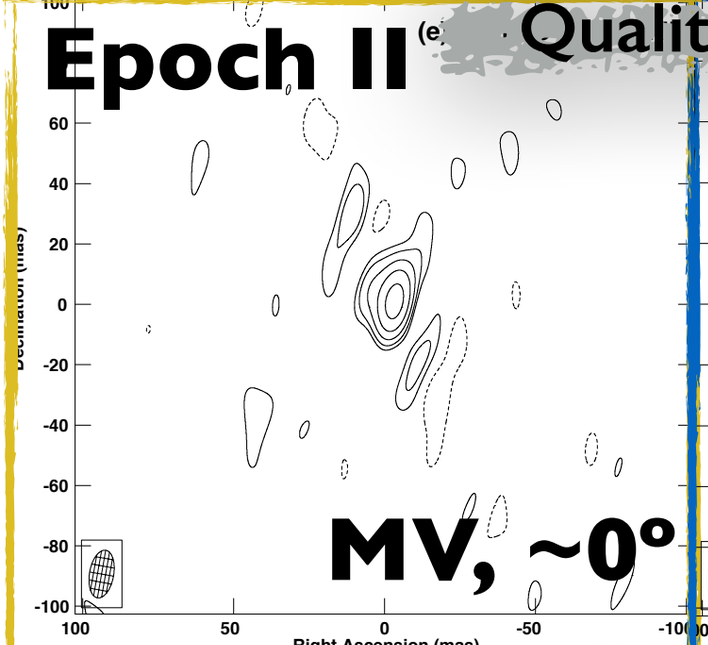


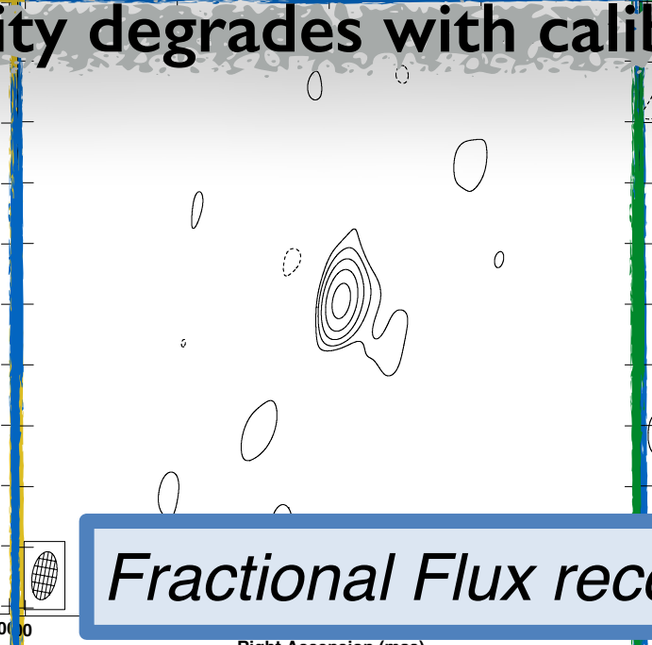


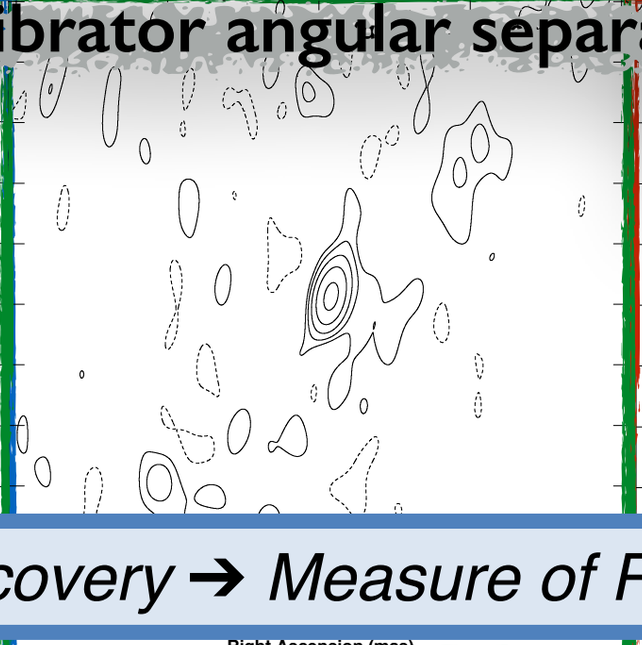


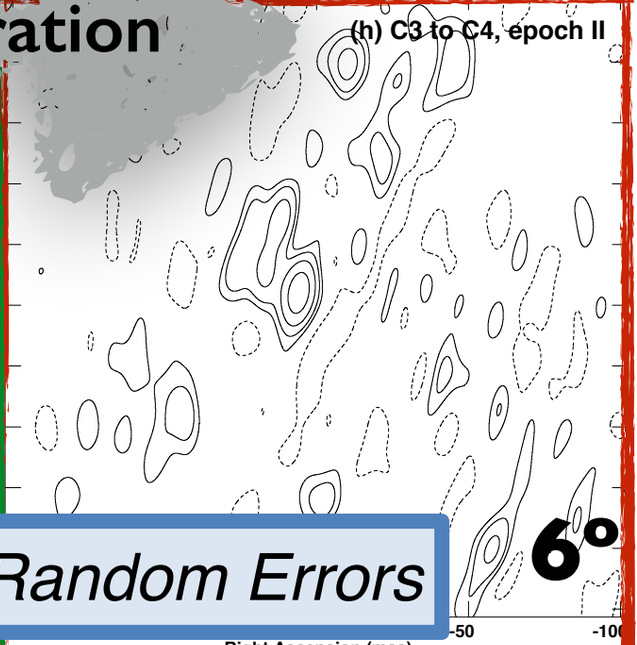


Epoch II







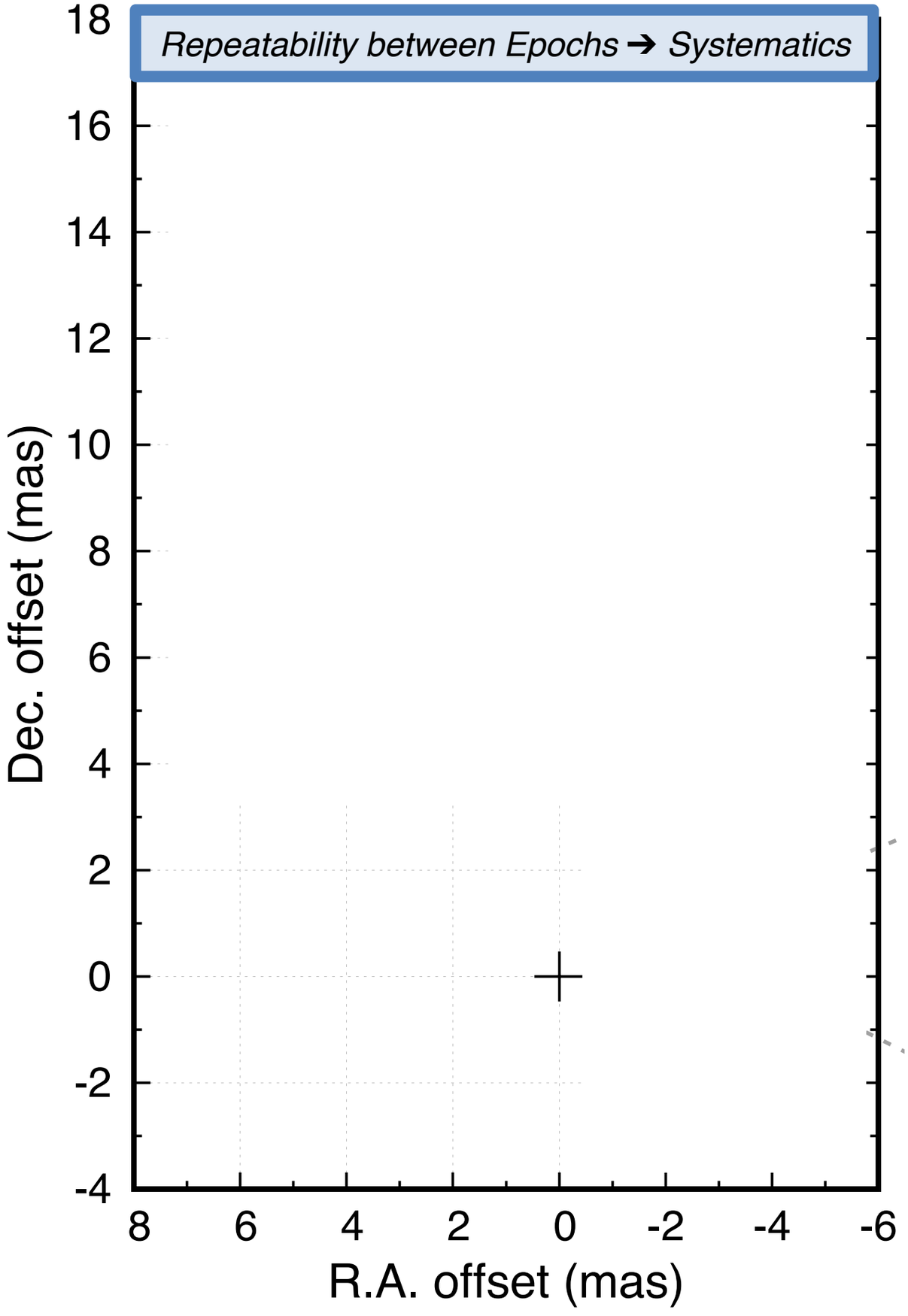


Quality degrades with calibrator angular separation

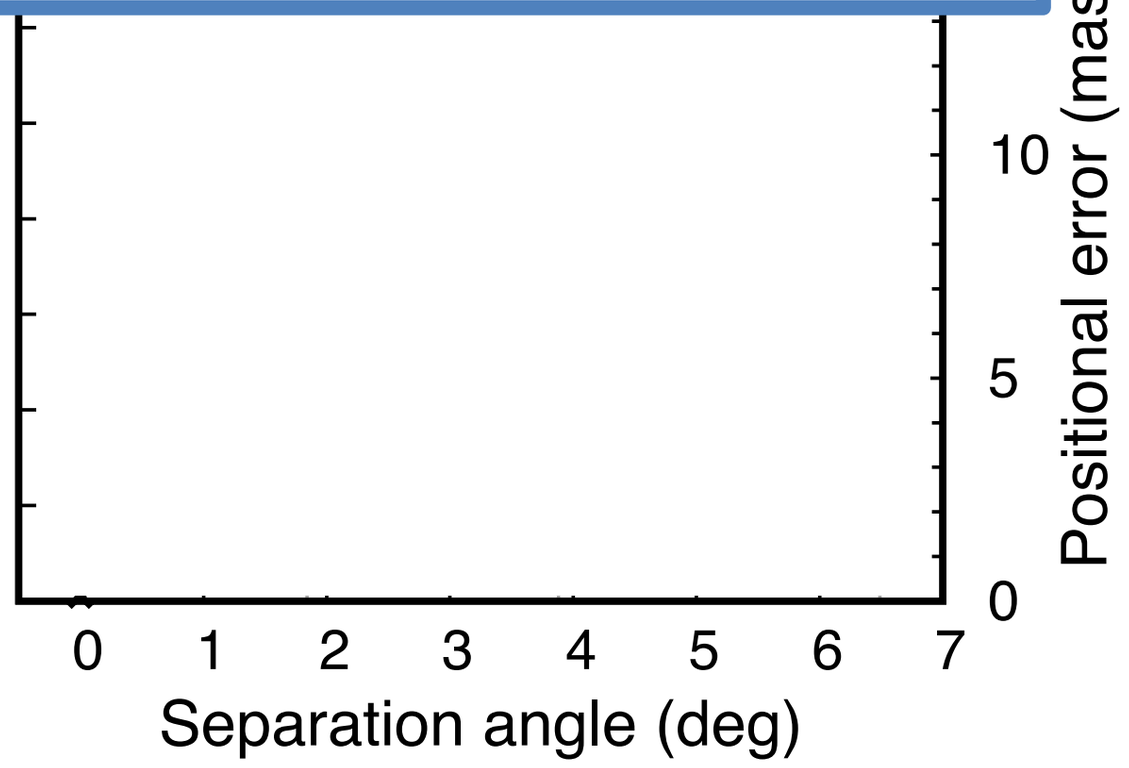
Fractional Flux recovery → Measure of Random Errors

Test #1: PR vs MultiView on AGN continuum

Repeatability between Epochs ➔ Systematics



MultiView vs. PR 2º, 4º, 6º: Position Accuracy



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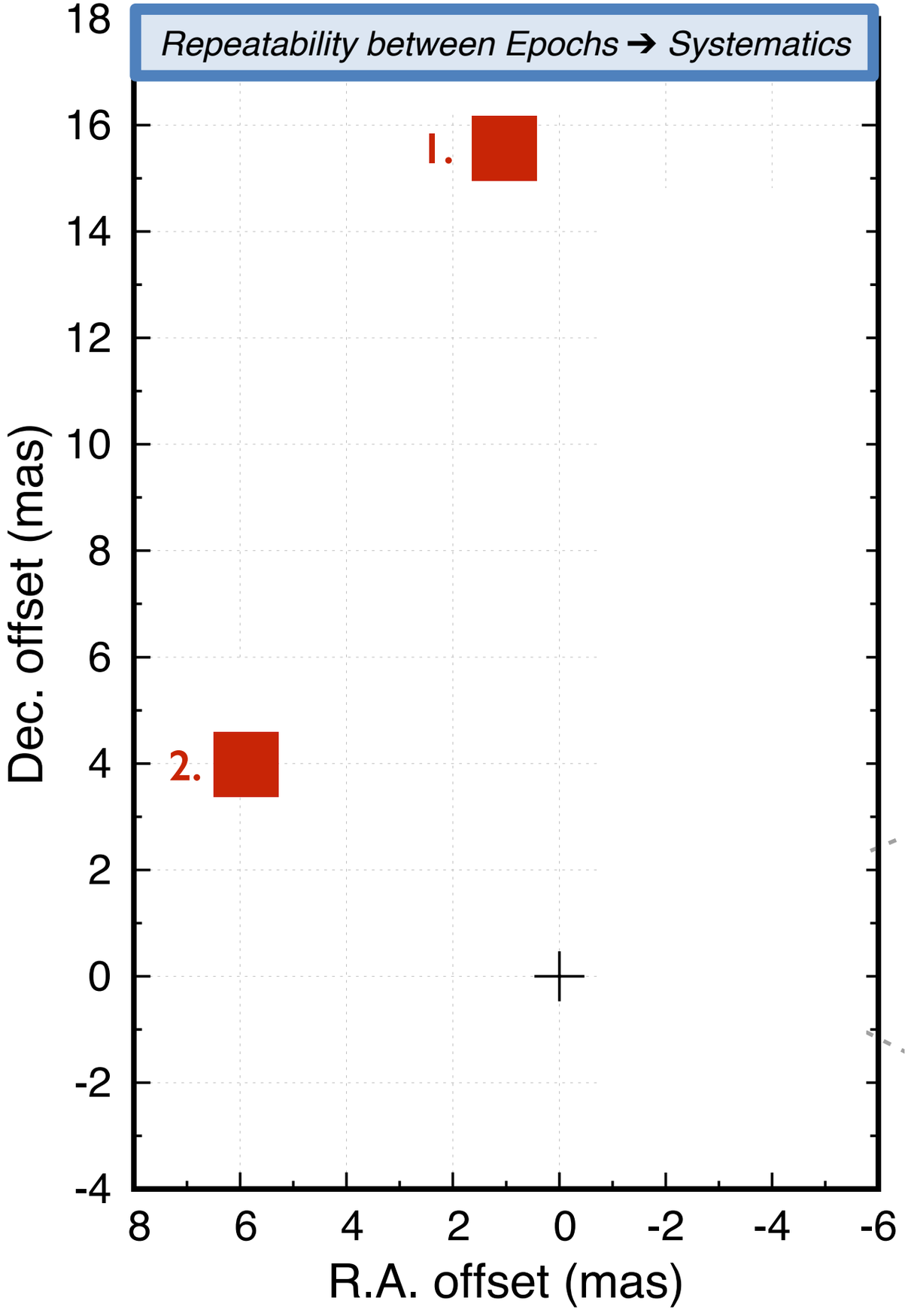
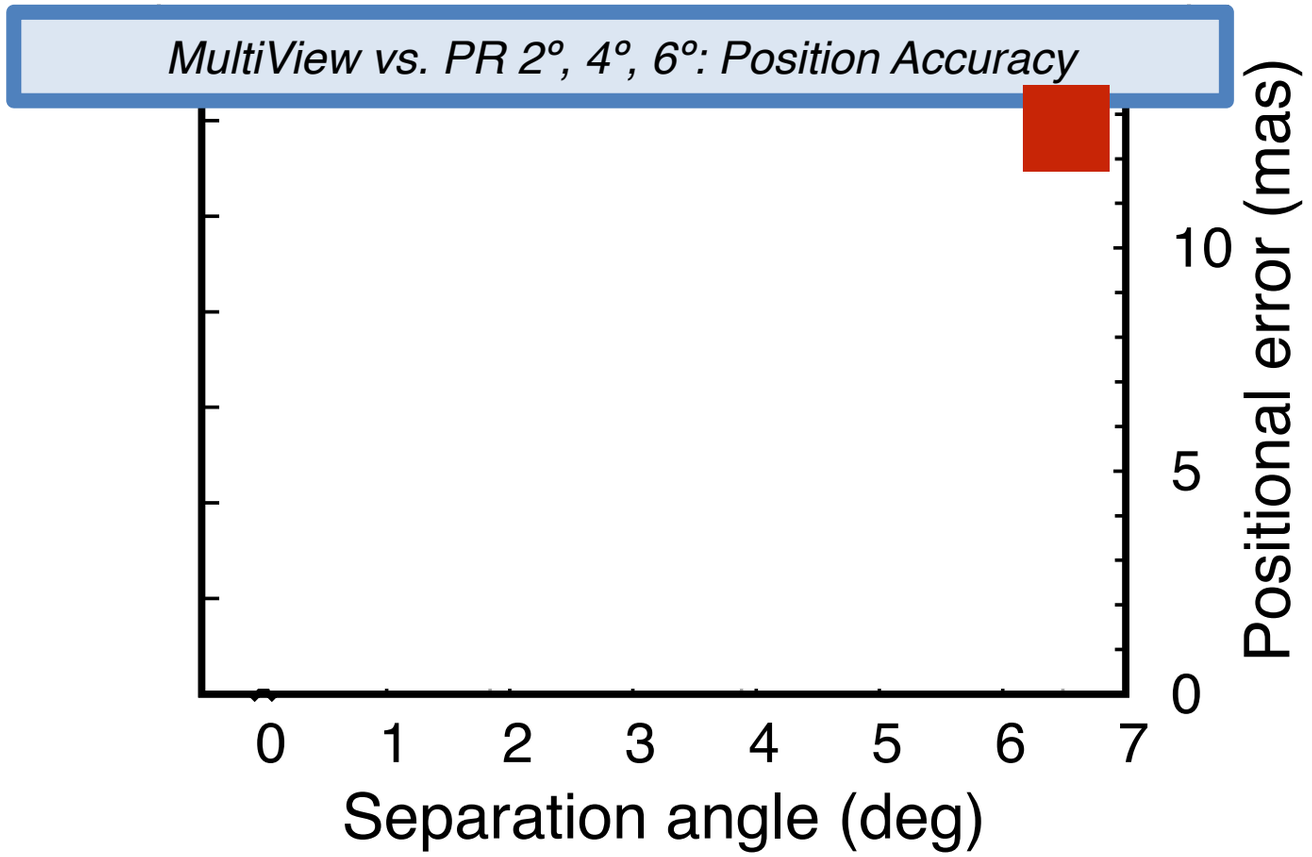
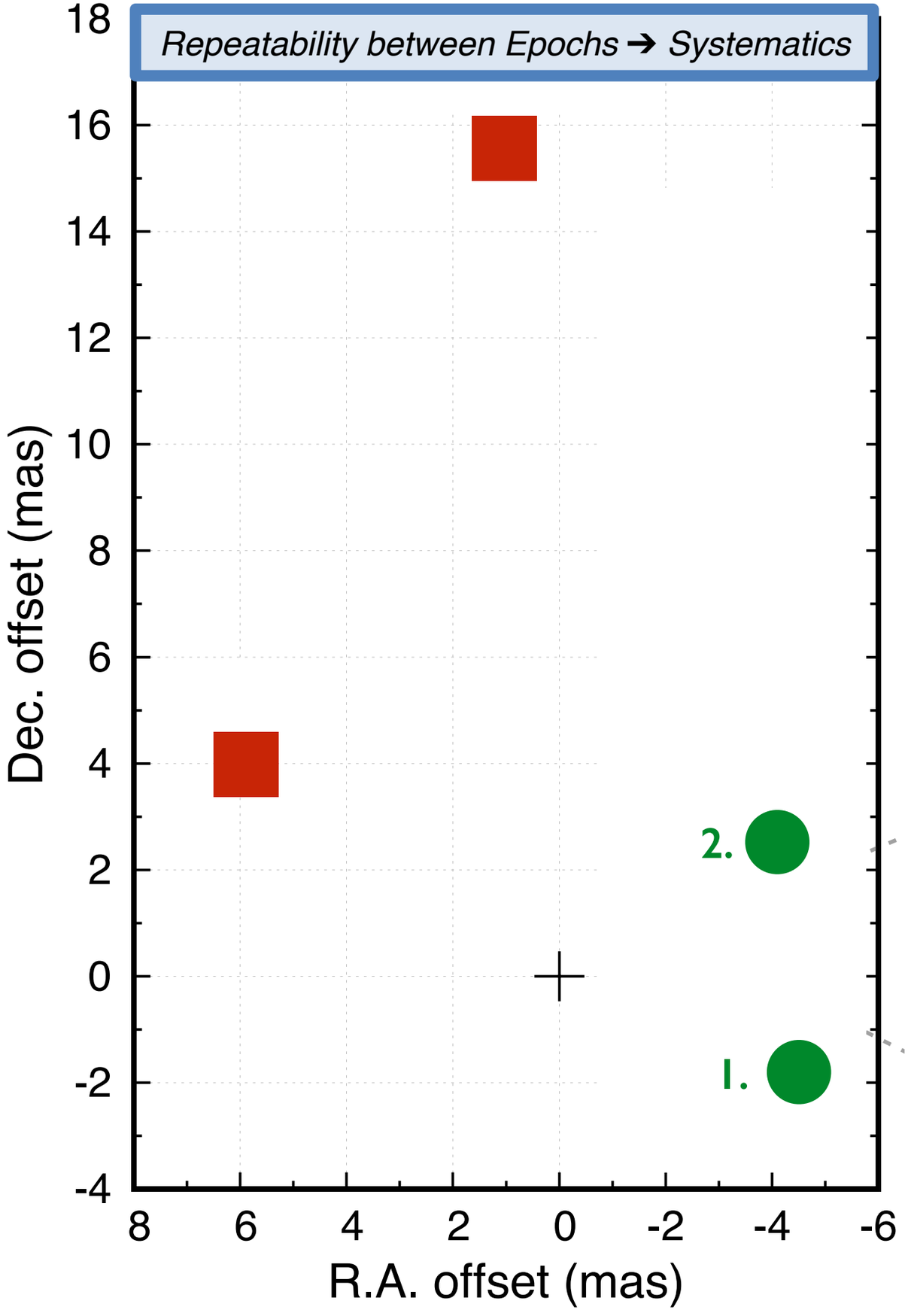
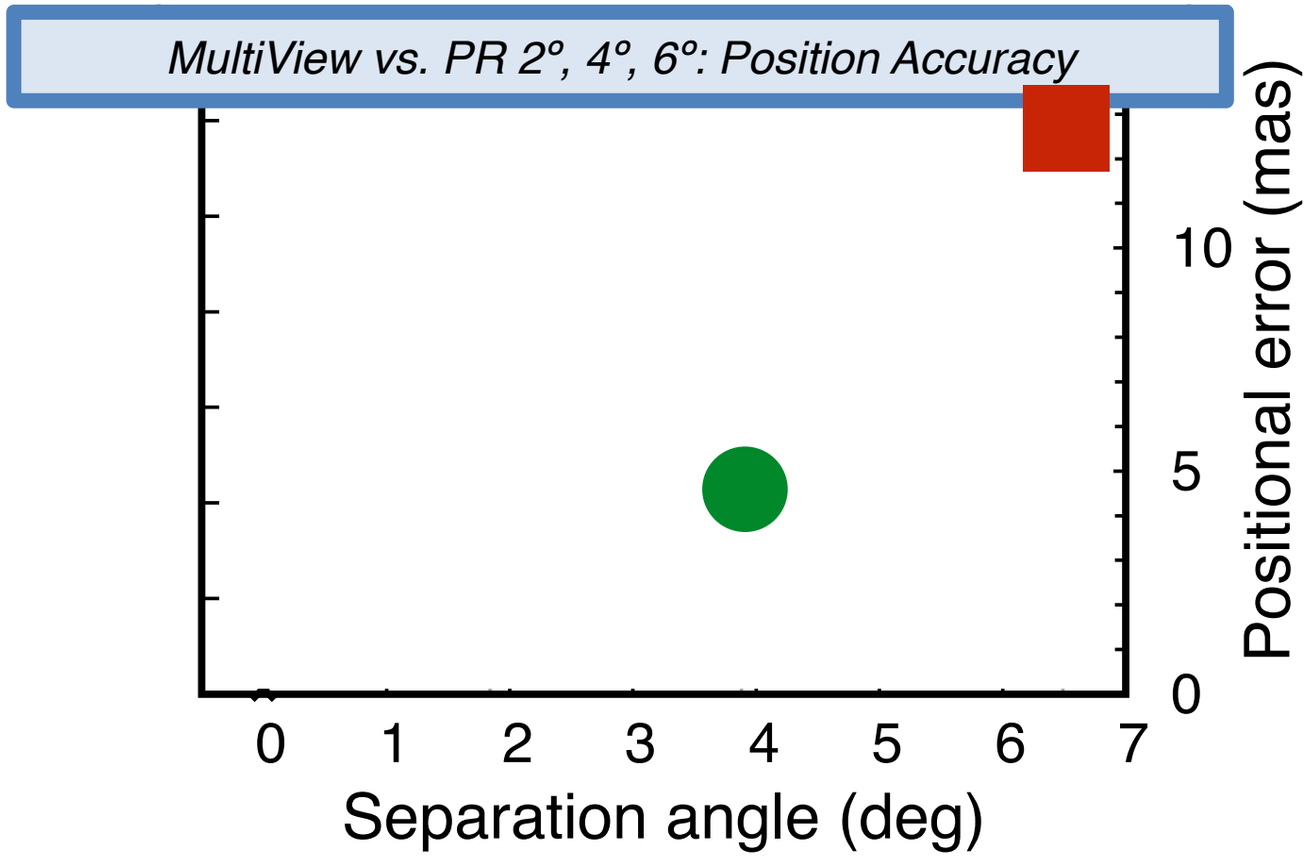




Phase referencing calibrator is 6 deg away

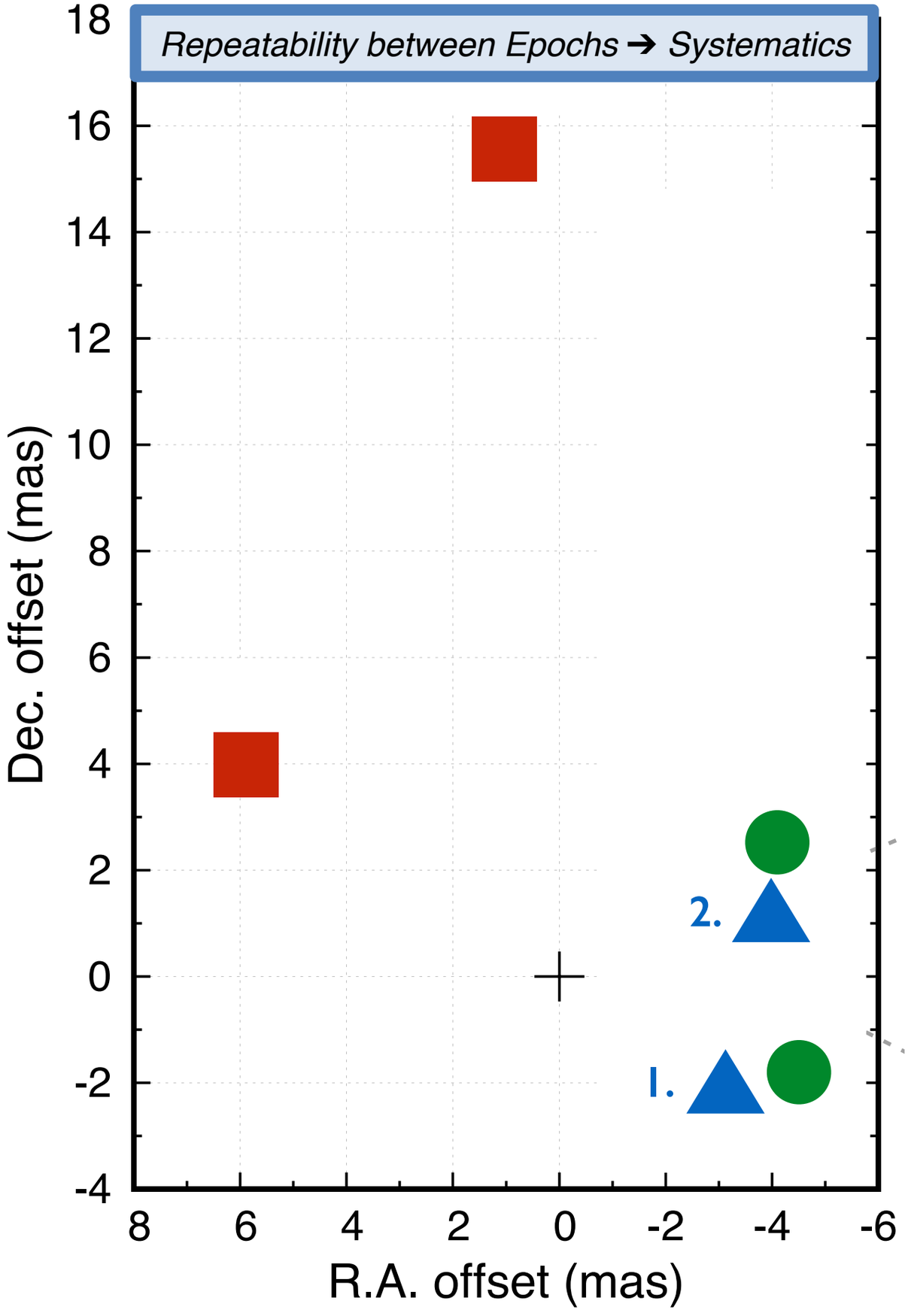
Test #1: PR vs MultiView on AGN continuum

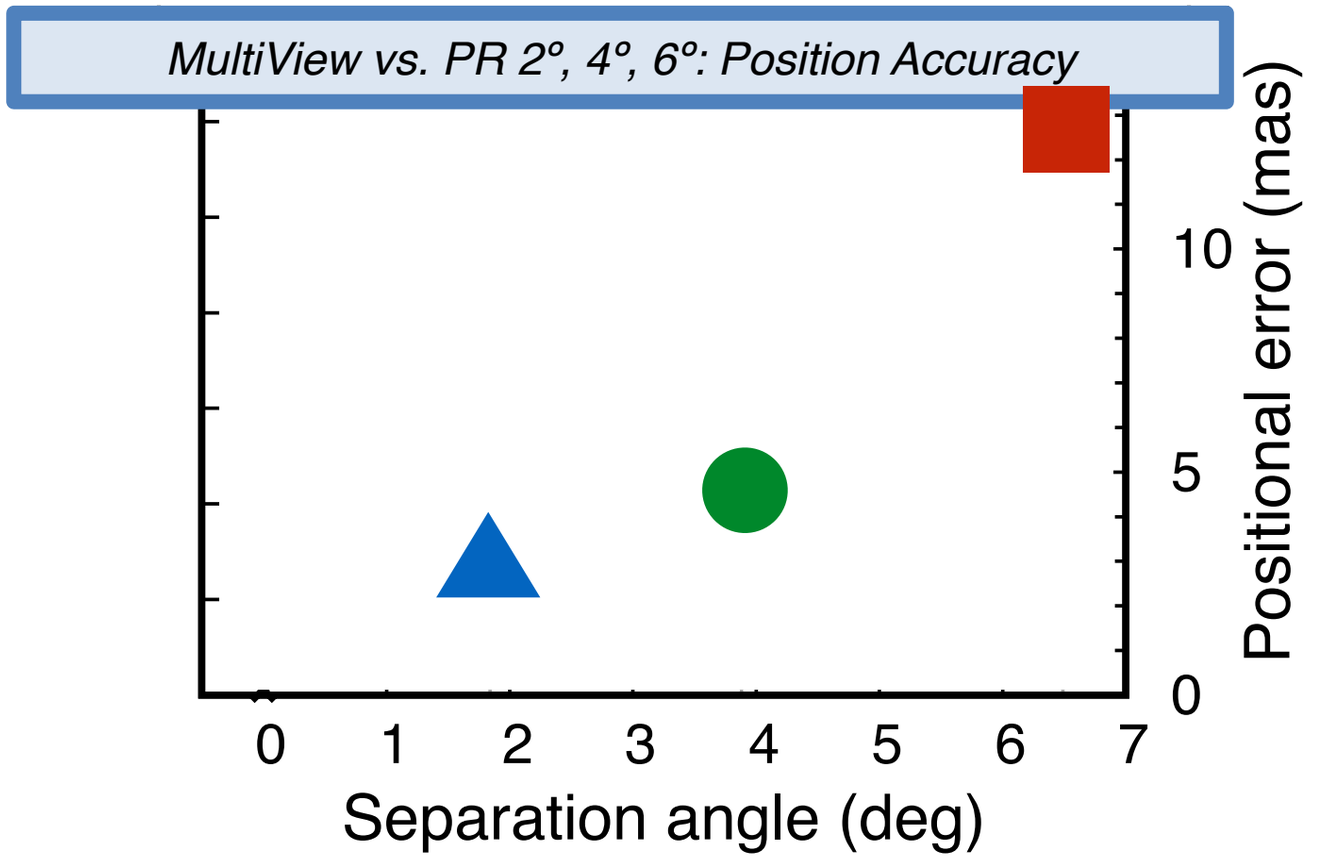




Phase referencing calibrator is 4 deg away

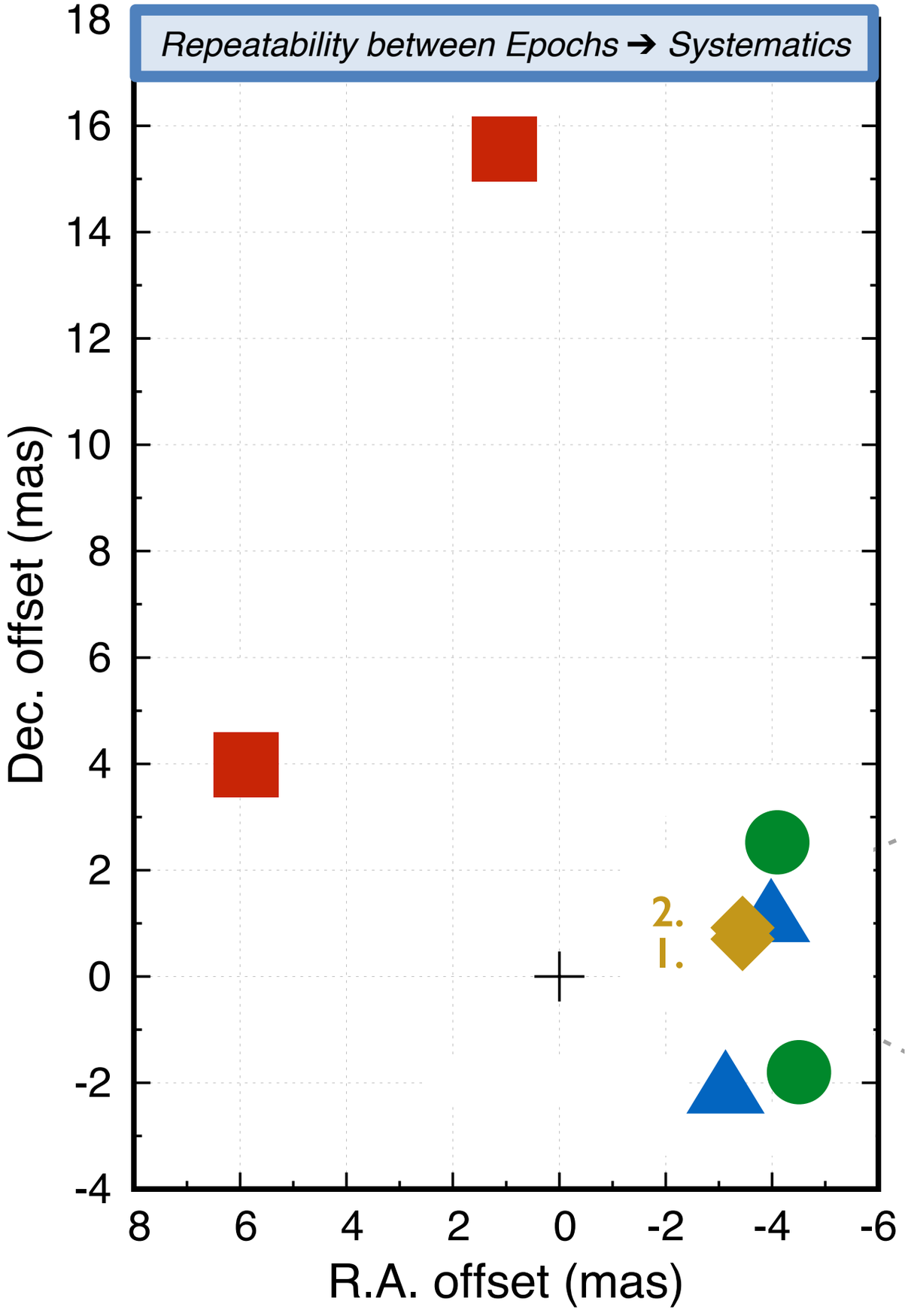
Test #1: PR vs MultiView on AGN continuum

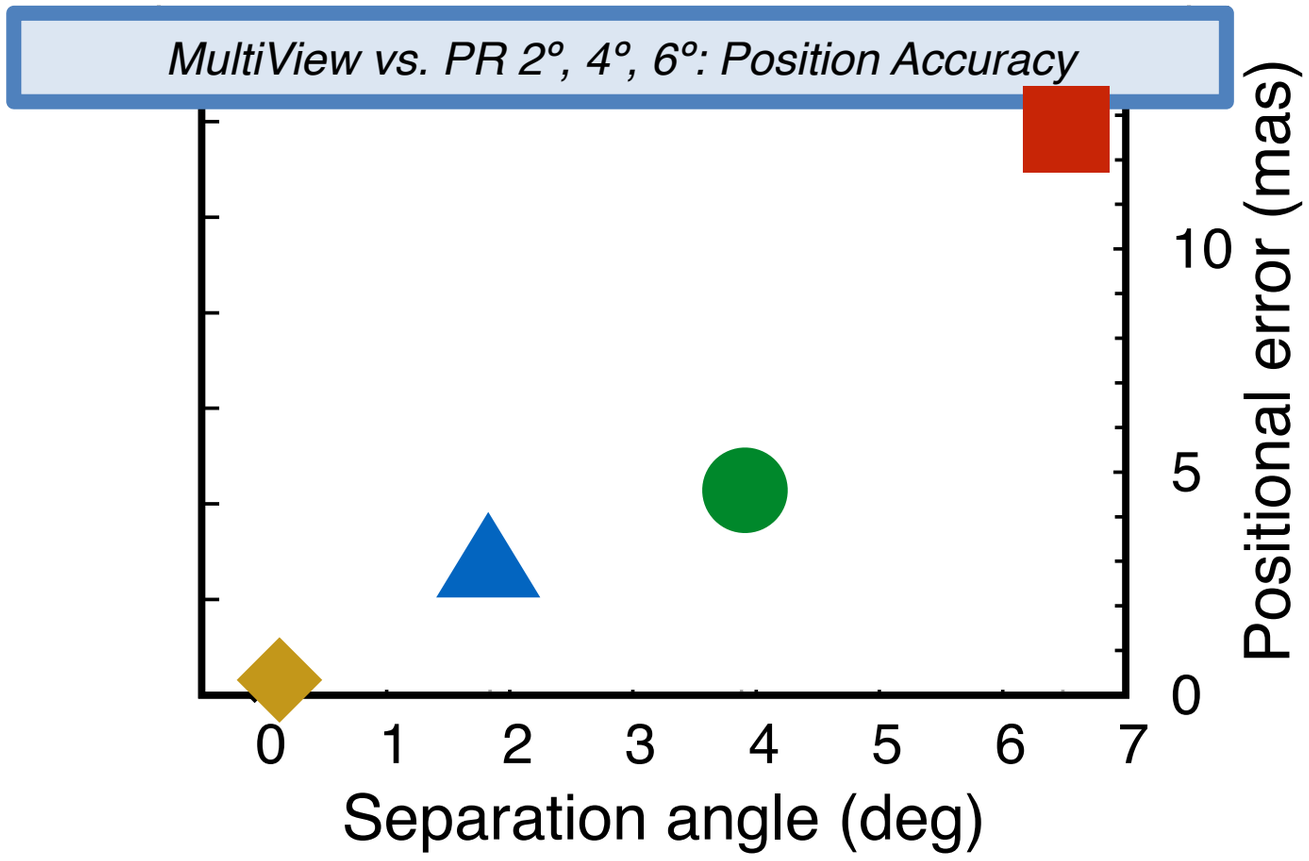




Phase referencing calibrator is 2 deg away

Test #1: PR vs MultiView on AGN continuum

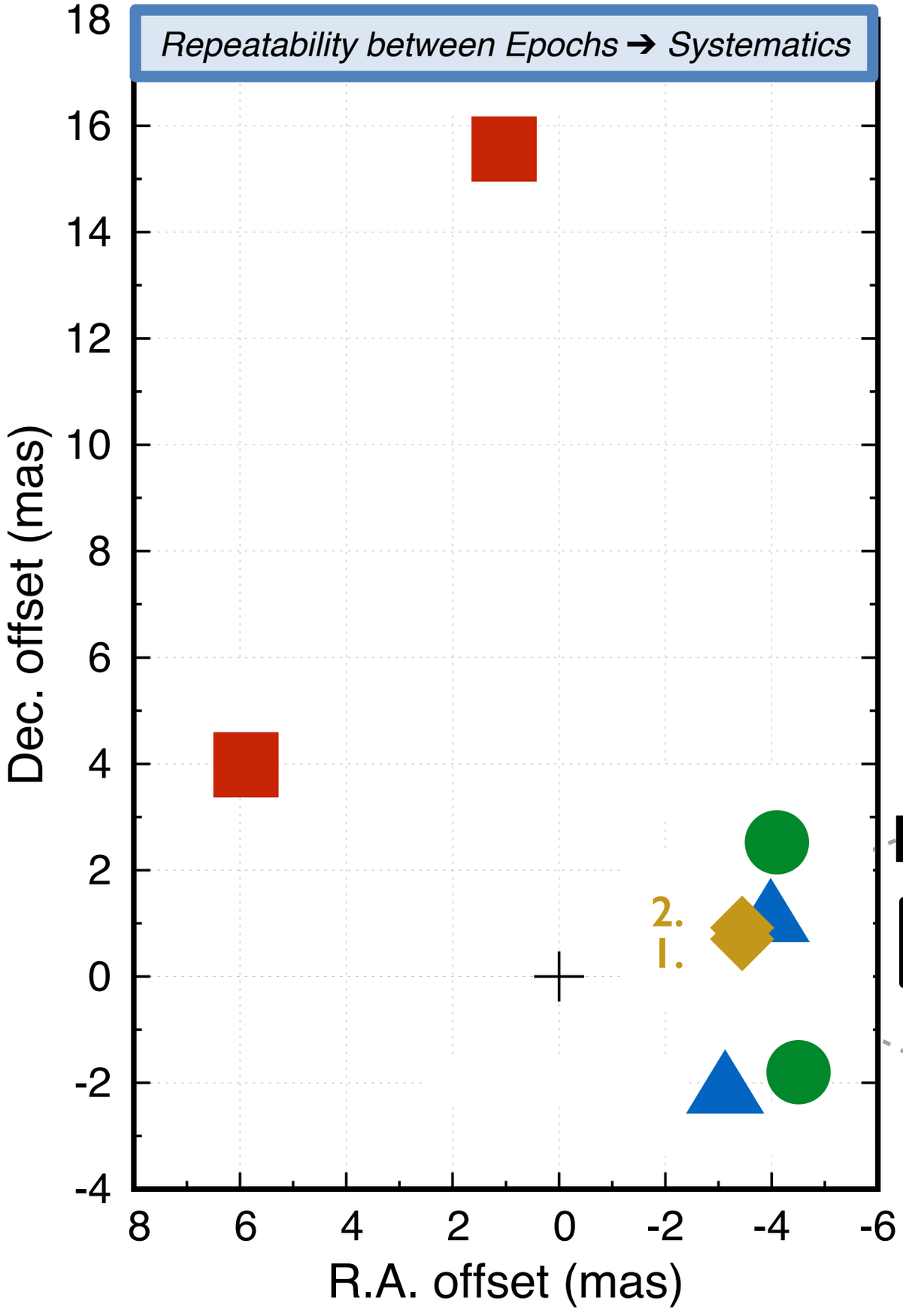




MultiView solution in target l.o.s.

Test #1: PR vs MultiView on AGN continuum

Repeatability between Epochs ➔ Systematics



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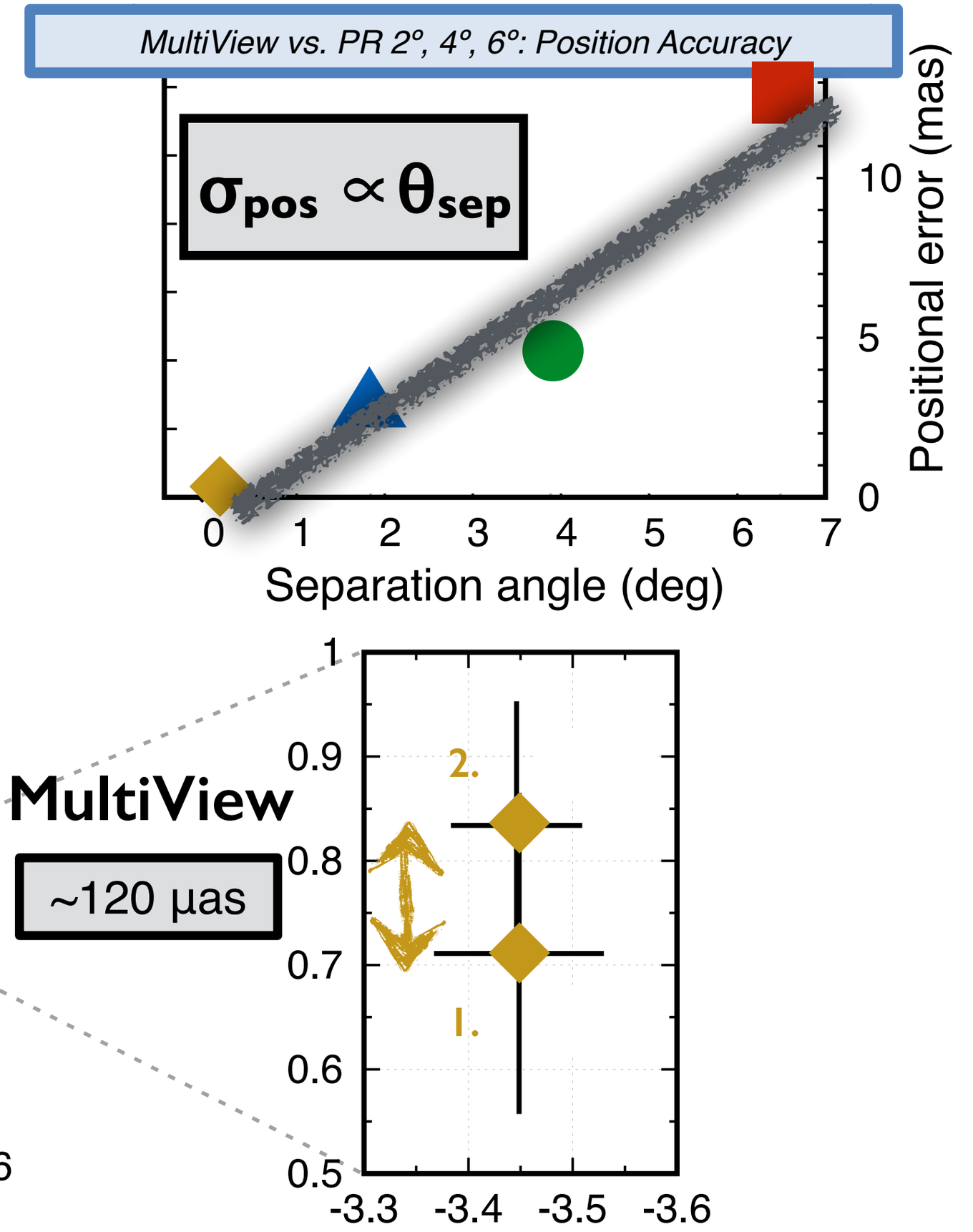

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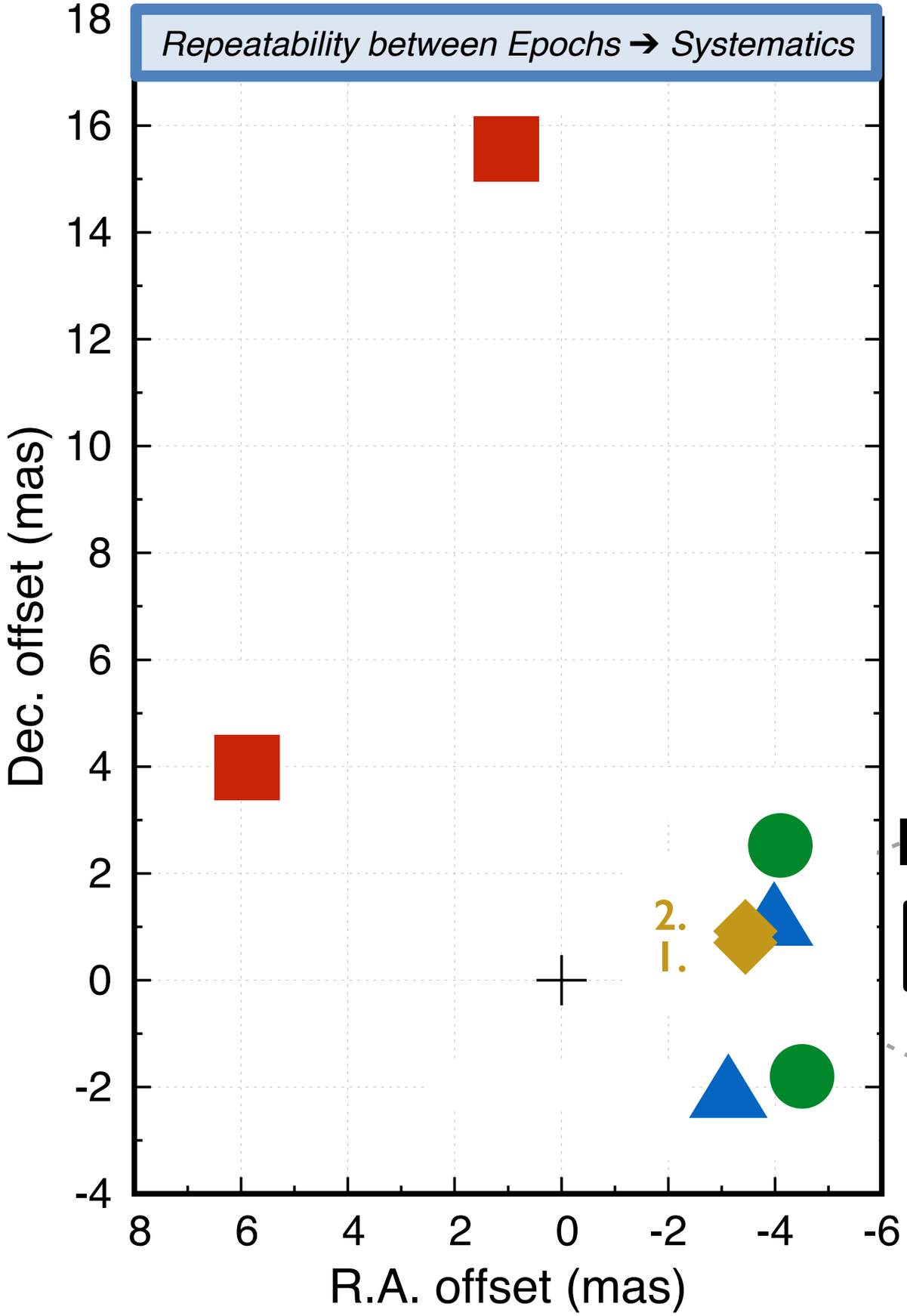
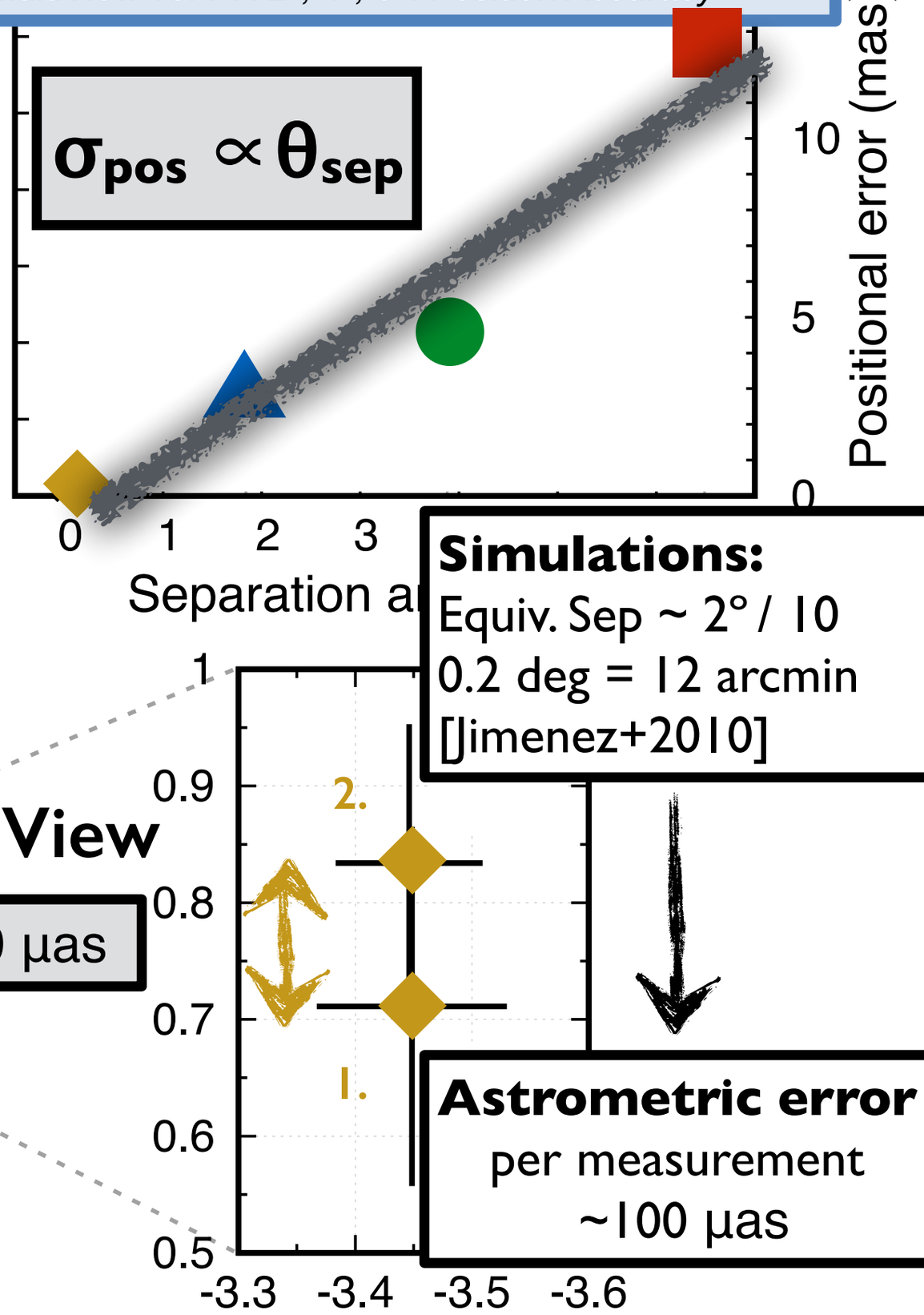


MultiView vs. PR 2°, 4°, 6°: Position Accuracy



Simulations:
Equiv. Sep ~ 2° / 10
0.2 deg = 12 arcmin
[Jimenez+2010]

MultiView

~120 µas

Astrometric error
per measurement
~100 µas

Test #1: PR vs MultiView on AGN continuum

Repeatability between epochs → Systematics

Dec. offset (mas)

R.A. offset (mas)

MultiView vs. PR 2°, 4°, 6°: Position Accuracy

$\sigma_{pos} \propto \theta$

Positional error (mas)

Reached theoretical thermal noise limit!

MultiView

~120 μas

Simulations:
Equiv. Sep ~ 2° / 10
0.2 deg = 12 arcmin
[Jimenez+2010]

Astrometric error
per measurement
~100 μas

So why should we be happy?

MultiView calibration:

- **superior atmospheric mitigation with angular sep. of a few degrees**
- effective ang. separation is ~0°
- benefit even more from simultaneous SKA multi-beam observations

Ultimate error limit on astrometry is the thermal noise:

- **we are achieving thermal noise limits**, therefore
- stronger calibrators result in higher accuracy

MultiView relaxes constraints for target-calibrator angular separation:

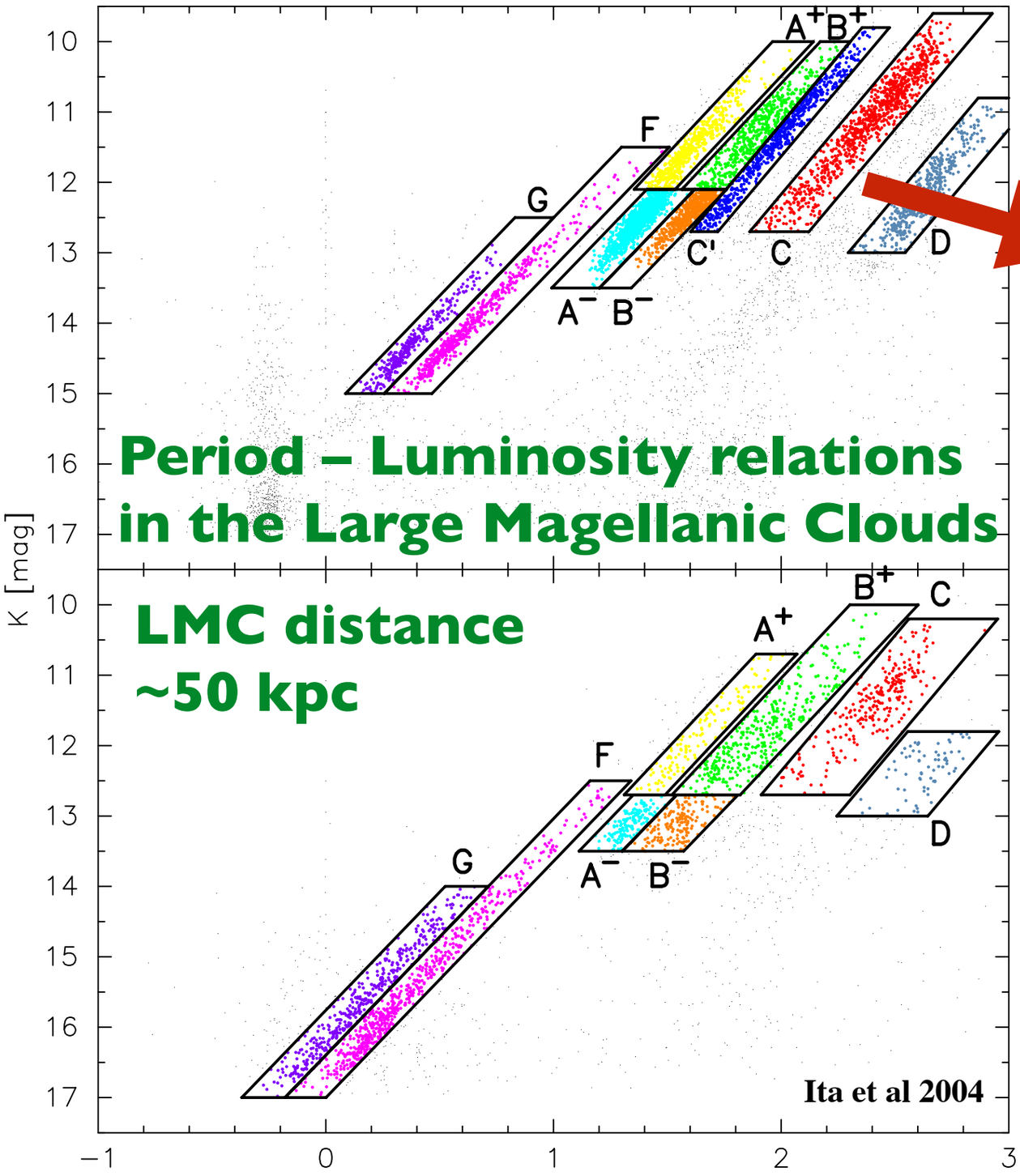
Multiple calibrators
a few degrees away
with MultiView

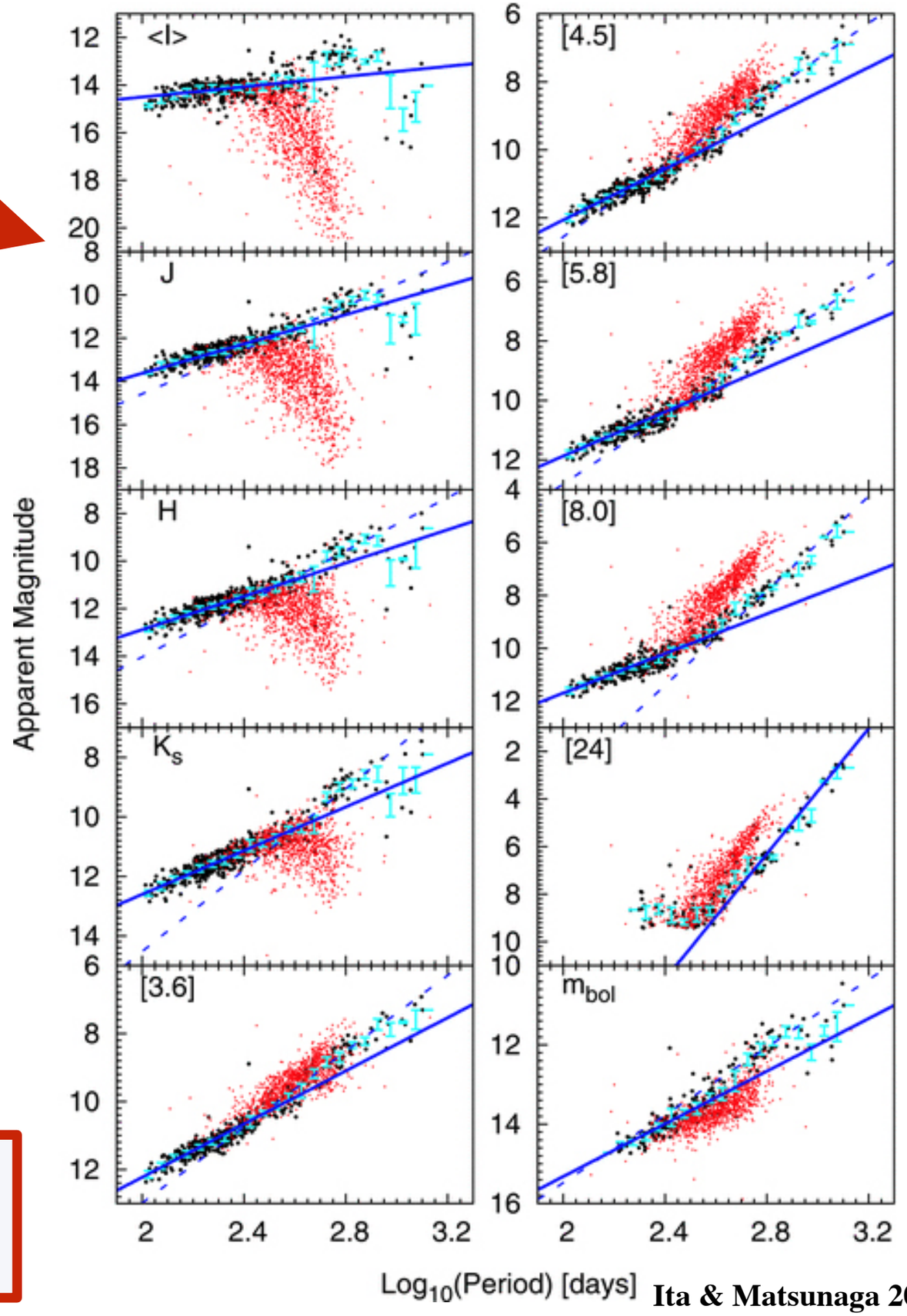
=

Single calibrator
in-beam (~10 arcmin)
with Phase Referencing

Close multiple in-beam calibrators even BETTER
Wider scientific applicability (I hope so…)

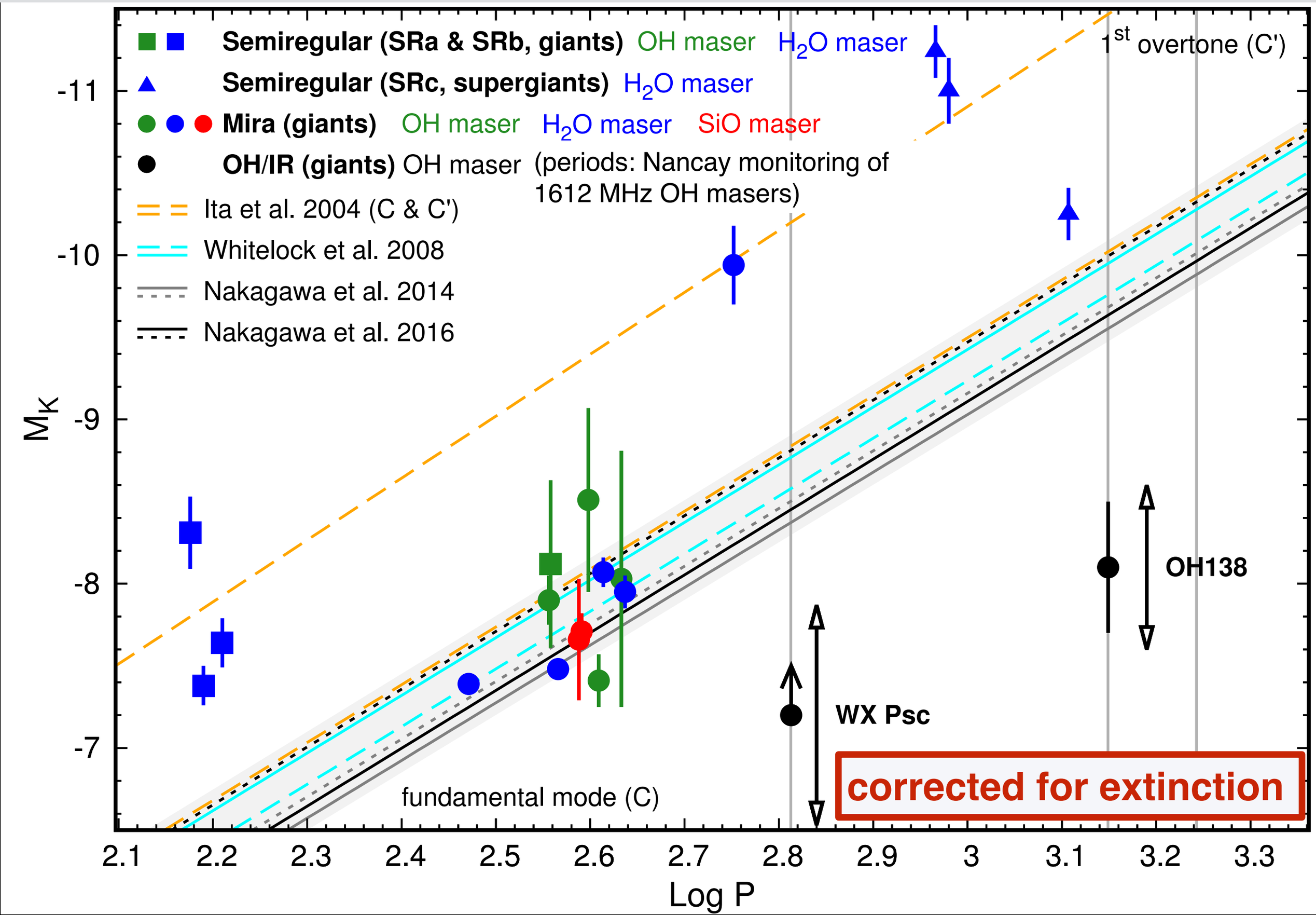
Period – Luminosity relation of AGB stars



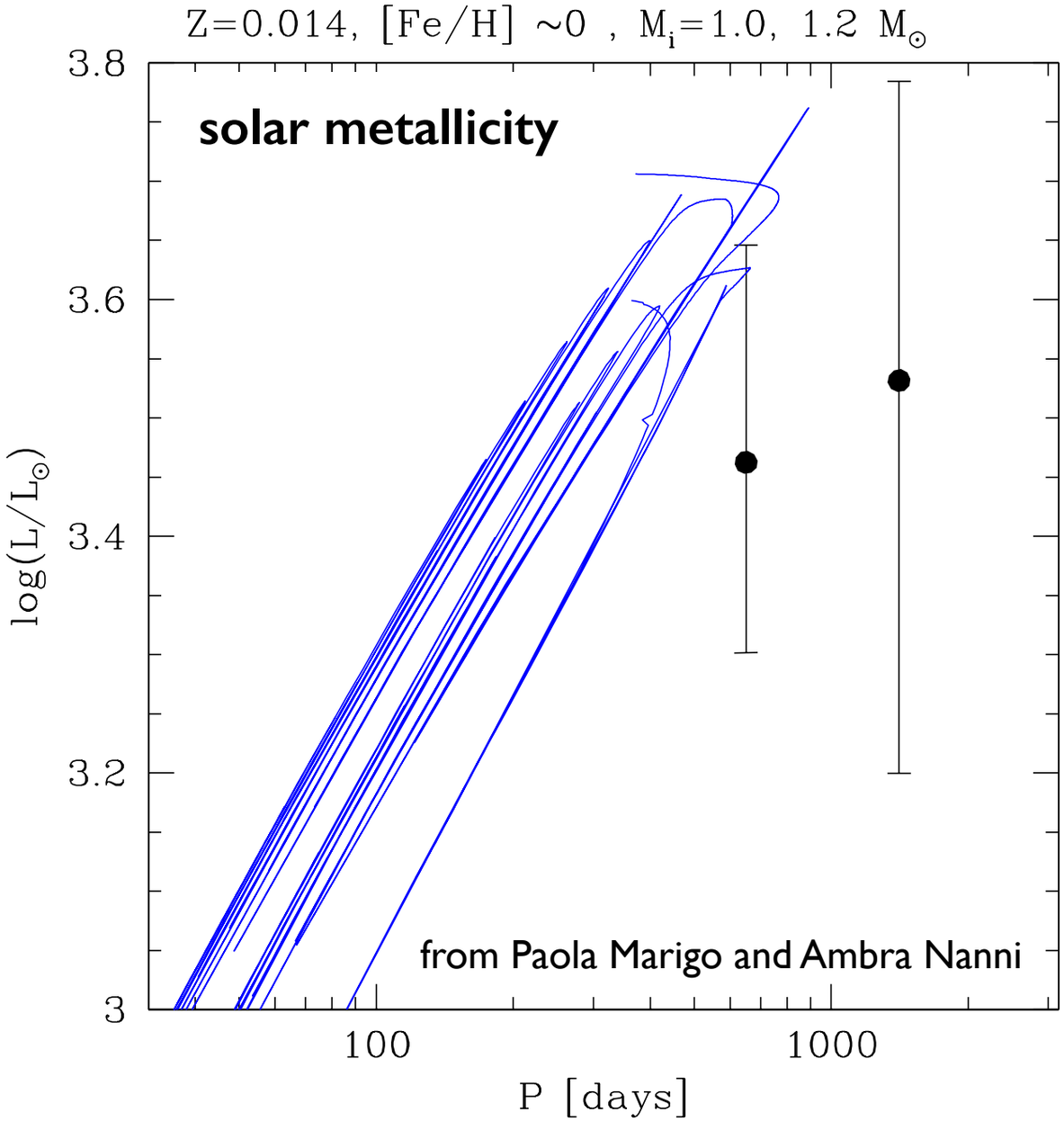


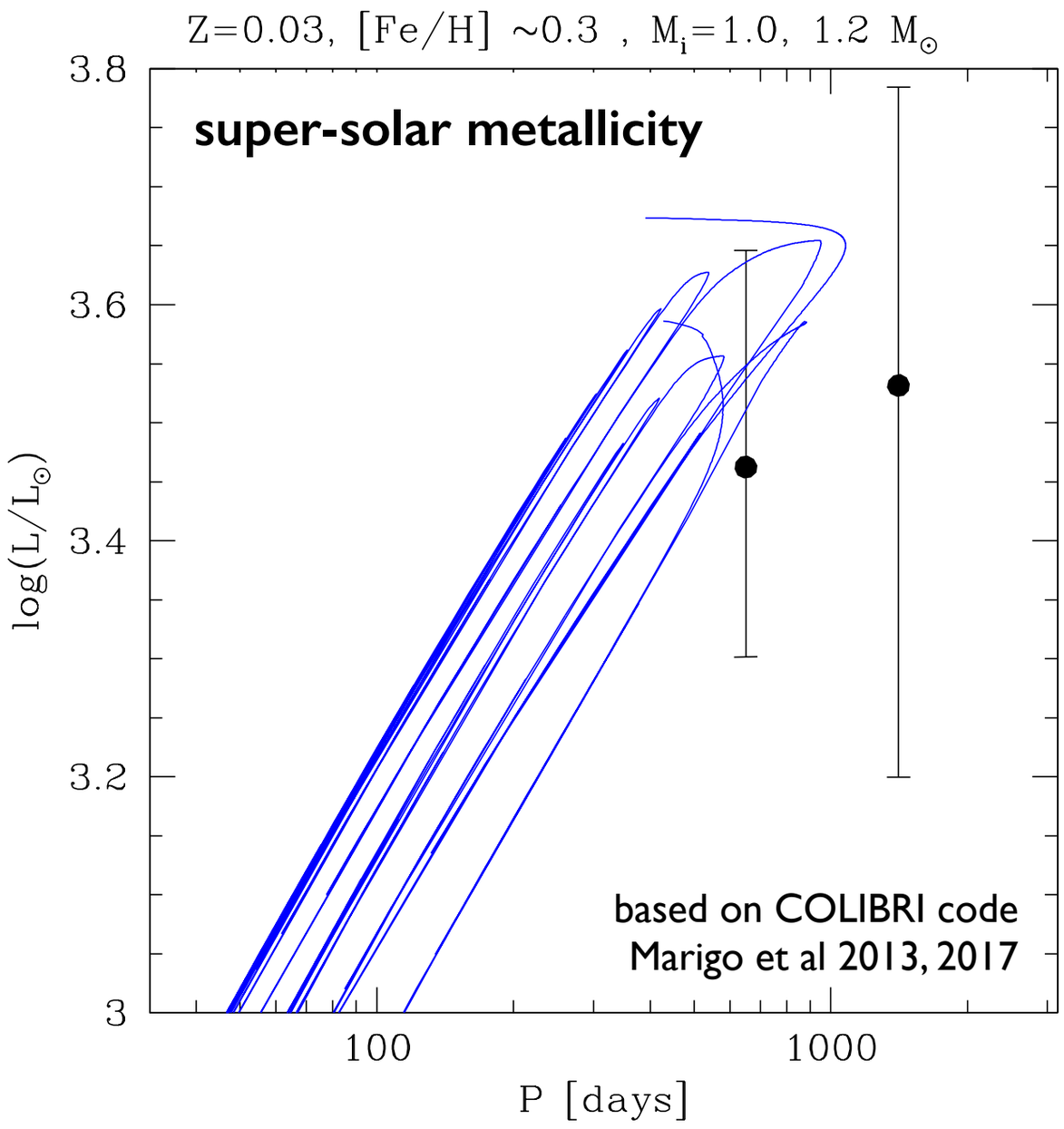
PL relation breaks at ~400 days for fundamental pulsators in the LMC

PL relation for long period variables



Constraining models of stellar evolution





Evolutionary tracks for initial masses of 1 - 1.2 M_{sun}

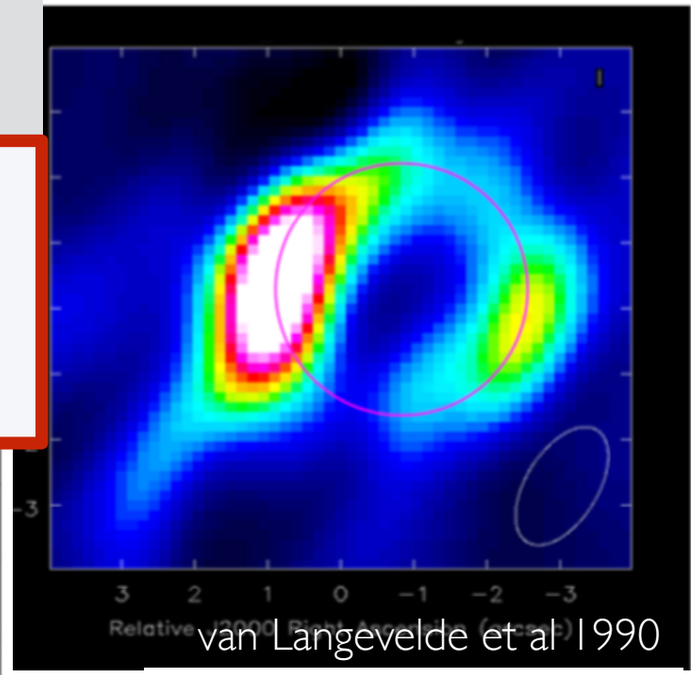
Assuming fundamental pulsation

Luminosities can be explained
Pulsation periods cannot (only C-rich stars could explain it)

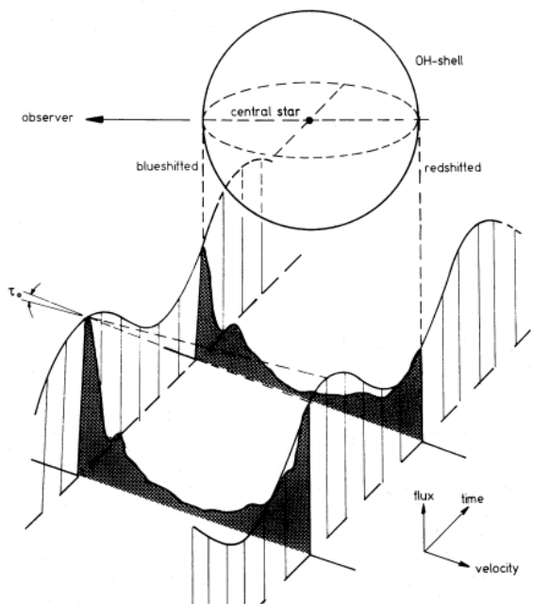
Phase-lag distance calibration

ϕ-lag distances don't need VLBI!
single dish for OH phase-lag
interferometry for size of OH shell

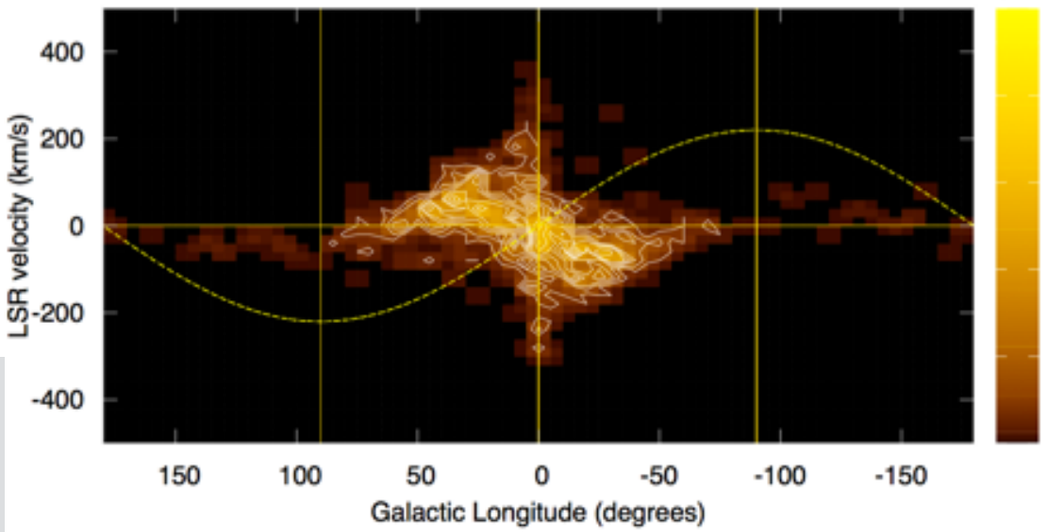
Engels et al 2015



van Langevelde et al 1990



OH/IR star density from Daniel Tafoya

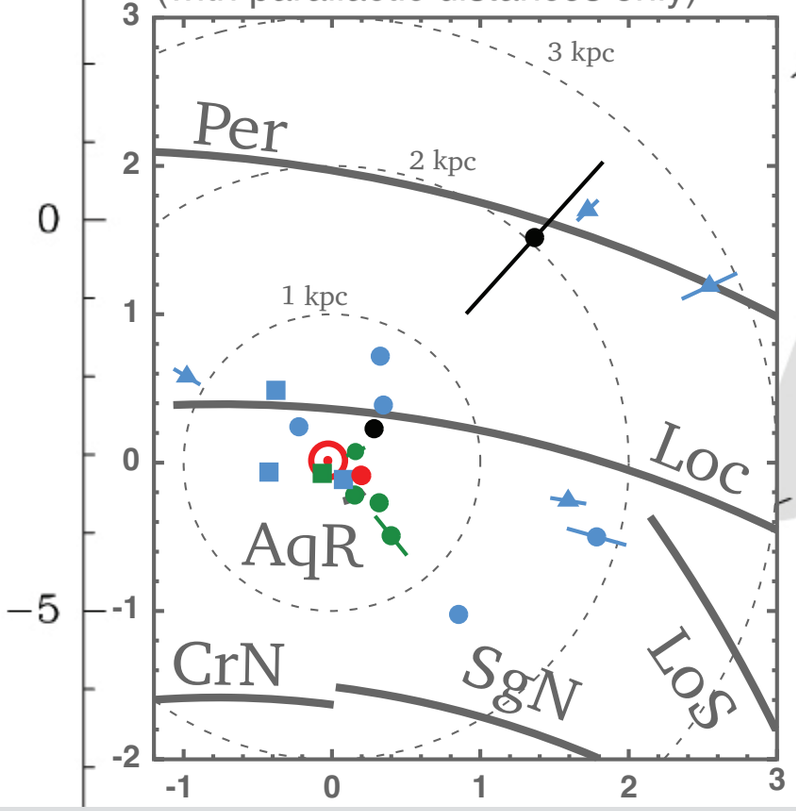


Semiregula
Semiregula
Mira (giants
OH/IR (gian
1612 MHz C
phase-lag (c

Maser molecule us
OH maser (1665 & 1667 MHz)
H_2O maser
SiO maser

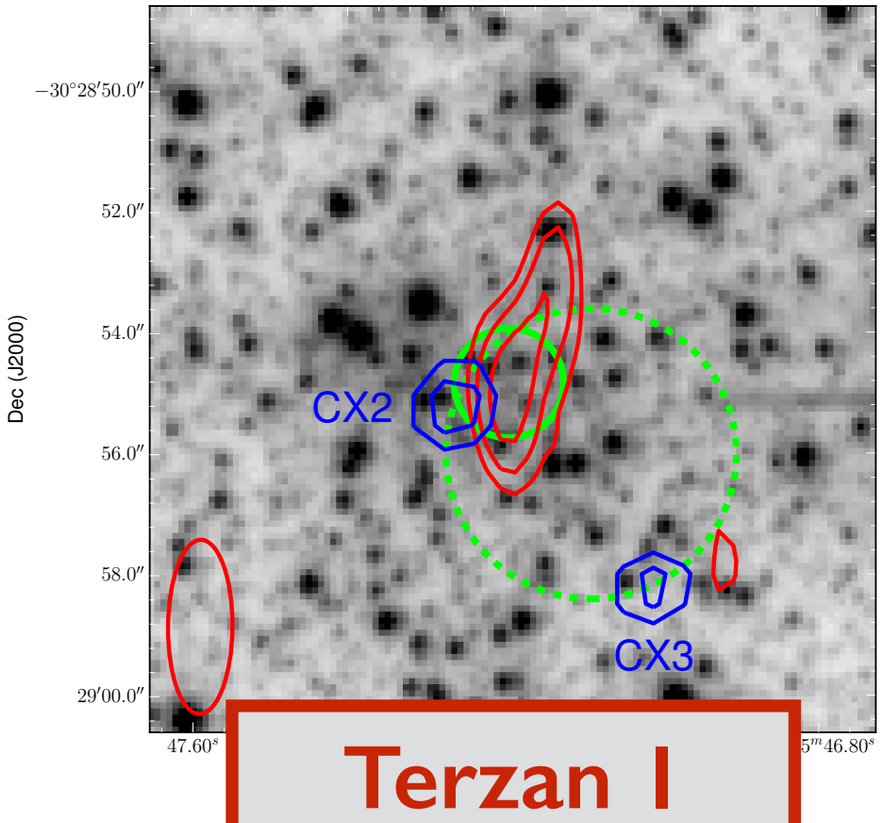
Reid et al 2016

Zoomed-in view of Solar region
(with parallactic distances only)

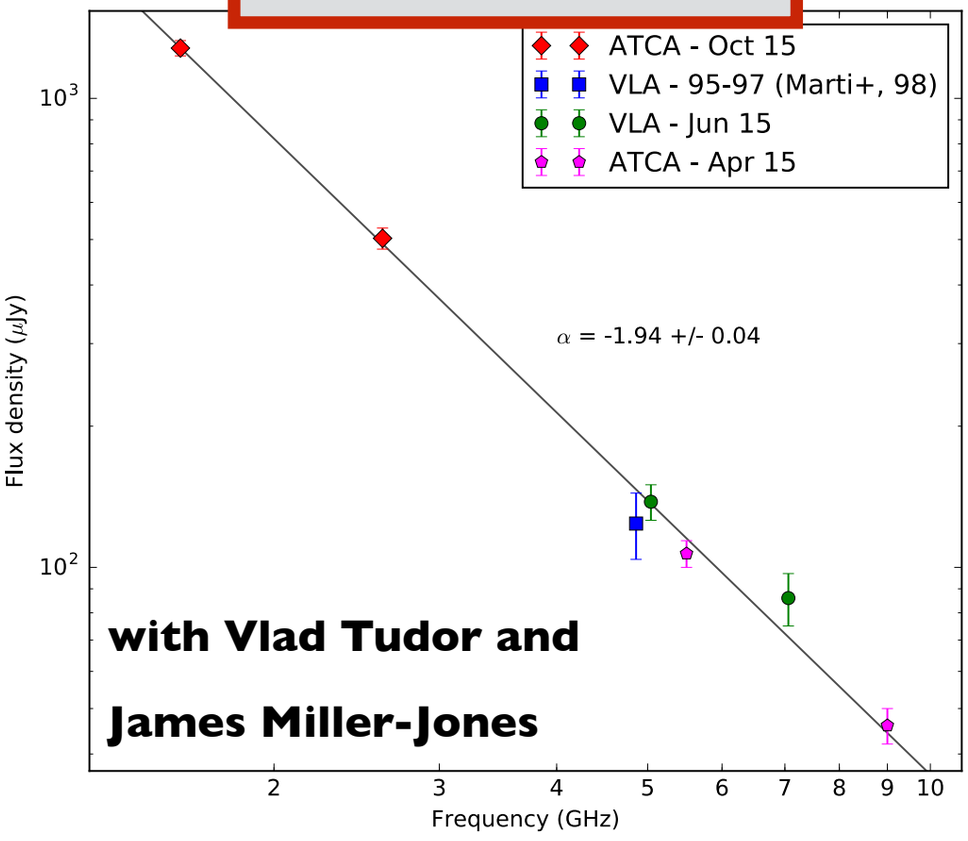


Galactic dynamics using AGBs

Applications in pulsar / radio continuum astrometry



Terzan I



with Vlad Tudor and

James Miller-Jones

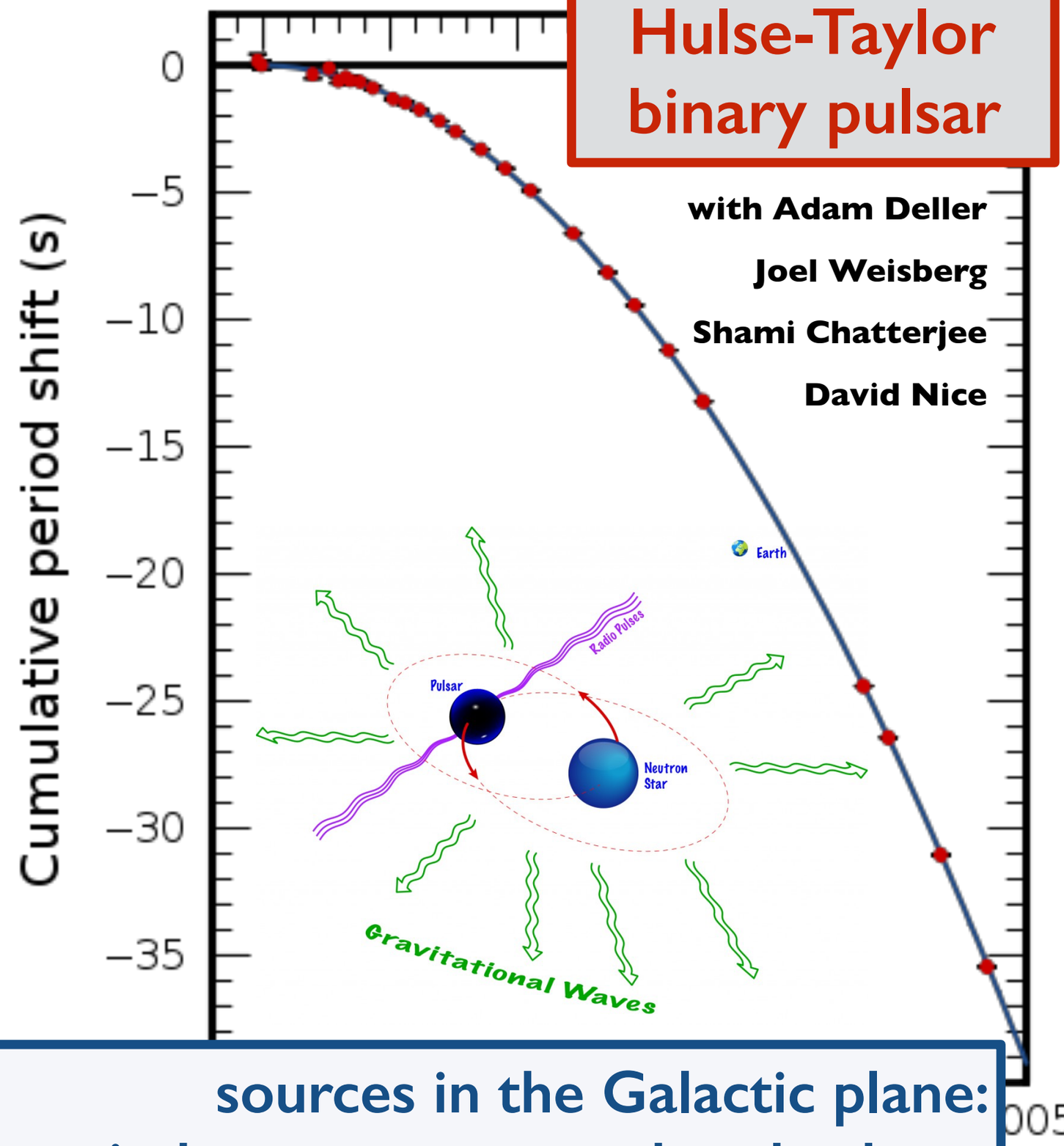
Hulse-Taylor binary pulsar

with Adam Deller

Joel Weisberg

Shami Chatterjee

David Nice



sources in the Galactic plane: in-beam astrometry breaks down

Applications in pulsar / radio continuum astrometry

Hulse-Taylor binary pulsar

Galactic acceleration terms have to be corrected for when comparing observations of orbital period derivatives to GR predictions: **we need to know Galactic parameters and source distance/prop. motion**

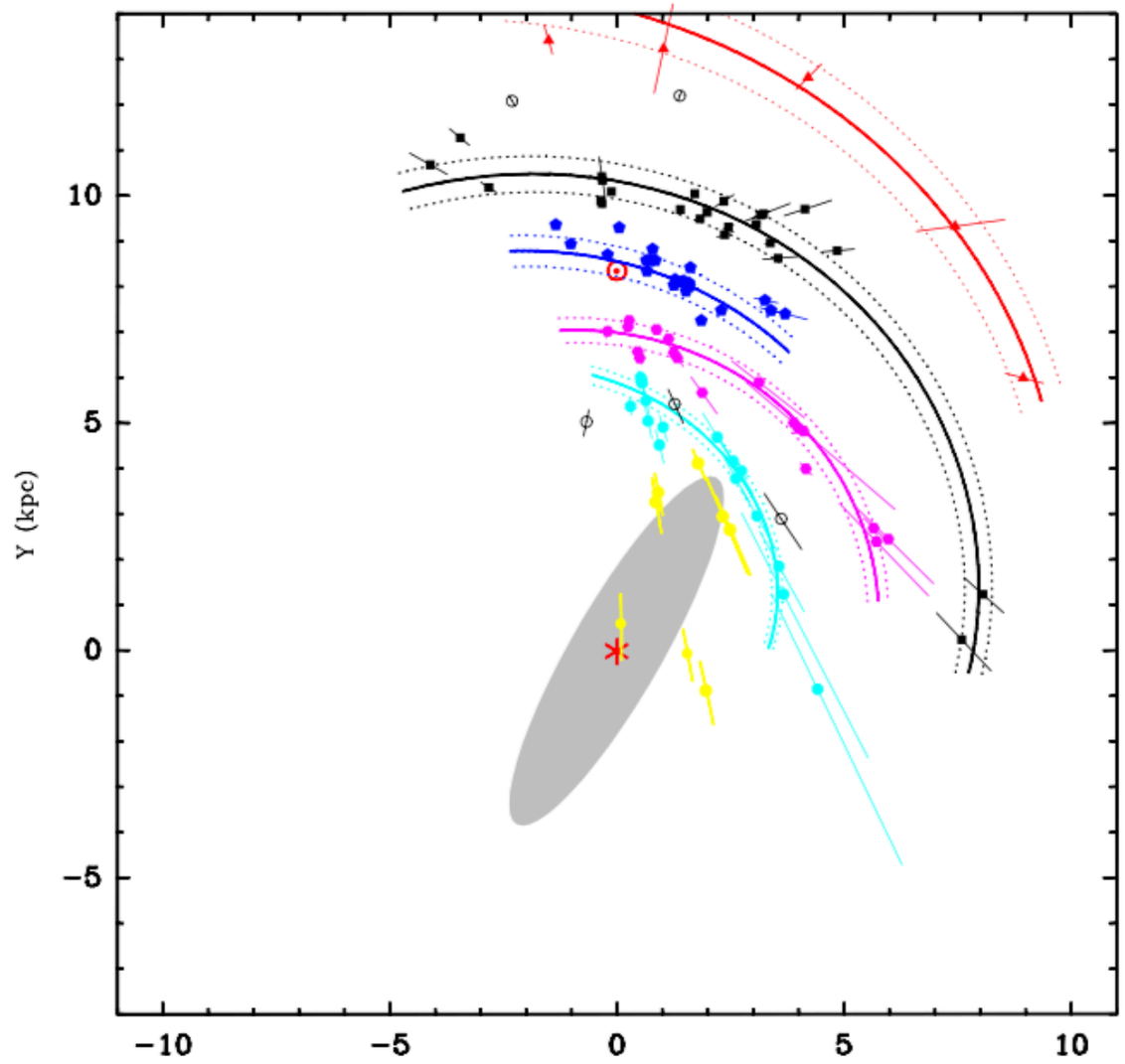
distance uncertainty is the main contributor to the error budget,
~1σ agreement now between GR model and observations
(Deller et al. 2017, in prep)

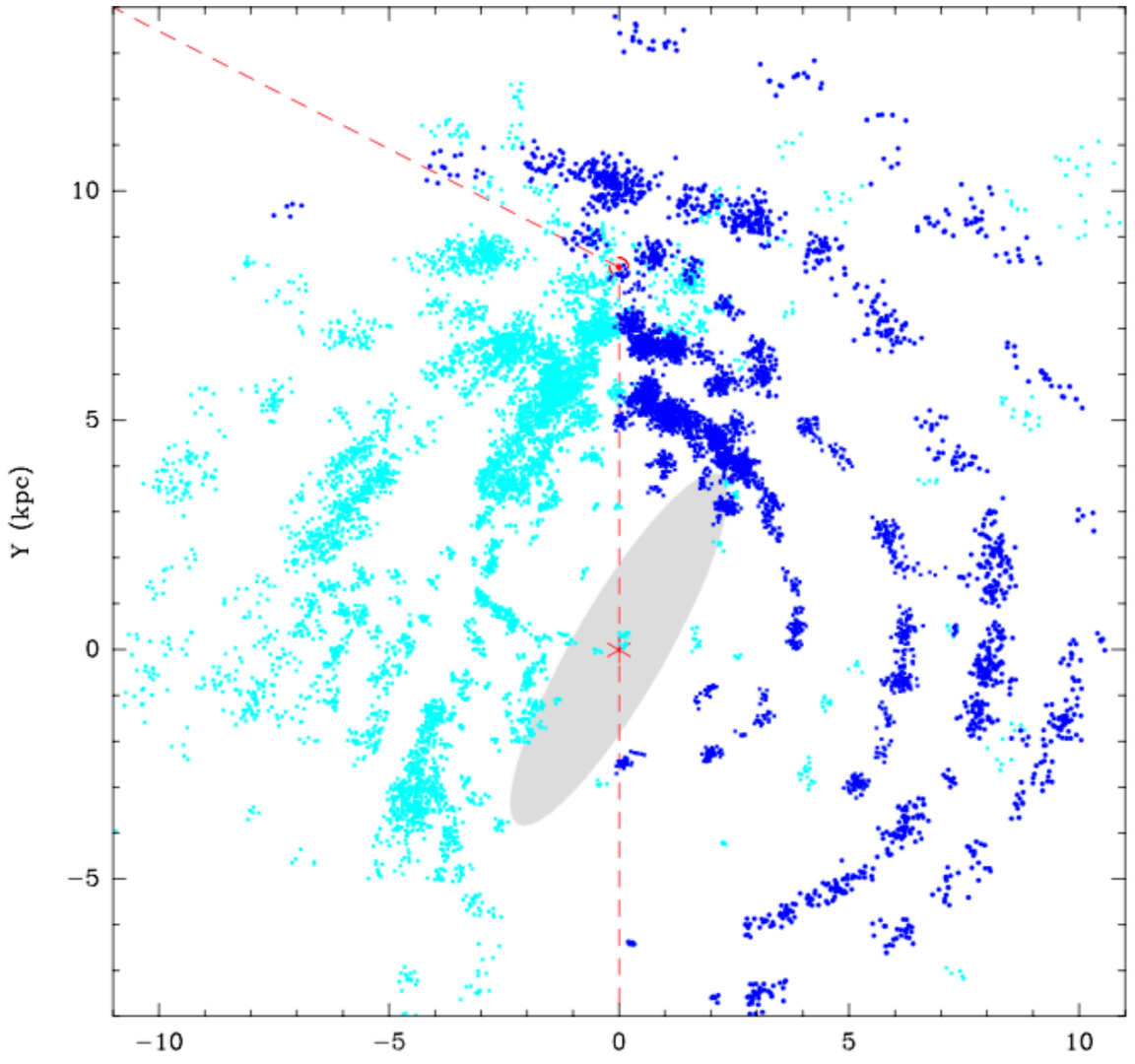
The ultimate MultiView test (VLBA BO54):

1. use the VLBI parallax to improve a test of GR

2. using GR as a test of the VLBI parallax measurements

sources in the Galactic plane:
in-beam astrometry breaks down





SπRALS

Southern Parallax Radio Astrometry Legacy Survey

1. Measure ~100 parallaxes to HMSFR
2. Use 6.7 methanol masers
3. Needs MultiView calibration
4. Use AuScope + Ceduna