Motivation for and Status of Portable Radio Science Receiver

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Overview

- Motivation for Portable VLBI recorder
  - Need 2nd southern site
  - Rapid interface to any compatible analog
  - ESA-NASA radio catalog, deltaDOR
- Plan

  Phase I: Build team, build Portable RSR
  Phase II: Test P-RSR at SPC 60
  PhaseIII: Test at ESA's Cebreros station
  PhaseIV: Test at ESA's Malargue, Argentina
- Hardware status:

  Unit designed, being assembled and tested

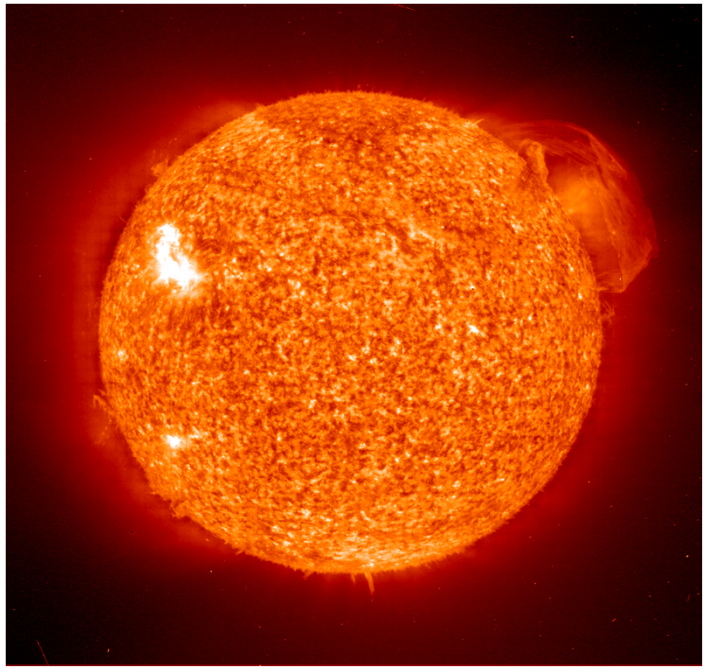
Motivation and Background for Portable RSR Project

Motivation for Ka-band: 9mm/32 GHz

- Astrometry, Geodesy and Deep Space navigation, have been at 3.6cm/8.4 GHz (X-band) with 2.3 GHz (S-band) plasma cals

Ka-band (9mm/32 GHz) provides

- More *compact* sources which should lead to more *stable* positions!
- Higher Telemetry Rates: +5 to +8 dB
- Smaller, lighter RF spacecraft systems
- Avoid S-band *RFI* issues
- Ionosphere & solar plasma down 15X !! at 32 GHz (Ka-band) compared to 8 GHz thus observe closer to Sun & Galactic center



Picture credit: SOHO/ESA/NASA

Drawbacks of Higher radio frequencies:

- More weather sensitive, higher system temp.
- Shorter coherence times
- Weaker sources, Many sources resolved
- Antenna Pointing more difficult

Improving VLBI

Systems Analysis shows dominant Errors are

- Limited SNR/sensitivity
  - already increased bit rates: 112 to 448 Mbps. Soon to 2048?
- Instrumentation: already building better hardware
  - Ka-band phase calibrators, Digital Back Ends (filters)
- Troposphere: better calibrations being explored

- **Weak geometry in Southern hemisphere**
  - Limits accuracy to about 1 nrad (200 μas) level
  - No observations below Declination of -45 Deg!
  - DSN at X/Ka has only Canberra, Australia (DSS 34)
  - Need 2nd site in the Southern hemisphere

    especially for upcoming southern ecliptic missions

How do we improve accuracy? Southern Coverage!

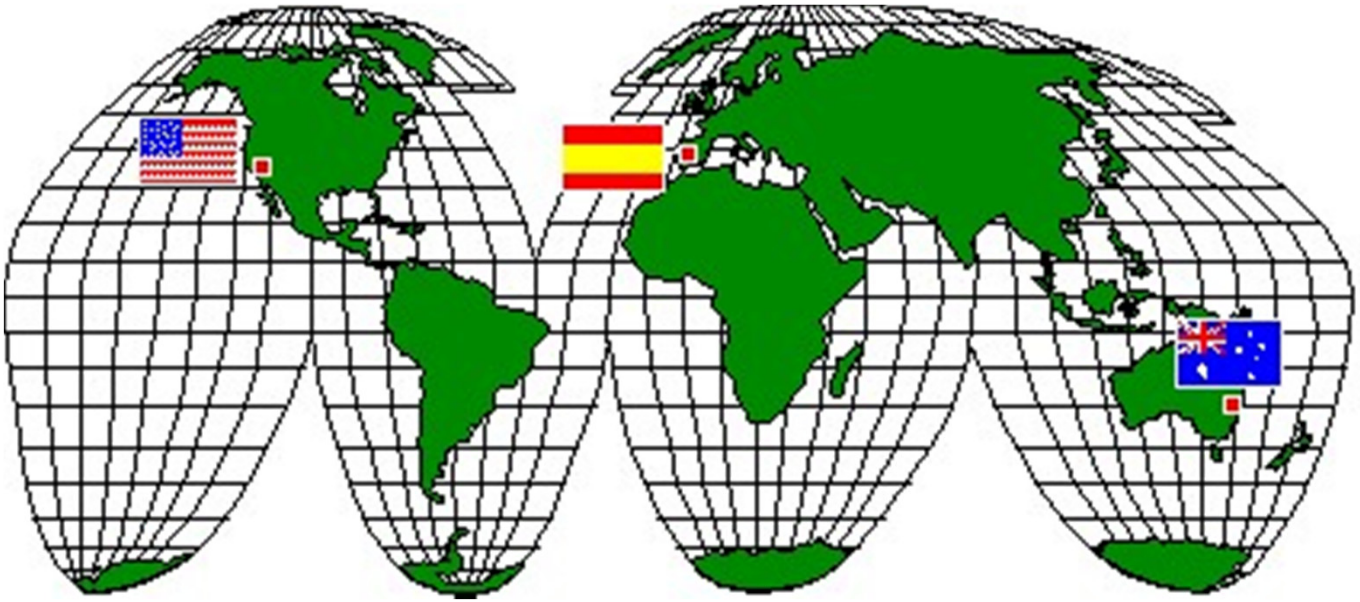
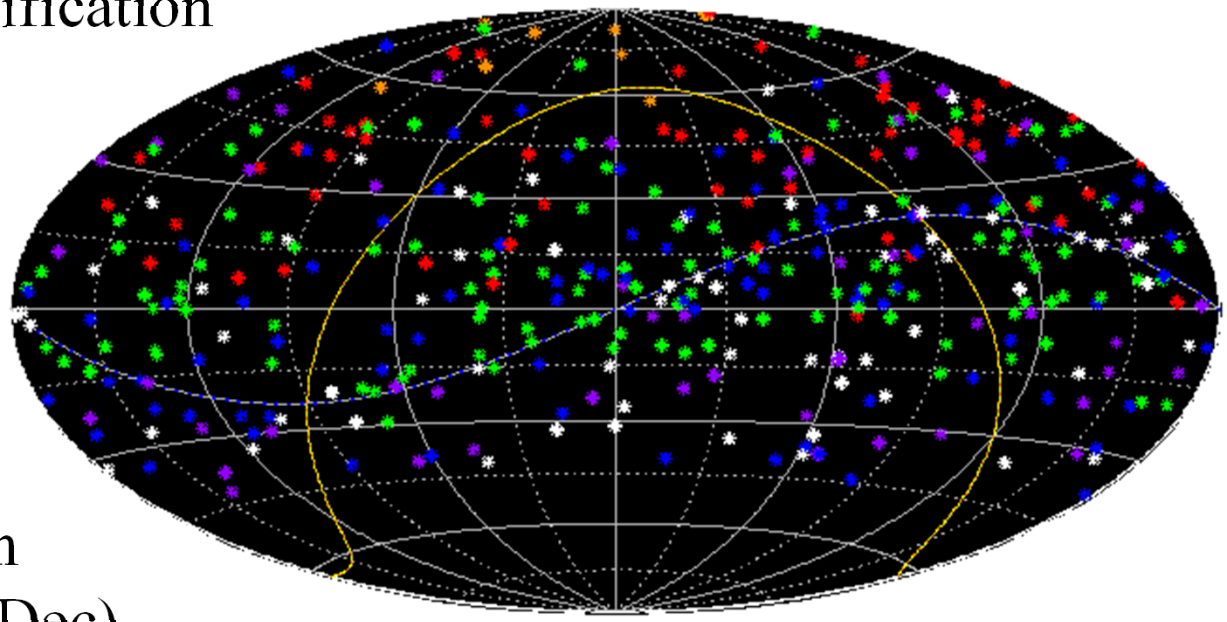


Figure credit: www.spacetoday.org/images/SolSys/DeepSpaceNetwork/NASA_DSN_WorldMap.gif

Celestial Frame needs the South

- No current Ka sources meet ΔDOR accuracy specification south of equator!

Current DSN X/Ka Frame



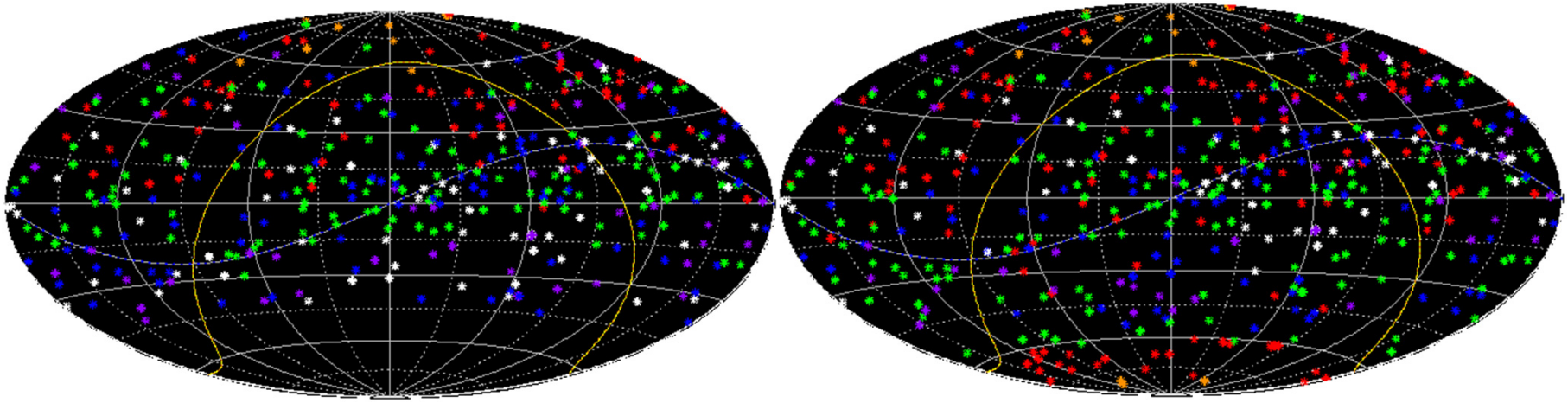
- No coverage of South polar cap (-45 to -90 Dec)

- DSN weakly covers southern Ecliptic: only one strong baseline as California-Spain is weak in south

Declination 1-sigma Uncertainty

Orange: 0.5 nrad meets future ΔDOR spec
Red: < 1.0 current ΔDOR spec
Green: < 1.5
Blue: < 2.5
Purple: < 5.0
White: > 5.0

Simulation of Added Southern Station



Before Southern Data *After*

Declination Sigma

Orange: < 100 μas
Red: < 200
Green: < 300
Blue: < 500
Purple: < 1000
White: > 1000

- 50 real X/Ka sessions augmented by simulated data
  simulate 1000 group delays, SNR = 50
  ~9000 km baseline: Australia to S. America or S. Africa

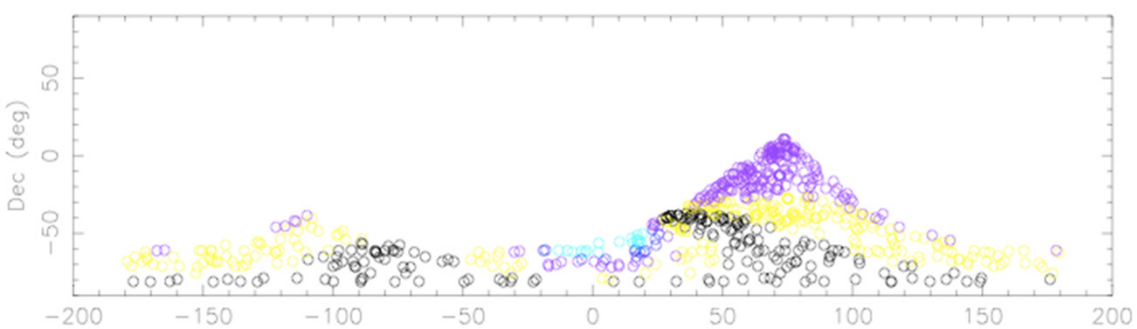
- Completes Declination coverage: cap region -45 to -90 deg
  200 μas (1 nrad) precision in south polar cap,
  mid south 200-1000 μas, all with just a few days observing.

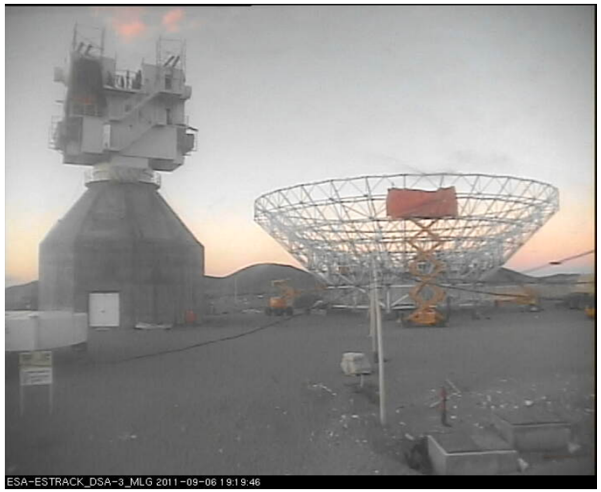
Benefit of ESA Stations

- ESA Deep Space Antennas (DSA-1, 2, 3)
  - Cebreros, Spain: only few km's from DSN Robledo/Madrid
    Ideal for testing ESA-DSN instrumental & procedural interfaces
  - New Norcia/Perth, Australia: 3000 km from DSN Canberra
    Online now. Covers +45 to -90 deg Dec, southern polar cap.
    No Ka-band until 2015
  - **Malargue, Argentina:** Ideal baseline, online ~mid-2012

ESA-DSN collaboration would provide:

- **9,500 km ESA-DSN X/Ka-band baseline**
- Dry desert site is good for Ka-band
- HA-Dec coverage: ESA-Malargue to DSN-Canberra from Declination +10 to -90 deg.

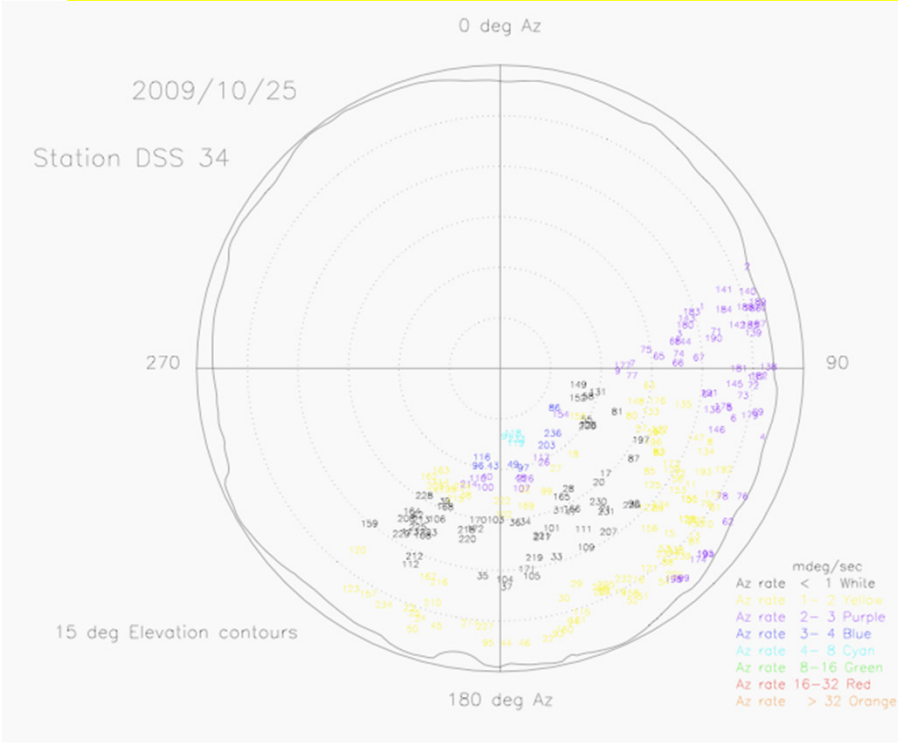


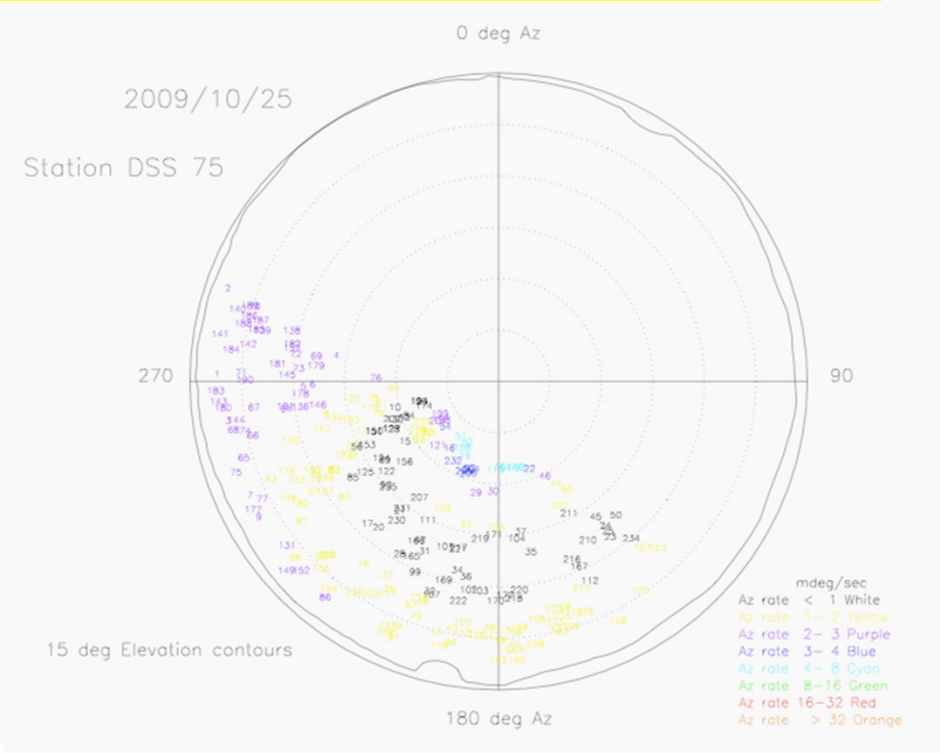


ESA Deep Space Antenna
35m, Ka-band capable
Visual status as of 2011 Sep 06

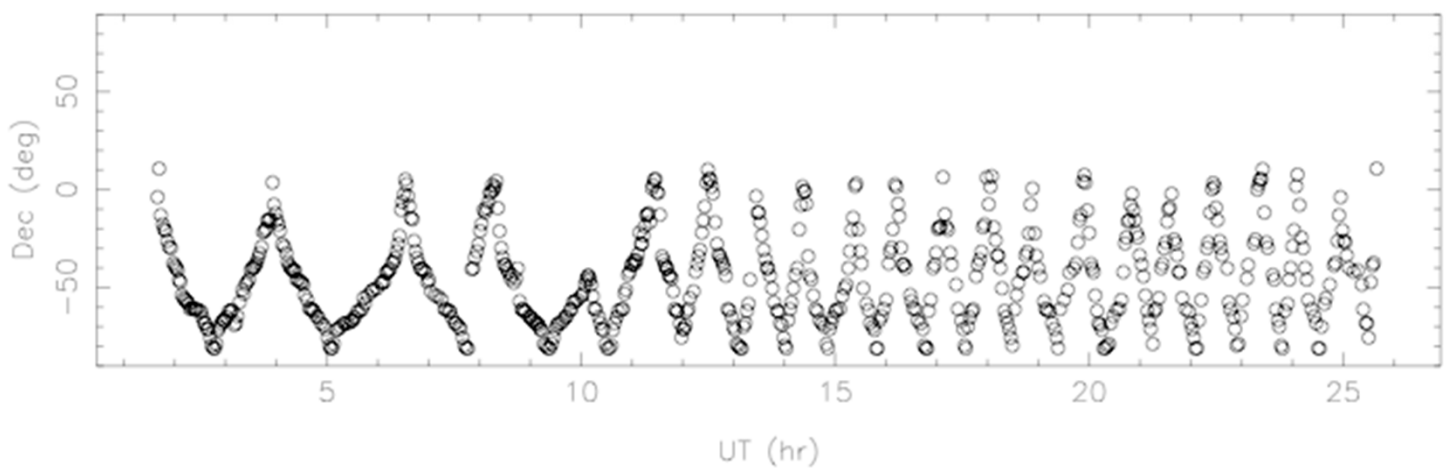
Credit: ESA
http://www.esa.int/esaMI/Operations/SEME9C19Y8G_0.html

DSS 34 to Malargue, Argentina (DSA-3)





Simulated Schedule:
Dec +10 deg to –90 deg



Collaboration Plan

- Phase I: Build collaboration team

  Build Portable RSR hardware to record VLBI data
- Phase II: Test procedural and instrumental interfaces using P-RSR

  Lead: C. Garcia-Miro, I. Sotuela. Currently in planning stages.

  Cebreros (DSA-2) to Robledo (DSS 55)

- Phase III: extend coverage to southern polar cap

  Lead: S. Horiuchi. Currently in planning stages.

  New Norcia (DSA-1) to Canberra (DSS 34) no Ka until 2015

  Collaborate with ATCA, Mopra, or AuScope?
- Phase IV: Improve accuracy to sub nano-radian

  Malargue (DSA-3) to Canberra (DSS 34): South polar cap & mid-south

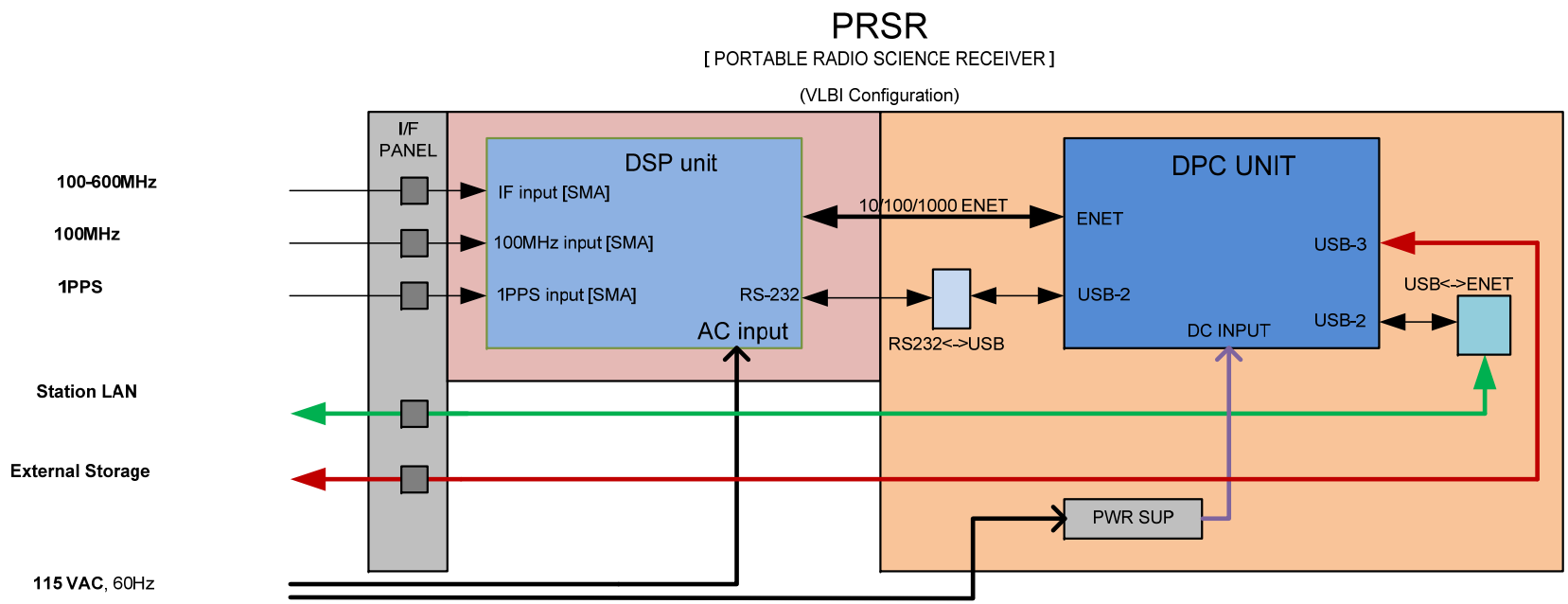
  Malargue (DSA-3) to California (DSS 25), augments mid-south

  Target date: mid-2012 when Malargue, Argentina comes online

Portable RSR Status

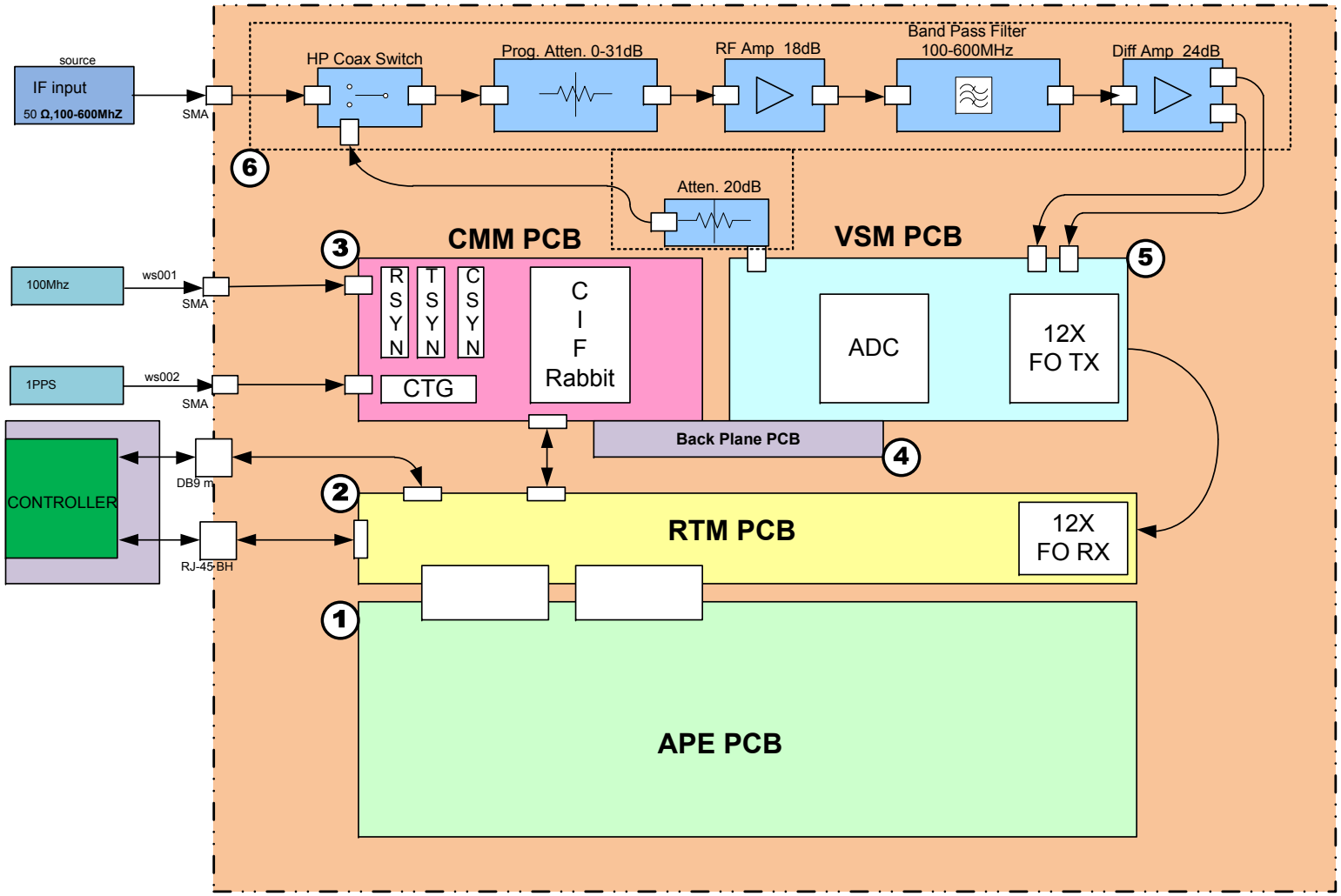
Portable RSR **Status**

- Block diagram PRSR System



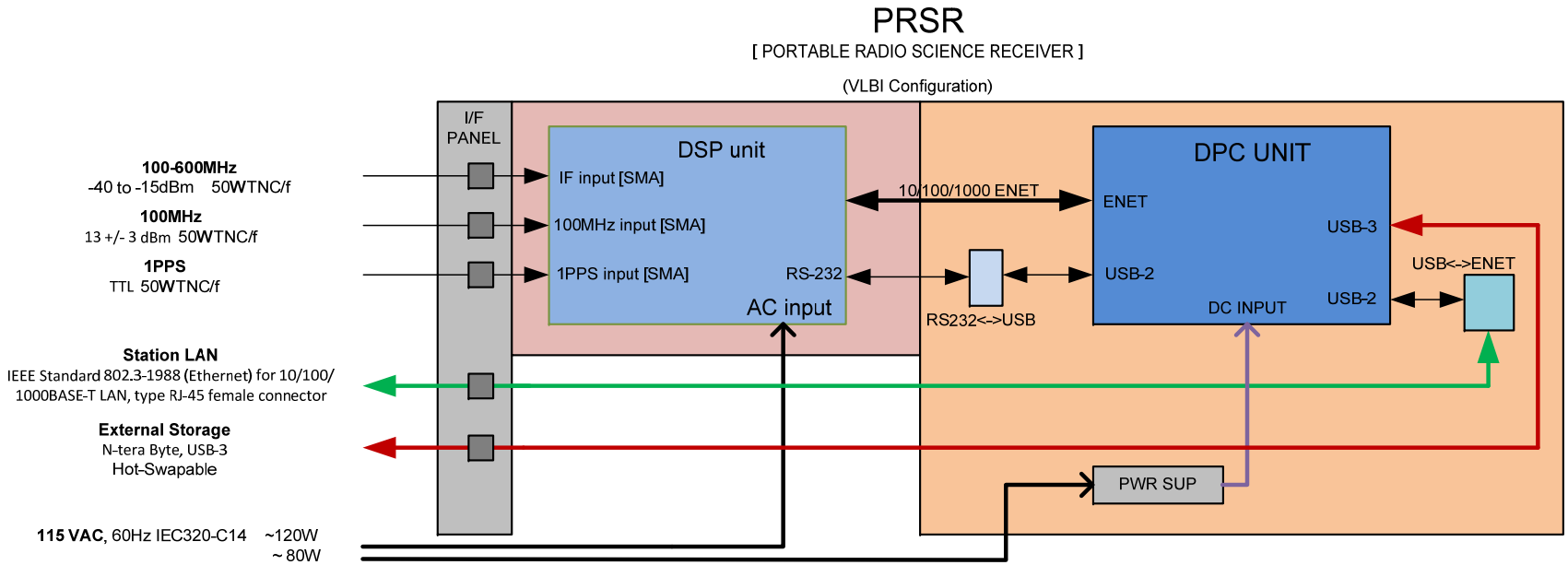
Portable RSR Status

- Block diagram DSP unit



Portable RSR Status

- Signal interface: AC power, 1PPS, 100 MHz, IF



Portable RSR Status

- Photos of hardware being assembled
- DSP Unit

DPC Unit

Portable RSR Status

- Photos of hardware being Tested

Conclusions

- Future tracking is moving to Ka-band: +5 to 8dB telemetry
- Quasar astrophysics: Ka-band is better than X-band
- However, DSN lacks 2nd southern station
- ESA and DSN have *complementary* geometry

  ESA- DSN collaboration has potential for

  Full sky coverage, Sub-nano-radian accuracy

- Portable RSR hardware being built to bridge ESA-DSN

- Benefits to ESA and DSN collaboration:

  ΔDOR: increased accuracy and long term stability

  Ties ESA-DSN reference frames for inter-operability

  Increased weather immunity for critical events

  Potential sub-nrad tie of Gaia optical to radio frame

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BACKUP Slides

Space Navigation:

Historical Perspective

Paradigm of "Sailing by the stars"

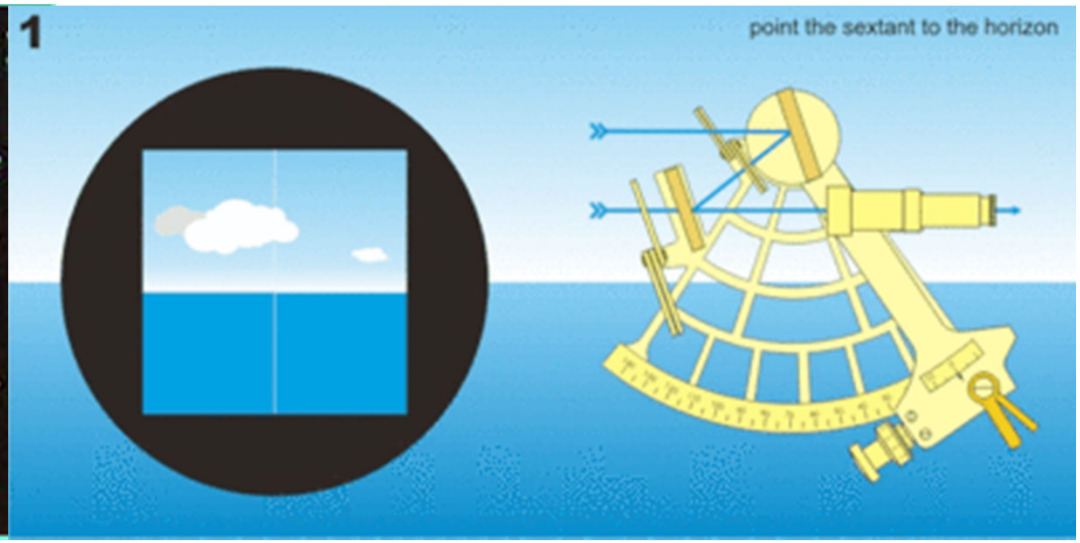


Photo Credit: Dimitry Bobroff, www.ludmillaalexander.com

Credit for sextent/octant: en.wikipedia.org/wiki/Sextant (GNU Free Doc license)

Background: History of Astrometry

130 B.C.	Hipparchus	Precession	50 asec/yr
Telescope era:			
1718 A.D.	Halley	proper motions	1 asec/yr
1729	Bradley	annual aberration	20 asec
1730	Bradley	18.6yr nutation	9 asec
1838	Bessell	parallax	~ asec
1930s	Jansky, Reber	Radio astronomy	
1960s	*several groups*	Very Long Baseline Interferometry (VLBI) invented	
1970s	"	VLBI	sub-asec
1980s	"	"	few 0.001 asec
1990s	"	"	< 0.001 asec
2000s	"	"	~0.0001 asec
2010s	GAIA,SIM	Optical astrometry	70 μas for Vmag=18 quasar
2010s	ESA-DSN?	X/Ka VLBI	20-70 μas? 0.3 Jy quasar

How Does VLBI Work?

Point Source at Infinity as Reference Beacon

How does VLBI work?

- **Point source at infinity as a direction reference**

  Extragalactic "nebulae" idea from

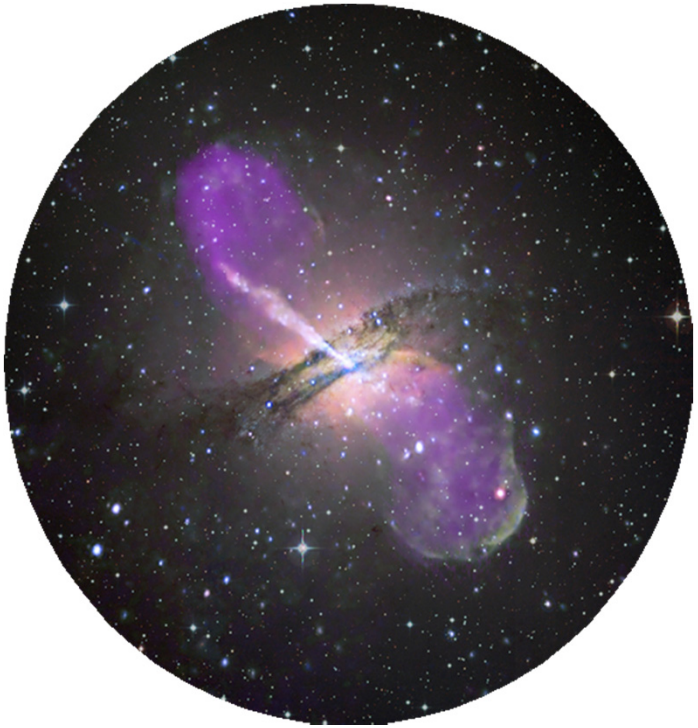
  Laplace (1749-1827) and

  Wm. Herschel (1738-1822): *in 1785*

  realized that "nebulae" likely very distant

  `On the Construction of the Heavens,' Ph.Trans.Roy.Soc., 1785, p. 213 ff.

- **Advantage: sources don't move**



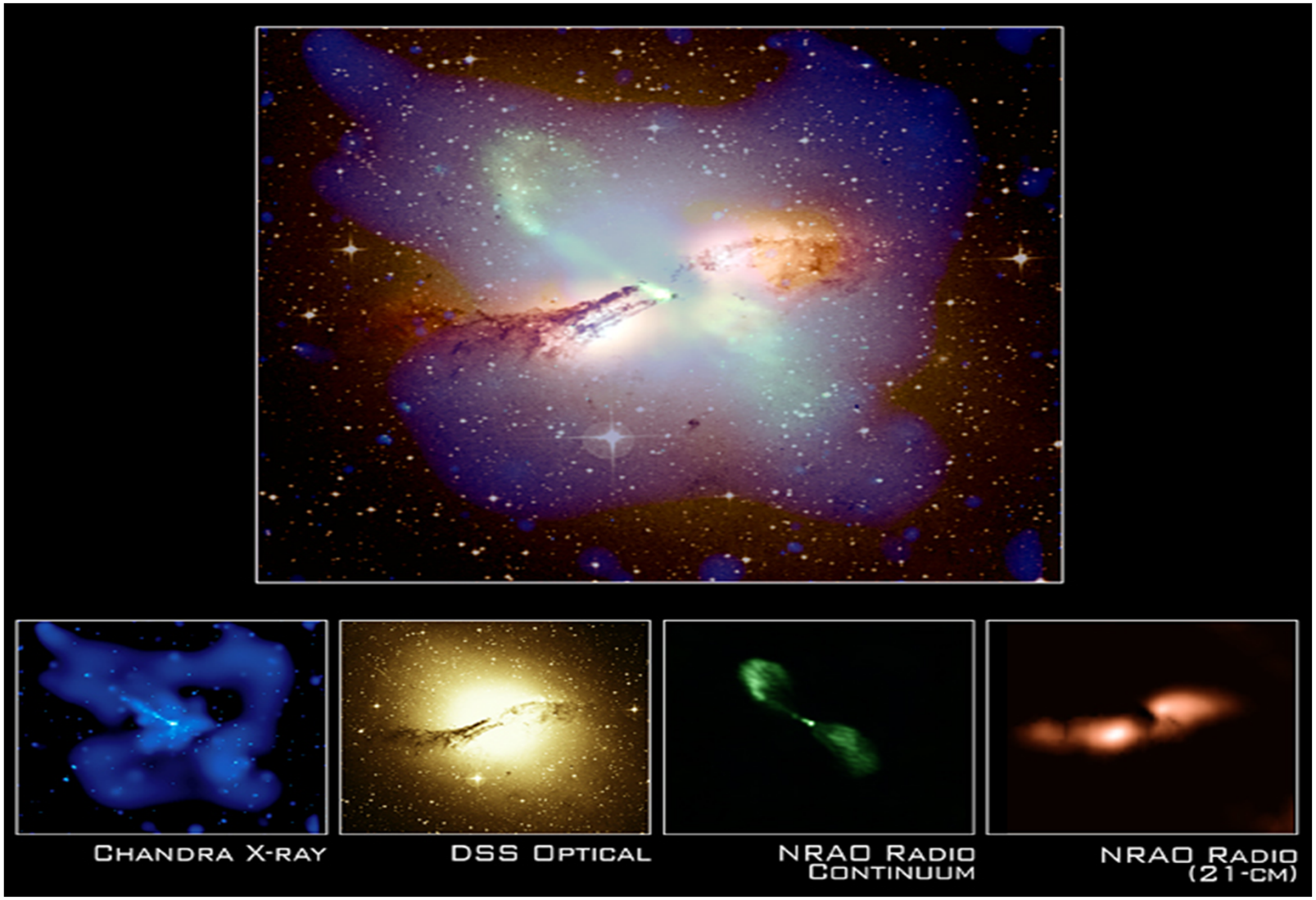
Credit: chandra.harvard.edu/photo/2008/cena/cena_multi.jpg

BUT at a distance of a *billion* light years . . .

- **The price to be paid is**

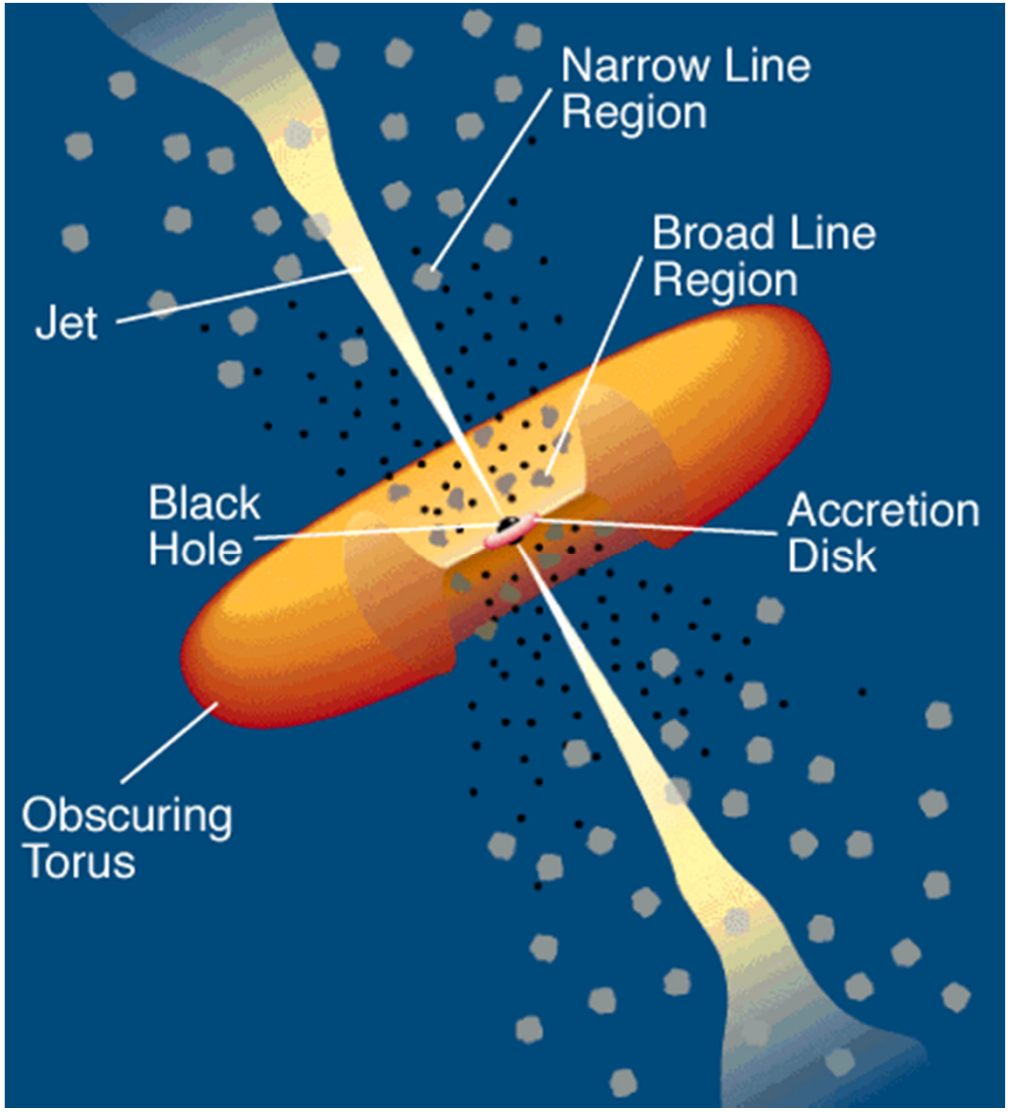
Very weak sources	**1 Jy = 1.0E-26 watt/m**2/Hz**
need lots of square meters	**=> 34 - 70m Antenna**
lots of Hz bandwidth	**=> 0.1 to 4 Gbps**
low system temperature	**=> Tsys = 20 - 40 Kelvin**

AGN Centaurus-A in X-ray, Optical, Radio



Credits: X-ray (NASA/CXC/M. Karovska et al.); Radio 21-cm image (NRAO/VLA/Schiminovich, et al.), Radio continuum image (NRAO/VLA/J.Condon et al.); Optical (Digitized Sky Survey U.K. Schmidt Image/STScI)

Active Galatic Nuclei (AGN) schematic



http://heasarc.gsfc.nasa.gov/docs/objects/agn/agn_model.html

Credit: C.M. Urry and P. Padovani

Schematic of
Active Galactic Nuclei
Redshift z~ 0.1 to 5
Distance:
billions light years
Parallax = 0
Proper motion
< 0.1 nrad/yr

Centroid of radiation
Gets closer to central
engine (black hole)
As one goes to higher
frequencies, therefore,

Ka-band (9mm, 32 GHz)
is better than
X-band (3.6cm, 8.4 GHz)

ΔDOR accuracy depends on Quasar frame

ΔDOR VLBI
is station differenced range referred to a quasar position.

- Measures geometric delay by cross-correlating signal from two (2) stations
- Double-differencing cancels large portion of common error sources

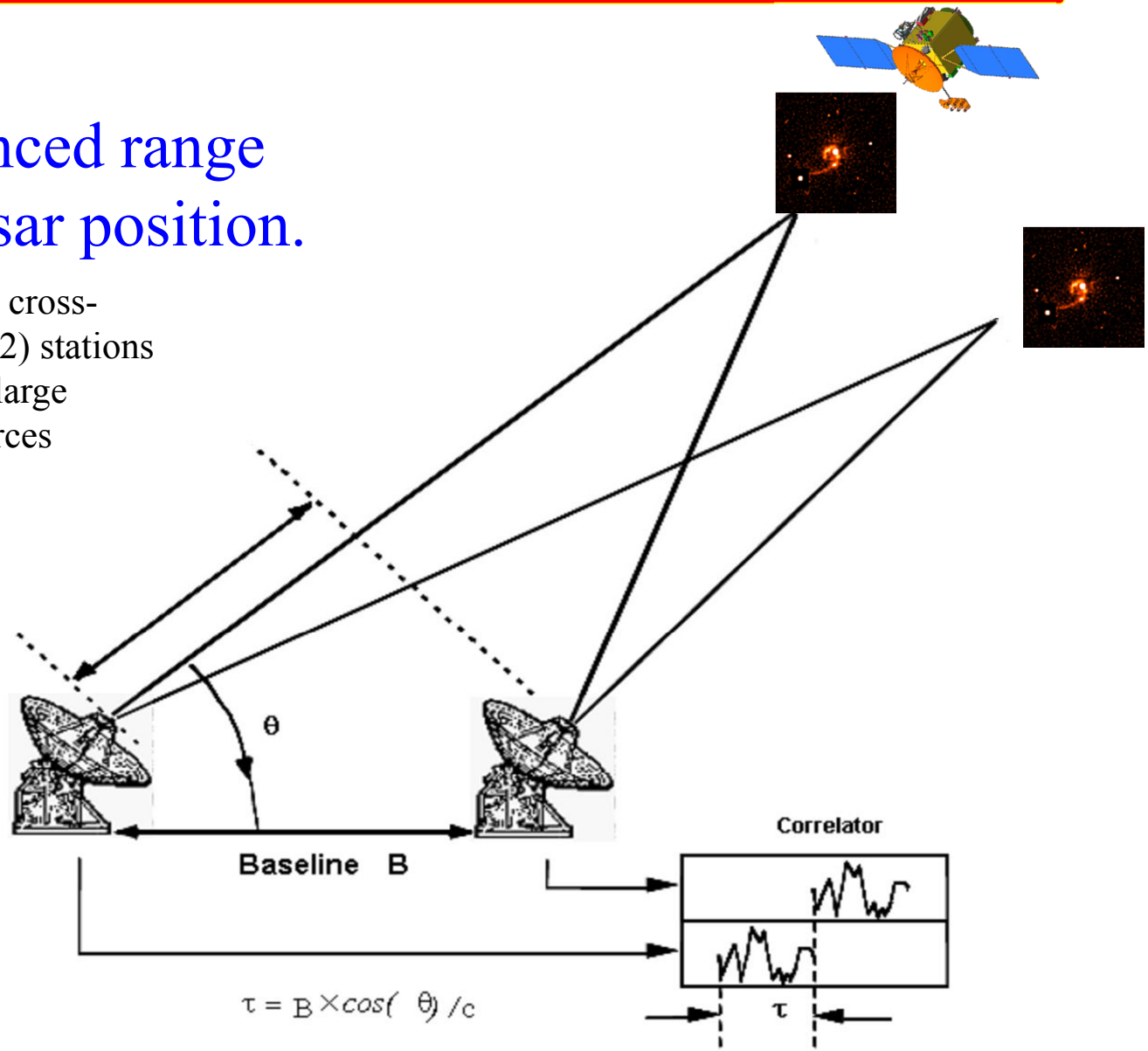
  -instrumental effects

  -baseline uncertainty

  -clock errors

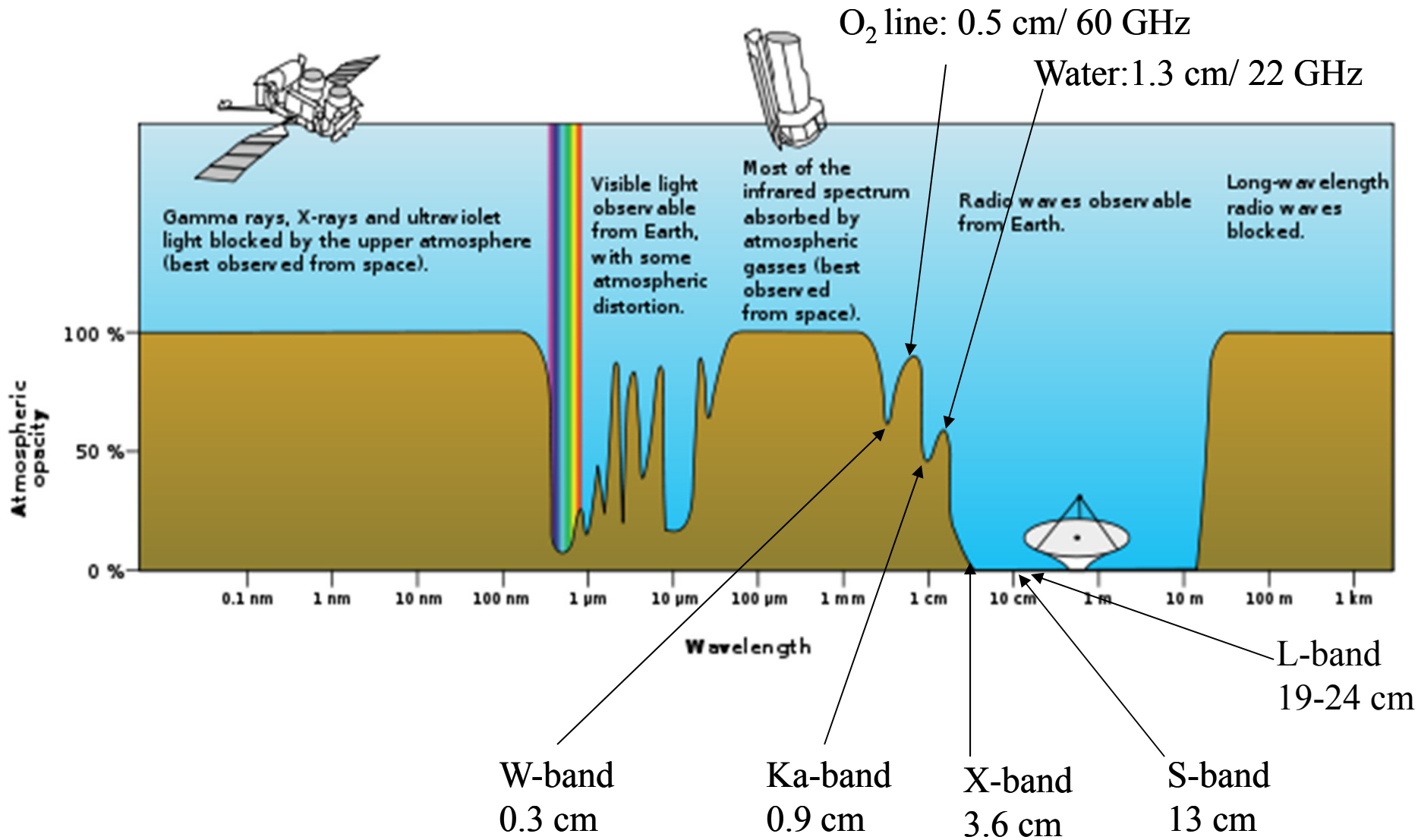
  -media effects

- ***Accuracy from apriori quasar position***



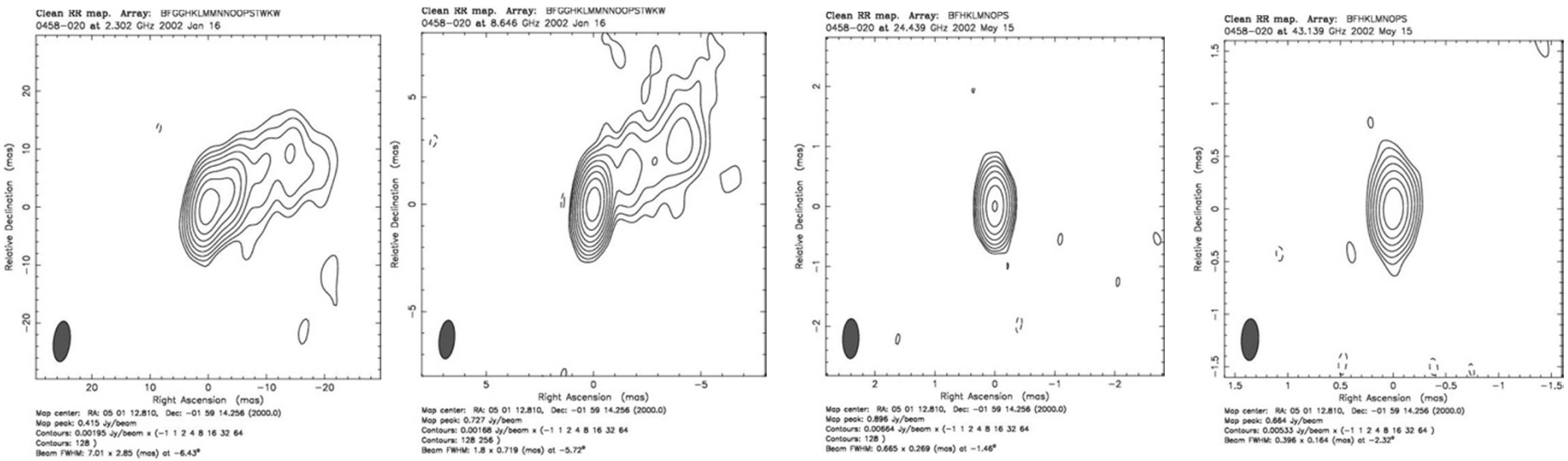
Credit: J.S.Border, C.D Edwards, J.E. Patterson, D. Shin

Ka-band: on the edge of the Radio Window



Credit: NASA; http://en.wikipedia.org/wiki/Radio_window

Source Structure vs. Wavelength



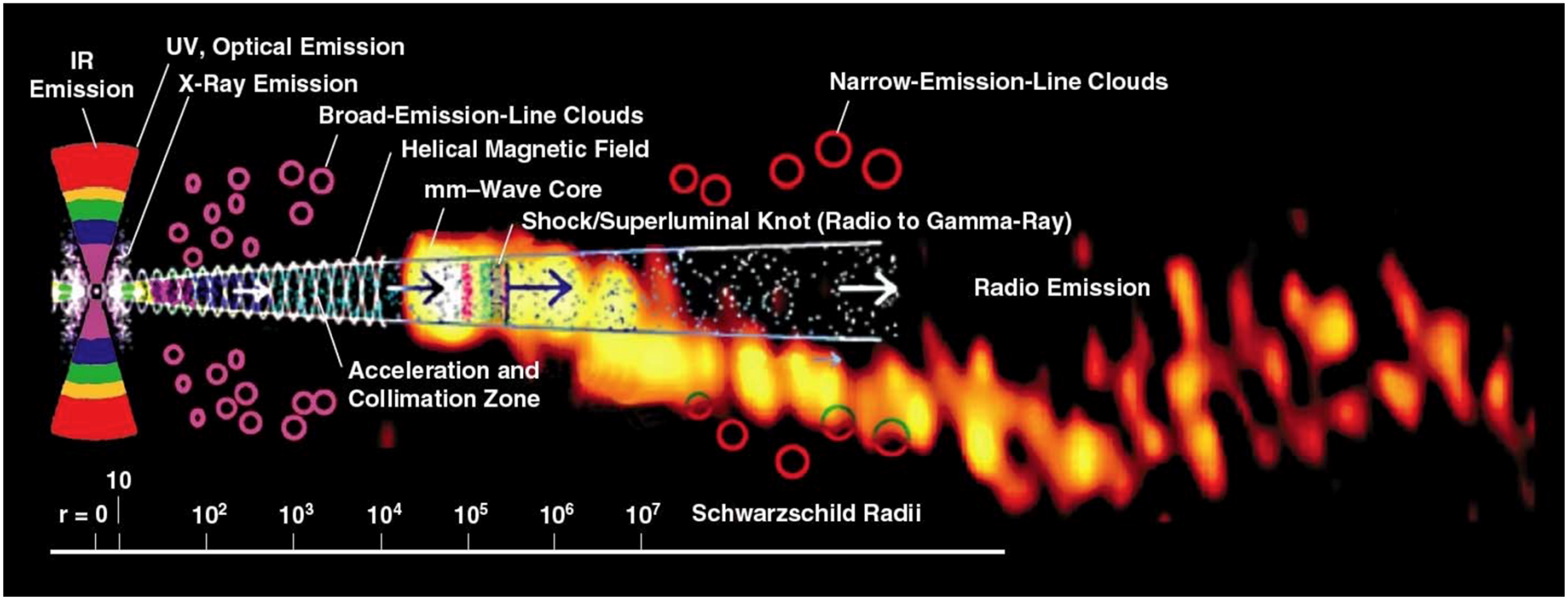
S-band	X-band	K-band	Q-band
2.3 GHz	8.6 GHz	24 GHz	43 GHz
13.6cm	3.6cm	1.2cm	0.7cm

The sources become better ----->

Ka-band
32 GHz
0.9cm

Image credit: P. Charlot et al, AJ, 139, 5, 2010

Ka vs. X-band? Core shift & structure



Credit: Marscher, Proc. Sci., Italy, 2006
Krichbaum et al, IRAM, 1999
Wehrle et al, ASTRO-2010

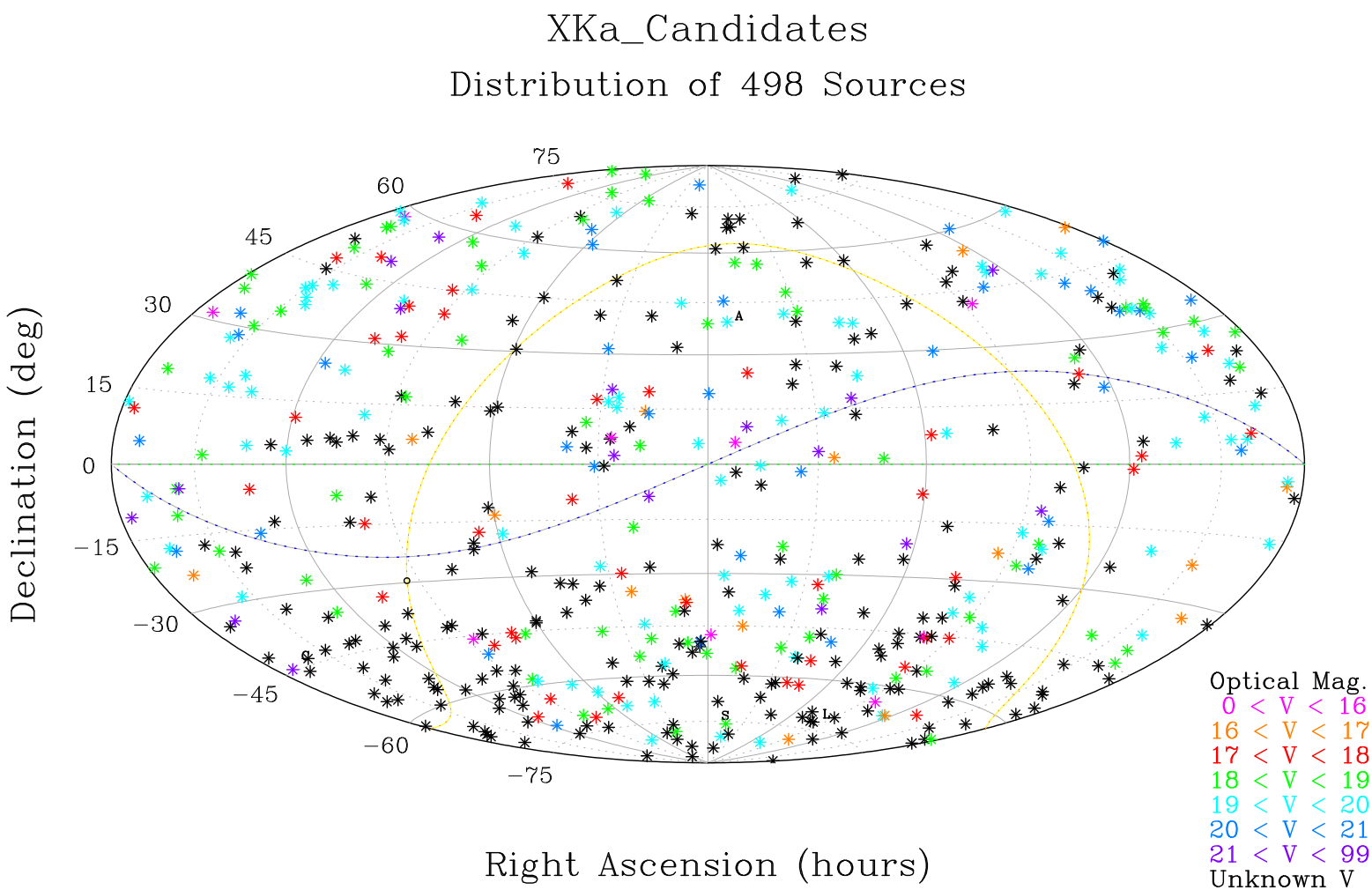
Positions differences from 'core shift'

- wavelength dependent shift in radio centroid.
- *3.6cm (X) to 9mm (Ka) core shift:*

  100 μas in phase delay centroid?

  <<100 μas in group delay centroid? (*Porcas, AA, 505, 1, 2009*)
- shorter wavelength closer to Black hole and Optical: 9mm X/Ka better

Ka-band candidates: 498 sources identified



Ka candidate criteria: 200 mJy, 70% flux in unresolved X-band core

Credit: Sotuela et al, GREAT-ESF Conf., Porto, Portugal, 2011
http://www.fc.up.pt/great-ws-porto/Ioana_Sotuela.pdf