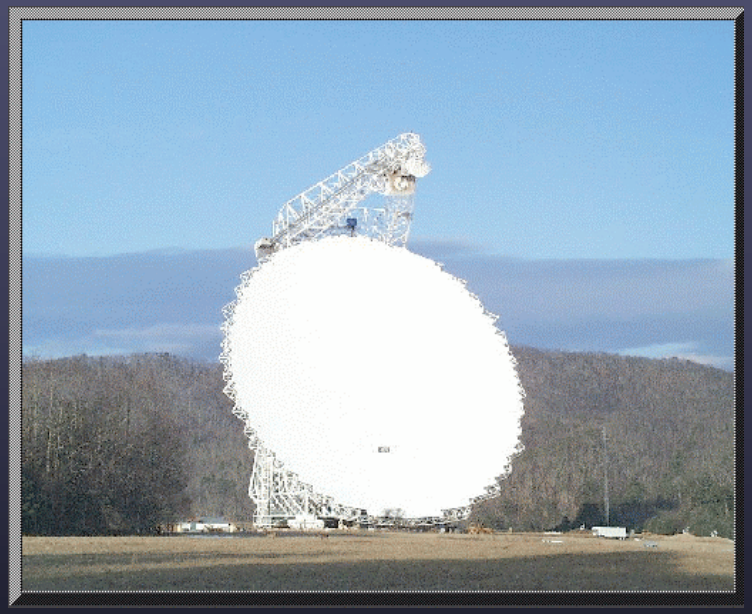
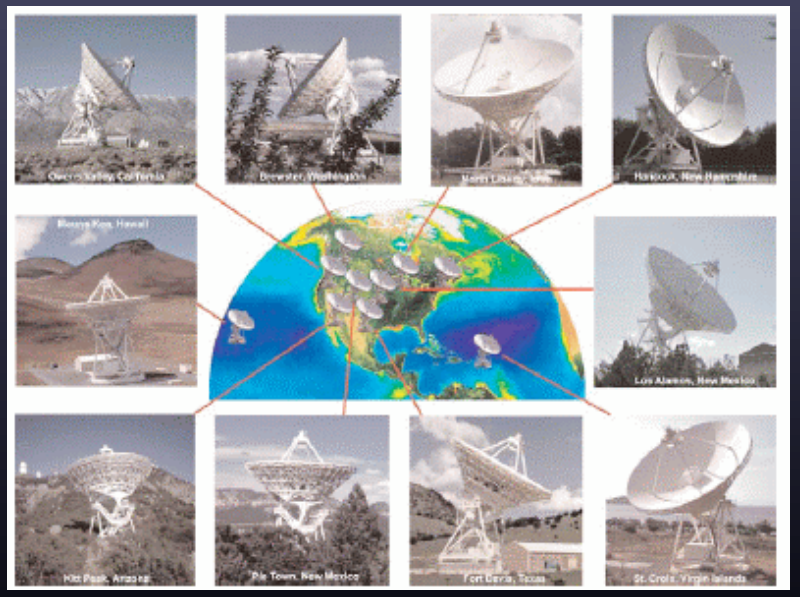
VLBI: Instruments and Capabilities





Jim Ulvestad

VLBI in the GLAST Era

Goddard Workshop, April 2007

Outline

- Introduction to VLBI Arrays
- Strengths of Different VLBI Arrays
- Angular Resolution and Science Examples
- VLBI Evolution, 2007-2012
- Programmatic Considerations

Very Long Baseline Array

- http://www.vlba.nrao.edu
- World's only dedicated astronomical imaging array
- U.S. National Science Foundation/NRAO
- 10 dedicated 25m antennas
- Strengths
  - Year-round availability, dynamic scheduling
  - Wide range of frequency bands, 0.3-86 GHz, frequency agility
  - Common calibration, repeatable aperture coverage
  - Simple operations
- Weaknesses
  - Small dishes and limited bandwidth
  - No eVLBI capability

European VLBI Network

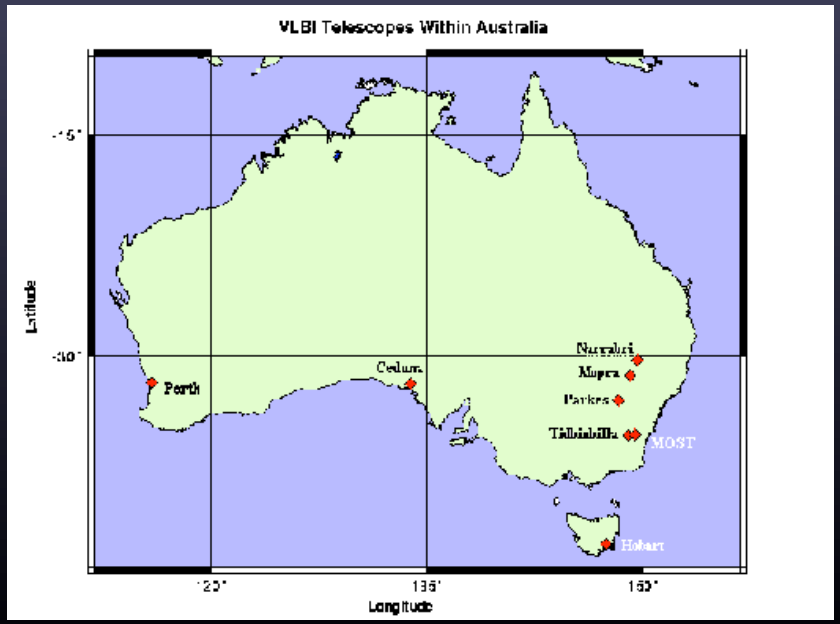
- http://www.evlbi.org
- Operated by national agencies in “Europe”
- Antennas of different sizes and capabilities
- Strengths
  - Some large apertures, and higher bandwidth
  - Sensitive short/intermediate spacings
  - eVLBI capabilities
  - Handy sensitivity calculator for mixed arrays!
- Weaknesses
  - Fixed observing schedules
  - Sessions limited to < 10 weeks/yr
  - Non-uniform antenna capabilities
  - High-frequency capabilities limited
    - Yebes, Sardinia telescopes will help

Other Northern Arrays

- High Sensitivity Array (HSA)
  - http://www.nrao.edu/hsa
  - Combines VLBA with GBT, VLA, Arecibo, Effelsberg
  - Increased sensitivity, loss of flexibility
- Global VLBI
  - Essentially combines European VLBI Network and HAS
  - Long baselines, excellent sensitivity
  - Poor flexibility, difficult calibration
- Global MM VLBI Array
  - VLBA, Effelsberg, Onsala, IRAM, Metsahovi
  - 3mm sensitivity still limited
- VERA – Japanese 4-element network
- KVN – Under construction in Korea

Australian Long Baseline Array

- http://www.atnf.csiro.au/vlbi
- Mix of telescopes, most baselines < 1000 km
- 1 week block schedules, several times per year
- Frequencies up to 22 GHz
- Strengths
  - Only Southern Hemisphere array
  - eVLBI development
- Weaknesses
  - Low availability
  - Mix of telescopes
  - Paucity of long baselines



Arrays of Choice

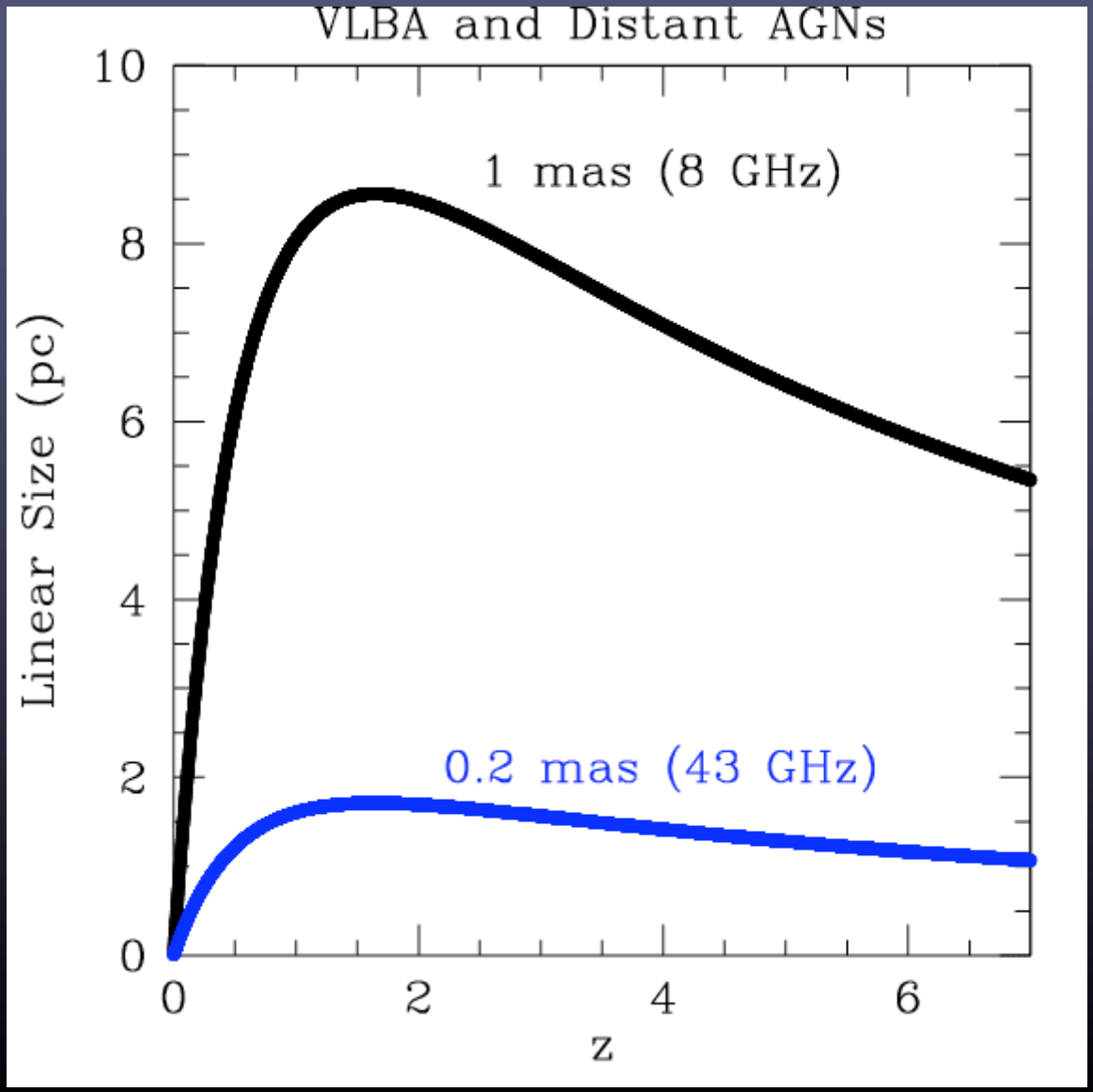
- Frequent monitoring: VLBA
- High frequencies (22-43 GHz): VLBA, HSA, EVN
- High sensitivity: EVN, HSA, Global VLBI
- Astrometry: VLBA, HSA, EVN
- Southern Hemisphere: ALBA, (VLBA)
- “Real” time: EVN
- 3mm (86 GHz): VLBA, GMVA
- Highest resolution: Space VLBI (see below and Kellermann talk)

Angular Resolution of VLBA

Frequency (GHz)	*Beam FWHM (mas)*	*Beam (at z=0.5)*
0.3	21	150 pc
0.6	12	70 pc
1.6	5	30 pc
2.3	3	15 pc
5	1.4	7 pc
8	0.8	5 pc
15	0.5	3 pc
22	0.3	1.8 pc
43	0.2	1.2 pc
86	0.1	0.6 pc

Resolution for Distant AGNs

- Can distinguish motions and changes on scales as small as 0.1 resolution elements
- Superluminal motion enables changes in small fraction of GLAST lifetime



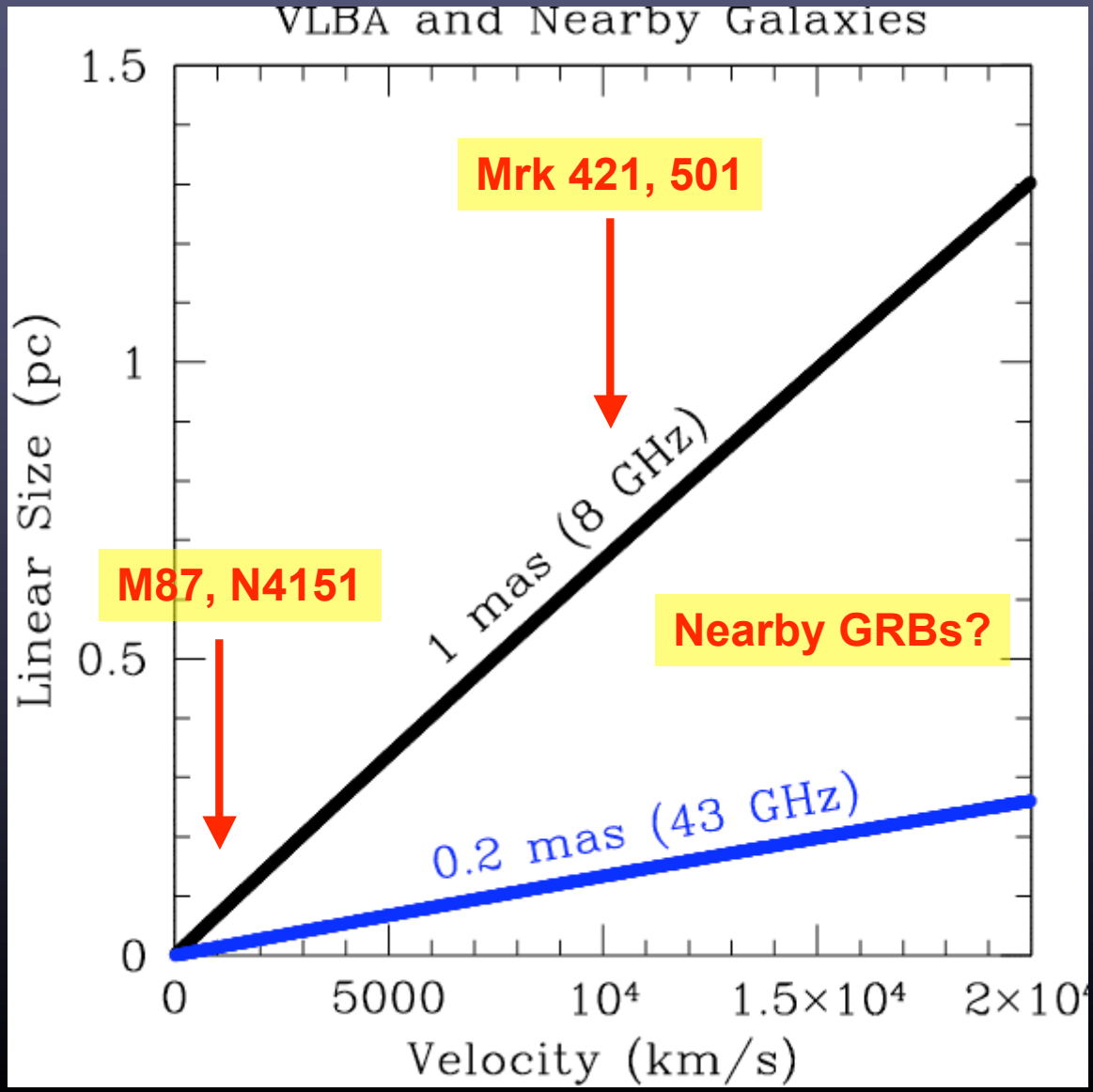
Requirements for Imaging Blazar Jets

- High-frequency capability (> 20 GHz) to image jets where they are optically thin
- Full-polarization imaging
- Dynamic scheduling for response to gamma-ray flares at any time of year, and for repeated reliable observations
- Sub-milliarcsecond resolution to detect changes on time scales of days to months

➢ Only the VLBA meets these requirements

Resolution for Nearby AGNs

- At a distance of 20 Mpc, resolution of 0.02 to 0.1 pc is achievable
- Nearby, low-luminosity AGNs may be a GLAST "sleeper"



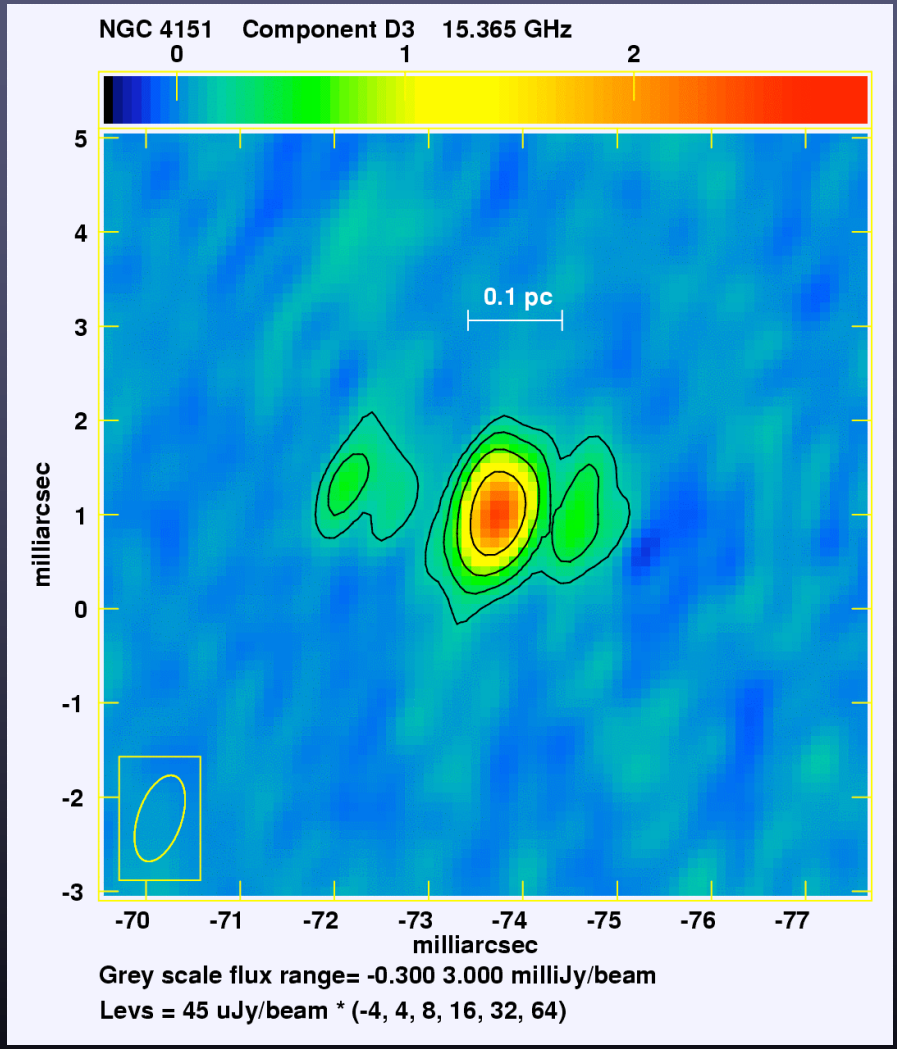
Angular Resolution of VLBA

Object	*BH Mass*	*BH Diameter*
Z=1 Quasar	10^9 M_{Sun}	0.1 _as
M87	3 x 10^9 M_{Sun}	10 _as
NGC 4151	10^7 M_{Sun}	0.1 _as

- VLBI resolution typically is about 1000-10,000 Schwarzschild radii
- A few exceptions in the range of 100 Schwarzschild radii

VLBI Core of NGC 4151

- NGC 4151 was an OSSE hard X-ray source many years ago
- 15 GHz VLBI image at the right used VLBA+VLA+GBT+Eb (Ulvestad et al. 2005)



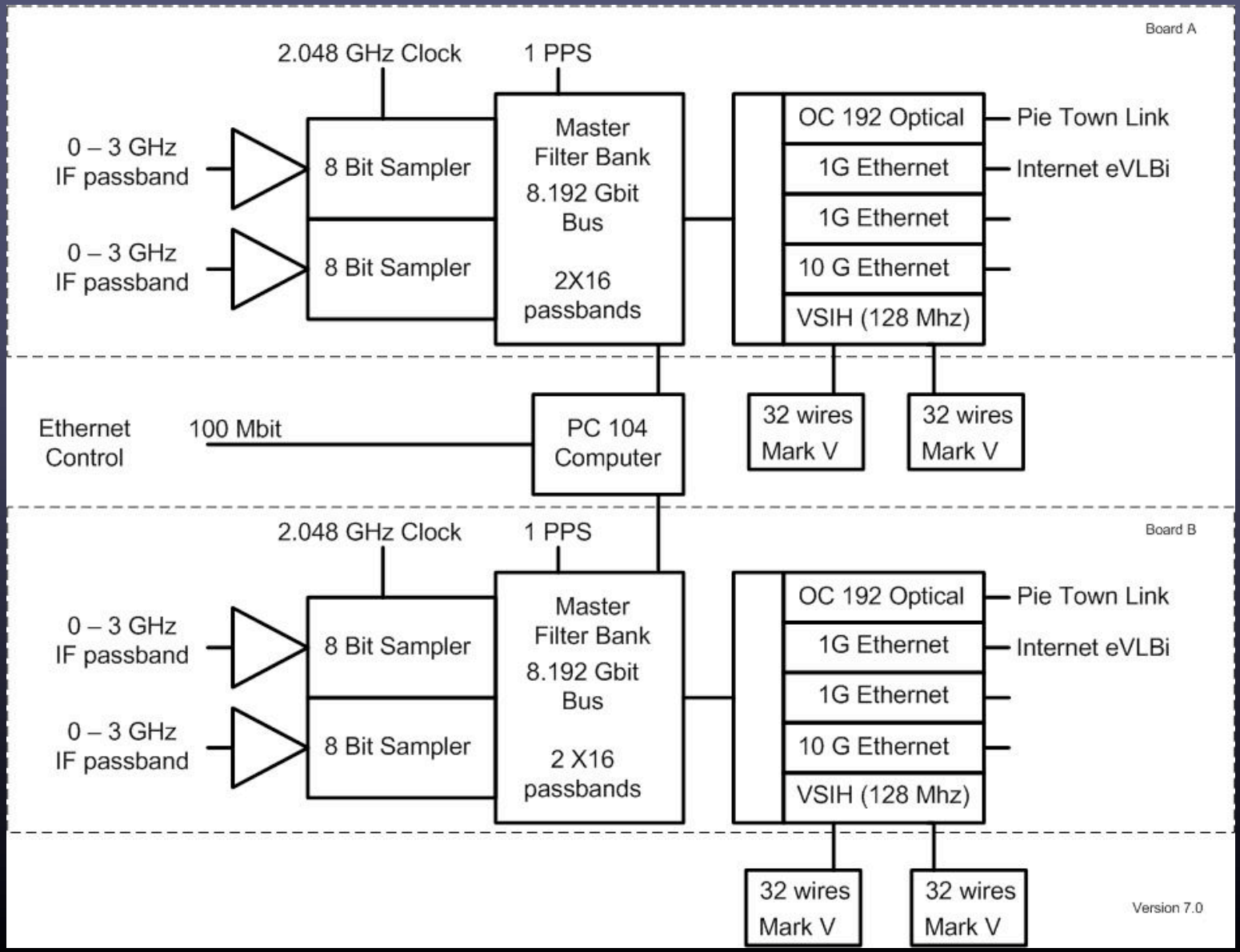
A Gratuitous Viewgraph

- Don’t forget about VLBI for galactic science associated with GLAST!
  - Microquasar imaging and motions
  - Pulsar parallaxes
  - Distances to star-formation regions
  - Colliding-wind binaries

VLBI Developments, 2007-2012

- European VLBI Network
  - New 40m antenna in Yebes, Spain
  - New 64m antenna in Sardinia, Italy
  - New antennas in China
  - Increased high-frequency capability
  - Further eVLBI development, higher bandwidth
- Construction of Korean VLBI Network
- VLBA High-Sensitivity Project
  - Increase data rate by factor ~16 by 2010, thus increasing sensitivity by factor of 4
  - 22 GHz amplifier upgrade, 40% improvement in 2007
  - 43 GHz amplifier upgrade proposed for 2008

NRAO/Haystack Digital Back End—4+ Gbps



Space VLBI (see Kellermann talk)

- Radioastron
  - Scheduled launch, 2008-2009
  - Very high orbit
  - Poor imaging capability, exploratory at long baselines
  - Has not met predicted launch dates in the past
- VSOP-2
  - Scheduled launch, February 2012
  - 10m antenna in imaging orbit, 1 Gbps
  - 8, 22, 43 GHz
- ARISE and iARISE (ARISE+VSOP-2) not under development

Programmatics – Senior Review

- NSF Senior Review praised VLBA uniqueness and capabilities for GLAST support
- But, Senior Review recommended that NSF pay only $3M of $6M direct costs of VLBA by 2011, or VLBA should be closed
  - Necessitated by cost of new developments (GSMT, LST, SKA) and ALMA operations
  - ALMA operations costs hitting NSF before 2011
- NRAO plans to be successful at finding scientific and financial partnerships
  - This may well result in reduced flexibility and reduced astronomical observing time available for GLAST

Programmatics – NRAO/GLAST MOU

- NRAO making available up to 10% of NRAO telescope time for collaborative GLAST observations during Cycle 1
  - Includes VLBA, VLA, and GBT
  - Hence, includes NRAO part of High Sensitivity Array
- Two proposal mechanisms
  - Multiwavelength science, up to 200 hours of NRAO time, directly through Cycle 1 call
  - Large proposals (> 200 hr) and Targets of Opportunity via direct proposal to NRAO

Summary

- VLBI observations are critical for GLAST to succeed in achieving its scientific potential
- World's VLBI observatories have a variety of capabilities that will be useful for GLAST science
- Astronomical VLBI is supported by several different ground-based research organizations, not by NASA

⌡ Partnerships are critical for GLAST success