The Green Bank Telescope:
Science Results and Lessons Learned

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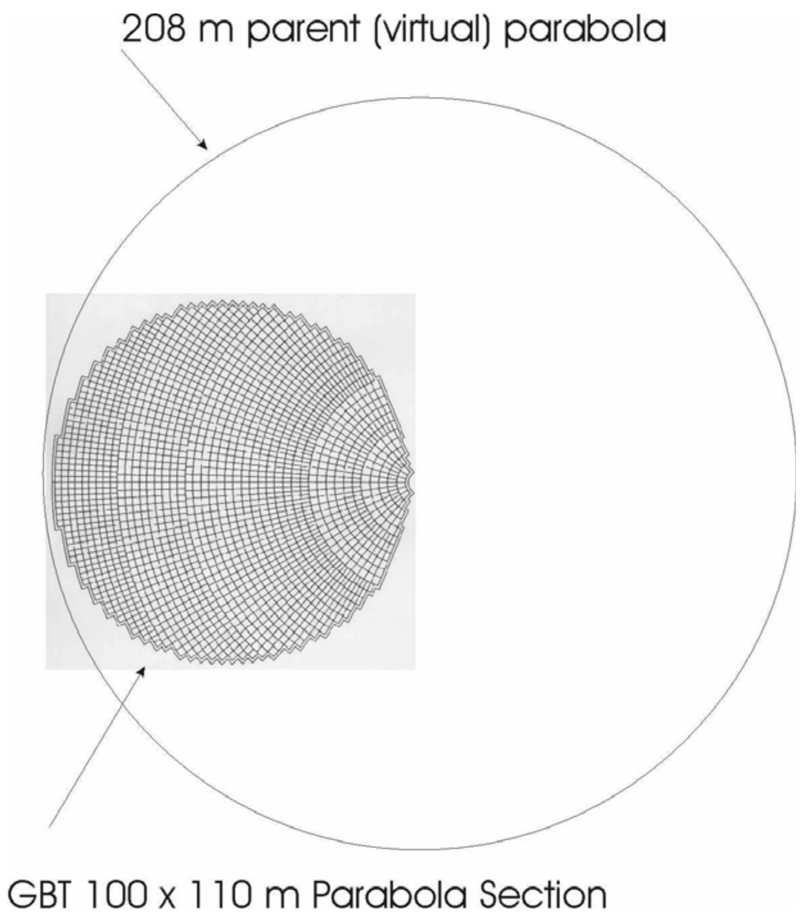
Overview

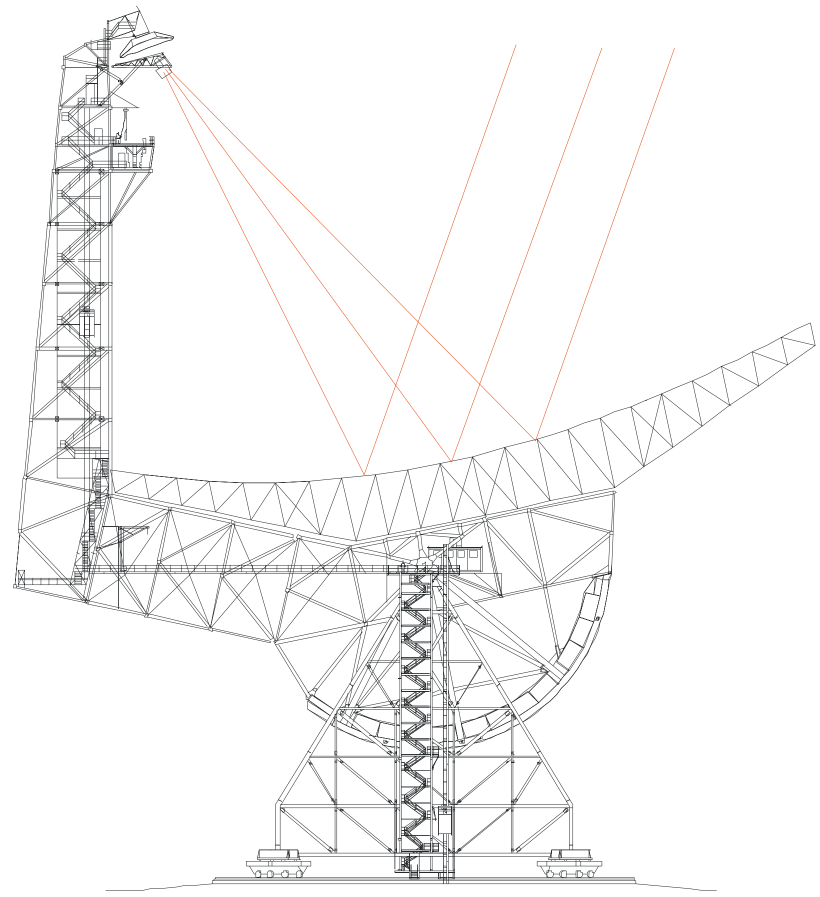
- ***Brief summary of telescope and performance requirements***
- ***Lessons learned – or at least identified?***
- ***Recent Science results***

The GBT

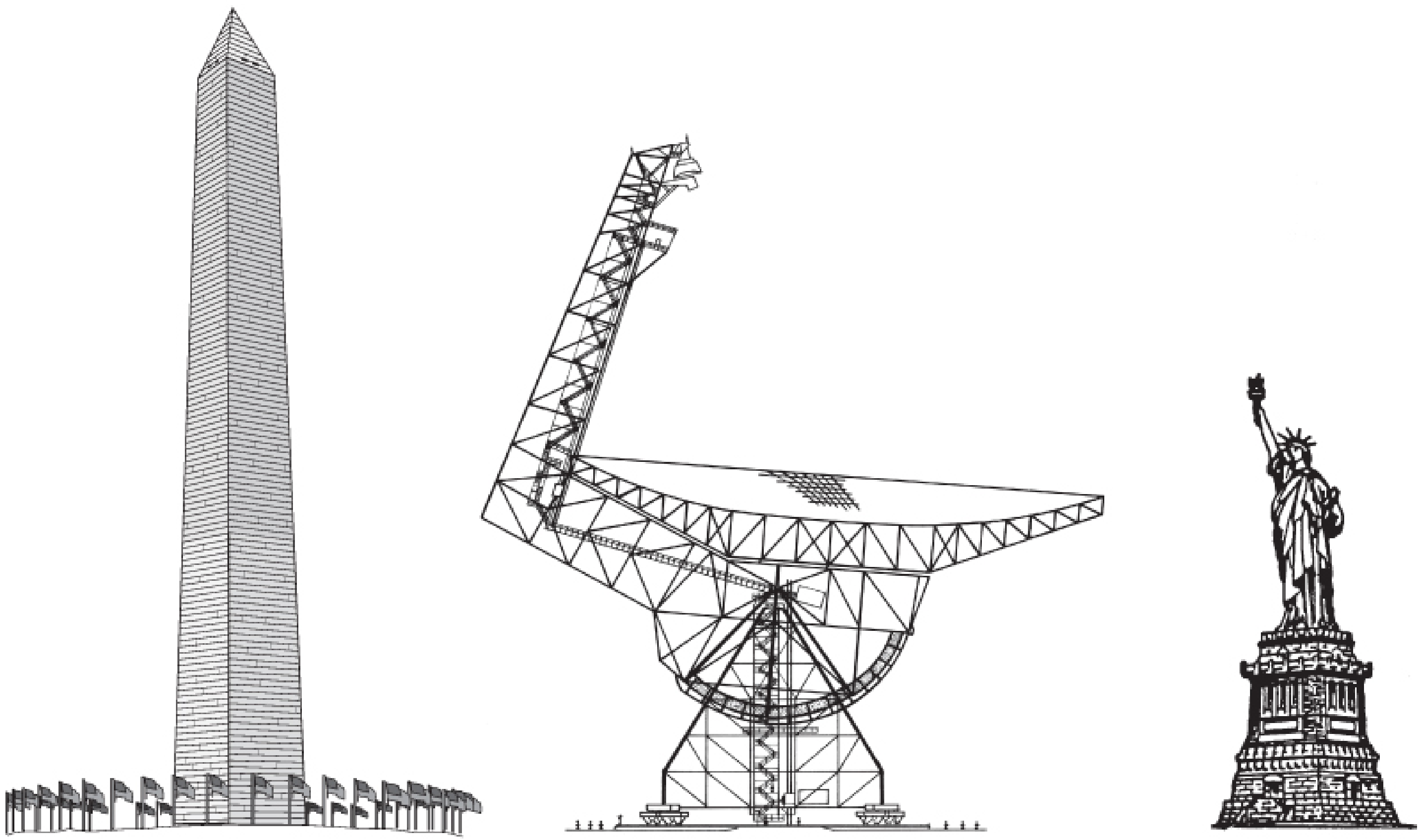
GBT optics

- *100 x 110 m section of a parent parabola 208 m in diameter*
- *Cantilevered feed arm is at focus of the parent parabola*





GBT Size

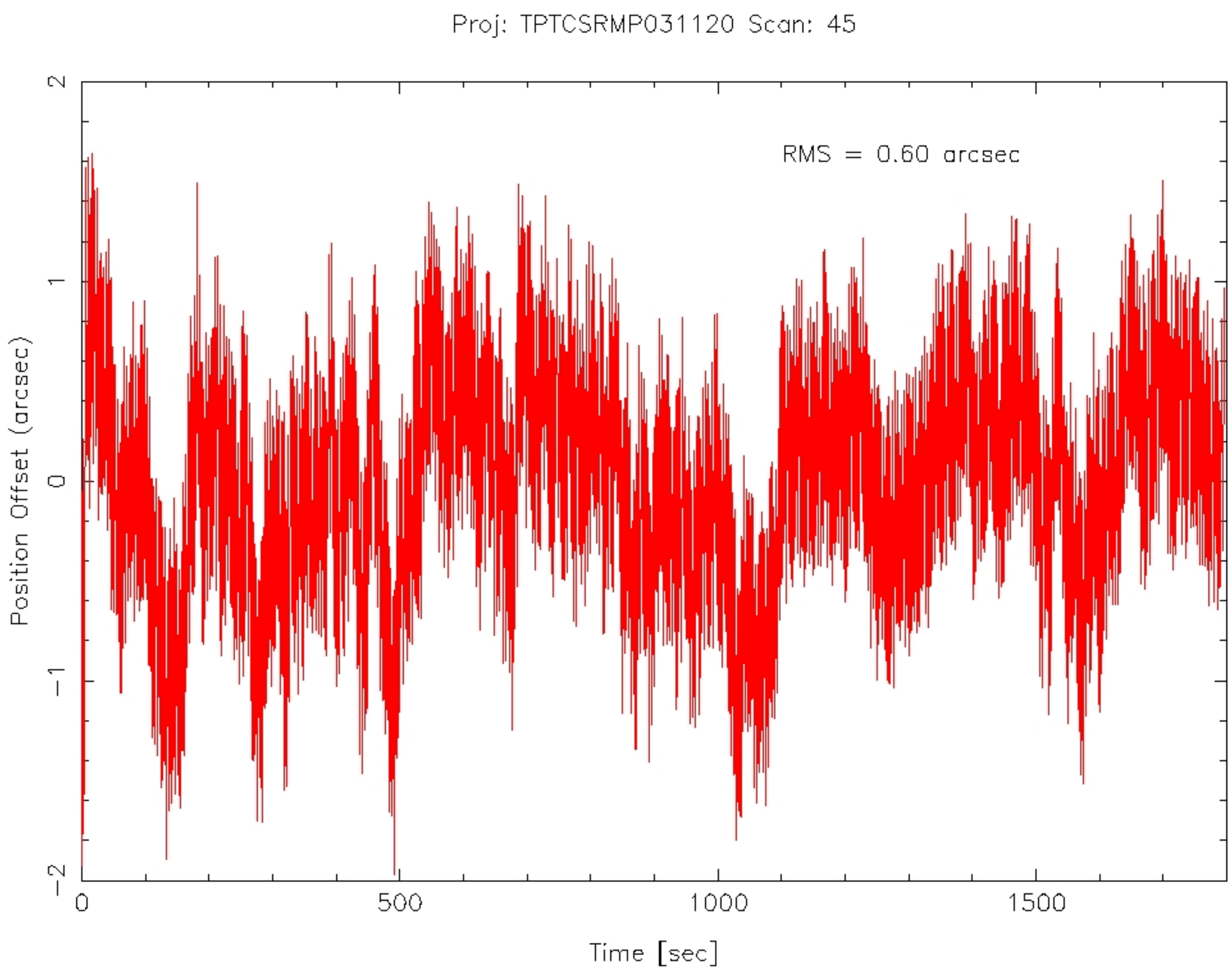


Scientific Requirements

Table 1. GBT Scientific Requirements

ν (MHz)	tracking σ_2 ($f < 0.2$) (arcsec)	blind σ_2 ($f < 0.43$) (arcsec)	ϵ (mm)
52	2.8	6.1	0.36 ($\lambda/16$)
92	1.6	3.5	0.21 ($\lambda/16$)
115	1.3	2.8	0.21 ($\lambda/(4\pi)$)

14GHz half-power track



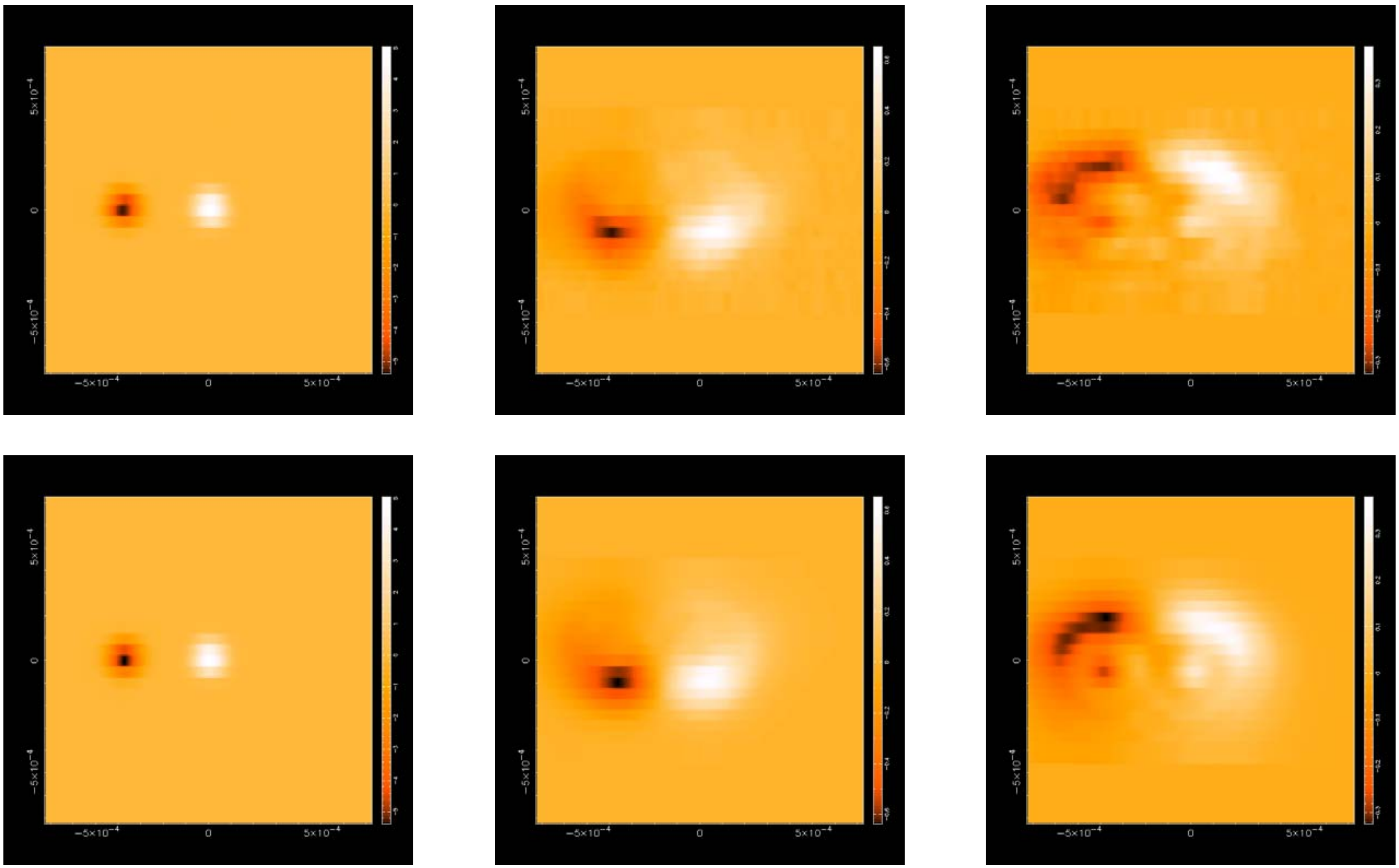
$$\sigma_2 \approx 1 \quad arc\sec$$

$$(Az, El) \approx (290^\circ, 58^\circ)$$

$$(\Delta Az, \Delta El) \approx (1^\circ, 5^\circ)$$

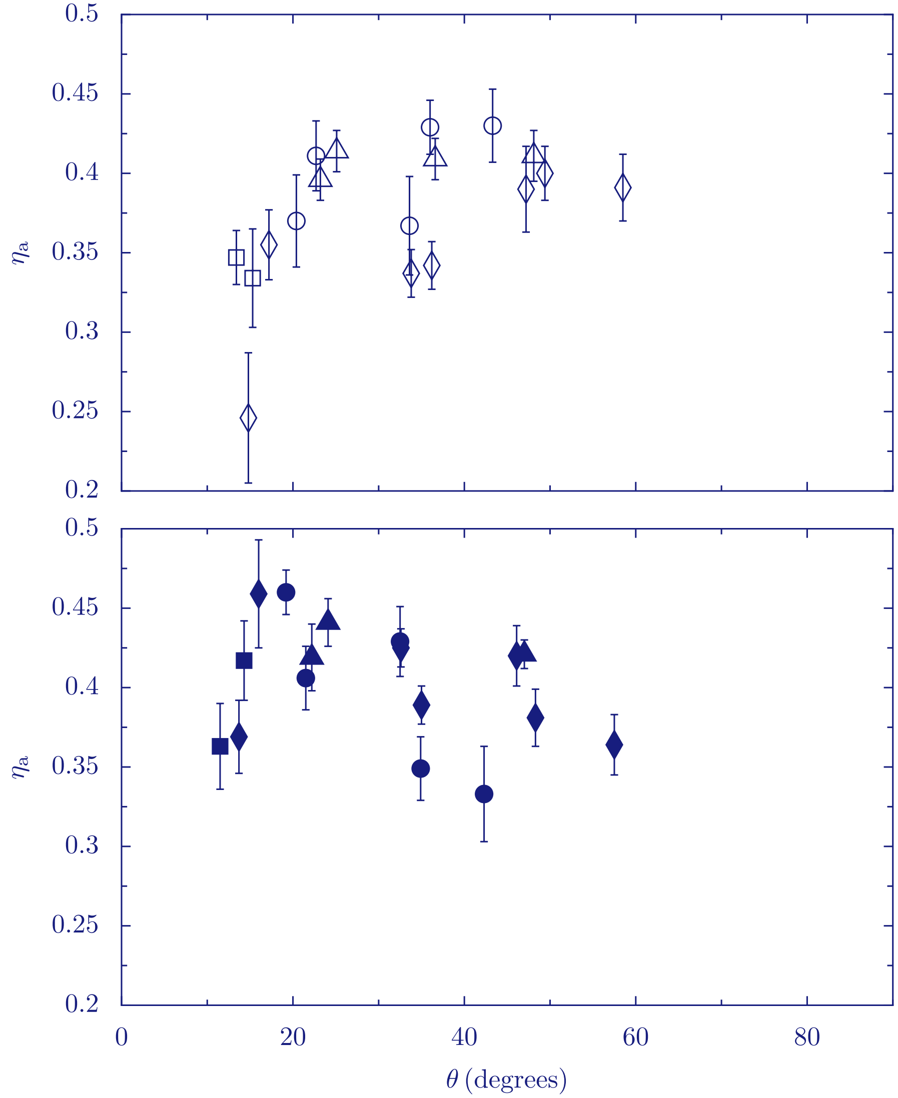
$$\left(\frac{\Delta Az}{\Delta t}, \frac{\Delta El}{\Delta t}\right) \approx (2'/m, 10'/m)$$

“Out-of-focus” Holography



Surface Accuracy

- ***Large scale gravitational errors corrected by "OOF" holography.***
- ***Benign night-time rms***
  ~ 350µm
- ***Efficiencies:***
  43 GHz: η_S = 0.67 η_A = 0.47
  90 GHz: η_S = 0.2 η_A = 0.15
- ***Now dominated by panel-panel errors (night-time), thermal gradients (day-time)***



Lessons learned (identified?)

- ***Be very aware of system complexity***
- ***Be wary of scaling up existing designs***
- ***Pay attention to fabrication, quality assurance, hardware prototyping and testing***
- ***Development work must clearly lead to concrete, intermediate deliverables***
- ***Leave some flexibility and agility in your project plan***
- ***Prototypes will remain in the system forever***
- ***Plan to replace one sub-system before all the rest are fully in use***
- ***Have some clearly defined observing modes fully implemented from day one***
- ***Minimize the number of items to commission at any one time***
- ***And be prepared for the lengthy commissioning process...***

Complexity – metrology system

- *Ambitious project to measure and control location and figure of each mirror to 100μm over 100m length-scales in unprotected open-air environment*

- *Had high-level system design*
- *High-level system design didn't flow down into M&C implementation*
- *Interfaces were defined, but not implemented*
- *Extremely high level of system complexity, but little focus on system integration, field deployment, etc.*
- *Project was not on critical path to initial operation of the telescope*

- *Now have a huge, "cannot back out of existing implementation" problem*
- *From a reasonable start, project is now on hold*

Complexity – software

- GBT delivered with monitor and control software (largely) complete
- System delivered with two, incomplete user interfaces; one which could configure the instrumentation but not execute observations, and vice-versa
- Telescope was extremely difficult to use, even for black belts

- Not really a software problem, more a requirements and project management problem
- Individual software components are not that challenging
- Root cause: lack of a plan for defining observing modes, defining and controlling system complexity

- Still some issues (latencies and efficiency) a but huge turn-around in about two years, delivering incremental improvements (config tool, then turtle, then full-up Astrid)
- Project has gone from depths of despair to resounding success

Lessons learned

- ***You have to actively manage system complexity.***
- ***Define in detail an initial set of observing modes; these will be useful throughout the development process.***
- ***Sub-projects must have concrete, intermediate deliverables, which appear on the critical path of the project (this is different from early integration).***

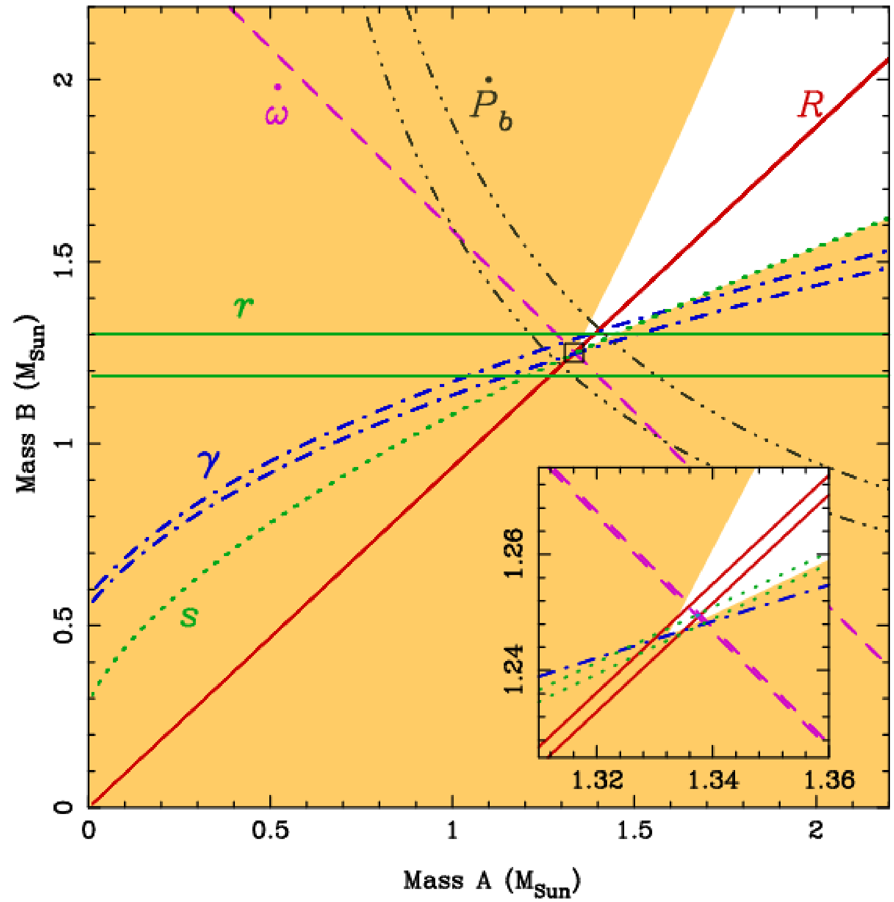
Science Highlights - Pulsars

Double pulsar system J0737-3039

- *Most stringent test of GR in the strong-field limit so far (Kramer et al.)*

Globular cluster pulsars

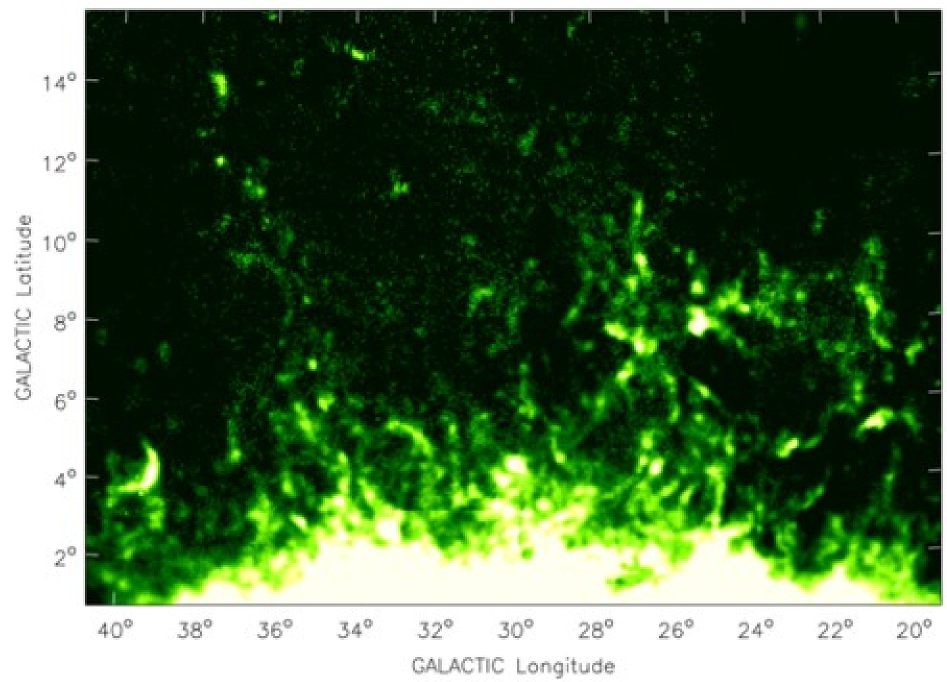
- *The GBT has found at least 57 new globular cluster pulsars since it has been in operation*
- *More in only 3 years than any of the other radio telescopes in the world have uncovered in their entire lifetimes*
- *Terzan5ad - fastest millisecond pulsar yet discovered: 1.39ms (716 Hz) (Hessels, Ransom et al.)*



Mass-mass diagram summarizing observational constraints on the masses of the neutron staff in the double pulsar system. (Kramer et al.)

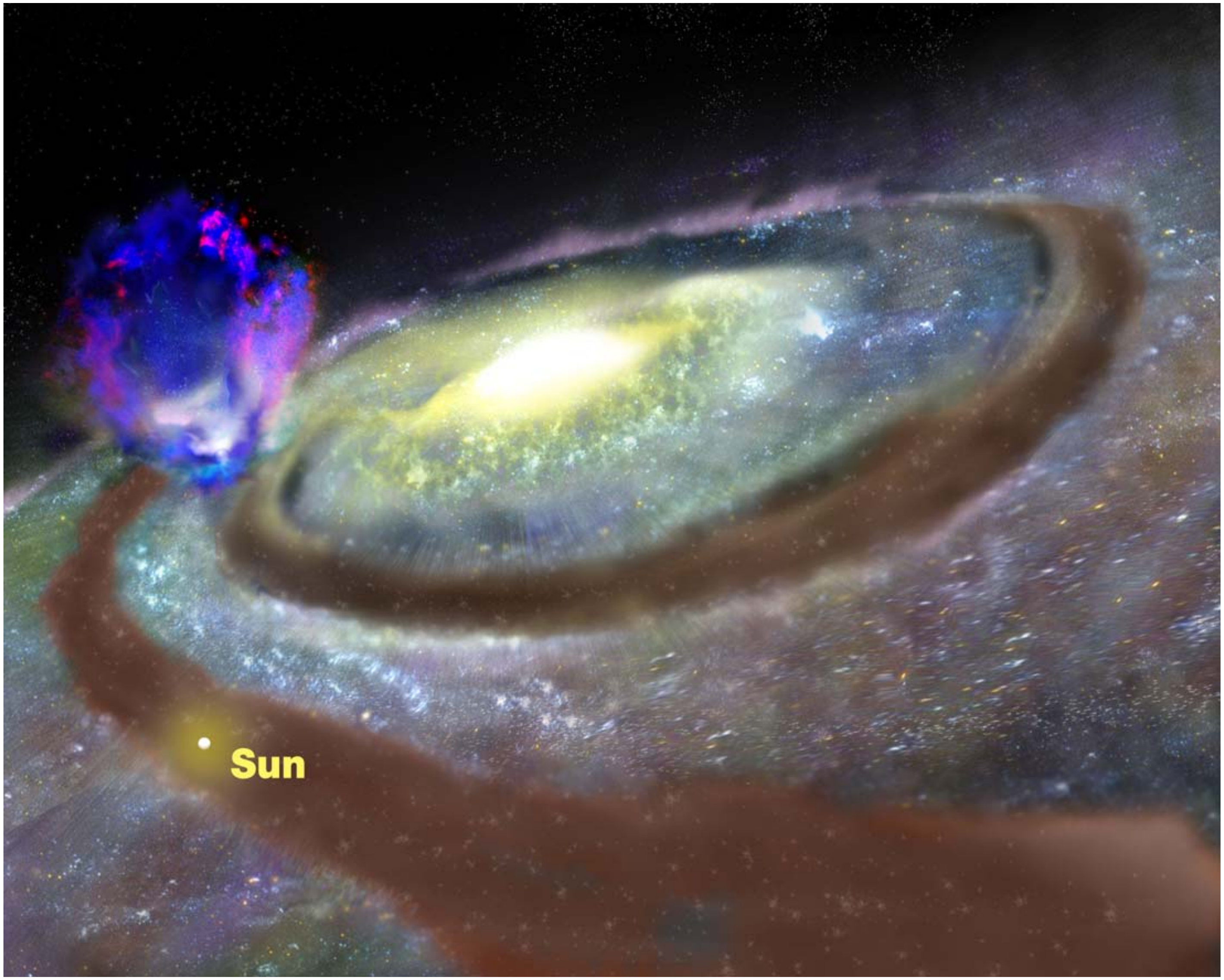
Science Highlights - HI

- *HI (neutral hydrogen) halo of the Milky Way near the Scutum spiral arm*
- *7 kpc from the Sun and 4 kpc from the Galactic center*
- *Total mass ~ 1M solar masses*
- *energy powering outflow ~ 100 supernova explosions*
- *10-30 million years old*

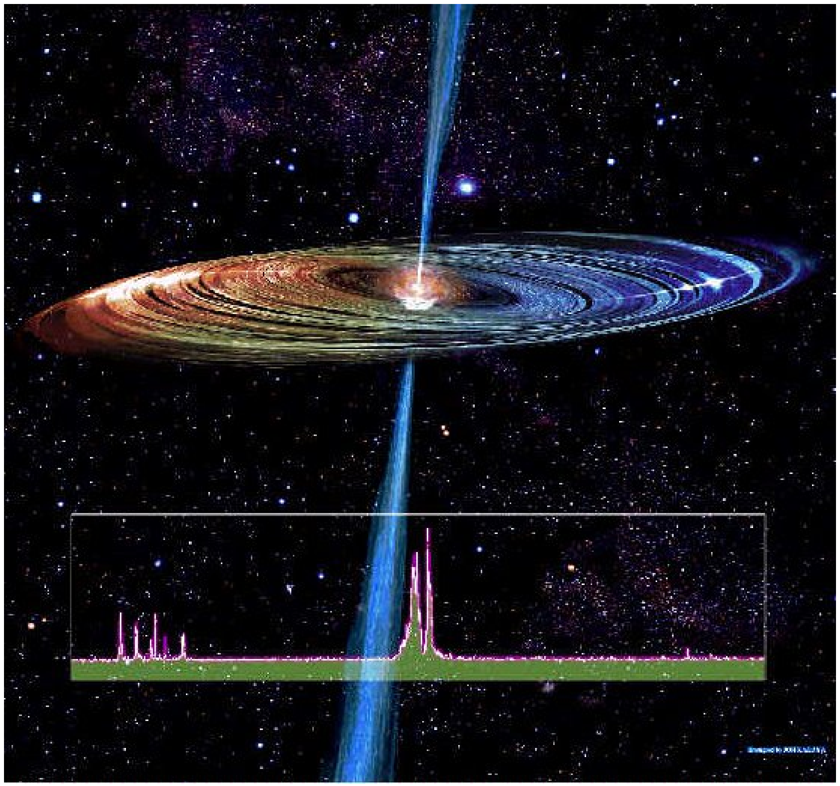


Yurii Pidopryhora, Jay Lockman & Joe Shields

super-bubble in our own back yard



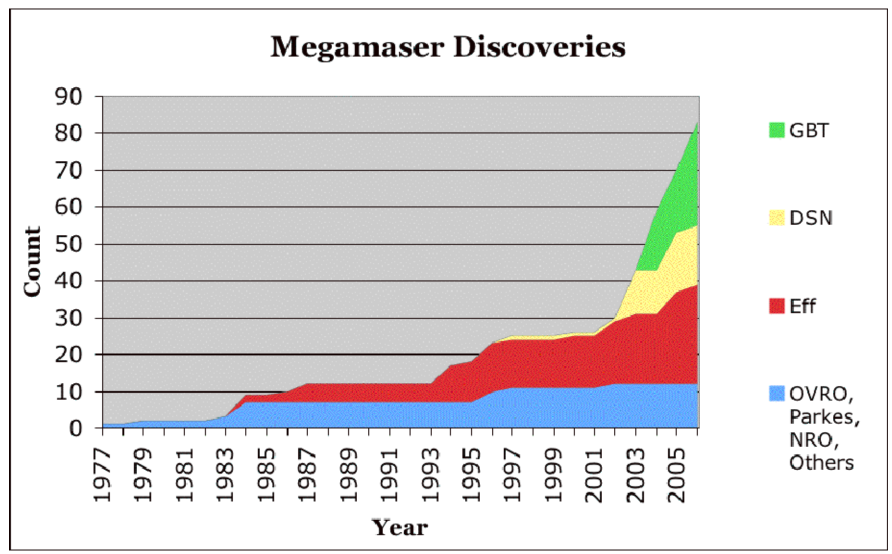
Distances to H_2O Megamasers



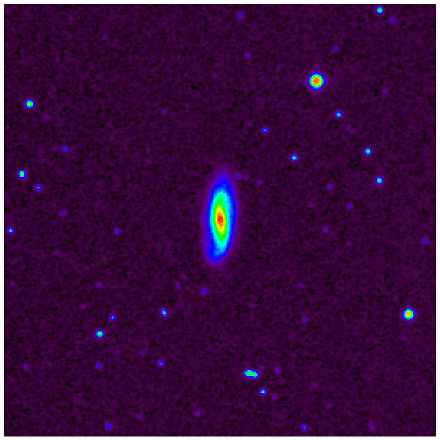
NGC 4258

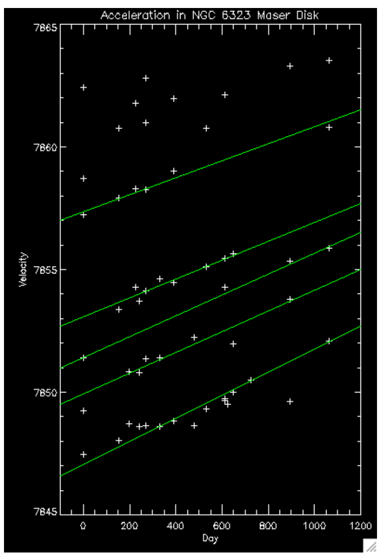
Requires:
- ***Detect the best candidates (GBT surveys)***
- ***Measure accelerations (GBT Monitoring)***
- ***Assess VLBI calibrators (VLA snapshots)***
- ***VLBI imaging (VLBA + GBT + Eff)***
- ***Modeling***

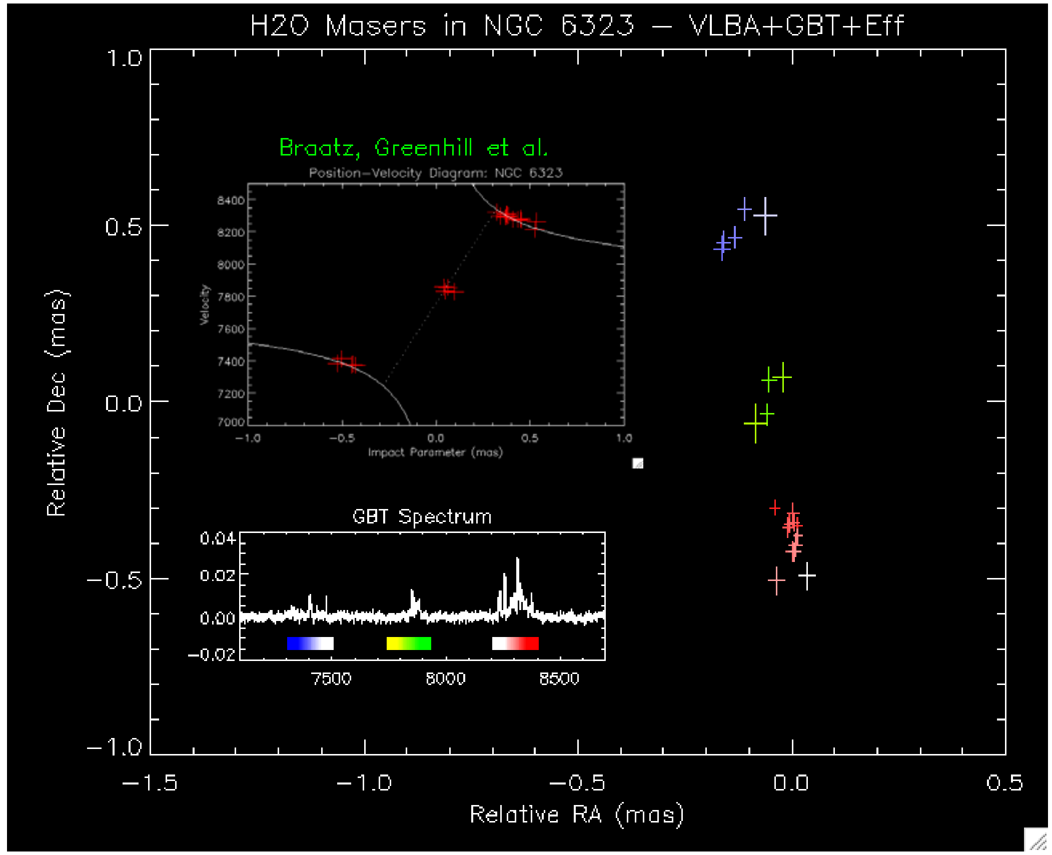
Goal:
- ***10+ distances to obtain H_0 with better than 3% uncertainty***



NGC 6323







V = 7772km/s, D ~ 110Mpc for H_0 = 70 (km/s)/Mpc

(Work by Braatz et al.)

Conclusions

- **GBT is now in reliable, routine operation at frequencies up to 50 GHz**
  => All "phase II" specifications met or exceeded

- **Lessons learned:**
  - **Development projects must be tied to main project**
  - **Must have concrete intermediate goals which in a real sense tie in to critical path of the whole project**
  - **Have an "early science" plan which can make genuine bread and butter use of the telescope while continued development/commissioning is underway**
  - **Be prepared for 2-3 challenging years from first light to stable operation, and be prepared for one major sub-system to be replaced**

- **The potential of the GBT is fantastic. All commissioning tests to date confirm full 3mm operation is technically within our grasp!**

- **Delivery of array receivers to the GBT will increase productivity by further orders of magnitude**