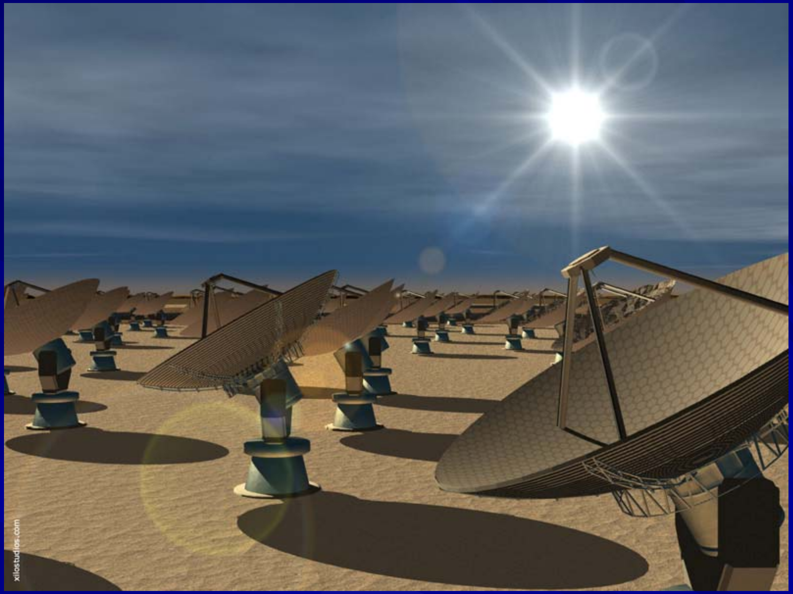
Pulsar Surveys Present and Future: The Arecibo-PALFA Survey and Projected SKA Survey

Arecibo Telescope



SKA concept design

Julia Deneva, Cornell University, USA

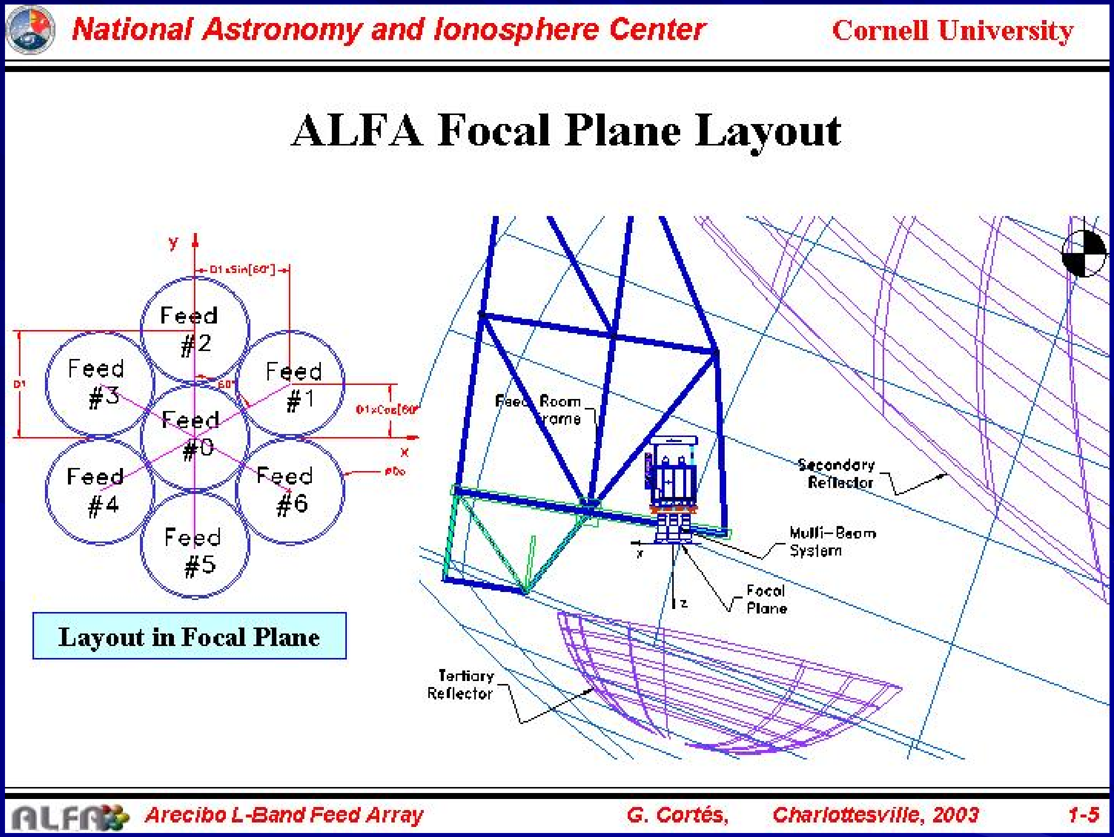
15 May 2006

363rd Heraeus Seminar, Bad Honnef, Germany

Pulsar-ALFA Consortium

- USA
  - Bryn Mawr College
  - Carleton College
  - Cornell University
  - Columbia University
  - Franklin and Marshall College
  - Harvard-Smithsonian Center for Astrophysics
  - Harvard University
  - NASA Goddard Spaceflight Center
  - National Astronomy and Ionosphere Center
  - National Radio Astronomy Observatory
  - University of California-Berkeley
  - U.S. Naval Research Laboratory
- Canada
  - McGill University
  - University of British Columbia
- Australia
  - Swinburne University of Technology
- India
  - Raman Research Institute
- China
  - National Astronomical Observatories of China
- UK
  - Jodrell Bank Observatory
  - University of Manchester
- Netherlands
  - Astronomical Institute "Anton Pannekoek"

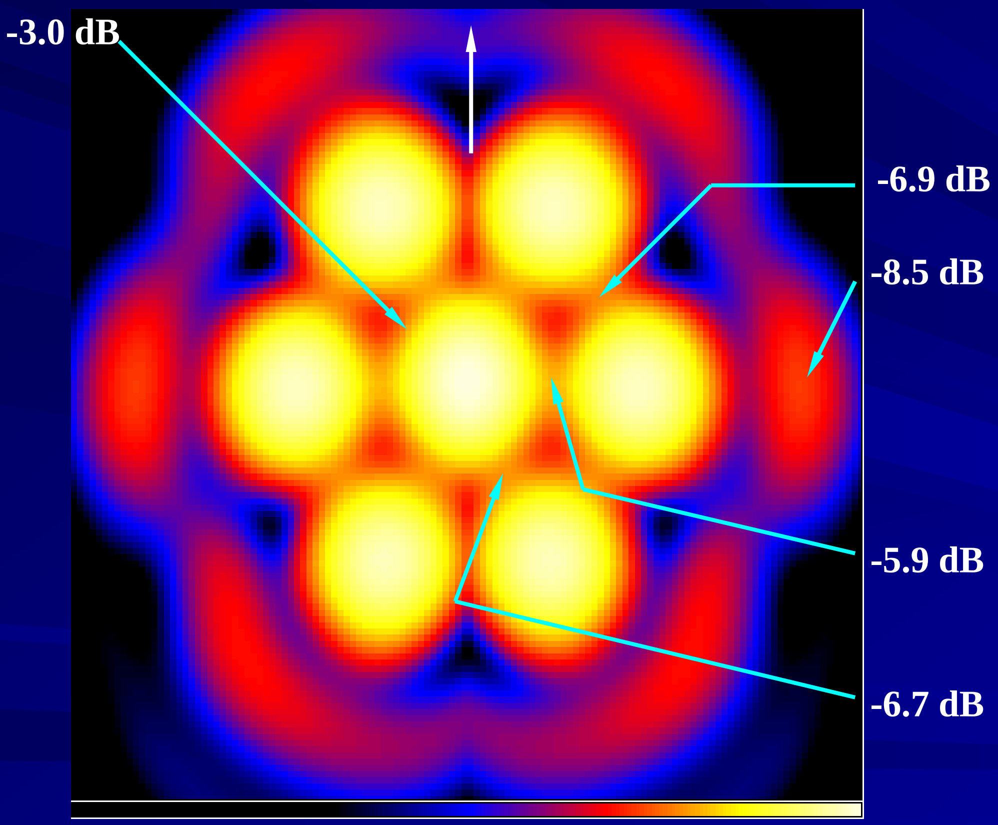
The Arecibo L-band Feed Array (ALFA)



- ALFA receiver: 7 beams; 1.42 GHz
- PALFA (pulsar), GALFA (galactic), EALFA (extragalactic)
- PALFA survey to last 3-5 years and find hundreds of pulsars
- Started in Aug 2004

Multi Beam Pattern

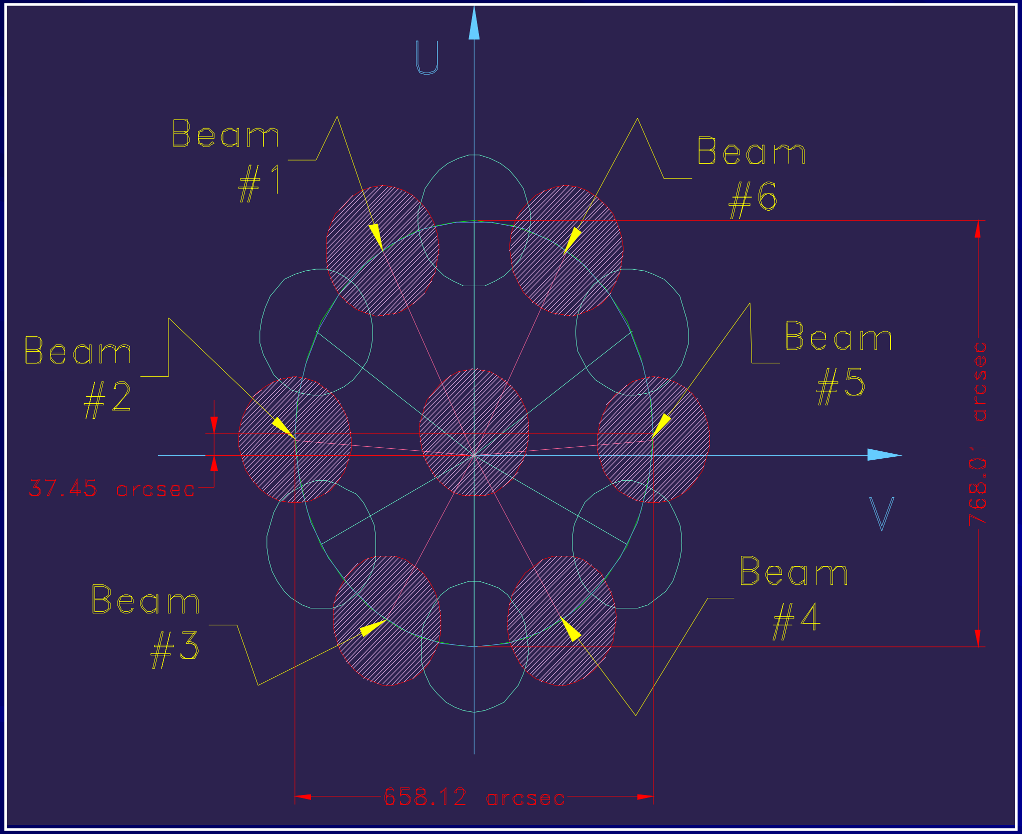
TE11 25cm x 26.0cm

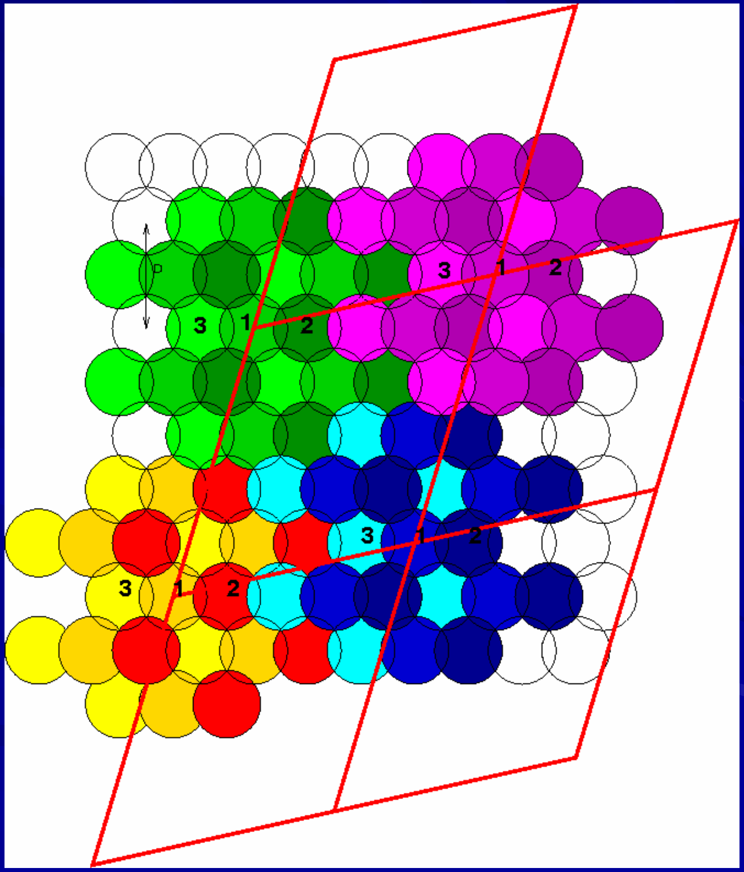


Sky Area 25’ x 25’

- Dense vs. sparse sampling:
  - Tile pointings densely and do 1 pass?
  - Tile pointings sparsely and do several (non-redundant) passes to fill in holes?
- Survey efficiency depends on volume searched per time
- Sparse sampling is more efficient because pulsars can also be detected with the *sidelobes*

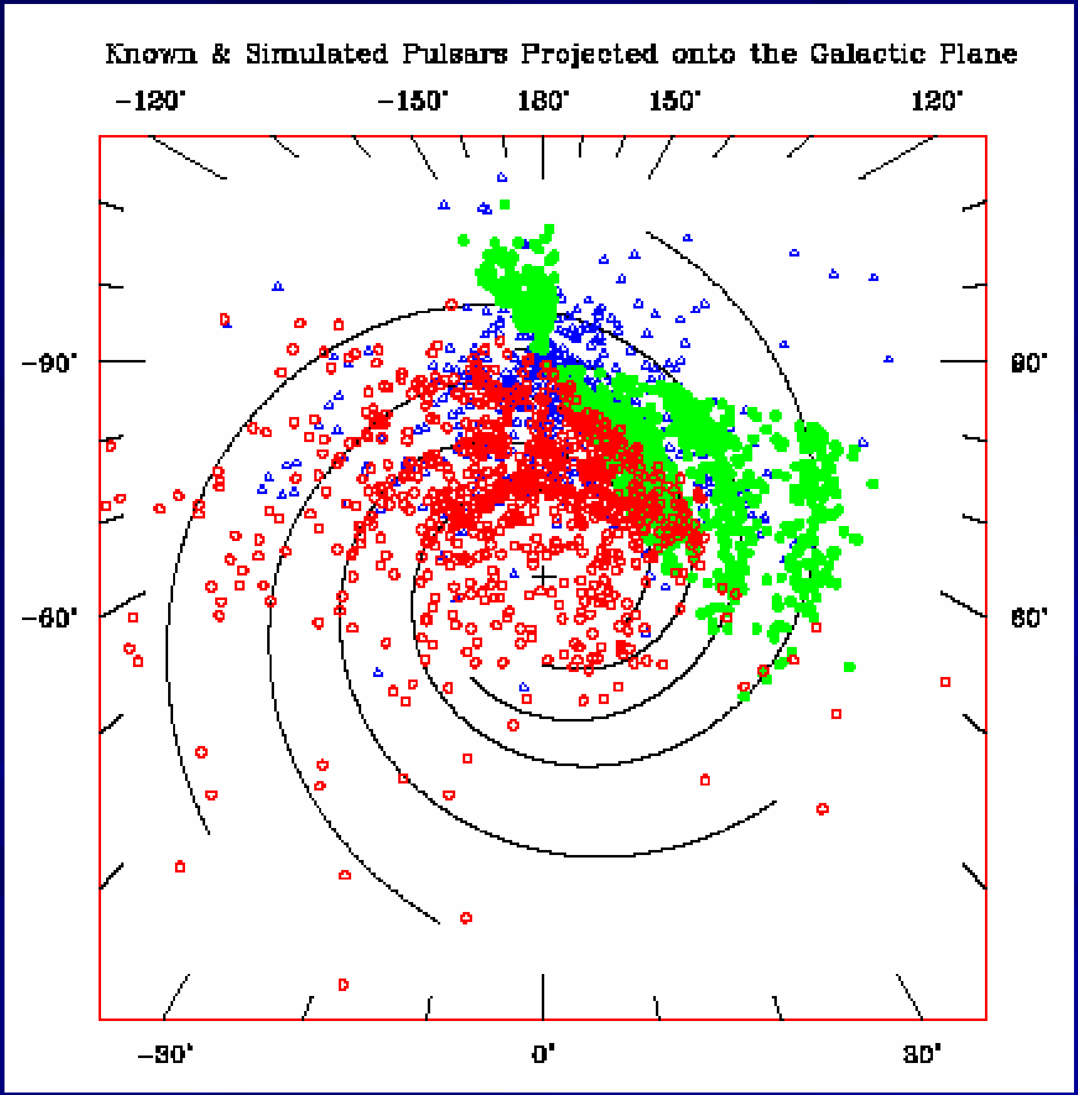
Multi Beam Sky Footprint and Pointing Tiling Pattern





http://www.naic.edu/~pfreire/tiling/

Survey Comparison



- Blue: known pulsars from surveys other than Parkes MB
- Red: pulsars discovered by Parkes MB
- Green: simulated pulsar discoveries by PALFA (~1000)

PALFA Survey Parameters

COMPARING PALFA AND PARKES MULTIBEAM SURVEYS

Item	ALFA + WAPPs	ALFA II	PMB
System Parameters:			
SEFD[a] (Jy)	3.6 (4.6)	3.6 (4.6)	36
FWHM/beam (arcmin)	3.6	3.6	14
No. of beams	7	7	13
Total Bandwidth (MHz)	100	300	288
Spectral channels	256	1024	96
Bandwidth/channel (MHz)	0.39	0.29	3.0
Dump time (μs)	64	64	250
Dwell time/position (s)	67, 134, 268	134, 268	2100
Sky coverage rate[b] (deg^2 hr^{-1}	1.2	3.6	0.95
${S_{\min_1}}^{c}$ in 1 min (μJy)	330 (420)	190 (241)	1900
$\Delta t_{\rm DM}$ (DM = 50) (μs)	59	44	453
Survey Parameters:			
${S_{\min}}^{*}$ (μJy)			
(1 s, DM = 0 pc cm^{-3})	119	48	150
(1 ms, DM = 50 pc cm^{-3})	700	460	6,600
${D_{\max}}^{\dagger}$ (kpc)			
(1 s, 1 mJy kpc^2)	2.9	4.6	2.6
(1 ms, 1 mJy kpc^2)	1.2	1.5	0.4
${V_{\max}}^{\sharp}$ (kpc^3 sr^{-1})			
(1 s, 1 mJy kpc^2)	8.1	32	5.8
(1 ms, 1 mJy kpc^2)	0.6	1.1	0.02

PALFA Pipeline

- *Quicklook* software—periodicity and giant pulse search in decimated data (on-site, while observing)
  - Discoveries so far were made by Quicklook output
  - Almost real time!
- Data shipped to Cornell for permanent archiving
  - Tape archive at Cornell Theory Center
  - Tools for remote access and data processing
- Full-resolution processing at Cornell and other institutions
- Several different codes (sanity check): *Presto, Sigproc*
- Collaboration on harvesting most efficient parts of each code and combining them

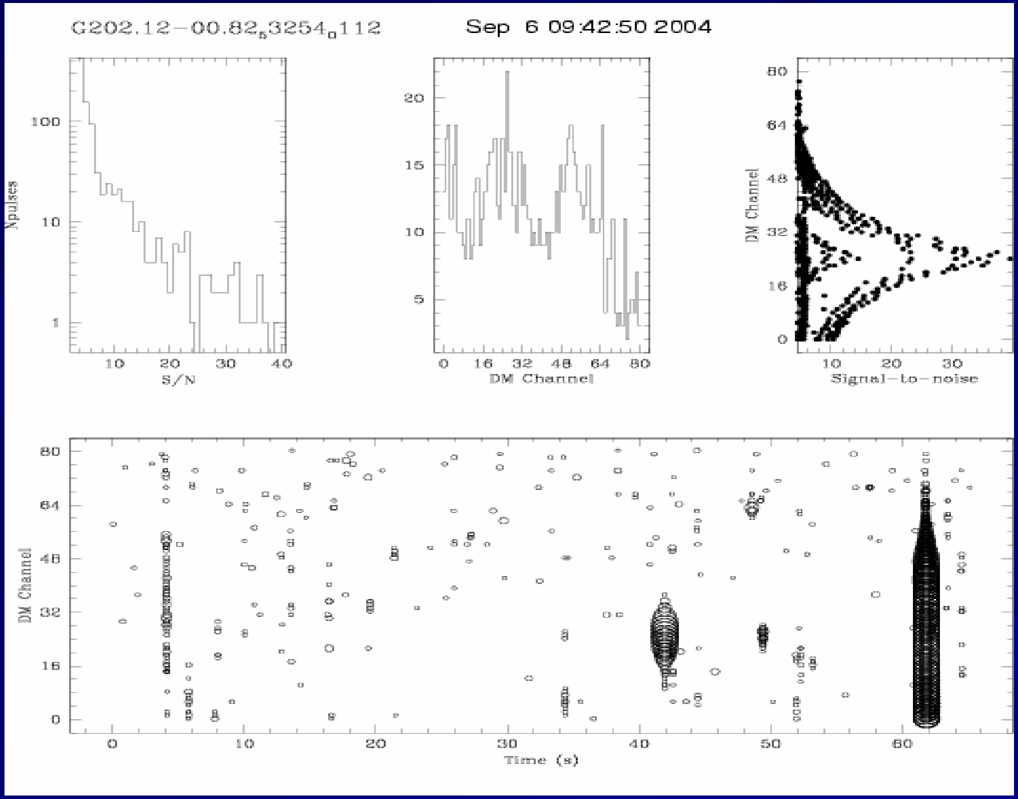
PALFA Discoveries

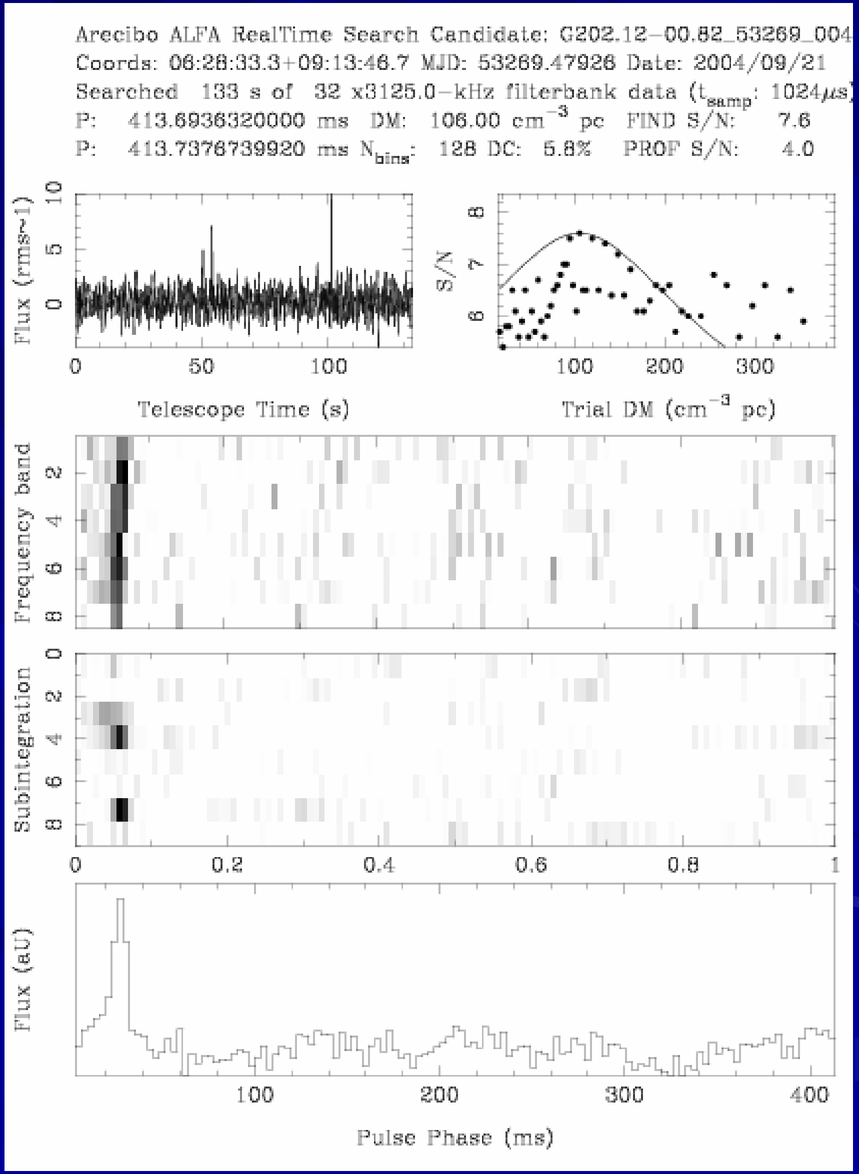
- 29 pulsars total (from real-time processing of decimated data)
- 2 in Anticenter
- 1 RRAT-like object (J0628+09)
- 1 relativistic binary (J1906+07)

Rotating RAdio Transients (RRATs)

- Newly defined class of radio-loud neutron stars
- 11 found in Parkes data (McLaughlin et al. 2006)
- 1 found by PALFA so far
- Sporadic bright bursts with distribution different from giant pulses
- Emission mechanism likely different from GPs
- B at light cylinder much lower than for GP-emitting pulsars
- Re-assessment of total Galactic pulsar population
- On/off ratio very low--how many RRATs are there?

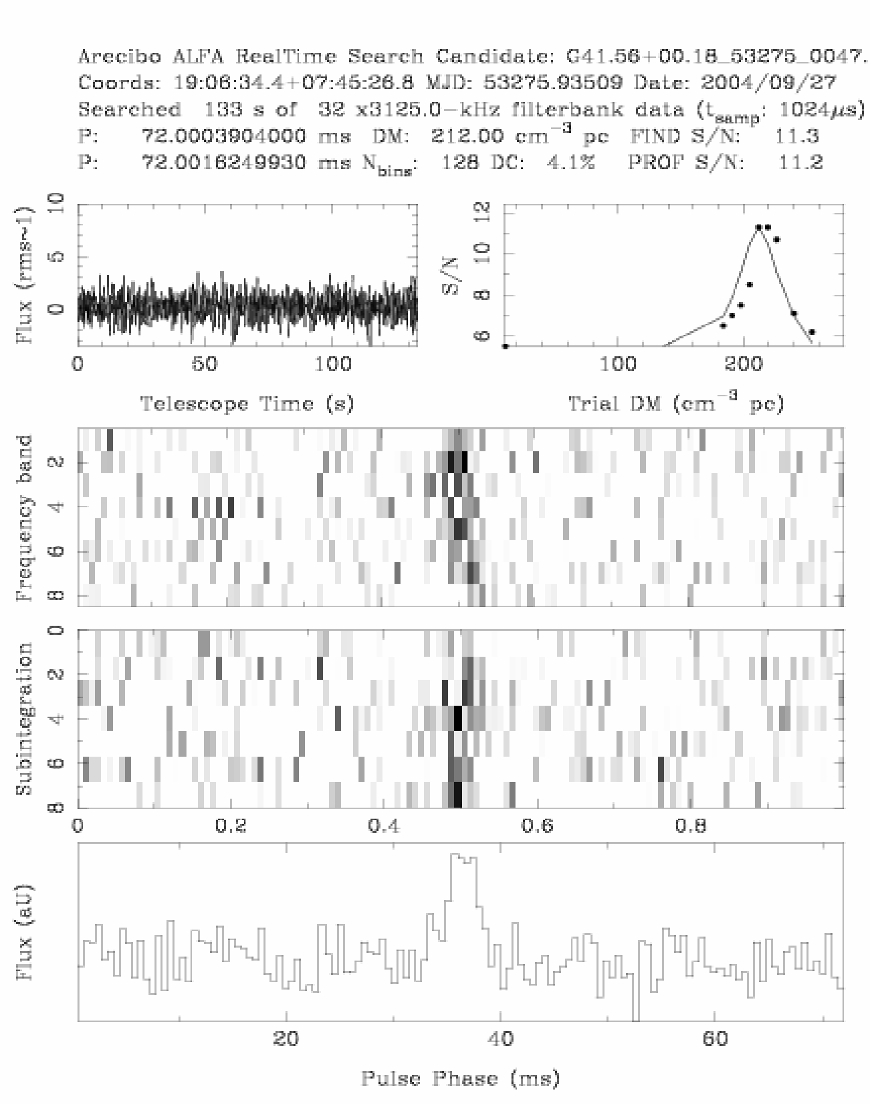
J0628+09

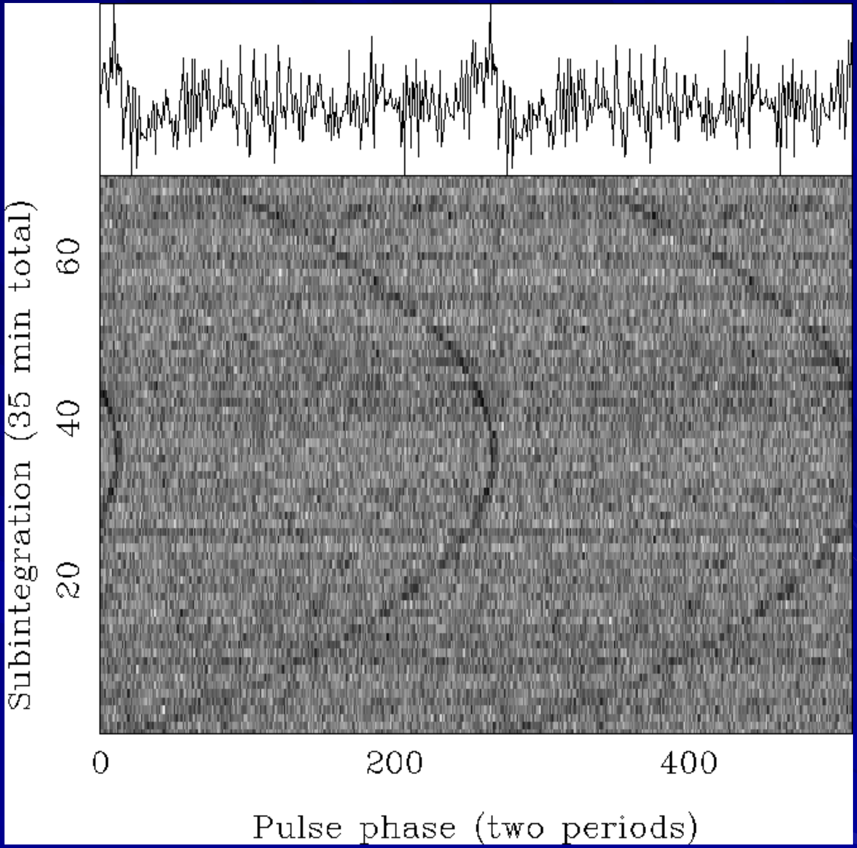




Discovery observation

J1906+07 Discovery



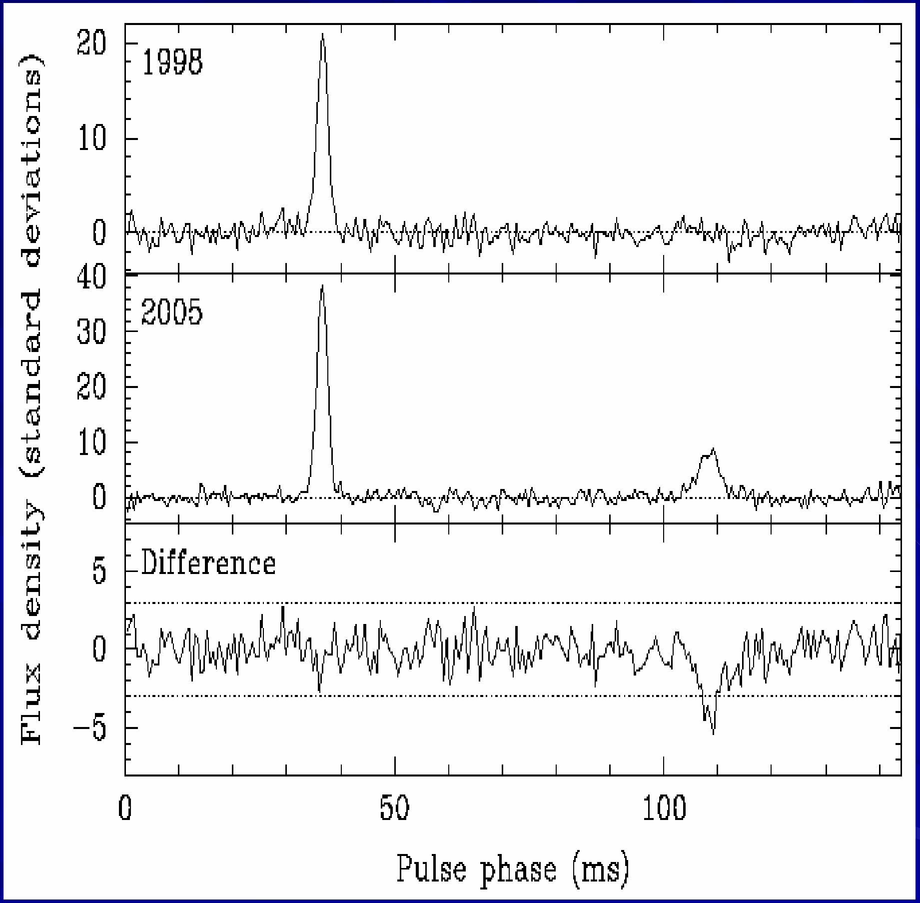


Folded Parkes data from 1998
24.05.2005

Discovery observation 27.09.2004

J1906+07 Parameters

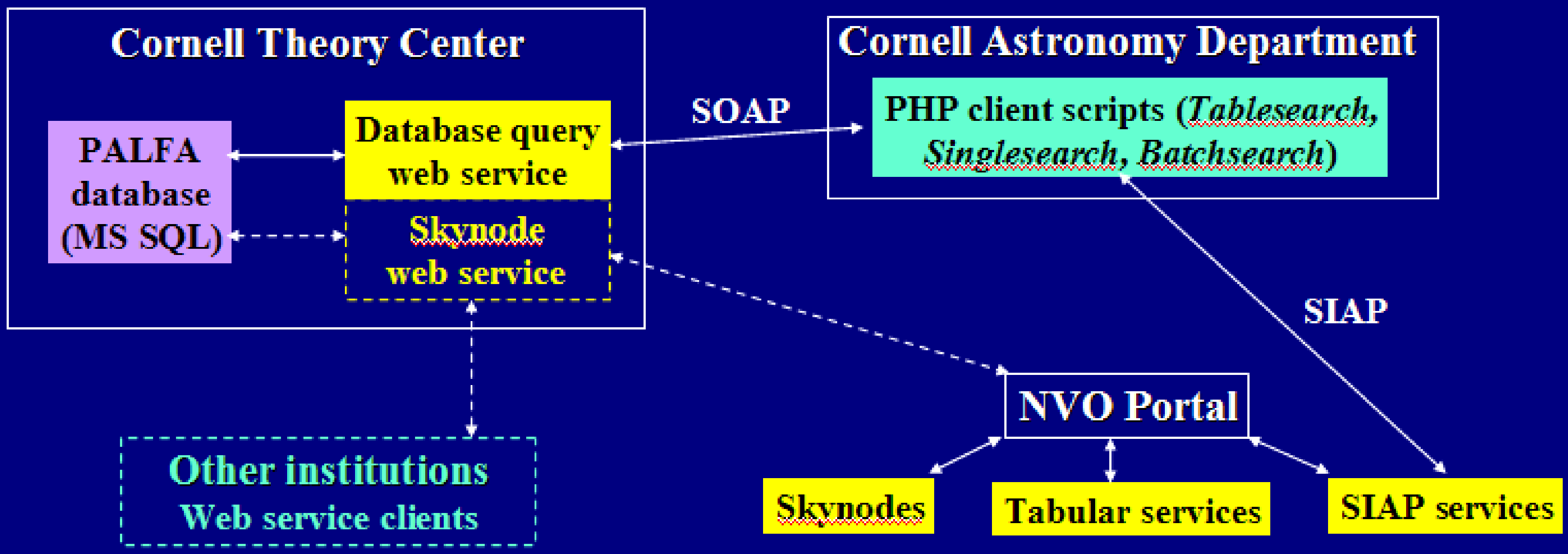
- $P = 144$ ms
- $P' = 2.03 \times 10^{-14}$ s/s
- $P_b = 3.98$ h
- Eccentricity: $e = 0.085$
- DM = 217
- $S_{1.4} = 0.55$ mJy
- Characteristic age, $\tau_c = P/2P'$ = 112 000 yr
- Magnetic field: $B = 1.7 \times 10^{12}$ G
- Spectral index: –1.3
- Total system mass, $M = 2.61 M_{sun}$
- Gravitational wave coalescence time, $\tau_g \sim 300$ Myr



Evolution of interpulse due to geodetic precession: data taken at Parkes in 1998 (top) and 2005 (bottom).

Getting the Goods

- Tape archive at Cornell Theory Center—to grow to ~1PB (ideally 40000+ pointings)
- Database of data products hosted at CTC—to grow to ~25TB
- Dedicated 16-proc Unisys machine to process full-resolution data and run MS SQL server
- Web service for querying database and retrieving info in VOTable format
- Web service clients written by PALFA members (or any user of the archive)



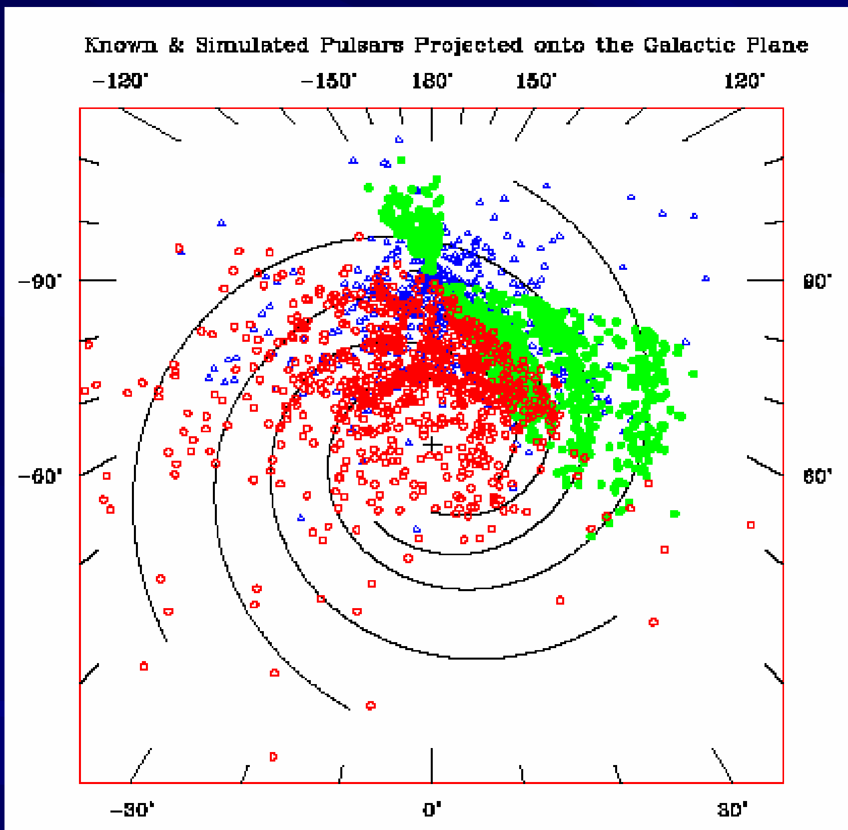
Square Kilometer Array Specifications

Parameter	Design Goal
Frequency range	100 MHz - 25 GHz Goal: 60 MHz - 35 GHz
Simultaneous independent observing bands	2 pairs (2 polarizations at each of two independent frequencies,with same FoV centers)
Instantaneous bandwidth of each observing band	Full width = 25% of observing band center frequency, up to a maximum of 4 GHz BW for all frequencies above 16 GHz
Configuration	Minimum baselines 20 meters, 20% of total collecting area within 1 km diameter, 50% of total collecting area within 5 km diameter, 75% of total collecting area within 150 km diameter, maximum baselines at least 3000 km from array core (angular resolution < 0.02 / fGHz arcsec)
Contiguous imagingfield of view (FoV)	1 sq. deg. within half power points at 1.4 GHz, scaling as λ^2, 200 sq. deg. within half power points at 0.7 GHz, scaling as λ^2 between 0.5-1.0 GHz

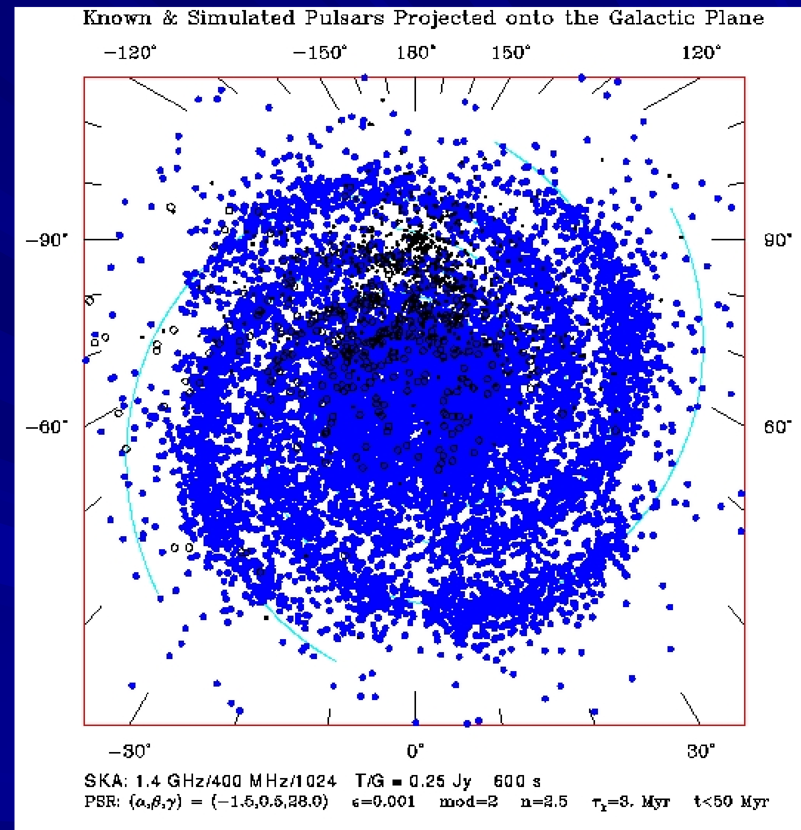
Complete Galactic Pulsar Census

- ~10000-20000 projected pulsar discoveries!
- Statistically likely to include exotic objects: double pulsars binaries, pulsar-BH binaries, sub-millisecond pulsars
- High-precision timing of binary and MSPs
  - Measuring relativistic orbital effects
  - Many objects to follow up—multiplexed timing and astrometry with separate sub-arrays

Find them!
Time them!
VLBI them!



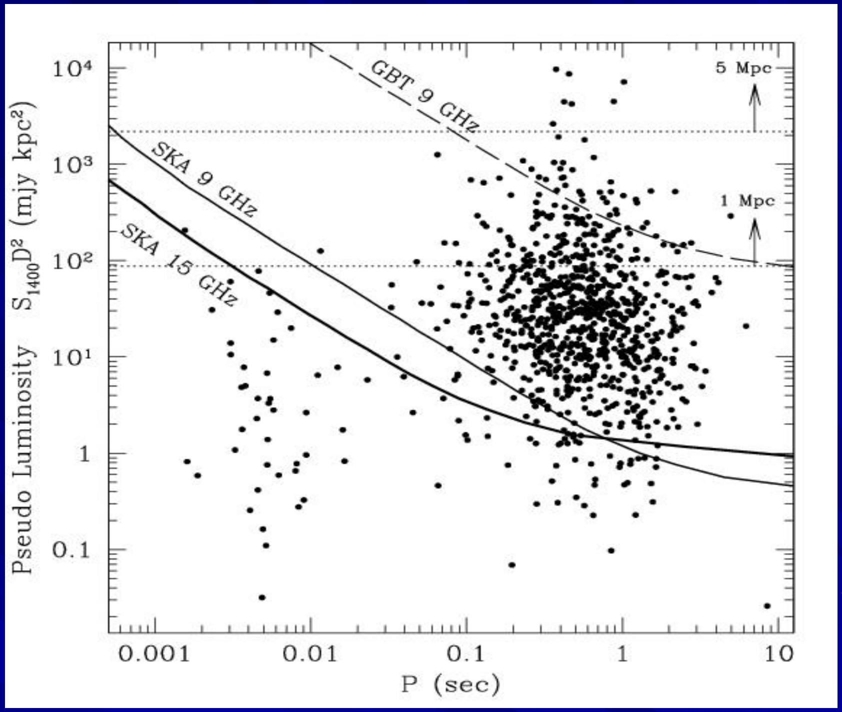
Blue: known pulsars from surveys other than PMB
Red: pulsars discovered by PMB
Green: simulated pulsar discoveries by PALFA (~1000)

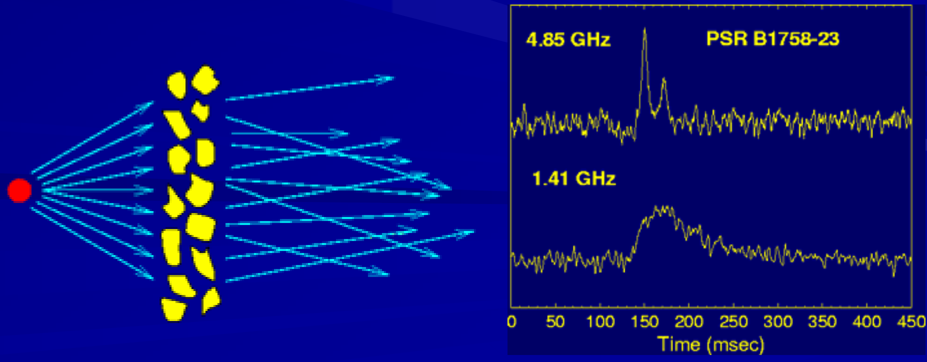


Black: known pulsars
Blue: simulated pulsar discoveries by SKA (~10000)--64 μs samples, 1024 channels, 600 s per beam

Galactic Payoffs

- Galactic Center pulsars
  - Probing location and depth of GC ionized gas “screen”
  - Movement in potential of central BH
  - Measuring spin of BH from timing
- Probing electron number density
- Star formation history
- Galactic grav. potential
- Proper motions and parallaxes





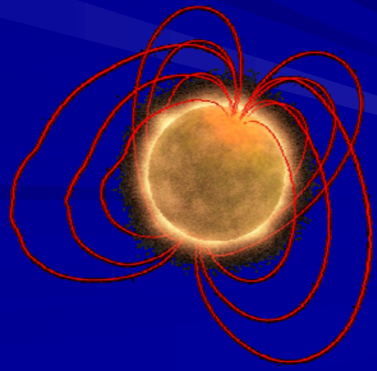
Electron distribution

Extragalactic Payoffs

- Giant pulse detection: pulsars in other galaxies
  - Current: a few pulsars known in LMC and SMC
  - Searches for giant pulses from M31
- Missing baryon problem
  - 4% of energy density in Universe as baryonic matter
  - Only a fraction of that accounted for by observations; what about not easily observable, compact dense objects?
- Probes of inter-galactic medium
  - Analogous to probing interstellar medium in the Galaxy
- Formation and population statistics

Pulsar Astrophysics Payoffs

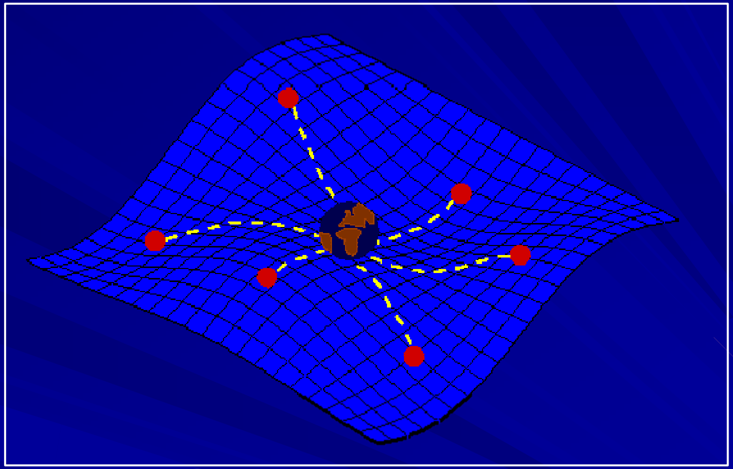
- Magnetospheric properties
- Emission processes
- Pulsar wind nebulae, bow shocks and jets
- Equations of state
  - Properties of matter under extreme conditions
  - Fastest, slowest, most massive, least massive pulsar?



Gravitational Wave Detection

- Pulsar serve as arms of a huge grav. wave detector
- Oscillations in space-time can be detected in timing residuals
- Maybe hidden in timing noise—how to process and extract them?
- "Strain" $h_c(f)$—measure of space-time distortion:

$$h_c(f) \sim \frac{\sigma_{TOA}}{T}$$



PTA: Pulsar Timing Array