TRAPUM

TRAnsients And PUlsars with MeerKAT

Stappers and Kramer
Plus international cast

Members

NAME	Country	Specialism
B. W. Stappers (University of Manchester)	UK	Pulsars and transeints
M. Kramer (MPI für Radioastronomie, co-PI)	DE	Searches and Gravity tests.
A. Berndsen (University of British Columbia)	CA	Beamforming
M. Bietenholz (HartRAO/York University)	ZA	PWNe, VLBI with MeerKAT PI
A. Bouchard (University of McGill)	CA	Pulsars Searches and Follow up
G. Bower (University of California at Berkeley)	USA	Transients
S. Buchner (HartRAO)	ZA	Young pulsars \& outreach
I. Cognard (CNRS - Orleans)	FR	Pulsar searches and follow up timing
J. Cordes (Cornell University)	USA	Galactic center pulsars
J. Deneva (NAIC)	USA	Galactice center and transients
R. Dodson (University of Western Australia)	AU	Beamforming and transients, CRAFT
R. Eatough (MPI für Radioastronomie)	DE	Acceleartion searches and NNETs
C. Englebrecht (University of Johannesburg)	ZA	Neutron star theory and statistics
J. Hessels (ASTRON)	NL	Fast transients and deep targeted searches
R. Fender (University of Southampton	UK	X-ray Binaries, ThunderKAT co-PI
C. Flanagan (Johannesburg Planetarium)	ZA	Outreach & Education
F. Frescura (University of Witwatersrand)	ZA	Neutron star theory and statistics
J. Jonas (SKA South Africa Project Office)	ZA	Search and transients
A. Karastergiou (Oxford University)	UK	Pulsar beams and fast transients
V. Kaspi (University of McGill)	CA	Pulsar Searches and Follow up
J. Lazio (NRL/SPDO)	USA	Galactic center, technology
J. van Leeuwen (ASTRON)	NL	Pulsar searches, technology
W. A. Majid (JPL)	USA	Transients detection, technology
M. McLaughlin (West Virginia University)	USA	Transients
S. Ransom (NRAO)	USA	Globular clusters and search software
R. Smits (University of Manchester/ASTRON)	NL	Simulations and outreach
I. Stairs (University of British Columbia)	CA	Pulsar Searches and COAST
A. Tiplady (SKA South Africa Project Office)	ZA	Pulsar searches
P. Weltevrede (University of Manchester)	UK	Transient Detection

Pulsar Searches in many guises

Targeted pulsar searches of SNRs, PWNe, and high-energy point sources

- Rich locations for pulsars, in particular young pulsars, and energetic MSPs
- Relatively "point like" so not many beams needed
- High gain of meerKAT beats current Southern telescopes

Globular Cluster Searches

- Rich locations for pulsars, in particular MSPs and interesting binaries
- Relatively "point like" so not many beams needed
- High gain of meerKAT beats current Southern telescopes

Extragalactic searches

- Relatively "point like" so not many beams needed
- High gain of meerKAT beats current Southern telescopes
- Predictions indicate that should be able to find a "few'

Using Radio Pulsars to Probe Gravity, Dark Matter and Stellar Populations in the Galactic Center

- Unique high frequency capability of meerKAT
- Implemented later when these frequencies became available
- Extremely interesting science

3000 hours Allocated

Galactic plane survey

- Ambitious, requires about 500 tied-array beams
- Will be developed in collaboration with meerKAT team
- An absolutely vital step towards the SKA

Fast transients: expanding the parameter space

- Search all of the pulsar obs, but also commensal high time resoln.

Commensal & Targetted

Why large FoV is good!

Large Field of View allows
- fast surveys
- multiple sweeps over Galactic plane
- even repeated coverage of the whole sky
  - -> Very sensitive to RRATS and Intermittent pulsars which are only visible for very limited time (e.g. RRATS for ~1s/day)
  - -> Also good for eccentric binaries as can catch at apastron
- short integration times are good for fast binaries in general

Speed-up in survey time means that we can afford long integration times and achieve large sensitivity for
- finding lots of pulsars / MSPs

Long stares are also possible when have good FoV like this

Why FoV is hard

To search for radio pulsars need high time & freq. resoln.

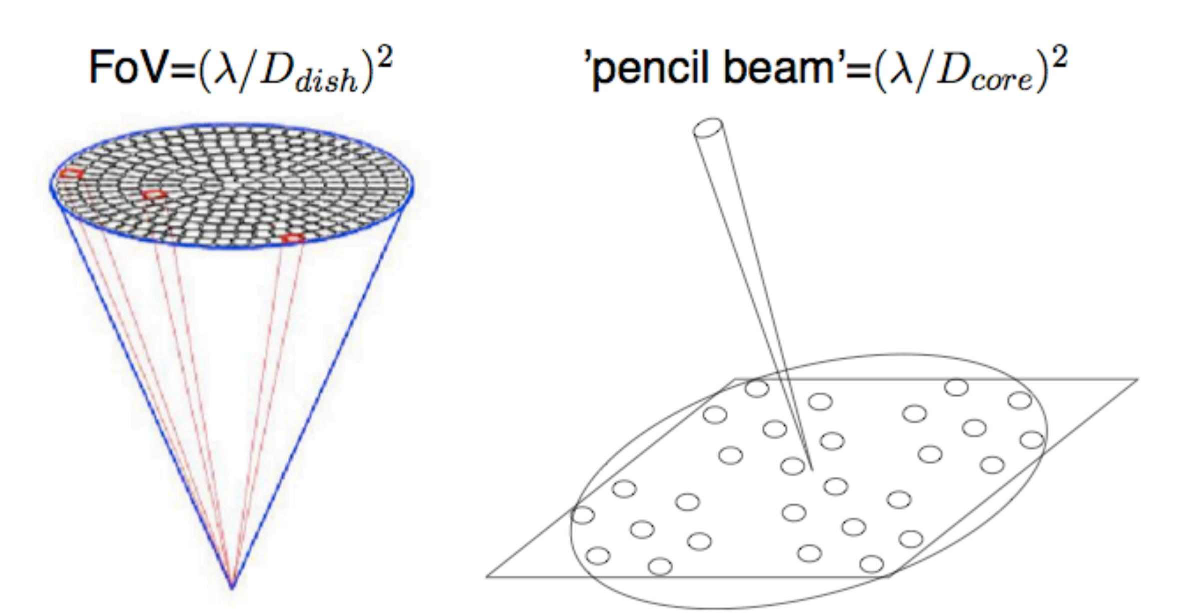
How do we do this for the whole FoV?

Dump correlation products every 50us -- Unlikely

Form large numbers of tied-array or pencil beams

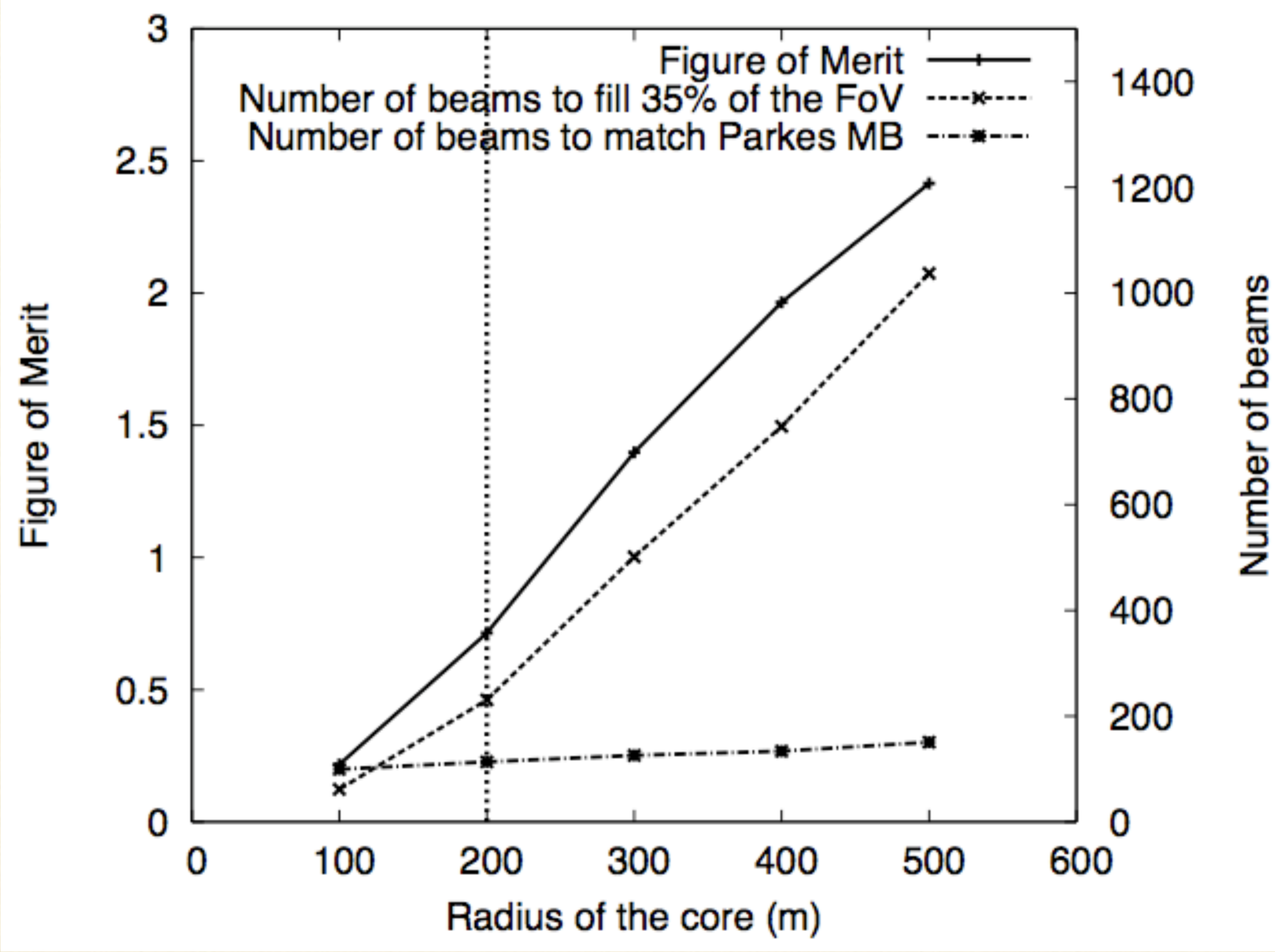
Nbeams = (Dcore/Ddish)^2; Nbeams = (1000/13.5)^2 = 5500

Vast majority of these beams at much lower sensitivity as near half power point



And a "pulsar backend" is required to search each one.

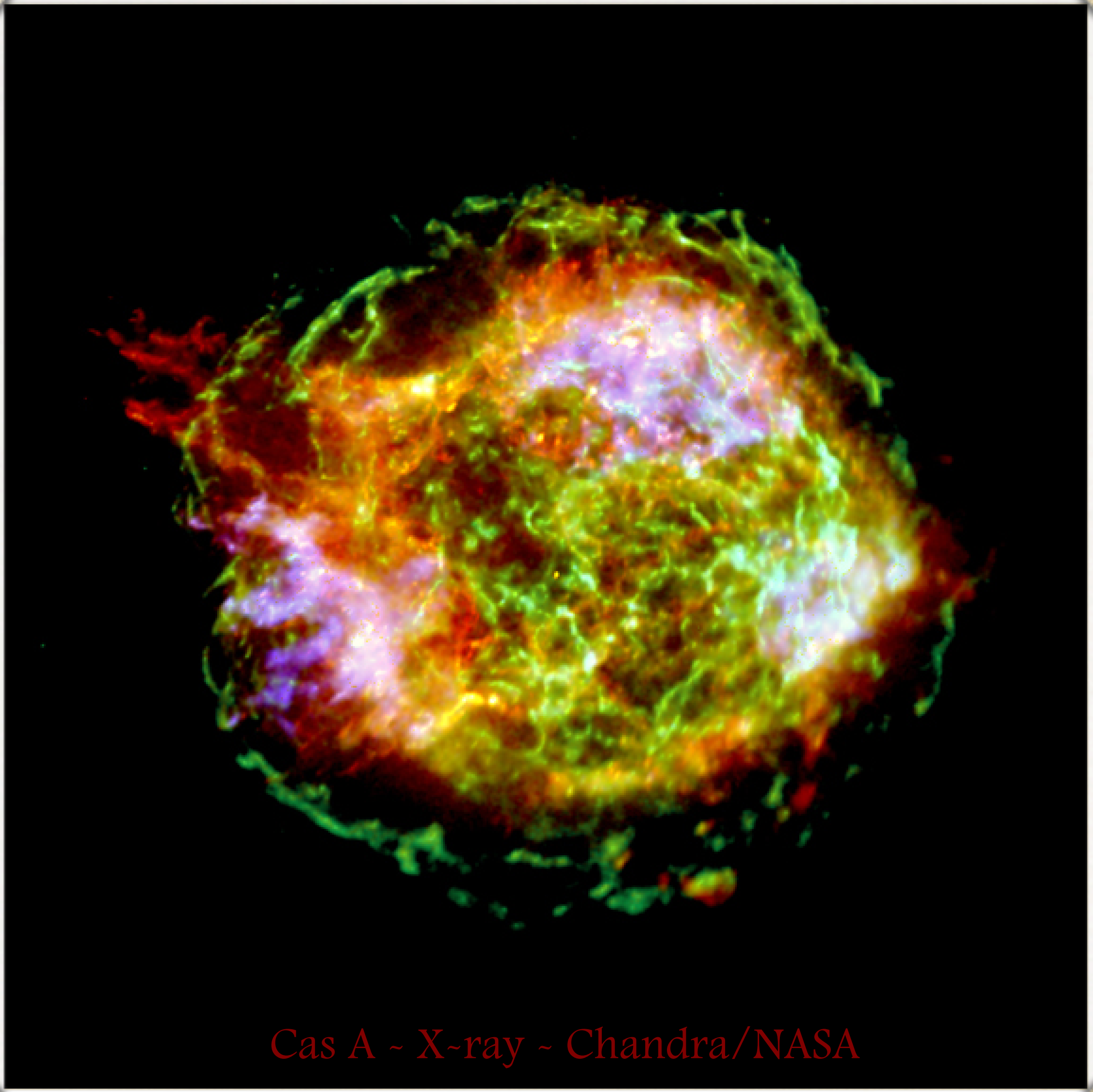
Why meerKAT



Only indicative, needs update for new specs
Will be better now that have more compact core

Supernova Remnants

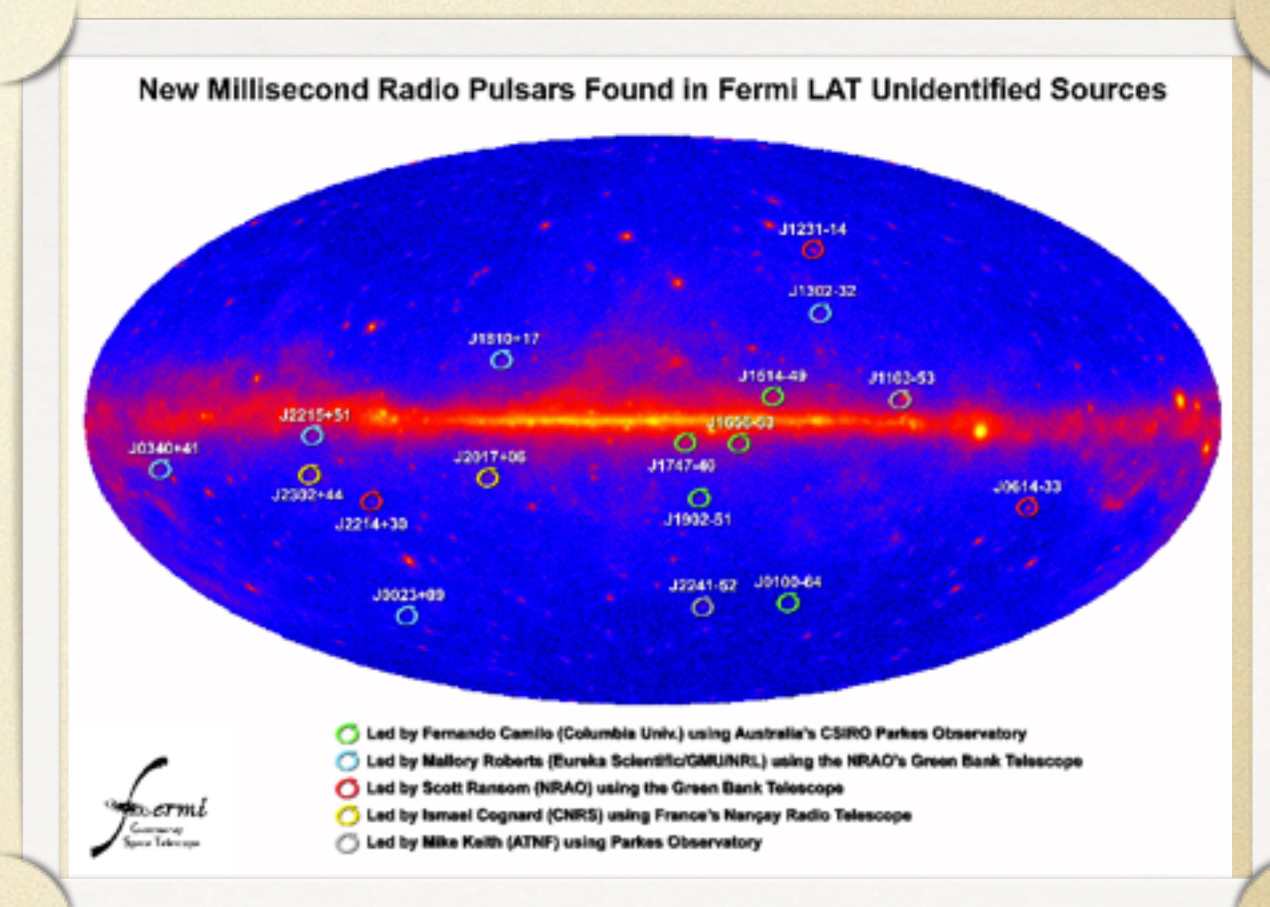
- Big problem in `90s about where were all PSRs in SNRs
- Then Camilo et al found a few very faint objects in SNRs
- Discovery of RRATs, plus magnetars and new types NSs => population problem (Keane & Kramer 2008)
- CCOs: what fraction really radio quiet?
- High freqs to get to SNRs in plane.
- Young pulsars useful for spin evolution.

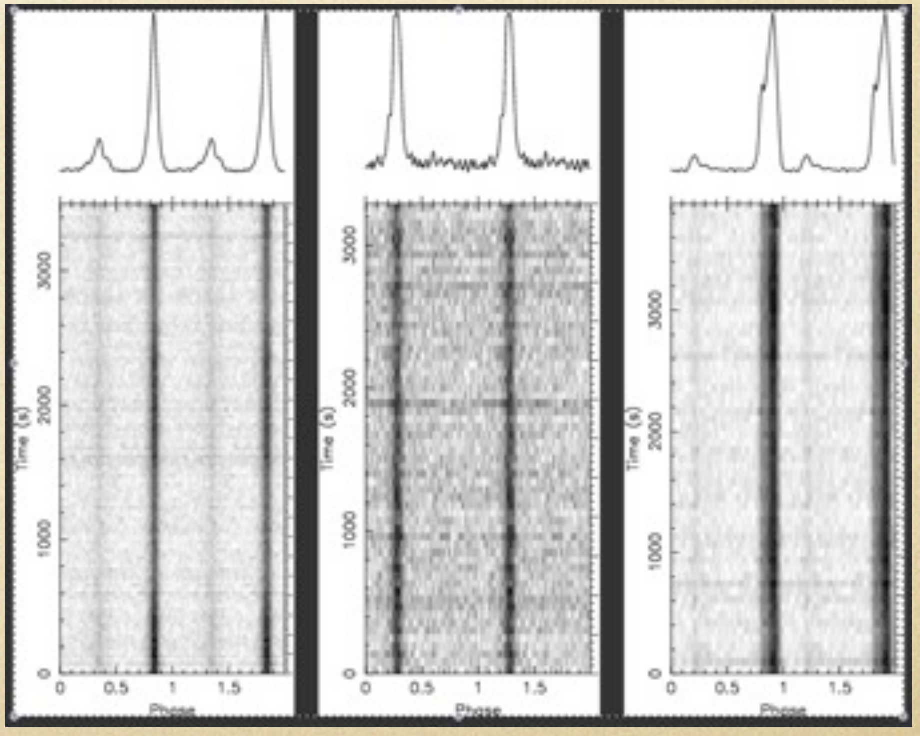


Cas A ~ X-ray ~ Chandra/NASA

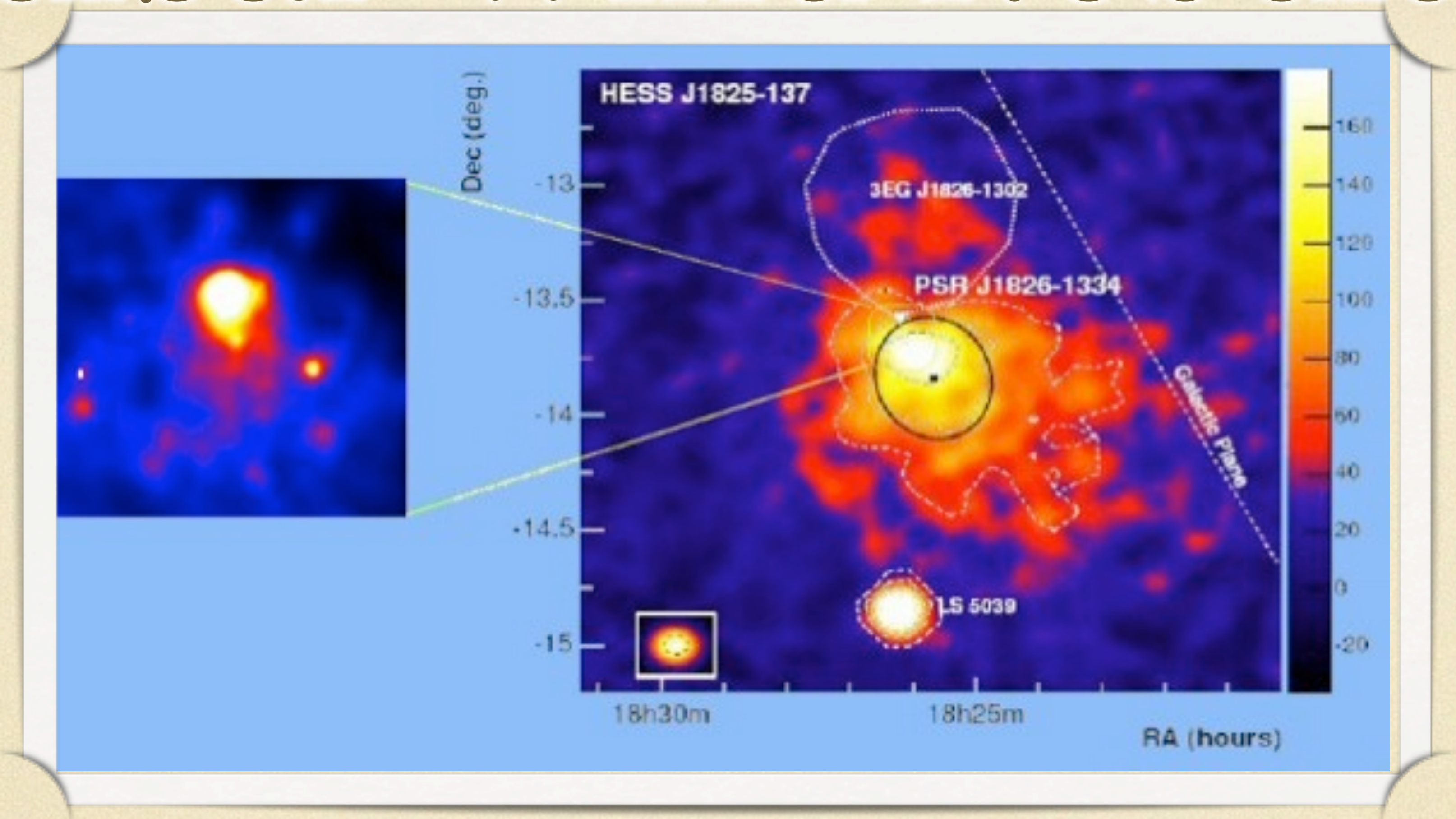
High Energy Point Sources

- Fermi has seen gamma-ray emission from many 10s pulsars
- Many UNID sources
- > 16 found as pulsars from gamma-ray only, only 3 of those seen in radio!
- Some 20 UNIDs have turned out to be MSPs! Probably most efficient way yet to find MSPs
- MeerKAT sensitivity and FoV (only few beams needed) mean can find many more of these MSPs





Pulsar Wind Nebulae



- HESS, and now the other Cerenkov arrays, VERITAS, Magic, etc... are finding very interesting PWNe
- Telling us a lot about the energetics of pulsar winds and point to the locations of young, energetic and fast moving psrs.
- Ideally places to search for new sources, ideally co-located cf. HESS

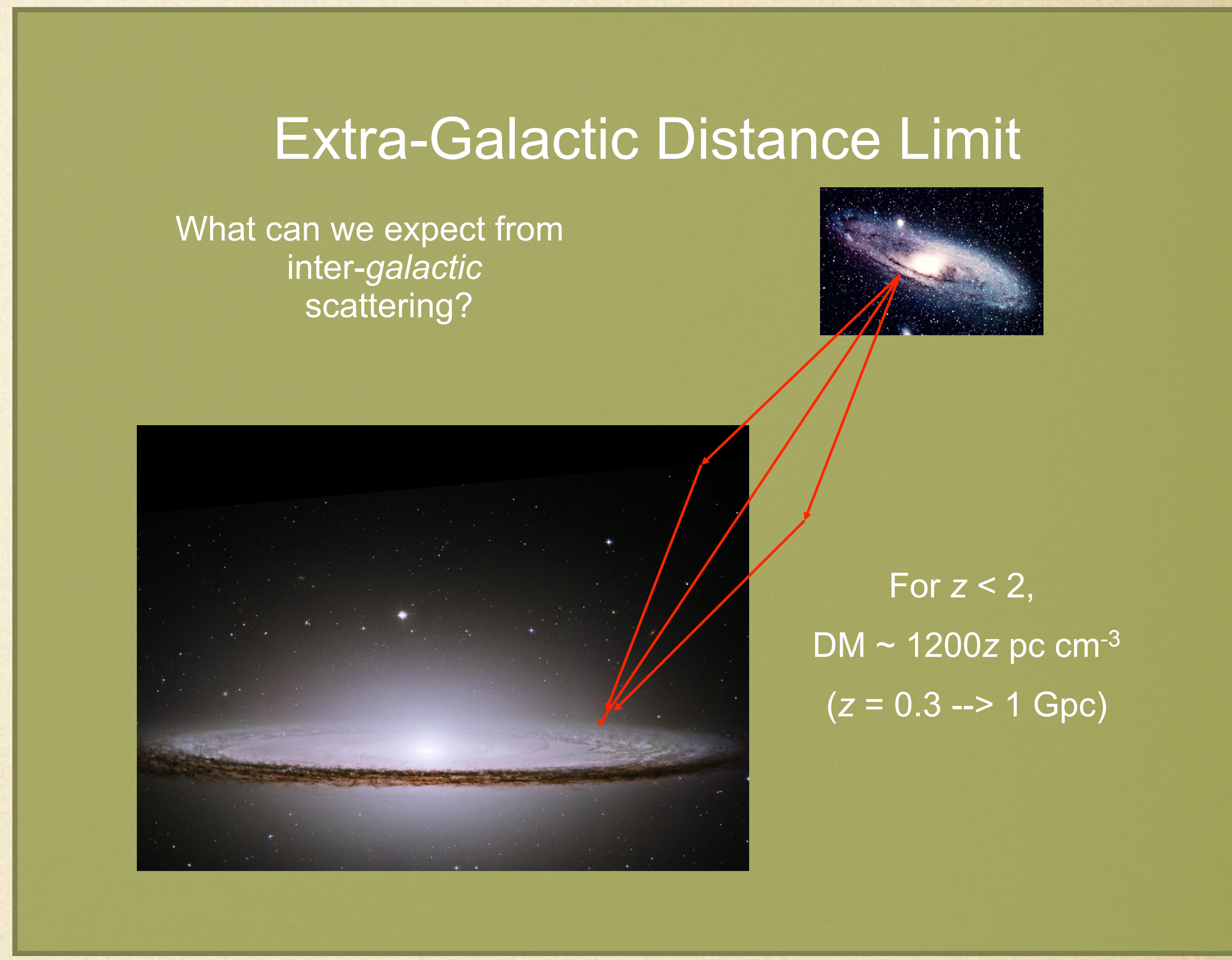
Globular Clusters

- very large number of MSPs per unit stellar mass compared with the Galactic plane
- e.g. Terzan 5 and 47 Tuc, which contain 33 and 22 known pulsars respectively
- MeerKAT's geographical location gives it an excellent view of the rich, dense GCs located in the Galactic bulge
- Many known pulsars in these clusters are in exotic binary systems (e.g. DNSs, planetary mass companions)
- Full scope of possible pulsar binary systems => understanding of the environment of GCs & evolution of these pulsar systems.
- Possibles: e.g. a sub-millisecond pulsar,
- Access more extreme binaries, perhaps even BH-PSR, or IMBH-PSR, as shorter integration times can be used to detect these sources, reducing computation time.

Even largest GCs are small enough that can use a "few" beams from full array

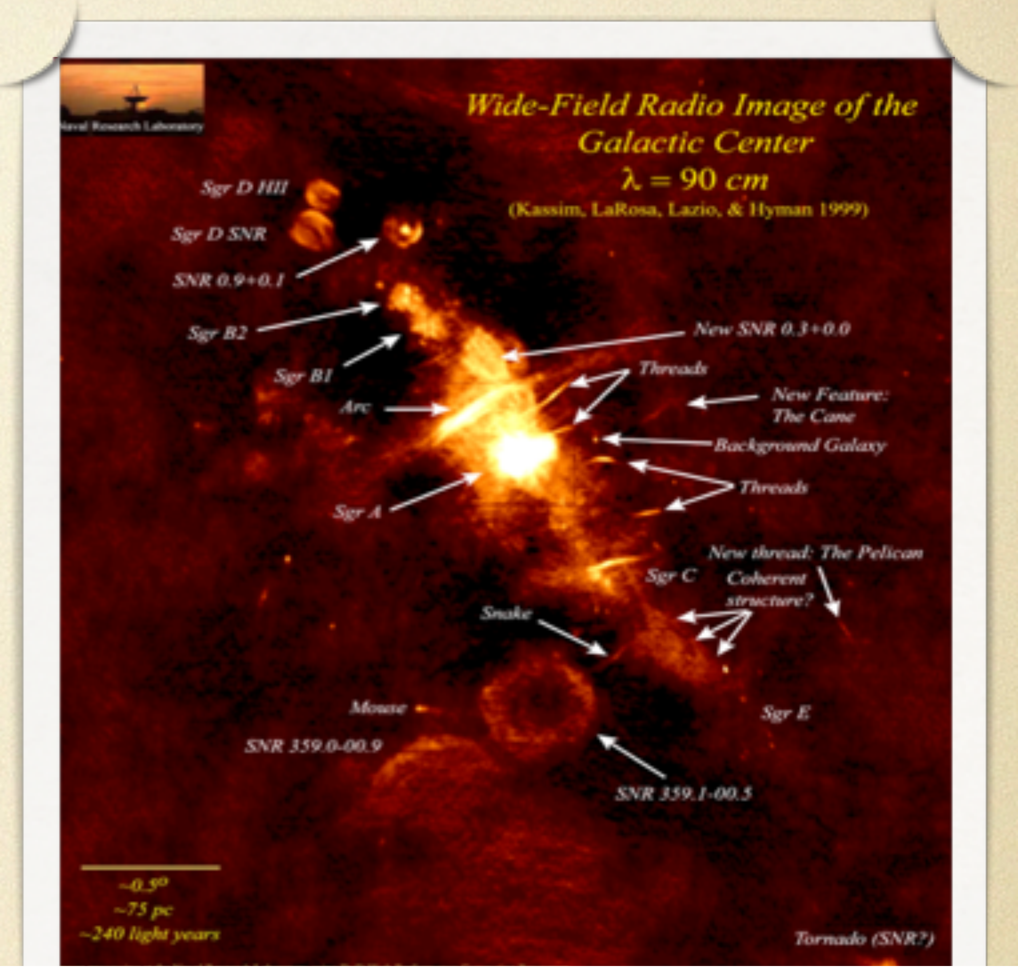
Extragalactic Searches

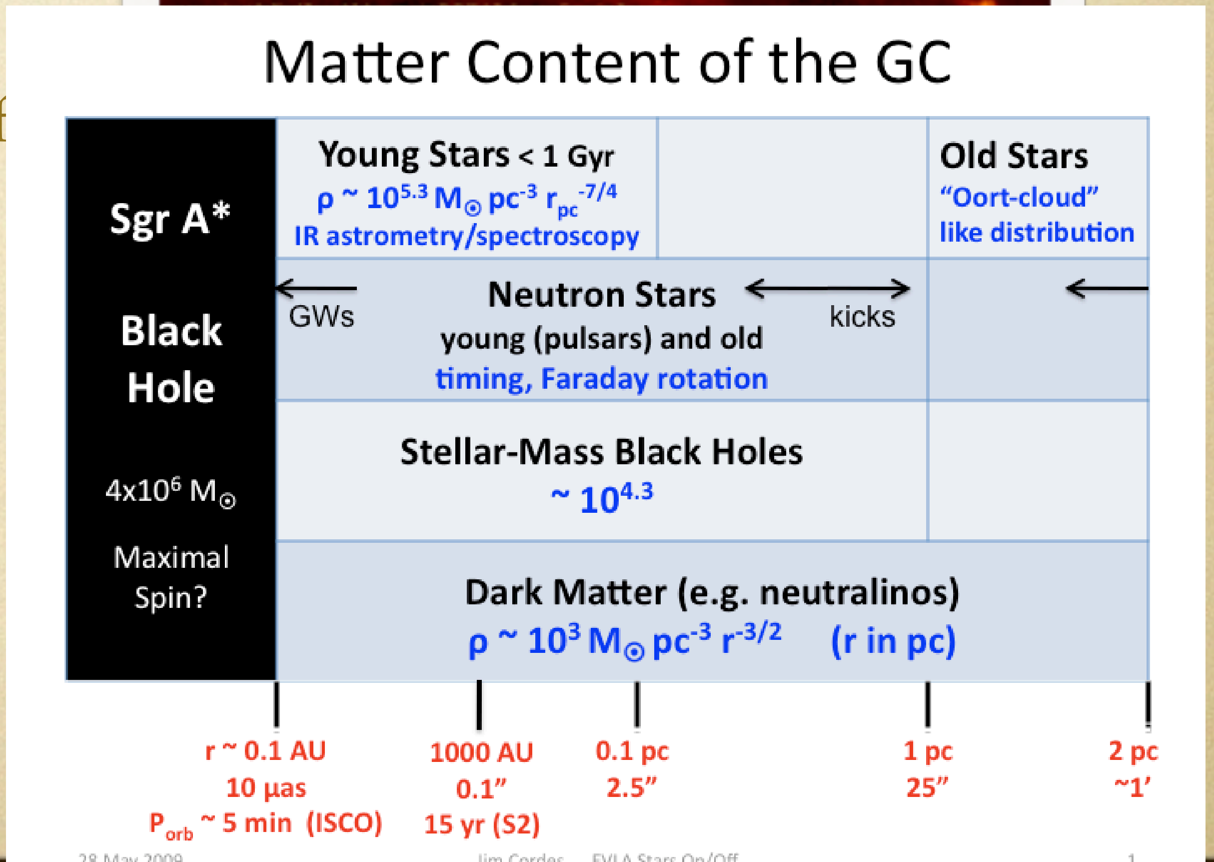
- MeerKAT will have sensitivity to find pulsars in and beyond the "clouds"
- Typically "small" on the sky, don't need many beams.
- Our analysis shows that MeerKAT could find normal pulsars in nearby galaxies and Crab-like giant pulses out beyond the local group galaxies
- Probe the intergalactic medium, probe the WHIM, get around the issues associated with spectral line methods
- Populations compared to galaxy type, star formation rates, metallicity etc...
- Propose to observe 15 nearby galaxies



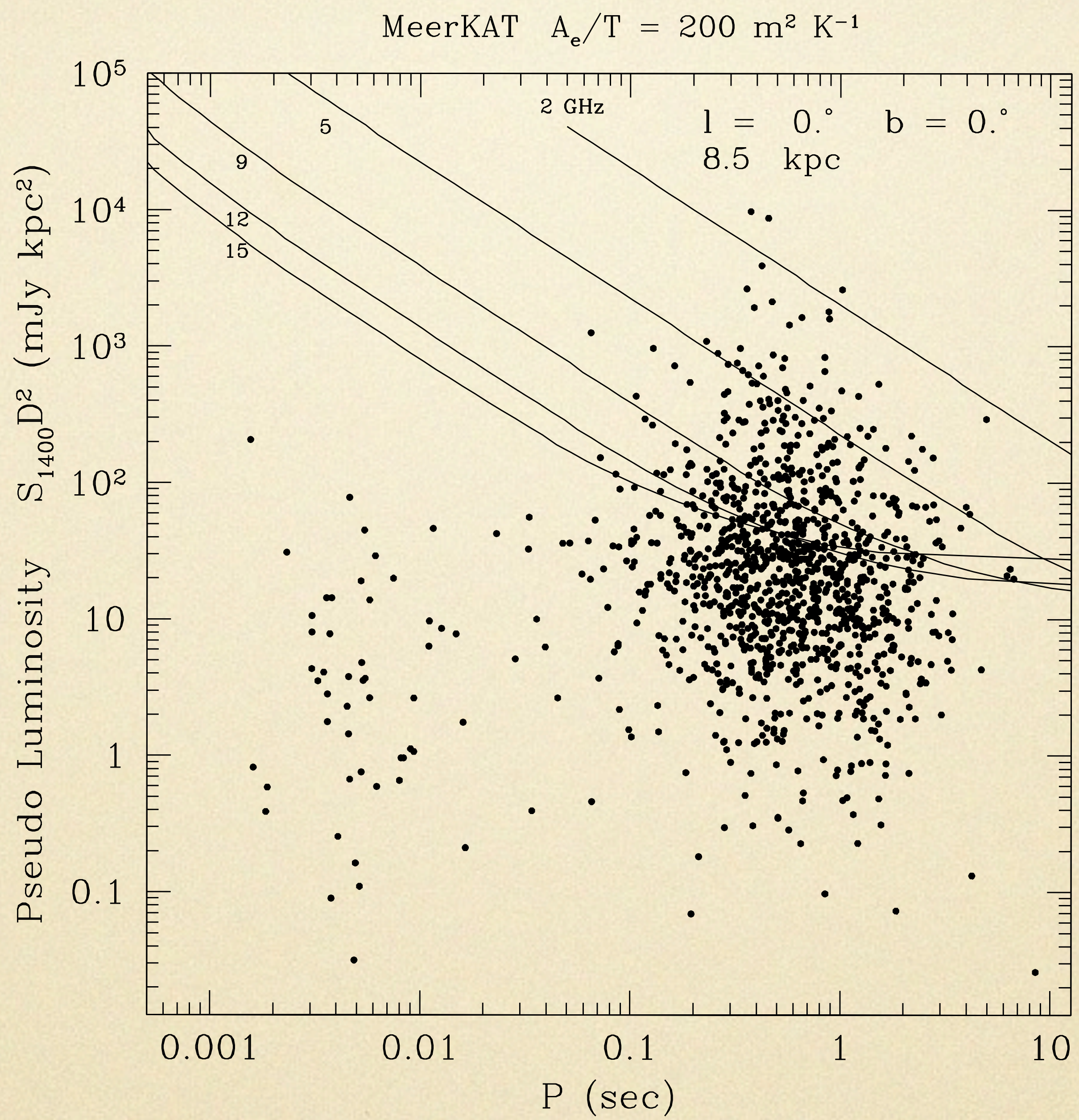
Galactic Center

- 10% of star formation and SGR A*
- expect some 100s to 1000s pulsars present
- Timing can determine precision masses for pulsars with stellar-mass companions and can detect perturbations from the dark matter cloud.
- timing provides unique opportunity to study gravity in strong-field regime
- test no hair theorem
- need to find them within 100pc and preferentially at 1000 AU (IR stars)
- Limited by source confusion, pulsed signals of pulsars are not
- BUT are affected by multi-path propagation effects, scattering
- need to go to high frequencies
- timing also affected, but gravity effects scale as some power of pulsar mass and this is 10^6 times higher!





Galactic center



Sensitivity curves for periodicity searches for pulsars in the Galactic Center. Pulsars above the curves are detectable. Curves are plotted against spin period and pseudo-luminosity, Lp, and assume 6-hr data sets with a threshold of 10σ for bandwidths of 1, 1, 2, 4 and 4 GHz at center frequencies 2, 5, 9, 12 and 15 GHz.

Galactic Plane

Galactic plane survey Most of the pulsars known have been discovered in the Galactic plane. This is not surprising as pulsars are expected to form from massive stars which are indeed located in this area. A survey along the Galactic plane should therefore mostly discover and detect young pulsars which have not moved far away from their birth place. This is indeed confirmed by discoveries of history's most successful survey, the Parkes Multibeam survey [27, 22]. But other, arguably even more intersting sources are expected to be in this region, namely highly dispersed MSPs missed by previous surveys with poor time and frequency resolution, and in particular relativistic binary pulsars. Indeed, in order to form the most sought-after double neutron star systems (or even the enormously exciting pulsar - black hole system that we strive to find!) the system needs to survive two potentially disruptive supernova explosions which usually separate the pulsar from its companion. However, depending on the kick direction imparted on the formed neutron star in the asymmetric supernova explosion, the binary system may survive with a low systemic velocity, again suggesting that such system stills remain near their birthplace in the Galactic plane. Again, this is confirmed by the known population of relativistic double neutron stars. A survey in the Galactic plane is therefore highly interesting for two reasons; a) to provide a step towards the Galactic census of pulsars that is complementary to low-frequency surveys with LOFAR which will explore the local solar neighbourhood and b) the discovery of highly relativistic pulsars that enable precision tests of general relativity and other theories of gravity (e.g. [24]).

Recent efforts by some of us have shown that even in previously searched areas, a large number of exciting sources can be detected. Previous non-detections can be caused by scattering or dispersion smearing at lower frequencies, scintillation, acceleration smearing and/or effects intrinsic to the pulsars, namely their nature as intermittent pulsars [23] or RRATs [28]. A repeated survey therefore delivers usually a higher percentage of interesting pulsars that can be exploited for various physical or astrophysical questions, as most 'ordinary' stars are already known in the survey area. This is particularly true in this survey which will combine excellent sensitivity, allowing shorter integrations, and a sophisticated acceleration search to reveal relativistic binaries.

As discussed in detail below we propose to search a 5700 square degrees area ($|b| < 15$) along the plane which is somewhat larger that the area covered in the Parkes Multibeam surveys. Simulations show that the survey will able to find 1000 new pulsars in this region, of which more than 100 will be MSPs.

In summary, the Galactic Plane survey will enable us to pursue the questions about the Galactic population of neutron stars (incl. the relative number of RRATs and pulsars), and the search for exotic relativistic binary pulsars and MSPs which will be suitable for pulsar timing array experiments.

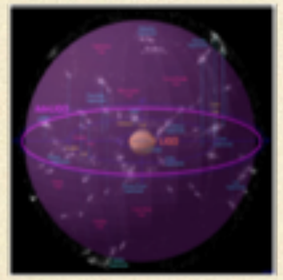
1000 new pulsars and

100 new MSPs

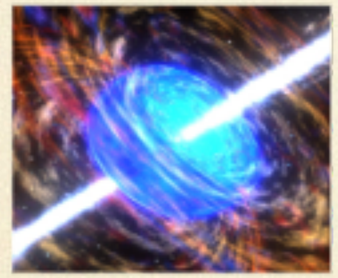
Fast Transients

Timescales ~< 1 s. Time Domain

GW sources



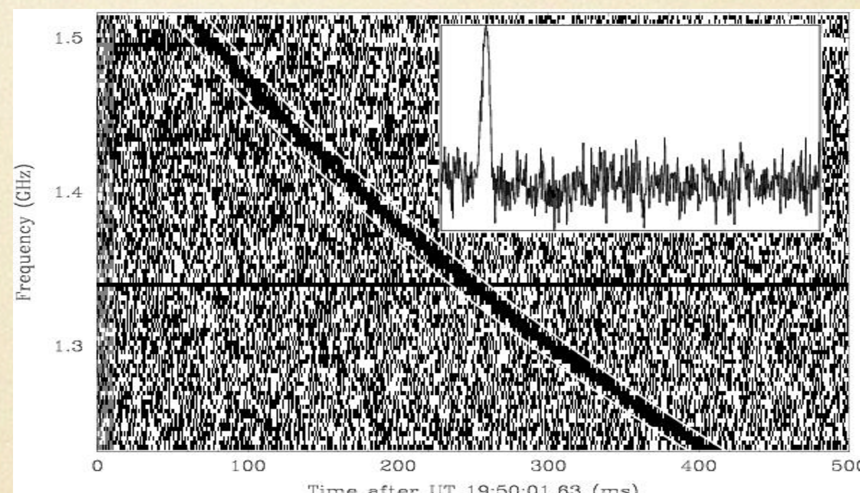
Jet sources



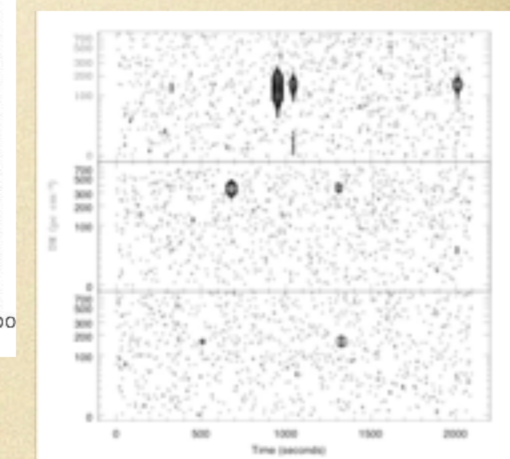
GRBs

SNe

- •Ultra-high-energy particles
- •The Sun (Type II and III bursts)
- •Flare Stars
- •AGN
- •Brown dwarfs (scaling from NSs?)
- •Planets (Jupiter, Saturn, Exoplanets (low freq?))
- •ETI
- •Lorimer et al. burst(s) -- note possible “new” source.
- •Annihilating black holes, coalescing NSs
- •Supernovae
- •**Neutron Stars**, e.g. RRATs (nullers,burpers,etc.),“sometimes a pulsars”, radio magnetars
- •Electromagnetic counterparts to GW sources, Advanced LIGO on similar timescale

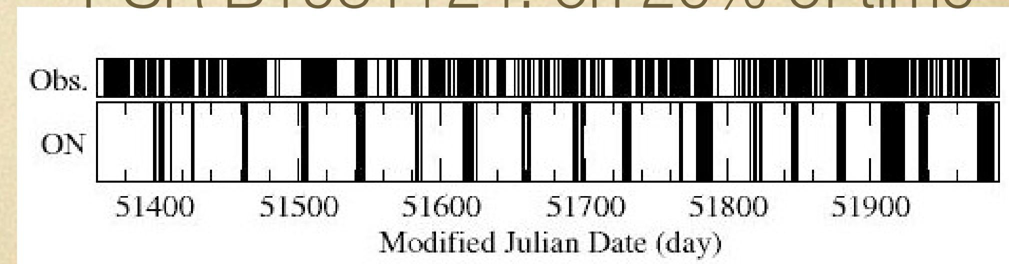


Spectral index -4+/-1, Dispersion and Pulse Broadening (Komolgarov)



Burst rates as low as 1/4hr!

PSR B1931+24: on 20% of time



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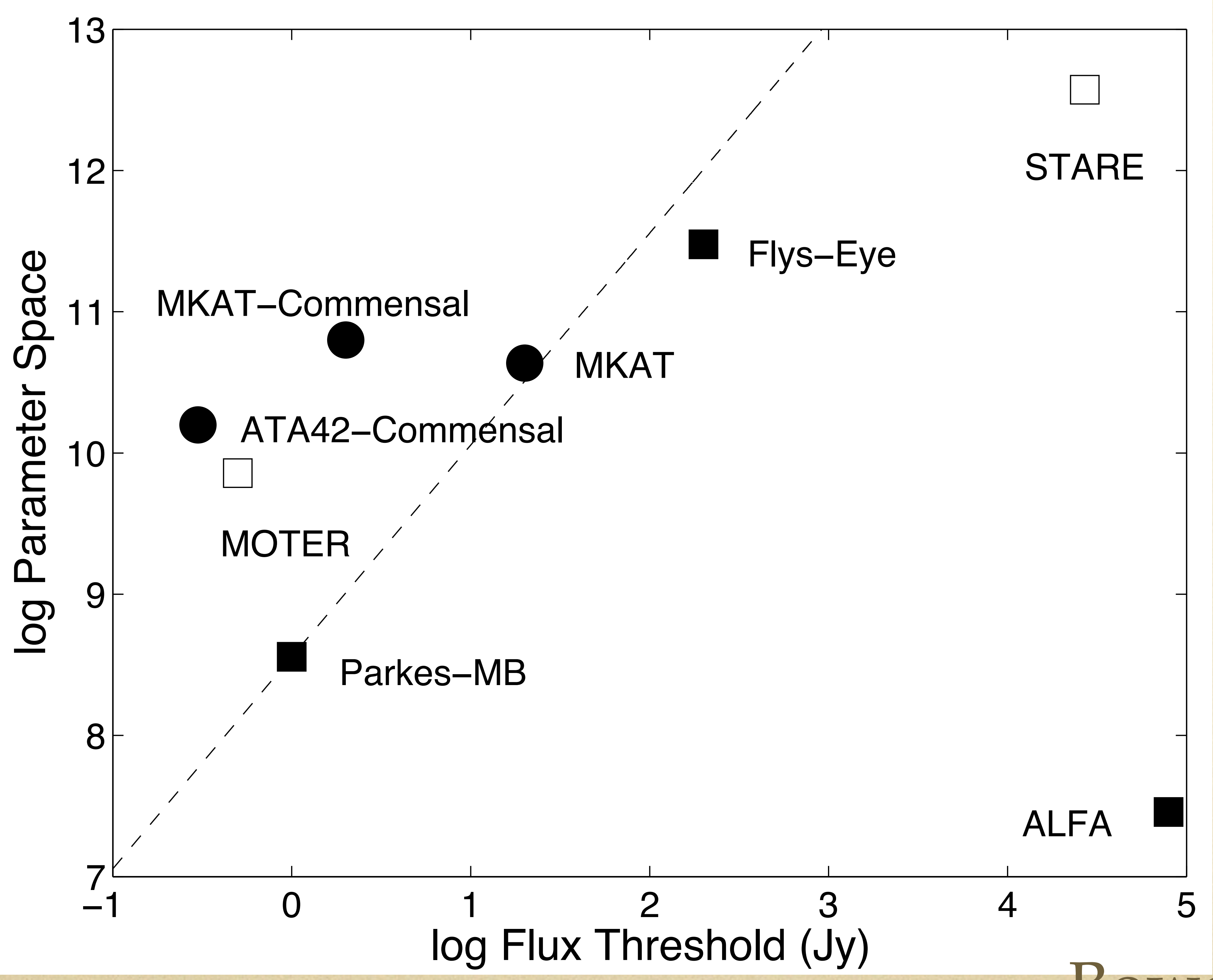

Bower

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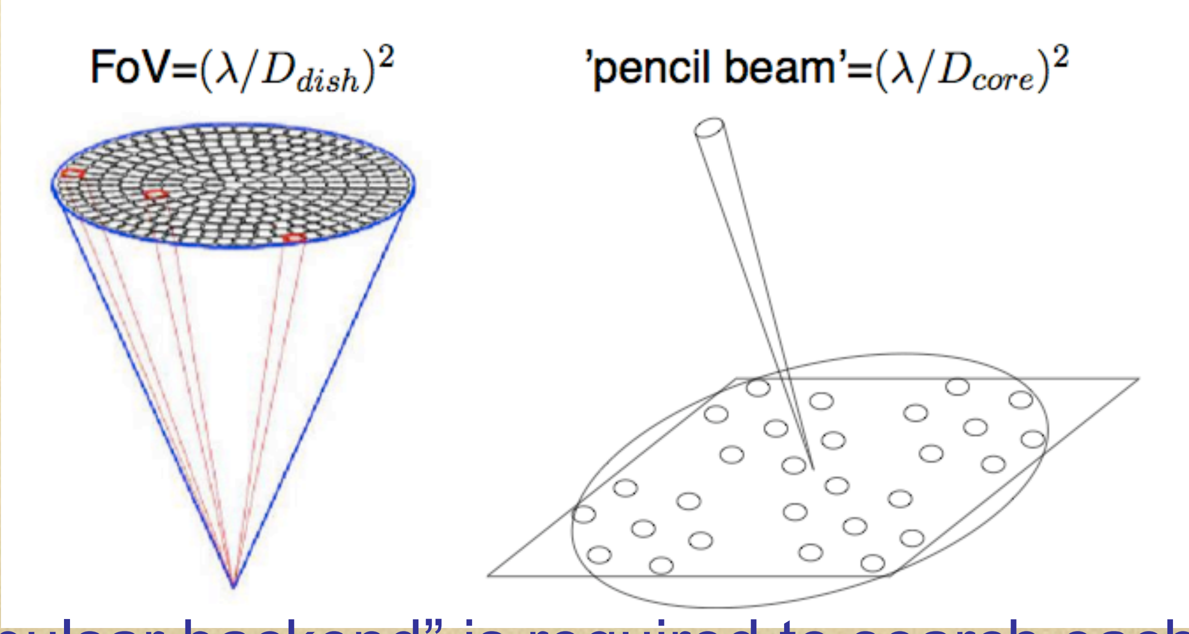

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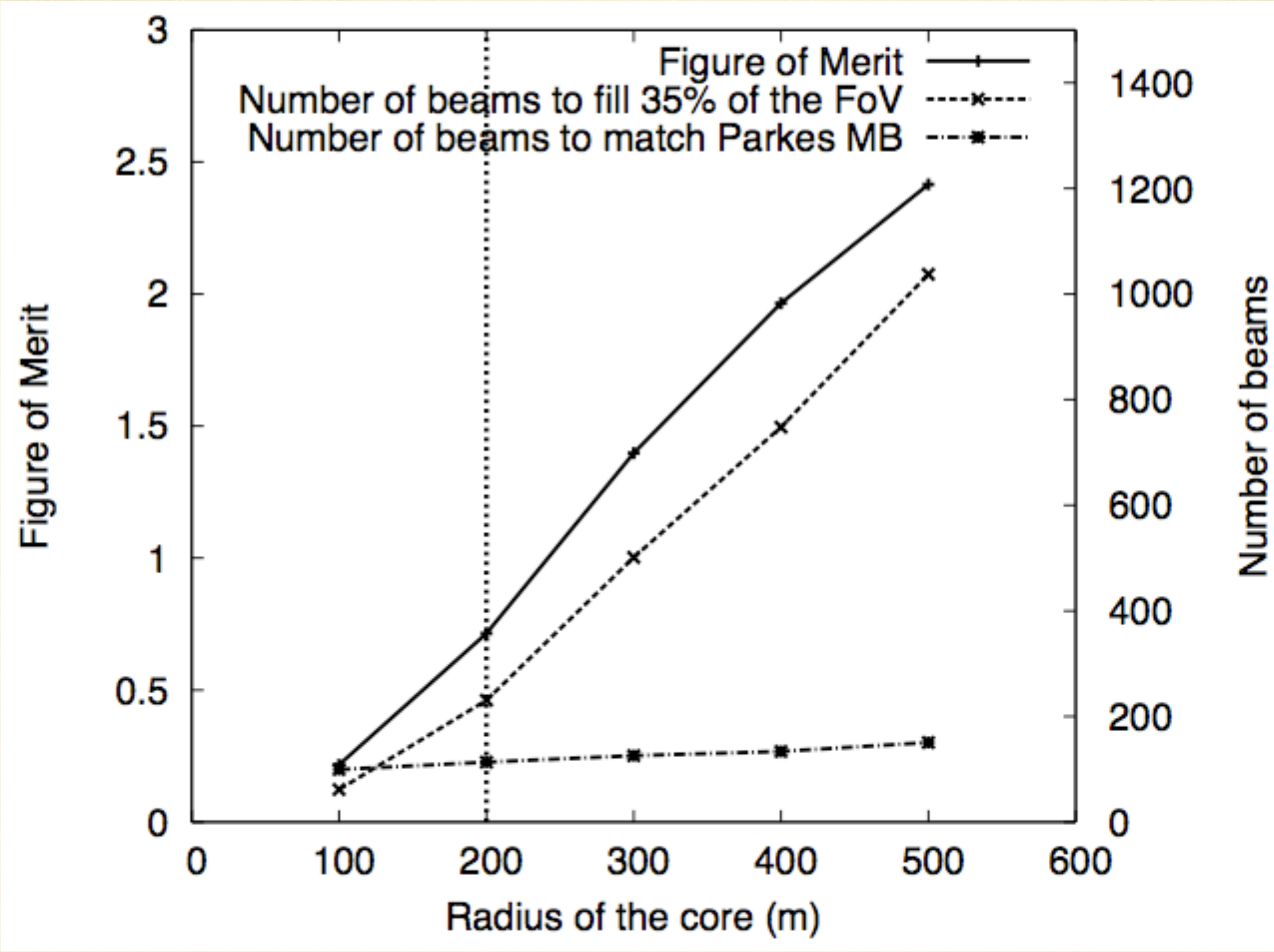

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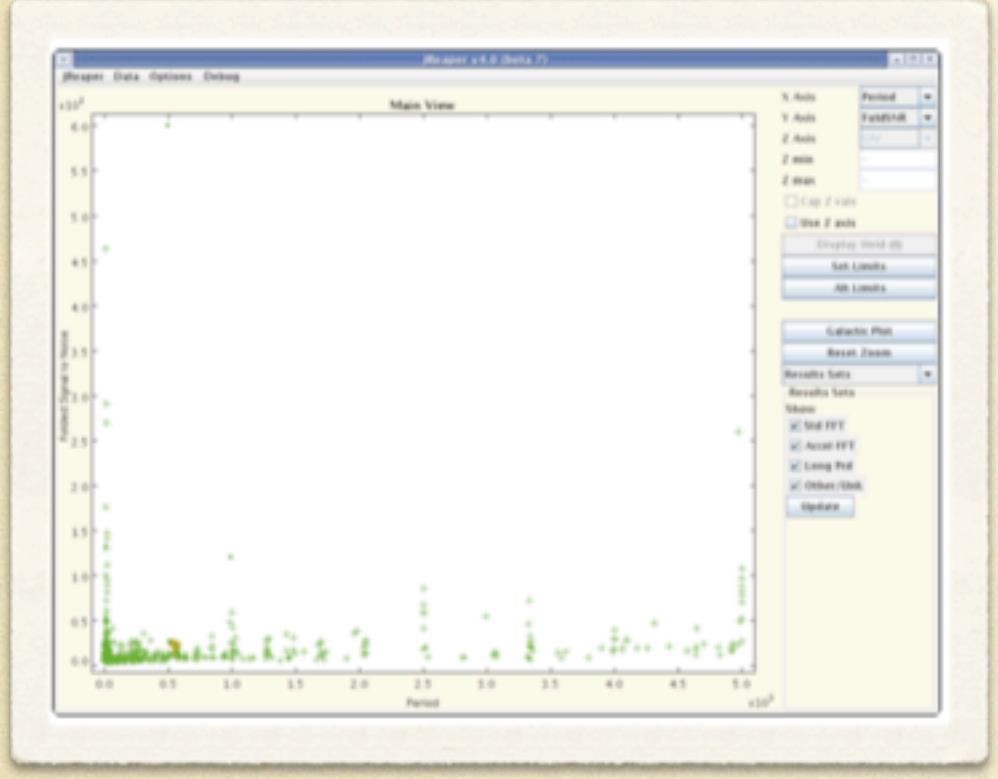
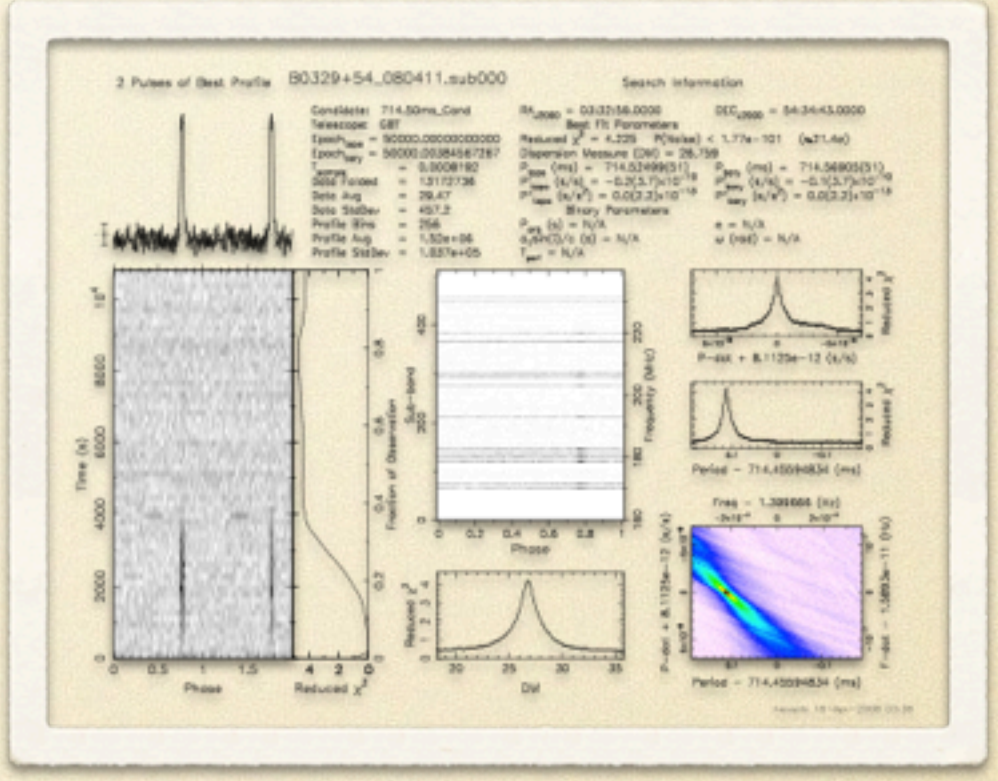
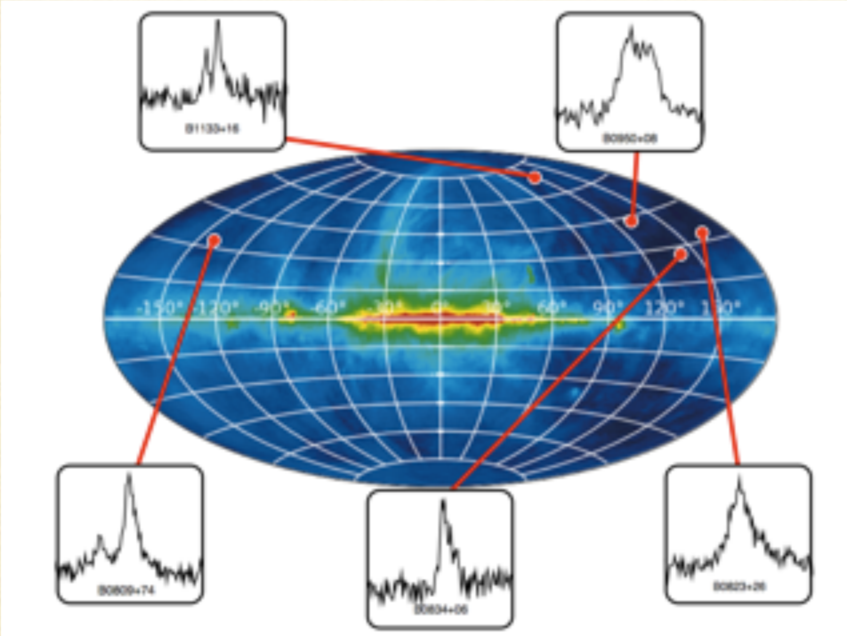
Why large number beams good,



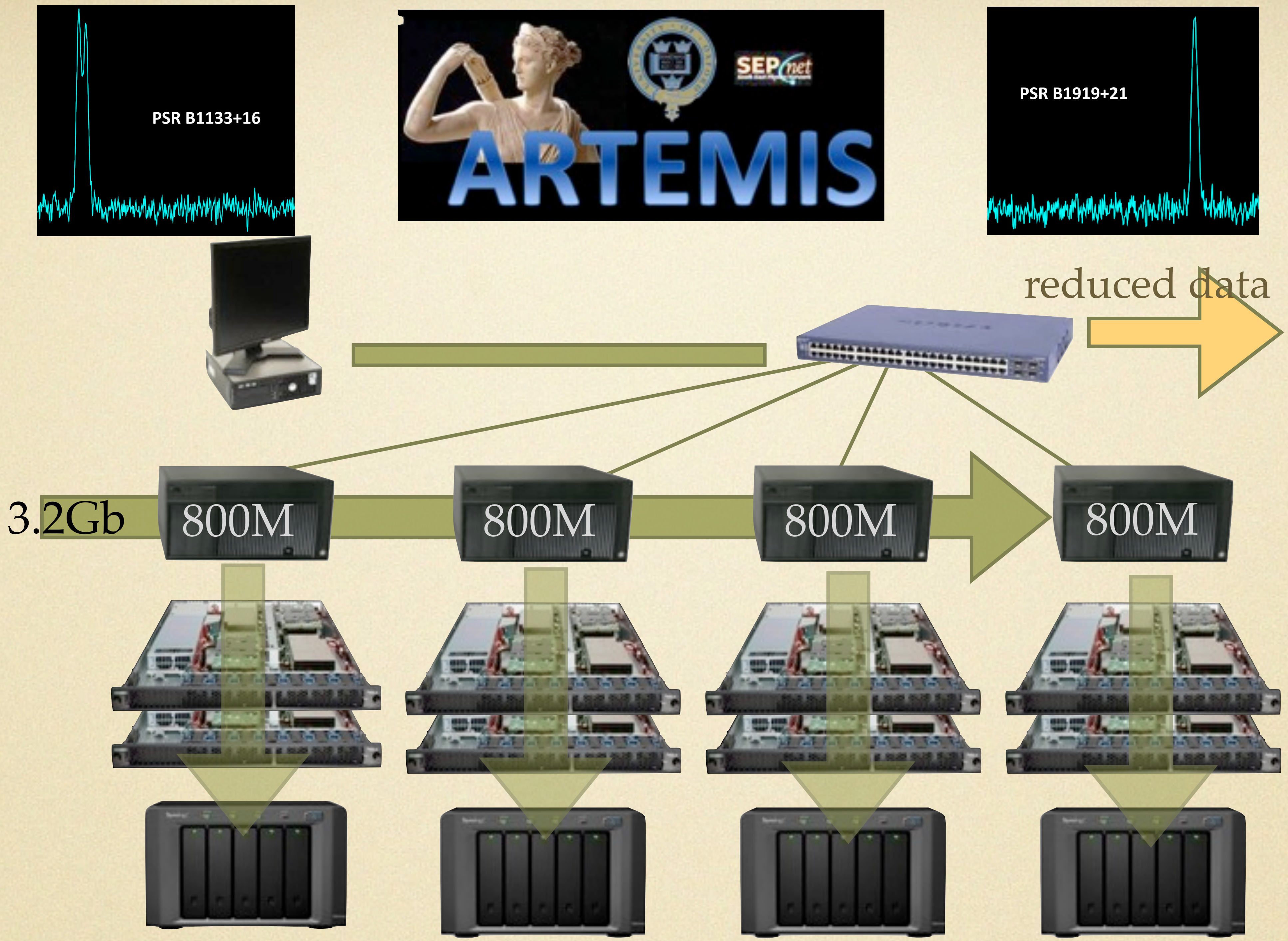


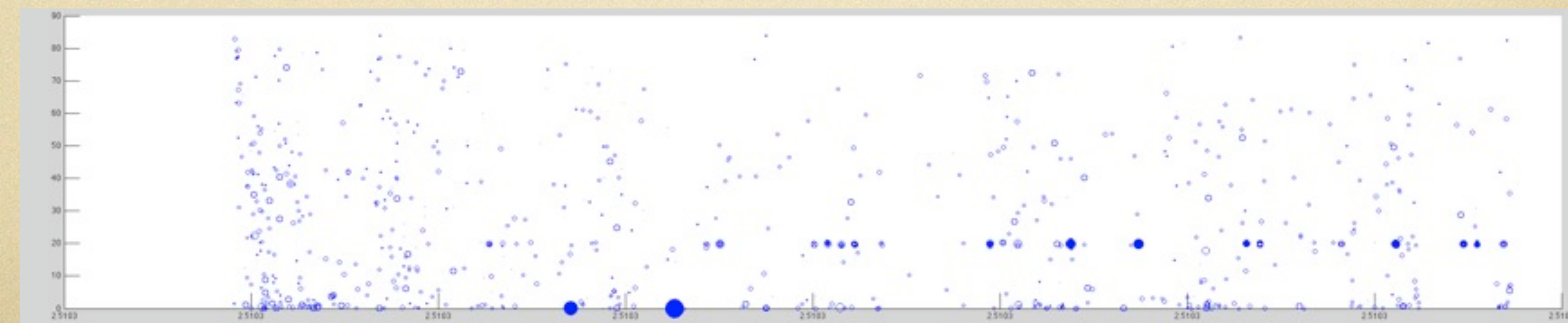
- Modern pulsar surveys are so sensitive they find millions-billions of candidates, can't inspect manually
- Need better way --> NNets, currently achieving about 98%
- Need to also develop similar for fast transients

LOFAR



- incoherent shallow survey already underway
- multiple coherent beams possible, expect couple hundred with new CEP (now)
- Some point source searching started
- Processing will be done offline, many more DM trials than needed for MeerKAT


PSR B1133+16
ARTEMIS
PSR B1919+21
reduced data
3.2Gb
800M
800M
800M
800M



Overlap

- Plenty of fields that are in common with other projects, but in particular with TKat
- Like Tkat, if possible we would want to be commensurate on as many projects as possible.
- May require we run with reduced resources, e.g. incoherent sum.
- Especially interesting to get to the GP, but there we do need maximal resources.

Conclusions

- MeerKAT will be an excellent telescope for finding new pulsars and fast transients.
- There are many interesting regions of the sky that we can survey without needing hundreds of beams
- Doing the Galactic Plane is where vast riches are to be found, it looks like quite large numbers of beams poss.
- We can start already with KAT-7, in particular for the fast transients even incoherent sum!
- Can “reuse” lots of other work going on!
- TRAPUM is ready to be SPRUNG