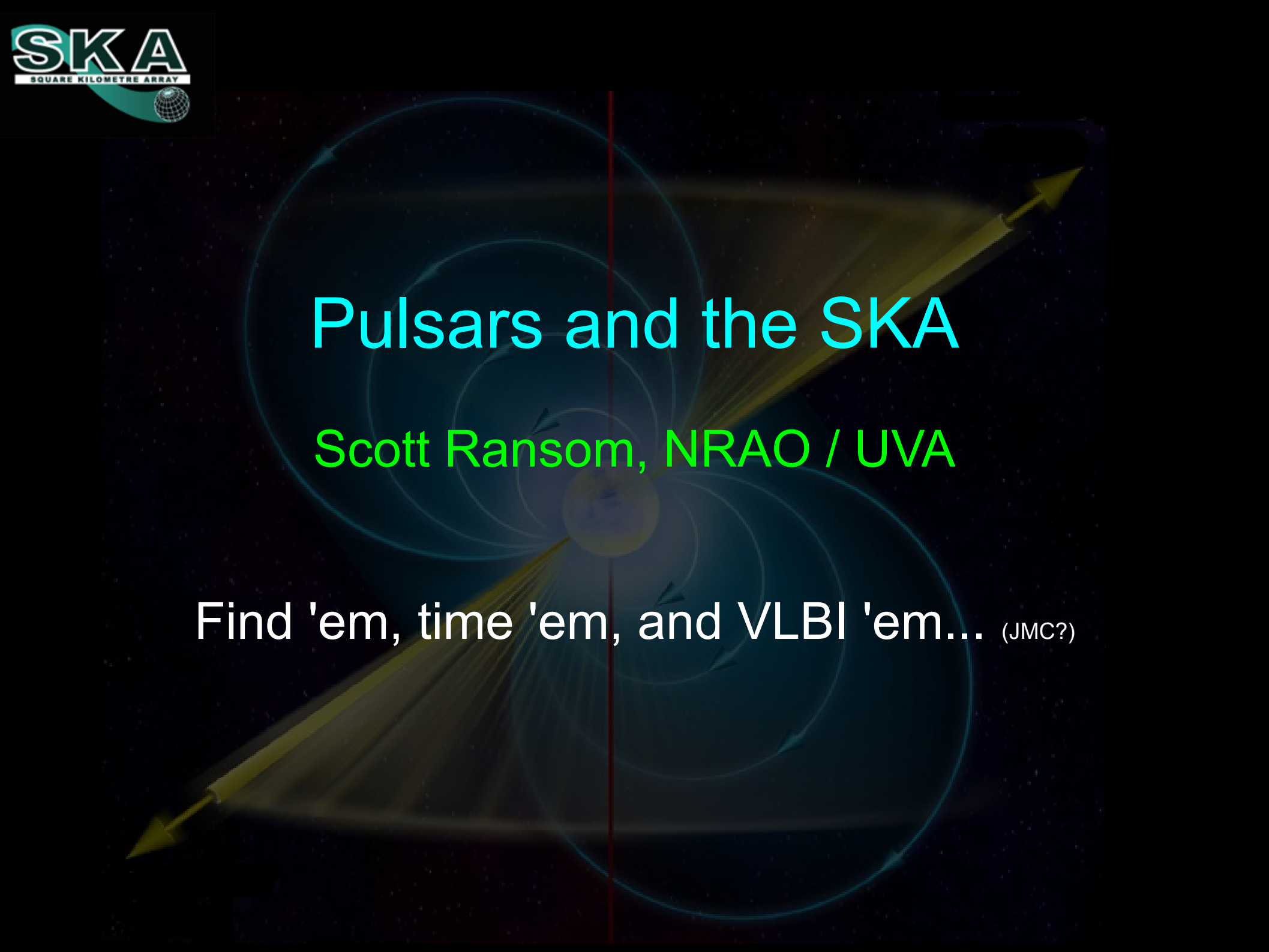


Pulsars and the SKA

Scott Ransom, NRAO / UVA

Find 'em, time 'em, and VLBI 'em... (JMC?)

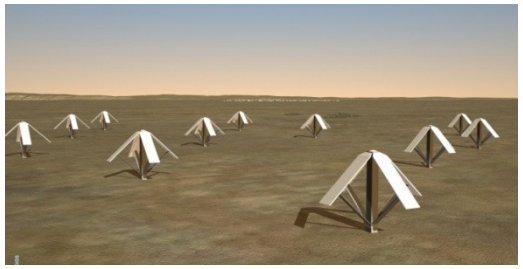
Pulsars are 1 of the 5 KSPs (and Phase 1 headline science)

- Strong Field Tests of Gravity (PSR-NS, PSR-BH)
  - Was Einstein right?, Cosmic Censorship Conjecture (i.e. Naked singularities), No-hair theorem
- Detection of a Stochastic Gravitational Wave Background (MSP timing)
- Equation of State of Matter at Supra-Nuclear Density
- Lots of other astrophysics
  - NS masses, ISM structure, Galactic magnetic fields, plasma physics, binary evolution, SNR kicks...

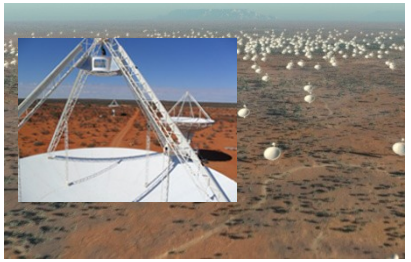
(See Kramer et al. In "Science with the Square Kilometer Array", eds. C. Carilli and S. Rawlings)

Phase 1 SKA (notional design)

Win-Win!

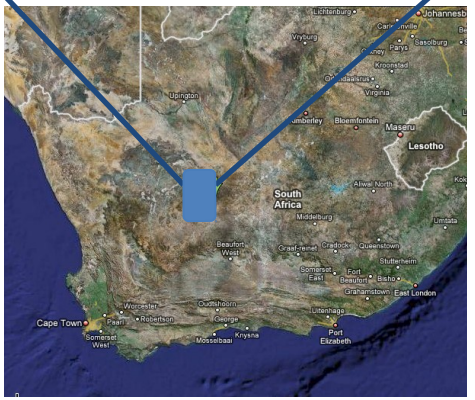


SKA1_Low: 50 low frequency aperture array stations



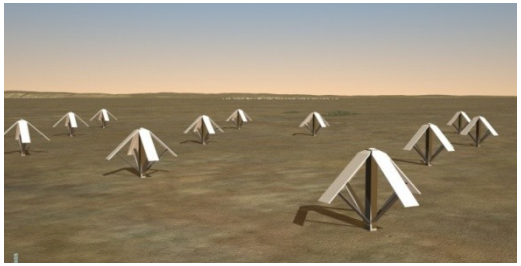
SKA1_Survey: 60 SKA dishes + 36 ASKAP dishes

SKA1_Mid: 190 SKA dishes + 64 MeerKAT dishes



Artist renditions from Swinburne Astronomy Productions

Phase 2 SKA (notional design)



SKA2_Low: 250 low frequency aperture array stations

SKA2_AA: 250 mid-frequency aperture array stations

SKA2_Mid: 3000 dishes

Artist renditions from Swinburne Astronomy Productions

Possible Specs for SKA

- ~2020?: Phase 1 Mid (Dishes)
  - Dishes: 250 x 15m @ 30K, 70% Ap eff
  - 3 bands: 0.45-0.9 GHz / 0.8-1.6 GHz / 1.5-3.0 GHz
  - Sensitivity: 1000 m^2k^{-1}
  - FoV: ~1 deg^2 @ 1GHz
  - 50% within 1 km diam (crucial for searching)
- ~2025+?: Phase 2 Mid (Dishes)
  - Dishes: 2500 x 15m @ 30K, 70% Ap eff
  - Observing bands TBD
  - Sensitivity: 10000 m^2k^{-1} (Square 0.5Km Array)
  - 20% within 1 km diam

Sensitivity Summary

- Phase 1 Dishes (~250 x 15m):
  - 1000 m^2k^{-1} (~500 m^2k^{-1} within 1km diam)
- Phase 2 Dishes (~2500 x 15m):
  - 10000 m^2k^{-1} (~2000 m^2k^{-1} within 1km diam)

FAST:	2000 m^2k^{-1}	
Arecibo:	900 m^2k^{-1}	< Factor of ~2
GBT / MeerKAT:	250 m^2k^{-1}	< Factor of ~4
Parkes:	80 m^2k^{-1}	< Factor of ~3

Moving Target: Specs from 2007

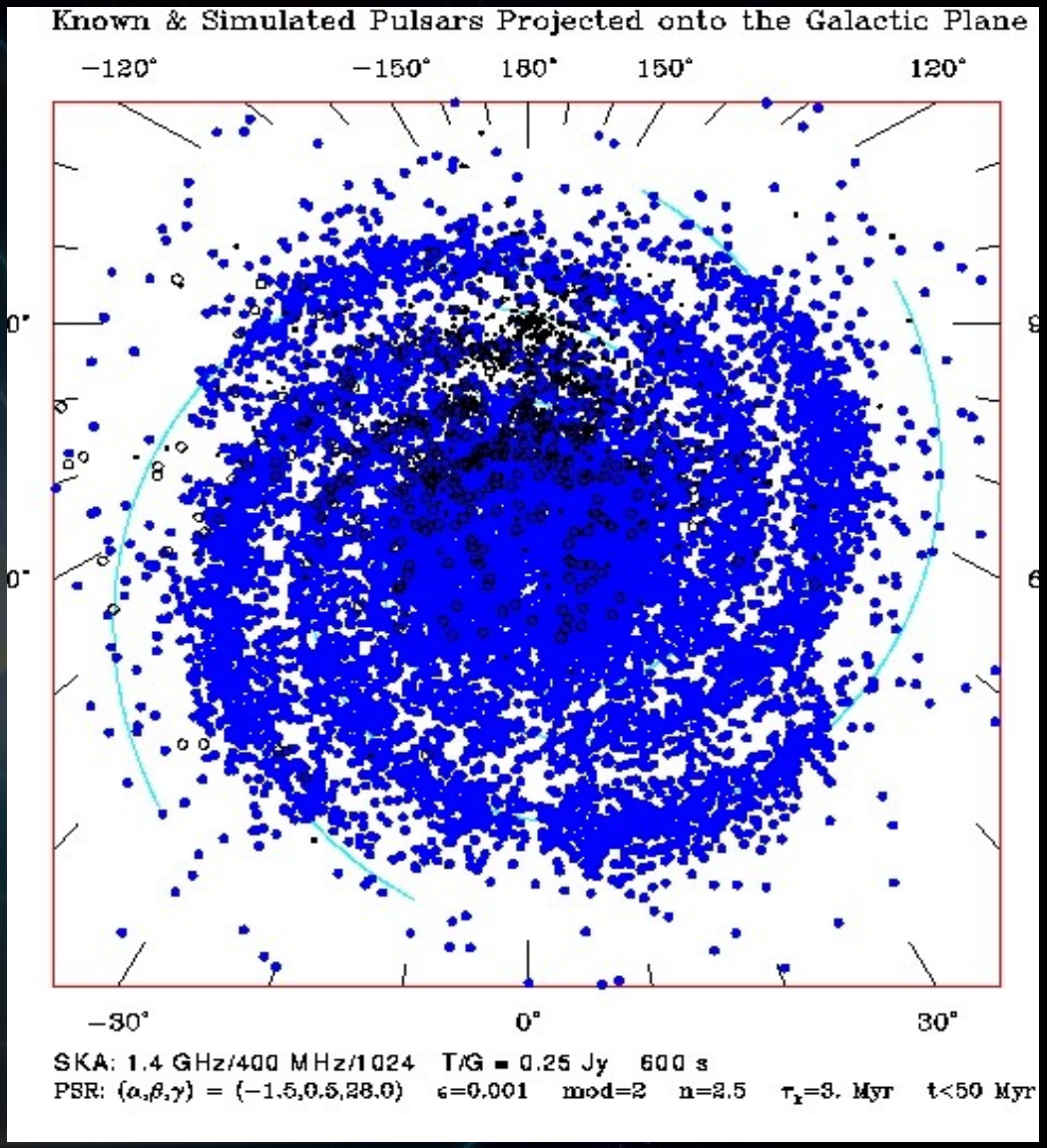
- ~2014: Phase 1 (WBF / WBF+PAF)
  - Min sensitivity: 2000 / 1100 m^2k^{-1} @ 500-5000 MHz
  - Survey speed: $1x10^7$ / $3x10^7$ $m^4k^{-2}deg^2$ @ 700 MHz
  - Dishes (15m): 650 @ 35K, 65% / 490 @ 50K, 70%
  - FoV: 0.75 deg^2 / 20 deg^2
  - 50% (325 / 245) within 1 km (n_a)
- ~2020: Phase 2 (WBF / WBF+PAF)
  - Min sensitivity: 12000 / 7000 m^2k^{-1} @ 500-5000 MHz
  - Survey speed: $3x10^8$ / $1x10^9$ $m^4k^{-2}deg^2$ @ 700 MHz
  - Dishes (15m): 3000 @ 30K, 70% / 2000 @ 35K, 70%
  - 20% (600 / 400) within 1 km (n_a)

Other aspects of possible SKA

- Phase 1:
  - Sparse Aperture Array (~1500-700 m^2k^{-1})
    - 0.07 – 0.45 GHz
  - Survey Array (aka ASKAP++)
    - 60 SKA dishes + 36 ASKAP dishes
- Phase 2:
  - Sparse Aperture Array (~4000 m^2k^{-1})
    - 0.07 – 0.45 GHz
  - Survey Array
    - PAFs on SKA dishes within 180m

Find 'em: Searching

- Smits et al. 2009
- ~20,000 each of potentially visible normal pulsars, RRATs, and MSPs
- SKA has the potential to find a large fraction of these pulsars
- Survey speed for Phase 1 with 15m dishes and fully sampled primary beam is: 700x Parkes, 180x GBT, 85x Arecibo, 25x FAST



Simulation by J. Cordes

Possible Phase 1 Searches

- Very Early Science: Targeted Searches
  - SNRs, gamma-ray sources, PWNe (0.5-3 GHz)
  - Globular Clusters (0.5-3 GHz)
- Early Science: Limited Surveys
  - Local Galaxies (LMC, SMC; 1.5-3 GHz)
  - Gal Ctr Region (1.5-3 GHz)
  - Low Latitude Galactic Plane (<|1deg|, ~1.5-3 GHz)
- Full Science: Large Area Surveys
  - Galactic Plane (<|5deg|, 0.8-1.6 GHz, ~5-30min)
  - All-sky survey (0.45-0.9 GHz, ~5min)

Finding them will be difficult...

- Searches can't be spread over many integrations (need long individual observations for periodicities)
- High spatial resolution is bad for searches (want a large fraction of SKA in a compact core, <~1km)
  - Number of synthesized beams per primary beam is
    $N_{beams} \sim (D_{core} / D_{dish})^2 \sim (1000m / 15m)^2 \sim 4000(!)$
- Data rates and computational demands are huge
  - ~50-100MB/s for each beam ~ 100s of GB/s!
- Process in pseudo-realtime (~10min)
  - Buffer at least 1 obs: ~100TB in RAM(?)!
  - Accel searches require ~10^{18} ops or PFLOPs-scale

So what will we find?

- If the SKA design keeps a significant amount of the planned sensitivity, pulsar surveys will find a large percentage of the pulsars in the Galaxy (5,000+ normal pulsars and >1000 MSPs)
- Hundreds of new “exotica”
- Dozens of new high precision MSPs

Then what?

Time 'em

- Follow up timing will take more time than the surveys (although spread over more time).
- Timing can use *all* of the SKA instead of the core, *or*, the SKA can be sub-arrayed...
- Large FoV will allow some PSRs to be timed simultaneously (number of PSRs will *require* it)
  - This is not the case for IPTA MSPs
- Imaging capabilities should provide excellent starting positions for the pulsars (requiring fewer timing observations for “boring” pulsars)
- Triage will be crucial...

Sub-arraying to combat jitter

- Phase 1/2 for timing instantaneous sensitivity: ~1x/10x AO, ~4x/40x GBT or ~12x/120x Parkes

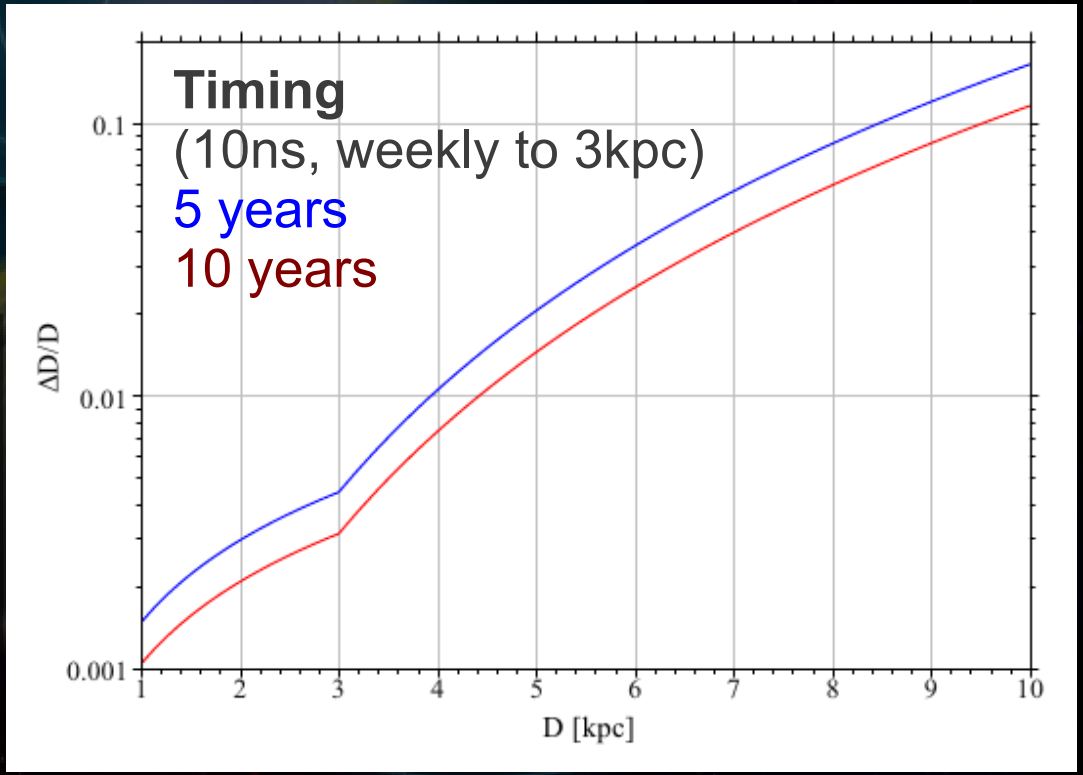
$$\sigma_{\mathrm{TOA}} \propto \frac{\mathrm{W}}{\mathrm{SNR}} \propto \frac{T_{\mathrm{sys}}}{A_{\mathrm{eff}}\sqrt{T_{\mathrm{int}}}} \propto \frac{1}{N_{\mathrm{dishes}}\sqrt{T_{\mathrm{int}}}}$$

- Sub-arraying into *m* pieces requires an increase in observing time of m^2 for same SNR: *inefficient!*
- Arecibo doesn't seem jitter noise dominated now, so using 10 subarrays requires integration times 100x longer than full SKA and about the same as AO for same SNR! That's no improvement over AO!
- Might only be good for brightest IPTA pulsars...

VLBI 'em

- See Smits et al. 2011
- With max baselines out to 3000km (?):
  - 20% parallaxes for 1000s of PSRs out to 13kpc
- MSP timing parallaxes to <20% for 100s-1000s

Not good enough for GW pulsar term...



Operational Model

- The SKA will likely operate very differently than current radio telescopes: primarily survey driven
- Unique capabilities and international nature will likely force a "Big Science" model on us:
  - e.g. Pseudo-realtime PSR search capabilities built-into the correlator / backend makes the SKA search project like a particle physics experiment
- Follow-up timing may be similarly forced
- IPTA may be *the* pulsar timing "user" of the SKA

Summary

- SKA will be revolutionary for pulsar science
- Searches: Not easy! We need to push now
  - We need a compact core and very special computing
  - Phase 1 will find 1000s of PSRs to be timed long-term with Phase 2 – these most useful for IPTA
- Timing: This is where the science comes
  - Sub-arraying is inefficient use of collecting area
  - Use SKA-Low for DM obs for all IPTA MSPs?
  - Coordination with Arecibo(?) and FAST will be key
- Operational model is unknown, but will be different

Simon says "Get involved in SKA now!