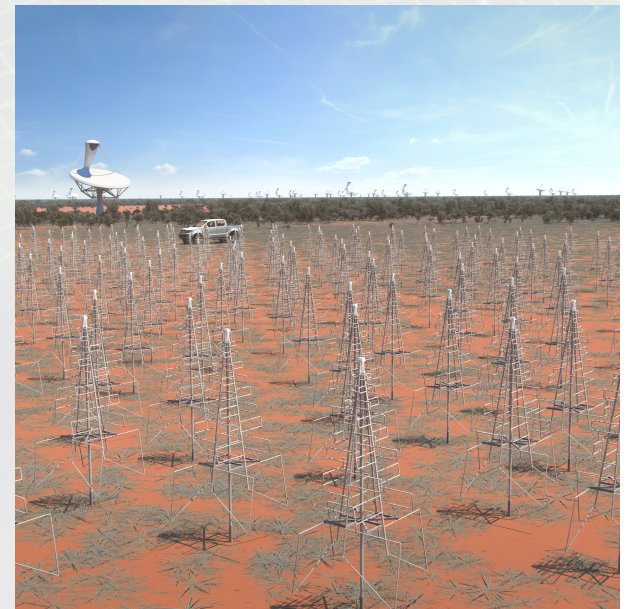
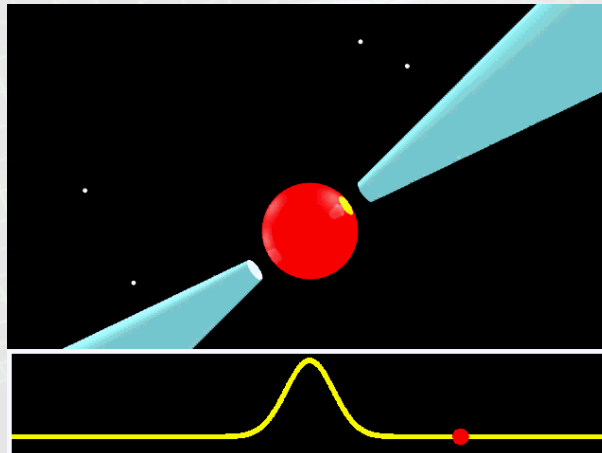


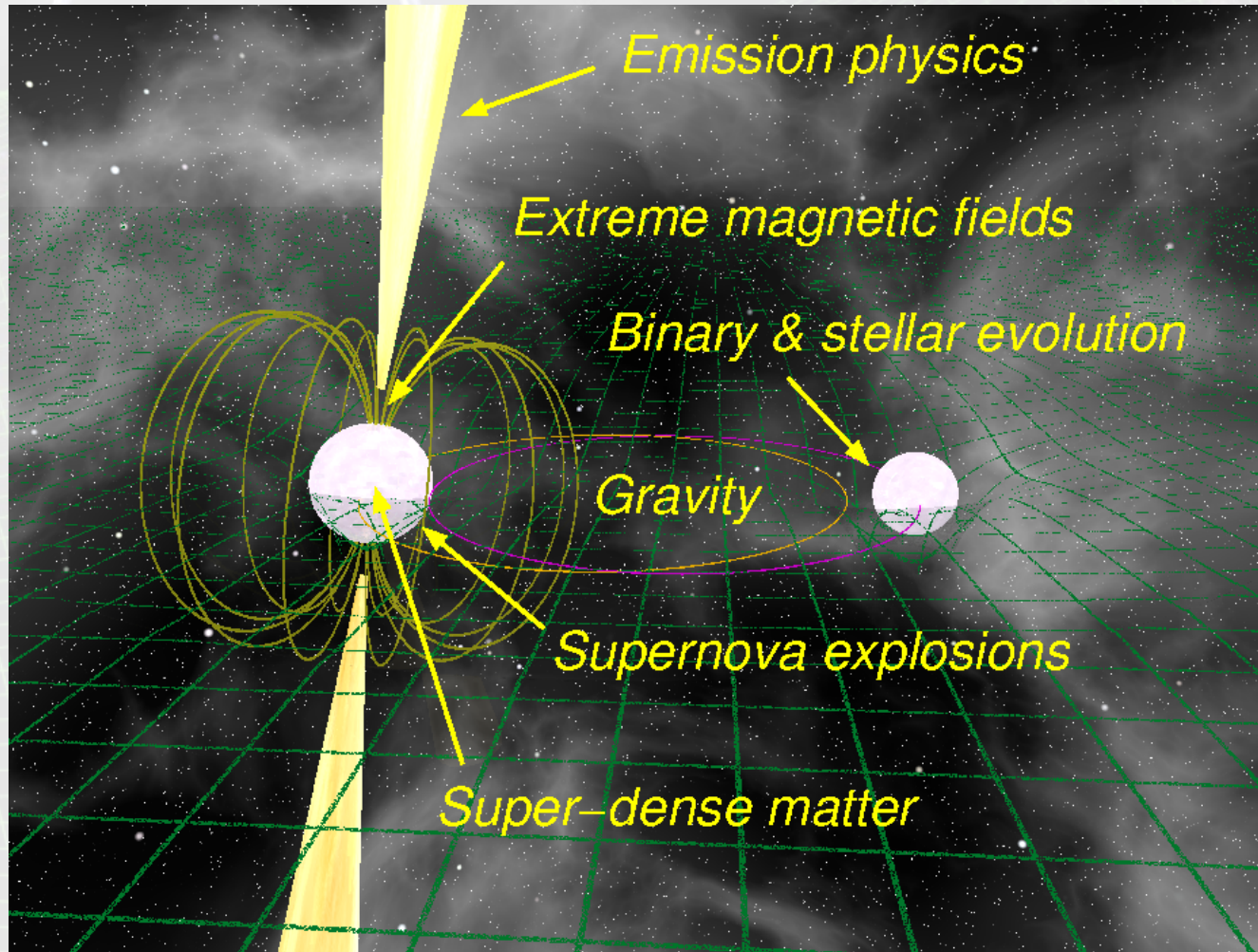


Concepts on KSPs focused on Pulsar science with the SKA

Andrea Possenti for the PSWG



Observations of pulsars have wide scientific impact



For details... Gemma Janssen talk of Monday



the large variety of SKA pulsar science

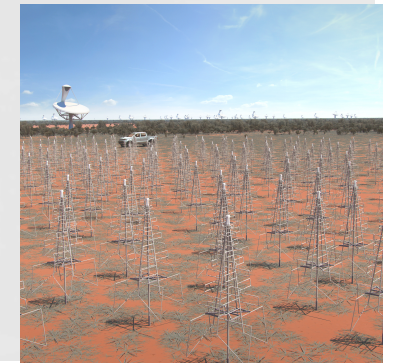
from SKA Science book (Sicily 2014)

- Cosmic census (Keane et al. 1501.00056)
- Testing Gravity (Shao et al. 1501.00058)
- GW astronomy (Janssen et al. 1501.00127)
- Understanding PSR Magnetospheres (Karastergiou et al. 1501.00126)
- Understanding NS population (Tauris et al. 1501.00005)
- Galactic & Intergalactic medium (Han et al. 1412.8749)
- NS Equation of State (Watts et al. 1501.00042)
- Pulsars in the Galactic centre (Eatough et al. 1501.00281)
- Pulsars in Globular clusters (Hessels et al. 1501.00086)
- Pulsar wind nebulae (Gelfand et al. 1501.00364)
- Overview (Kramer & Stappers 1507.04423)



How can one use the concept of KSPs in order to maximize the pulsar science outcomes from SKA?

In this report... some KSP concepts discussed here these days and to be taken back and discussed with the Pulsar SWG at large





Science focus and results

A clear statement of the overall objective of the KSP

Understanding gravity and fundamental interactions
using pulsars and black holes

By what measures at its conclusion will the KSP be deemed to have been successful?

0. Tripling the currently known pulsar population
1. Finding highly relativistic systems and improving tests of gravity in the strong field regime by at least one order of magnitude
2. Finding at least one pulsar - black hole binary and informing quantum gravity
3. Detecting gravitational waves at nanoHertz frequencies
4. Improving the mass-radius relation (NS equation of state) by more than an order of magnitude

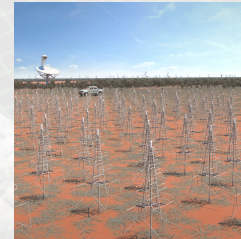


0. Tripling the currently known pulsar population via SKA1-Mid and SKA1-Low searches



MID

- **1500 Beams**
- **300 MHz BW (any band) ; ~ 74kHz chans**
- **$T_{res} < 64 \mu s$**

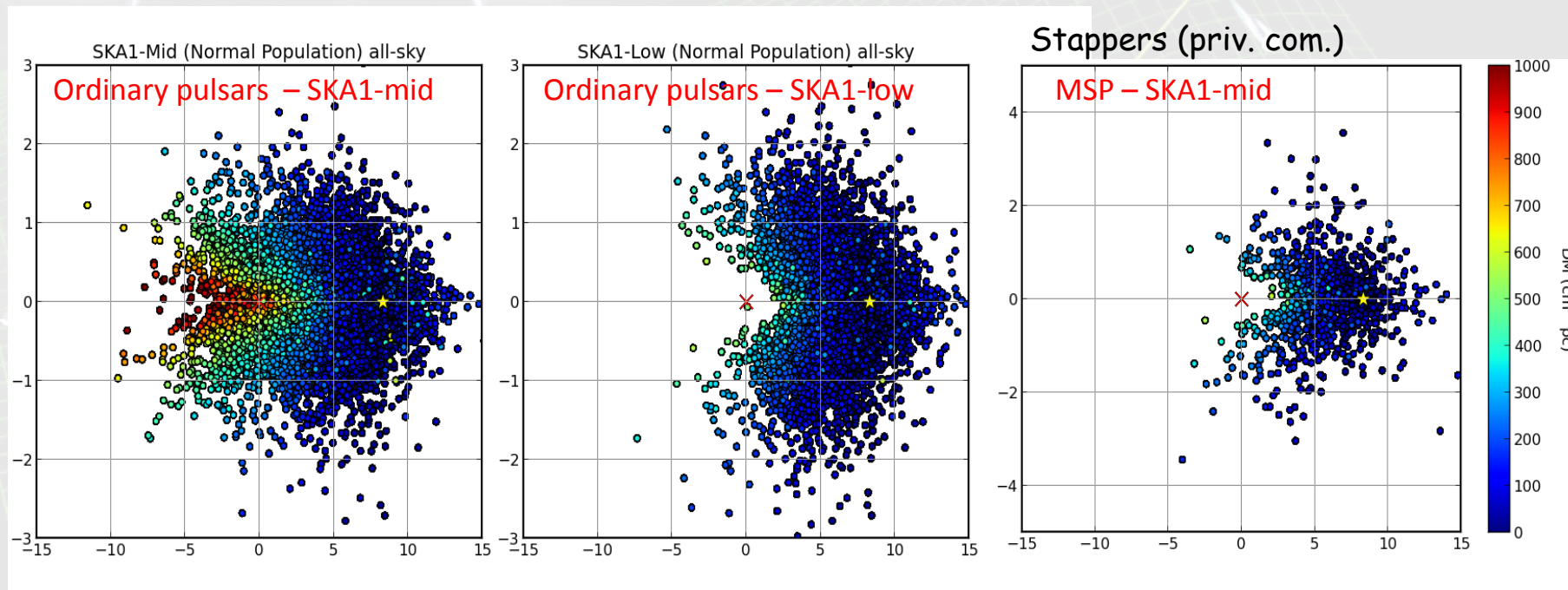


LOW

- **500 Beams**
- **96 MHz BW (50-350 MHz) - ~12 kHz chans**
- **$T_{res} < 100 \mu s$**

- **can trade beams for BW, can subarray, include dishes/stations out to 20 km.**
- **real time processing**
- **DM 0-3000 pc/cm³ — for single pulses/transients, and in the Gal plane**
- **$T_{obs} = 180-1800$ seconds**
- **Acceleration trails - 0 to no less than 350 ms⁻², for no fewer than 500 operator selected dispersion measure trials for $T_{obs} \sim 600s$**

Expected yields



Phase I will be great for searching: expected **9000** Ordinary pulsars and **1500** MSPs

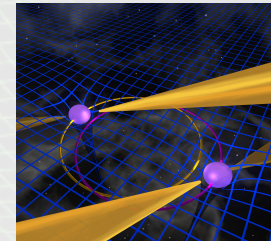
Required time on sky

≈ 65 days on SKA1-LOW and **≈ 130 days** on SKA1-MID

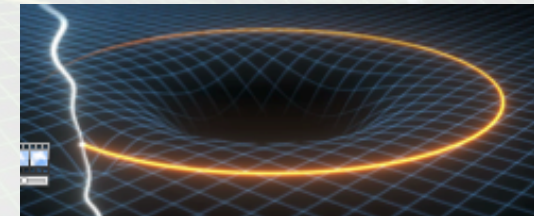


The Galactic Census of the pulsar population will enable exciting science packages, which will be based on extended and intense programs of TIMING observations

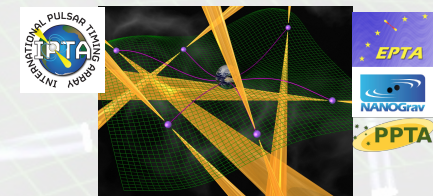
1. Finding highly relativistic systems and improving tests of gravity in the strong field regime by at least one order of magnitude



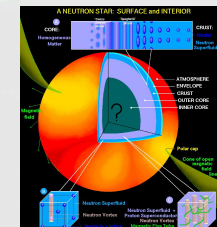
2. Finding at least one pulsar - black hole binary and informing quantum gravity



3. Detecting gravitational waves at nano-Hertz frequencies



4. Improving the mass-radius relation (NS equation of state) by more than an order of magnitude



Required time on sky (current estimates):

>≈ 40 days on SKA1-LOW and **>≈ 180 days** on SKA1-MID over 5 years

Bonus/byproducts

Objectives that are non-essential but highly desirable

- ✧ mapping the structure of the Milky Way: ISM – dispersion, birefringence, scintillation, scattering, etc.
- ✧ exploring the extremes and the properties of the pulsar population (luminosity, etc.)
- ✧ environment and dynamics of the Galactic centre
- ✧ pulsar physics: magnetospheres, interior++, environments, etc.

Outputs

What outputs will the KSP undertake to deliver to the broader astronomical community?

- ✧ Pulsar catalog
- ✧ Arrival times
- ✧ Folded profiles
- ✧ Survey candidates
- ✧ Observation plans/schedules/logs
- ✧ Characterization of RFI environment



Resources

What internal resources are required by the KSP group?

Postdocs, students, off-site disk space (few Petabytes) & computing (few Petaflops)

What external hardware will be attached to the telescope to realize the KSP science?

✧ PSS and PST on site will suffice for most things

✧ Deep search mode (eg for Sgr A*) may require an off-site resource

Does the KSP need to fund data processing resources (e.g. compute clusters, data centres, archives)?

Yes – off-site compute and disk space (e.g. data centres at research institutions)

Software/firmware requirements

Nothing special (typical pulsar tools)



Primary Resources from SKA and further actions

What primary resources are required from the SKA?

Pulsar Search: pulsar candidate lists, metadata (such as decision thresholds), RFI conditions, heuristics, environmental, single pulse and periodicity candidates, mechanisms to test response, system health, calibration, beam models.

Pulsar Timing: archives, toas, timing models, ephemerides, calibration – flux, polarisation, quality of coherence, RFI environment, multi-beaming, multiple sub-arrays, beam models,

Common: mechanisms to assess reality/robustness of detections (e.g., input test vectors, processing negative (RFI and other false positives) and positive (pulsar) survey candidate signals, various statistics of detections vs. strength/position, cross-communication between tied-array beams).

Further actions

Is further action required to see that key capabilities are implemented on the SKA?

- ✧ Freeze the design as soon as practicable; document and communicate changes and their rationale
- ✧ Define the implementation of the phasing and polarimetric calibration of the array (e.g. is off-axis polarization calibration possible?)
- ✧ Define how the KSP will interact/interface with the Data Archive



Secondary Resources from SKA

What secondary resources are required from the SKA? (i.e. resources that are not absolutely essential but which add value to the primary data product)

- ✧ Any images taken in parallel with non-imaging observations (e.g. images of highly linearly polarized point sources could be used to supplement periodicity search; an imaging candidate might allow a weak periodicity detection to be selected, via some sort of combination of evidence)
- ✧ Quasi dynamic scheduling, such as ability to generate and respond to automatic triggers, e.g.: to immediately follow up interesting binary, to obtain phase-connected timing solutions, to monitor an important intermittent pulsar when it is on, to switch to baseband/filterbank recording mode

During observations of this KSP

- ✧ Ability to stop timing observations when S/N is good (already in requirements)
- ✧ Optimal and dynamic scheduling tools with hard constraints (timing and survey pointings at specific hour angles)



Secondary Resources from SKA (cont'ed)

Capability for access to SKA1 hardware/firmware/software

Define a policy and mechanism for upgrade paths and user-supplied software, guest instruments, and capacity for future modes, with eventual adoption by the SKA

Support needed from SKA1 operations/staff

- ✧ Ability to request/impose schedule constraints; access to engineering interfaces during development: e.g., consultation, expert advice, access to designers, access to SKA simulators, regular review/oversight, ...

After the KSP is over

- ✧ It is expected that the SKA will maintain a long-term archive whilst the KSP will maintain its own data archive: folded profiles, TOAs, timing solutions, other physical parameters (e.g. RM), pulsar catalog, etc.
- ✧ The KSP will manage its software (open source)



Resources from external organizations

What resources are required from external organizations?

- ✧ Observing time for follow-up at other facilities, including Optical, High Energy satellites, high energy ground based, GW observatories, other radio telescopes
- ✧ Competitive computing resources for data modeling, etc.

What is the timetable for forging the required external connections?

In time to prepare and submit the KSP proposal



People

How many FTE's are required to realize the project's objectives?

A first attempt indicates

≈ 50 PhD + (≈ 30 post-docs FTE, ≈ 20 staff FTE) x 5 years = ~ 500 FTE
but additional work is needed for a detailed breakdown

I.D. key personnel (or personnel types) who are fundamental to the KSP's success

- ✧ DSP – software/engineer types
- ✧ Theory – GW, NS, ISM, GR, CS
- ✧ Observing
- ✧ Outreach
- ✧ Management and communication
- ✧ Leadership and vision



Commensality

General suggestion:

SKA should rank the projects when observing in parallel, especially the primary project that will drive the configuration/schedule

How will this KSP affect other observers:

During development/testing/commissioning

it is needed to point the telescope at bright known pulsars (e.g. high DM/P)

During regular observations

- ✧ It is needed to point the telescope and set bandwidth / centre frequency
- ✧ PSS: fixed observation lengths, no noise source, gridding/plan
- ✧ PST: bore-sight pointings, dynamic scheduling, high polarization fidelity / stability, access to noise source for calibration
- ✧ On Low: avoid dawn and dusk and other ionospheric disturbances (dynamic scheduling for both PSS and PST)

In post-processing (e.g., data access rights)

No impact



Commensality (cont'ed)

What this KSP requires for observations that are commensal with its project?

- ✧ The other project(s) point(s) at the same places that this KSP wants to point, with similar cadence and integration length.
- ✧ The integration times of this KSP are limited (owing to acceleration search cost)
- ✧ Accrue only useful time against KSP budget
- ✧ Fixed on sky (tracking not drifting)

Over-rideable

Yes, survey pointings can be stopped without great loss (as long as integration clock is reset and we are not expected to pick up where we left off)

Split into subarrays

Survey – other projects may wish to make use of some dishes outside of the core

Timing – unused timing beams could be picked up for use by anyone (e.g. SETI, IPS, etc.); imaging can also be done in parallel with timing (e.g. timing could piggy back)



Commensality (cont'ed)

Immediate access to the data collected by other KSPs

Not required but nice to have images

What about the noise source, i.e. the Cal signal, pulsed!

Ability to disable or remove noise diode.

What this KSP will provide as “value-added” capabilities to commensal folks?

- ✧ RFI detection
- ✧ Real-time quality checks
- ✧ Calibration
- ✧ Quasi-real-time ionospheric conditions (e.g. from phasing array)



Developing Capabilities

Will this KSP result in new generally accessible, long-lived capabilities for the SKA?

✧ general-use archive

✧ real-time RFI masks (drop visibilities on SDP?)

Collaboration with industry – any knock-on benefits?

Not after construction

Training students/postdocs

Schools, workshops (e.g. IPTA Student Week)

Education and Public Outreach (EPO) components: are this KSP discoveries likely to be so awesome that a BBC nature series will result?

In this field of research, people are traditionally pretty active in EPO (IMAX, Jodcasts, etc.)



Data Access

Proprietary period

- ✧ Mostly as short as is possible/reasonable
- ✧ The main desire is to allow the field to flourish.
- ✧ Period depends on sub-project/science goal.
- ✧ The main sticking point is the GWB and PTA effort

Public access to “value-added” data products, in near and long term (e.g., Web page, data archive)

The intent is yes: timing solutions, pulsar catalog, mean profiles, etc.



Funding and timescale

How will internal resources be funded?

- ✧ Likely at the national level
- ✧ SKA funded science fellowships/grants would be nice (similar to NASA?)

By what stage do certain resources need to be in place?

- ✧ Early science on SKA – we would start early and learn as we go
- ✧ We are discussing how existing collaborations on precursor telescopes evolve into the KSP

Does this KSP need to buy into external organizations to access data at other wavelengths?

No

How will the requisite number of FTEs be funded?

Grants (TBD)

Governance

What is the appropriate internal governance structure for this KSP?

A SINGLE KSP enabled by a Galactic census of the pulsar population, organized into a number (tdb) of **COMPLEMENTARY SCIENCE PACKAGES** driven by specific outcomes (examples listed above)



Each science package has individual leadership composed of:

- a spokesperson / chairperson
- a steering committee (size tbd)

with a broad representation from member countries



There will also be an over-arching Board that provides high-level direction (and funding) composed of:

- 1 or 2 leading types from each sub-project
- a single figure-head chair person (the PI for the pulsar KSP)
- a representative from the SKAO



Governance (cont'ed)

- ✧ **Any individual** should be limited to participating in **at most 2 or 3 sub-projects**.
- ✧ **All leadership / board** membership will be **rotating** (e.g. fixed terms).
- ✧ Normal members:
 - commitment of time and effort (tbd)
 - terms of accountability and membership criteria (tbd)

Nominal focus areas (sub-projects) include those reported above

Cross-project science and support could require separate working groups with leadership structures; e.g. software, statistics, engineering, RFI mitigation, outreach

KSP membership could be made contingent on contributions to working groups



Governance (cont'ed)

Does this organization require any of the following: KSP manager(s), project scientist, project engineer, project software manager ?

Yes, they could lead the working groups and sub-projects

What is the (rough) data pipeline/governance structure through which data delivery will occur?

As per governance model, each sub-project will be responsible for delivery of data to its members, ultimately ending in the hands of students and people directly involved in specific and relevant tasks.



Thanks!