The Square Kilometre Array

Past, present & future – a German perspective

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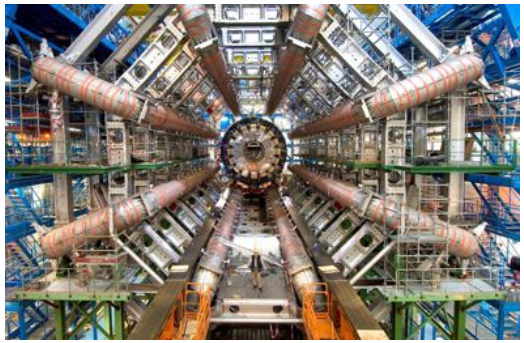
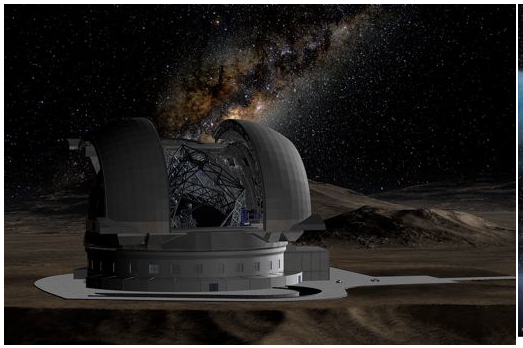
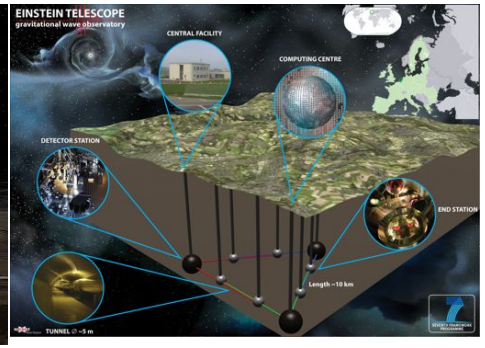
Time for Big Machines

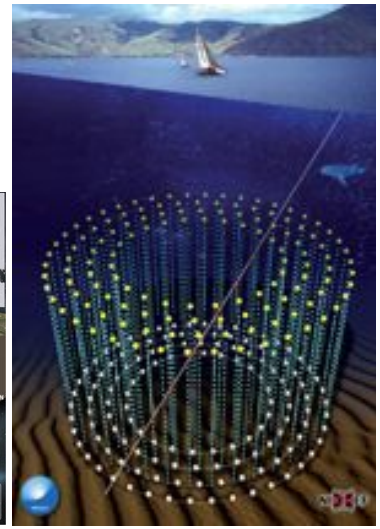
We live in exciting times:

- we are on the verge of confirming some of the most revolutionary theories of the last century
- we find clues as to whether these theories are complete or not
- we may find a way to describe large and small scales with one theory
- we are about to trace the complete history of the universe
- we are about to study extra-solar worlds and Earth-like planets
- we are about to open a truly new window to the Universe and its wonderful constituents









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But…. It takes increasing efforts to make such fundamental and important discoveries – it needs (typically) BIG machines

They are very expensive and require multi-national/global collaborations

Outline

- The Square Kilometre Array
- Progress, status & timeline
- Science
- German activities

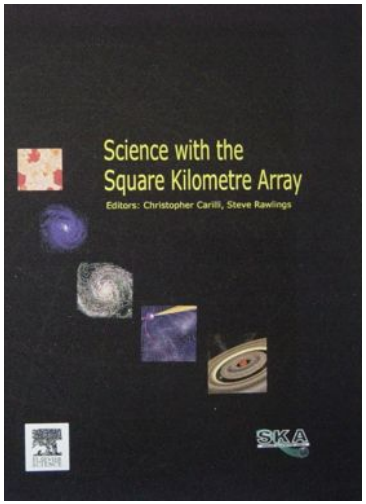
SKA Key Science Drivers

ORIGINS

- Neutral hydrogen in the universe – from the Epoch of Re-ionisation to now

  When did the first stars and galaxies form?
  How did galaxies evolve?
  What are Dark Energy & Dark Matter?

- Astro-biology



Science with the Square Kilometre Array
(2004, eds. C. Carilli & S. Rawlings, *New Astron. Rev.*, 48)

FUNDAMENTAL FORCES

- Pulsars, General Relativity & gravitational waves
- Origin & evolution of cosmic magnetism

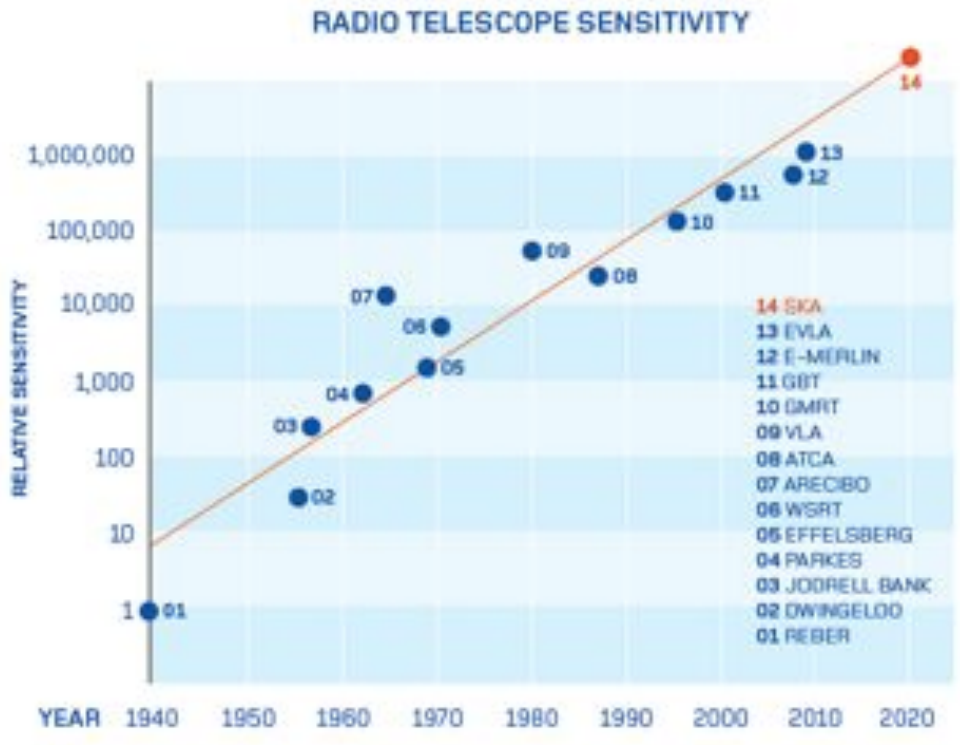
NEW PHENOMENA (incl. Transients)

The Telescope

In a nutshell: The SKA is…

…a large radio telescope for transformational science

- up to 1 million m^2 collecting area distributed over a distance of 3000+ km
- operating as an interferometer at frequencies from 70 MHz to >10 GHz (4m-3cm) with two or more detector technologies
- connected to a signal processor and high performance computing system by an optical fibre network



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…providing

- 100 x Effelsberg, and 10 x Arecibo, and
- at least 10,000 x survey speed of current telescopes

HST

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…67 institutes in 20 countries are participating

- on ESFRI List as only global project (selected for construction)
- with E-ELT selected for highest priority on ASTRONET roadmap
- ASTRO2010: “long-term future of radio astronomy”
- Canadian Long-Range Plan: SKA next priority behind TMT (10%!)
- African Union Heads of State acknowledge importance
- Australia and South Africa invest about €200M each

ASTRONET

The Telescope

The Telescope

Construction will proceed in two phases: SKA_1 ➔ SKA_2

- SKA_1 will be a subset (~10%) of SKA_2

- Major science observations already possible with SKA_1 in 2020:

  - Neutral hydrogen in the universe from Epoch of Re-ionisation to now
  - Fundamental forces: pulsars, gravity and gravitational waves
  - much more science possible…!

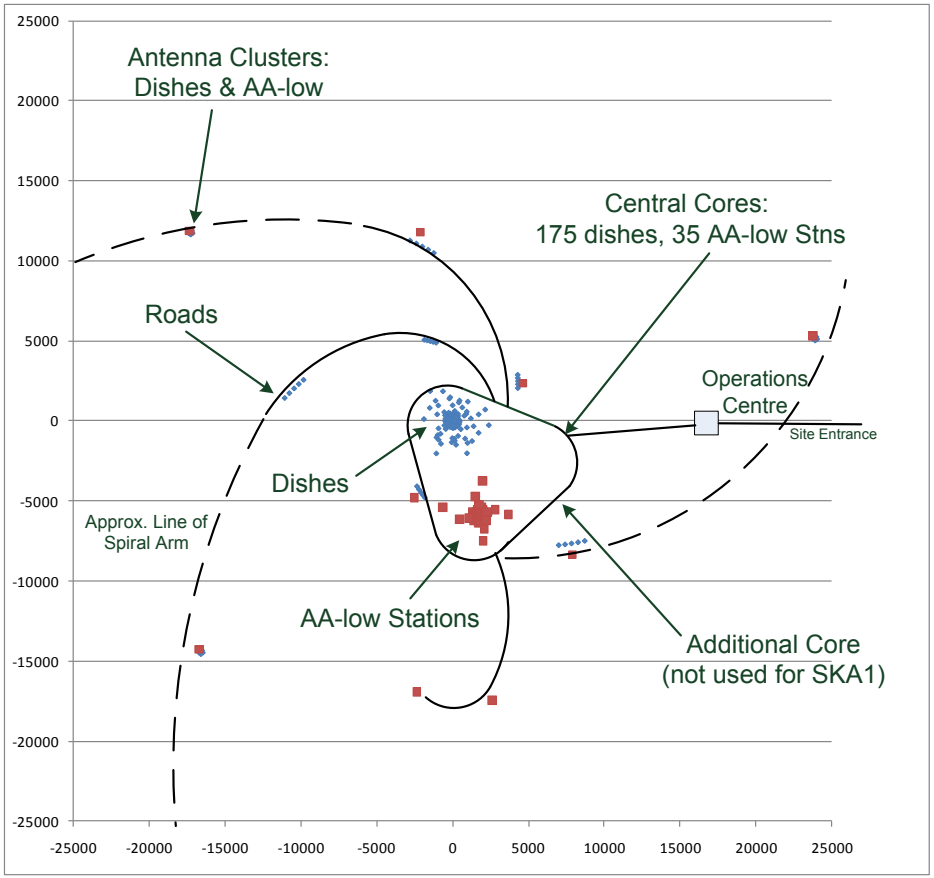
- Phased construction allows maximum use of advances in technology:

  Phase I: SKA_1 can be built now with proven and secure technology (baseline)

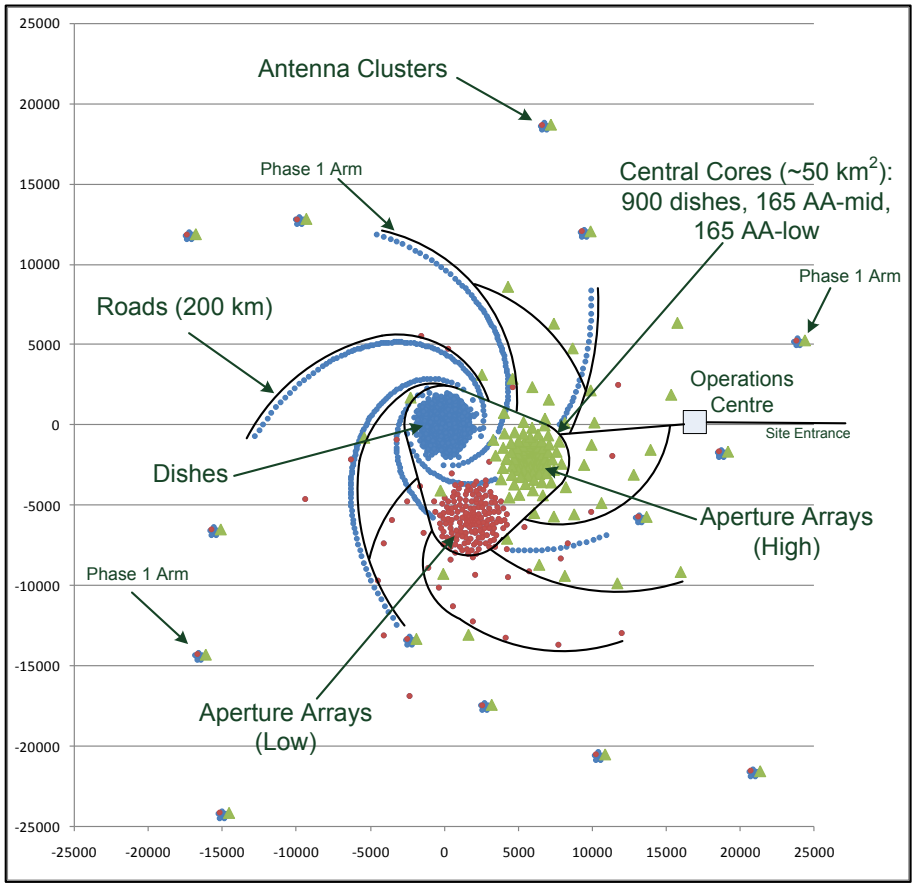
  Phase II: SKA_2 can make use of new, future matured technology (AIP)

From Phase I to Phase II

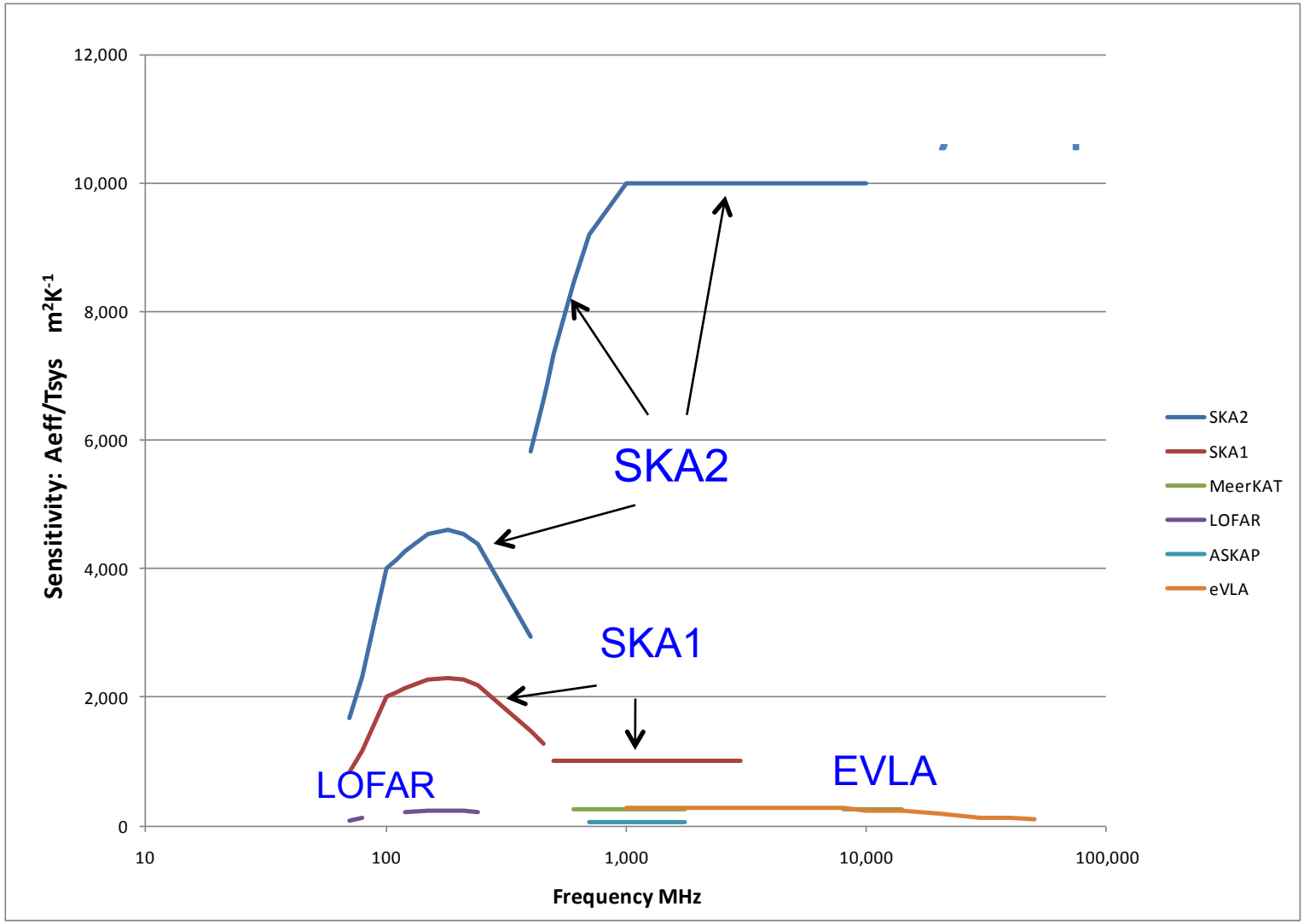
Central SKA1 Site



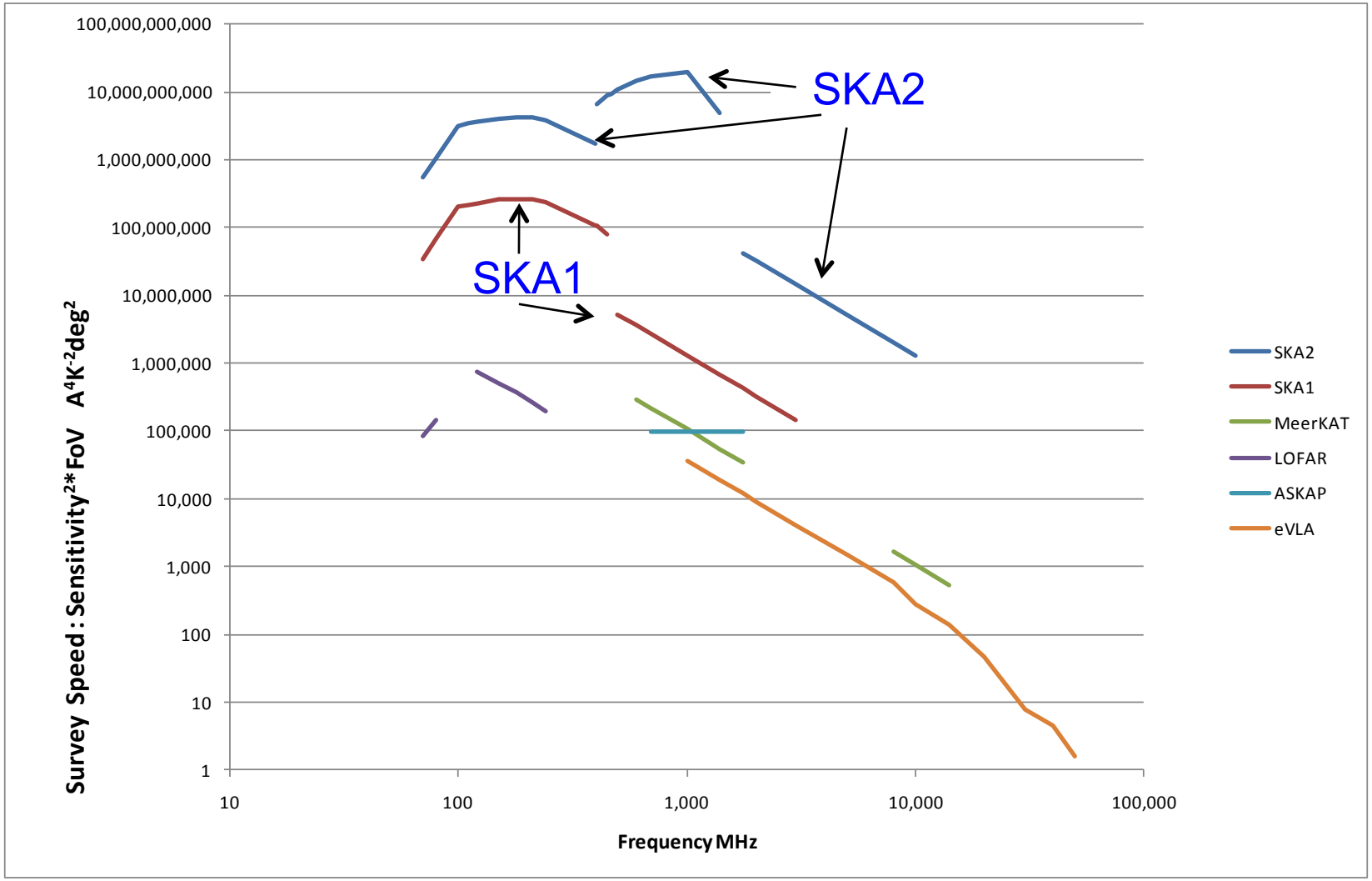
Central SKA2 Site



Sensitivity comparison



Survey speed comparison



SKA System Design (2007-2012)

Contributing programs

EC FP6 SKA Design Study (SKADS)

EC FP7 Preparatory Phase (PrepSKA)

US Technology Development Program

“Precursor” telescopes on the candidate sites (ASKAP, MeerKAT)

“Pathfinder” telescopes like LOFAR, APERTIF

➔ a lot of science and techniques can already be learnt

also condensation core and focus point of German community

LOFAR (Europe)

KAT-7/MeerKAT (SA)

ASKAP (Australia)

Top level schedule for the SKA

Technical

2008-12 telescope system design and cost

2013-15 detailed design in the pre-construction phase

2016-19 Phase 1 construction

2016 Advanced Instrumentation Program decision

2018-23 Phase 2 construction

2020→ full science operations with Phase 1

2024→ full science operations with Phase 2

Programmatic

2011 approve funding for pre-construction phase
establish SKA organisation as a legal entity
select location for SKA Project Office

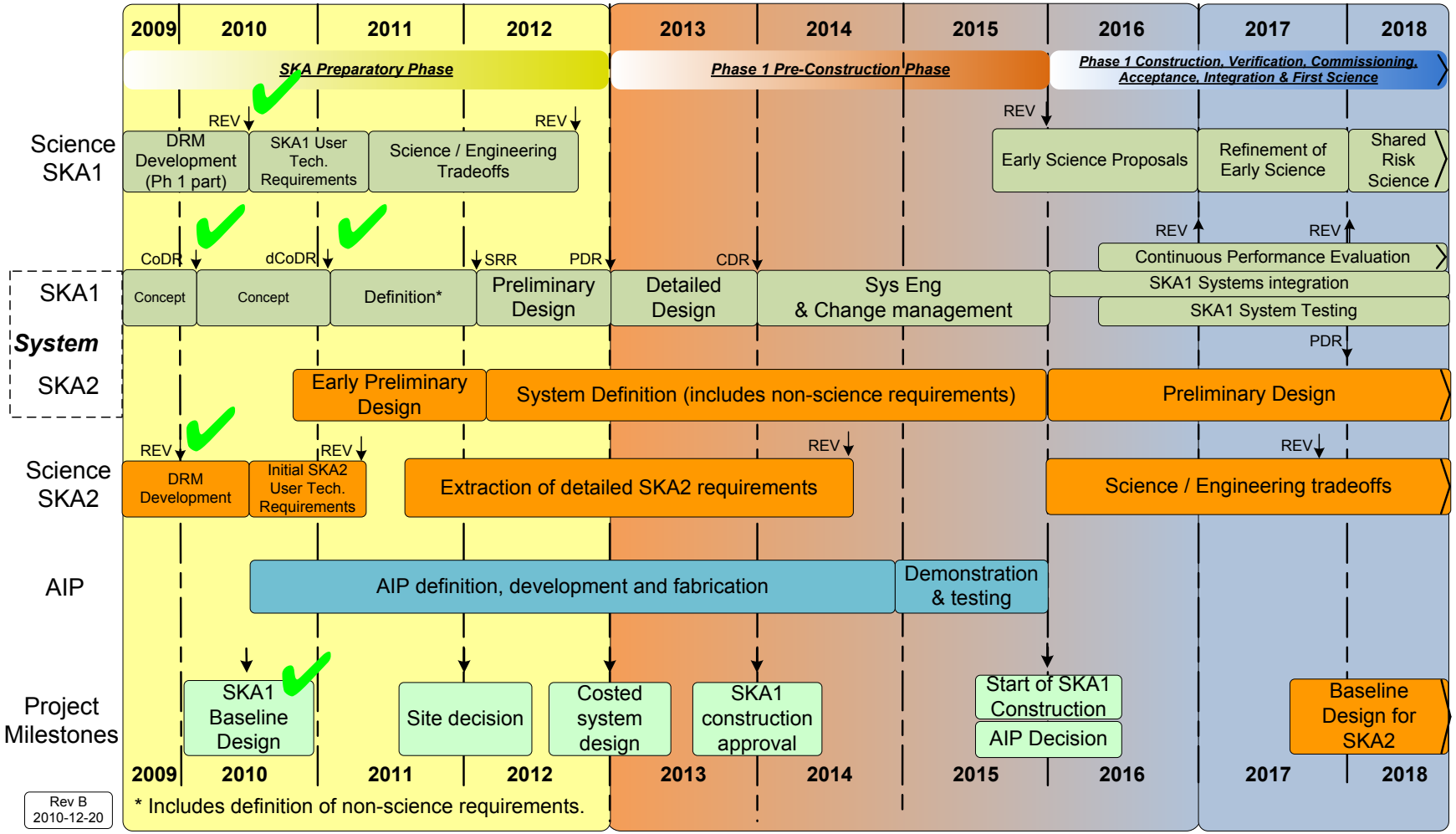
2012 site selection

2014 approve construction funding for Phase 1 (350 M€, 2007)

2018 approve construction funding for Phase 2 (1.2 B€, 2007)

Detailed Timeline

Preparatory Phase → Preconstruction Phase → SKA_1 Construction



Current task in 2011 and 2012 is to convert this SKA-relevant design and development into PDR-ready SKA-specific designs and costs

Total resources proposed (4 years): 90.9 M€

External independent reviews

Example:

External Review of the Project Execution Plan

At the ASG meetings in June 2010, the group commissioned the preparation of a 'Project Execution Plan' (PEP) to describe the required technical and organisational programme for the SKA in the pre-construction period. Following initial discussion of the resulting PEP in October 2010, it was agreed that an external expert review would be organised to consider the PEP and report back to the ASG at the March 2011 meetings.

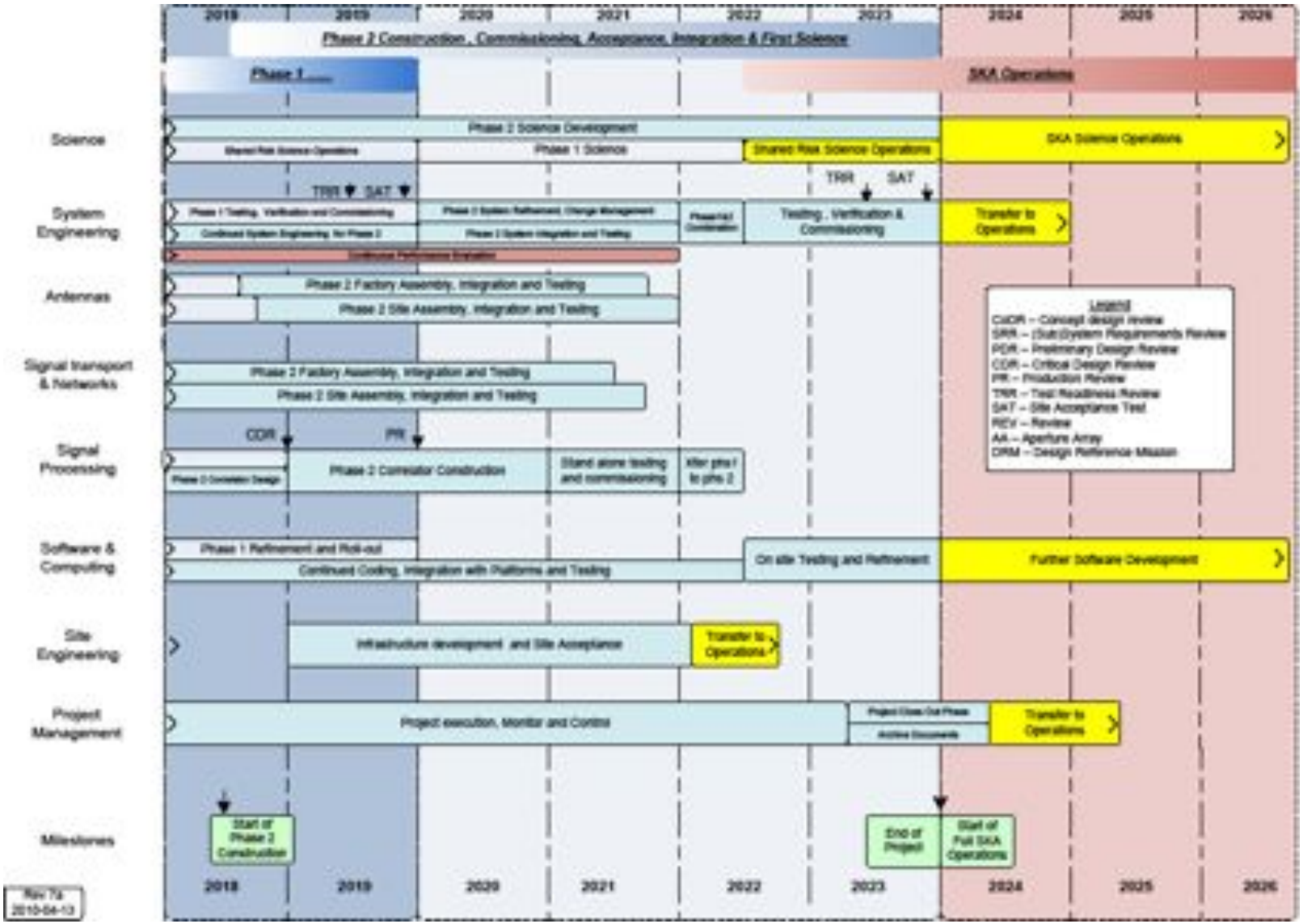
Following this instruction, a Panel was organised to undertake the review. The membership was:

- Gary H. Sanders – Caltech/Thirty Metre Telescope – Panel Chair
- Ian Bird – CERN
- Antonella Calvia – European Investment Bank
- James H. Crocker – Lockheed Martin Space Systems
- Adrian Russell - ESO

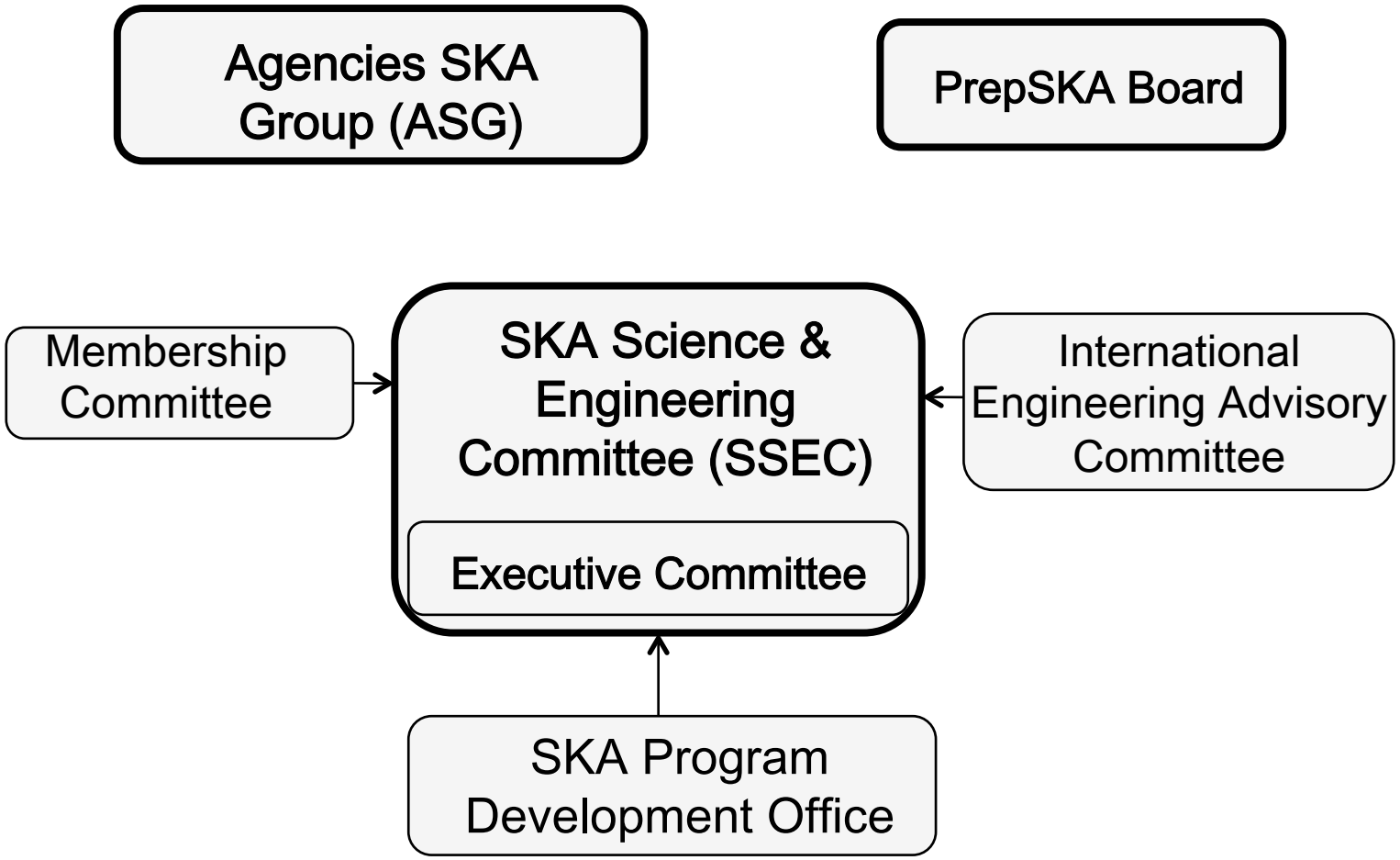
The Panel met on 8-9th March 2011 in Brussels (financial support from the EC is acknowledged for this process). Simon Berry and Elena Righi-Steele were in attendance.

Further Timeline

SKA_1 Construction → SKA_2 construction



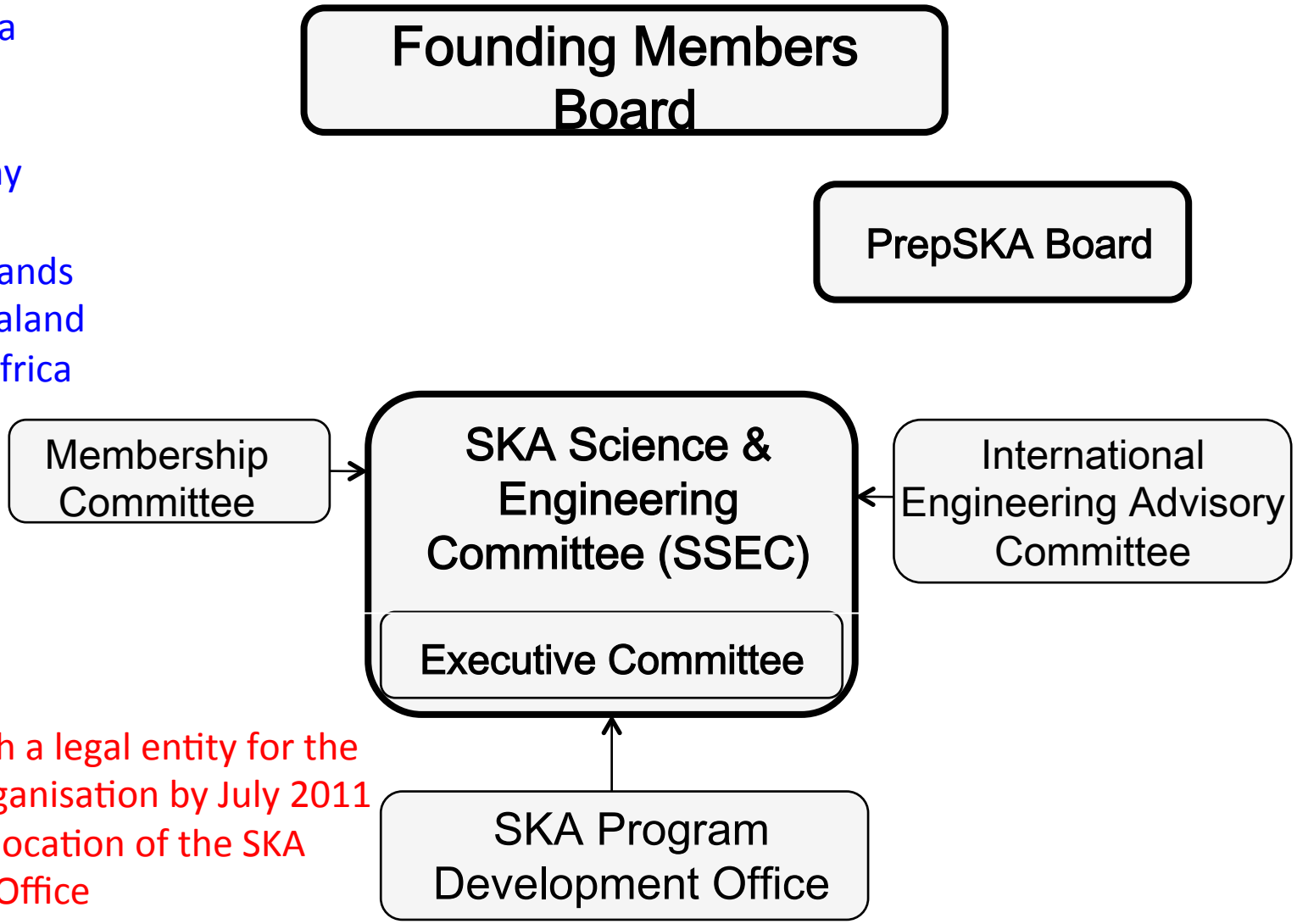
Former governance structure: April 2008 – March 2011



Interim governance (April-now)

Founding Board Signatories

Australia
China
France
Germany
Italy
Netherlands
New Zealand
South Africa
UK



Tasks

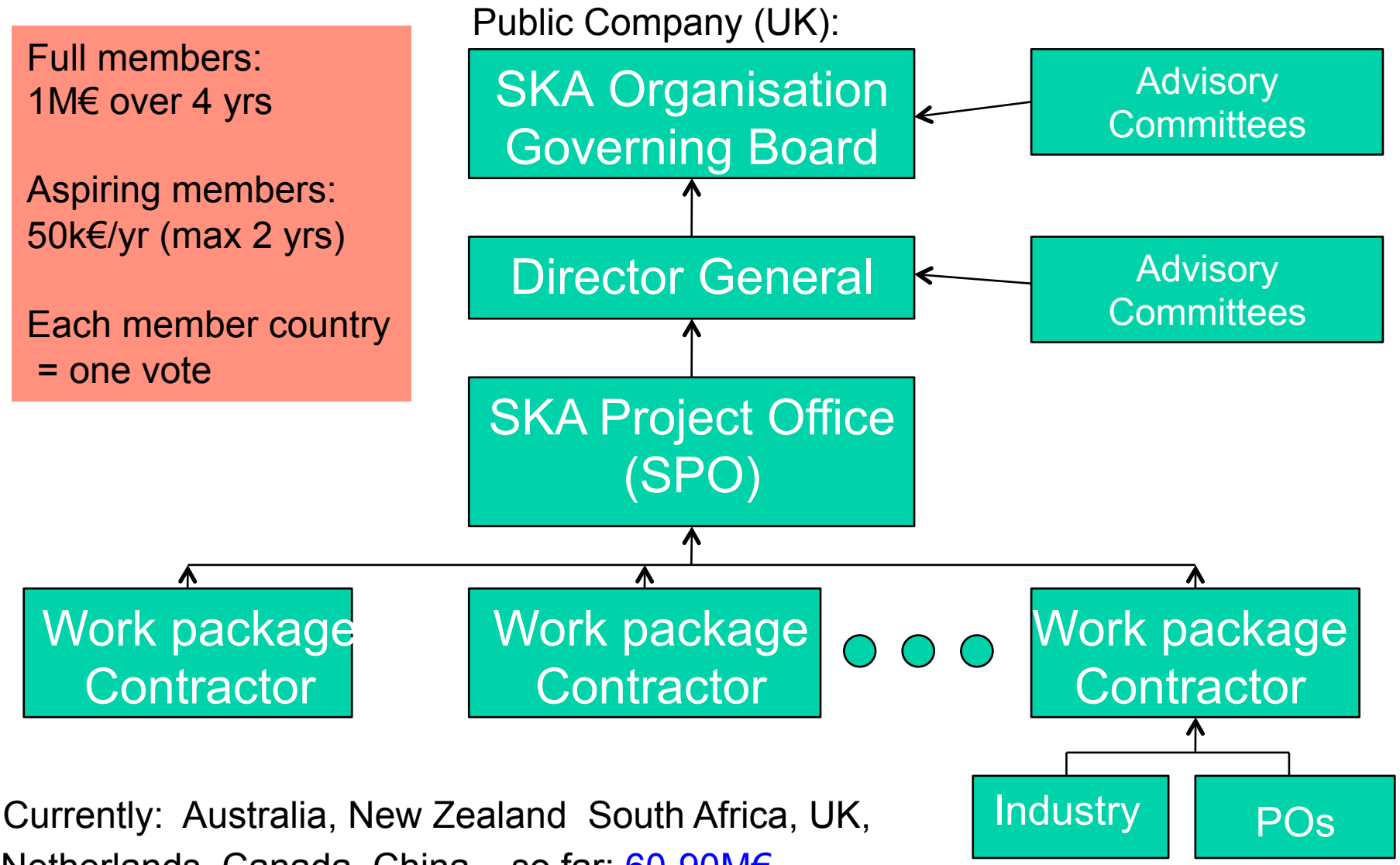
1. Establish a legal entity for the SKA Organisation by July 2011
2. Decide location of the SKA Project Office

SKA Governance: January 2012 →

Full members:
1M€ over 4 yrs

Aspiring members:
50k€/yr (max 2 yrs)

Each member country
= one vote



- Currently: Australia, New Zealand South Africa, UK, Netherlands, Canada, China – so far: 60-90M€

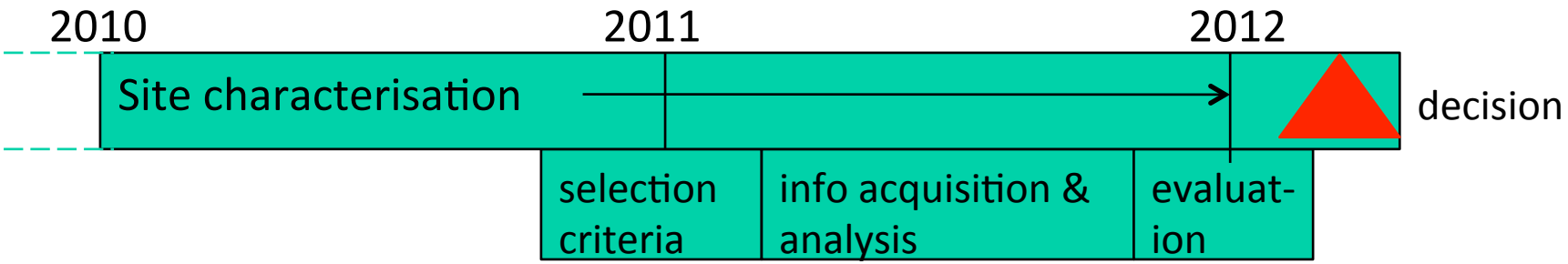
One of the first decisions: Site selection

Physical requirements

- Extremely radio quiet environment
- At least 3000 km in extent
- Low ionospheric turbulence
- Low tropospheric turbulence

Two candidates short-listed in 2006: Western Australia and Southern Africa

Site selection process



Western Australia & New Zealand

South Africa + 7 countries

German activities: Bonn was proposed as SKA HQ

Proposal to host pre-construction SKA HQ

Locational advantages at a glance:

- A very international city in the heart of Europe
- Word-class infrastructure and facilities
- Part of one of Europe's largest metropolitan area
- Superbly connected to European and global destinations
- Proximity to world-class academia and research facilities
- Long tradition of outstanding radio astronomical expertise
- Vicinity to national and European institutions & funding agencies
- Access to international services and schools
- Full of history and culture
- Great place to life with lots of green and natural reserves

German activities: Bonn was proposed as SKA HQ

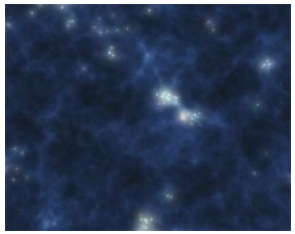
Proposal to host pre-construction SKA HQ

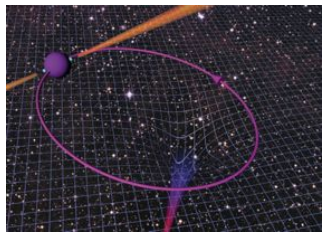
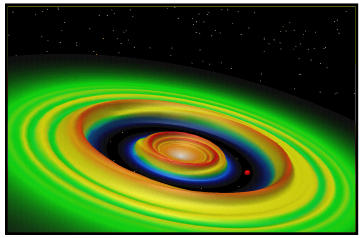
Supported by:

- Max Planck Institut für Radioastronomie (MPIfR)
- Argelander Institut für Astronomie (AIfA)
- Max Planck Institut für Astrophysik (MPA)
- Max Planck Institut für Gravitationsphysik (AEI)
- Astrophysikalisches Institut Potsdam (AIP)
- Forschungszentrum Jülich (FZ)
- Fraunhofer Institut für Solare Energiesysteme (ISE)
- University of Bochum
- Jacobs University of Bremen
- University of Cologne
- Thüringer Landessternwarte Tautenburg
- German Long Wavelength Consortium (GLOW)

BUT given to Jodrell Bank, Manchester (UK)

SKA Key Science: 21st Century Astrophysics



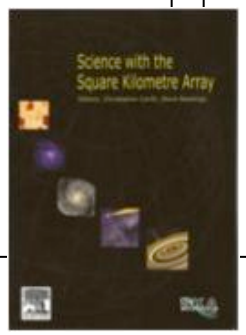
Cosmology & Fundamental Physics

- Gravity
  - Is GR our last word in understanding gravity?
  - Can we observe strong gravity in action?
  - What are the properties of black holes and gravitational waves?
  - What is dark matter and dark energy?
- Magnetism
- Strong force

  Nuclear equation of state

Galaxies Across Cosmic Time, The Galactic Neighborhood, Stellar and Planetary Formation

- Galaxies and the Universe
  - How did the Universe emerge from its Dark Ages?
  - How did the structure of the cosmic web evolve?
  - Where are most of the metals throughout cosmic time?
  - How were galaxies assembled?
- Stars, Planets, and Life
  - How do planetary systems form and evolve?
  - What is the life-cycle of the interstellar medium and stars? (biomolecules)
  - Is there evidence for life on exoplanets? (SETI)

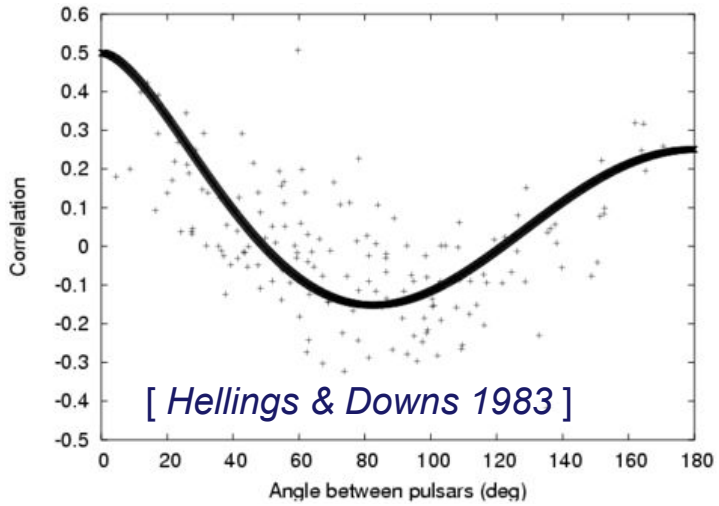


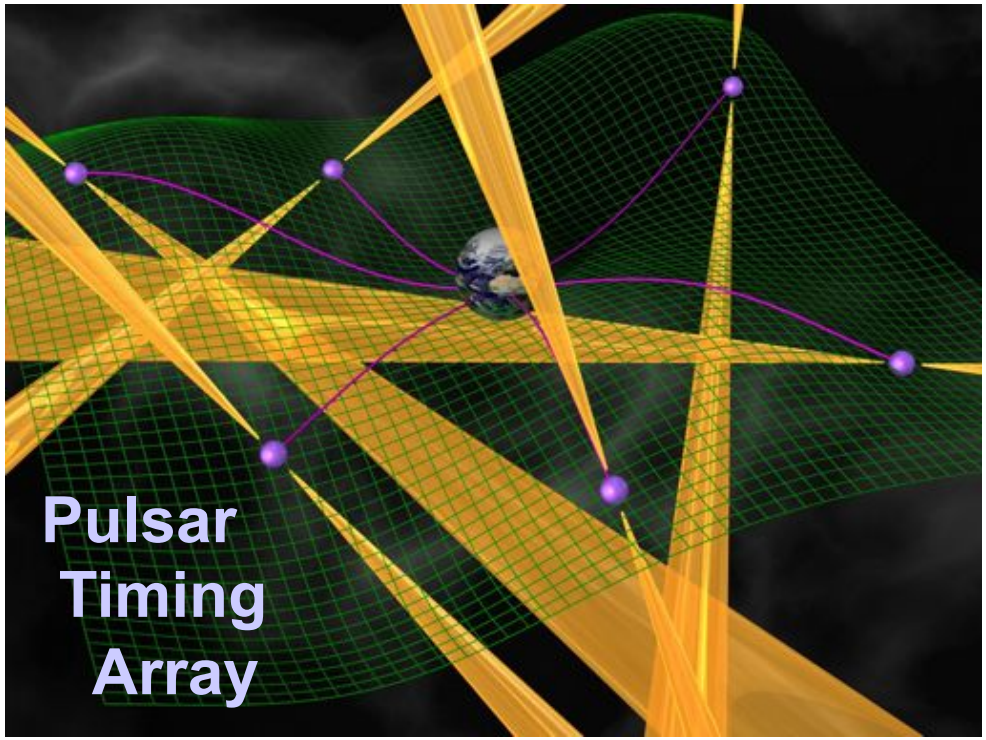
But MUCH more science possible: Carilli & Rawlings (eds), 2004:

Pulsars as gravitational wave detectors

Pulse arrival times will be affected by low-frequency gravitational waves – correlated across sky!

In a "Pulsar Timing Array" (PTA) pulsars act as the arms of a cosmic gravitational wave detector:

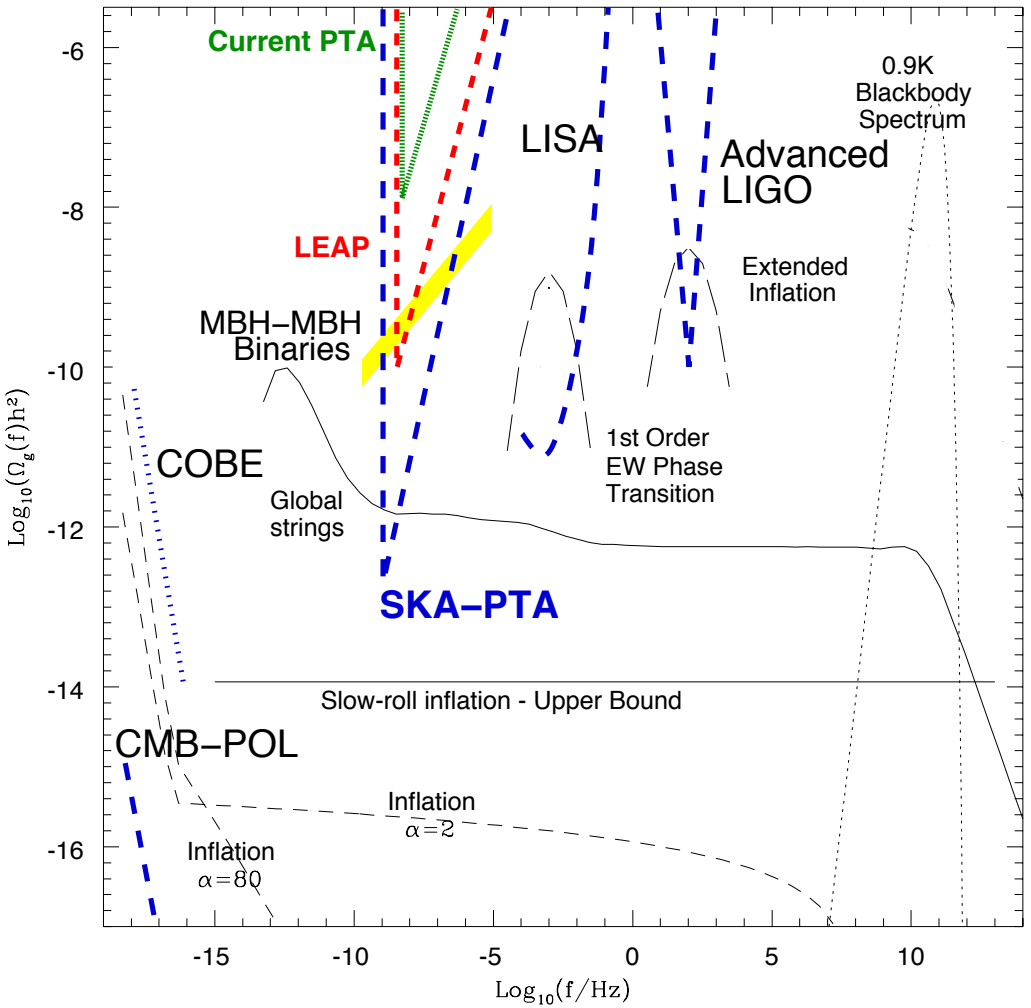




Pulsars as Gravitational Wave Detectors

- PTA is sensitive to nHz gravitational waves
- Complementary to LISA, LIGO and CMB-pol band
- Expected sources:
  - binary super-massive black holes in early Galaxy evolution
  - Cosmic strings
  - Cosmological sources
- Types of signals:
  - stochastic (multiple)
  - periodic (single)
  - burst (single)

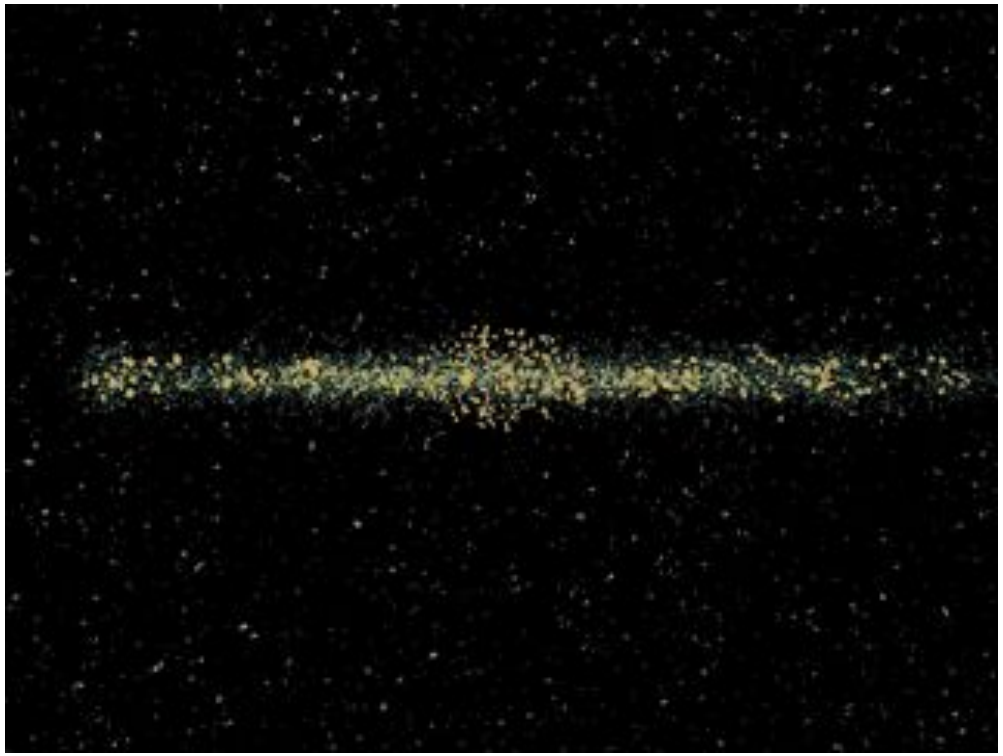
(Kramer et al. 2004)

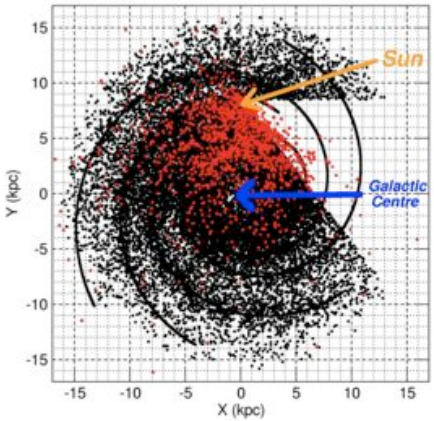


Galactic census with the SKA

With the SKA's collecting area and increase in survey speed:

(Kramer et al. 2004, Smits et al. 2008)





- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 rel binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

➔ with sensitivity also timing precision is expected to increase by factor ~100

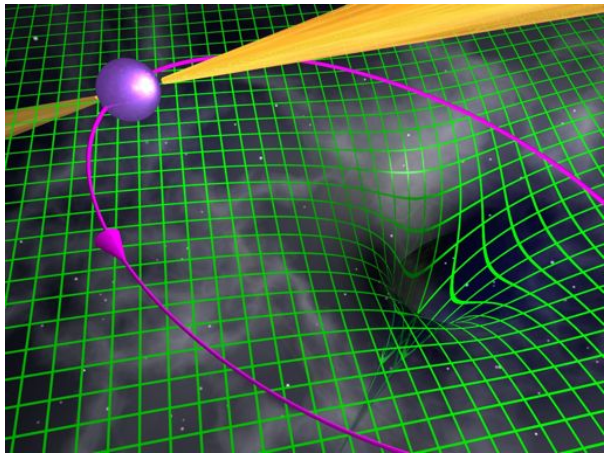
➔ rare and exotic pulsars and binary systems: including PSR-BH systems!

Black Hole properties

BH spin:

$$\chi \equiv \frac{c}{G}\frac{S}{M^2}$$

S = angular momentum



BH quadrupole moment:

$$q \equiv \frac{c^4}{G^2}\frac{Q}{M^3}$$

Q = quadrupole moment

Relativistic spin-orbit coupling:

- Precession of the orbit
  higher order derivatives in semi-major axis and longitude of periastron

Classical spin-orbit coupling:

- characteristic signals in timing residuals

- For all compact massive, BH-like objects, we'll be able to measure spin χ very precisely
- In GR, for Kerr-BH we expect:

$$\chi \leq 1$$

"Cosmic Censorship Conjecture" (Penrose 1969)

- For Kerr-BH we expect:

$$q = \chi^2$$

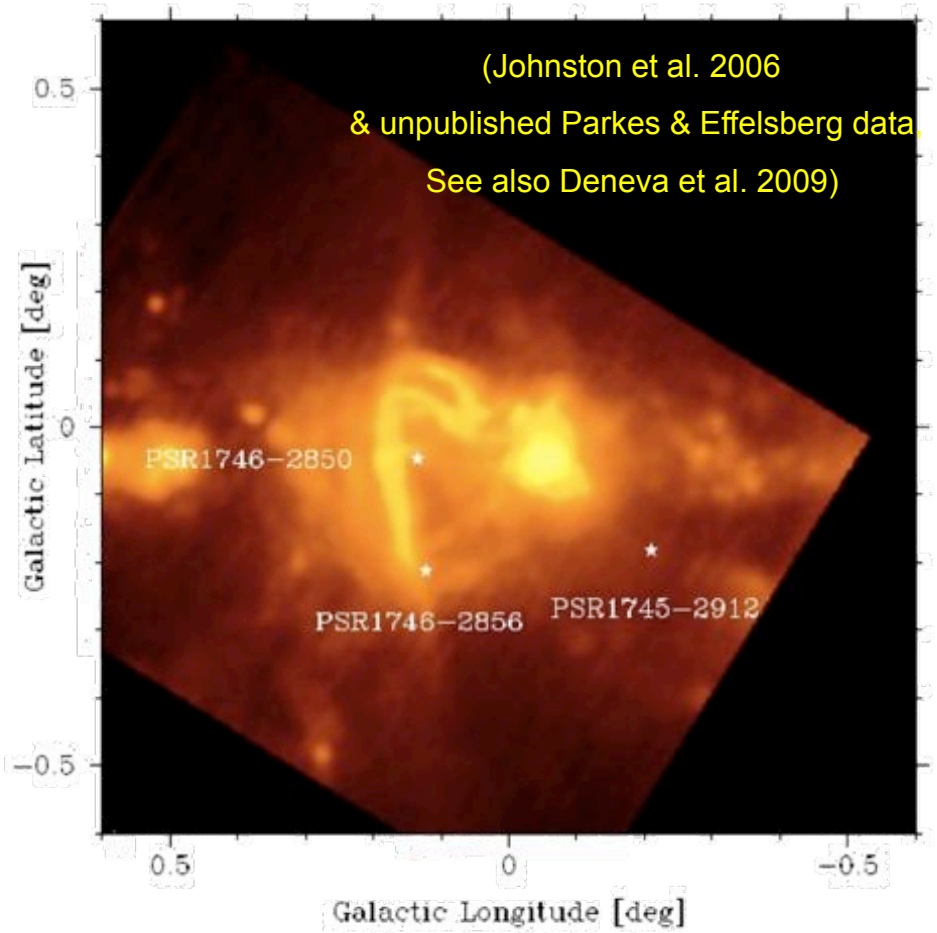
"no-hair" theorem

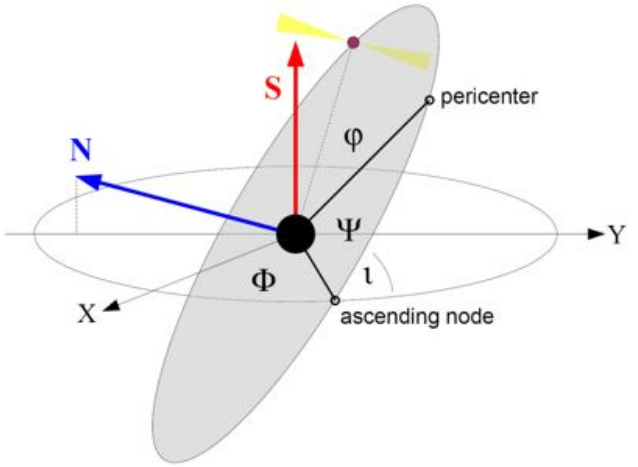
"Easy" for MBH!

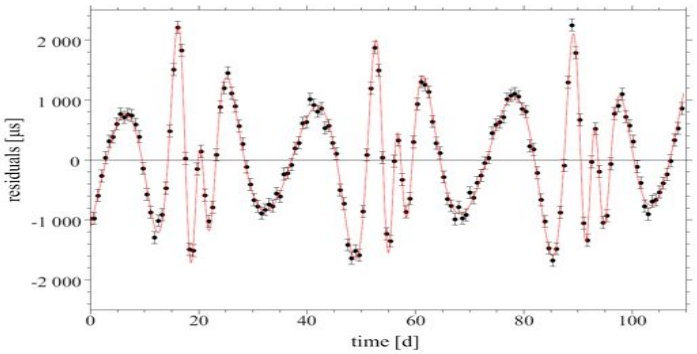
… Galactic Centre!

Pulsar orbiting SGR A*

Finding even a "simple" normal slow pulsar, we can measure the BH with amazing precision:



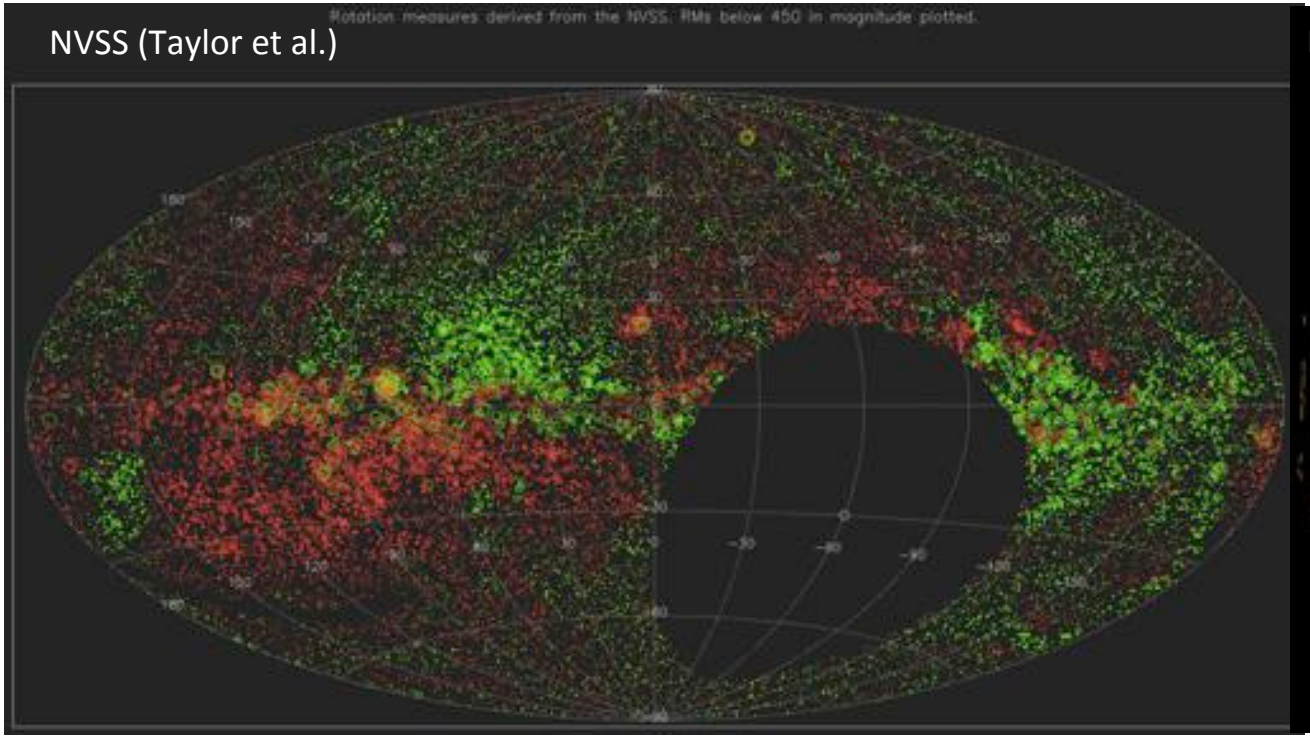




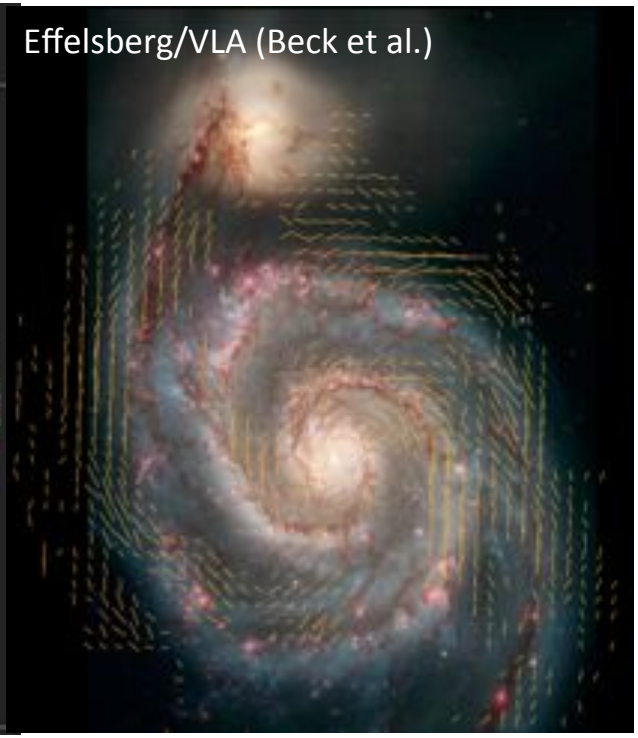
- Measure spin of SGR A* to precision of 10^{-4} to 10^{-3} : Cosmic Censorship!
- Measure quadrupole moment to 10^{-3} to 10^{-2} : No hair! (Liu et al. submitted)

Origin & Evolution of Cosmic Magnetism

- Magnetic fields are fundamental, but poorly constrained and their origin little understood
  - Affects galaxy, cluster evolution?
  - Affects propagation of cosmic rays in ISM and IGM
- All-sky rotation measure surveys provide **B** fields along lines of sight
- Continuum in I, Q, and U!



NVSS (Taylor et al.)


Effelsberg/VLA (Beck et al.)

German SKA Community & Engagement

- Already two KSPs (co-) lead by German scientists – but much wider interest/expertise
- GLOW as condensation core, already excellent representation from

  Universities, Helmholtz, Fraunhofer, Leibniz und Max-Planck Institutes

- Build on experiences with LOFAR
- In preparation: German SKA Consortium
- The MPIfR hosts the European SKA Project Scientist Heino Falcke
- and Vice-Project Scientist Hans-Rainer Klöckner
- Begun: White Paper to capture German science interests and contribution to National Roadmap:
  - broad science topics – not only astronomy! – Computing, energy etc.
  - broad representation (authors form about 30 different institutions)
  - Editors: Falcke, Klöckner, Eckart, Kauffmann, Schwarz et al.
- Further community engagement needed!

JÜLICH FORSCHUNGSZENTRUM

GLOW

And others

Conclusions

- Note: There wasn't time to talk about German ASKAP, MeerKAT etc. involvement
- Lots things are happening in all areas of SKA technology and science
- We are getting a glimpse of the exciting science by testing SKA technology on existing telescope (e.g. wide-bandwidth feed on Effelsberg, APERTIF on Westerbork) or new telescopes like LOFAR.
- SKA_1 will be a superb world-class instrument in its own right!
- SKA_2 will be overwhelming: a revolution in various ways
- German community already involved but big participation in SKA proper missing
- Politically, things are moving fast and decisions are made now

- Let's engage on how to move things forward…! Suggstions???