From the European VLBI Network to the SKA

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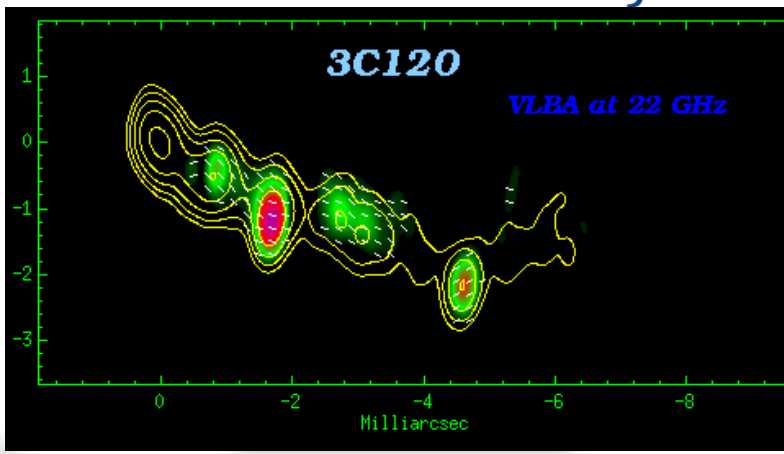
University of Manchester

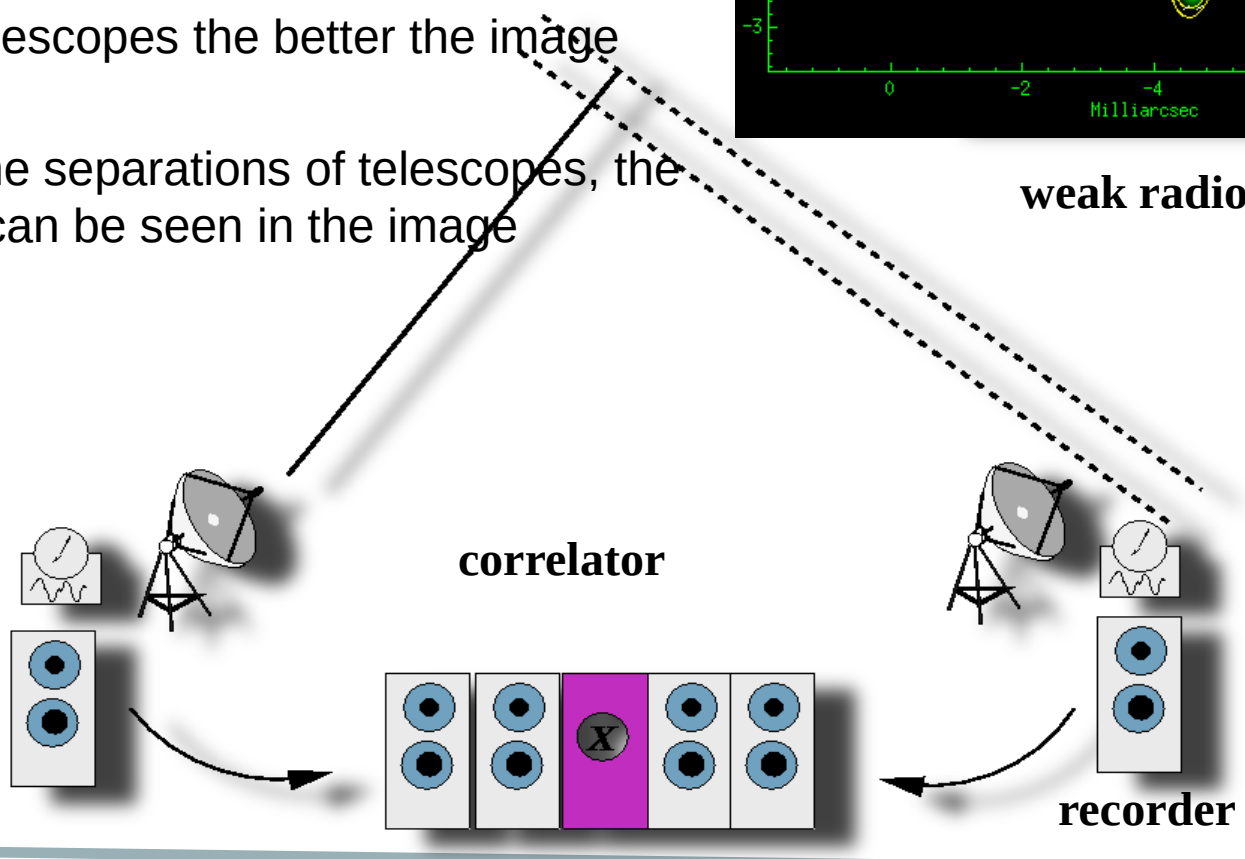
8 October 2016

Very Long Baseline Interferometry

- A network of radio telescopes
- Each pair of telescopes acts as an interferometer
- The information from each pair is combined to produce an image of the radio source
- The more telescopes the better the image quality
- The larger the separations of telescopes, the more detail can be seen in the image



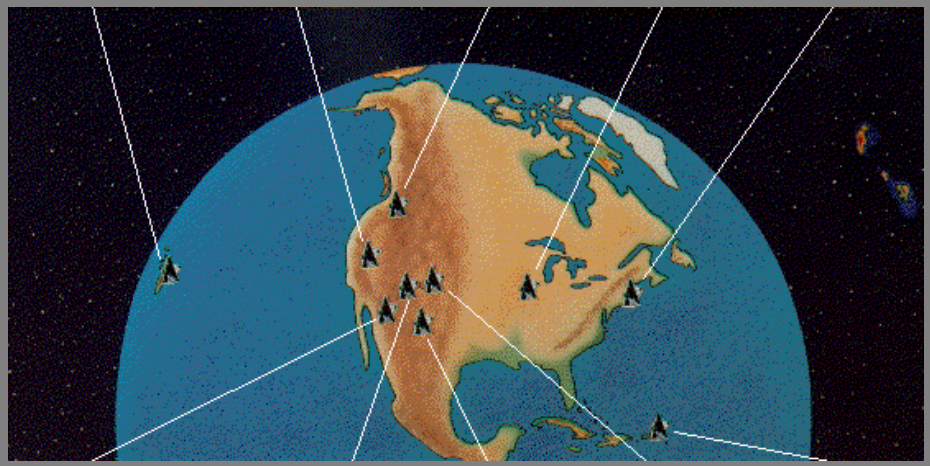
weak radio source



Very Long Baseline Interferometry

European VLBI Network

US Very Long Baseline Array



A brief history of Very Long Baseline Interferometry

1968 first VLBI observations, in the US
1968 first US-Europe (Sweden) observations
1975 first discussions of European VLBI
1976 US VLBI Network formed
1976 first intra-European VLBI observations
1980 European VLBI Network formed
1993 Joint Institute for VLBI in Europe (JIVE) established
1993 US VLB Array opened
1997 Japanese space VLBI telescope launched
1998 JIVE Data Processor opened, in Dwingeloo
2011 Russian space VLBI telescope launched
2015 JIVE becomes a European legal entity (ERIC)

European VLBI in the 1970s

1975	June	MPIfR cafetaria Bonn (Miley, Booth, Pauliny-Toth, Preuss)
	Sept	first meeting of interested astronomers, Bonn (Miley, Casse, Baud, Brouw, Habing)
1976	Oct	first intra-European observations Onsala-Dwingeloo-Effelsberg (ODE) on 3C236 (RTS, GKM) and NML Cygnus (BB, HJH)

Astron. Astrophys. 77, 1–6 (1979)

ASTRONOMY AND ASTROPHYSICS

High Resolution Observations of the Compact Central Component in the Giant Radio Source 3 C 236

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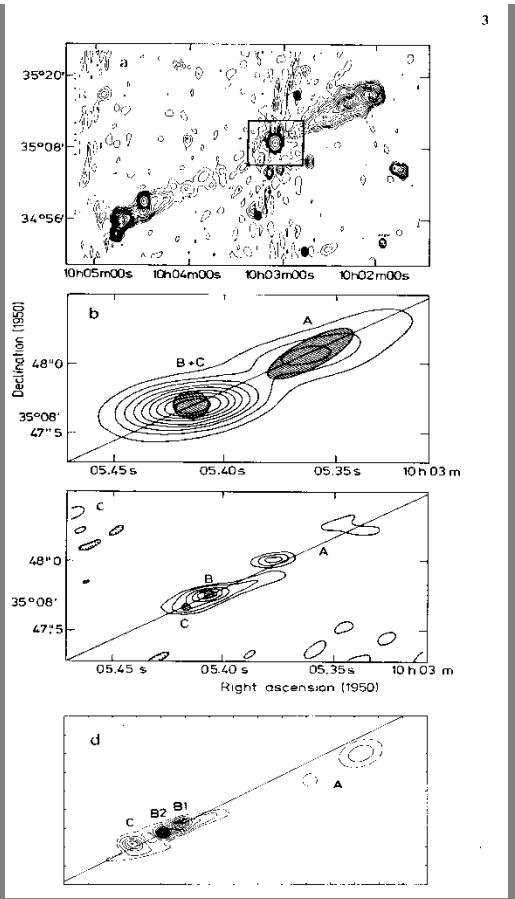
Received October 16, 1978

ODE EXPERIMENT

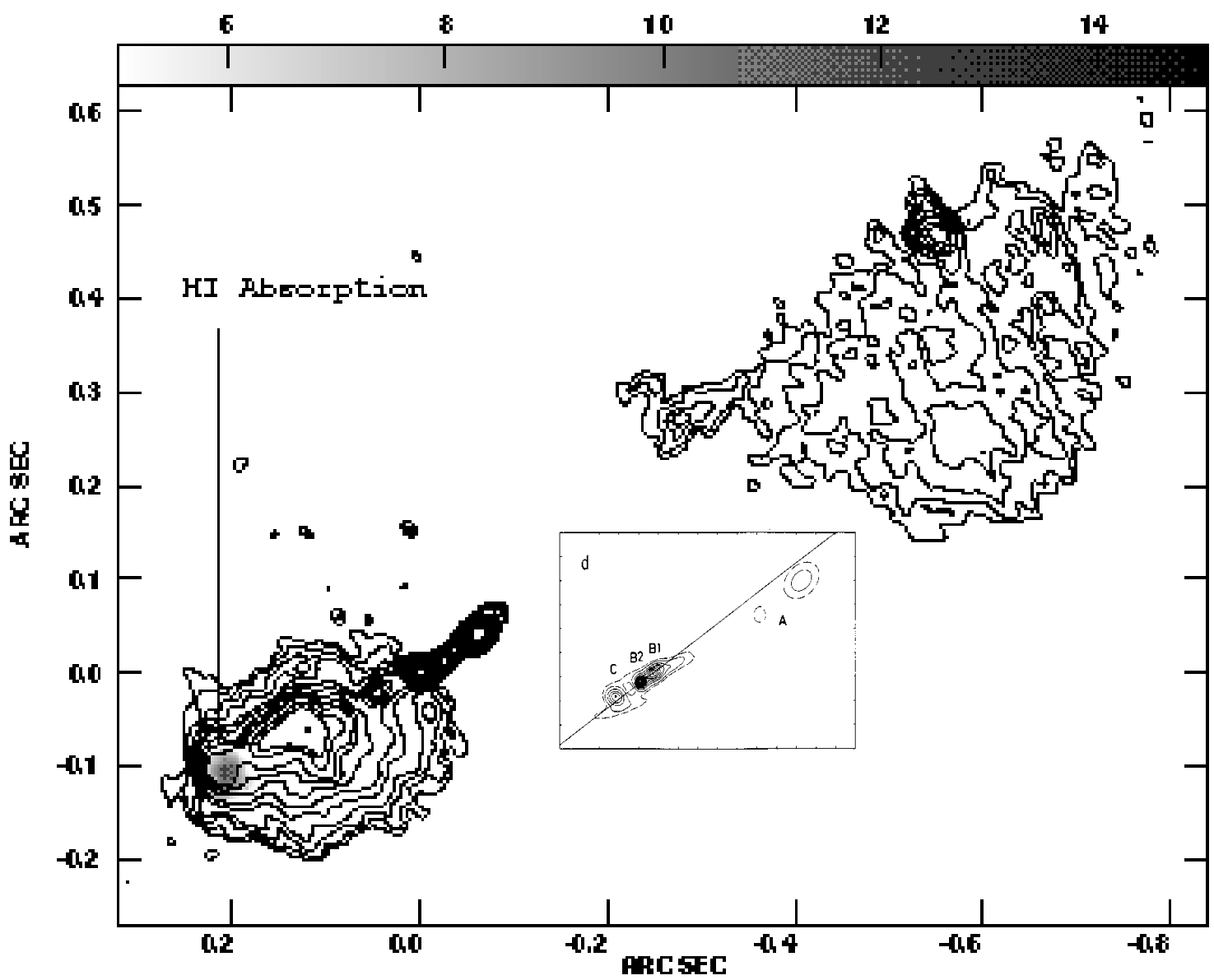
OCTOBER 1,2

[A] CONTINUUM . F = 1610.MHz . BW = 2. MHz . STATION B = EFFELSBERG , C =

SOURCE	SCAN #	START B	START C	START A	STOP	TAPES B	TAPES C	TAPES A	SCAN TIMES B-C	SCAN TIMES A-C	SCAN TIMES A-B
3C273	275-1530	15 02 32	14 59 55	1500 00	15 30	MPI-151	MPI-76	050-1	27½	30	27½
3C315	-1600	15 36 45	15 35 55	15 33 10	16 00	"	"	"	23½	24	23½
4C39.25	276-0230	02 02 00	02 00 00	02 0100	02 30	MPI-041	MPI-018	050-7	28	29	28
A00235	-0300	02 35 00	02 38 06	02 35 18	03 00	"	"	"	22	22	25
3C22	-0330	03 04 30	03 04 40	03 03 07	03 30	"	"	"	25½	25½	25½
3C84	-0400	03 35 00	03 35 15	03 33 15	04 00	"	"	"	25	25	25
3C263	-0430	04 07 06	04 08 05	04 06 20	04 30	MPI-042	MPI-019	050-8	22	22	23
4C39.25	-0500	04 40 15	04 34 33	04 32 15	05 00	"	"	"	20	25½	20
3C236	-0600	05 02 30	05 04 11	05 01 14	06 00	"	"	"	56	56	57½
"	-0700	06 06 10	06 07 46	06 05 42	07 00	MPI-043	MPI-045	050-9	52½	52½	54
"	-0800	07 02 10	07 02 33	07 00 27	08 00	"	"	"	57½	57½	58
"	-0900	08 05 00	08 08 25	08 05 18	09 00	MPI-053	MPI-012	050-10	51½	51½	55
"	-1000	09 00 00	09 02 39	09 00 25	10 00	"	"	"	57½	57½	59½
"	-1100	10 06 30	10 09 39	10 05 00	11 00	MPI-055	MPI-013	050-11	50½	50½	53½
"	-1200	11 00 00	11 03 44	11 00 48	12 00	"	"	"	56½	56½	59½
"	-1300	12 05 30	12 07 00	12 06 07	13 00	MPI-056	MPI-014	050-12	53	53	54



MANCHESTER
1824


6
8
10
12
14
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
ARC SEC
HI Absorption
d
A
B2
B1
C
0.2
0.0
-0.2
-0.4
-0.6
-0.8
ARC SEC

European VLBI in the 1970s

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1977 ESA Feasibility Study of satellite-linked VLBI

1978 First VLBI fringes with Westerbork in phased array mode

1979 MPIfR decision to purchase 3-station Mk3 correlator from Haystack

The 1980s

Annual Meetings of Observatory Directors

including Harry representing SRZM until 1987, and Wim thereafter

1980-2 formed EVN

discussed new generation real-time correlator for Satellite-linked VLBI

- Exchange of letters between EVN (HvdL) and ESA on L-SAT opportunity
- Proposal to use DLB at Westerbork for VLBI processing (RTS, Miley, Goss)
- L-SAT use too expensive for EVN→ Demise of satellite-linked VLBI

1983-5 discussed alternative proposals for large data processors

- upgrade Mk3 processor at MPIfR to 8 stations (10 Mfl)
- develop new generation (12 station) user-friendly data processor in Dwingeloo (15 Mfl)

European Consortium for VLBI established (8 members).

- Consortium agrees to seek funding for new generation processor in Dwingeloo

The 1980s (2)

1986 contact with EC in Brussels on funding (Fasella, van Lieshout, HvdL, RTS)

First contacts with Peter Tindemans and John Marks in NL Min. Education and Science (HvdL)

1987 Harry leaves centre-stage EVN to go to ESO

1988 EVN proposal to EC in Brussels (20 stations, 17.8 M€)

The 1990s

1990 ESF Review Panel on ground-based astronomy instigated by Deetman gave strong support to processor

1992 pressure from Ritzen on Pandolfi (vice-president EC in Brussels)

1992 Funding at last!

- 1 M€ from EC (Access to Large Scale Facilities)
- 5.5 M€ from Ministry of Education and Science in NL
- 0.3 M€ from CNRS in France
- 0.55 M€ from the Swedish Wallenberg Foundation

1993 Joint Institute for VLBI in Europe (JIVE) formally established as a Foundation in the Netherlands

1993 –1998 design, prototyping, and construction of 16 station processor by international consortium (8.7 M€ including manpower)

The 1990s (2)

22 October 1998

official opening of EVN Data Processor at JIVE by Relus ter Beek

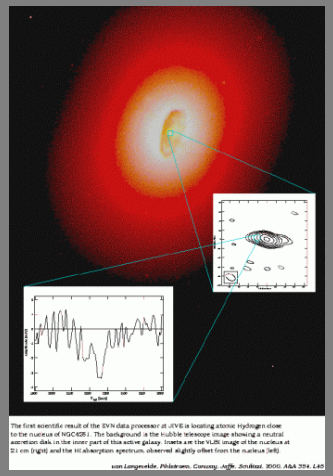
(Harry, Renate, and the children were on holiday in Tunisia!)

1998 - 2016

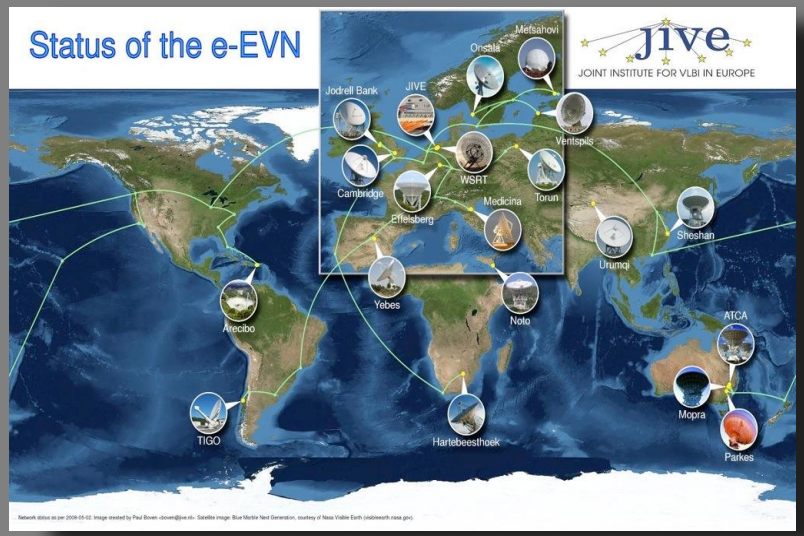
First EVN correlation in ~ July 1999

By 2000, essentially all EVN observations and ~50% of global observations correlated at JIVE

First science: van Langevelde et al 2000
“A thin HI circumnuclear disk in NGC4261"



e-VLBI



SKA Pathfinder

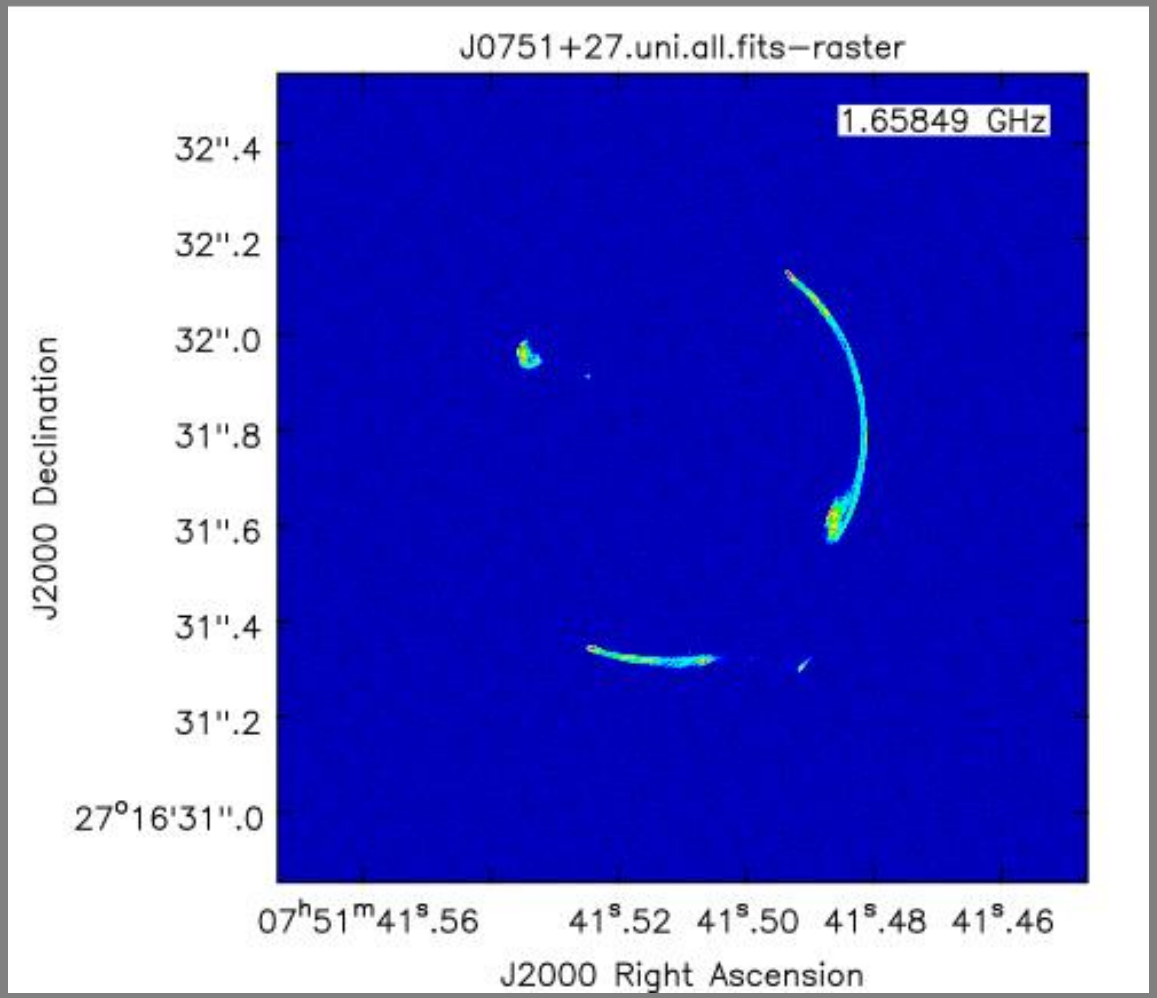
JIVE → European Research Infrastructure Consortium

- JIVE was inaugurated as an ERIC on April 21 2015
  - Legal transition since then
  - Completed the financial transition

Gravitational lens

22 station global array

McKean et al



VLBI → SKA

VLBI is a broad church

EVN

12 countries

20+ telescopes

Global VLBI

17 countries

40+ telescopes

Culture of collaboration set the scene for the development of the SKA in the 1990s

Square Kilometre Array

3 sites; 2 telescopes + HQ
1 Observatory

Design Phase: ~€170M; 600 scientists+engineers

Phase 1
Construction: 2018 – 2024
Construction cost: €674M (inflation-adjusted cost cap)
Operations cost: ~€130M/yr

Phase 2
2024 - 2033
Multi-billion Euro project

SKA– Key Science Drivers:

The history of the Universe

Cosmic Dawn

(First Stars and Galaxies)

Testing General Relativity

(Strong Regime, Gravitational Waves)

Galaxy Evolution

(Normal Galaxies z~2-3)

Cradle of Life

(Planets, Molecules, SETI)

Cosmology

(Dark Matter, Large Scale Structure)

Cosmic Magnetism

(Origin, Evolution)

Exploration of the Unknown

The SKA:
Good ideas have many fathers…

Govind Swarup

1981 GERT proposal

1984 GMRT proposal

1989 GMRT funded

Peter Wilkinson

1985 note on Large Radio Flux Collector

1986 presentation to RAS-RS Study Group on the Priorities for British Astronomy

Robert Braun
Jan Noordam
Ger de Bruyn

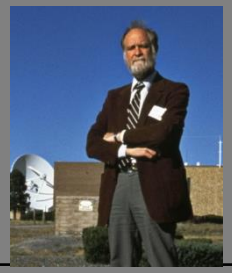
1987? Robert and Ron discuss VLA sensitivity for extragalactic HI

1989 discussions in Dwingeloo on large collecting area concepts and science case

Yuri Parijskij

Director of RATAN-600

Ron Ekers



Ex-SRZM Algemeen Bestuur member

Ex-VLA Director

ATNF Director

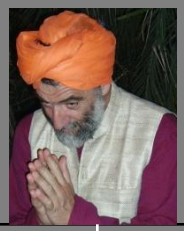
Chair URSI Comm J on Radio Asronomy

IAU Colloquium 131 in Oct 1990

Govind Swarup

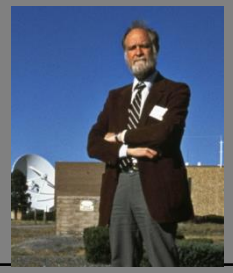
Peter Wilkinson

Jan Noordam



Yuri Parijskij

Ron Ekers



Presentation on Hydrogen Array

Hydrogen Array

Imaging HI at <1" resolution needs 100x sensitivity of VLA → 1 sq km

URSI Large Telescope WG formed in August 1993, now seen as the start of the SKA project

NL: Early leadership in the SKA

1993 Robert Braun, first chair of URSI WG on Large Telescopes

1994 Harvey Butcher, first chair of IAU WG on Future Large Scale Facilities

1995 Arnold van Ardenne, PI of first grant for SKA R&D on Aperture Arrays

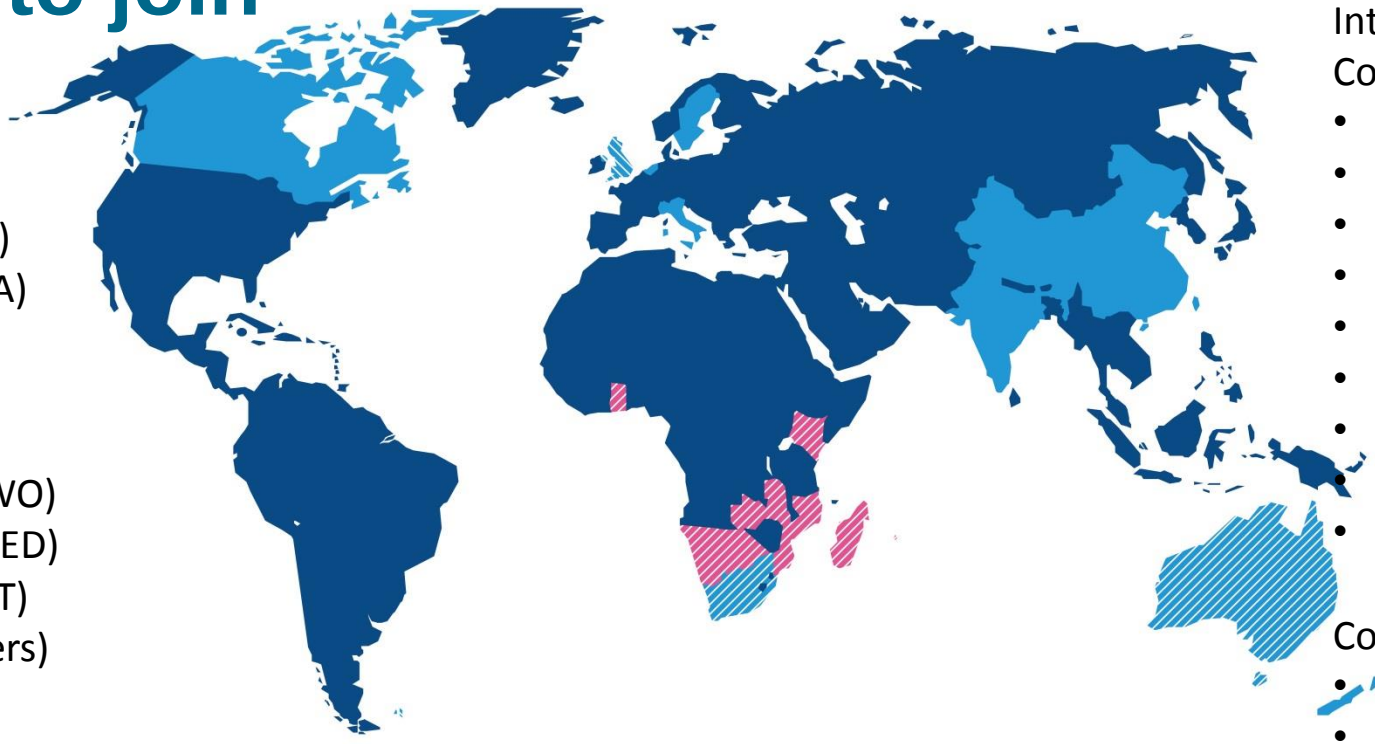
1996 Harvey Butcher, initiator of first global MoA on Technical Cooperation in the SKA

1998 George Miley, initiator of first SKA Pathfinder, LOFAR

2003 RTS, first International Project Director of the SKA

SKA Organisation: 10 countries, more to join

Australia (DoI&S)
Canada (NRC-HIA)
China (MOST)
India (DAE)
Italy (INAF)
Netherlands (NWO)
New Zealand (MED)
South Africa (DST)
Sweden (Chalmers)
UK (BEIS/STFC)

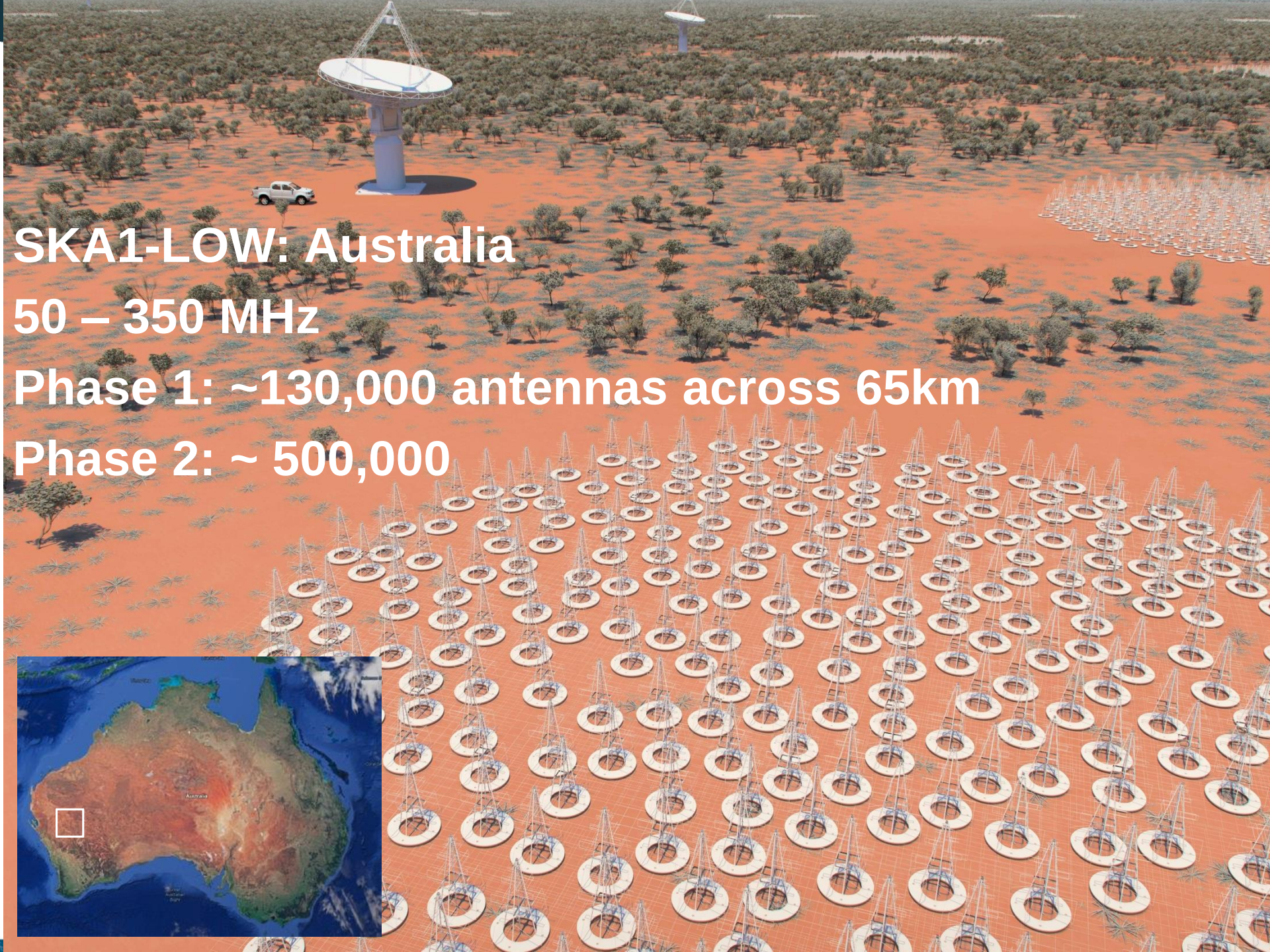


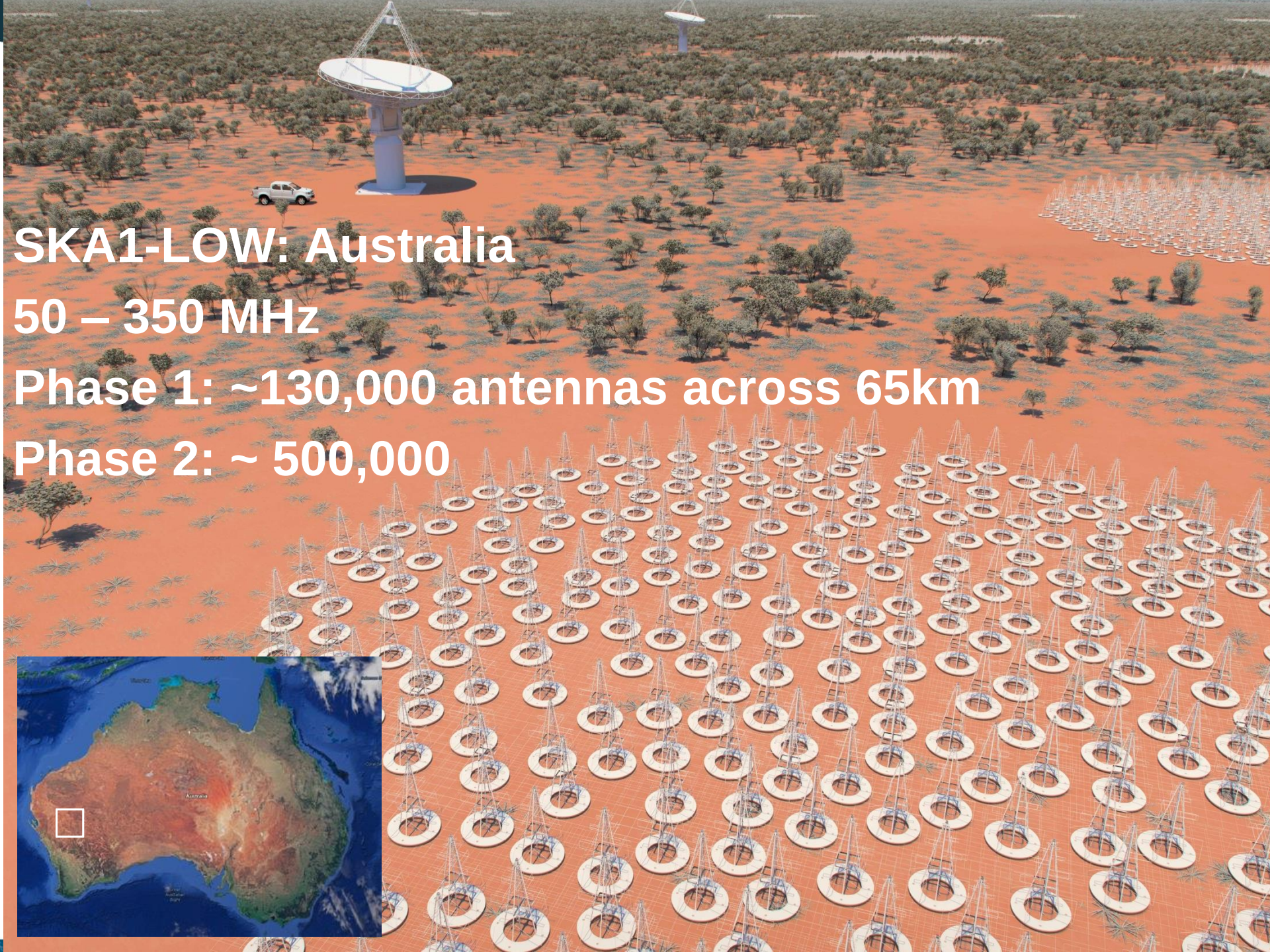
Interested Countries:

- France
- Germany
- Japan
- Korea
- Malta
- Portugal
- Spain
- Switzerland
- USA

Contacts:

- Brazil
- Ireland
- Russia


SKA1-LOW: Australia
50 – 350 MHz
Phase 1: ~130,000 antennas across 65km
Phase 2: ~ 500,000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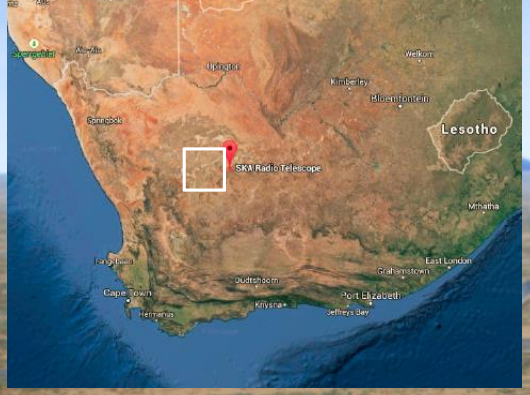
SKA1-Low


Phase 1: 200 15-m dishes across 150 km
Phase 2: ~2,000 dishes across southern Africa
Lesotho
SKA Radio Telescope
Mthatha
East London
Graaff-Reinet
Oudtshoorn
Cape Town
Port Elizabeth
Knysna
Hermanus
Jeffreys Bay
SKA1-MID: Africa
350 MHz – 20 GHz



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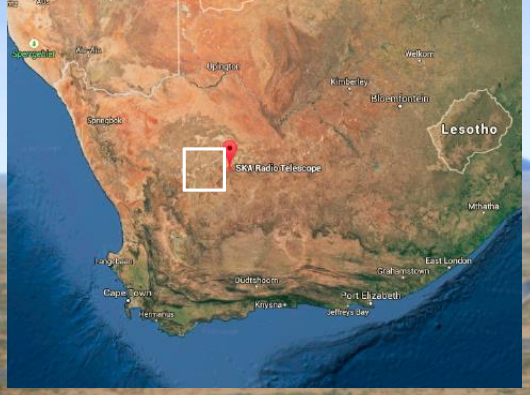
350 MHz – 20 GHz



Phase 1: 200 15-m dishes across 150 km

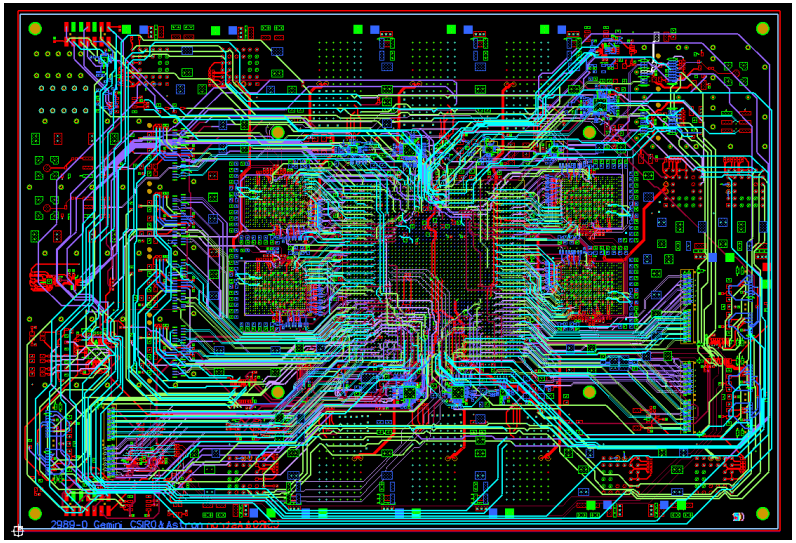
Phase 2: ~2,000 dishes across southern Africa

SKA1-MID: Africa

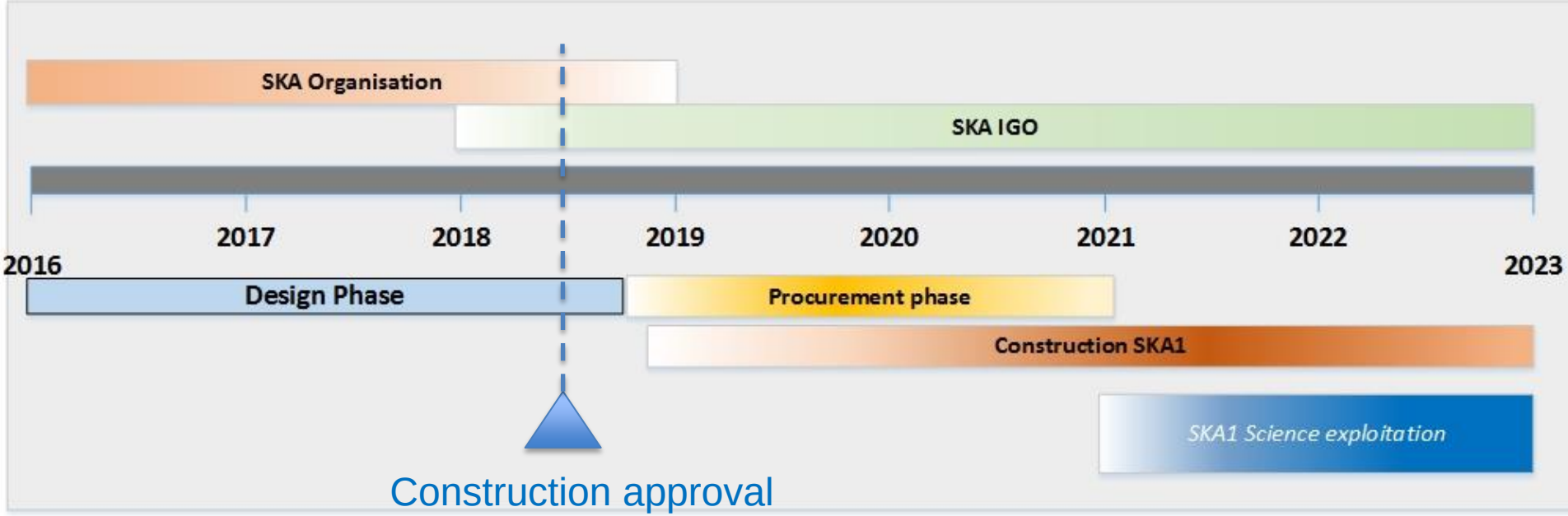
350 MHz – 20 GHz

Phase 2: Mid-frequency aperture array

Prototypes



Overall project timeline



Key dates:

- Convention agreed Q4 2016
- CDRs Q4 2017
- IGO in force Q1 2018
- SKA1 Construction approval Q3 2018

Negotiations underway to establish an Inter-Governmental Organisation.

4th meeting in Rome, Sept 27-29, 2016. Intent is to agree convention and protocols, with Ministerial signing event early 2017. Transition planning in progress.

Why has NL played such a prominent role in the EVN, SKA and other projects?

- On the European stage, NL punches above its weight
  - Strong leaders, with vision (Harry)
  - Internally well-organised
  - Tradition of working with foreigners

  →Chairs of committees, Directors of European organisations
- World-class astronomers and engineers
- World class facilities
- Tradition of daily science-engineering interaction → WSRT, wifi, JIVE, LOFAR, SKA,….
- Consistent government support

Happy Birthday, Harry!