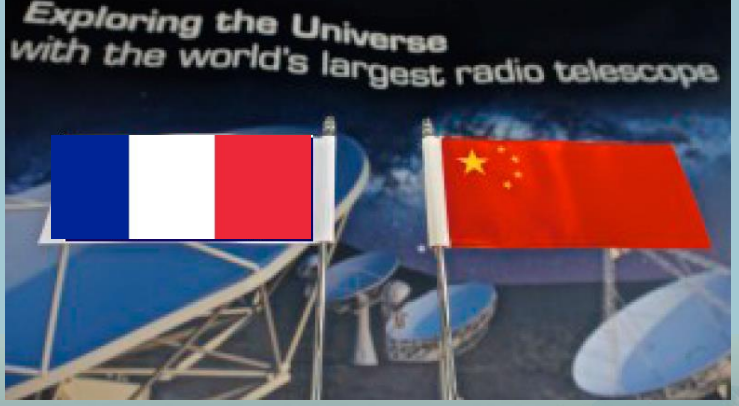


The Square Kilometre Array

（平方公里阵射电望远镜）

— New Opportunities for Sino-French Collaboration

Bo Qin (NAOC)

国家天文台 秦波

FCPPL Marseille, May 25, 2018

起源 ORIGINS

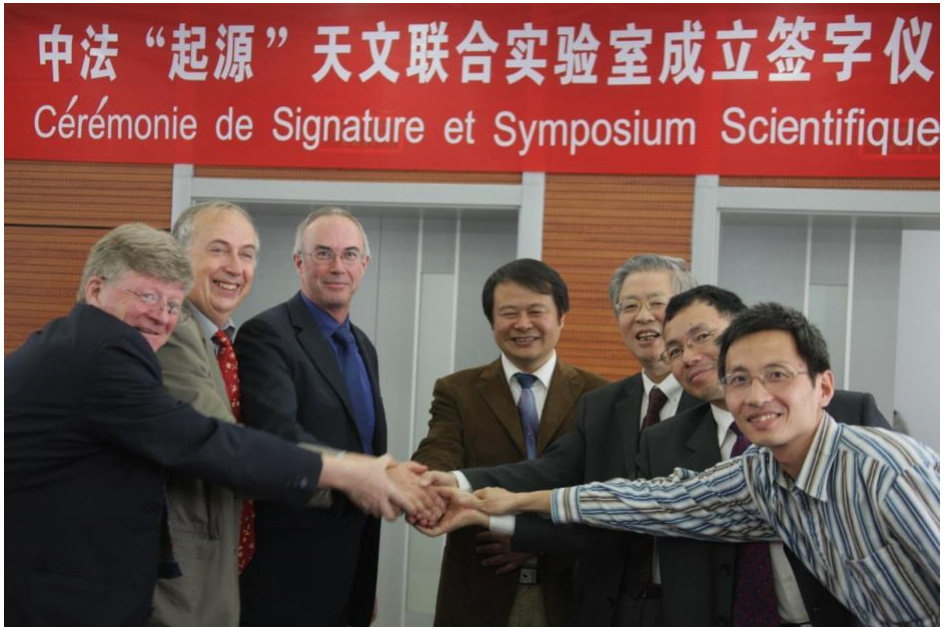
Exoplanets

Matter

Galaxies

Establishment of LIA Origins

(Oct 22, 2008)



LIA Origins Workshops are held every other year

Welcome to

" **LIA-Origins 2018 Workshop** ", Nov 2-5, Kunming

+ LIA-Origins 2018 School, Oct 22-Nov 1

SKA -- the "LHC" in Astronomy

- **SKA: an overview**
- **Chinese contribution to the SKA**
- **SKA in China**

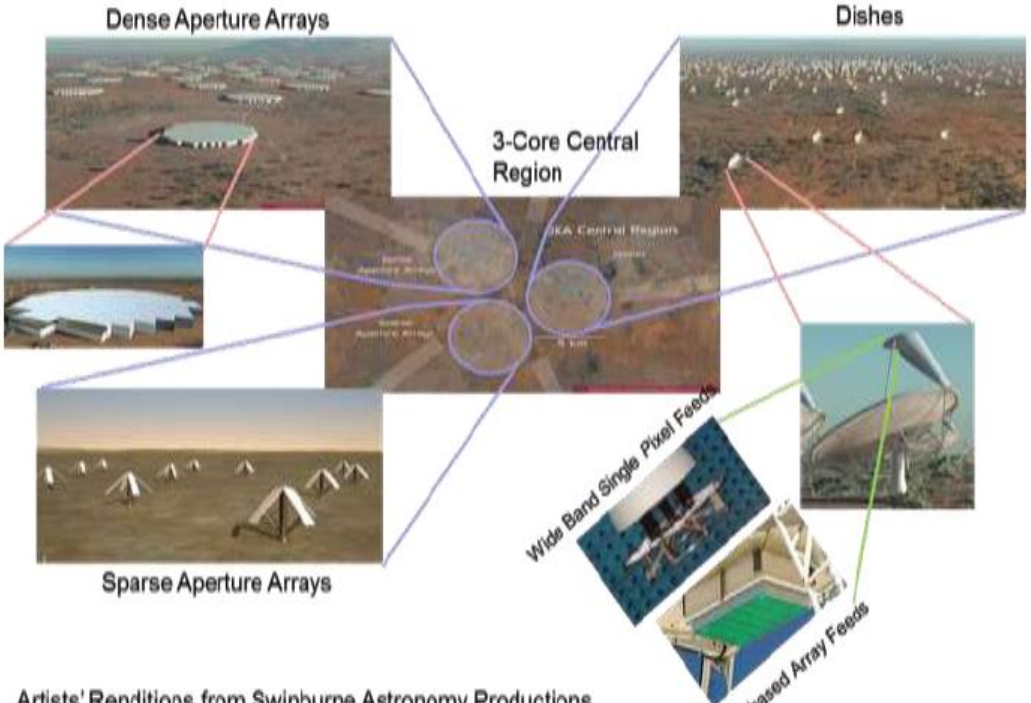
平方公里阵 SKA（Square Kilometer Array）

will be the largest and most ambitious astronomical facility that has ever been built on this planet

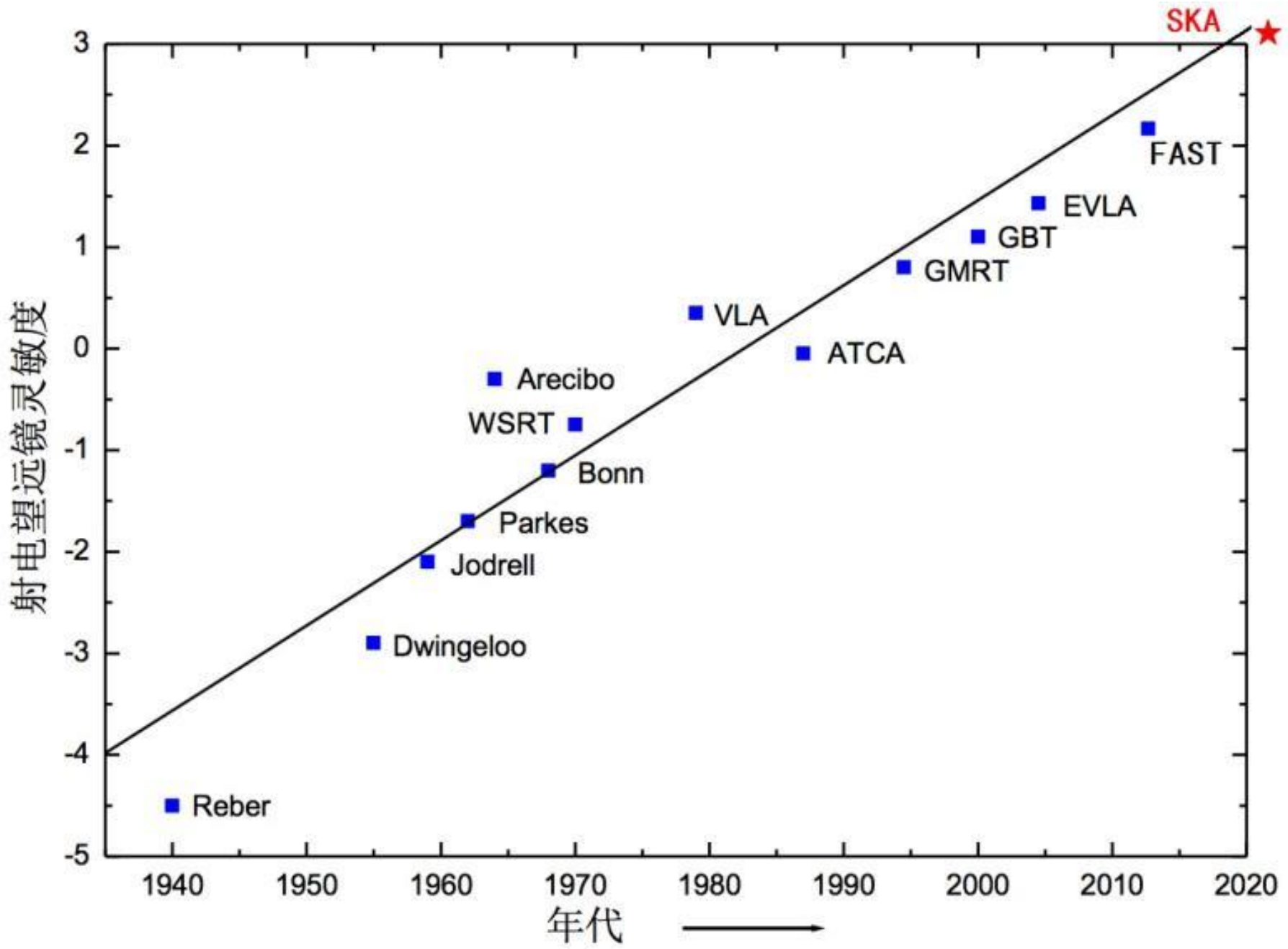
Consists of 2000 15m dishes, baseline 3000km & 0.5 million antennas equivalent collecting area at km^2 level

Revolutionary：5 advantages combined into 1

1. High sensitivity：large area
2. High spatial resolution：
   milli-arcsec level
   baseline 3000km
3. Large FoV
4. High survey speed：
   10,000×JVLA
5. Wide frequency coverage：
   50MHz – 20GHz



Artists' Renditions from Swinburne Astronomy Productions


SKA
FAST
EVLA
GBT
GMRT
VLA
ATCA
Arecibo
WSRT
Bonn
Parkes
Jodrell
Dwingeloo
Reber
射电望远镜灵敏度
年代
3
2
1
0
-1
-2
-3
-4
-5
1940
1950
1960
1970
1980
1990
2000
2010
2020

SKA Timeline, Costs, and Hosts

- Timeline

  Pre-construction: 2012-2020 Design, RfP, IGO

  SKA1 construction: 2020-2025 ~10% SKA

  SKA2 construction: complete after 2030

- SKA1 Costs: 1.7 B€ (construction + 10 year operation)

- Dual Site： (voted Nov 2012)

  Australia (low frequency site)

  South Africa (higher frequency site)

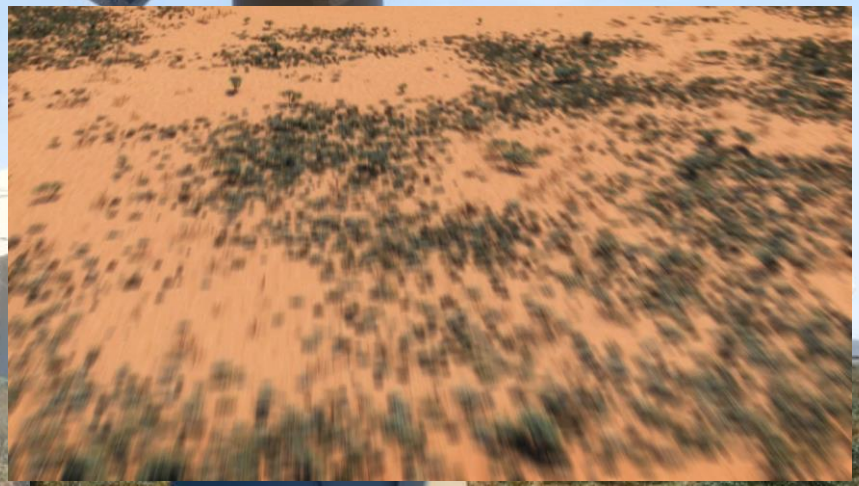
- Headquarter： (voted April 2015)

  UK (Manchester) as permanent HQ

SKA1-MID: Africa

200 15-m dishes across 150 km

~2,000 dishes in Phase 2, across southern Africa



Massive increase in capability over current facilities

Huge data rates and infrastructure challenge

SKA1-LOW: Australia

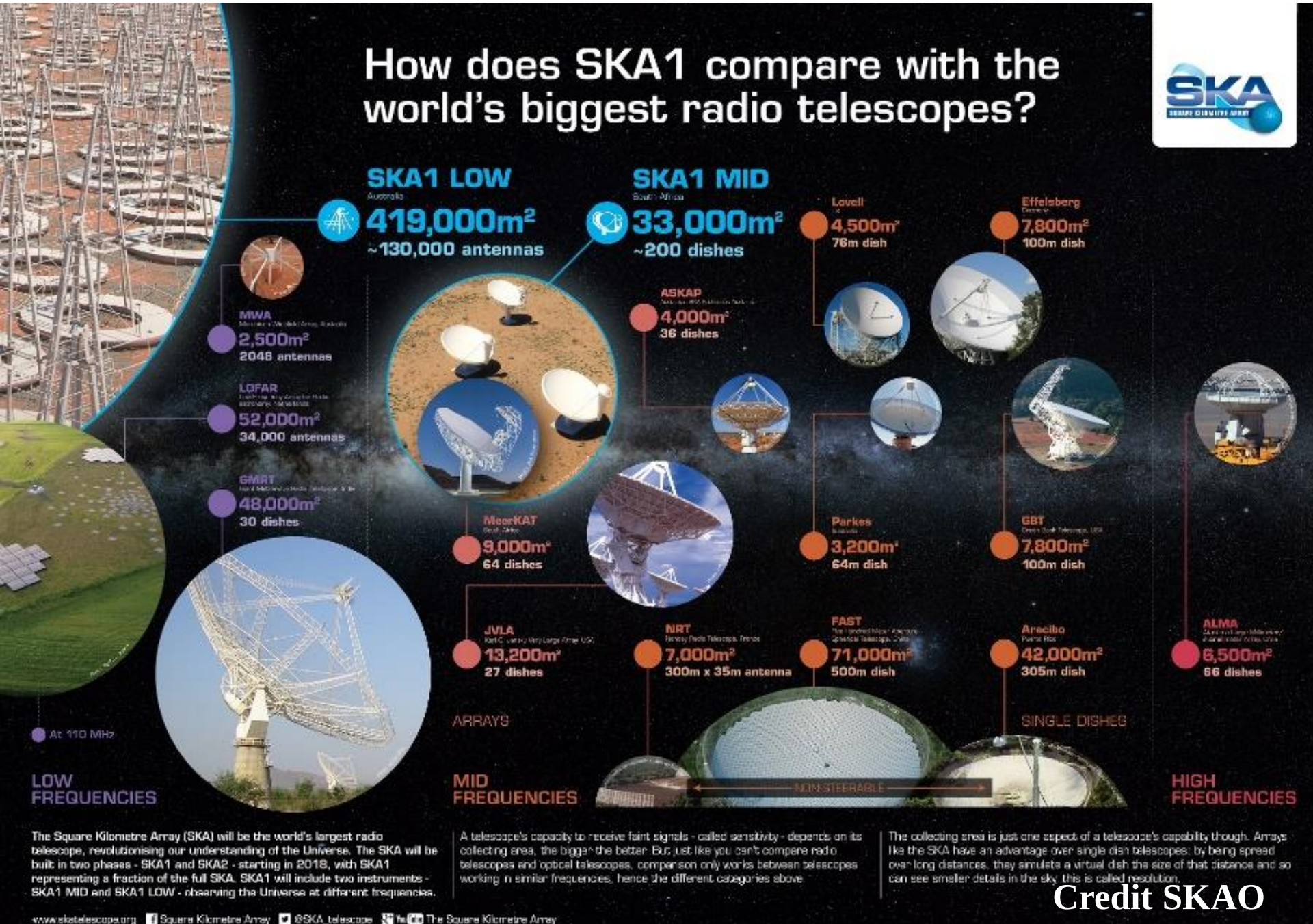
~130,000 antennas then 500,000 in Phase 2

500 stations over 80 km

Raw data output: Tb/sec, ZB/yr

Huge engineering, computational and science challenge

SKA1与主要大望远镜接收面积一览



Credit SKAO

SKA1 Compared with Other Telescopes

SKA1 will be the most powerful radio telescope in the world

参 数	单 位	JVLA (1.4 GHz)	SKA1-MID (1.4 GHz)	FAST (1.4 GHz)	LOFAR-NL (140 MHz)	SKA1-LOW (140 MHz)
Aeff/Tsys	(m^2/K)	**168**	×7.9 **1330**	**1470**	**85**	×6.1 **520**
			$2.7\times10^4\ m^2$/20 K	**$4\times10^4\ m^2$/27 K**		
Survey Speed FoM **FoV x (Aeff/Tsys)^2**	(deg^2 m^4/K^2)	**4.8×10^3**	**8.3×10^5** ×170	**4.6×10^4**	**6.7×10^4**	**1.9×10^6** ×28
B_{MAX}	(km)	**36.4**	**154**	**0.3**	**52**	**65**
角分辨率	(arcsec)	**1.2**	×4.3 **0.28**	**148**	**8.5**	×1.3 **6.7**

SKA1 v.s. FAST

技术指标	FAST	SKA1-mid
工作频率(GHz)	0.07-3	0.3-13.8
基线（或口径）(km)	0.3	154
灵敏度(m^2/K) (A_{eff}/T_{sys})	1480 ($4\times10^4 m^2/27$ K)	1330 ($2.7\times10^4 m^2/20$ K)
视场 (deg^2)	0.021	0.47
巡天速度 ($deg^2\, m^4/K^2$)	4.6×10^4	8.3×10^5
分辨率(arcsec)	148	0.28

SKA Key Science Drivers

ORIGINS

- Cosmology and Galaxy Evolution
  - Galaxies, Dark Energy and Dark Matter
- Probing the Dark Ages
  - When & how were the first stars formed?
- Cradle of Life
  - What are the conditions for life and where can it be found?

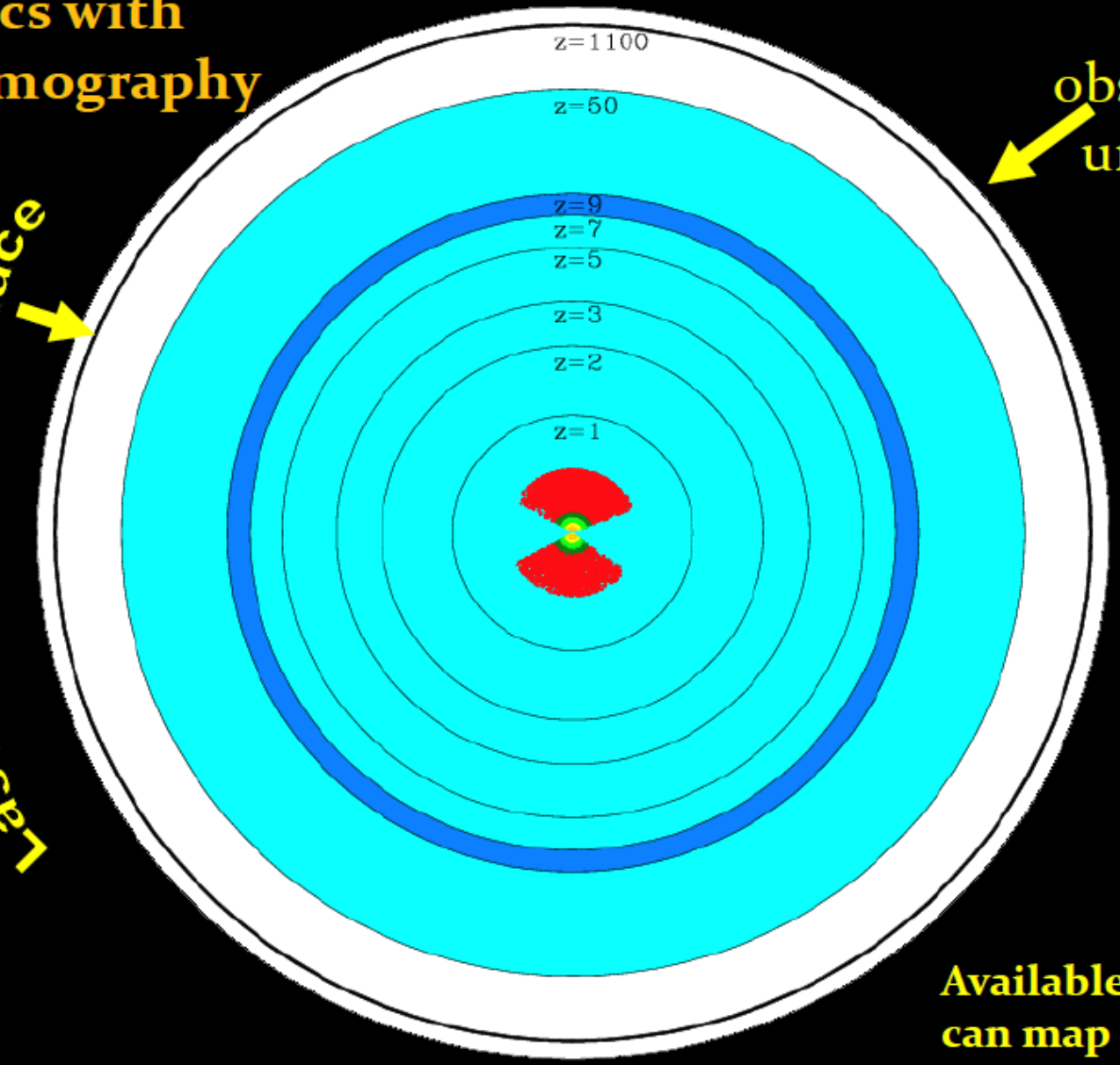
FUNDAMENTAL FORCES

- Strong-field tests of General Relativity
  - Was Einstein correct?
- Origin & Evolution of Cosmic Magnetism
  - Where does magnetism come from?

plus The Exploration of the Unknown as an underlying philosophy for design & costing

SKA与宇宙学

Physics with
21cm tomography

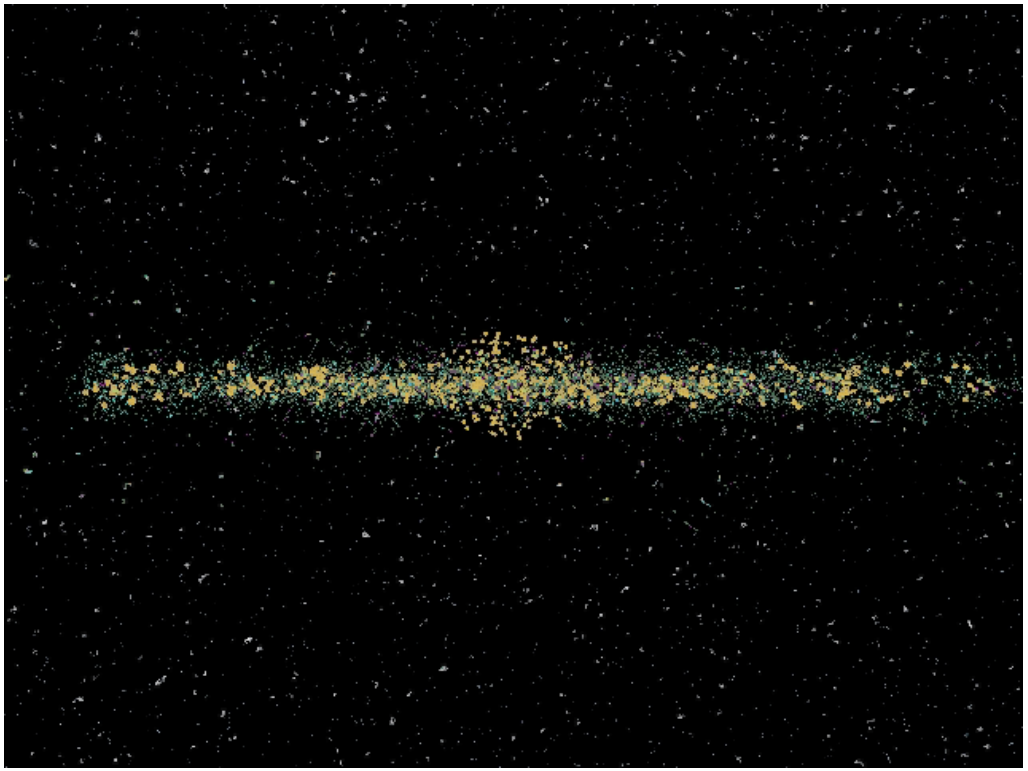


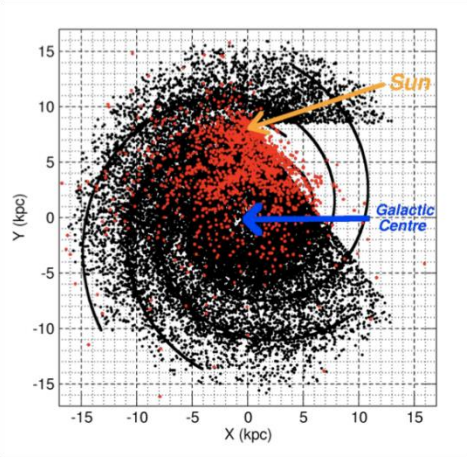
Red - SDSS

Available space in blue – can map most of our Observable Universe!

脉冲星与引力：利用SKA搜寻脉冲星

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





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

- Timing precision is expected to increase by factor ~100
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Direct detection of gravitational waves passing through the Galaxy**

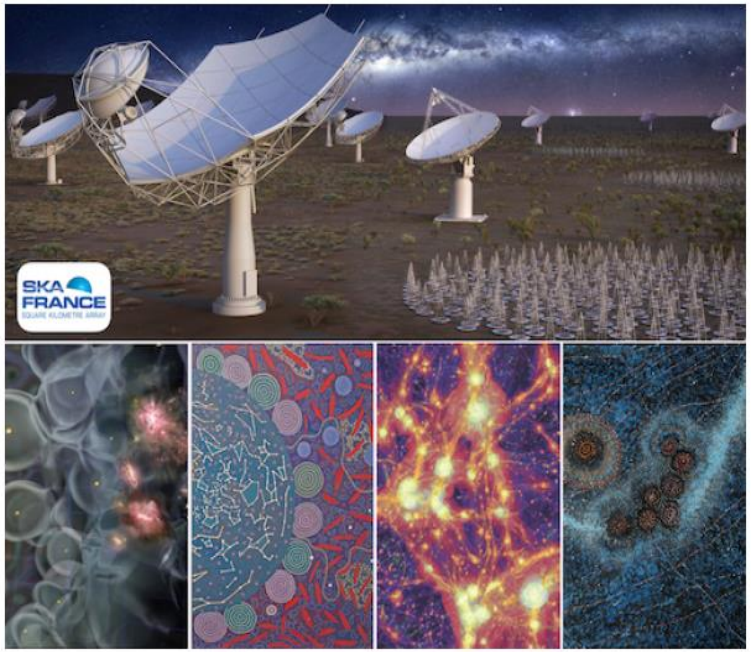
Establishment of the SKA Orgranisation (November 2011, Rome)

- China and France
  - among the 9 countries that established the SKA Organisation
- France quit the SKA in 2012, due to financial reasons
- France is coming back to SKA

Both China and France have published SKA Science Books

French SKA White Book

The French community towards the Square Kilometre Array



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中国 SKA 科学白皮书

SKA
SQUARE KILOMETRE ARRAY
中 国 China

中国 SKA 科学团队

武向平 主编

2017 年 5 月

中国平方公里阵科学目标

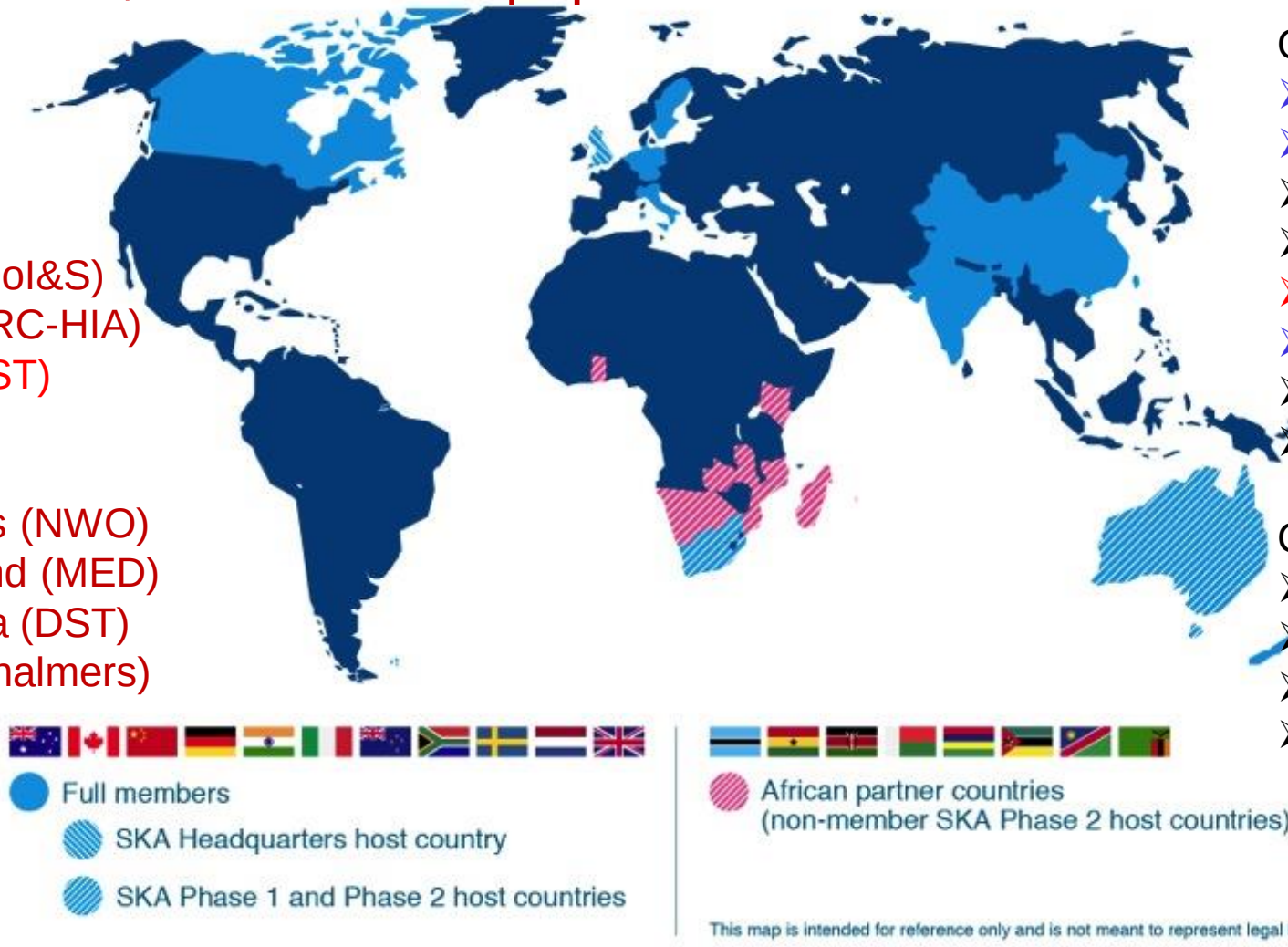
秦波　彭勃　/主编

北京大学出版社
PEKING UNIVERSITY PRESS

SKA Organisation: 10 Members + New

5 continents, 40% of world population

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



Observers:

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

Contacts:

- Brazil
- Ireland
- Russia
- Switzerland

	成员国	代表机构
	澳大利亚	Department of Industry
	南非	National Research Foundation
	加拿大	National Research Council
	中国	Ministry of Science and Technology
	意大利	National Institute for Astrophysics
	新西兰	Ministry of Economic Development
	瑞典	Onsala Space Observatory
	荷兰	Netherlands Organisation for Scientific Research
	印度	National Centre for Radio Astrophysics
	英国	STFC

- SKA now in Inter-Governmental Formal Negotiation (政府间正式谈判)
- SKAO will develop into an IGO (政府间国际组织), like CERN / ITER

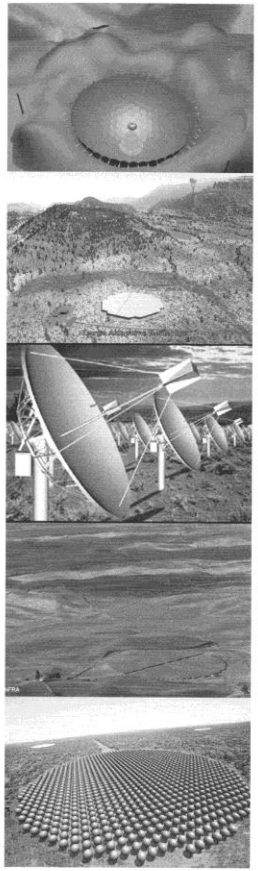
The Chinese Contribution to the SKA

- China is now an important/leading role in the SKA project, especially in the SKA construction

Very interestingly:

- France is now "leading" the **SKA Board of Directors**（SKA董事会） even though France is NOT a member of the SKA ! (Prof **Catherine Cesarsky** from Paris Observatory, is now **Chair of SKA Board of Directors**),

- **China was among the countries that initiated the SKA Idea (1993)**
- **China had been one of SKA's candidate site (before 2006)**



Options for the stations of the SKA, from the top:
A set of large (>300m) spherical reflectors;
A large (>200m) reflector with the receiver supported by an aerostat;
An array of small (<10m) parabolic dishes;
A fixed planar (electronically phased) array;
An array of spherical (>10m) refracting lenses.

Astronomers Sign International Agreement to Plan Square Kilometre Array

Leading astronomers from Europe, North America, Asia and Australia will today sign an agreement jointly to plan a huge new radio telescope, the Square Kilometre Array (SKA), which will come into operation in the middle of the next decade. The General Assembly is an ideal opportunity to inaugurate the next stage of development of this truly global project.

The signing ceremony will take place at 17:30hrs in the Bragg Lecture Theatre in the Schuster Building at the end of the joint session on 'Future Observational Multi-Wavelength capabilities in Astrophysics' organized by the Working Group on Future Large Scale Facilities (WGFLSF) and IAU Division XI (Space and High Energy Astrophysics). The last part of the programme is a round-table discussion about the process of international co-operation and coordination.

Radio astronomers regard the SKA as a paradigm for the organization of future global astronomy projects. The SKA was the first radio astronomy project to have been 'born global' following the guidelines for successful international collaboration discussed at the 1994 IAU General Assembly in The Hague. The current concept has grown out of discussions over the past six years within the URSI/IAU Large Telescope Working Group and the OECD Global Science Forum. An International SKA Steering Committee (ISSC) has now been constituted to promote and to oversee the planning of the project. The signing of a formal Memorandum of Understanding will establish the ISSC for a period of five years. The signatories will be:

Prof. Ron Ekers: Australian SKA consortium
Dr. Don Morton: Herzberg Institute of Astrophysics, Canada
Prof. Ai Guoxiang: National Astronomical Observatory, PR China
Prof. Rajaram Nityananda: National Centre for Radioastrophysics, TIFR, India
Prof. Harvey Butcher: European SKA
Dr. Jill Tarter: United States SKA Consortium

At present 24 leading institutions in ten countries have agreed to pool their research and development efforts, with each individual institution concentrating on only a part of the overall design. Their shared aim is to reach agreement on the fundamental design of the SKA by 2005 and to begin construction in 2010.

In order to achieve its ambitious astronomical goals, the design of the SKA will integrate computing hardware and software on a massive scale in a revolutionary break from current radio telescope designs. The SKA is a challenging project, and as Ron Ekers of the Australia Telescope National Facility says:

"Designing, let alone building, such an enormous technologically-advanced instrument is beyond the scope of individual nations, or even small groups of nations. The SKA is therefore being planned from the outset as a truly-global telescope project."

The SKA will be a uniquely sensitive instrument. Its collecting area will be 50 to 100 times larger than today's biggest radio imaging telescopes, the VLA and the GMRT, and 200 times larger than the pioneering Lovell Telescope at Manchester University's Jodrell Bank Observatory (which can be visited during the General Assembly).

The idea of the SKA sprang from radio astronomers' desire to detect the faint 21-cm emission from atomic hydrogen in structures formed soon after the Big Bang, and in the galaxies which developed from these structures. As ISSC member Peter Wilkinson (University of Manchester) says:

"One square kilometre is not just a convenient round number—it arises naturally from a desire to image the hydrogen gas in distant galaxies with 0.1 arcsecond resolution".

Radio astronomy has been crucial in

Maxwell Telescope show that dust can even obscure entire galaxies at visible wavelengths. Radio telescopes have another advantage in that they can be combined in arrays to produce images with the highest resolution in all branches of astronomy. On completion the SKA will, therefore, be the world's premier instrument for astronomical

widely distributed during the General Assembly. The full current science case for the SKA, and an electronic version of the brochure can be obtained from the SKA Web site at http://www.ras.ucalgary.ca/SKA

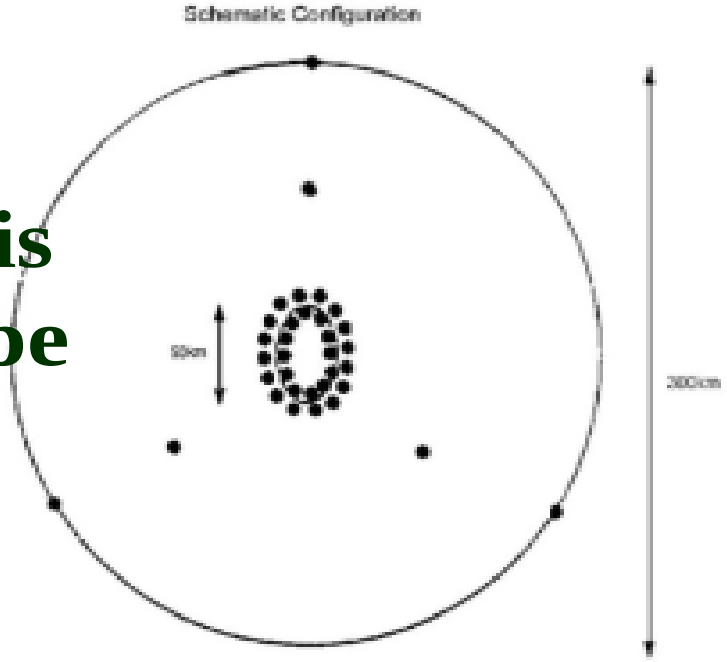
Peter N. Wilkinson
University of Manchester

(2000，ISSC)

The Chinese SKA Concept had been one of SKA's candidate design (before 2006)

- Chinese concept of the SKA -- KARST (1994) **Developed into China's FAST !**
  - KARST → FAST (500m Telescope)
  - Using FAST as basic component of the SKA
  - LDSN (Large Diameter Small Number)

Kilometre-square Area Radio Synthesis Telescope



FAST (500m Radio Telescope)

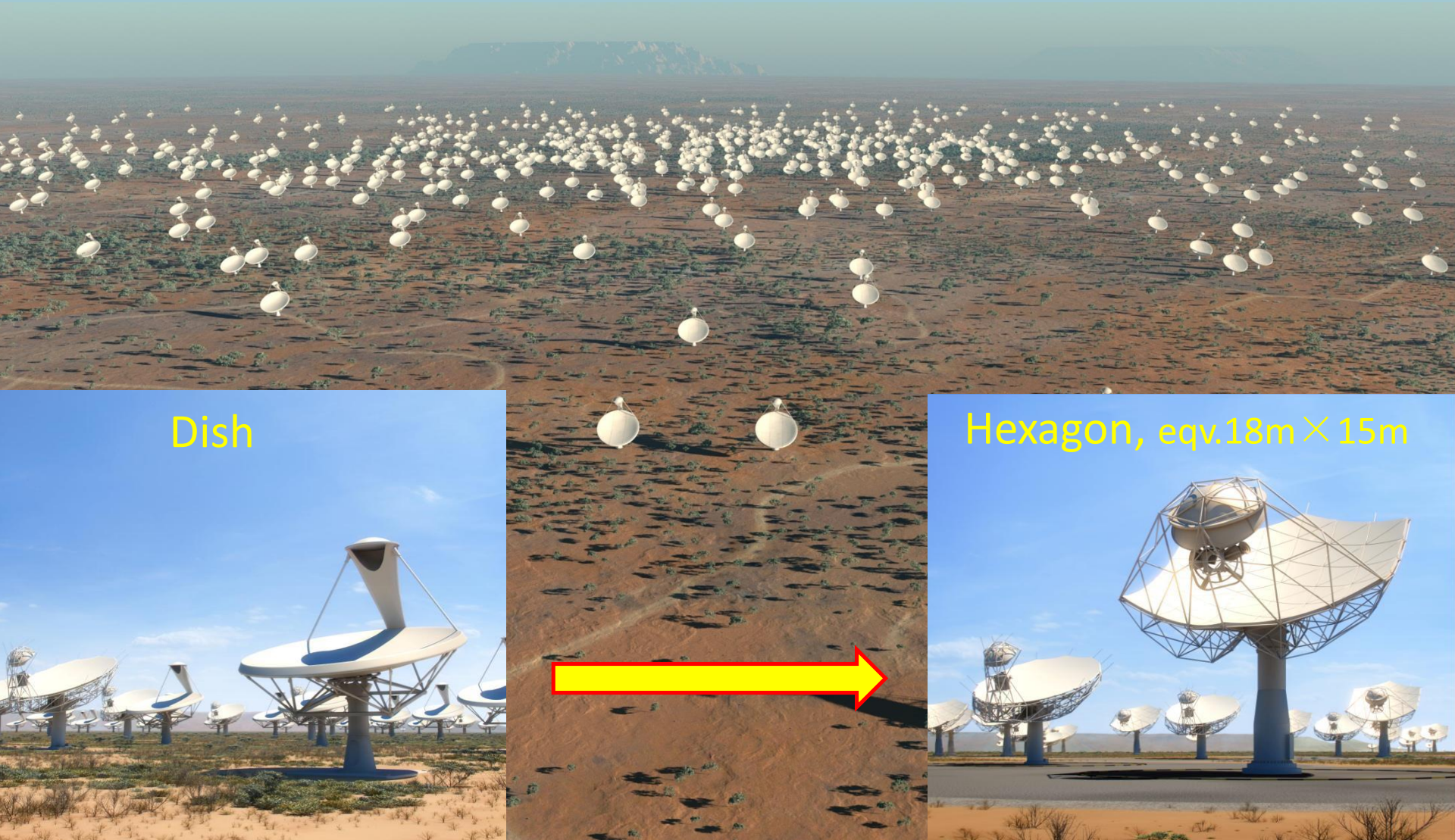
- FAST was indeed born from the Chinese SKA Concept

SKA1 Construction: China Joined 6 (of 11) Work Package Consortia

工作包名称	参与国际工作包联盟		
	国内参与单位	国际参与单位(国际牵头单位*)	中方已认领的任务
反射面天线 (Dish Array)	中电第54所 国家天文台	**Australia(CSIRO)*** Canada(NRC) China(CETC54/NAOC) Italy(INAF), South Africa(SKA SA) Sweden(Chalmer/Onsala) UK(STFC-RAL & Oxford) Germany(MPIFR)	1.天线结构 2.单像素馈源和低噪放大器-参与波段1，**牵头**波段4&5 3.**牵头**本地监控 4.**牵头**天线设计/样机验证
宽带单像素馈源 (WBSPF)	国家天文台 中电第54所	China(CETC54/NAOC) **Sweden(Chalmer/Onsala)*瑞典天文台**	**牵头**0.35-2GHz 宽带单像素馈源
低频孔径阵列 (LFAA)	中电38所	**荷兰Astron*** 联盟：Astron, Cambridge, ICRAR, INAF, Oxford, U.of Malta, Univ.of Manchester, JIVE	1.系统工程；2.天线与低噪声放大器；3.接收机；4.信号处理
中频孔径阵列 (MFAA)	中电38所	**荷兰Astron***联盟：Astron, Cambridge, Obs de Paris, Bordeaux 1, Oxford, Univ.of Manchester, RSA	1.系统工程；2.前端设计（前端：天线与低噪声放大器）；3.集成接收机；4.信号处理；5.陈列原型机
信号数据传输 (SADT)	北大、清华	**曼彻斯特大学***、英国NPL、澳大利亚NTFN、JIVE	同步与授时
科学数据处理 (SDP)	上交、清华、复旦、国台、浪潮、NDSC、中电32所、国家超级计算天津中心	**英国剑桥大学***，还有澳洲、加拿大和南非等单位	委派赵蒙加入System Engineering Team；参与Project Management, Computing Platform, Data Layer, & Local Monitor & Contro等任务的开发（计划）

China's leading role in SKA1 construction

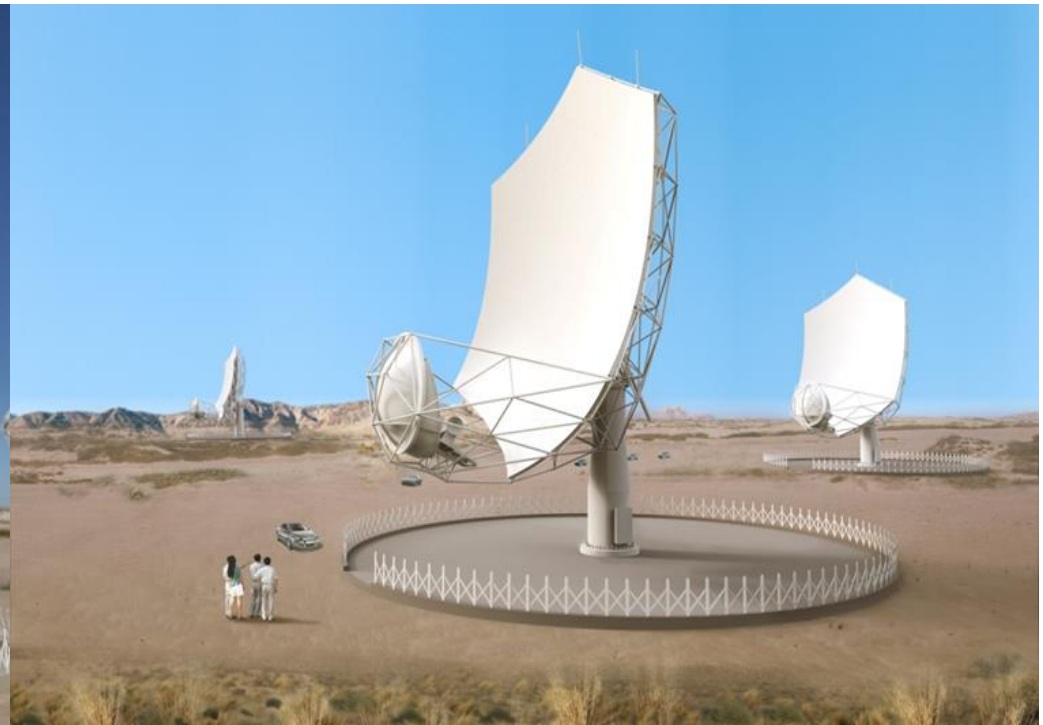
- Chinese Design is now the **Only Candidate** for the Dish Array Consortium
- China is Chair of the Dish Consortium



Advantages of Chinese Design:

- Higer precision of dish surface (0.5mm)
- Lighter (35tons, 50% lighter than conv.)
- Lower power consumption
- Lower costs
- Much easier to install
- Much easier to produce & transport in large quantities

- 空间网架支撑金属分块面板反射体方案(PSM)
  - ✓ 高反射面精度(0.5mm)
  - ✓ 轻重量（约35吨，常规天线重量一半）
  - ✓ 低功耗
  - ✓ 低成本
  - ✓ 易安装
  - ✓ 易于运输和批量生产
- 全数字高精度伺服驱动控制
  - ✓ 高指向精度(千分之三度)
- 高电磁屏蔽天线座架设计
  - ✓ 高磁屏蔽性(80dB)



e.g. Dish Array

China built all the 36 antennas of ASKAP (Australian SKA Pathfinder) (CETC-54)

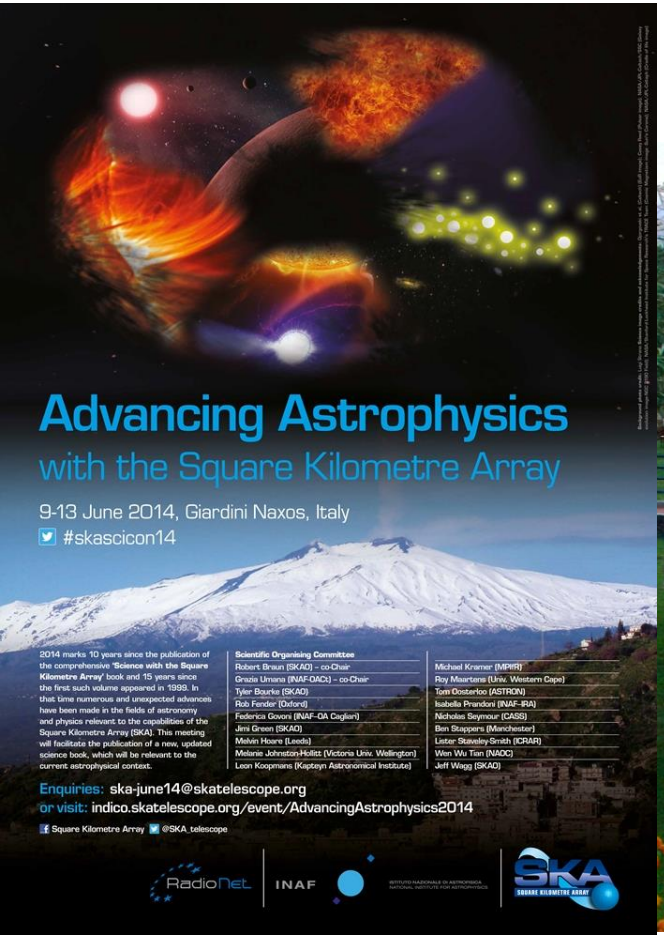
The 24th Tower was named “Janimaarnu” (Chinese) to memorize Chinese contribution

International SKA Science Book

~40 Chinese researchers contributed.

of the total 131 chapters， 25 have Chinese participations (19%)

7 lead-author chapters (5.3%）



SKA in China: Preparing for the SKA

- China was an initial member that established the SKAO (2011)
- China State Council approved China's joining the SKA preconstruction

  国务院批准中国参加SKA建设准备阶段（2012.09）
- MOST is representing China at the SKAO (2012) 科技部代表中国参加SKA
- SKA LoI signed by MOST, Deputy Minister Cao Jianlin (2015)
- China State Council listed SKA into China's 13th 5-year Plan (2016.08)

  国务院将SKA列入十三五规划
- Next Step: Approval of SKA Obs. Convention, and SKA1 construction

- Strong will to build SKA China/East Asia Regional Center
  (SKA listed in Shanghai City's 13th 5-Year Plan)
- Funding: 150M RMB allocated to Science and Industry

China State Council has listed SKA in the "13th 5-Year Plan"

国务院印发的“十三五”国家科技创新规划

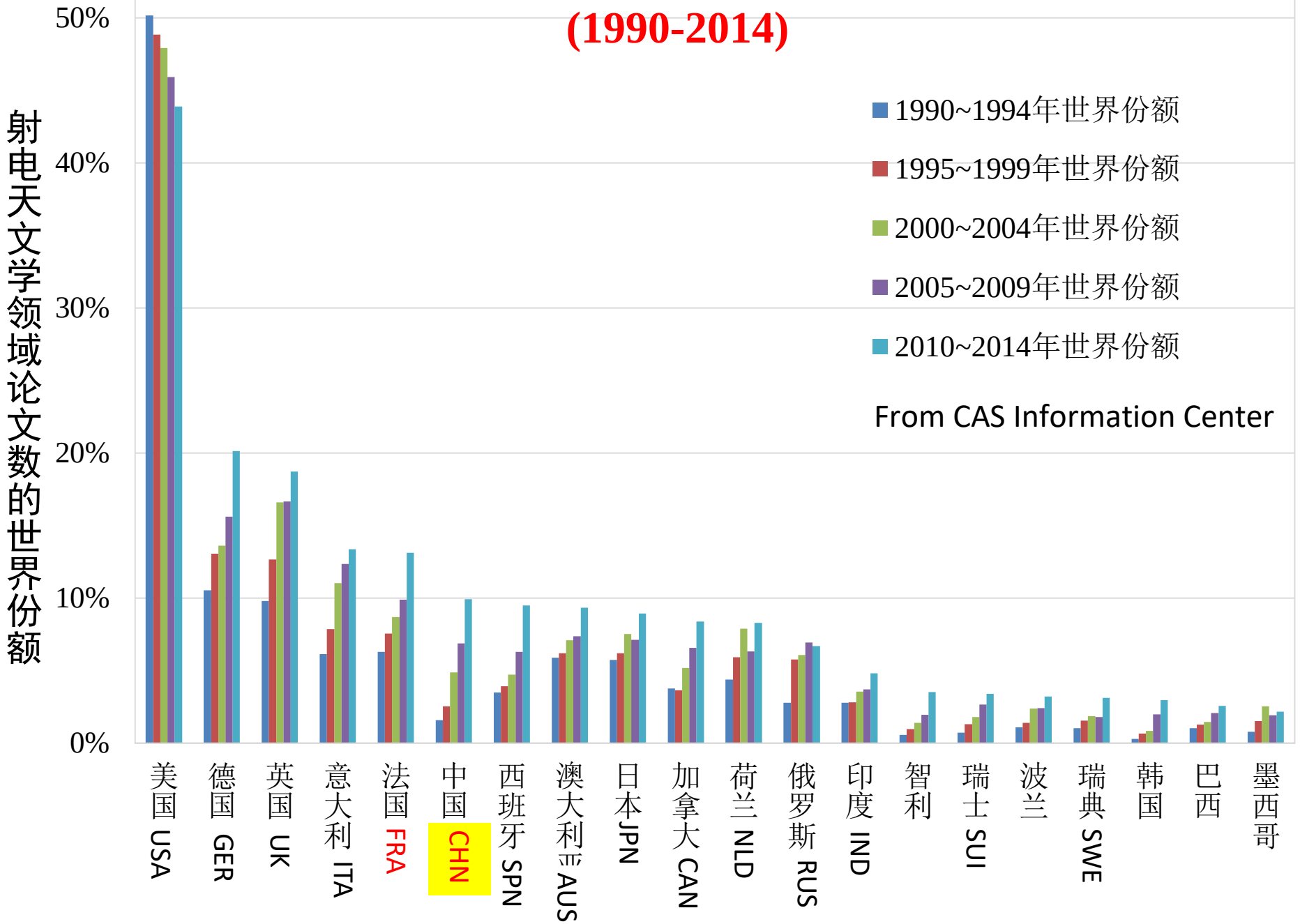
专栏22 国际大科学计划和大科学工程

1.国际热核聚变实验堆（ITER）计划。全面参与ITER计划国际组织管理，提升我国核聚变能源研发能力；以参加ITER计划为契机，带动更多国内相关机构参与国际研发，提升我国参与大科学工程项目管理的能力，树立我国参与国际大科学工程项目管理的典范。

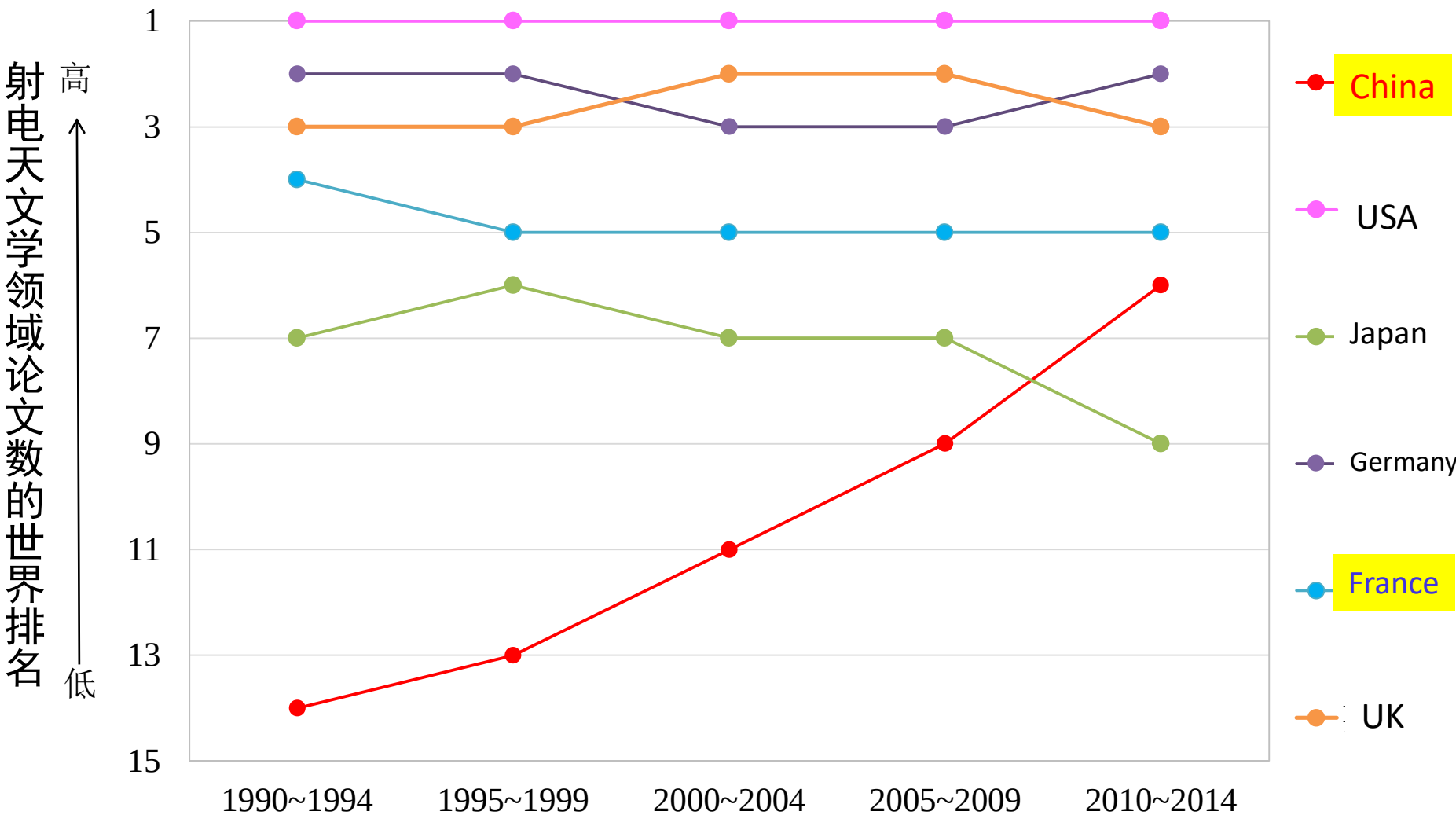
2.平方公里阵列射电望远镜（SKA）计划。积极参与SKA计划政府间正式谈判，继续深入参与SKA国际工作包研发并确保我国工业界在SKA-1建设中的优势地位，在国内部署开展科学预研及推动设立SKA-1专项。

3.地球观测组织（GEO）。构建综合地球观测领域全球合作体系，主导亚洲大洋洲区域全球综合地球观测系统（GEOSS）的建设，运行我国全球综合地球观测数据共享服务平台，向全球发布专题报告。选择“一带一路”区域开展遥感产品生产与示范应用。

Publications in Radio Astronomy: Top20 Countries (1990-2014)



Evolution of World Rankings: Radio Astronomy Publications (1990-2014)



Fast Growing Chinese Astronomy /Radio Astronomy !

International Collaborations: with UK:

China-UK Joint Agreement

（June 17, 2014, London）

十九、双方重视中英联合科学创新基金的作用，将推进卫生、环保科技、水和食品、城市化、能源和教育等六个优先发展领域的科研。双方肯定中英在科研领域的全球领先地位，强调向未来前沿技术研究大型设施投资的重要性。双方欢迎牛顿奖学金、博士伙伴关系、科技创新桥和气候科技伙伴关系等项目的启动。中方同意与英方共同推动“平方公里阵列射电望远镜”项目。

→ China agreed to work with the UK to push the SKA Project

International Collaborations: with Australia

Australia-China Consortium for Astrophysical Research (ACAMAR)

Established Sept 12, 2015, Collaboration Areas：

- Antarctic Astronomy
- SKA Preconstruction
- FAST Receiver
- Australian SKA Precursors: ASKAP & MWA
- Gravitation Waves

Exchange Programs, Postdocs, Students, Scholars, Conferences & Workshops

Directors: Australia: Brian Schmidt (Nobel Laureate)

China: Lifan Wang (Purple Mt Obs)

International Collaborations: with South Africa:

SA Delegation visited CN, Oct 2015

National Meeting Nov 2015, on “CN-SA Collaboration on MeerKAT”

致我们终将迎来的新一代天文学家——

China SKA Training Platform
(中国SKA人才培养专项)

With UK (SKA Headquarter), and with Australia (SKA Site):

CN-UK / CN-AUS SKA Joint PhD and Postdoc Programme

Fully support 10 places per year

"3+2" – 3 years in China, 2 years overseas study

→ **Starting point only**
Starts small, will expand, +FR?

Chinese Support	UK top-ups (by STFC)
~1000 GBP/mon + airticket	250 GBP/mon + travel grant
Chinese Support	**Australian top-ups**
1700 AUD/mon + airticket	5000 AUD p.a. + research grant

15 students already funded by the programme,

some have done excellent research in UK/Australia