French SKA White Book

The French community towards the Square Kilometre Array

Editor in Chief:
C. Ferrari

Editors:
G. Lagache, J.-M. Martin, B. Semelin — Cosmology and Extra-galactic astronomy
M. Alves, K. Ferrière, M.-A. Miville-Deschenes, L. Montier — Galactic Astronomy
E. Josselin, N. Vilmer, P. Zarka — Planets, Sun, Stars and Civilizations
S. Corbel, S. Vergani — Transient Universe
S. Lambert, G. Theureau — Fundamental Physics
S. Bosse, A. Ferrari, S. Gauffre — Technological Developments
G. Marquette — Industrial Perspectives and Solutions

Presented by
Steve Torchinsky
satorchi@apc.in2p3.fr

SKA France Whitebook

- Co-authors
- History of SKA in France
- SKA coordination in France (*Maison SKA France*)
- Science topics in France
- Topics of interest at IN2P3
  - Gravitational waves
  - High energy cosmic rays
  - Dark energy (Baryon Acoustic Oscillations)
  - Neutrino Mass

France SKA Whitebook contributors

- arXiv:1712.06950
- 178 co-authors from ~40 labs
- 25 co-authors from IN2P3
- Including 9 from APC


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G. Marquette — Industrial Perspectives and Solutions

IN2P3 co-authors

IN2P3 labs (not APC)

- **Reza ANSARI, LAL**
- Anabella ARAUDO, LUPM
- Maria Grazia BERNARDINI, LUPM
- Matteo CERRUT, LPNHE
- Johann COHEN-TANUGI, LUPM
- Barbara COMIS, LPSC
- Richard DALLIER, SUBATECH
- Anthea F. FANTINA, GANIL
- Eric JOSSELIN, LUPM
- Marianne LEMOINE-GOUMARD, CENBG
- Juan MACIAS-PEREZ, LPSC
- Alexandre MARCOWITH, LUPM
- Jérôme MARGUERON, IPNL
- Lilian MARTIN, SUBATECH
- Matthieu RENAUD, LUPM
- Benoît REVENU, SUBATECH

APC

- Begoña ASCASO (Cosmologie)
- Stanislav BABAK (Gravitation)
- Andrea BRACCO (Cosmologie)
- Martin BUCHER (Cosmologie)
- Eric CHASSANDE-MOTTIN (Gravitation)
- Arache DJANNATI-ATAÏ (Haute Energie)
- Cyril LACHAUD (Haute Energie)
- Antoine PETITEAU (Gravitation)
- Stephen TORCHINSKY (Cosmologie)

History of SKA in France

- 1966 Jean Heidmann
- 1993 URSI Large Telescope Working group
- 2000 IAU SKA working group
- 2005 - 2009 SKADS
- 2010 – 2011 PrepSKA
- 2012 – SKA Org (France does not join)

France SKA Whitebook, Section 4.2.1, Torchinsky, van Driel

Heidmann 1966

CENT FOIS NANÇAY ?

par J. HEIDMANN

(Observatoire de Meudon)

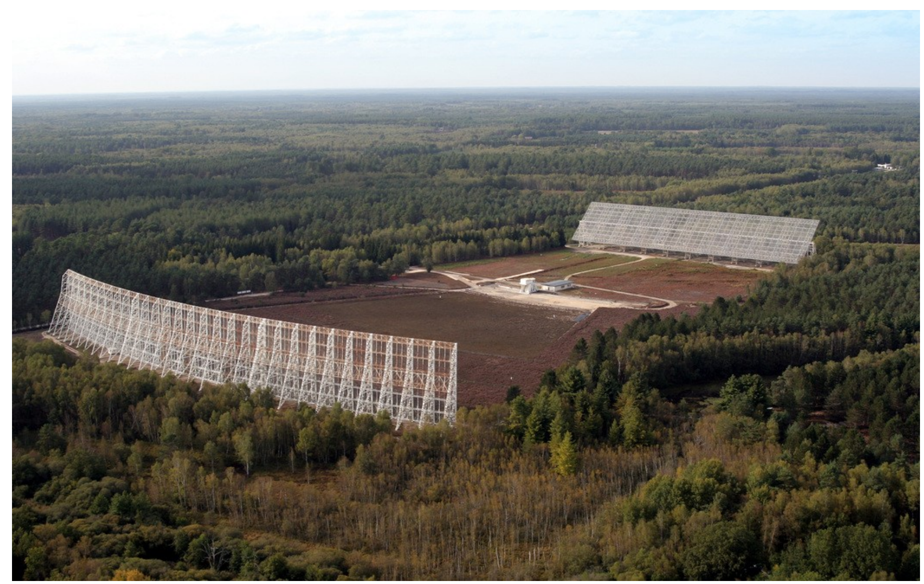
Le film qui vient d'être projeté a été terminé l'été dernier (1). Depuis, le grand radiotélescope de Nançay s'anime peu à peu. En 1966 il prendra progressivement sa pleine puissance. Sa portée sera énorme et le classera deuxième au monde, après l'interféromètre à synthèse d'ouverture de Cambridge, instrument très spécialisé mais rapidement construit ; le télescope de Nançay pourra observer des *quasars* paraissant s'éloigner de nous à dix fois la vitesse de la lumière. Selon le modèle d'univers d'Einstein-de Sitter, ces astres seront vus dans l'état où ils étaient 200 millions d'années seulement après le « gros boum » marquant le début de l'expansion (2).

Cet appareil étant près d'entrer en exploitation, on doit déjà envisager l'avenir. A ce propos, posons nous une question bien simple et essayons d'y répondre objectivement : quelle serait la situation si nous disposions d'un réflecteur de même qualité que celui de Nançay, mais ayant cent fois sa surface ?

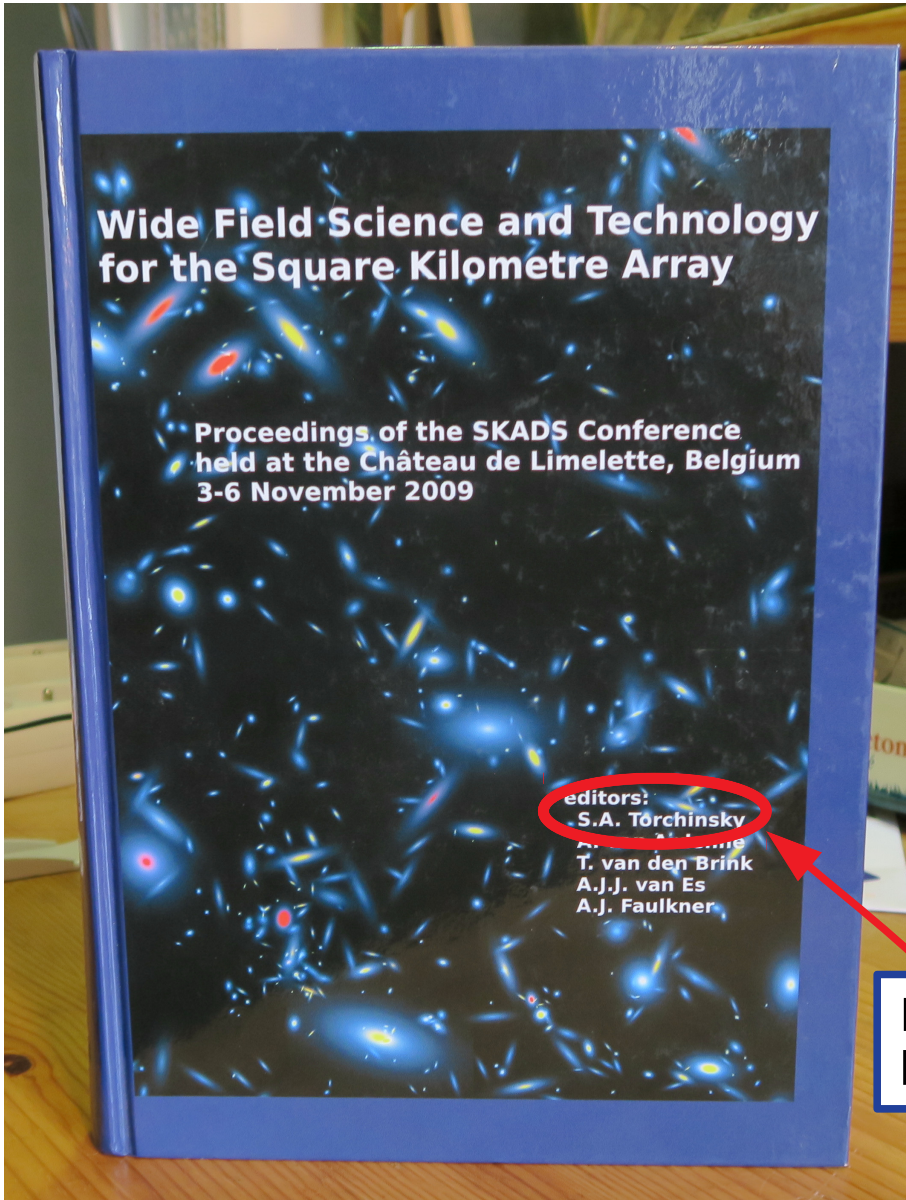
Son pouvoir séparateur serait tellement fin, et sa puissance de captation serait si grande, qu'il pourrait observer effectivement, parmi la multitude d'astres parsemant la voûte céleste, 10 000 000 d'entre eux.

1966, L'Astronomie, Vol. 80, p.157

- 100x Nançay ~700 000 m^2
- Survey of 10^7 extragalactic objects
- Understand the evolution of Cosmology



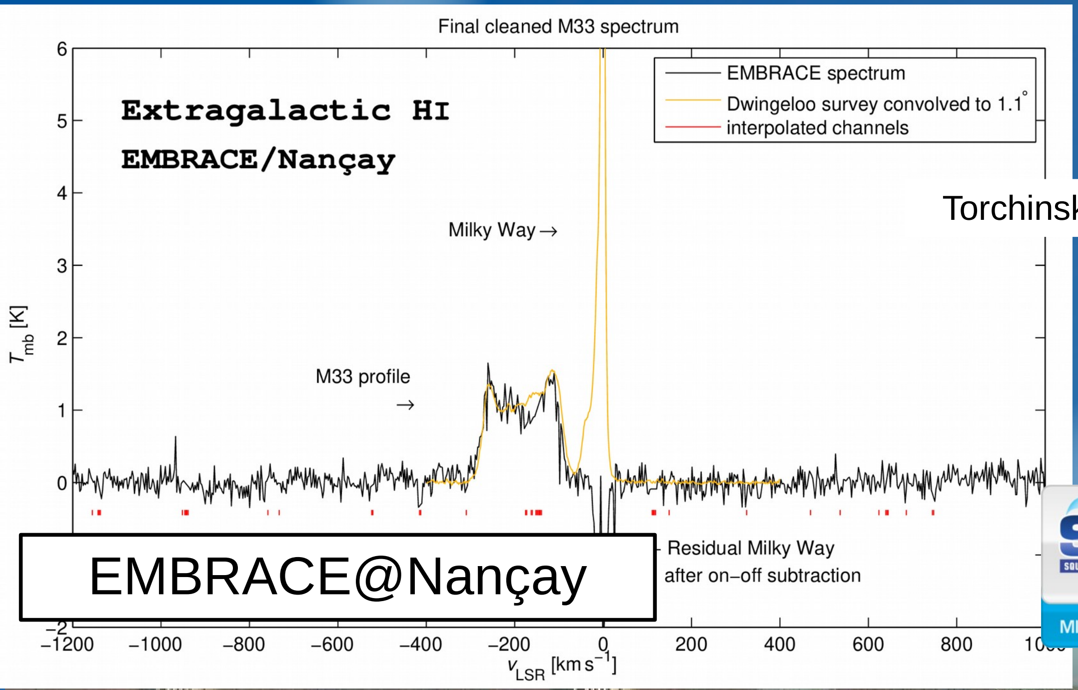
SKADS 2005-2009



- European Commission Framework Programme 6
- French participation in:
  - Management Team (Project Scientist)
  - Board of directors
  - R&D (integrated beam former chip)
  - Prototype instrument (EMBRACE)
  - Science simulations
- Emphasis on the Dense Aperture Array

Proceedings of Science
https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=132

Mid Frequency Aperture Array

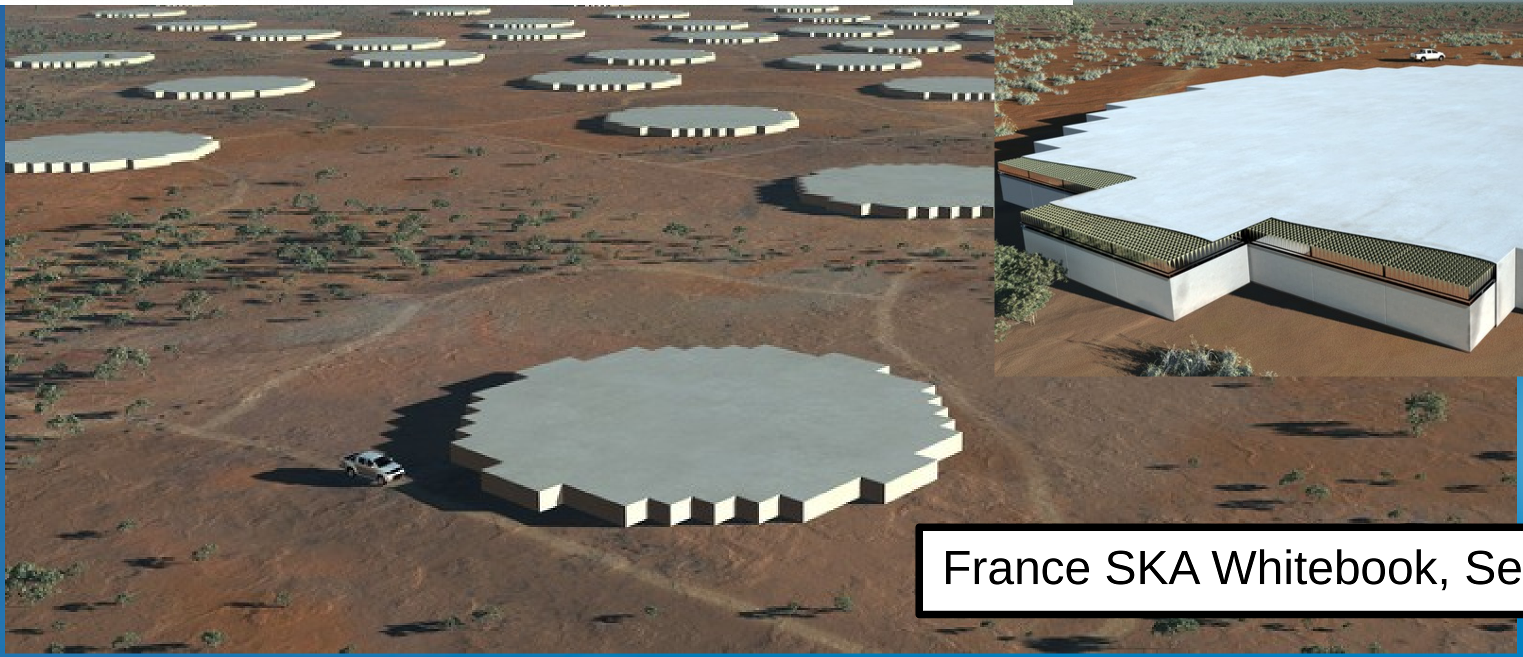


EMBRACE@Nançay

Torchinsky et al, 2016, A&A, 589, A77

SKA SQUARE KILOMETRE ARRAY

MID-FREQUENCY APERTURE ARRAY



France SKA Whitebook, Section 4.1.2, Torchinsky

Maison SKA France

- 2016: SKA France
  - Members:
    - CNRS/INSU
    - Obs de Paris
    - OCA
    - U. Bordeaux
    - U. Orléans
  - Coordinator: Chiara Ferrari (OCA)
  - INSU:
    - chargé de mission SKA: Michel Pérault
    - liaison avec industrie: Gabriel Marquette
    - Action Spécifique SKA-LOFAR: Stéphane Corbel
  - Obs de Paris
    - Coordinator: Fabienne Casoli

- 2017: Maison SKA France
  - "SKA France Coordination" + Industry
  - Director: Chiara Ferrari (OCA)
  - Industry partners:
    - Air Liquide
    - Ariane Group
    - ATOS
    - Callisto
    - CNIM
    - DDN Storage
    - ENGIE
    - FEDD
    - NVIDIA
    - TAS

https://ska-france.oca.eu

Infrastructure de Recherche

- SKA a été inscrit en tant que projet sur la Feuille de Route nationale des Très Grandes Infrastructures de Recherche, publiée le 17 mai dernier par le Ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation

LISTE DES INFRASTRUCTURES DE RECHERCHE DANS LE DOMAINE ASTRONOMIE ET ASTROPHYSIQUE

CATÉGORIE	NOM	NOM COMPLET	ESFRI
OI	ESO	European Southern Observatory	
	ESO ALMA	Atacama Large Millimeter/Submillimiter Array	
TGIR	CFHT	Canada-France-Hawaii Telescope	
TGIR	*CTA[1]*	*Cherenkov Telescope Array*	*CTA (2008)*
TGIR	IRAM	Institut de RadioAstronomie Millimétrique	
IR	CDS	Centre de Données astronomiques de Strasbourg	
TGIR	*EGO-VIRGO[2]*	*Observatoire Européen Gravitationnel – VIRGO/ European Gravitational Observatory – VIRGO*	
IR	*HESS[3]*	*High Energy Stereoscopic System*	
IR	*INSTRUM-ESO*	*Instrumentation pour les grands télescopes de l'ESO*	
IR	LOFAR FR-ILT	International Low Frequency Radio Array Telescope – LOFAR FR	
IR	*LSST[4]*	*Large Synoptic Survey Telescope*	
Projet	SKA	Square Kilometre Array	SKA (2006)

http://www.enseignementsup-recherche.gouv.fr/cid70554/la-feuille-de-route-nationale-des-infrastructures-de-recherche.html

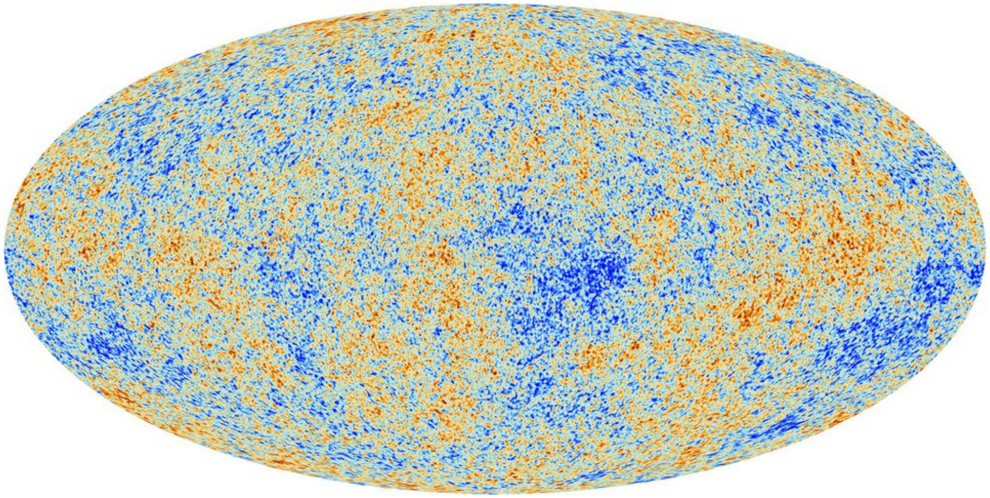
French SKA Involvement

- Science Working Groups
  - Members, core-group members, of nearly all SWG
- Low Frequency Aperture Array
  - Integrated beamformer chips (Nançay)
  - Signal processing (OCA)
- Mid Frequency Aperture Array
- Mid Frequency Dish Array
  - Wide band digital signal processors (Bordeaux)

SKA France Whitepaper Science Topics

- Early Universe, cosmology and large scale structure
  - EoR, Cosmic Magnetism, BAO (Dark Energy),…
- Extragalactic astronomy
- Galactic astronomy
- Planets, Sun, Stars and Civilizations
- Transient Universe
  - Accreting transients, Ultra Luminous X-ray sources, Gamma-ray bursts, High Mass X-ray Binaries, AGN, Supernovæ, Fast Radio Bursts, GW event follow-up, Neutron stars magnetosphere and wind, Cosmic rays
- Fundamental physics
  - Pulsar timing arrays as gravitational wave detectors
  - Binary pulsars as natural laboratories to test Gravitation theories
  - Neutron star equation of state

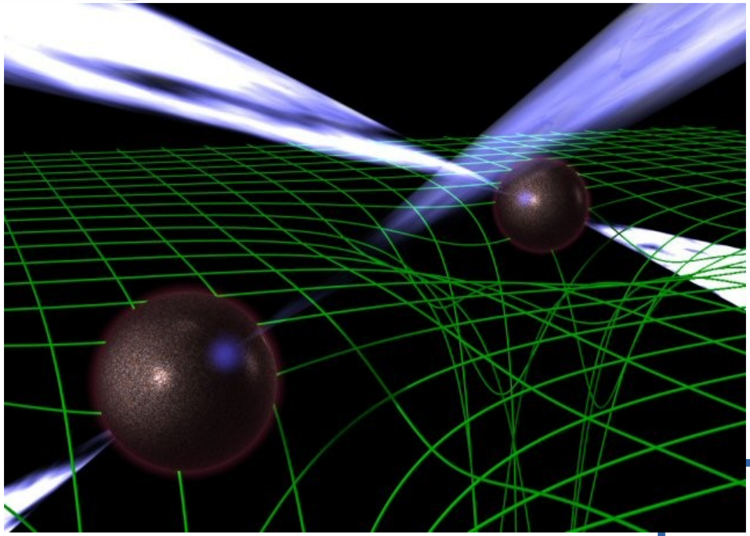
Intensity Mapping



- Make an image like this one of the CMB but of HI intensity
- Each frequency bin corresponds to a redshift range
- Don’t detect individual sources. Instead we measure the total HI in a volume (angular extent x depth given by frequency)

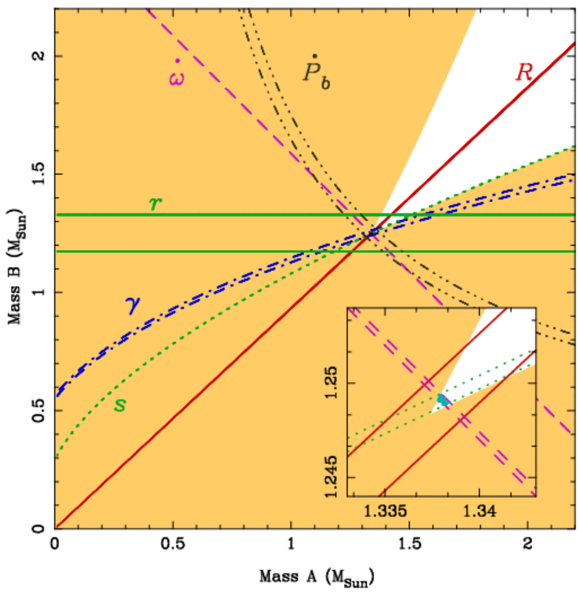
France SKA Whitebook, Section 2.1.7, Ansari, Torchinsky, Bucher, Magneville

Tests of Gravity with Pulsars

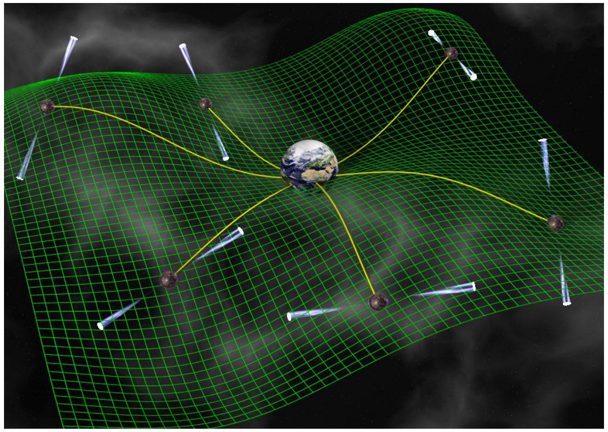


Relativistic effects measured by timing pulsar “clock” ticks permit (re) determination of binary masses.

France SKA Whitebook Section 2.6.2, Theureau, et al



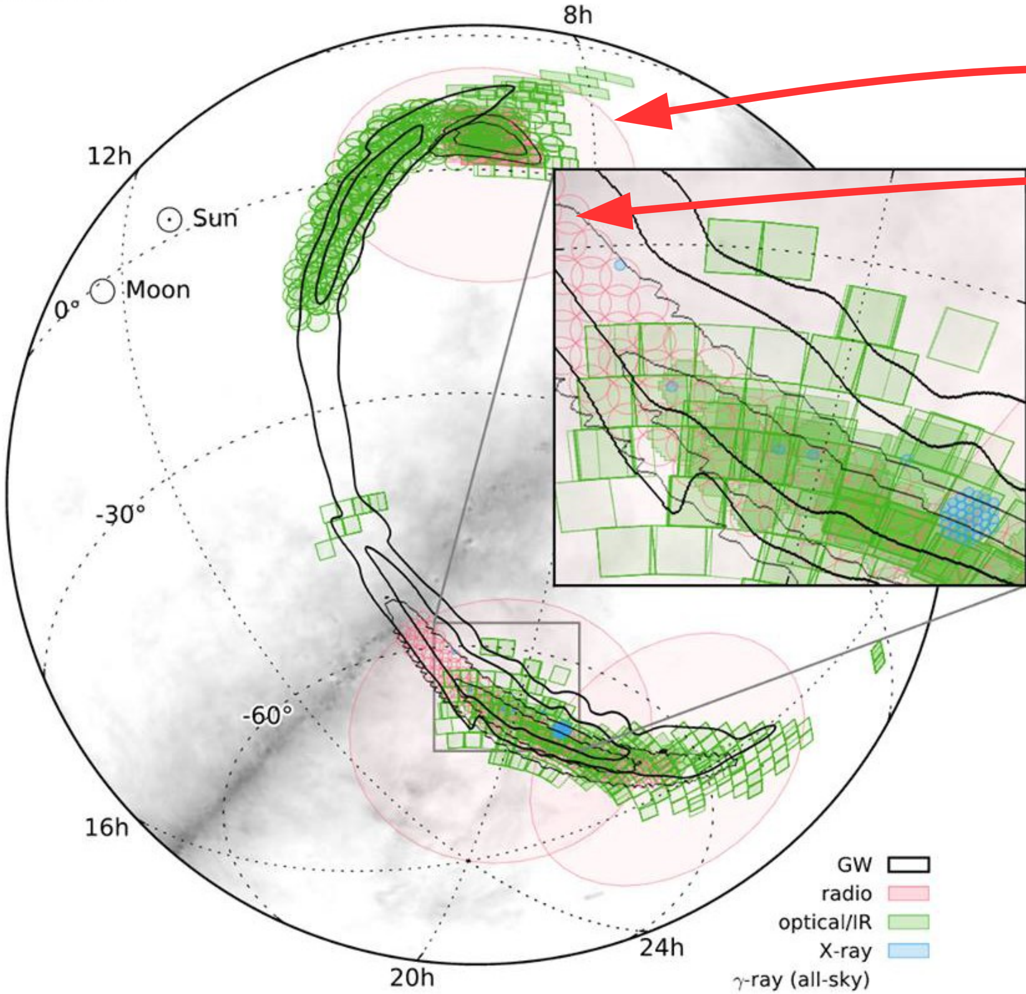
Pulsar timing array will detect Gravitational Waves of nHz (galactic length scale)



see for example, Desvignes et al 2016, MNRAS, 458, 3341

France SKA Whitebook Section 2.6.1, Theureau, Petiteau, et al

EM Follow-up LIGO/VIRGO Detections



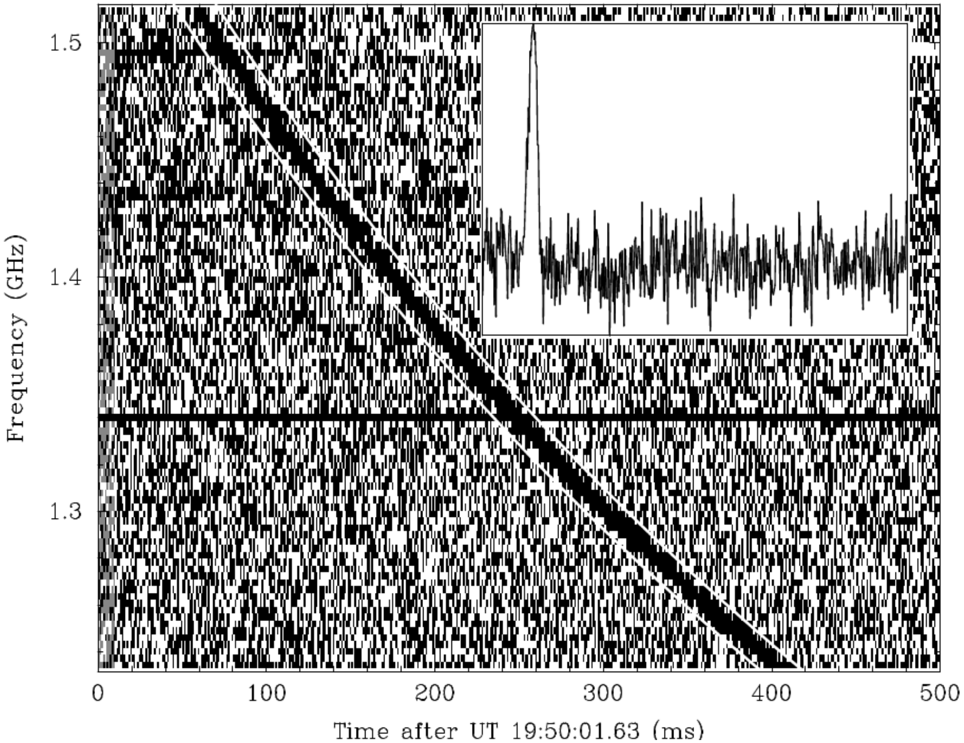
Radio follow-up by ASKAP, MWA, LOFAR, and Jansky VLA

Astrophysical Journal Letters, 826, L13. (2016)

Footprints of follow-up observations, showing radio fields shaded red, optical/infrared fields in green, and XRT fields as blue circles. The radio telescopes involved program (ASKAP, MWA, LOFAR and the VLA) have the capability to observe a wide range of frequencies with different levels of sensitivity, and a range of FOVs covering both the northern and southern skies.
Credit: LOCALIZATION AND BROADBAND FOLLOW-UP OF THE GRAVITATIONAL-WAVE TRANSIENT GW150914 (arXiv: 1602.08492v1)

France SKA Whitebook Section 3.9, Chassand-Mottin, et al

Fast Radio Bursts

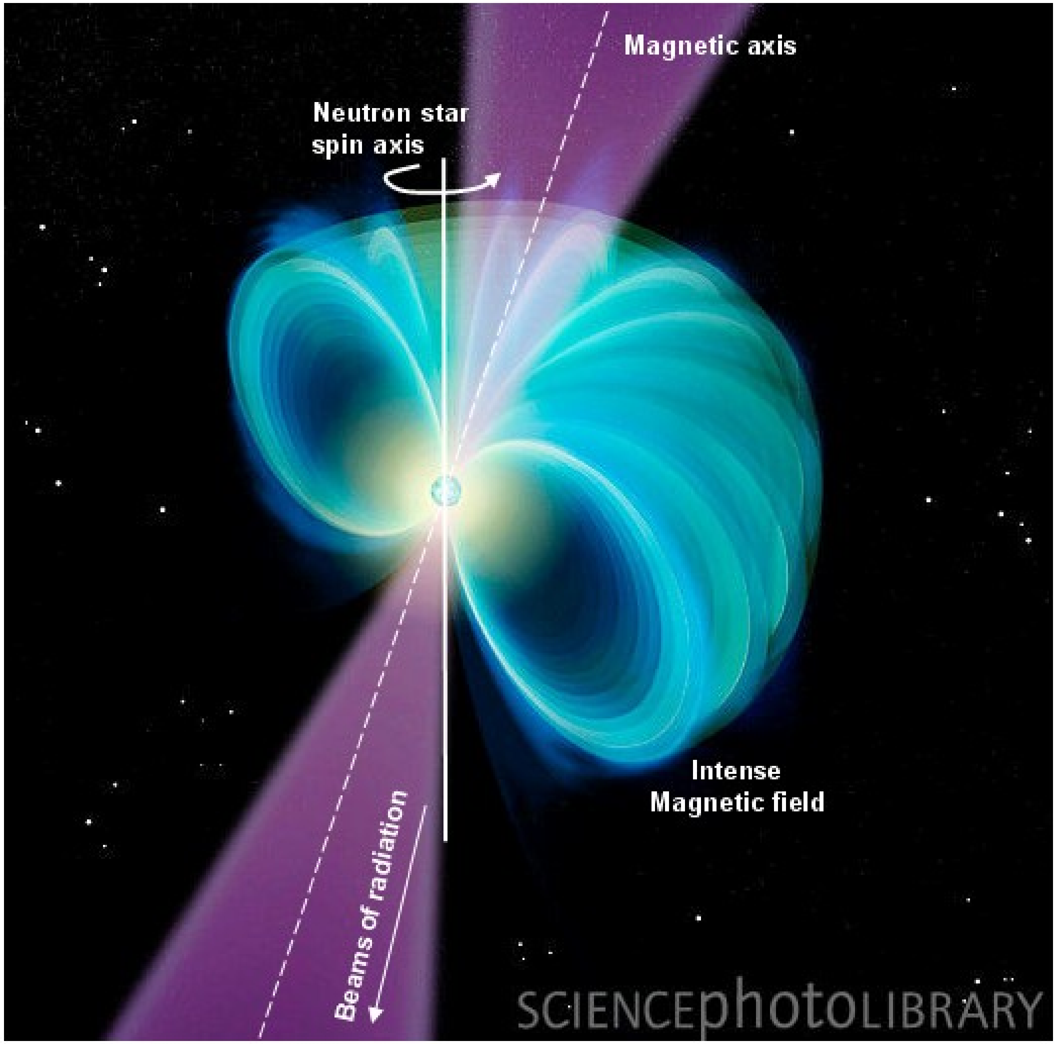


Lorimer et al, 2007, Science, 318, 777L

- Extremely energetic, extragalactic transient radio source
- 31 events known (as of March 2018)

France SKA Whitebook Section 2.5.2.2, “GW Event Follow-up,” Vergani, Chassande-Mottin

Pulsar Magnetospheres



- High energy emission
  - Gamma rays
  - Giant Radio Pulse

SKA France Whitebook, Section 2.5.2.3 “Neutron stars magnetosphere and wind,” Djannati, et al

SKA Topics of Interest at APC

- High Energy (pulsars, FRB, cosmic rays,...)
- Gravitational Waves (pulsar timing array)
- GW follow-up observations (LIGO/VIRGO)
- Strong Field Tests of Gravity (pulsar binary systems)
- Dark Energy (BAO and LSS)
- Neutrino Mass (from CMB and LSS)
  - Not mentioned in the SKA France Whitebook

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Steve Torchinsky
satorchi@apc.in2p3.fr

Organization of Research in France

- 3 principle research organizations
  - CNRS (National Scientific Research Council)
  - CEA (Atomic Energy Commission)
  - Universities including Obs de Paris
    (Ministry of Higher Education and Research)
    - Universities are also grouped together in federations, such as the Paris Science et Lettres University
- Each lab has multiple lines of management
  - We call it a “mixed” lab.
  - Each managing agency is called a “tutelle”
  - personnel payroll is divided amongst the “tutelles”
    - University faculty (professors, lecturers, some admin) paid by the University
    - Research Scientists and Research Engineers paid by CNRS or CEA
      - except at Obs de Paris where some Research Scientists and Research Engineers are paid by Obs de Paris
  - funding for travel, equipment, students, etc, can come from any or all of the tutelles
    - administration slightly different for each, and goes through different people
  - further funding can also come from external sources:
    - ANR: National Research Agency
    - European Commission
    - other programs

CNRS Organization

- Divided into 10 institutes
  - biology
  - chemistry
  - ecology
  - humanities
  - engineering
  - mathematics
  - physics
  - computing
  - Nuclear and Particle Physics (IN2P3)
  - Natural Science (Science of the Universe - INSU)

Cosmology is done here

examples: LAL, APC, GEPI

- LAL
  - CNRS/IN2P3
  - Université Paris-Sud

- GEPI
  - Obs de Paris (and Paris Science & Letters)
  - CNRS/INSU
  - Université Paris-Diderot

- APC
  - CNRS/IN2P3
  - Université Paris-Diderot
  - CEA
  - Obs de Paris (which is also a member of Paris Science & Letters)

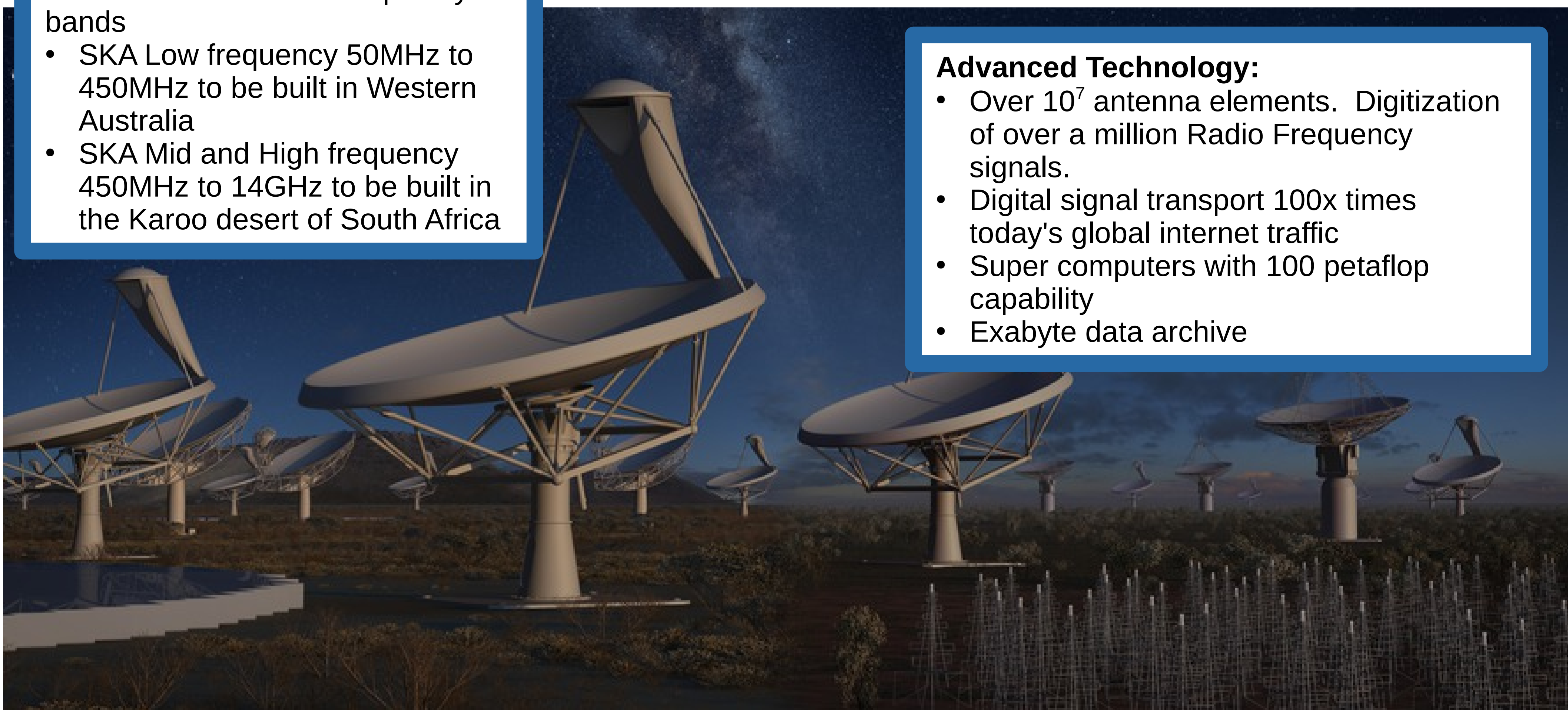
SKA Science

Fundamental Physics:

- The formation of large scale structure and the first luminous objects
- The distribution of mass in the Universe and the nature of the Dark Energy
- The origin of magnetic fields in the Universe
- The limits of General Relativity
- Gravitational Waves from black hole mergers and possibly from the Big Bang
- The formation of planetary systems and the detection of bio markers (pre-biotic molecules, artificially generated transmissions from ETI)
- Transient phenomena at very fast time scales (Bursts from Active Galactic Nuclei and others)

A square kilometre of collecting area for each of three frequency bands

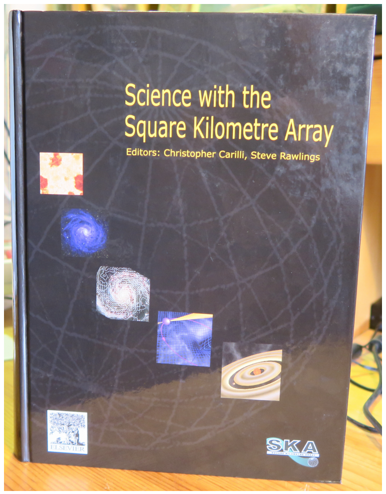
- SKA Low frequency 50MHz to 450MHz to be built in Western Australia
- SKA Mid and High frequency 450MHz to 14GHz to be built in the Karoo desert of South Africa



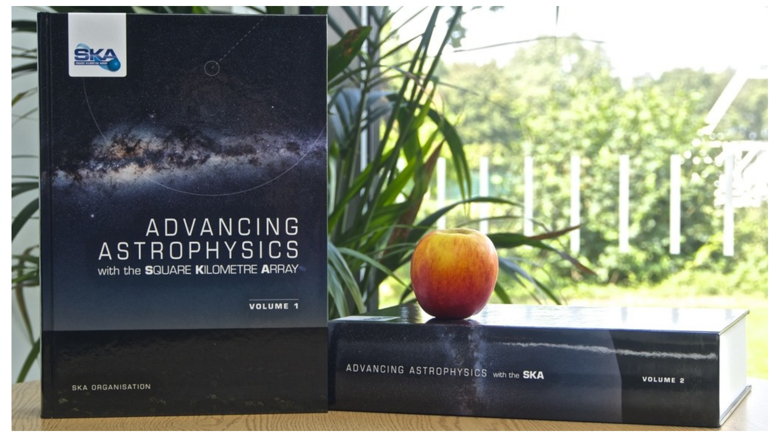
Advanced Technology:

- Over 10^7 antenna elements. Digitization of over a million Radio Frequency signals.
- Digital signal transport 100x times today's global internet traffic
- Super computers with 100 petaflop capability
- Exabyte data archive

SKA Science Books

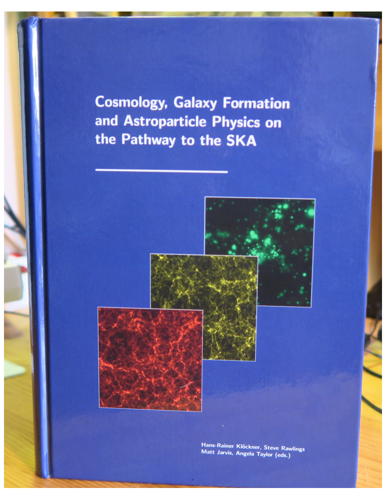


2004: New Astronomy Reviews
Carilli & Rawlings, eds.



2015, Advancing Astrophysics with the SKA
135 chapters, 1200 co-authors
Available at Proceedings of Science

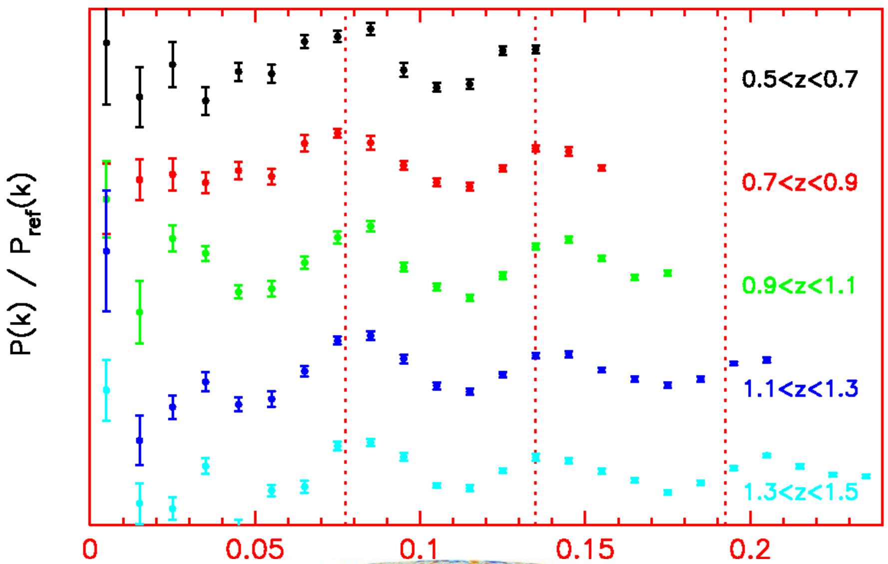
- https://www.skatelescope.org/news/ska-science-book/
- http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215



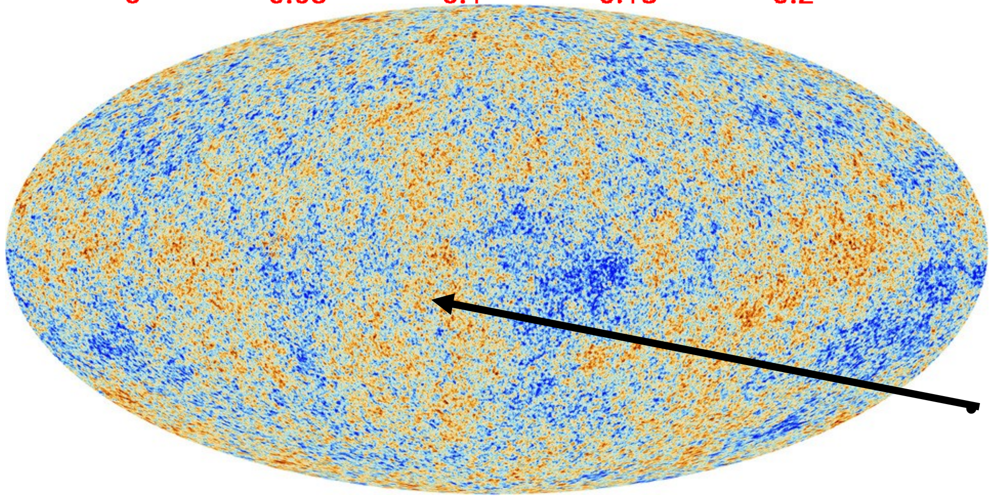
2006, Cosmology, Galaxy Formation, and Astroparticle Physics on the Pathway to SKA
Klockner, Rawlings, Jarvis, Taylor, eds.

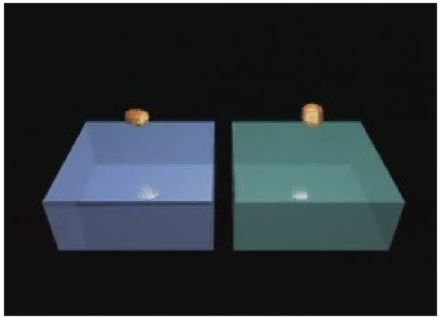
Dark Energy

Baryonic Acoustic Oscillations



BAO signature traces the length scale of the Universe at different epochs. This gives the evolution of Dark Energy and the Equation of State of the Universe.





There are fluctuations at all scales but there is a preferred scale of around 1 deg.

Neutrino Mass from LSS and CMB

Mon. Not. R. Astron. Soc. **381,** 1313–1328 (2007) doi:10.1111/j.1365-2966.2007.11919.x

Determining neutrino properties using future galaxy redshift surveys

F. B. Abdalla[1,2]★ and S. Rawlings[1]
[1]*Department of Physics, Oxford University, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH*
[2]*Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT*

Accepted 2007 April 25. Received 2007 April 24; in original form 2006 November 14

Abdalla & Rawlings, 2007, MNRAS, 381, 1313

ABSTRACT
Current measurements of the large-scale structure (LSS) of galaxies are able to place an $\sim$0.5 eV upper limit on the absolute mass scale of neutrinos. An order-of-magnitude improvement in raw sensitivity, together with an insensitivity to systematic effects, is needed to reach the lowest value allowed by particle physics experiments. We consider the prospects of determining both the neutrino mass scale and the number of massive neutrinos using future redshift surveys, specifically those undertaken with the Square Kilometre Array (SKA), with and without additional constraints from the upcoming *Planck* cosmic microwave background (CMB) experiment. If the sum of the neutrino masses $\sum m_i \gtrsim 0.25$ eV then the imprint of neutrinos on LSS should be enough, on its own, to establish the neutrino mass scale and, considered alongside CMB constraints, it will also determine the number of massive neutrinos N_ν, and hence the mass hierarchy. If $\sum m_i \sim 0.05$ eV, at the bottom end of the allowed range, then a combination of LSS, CMB and particle physics constraints should be able to determine $\sum m_i$, N_ν and the hierarchy. If $\sum m_i$ is in the specific range 0.1–0.25 eV, then a combination of LSS, CMB and particle physics experiments should determine $\sum m_i$, but not N_ν or the hierarchy. Once an SKA-like LSS survey is available there are good prospects of obtaining a full understanding of the conventional neutrino sector, and a chance of finding evidence for sterile neutrinos.

Key words: neutrinos – surveys – cosmic microwave background – cosmological parameters – large-scale structure of Universe.

Neutrinos slow the growth of structure

VOLUME 80, NUMBER 24 PHYSICAL REVIEW LETTERS 15 JUNE 1998

Weighing Neutrinos with Galaxy Surveys

Wayne Hu, Daniel J. Eisenstein, and Max Tegmark

Institute for Advanced Study, School of Natural Sciences, Princeton, New Jersey 08540

(Received 3 December 1997; revised manuscript received 13 March 1998)

We show that galaxy redshift surveys sensitively probe the neutrino mass, with eV mass neutrinos suppressing power by a factor of 2. The Sloan Digital Sky Survey can potentially detect N nearly degenerate massive neutrino species with mass $m_\nu \gtrsim 0.65(\Omega_m h^2/0.1N)^{0.8}$ eV at better than 2σ once microwave background experiments measure two other cosmological parameters. Significant overlap exists between this region and that implied by the Liquid Scintillator Neutrino Detector experiment, and even $m_\nu \sim 0.01-0.1$ eV, as implied by the atmospheric anomaly, can affect cosmological measurements. [S0031-9007(98)06410-2]

Hu, et al, 1998, Phys. Rev. L., 80, 5255

“Growth of fluctuations is suppressed on all scales below the horizon when the neutrinos become non-relativistic”

LSS damping by Neutrinos

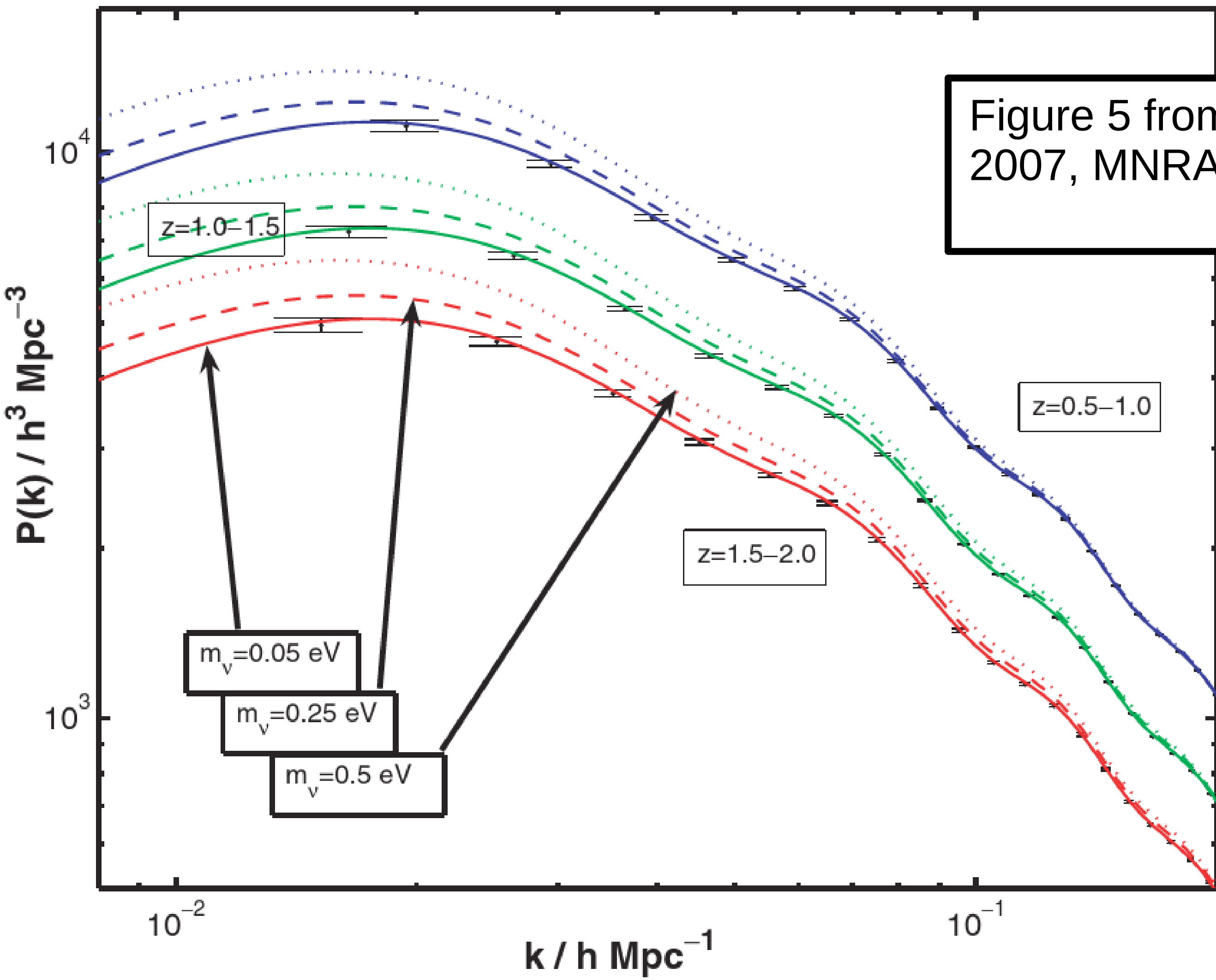


Figure 5 from Abdalla & Rawlings, 2007, MNRAS, 318, 1313

Small error bars because of the large redshift and sky coverage provided by SKA. Also, high accuracy spectroscopic redshifts and angular positions of SKA.

Combined CMB and LSS

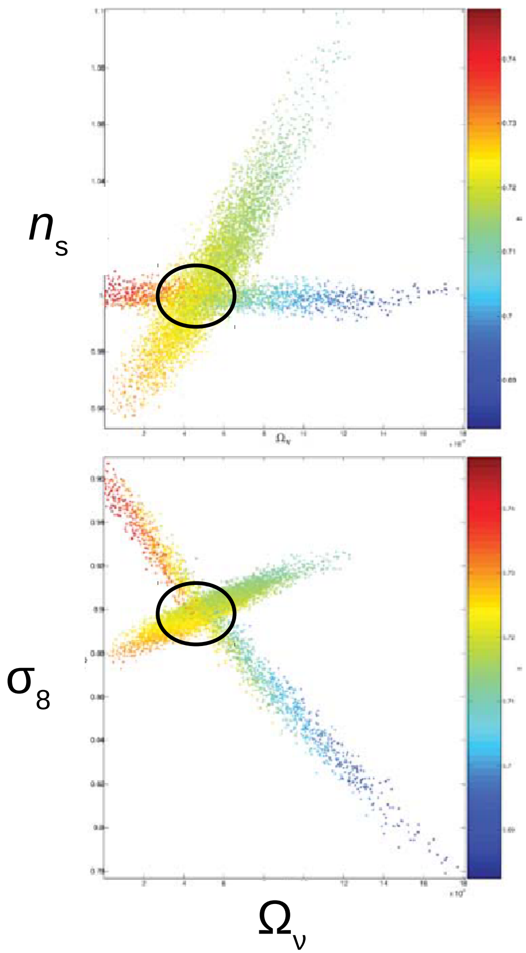


Figure 9 from Abdalla & Rawlings, 2007, MNRAS, 318, 1313

Combining SKA LSS survey with Planck CMB gives strong constraints on Ω_ν, σ_8, n_s

- constrain m_ν upper limit to 0.05eV

  - σ_8 measures the amplitude of the (linear) power spectrum on the scale of 8 h^{-1} Mpc
  - Ω_ν is the fraction of total matter in neutrinos
  - n_s is the Scalar spectral index