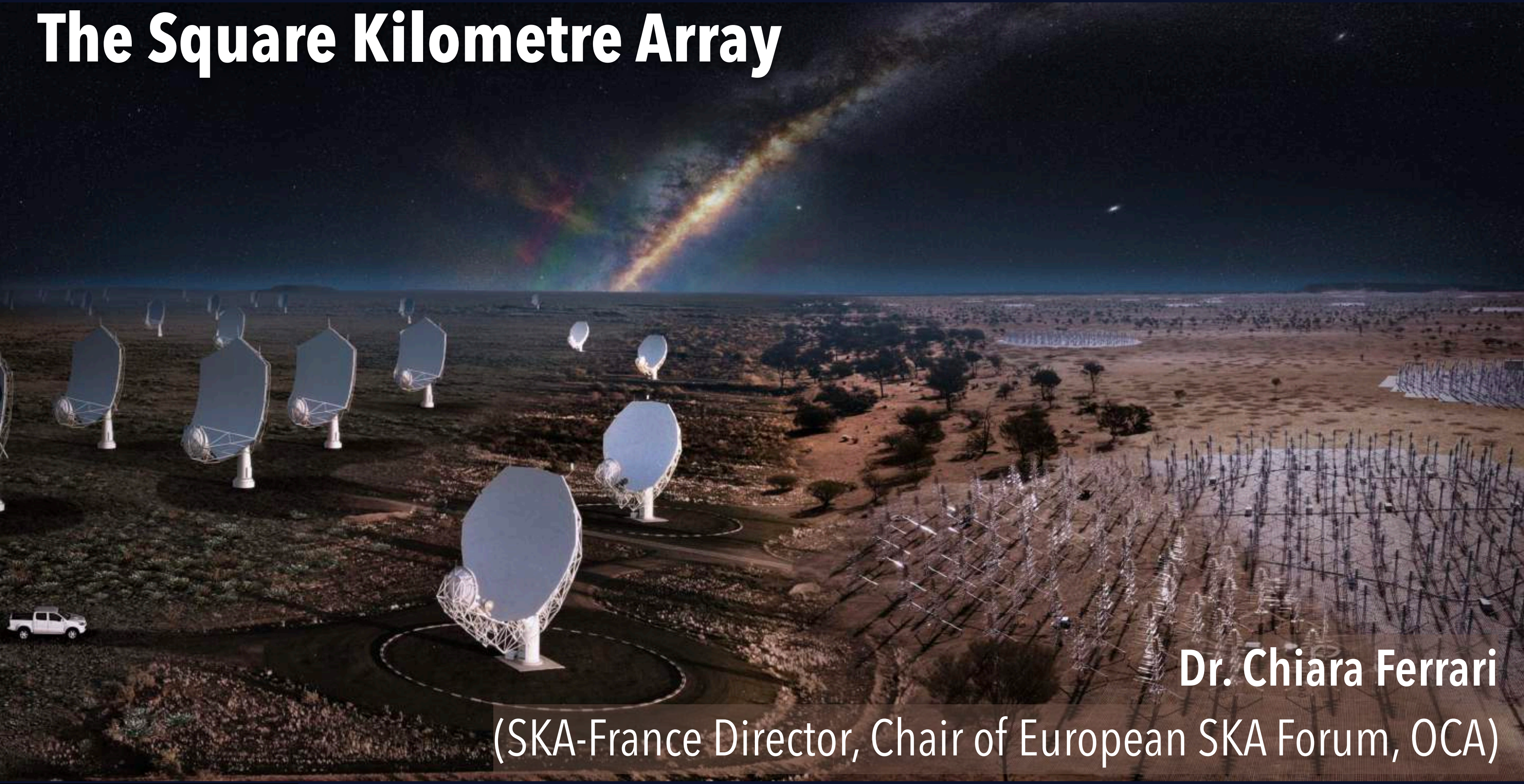
The Square Kilometre Array



Dr. Chiara Ferrari
(SKA-France Director, Chair of European SKA Forum, OCA)

SKA at a glance

- A global collaboration to design, build and operate the next generation radio astronomy observatory
- A new Inter-Governmental Organisation for astronomy and fundamental physics with 50+ year lifetime
- It will consist of:
  - An array of ~200 dishes in ZA
  - An array of ~131000 antennas in AU
  - A global HQ in UK
  - Two data computing centres in ZA & AU + A world-wide network of SKA regional centres (SRC)
- SKA is now:
  - Q4/2020: IGO exists
  - Q2/2021: construction activity begins

Courtesy: SKAO, H2020 AENEAS

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Courtesy: SKAO, H2020 AENEAS

SKA Phase 1 (SKA1)

SKA1-LOW (AUS)
130,000 log periodic antennas

SKA1-MID (SA)
197 dishes (15m)

50 MHz —— **350 MHz** —— **15 GHz** →

SKA at a glance

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> "This is the culmination of many years of work by hundreds of people, whose talents and dedication are the driving force behind the SKA. That collective effort, guided with skill and efficiency by the safe hands of the SKA Office, has brought us to this point."
>
> Dr Catherine Cesarsky
> Chair of the SKA Board of Directors

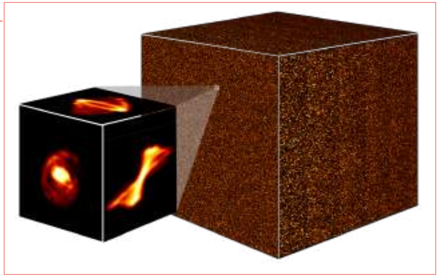
Courtesy: SKAO, H2020 AENEAS

Development of the SKA project

2012 — 2016 — 2019 — 2020 — *2021*

2013 — 2018 — 2019 — 2020 — *2021* — *2029*

2014 — 2015 — 2018 — 2019 — 2020



	SKA-Low	SKA-Mid
Start of construction (T0)	1st July 2021	1st July 2021
Earliest start of major contracts (C0)	August 2021	August 2021
Array Assembly 0.5 finish (AA0.5) SKA-Low = 6-station array SKA-Mid = 4 stations	February 2024	March 2024
Array Assembly 1 finish (AA1) SKA-Low = 18-station array SKA-Mid = 8 stations	February 2025	February 2025
Array Assembly 2 finish (AA2) SKA-Low = 64 stations SKA-Mid = 64 stations, baselines mostly <20km	February 2026	December 2025
Array Assembly 3 finish (AA3) SKA-Low = 256-station array, including long baselines SKA-Mid = 128-station array, including long baselines	January 2027	September 2026
Array Assembly 4 finish (AA4) SKA-Low = full Low array SKA-Mid = full Mid array, including MeerKAT dishes	November 2027	June 2027
Operational Readiness Review (ORR)	January 2028	December 2027
End of construction	July 2029	July 2029

Development of the SKA project

2012 — 2016 — 2019 — 2020 — 2021

2013 — 2018 — 2019 — 2020 — 2021 — 2029

2014 — 2015 — 2020 — 2024 — 2025 — 2026 — 2028

Science Commissioning

Data Challenges

Early Science | *Shared Risk* | *PI Proposals*

KSP Workshops | *KSP Proposals*

Major Science Meetings

A Golden Age for Radio Astronomy

Some of the SKA Pathfinders

NenuFAR
France
10-85 MHz

LOFAR
Europe
30-80 MHz + 110-240 MHz

CHIME
Canada
400-800 MHz

APERTIF
The Netherlands
1 – 1.750 GHz

JVLA
US
1- 50 GHz

SKA Precursors

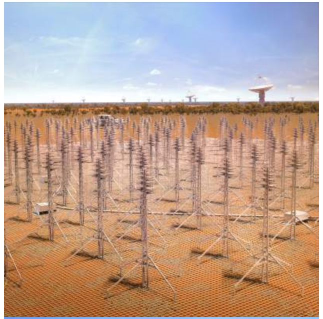
MWA
Australia
80 - 300 MHz

ASKAP
Australia
700 - 1800 MHz

HERA
South Africa
50 - 250 MHz

MeerKAT
South Africa
0.580 – 14 GHz

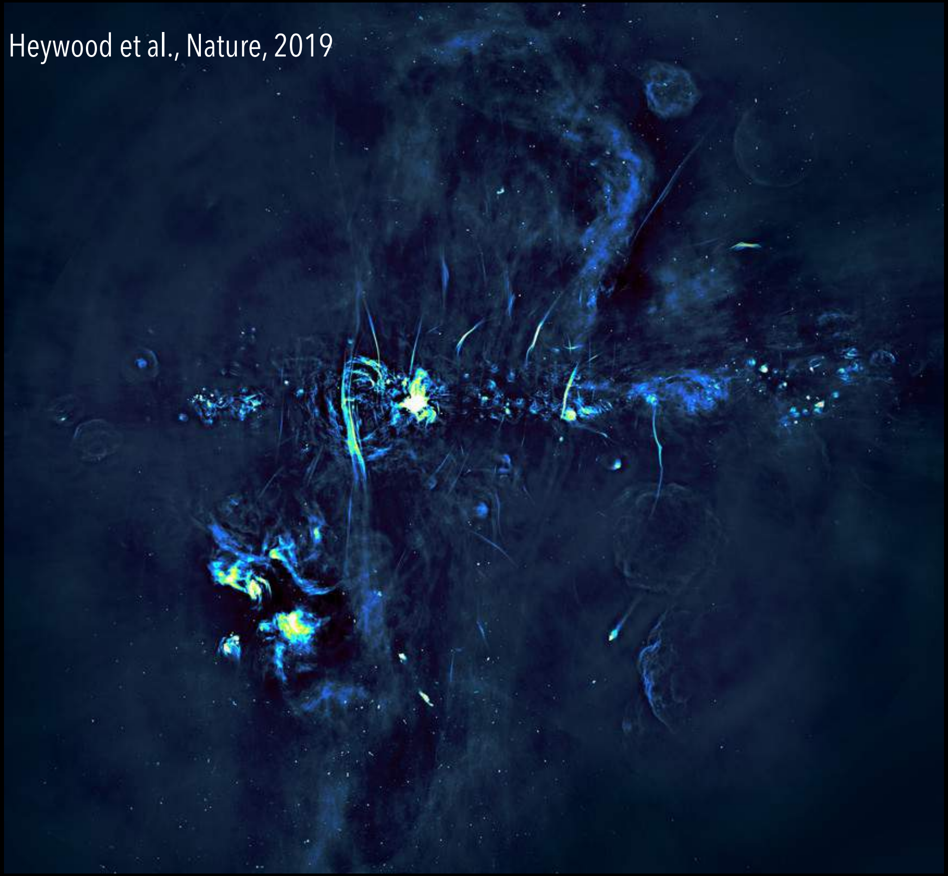
SKA

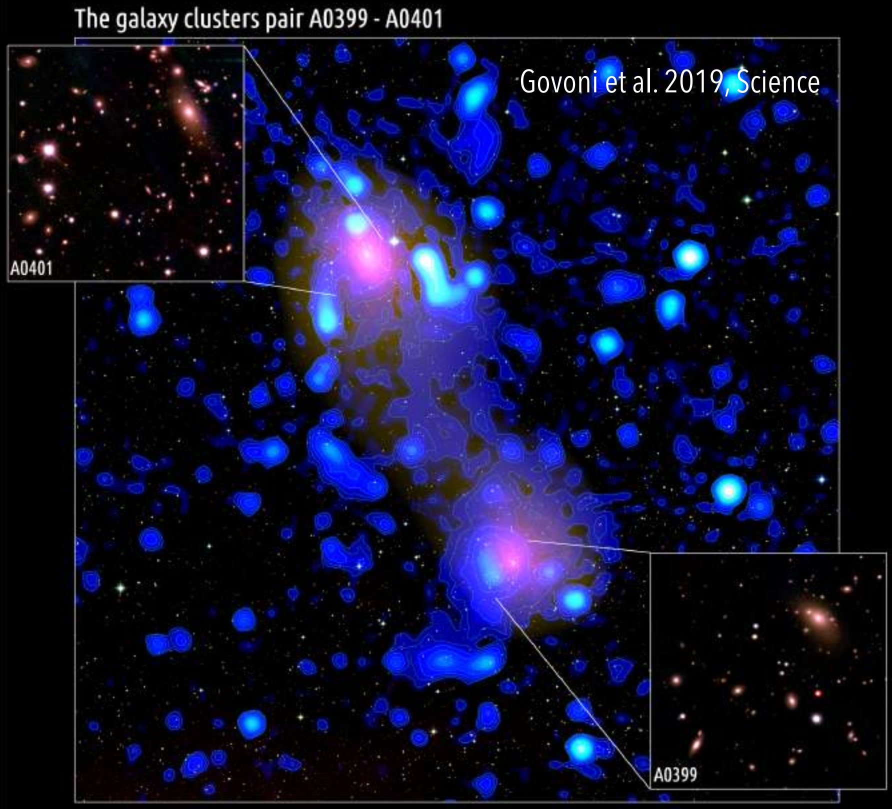


SKA1-LOW
Australia
50 MHz - 350 MHz

SKA1-MID
South Africa
350 MHz – 15.4 GHz

Diffuse emission and filaments at different scales





"A radio ridge connecting two galaxy clusters in a filament of the cosmic web", F.Govoni et al. 2019, Science.
Optical: DSS and Pan-STARRS1 (insets) -- Red, X-rays: XMM-Newton -- Yellow, y-parameter: PLANCK satellite -- Blue, radio 140 MHz: LOFAR
Image credits: M.Murgia - INAF

Radio continuum surveys

Mauch et al., AJ, 2020

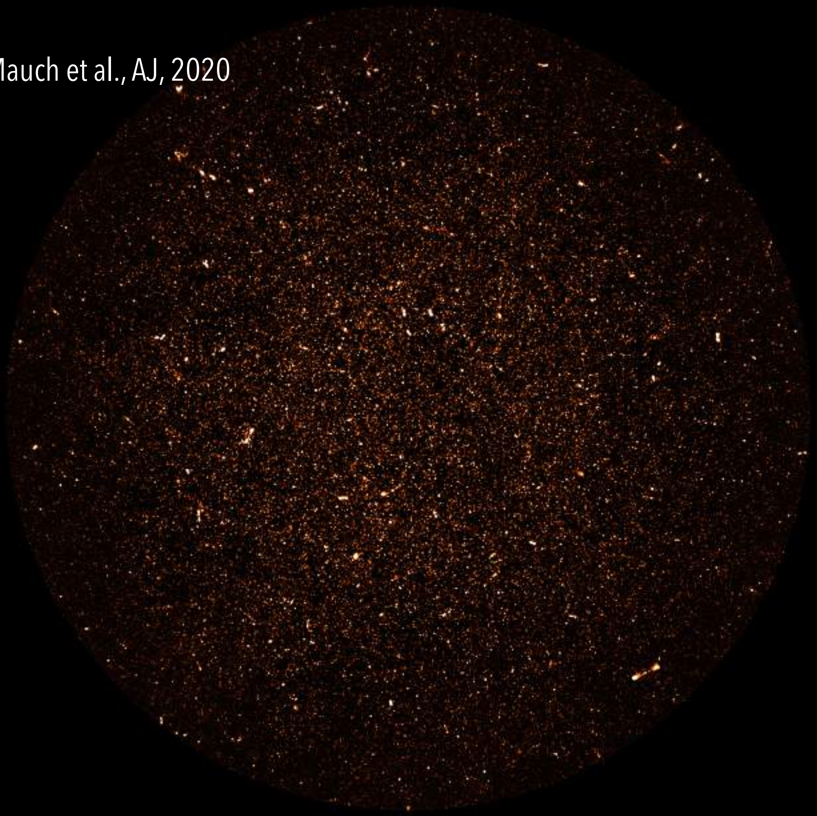
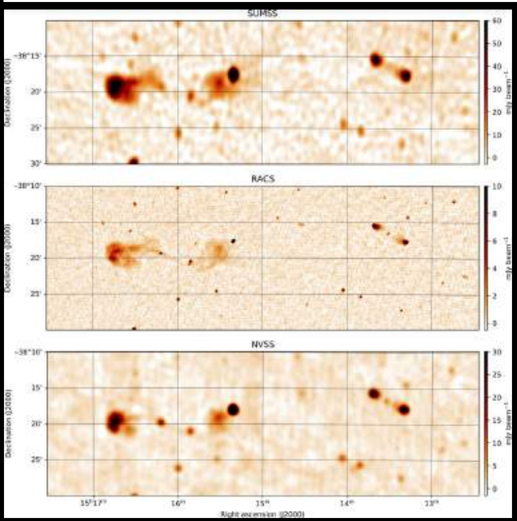


Table 1. Summary of RACS parameters with those of other comparable surveys. The tabulated data allow comparison with RACS; for detailed information consult the reference papers mentioned in Section 1.

Survey	Frequency (MHz)	Bandwidth (MHz)	Resolution (arcsec)	Sky coverage (deg^2)	Sensitivity ($mJy\ beam^{-1}$)	Polarization	$N_{sources}$ ($\times 10^6$)
VLSSr	73.8	3.12	75	30 793	100	*I*	0.93
GLEAM	87, 118, 154, 185, 215	30.72	120	27 691	6–10	*I, Q, U, V*	0.33
TGSS	150	16.7	25	36 900	2–5	*I*	0.62
RACS [a]	887.5 1 295.5 1 655.5	288	15	36 656	∼0.25	*I, Q, U, V*	4
RACS [b]	887.5	288	15–25	34 240	0.2–0.4	*I*	2.8
SUMSS +MGPS-2	843	3	45	10 300	1.5	RC	0.2
NVSS	1 346, 1 435	42	45	33 800	0.45	*I, Q, U*	2
VLASS	3 000	2 000	2.5	33 885	0.07	*I, Q, U*	5.3

[a] RACS full survey capability.
[b] RACS first data release.

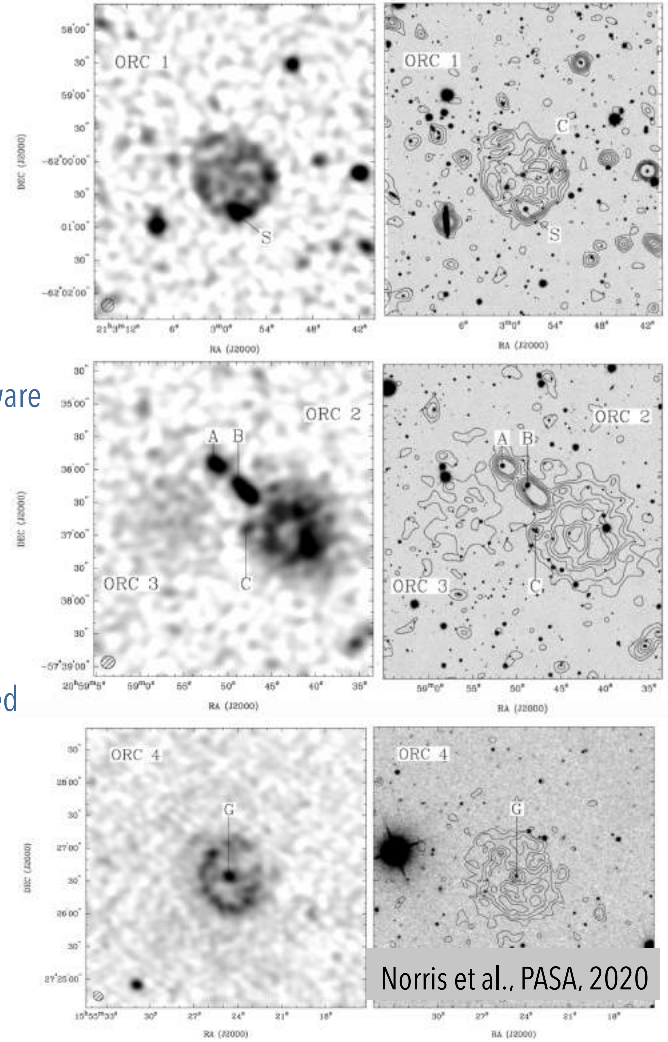


McConnell et al., ASA, 2020

Circular radio objects

- Similar features
  - Strong circular symmetry with ~1 arcmin diameter
  - Steep spectral index ($\alpha \sim 1$)
  - Located at high galactic latitude & Two of them are very close together

- Imaging artefacts? **No:** detected by more than one telescope and with different software
- SNR? **Very unlikely:** very unlikely position, except if new class of high-latitude SNR
- Planetary Nebulae? **No:** very unlikely density at ORC galactic latitudes; too steep spectrum
- Ring around Wolf-Rayet star? **No:** too big; too steep spectrum
- Face-on SF or ring galaxy? **No:** no associated optical emission
- Galactic wind termination shock? **Possible???** Size/energetics OK; never observed before
- Bent-tail radio galaxies? **No:** no host galaxy; no cluster/ICM
- Lobe from radio galaxies? **No:** no companions/central galaxy; too big (ORC4)
- Cluster halos? **No:** no clusters/too regular morphology
- Einstein ring? **Very unlikely:** too big/regular



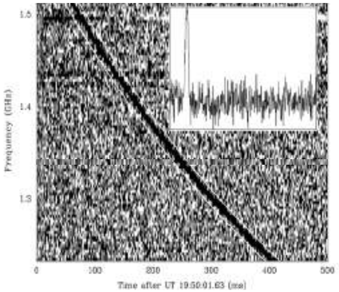
Norris et al., PASA, 2020

Fast Radio Bursts (FRB)

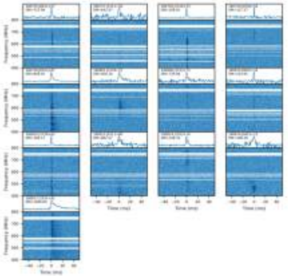
- First FRB discovered in 2007 in Parkes data of 2001 (Lorimer et al. 2007)
- After a low detection rate (few dozens until 2017), hundreds of FRBs known today, repeaters or non-repeaters - Big impact from CHIME and ASKAP

- First repeater detected in 2012 at Arecibo, host galaxy identified in 2017 (Chatterjee et al. 2017) - low mass, low-metallicity dwarf galaxy at redshift z = 0.193 (Tendulkar et al. 2017)
- Non repeaters discovered later on in higher-z more massive, less SF active galaxies (e.g. Bannister et al. 2019, Ravi et al. 2019) : different physical origin?
- But: repeating FRBs seems to have a wide range of luminosities, and originate from diverse host galaxies and local environments

- In 2020, first likely FRB - repeating - associated to a galactic magnetar (CHIME/FRB Coll. 2020, Bochenek et al. 2020, Kirsten et al. 2020)
- Recent analysis of archival radio and X-ray data of another galactic source suggests that there exists a continuum of magnetar radio burst energies, sometimes looking like FRB (Israel et al. 2020)

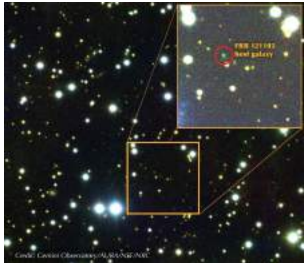


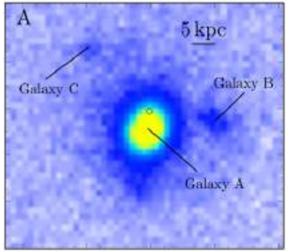
Lorimer et al. 2007



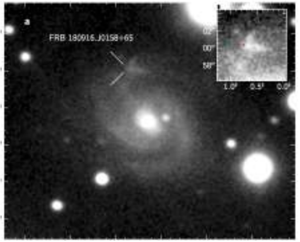
CHIME/FRB Coll. 2019

Adapted from Chatterjee et al. 2017

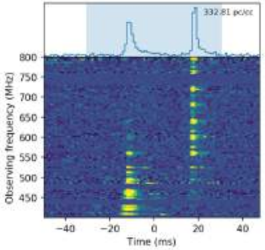




Bannister et al., 2019



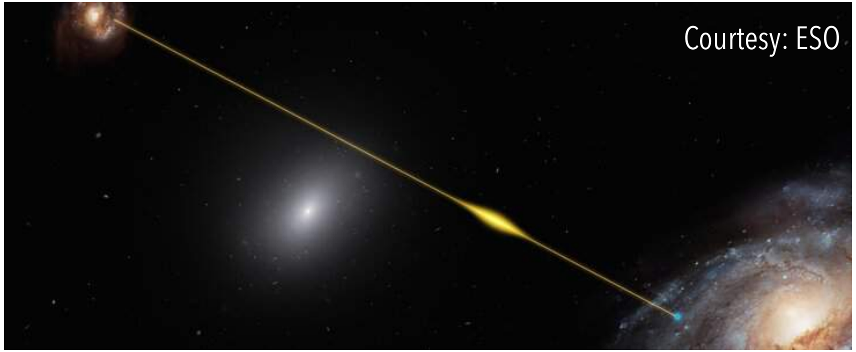
Marcote et al. 2000



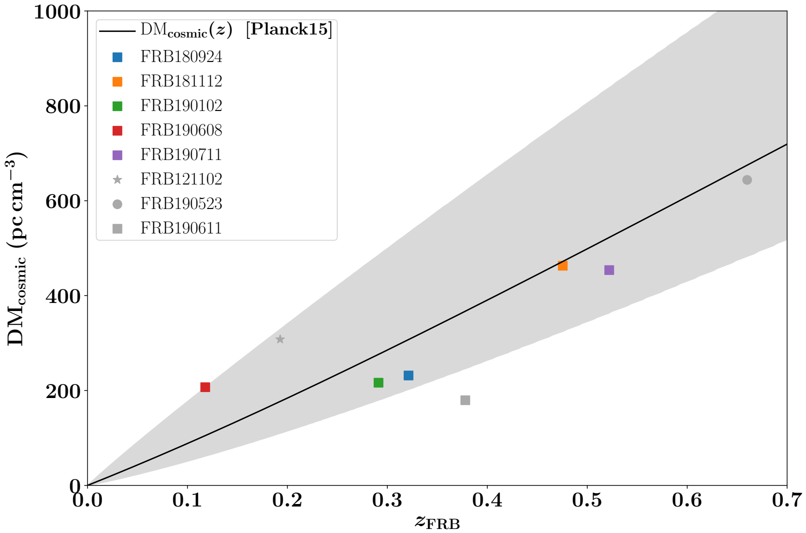
CHIME/FRB Coll. 2020

FRBs: powerful cosmological tools

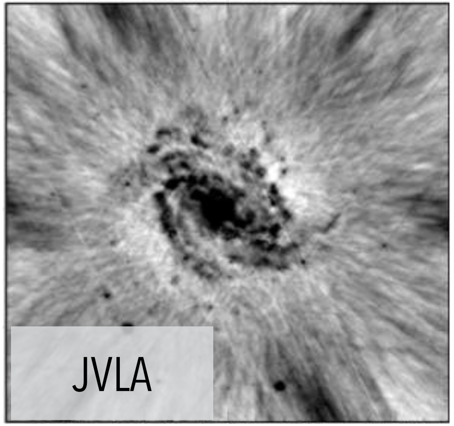
- FRB traversing the halo of a galaxy with surprisingly low density and weak magnetic field : new and transformative technique for exploring the nature of galaxy halos (Prochaska et al. 2019)

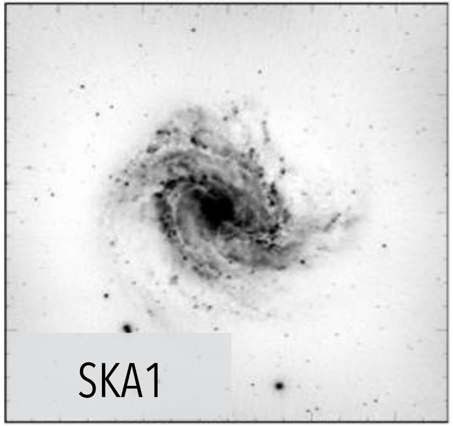


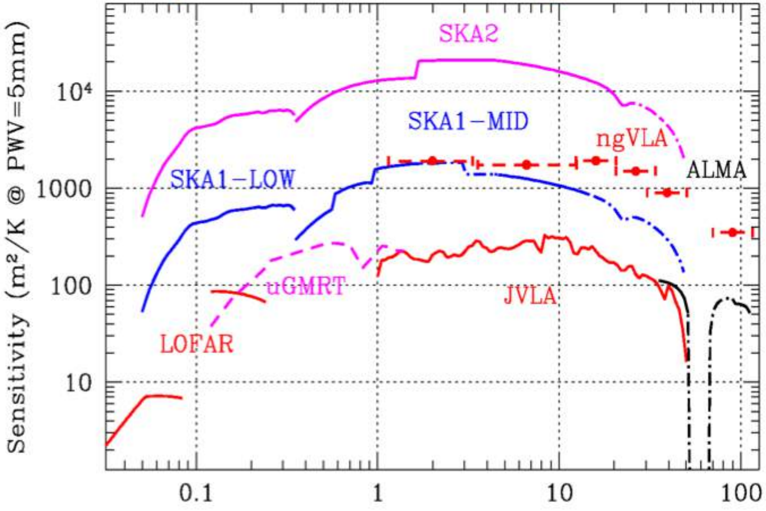
- Direct measurement of the baryon content of the Universe using the dispersion of a sample of localized fast radio bursts (FRBs): cosmic baryon density consistent with Cosmic Microwave Background and Big Bang Nucleosynthesis (Macquart et al. 2020)

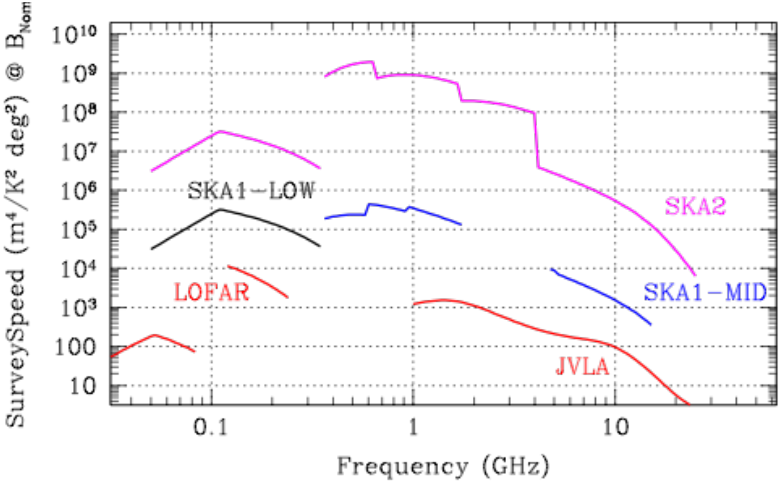


Why building the SKA?









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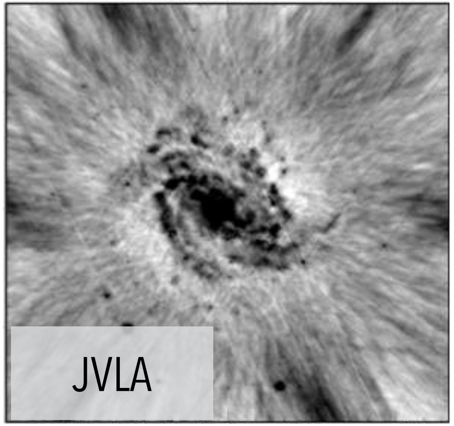
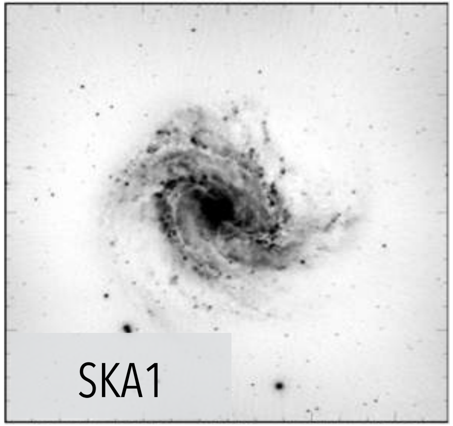
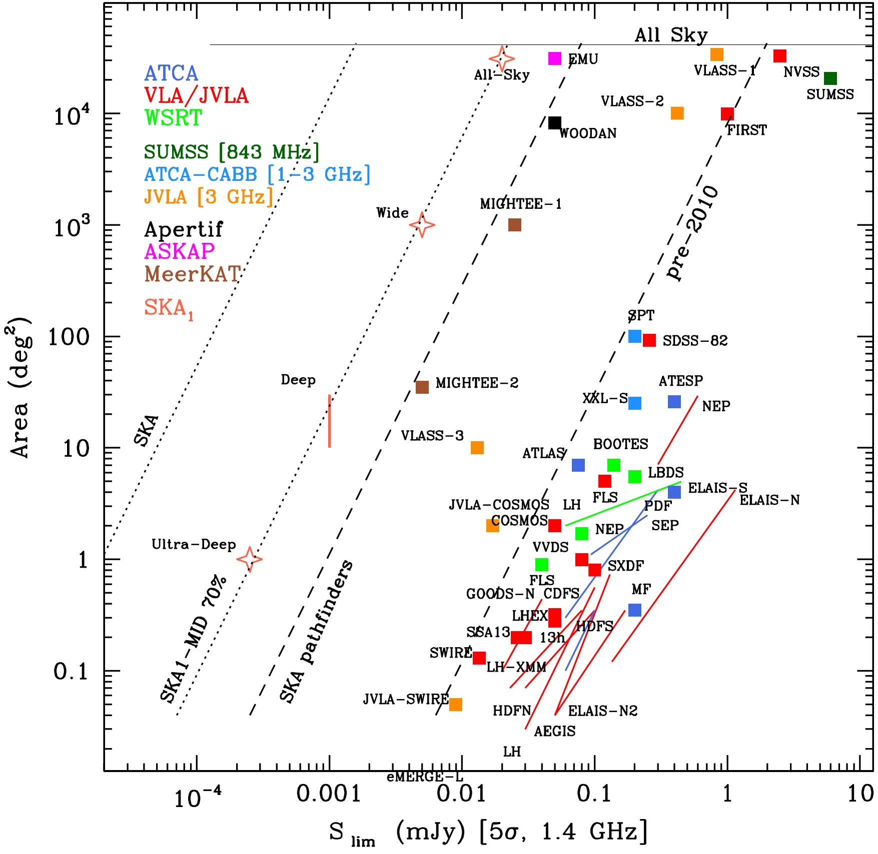


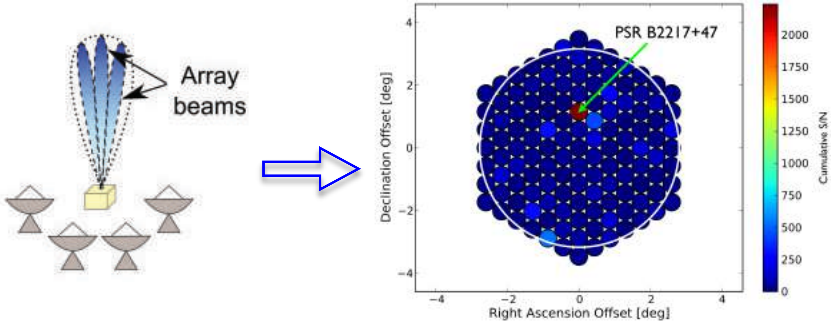


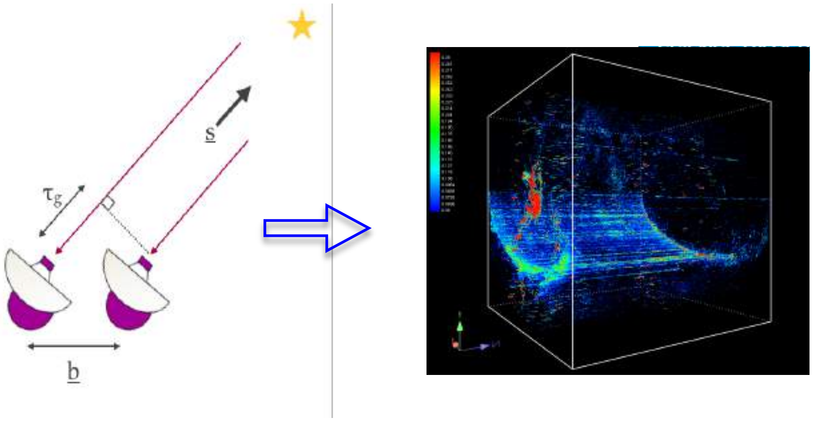
Prandoni & Seymour 2015



SKA observing modes

- Imaging
  - Continuum imaging: images of areas of the sky over a broad bandwidth
  - Spectral line/Zoom window imaging: higher spectral resolution images (hundreds of Hz)
- Pulsar Transient/Search: periodic/non-periodic pulses over a range of possible dispersion measure values (buffer for transients)
- Pulsar Timing: Converts tied-array voltage beams into folded integrated pulse profiles of pulsars to accurately measure the time-of-arrival (ToA)
- Flow-through: Record raw tied-array beam data for offline analysis
- Dynamic Spectrum: generic, high time-resolution, dynamic spectrum (time-versus-frequency distribution of intensity) that may be used for a broad range of scientific applications
- Very-Long Baseline Interferometry: tied-array beams to participate in VLBI observations, with other radio astronomy observatories located around the globe

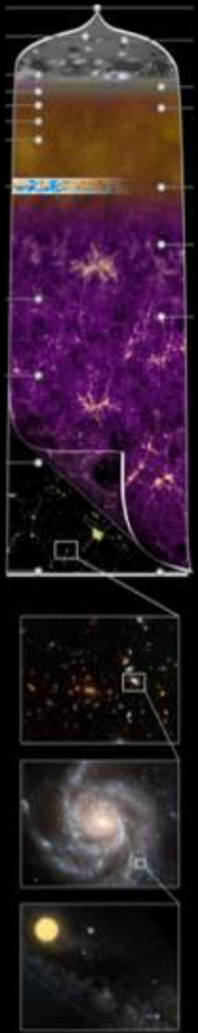




Exploring the cosmos with the SKA

Braun et al. 2015

- **Cosmic dawn & Epoch of Reionisation**
- **Cosmology**
- **Galaxy evolution**
- **Cosmic magnetism**
- **Fundamental physics**
- **Transient sky**
- **Cradle of life**
- **Solar, Heliospheric and Ionospheric Physics**



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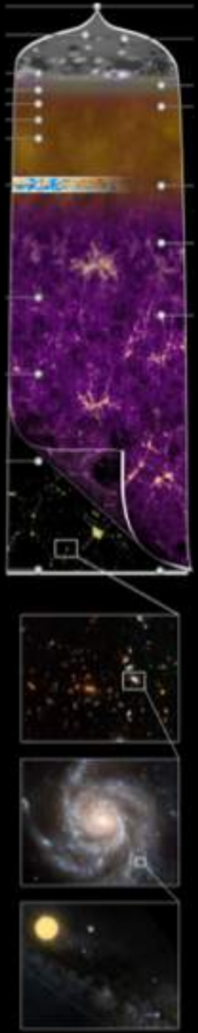
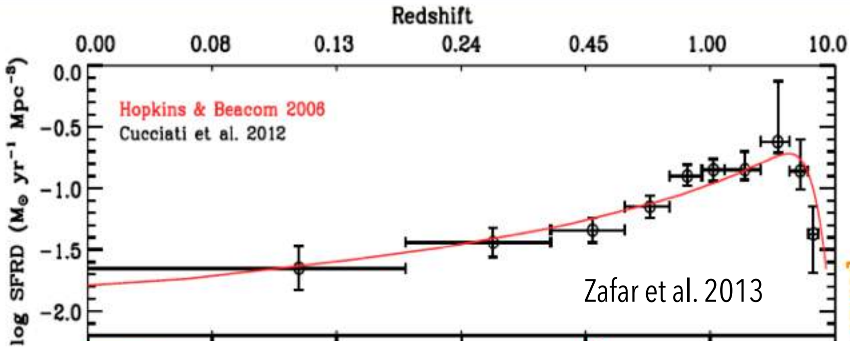
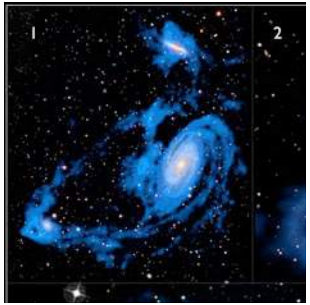


Galaxy evolution



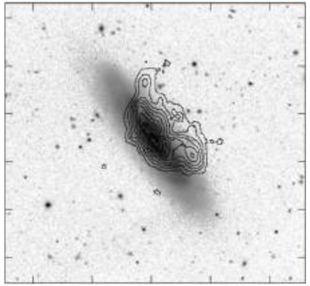
Osterloo et al. 2017

Accretion of cold gas from the environment



Duc & Renaud 2014

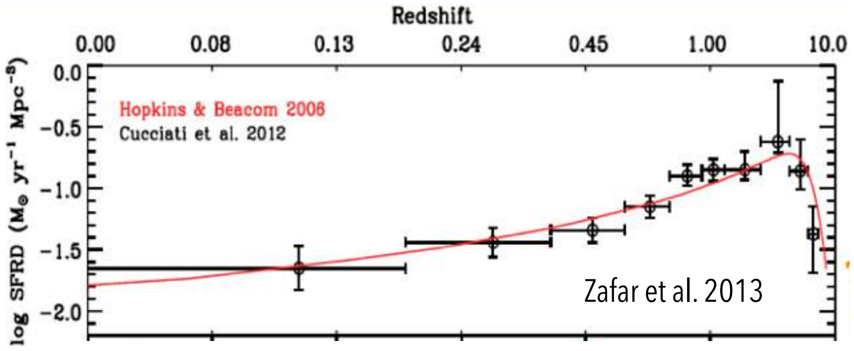
Galaxy interactions

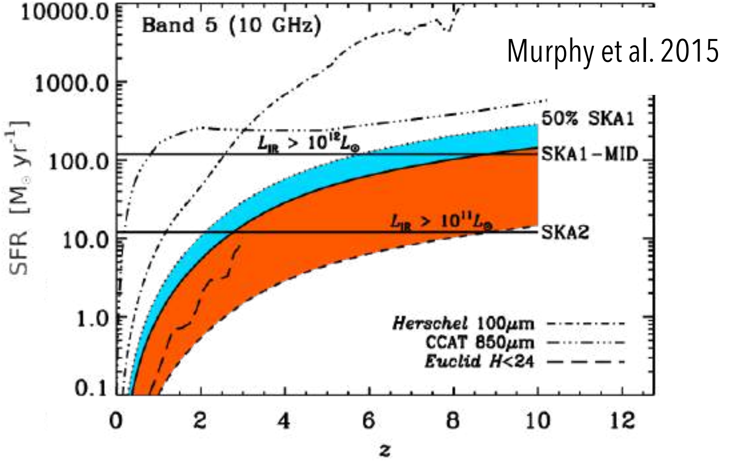


Kenney et al. 2004

Environmental effects on gas content

Galaxy evolution





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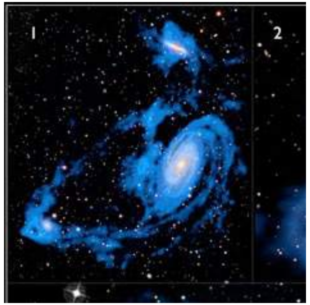

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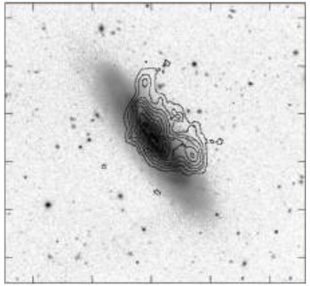

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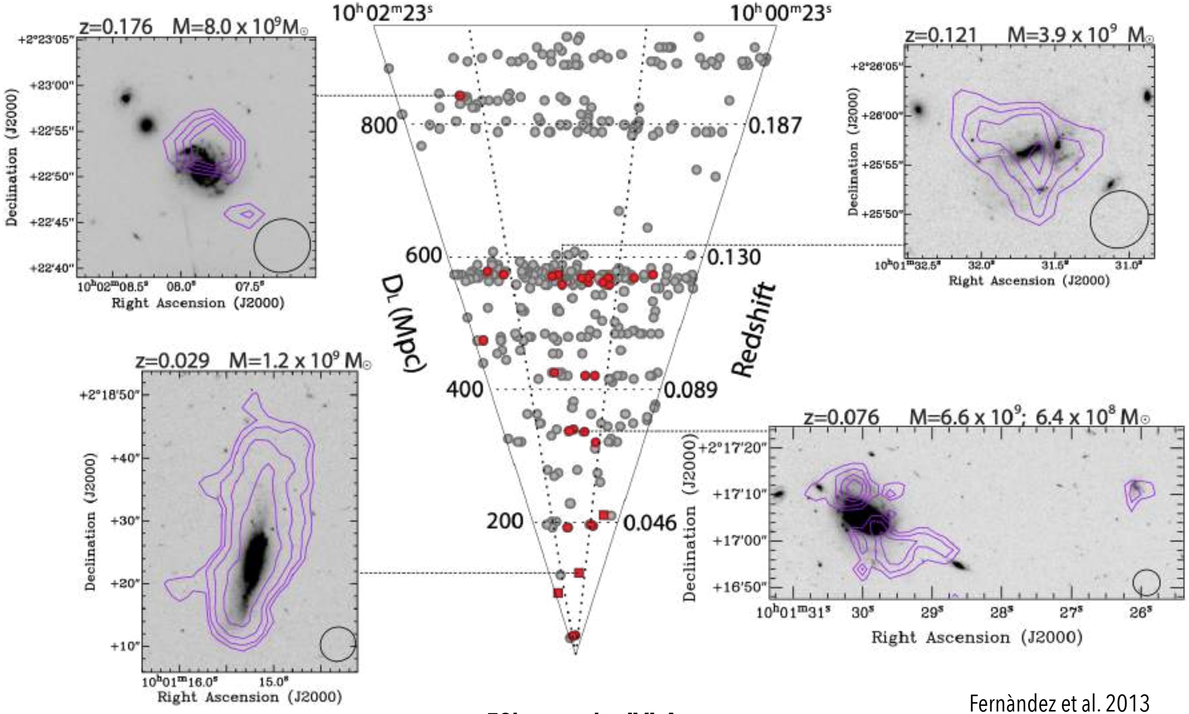
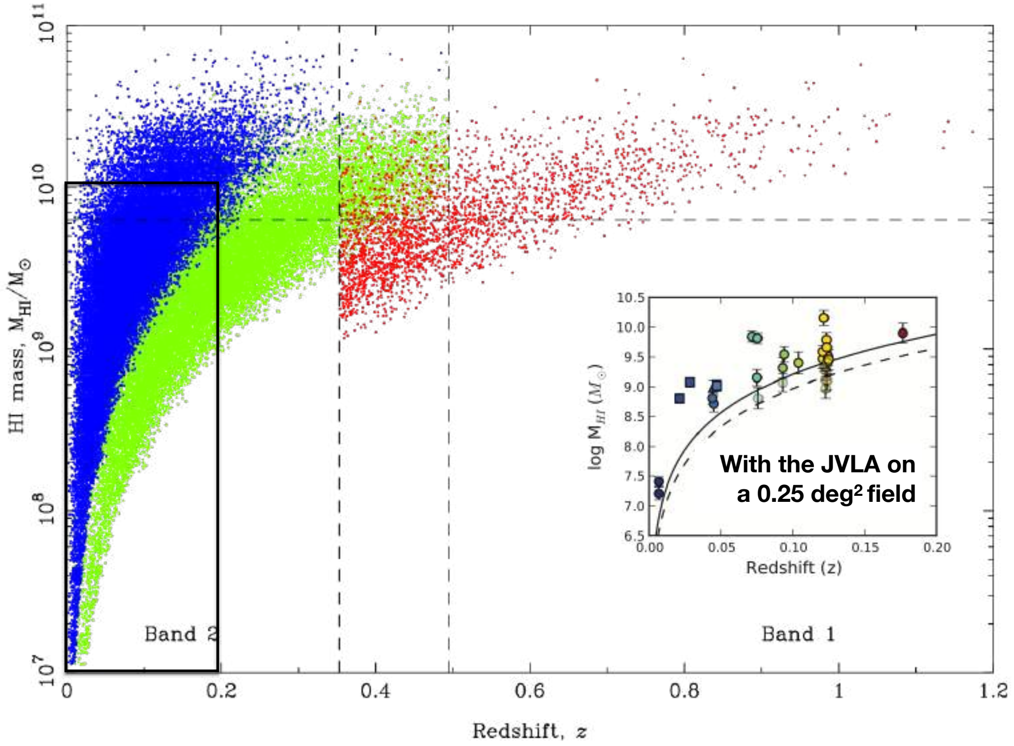


Fernàndez et al. 2013

50h avec le JVLA

Galaxy evolution



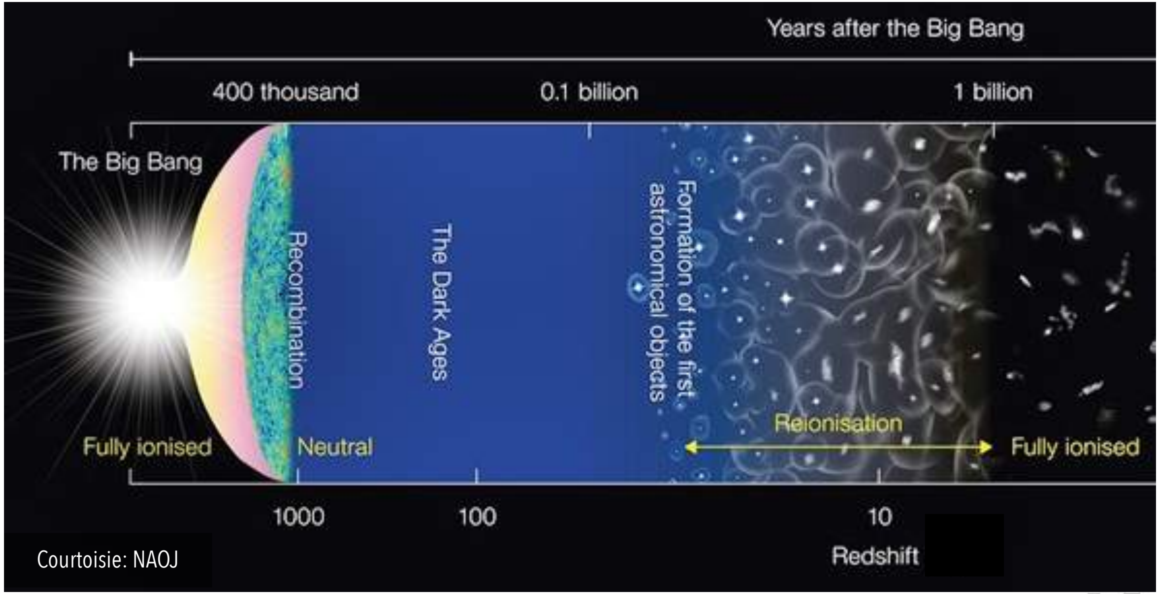
With SKA1

400 deg²
20 deg²
1 deg²

Survey	Ω deg²	Frequency[1] MHz	Resolution[2]	N	$<z>$ (z_{lim})	N_{HI} 10^{20} cm^{-2}
Galaxy/MS (absorption)	400	1418-1422	5″	4,000		
Extragalactic (absorption)	1000	350-1050	2″	5,000	1(3)	
	1000	200-350[3]	10″	?	4(6)	
Galaxy/MS	600	1418-1422	10″-1′			2
Medium wide	400	950-1420	10″	34,000	0.1 (0.3)	2
Medium deep	20	950-1420	5″	25,000	0.2 (0.5)	0.6
Deep	1	600-1050	2″	2,600	0.5 (1)	0.4
Targeted	–	1400-1420	3″-1′	50	0.002 (0.01)	0.5

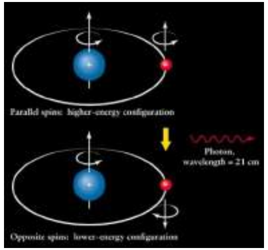
Staveley-Smith & Oosterloo 2015

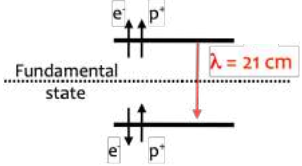
Epoch of Reionisation and Cosmic Dawn



$$\delta T_B \propto 28\,\mathrm{mK}\,(1+\delta)\,x_{HI}\left(\frac{T_S - T_{\mathrm{CMB}}}{T_S}\right)\left(1+\frac{1}{H}\frac{dv}{dr}\right)^{-1}$$

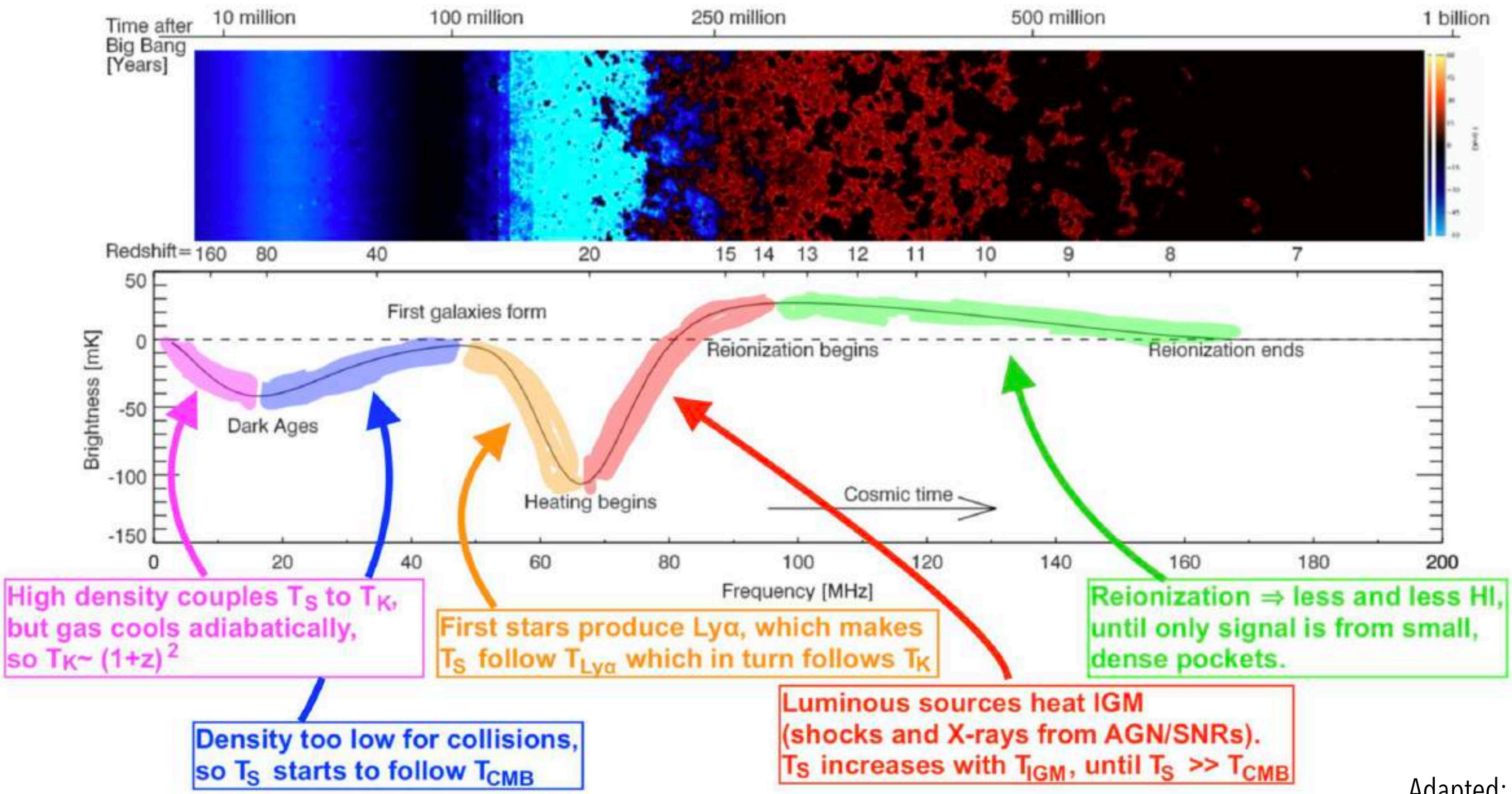
astro — cosmo





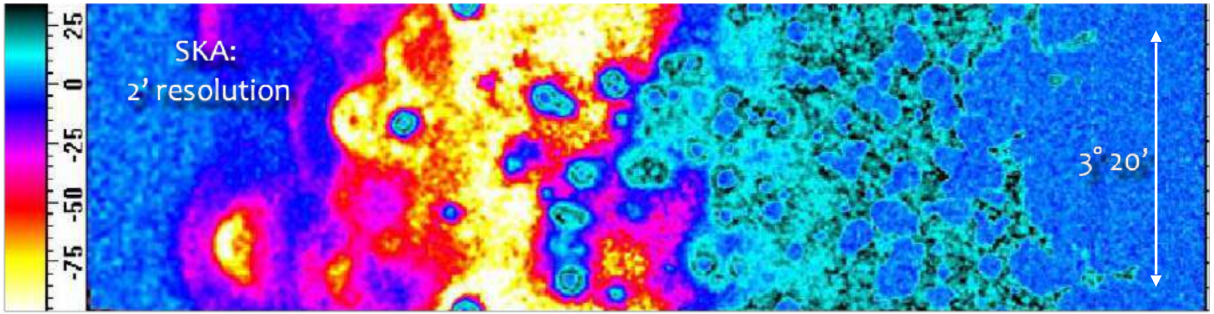
$$\frac{n_1}{n_0} \propto \exp\left(-\frac{h\nu_{21}}{k_B T_s}\right)$$

Epoch of Reionisation and Cosmic Dawn

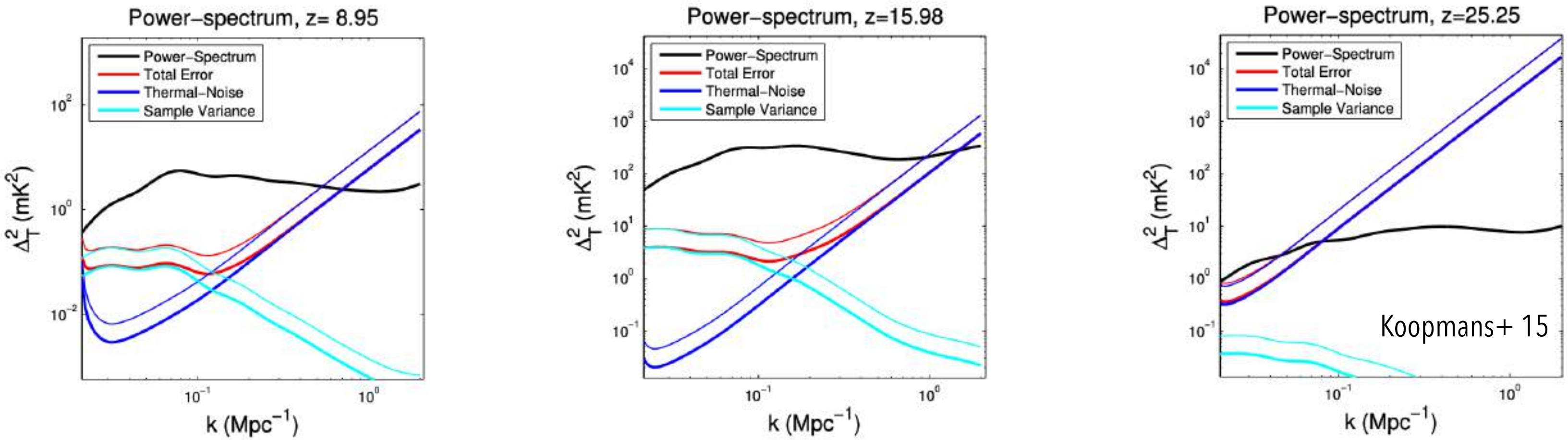


Adapted: Pritchard & Loeb

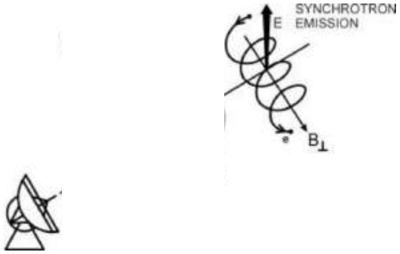
Epoch of Reionisation and Cosmic Dawn



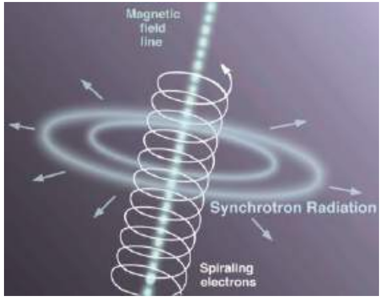
Courtesy: B. Semelin

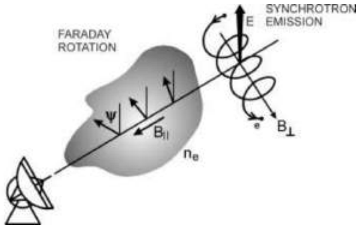


Cosmic magnetism

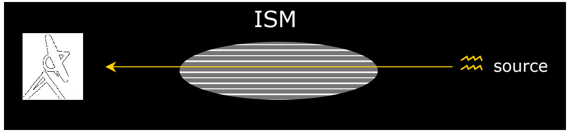


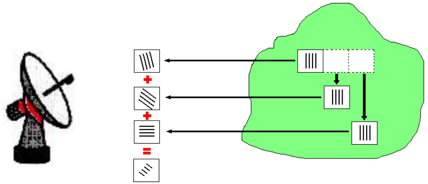
Total intensity and polarisation of synchrotron radiation



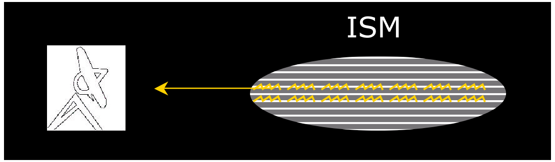


Faraday Rotation



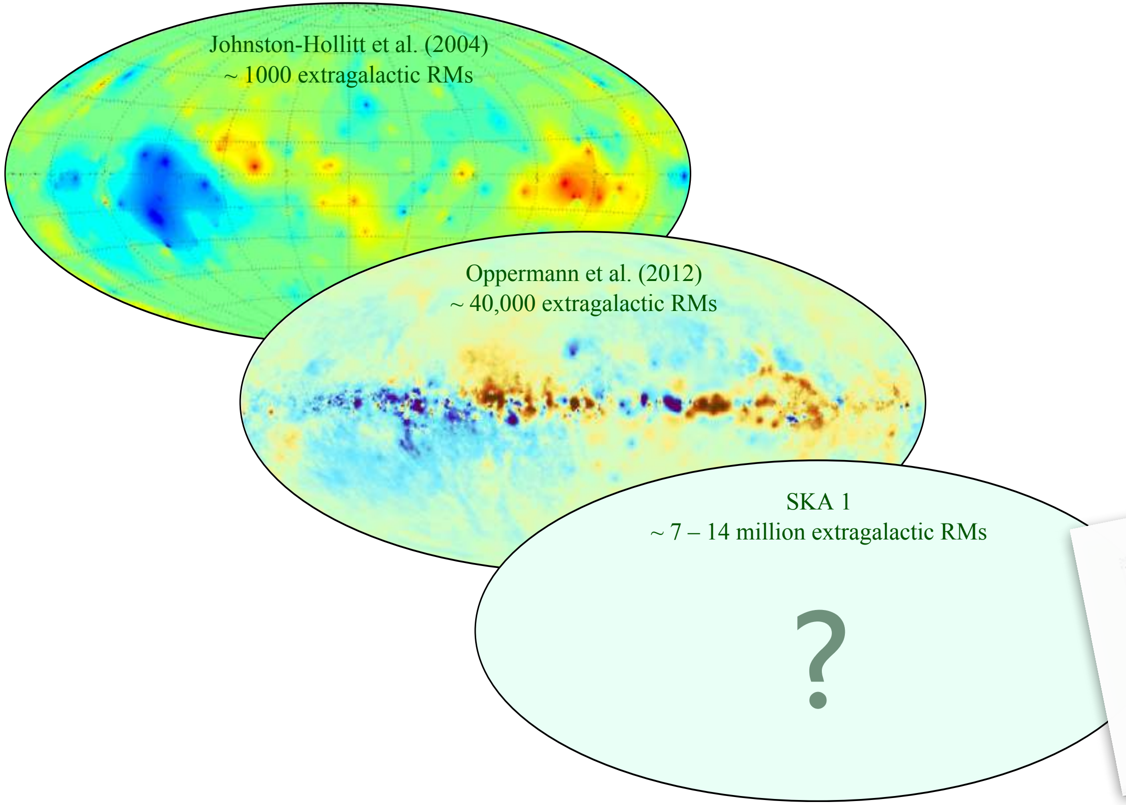


Faraday Tomography



Credit: *Marijke Haverkorn*

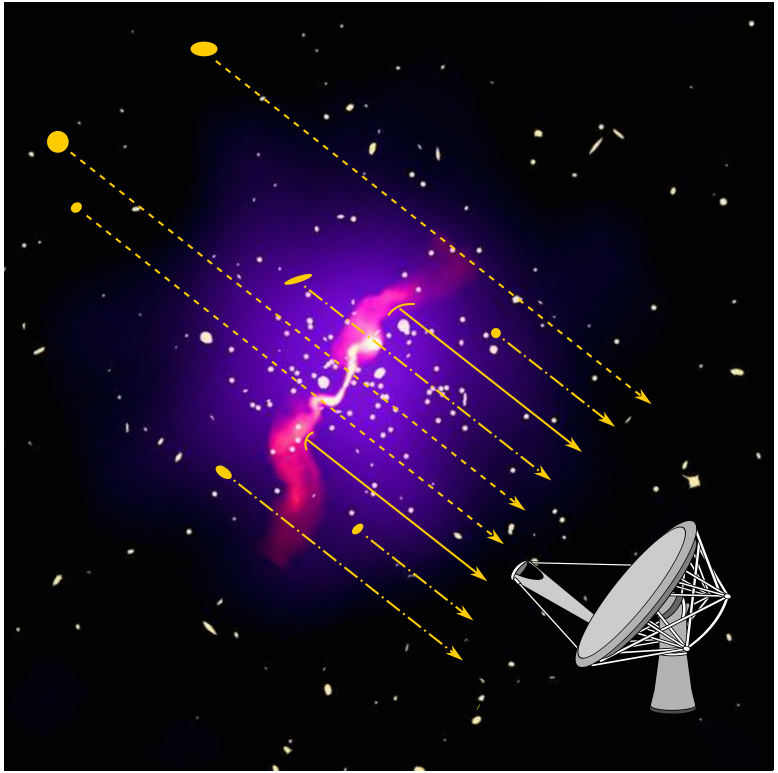
Cosmic magnetism

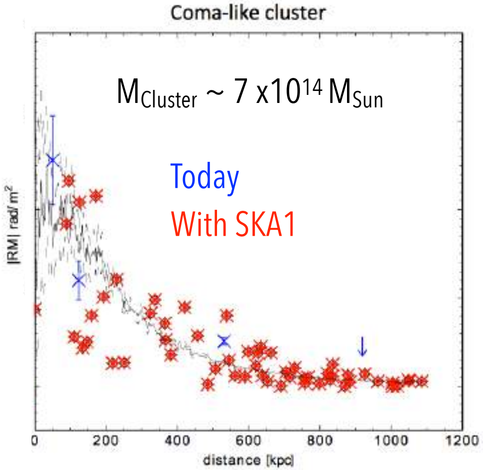


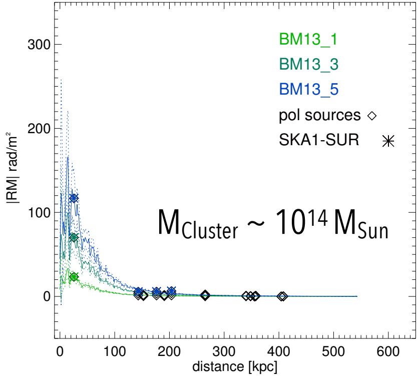
SKA1

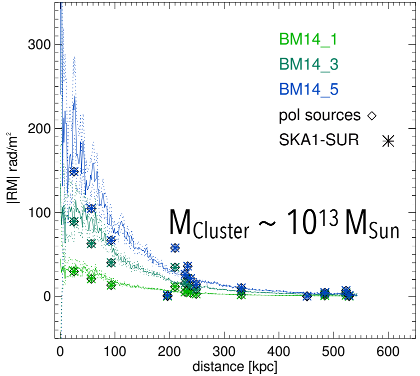
Density of background sources ~300x higher!

Cosmic magnetism



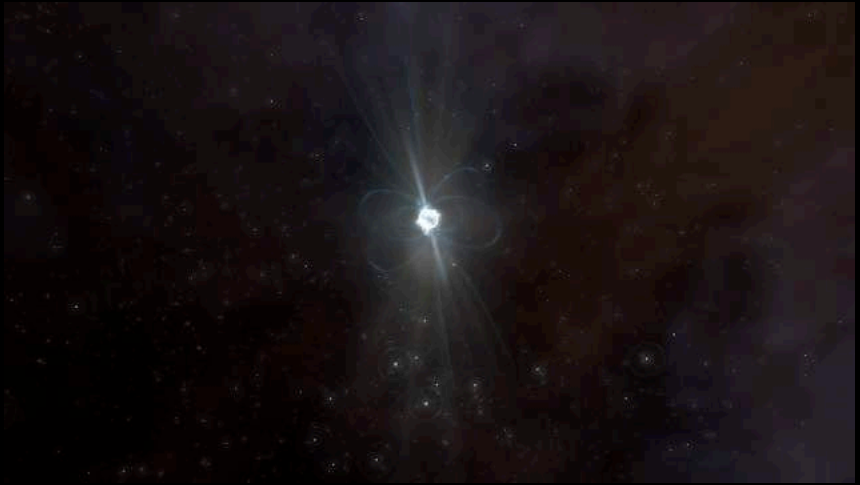






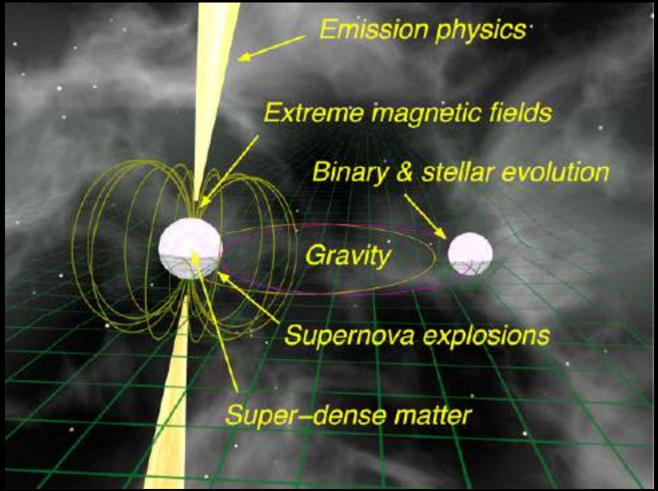
Pulsars

- Strongly self-gravitating compact bodies
- Very stable clocks

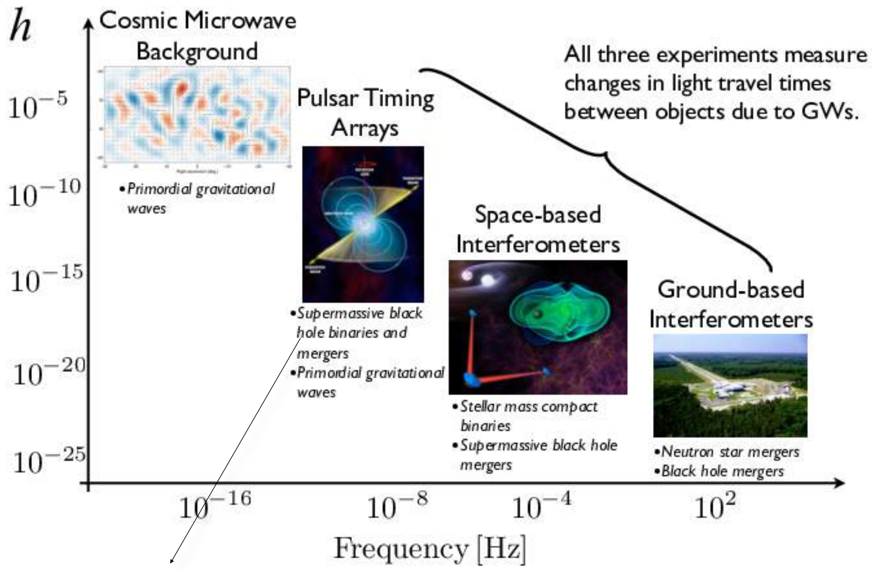


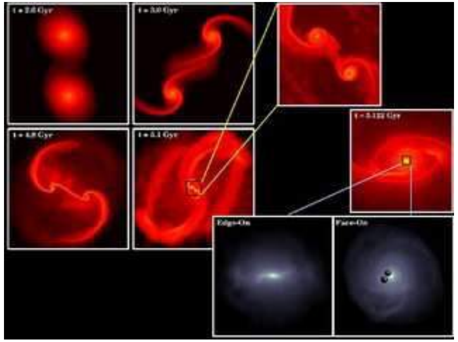
Test of gravitation theories

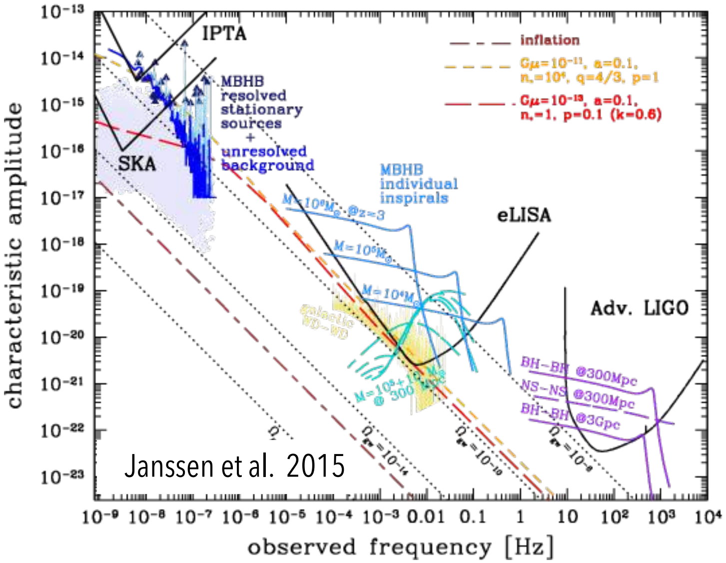
Astrophysics

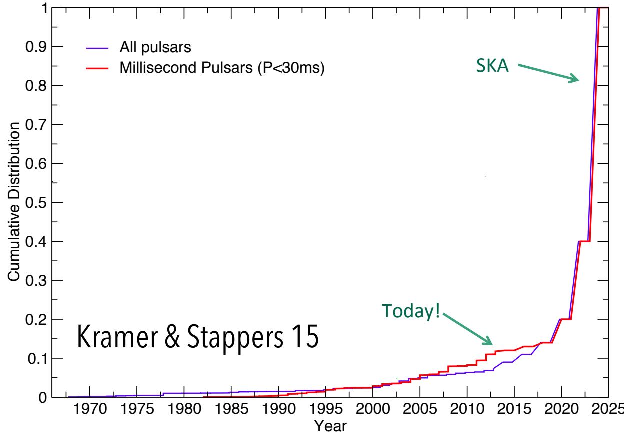


The spectrum of gravitational wave astronomy

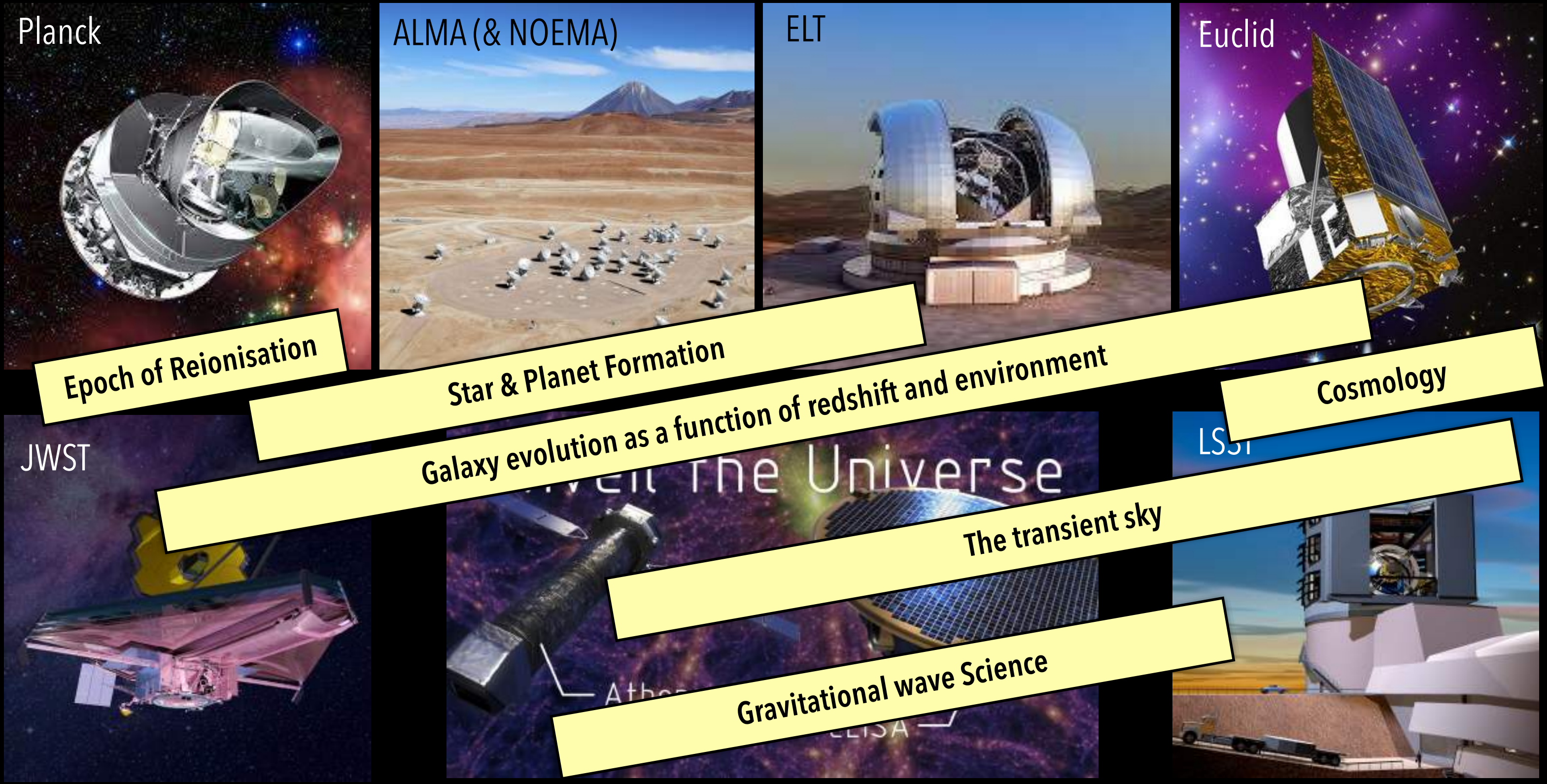








Synergies



Epoch of Reionisation

Star & Planet Formation

Galaxy evolution as a function of redshift and environment

Cosmology

The transient sky

Gravitational wave Science

The French SKA White Book


French SKA White Book

The French community towards the Square Kilometre Array

SKA FRANCE

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arXiv:1712.06950

178 co-authors from

- 40 research institutes
- 6 private companies

The richest synergy chapter ever published about SKA vs. other projects, including:

- instruments covering the whole electromagnetic spectrum
- gravitational wave detectors

SKA-France milestones

October 16, 2017

First SKA-France Day

July 1st, 2016

SKA-France Coordination

SKA-France milestones

February 1st , 2018

Kick-off meeting of Maison SKA-France

SKA-France milestones

Mai 17, 2018

MESRI publishes the French Large Research Infrastructure Roadmap

SKA-France milestones

July 12, 2018

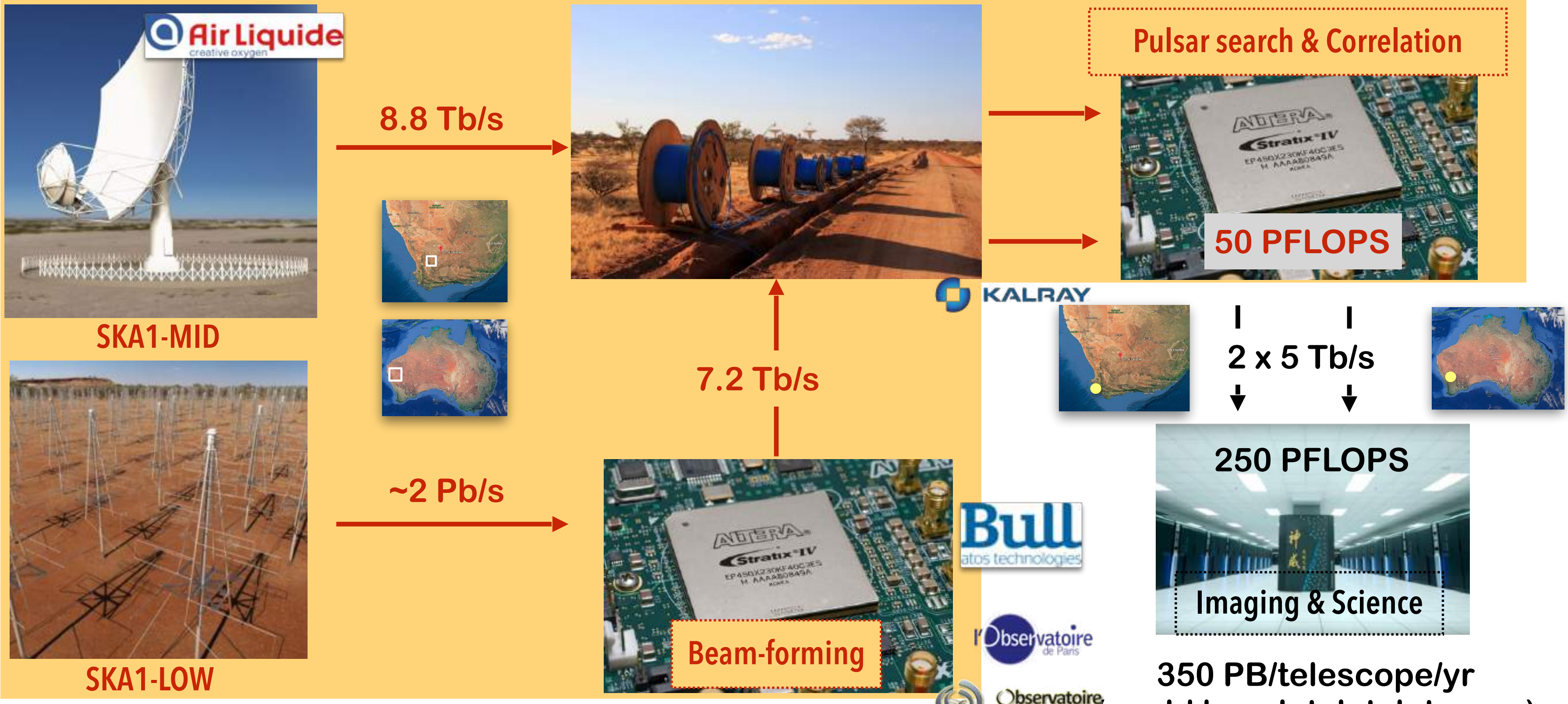
CNRS approved as new member of SKAO by the SKA Board of Directors

SKA-France milestones

November 15, 2019

Two new academic partners of Maison SKA-France

Technology



350 PB/telescope/yr
(could be a lot, lot, lot more)

SKA contribution to a knowledge society

- SKA offers challenge and opportunities in terms of energy needs:
  - Reduction of the environmental impact associated with energy consumption of computing centre
  - Broader driver for the collaboration between Africa and Europe in the development of carbon-free energy system
- One of the "big science" Big Data projects driving the development of:
  - Open Science practices with much wider impact
  - Artificial Intelligence / Machine Learning-optimized exascale platforms
  - Networking and communication
- A lively collaboration between academia, society, research infrastructures and industry:
  - Acquired expertise in critical elements of the innovation sector (electricity supply, connectivity, IT, …)
  - Adaptability and capacity to produce novel solutions in emerging challenges

SKA contribution to a knowledge society

Open Science

ESCAPE

EUROPEAN OPEN SCIENCE CLOUD

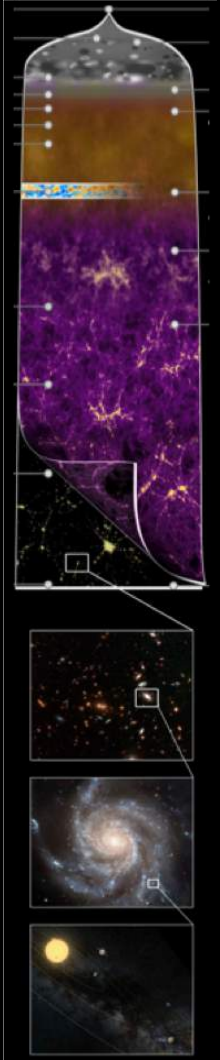
Findable Accessible Interoperable Reusable

Human capital development

DARA
DEVELOPMENT IN AFRI
WITH RADIO ASTRONO

DARA BIG DATA

DOPPLER
development of palop knowledge in radioastronomy



Initial signatories of the SKA Observatory Convention

Human Capital Programmes

SKA Session in Science Digital@UNGA75