Strumentazione Astronomica: Radioastronomia

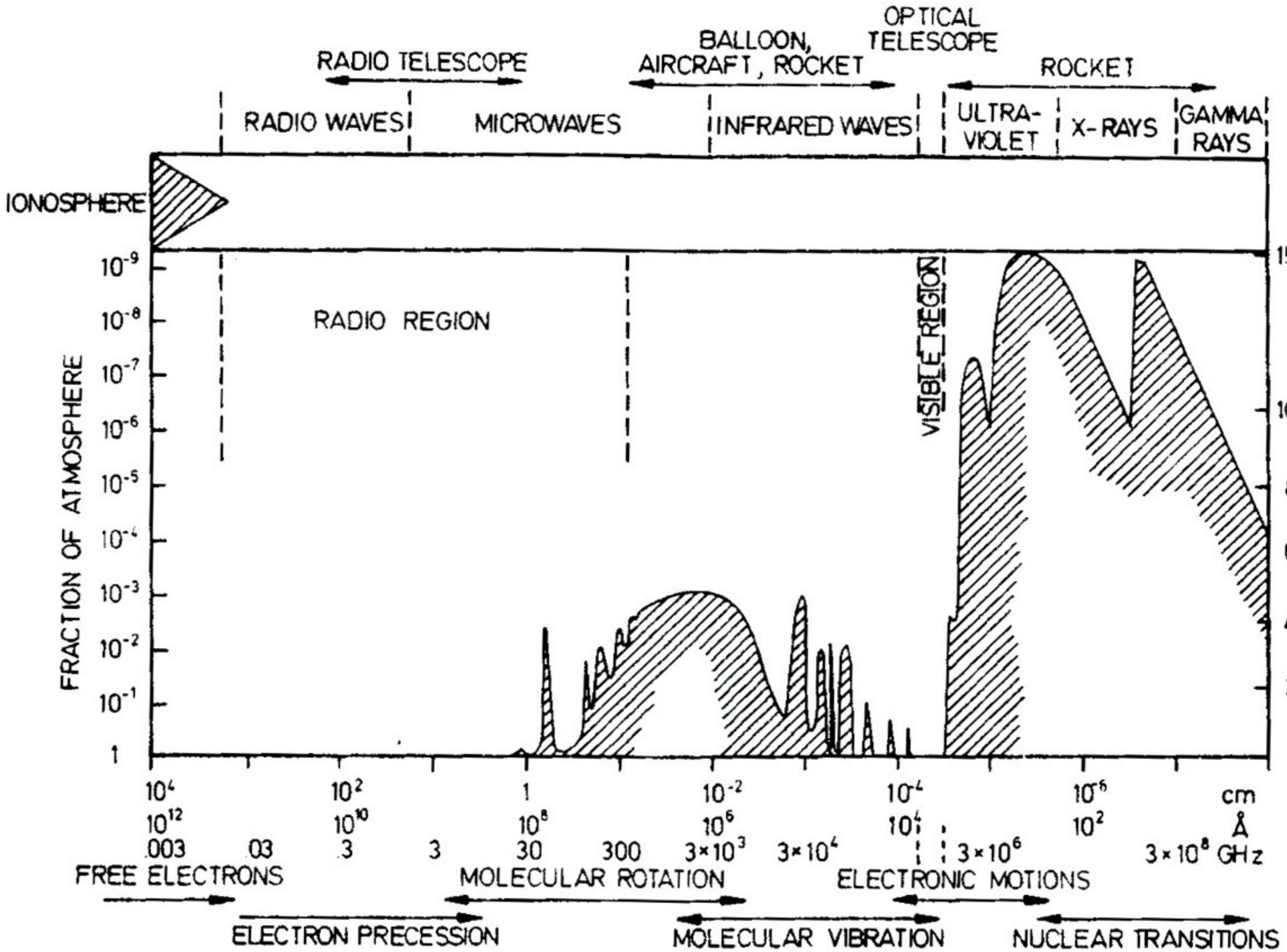
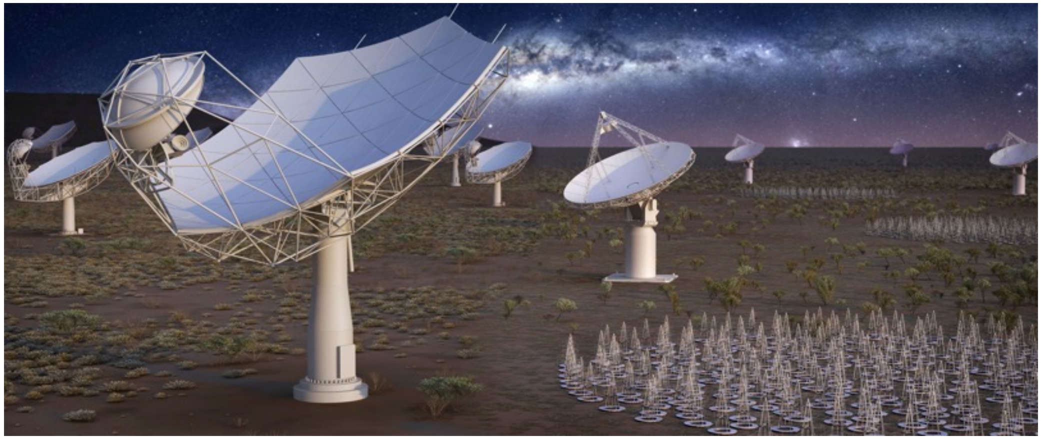


Fig. 1.1. The transmission of the earth's atmosphere for electromagnetic radiation. The diagram gives the height in the atmosphere at which the radiation is attenuated by a factor 1/2

In questa lezione vediamo da vicino due strumenti che per le loro caratteristiche rappresentano lo stato dell’arte.

ALMA (Atacama Large Millimeter Array) operante tra 100 GHz e 1 THz

SKA (Square Kilometer Array) operante tra 70 MHz e 10 GHz



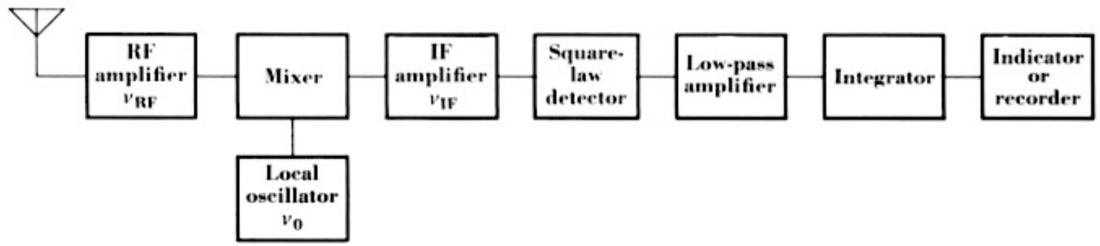
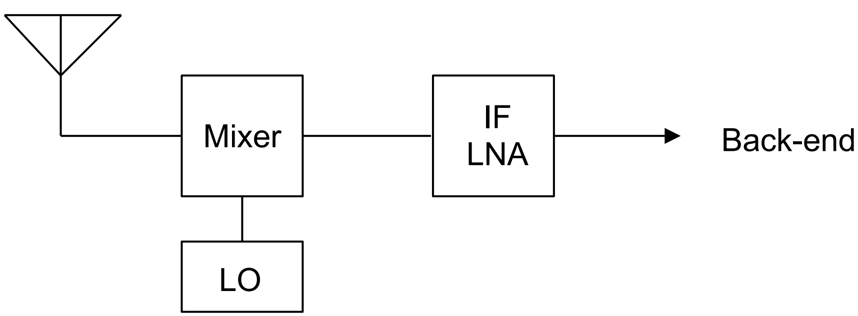


Fig. 7-2. A superheterodyne radio-telescope receiver.

Se la frequenza RF è troppo alta (>100 GHz) gli amplificatori di testa, sebbene siano definiti LNA (Low Noise Amplifier), sono troppo rumorosi.

Soluzione: spostare il mixer prima dell'LNA.



Problema: i mixer convenzionali (a stato solido) non sono sufficientemente sensibili.

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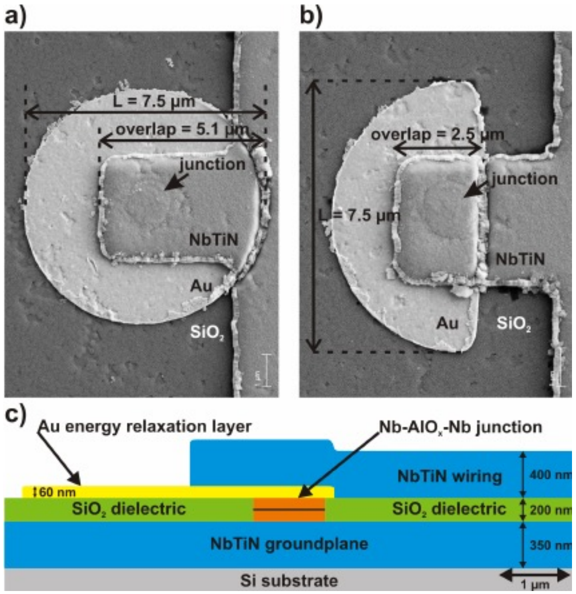


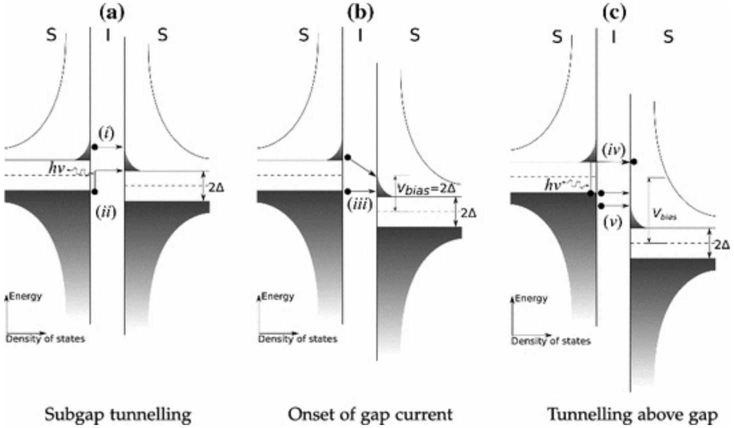
Si parte da una giunzione Josephson costituita da un tristrato superconduttore-isolante-superconduttore (SIS)

Tipicamente Nb-AlOx-Nb con AlOx spesso pochi atomi

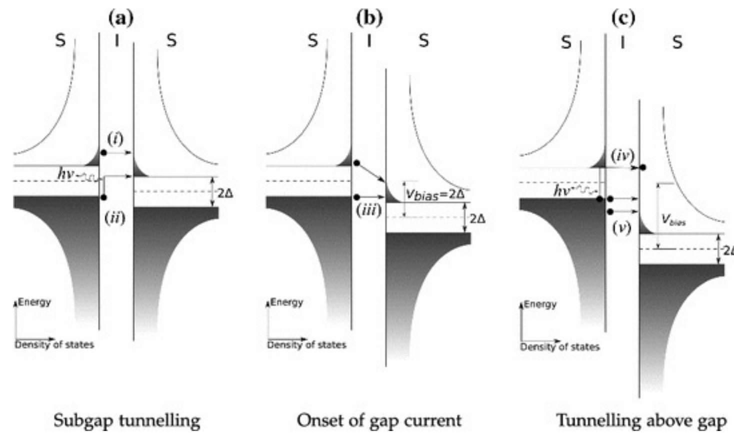
Si usa Nb perché superconduttivo sotto i 9.2K

Elettroni e coppie di Cooper possono attraversare la barriera per effetto tunnel.

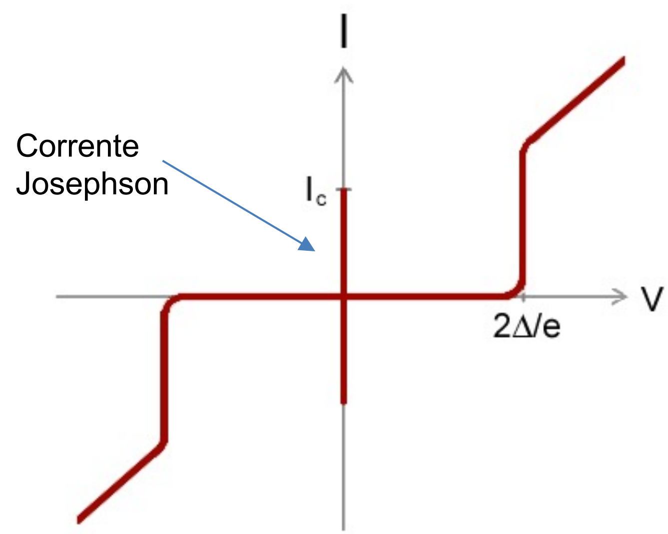
Nei materiali superconduttori allo stato superconduttivo gli elettroni formano coppie debolmente legate (coppie di Cooper) formate da due elettroni.
Queste coppie si comportano da bosoni (avendo spin 0 o 1) e possono occupare lo stato energetico più basso, uguale per tutte le coppie.

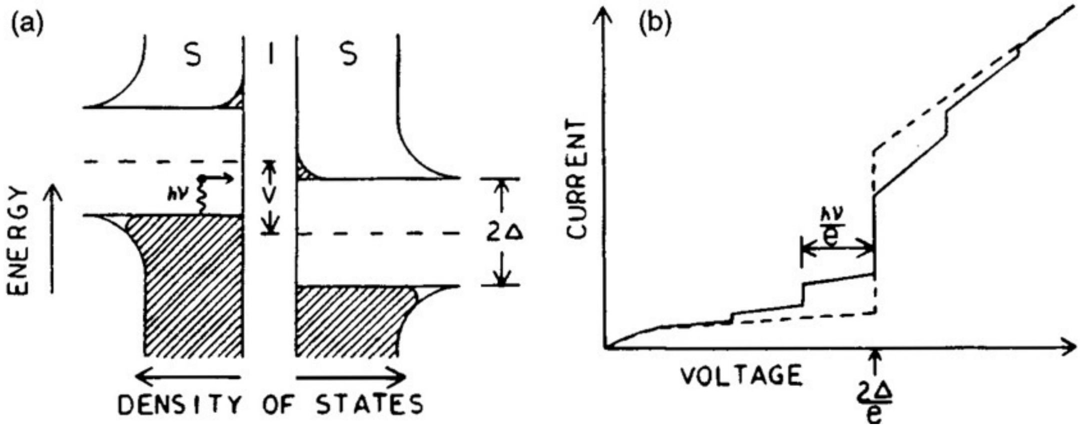


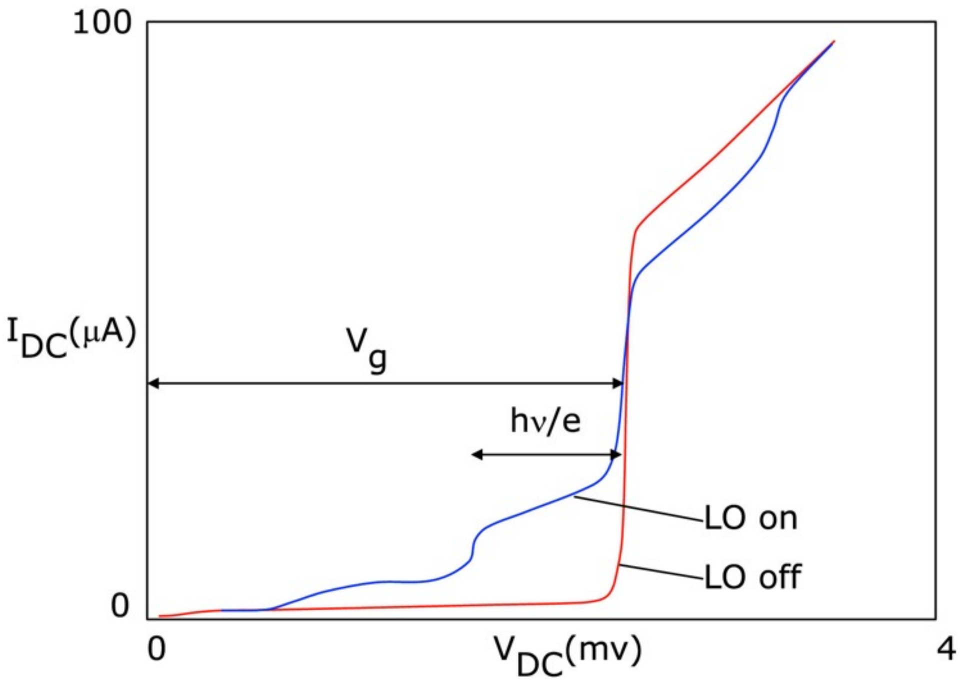
In assenza di differenza di potenziale ai capi della giunzione avviene esclusivamente il tunnel delle coppie di Cooper (a parte quello delle *quasiparticelle* che sono presenti per agitazione termica).



Applicando una differenza di potenziale ai capi della giunzione la corrente non aumenta sino ad un potenziale pari all'energia di legame delle coppie 2Δ/e, quando le coppie si scindono e possono effettuare il tunnel.

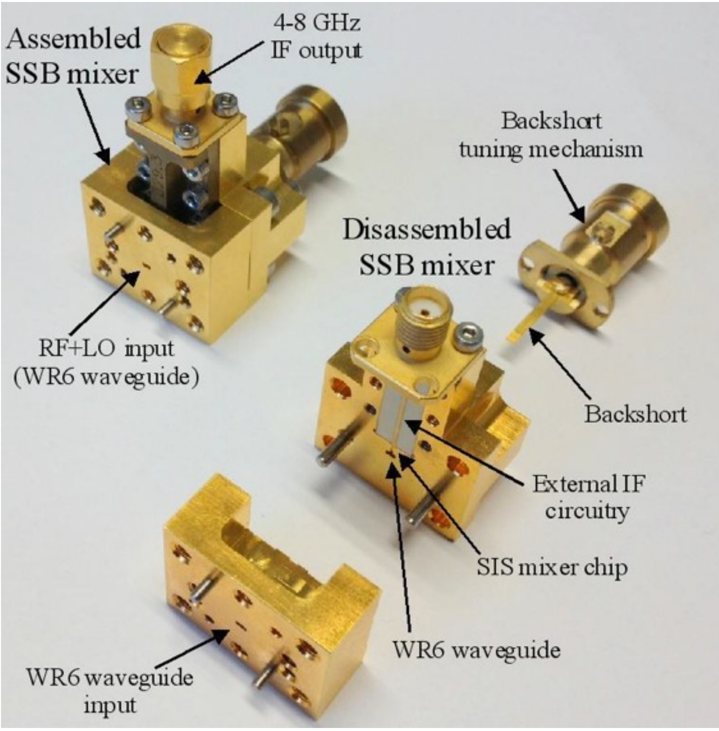




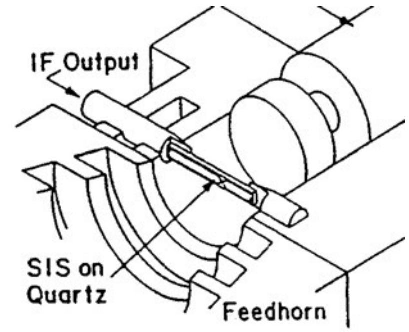


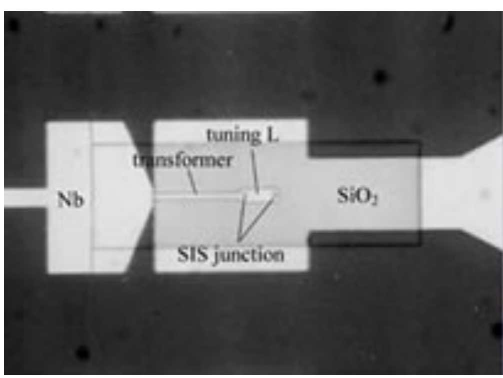
In presenza di un campo di microonde (Oscillatore Locale + RF) il tunnel avviene a tensioni più basse (tunnel *foto-assistito*) e l'ampiezza della corrente che attraversa la barriera è modulata dalla somma e dalla differenza della frequenza dei fotoni e dell'oscillatore locale.

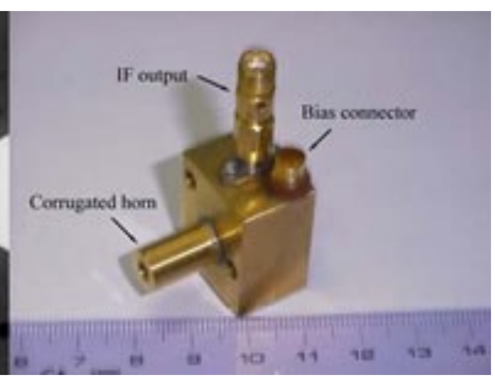
Ne risulta perciò un segnale a frequenza intermedia (IF) come in un mixer tradizionale.

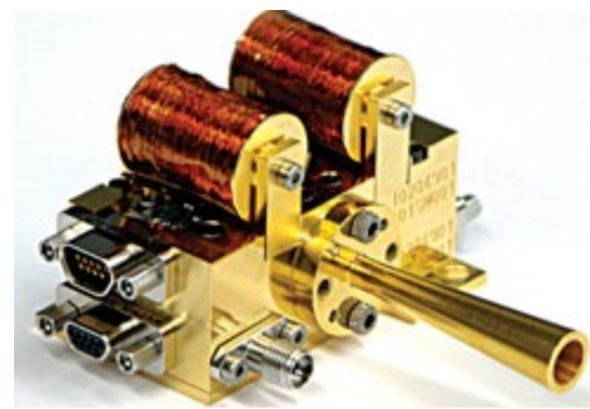


Esempi di front-end SIS dove sono visibili le antenne a tromba che raccolgono l’RF (e spesso anche l’LO), l’uscita dell’IF e le bobine di soppressione della corrente Josephson.



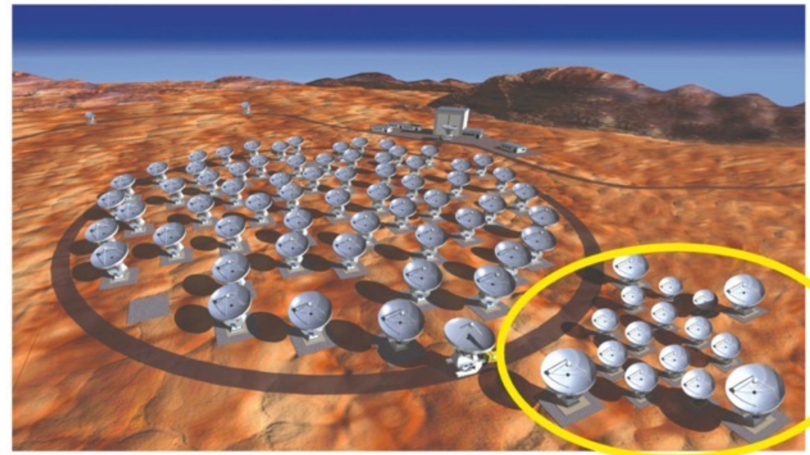






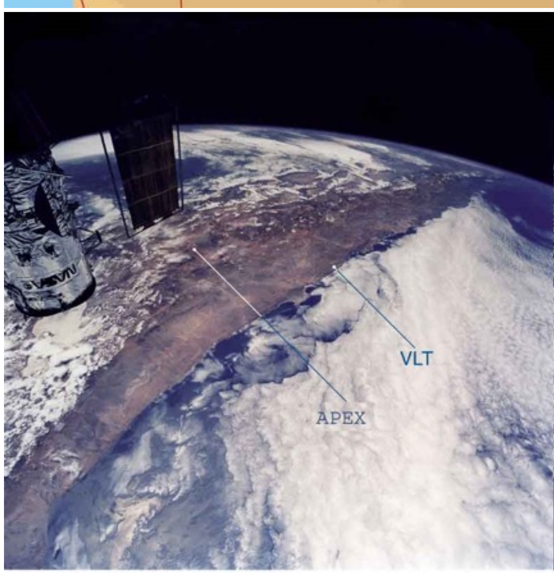
Atacama Large Millimeter Array

http://www.almaobservatory.org



The ACA System

- Twelve (12) 7-meter diameter antennas (18 stations)
- Four (4) 12-meter diameter antennas (4 stations)
- ACA Correlator in AOS building



Strumentazione Astronomica: Radioastronomia

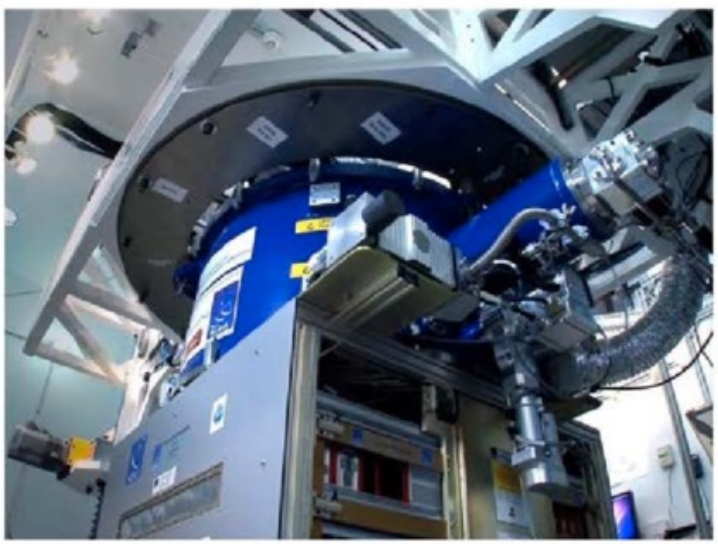
		12m Array	ACA
Array	Altitude	From 5,000m to 5,100m	
	Number of Antennas	64	12(7m) + 4 (12m)
	Total Collecting Area	7240 m^2	460 + 450 m^2
	Angular Resolution	0.02" (λ/1 mm)(10 km/distance)	5.7" (λ/1mm)
	Baseline Lengths	15 - 16,000 m	
Antennas	Diameter	12m	7m, 12m
	Surface Accuracy	<25 μm	<20μm, <25μm
	Offset Pointing	<0.6", 2" all-sky absolute pointing under primary operating conditions	
Correlator	Baselines	up to 2016	120
	Bandwidth	16 GHz per base line	
	Spectral Channels	4096	

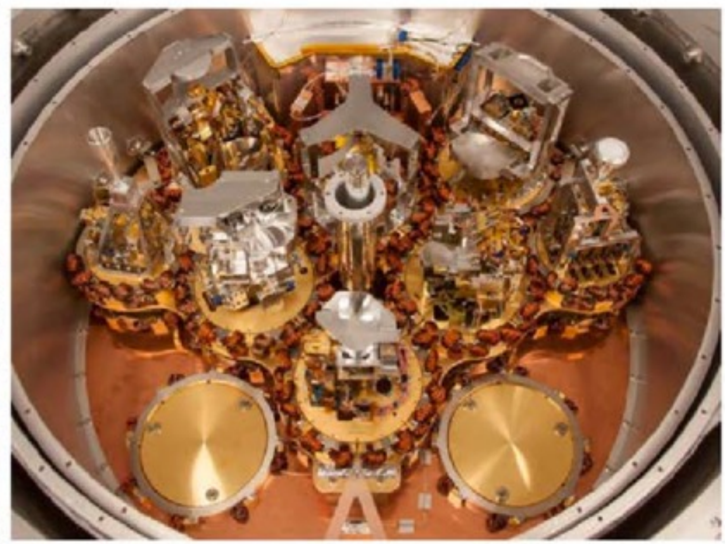
ALMA Band	Frequency Range (GHz)	Receiver Noise over 80% of the RF band	Temperature (K) at any RF Frequency	To be produced by [1]	Receiver Technology
1	31-45	17	26	tbd	HEMT
2	67-90	30	47	tbd	HEMT
3	84-116	37	60	HIA	SIS
4	125-163	51	82	NAOJ	SIS
5*	163-211	65	105	OSO	SIS
6	211-275	83	136	NRAO	SIS
7	275-373	147	219	IRAM	SIS
8	385-500	196	292	NAOJ	SIS
9	602-720	175	261	NOVA	SIS
10	787-950	230	344	NAOJ	SIS

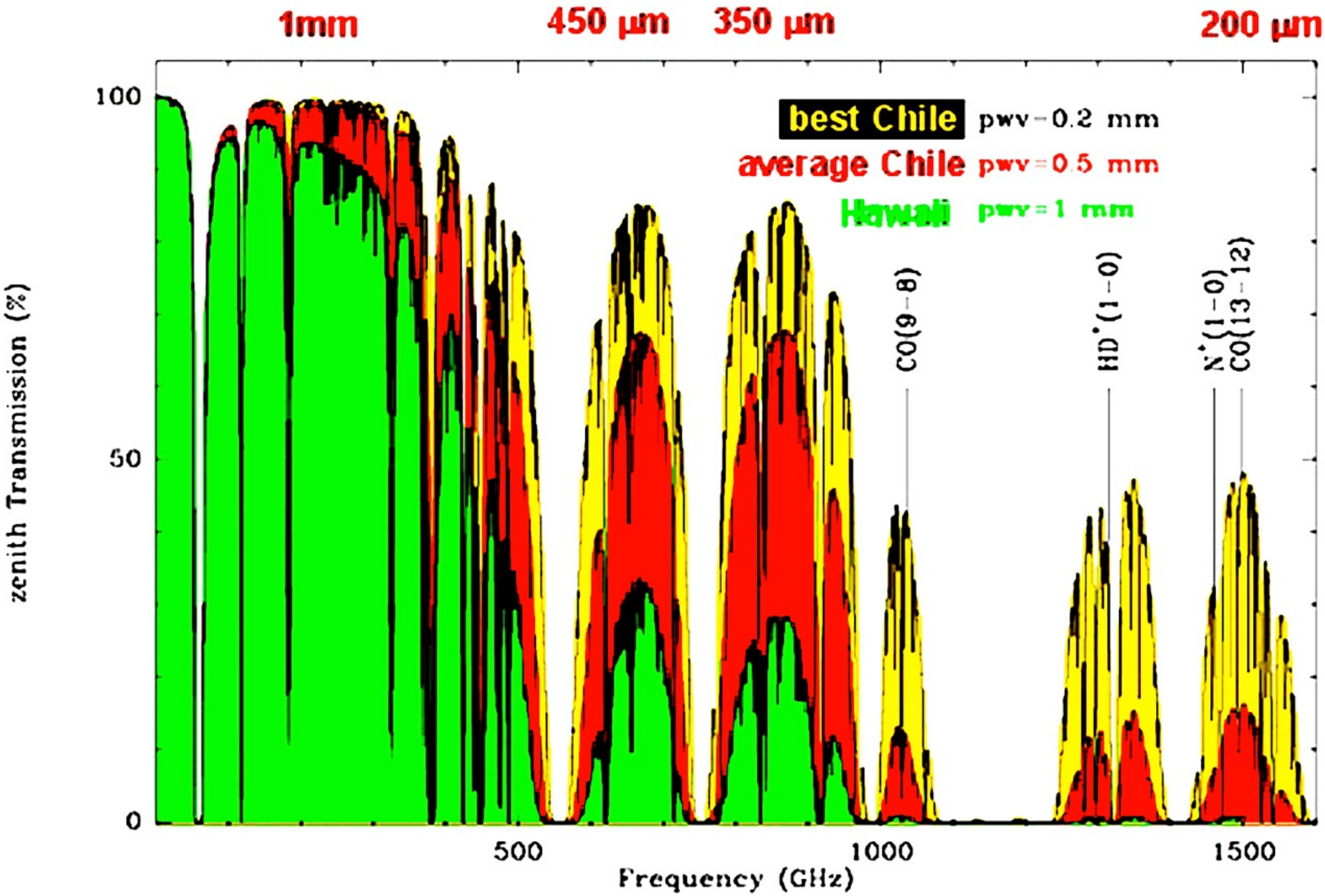
[1]tbd: to be decided
IRAM: Institut de Radio Astronomie Millimétrique (Grenoble, France)
HIA: Herzberg Institute of Astrophysics (Victoria, Canada)
NAOJ: National Astronomical Observatory of Japan (Mitaka, Japan)
NOVA: Nederlandse Onderzoekschool voor Astronomie (Groningen, the Netherlands)
NRAO: National Radio Astronomy Observatory (Charlottesville, USA)
OSO: Onsala Space Observatory/Chalmers University (Onsala, Sweden)
* EU FP6 receivers from Onsala

Strumentazione Astronomica: Radioastronomia

Strumentazione Astronomica: Radioastronomia






1mm
450 µm
350 µm
200 µm
best Chile pwv=0.2 mm
average Chile pwv=0.5 mm
Hawaii pwv=1 mm
CO(9−8)
HD⁺(1−0)
N⁺(1−0)
CO(13−12)
100
50
0
500
1000
1500
zenith Transmission (%)
Frequency (GHz)

Strumentazione Astronomica: Radioastronomia

Bande unificate con utilizzo di HEMT

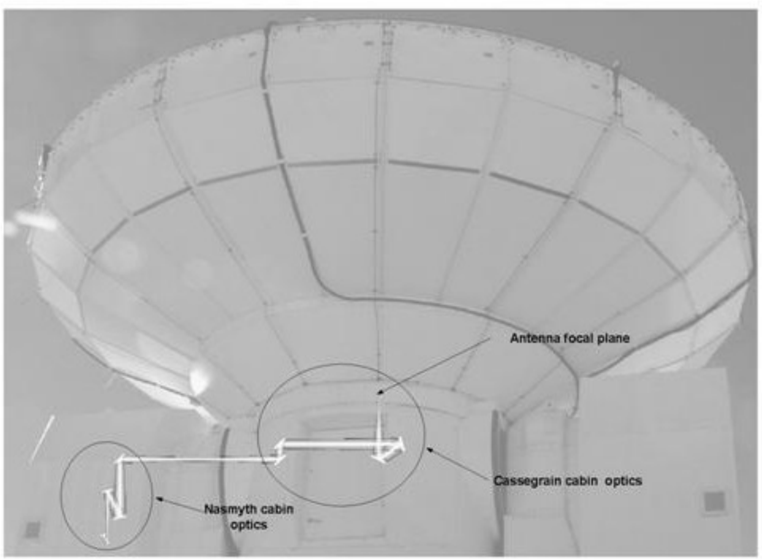
ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Receiver technology
		T_{Rx} over 80% of the RF band	T_{Rx} at any RF frequency		
1	31.3 – 45 GHz	17 K	28 K	USB	HEMT
2	67 – 90 GHz	30 K	50 K	LSB	HEMT
3	84 – 116 GHz	37 K	62 K	2SB	SIS
4	125 – 169 GHz	51 K	85 K	2SB	SIS
5	163 - 211 GHz	65 K	108 K	2SB	SIS
6	211 – 275 GHz	83 K	138 K	2SB	SIS
7	275 – 373 GHz*	147 K	221 K	2SB	SIS
8	385 – 500 GHz	98 K	147 K	DSB	SIS
9	602 – 720 GHz	175 K	263 K	DSB	SIS
10	787 – 950 GHz	230 K	345 K	DSB	SIS

* - between 370 – 373 GHz T_{rx} is less then 300 K

- Dual, linear polarization channels:
  - Increased sensitivity
  - Measurement of 4 Stokes parameters
- 183 GHz water vapour radiometer:
  - Used for atmospheric path length correction

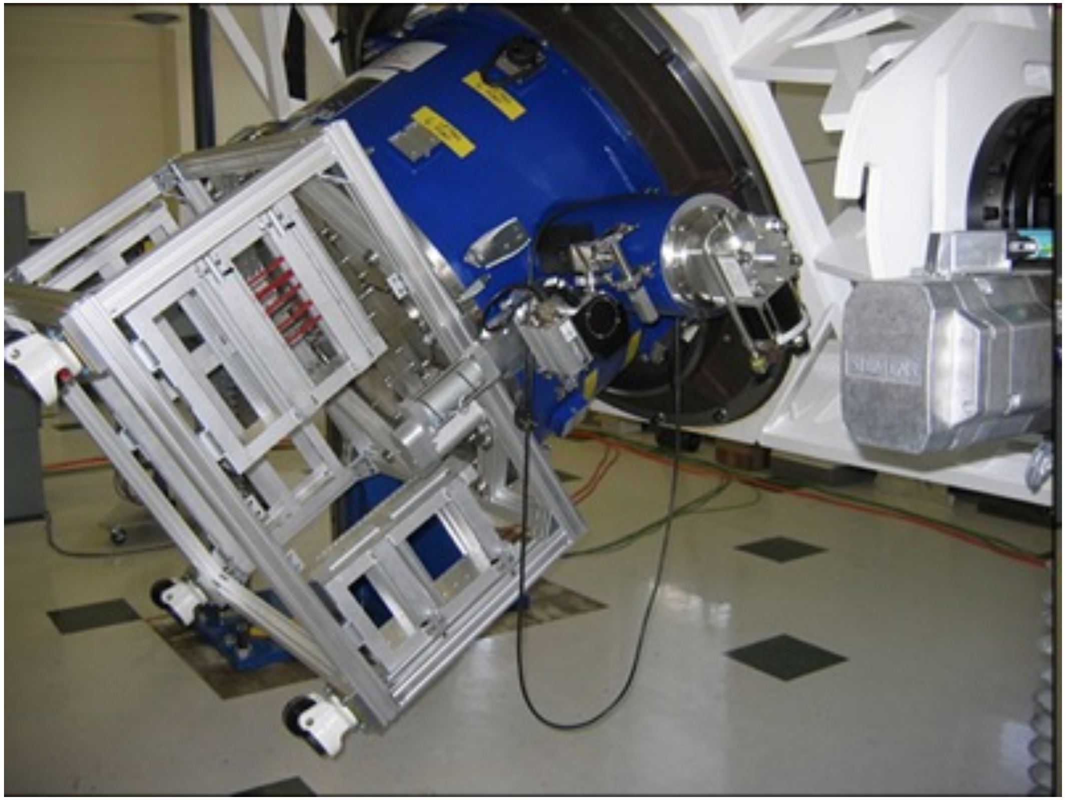
APEX: Atacama Pathfinder Experiment

Prototipo di antenna di ALMA
oggi usata per altre osservazioni nello stesso dominio di frequenza

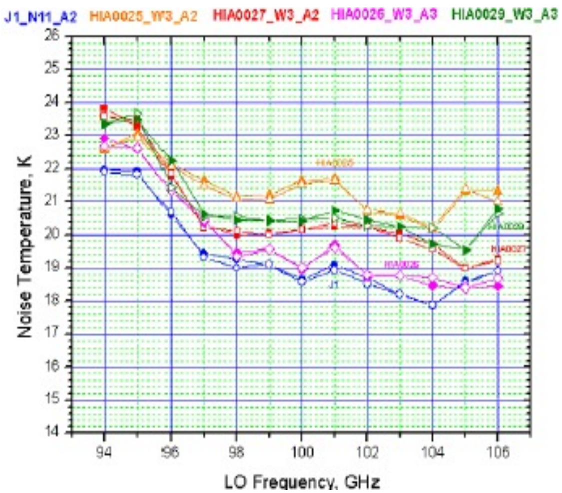


Visualizzazione del percorso dei fotoni dal fuoco Cassegrein al fuoco Nasmyth

Strumentazione Astronomica: Radioastronomia



Criostato che ospita le cartucce con i differenti ricevitori raffreddati dal criogeneratore.

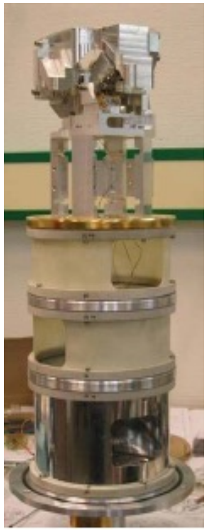


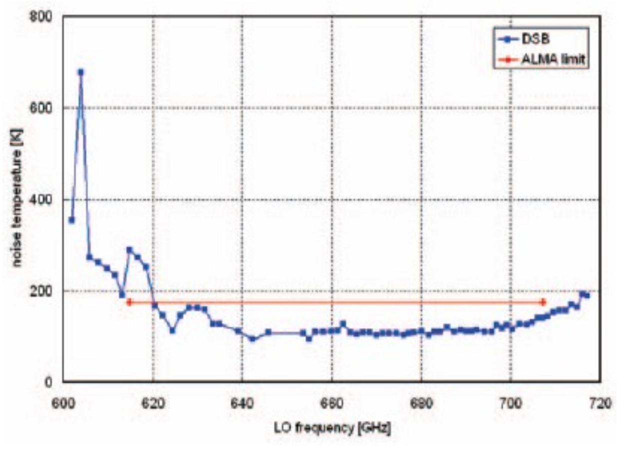
Band 3 (“3mm”)

Esempio di cartridge (letteralmente ‘cartucce’) di front-end di ALMA

Da notare la temperatura di rumore (TN).

I migliori LNA hanno una TN che scala circa come 0.5K/GHz.
Nel caso della Banda 3 il rumore è un fattore 2 più basso.
Sopra ai 150-200 GHz i migliori LNA hanno TN di centinaia di K





Band 9 (“450μm”)

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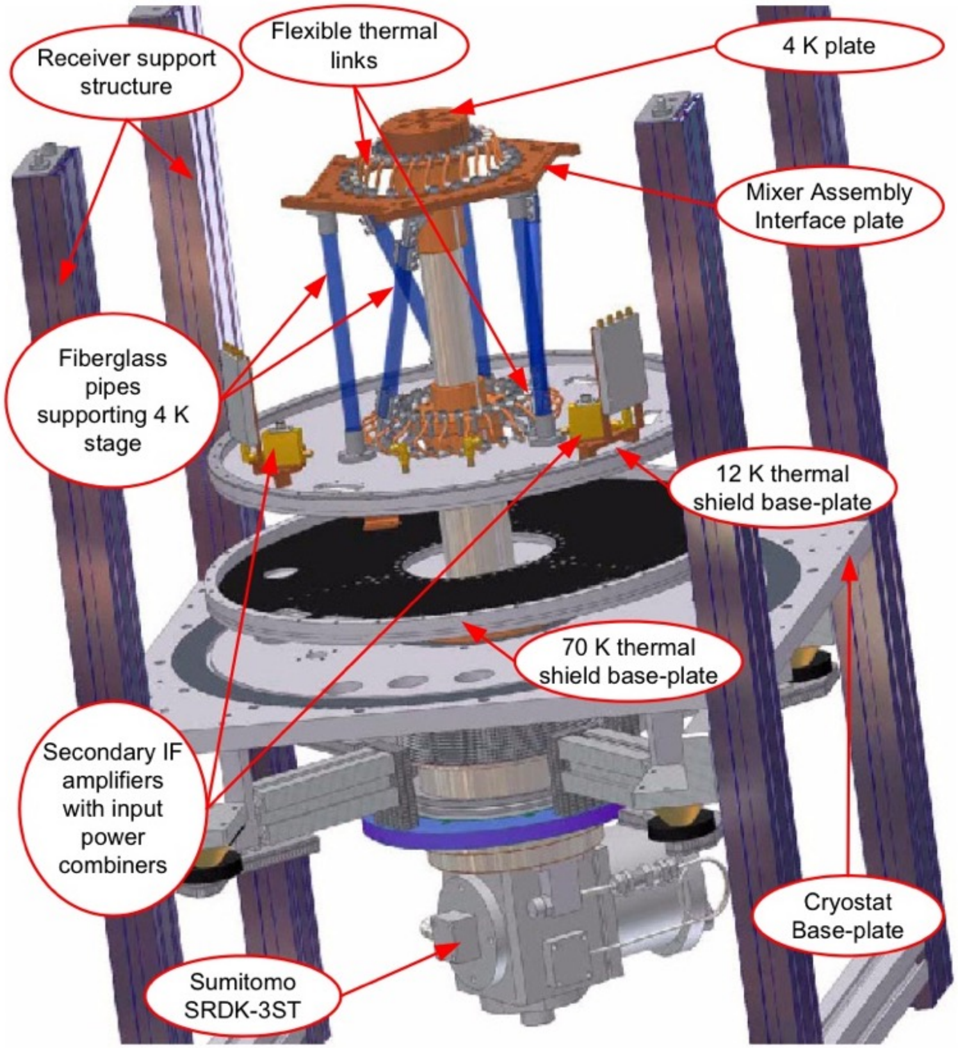
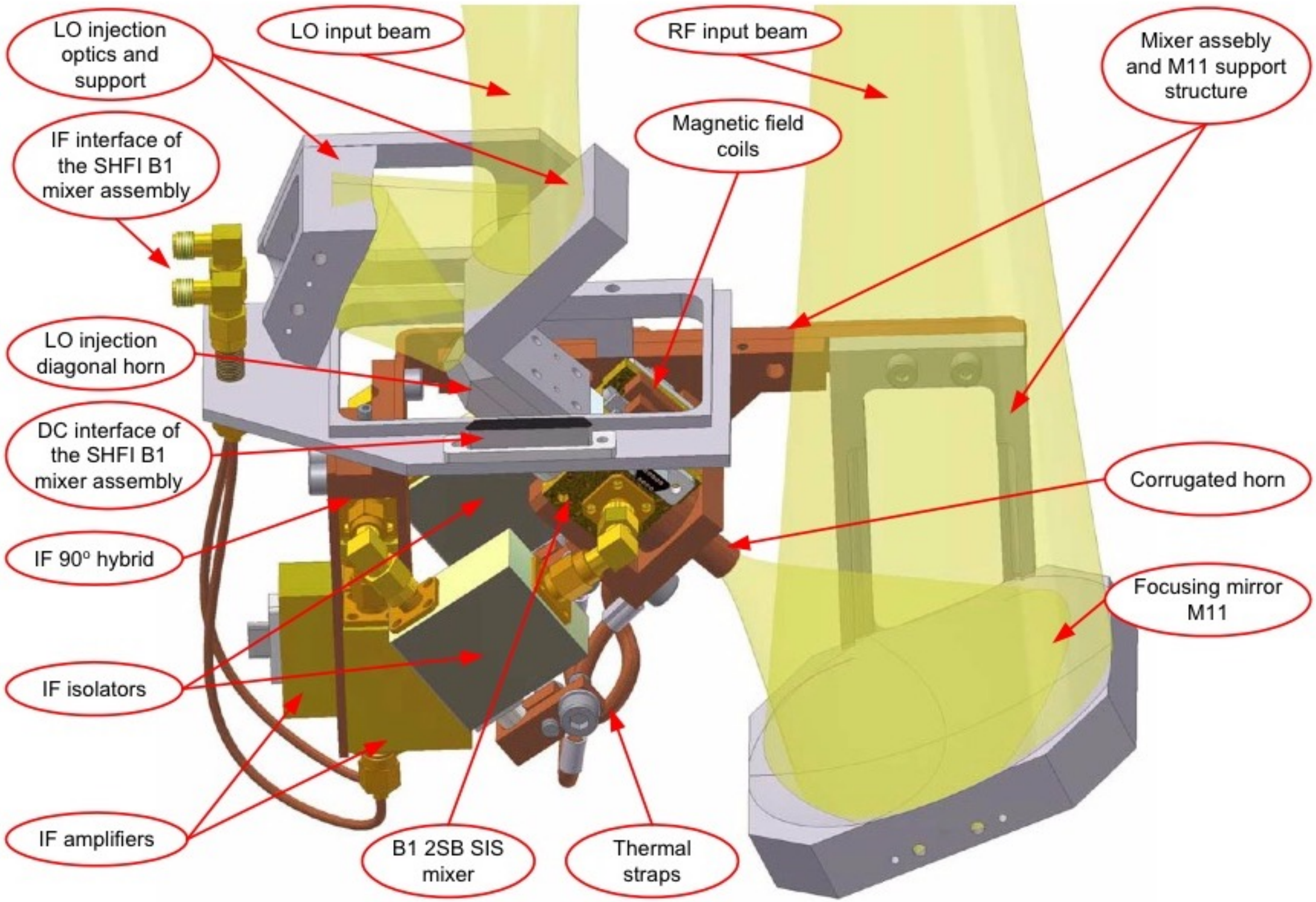
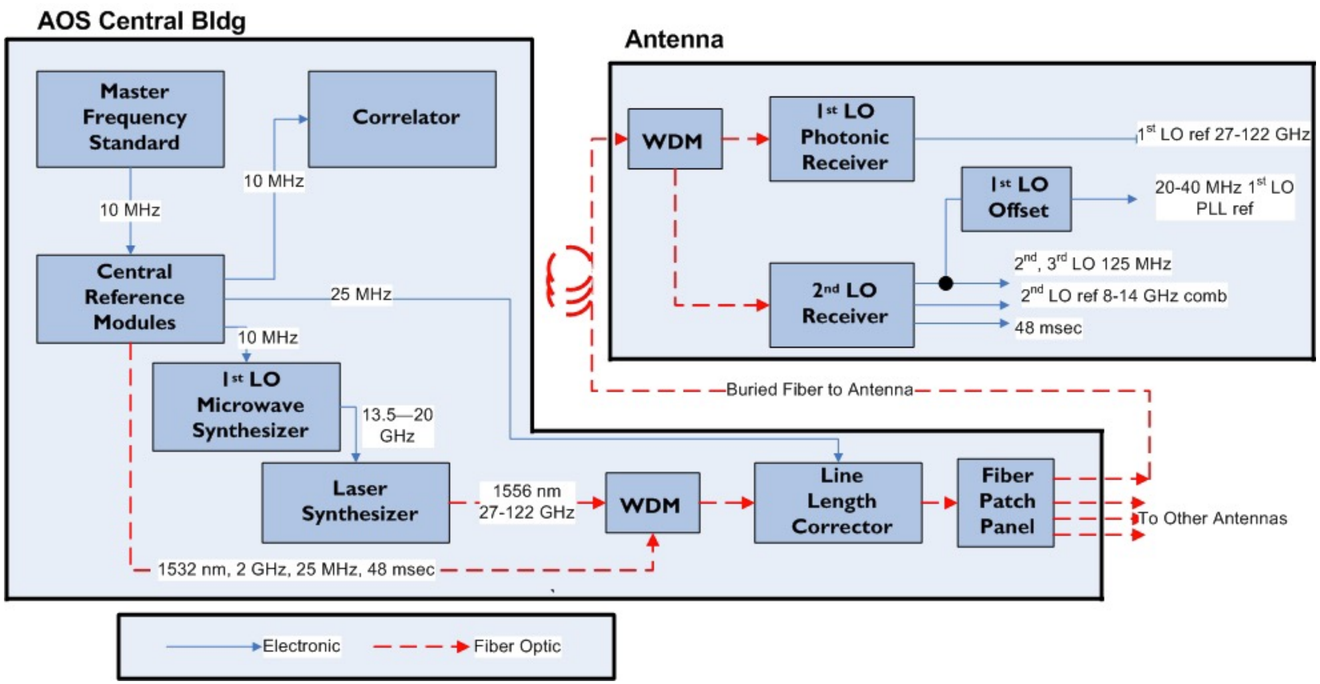


In questo modello solido è messo in evidenza il sistema criogenico.
Ci sarà una lezione dedicata alle tecniche criogeniche.



Modello solido di un front-end di ALMA con ingresso dell'LO da un secondo illuminatore.

Come mantenere la coerenza fra le antenne?
Un oscillatore locale distribuito, a queste frequenze e a queste distanze, è impraticabile (insertion loss).
Si ricorre ad un sistema basato sui battimenti di due laser IR che propagano in fibra ottica sino ad ogni antenna.



Come mantenere la coerenza fra le antenne?
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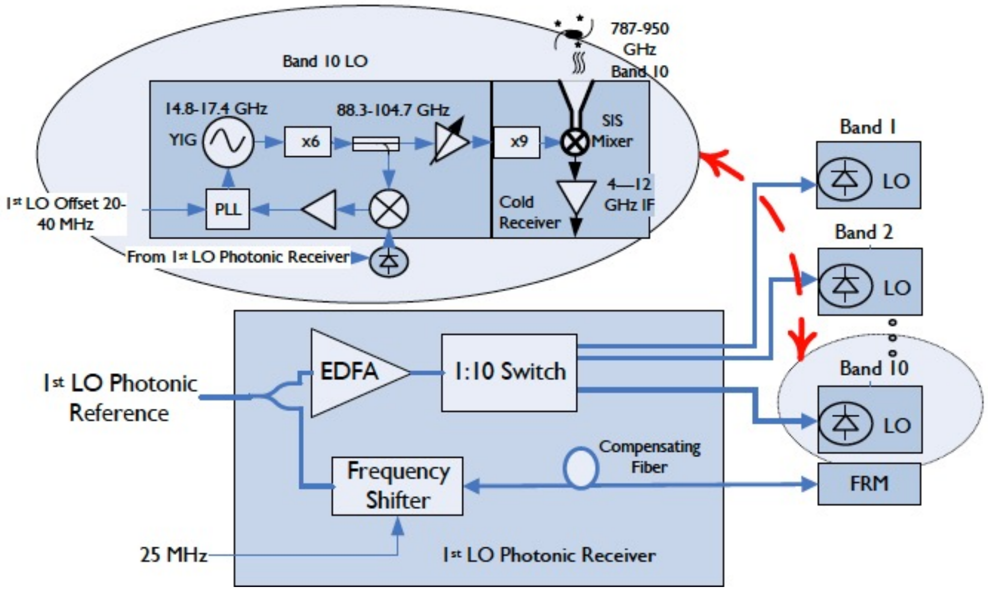
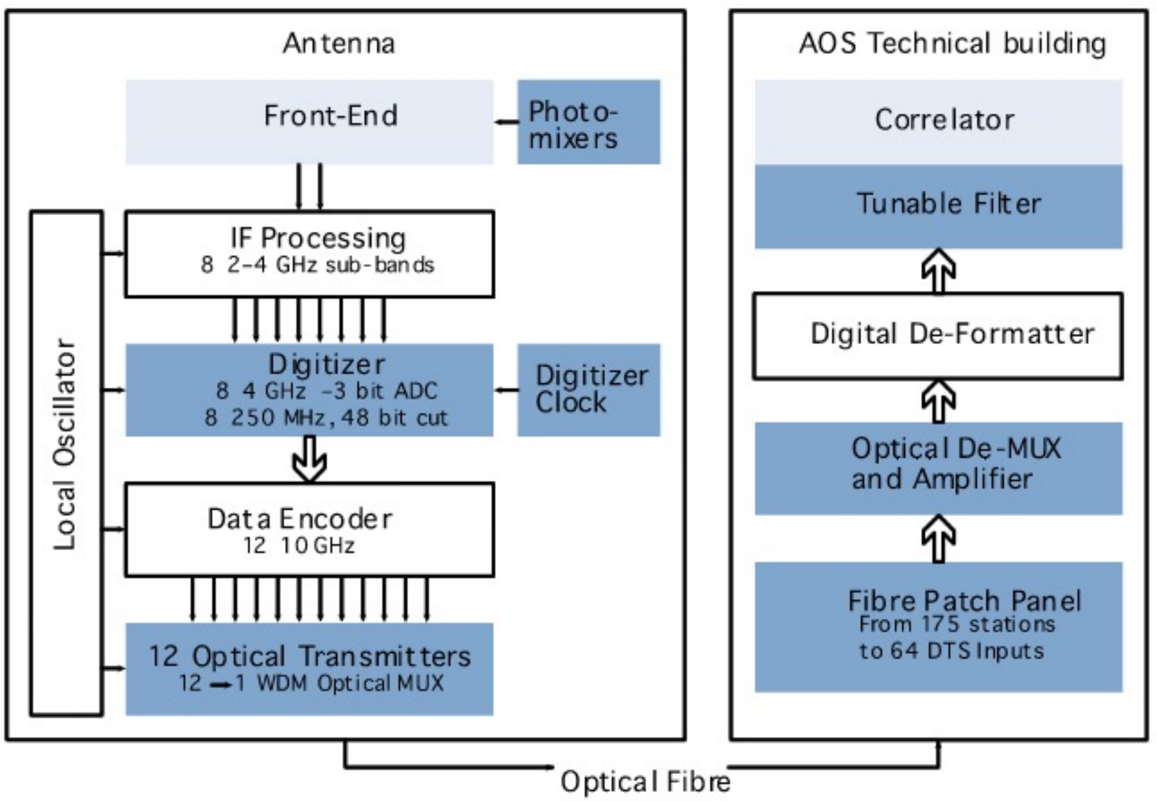


LO generato dal segnale di un fotorivelatore che *vede* i battimenti tra i due laser

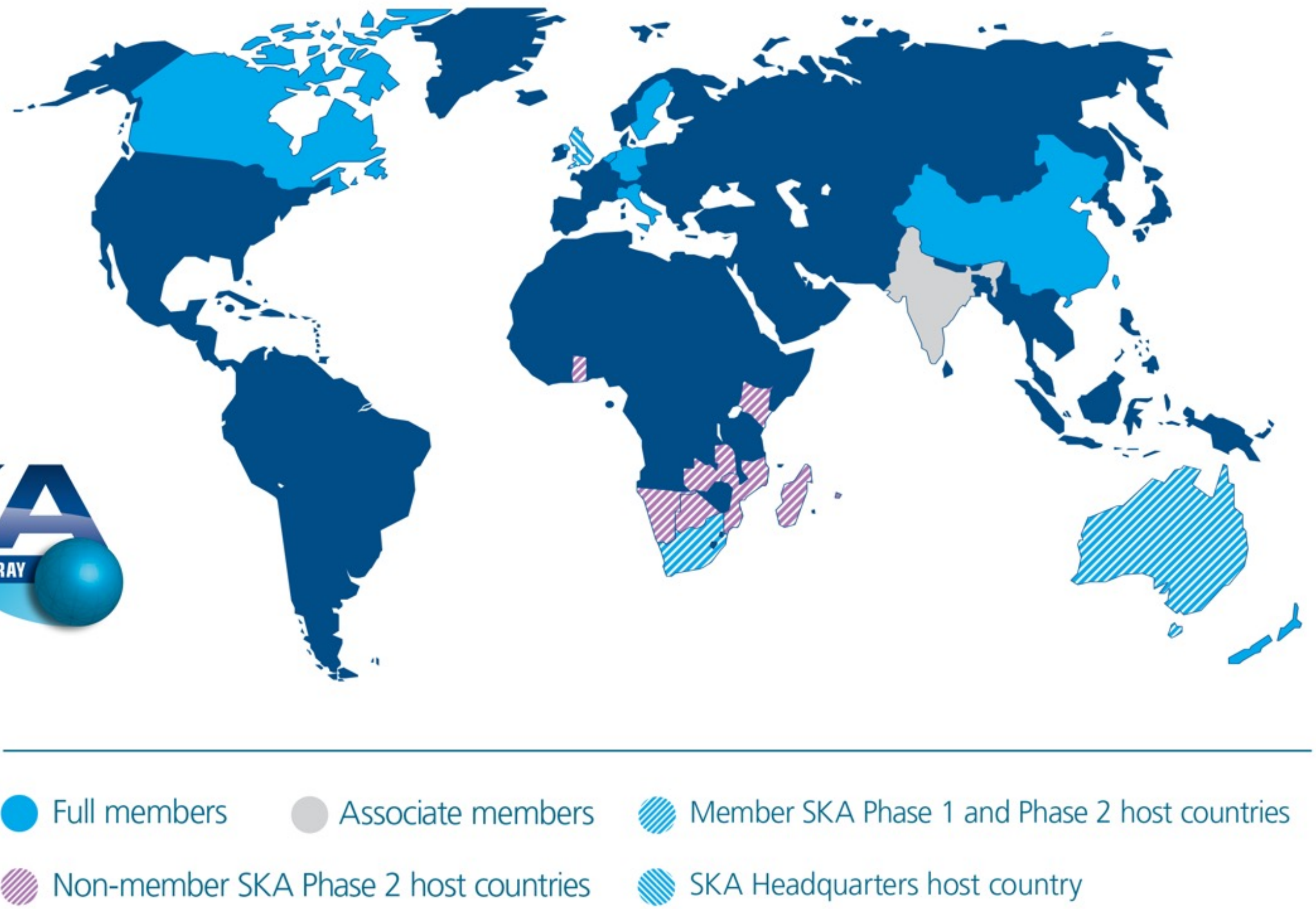
Strumentazione Astronomica: Radioastronomia



Il correlatore di ALMA è uno dei Supercomputer più potenti al mondo. Esegue $1.7x10^{16}$ operazioni al secondo

SKA sarà il radiotelescopio più sensibile e potente dei prossimi 50 anni.
Nessuna tecnologia particolarmente raffinata, ma area di raccolta enorme.

SQUARE KILOMETRE ARRAY



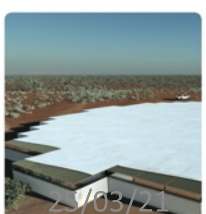
SKA SQUARE KILOMETRE ARRAY

www.skatelescope.org

Timeline

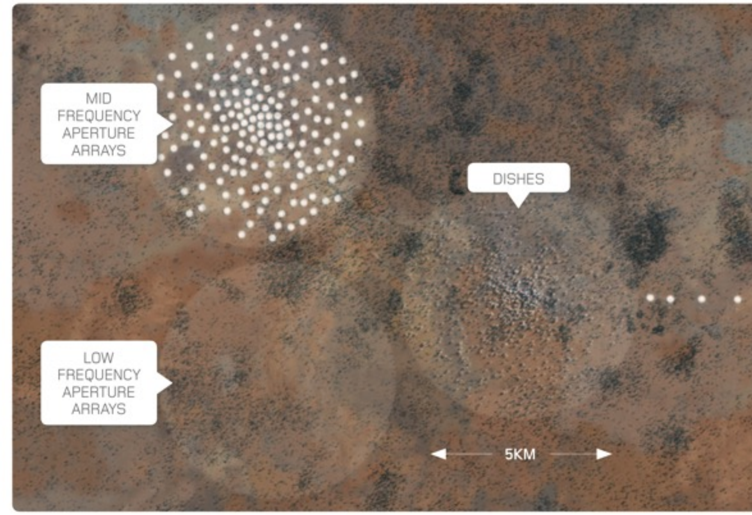
Five stages of development of the SKA are planned:

2008-2012	System design and costing.
2012	Site decision.
2013-2015	Detailed design and production engineering.
2016	Initial construction.
2019	First science.
2023	Completion of construction and commissioning.
2024	Full operation.



The ambition and scale of the SKA projects demand innovative technical developments.

The SKA will use 3 000 dishes, each about 15 m wide. Two other types of receptor, known as aperture arrays, will also be used to observe very large areas of the sky simultaneously. The antennas will cover the frequency range 70 MHz to 10 GHz (4 m to 3 cm wavelength).



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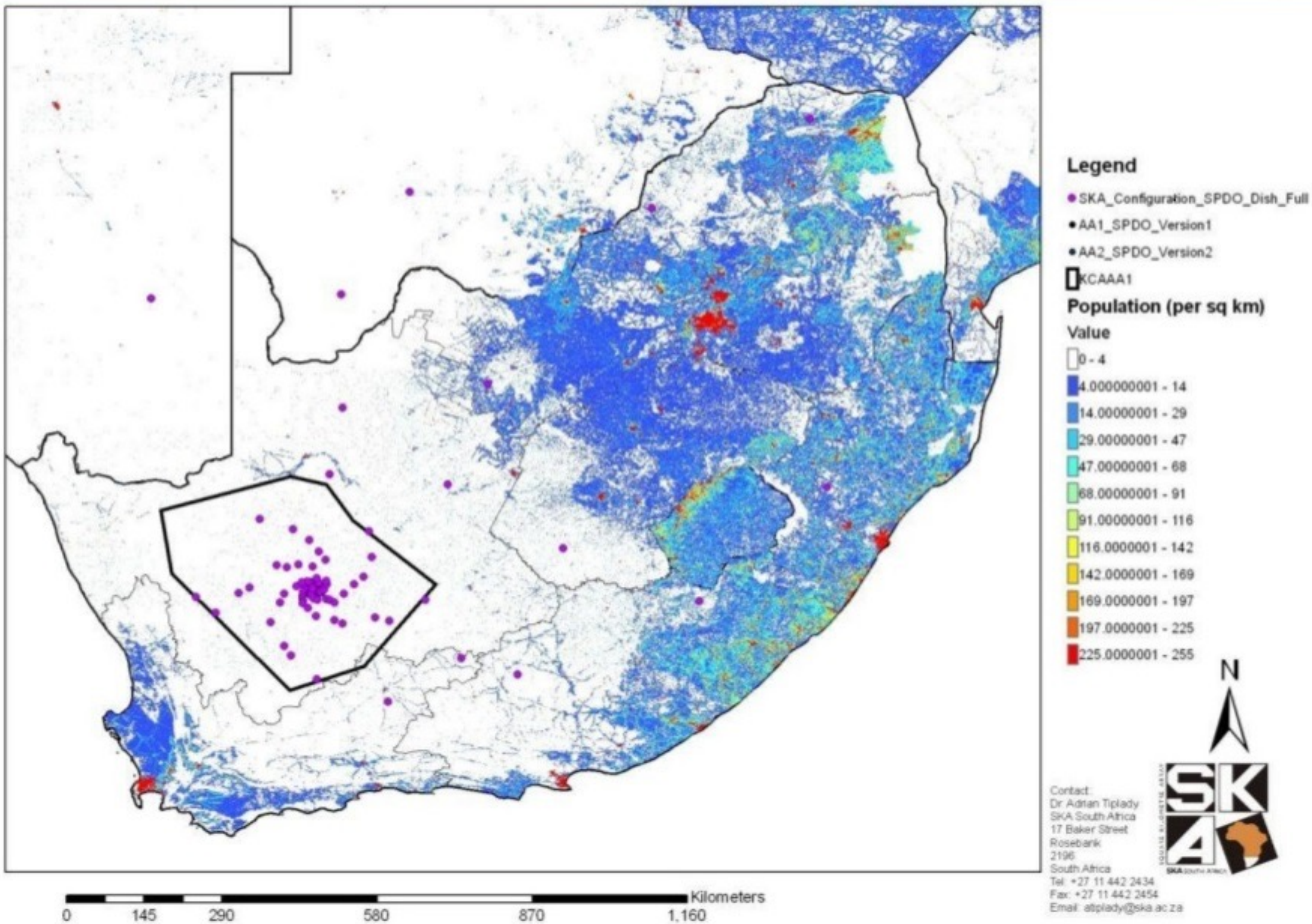

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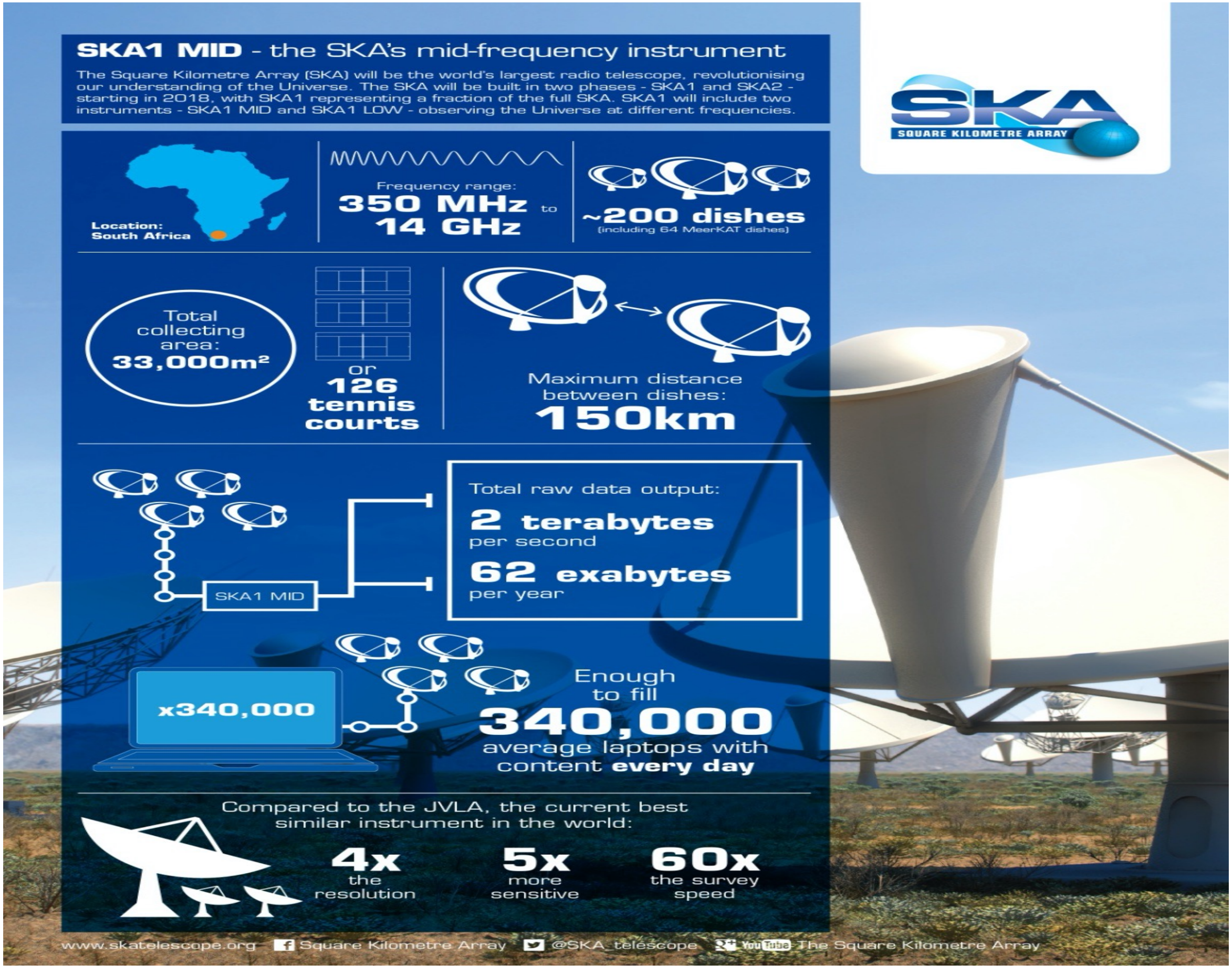


Strumentazione Astronomica: Radioastronomia

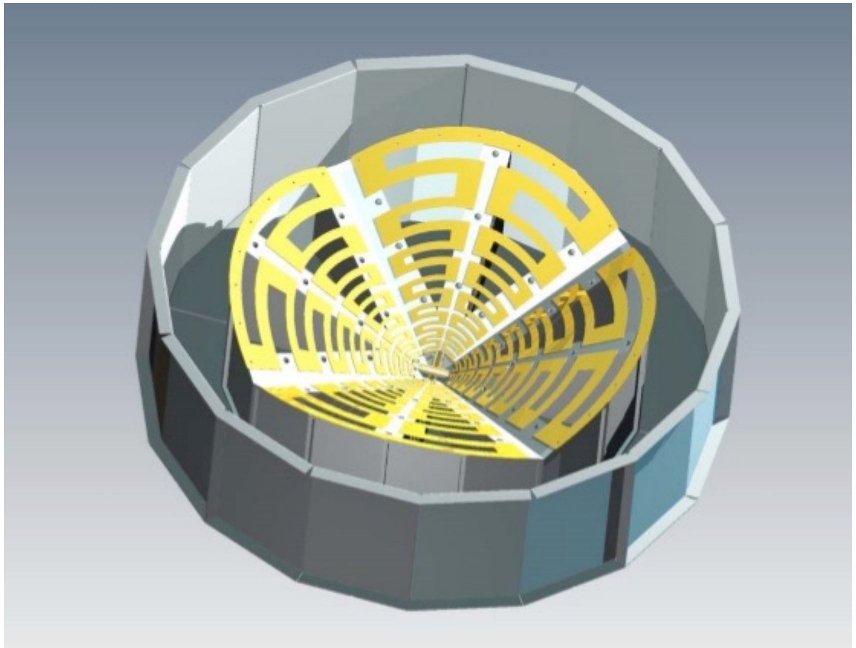
Specifiche

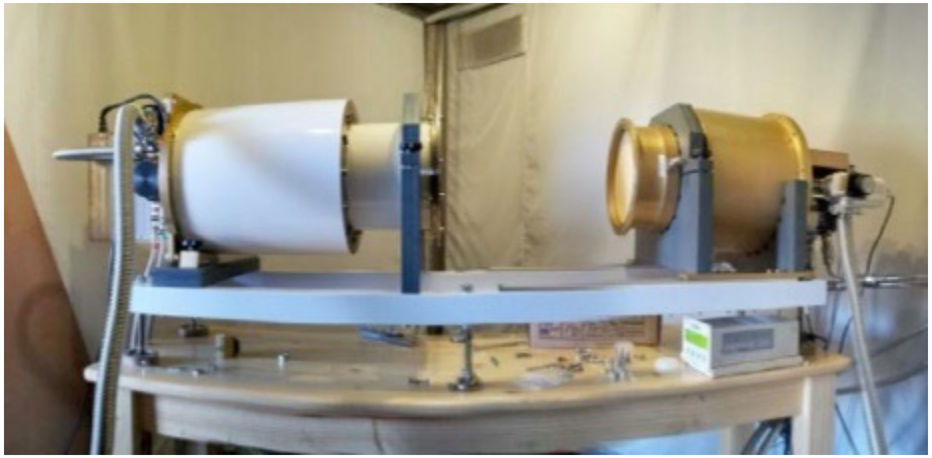
Equivalent physical aperture diameter	15 m	
Low Frequency	350 MHz	
High Frequency	20 GHz	
Optics	Clear aperture	
1st sidelobe	-21 dB	
Far-out sidelobe level	<-50 dB	
Polarization purity	-30 dB	Within HPBW
Beam symmetry	TBD	
Receivers	5	Cryo-cooled, spanning frequency range
Elevation limit	<15 deg	
Azimuth range	±270 deg	
Pointing repeatability	10, 17,180 arcsec	P, S, D respectively arcsec, rms
Receiver noise temperature & Feed Losses	<15 K	Assumed for performance estimates
Classes of Environmental Operating Conditions	Precision	Wind <7 m/s; night
	Standard	Wind <7 m/s; day
	Degraded	Wind <20 m/s
Operation	continuous	Except for extreme weather.

Table 2 Summary of the most important Dish Performance Requirements – Extracted from [5, Sect. 7, Table 5].

Strumentazione Astronomica: Radioastronomia

Band #.	Band (GHz)	RF BW	IF BW (GHz)	Antenna & Feed Efficiency
Band 1	0.35 – 1.05	3:1	1	0.65 @ 400 MHz 0.78 above 600 MHz
Band 2	0.95 – 1.76	1.85:1	1	0.78
Band 3	1.65 – 3.05	1.85:1	2.5	0.78
Band 4	2.8 – 5.18	1.85:1	2.5	0.78
Band 5	4.6 – 13.8	3:1	2.5	0.78 @ 8 GHz 0.7 above 8 GHz





Banda 1 (a sinistra, riproduzione con CAD) e banda 2 (sopra, su banco di prova per testare il rumore)

SKA 1

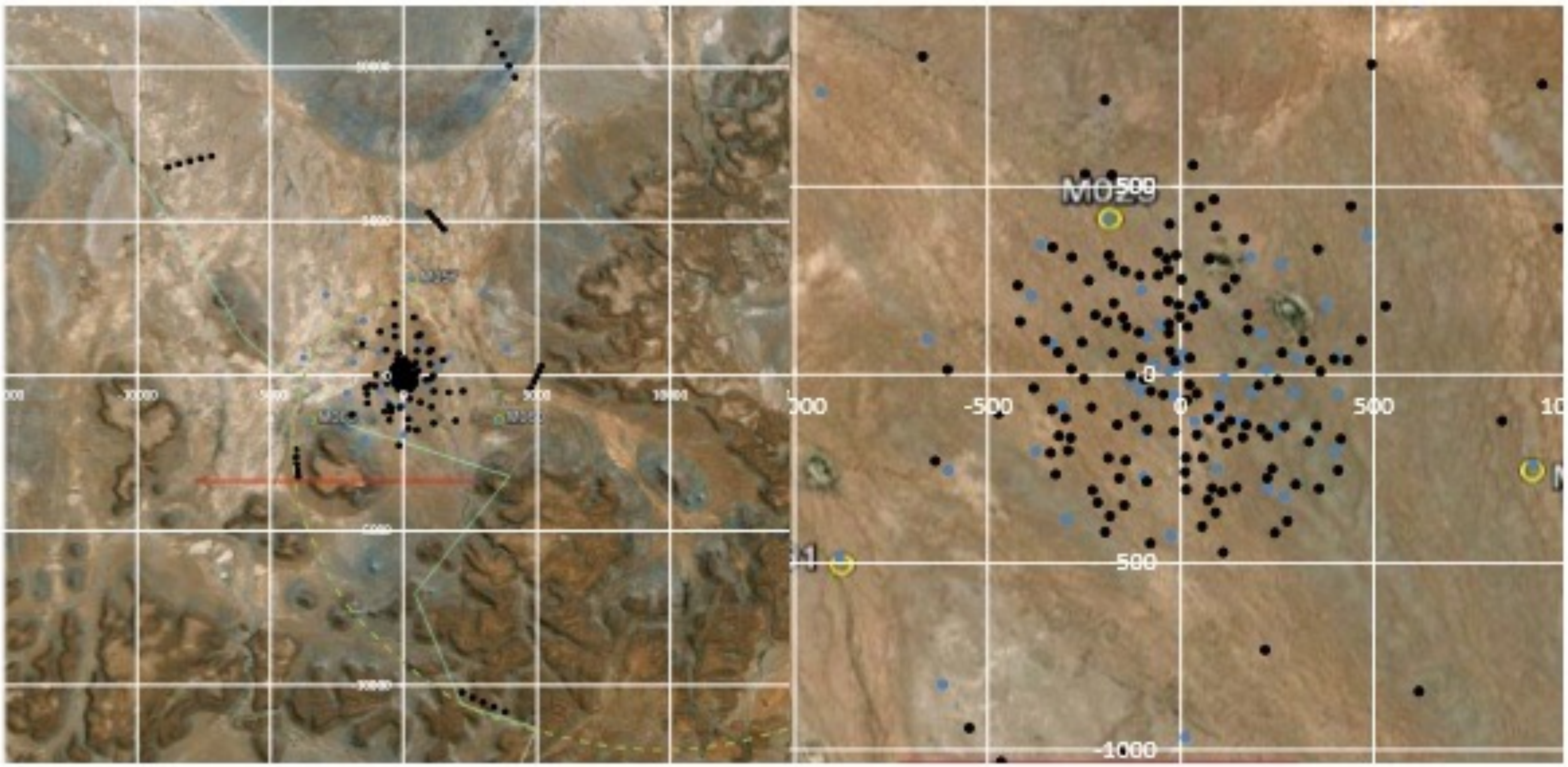


Figure 12 The generic SKA1-mid configuration superimposed on the site topology. No attempt here has been made to adapt to the landscape or other mask components. The black dots are SKA dishes; blue are MeerKAT dishes. The black dots are drawn from a 250-dish configuration and represent an over-density in the core.

SKA 2

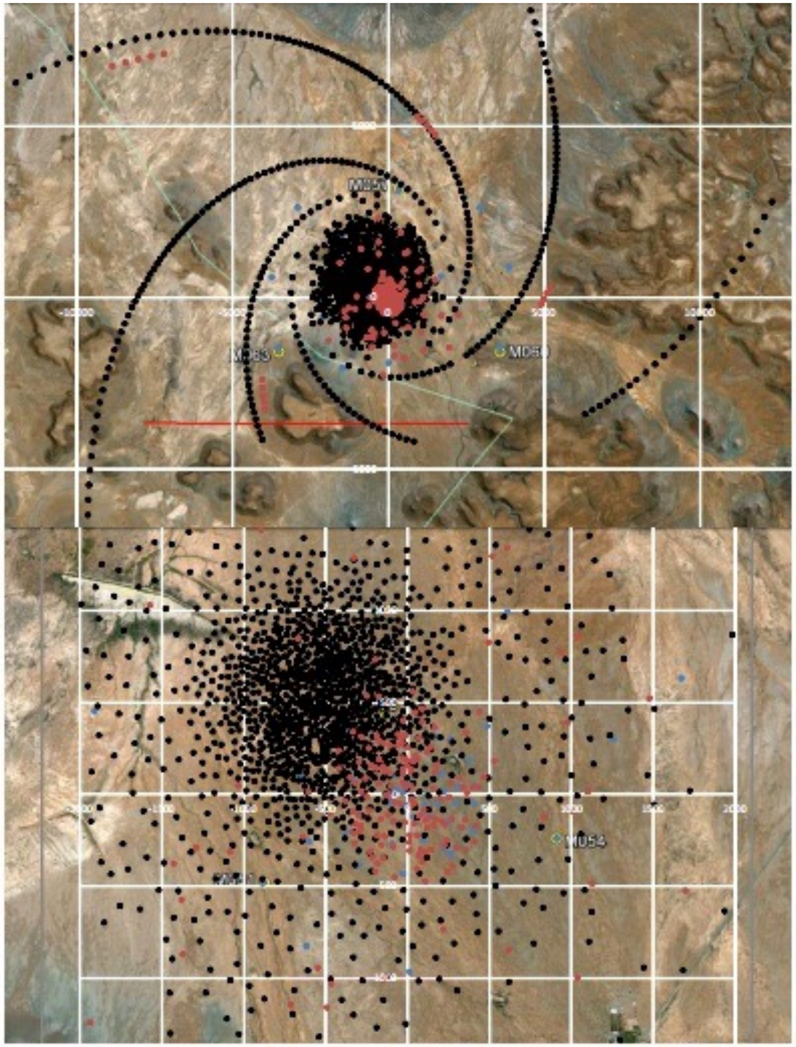


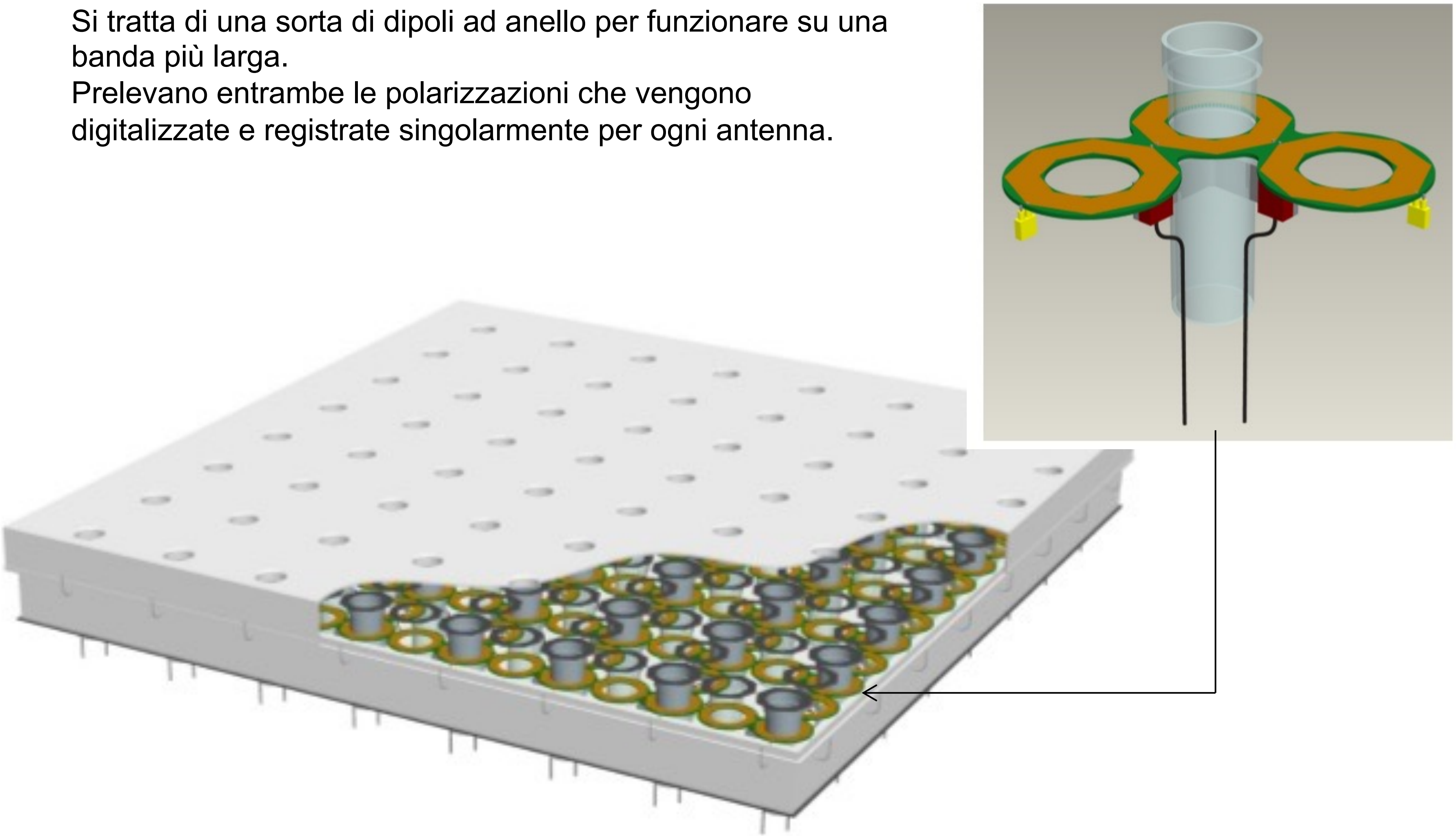
Figure 13 The generic SKA2 configuration with the SKA1 configuration embedded in a position in which the antenna densities of the two configurations are matched. Red dots are SKA1; blue are MeerKAT; black are SKA2 antennas.

Mid-Frequency Aperture Array

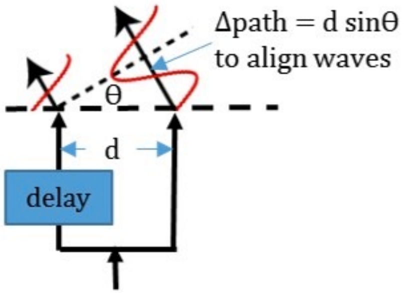
Andranno a coprire la frequenza tra 200 – 500 MHz

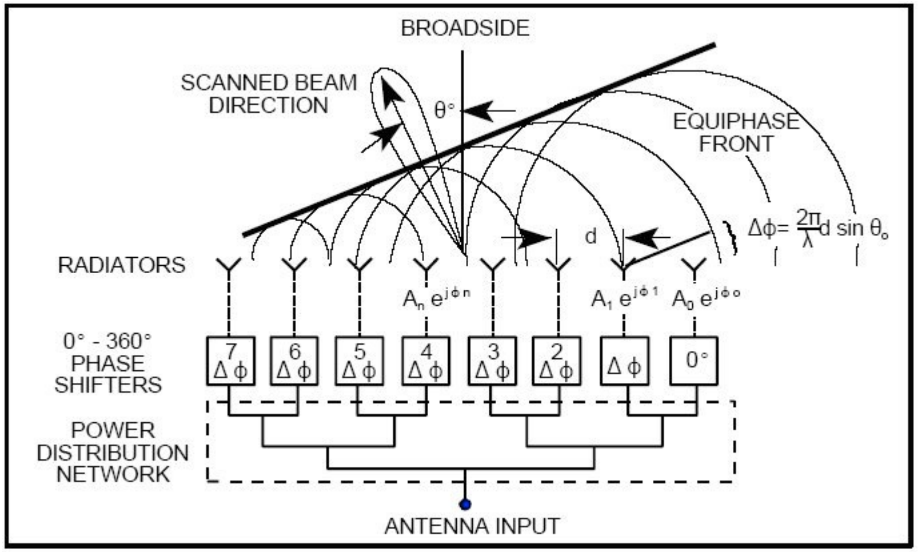
Strumentazione Astronomica: Radioastronomia

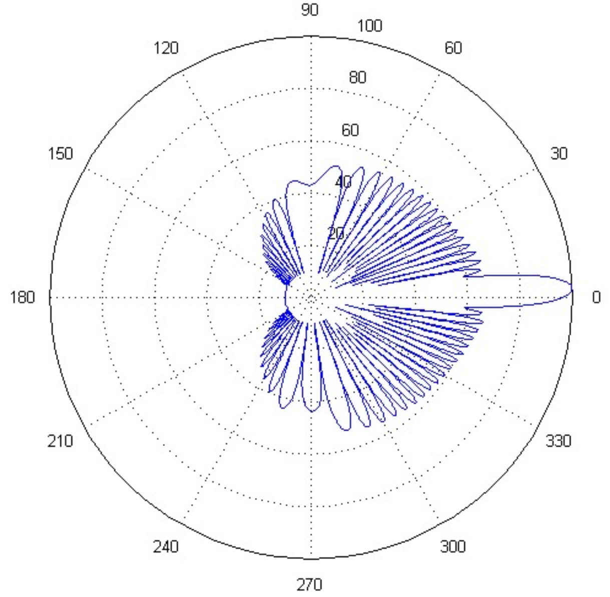
Si tratta di una sorta di dipoli ad anello per funzionare su una banda più larga.
Prelevano entrambe le polarizzazioni che vengono digitalizzate e registrate singolarmente per ogni antenna.



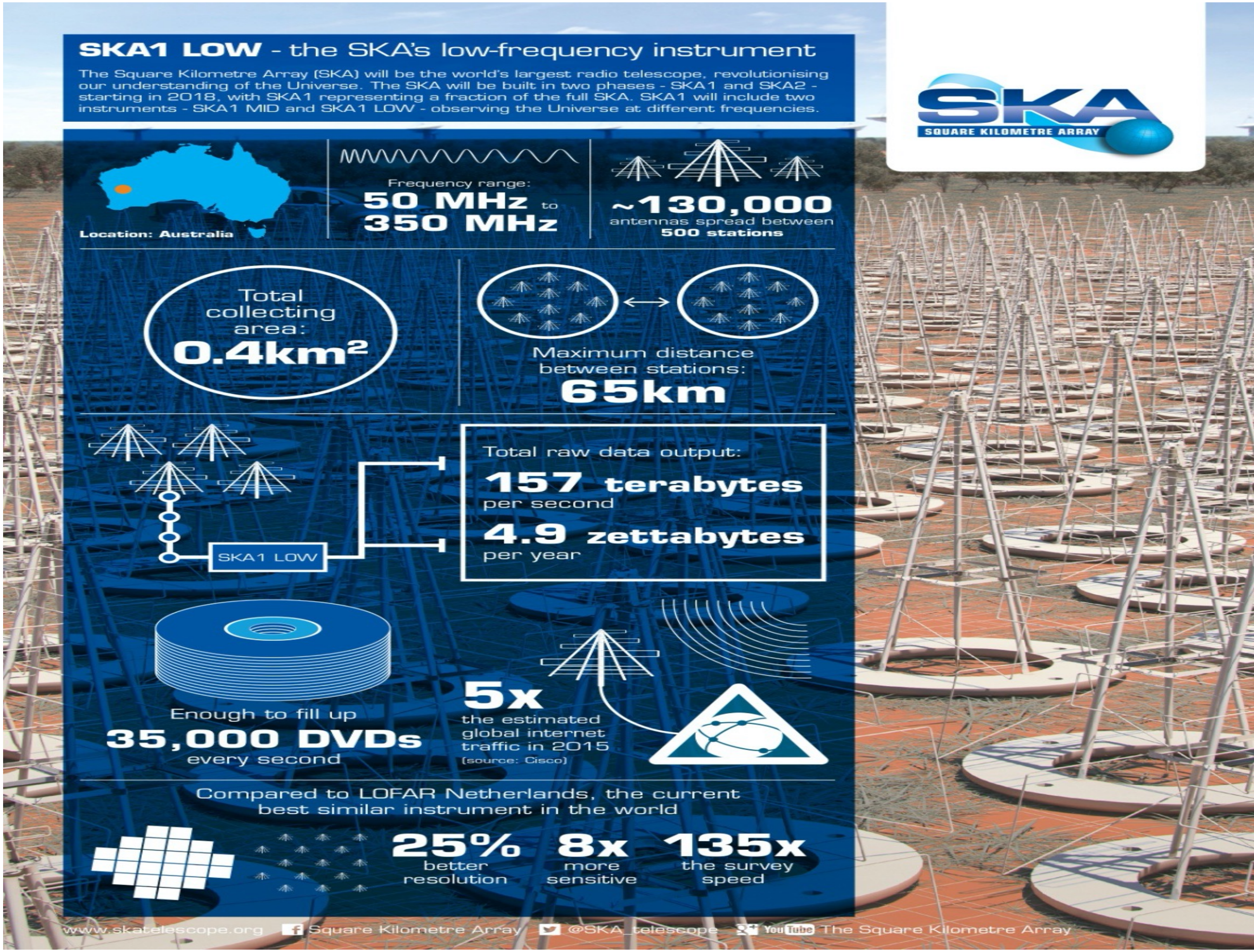
La strumentazione di SKA funziona sul principio dei phased array.
Impostando le differenze di fase tra i segnali acquisiti dalle singole antenne è possibile formare ed orientare il beam sintetico in una direzione qualunque.
Questo si può fare anche a posteriori, sui segnali acquisiti e digitalizzati.
Si potrà, con gli stessi dati d'archivio, fare osservazioni di sorgenti in punti completamente diversi in cielo.



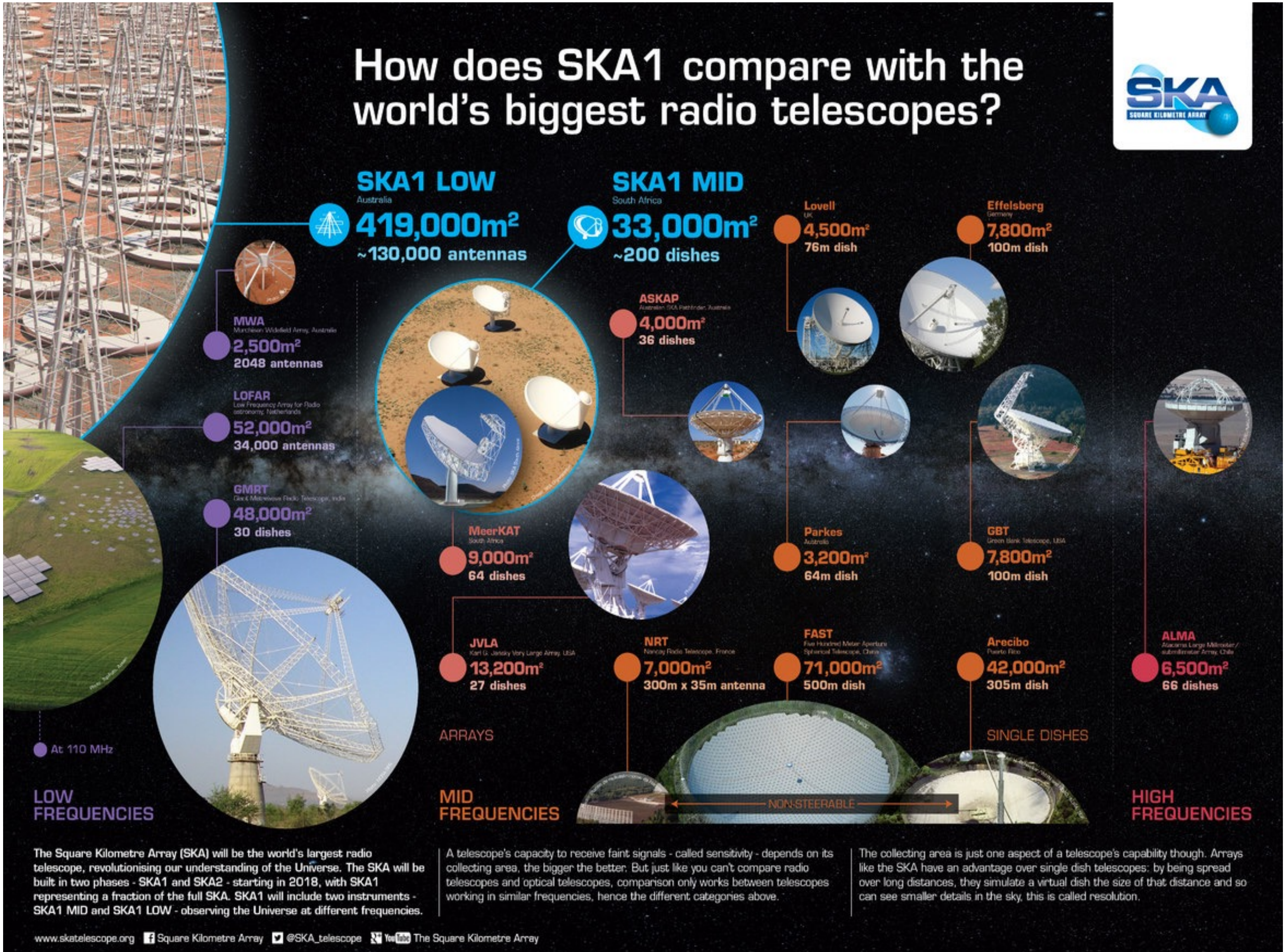


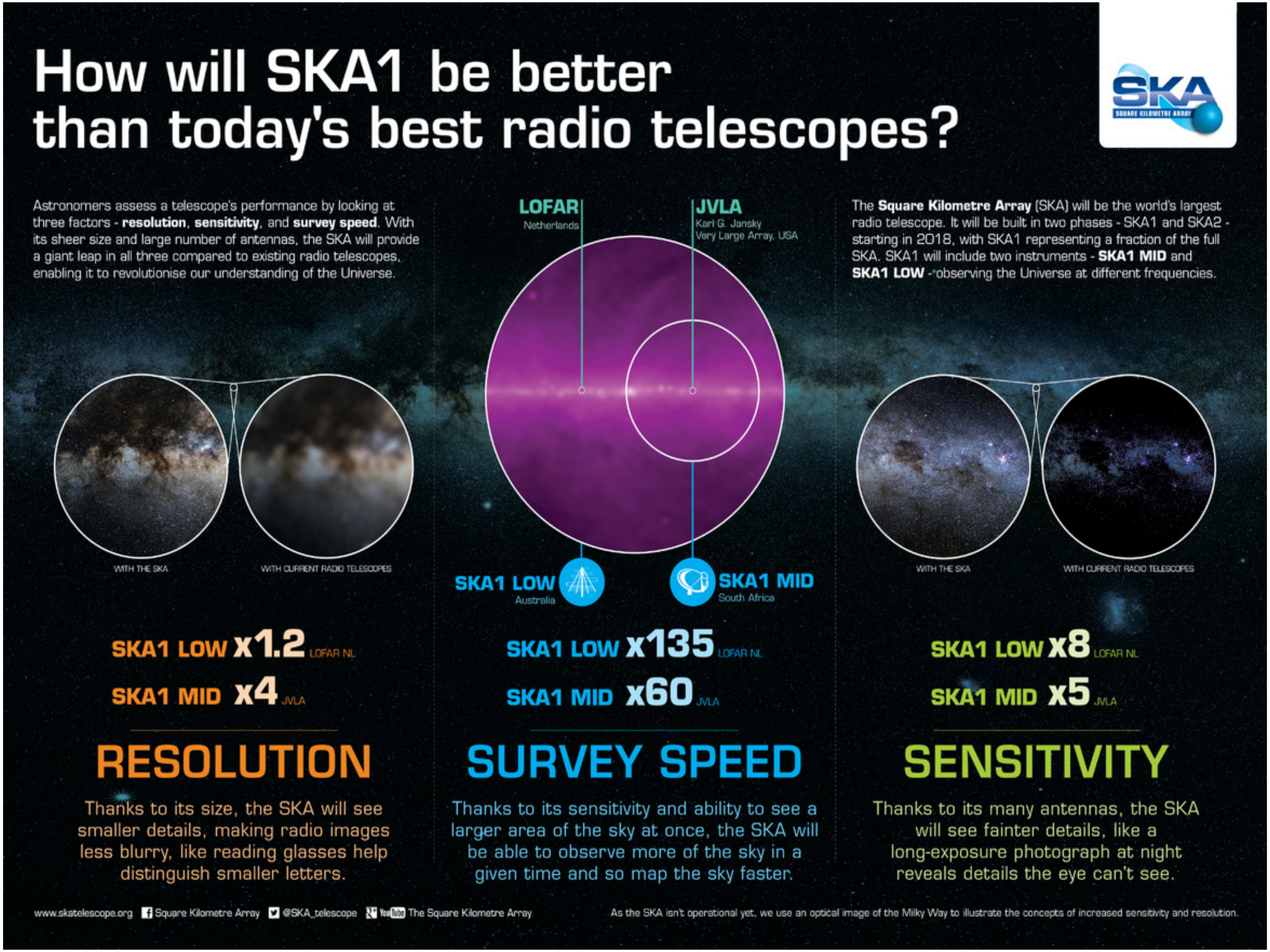


Strumentazione Astronomica: Radioastronomia



Strumentazione Astronomica: Radioastronomia





How will SKA1 be better than today's best radio telescopes?
SKA SQUARE KILOMETRE ARRAY
Astronomers assess a telescope's performance by looking at three factors - resolution, sensitivity, and survey speed. With its sheer size and large number of antennas, the SKA will provide a giant leap in all three compared to existing radio telescopes, enabling it to revolutionise our understanding of the Universe.
LOFAR
Netherlands
JVLA
Karl G. Jansky Very Large Array, USA
The Square Kilometre Array (SKA) will be the world's largest radio telescope. It will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.
WITH THE SKA
WITH CURRENT RADIO TELESCOPES
SKA1 LOW
Australia
SKA1 MID
South Africa
WITH THE SKA
WITH CURRENT RADIO TELESCOPES
SKA1 LOW x1.2 LOFAR NL
SKA1 MID x4 JVLA
SKA1 LOW x135 LOFAR NL
SKA1 MID x60 JVLA
SKA1 LOW x8 LOFAR NL
SKA1 MID x5 JVLA
RESOLUTION
Thanks to its size, the SKA will see smaller details, making radio images less blurry, like reading glasses help distinguish smaller letters.
SURVEY SPEED
Thanks to its sensitivity and ability to see a larger area of the sky at once, the SKA will be able to observe more of the sky in a given time and so map the sky faster.
SENSITIVITY
Thanks to its many antennas, the SKA will see fainter details, like a long-exposure photograph at night reveals details the eye can't see.
www.skatelescope.org Square Kilometre Array @SKA_telescope The Square Kilometre Array
As the SKA isn't operational yet, we use an optical image of the Milky Way to illustrate the concepts of increased sensitivity and resolution.