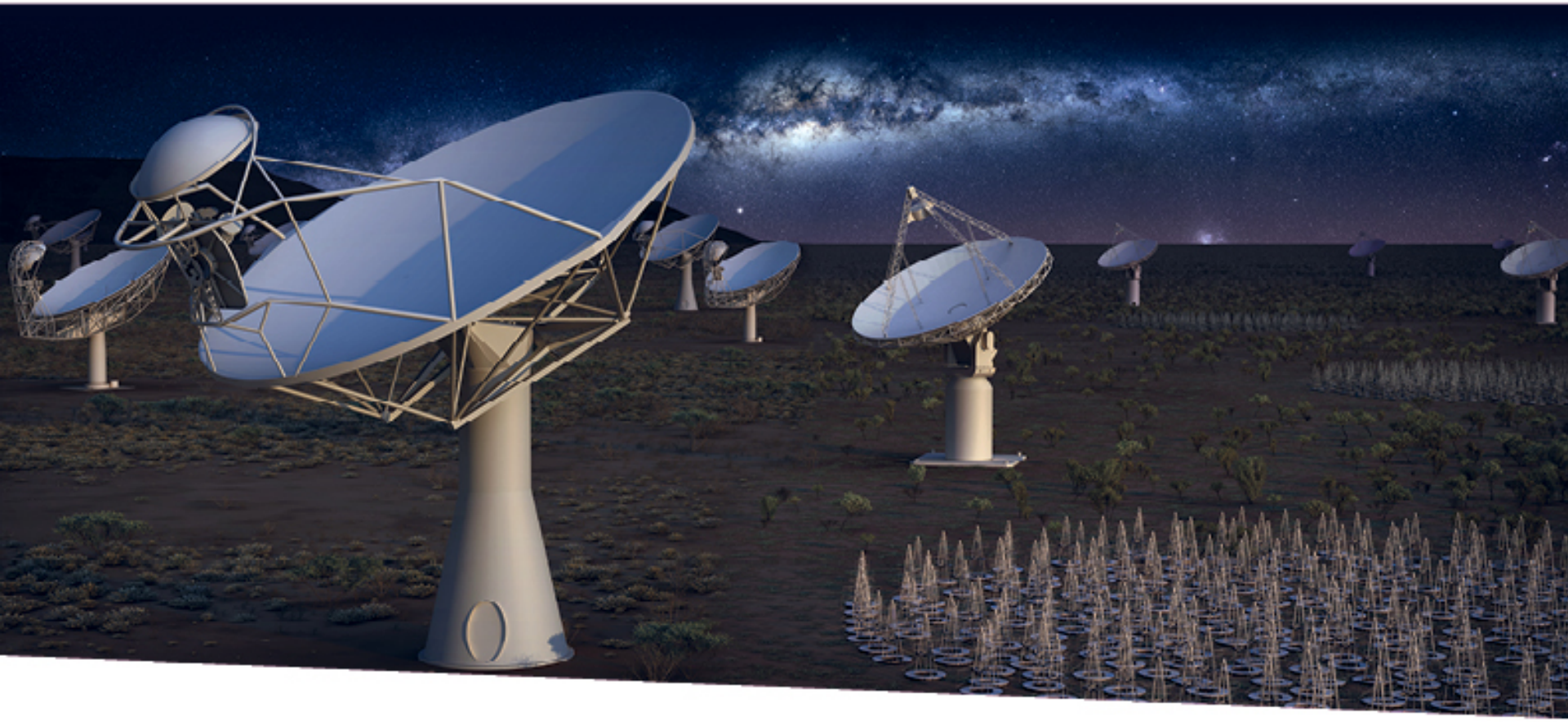
Time Domain Astronomy with the SKA



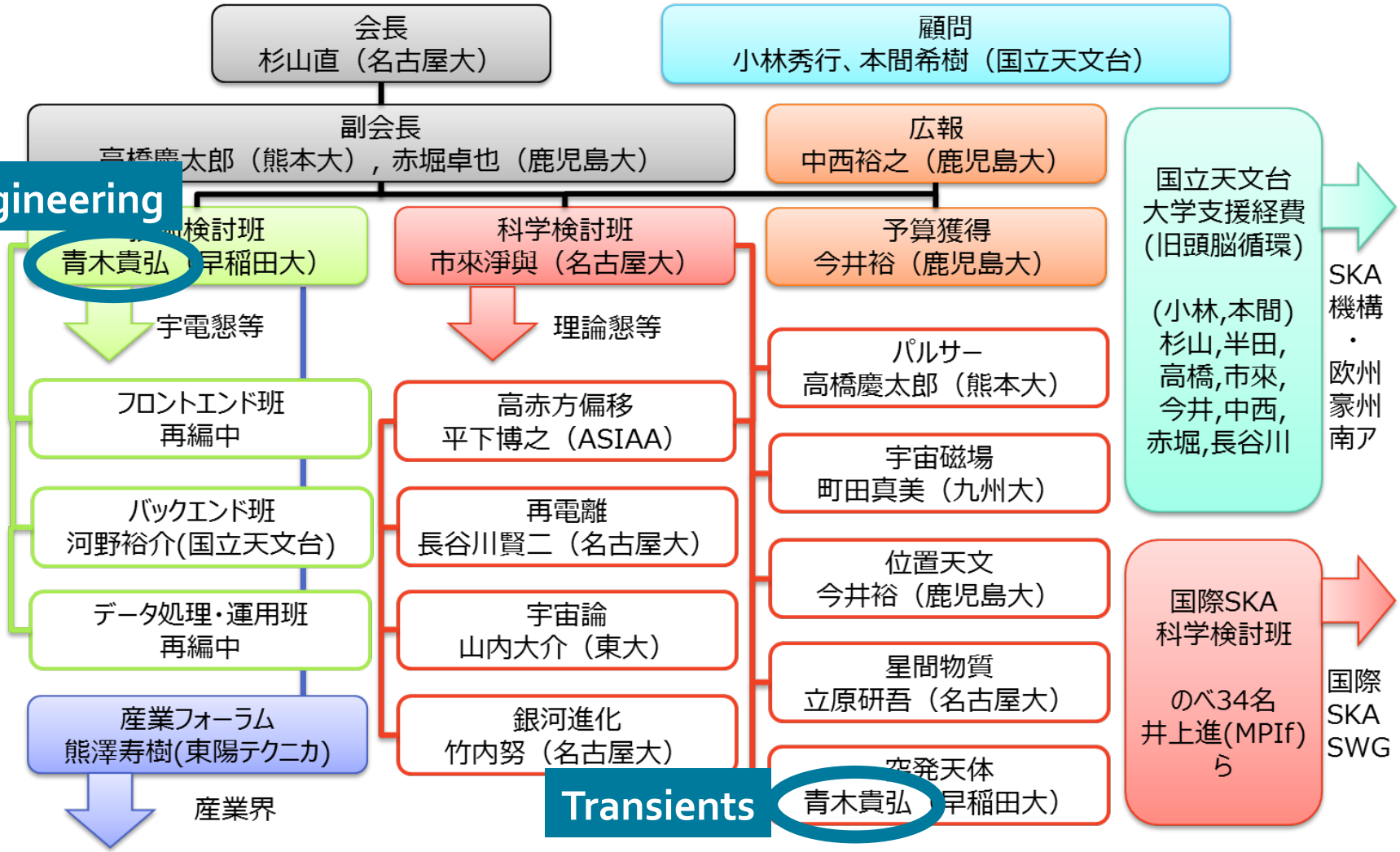
SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

Takahiro AOKI (Yamaguchi Univ.)

2016-12-16, CTA-Japan Workshop

SKA-Japan



From Akahori's slide @ several workshops

Radio Telescopes I've Operated

Yamaguchi 32 & 34 m

Nasu 20 m x 8 & 30 m

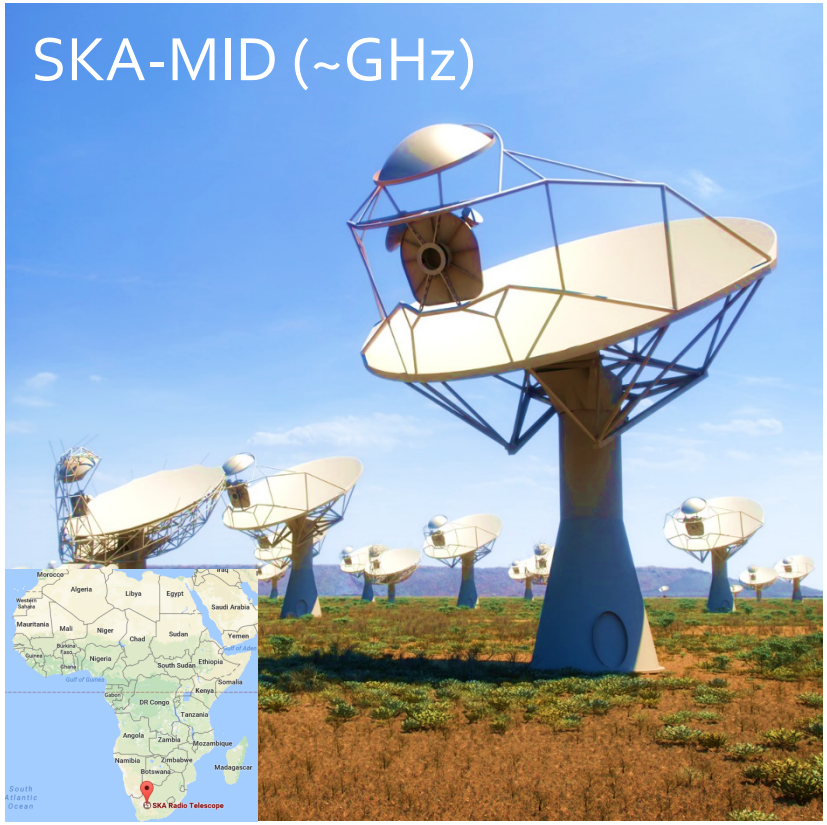
Talk

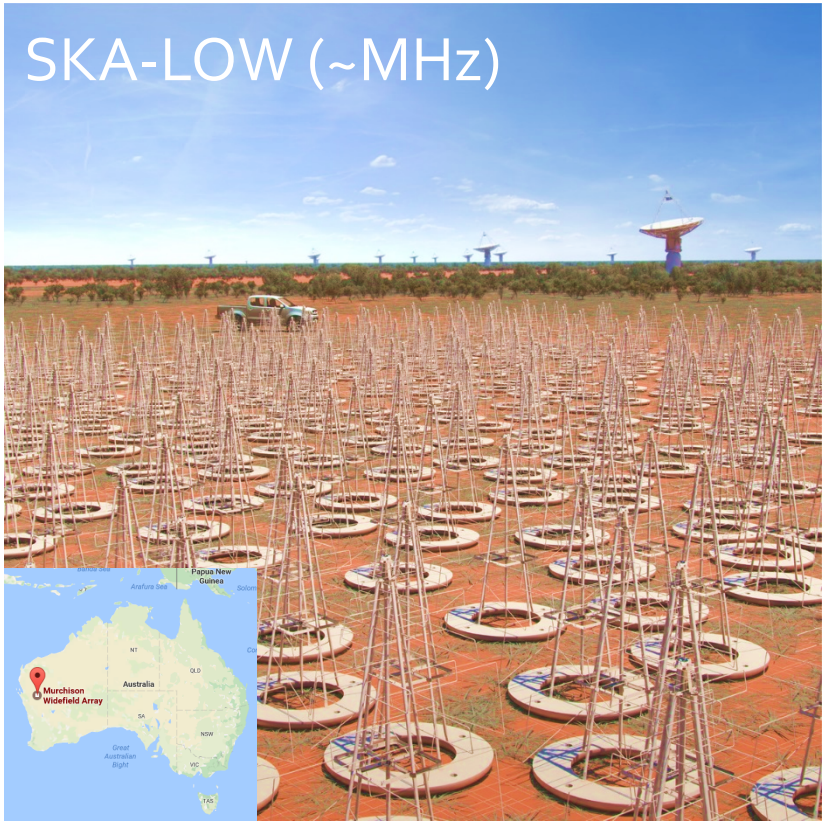
1. Introducing the SKA project

2. SKA Transient Science

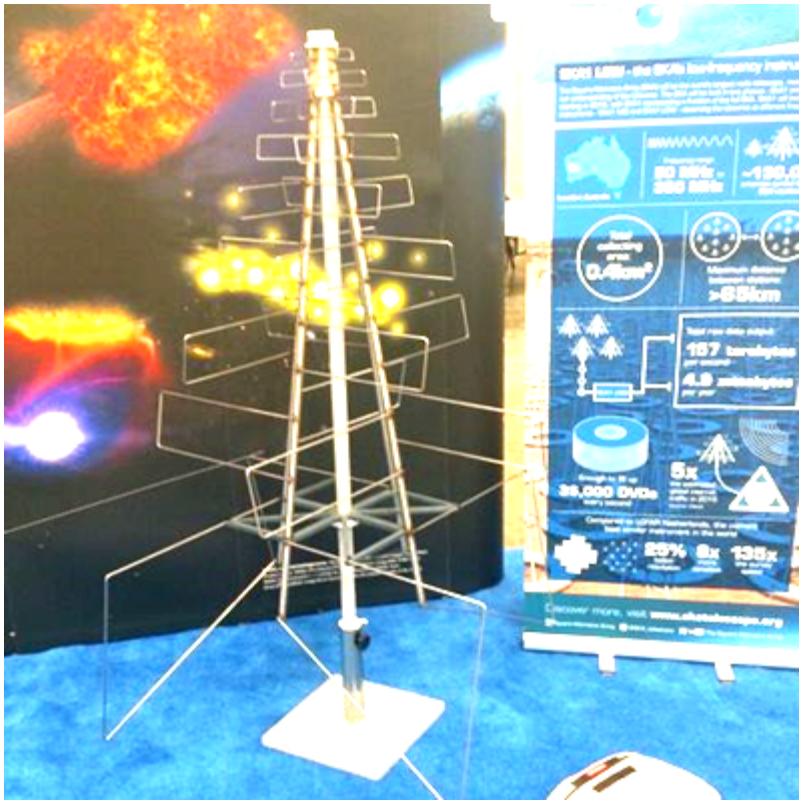
3. Japanese possible contribution to the SKA

Square Kilometre Array (SKA)

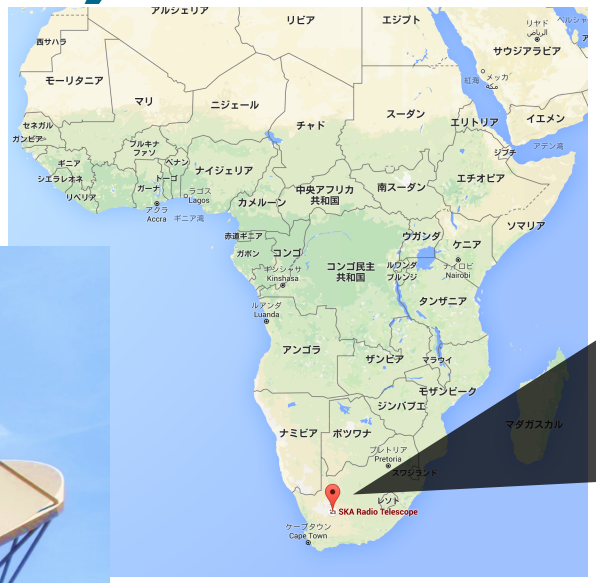


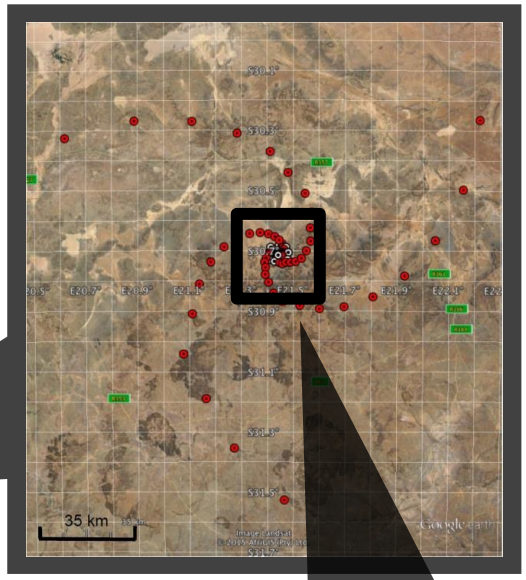


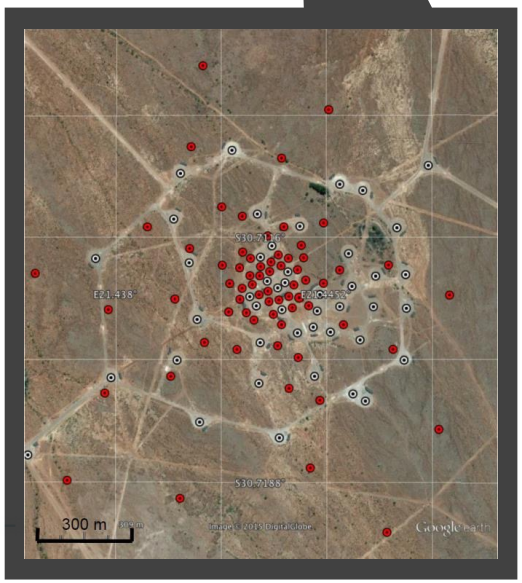
SKA Antennas @ IAU Hawaii



SKA-MID (~GHz)



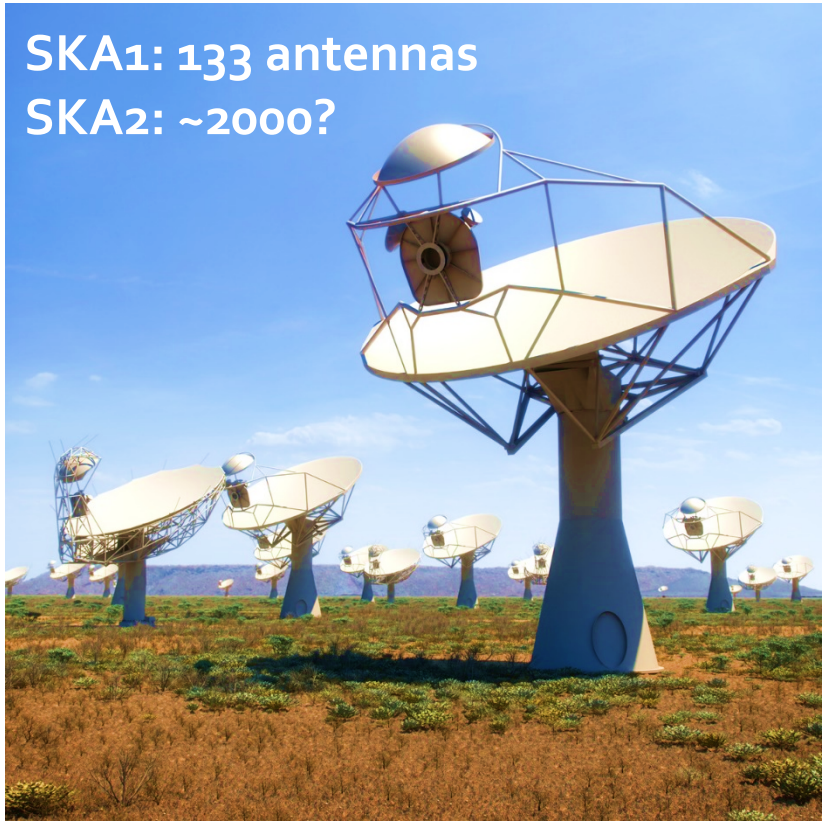




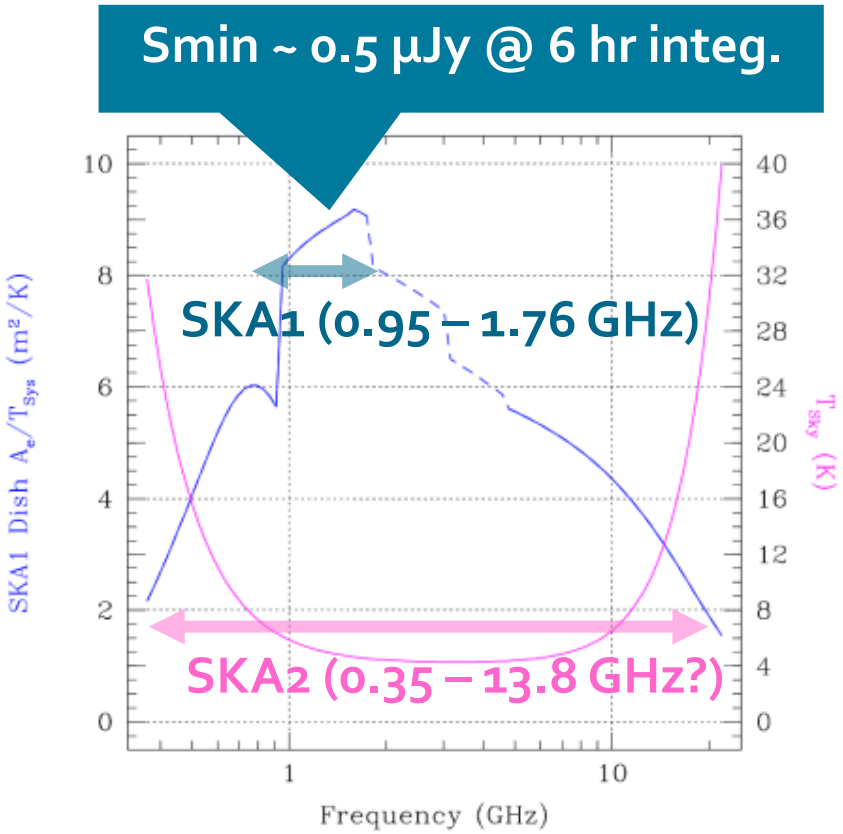
Exploring the Universe with the world's largest radio telescope

SKA-MID (~GHz)

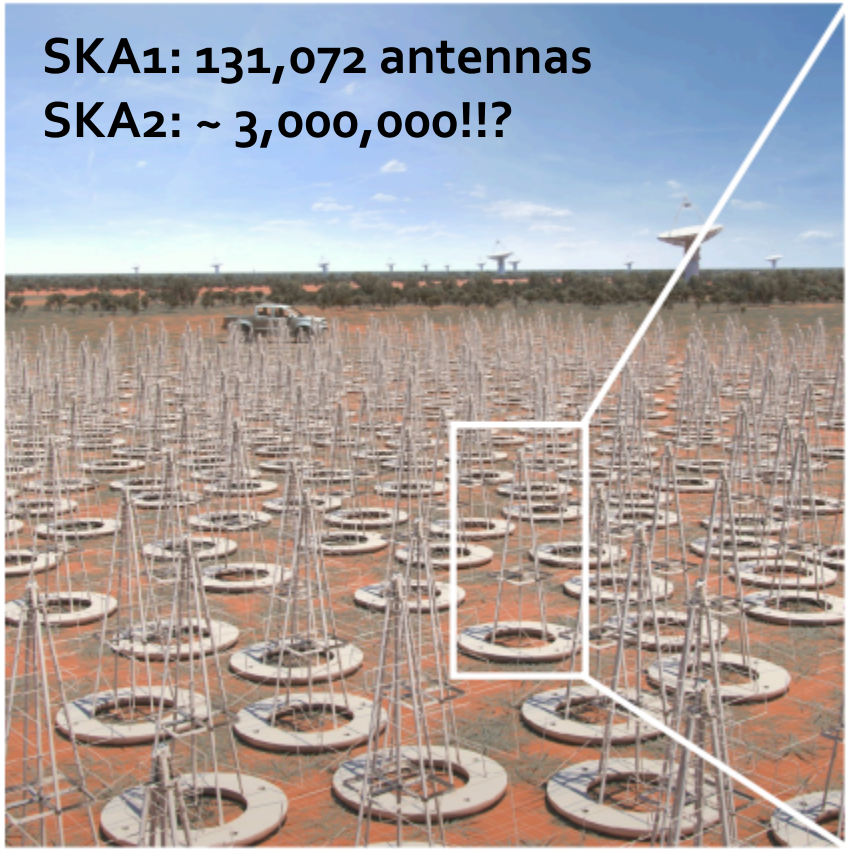
Design



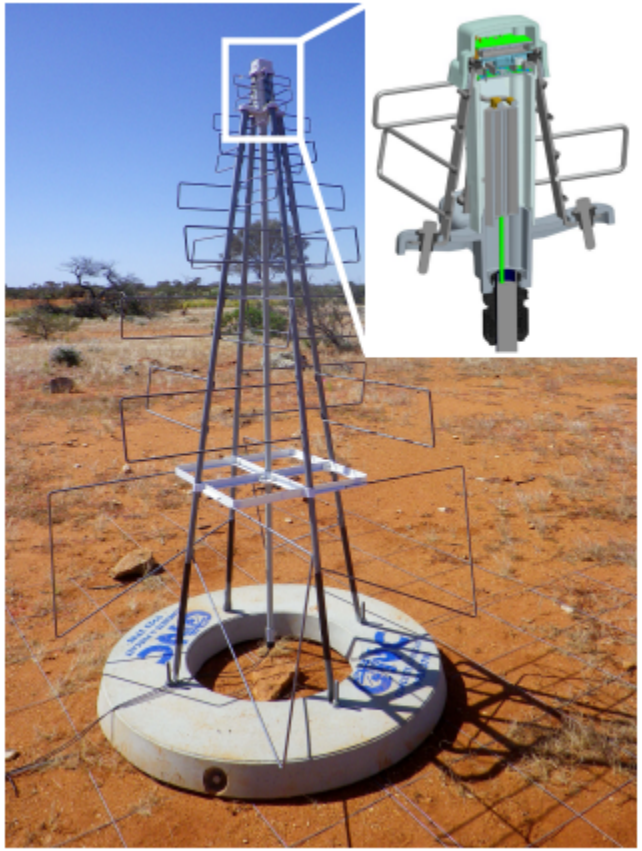
Sensitivity



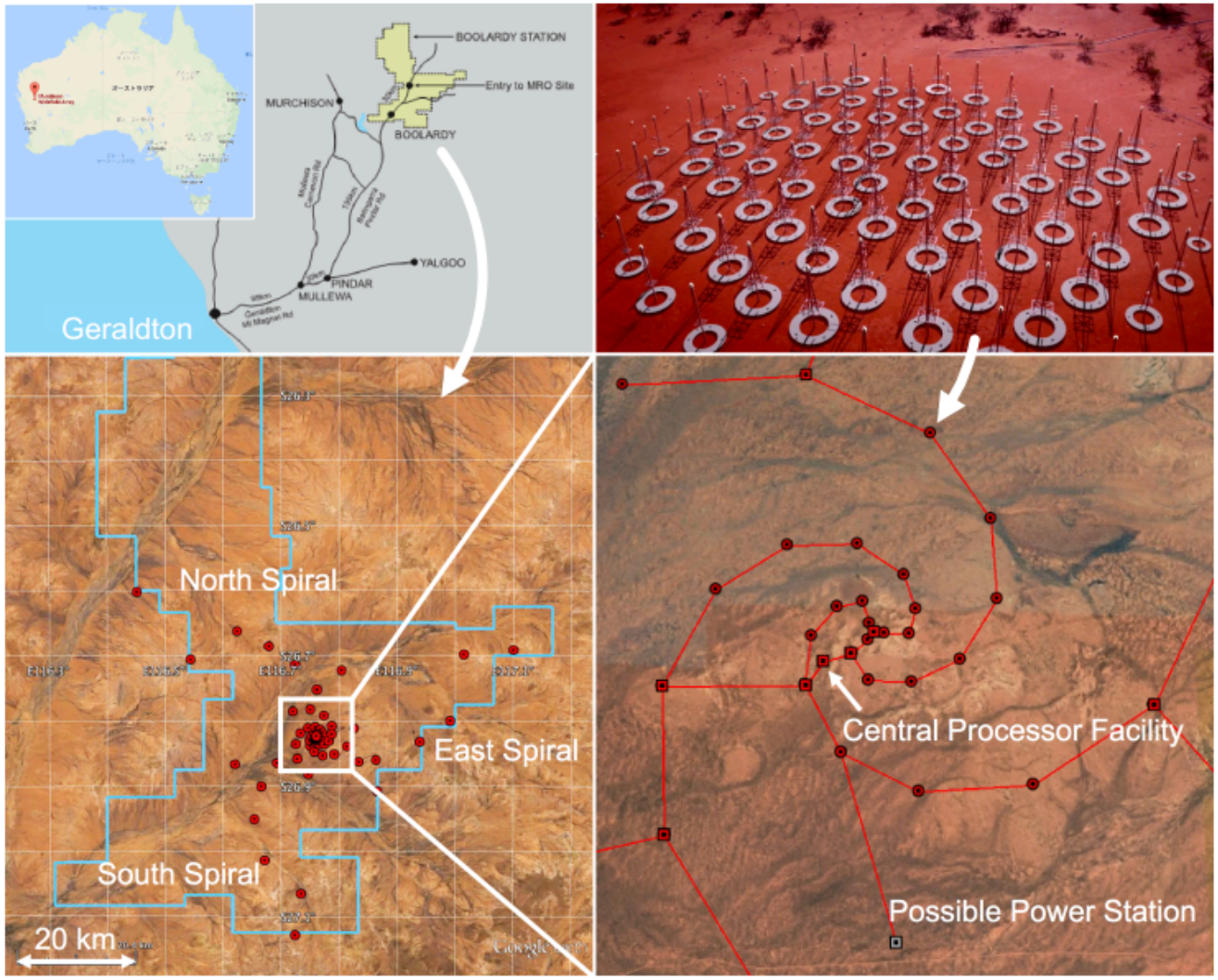
SKA-LOW (~MHz)



Log-periodic dipole antenna

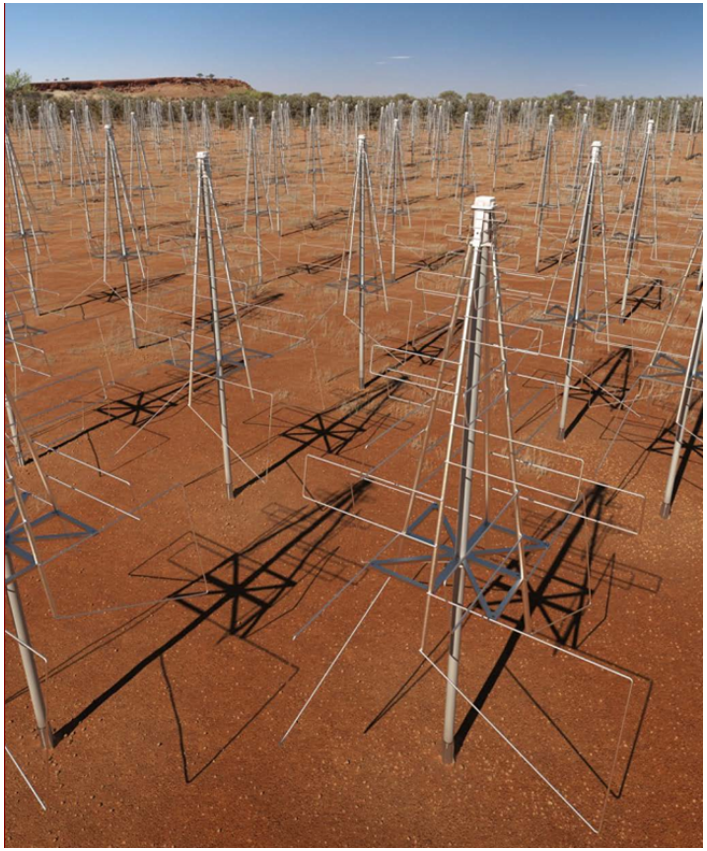


SKA-LOW (~MHz)

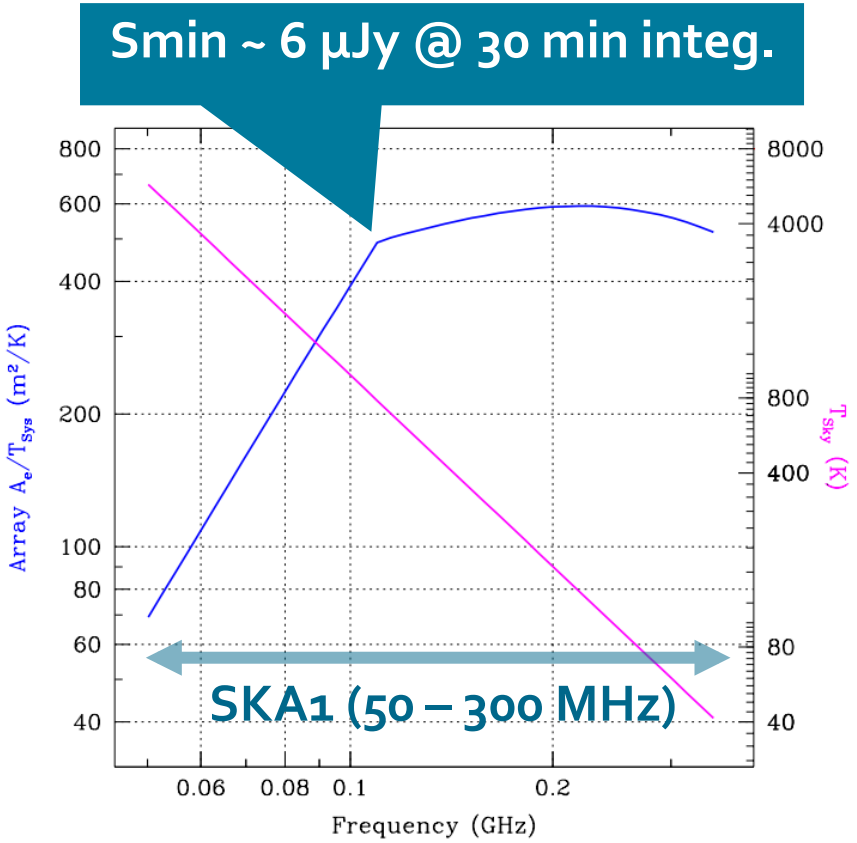

BOOLARDY STATION
Entry to MRO Site
MURCHISON
BOOLARDY
YALGOO
PINDAR
MULLEWA
Geraldton
North Spiral
East Spiral
South Spiral
20 km
Central Processor Facility
Possible Power Station

SKA-LOW (~MHz)

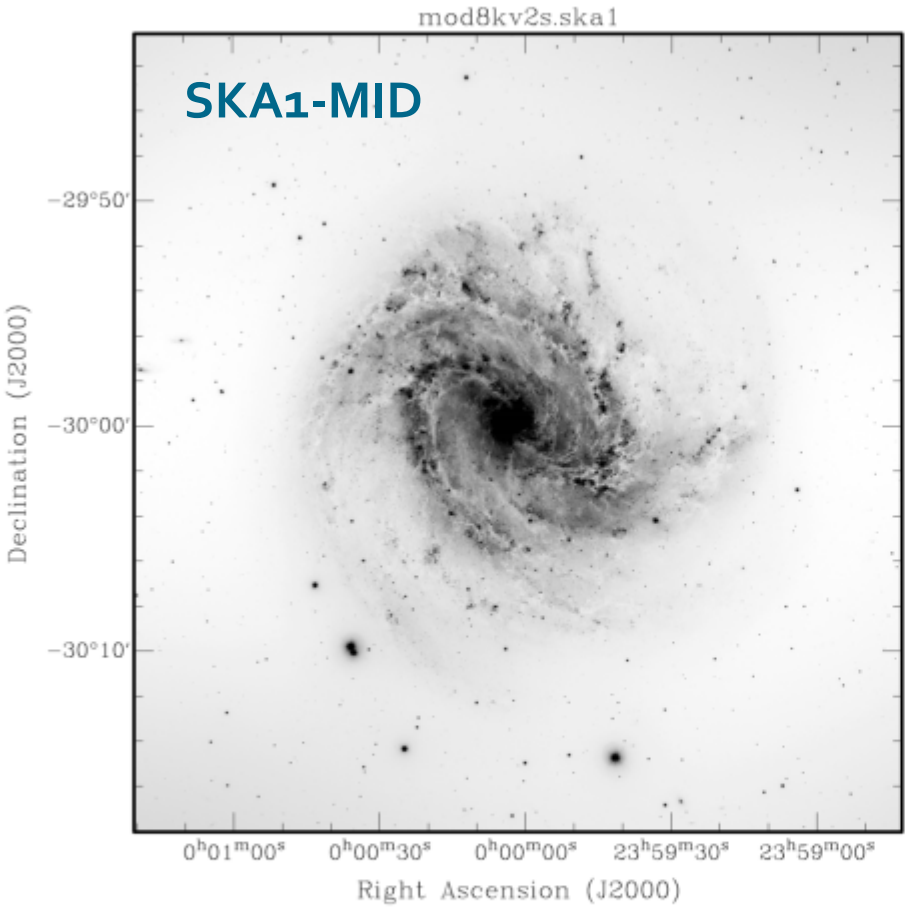
Design

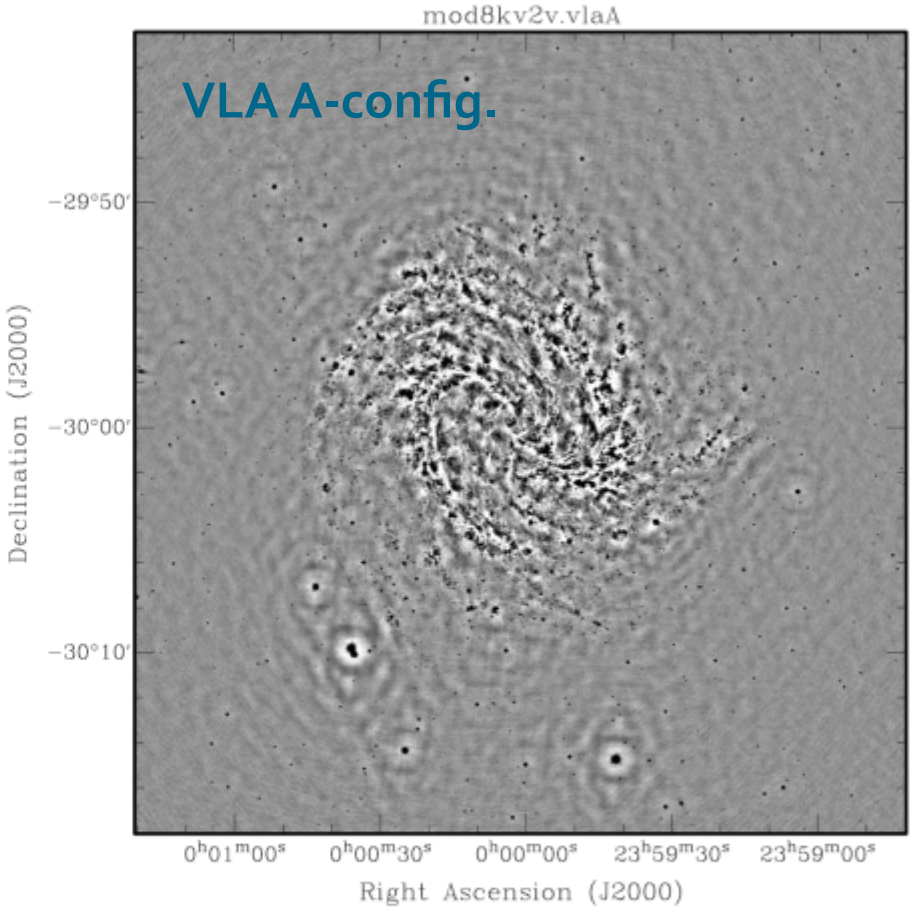


Sensitivity



Dirty Image Quality Comparison

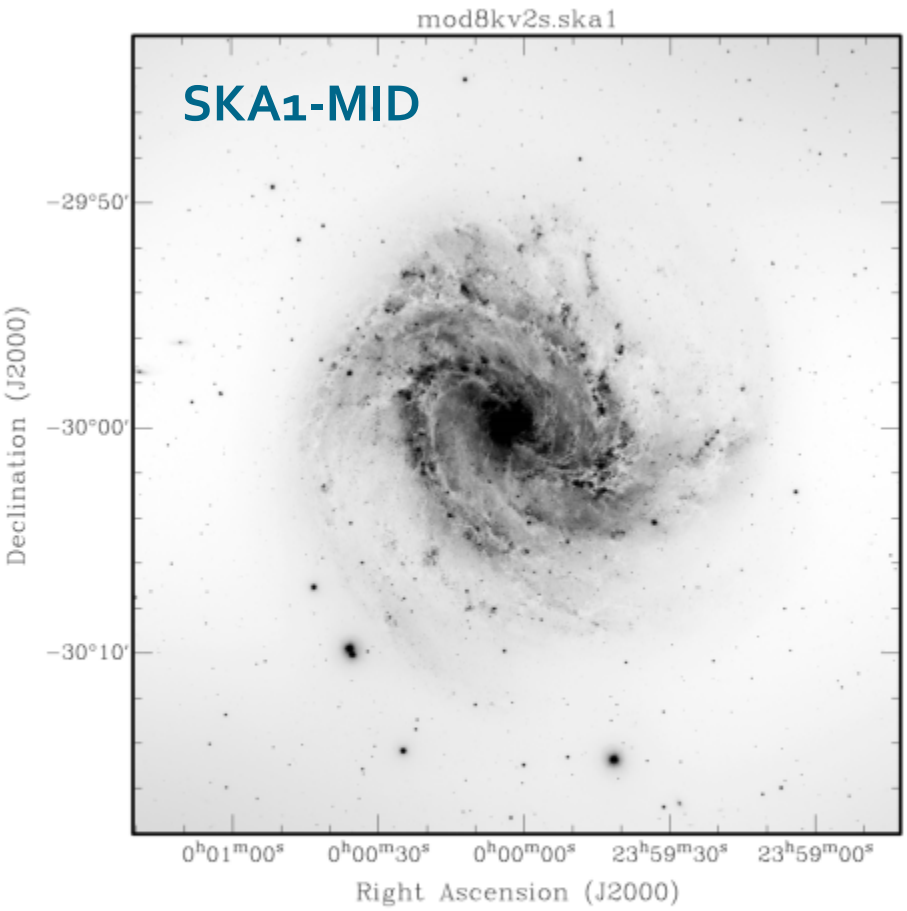


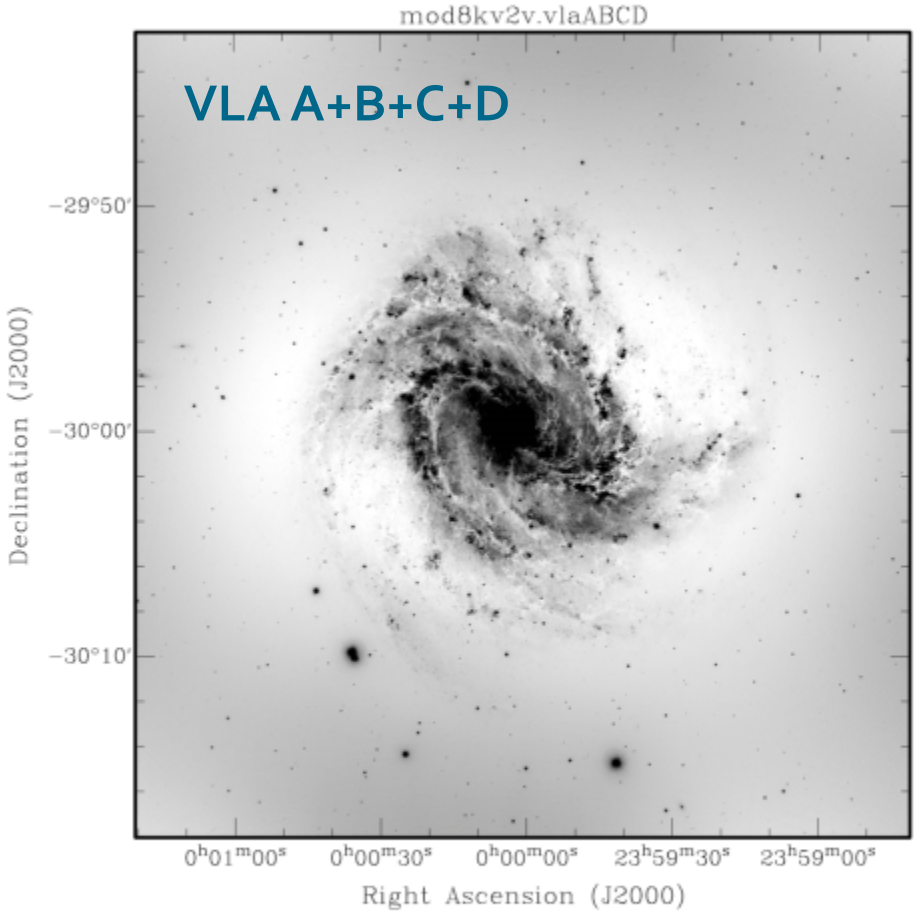


- "Structural" dynamic range of ~1000:1 rather than ~3:1 per VLA track (eg. SKA1-Mid vs. VLA A-config.)

From Braun's slide @ skaengcon16

Dirty Image Quality Comparison

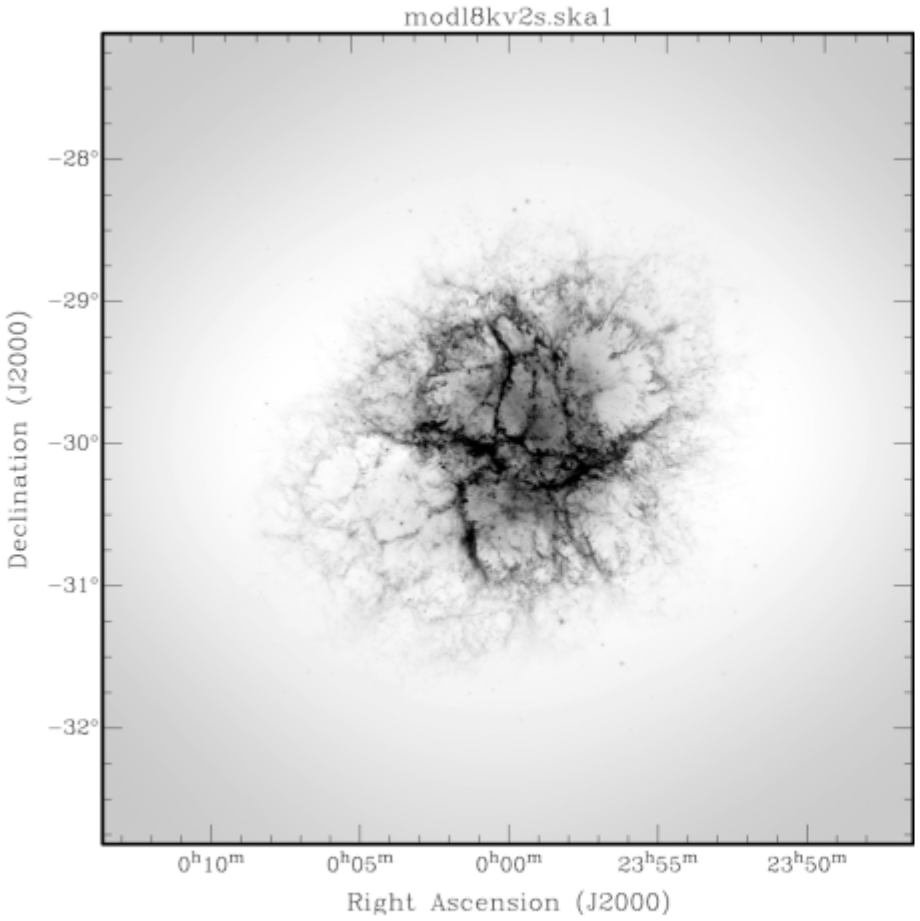


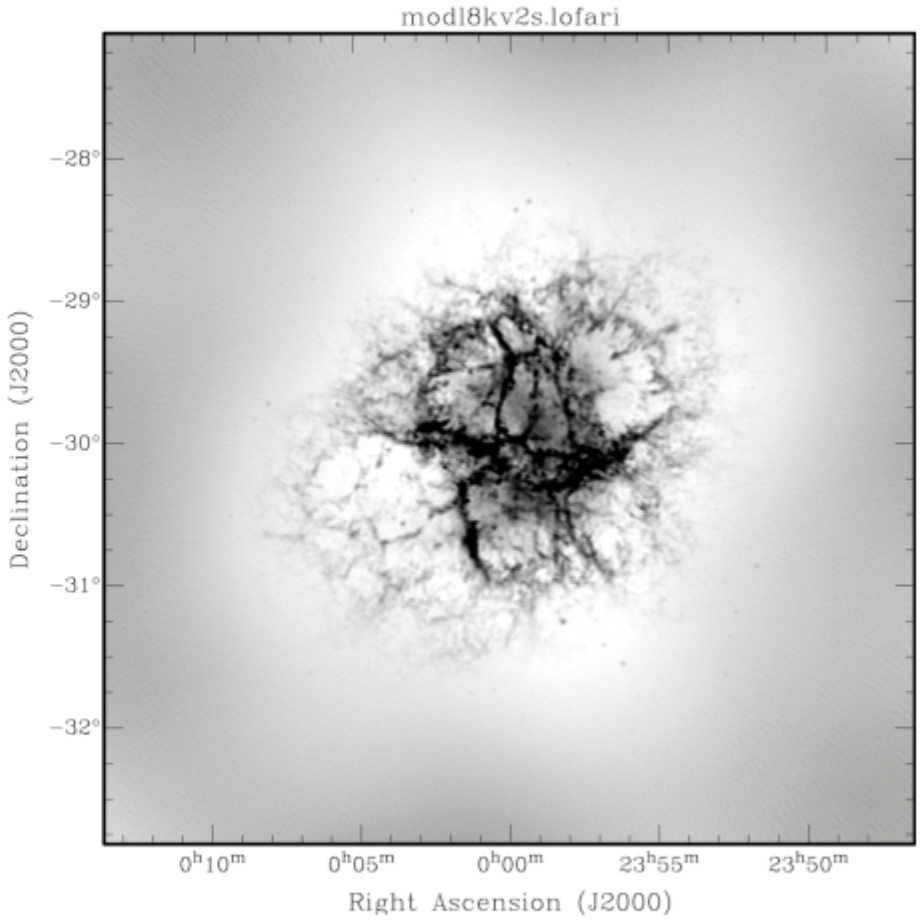


- Single SKA1-Mid track compared to combination of tracks in each of VLA A+B+C+D

From Braun's slide @ skaengcon16

Dirty Image Quality Comparison

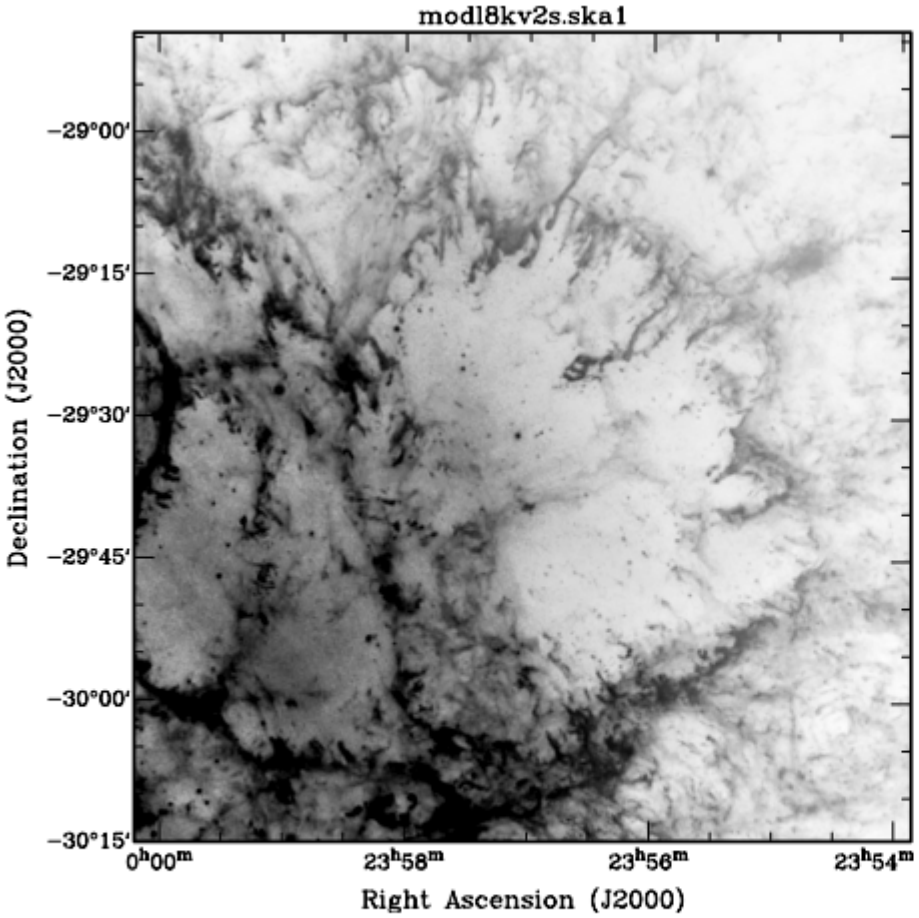


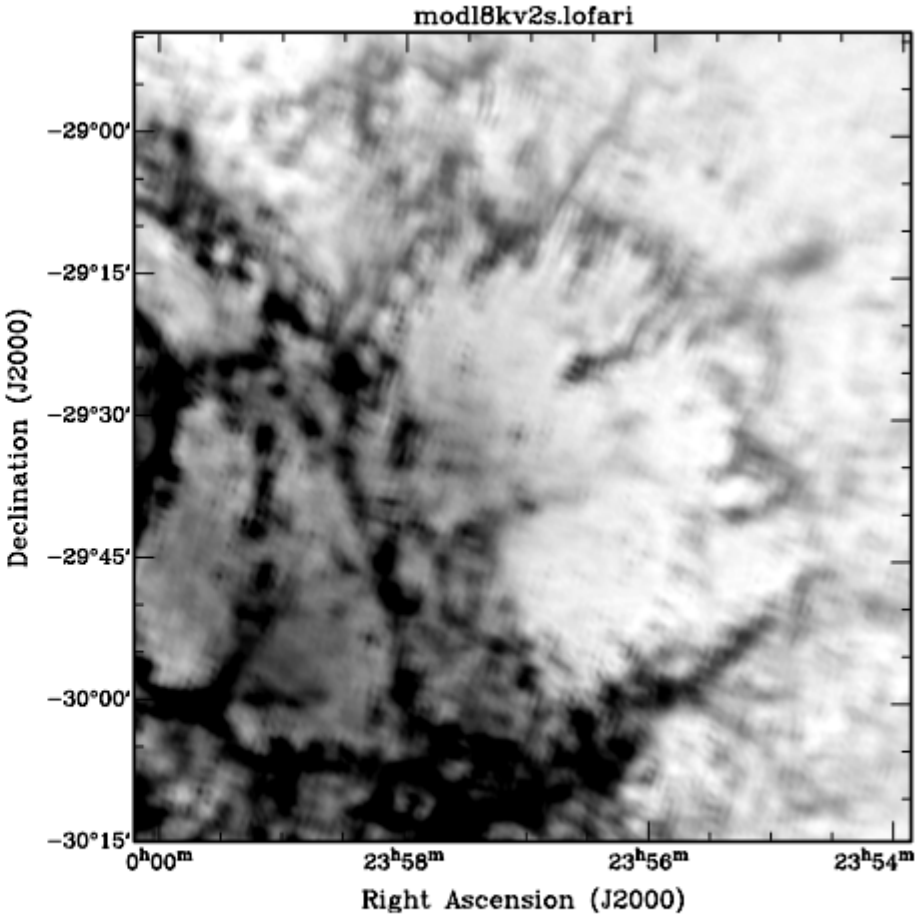


- Single SKA1-Low track compared to LOFAR-INTL

From Braun's slide @ skaengcon16

Dirty Image Quality Comparison





- Single SKA1-Low track compared to LOFAR-INTL

From Braun's slide @ skaengcon16

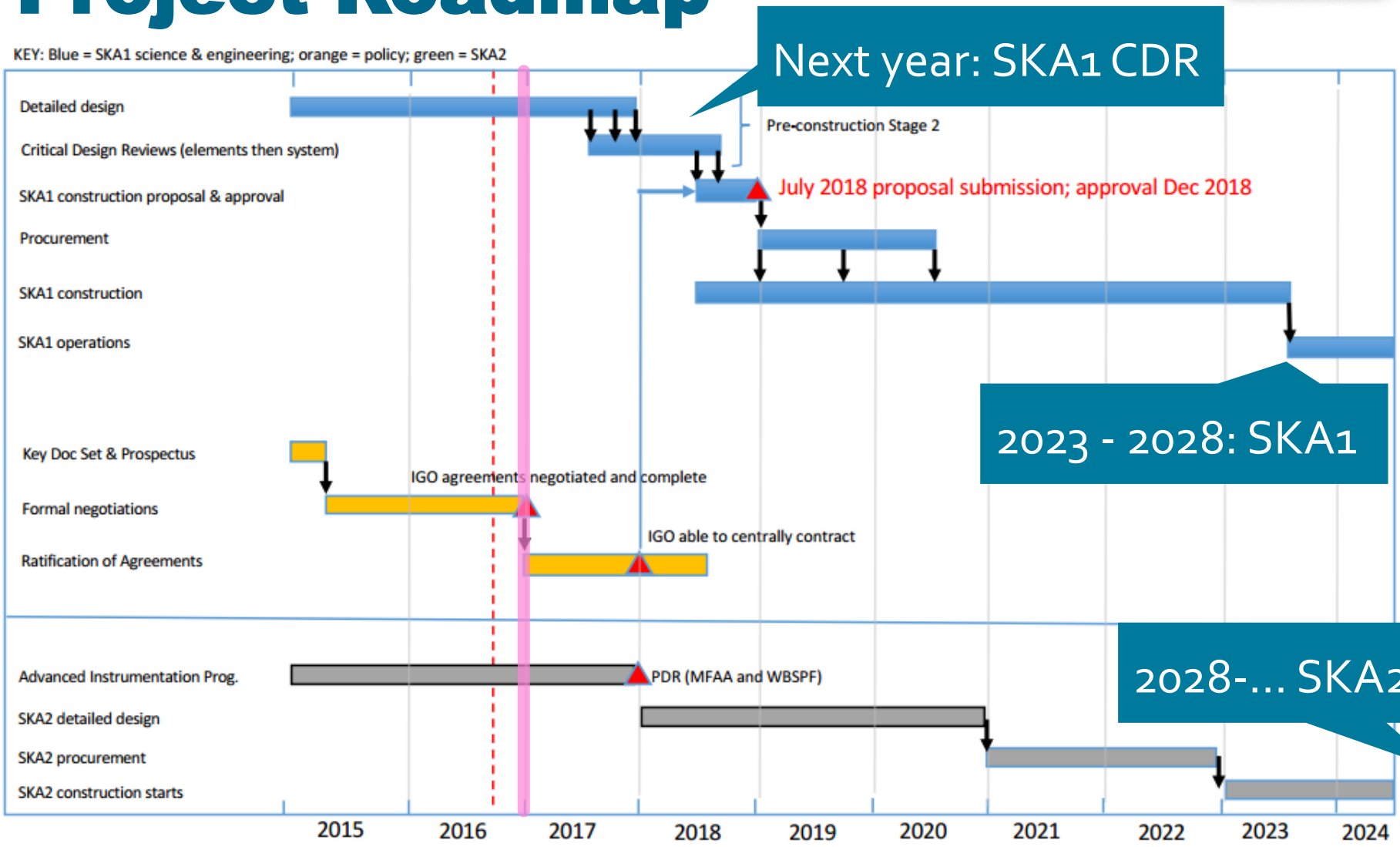
Performance Comparison

Table 1: A table of typical performance measures for a variety of radio telescopes (extant and under construction).

Parameters for Comparable Telescopes														
		eMERLIN	JVLA	GBT	GMRT	Parkes MB	LOFAR	FAST	MeerKAT	WSRT	Arecibo	ASKAP	SKA1-low	SKA-mid
A_{eff}/T_{sys}	m^2/K	60	265	276	250	100	61	1250	321	124	1150	65	559	1560
FoV	deg^2	0.25	0.25	0.015	0.13	0.65	14	0.0017	0.86	0.25	0.003	30	20.77	0.49
Receptor Size	m	25	25	101	45	64	39	300	13.5	25	225	12	35	15
Fiducial frequency	GHz	1.4	1.4	1.4	1.4	1.4	0.12	1.4	1.4	1.4	1.4	1.4	0.11	1.67
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	9.00×10^2	1.76×10^4	1.14×10^3	8.13×10^3	6.50×10^3	5.21×10^4	2.66×10^3	8.86×10^4	3.84×10^3	3.97×10^3	1.27×10^5	6.49×10^6	1.19×10^6
Resolution	arcsec	$10\text{-}150 \times 10^{-3}$	1.4 - 44	420	2	660	5	88	11	16	192	7	7	0.25
Baseline or Size	km	217	1 - 35	0.1	27	0.064	100	0.5	4	2.7	225	6	80	150
Frequency Range	GHz	1.3-1.8, 4-8, 22-24	1 - 50	0.2 - 50+	0.15, 0.23, 0.33, 0.61, 1.4	0.44 to 24	0.03 – 0.22	0.1 – 3	0.7 - 2.5, 0.7 - 10	0.3 – 8.6	0.3 - 10	0.7-1.8	0.050 – 0.350	0.35-14
Bandwidth	MHz	400	1000	400	450	400	4	800	1000	160	1000	300	300	770
Cont. Sensitivity	$\mu Jy\text{-}hr^{-1/2}$	27.11	3.88	5.89	6.13	16.26	266.61	0.92	3.20	20.74	0.89	28.89	3.36	0.75
Sensitivity, 100 kHz	$\mu Jy\text{-}hr^{-1/2}$	1714	388	373	411	1029	1686	82	320	830	89	1582	184	66
SEFD	Jy	46.0	10.4	10.0	11.0	27.6	45.2	2.2	8.6	22.3	2.4	42.5	4.9	1.8

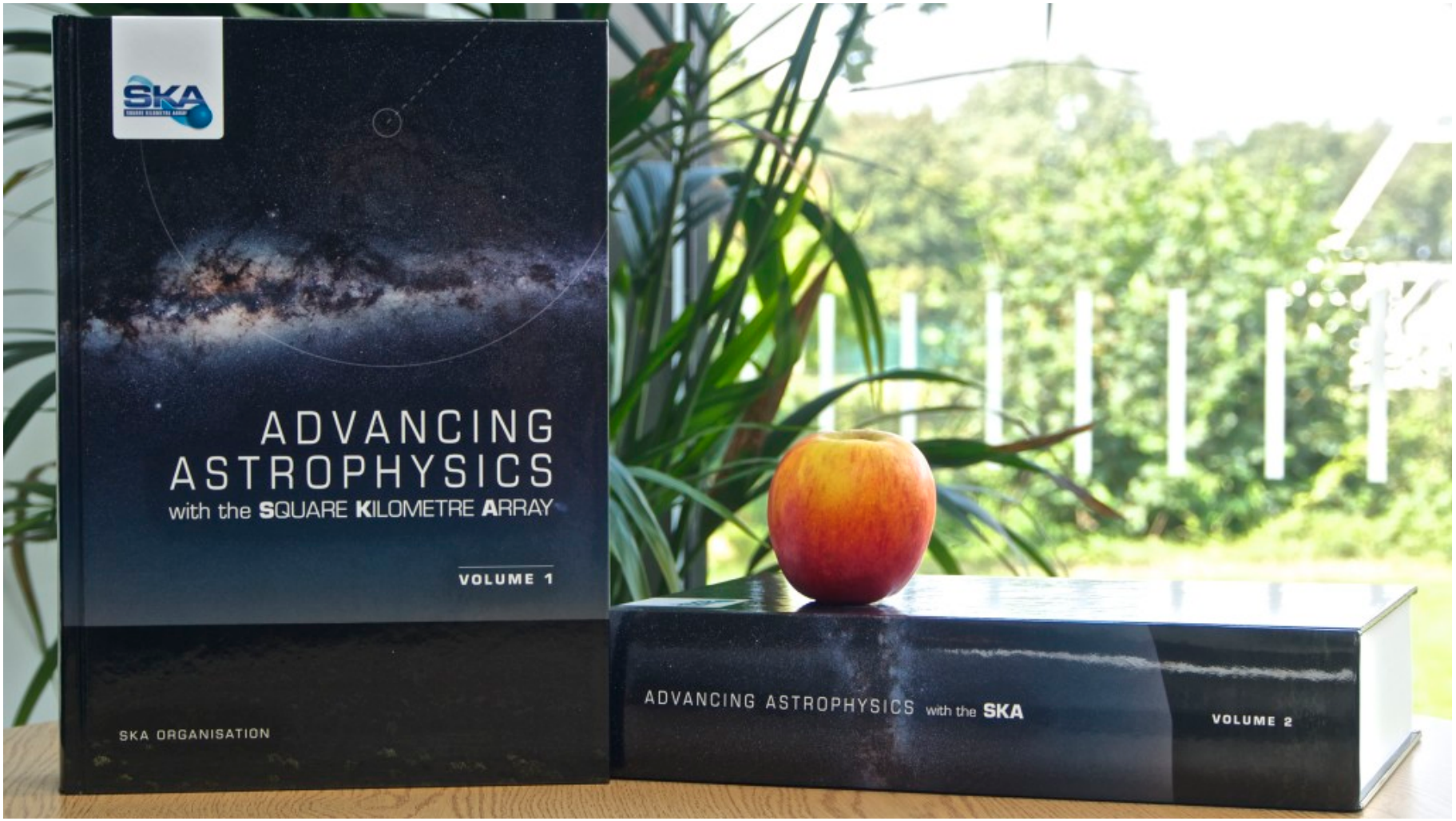
- **SKA (Resulting) Concept: High Sensitivity & Wide Field of View**
  (& Wide Band in SKA2?)
  - Consisting of many small antennas
  - World's highest sensitivity
  - World's highest survey speed
    - Time Domain *Radio* Astronomy available!
    - Transient science effective

Project Roadmap



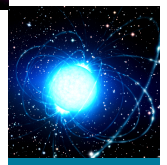
McPherson's slide @ skaengcon16

SKA Science Book

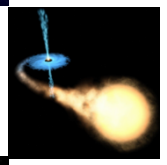


Transient Science in the Book

1. The Transient Universe with the Square Kilometre Array
2. The SKA View of **Gamma-Ray Bursts**
3. Incoherent transient radio emission from stellar-mass **compact objects** in the SKA era
4. SKA as a powerful hunter of jetted **Tidal Disruption** Events
5. **Fast Transients** at Cosmological Distances with the SKA
6. The SKA contribution to **GRB cosmology**
7. Time domain studies of **Active Galactic Nuclei** with the Square Kilometre Array
8. Core-collapse and Type Ia **supernovae** with the SKA
9. Thermal radio emission from **novae & symbiotics** with the Square Kilometre Array
10. Investigations of supernovae and **supernova remnants** in the era of SKA
11. The SKA and **the Unknown Unknowns**
12. Early Phase Detection and Coverage of Extragalactic and Galactic **Black Hole X-ray Transients** with SKA

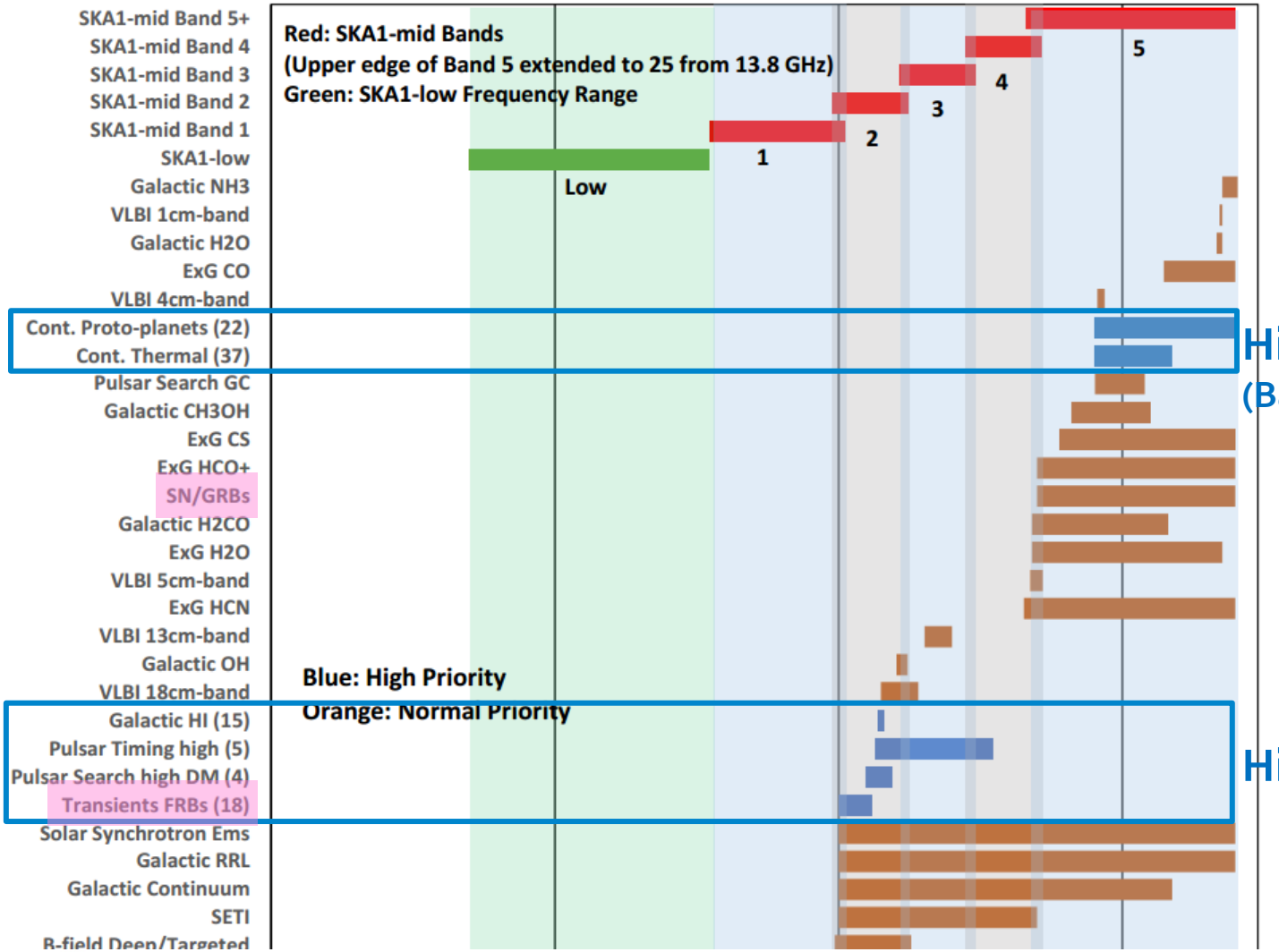
FRB



?

Get them from www.skatelescope.org/books/

SKA1 Science Priority & Freq. Ranges



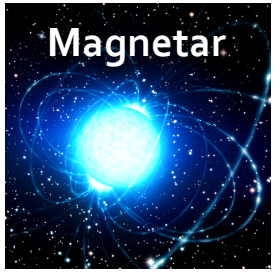
High priority @ SKA2
(Band 5 unavailable in SKA1)

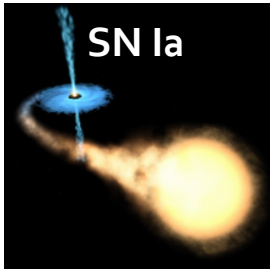
High priority @ SKA1

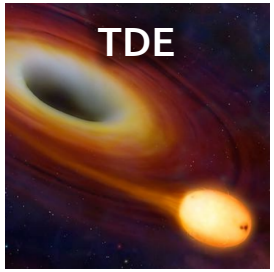
From System Baseline Design 2.0

Transients/Variables

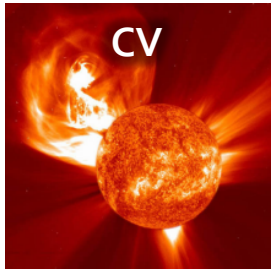
Transients





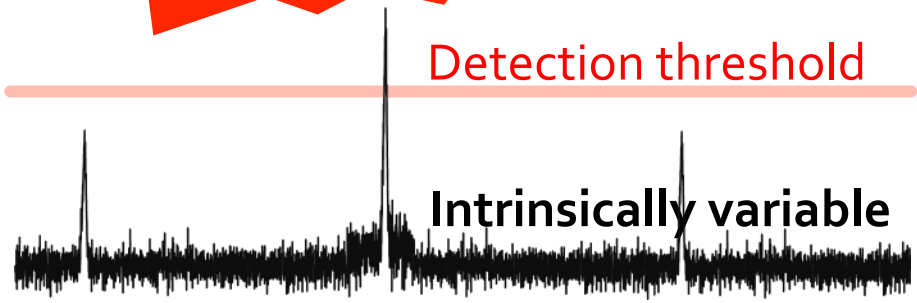


Variables



etc.

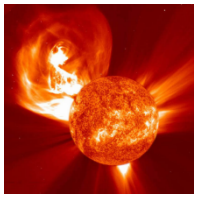
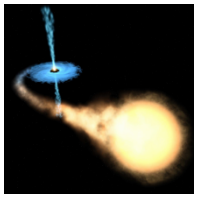
Transient!



Light Curve

No *observational* sense to distinguish transients from variables

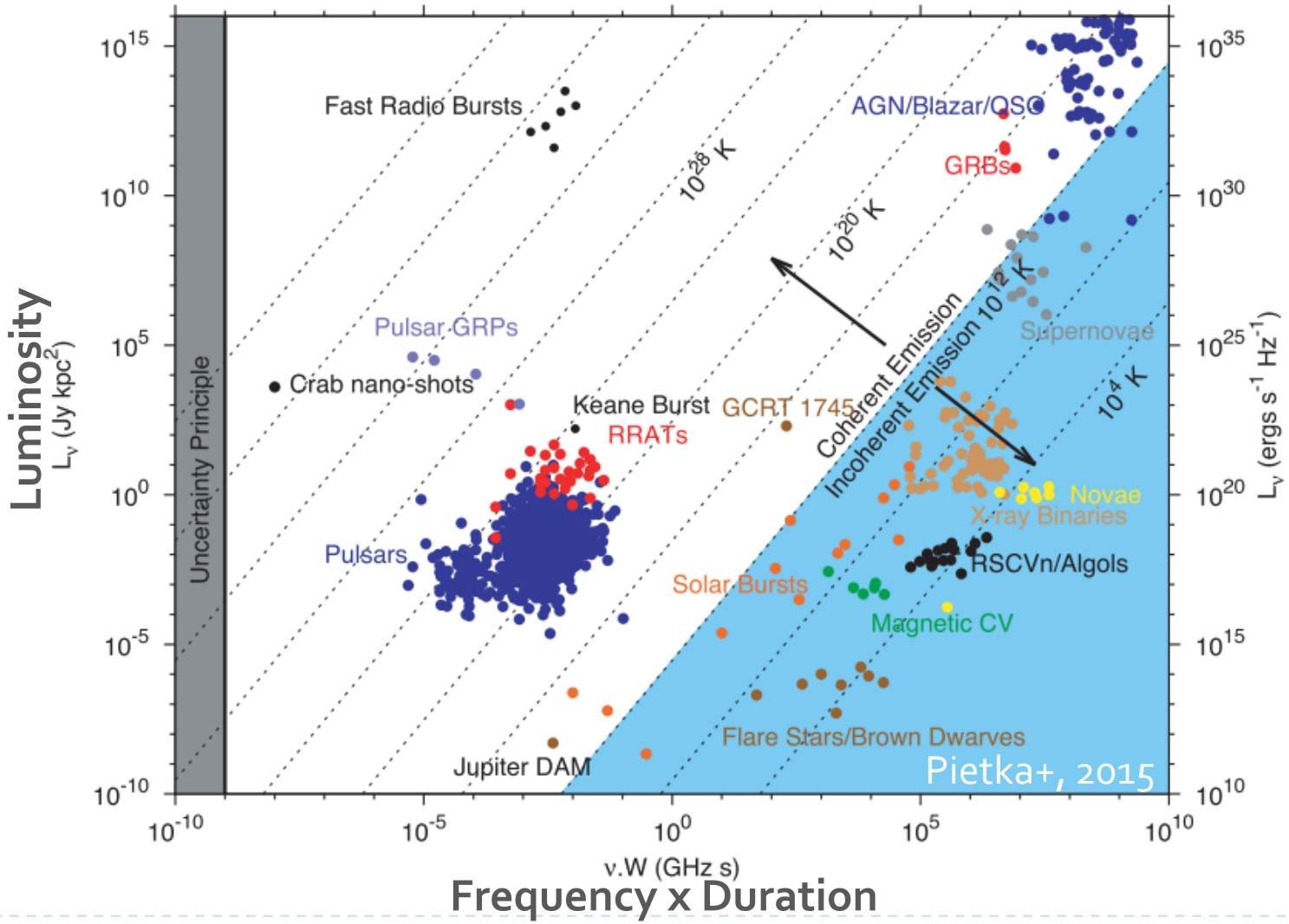
Observational Classification

	Short duration (< 1 s)	Long duration (> 1 s)
Extra-galactic	Fast Radio Bursts (FRBs) FRB	Supernovae, AGN,…   …
Galactic	Pulsars 	Flare stars, X-ray binaries,…   …

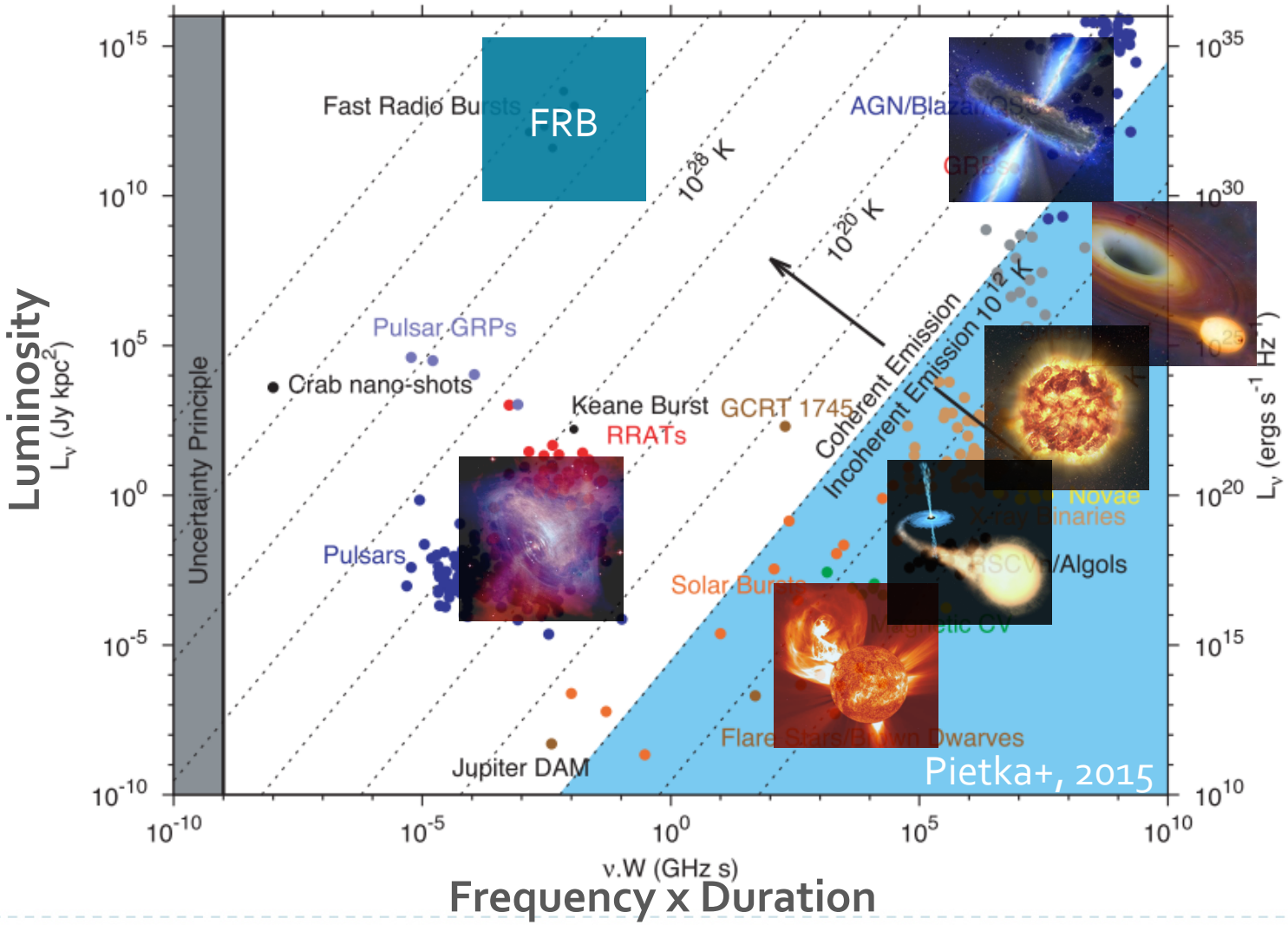
Time-series observation

Imaging observation

Phase Space


Luminosity
L_ν (Jy kpc^2)
L_ν (ergs s^{-1} Hz^{-1})
Frequency x Duration
ν.W (GHz s)
Uncertainty Principle
Fast Radio Bursts
Crab nano-shots
Pulsar GRPs
Keane Burst
RRATs
GCRT 1745
Pulsars
Jupiter DAM
AGN/Blazar/QSO
GRBs
Supernovae
Novae
X-ray Binaries
RSCVn/Algols
Solar Bursts
Magnetic CV
Flare Stars/Brown Dwarves
Coherent Emission
Incoherent Emission
10^{28} K
10^{20} K
10^{12} K
10^{4} K
Pietka+, 2015

Phase Space


Luminosity
L_ν (Jy kpc^2)
L_ν (ergs s^{-1} Hz^{-1})
Frequency x Duration
ν.W (GHz s)
Uncertainty Principle
FRB
Fast Radio Bursts
Pulsar GRPs
Crab nano-shots
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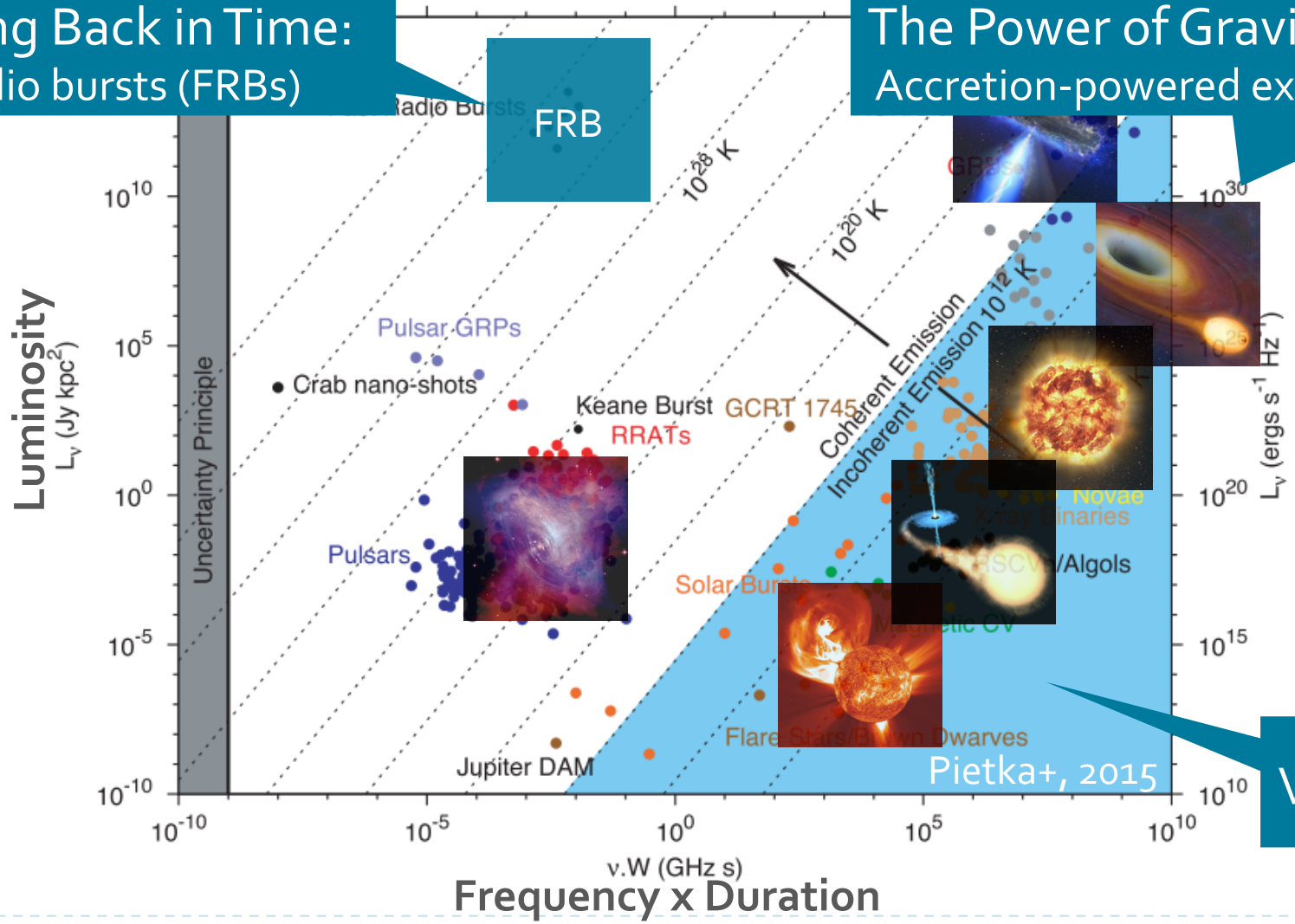
RRATs
GCRT 1745
Pulsars
Jupiter DAM
Solar Bursts
AGN/Blazars
GRBs
Novae
X-ray Binaries
RSCVn/Algols
Flare Stars/Brown Dwarves
10^{28} K
10^{20} K
10^{12} K
Coherent Emission
Incoherent Emission
Pietka+, 2015

Phase Space

Looking Back in Time:
Fast radio bursts (FRBs)

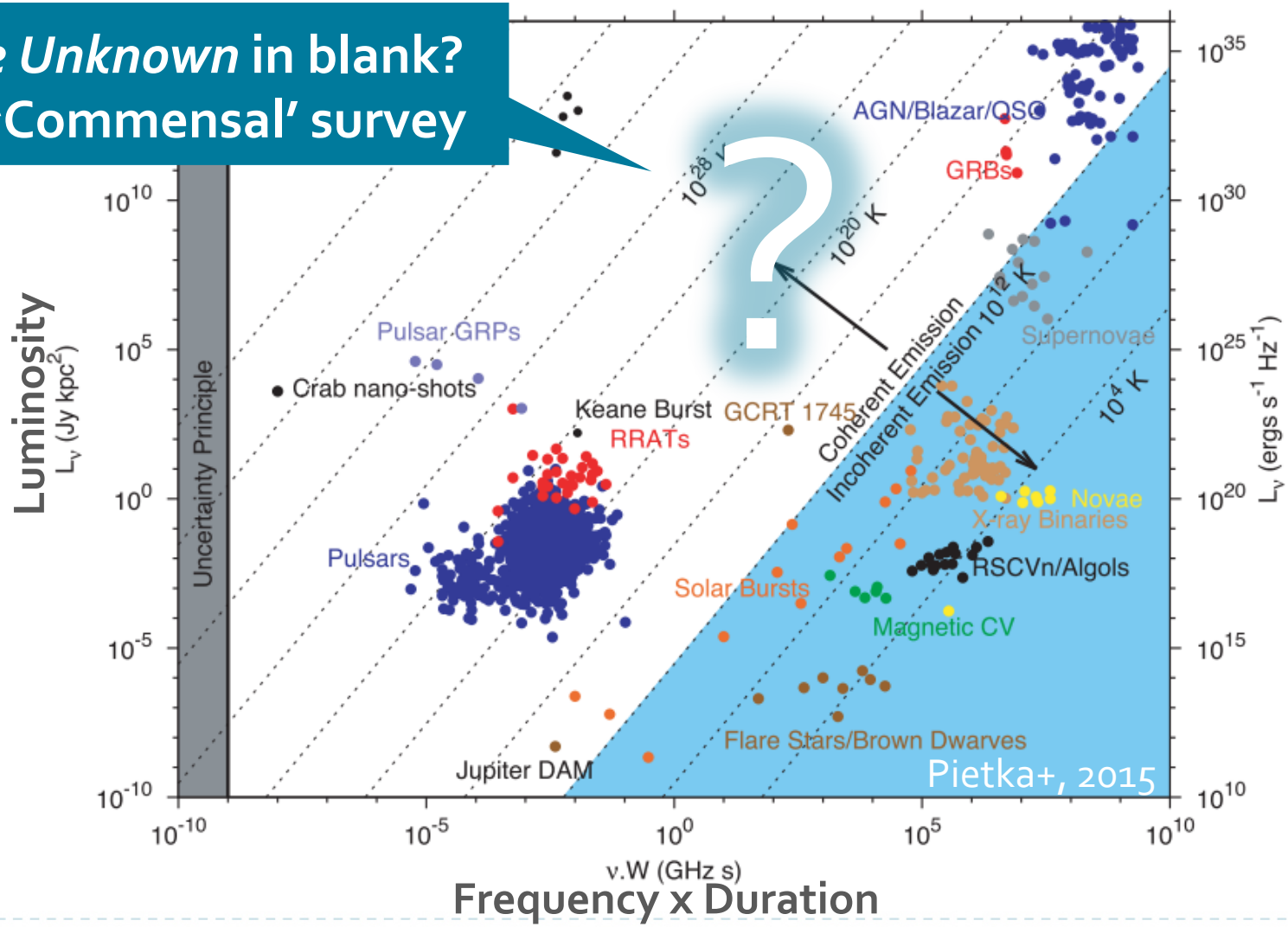
The Power of Gravity:
Accretion-powered explosions



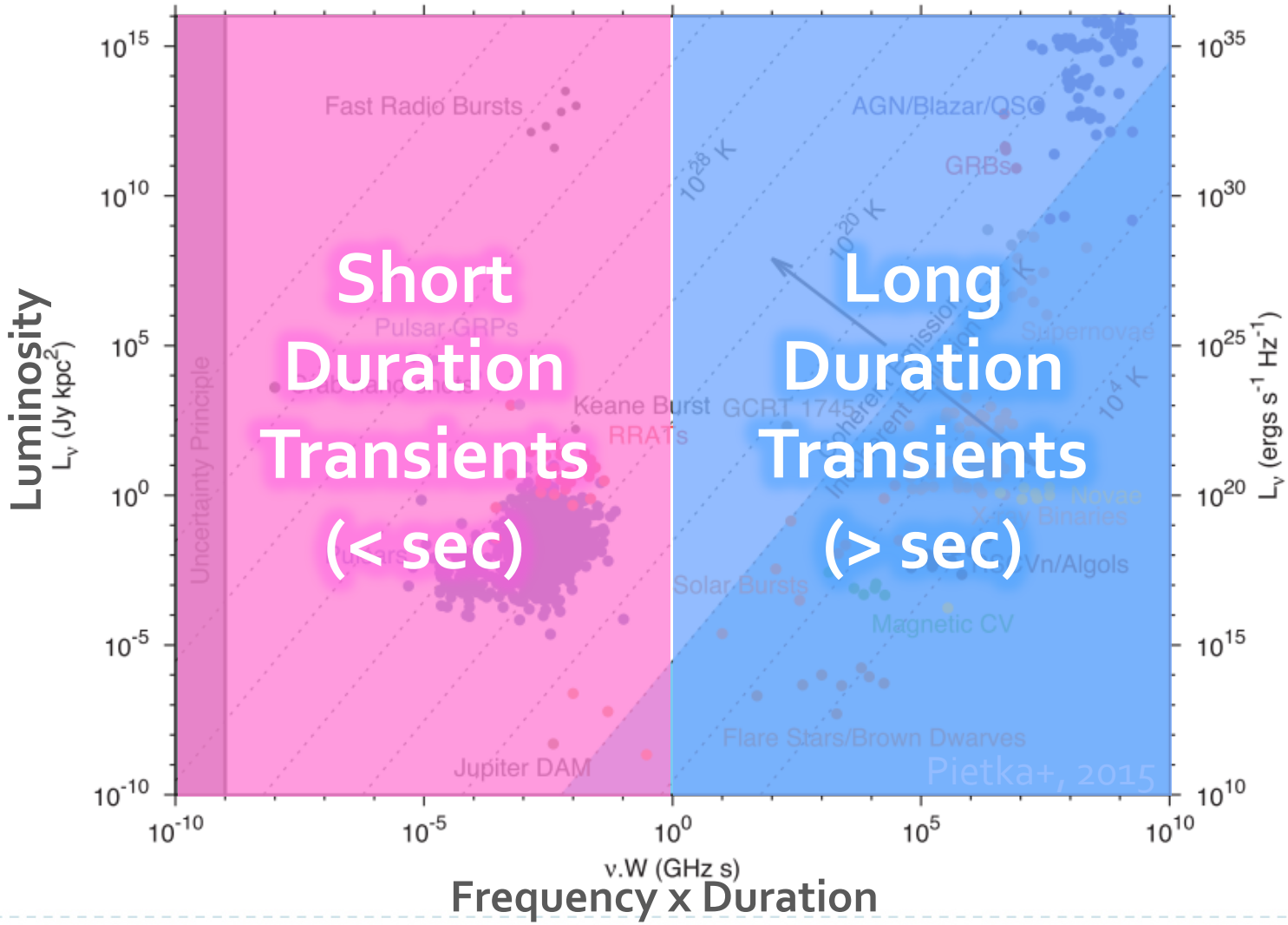
Variables

Phase Space

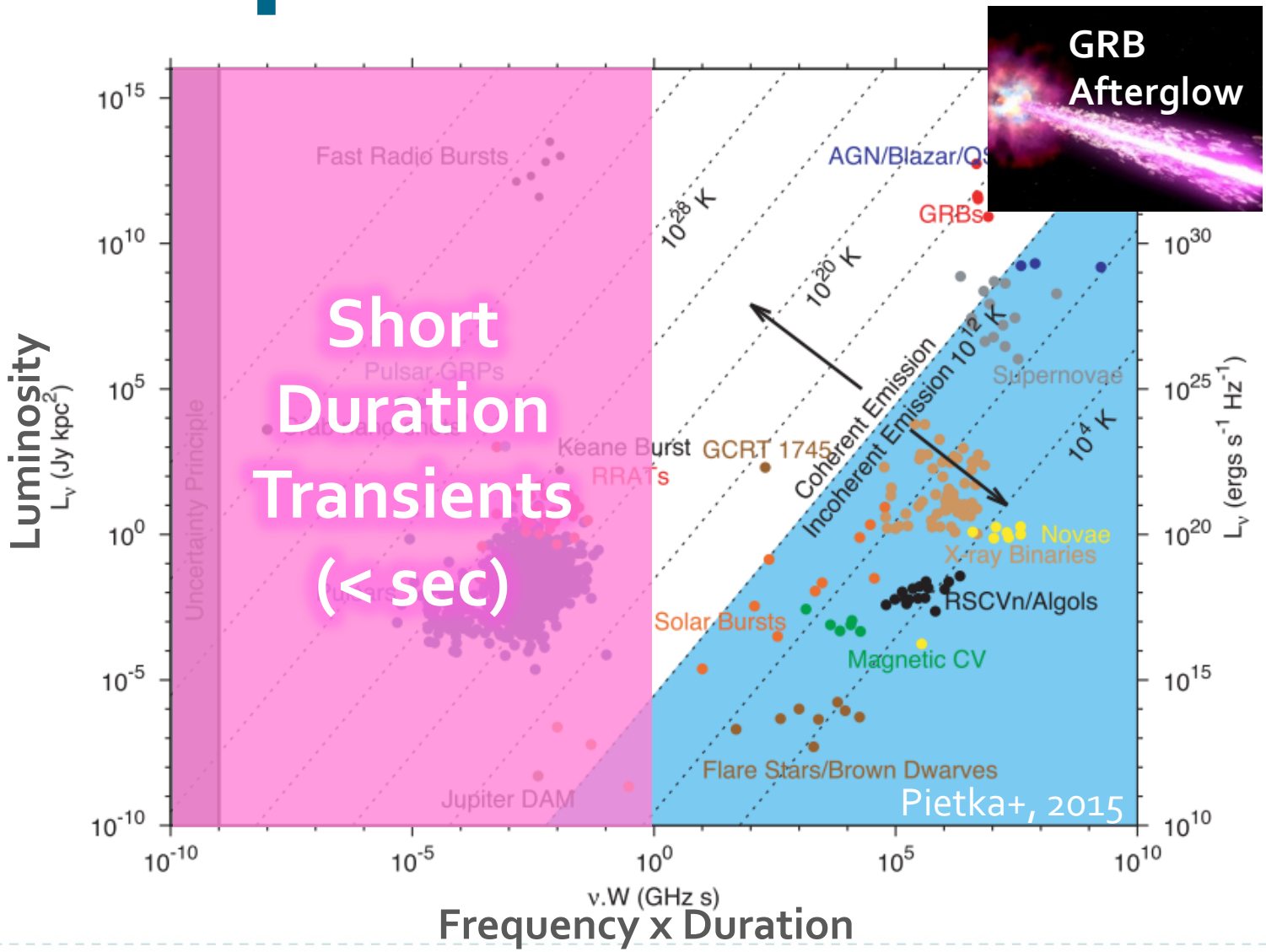
The Unknown in blank?
→ 'Commensal' survey



Phase Space


Short Duration Transients (< sec)
Long Duration Transients (> sec)
Fast Radio Bursts
AGN/Blazar/QSO
GRBs
Pulsar GRPs
Supernovae
Keane Burst
RRATs
GCRT 1745
Novae
X-ray Binaries
UV Cet/Algols
Solar Bursts
Magnetic CV
Flare Stars/Brown Dwarves
Jupiter DAM
Uncertainty Principle
Pietka+, 2015
Luminosity
L_ν (Jy kpc^2)
L_ν (ergs s^{-1} Hz^{-1})
ν.W (GHz s)
Frequency x Duration

Phase Space


GRB Afterglow
Short Duration Transients (< sec)
Fast Radio Bursts
Pulsar GRPs
Keane Burst
RRATs
GCRT 1745
Uncertainty Principle
Jupiter DAM
AGN/Blazar/QS
GRBs
Supernovae
Novae
X-ray Binaries
RSCVn/Algols
Magnetic CV
Solar Bursts
Flare Stars/Brown Dwarves
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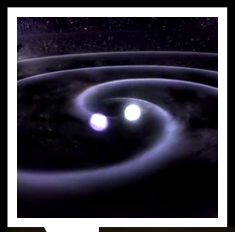
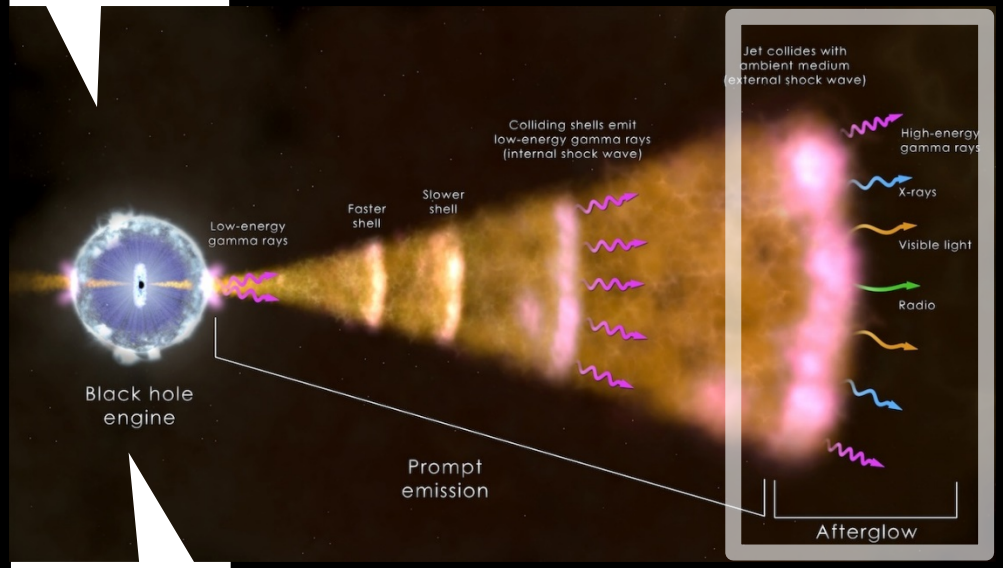
Incoherent Emission
10^{28} K
10^{20} K
10^{12} K
10^{4} K
Luminosity
L_ν (Jy kpc^2)
L_ν (ergs s^{-1} Hz^{-1})
ν.W (GHz s)
Frequency x Duration
Pietka+, 2015

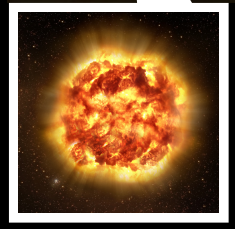

GAMMA-RAY BURSTS

Gamma-ray Bursts

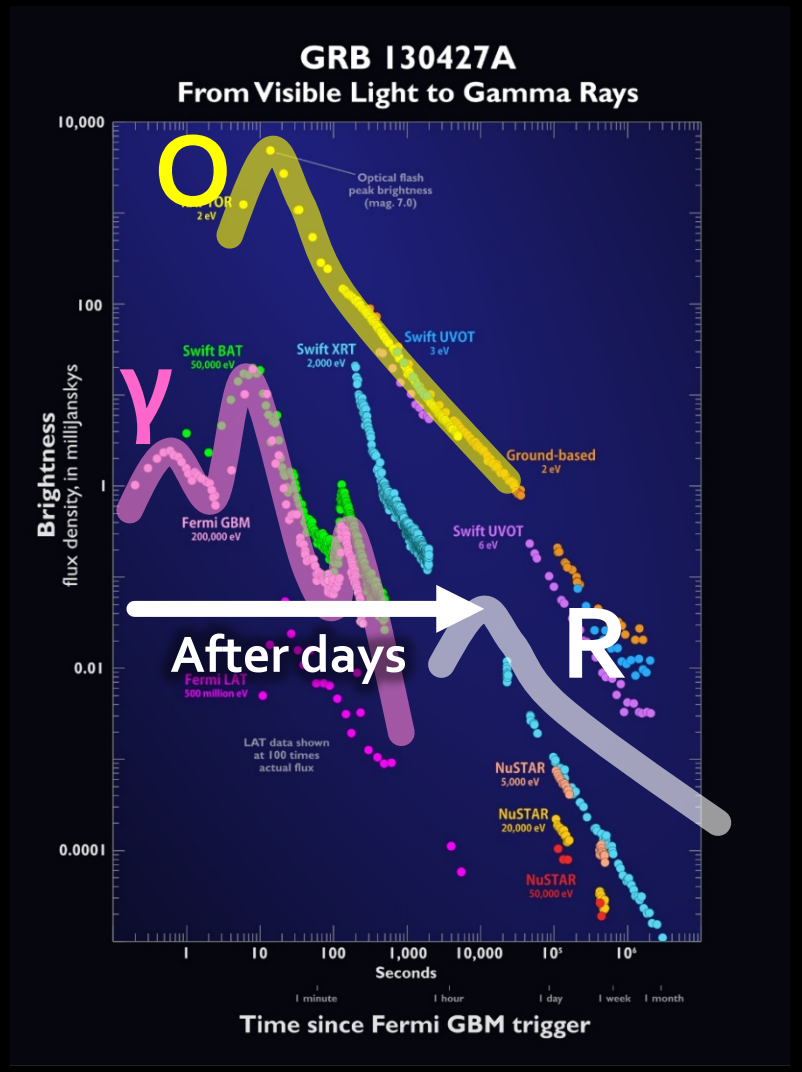


NS-NS/BH merger?
(Short-duration GRB)





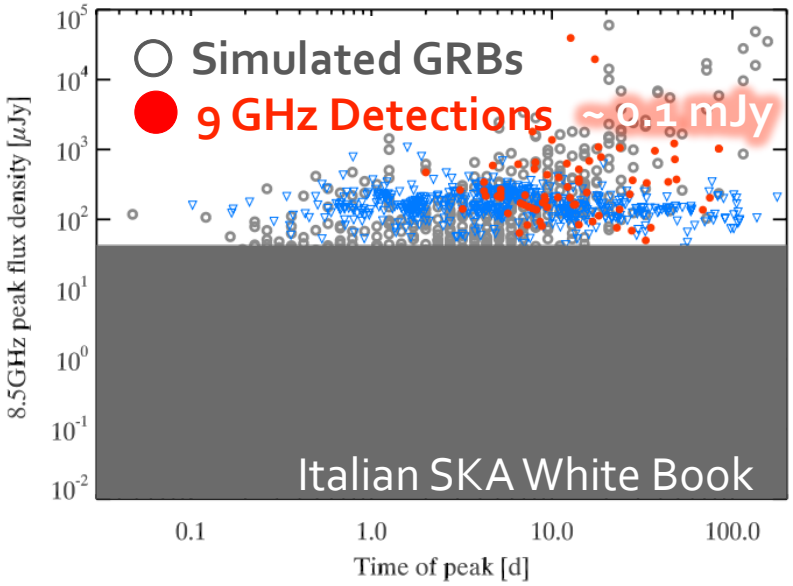
Collapse of a massive star?
(Long-duration GRB)



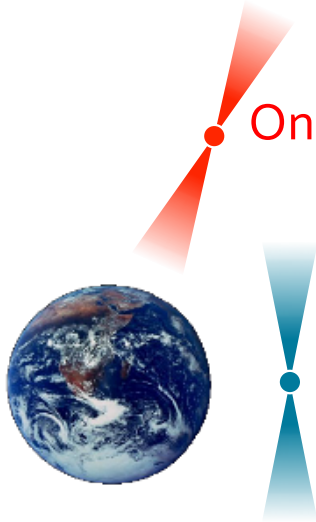
GRB Afterglow: Issues in Radio

Low Detection Rate

- GRB follow-up results
  - X-ray: 93% detected
  - Optical: 75% detected
  - **Radio: 30% detected**



Orphan Afterglows Undiscovered



On-axis GRB afterglow:
30% radio detected

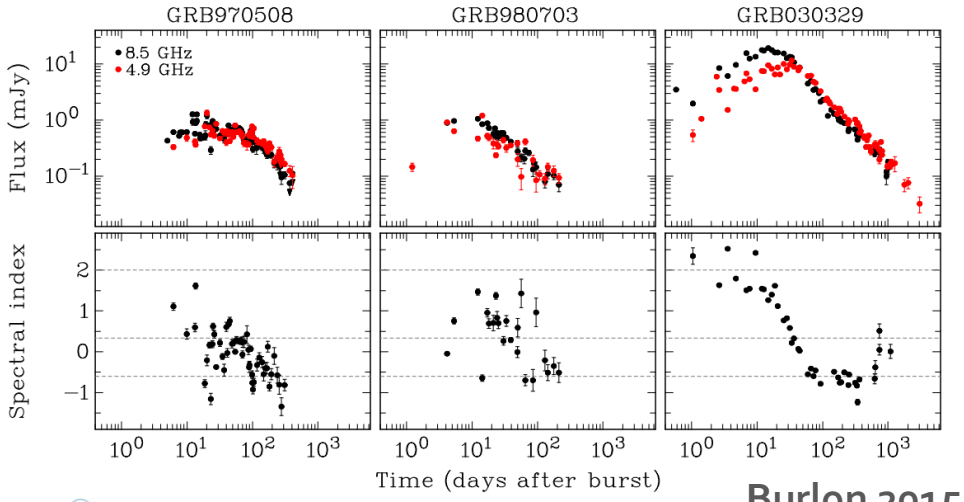
Orphan/off-axis GRBA
(99% of population):
Undiscovered in radio

On-axis GRB: 1% of the all GRBs

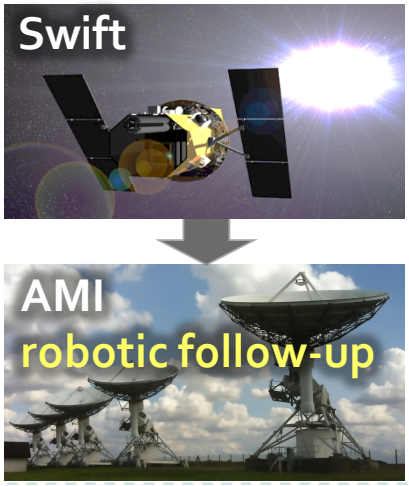
- Radio detection: 30% of on-axis GRBs
- **Radio detection: 0.3% of population**
- **Need for the high sensitive SKA-MID**

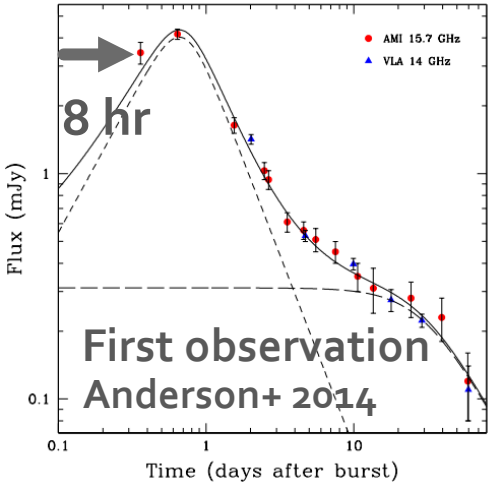
GRB Afterglow: Why Radio?

- **Revealing Blast Wave Kinetic Energy**
  - › Bright in radio at the spherical outflow phase
  - › Energy estimation easy!
- **Revealing Jet Particles & Magnetism**
  - › Reverse shock observation
  - › Need for immediate **follow-ups within several hours**

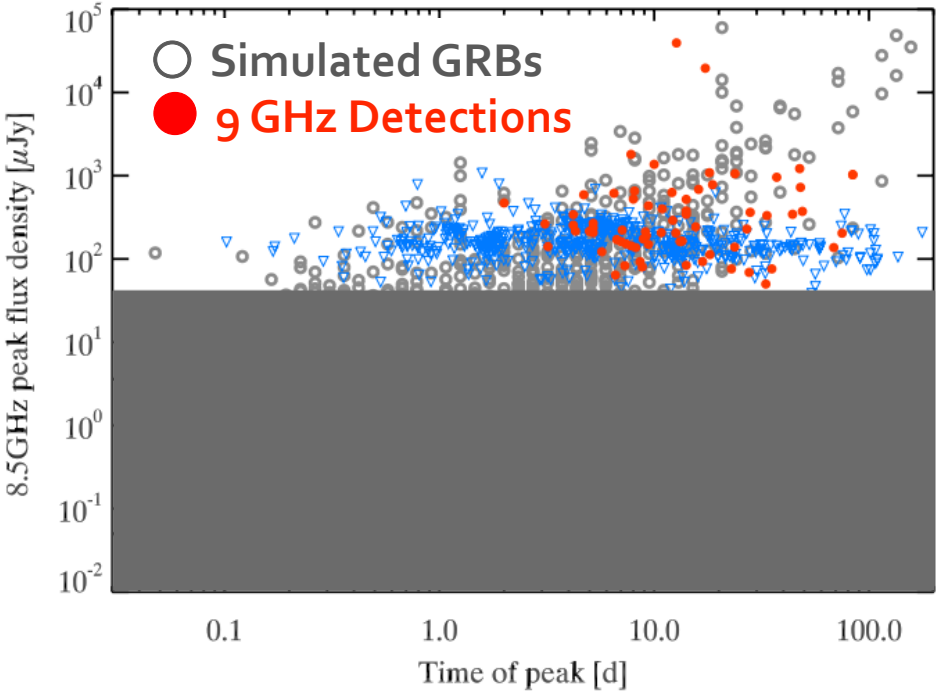


Burlon 2015

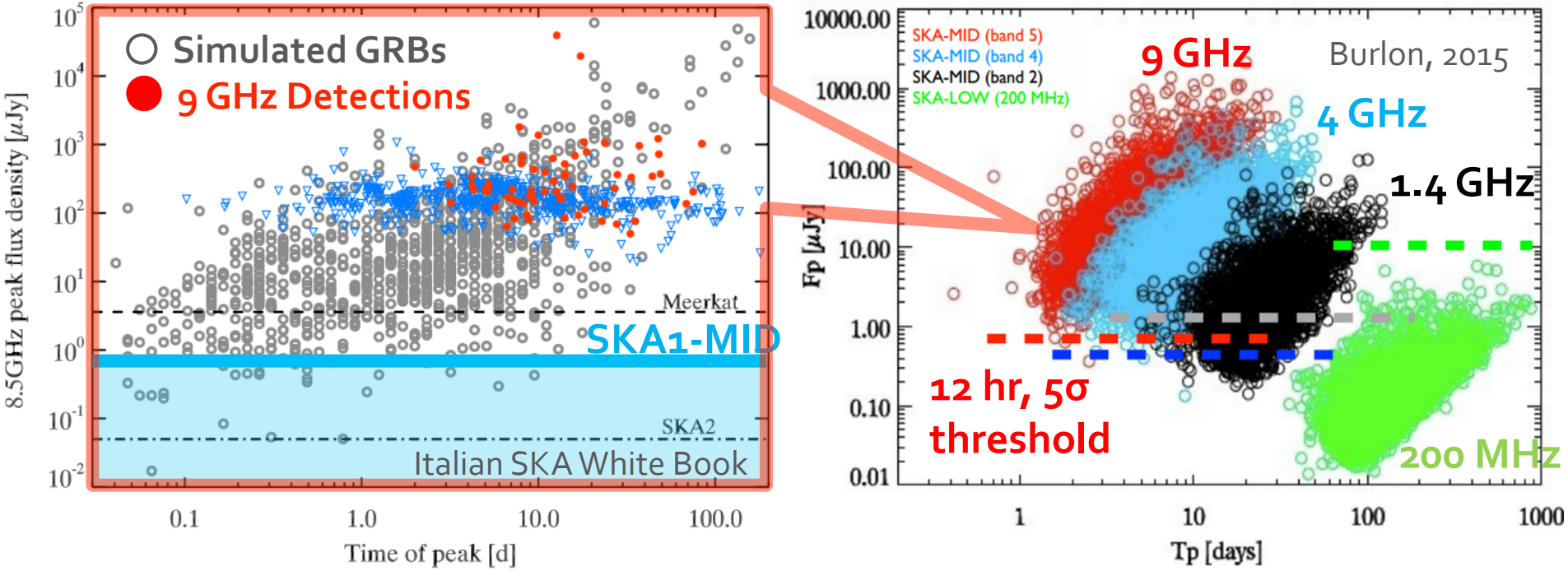




GRB Afterglow: Why SKA?

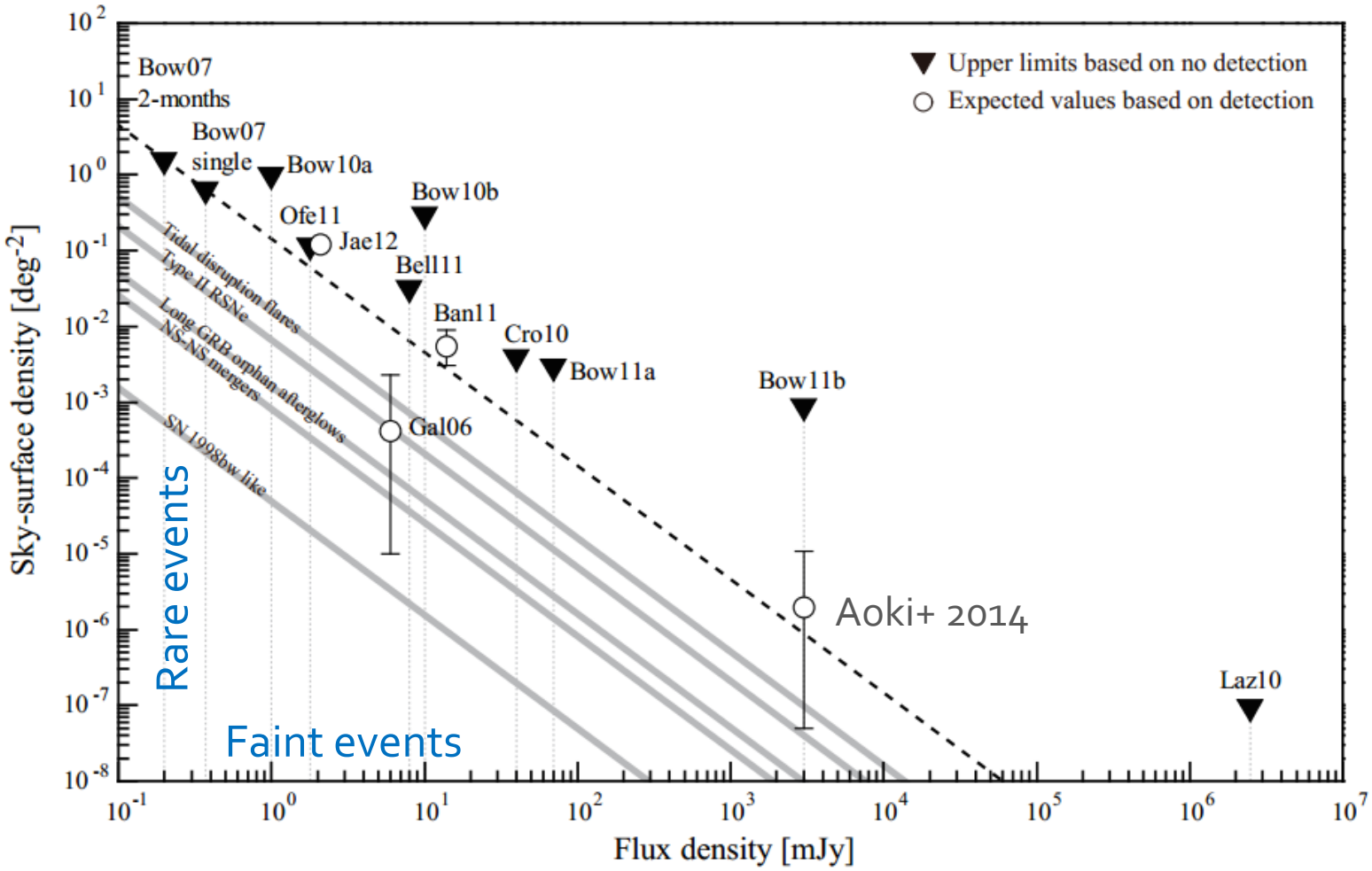


GRB Afterglow: Why SKA?

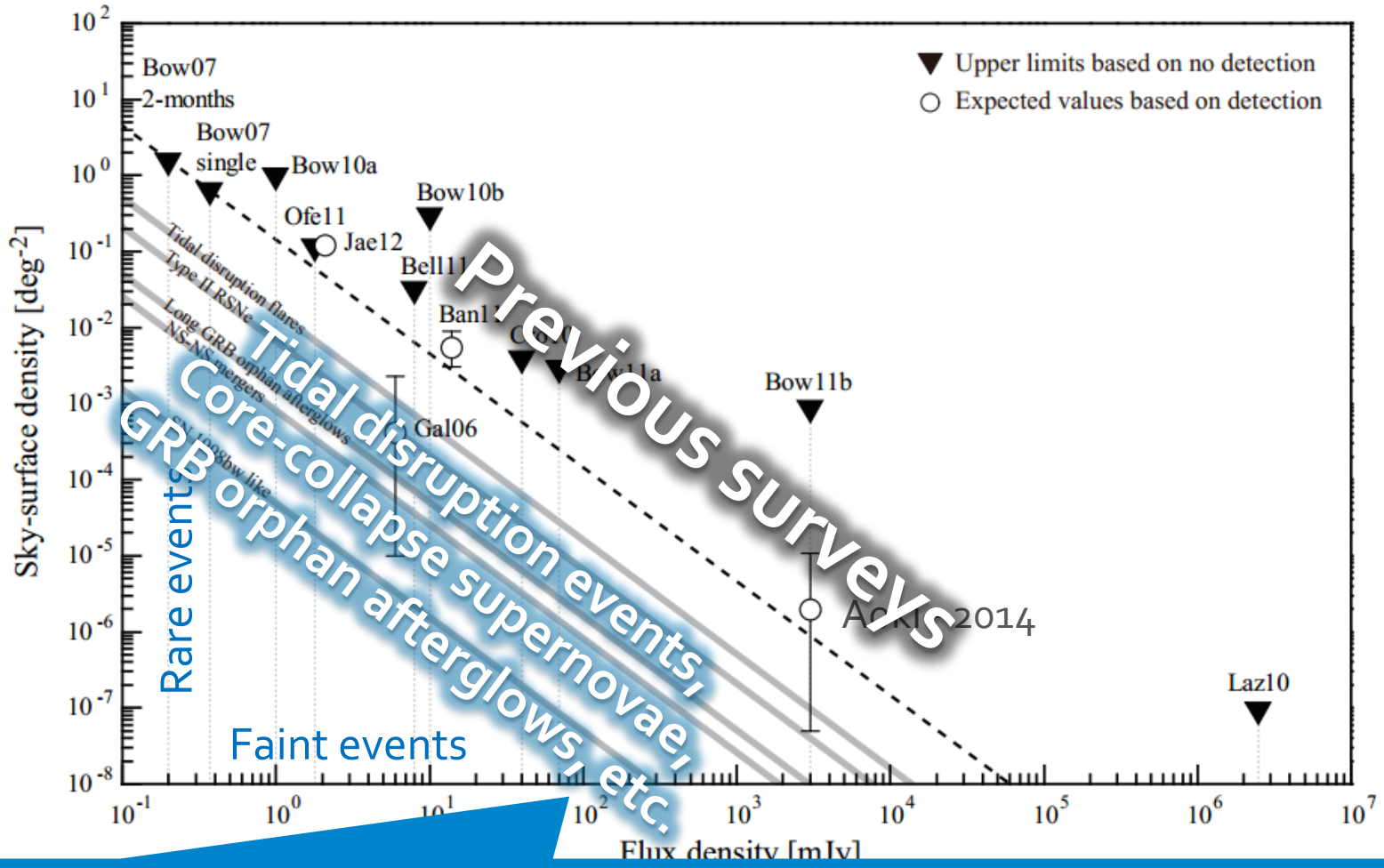


- Almost all the GHz afterglows detectable using SKA-MID
- However, MHz afterglows undetectable using SKA-LOW…

Orphan GRBA Surveys



Orphan GRBA Surveys

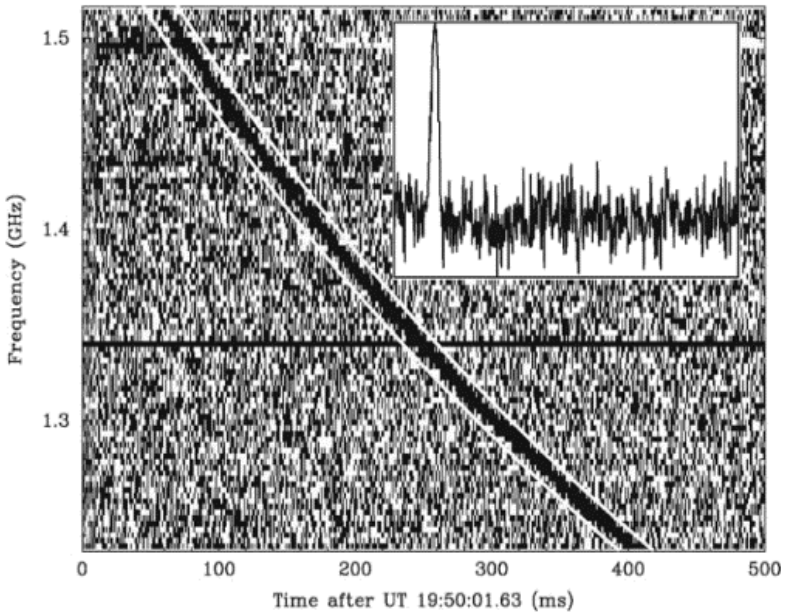


SKA is a *powerful hunter* of these sources!

Unknown Transients

Fast Radio Bursts

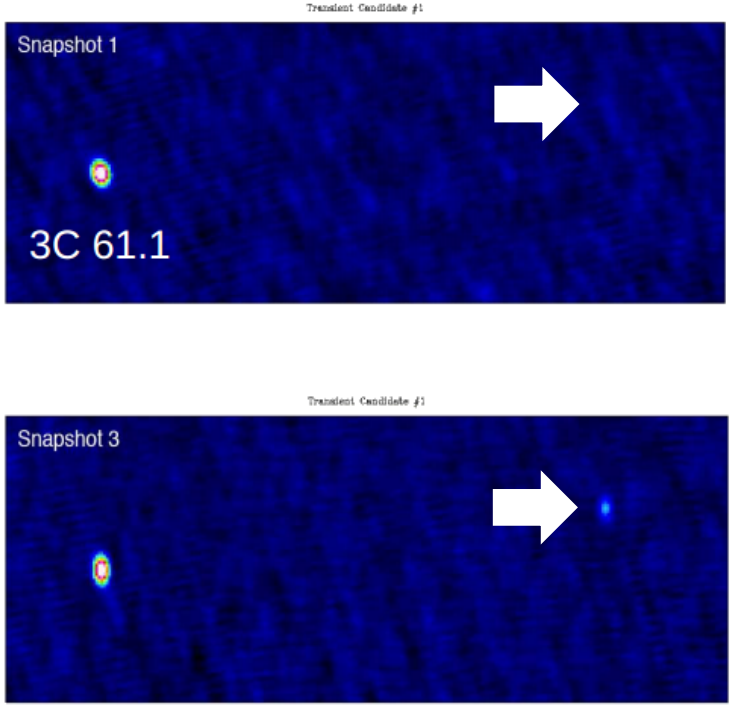
1 ms duration, 1 Jy intensity



Lorimer+ 2007 (Parkes)

Long Duration Transients

Minutes duration



Stewert+ 2015 (LOFAR)

Performance Comparison

Table 1: A table of typical performance measures for a variety of radio telescopes (extant and under construction).

Parameters for Comparable Telescopes														
		eMERLIN	JVLA	GBT	GMRT	Parkes MB	LOFAR	FAST	MeerKAT	WSRT	Arecibo	ASKAP	SKA1-low	SKA-mid
A_{eff}/T_{sys}	m^2/K	60	265	276	250	100	61	1250	321	124	1150	65	559	1560
FoV	deg^2	0.25	0.25	0.015	0.13	0.65	14	0.0017	0.86	0.25	0.003	30	20.77	0.49
Receptor Size	m	25	25	101	45	64	39	300	13.5	25	225	12	35	15
Fiducial frequency	GHz	1.4	1.4	1.4	1.4	1.4	0.12	1.4	1.4	1.4	1.4	1.4	0.11	1.67
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	9.00×10^2	1.76×10^4	1.14×10^3	8.13×10^3	6.50×10^3	5.21×10^4	2.66×10^3	8.86×10^4	3.84×10^3	3.97×10^3	1.27×10^5	6.49×10^6	1.19×10^6
Resolution	arcsec	$10\text{-}150 \times 10^{-3}$	1.4 - 44	420	2	660	5	88	11	16	192	7	7	0.25
Baseline or Size	km	217	1 - 35	0.1	27	0.064	100	0.5	4	2.7	225	6	80	150
Frequency Range	GHz	1.3-1.8, 4-8, 22-24	1 - 50	0.2 - 50+	0.15, 0.23, 0.33, 0.61, 1.4	0.44 to 24	0.03 – 0.22	0.1 – 3	0.7 - 2.5, 0.7 - 10	0.3 – 8.6	0.3 - 10	0.7-1.8	0.050 – 0.350	0.35-14
Bandwidth	MHz	400	1000	400	450	400	4	800	1000	160	1000	300	300	770
Cont. Sensitivity	$\mu Jy\text{-}hr^{-1/2}$	27.11	3.88	5.89	6.13	16.26	266.61	0.92	3.20	20.74	0.89	28.89	3.36	0.75
Sensitivity, 100 kHz	$\mu Jy\text{-}hr^{-1/2}$	1714	388	373	411	1029	1686	82	320	830	89	1582	184	66
SEFD	Jy	46.0	10.4	10.0	11.0	27.6	45.2	2.2	8.6	22.3	2.4	42.5	4.9	1.8

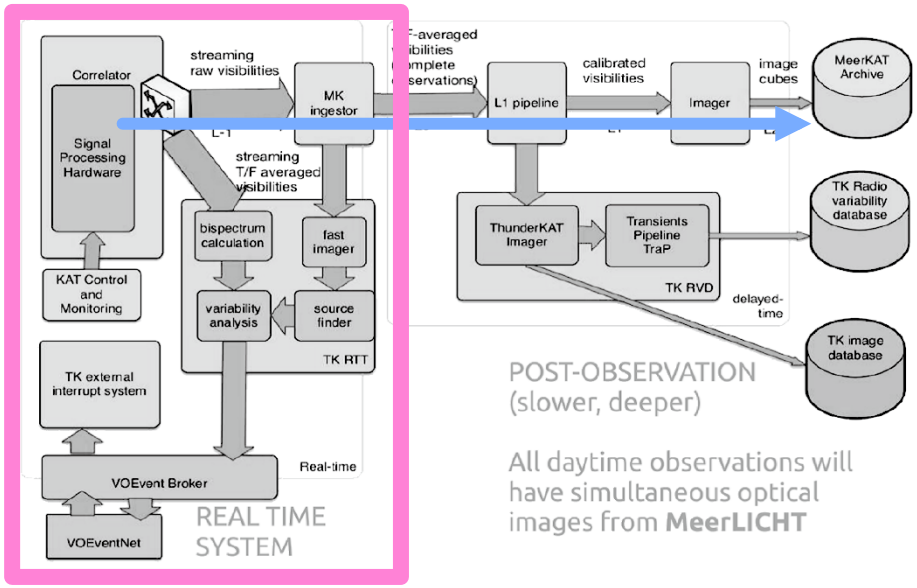
- **SKA (Resulting) Concept: High Sensitivity & Wide Field of View**
  (& Wide Band in SKA2?)
  - Consisting of many small antennas
  - World's highest sensitivity
  - World's highest survey speed
    - Time Domain *Radio* Astronomy available!
    - Transient science effective

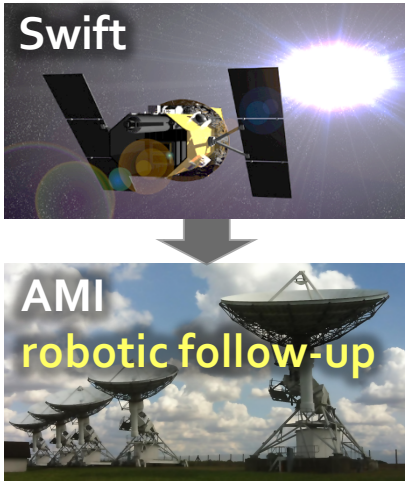
Requirements

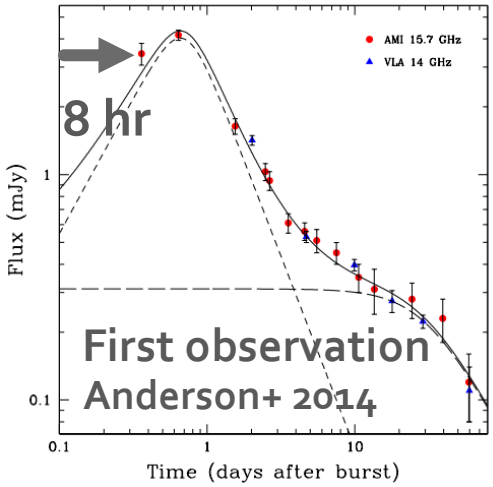
Commensal System

Robotic Follow-up System

Commensal System

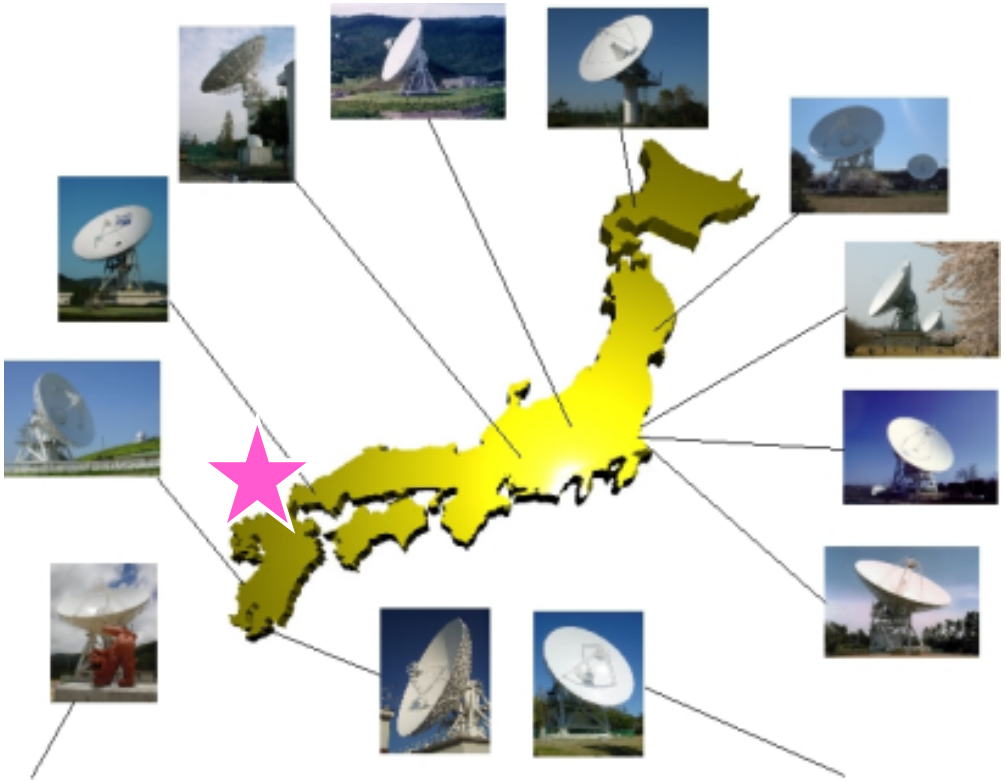


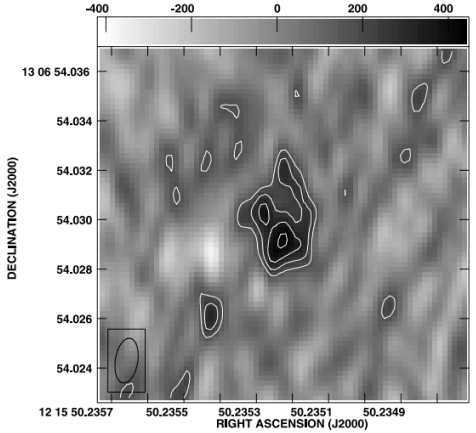




Japanese Contribution?

- VLBI Follow-up





VLBI = Very Long Baseline Interferometry

SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

- The slide design is based on an SKA official (?) template but slightly customized.
- The SKA webpage: www.skatelescope.org