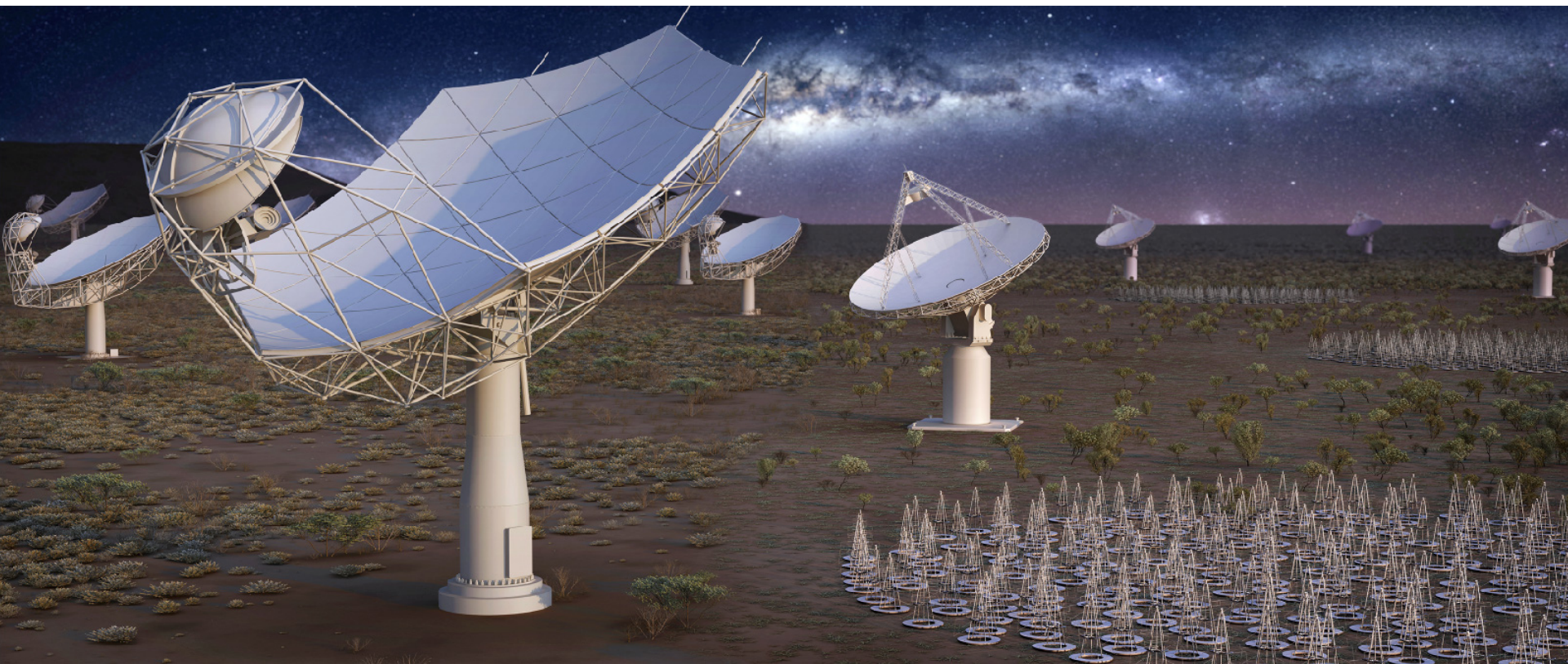


SKA-VLBIの性能とサイエンス事例



NAOJ SKA1 STUDY GROUP
国立天文台SKA1検討グループ

廣田朋也



References

■ SKA Science book (2014)

<https://www.skatelescope.org/news/ska-science-book/>

■ ANTICIPATED SKA1 SCIENCE PERFORMANCE (2017)

https://astronomers.skatelescope.org/wp-content/uploads/2017/10/SKA-TEL-SKO-0000818-01_SKA1_Science_Perform.pdf

■ ngVLA Science book (2018)

<https://ngvla.nrao.edu/page/scibook>

■ SKA VLBI KSP WS (2019 October @ Manchester)

<https://indico.skatelescope.org/event/539/page/280-conference-presentations>

■ SKA Science book beyond band 5(2020)

https://www.skatelescope.org/wp-content/uploads/2020/02/ScienceCase_band6_Feb2020.pdf

■ SKA-J Science book (2020)

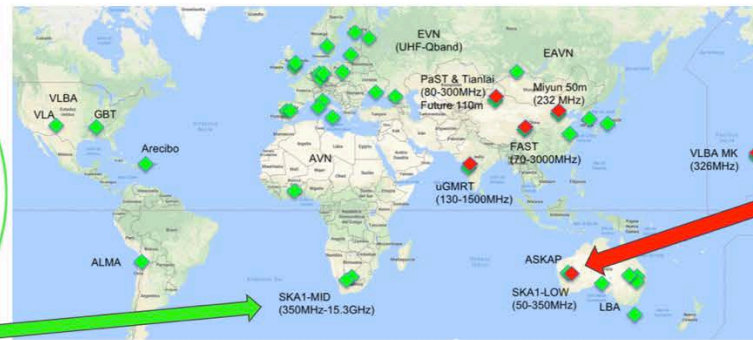
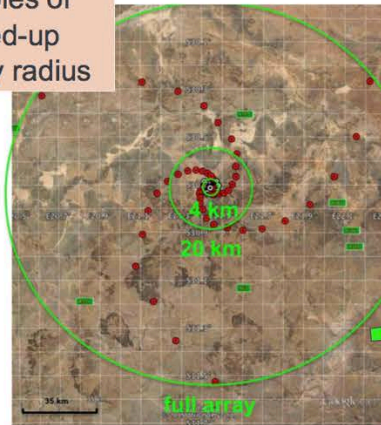
http://ska-jp.org/SKAJP_Science_Book_2020.pdf

■ SKA-VLBI性能諸元(2020 September version)

<https://mwg.sci.kagoshima-u.ac.jp/wiki/pages/m0e1R6Q5/2020.html>

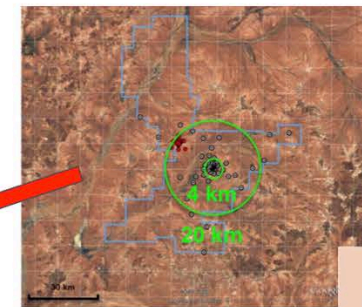
SKA-VLBI CONFIGURATIONS: networks & sensitivities

SKA1-MID
Examples of
phased-up
subarray radius



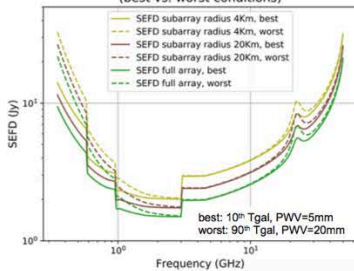
VLBI-MID

VLBI-LOW

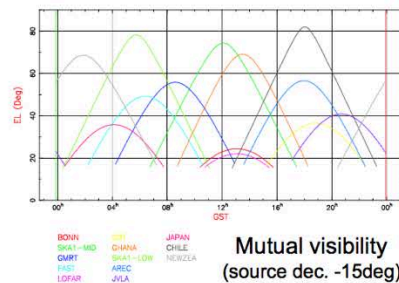
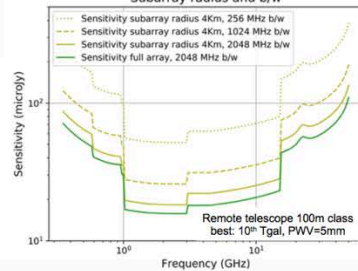


SKA1-LOW
Examples of
phased-up
subarray radius

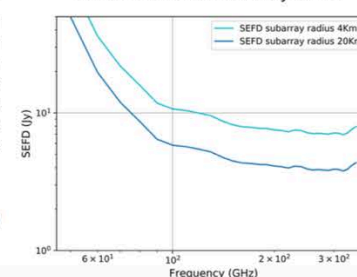
SEFD - SKA1-MID subarray radius (best vs. worst conditions)



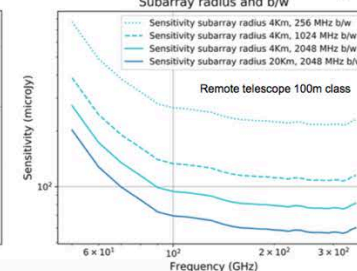
SKA1-MID VLBI baseline sensitivity Subarray radius and b/w



SEFD - SKA1-LOW subarray radius



SKA1-LOW VLBI baseline sensitivity Subarray radius and b/w

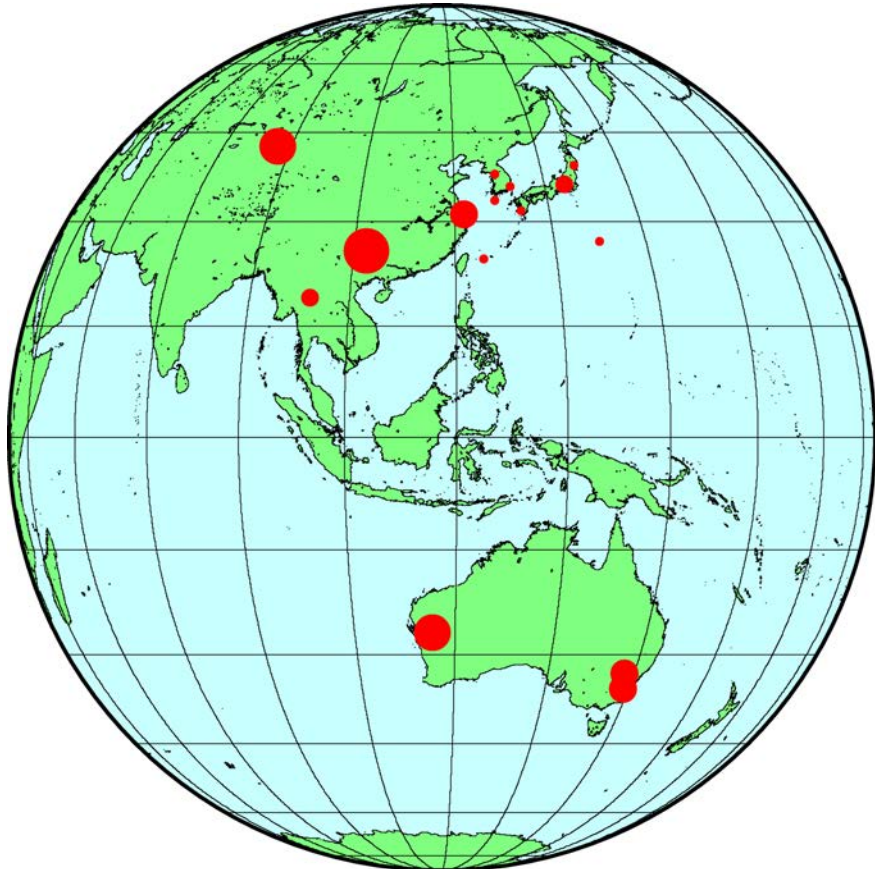


Access to Southern skies, (sub-)uJy sensitivity on mascales, superior calibration

Multi-beam capability: high-precision astrometry!

Simultaneous SKA products: range of angular scales, unique commensal applications

■ Possible collaboration for future global VLBI



- Ultimate global VLBI with SKA1

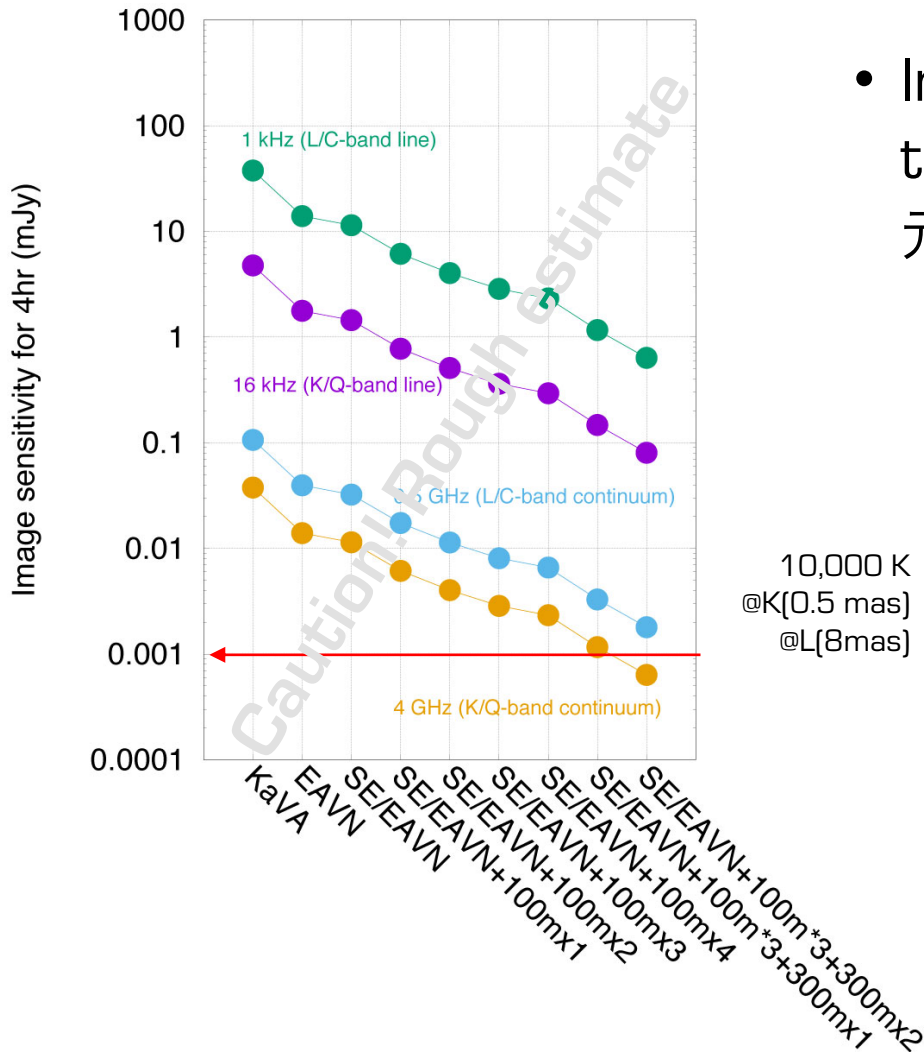
- Along with a few 100 m-class
- Several 50 m-class
- Many 20-30 m antennas

+Phased ALMA Band 1(O?)

+ngVLA LBA

- Common frequency?
- Common sky?
- Need more detailed study

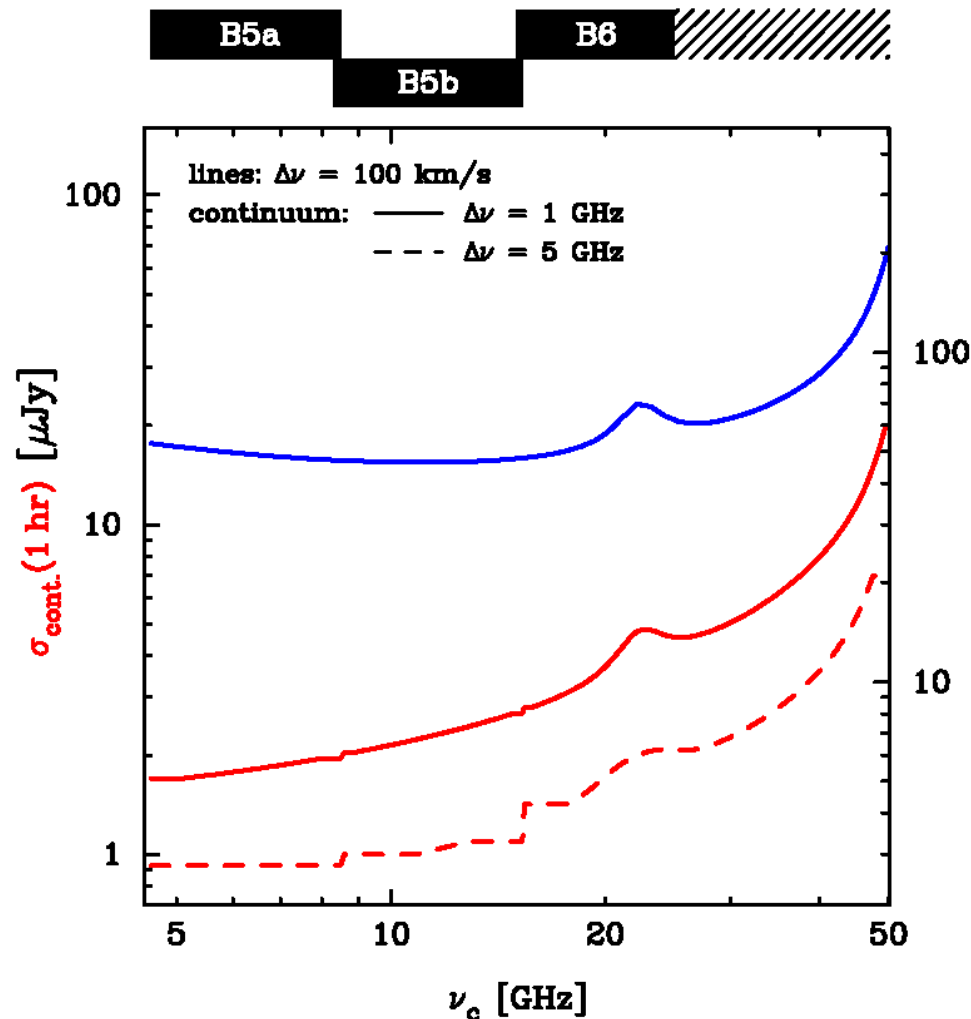
Improvement from KaVA by a factor of 100



- Image sensitivity of 4hr on-source time (1σ) based on “SKA-VLBI 性能諸元(2020 September version)”

- Assuming $T_{\text{sys}}=100$ K and $e=50\%$ if there is no information
- Rough estimate with uncertainties of a factor of 3-10

■ c.f. Image sensitivity at Bands 5 and 6

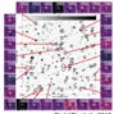


- Parameters are different from my rough estimate
- Still my rough estimate is comparable with that of SKA official document
 - Achieving μJy level

VLBI with SKA1-MID: 6 science cases updated

SKA continuum surveys

Adding high angular resolution to SKA surveys: **Giochetti et al.**



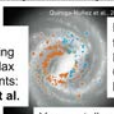
Transients

Resolving (ultra-relativistic) outflows with SKA-VLBI: **Paragi et al.**



Our Galaxy, Astrometry and CoL

Galactic structure using maser parallax measurements: **Ellingsen et al.**



Dynamics of the Galactic Bulge using OH masers: **Imai et al.**

Pulsars, Astrometry



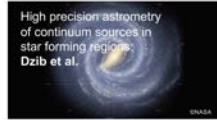
Parallax measurements of SH pulsars: **Deller et al.**

Young stellar cluster deep field: **Hoare et al.**

VLBI with SKA1-MID: 16 new science cases: Astrometry

High-precision astrometry

High precision astrometry of continuum sources in star forming regions: **Dzib et al.**

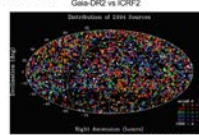


Ultra-precise astrometry to the MCs: **Rioja et al.**



Global astrometry

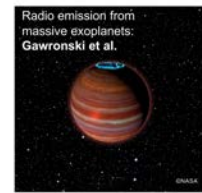
Massive densification of the radio RF: searching for Gaia counterparts. **Charlot et al.**



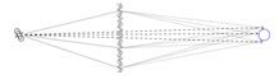
Radio and Gaia reference frames tie with radio stars: **Zhang et al.**

VLBI with SKA1-MID: 16 new science cases: stars, planets, ISM

Radio emission from massive exoplanets: **Gawronski et al.**

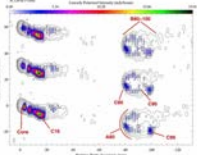


Pulsar scintillometry with SKA1-MID: **Kirsten et al.**

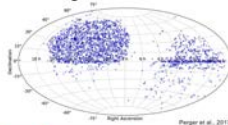


VLBI with SKA1-MID: 16 new science cases: AGNs (1/2)

Deep multi-frequency Polarimetric survey of a big AGN sample: **Agudo et al.**



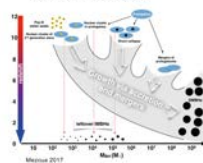
Extremely high-z AGNs: **Pergler et al.**



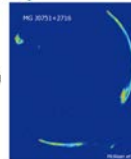
Chasing merged and merging SAGB: **Anton et al.**

VLBI with SKA1-MID: 16 new science cases: AGNs (2/2)

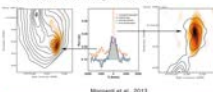
Intermediate mass black holes: **Mezcua et al.**



Testing models of galaxy formation and dark matter with strong gravitational lensing: **McKean et al.**

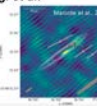


Characterising feeding and feedback in high-z radio AGN using HI absorption: **Morganti et al.**



VLBI with SKA1-MID: 16 new science cases: Transients

FRBs and their hosts: **Paragi et al.**



ULXs in the local Universe: **Middleton et al.**



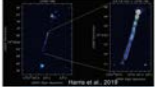

Inhomogeneous SNe at low freqs: **Chandra et al.**



Superflares on low-mass stars: **Villadsen et al.**




VLBI with SKA1-LOW: 7 new science cases

<p>Galaxies and AGN</p> <p>AGN physics at very low freqs: Morabito et al.</p>  <p>HI absorption at high z: Gupta et al.</p> 	<p>Transients</p> <p>Jets from low mass YSO at very low frequencies: Ainsworth et al.</p>  <p>Inhomogeneous SNe at low freqs: Chandra et al.</p> 
<p>Pulsars and ISM</p> <p>Pulsar scintillometry at very low freqs: Kirsten et al.</p> 	<p>Stars, Planets, Astrometry</p> <p>Precise astrometry of low frequency pulsars: Dodson et al.</p>  <p>Precise astrometry for exoplanets detection: Guirado et al.</p> 

Exploring the Universe with the world's largest radio telescope 12

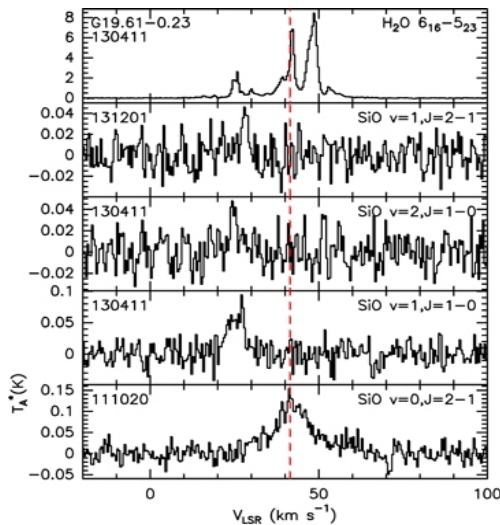
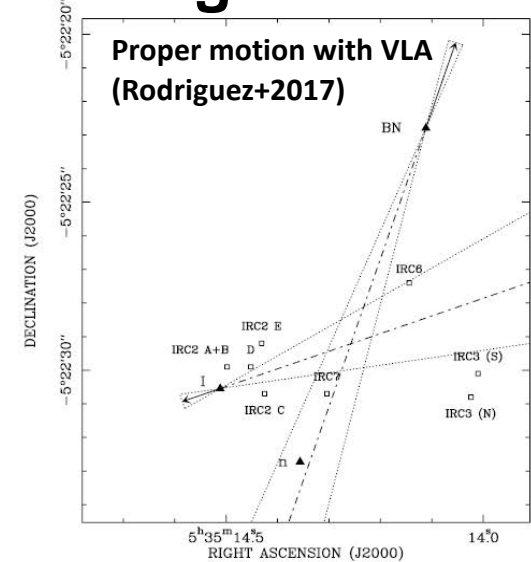
■ Increased number of new rare/weak lines

band	Range (GHz)	Species and line frequencies (GHz)	# lines
1	1.2 - 3.5	ground-state OH (1.612, 1.665, 1.667, 1.720)	4
2	3.5 - 12.3	excited OH (4.66, 4.75, 4.765, 6.031, 6.035, 6.049)	6
		CH ₃ OH Class I (9.936)	1
		CH ₃ OH Class II (6.668, 12.18)	2
		ortho-H ₂ CO (4.83)	1
3	12.3 - 20.5	CH ₃ OH Class II (19.97)	1
		excited OH (13.441, Baudry et al. 1981; Caswell 2004)	1
4	20.5 - 34	H ₂ O (22.235)	1
		CH ₃ OH J_2-J_1 -series Class I (24.9-30.3)	15
		CH ₃ OH Class I (23.445, Voronkov et al. 2011)	1
		CH ₃ OH Class II (23.12, Cragg et al. 2004)	1
		ortho-NH ₃ (3,3) (6,6) (9,9) (12,12)	4
		other NH ₃ inversion lines (thermal and/or maser)	~dozen
		excited OH (23.8, Baudry et al. 1981)	1
5	30.5 - 50.5	Class I CH ₃ OH (36.169, 44.069)	2
		Class II CH ₃ OH (37.7, 38.29, 38.45)	3
		SiO 1-0 $v=1,2$ (43.12, 42.82)	2
6	70 - 116	CH ₃ OH Class I (84.521, 95.169, 104.3)	3
		CH ₃ OH Class II (76.2, 76.5, 85.5, 86.6, 104.1, 107, 108.8)	7
		SiO 2-1 $v=1,2$ (86.24, 85.64)	2

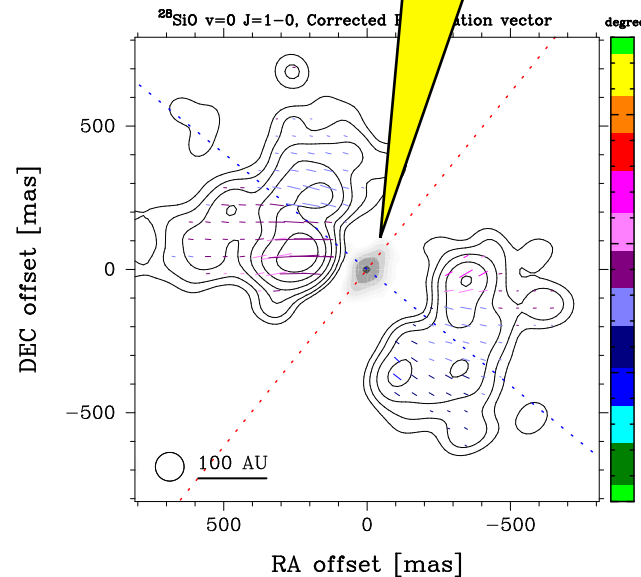
■ Increased number of new rare/distant targets

- SiO in SFRs
- Extra-galactic masers
- Polarization
- Combined with continuum

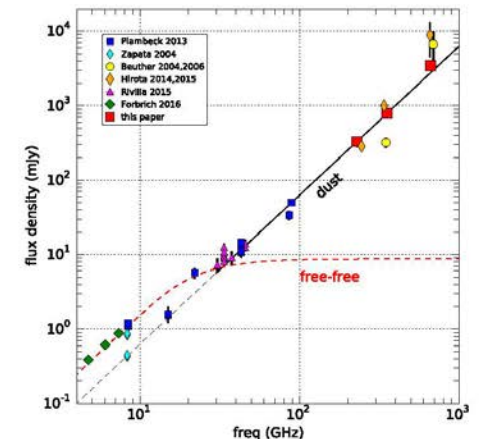
No radio jet?



New SiO maser source G19.61-0.23 detected by ALMA (Cho et al. 2016)



Linear polarization of SiO v=0 J=1-0 maser with VLA (Hirota et al. 2020)

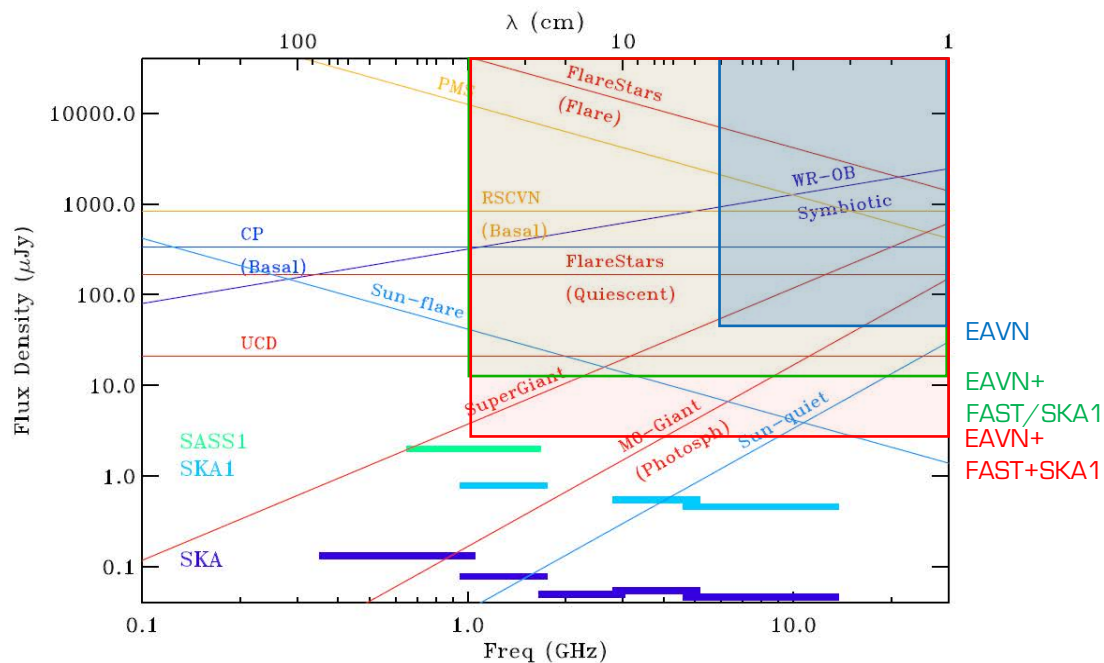


SED of Source I (Plambeck & Wright 2016)

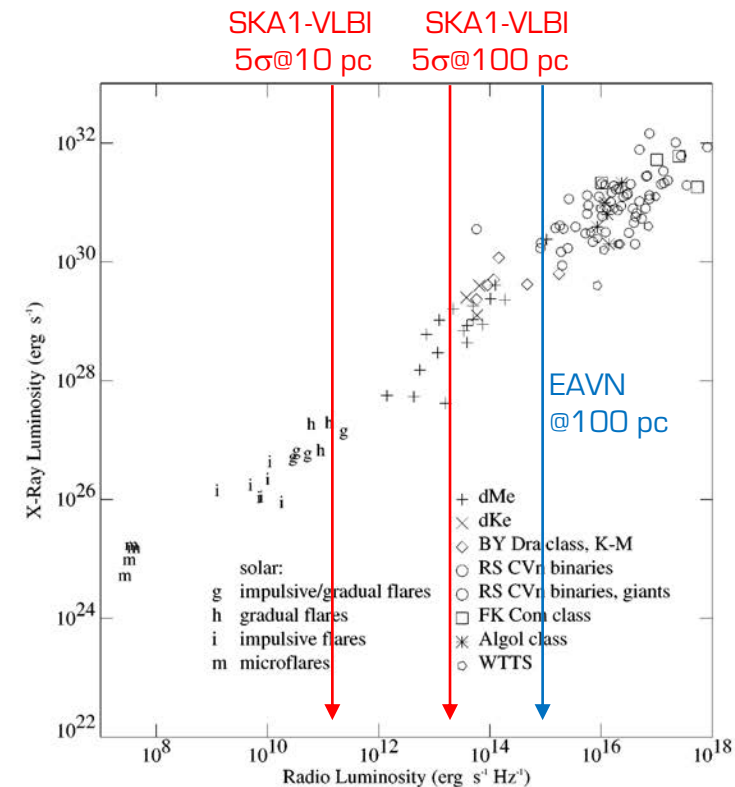
Targets of stellar radio emissions

■ Various classes of stars are possible targets

- Planets are also possible targets (mainly at SKA-Low)
- Non-thermal: good targets for VLBI
- Thermal: depending on size






Stellar radio spectra [Umana et al. 2015]

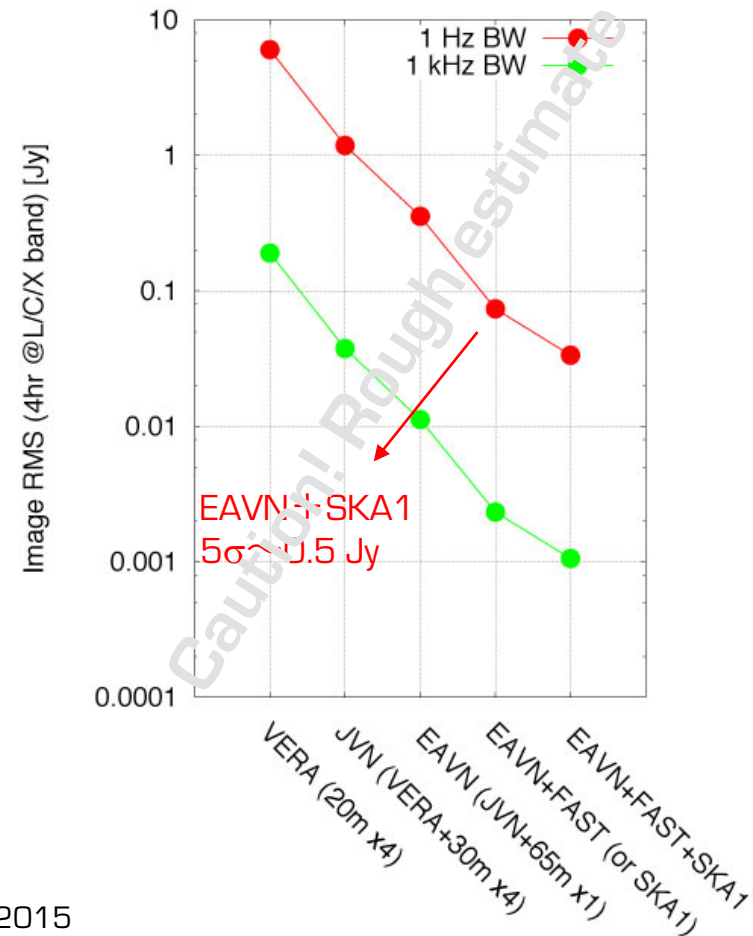


Relationship between X-ray and radio (5-8 GHz) luminosity [Gudel 2002]

Recent Unsuccess as Breakthrough Initiatives

- $F_{\nu} = 8 \times 10^{-16} \text{ EIRP} (D_{\text{pc}})^{-2} \text{ [Jy]}$ for $\Delta\nu = 1 \text{ Hz}$
 - ✓ Nearby planets; $\text{EIRP} < 5 \times 10^{19}$ at L band by GBT (Enriquez+2017)
 - ✓ Survey in Orion; $\text{EIRP} < 4 \times 10^{20}$ at FM by MWA (Tingey+2018)
 - ✓ Oumuamua; $\text{EIRP} < 7 \text{ kW} / 100 \text{ kW}$ (broad/narrow) (Tingey+2018)
- EAVN+SKA can detect airports?

Transmitter Type	Luminosity (EIRP) (ergs/sec)	Number on Earth
 Interplanetary Radar	$\sim 2 \times 10^{20}$	Few
 Long Range Aircraft Radar	$\sim 1 \times 10^{17}$	Dozens
 High Power TV and Radio	$\sim 5 \times 10^{12}$	Hundreds



■ SKA-VLBI will provide μJy images at mas resolution

- New science window will open
- Thermal emissions can be possible targets

■ Collaboration with ALMA Band 1 (0?) and ngVLA will be essential to achieve ultimate sensitivity at currently available EAVN frequency bands

■ FAST, LOFAR, etc. will also be essential to achieve ultimate sensitivity at lower frequency (not discussed in this presentation, though)