
# ngVLA計画概要と日本における活動報告、SWG-Jの活動とサイエンスケースの紹介

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On Behalf of ngVLA Study Group

# A next-generation Very Large Array (ngVLA)

ngvla
Next Generation Very Large Array

## Very Large Array (1980-)

- 27 x 25-meter antennas
- Max resolution 40 mas
- 73 MHz – 50 GHz

X 10 sensitivity
X 40 angular resolution

## Next generation Very Large Array (2034-)

- 248 x 18-meter +19 x 6-meter antennas
- Max resolution 1 mas (and 0.1 mas with LBA)
- 1 GHz – 116 GHz (Bridging SKA and ALMA)

- Project led by NRAO
- Seeking ~25% contribution from international partners

Timeline:
2024 – Construction Begins
2028 – Early Science
2034 – Full Science Operations

# ngVLA Key Science Goals
## (ngVLA memo #19)

1. *Unveiling the Formation of Solar System Analogues on Terrestrial Scales*

2. *Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry*

3. *Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time*

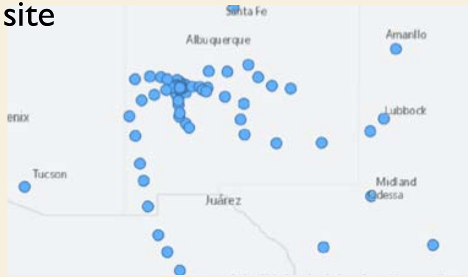
4. *Using Pulsars in the Galactic Center as Fundamental Tests of Gravity*

5. *Understanding the Formation and Evolution of Stellar and Supermassive BH's in the Era of Multi-Messenger Astronomy*

# Array Components

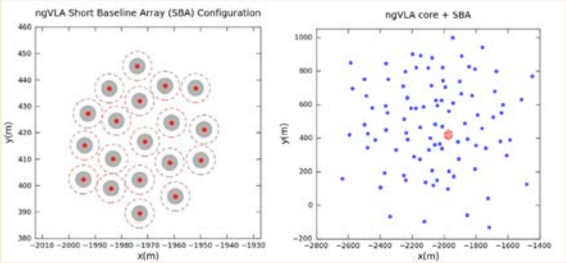
## Main Array (MA)

- 214 x 18m offset Gregorian antennas
- Up to 1000 km baselines
- Fixed antenna locations near VLA site



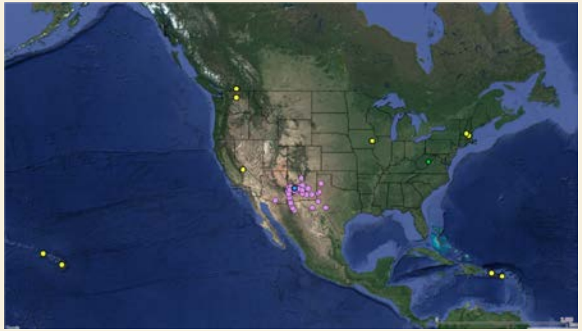

## Short Baseline Array (SBA)

- 19 x 6m antennas
- 4 x 18m in TP mode to fill in (u, v) hole  for imaging extended structure




## Long Baseline Array (LBA)

- 30 x 18m antennas located across continent for baselines up to ~9000km
- Operate in VLBI mode
- Max angular resolution = 0.1 mas



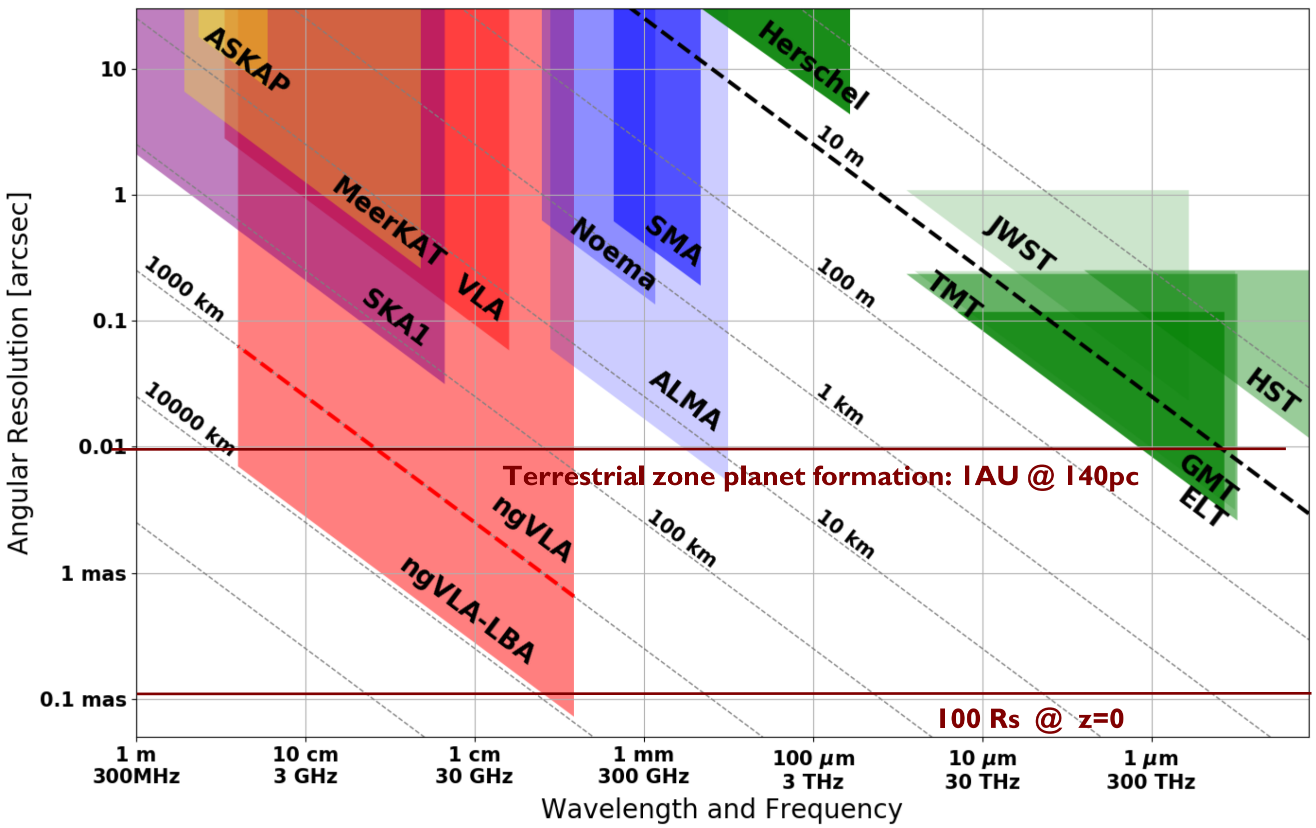
| Radius | Collecting Area Fraction |
|---|---|
| 0 km < R < 1.3 km | 44% |
| 1.3 km < R < 36 km | 35% |
| 36 km < R < 1000 km | 21% |

# Receiving Bands

Six frequency bands covering 1.2 – 116 GHz are planned. Highest frequency resolution is **400 Hz (0.1 km/s at 1.2GHz)** and highest instantaneous bandwidth is **20 GHz per pol.**

| Band # | $f_L$ GHz | $f_H$ GHz | RF BW GHz | Major Emission Line |
|---|---|---|---|---|
| 1 | 1.2 | 3.5 | 2.3 | HI |
| 2 | 3.5 | 12.3 | 8.8 | $H_2CO$ |
| 3 | 12.3 | 20.5 | 8.2 | |
| 4 | 20.5 | 34.0 | 13.5 | $H_2O$, $NH_3$ |
| 5 | 30.5 | 50.5 | 20.0 | SO, SiO, $CH_3OH$, CS |
| 6 | 70.0 | 116 | 46.0 | CO, HCN, $HCO^+$, DCN |

# Angular Resolution




- 10 x higher angular resolution than ALMA if we compare the highest angular resolution.
- 100 x times higher if we compare the at the overlap frequency (100GHz)
- LBA adds 10x resolution

- 10mas = 1AU at 140pc
  = 80pc at z = 3
- 0.1mas = 100Rs at z = 0

# Sensitivity

## Assuming 1 hour integration

| Receiver Band | B1 | B2 | B3 | B4 | B5 | B6 |
|---|---|---|---|---|---|---|
| **Center Frequency, f** | **2.4 GHz** | **8 GHz** | **16 GHz** | **27 GHz** | **41 GHz** | **93 GHz** |
| **Resolution [mas]** | **1000** | | | | | |
| Continuum rms, 1 hr, Robust [μJy/beam] | 0.52 | 0.34 | 0.35 | 0.39 | 0.59 | 2.24 |
| Line rms 1 hr, 10 km/s Robust [μJy/beam] | 88.9 | 61.1 | 43.3 | 47.9 | 70.9 | 179.6 |
| Brightness Temp ($T_B$) rms continuum, 1 hr, Robust [K] | 0.110 | 6.4E-3 | 1.7E-3 | 0.7E-3 | 0.4E-3 | 0.3E-3 |
| $T_B$ rms line, 1 hr, 10 km/s, Robust [K] | 18.76 | 1.16 | 0.21 | 0.08 | 0.05 | 0.03 |
| **Resolution [mas]** | **100** | | | | | |
| Continuum rms, 1 hr, Robust [μJy/beam] | 0.50 | 0.30 | 0.27 | 0.28 | 0.40 | 1.14 |
| Line rms 1 hr, 10 km/s Robust [μJy/beam] | 85.0 | 53.6 | 33.6 | 34.8 | 48.4 | 91.3 |
| Brightness Temp ($T_B$) rms continuum, 1 hr, Robust [K] | 10.58 | 0.56 | 0.13 | 0.05 | 0.03 | 0.02 |
| $T_B$ rms line, 1 hr, 10 km/s, Robust [K] | 1794.1 | 101.9 | 15.9 | 5.8 | 3.5 | 1.3 |
| **Resolution [mas]** | **10** | | | | | |
| Continuum rms, 1 hr, Robust [μJy/beam] | 0.41 | 0.27 | 0.26 | 0.27 | 0.38 | 0.97 |
| Line rms 1 hr, 10 km/s Robust [μJy/beam] | 69.9 | 48.3 | 32.4 | 33.2 | 46.3 | 77.7 |
| Brightness Temp ($T_B$) rms continuum, 1 hr, Robust [K] | 870.6 | 50.51 | 12.42 | 4.53 | 2.77 | 1.36 |
| $T_B$ rms line, 1 hr, 10 km/s, Robust [K] | 1.5E5 | 9173 | 1540 | 555 | 335 | 109 |

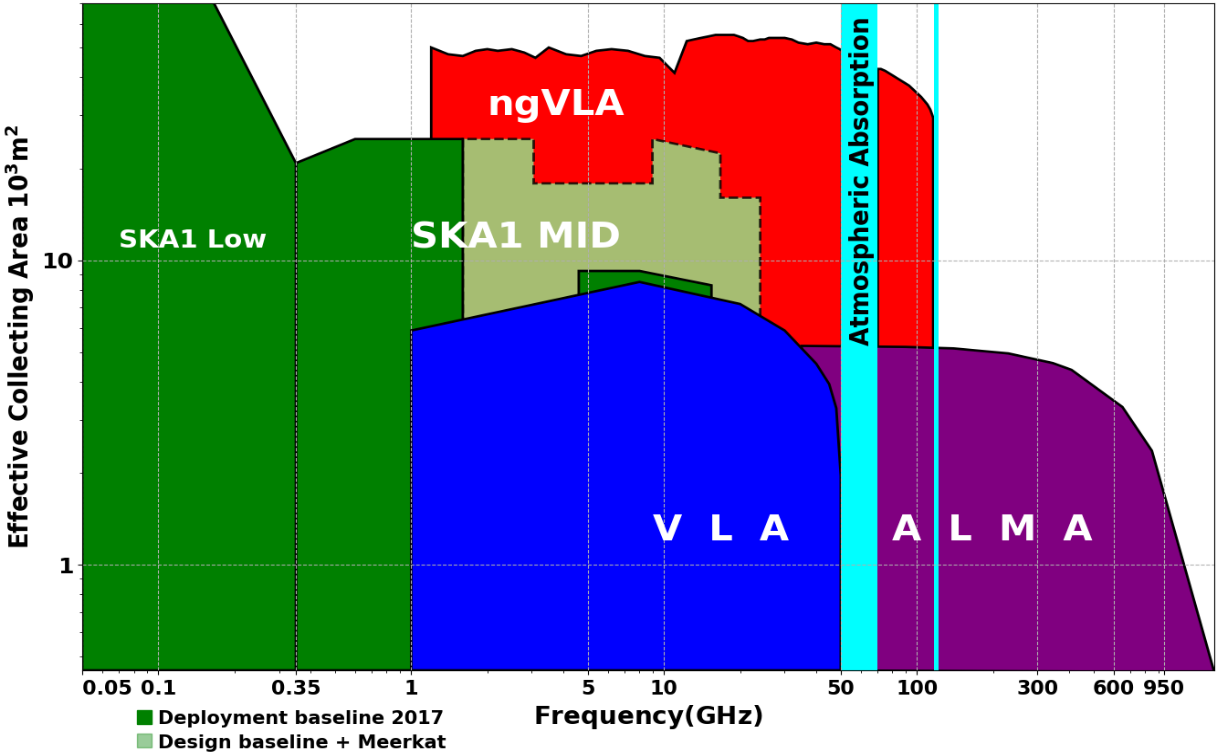
| Receiver Band | B1 | B2 | B3 | B4 | B5 | B6 |
|---|---|---|---|---|---|---|
| **Center Frequency, f** | **2.4 GHz** | **8 GHz** | **16 GHz** | **27 GHz** | **41 GHz** | **93 GHz** |
| **Resolution [mas]** | **1** | | | | | |
| Continuum rms, 1 hr, Robust [μJy/beam] | - | 20.87 | 0.31 | 0.21 | 0.29 | 0.90 |
| Line rms 1 hr, 10 km/s Robust [μJy/beam] | - | 3789.8 | 38.2 | 25.7 | 34.7 | 72.0 |
| Brightness Temp ($T_B$) rms continuum, 1 hr, Robust [K] | - | 4.5E5 | 1466 | 350 | 207 | 126 |
| $T_B$ rms line, 1 hr, 10 km/s, Robust [K] | - | 7.2E7 | 1.8E5 | 4.3E4 | 2.5E4 | 1.0E4 |
| Continuum rms, 1 hr, Robust [μJy/beam] | - | - | - | - | - | 20.96 |
| Line rms 1 hr, 10 km/s Robust [μJy/beam] | - | - | - | - | - | 1683.2 |
| Brightness Temp ($T_B$) rms continuum, 1 hr, Robust [K] | - | - | - | - | - | 2.9E5 |
| $T_B$ rms line, 1 hr, 10 km/s, Robust [K] | - | - | - | - | - | 2.0E7 |

**Table 3 - Projected imaging sensitivity as a function of angular resolution. All values at center frequency.**

Imaging sensitivity will be dependent on the required resolution and imaging fidelity. Figure 6 and Figure 7 show the effects of adjusting imaging weights to vary the resolution and quality of the point spread function (PSF). These figures are based on a four-hour simulation at 30 GHz using the 244 antenna array configuration (Main Array and Long Baseline Array combined), for a source at +24° Declination observed during transit. The reported beam size is the geometric mean of the major and minor axes full width at half maximum (FWHM) of the synthesized beam as parameterized by Gaussian fitting in the CASA 'tclean' task. [RD47]

# Bridging SKA & ALMA

## Complementary suite from cm to submm arrays for the mid-21st century




- **< 0.3cm:** superb for chemistry, dust, fine structure lines, and warm dust continuum
- **0.3 to 3cm:** ngVLA superb for terrestrial planet formation, dense gas history, baryon cycling
- **> 3cm:** SKA superb for pulsars, reionization, HI + continuum surveys

# Concept Development in the US

**2015**

Initiate science investigation at AAS

Technical workshop

**2016**

NRAO ngVLA Project office launched

SAC formed

Community studies program

Workshops

**2017**

Science case development by WG

TAC formed

Session at URSI

Workshops

**2018**

Science book published

Optics workshop

Science workshop

**2019**

Submitted to Astro2020

ngVLA-SKA alliance meeting

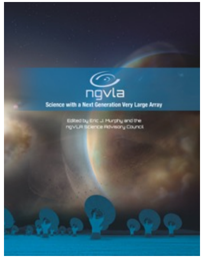
System design reference published

Workshops

**2020**

Astro2020 report

Astrophysical Frontiers Conference November 2018




Science Book

Radio/MM Astrophysical Frontiers Conference July 2019

# Status in Japan

2019 → 2020

## NAOJ ngVLA Study Group

- Established April 2019
- Purpose: Stimulate community interest and promote ngVLA

Group lead: D. Iono (NAOJ)
Project scientist: M. Momose (Ibaraki)
Technical lead: A. Gonzalez (NAOJ)

## ngVLA Workshop

- Sep 17-20, 2019 @ NAOJ, Mitaka
- Purpose: 1st international ngVLA workshop to promote ngVLA in Japan
- ~100 participants
- 34 talks, 4 posters

## ngVLA Kickoff Meeting

- Jan 31, 2020 using Zoom
- Purpose: introduction to ngVLA and science prospects
- 81 participants

# Science Working Groups

## Goal

Compile ngVLA science use cases tuned to the Japanese community

## Science Working Groups (SWGs)

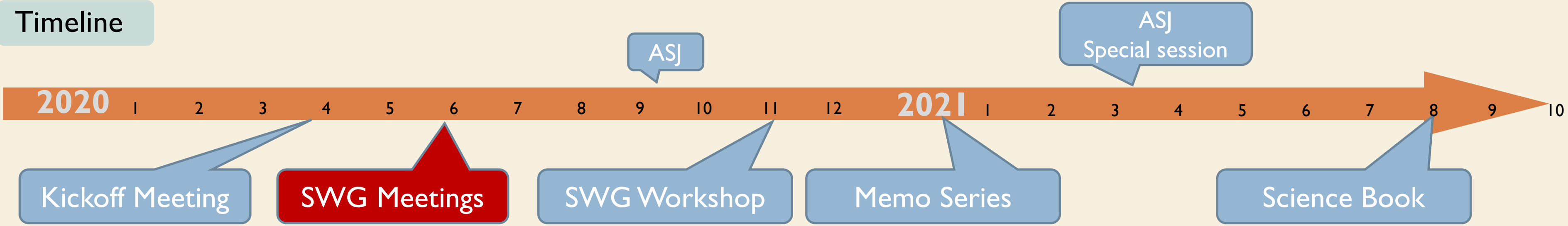
1. 惑星形成と惑星系円盤
2. 様々な天体階層における星形成と星間化学)
3. 宇宙史の中での銀河進化
4. 銀河中心パルサーを用いた重力理論の検証
5. ブラックホールの形成・進化とタイムドメイン・マルチメッセンジャー天文学

## Output

- ngVLA-J Memo series
- ngVLA-J Science Book

The contents of the memo series will be used as the basic material for the Science Book, which will be written in plain Japanese language.

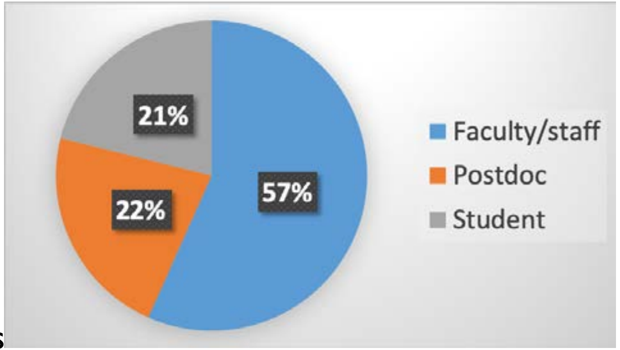
## Timeline



# Science Working Groups

## Group Leads

| SWG1 | SWG2 | SWG3 | SWG4 | SWG5 |
|---|---|---|---|---|
|  |  |  |  |  |
| M. Momose<br>Ibaraki University | K. Tachihara<br>Nagoya University | D. Iono<br>NAOJ | K. Niinuma<br>Yamaguchi University | H. Nagai<br>NAOJ |


## Advisory

- M. Fukagawa, NAOJ
- K. Kohno, University of Tokyo
- A. Gonzalez, NAOJ
- T. Hasegawa, NAOJ
- N. Sakai, Riken

# SWG5会合履歴

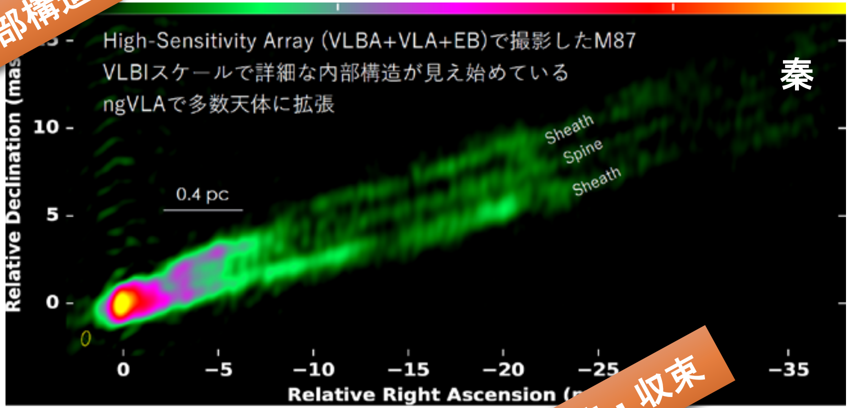
第1回　5/28（参加者約40名）
今西昌俊　Molecular gas around actively massaccreting　supermassive black holes　- From ALMA to ngVLA –
泉琢磨　高空間分解能で探るAGN直近の物理・化学的性質
秦和弘　AGN/SMBHジェット
竹川俊也　銀河系中心領域における中間質量ブラックホールの探査
稲吉恒平　Hunting of hidden wandering massive BHs with ngVLA

第2回　9/3 (SWG4との合同開催、参加者約40名)
出口真輔　ファラデートモグラフィー
沖野大貴　Global VLBI + ngVLAで探るAGNジェット形状
澤田佐藤聡子　1ミリ秒角分解能観測が暴くAGNサブパーセク領域の分子多相構造
笹田真人　重力波観測ランO3における電磁波対応天体の探査と今後の展開
浦田裕次　Gamma-ray bursts & Transient Science

SWG1-4も同様に2回のオンライン会合を実施

# SWG5のサイエンスケースの一部紹介

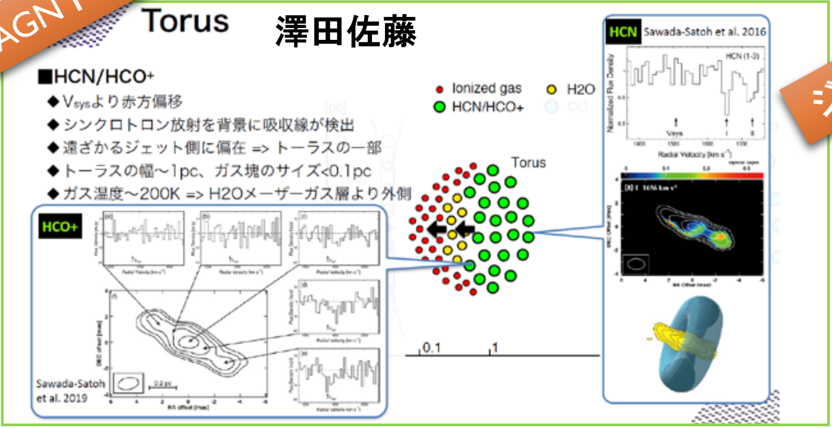
ジェットの内部構造




Hada+2017

これまでのVLBI観測を発展させ、
個別天体の研究から統計へ

AGNトーラス

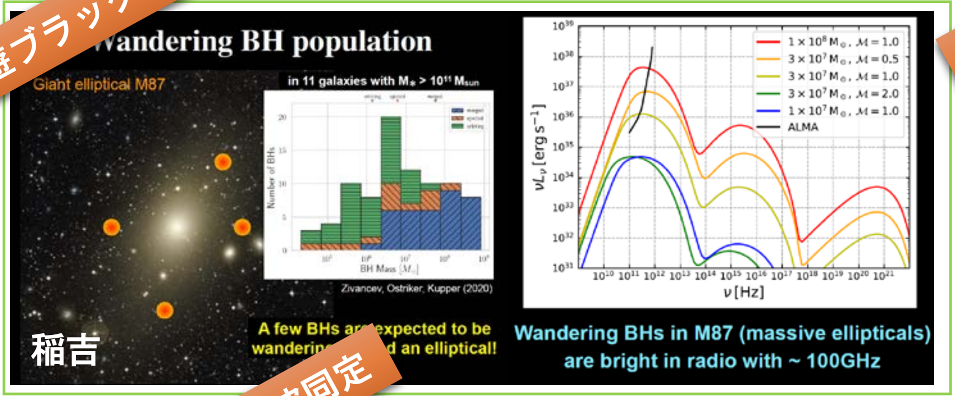



ジェットの加速・収束

沖野

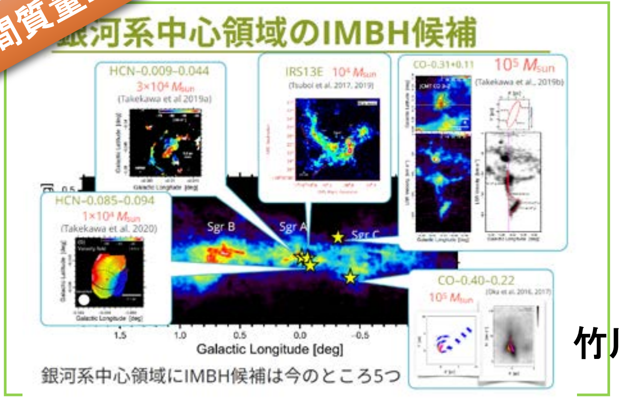
# SWG5のサイエンスケースの一部紹介

浮遊ブラックホール




稲吉

中間質量BH



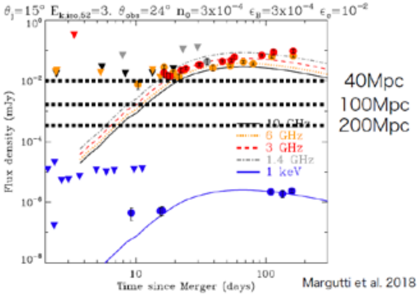

竹川

NS-NS合体の電波同定

## 電波放射と予想フラックス

笹田

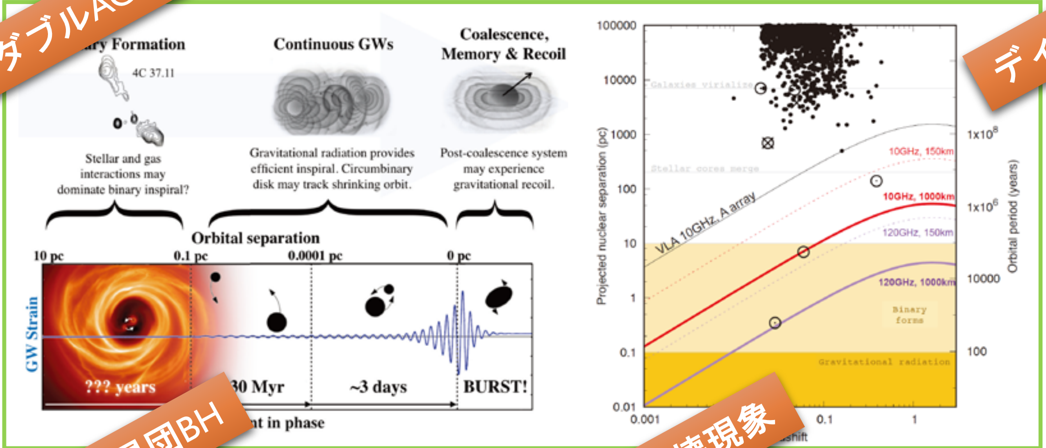
- GW170817の電波光度曲線を距離でスケール
- 100Mpcの距離に中性子星合体が起きた場合、1μJyの感度があれば検出可能（ただしO3では100Mpcのイベントは未検出）
- 200Mpcの距離だと、0.2μJyの感度が必要



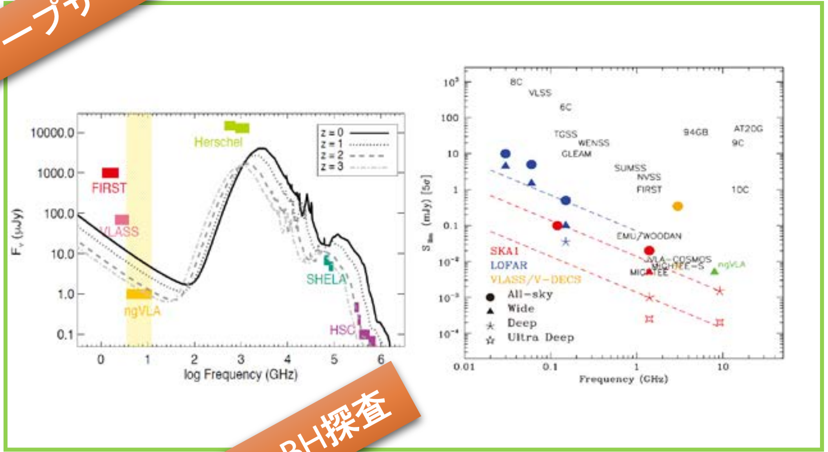

Margutti et al. 2018

# 米国版サイエンスケース

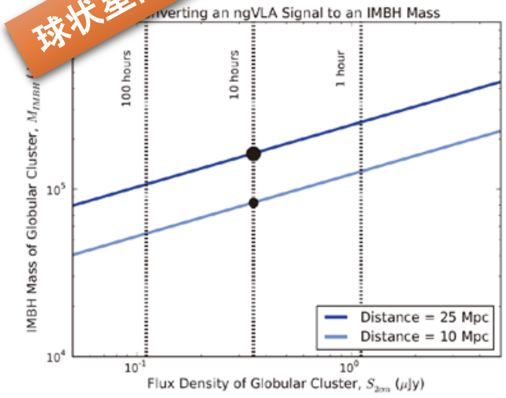
ダブルAGN探査



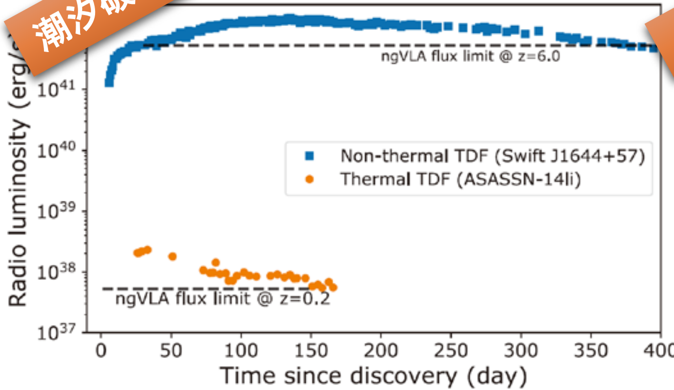

ディープサーベイ



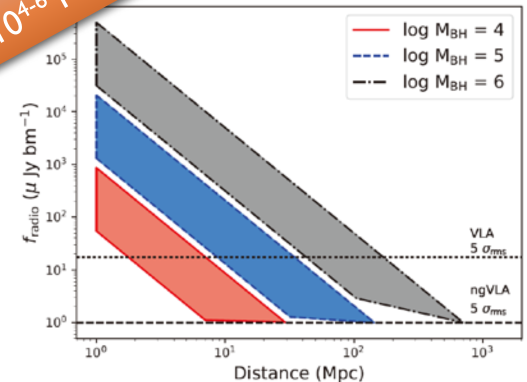

球状星団BH




潮汐破壊現象




$10^{4\text{-}6}\ M_\odot$ BH探査



ngvla

Next Generation Very Large Array

# appendix

# The Formation and Evolution of Black Holes in the Era of Multi-Messenger Astronomy

| | |
|---|---|
| Supermassive Black Hole Pairs and Binaries | Burke-Spolaor, S.; Blecha, L.; Bogdanović, T.; Comerford, J. M.; Lazio, J.; Liu, X.; Maccarone, T. J.; Pesce, D.; Shen, Y.; Taylor, G. |
| Compact Binary Mergers as Traced by Gravitational Waves | Corsi, A.; Frail, D. A.; Lazzati, D.; Carbone, D.; Murphy, E. J.; Owen, B. J.; Sand, D. J.; O'Shaughnessy, R. |
| Radio Emission from Short Gamma-ray Bursts in the Multi-messenger Era | Lloyd-Ronning, N. |
| Revealing the Galactic Population of Black Holes | Maccarone, T. J.; Chomiuk, L.; Strader, J.; Miller-Jones, J.; Sivakoff, G. |
| Local Constraints on Supermassive Black Hole Seeds from a Next Generation Very Large Array | Plotkin, R. M.; Reines, A. E. |
| Accretion and Jets in Local Compact Objects | Coppejans, D. L.; Miller-Jones, J. C.; Körding, E. G.; Sivakoff, G. R.; Rupen, M. P. |
| Tidal Disruption Events | van Velzen, S.; Bower, G. C.; Metzger, B. D. |
| Intermediate-Mass Black Holes in Globular Cluster Systems | Wrobel, J. M.; Miller-Jones, J. C. A.; Nyland, K. E.; Maccarone, T. J. |
| Science with Pulsar Timing Arrays and the ngVLA | Chatterjee, S. |
| Offset Active Galactic Nuclei | Blecha, L.; Brisken, W.; Burke-Spolaor, S.; Civano, F.; Comerford, J.; Darling, J.; Lazio, T. J. W.; Maccarone, T. J. |
| Serendipitous Fast Transient Science with the ngVLA | Law, C. J.; Bower, G. C.; Burke-Spolaor, S.; Butler, B. J.; Demorest, P.; Lazio, T. J. W.; Linford, J. D. |
| Flares from Coalescing Black Holes in the Centimeter-Wavelength Transient Sky | Ravi, V. |

# SMBH related science categorized in other Key Science Goals

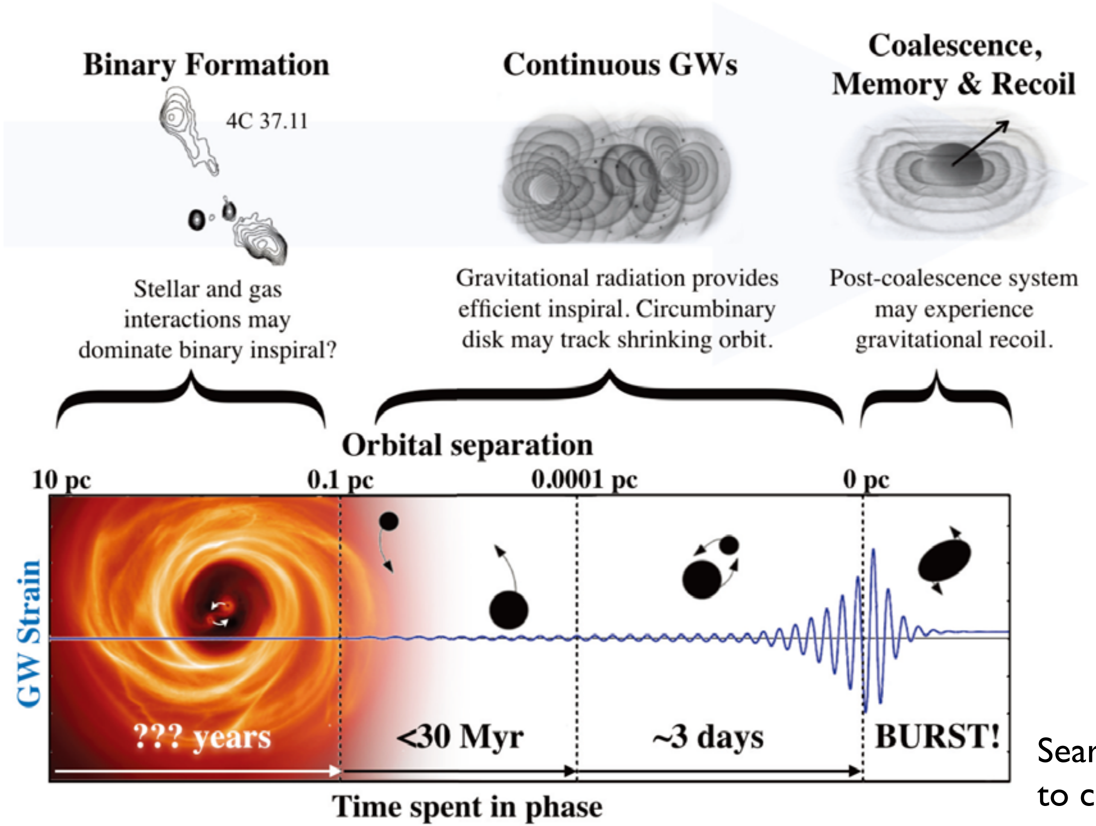
| | |
|---|---|
| An ngVLA Wide Area AGN Survey | Kirkpatrick, A.; Hall, K.; Nyland, K.; Lacy, M.; Prandoni, I. |
| High-resolution Imaging of Radio Jets Launched by Active Galactic Nuclei: New Insights on Formation, Structure, and Evolution Enabled by the ngVLA | Lister, M. L.; Kellermann, K. I.; Kharb, P. |
| From Megaparsecs To Milliparsecs: Galaxy Evolution and Supermassive Black Holes with NANOGrav and the ngVLA | Taylor, S. R.; Simon, J. |
| Probing Obscured Massive Black Hole Accretion and Growth since Cosmic Dawn | Rujopakarn, W.; Nyland, K.; Kimball, A. E.; Prandoni, I. |
| Young Radio AGN in the ngVLA Era | Patil, P.; Nyland, K.; Harwood, J. J.; Kimball, A.; Mukherjee, D. |
| Precision Gas-dynamical Mass Measurement of Supermassive Black Holes with the ngVLA | Boizelle, B. D.; Nyland, K.; Davis, T. A. |
| Radio Jet-ISM Feedback on Sub-Galactic Scales | Nyland, K.; Mukherjee, D.; Lacy, M.; Prandoni, I.; Harwood, J. J.; Alatalo, K.; Bicknell, G.; Emonts, B. |
| Accreting Supermassive Black Holes in Nearby Low-Mass Galaxies | Nyland, K.; Alatalo, K. |
| How Do Cold Gas Outflows Shape Galaxies? | Bolatto, A. D.; Armus, L.; Leroy, A. K.; Veilleux, S.; Walter, F.; Mushotzky, R. |

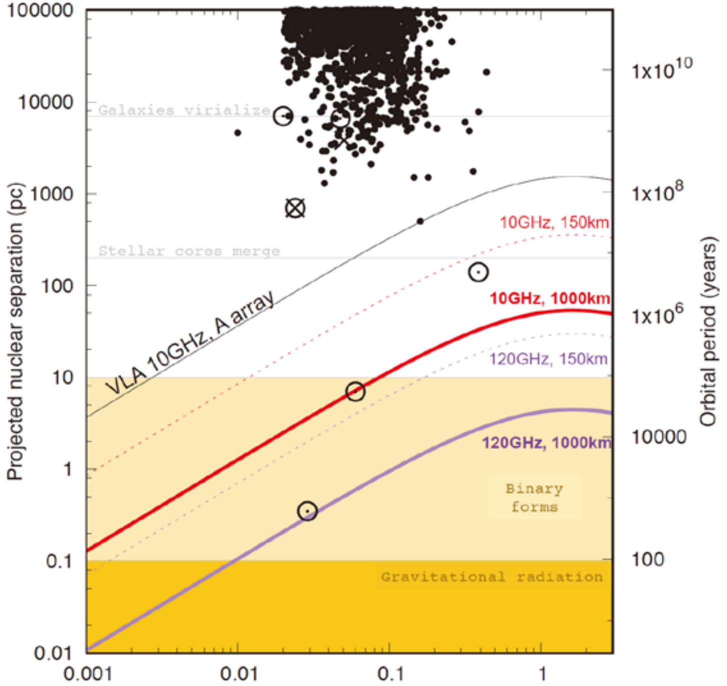
# Contexts

- SMBH Formation
  - Search for SMBH binaries, offset AGNs, low mass AGNs, IMBH in Globular clusters, TDEs
- Stellar BH Evolution
  - Increasing the sample of stellar mass BHs
- SMBH-Galaxy Evolution
  - AGN outflow/jet feedback
- Jets/Accretion Physics
  - Disk-Jet connection, Jet production
- AGN Survey
  - Radio-quiet AGNs, Dust-obscured AGNs

# Supermassive Black Hole Pairs and Binaries

Burke-Spolaor et al.



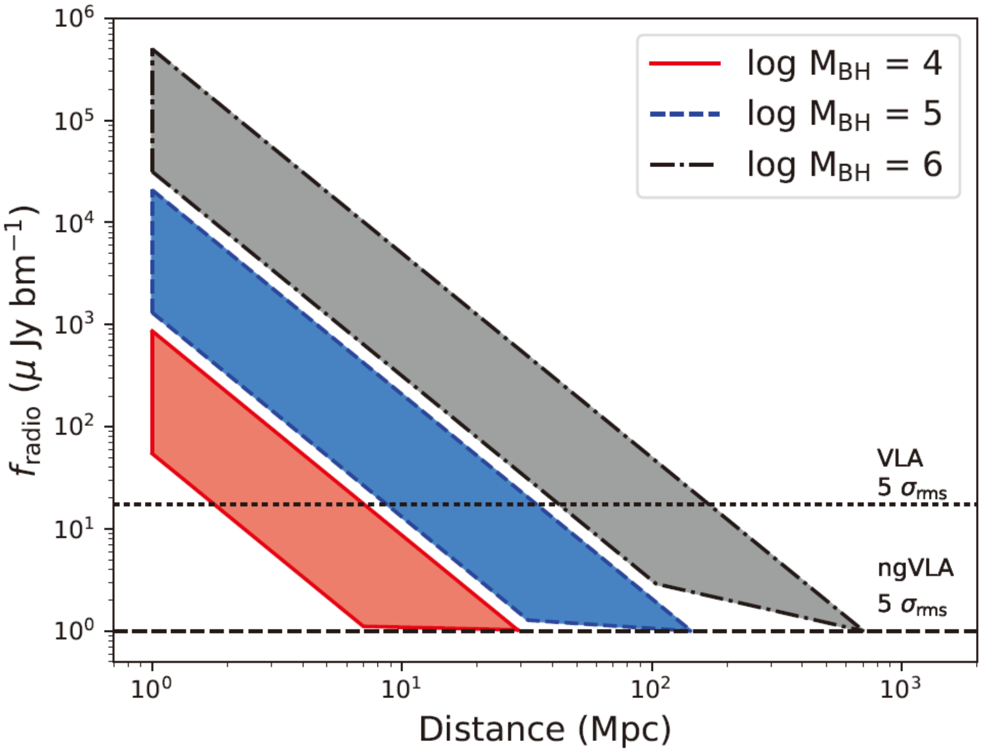

Searching dual AGNs allowing for merger-rate estimates to constrain PTA searches (Synergy with NANOGrav).

# Local Constraints on Supermassive Black Hole Seeds from ngVLA

- Seach for massive (not supermassive) BH in nearby low-mass galaxies

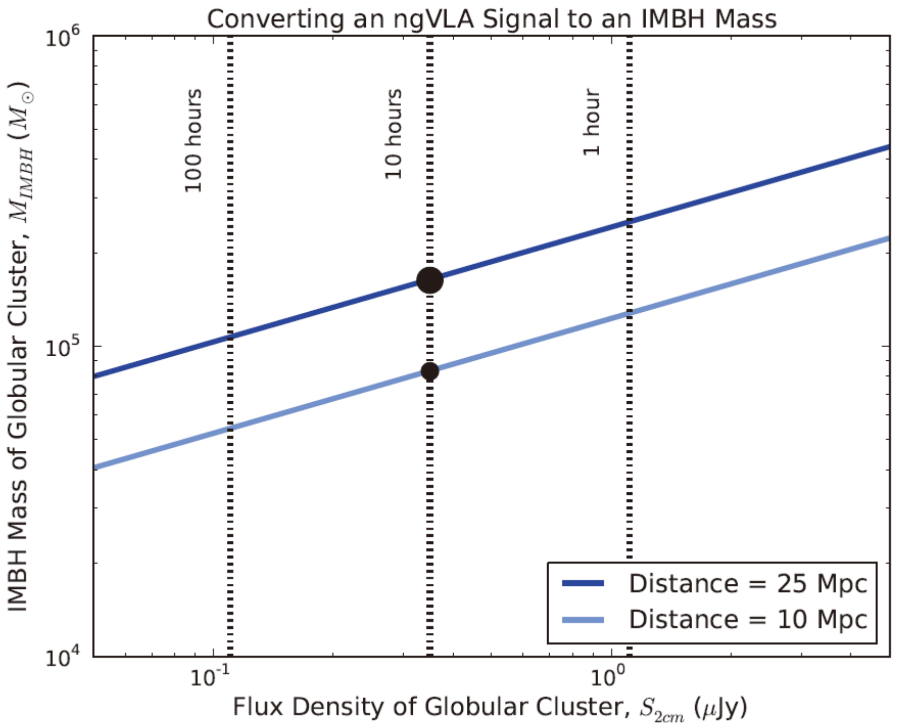
$\log L_R = 0.6 \log L_X + 0.78 \log M_{BH} + 7.33$
(e.g., Merloni et al. 2003; Falcke et al. 2004; Plotkin
et al. 2012),

Plotkin & Reines



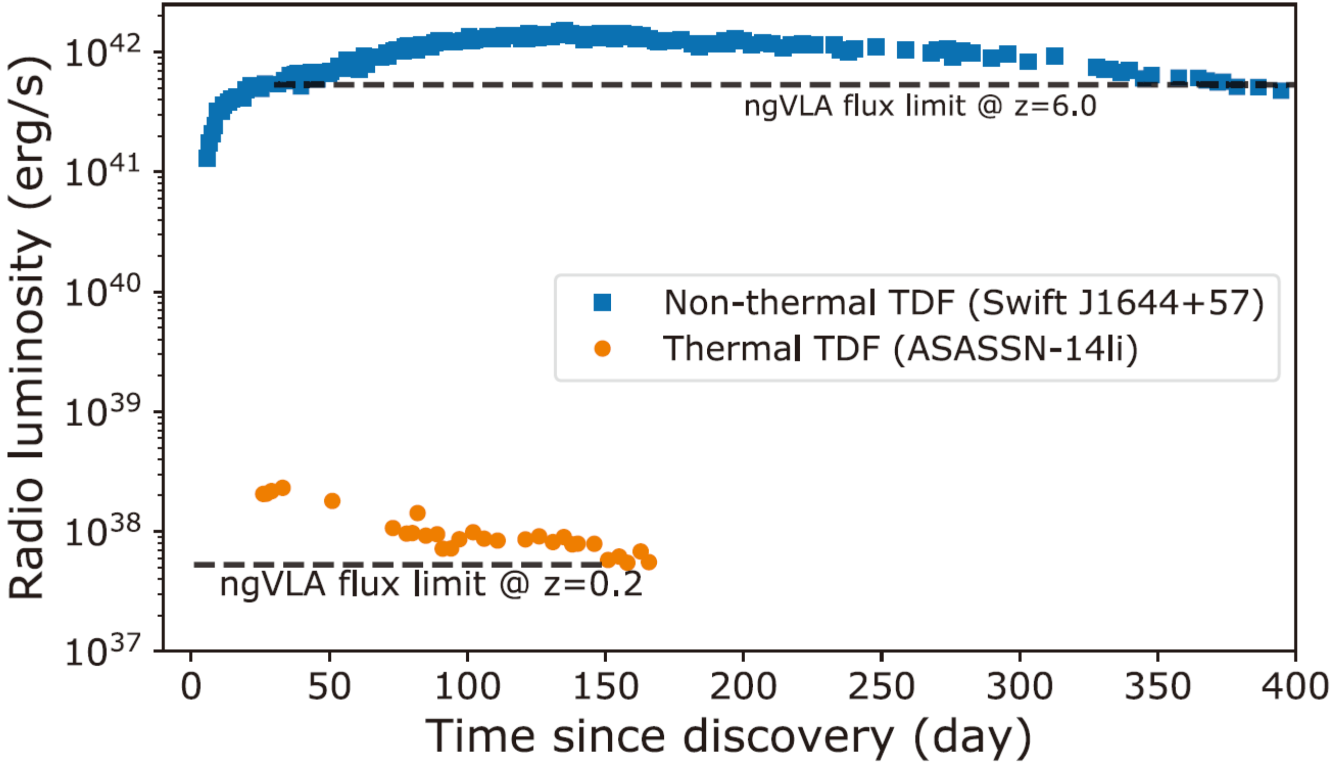
# IMBH in Globular Cluster Systems

Wrobel et al.



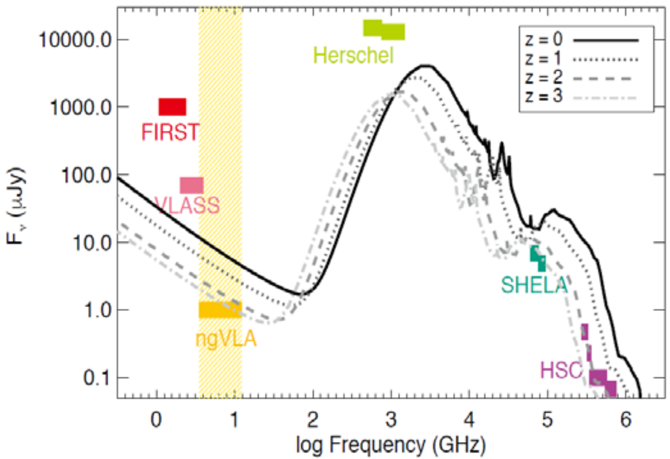
# Tidal Disruption Events

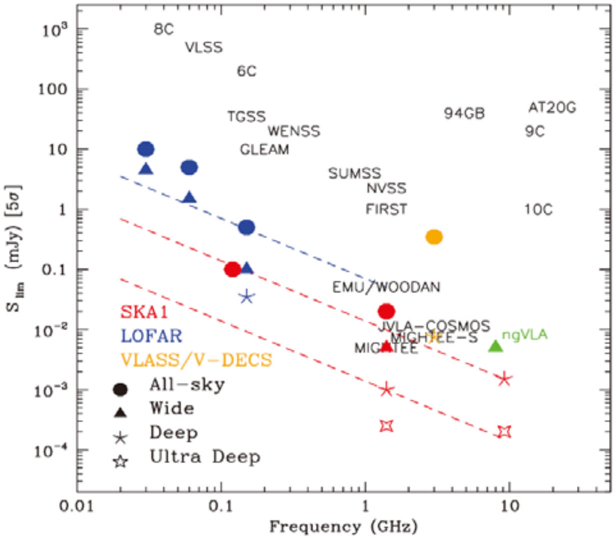
van Velzen et al.

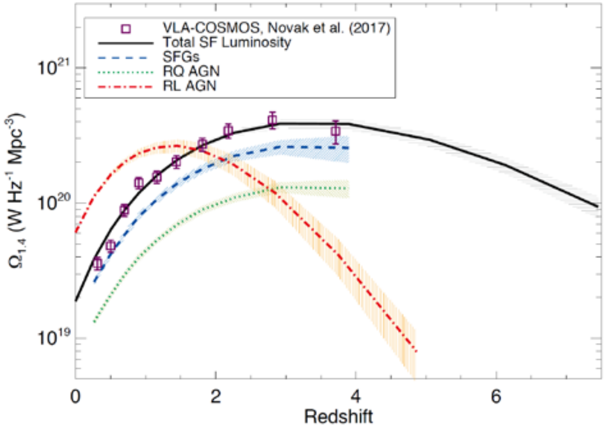


# An ngVLA Wide Area AGN Survey

Kirkpatrick et al.




Propose a 10 deg2 survey in the Stripe 82 field using the 8 GHz band with an rms depth of 1 μJy beam−1. We will detect ~130,000 galaxies, including radio-quiet AGN out to z ~ 7.

# Key Performance Matrix

| Center Frequency | 2.4 GHz | 8 GHz | 16 GHz | 27 GHz | 41 GHz | 93 GHz |
|---|---|---|---|---|---|---|
| Band Lower Frequency [GHz] | 1.2 | 3.5 | 12.3 | 20.5 | 30.5 | 70.0 |
| Band Upper Frequency [GHz] | 3.5 | 12.3 | 20.5 | 34.0 | 50.5 | 116.0 |
| Field of View FWHM [arcmin] | 24.4 | 7.3 | 3.7 | 2.2 | 1.4 | 0.6 |
| Aperture Efficiency | 0.78 | 0.77 | 0.86 | 0.85 | 0.81 | 0.60 |
| Effective Area, $A_{eff}$, x $10^3$ [$m^2$] | 42.2 | 41.7 | 46.8 | 46.0 | 44.0 | 32.4 |
| System Temp, $T_{sys}$ [K] | 23 | 25 | 22 | 33 | 45 | 62 |
| Max Inst. Bandwidth [GHz] | 2.3 | 8.8 | 8.2 | 13.5 | 20.0 | 20.0 |
| Sampler Resolution [Bits] | 8 | 8 | 8 | 4 | 4 | 4 |
| Antenna SEFD [Jy] | 328.6 | 361.8 | 283.2 | 432.4 | 617.0 | 1153.7 |
| Resolution of Max. Baseline [mas] | 26 | 8 | 4 | 2.3 | 1.5 | 0.7 |
| Resolution FWHM @ Natural Weighting [mas] | 163 | 49 | 24 | 14 | 10 | 4 |

# Key Operation Concepts

### Proposal Evaluation

Peer review system will be adopted. Proposals will be evaluated based on scientific merit and technical feasibility

### Time Allocation

PIs awarded time and not sensitivity. This is different from ALMA

### Dynamic Scheduling

Time allocated dynamically according to the priority built into the queue.

### Data Product

Pipeline will automatically generate Science Ready Data Products for most standard projects (~80%). Expert mode will exist too.

Operated from the Array Operation Center in Socorro NM

### Array Availability

No reconfiguration, meaning that the array will used continuously with minimum downtime. Subarrays will be used for maintenance and commissioning activities