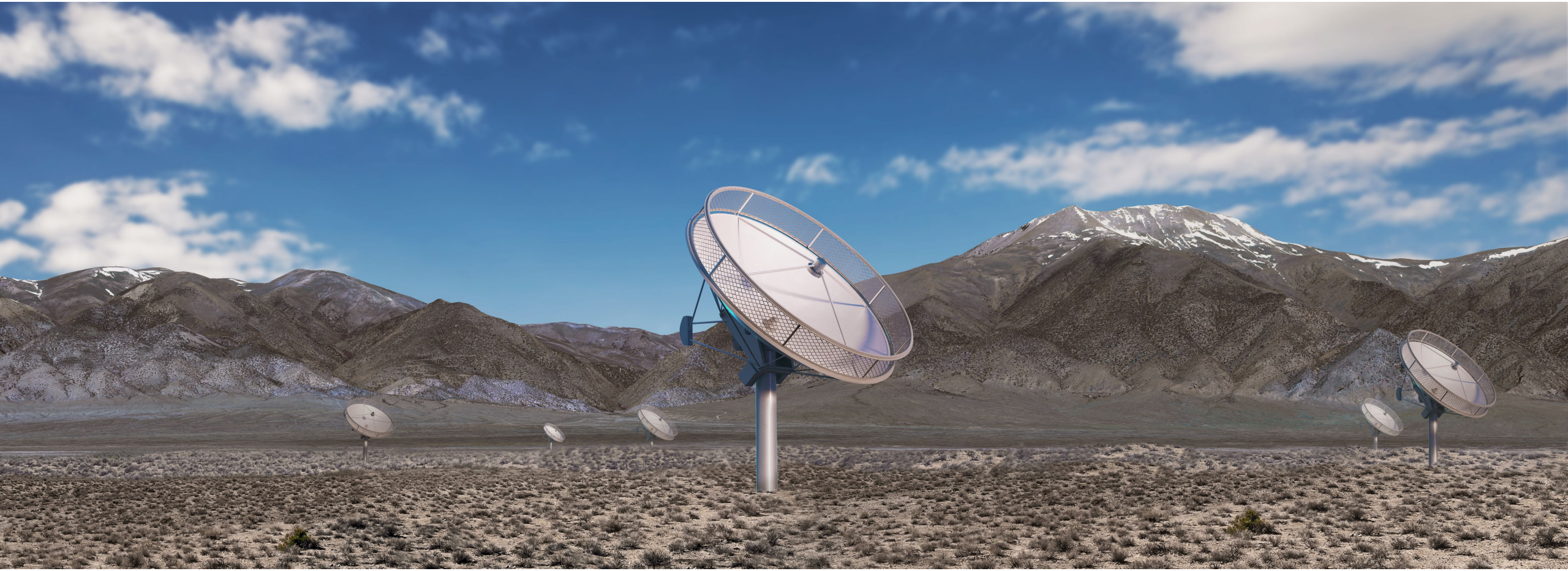
The Deep Synoptic Array – DSA-2000

Vikram Ravi, Professor of Astronomy, Caltech



Schmidt Sciences

DSA-2000

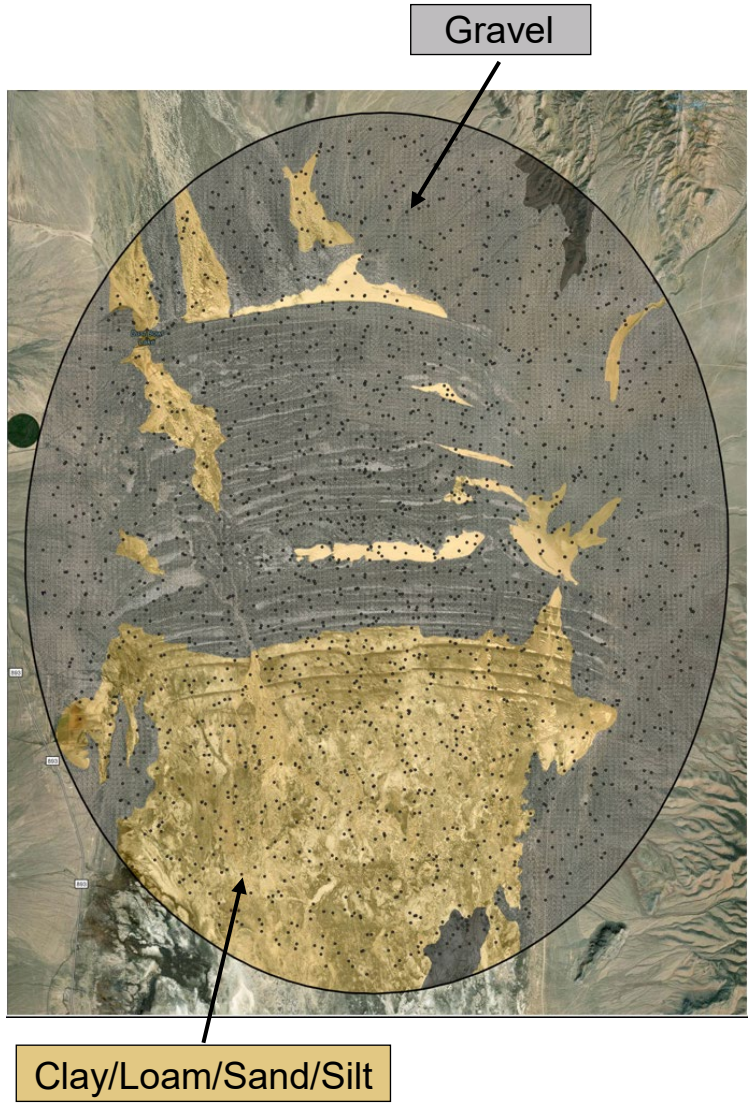
Caltech

What is the DSA-2000?

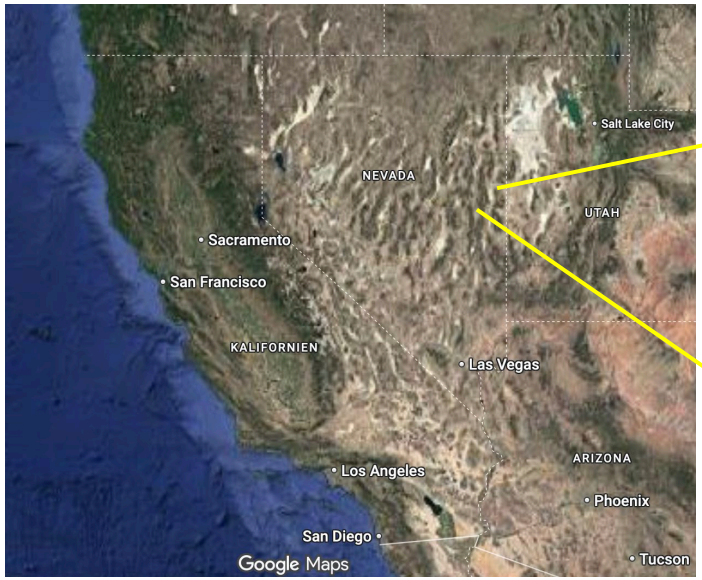
- **1650** x **6.15m** antennas (~250m dish), 1.6Jy SEFD at zenith (**==FAST**).
- **19x15km** array in Spring Valley, Nevada (2.7” PSF @ 1.35GHz); access to **DEC > –38deg**.
- Simultaneous coverage of **0.7 – 2GHz**, with **commensal** surveys
  - **Radio Camera** (continuum, spectral-line, and polarization imaging, slow time domain)
  - **Chronoscope** (pulsar searching / characterization, fast time domain)
  - **Pulsar timing**
- **Public data products** made available in an archive with no proprietary period.

Construction: 2026 – 2028. Key surveys: 2029 – 2034.

Our site: Spring Valley, Nevada

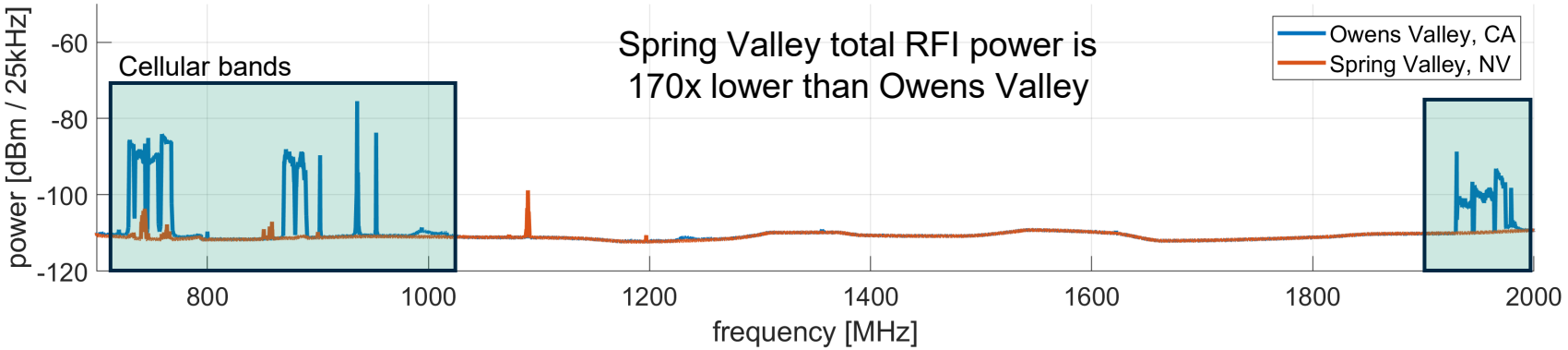


- Top-ranked site from extensive survey
- Excellent RFI environment
- Preferred soil conditions for construction
- Environmental permitting process progressing well
- Nearby town of Ely will host the compute hardware, and staff



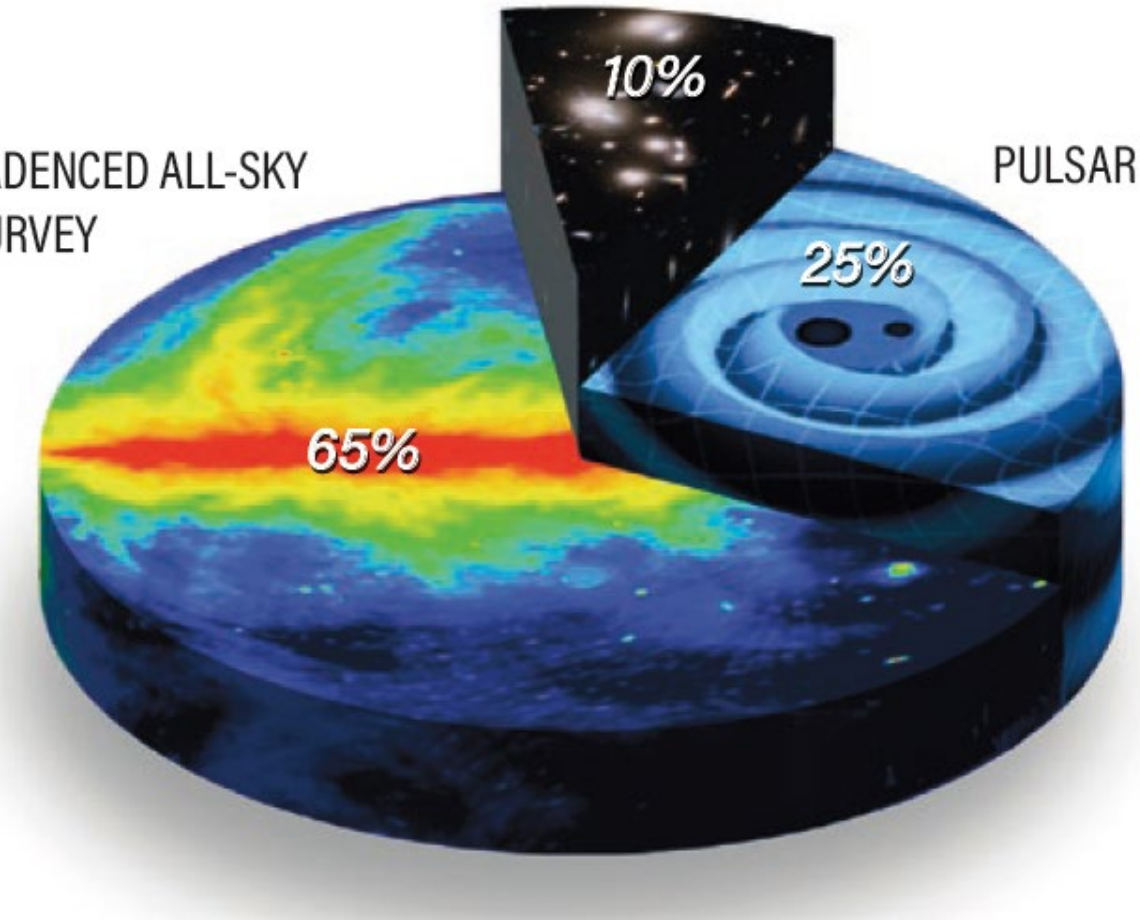
Spring Valley (antennas)

Ely (staff, compute)



DSA-2000

Planned surveys over five years



GW (Triggered)

Deep: 30 deg^2 to 50 nJy

(or confusion limit)

31,000 deg^2 to 0.4-1 uJy (or confusion limit)

Variable depth and cadence

~2,000 deg^2 to 200 nJy

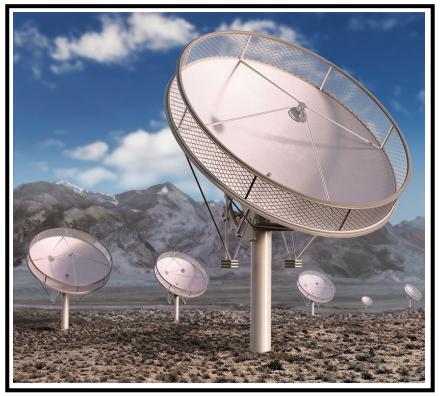
~weekly cadence

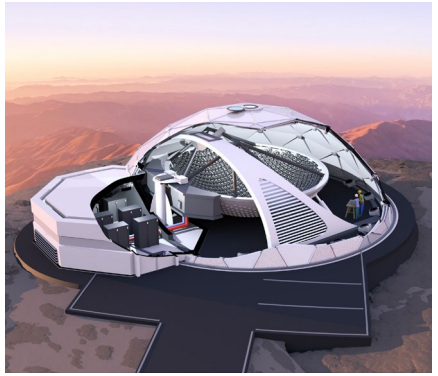
NANOGrav Physics Frontiers Center

DSA-2000

The 2020s is the decade of surveys

Matthew Bailes: "The DSA-2000 can keep all radio astronomers worldwide busy for a decade"





GROUND

Rubin: 2025

DSA-2000: 2028

Argus Array

Cryoscope

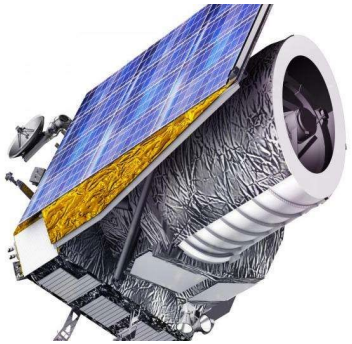
SPACE

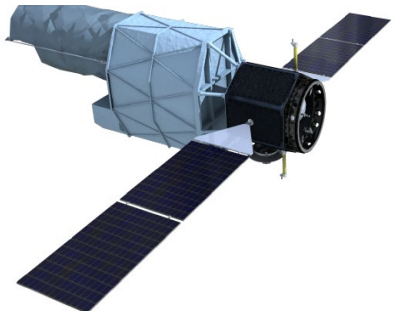
Euclid: 2023

Sphere-X: 2025

Roman: 2027

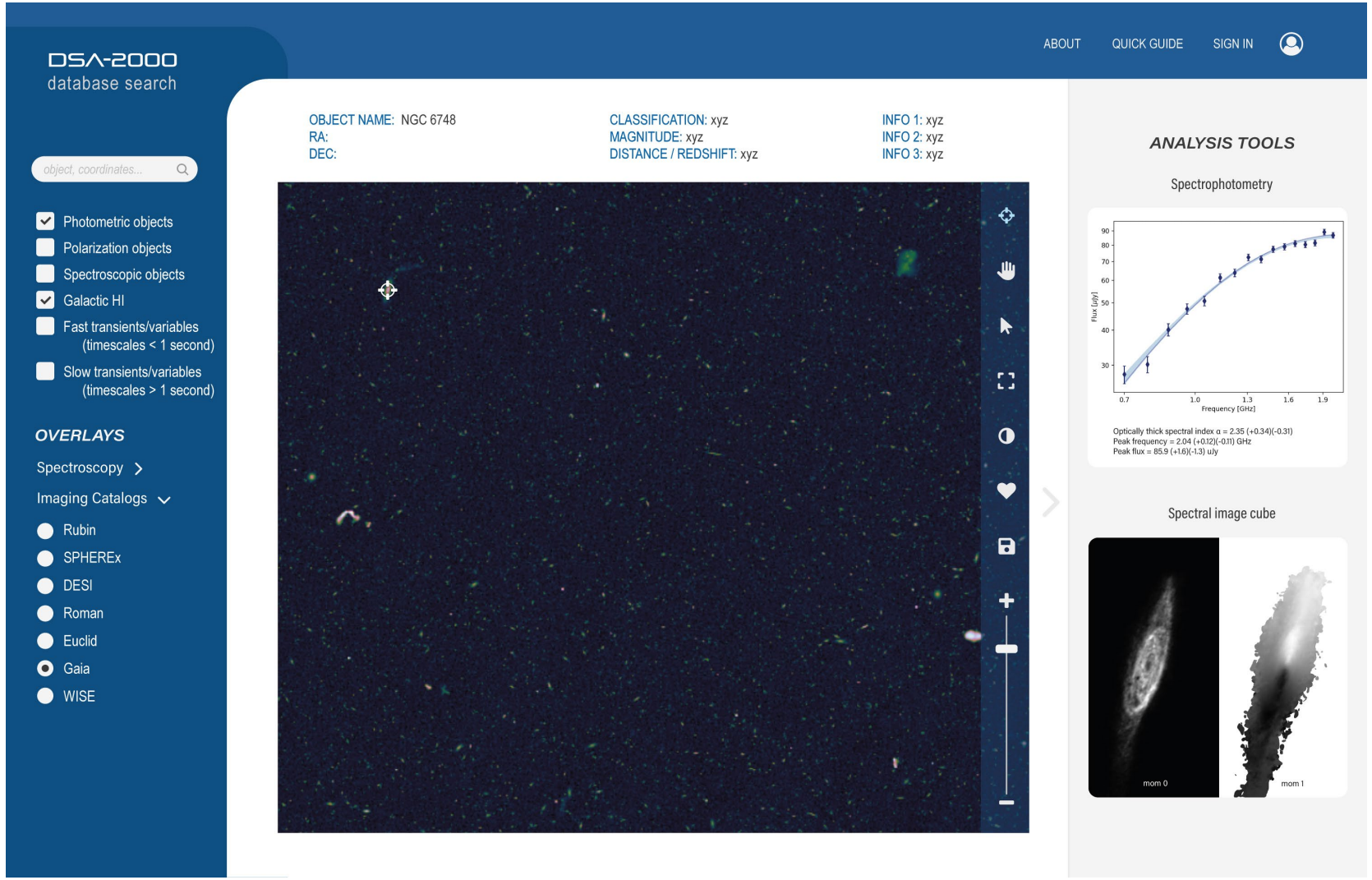
UVEX: 2030





DSA-2000

Public data with no proprietary period



Science-ready datasets

- Continuum data (10 sub-bands)
- Spectral image cubes (HI, OH)
- Polarization (IQUV)
- Photometry
- Spectra and light curve fits
- Pulsar and FRB data

Public Archive under development by Schmidt Sciences.

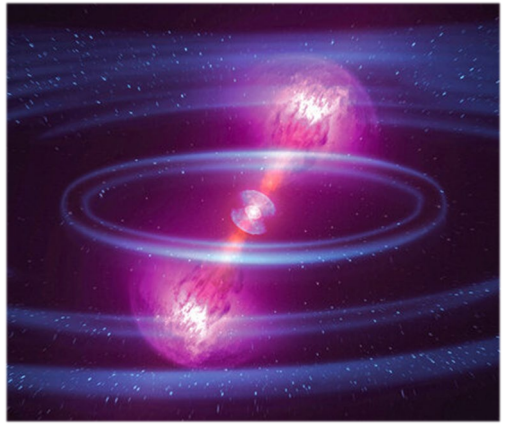
Commissioning and science verification archive maintained by the Project.

DSA-2000

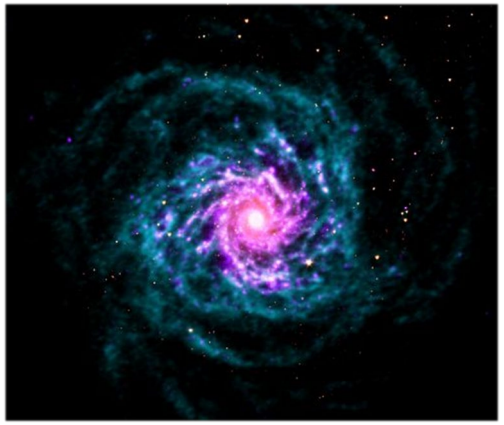
Science case

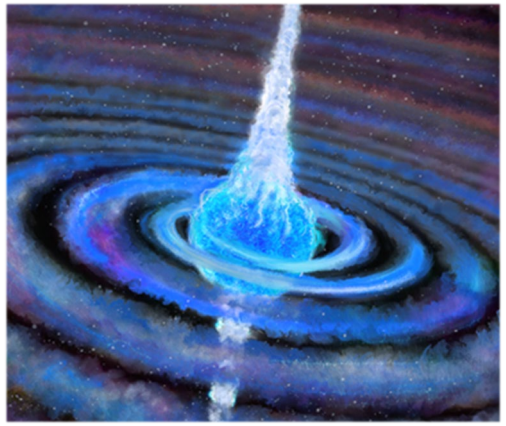
SCIENCE THEMES

Multi-Messenger Astronomy

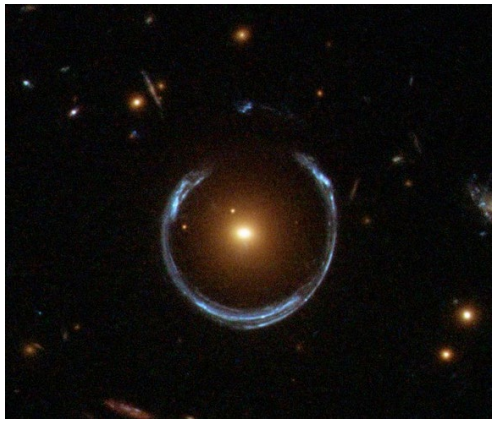


Our Cosmic History

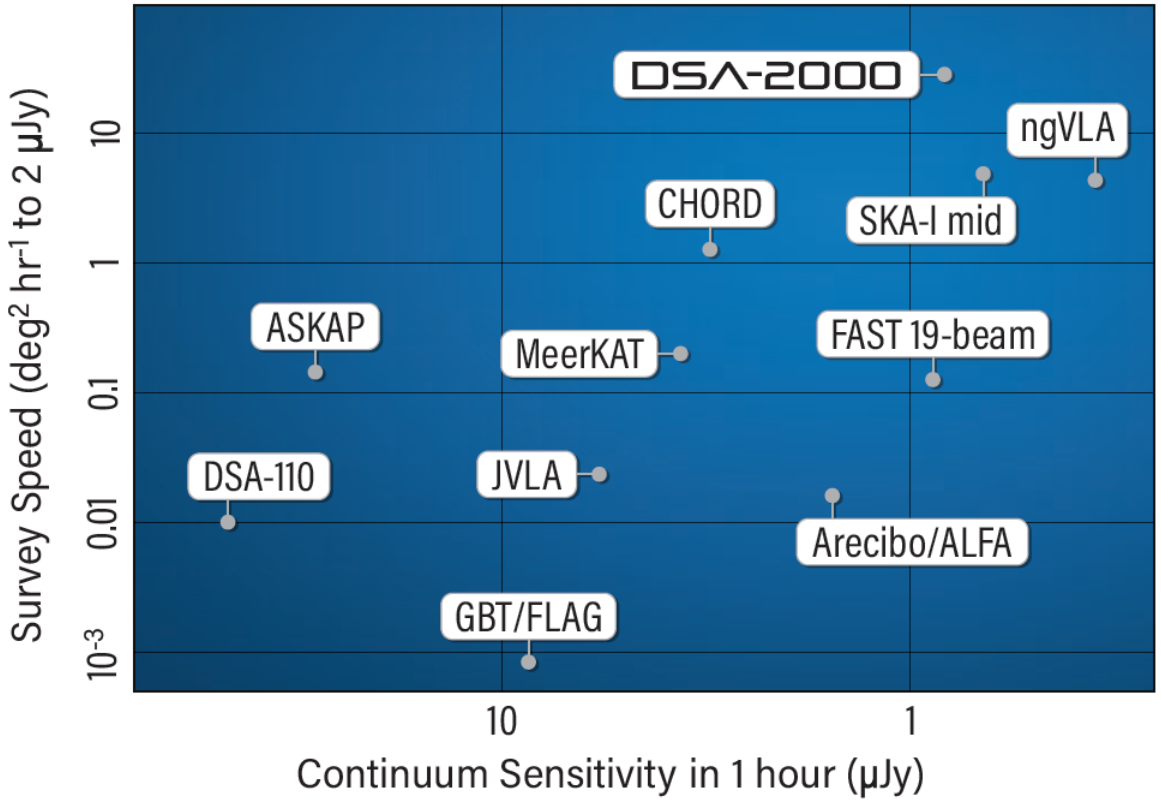




The Dynamic Radio Sky



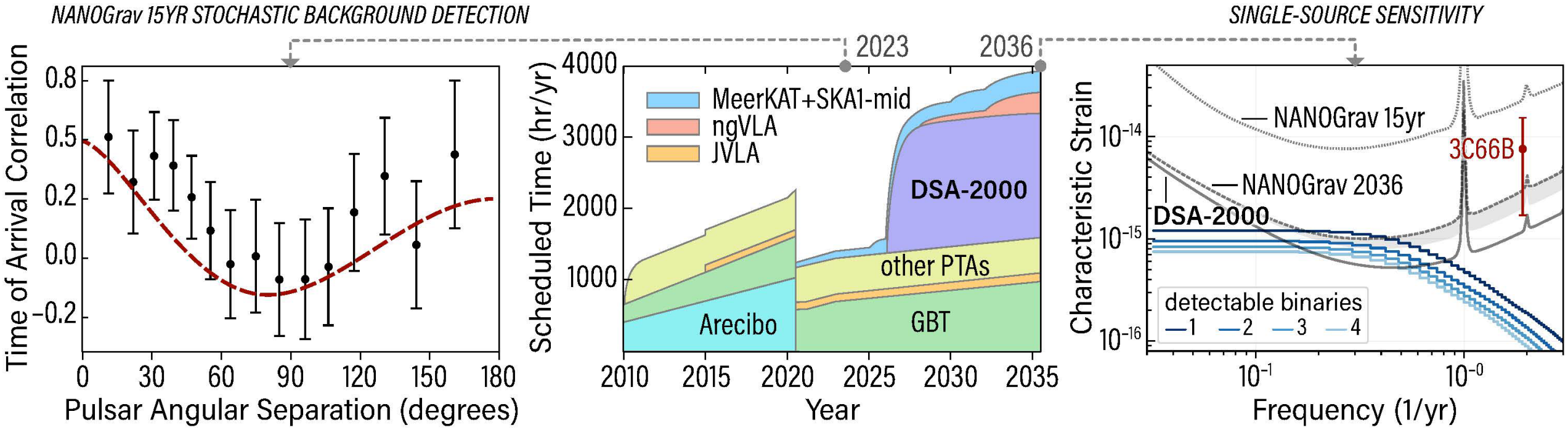
The Dark Sector and Strong Gravity



Approximate detection forecasts… 10^9 new radio sources – 10^7 galaxies in HI – 10^5 FRBs – 20,000 new pulsars – 10^6 slow transients – few to few tens of individual GW sources

DSA-2000

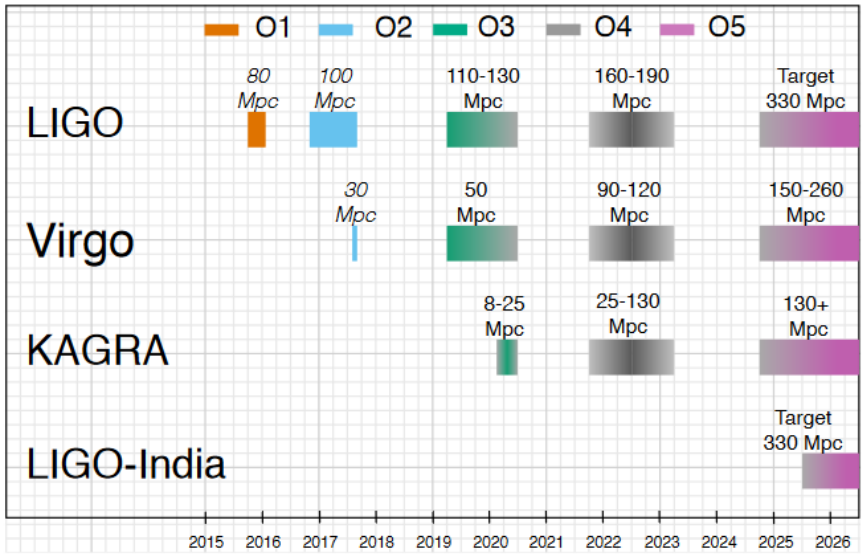
KSG1: Characterizing the nanoHertz gravitational-wave universe via pulsar timing

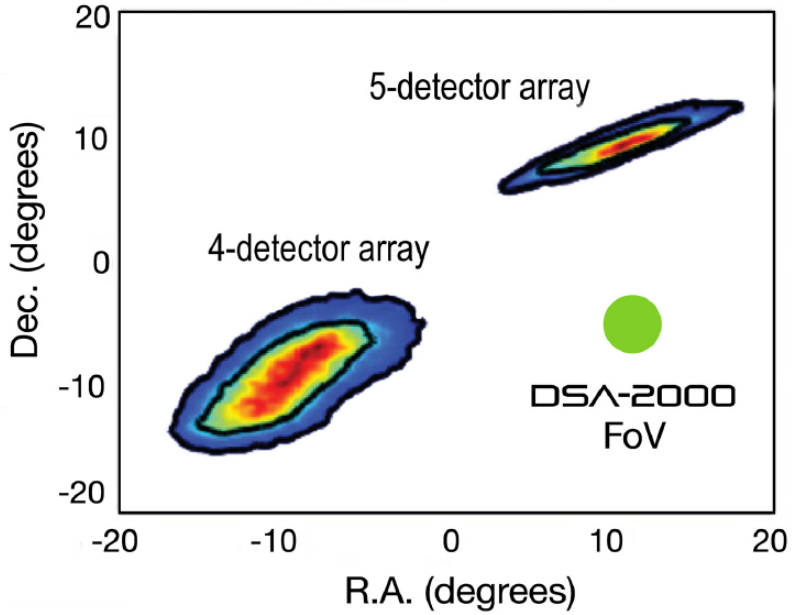


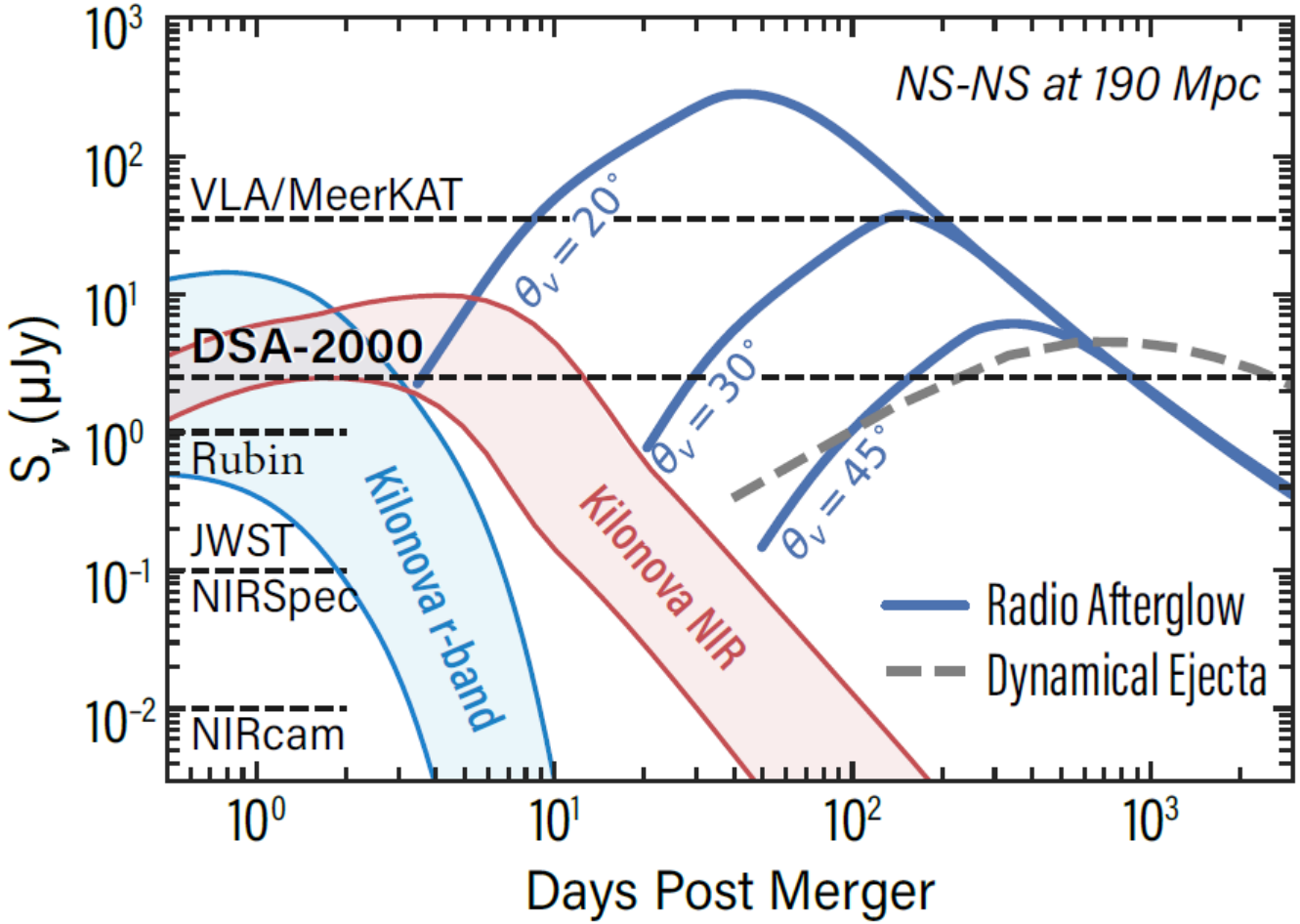
- Will identify and localize tens of individual sources within the stochastic GW background (GWB).
- Will measure the GWB spectrum, probing binary-SMBH formation

DSA-2000

KSG2: Discovering the counterparts to compact binary coalescences detected in gravitational waves



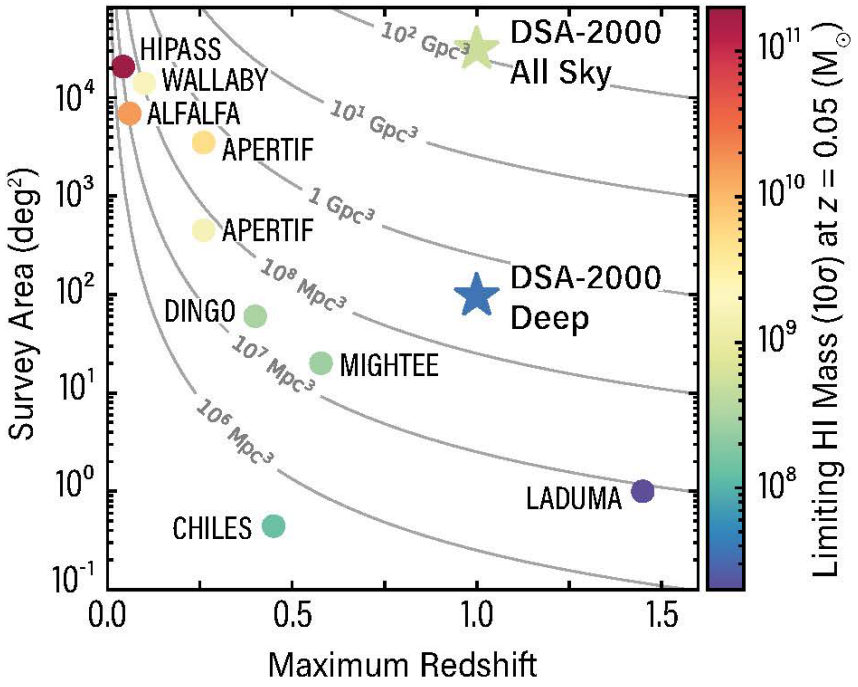


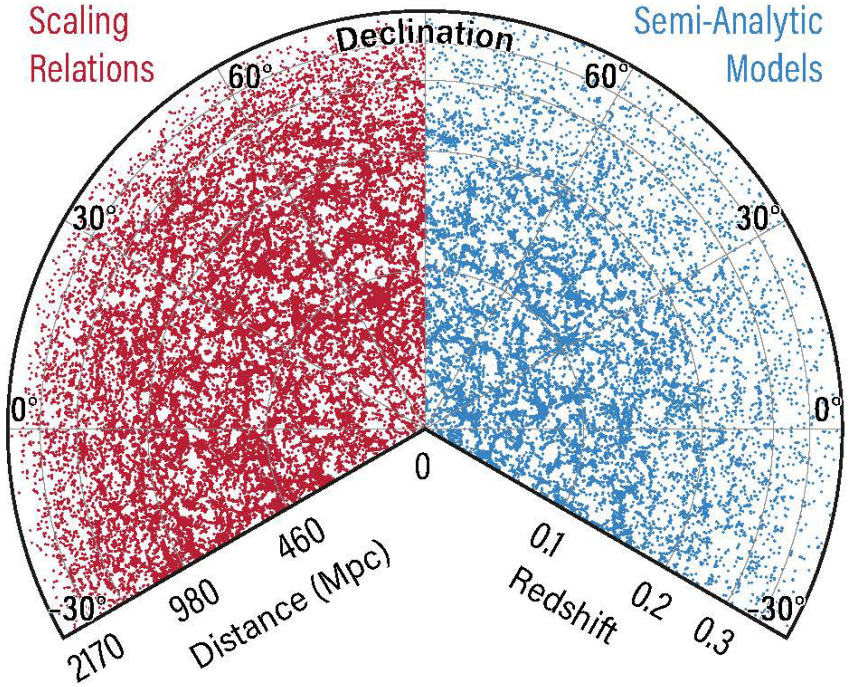


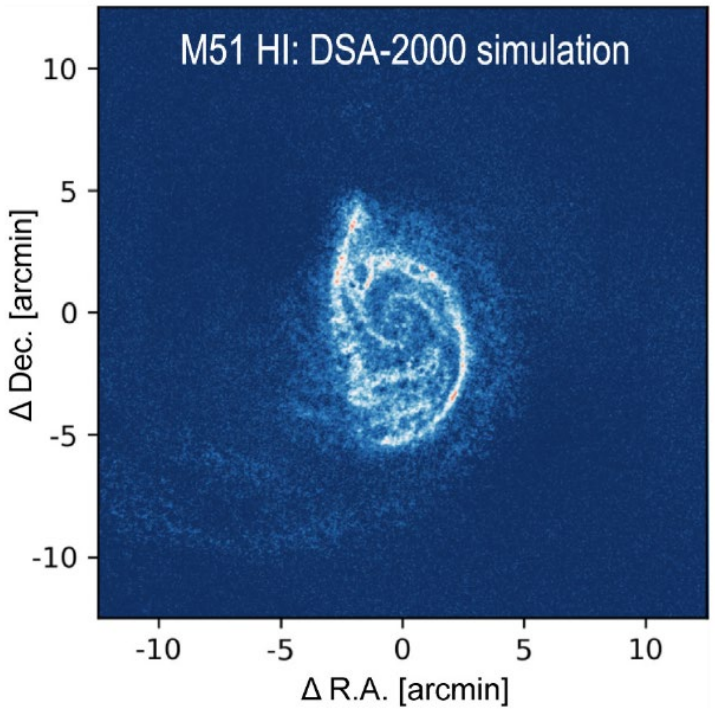
DSA-2000 can map median localization in a few pointings
DSA-2000 can detect median events to the full range of a 5-detector array

DSA-2000

KSG3: Neutral hydrogen census through half of the Universe's age



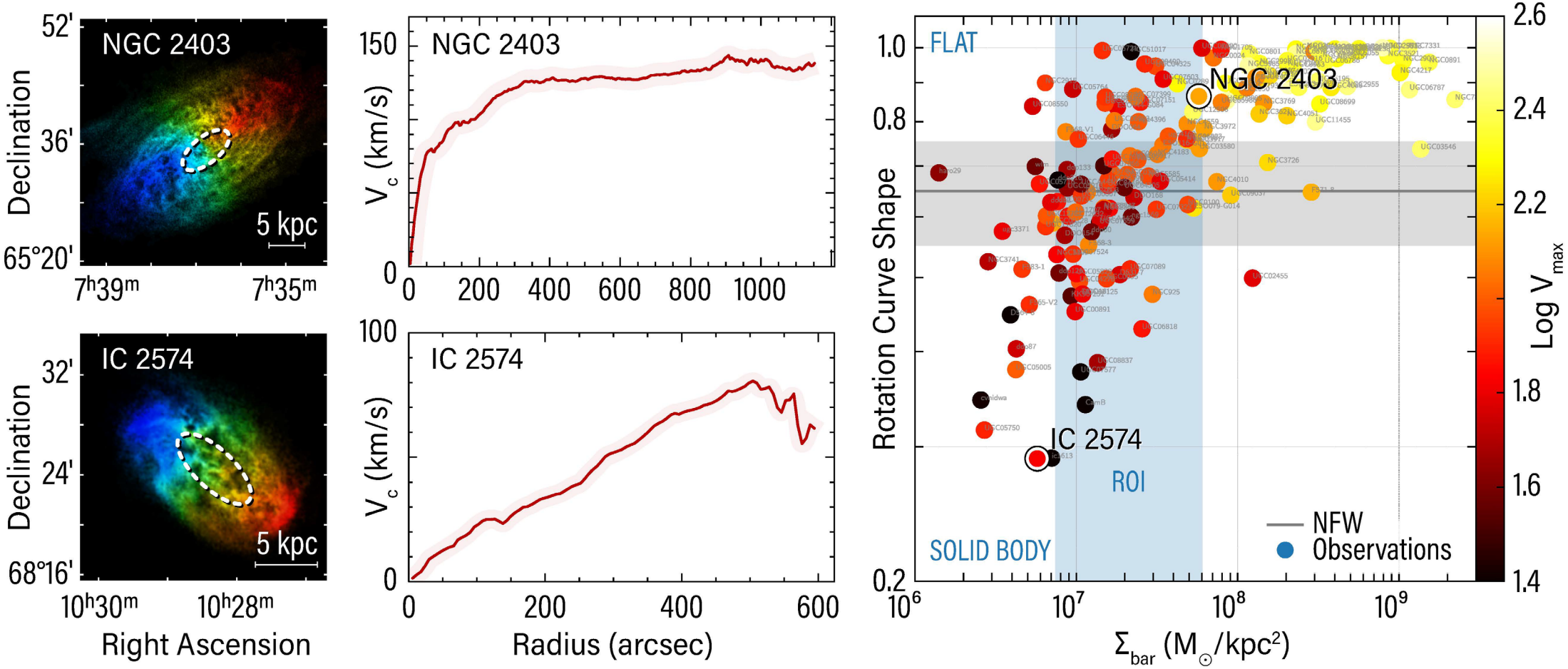




- **Millions of galaxies in HI**
- Our Galaxy in unprecedented sensitivity and spatial resolution
- ~10^5 galaxies (<100 Mpc): gas contents, kinematics, spatial distribution, rotation curves
- Few million galaxies (z~1): First robust measurement of the galaxy HI mass function beyond the local Universe.

DSA-2000

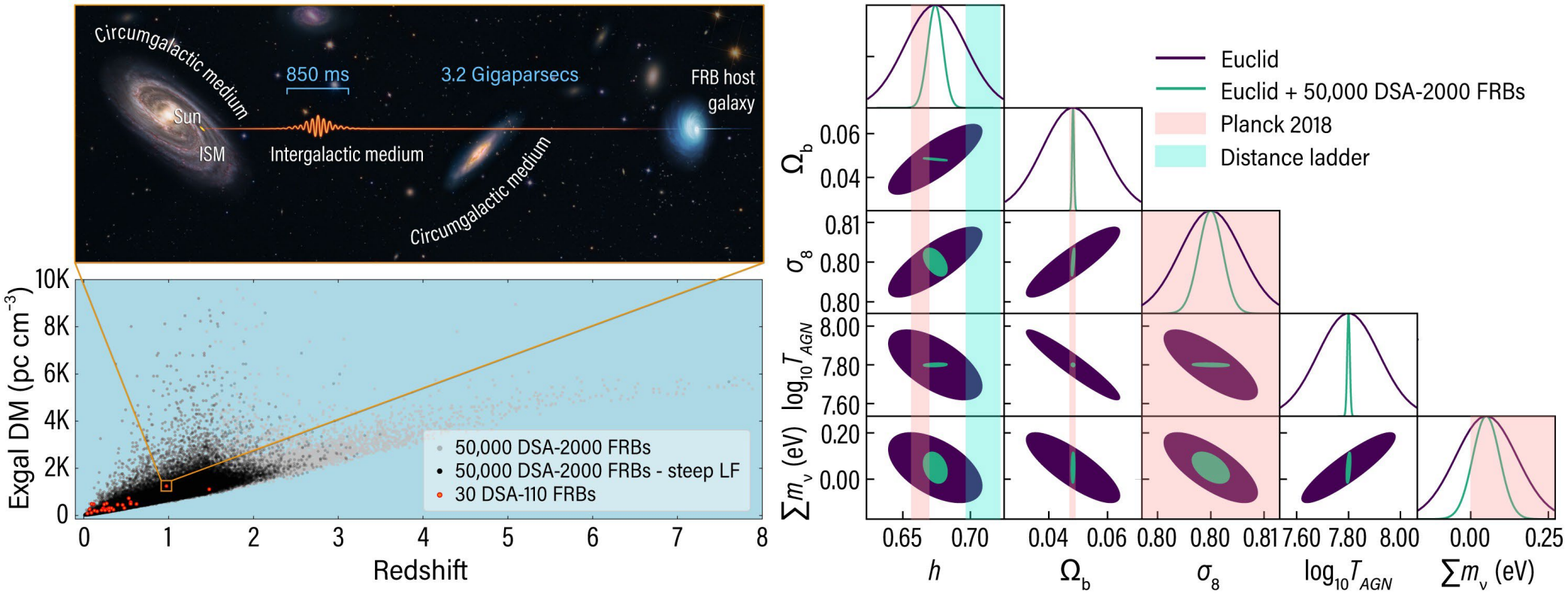
KSG7: Physical Characteristics / Fundamental Properties of Dark Matter and Dark Energy



DSA-2000 will uniquely constrain the HI kinematics and rotation curves to derive precise dark matter mass profiles for few ×10⁴ galaxies

DSA-2000

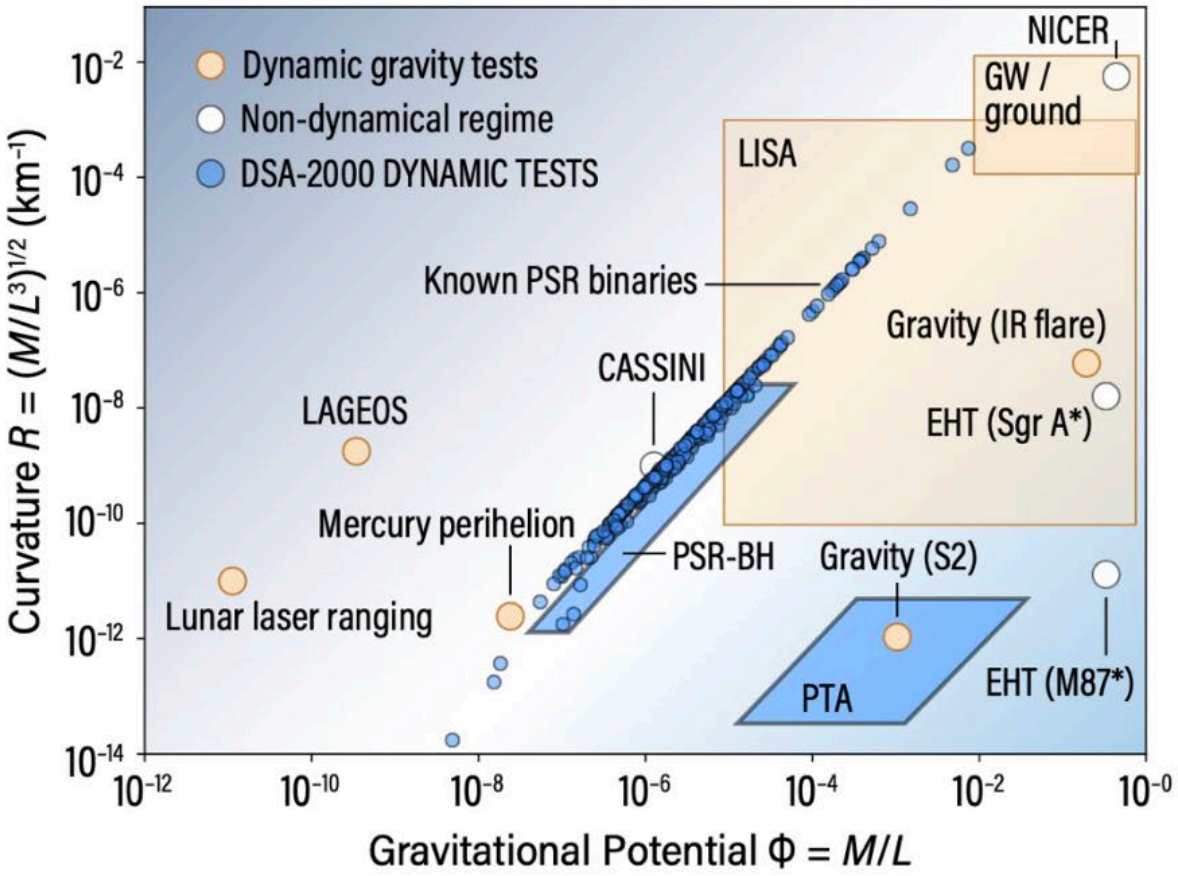
KSG5: Determining the distribution of matter in the circum- and inter-galactic medium with FRBs

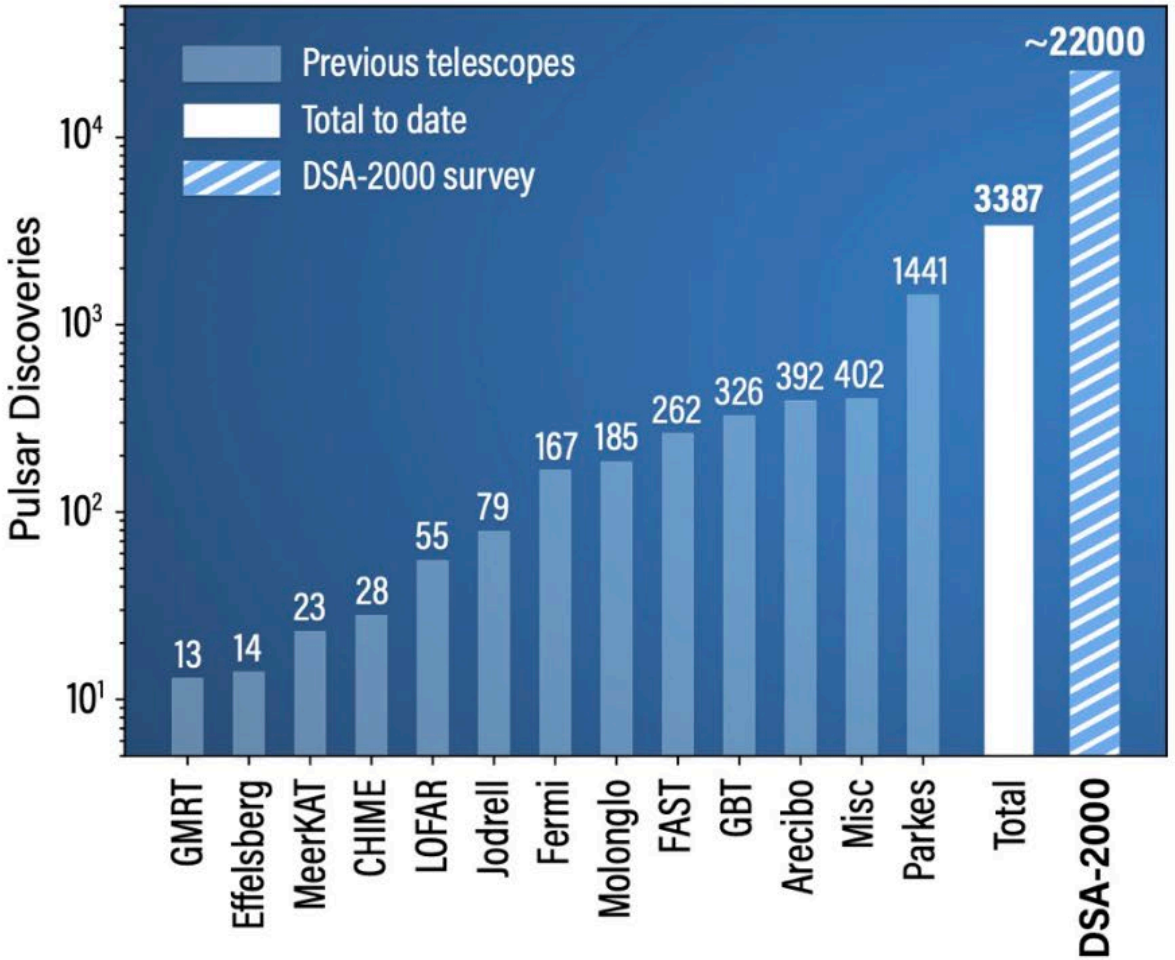


- DSA-2000 will **localize ~10^4 FRBs/year to <0.5”**
- Transformative for the **measurement of the baryon power spectrum**, breaking the degeneracy between baryonic feedback and critical cosmological parameters

DSA-2000

KSG8: A Galactic census of radio pulsars to test theories of gravity, bulk nuclear matter, and the endpoints of stellar evolution





DSA-2000

Continuous and commensal data products

12.7k spectral and polarimetric images every 21 min

Radio camera
Continuum images (variable depth and cadence)
~2 μJy rms per epoch (10 spectral windows)

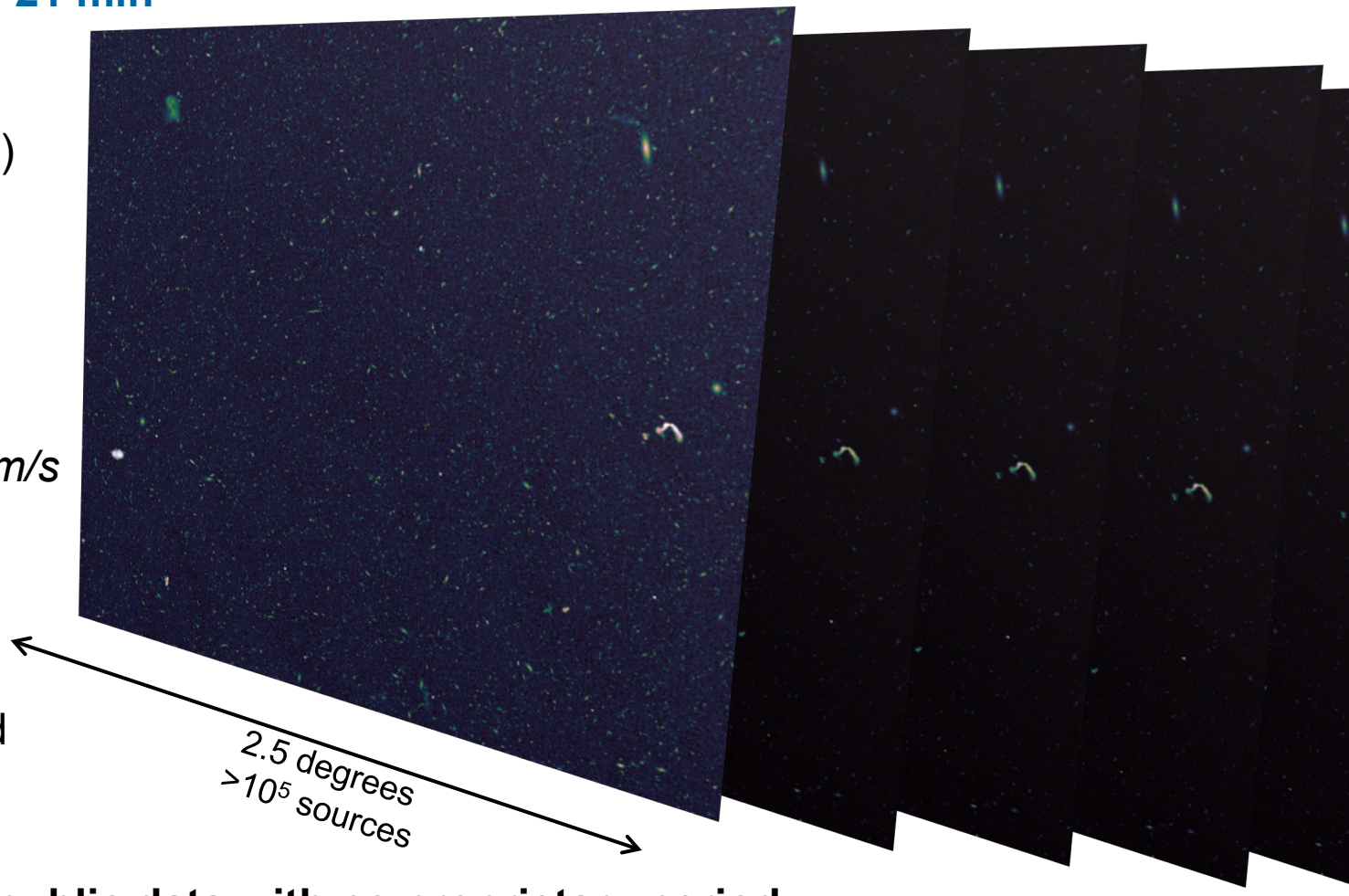
Spectral Line images

Galactic HI	960 channels	*0.2 km/s*
HI (<100 Mpc)	4192 channels	*1.7 km/s*
HI (z<1)	5600 channels	*27.5 – 55 km/s*

Stokes IQUV images (500 x 2.6 MHz)

Chronoscope
FRB search, pulsar search [dedispersed / folded profiles]

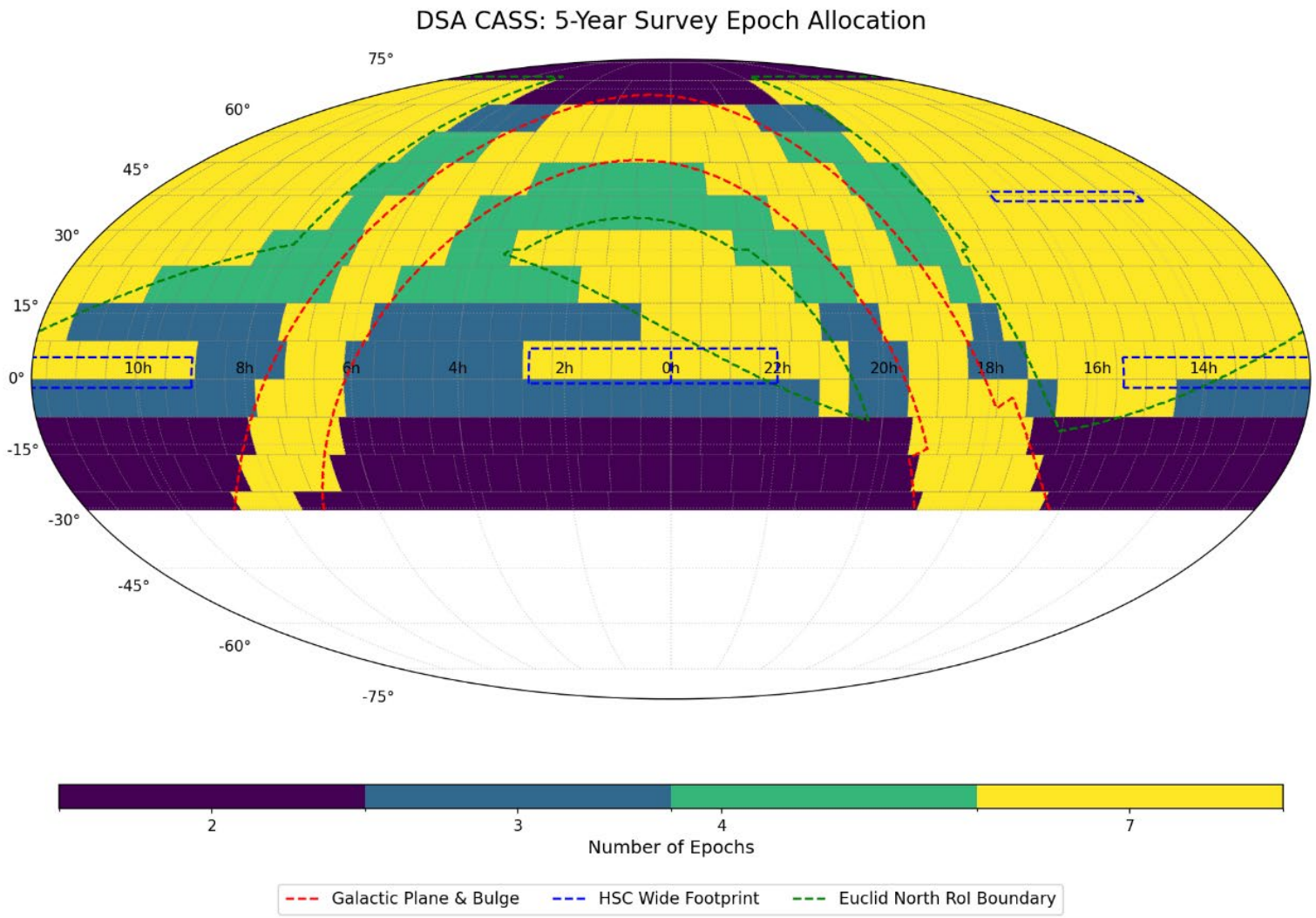
Pulsar timing (4 beams)



Fully public data with no proprietary period

DSA-2000

Design refinements: cadenced all-sky survey strategy



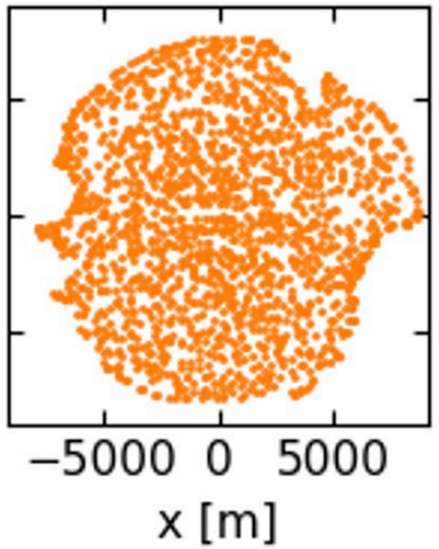
A variable **depth** and **cadence** survey, to 0.4—1 micro-Jy rms in different regions over 5 yr.

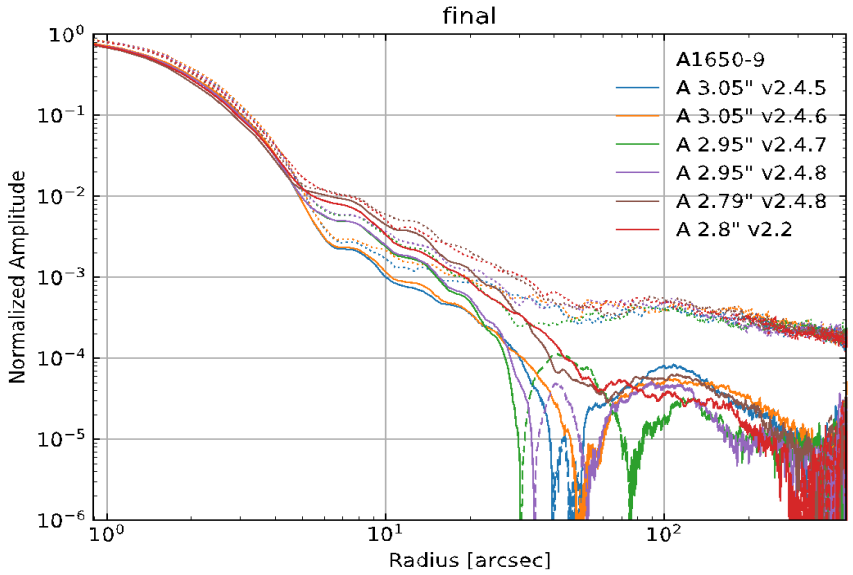
One concept is shown here.

Hallinan

DSA-2000

Design refinements: optimized configuration and infrastructure



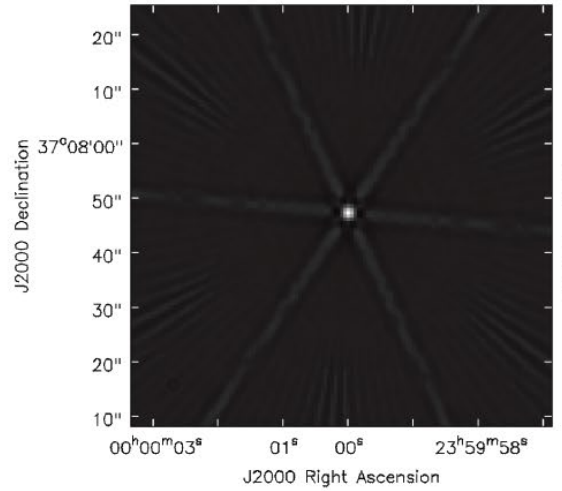


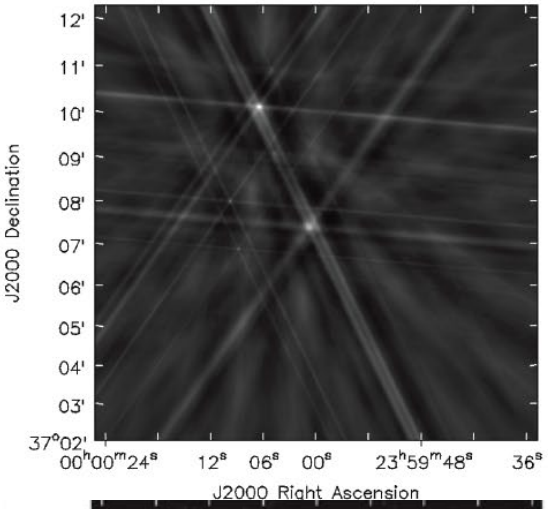
A 1650-antenna configuration with 6.15-m reflectors delivering a 2.7” PSF (1350 MHz) and outstanding sidelobe levels: image-plane CLEAN only.

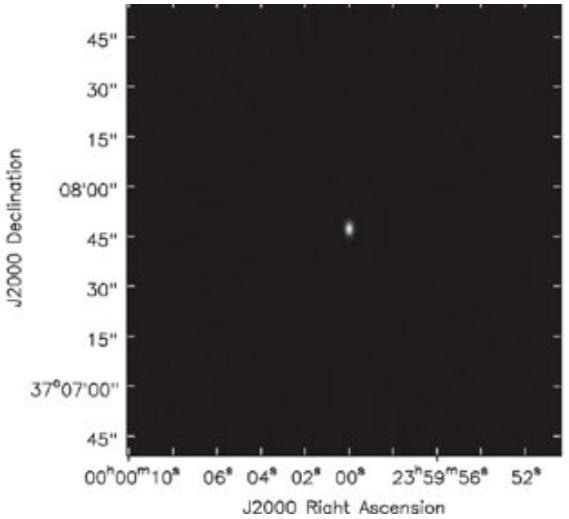
DSA-2000 ArcGIS Collaboration Site

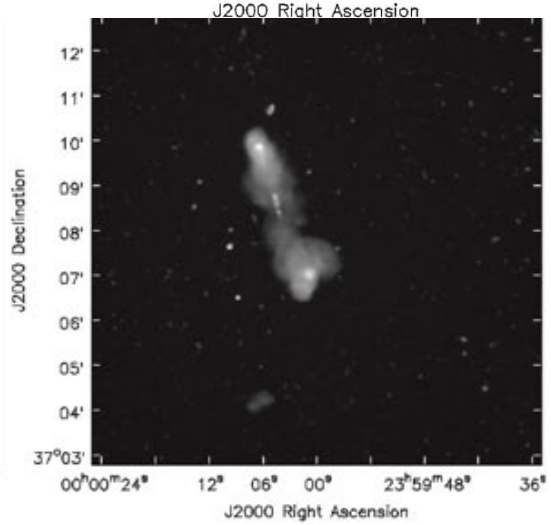
Data are digitized on site, and transported over backhaul fiber over 110km to the nearby town of Ely.

Key Technology: A Radio Camera









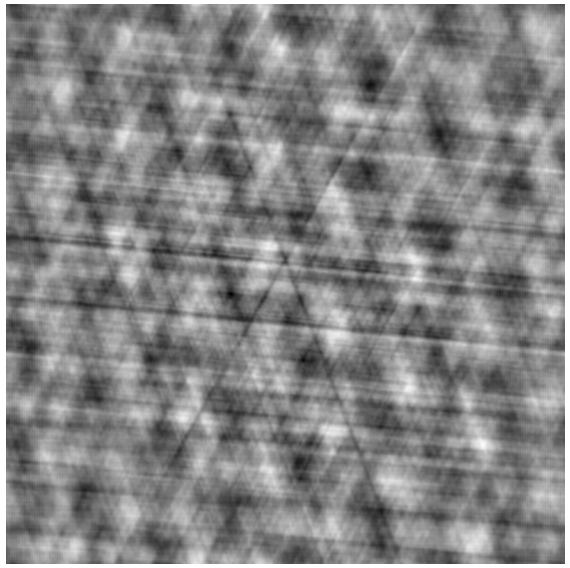
No need for visibility-based deconvolution

Enables a deterministic stream processing pipeline that creates images

DSA-2000

Key Technology: A Radio Camera

VLA
(27 antennas)



MeerKAT
(64 antennas)

SKA-mid
(197 antennas)

DSA-2000
(2000 antennas)

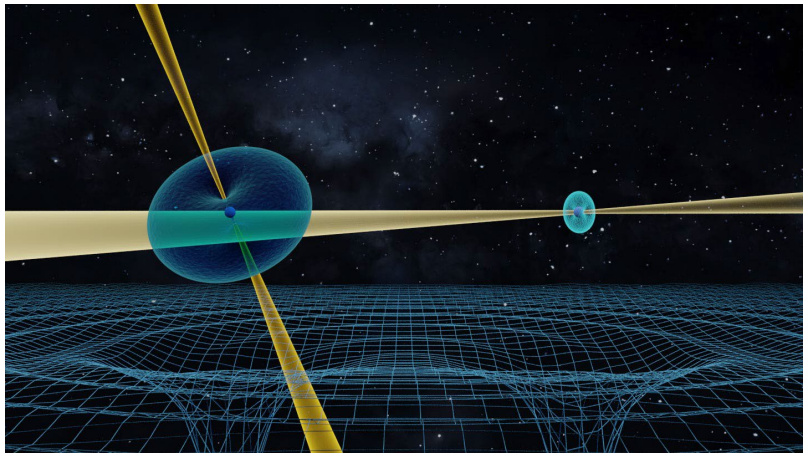
No need for visibility-based deconvolution
Enables a deterministic stream processing pipeline that creates images

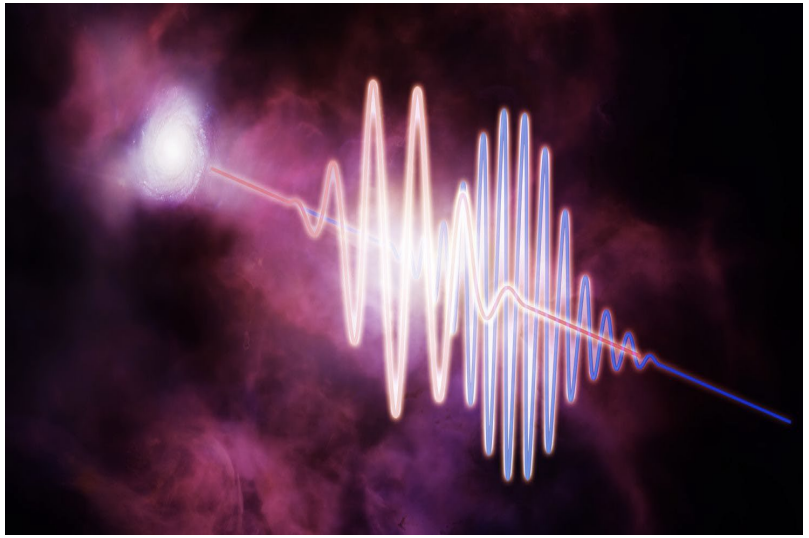
DSA-2000

Key Technology: A Chronoscope

- Executes **commensal** searches for **pulsars** and fast radio bursts (**FRBs**) in **real time**.
- FRB searches on ms-s timescales for dispersed pulses (FRBs etc) in 6×10^6 full-sensitivity beams that tile the FoV.
  - Public alerts, including localizations.
- Full-sensitivity pulsar searches:
  - Targeted searches towards continuum sources from DSA-2000 surveys in 4000 beams.
  - Blind searches in 2×10^5 beams at a time.

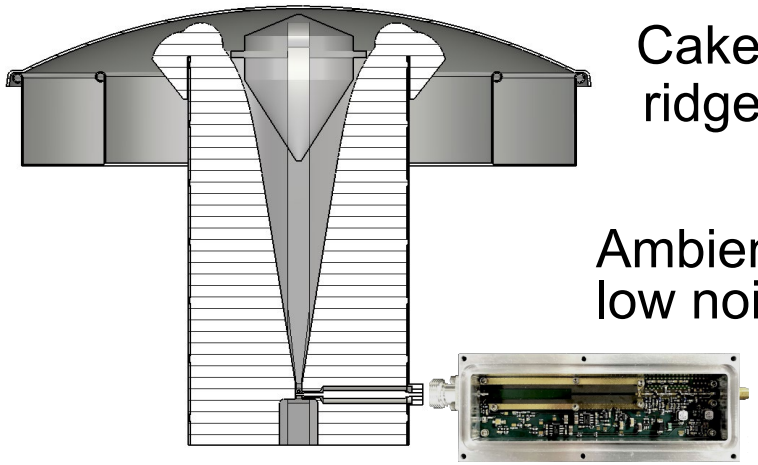
A chronoscope is an instrument designed to measure very short time intervals with high precision. In science fiction, a chronoscope is typically portrayed as a device that can observe events across time - essentially a "time viewer" that allows you to see into the past or future without physically traveling there.





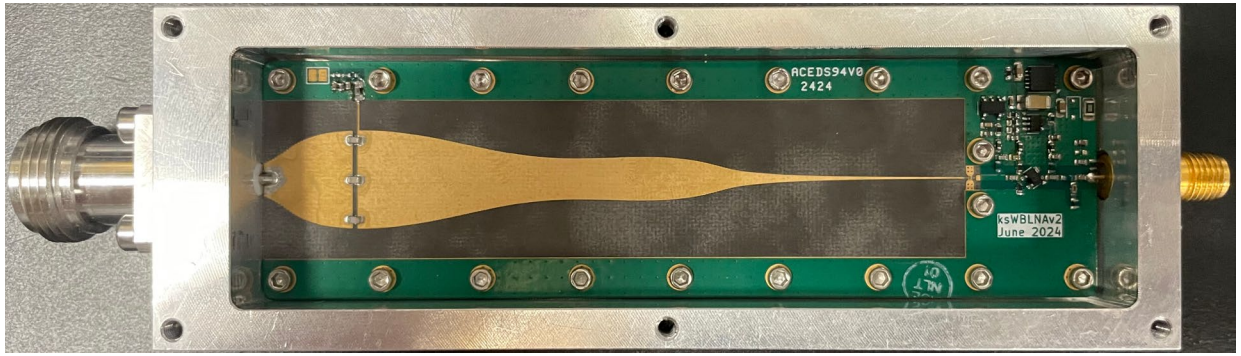
DSA-2000

Design refinements: antennas + analog signal path

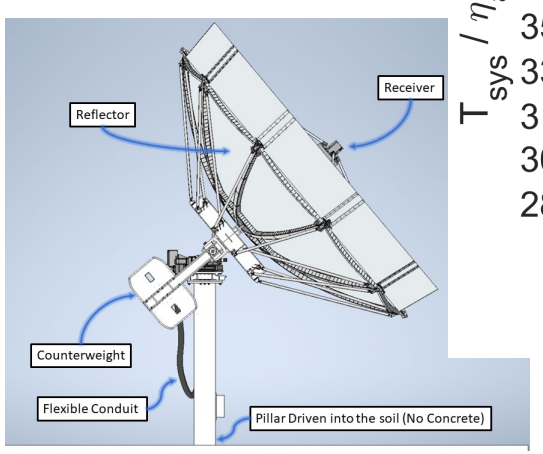


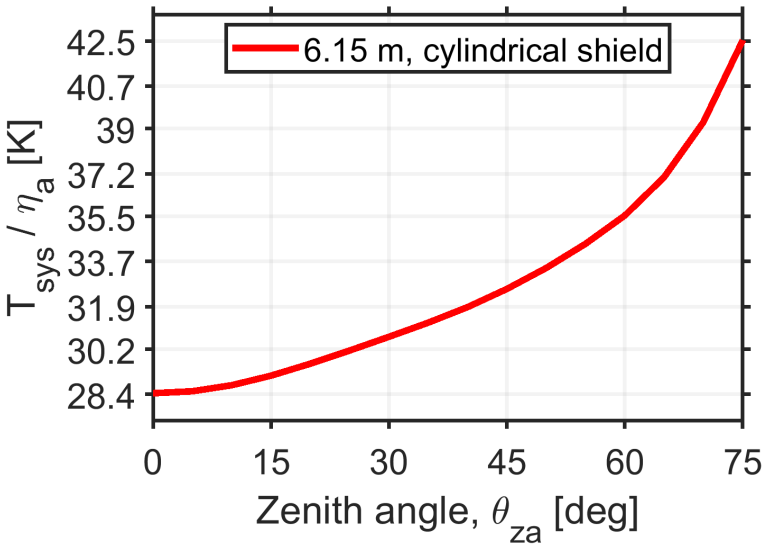
Cakepan quad-ridge feed horn

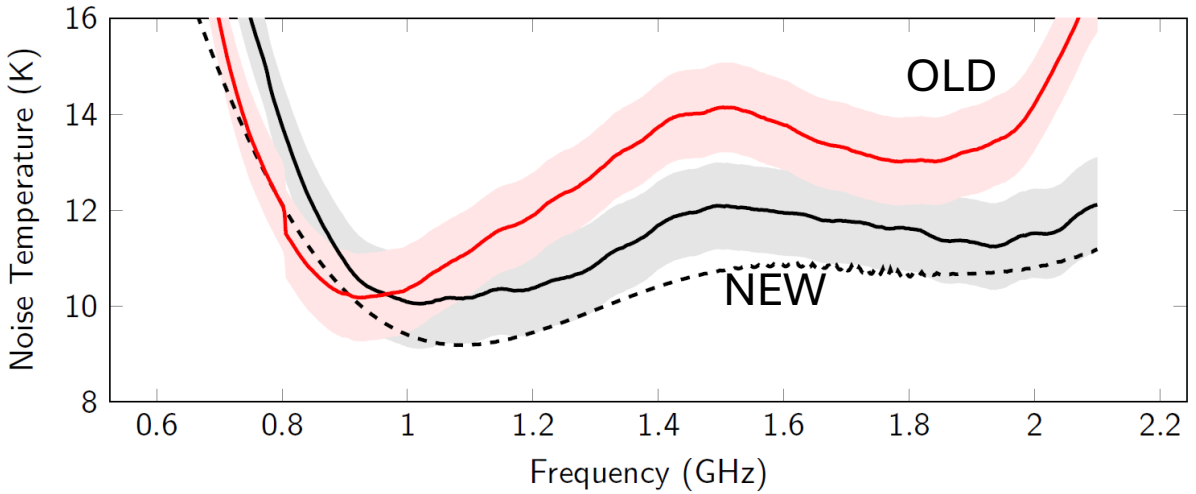
Ambient-temperature low noise amplifier



Low-cost, highly performant antenna







Embedded, optimized 0.7—2GHz ambient-temp LNA. RFI resilient!

DSA-2000

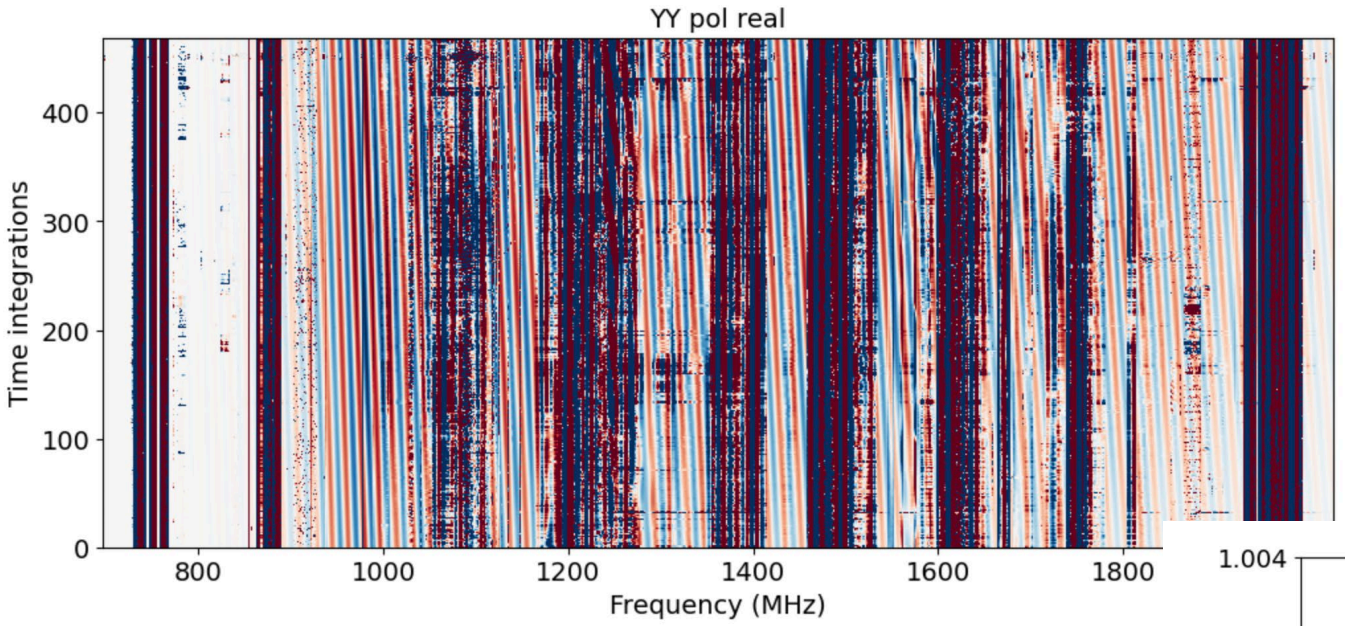
Padin, Shila, Weinreb, Flygare

Test Array @ OVRO

Image: Jasmine Beaghler

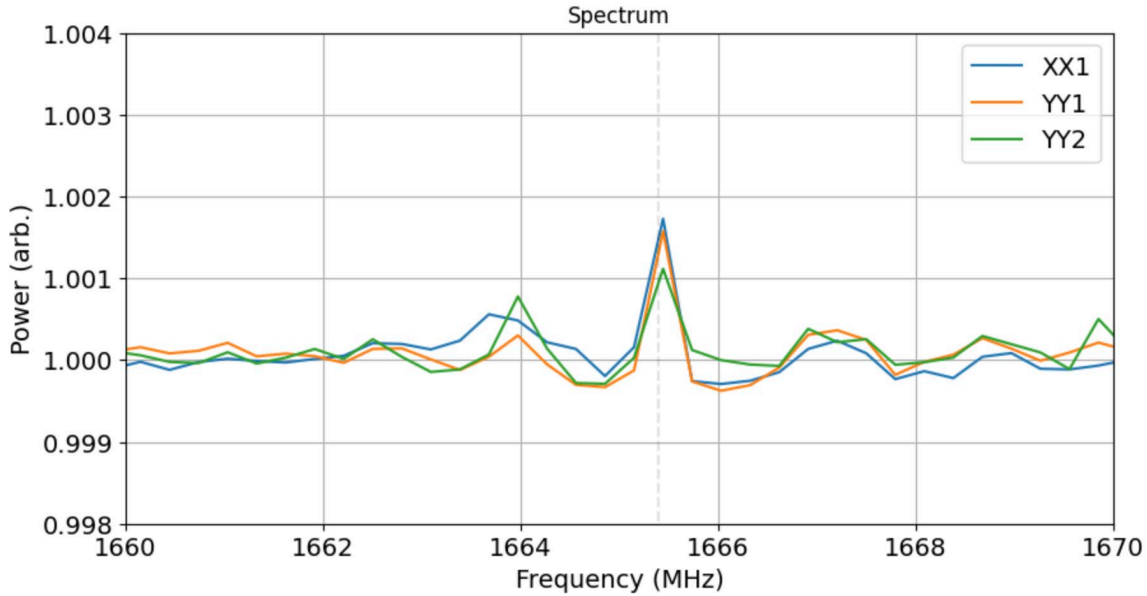
DSA-2000

Test Array @ OVRO



Interferometric fringes during drift scan of Cas A.

Detection of OH maser emission (note mismatch of ~0.2 km/s emission with ~50 km/s channels).



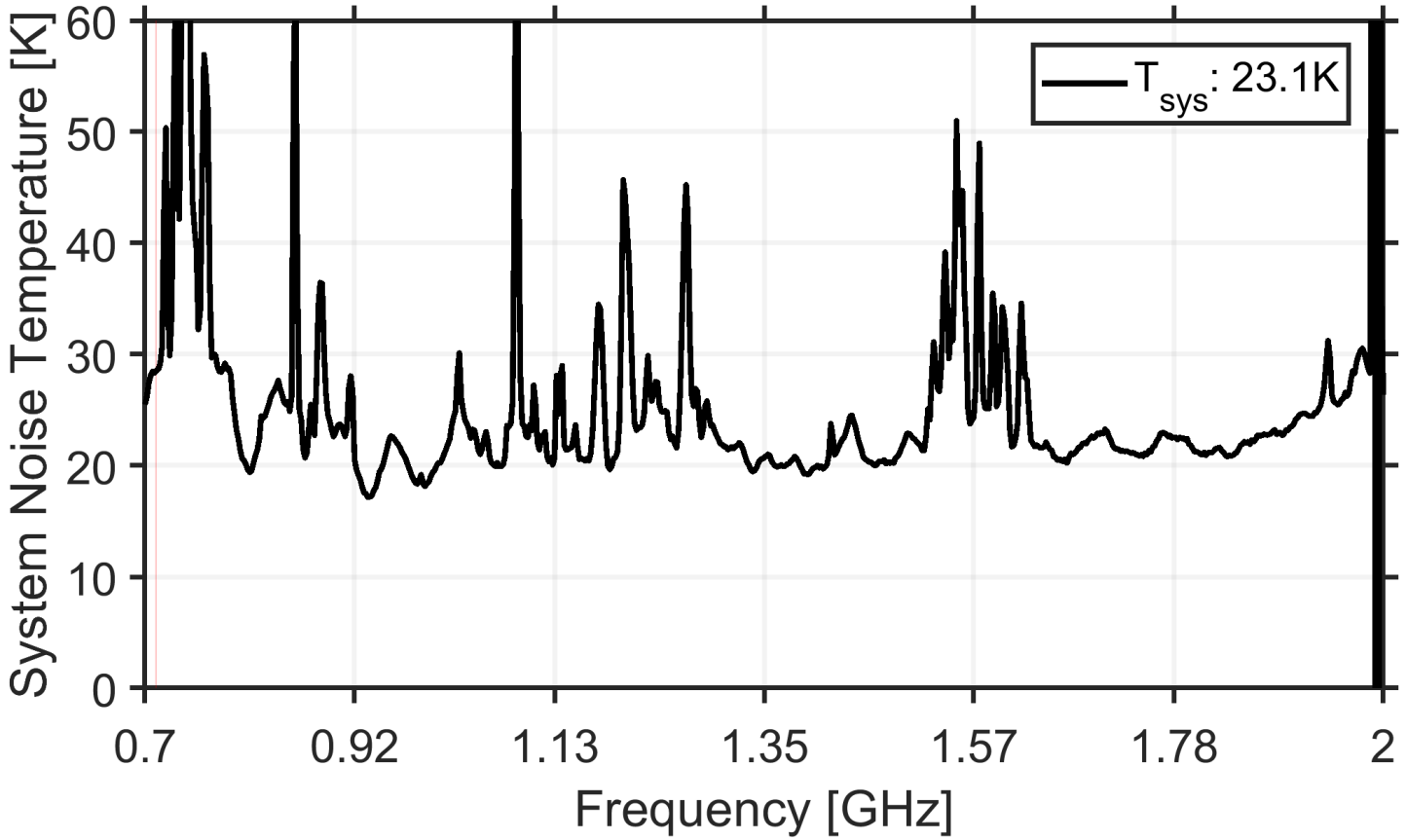
DSA-2000

Testing in Spring Valley

DSA-2000

Image: Jonas Flygare

Testing in Spring Valley



For more see:

Advances in radio astronomy antennas and systems - ICEAA, 08:20-15:20 Wednesday, room 2 Enrico

Paper 693, 11:20, DSA-2000 Antenna System Characterization and Design Overview - J. Flygare

At ICEAA, Palermo, Sep 2025

DSA-2000

Design refinements: compute hardware

- New rack-scale compute hardware from NVIDIA (e.g., NVL72 / Oberon) and AMD (e.g., Helios) are **revolutionary for large radio-astronomy arrays**.
- Targeting **~6 ExaFLOP** of processing at FP8 in **5 racks** at **<<1MW**!
- Implementation of key Radio Camera and Chronoscope components being benchmarked.

Nvidia

- When operational in 2029, the DSA-2000 will be the most powerful GHz-frequency telescope worldwide.
  - Enabled by several groundbreaking technologies
  - A low-band (~10-350MHz) complementary system is also being pursued
- Transformational science: multimessenger astronomy, cosmic history, dynamic radio sky, dark sector and strong gravity.
- Science-ready data served publicly with no proprietary period.

Leadership: Gregg Hallinan (PI), Vikram Ravi (Co-PI), Katie Jameson (Project Manager), Francois Kapp (Project Engineer), Fabian Walter (Project Scientist).

Schmidt Sciences

DSA-2000

Caltech