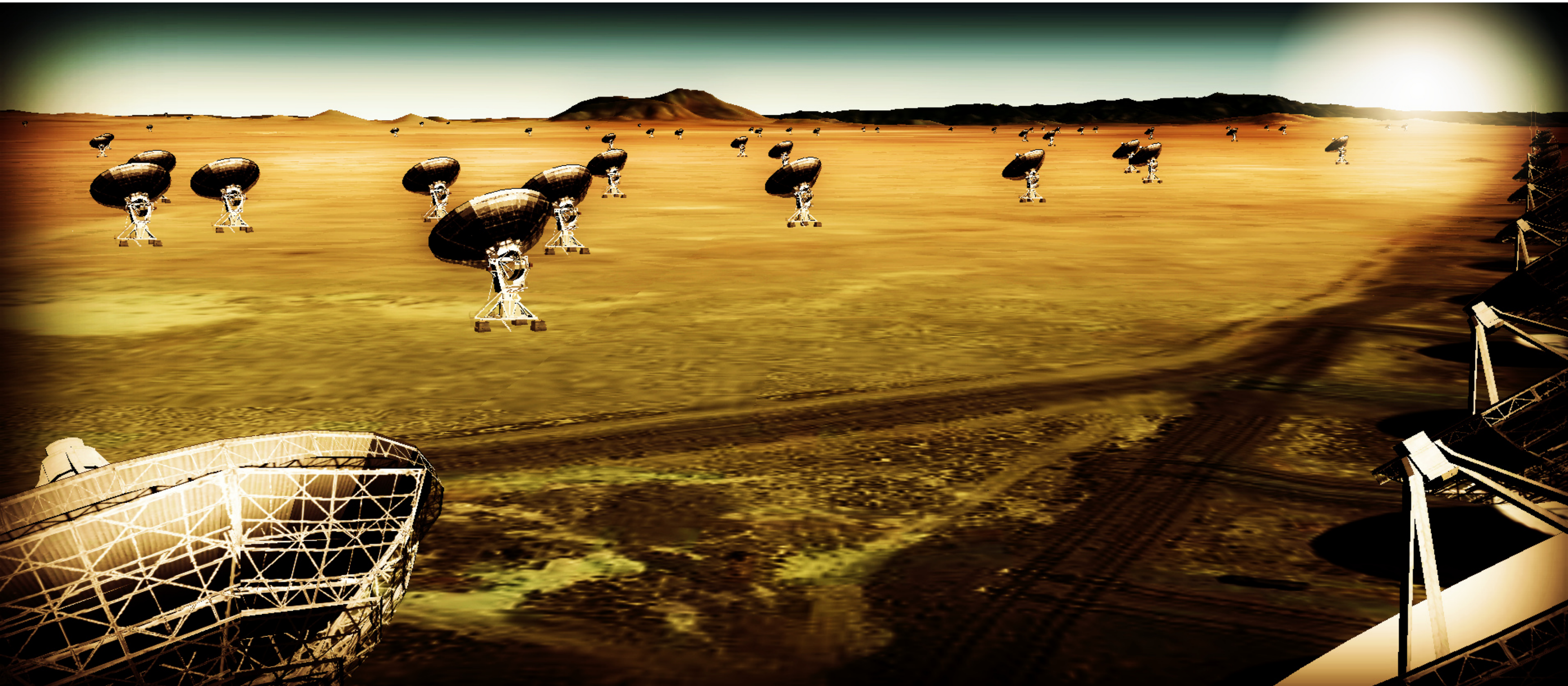
Science with

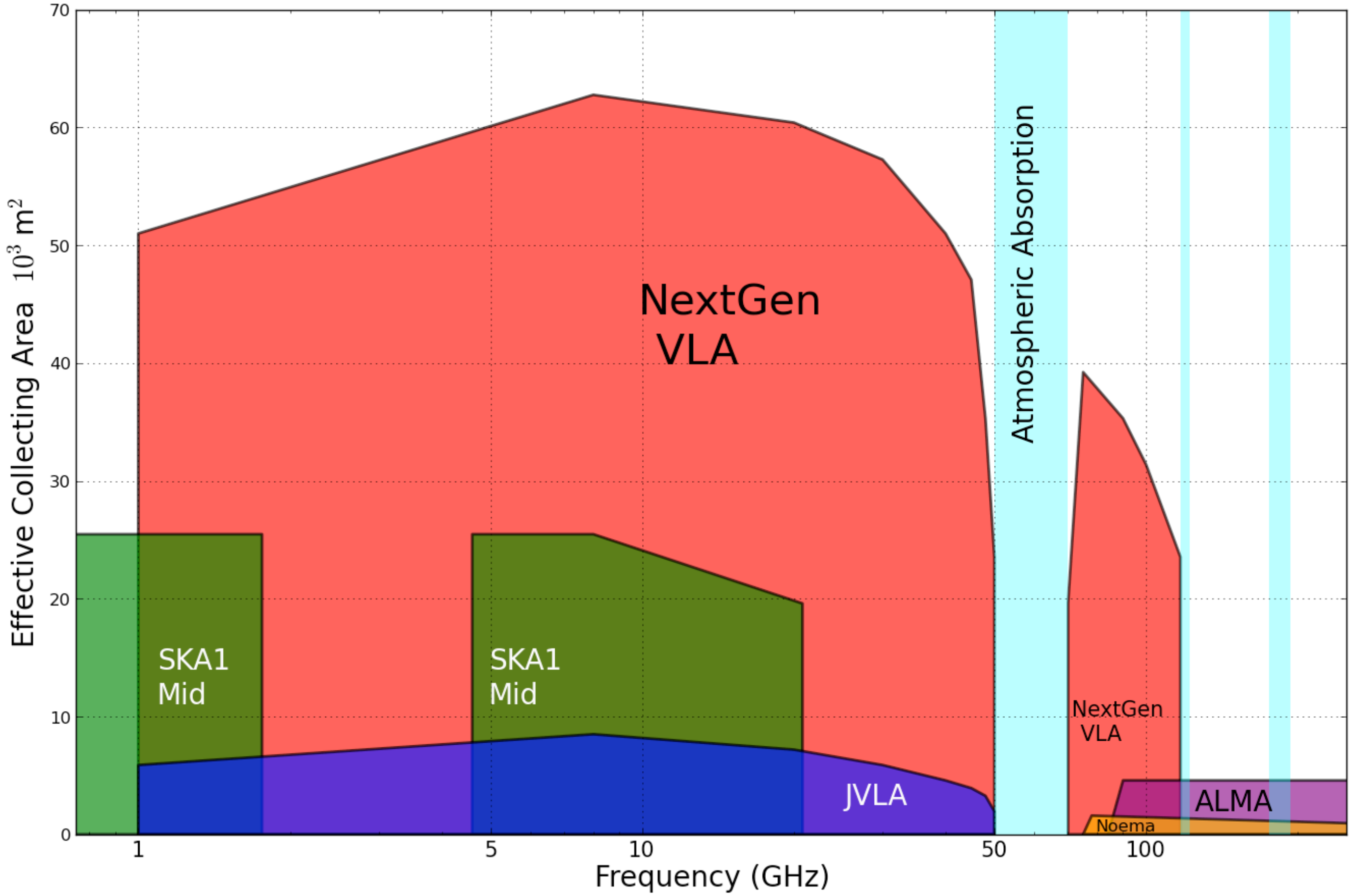
THE VERY LARGE ARRAY

THE NEXT GENERATION

- Effective area at 40GHz ~ 10x JVLA
- Frequency range: 1 – 50, 70 – 115 GHz
- ~300 18m antennas w. 50% to few km + 40% to 200km + 10% to 3000km?
- Design goal: minimize mass production and operations costs

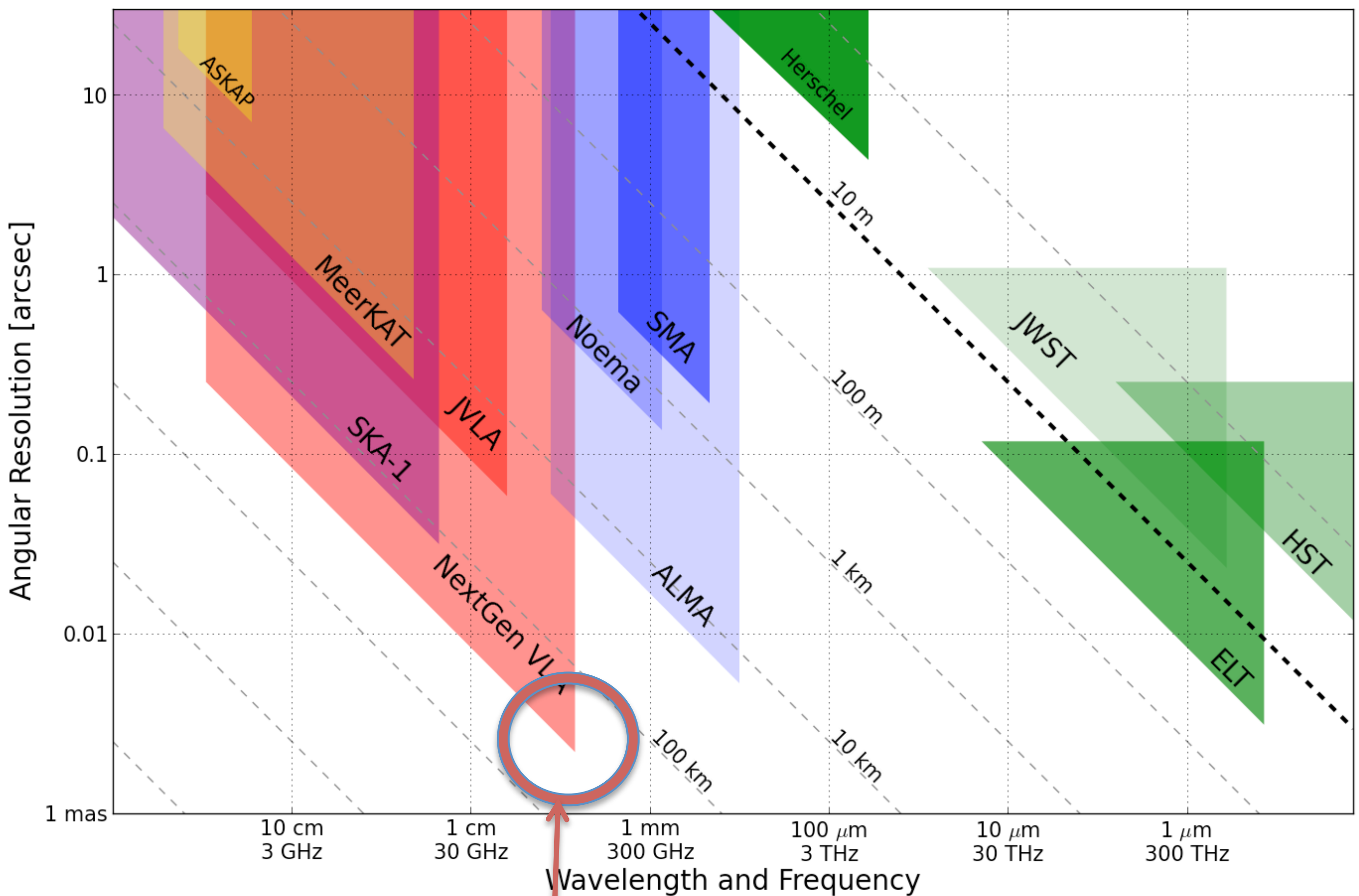


Thermal imaging on mas scales at λ ~ 0.3cm to 3cm



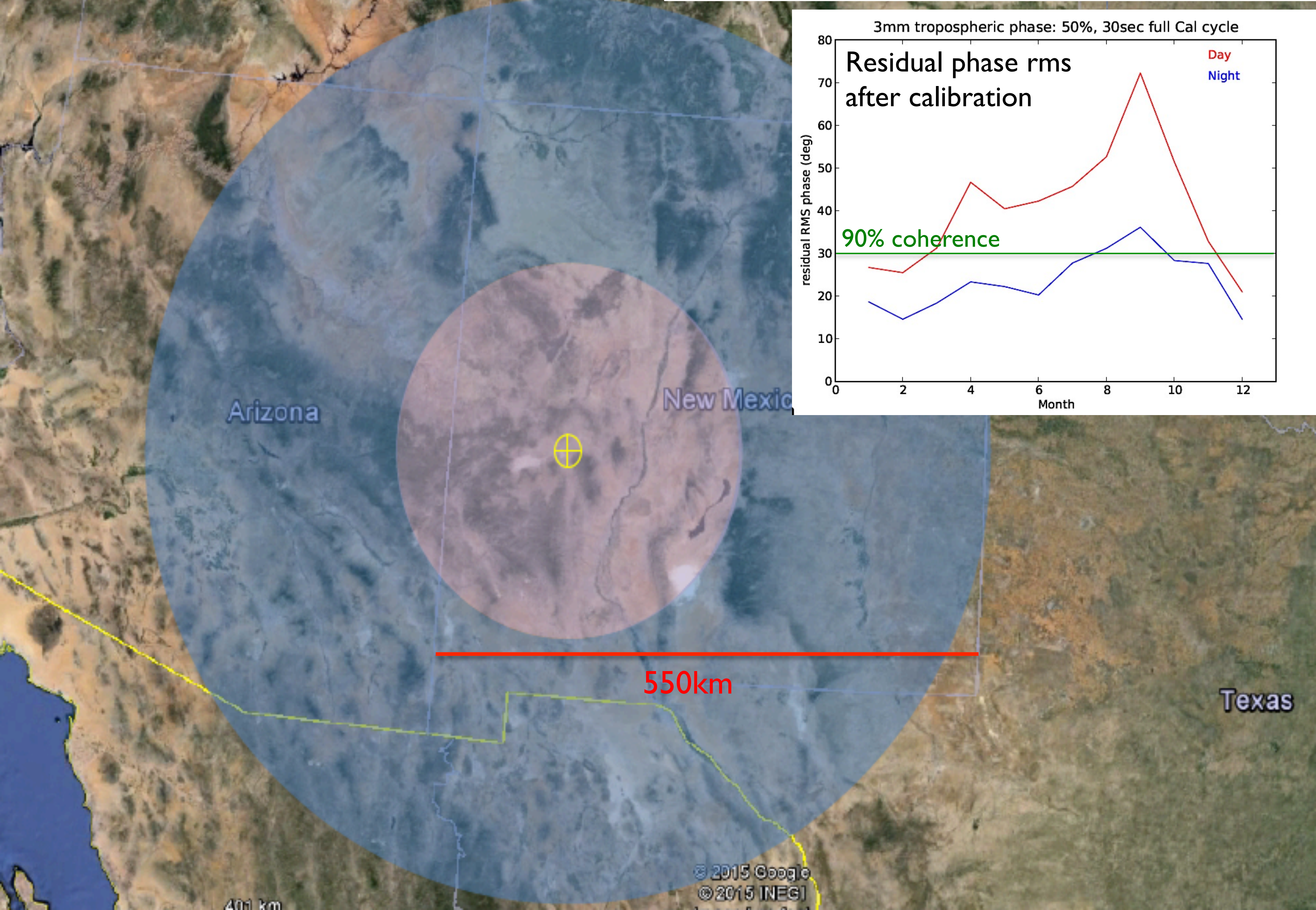
- Sensitivity ~ 0.1uJy @ 1cm, 10hr, BW = 20GHz
- T_B ~ 1K @ 1cm, 10mas
- Molecular lines become prevalent above 15GHz

Resolution ~ 10mas @ 1cm (300km)



1AU @ 140pc
Terrestrial Zone Planet Formation

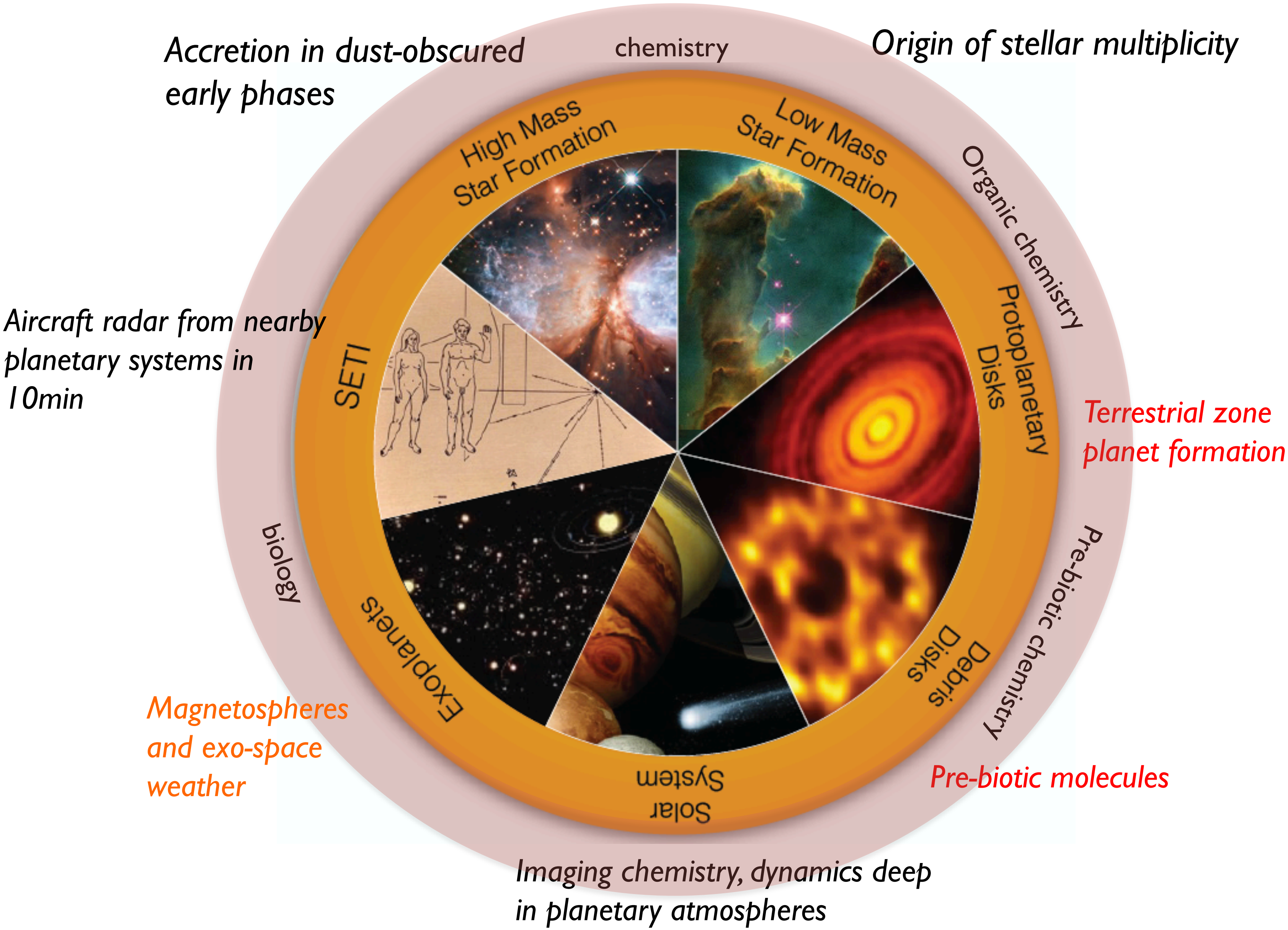
JVLA: Good 3mm site, elev. ~ 2200m



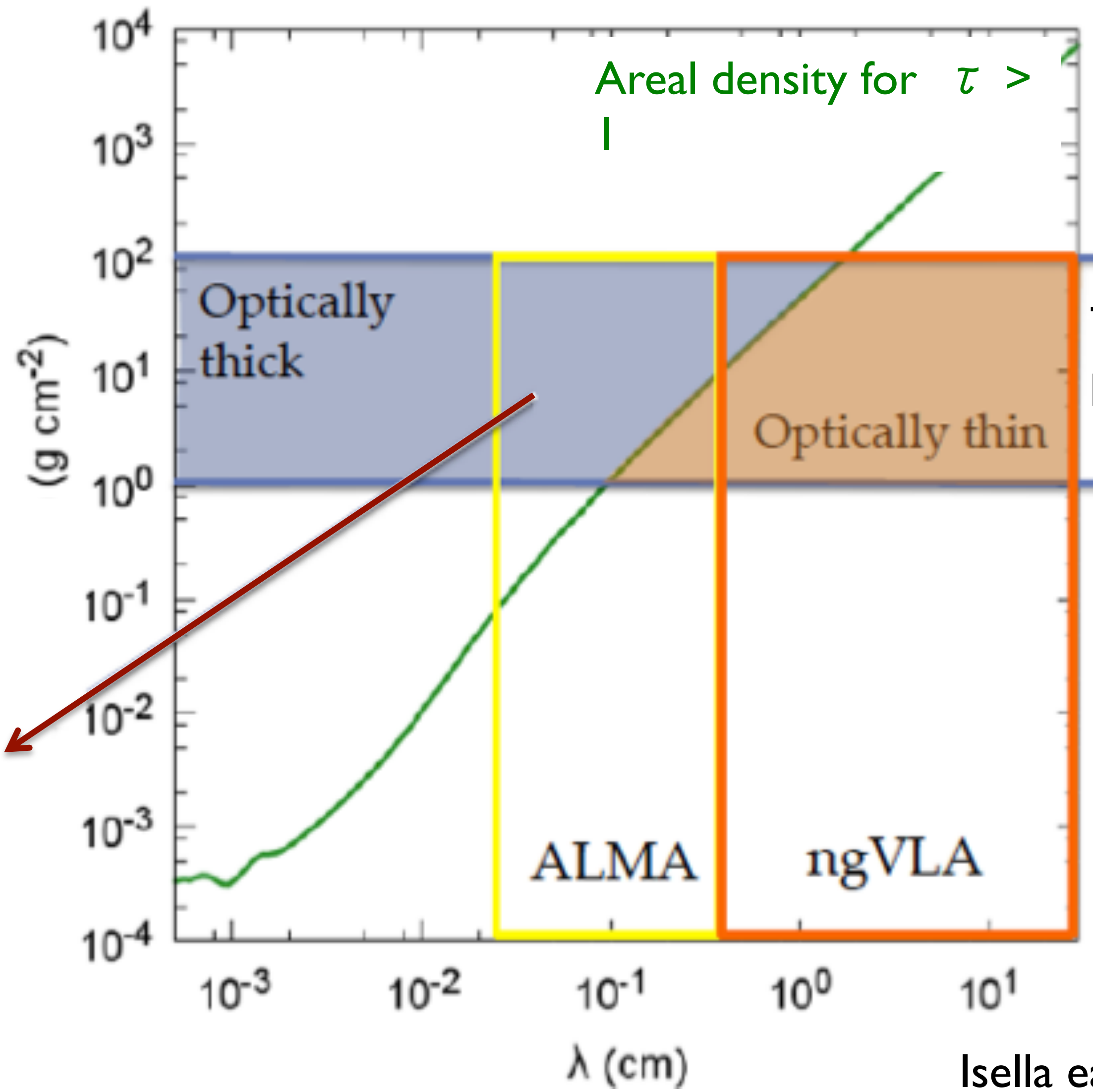
Ongoing Process

- Science working groups ~100 authors
  - Cradle of Life (chairs: Isella, Moullet, Hull)
  - Galaxy ecosystems (chairs: Murphy, Leroy)
  - Galaxy assembly (chairs: Lacy, Casey, Hodge)
  - Time domain, Cosmology, Physics (chairs: Bower, Demorest)
  - White papers are now online on ngVLA memo series and arXiv
- Jan 2015: AAS Jan community discussion
- April 2015: Pasadena technology meeting
  - Antennas, correlators, receivers
- Dec 8/9, 2015: 2nd technical meeting in Socorro
  - LO/IF, data transmission, operations, computing
- Jan 4, 2016: 2nd AAS Jan community meeting

Circle of Life: origin stars, planets, life



Terrestrial zone planet formation = ‘ngVLA zone’



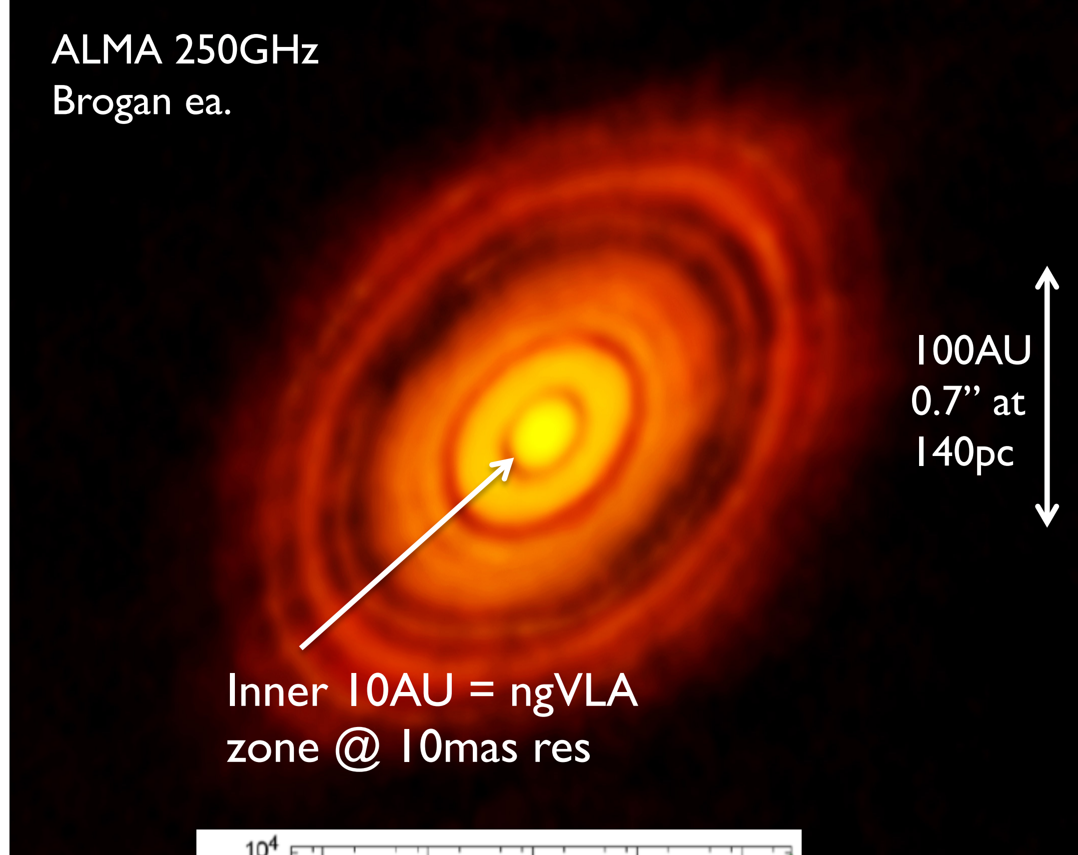
Optically thick at short ALMA wavelengths, but unresolved at long ALMA wavelengths

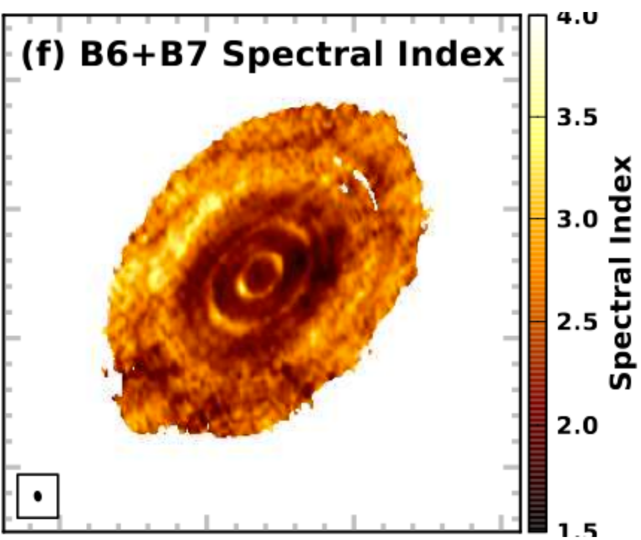
Typical ~ 1Myr protoplanetary disk at R ~ few AU

Isella ea.

ngVLA: Terrestrial zone planet formation imager

- See through dust to pebbles: inner few AU disk optically thick in mm/submm
- Grain size stratification at 0.3cm to 3cm
  - ➢ Poorly understood transition from dust to planetesimals
  - ➢ SI => combination of grain growth and optical depth





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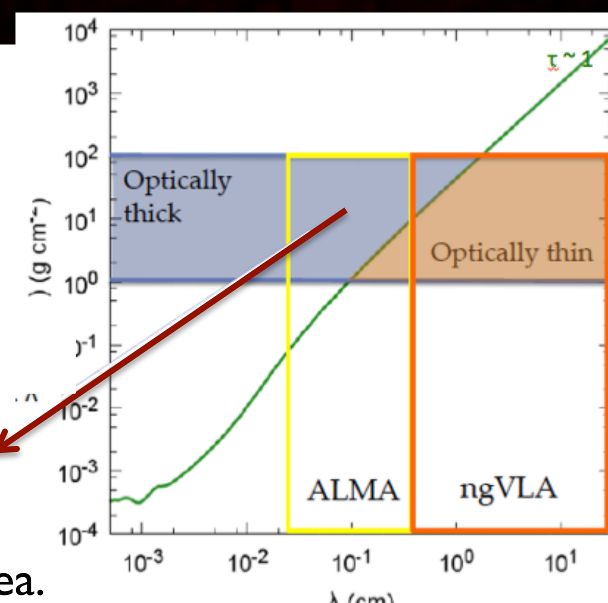
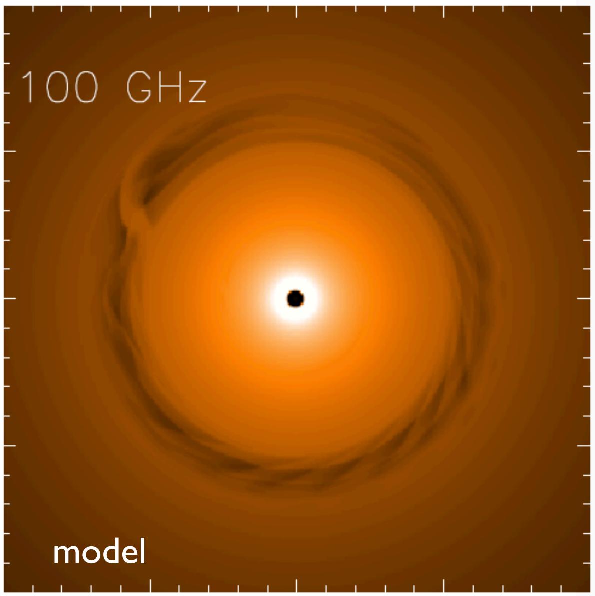
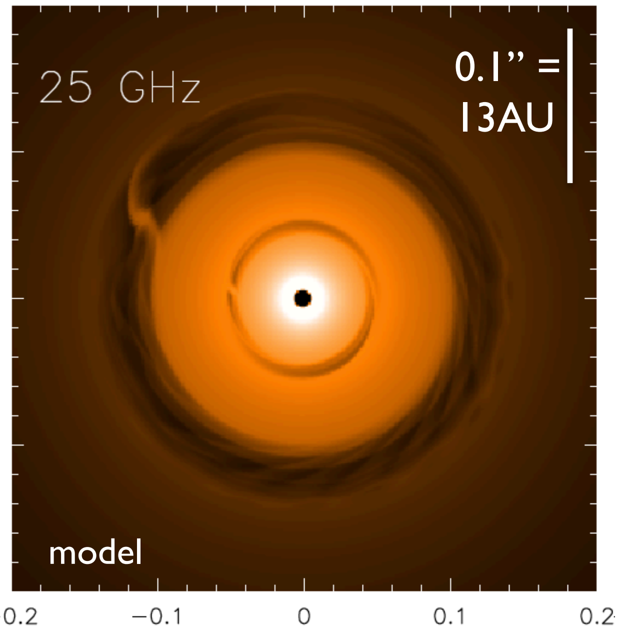
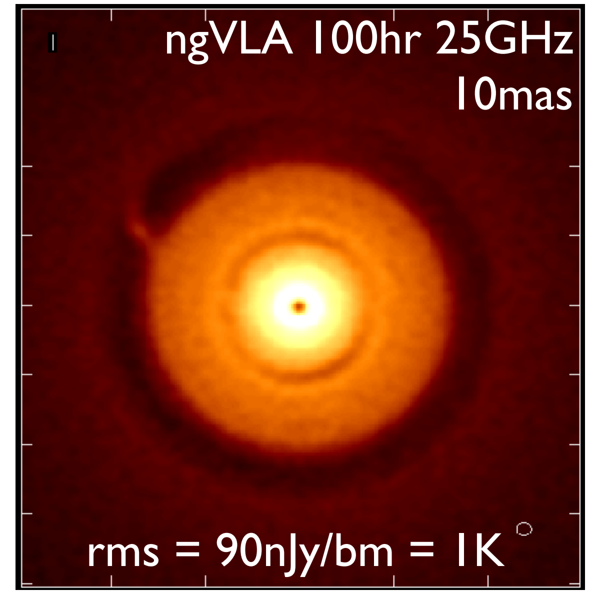


Typical ~ 1Myr protoplanetary disk at R ~ few AU

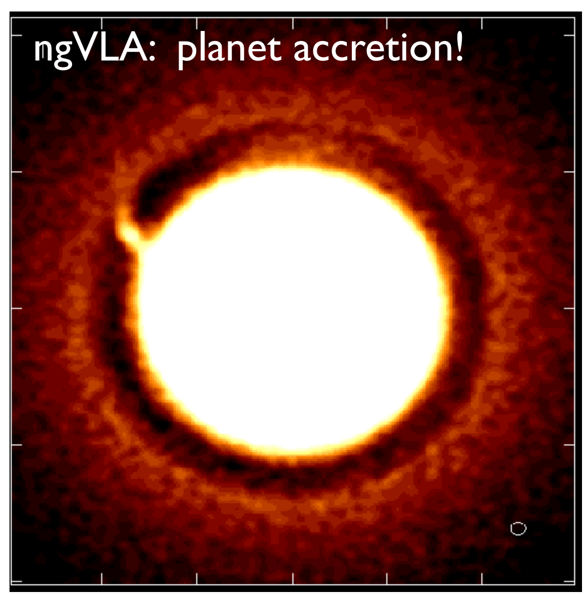
NGVLA: Protoplantary disk at 130pc distance

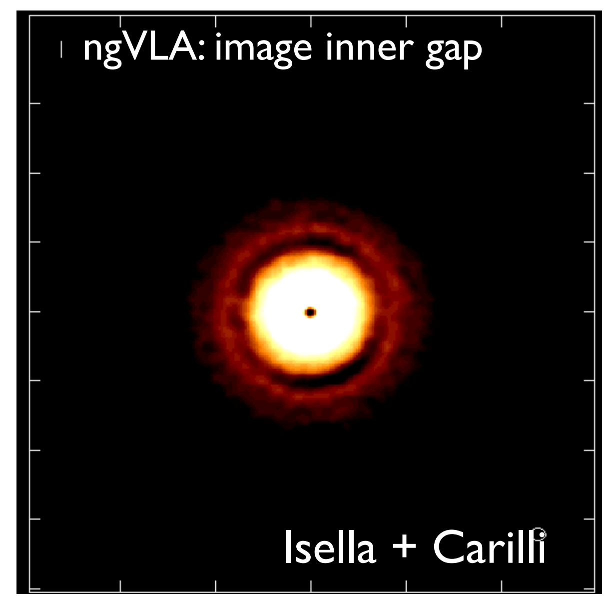






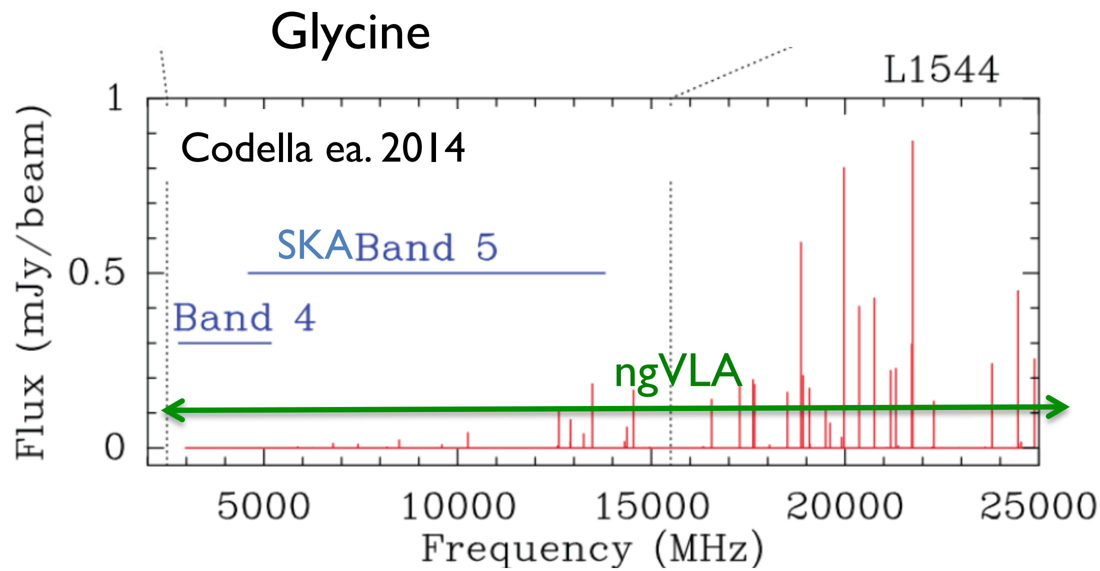
- Jupiter at 13AU, Saturn at 6AU
- Inner gap optically thick at 100GHz
- Image both gaps + annual motions
- Circumplanetary disks: imaging accretion on to planets

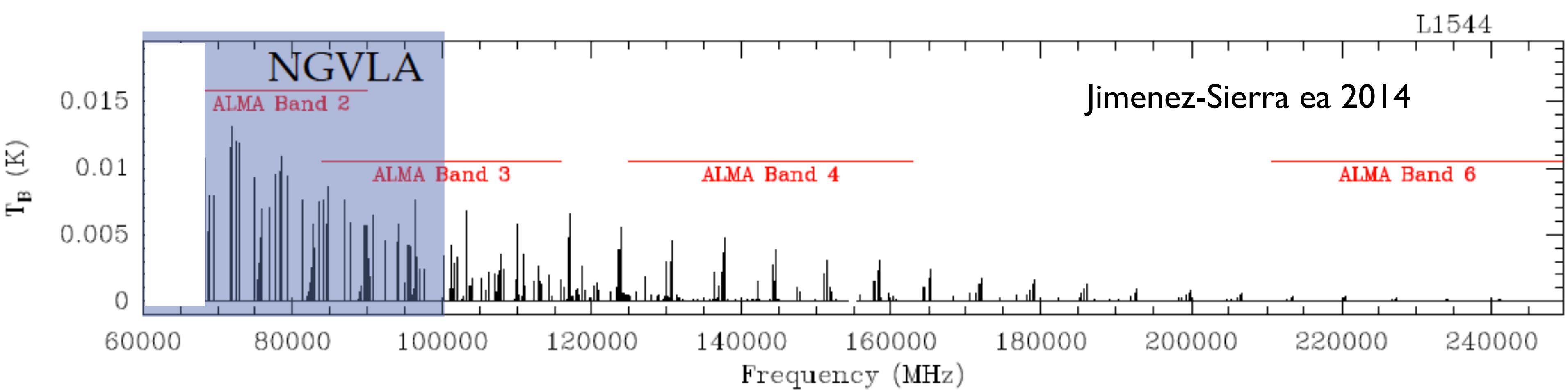




Circle of life: pre-biochemistry

- Pre-biotic molecules: rich spectra in 0.3cm to 3cm regime
- Complex organics: ice chemistry in cold regions
- Ammonia and water: temperature, evolutionary state, PP disks, comets, atmospheres…

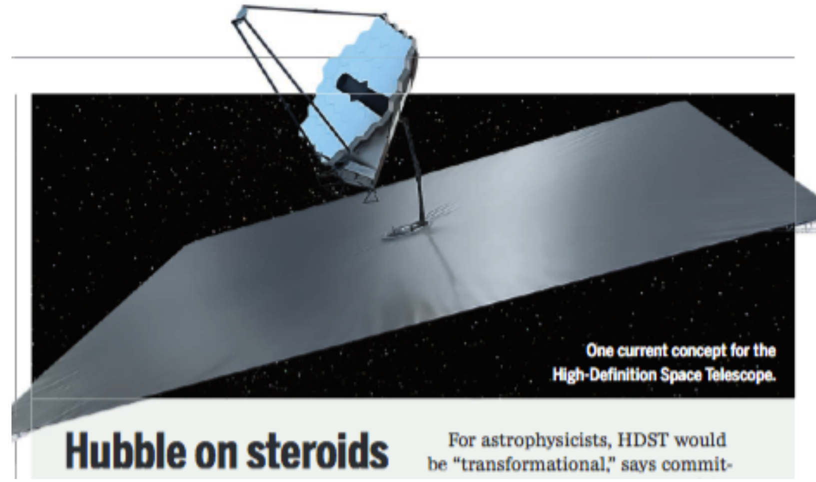




ng-Synergy: Solar-system zone exoplanets
'ALMA is to HST/Kepler as ngVLA is to HDST'

High Definition Space Telescope
Terrestrial planets: top science goal

- Direct detection of earth-like planets
- Search for atmospheric bio-signatures

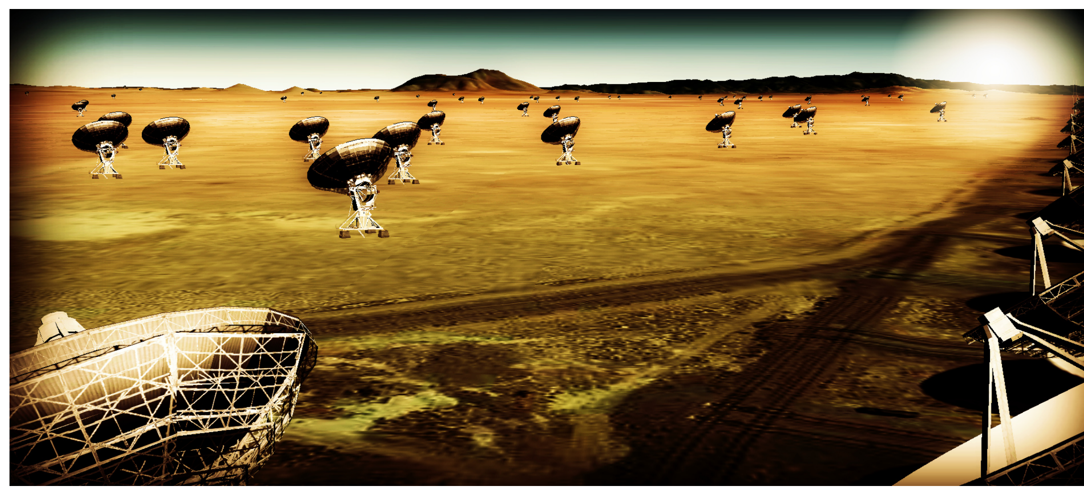

One current concept for the High-Definition Space Telescope.

Hubble on steroids

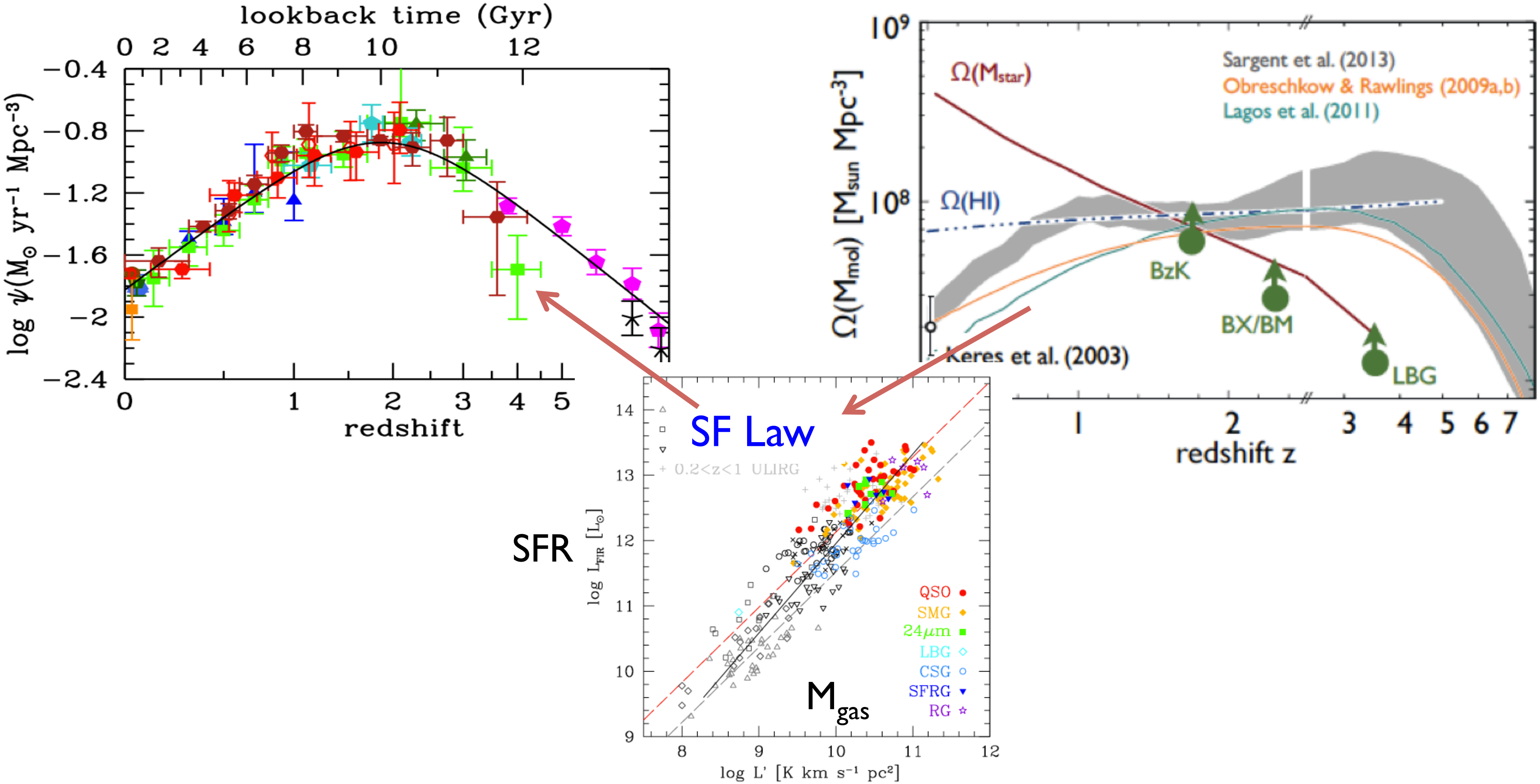
For astrophysicists, HDST would be "transformational," says commit-

ngVLA

- Imaging *formation* of terrestrial planets
- Pre-biotic chemistry



Cool Gas History of the Universe

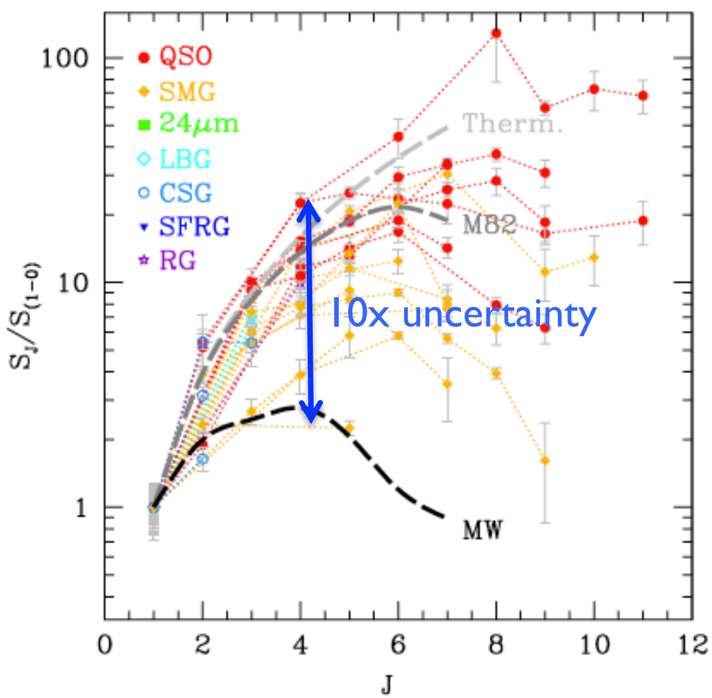


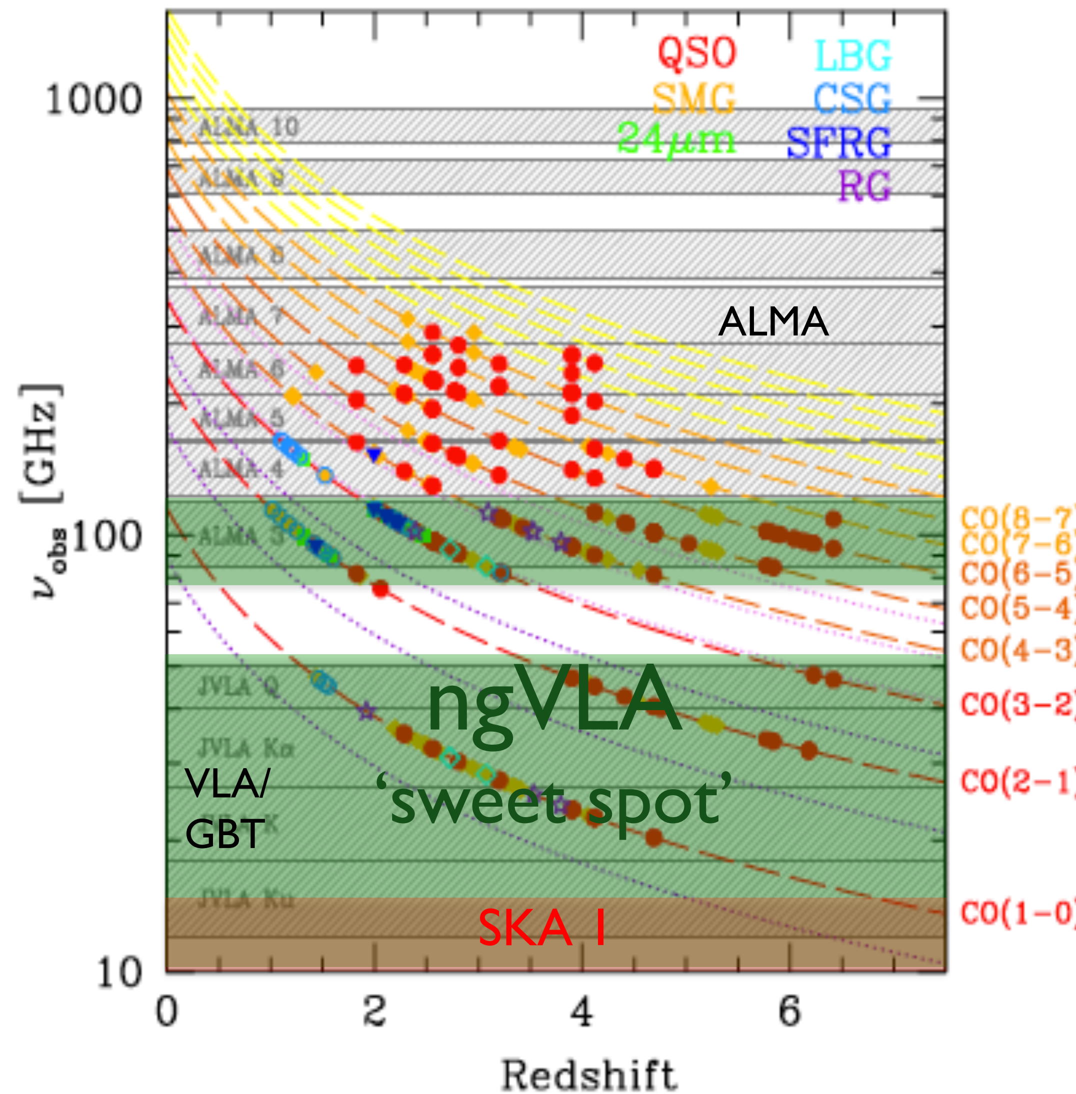
- SFHU has been delineated in remarkable detail back to reionization
- SF laws => SFHU is reflection of CGHU: study of galaxy evolution is shifting to CGHU (source vs sink)

Low order CO: key total molecular gas mass tracer

$M_{H2} = \alpha \times L_{CO1-0}$

- Total molecular gas mass
- w. ALMA => gas excitation
- Dense gas tracers associated w. SF cores: HCN, HCO^+

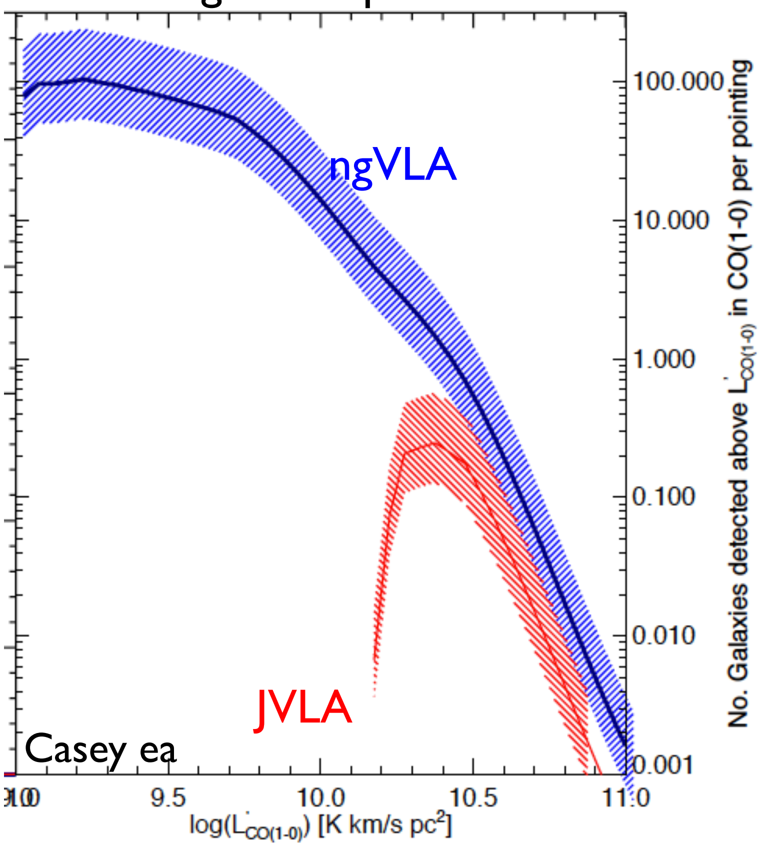


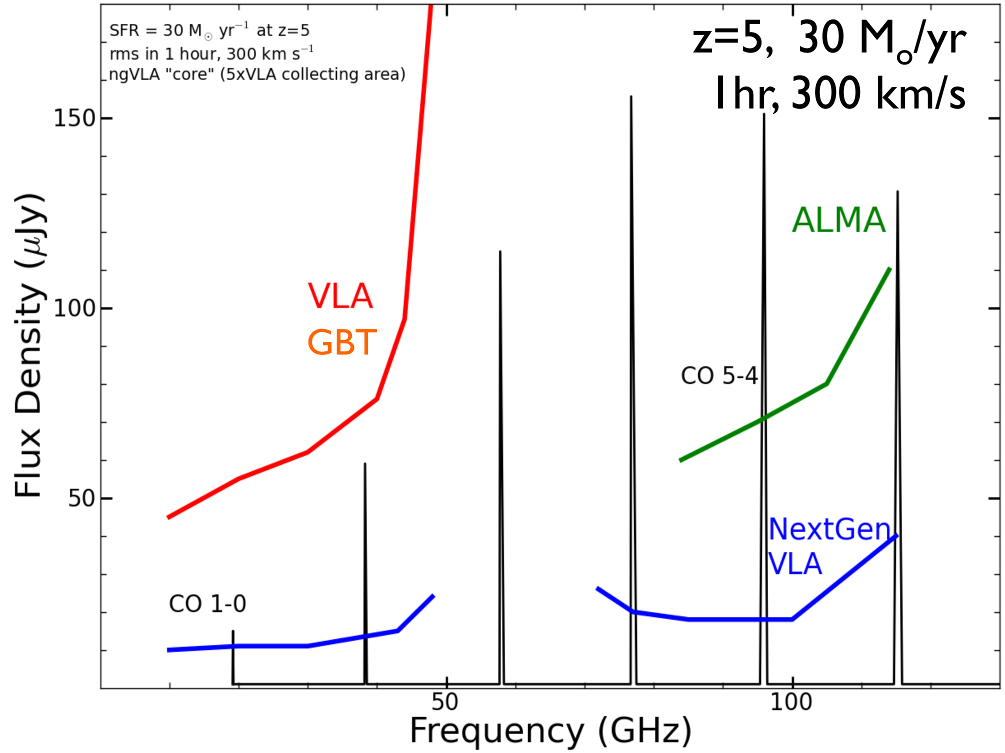


New horizon in molecular cosmological surveys

CO emission from typical star forming, 'main sequence' galaxies at high z in 1 hour

Number galaxies per hour



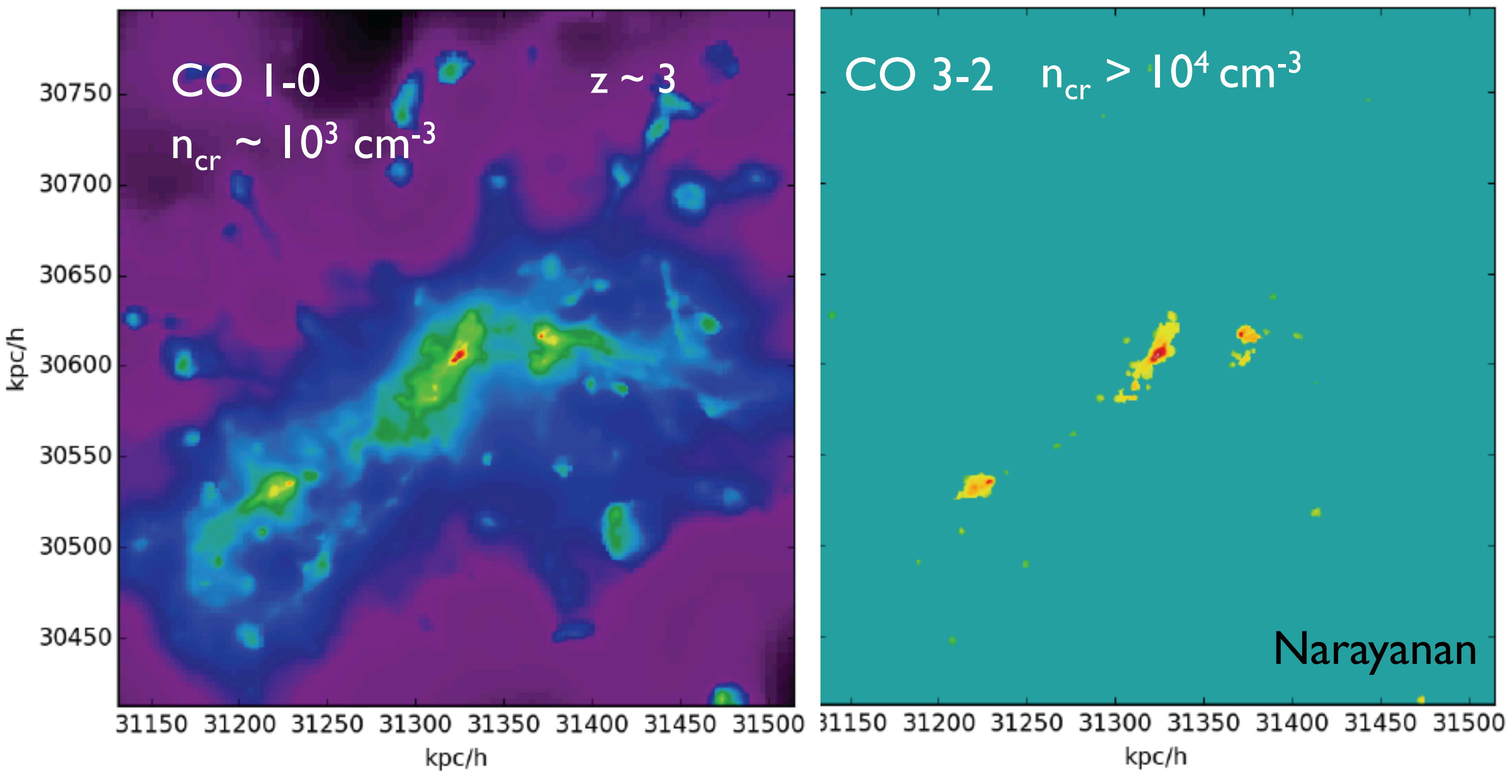


Increased sensitivity and BW => dramatic increase molecular survey capabilities. Number of CO galaxies/hour, 20 – 40 GHz:

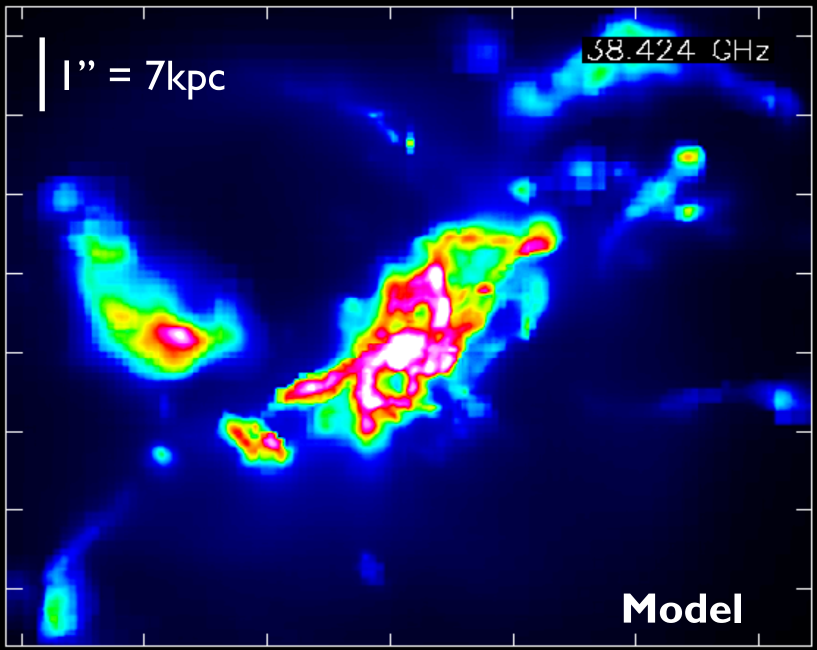
- JVLA ~ 0.1 to 1, $M_{gas} > 10^{10}$ M_o
- ngVLA: tens to hundreds, $M_{gas} > 2 \times 10^{9}$ M_o

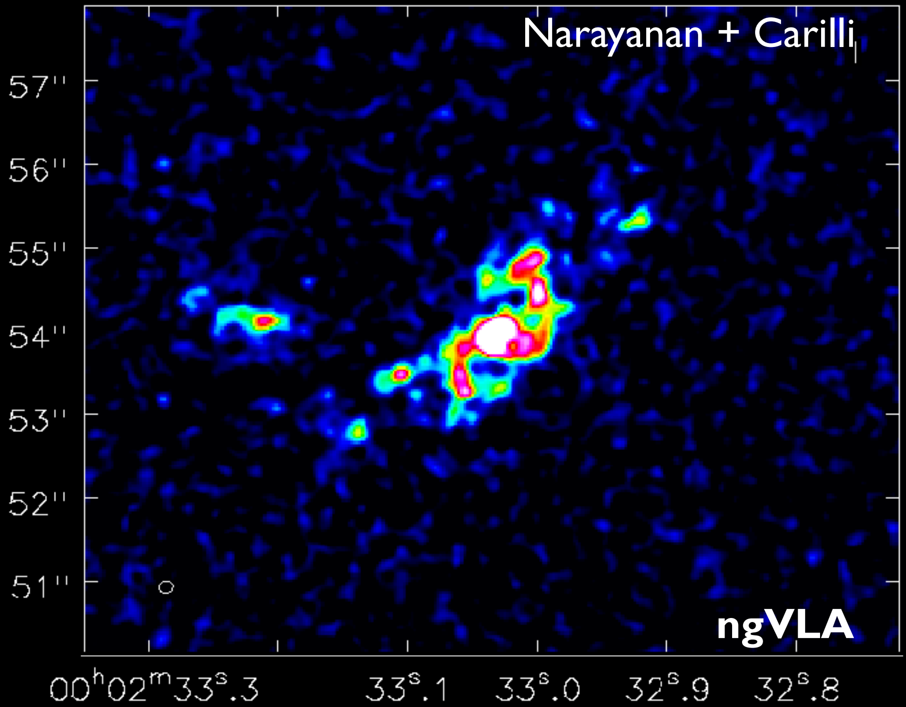
Galaxy assembly: Imaging on 1 kpc-scales

- Low order: large scale gas dynamics, not just dense cores
- w. ALMA dust imaging: resolved star formation laws at ~ 1kpc



ngVLA: SMG at z=2, CO1-0



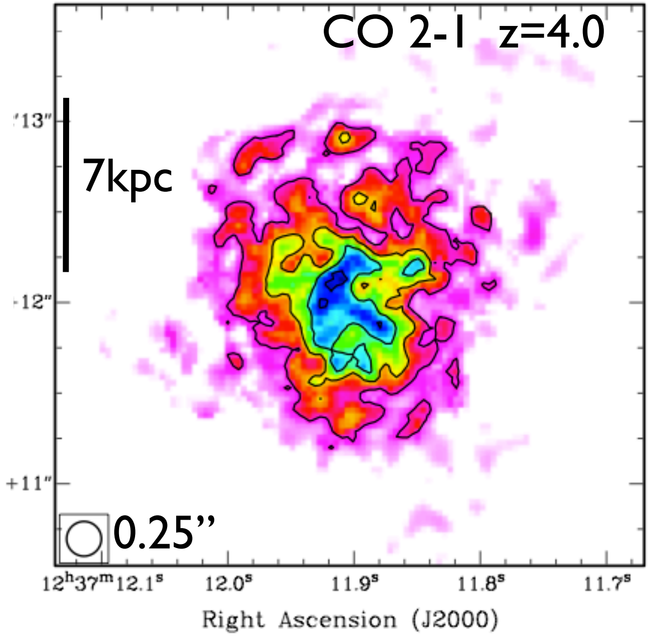


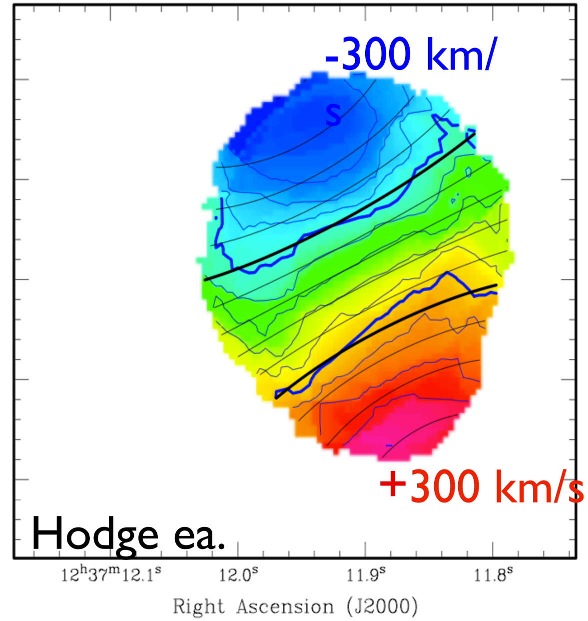
- 38GHz, 10hrs
- rms(100 km/s) = 12uJy => 2e8 (α /0.8) M_o !
- Resolution = 0.15"
- Low mass sattelite galaxies, streamers, accretion?

JVLA state of art
Beyond blob-ology

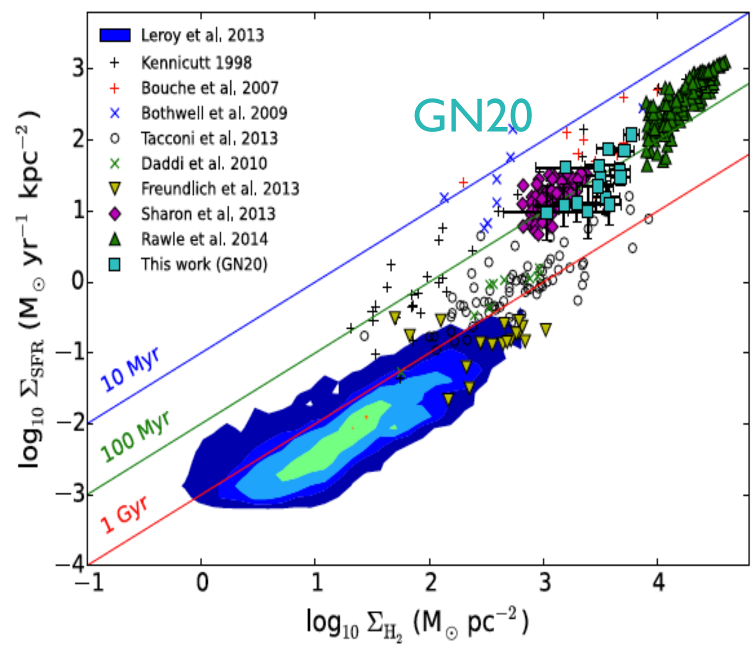
GN20 z=4.0

- CO2-1 at 0.25”
- Resolved gas dynamics
  - ➢ 14kpc rotating disk
  - ➢ $M_{dyn} = 5.4\ 10^{11}\ M_o$
- Resolve SF law





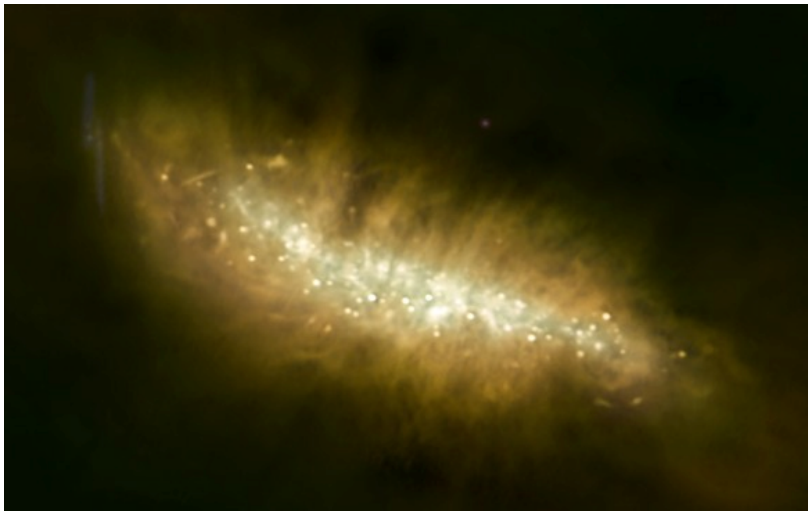
- 120 hours on JVLA
- Few hours on ngVLA

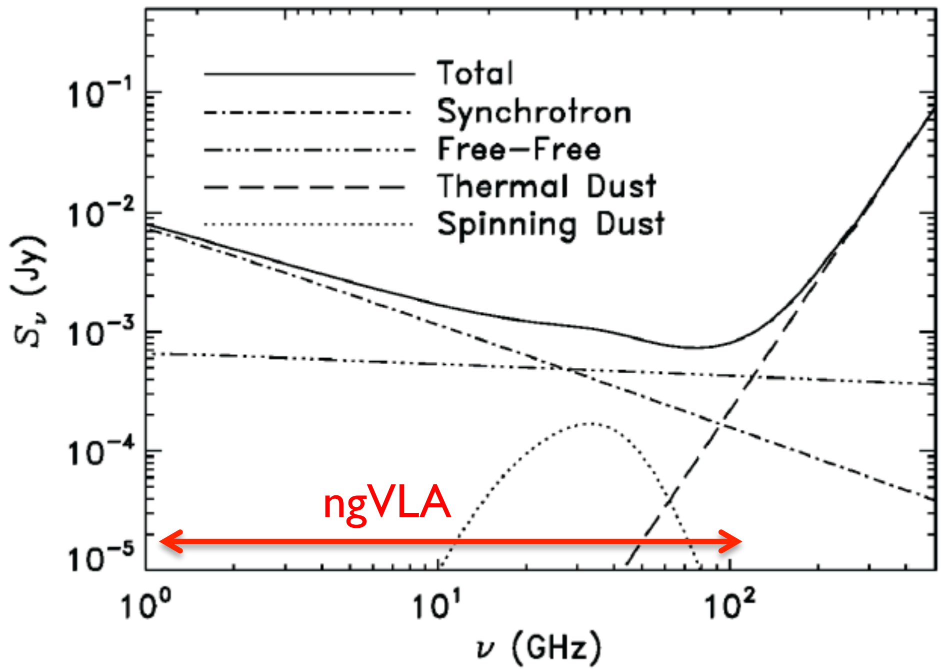


Spatially resolved SF Law

Galaxy eco-systems

Wide field, high res. mapping of Milky Way and nearby Galaxies

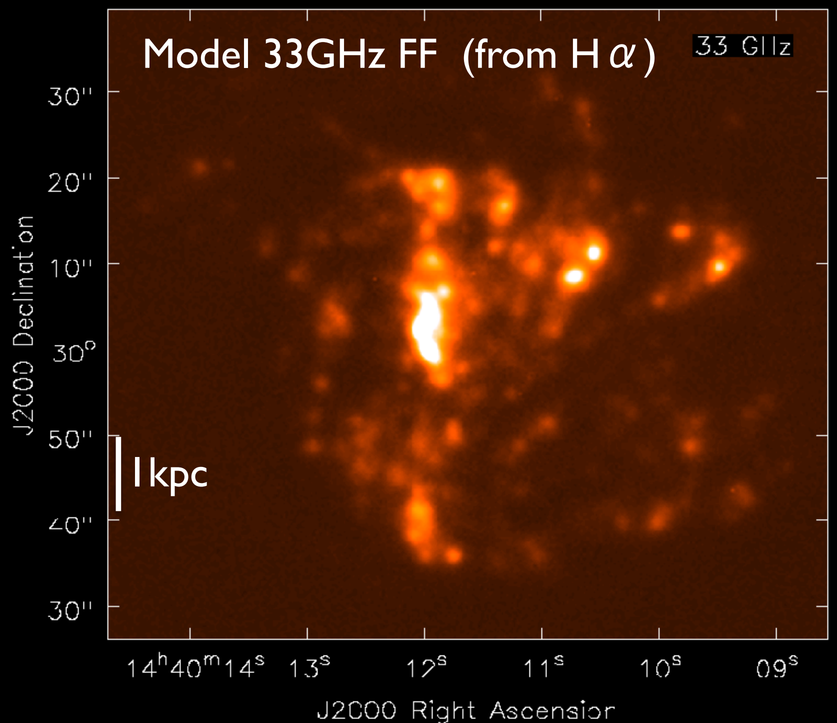


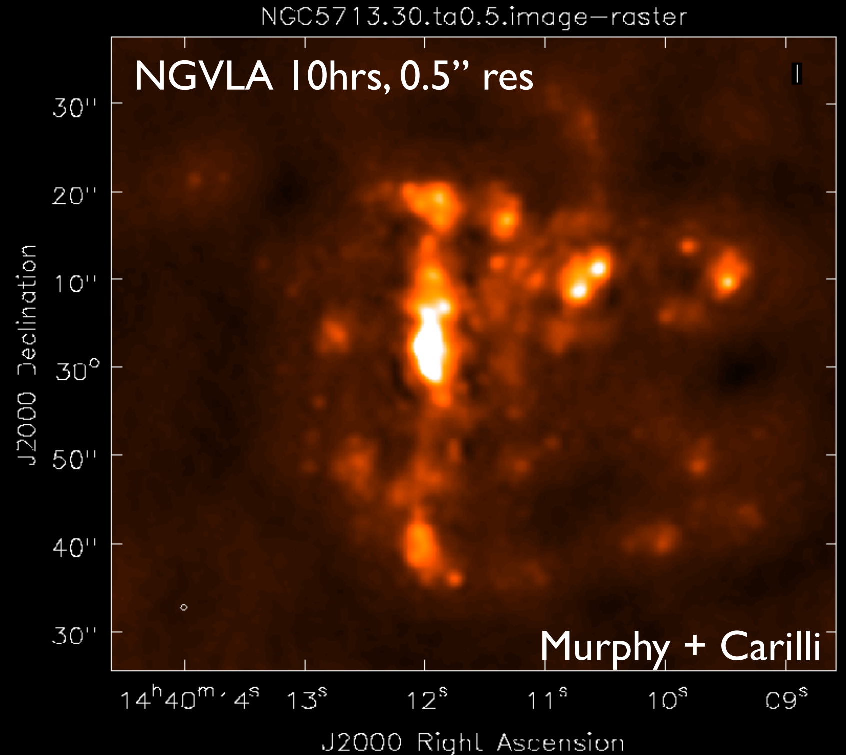


Broad-Band Continuum Imaging

- Cover multiple radio emission mechanisms: synchrotron, free-free, cold (spinning?) dust, SZ effect
- Independent, obscuration free estimates of SFR
- Physics of cosmic rays, ionized gas, dust, and hot gas around galaxies

NGVLA: Free Free emission from peculiar spiral in Virgo

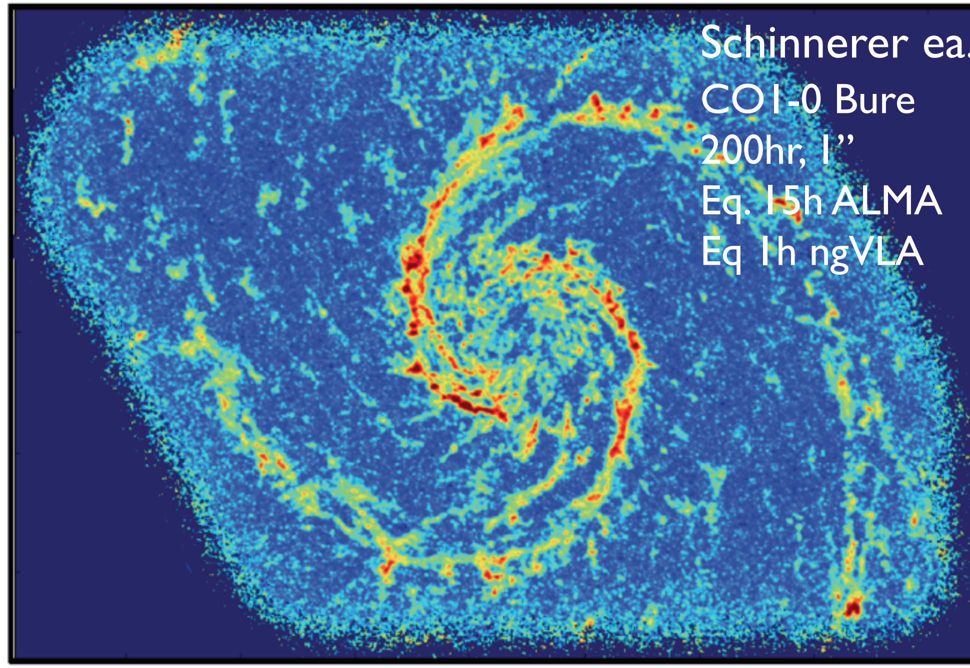


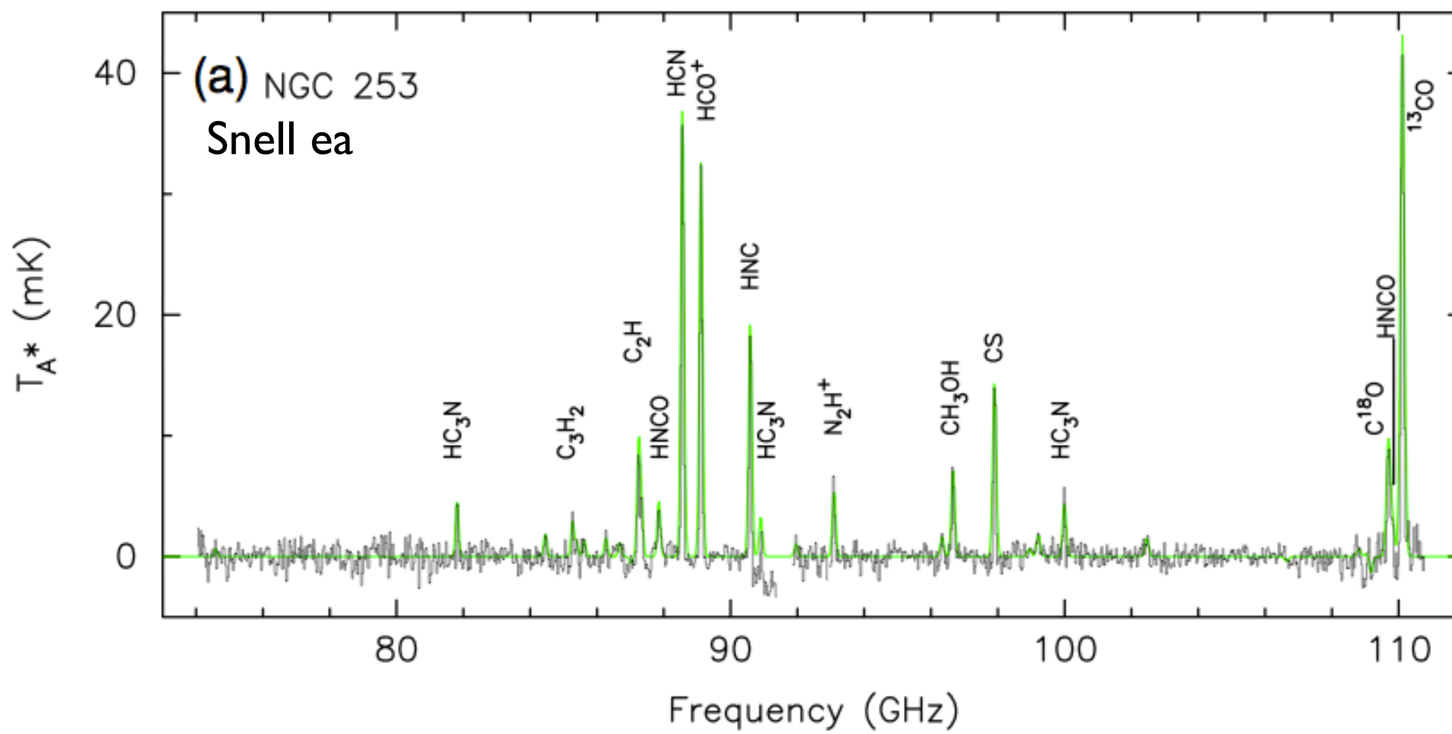


- NGC 5713: distance ~ 30Mpc, total SFR ~ 5 $M_o\ yr^{-1}$
- Free-Free ideal estimator of ionizing photon rate
- Full array point source sensitivity at 1cm, 10hrs is 0.1uJy => *HII region associated single O7.5 main sequence star*
- BW+resolution => spatially/spectrally separate thermal/non-thermal
- Local-group-type studies out to Virgo!

Spectral Line Mapping: Map cool ISM 10x faster than ALMA ('gold mine' A. Leroy)

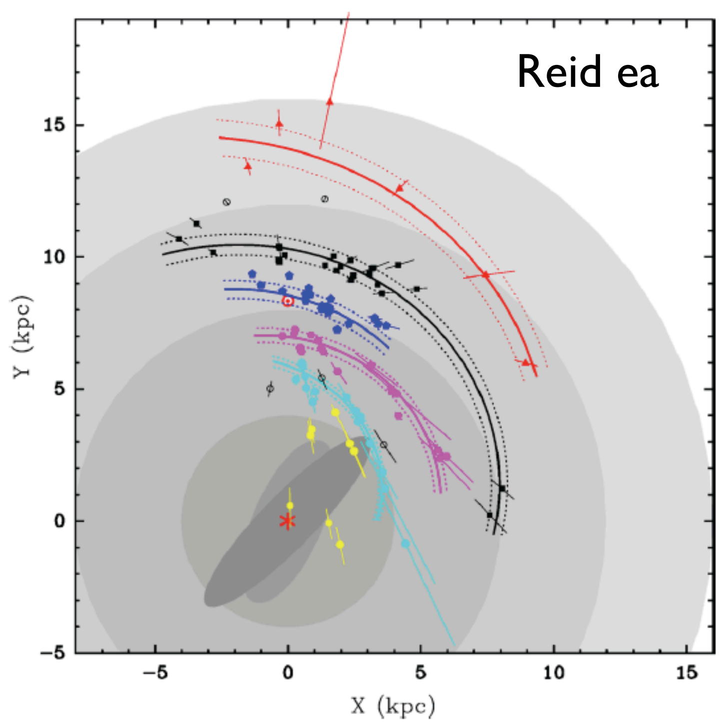
- Rich frequency range: 1st order transitions of major astrochemical, dense gas tracers
- Current CO mapping: tens hours
- Other tracers: 10x fainter => need ngVLA

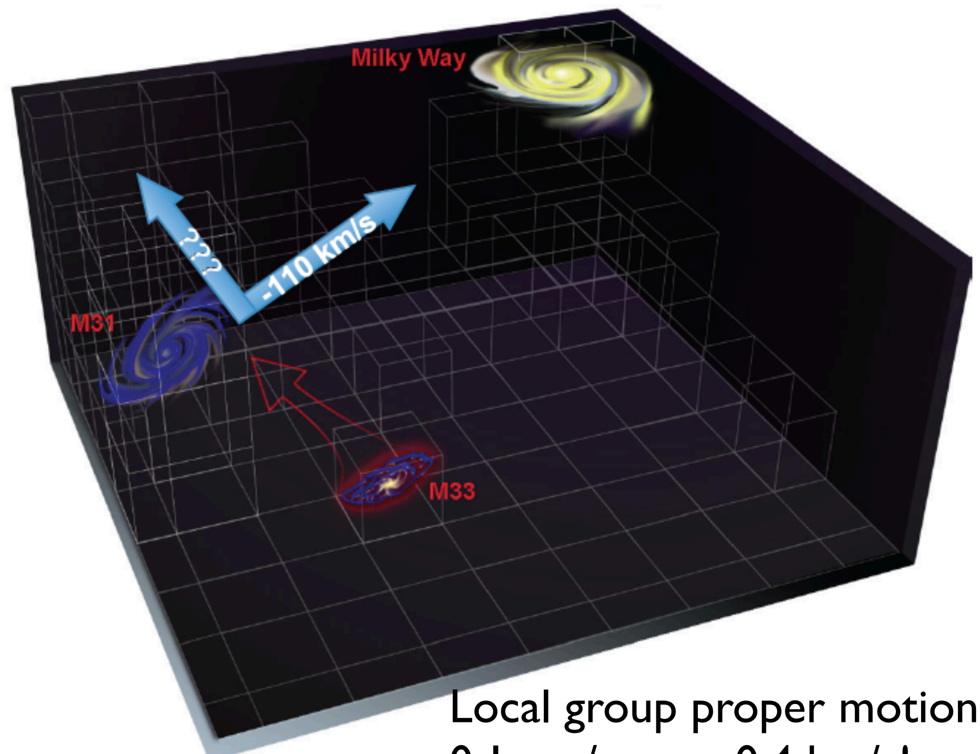




VLBI μas astrometry

- Spiral structure of MW: masers in SF regions to far side of Galaxy
- Local group cosmology: proper motions + parallax w. masers + AGN: 0.1 uas/yr => dark matter, fate MW, real-time cosmology (local Hubble expansion)
- Not DNR limited imaging => include few big antennas ~ 10% area?





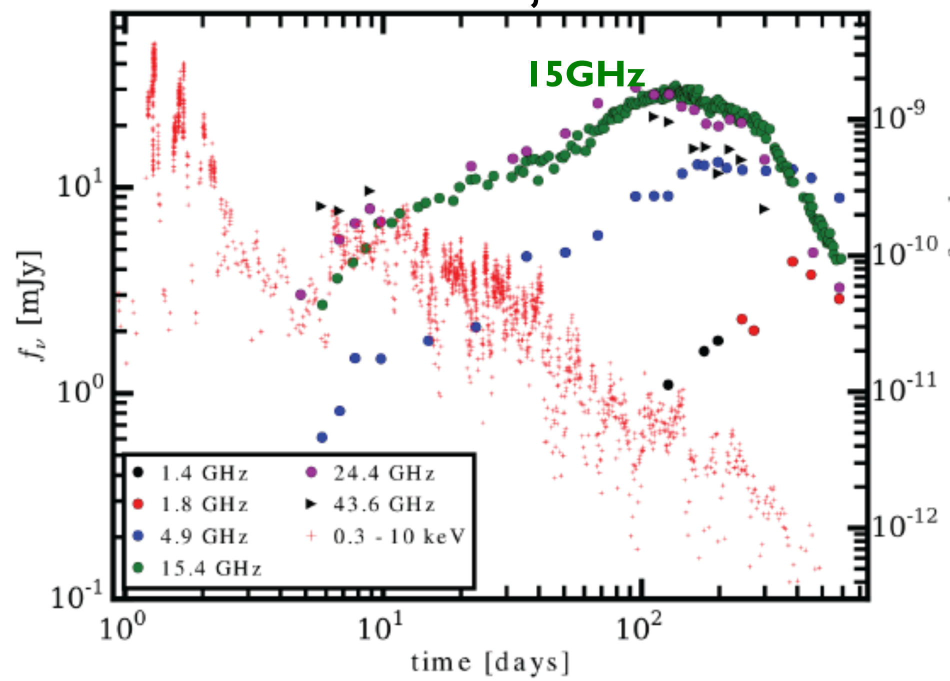
Local group proper motions
0.1 uas/year = 0.4 km/s!
(Darling)

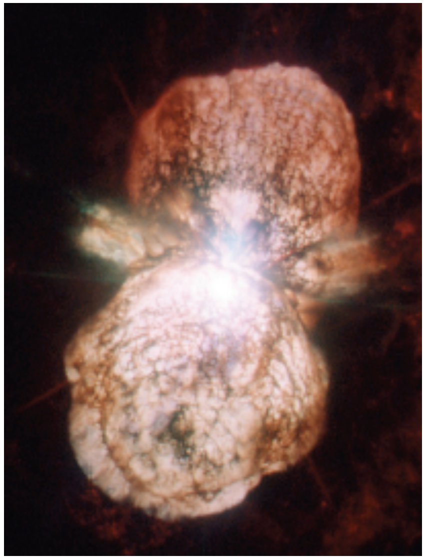
Physics, cosmology, time domain
(Bower et al. SWG4)

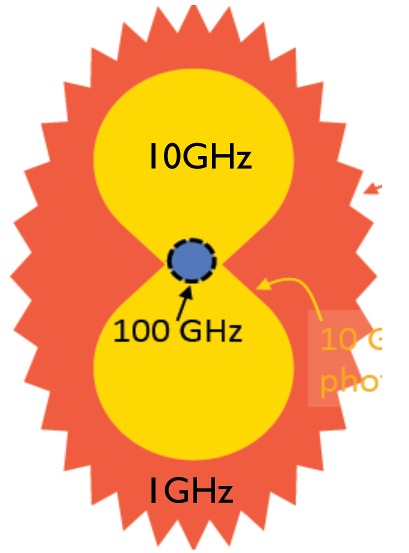
Time domain: bursts brighter and peak earlier at high frequency (0.3cm to 3cm)

- GRB, TDE, FRB
- Novae: ‘peeling onion’
- Radio counterparts to GW events
- Galactic Center Pulsars

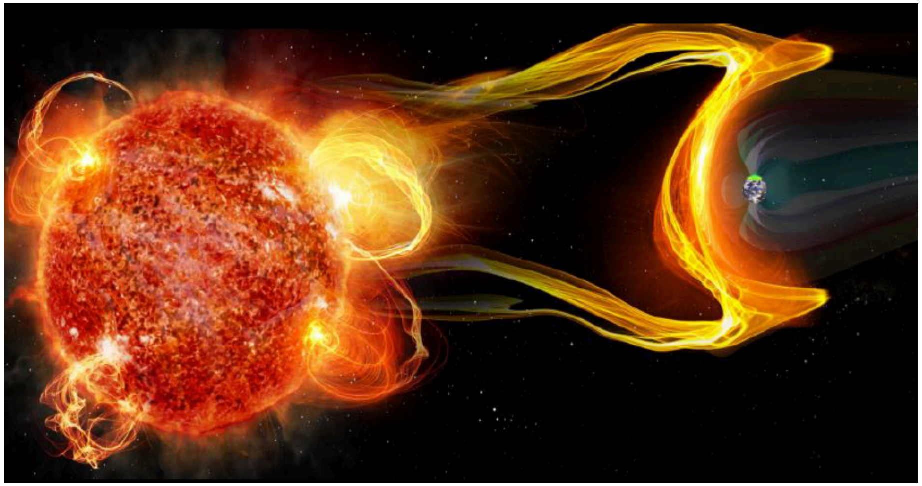
GRB/TDE: late time jet shock

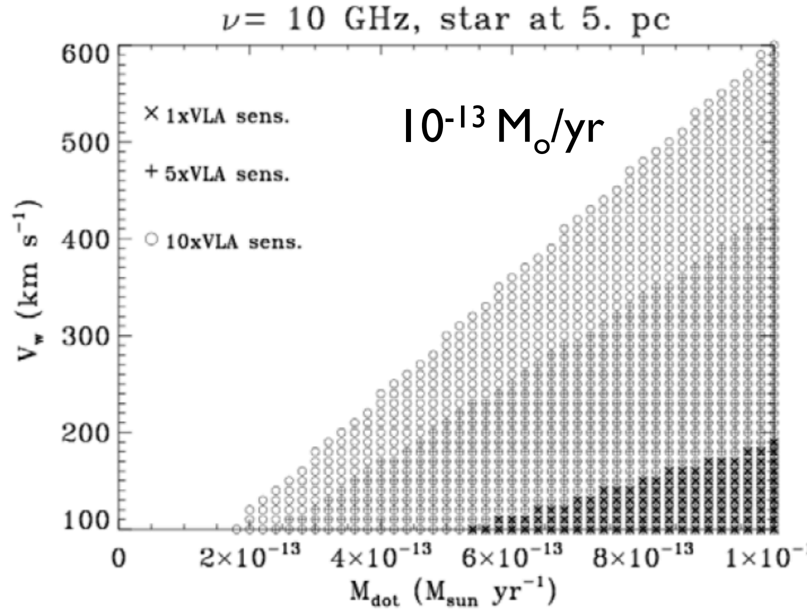




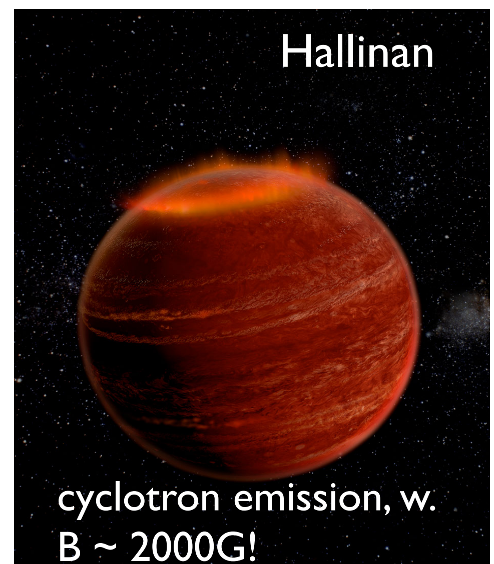


Star – Planet interactions: exo-space weather
NGVLA most sensitive telescope to study broad-band stellar radio phenomena

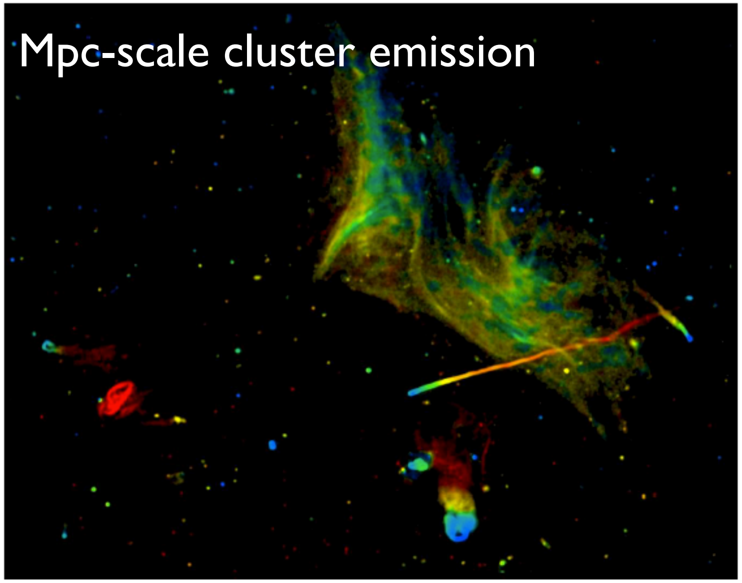


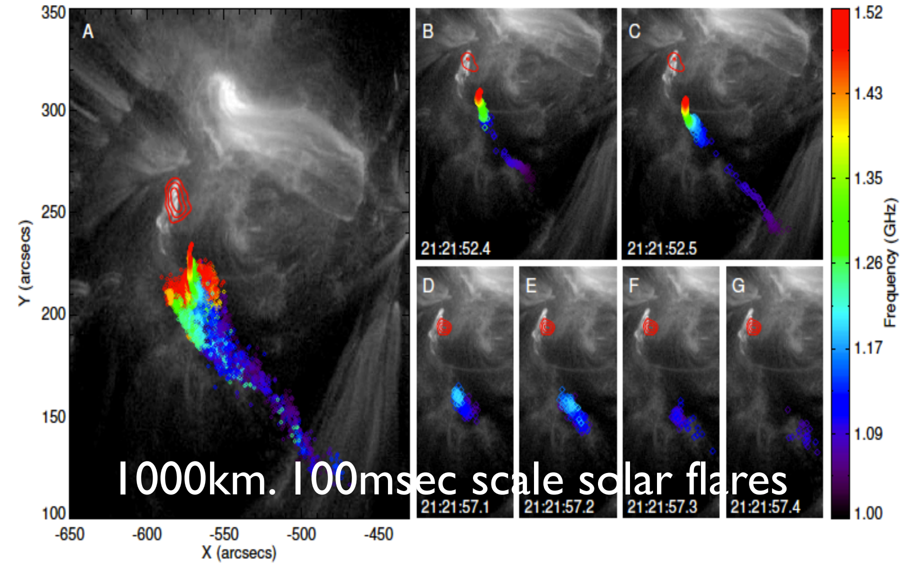


- Thermal stellar winds
    - M dwarfs most likely hosts habitable planets, but very active, flares up to 10^4 x Sun
    - Wind – planet interactions => early evaporation of planetary atmospheres?
- Brown dwarf Auroras! Star-planet magnetospheric interactions
- Key drivers of exo-space weather: dictate exo-planet environments (and the development of life)

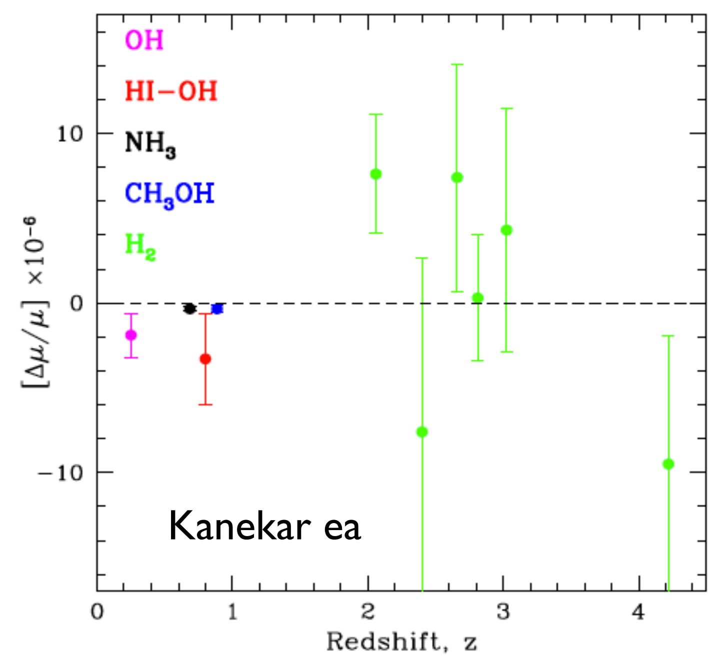


Plasma Universe





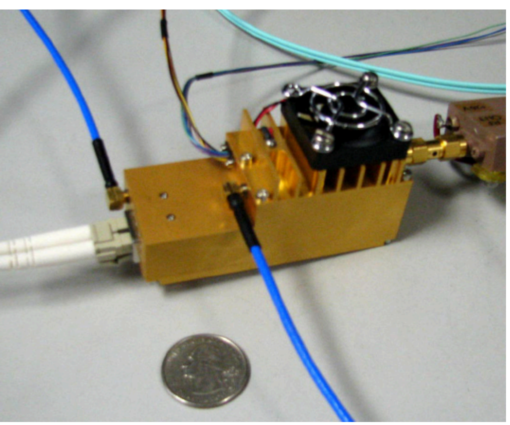
- Magnetic reconnection vs. shock acceleration: broad band phenomena
- S-Z for individual galaxies
  - ➢ ngVLA-short (1cm, 3”, 10hrs) ~ 1μK
  - ➢ nT ~ 10^6 over 10kpc => 20μK
- Evolution of fundamental constants using radio absorption lines: most promising ~ 1cm



Pasadena Technical Meeting (Weinreb)

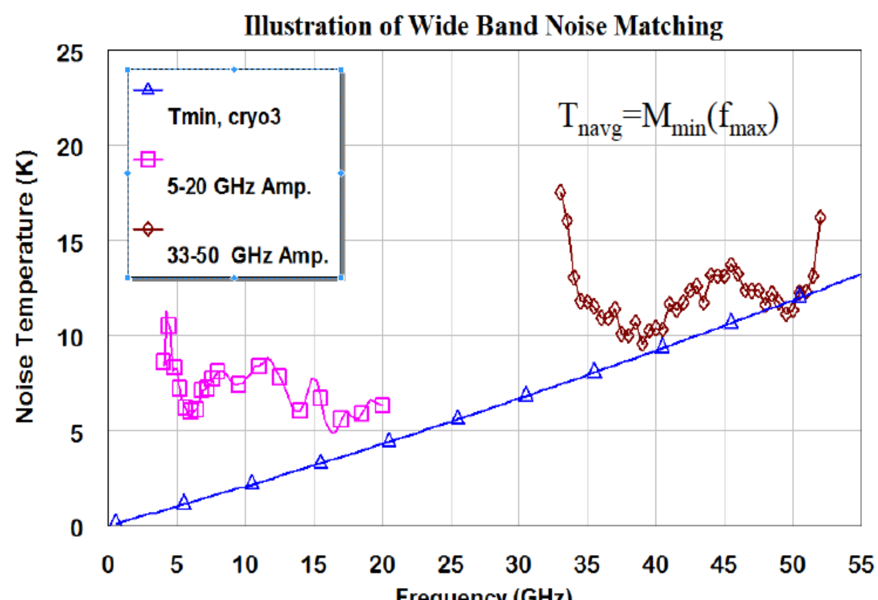
https://safe.nrao.edu/wiki/bin/view/NGVLA/NGVLAWorkshopApril2015

- Antennas (Padin, Napier, Woody, Lamb…)
  - 12m to 25m? 75% eff at 30GHz
  - Offaxis (high/low), symmetric?
  - Hydroform, panel?
  - Reconfigurable?
- Feeds, Receivers (Weinreb, Pospiezalski, Morgan…)
  - 1 – 115GHz: 3 bands? 4 bands? more?
- Correlator: FPGA (Casper), GPU (nVidia), ASIC (JPL), Hybrid (DRAO)



RF/IF Amplification
Filtering
Power leveling
RF-to-baseband conversion
Analog-to-digital conversion
Copper-to-fiber conversion

Morgan mmic: Rack full of warm electronics in your hand



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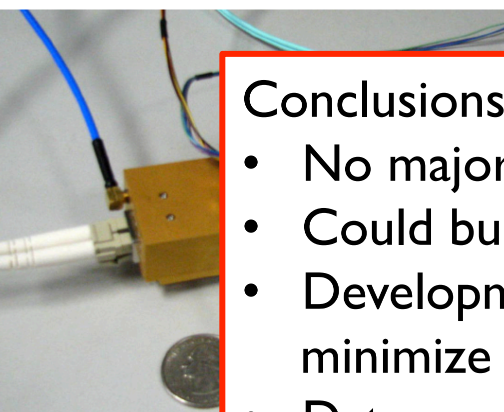

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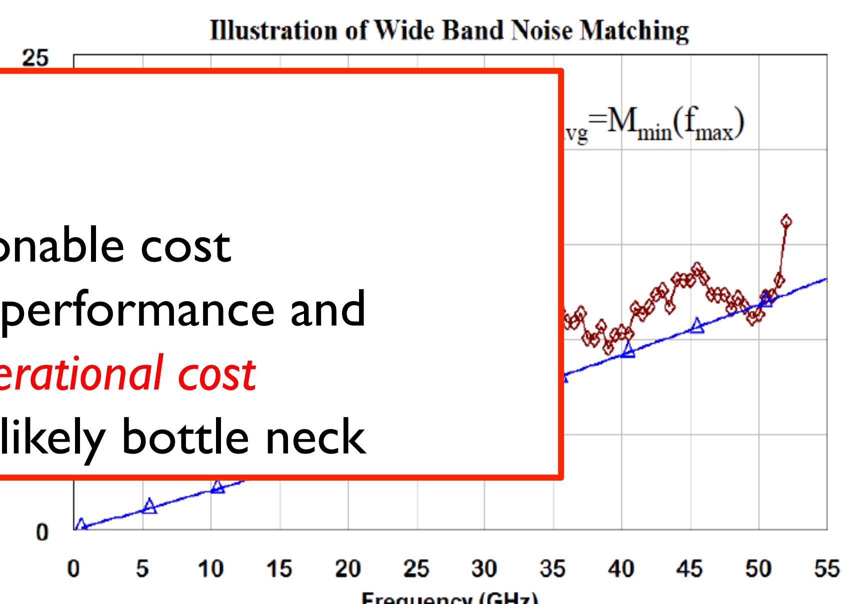


Conclusions

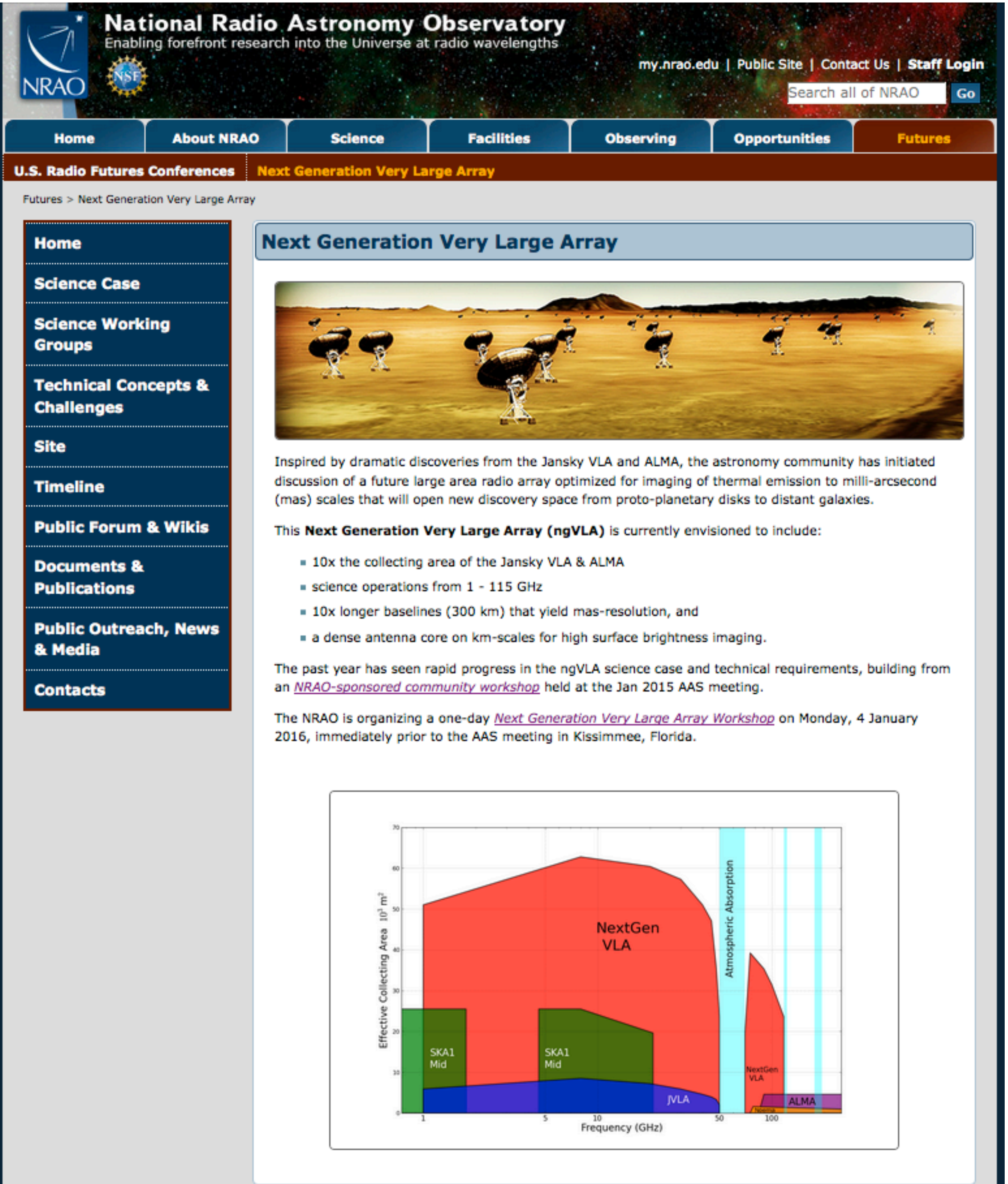
- No major single-point failures
- Could build today for not-unreasonable cost
- Development geared to optimize performance and minimize mass production *and operational cost*
- Data processing for KSP also not likely bottle neck

ngVLA: Next Steps

project manager: Mark McKinnon

- Broad, open community participation beyond the Working Groups
- Setup of a Science Advisory Board/Project Scientist
- Studies of weather impact, array configs, short spacing needs, Rx recommendations, VLBI, calibration strategies, simulations, …
- 2nd technical meeting Dec 8/9 2015 Socorro

  (operations, clock transfer, data transmission, algorithmic work, computing reqs ..)
- AAS meeting full day 4 January 2015 (2/3 science, 1/3 technical implications, with **call for abstracts deadline Nov 22**)
- Large ngVLA science meeting in 2016
- Goal to submit a solid project for the upcoming decadal plan in 2019



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Next Generation Very Large Array

Inspired by dramatic discoveries from the Jansky VLA and ALMA, the astronomy community has initiated discussion of a future large area radio array optimized for imaging of thermal emission to milli-arcsecond (mas) scales that will open new discovery space from proto-planetary disks to distant galaxies.

This **Next Generation Very Large Array (ngVLA)** is currently envisioned to include:

- 10x the collecting area of the Jansky VLA & ALMA
- science operations from 1 - 115 GHz
- 10x longer baselines (300 km) that yield mas-resolution, and
- a dense antenna core on km-scales for high surface brightness imaging.

The past year has seen rapid progress in the ngVLA science case and technical requirements, building from an *NRAO-sponsored community workshop* held at the Jan 2015 AAS meeting.

The NRAO is organizing a one-day *Next Generation Very Large Array Workshop* on Monday, 4 January 2016, immediately prior to the AAS meeting in Kissimmee, Florida.

ngVLA home page:

https://science.nrao.edu/futures/ngvla

Links to

ngVLA forum

WG wikis

ngVLA memo series:

Project overview and working group white papers