NEXT GENERATION – RADIO ASTRONOMY PROJECT –

VERY LARGE MILLIMETER/ SUBMILLIMETER ARRAY (VLMSA)

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Introduction

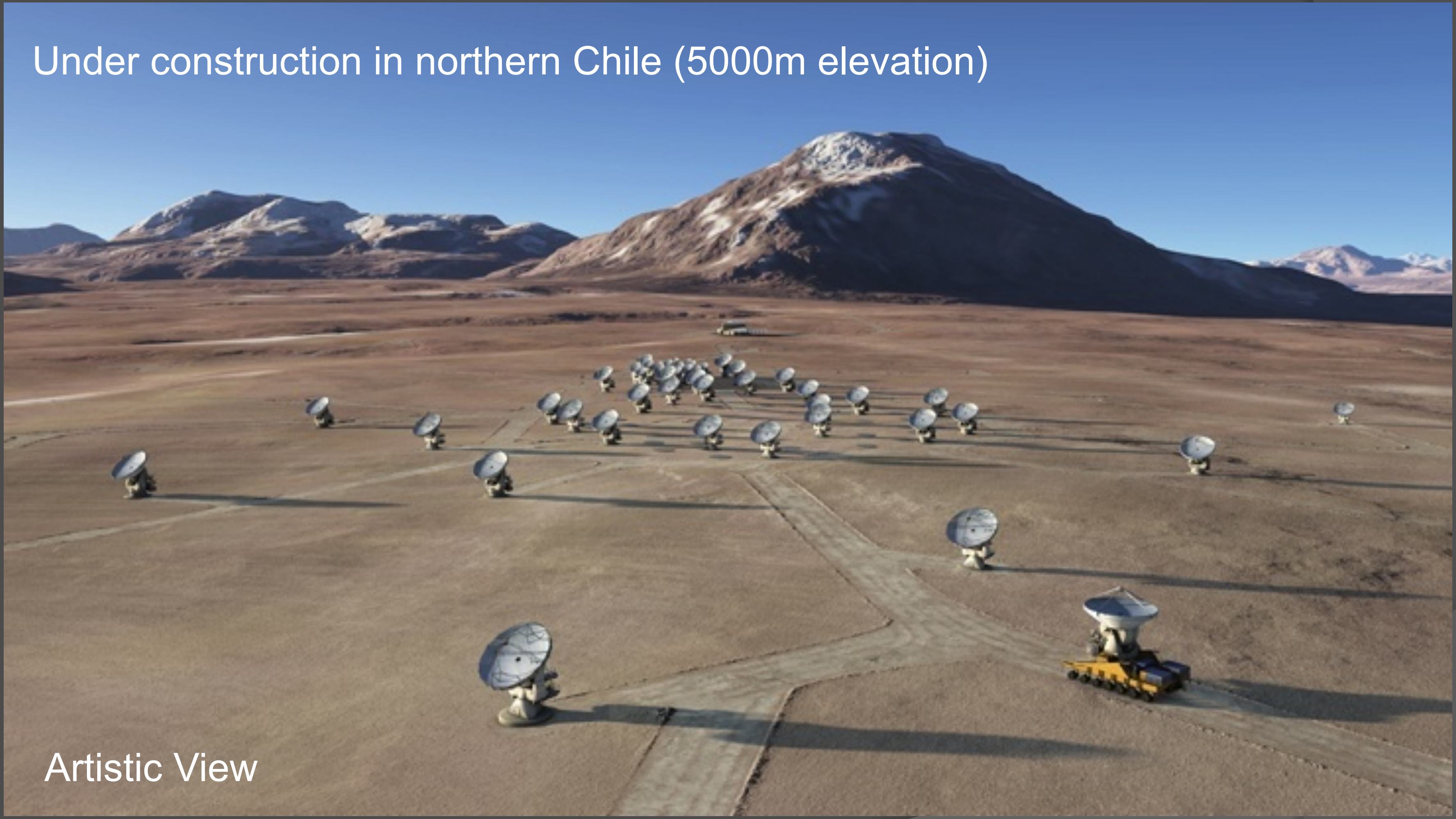
- ALMA (Atacama Large Millimeter/ submillimeter array)
  - High sensitivity (μJy) and resolution (0”.01)

Antennas	12m x 50	12m x 4 + 7m x 12
Resolution	0".01 - 10"	
Frequency	31-950 GHz	
Correlator	4 kHz	0.012 km/s at 100 GHz
Bandwidth	16 GHz	

Early Universe, Protoplanetary disks, and New Molecules

Even direct detection of nearby giant planets!

ALMA



Under construction in northern Chile (5000m elevation)
Artistic View

WHAT’S NEXT?

What telescope is desired in 2030?

Big leap between now and 2030 in science and technology.

Kick-off Meeting for Next-generation Radio astronomy

- On March 4, 2009, a private working group (WG) for the next-generation radio astronomy was launched at NAOJ.
  - The WG members included: Eiichiro Kokubo (NAOJ/theoretical); Kotaro Kohno (Univ. of Tokyo); **Masao Saito** (NAOJ, radio); **Munetake Momose** (Ibaraki Univ.); Naoki Yoshida (Univ. of Tokyo, IPMU); **Satoru Iguchi** (NAOJ, radio); Seiji Kameno (Kagoshima Univ.); Shogo Tachibana (Tokyo Univ., Frontier); Yasuhiro Murata (JAXA); Yuri Aikawa (Kobe Univ.); Yutaro Sekimoto (NAOJ, Advanced Technology Center). Wishing to achieve big scientific goal and give people a dream, the members discussed the concept and technical requirements of the next-generation telescope so that it could cover a wide range of research themes such as the origin of life, planets, and the universe.

Astronomy in 2030

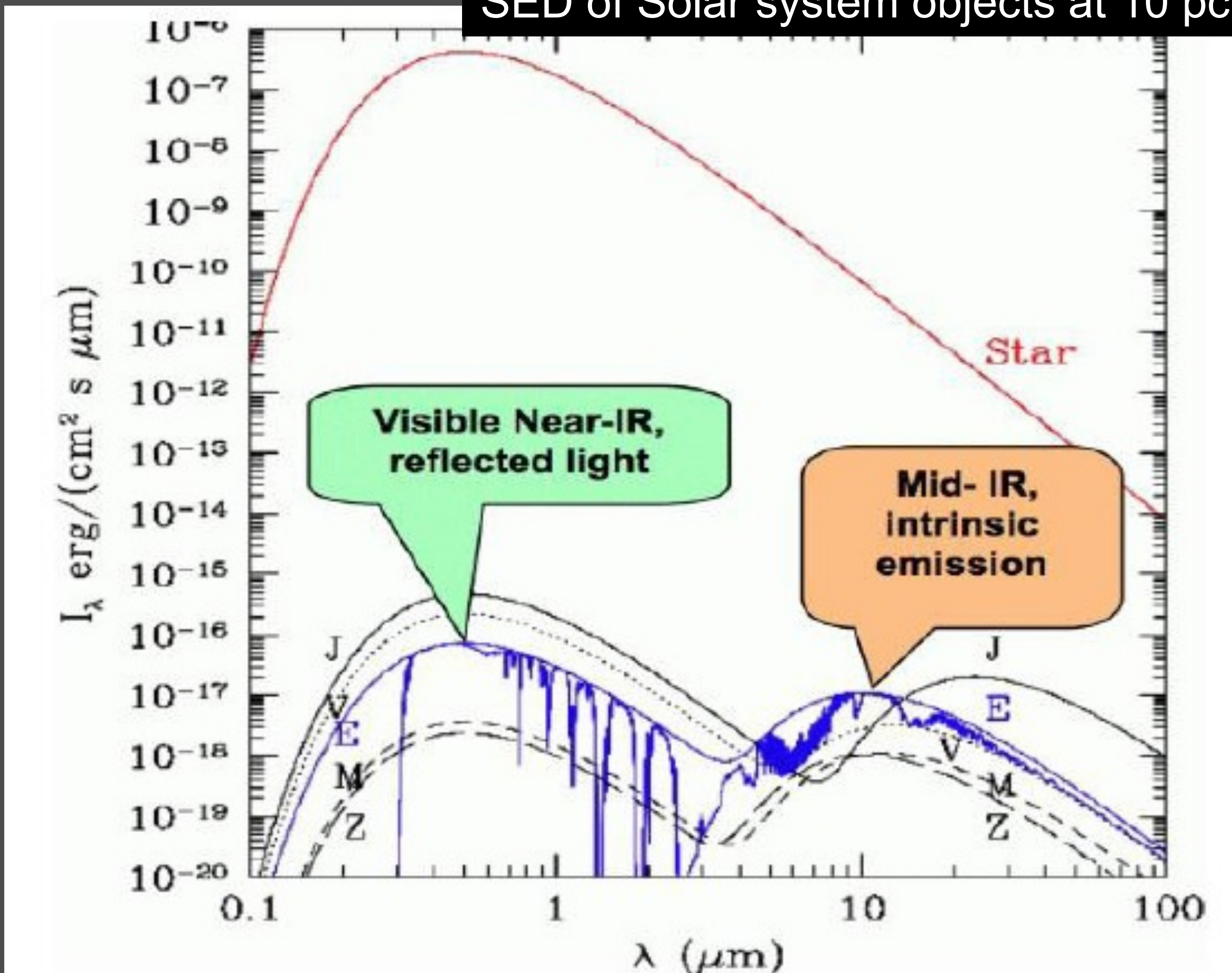
- Beginning of Universe
- Dark matter/energy
- Galaxy formation
- Black holes
- Star/Planet formation
- Life

- Telescope
- Detector
- Transmission
- Control
- Analysis software
- Virtual observatory

Direct Detection and imaging of 2nd Earth is a way to go!

Direct Detection of Exoplanets

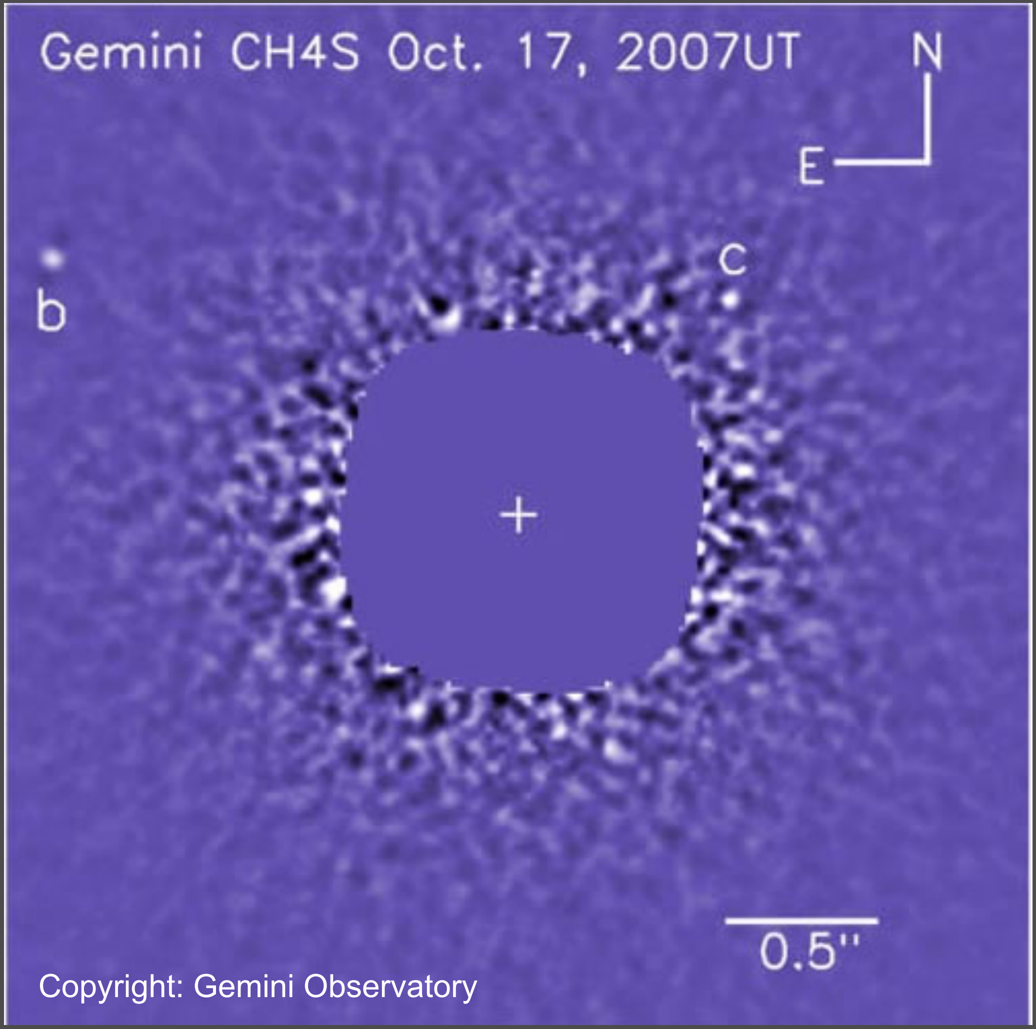
SED of Solar system objects at 10 pc distance



Brightness contrast of 10^9 at optical and 10^6 at FIR or Radio regime

In addition to Sensitivity and Resolution, High dynamic range imaging method is necessary.

Direct detection of Jovian Planets



C. Marois et al. 2008, Science

2nd Earth

- Detection and Imaging of Earth-like Planets (2nd Earth)
  - Main goal of next generation project
  - We have to find planets where we can migrate. Not Habitable planets, we need *“Migratable”* planets in the far future.

Past Initial Studies

- With this research, we aim not only to achieve mere scientific results but also change the paradigm in the way people see the world.
  - 2012.07.02 SPIE in Amsterdam
  - 2011.12.16 Japan Radio Astronomy Forum Symposium at the University of Tokyo
  - 2011.11.26-27 4th Astrobiology Workshop at Kobe University
  - 2010.09.26 AP-RASC 2010 in Toyama
  - 2009.09.25 Japan Radio Astronomy Forum Symposium at the University of Tokyo
  - 2009.07.04 Past Quarter Century of Nobeyama Radio Observatory and Future of Radio Astronomy at the NAOJ Mitaka campus
  - 2009.03.04 Kick-off Meeting for Next-generation submillimeter astronomy

Feasible Studies

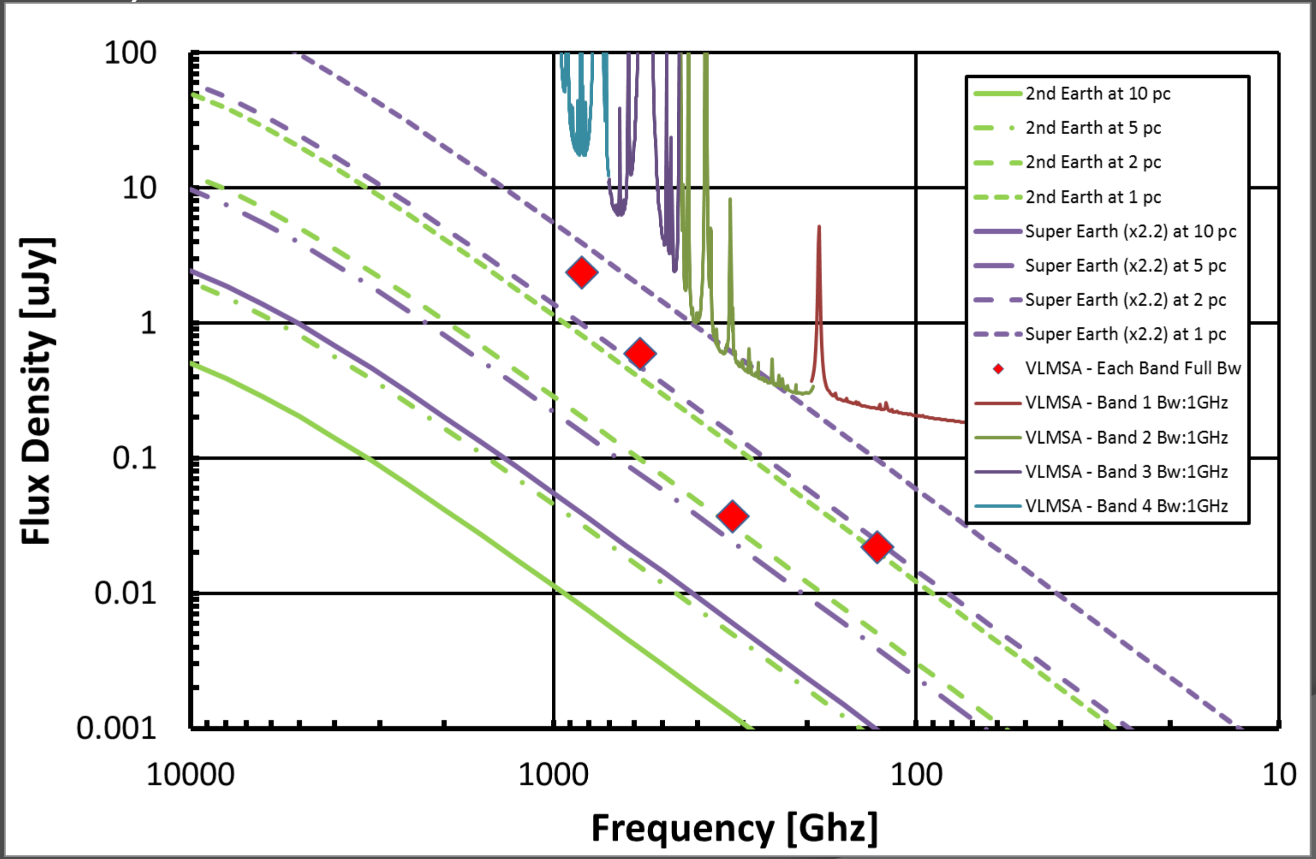
Confusion limit v.s. Minimum detectable temperature due to the angular resolution and sensitivity

Major Specification of VLMSA

Antennas	50m x 64
Surface	25 μm
Max Baseline	up to 3000 km
RF and IF Freq	64 GHz to 960 GHz
Band 1:	64-192 GHz
Band 2:	192-448 GHz
Band 3:	448-704 GHz
Band 4:	704-960 GHz
Receiver Temp	½ x ALMA and Dual

Detailed Analysis of VLMSA

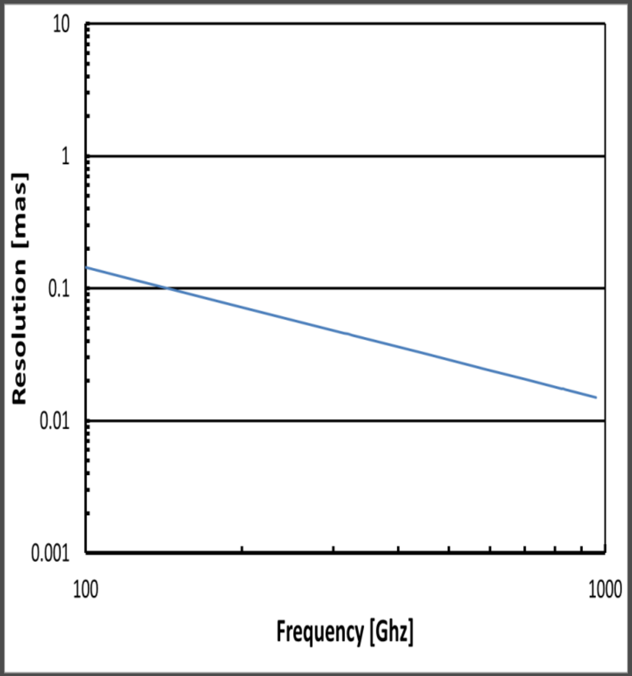
- *Reflected the ALMA-site atmospheric performance (1GHz step resolution) to sensitivities of VLMSA.*

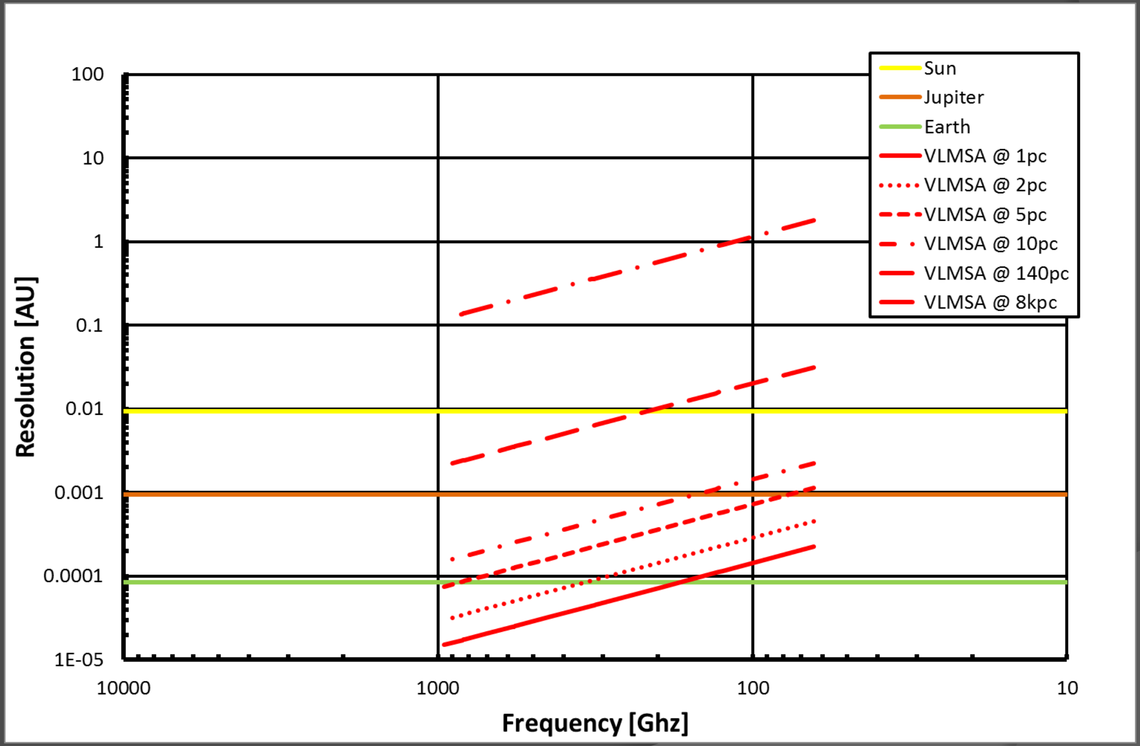


Direct Detection of 2nd Earth at 2 pc and Super Earth at 4 pc within 24 hr observations

Detailed Analysis of VLMSA

- *Reflected the ALMA-site atmospheric performance (1GHz step resolution) to resolution of VLMSA at maximum baseline of 3000 km.*





More Feasible Studies

- Comparison (in heterodyne)
  - Enhanced ALMA:
    - New 4 bands; 66 -> 80 Ant, BW 16GHz -> 256 GHz, Half Trx, Baseline 300 km
  - Ground VLMSA:
    - New 4 bands; 50 m(25μm) x 64 antennas, BW 256 GHz, Half Trx, Dual Pol., Baseline 3000 km
  - Space VLMSA:
    - Up to 2 THz; 25 m(16μm) x 64 antennas, BW 256 GHz, Half Trx, Dual Pol., Baseline 3000 km, LO stability of 10 times better
  - Space Direct Interferometer
    - 1-10 TH; 3.5 m x 5 satellite

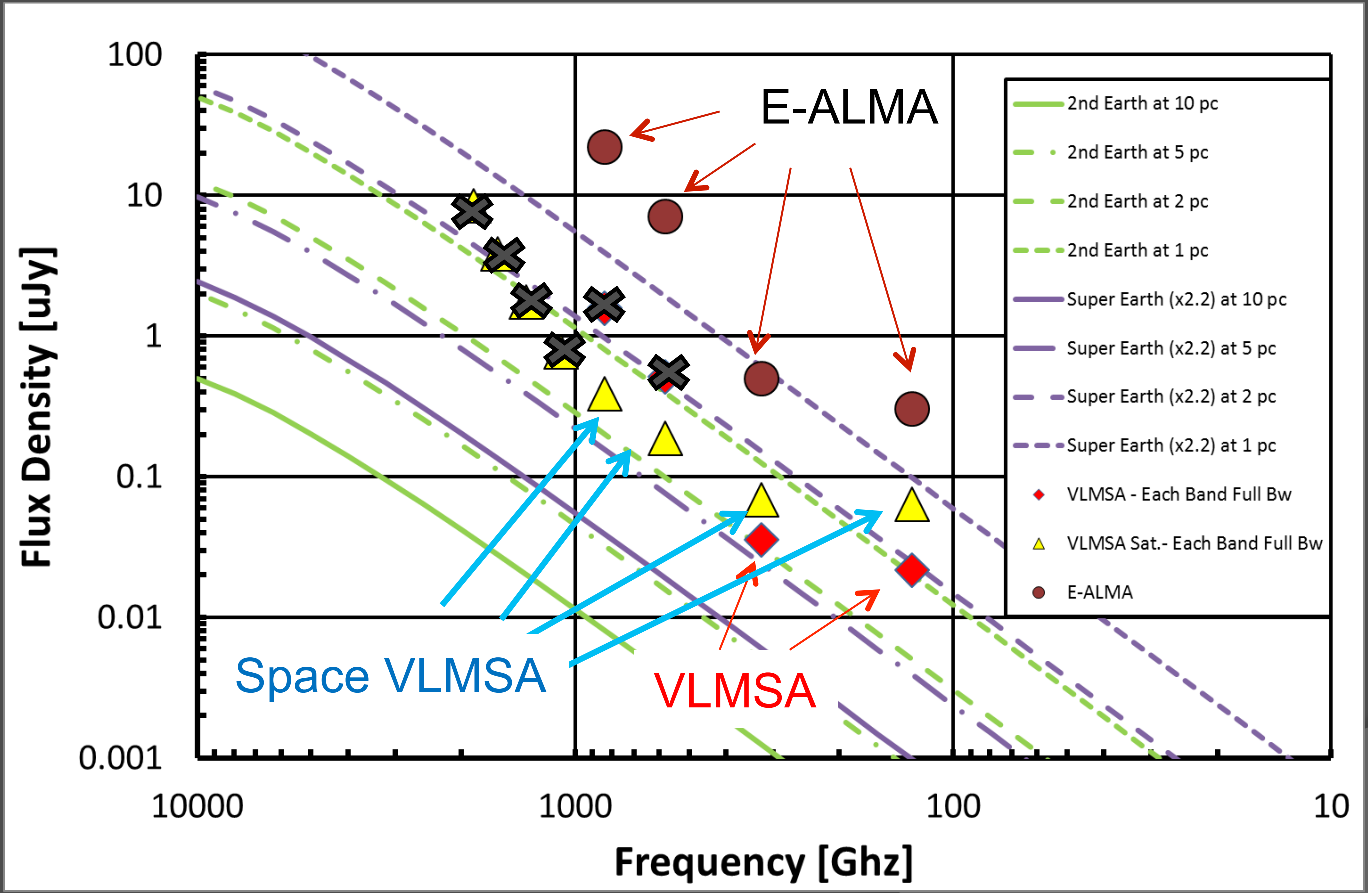
More Feasible Studies

- Comparison between Ground and Space
  - Space VLMSA:
    - 25 m(16μm) x 64 antennas, BW 256 GHz, Half Trx, Dual Pol., Baseline 3000 km, LO stability 10 times better
    - RF and IF Freq 64 GHz to 960 GHz SSB Trx

Band 1:	64-192 GHz	hv=2.5
Band 2:	192-448 GHz	hv=2.5
Band 3:	448-704 GHz	hv=4.0
Band 4:	704-960 GHz	hv=5.0
Band 5:	960-1216 GHz	hv=6.0
Band 6:	1216-1472 GHz	hv=8.0
Band 7:	1472-1728 GHz	hv=10.0
Band 8:	1728-1984 GHz	hv=12.0

More detailed Analysis of VLMSA

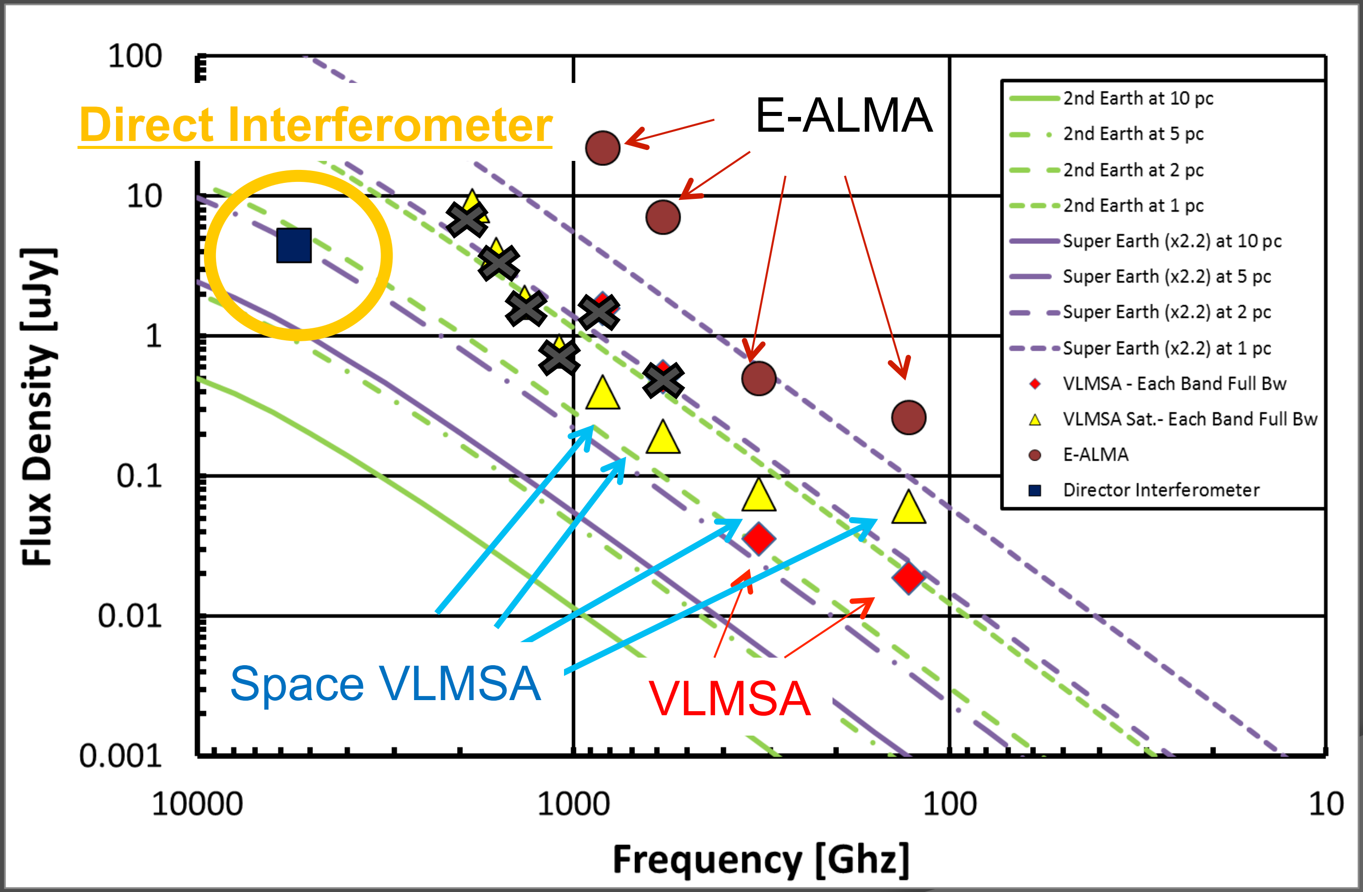
- *Comparison between Ground and Space*



Note: Cross mark means that minimum detectable temperature is higher than 300k!

More detailed Analysis of VLMSA

- *Comparison between Ground and Space*



Note: Cross mark means that minimum detectable temperature is higher than 300k!

Possibilities for Direct Detection of 2nd Earth

- What is reasonable??
  - *Enhanced ALMA:*
    - Yes Super Earth within 1 pc; *Technical feasibility : yes;*
    - Cost : 20 x 14 ants + 5 x 80 + 100 = 780 MUSD
  - Ground VLMSA
    - Yes 2nd Earth within 2 pc and Super Earth (*D*x2.2) within 5 pc; Technical feasibility: maybe Yes;
    - Cost: 100 x 64 ants + 1000 = 7,400 MUSD
  - *Space VLMSA*
    - Yes 2nd Earth within 2 pc and Super Earth (*D*x2.2) within 5 pc; *Technical feasibility: no;*
    - *Cost : 500 x 64 ants + 1000 = ~~33,000~~ MUSD*
  - Direct Interferometer
    - Yes!; But, baseline up to 900 km; Technical feasibility: no;
    - Cost: 1500 x 5 sat. + 1000 = 8,500 MUSD

Science Goal of ground VLMSA

- Direct Detection of 2nd Earth at up to 2 pc and Super Earth (*D*x2.2) at up to 5 pc within 24 hr observations
- Direct Imaging of 2^{nd} Earth and Super Earth at up to 2 pc
- Clear Image of a black hole with an accretion disk in the active central region of Sagittarius A and M87
- Astrometry of stars like the Sun at a distance within 1 kpc

Technology Development

- Antenna
  - Large steerable antennas with high pointing accuracy and high surface performance.
- Receiver
  - Noise level down to extreme.
- Backend
  - Wideband with good phase stability
- Correlator
  - High capability of handling large amount of data

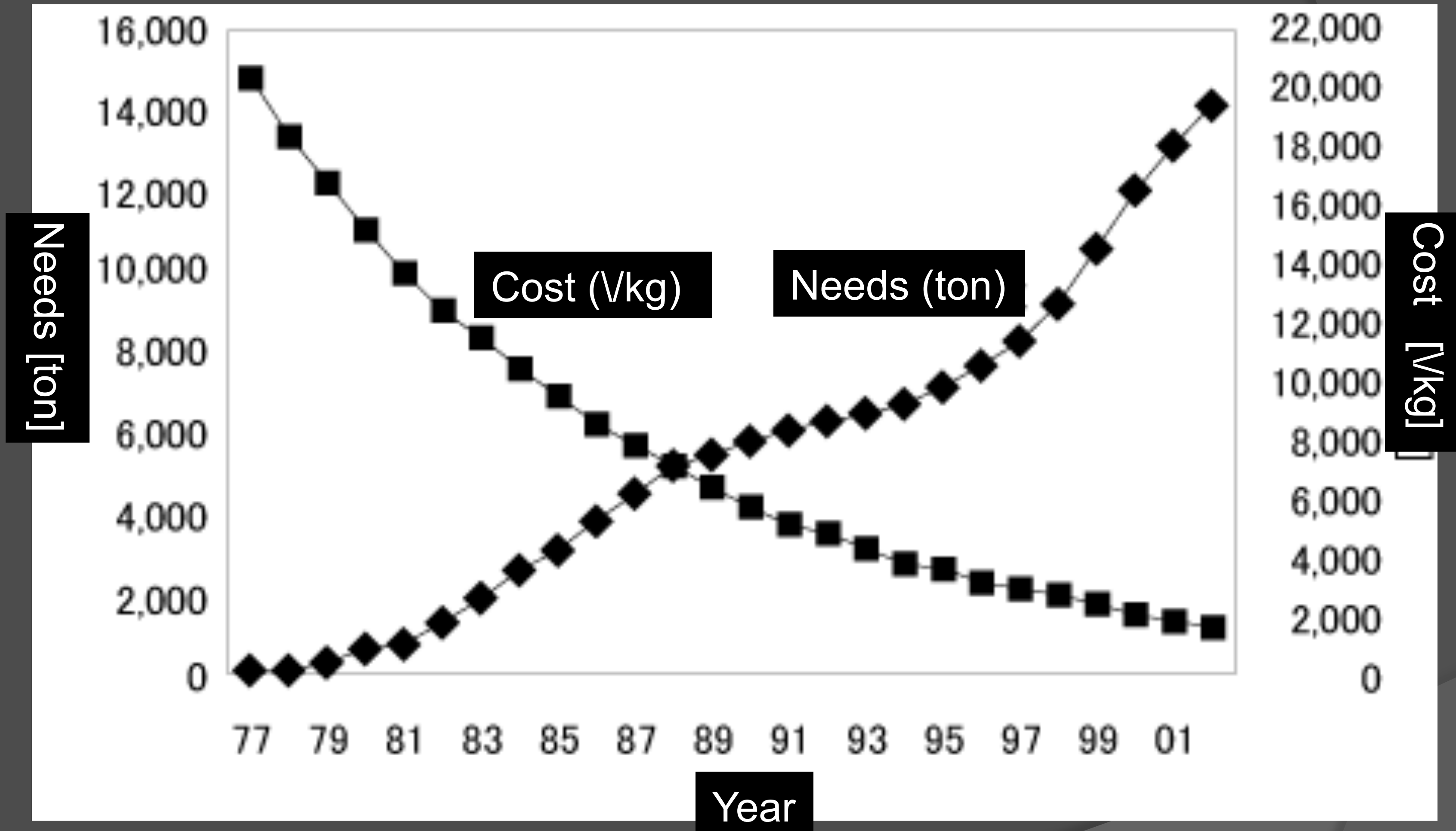
Innovative Developments

- Receiver technology
  - Transistor: 1956 Nobel Prize - W.B. Shockley Jr
  - Integrated Circuit: 2000 Nobel Prize - J. C. Kilby
  - Superconductive Transistor and Itegrated Circuit!!!
- Interferometry
  - Aperture Synthesis: 1974 Nobel Prize – M. Ryle
  - Ion Laser: 2012 Nobel Prize – D. H. Wineland
  - ???

Cost Issues

- Construction cost
  - Innovative way to construct antennas
  - Optical telescopes have been trough a big cost reduction with multi-segment mirror technology.
  - Material revolution
  - Superconductive Transistor
- Operation cost
  - Simple cryogenic system
  - HEMT amplifier technology
  - Reliability and Easy Maintenance

CFRP cost



Cost of PAN Carbon Fiber

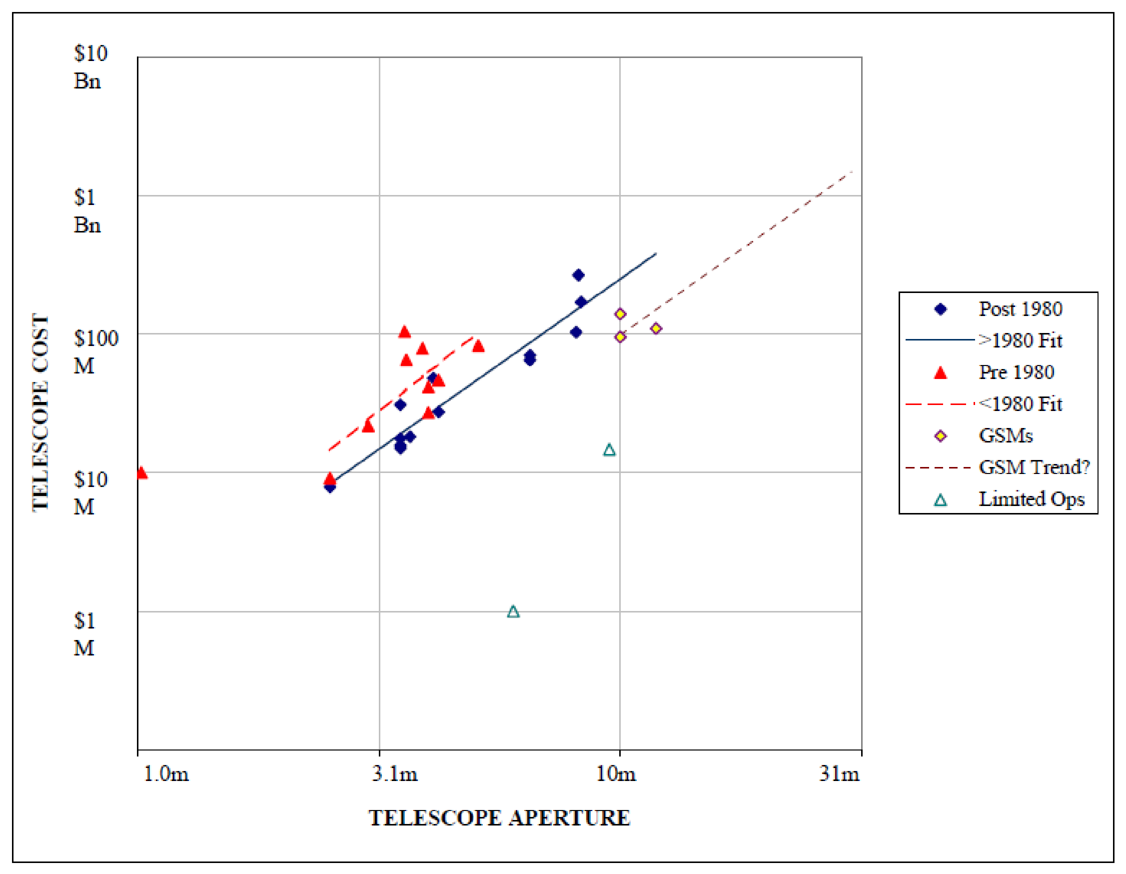
Our Challenge Continues

Summary

- We propose a next generation array, “Very Large Millimeter/Submillimeter Array”
- Scientific Goals
  - Direct Detection of 2nd Earth at up to 2 pc and Super Earth at up to 4 pc within 24 hr observations
  - Direct Imaging of 2nd Earth and Super Earth up to 2 pc
  - Clear imaging of a black hole
  - High precision of astrometry
- Specification
  - 50m x 64 antennas, 256-GHz bandwidth, Dual Pol.

Technically challenging, but it’s worth!

Cost of Optical Telescopes



Diameter-cost relation before and after 1980 (van Belle et al. 2004)