Star and Planet Formation with the *Next Generation* VLA

“Technology Concepts for a ngVLA”, Pasadena, CA

Laura Pérez

Jansky Fellow @ VLA, NRAO

With support from:
A. Isella,
M. Hughes,
C. Carilli

Collaborators and Contributors

"Cradle of Life" Science Working Group @ ngVLA

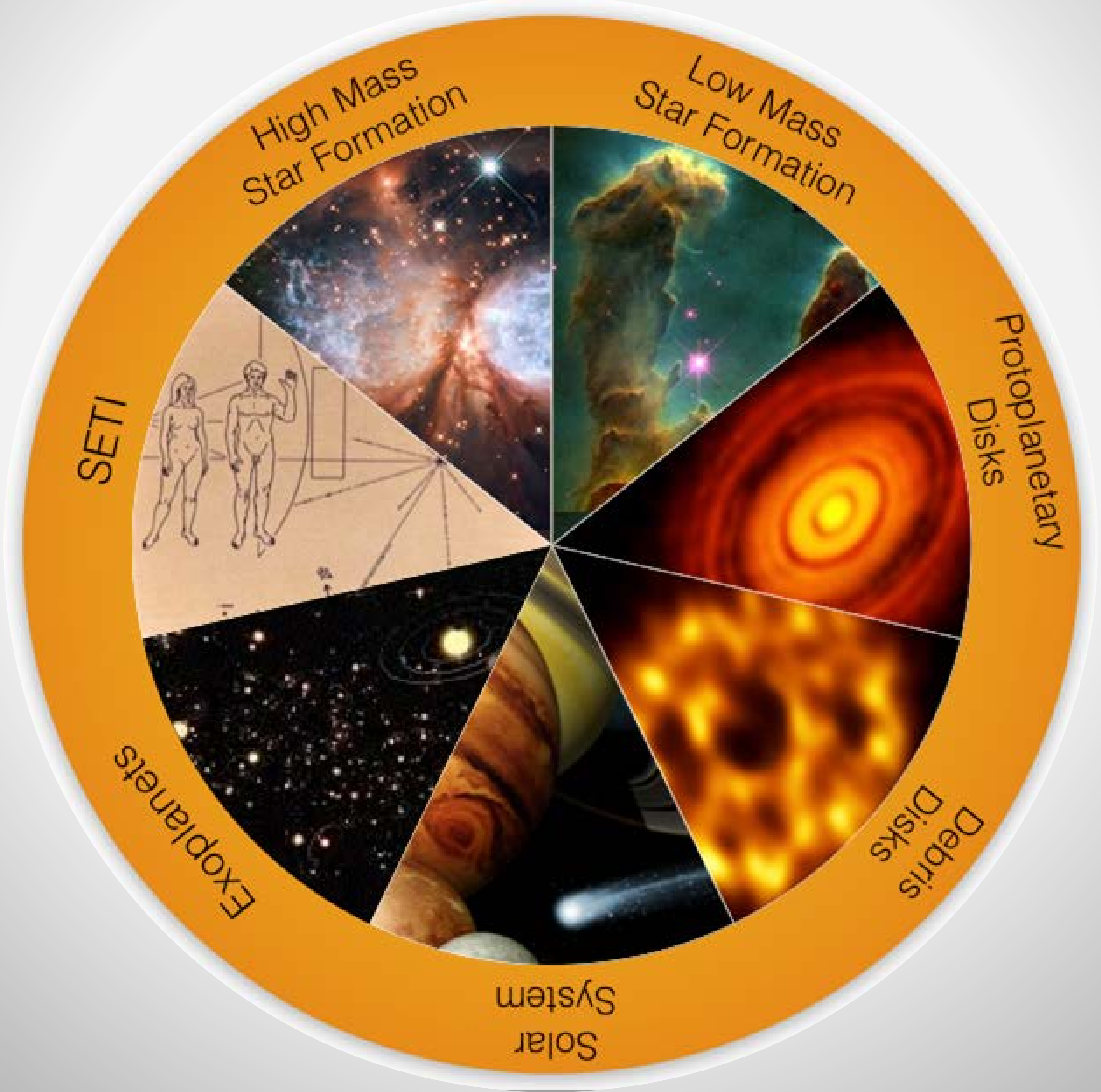
David Alexander
Sean Andrews
Henrik Beuther
Maite Beltran
Ted Bergin
Geoff Blake
Tyler Bourke
Crystal Brogan
Bryan Butler
Paola Caselli
John Carpenter
Claire Chandler
James di Francesco
Roberto Galvan-Madrid
Adam Ginsburg

Thomas Henning
Mark Hofstadter
Meredith Hughes
Chat Hull
Andrea Isella
Doug Johnstone
Joseph Lazio
Hauyu Baobab Liu
Laurent Loinard
Steve Longmore
Betsy Mills
John Monnier
Raphael Moreno
Arielle Moullet
Karin Öberg

Imke de Pater
Laura Pérez
Charlie Qi
Luca Ricci
Alvaro Sanchez-Monge
Peter Schilke
Andrew Siemion
Leonardo Testi
John Tobin
Jonathan Williams
David Wilner
Mark Wyatt
Qizhou Zhang

Areas of Interest

"Cradle of Life" Science Working Group @ ngVLA



Credit: A. Isella

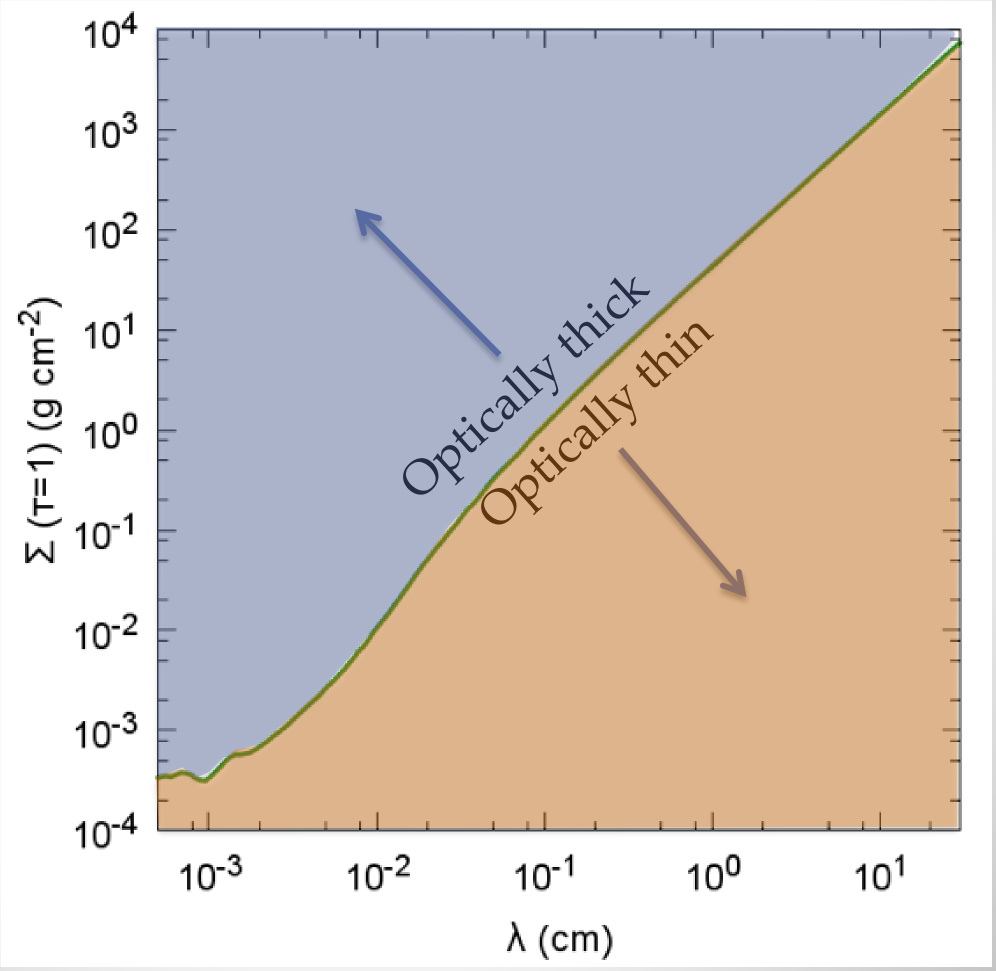
What do these areas of interest have in common?

They are *dusty* environments!

What do these areas of interest have in common?

They are dusty environments!

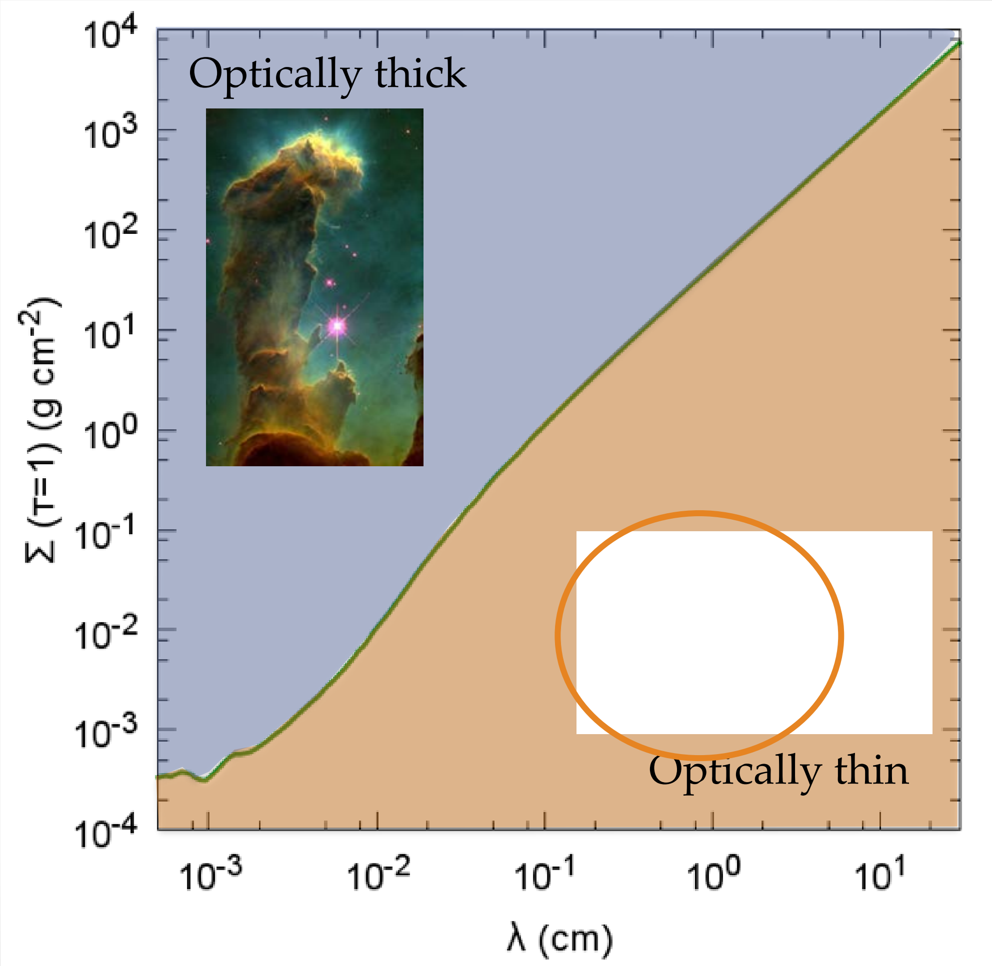
Amount of material needed to become optically thick



What do these areas of interest have in common?

They are dusty environments!

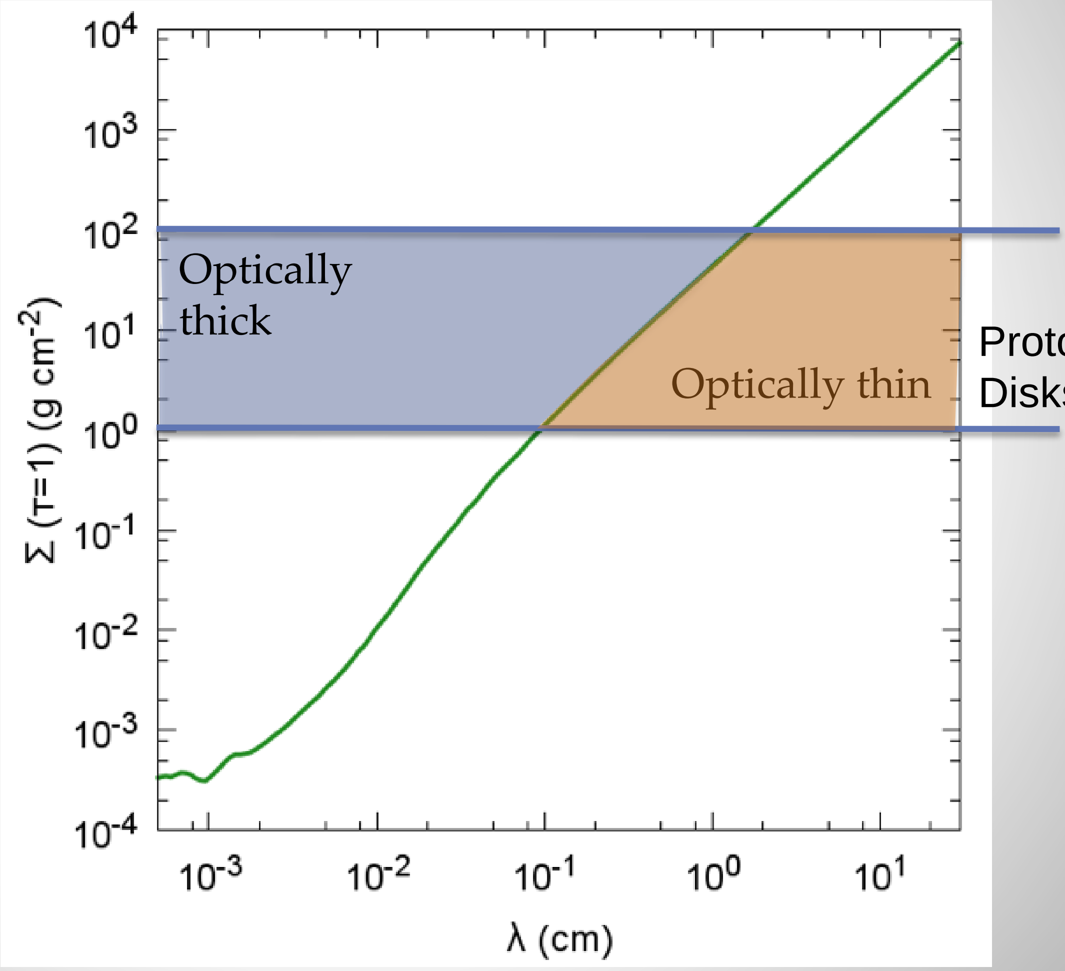
Amount of material needed to become optically thick



What do these areas of interest have in common?

They are dusty environments!

Amount of material needed to become optically thick

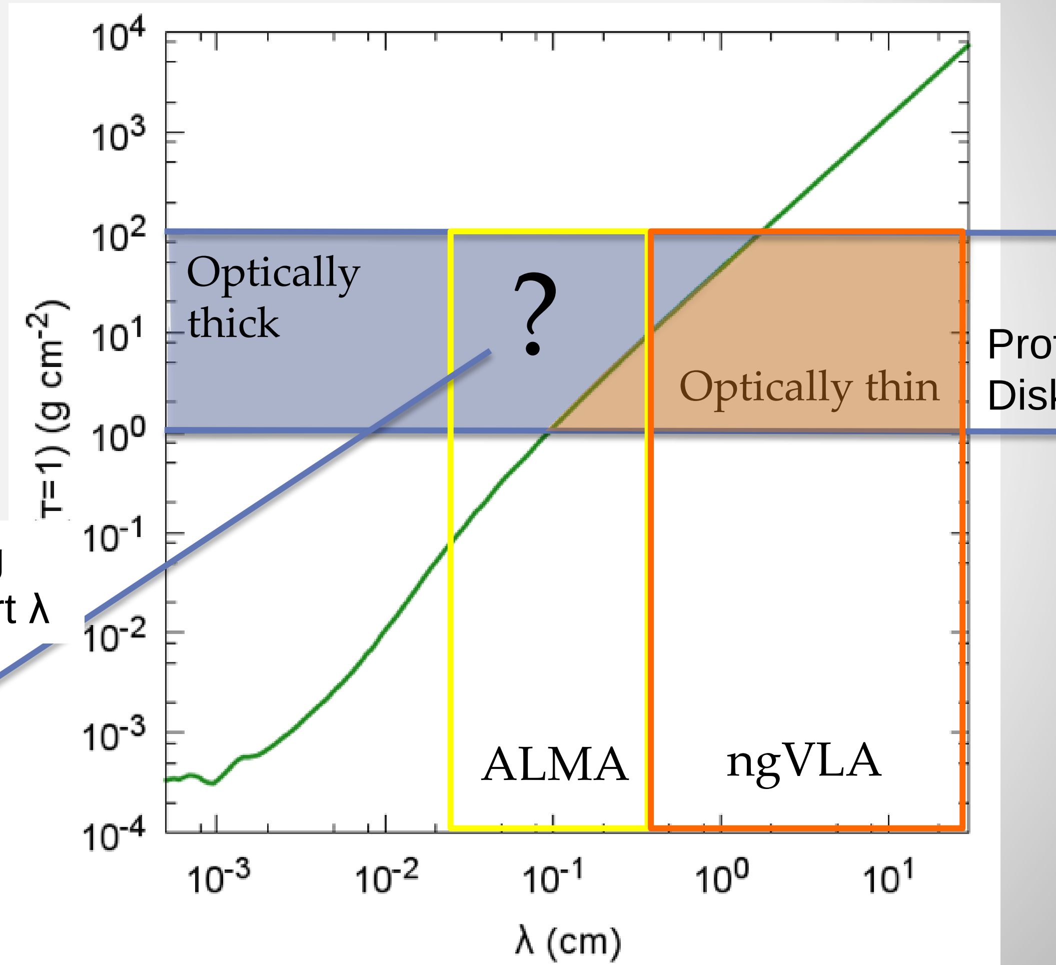


Protoplanetary Disks

What do these areas of interest have in common?

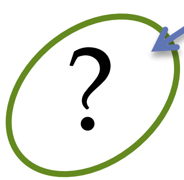
They are dusty environments!

Amount of material needed to become optically thick



Protoplanetary Disks

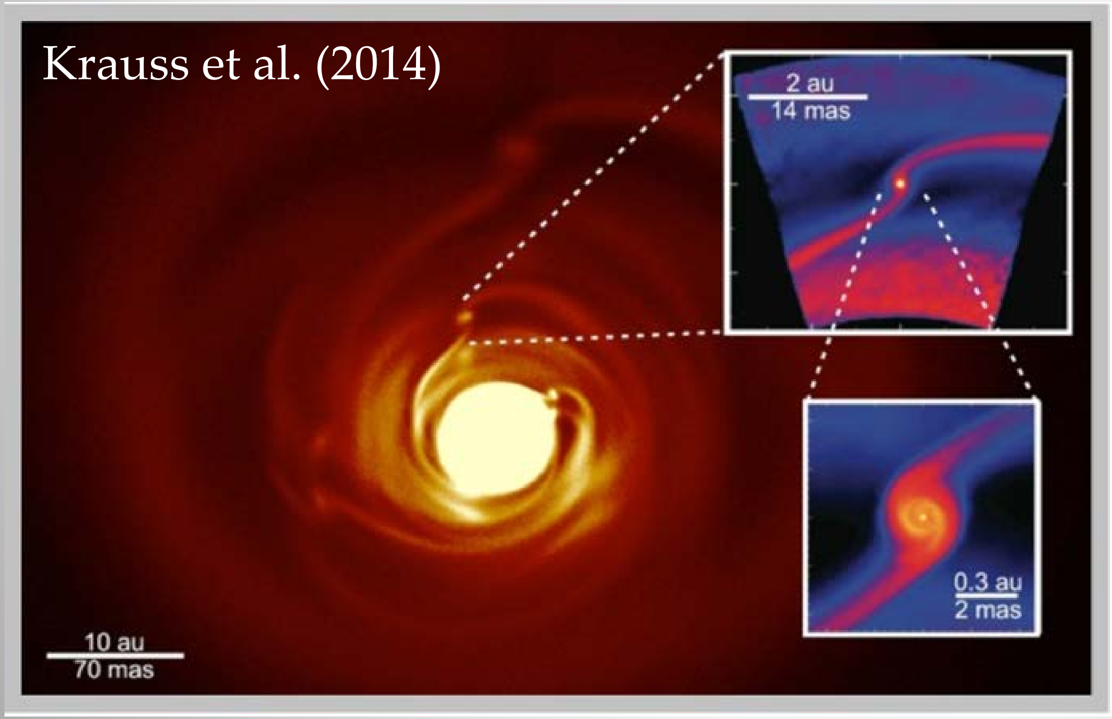
Terrestrial Planet forming region inaccessible for short λ



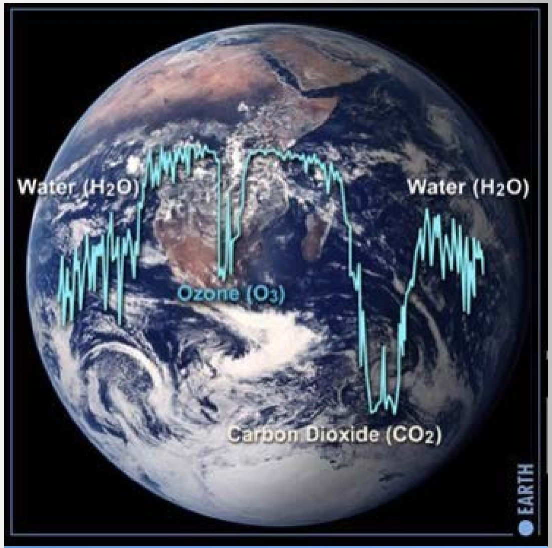
What do these areas of interest have in common?

They are compact in size!

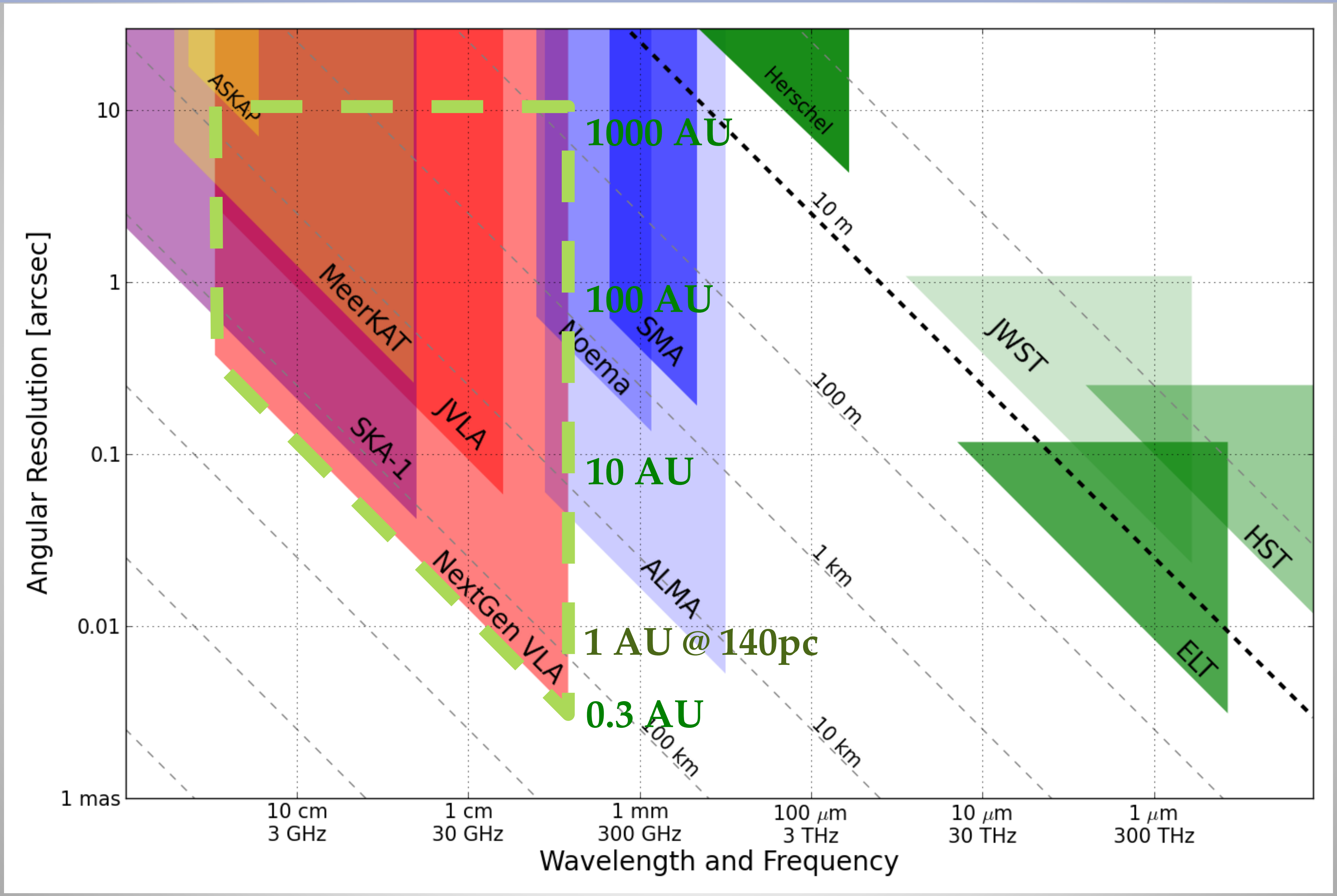
(Hyper/Ultra) Compact HII regions .. < 10^3 AU
Protoplanetary disks ....< 10^2 AU
Planet forming region .... < 10 AU



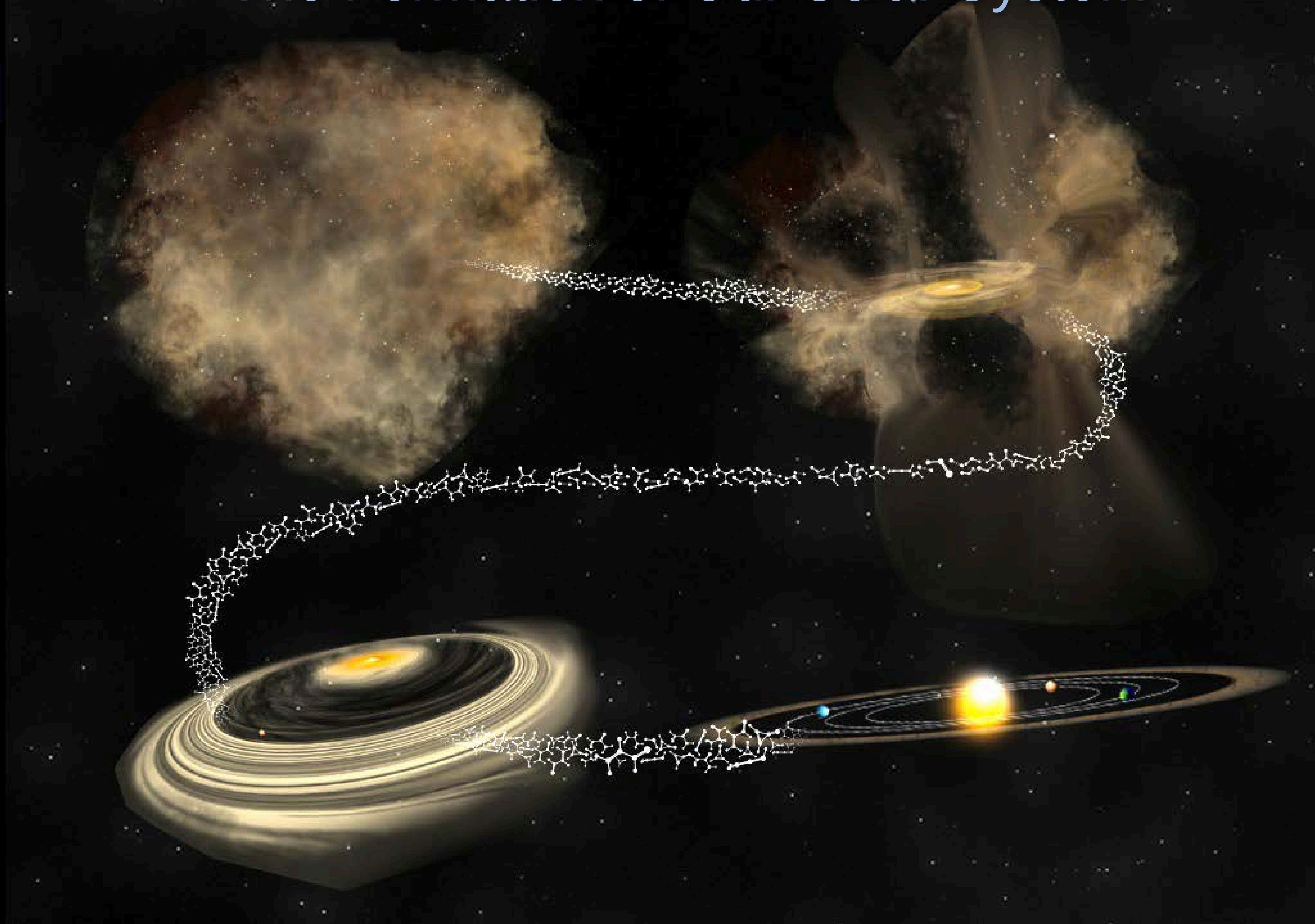
Synergy with
Exoplanet Science



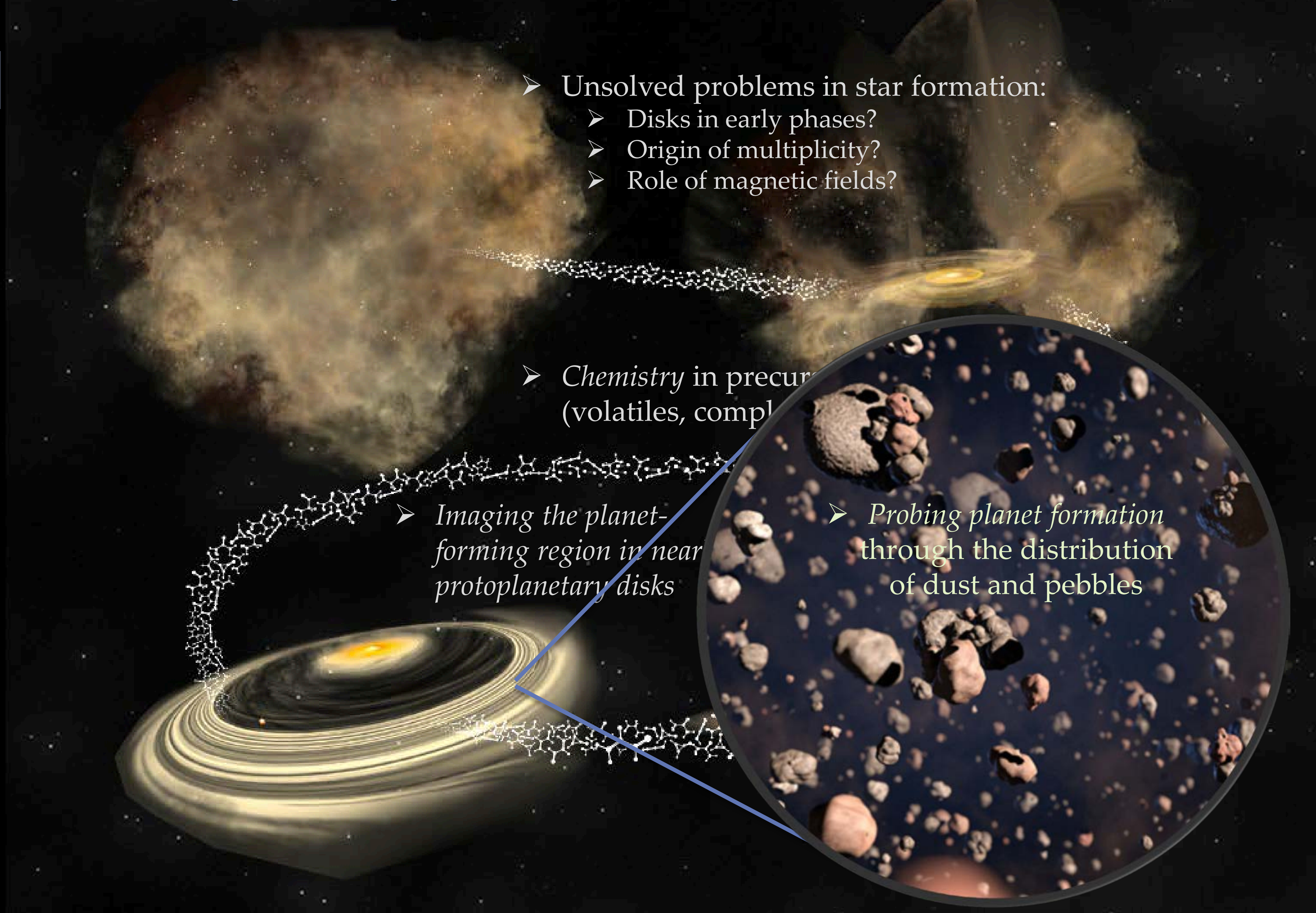
NextGen VLA will provide *critical* spatial resolution



The Formation of Our Solar System



(Some) NextGen VLA Science Cases



(Some) NextGen VLA Science Cases

High Mass Star Formation
- Resolving *inner ionized regions* of accreting *massive stars*
- *Star formation near a black hole* in the inner few pc in the Galactic Center

SETI:
- **Search for *artificial non-man-made* radio signals**

- Unsolved problems in star formation:
  - Disks in early phases?
  - Origin of multiplicity?
  - Role of magnetic fields?
- *Chemistry* in precursors to our Solar System (volatiles, complex organic molecules)
- *aging the planet-forming region in nearby protoplanetary disks*
- *Probing planet formation* through the distribution of dust and pebbles
- Mapping *atmospheres of giant planets* in Solar System
- *Chemistry* of comets (ammonia/water)

White Paper on Cradle of Life Science

Next Generation VLA Science White Paper

Working Group 1: "The Cradle of Life"

March 24, 2015

Andrea Isella[1], Chat Hull[2,3], Arielle Moullet[4], Roberto Galvan-Madrid[5], Leonardo Testi[6], Karin I. Öberg[7], Luca Ricci[7], John Tobin [8], Joseph Lazio[9], Andrew Siemion[10], Hauyu Baobab Liu[11]

[1] Physics & Astronomy Department, 6100 Main MS-61, Houston, Texas 77005, USA, isella@rice.edu
[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden St. MS 42, Cambridge, MA, 02138, USA, chat.hull@cfa.harvard.edu
[3] Jansky Fellow of the National Radio Astronomy Observatory
[4] National Radio Astronomy Observatory, amoullet@nrao.edu
[5] Centro de Radiostronomía y Astrofísica, Universidad Nacional Autónoma de México, 58089 Morelia, Michoacán, México
[6] ESO, Karl Schwarzschild str. 2, 85748 Garching, Germany
[7] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[8] Leiden Observatory, Leiden University, P.O. Box 9513, 2300-RA Leiden, The Netherlands
[9] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., M/S 138-308, Pasadena, CA 91109, USA
[10] University of California, Berkeley
[11] Academia Sinica Institute of Astronomy and Astrophysics, P.O. Box 23-141, Taipei, 106, Taiwan

Abstract

This paper summarizes the contribution of more than twenty scientists spread across North America, Europe, and East Asia and is aimed at developing science cases for the *Next Generation Vary Large Array* (NGVLA). The *Cradle of Life* science working group focuses on the formation of low and high mass stars, on the formation and evolution of protoplanetary disks, on the study of the Solar System, and on the possible detection of radio signals from extraterrestrial civilizations. The proposed science cases have been tailored based on the current specifications of the NGVLA, with particular attention

1

For more info:

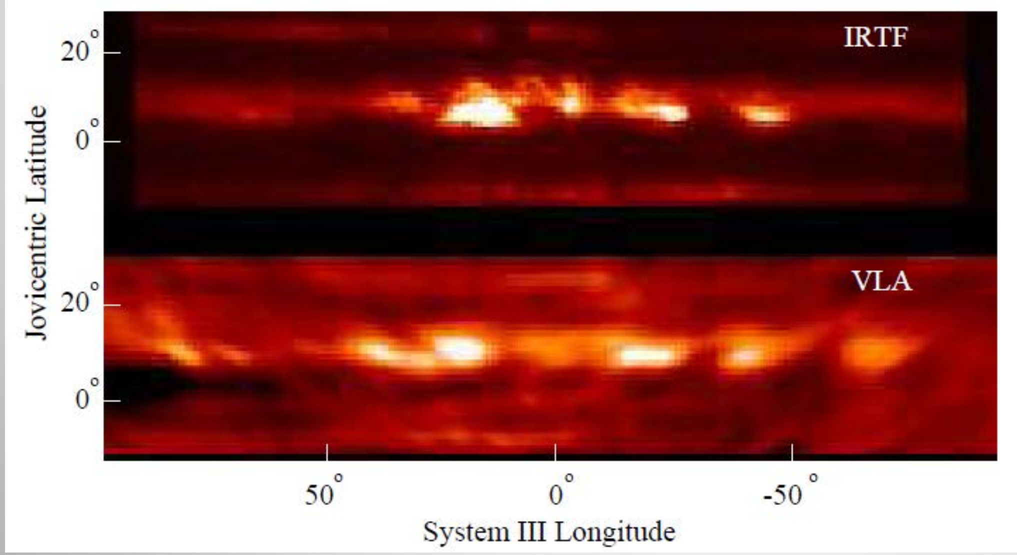
https://safe.nrao.edu/wiki/bin/view/NGVLA/CradleOfLifeSWG

Mapping atmospheres of giant planets in Solar System

NGVLA frequency coverage: ~5-100 GHz → trace deep atmospheric dynamics with different molecules

NGVLA high resolution → storms and small scale features gas giants

NGVLA sensitivity → longitudinal resolution on fast-rotating planets

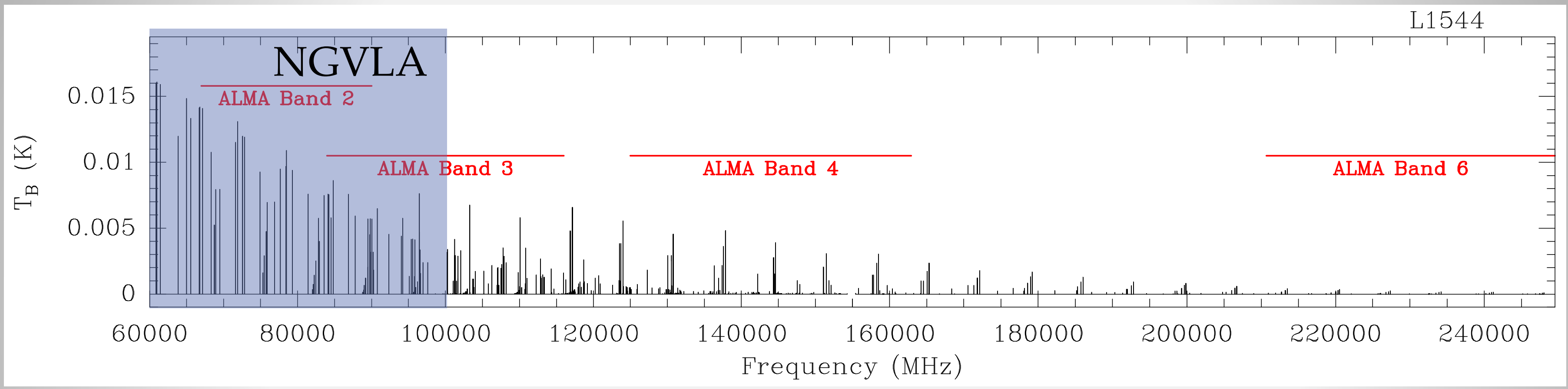


IR and radio (VLA-2cm) thermal maps of Jupiter (Sault et al., 2004)

Chemistry of COMs in Solar System Precursors

COMs = Complex Organic Molecules

Detectability of Glycine, Jimenez-Sierra et al. 2014



NGVLA frequency coverage: up to ~100 GHz → access to multiple COMs

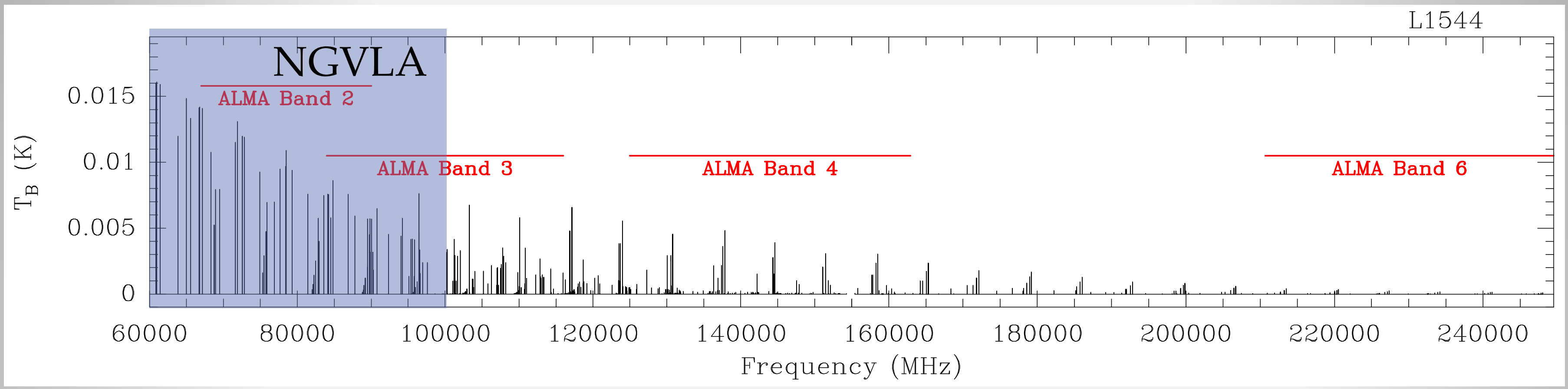
NGVLA resolution → detection more important than resolution

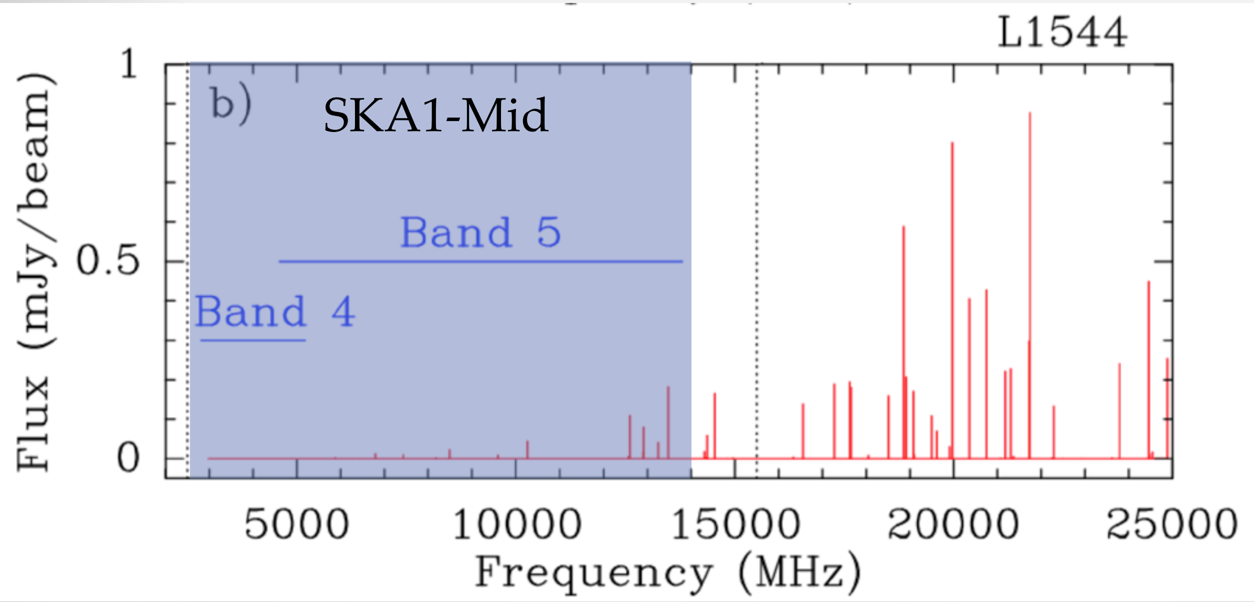
NGVLA sensitivity → ~2mk RMS for ~10-σ detection of Glycine @ ~60GHz

Chemistry of COMs in Solar System Precursors

COMs = Complex Organic Molecules

Detectability of Glycine, Jimenez-Sierra et al. 2014

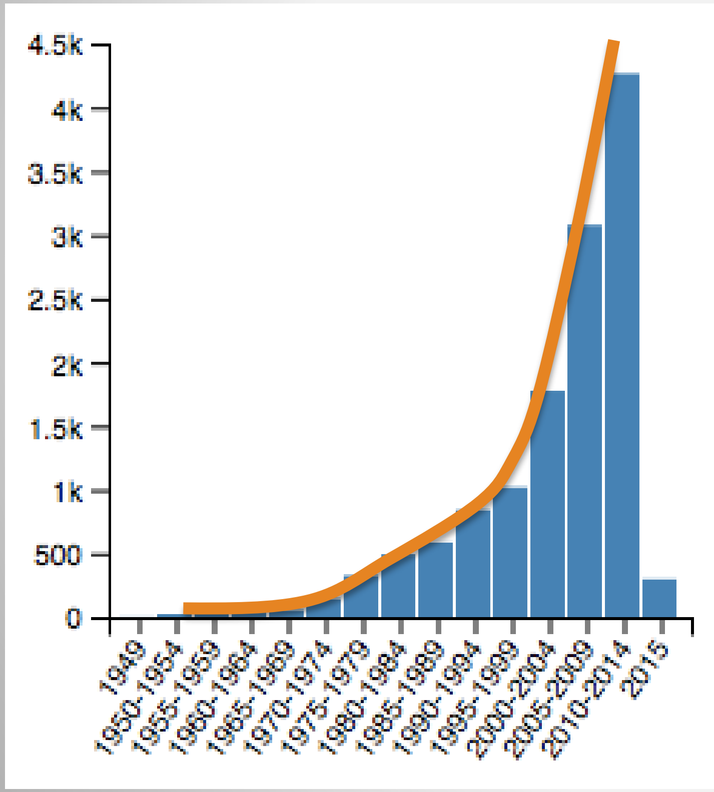




COMs in Protostellar Cores, Codella et al. 2014

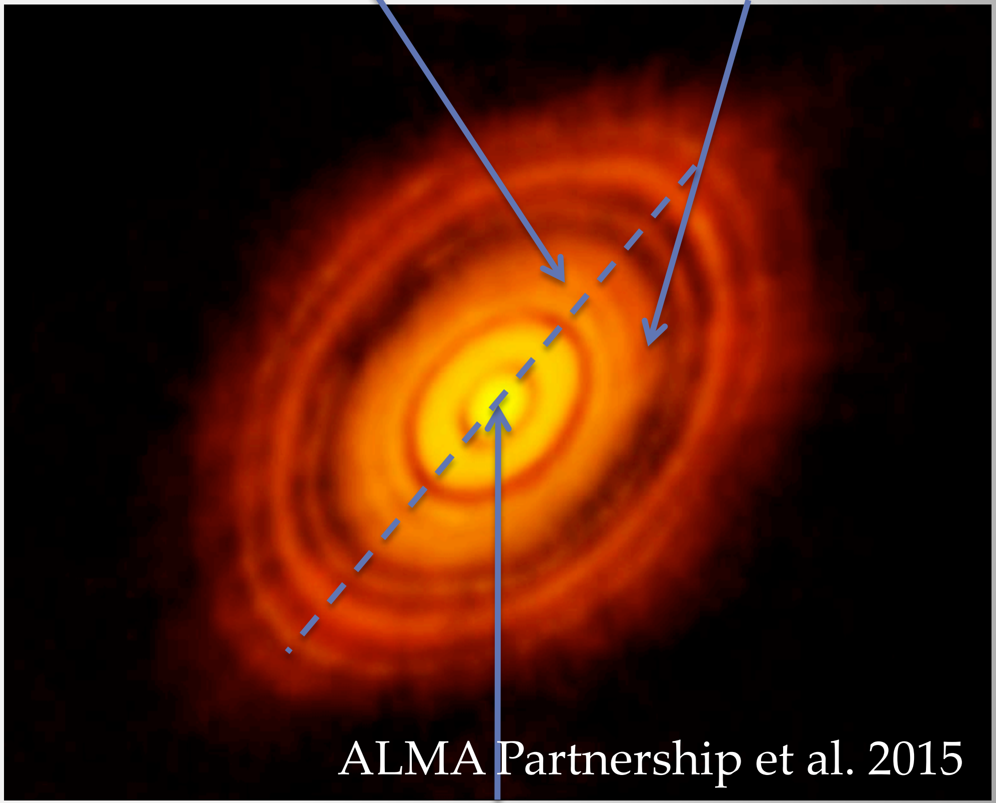
Imaging planet-forming region in nearby disks

Refereed papers with keyword "Protoplanetary Disks"



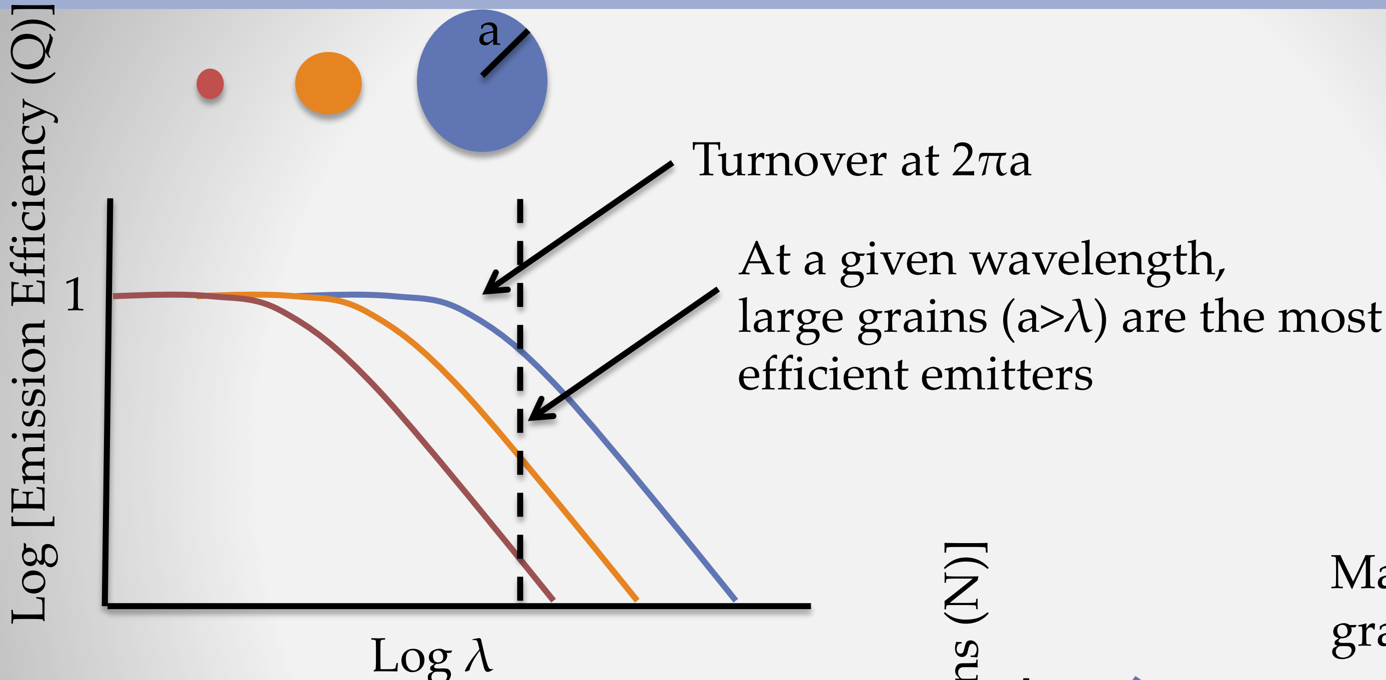
2. Low optical depth across disk radii

1. Pebbles and rocks throughout the disk



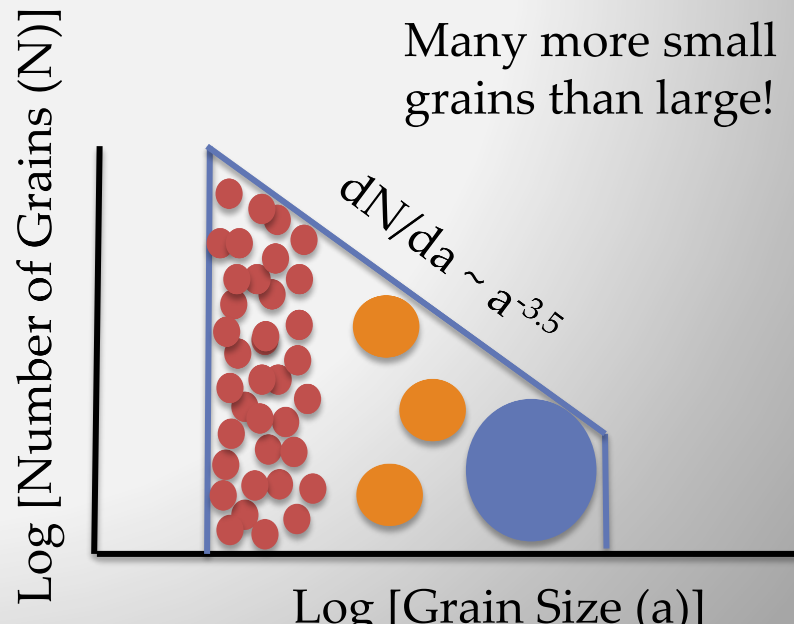
3. Access to terrestrial planet-forming regions

Seeing Pebbles and Rocks



Net effect: Smallest grain that can emit efficiently will dominate flux at a given wavelength.

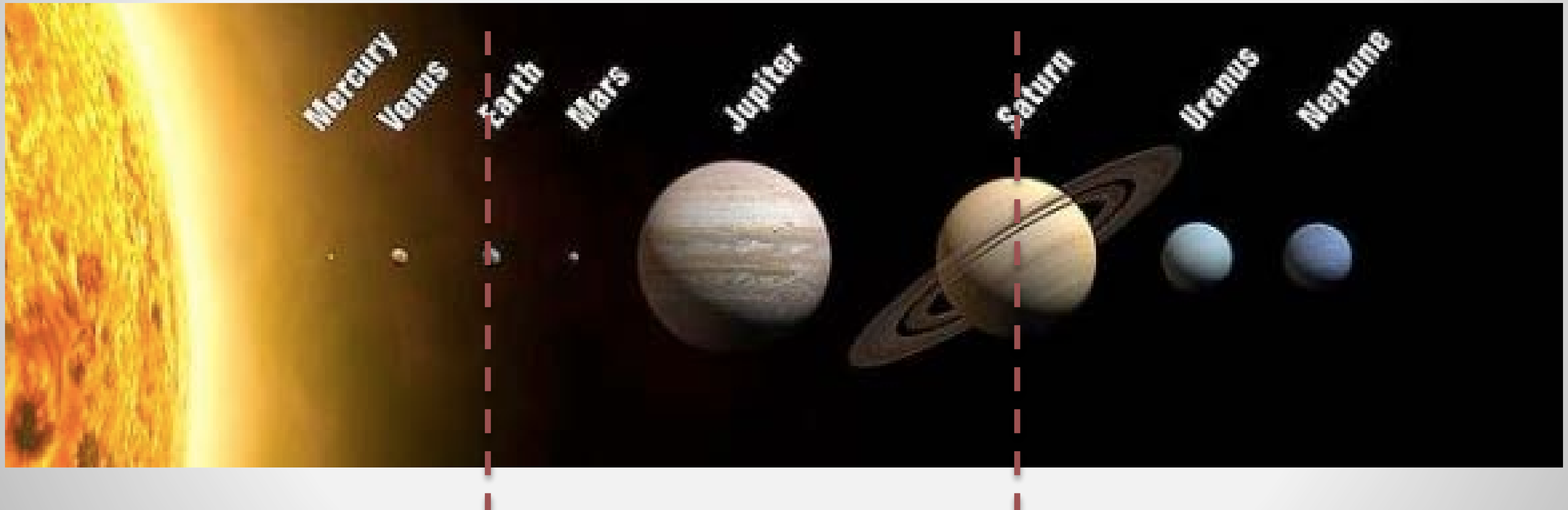
Grain size ≈ Wavelength of observation
Need long wavelengths to see pebbles



Credit: M. Hughes

Imaging planet-forming region in nearby disks

We can only trace underlying mass distribution of solids where $\tau < 1$
Want to know when, where, how much mass in pebbles exists



$\tau = 1$ at $\lambda = 3$cm
(NGVLA)

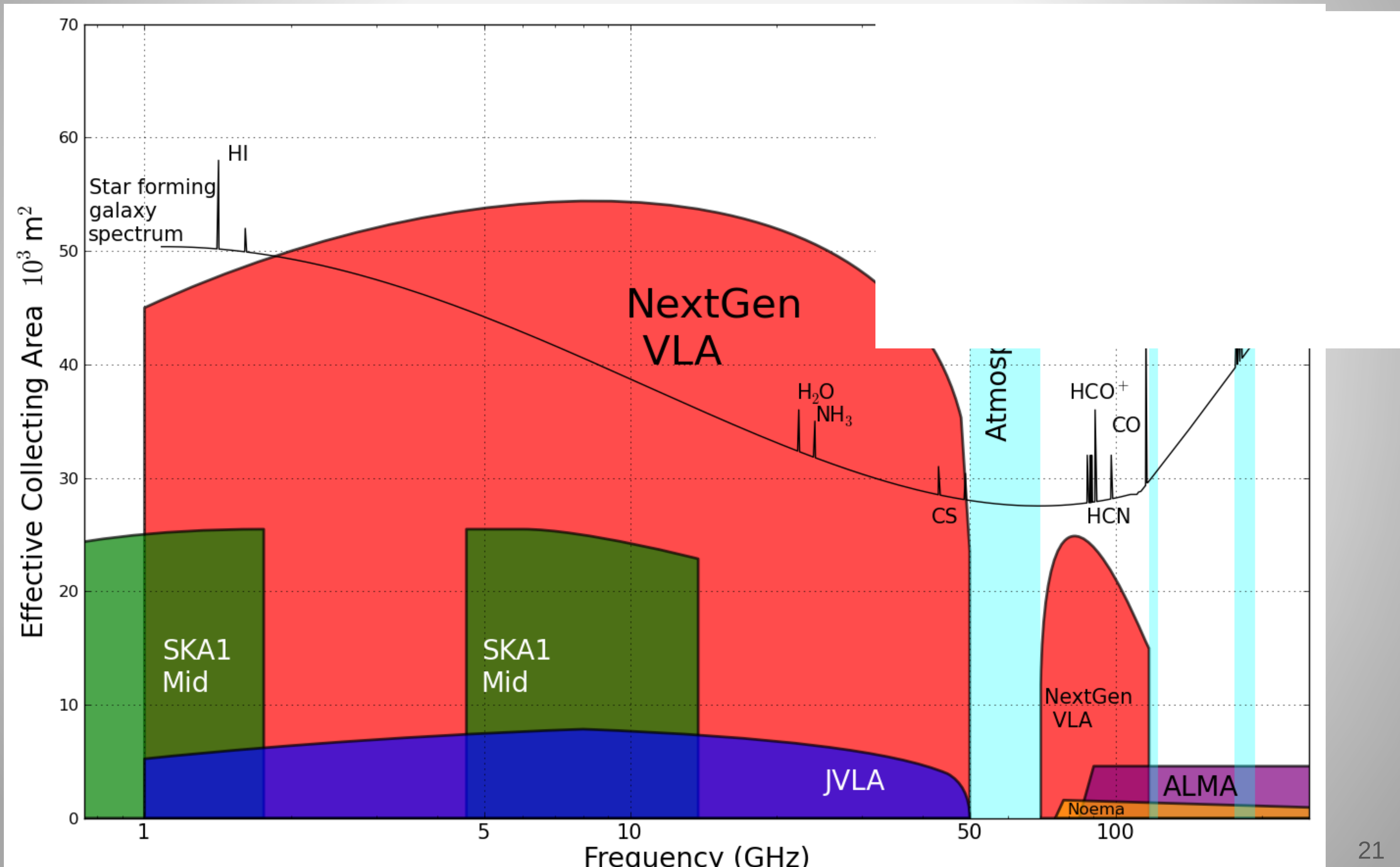
$\tau = 1$ at $\lambda = 1$mm
(ALMA)

* Note this is for "typical" and face-on disk

Credit: M. Hughes

Emission from pebbles declines steeply with frequency

Requiring lots of sensitivity!!



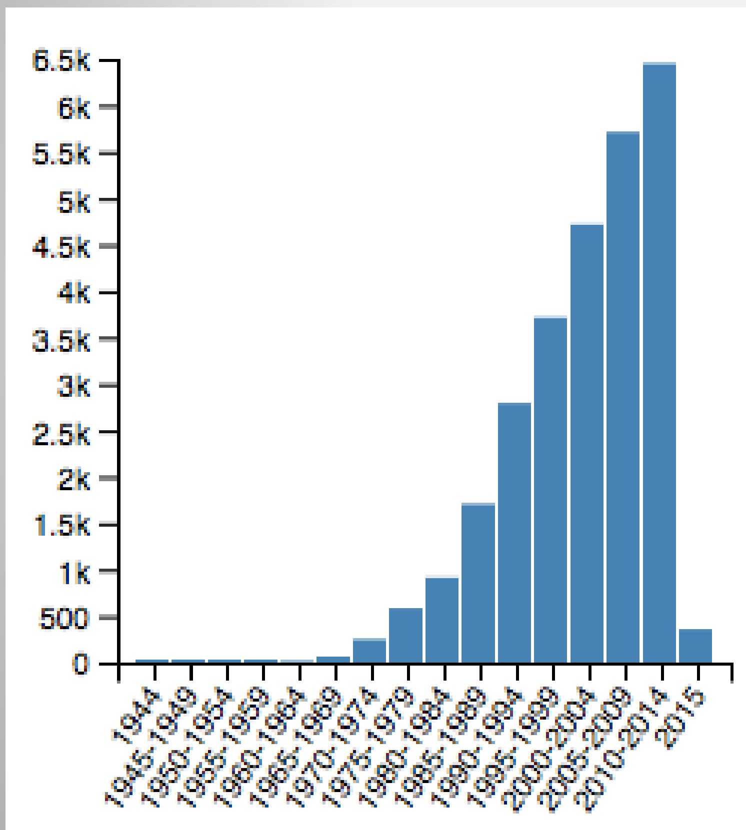
Guidance in parameter space for ngVLA

- 5-10x surface area, with *increased efficiency* compared to VLA antennas
- Continuum science pushes for wide bandwidths (32GHz *nice!*)
- COMs detections (multiple lines) pushes for wide bandwidths
- Terrestrial-planet formation science pushes for long baselines

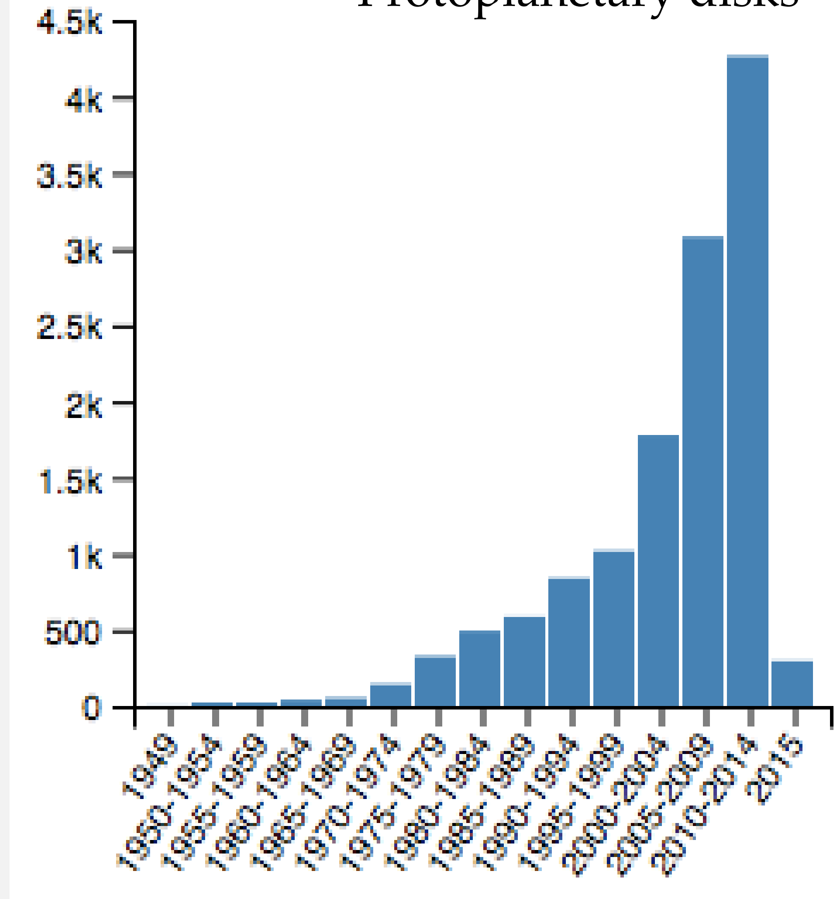
- Caveat: think carefully about array configuration:
- Continuum science pushing to sensitivity in long baselines
- But spectral line science needs short baselines for Tb sensitivity

- The NGVLA could push down to 5–10AU separation at distances out to 1 kpc → current ALMA science throughout the Galaxy!

Circumstellar disks



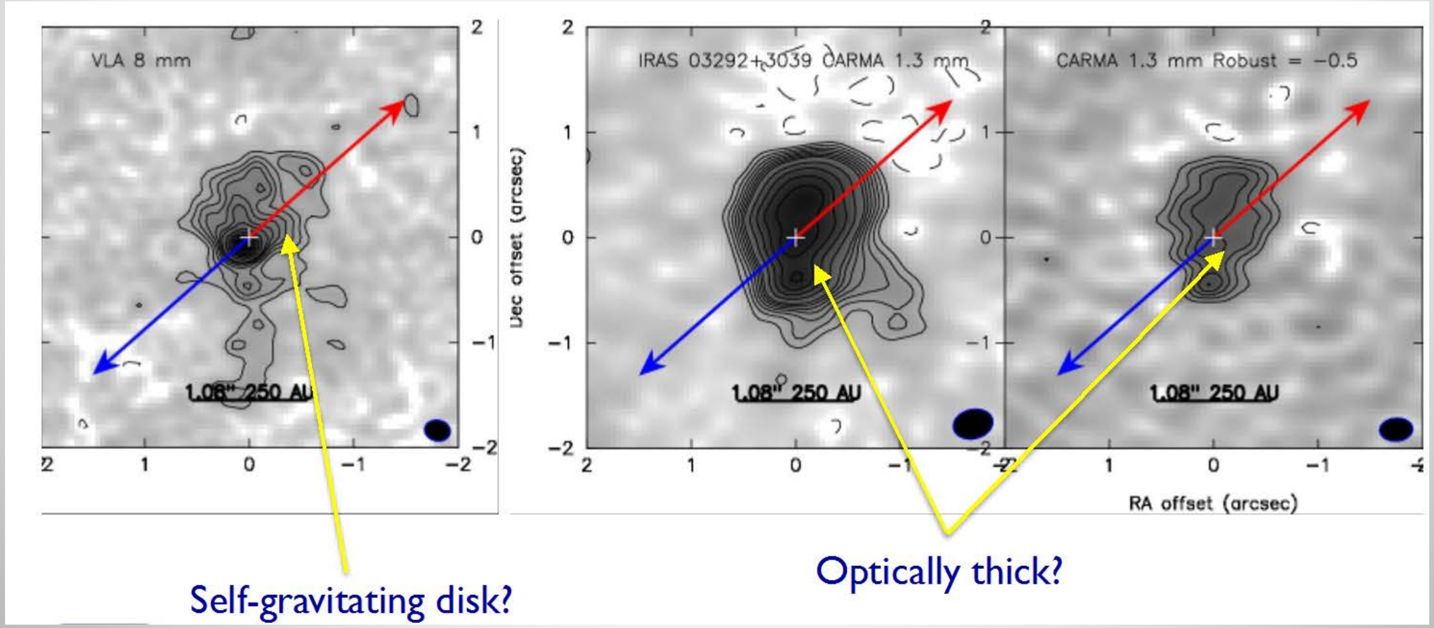
Protoplanetary disks



Why low optical depths?

We can only trace underlying mass distribution of solids where $\tau < 1$
Want to know when, where, how much mass in pebbles exists

VLA @ 8mm   CARMA @ 1.3 mm



Seeing Pebbles and Rocks

One more piece of the puzzle: $\kappa_\nu \propto \lambda^{-1}$

(opacity)

Millimeter flux (optically thin): $F_\nu \propto \Sigma * \kappa_\nu * B_\nu(T)$ $\propto \lambda^{-3}$

(Surface density) (Planck function $\propto \lambda^{-2}$)

The bottom line: Flux drops off like crazy with wavelength. Need LOTS of sensitivity to image pebbles.