

Minding the Gaps

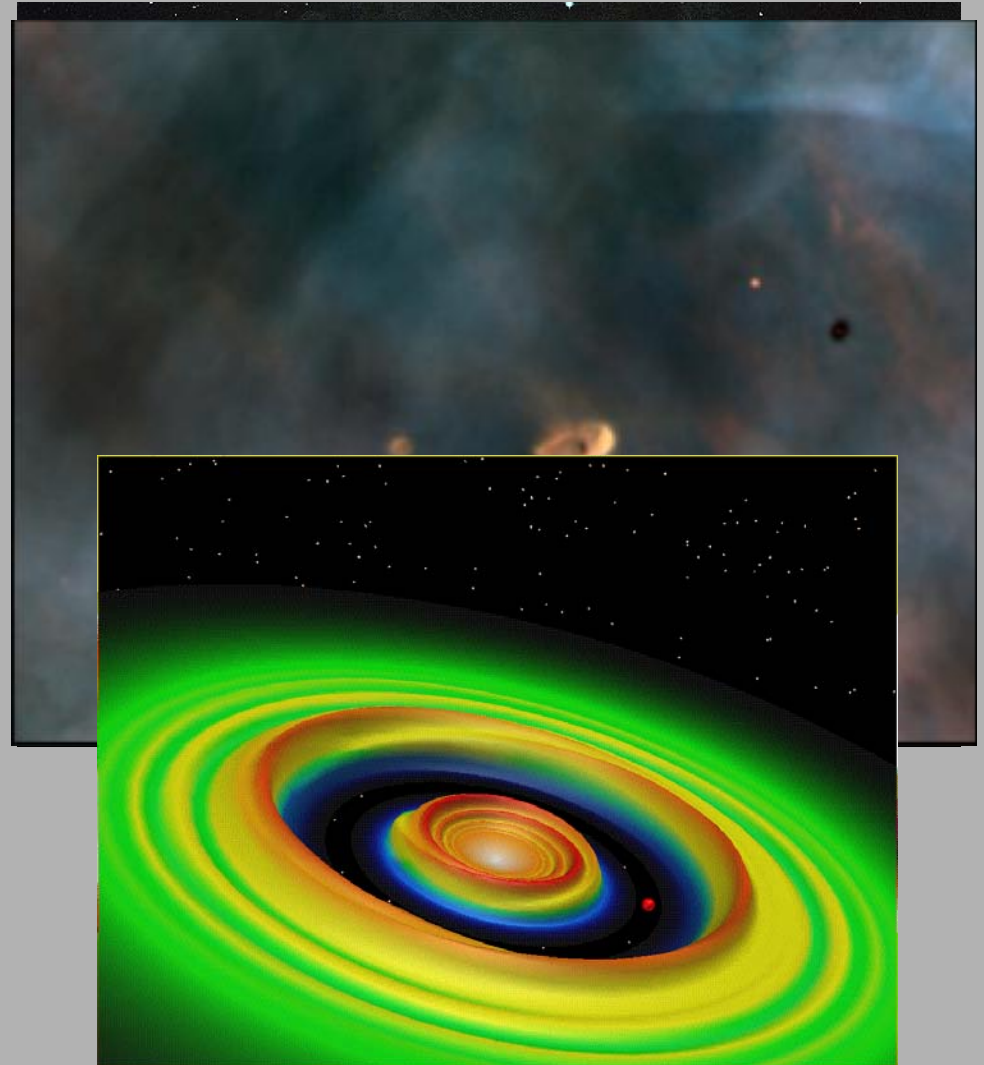
Joseph Lazio (NRL)

G. Taylor (UNM), N. Kassim (NRL),
D. Wilner (CfA)

Minding the Gap

Protoplanetary Disks

- Protoplanetary disks are expected to be dynamic.
 - Planetary formation
 - Planetary migration
- Planets and protoplanetary disks are a major theme in next-generation instruments
 - ALMA
 - ELT
 - *JWST*
 - *TPF/Darwin*
 - ...
- Astrobiology was a highlighted theme in *Astronomy & Astrophysics in the New Millennium*

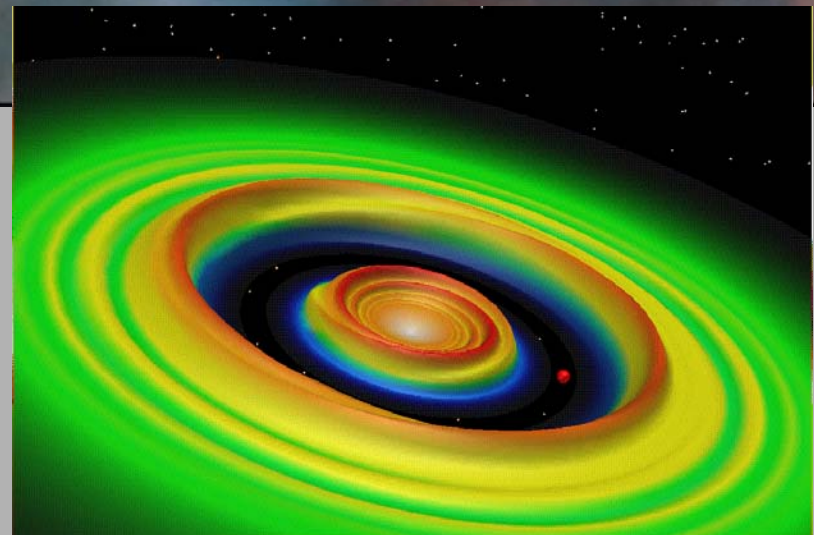


Minding the Gap

Protoplanetary Disks

Radio wavelengths (~ 1 cm) offer unique information about planetary formation

- Pebble accretion—crucial and poorly understood regime of planetary formation
- Unhindered by dust obscuration

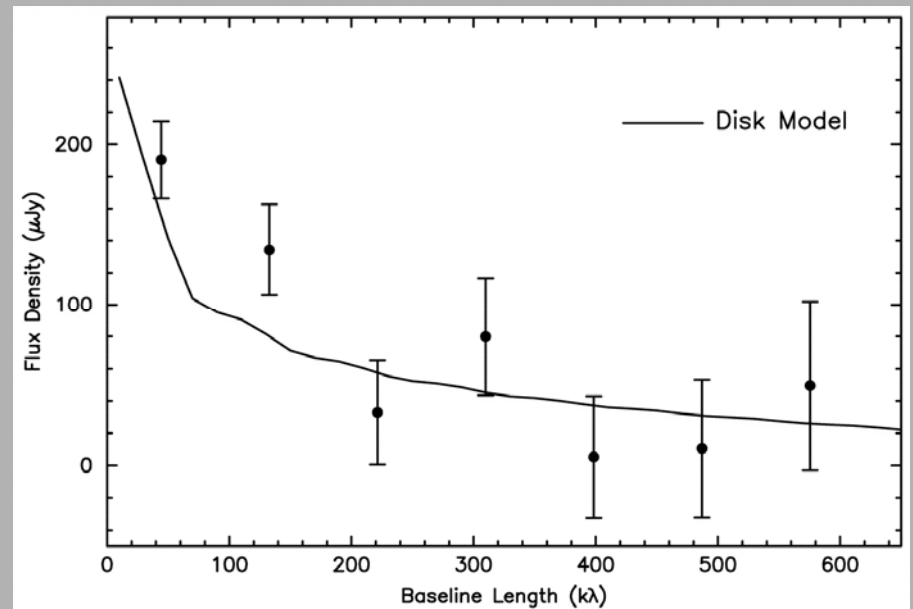


Minding the Gap

Imaging Protoplanetary Disks

Why don't pebbles destroy each other?

- Relevant size scale ~ 1 cm.
- VLA observations of TW Hyd at 3.5 cm detect and resolve its disk.
- Emission from centimeter-sized particles in disk—*on-going accretion*.
- TW Hyd is close (50 pc); insufficient sensitivity for observing more distant systems.



Wilner et al. (2005)

Long-Range Goal

A future cm-wave telescope should be built capable of addressing planetary formation in nearby protoplanetary disks.

- Will require order of magnitude increase in sensitivity over existing facilities

Near-term: construction of a single prototype “station”

Instrumental Requirements at Centimeter Wavelengths

Angular resolution: 5 milliarcseconds

- ~ 1 AU at 150 pc
 - 1500 km at 3.5 cm
 - 600 km at 1.5 cm (20 GHz)
- Easy, already achieved with VLBA

Sensitivity: $\Delta T \sim 10$ K on roughly 750 km baselines

- ~ 5 mas @ 2 cm
- $T_{\text{sys}} \sim 50$ K
- $A_{\text{eff}} \sim 200,000 \text{ m}^2$
 $A_{\text{eff}}/T_{\text{sys}} \sim 3500 \text{ m}^2/\text{K}$

Existing Instrumentation

- EVLA $\sim 10,000 \text{ m}^2$
 - ATA-42 $\sim 1000 \text{ m}^2$
 - ATA-350 $\sim 7000 \text{ m}^2$
 - North American infrastructure $\sim 20,000 \text{ m}^2$
- EVLA: $\Delta T \sim 0.2 \text{ K}$
240 mas
 - EVLA+VLBA: $\Delta T \sim 1000 \text{ K}$

EVLA + inner VLBA +
ATA-350

New telescope or substantial augmentation of existing telescopes required.

Outlier Station Proposal

The First Step



+



Construct an outlier station consisting of approximately 10-m diameter dishes at a Long Wavelength Array station.

- Leverage LWA and EVLA infrastructure.
- Leverage ATA and DSNA dish construction experience.
- Provide a “local” testbed for various technology prototyping, demonstrations, and education/training.

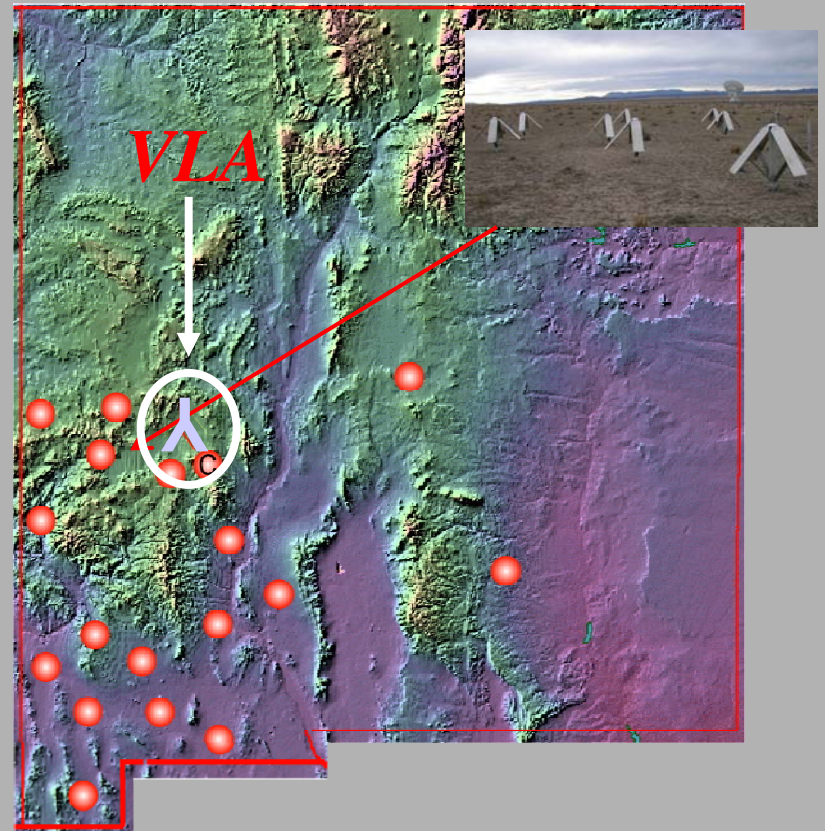
Outlier Station Foundation

Allen Telescope Array

- 350-element array under construction in California
- 6-m hydroformed antennas
- Wideband feeds: 0.5–11 GHz

Long Wavelength Array

- Dipole array under construction in New Mexico
- Consists of phased array “stations” of dipoles; about 50 stations to be constructed.
- Stations to be tied by fiber optic links to central processing facility





Outlier Station

Closing Technical Gaps

- Are stations the right way to proceed?
- Further antenna cost reductions?
- Improved wide-band feed performance?
- Cryogenic system performance in the field?
- Imaging with stations?
- Data transport?
- Reliability?
- Station-station correlation (ATA to station)?
- ...?

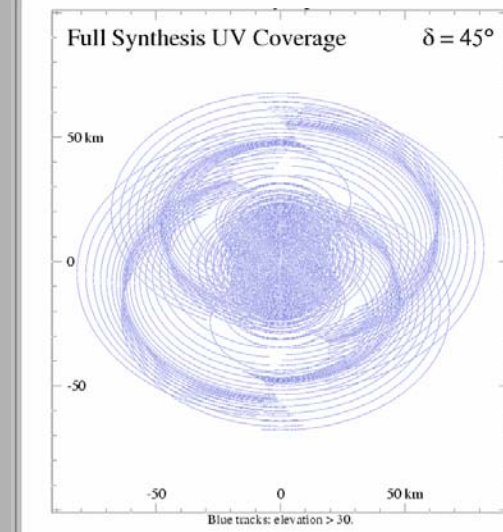
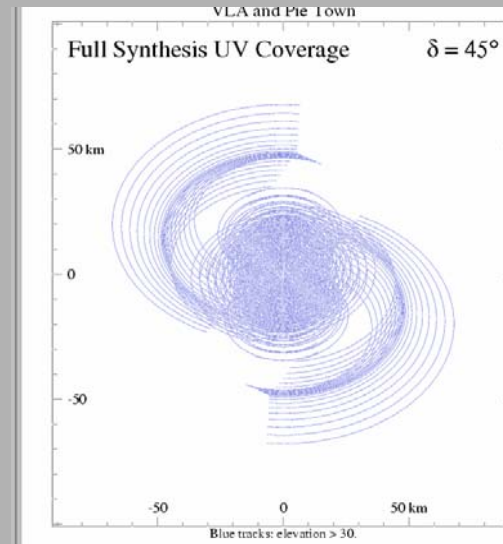
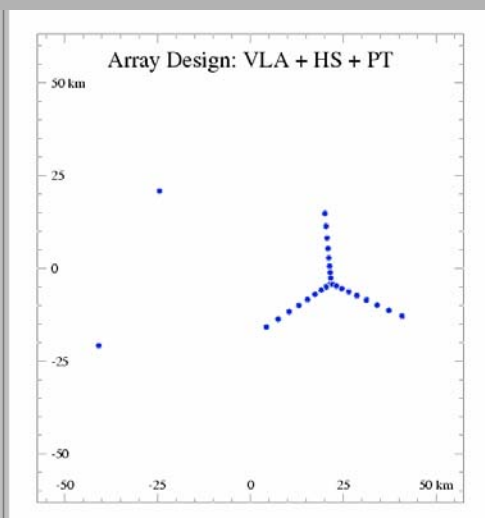
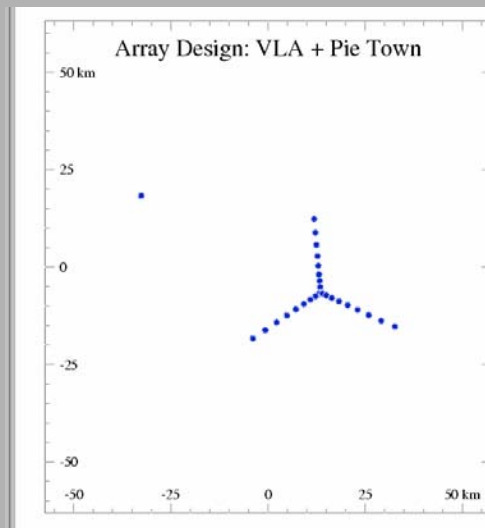
Outlier Station Science

Closing the u - v Gap

- LWA station locations will be about 50–100 km from the EVLA.
- “Pietown link” is formed from VLA + VLBA Pietown antenna
 - ~ 50 km distant, maximum baseline = 72 km
 - Popular, oversubscribed by ~ 2.5x
- Outlier station location could complement VLA Pietown link.
- Outlier station would complement VLBA by adding needed short spacings.

Outlier Station Science

Closing the u - v Gap



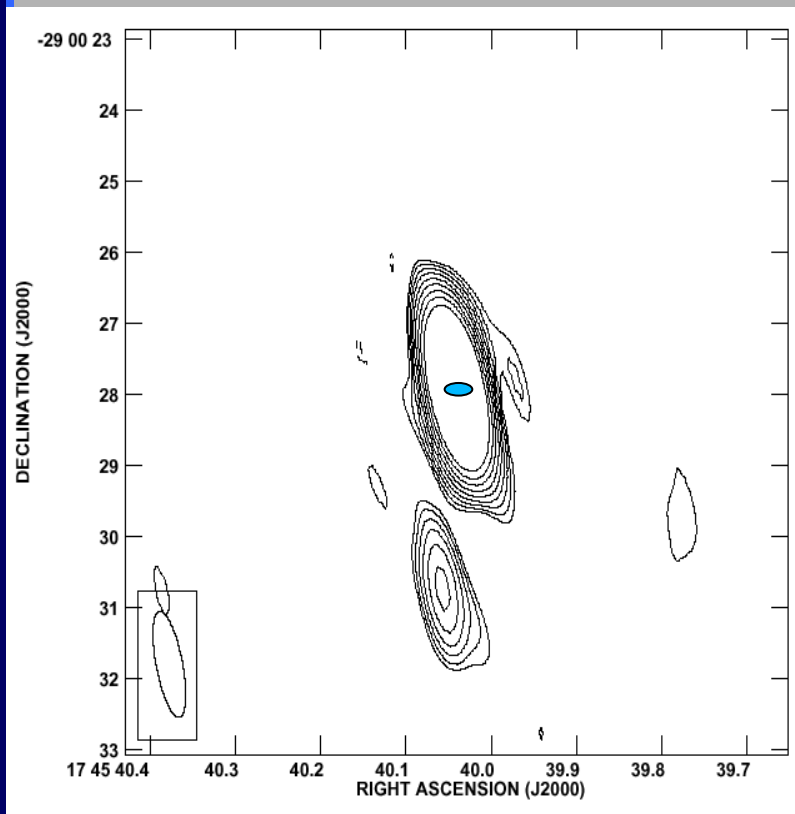
Outlier Station Science

Astronomy & Astrophysics in the New Millennium

- Map the galaxies, gas, and dark matter in the Universe, and survey the stars and planets in the Galaxy
- Search for life beyond Earth, and, if it is found, determine its nature and its distribution in the Galaxy
- Use the Universe as a unique laboratory to test the known laws of physics in regimes that are not accessible on Earth and to search for new physics.

Outlier Station Science

Closing the u - v Gap



(Bower et al. 2006)

- Sgr A* represents nearest supermassive black hole.
- Intrinsic size:
 - Local environment (jets vs. RIAFs vs. ...)
 - Density of object and limits on exotic physics
- VLA+PT can just barely resolve it at cm-wavelengths (Bower et al. 2006).

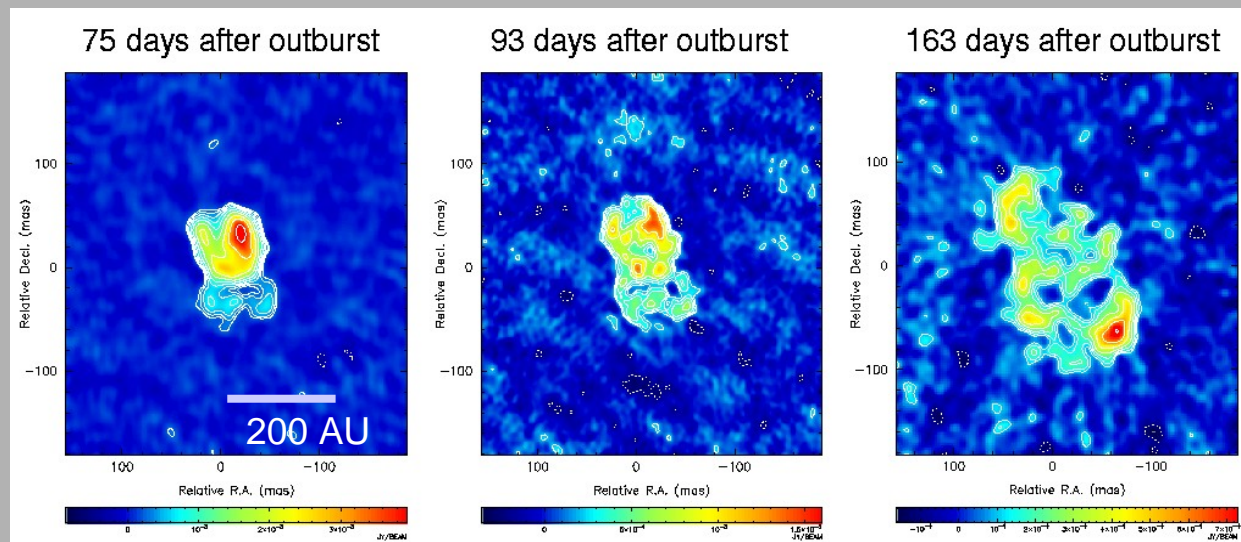
Beam is significantly elliptical.

Outlier Station Science

Closing the u - v Gap

Other potential science

- Massive star formation (e.g., Shepherd et al.)
- OH (1720 MHz) masers
- Evolution of AGN
- Continuum emission from starbursts
- Microquasar imaging (e.g., Hjellming & Rupen; Mioduszewski et al.)



CI Cam

Minding the Gaps

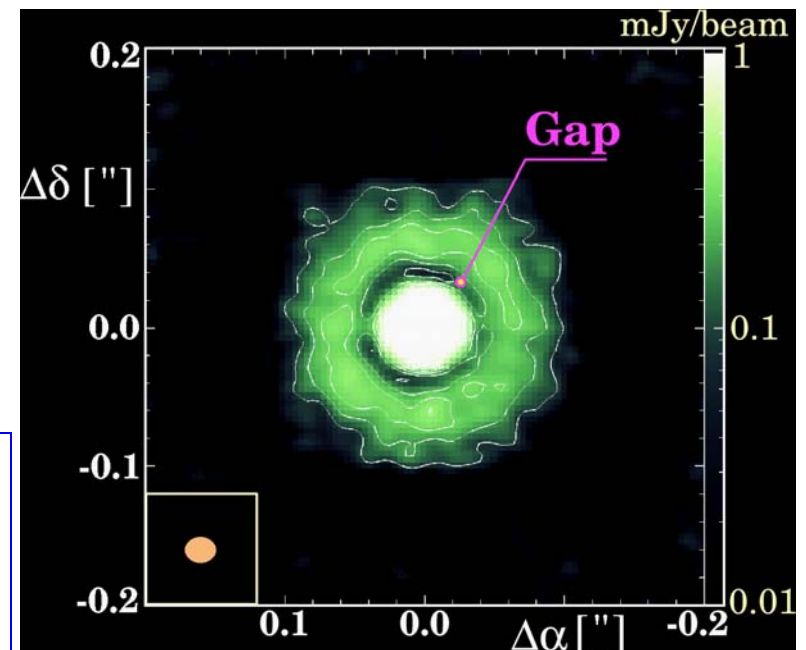
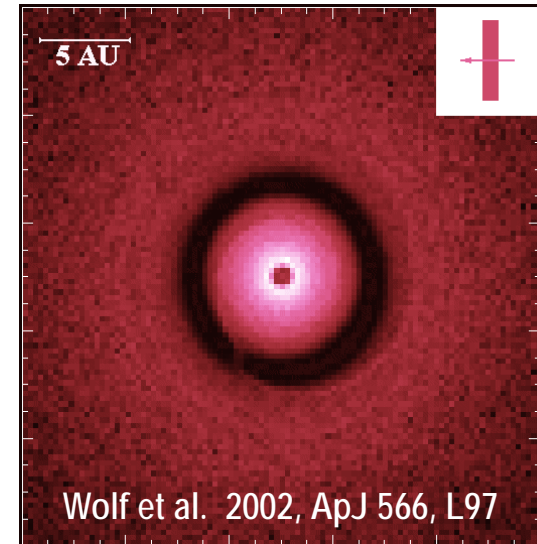
- Planetary formation is a key aspect of 21st astronomy.
- Cm-wave astronomy has a unique role.
 - dust \Rightarrow *pebbles* \Rightarrow boulders
- Existing infrastructure is only 10% of what is needed.
- Outlier station is the next step.
 - Addresses key technical issues
 - Delivers immediate science return



Basic research in radio astronomy at the NRL is supported by the Office of Naval Research.

Imaging Protoplanetary Disks

- ⊕ Protoplanetary disk at 140pc, with Jupiter mass planet at 5AU
- ⊕ ALMA simulation
 - ⊕ 428GHz (= 70 μm)
 - ⊕ max. baseline: 10km
 - ⊕ $\Delta\nu = 8 \text{ GHz}$, $\Delta t = 4 \text{ hr}$
- ⊕ Contrast reduced at higher frequency as optical depth increases
- ⊕ **Will push ALMA to its limits**



J. Richer

"Scientific Requirements of ALMA, and Its Capabilities for Key-Projects: Galactic"

The Square Kilometre Array

- Imaging protoplanetary disks is a prime aspect of one of the SKA's Key Science Projects.
- Considerable work being done worldwide on various technical aspects of the SKA.
 - Only the Allen Telescope Array is addressing some of the issues relevant to obtaining large amounts of additional collecting area at the relevant frequencies.
 - Opportunity to leverage U.S. infrastructure and knowledge to target important 21st century astronomical problem.