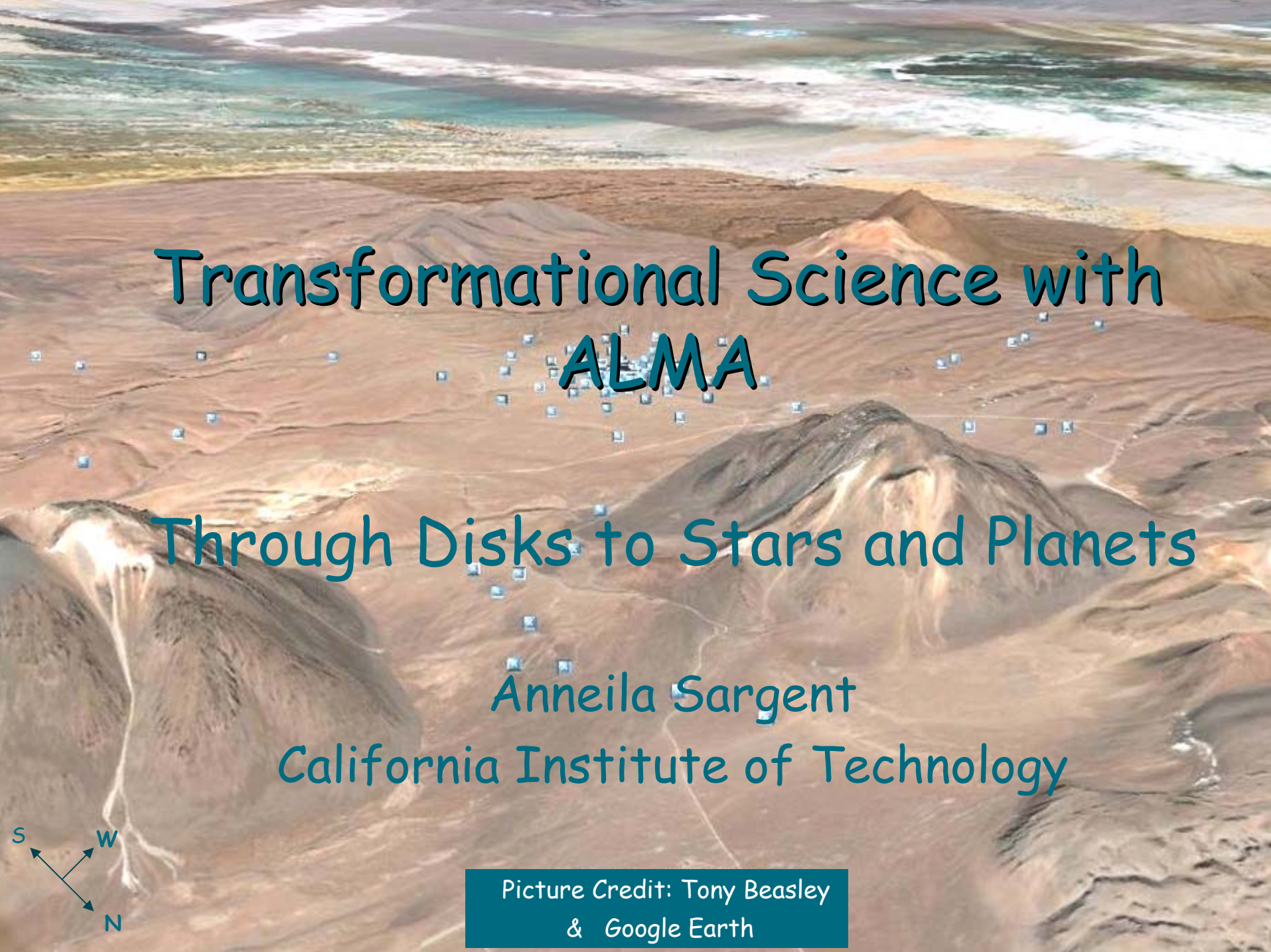


Transformational Science with ALMA

Through Disks to Stars and Planets

Anneila Sargent
California Institute of Technology

S W N

Picture Credit: Tony Beasley & Google Earth

Transformational Science?

- Evolution versus (R)evolution (E. Herbst, Madrid)
  - Evolution ≅ Current Expectations
  - Revolution ≅ Transformational
    ≅ Evolution + Serendipity?
- In terms of molecular chemistry…

Revolutionary or Evolutionary?

- New molecules: evolutionary at best
- Source structure/dynamics:revolutionary
- Chemical processes: evolutionary unless..
- Chemical models: more structure and dynamics, possibly revolutionary. With ALMA, the situation will require collaborations of experts in chemistry, dynamics, & hydrodynamics to cope.

From E. Herbst ALMA/Madrid Conference

Transformational Science?

- Evolution versus (R)evolution (E. Herbst, Madrid)
  - Evolution ≅ Current Expectations
  - Revolution ≅ Transformational
    ≅ Evolutionary + Serendipity?
- In terms of molecular chemistry…
- Experiences with other new facilities

Evolution + Opportunity + 'Vision'

ALMA – the Opportunity

- High sensitivity
  - submm continuum (< 0.2mJy in 1 min)
  - & spectral line (mK)
- Wideband frequency coverage
- Unprecedented angular resolution
- Flexible correlator
- Full polarization capability
- High fidelity imaging

ALMA Sensitivity

ALMA Median Sensitivities

(1 minute; AM=1.3; 75% Quartile opacities λ>1mm, 25% λ <1mm)

Frequency (GHz)	Continuum (mJy)	Line 1 km s^{-1} (mJy)	Line 25 km s^{-1} (mJy)
35	0.02	5.1	1.03
110	0.027	4.4	0.89
140	0.039	5.1	1.01
230	0.071	7.2	1.44
345	0.12	10	1.99
675	0.85	51	10.2
850	1.26	66	13.3

Brightness Temperature Sensitivity

(1 min, AM=1.3, 1.5mm, *0.35 PWV, 1 km/s)

Frequency (GHz)	B_{max} 0.2km T_{cont} (K)	B_{max} 0.2km T_{line} (K)	B_{max} 10km T_{cont} (K)	B_{max} 10km T_{line} (K)
35	0.002	0.050	0.48	130
110	0.003	0.049	0.84	120
230	0.0005	0.054	1.3	140
345	0.0014	0.12	3.6	300
490	0.0030	0.23	7.6	580
675*	0.0046	0.28	12	690
850*	0.011	0.58	27	1400

(from T Beasley presentation, this meeting)

ALMA Frequency Bands

First Light Bands:

3	6	7	9
3mm	1mm	850μm	450μm

Later Bands:

4	8	10	5
2mm	650μm	350μm	1.5mm

Bandwidth: 16 GHz

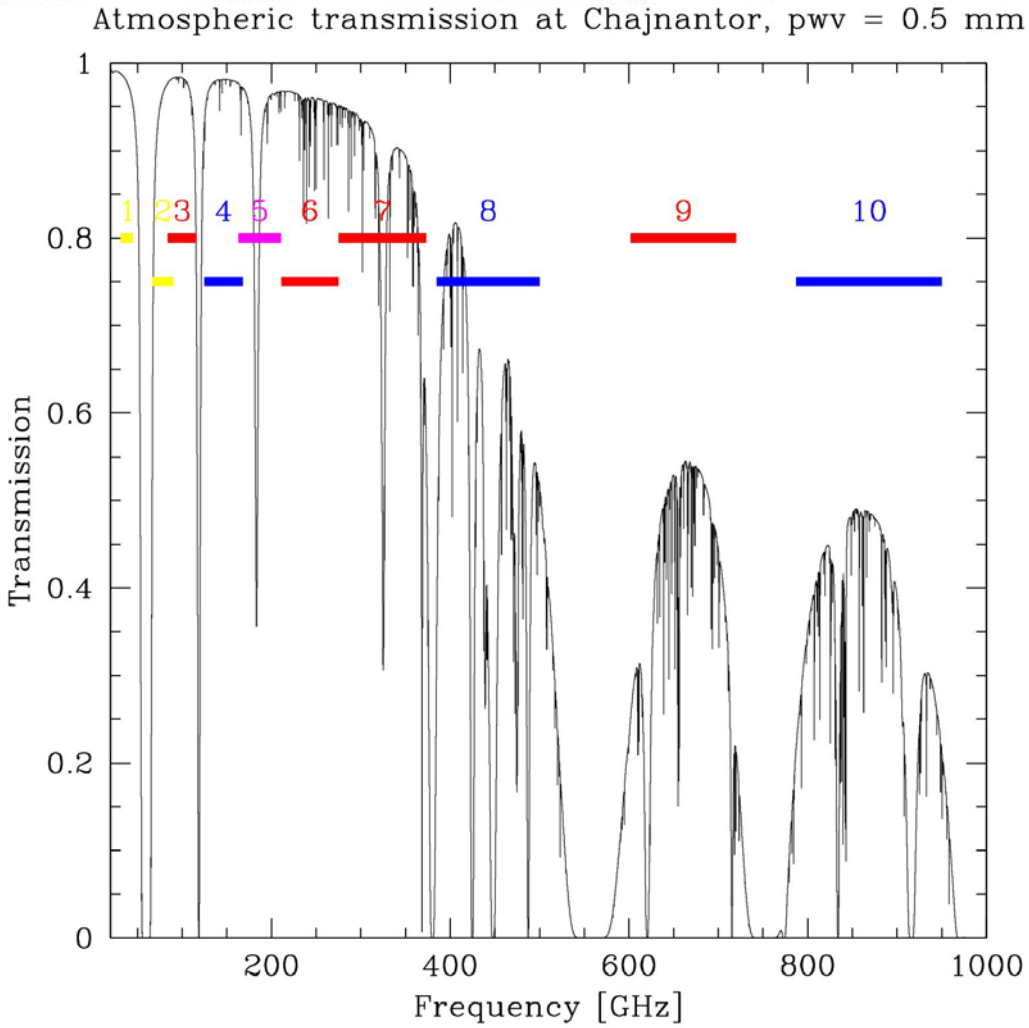
B6: 2polzns x 8 GHz

B3 B4 B8 B5:

2 polzns x 2SBs x 4 GHz

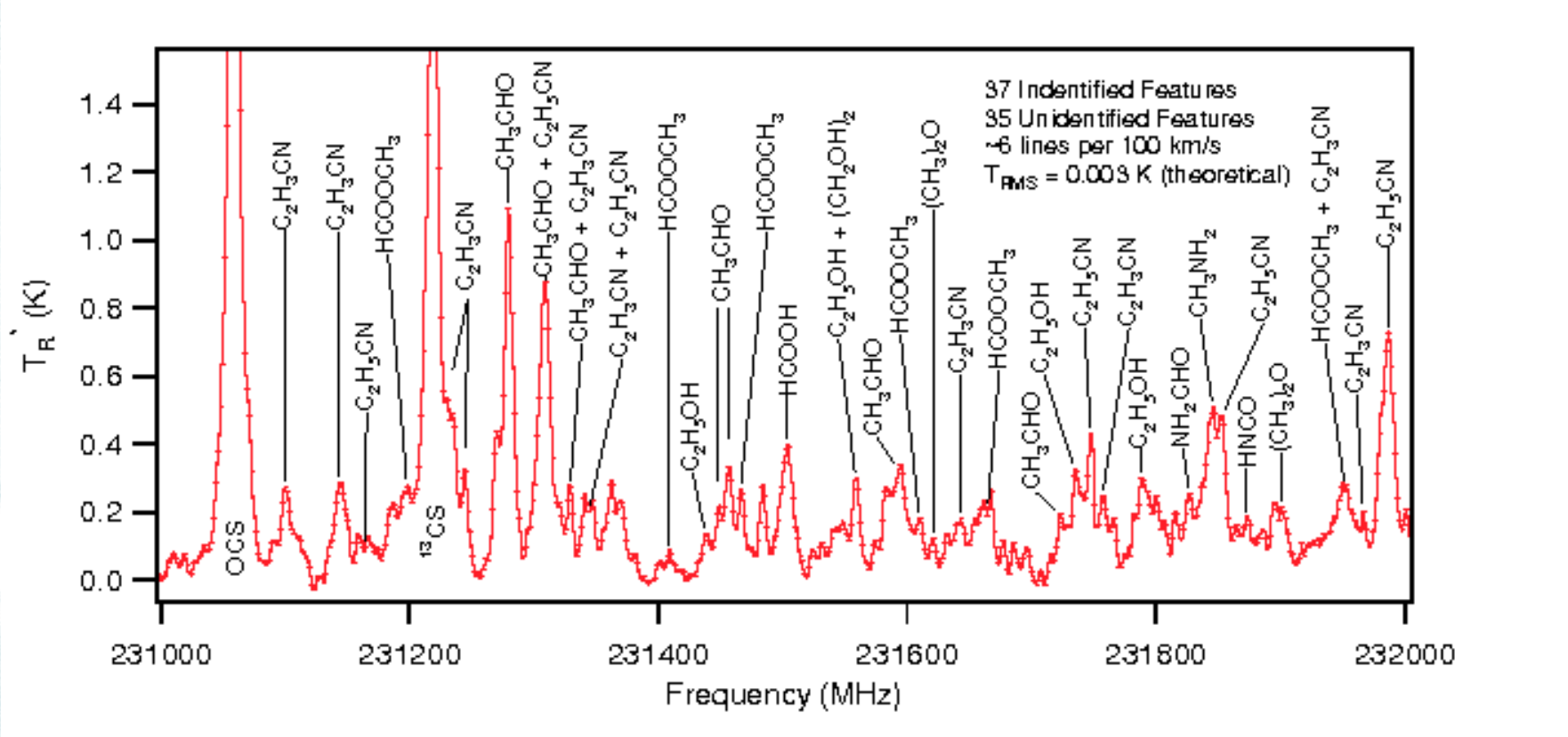
B9 B10:

2 polzns x DSB x 8 GHz



Credit: H. A. Wootten

From Band 6 Mixer Tests at SMT



- Sgr B2(N) spectrum at 232 GHz and 45° elevation
- T_{sys}(SSB) = 107 K (> 20db image rejection, good baselines)

(Credit: L. Ziurys (American Chemical Society, Atlanta)

Multiple ALMA Spectral Modes

- Multiple Spectral Windows
  - within 2 GHz IF bandwidth, for modes with total bandwidth 125 MHz – 1 GHz
  - enable high resolution observations of multiple lines within IF bandwidth
- Multiple Resolution Modes
  - simultaneous high & low resolution
  - observe line wings & cores at same time

Transformational/Revolutionary Studies in Disk, Star, & Planet Formation

- Major advances in last 20 years
  - remarkable evolution
- ALMA in 2012
  - amazing opportunity
- Visions?
  - could current questions ultimately lead to Revolutionary/Transformational Science?
- Wish List format of this meeting
  - sowing the seeds of revolution?

Cores, Fragmentation, IMF and all that

- Considerable theoretical efforts
- Fragmentation due to turbulence?
- Effect of magnetic fields?
- SCUBA & COMPLETE surveys
- 1.1 mm Bolocam* (CSO) + Spitzer c2d Surveys

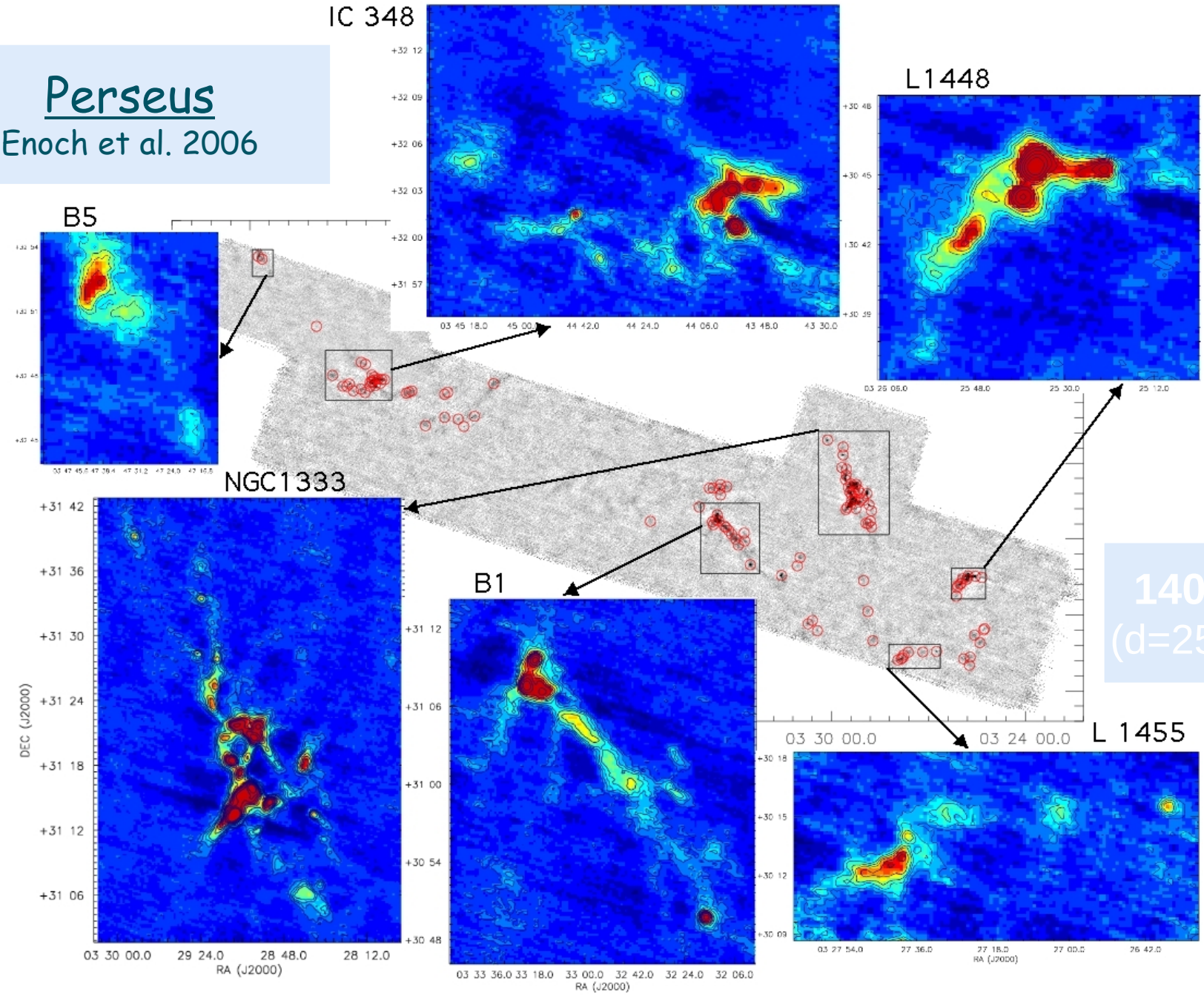
  (Melissa Enoch::Caltech Ph. D. Dissertation 2007)

  - **Perseus** (7.5deg^2), **Ophiuchus** (10.8deg^2),**Serpens** (1.5deg^2)
    - flux-limited surveys within clouds
    - mass detection limits vary between clouds
    - M_{lim}~ 0.2 $M_\odot$ (Per), 0.15 $M_\odot$ (Oph), 0.1 $M_\odot$ (Ser)

  *Bolocam: 144 element array, FOV = 7.5', resolution = 31" at λ = 1.1mm

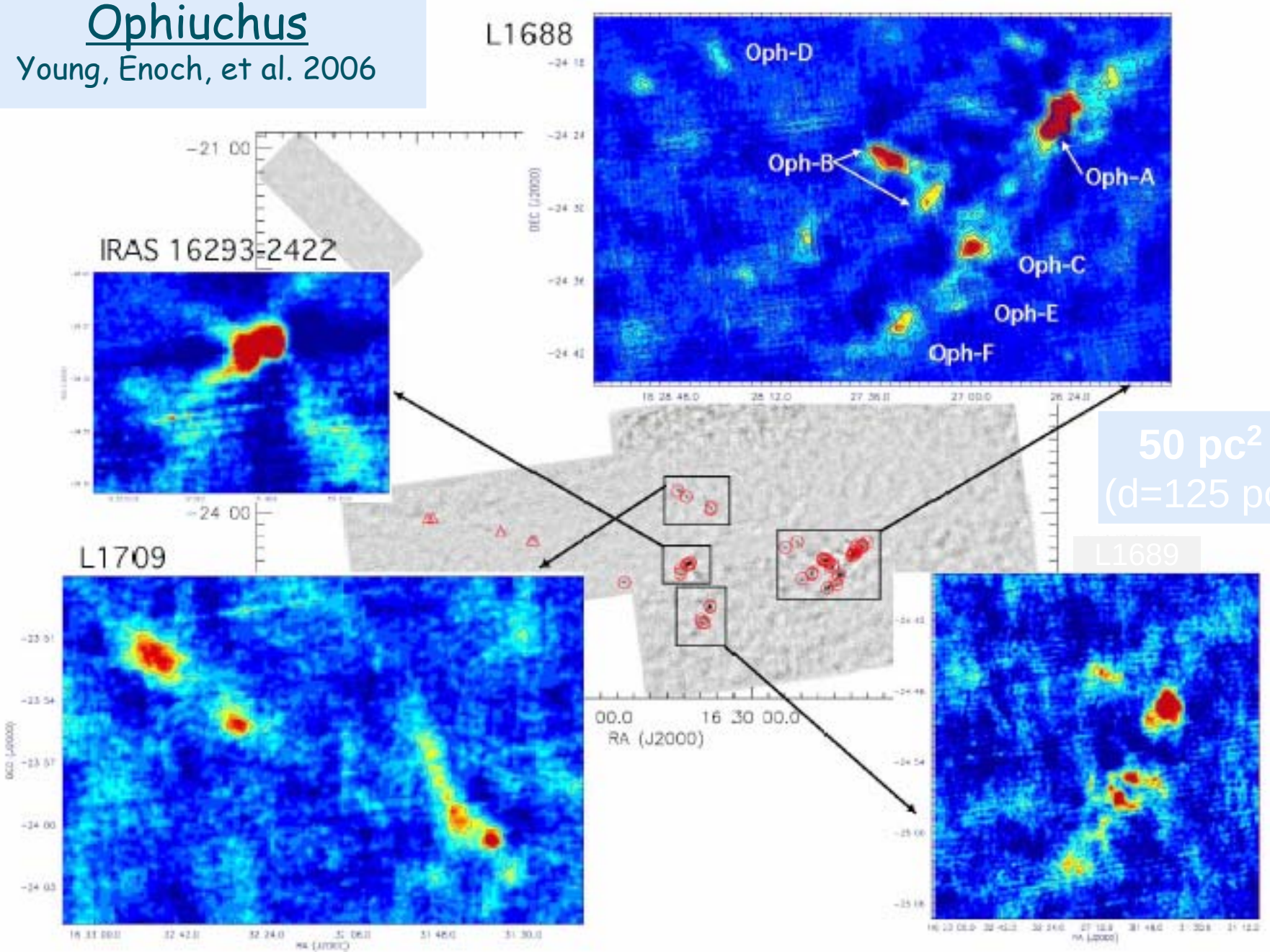
Perseus

Enoch et al. 2006



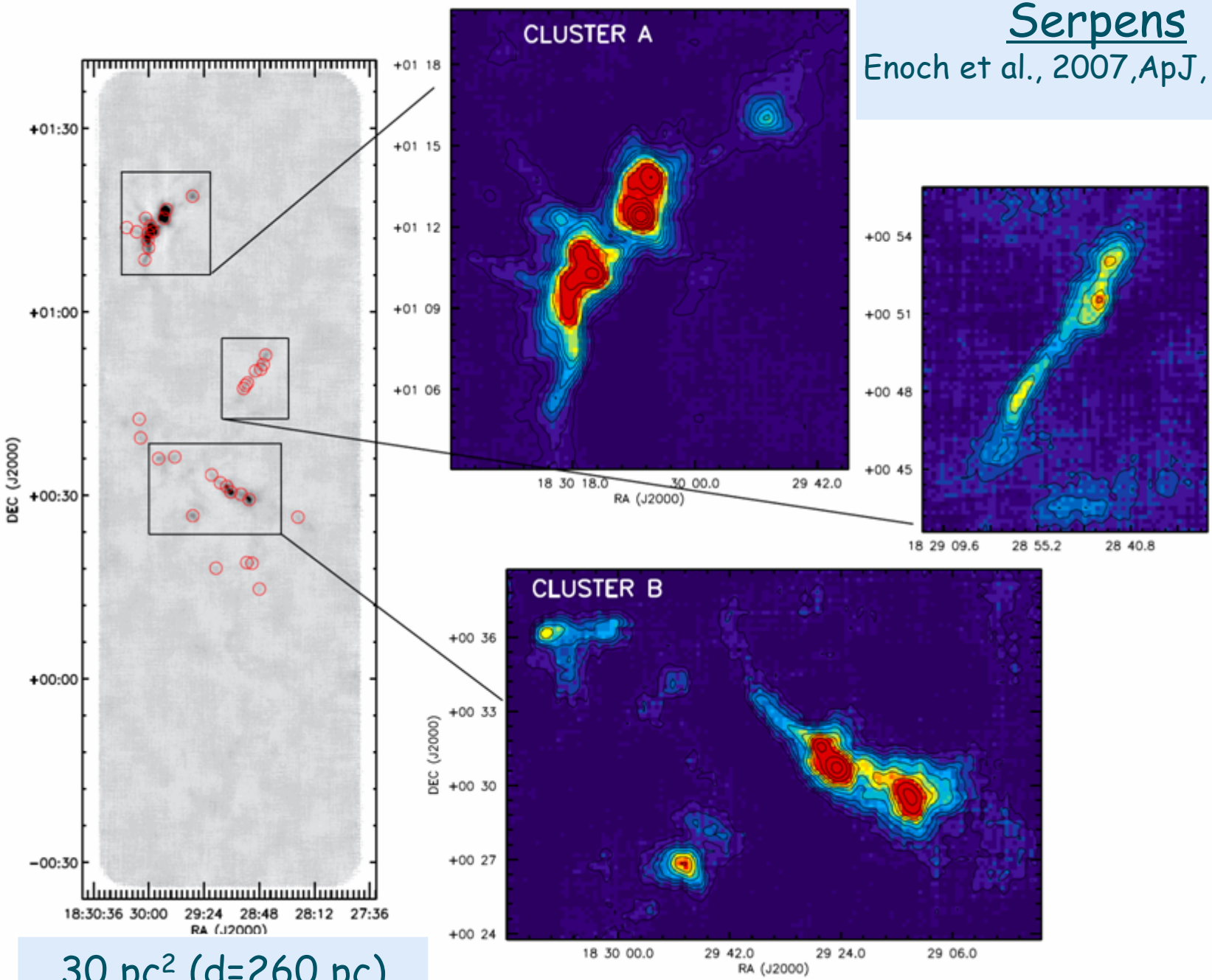
Ophiuchus

Young, Enoch, et al. 2006



Serpens

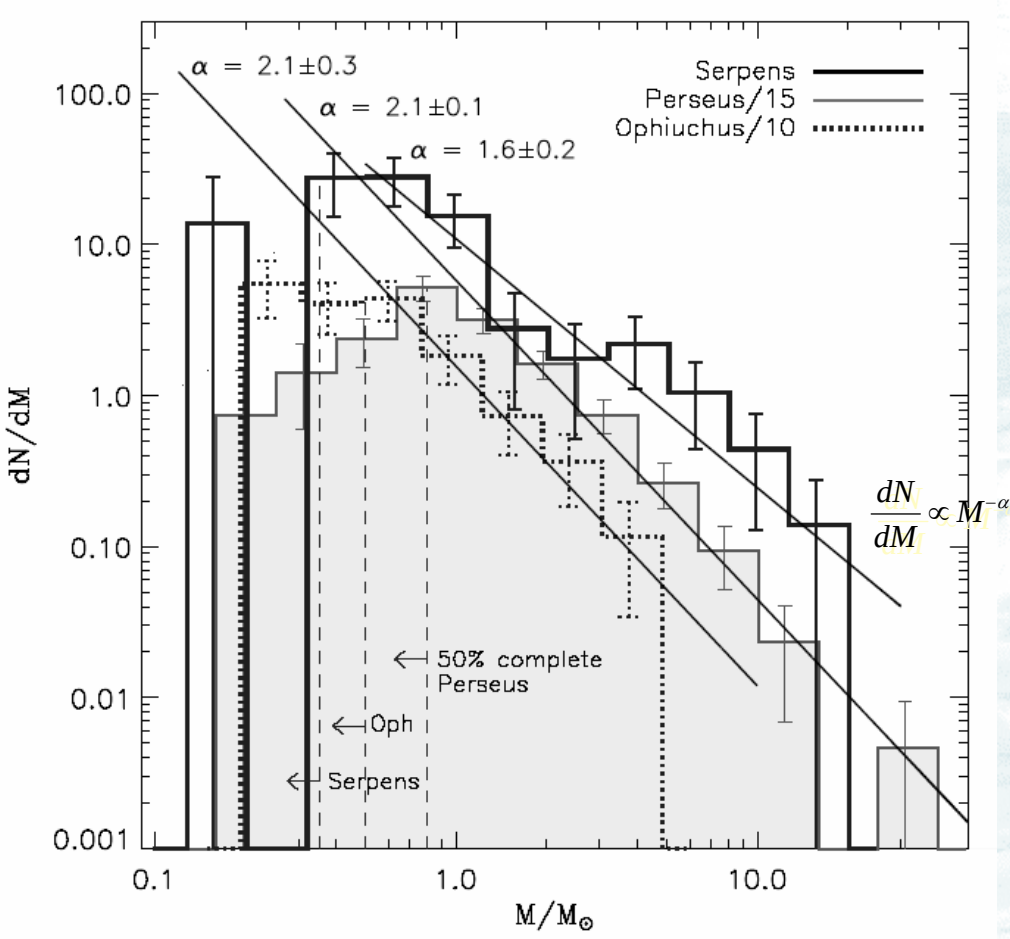
Enoch et al., 2007, ApJ, in press



30 pc² (d=260 pc)

Core Mass Distribution (CMD)

- Overall CMD consistent w. IMF → fragmentation determines stellar masses
- Prestellar core lifetime ~2-4x10^{5}yr → dynamic, turbulent formation
- BUT details of CMD dependence not consistent with turbulence simulations
- AND detection of dense cores in high column density ($A_V > 7$) regions → magnetic field role



(Enoch 2007; PhD Dissertation)

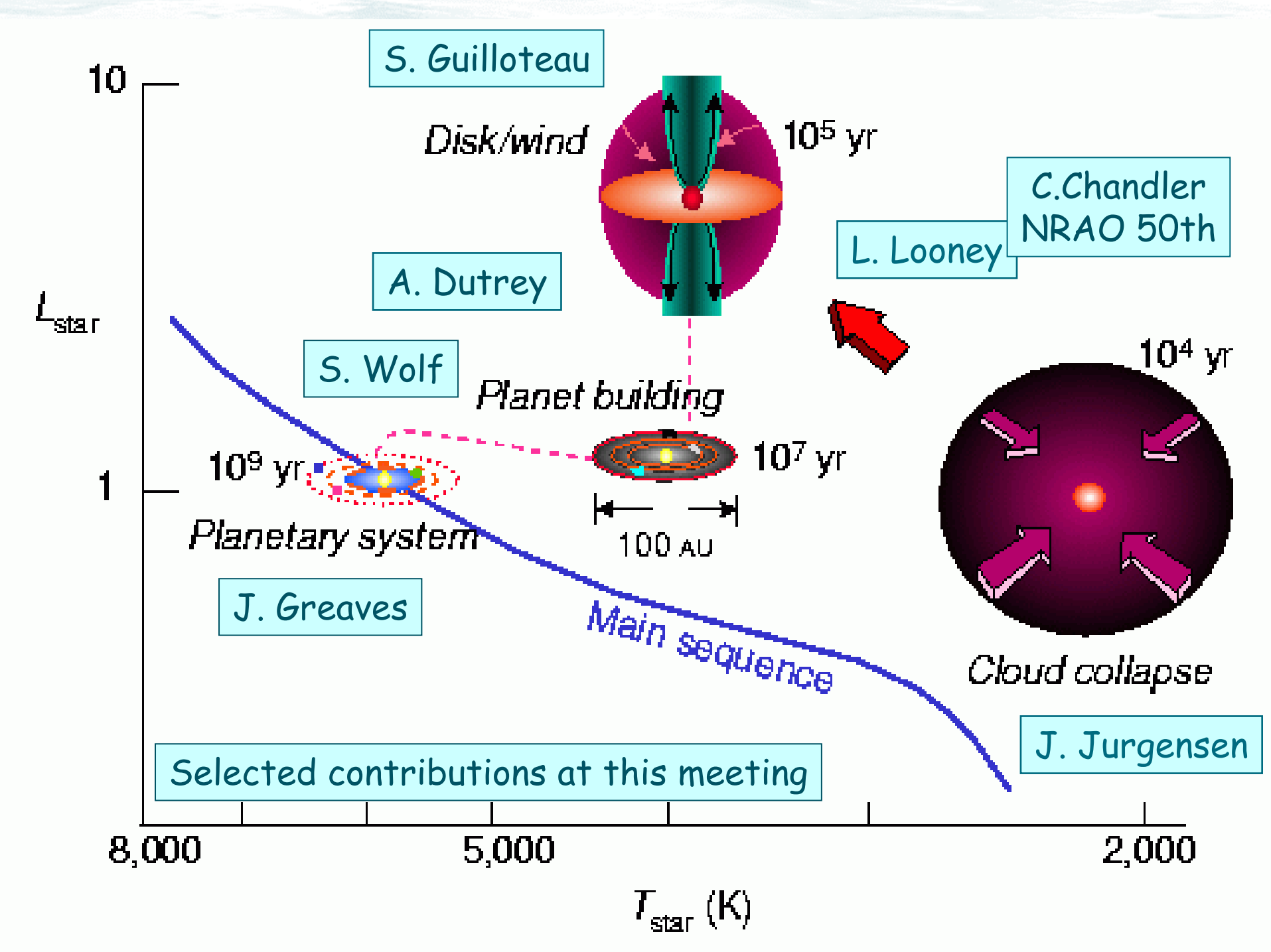
Bolocam + Spitzer c2d →108 prestellar cores
137 protostars (43 Class 0, 94 Class I)

Cores, Fragmentation, IMF and all that

- Considerable theoretical efforts
- Fragmentation due to turbulence?
- Effect of magnetic fields?
- SCUBA surveys, COMPLETE
- 1.1 mm Bolocam (CSO) + Spitzer c2d Surveys

- Unresolved problems
- Fundamental to star formation
- Transformational ? Probably

(see also J. Jurgensen's presentation this meeting)

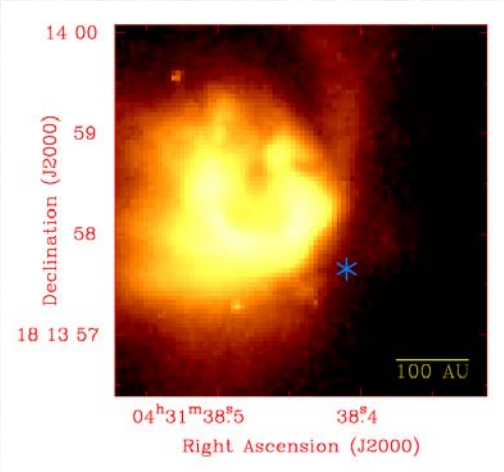

S. Guilloteau
Disk/wind
10⁵ yr
C.Chandler
NRAO 50th
L. Looney
A. Dutrey
S. Wolf
Planet building
10⁴ yr
10⁹ yr
10⁷ yr
100 AU
Planetary system
J. Greaves
Main sequence
Cloud collapse
J. Jurgensen
Selected contributions at this meeting
10
1
L star
8,000
5,000
2,000
T star (K)

Early Disks

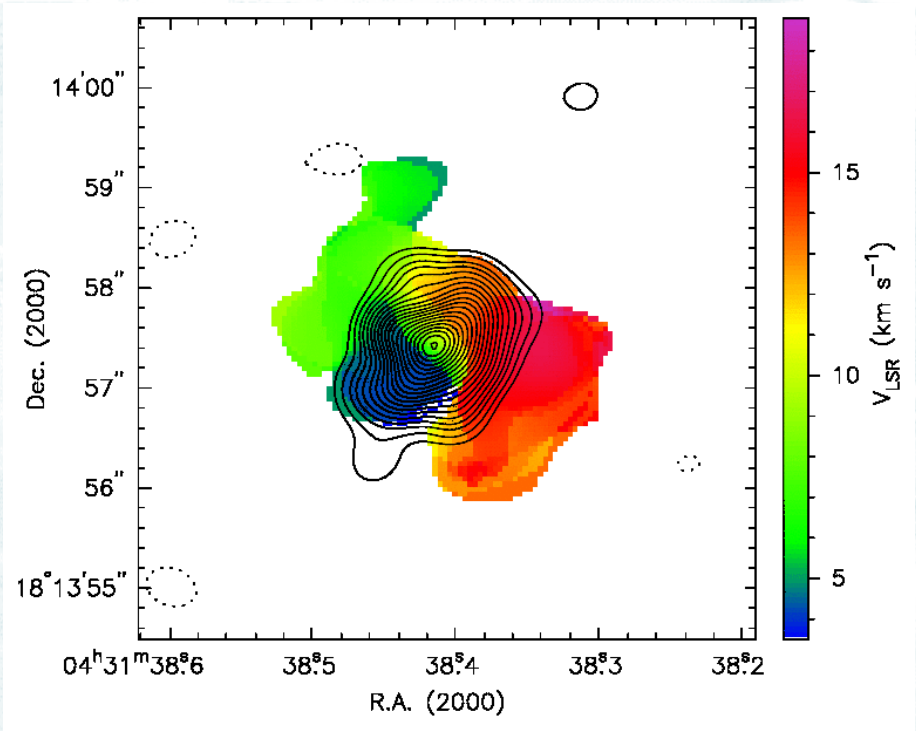
ALMA vital for:

- structure, dynamics, physical conditions (S. Guilloteau, A. Dutrey, V. Pietú, S. Andrews)
- chemistry (M. Krumholz, C. Qi, K. Willacy)
- role of the magnetic field (R. Crutcher)
- build-up of planetesimals (L.Testi)

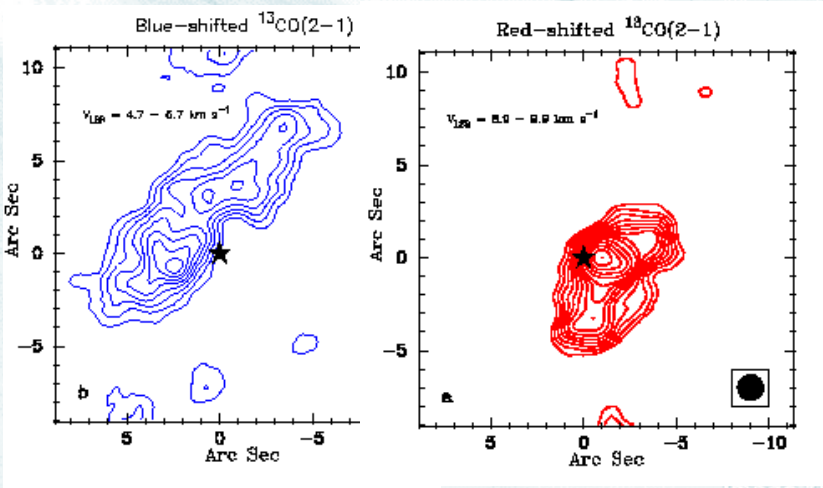
HL Tau: SMA Continuum & CO(3–2)



Stapelfeldt et al. (1995)



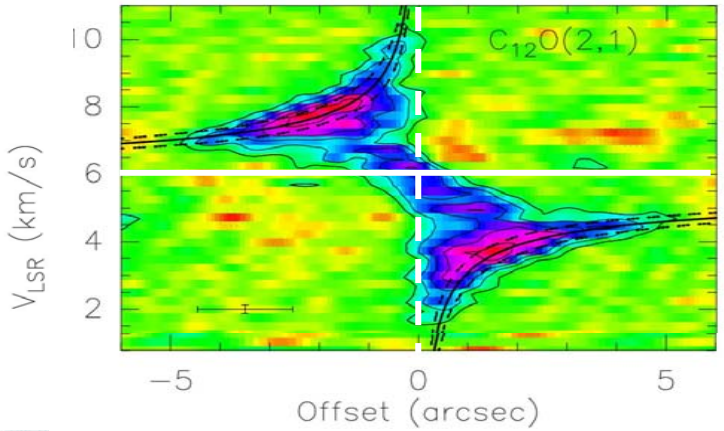
Chandler, Brogan, Koerner, Sargent, in prep

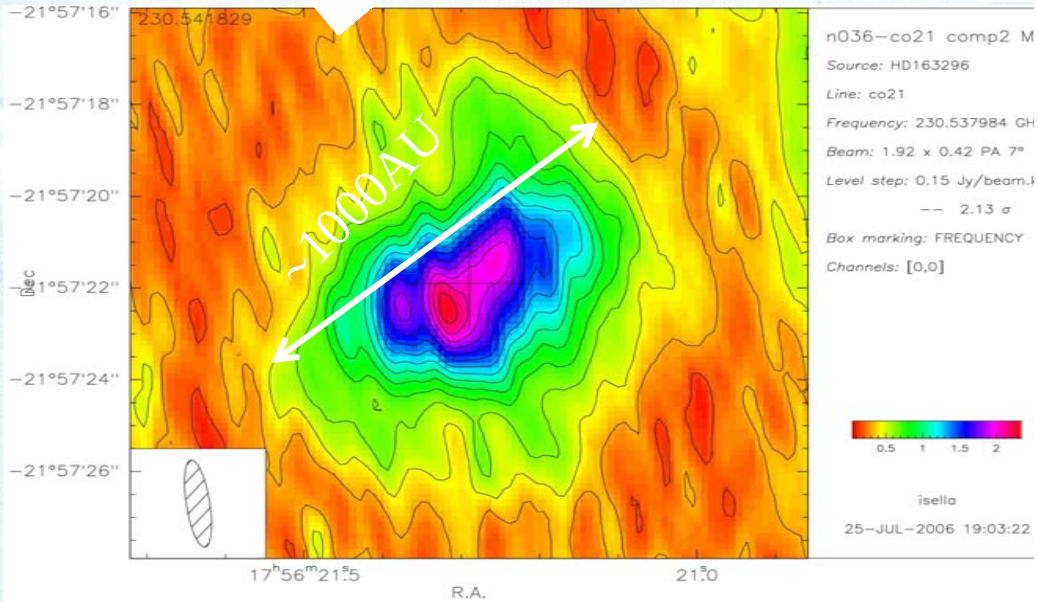


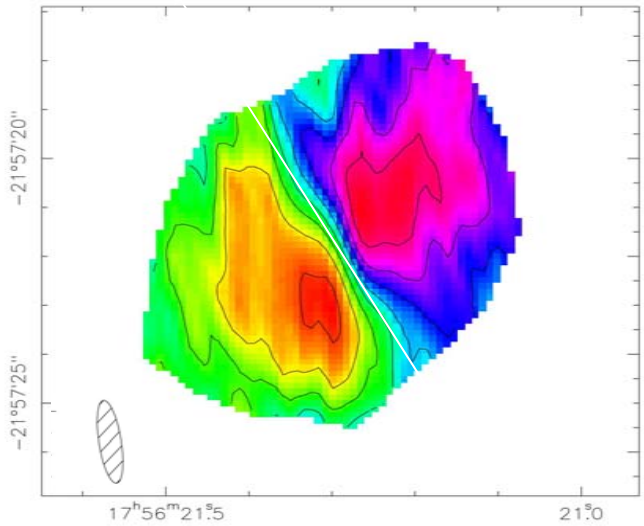
Credit: C. Chandler NRAO 50th Symposium

Resolving the disk properties

HD163296





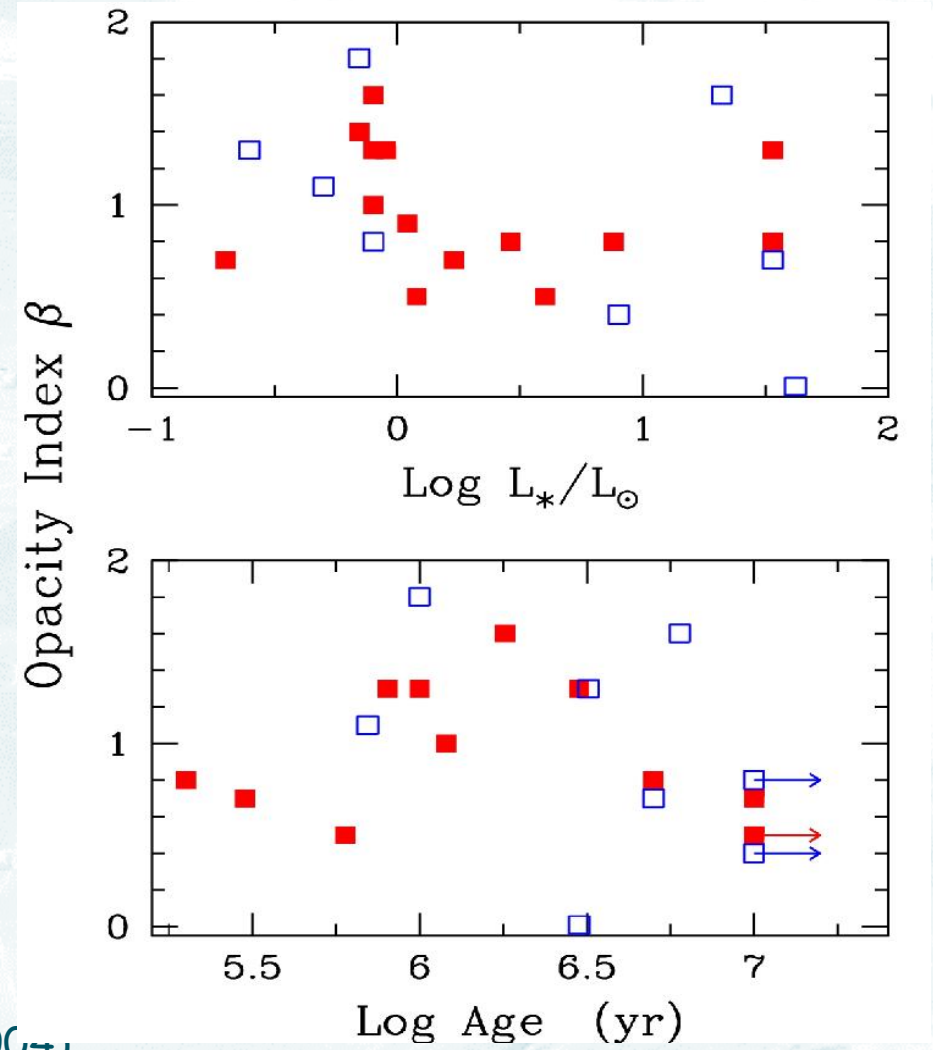


(Isella et al 2006)

from L. Testi presentation this meeting

Large grains in HAe and TTS systems

- Values of β range from 1.8 to 0.1 (from ISM grains to pebbles)
- No obvious correlation with stellar properties
- No obvious correlation with age
- No obvious correlation with disk surface grains
- Small, & biassed samples



Data:
HAe (Testi et al. 2001; 2003; Natta et al. 2004)
TW Hya (Wilner et al. 2000;Calvet et al. 2002)
TTauri stars (Rodmann et al. 2005)

(Natta, Testi, et al. PPV)

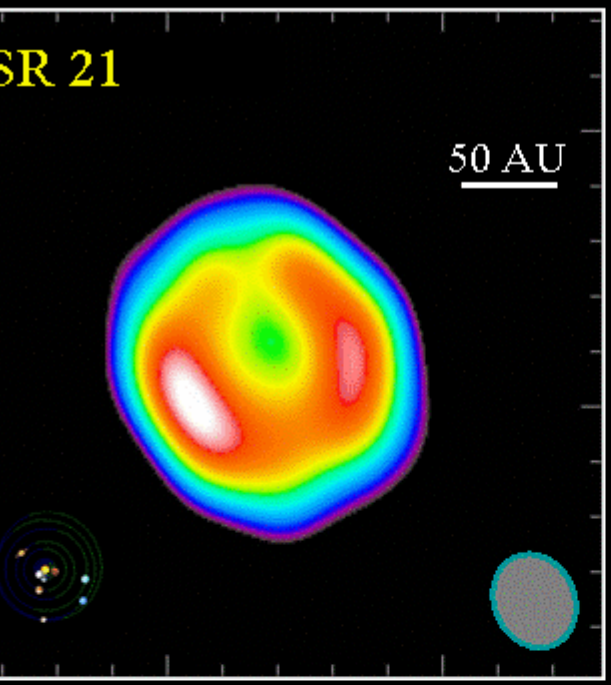
Early Disks

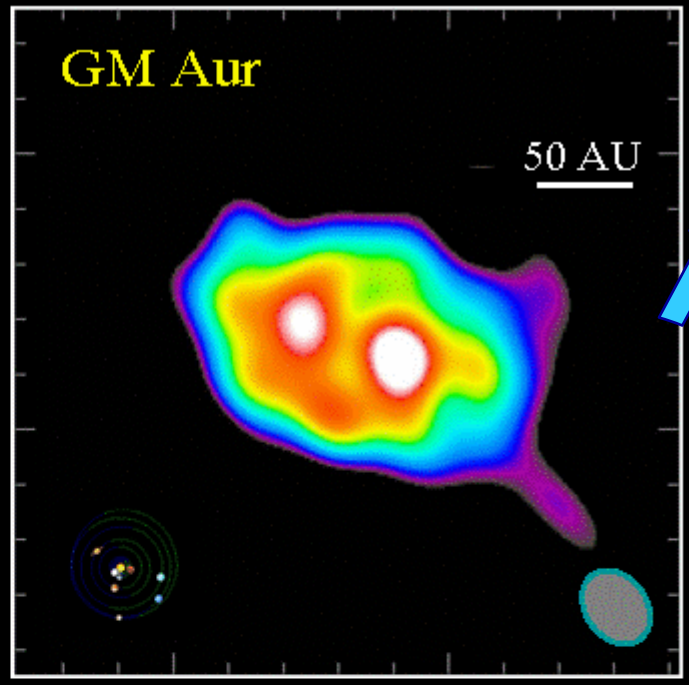
ALMA vital for:

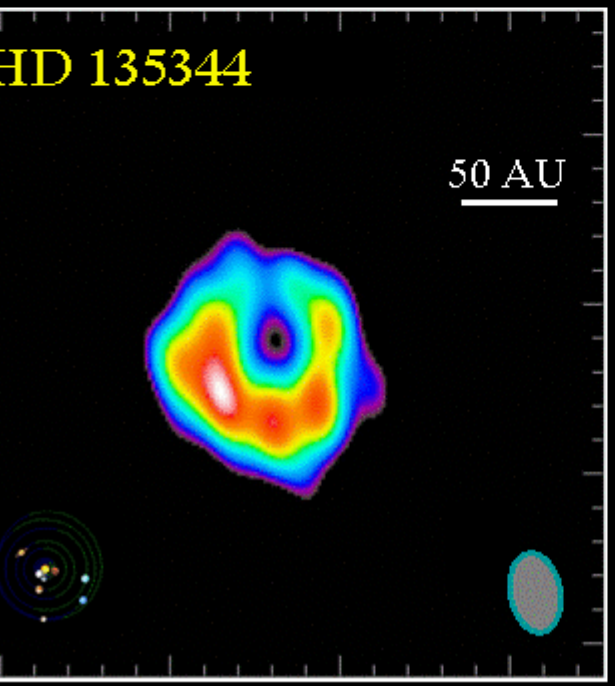
- structure, dynamics, physical conditions (S. Guilloteau, A. Dutrey, S. Andrews)
- chemistry (M. Krumholz, C. Qi, K. Willacy)
- role of the magnetic field (R. Crutcher)
- build-up of planetesimals
  - **evolution or revolution?**

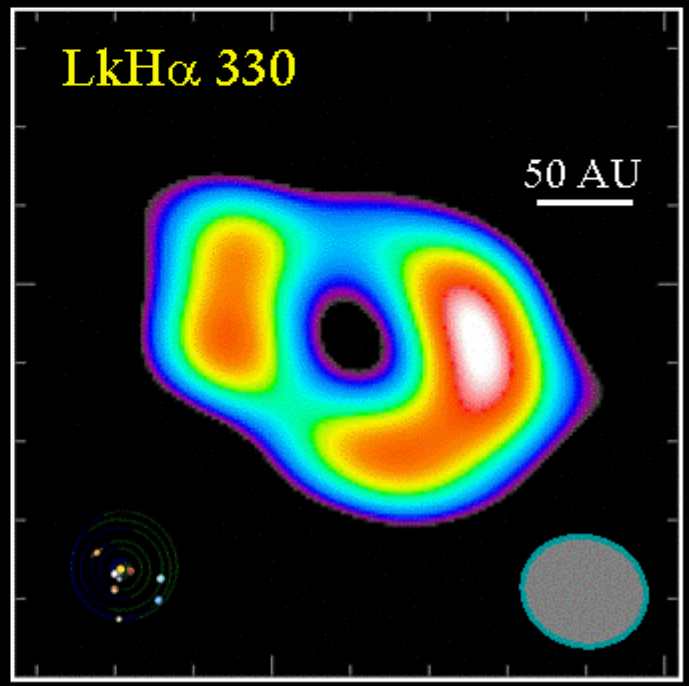
Transitional Disks?

Different Disks?









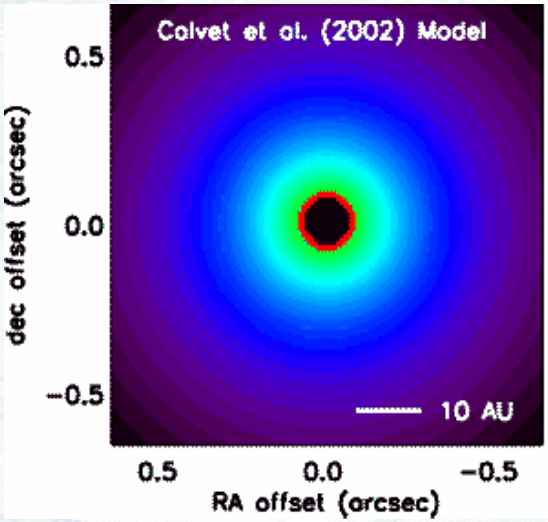
Transition Disks

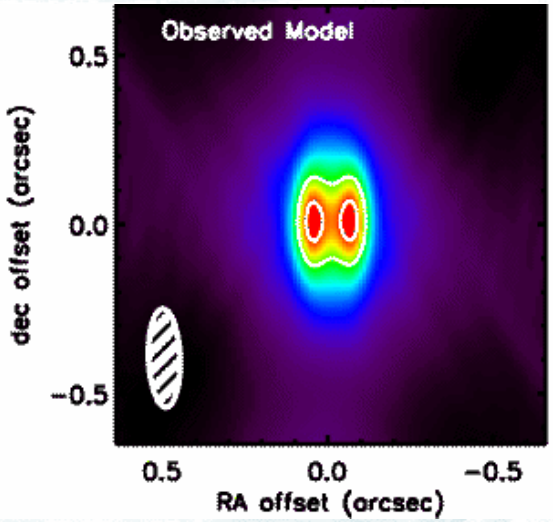
SMA 340 GHz continuum

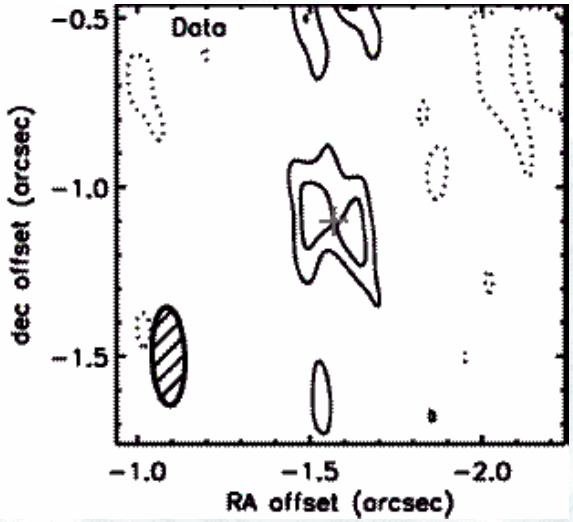
(Brown, Blake, et al. 2007)

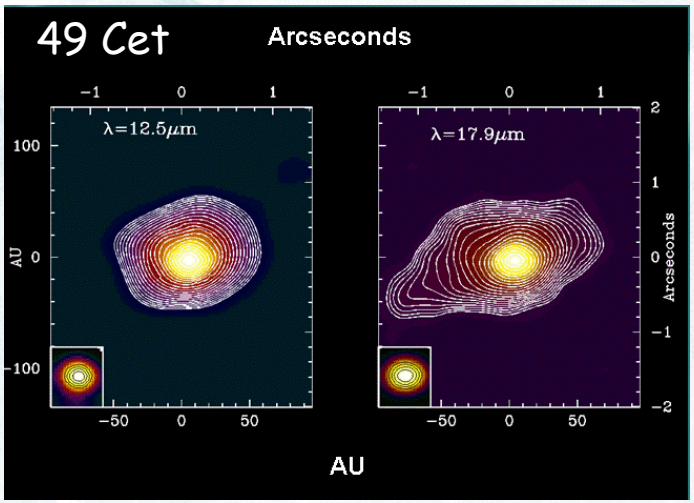
and more....

M. Hughes (Poster): TW Hya VLA 7mm – 4 AU hole

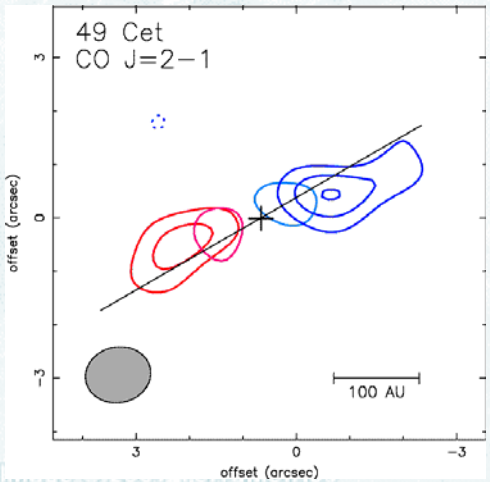




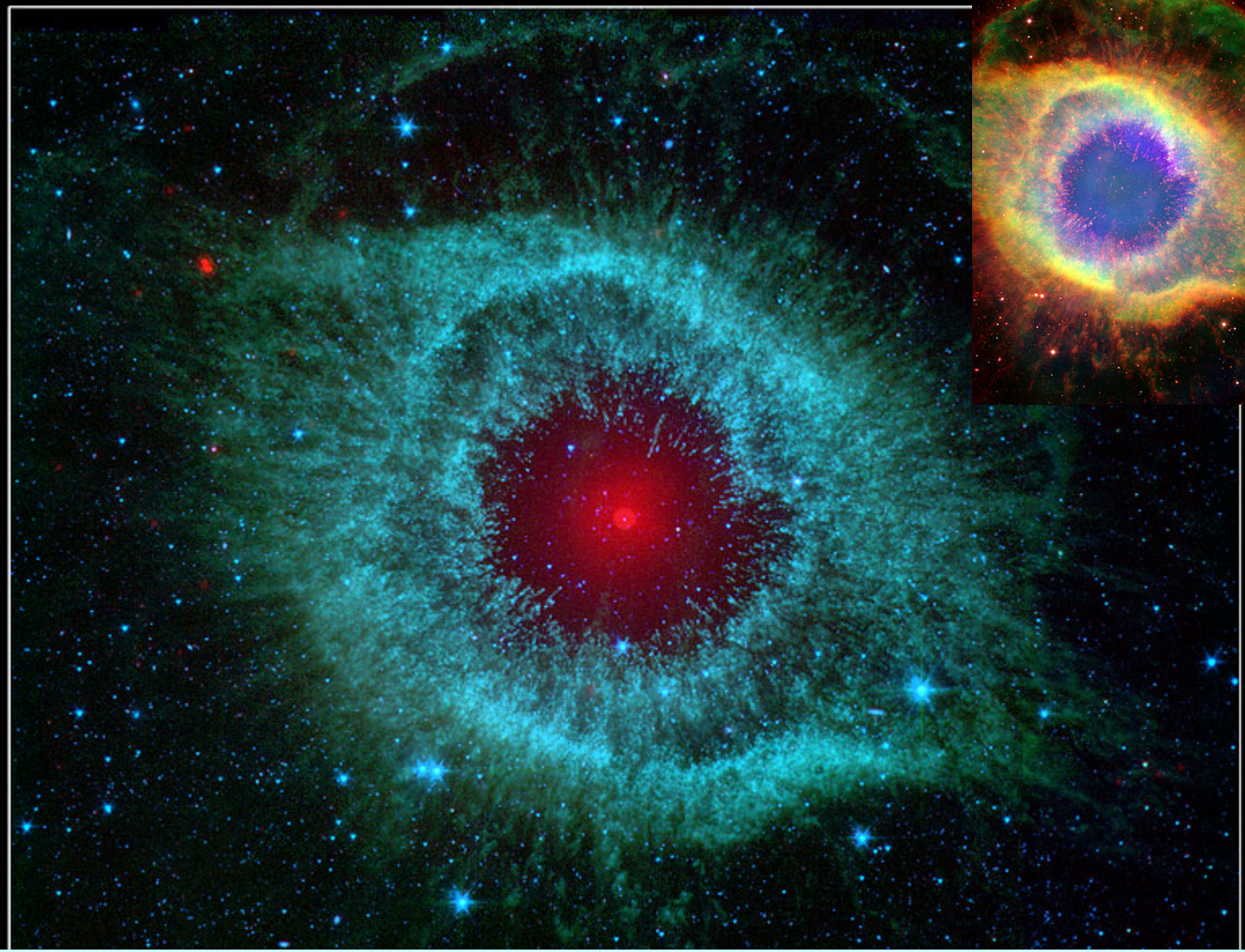




Wahhaj et al 2007



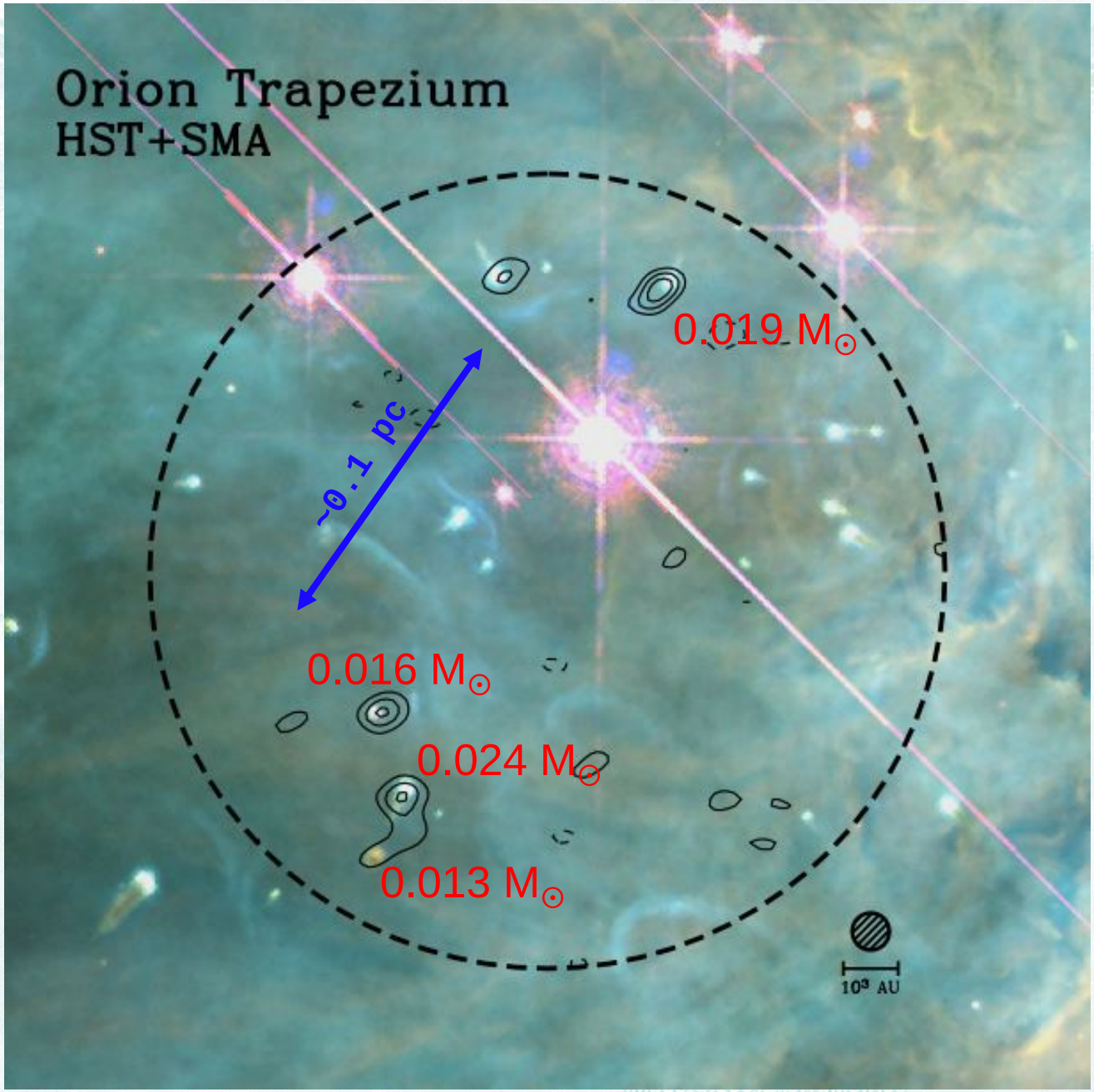
Wilner & Hughes



Helix Nebula: centered on hot, luminous WD star
IR excess consistent with associated debris disk
(Su et al. 2007; from M. Werner, this meeting)

Other Important Considerations

- ALMA observations closer to theoretical models (Neal Turner)
  - opportunities for revolutionary discovery? c.f. Eric Herbst's remarks re: models
- Effect of clustering on disk properties (Paul Clark)
  - effects on planet formation?
- Disks in massive star forming regions (John Bally)
  - could be transformational!



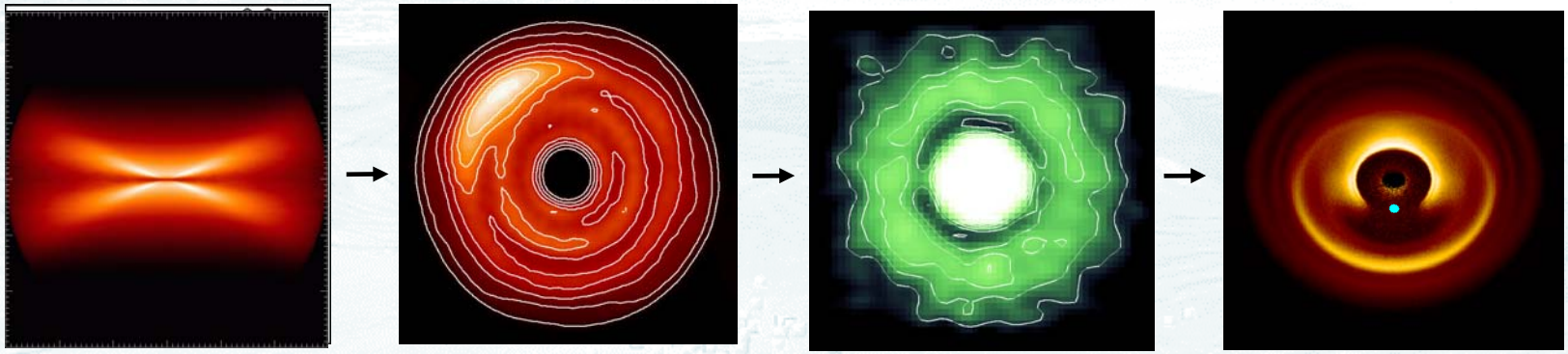
Protoplanetary disks detected at 880 μm in massive star forming region

Capable of forming solar system scale architectures

Williams, Andrews, & Wilner 2005

from J. Bally, this meeting

Theory and Observations: S. Wolf

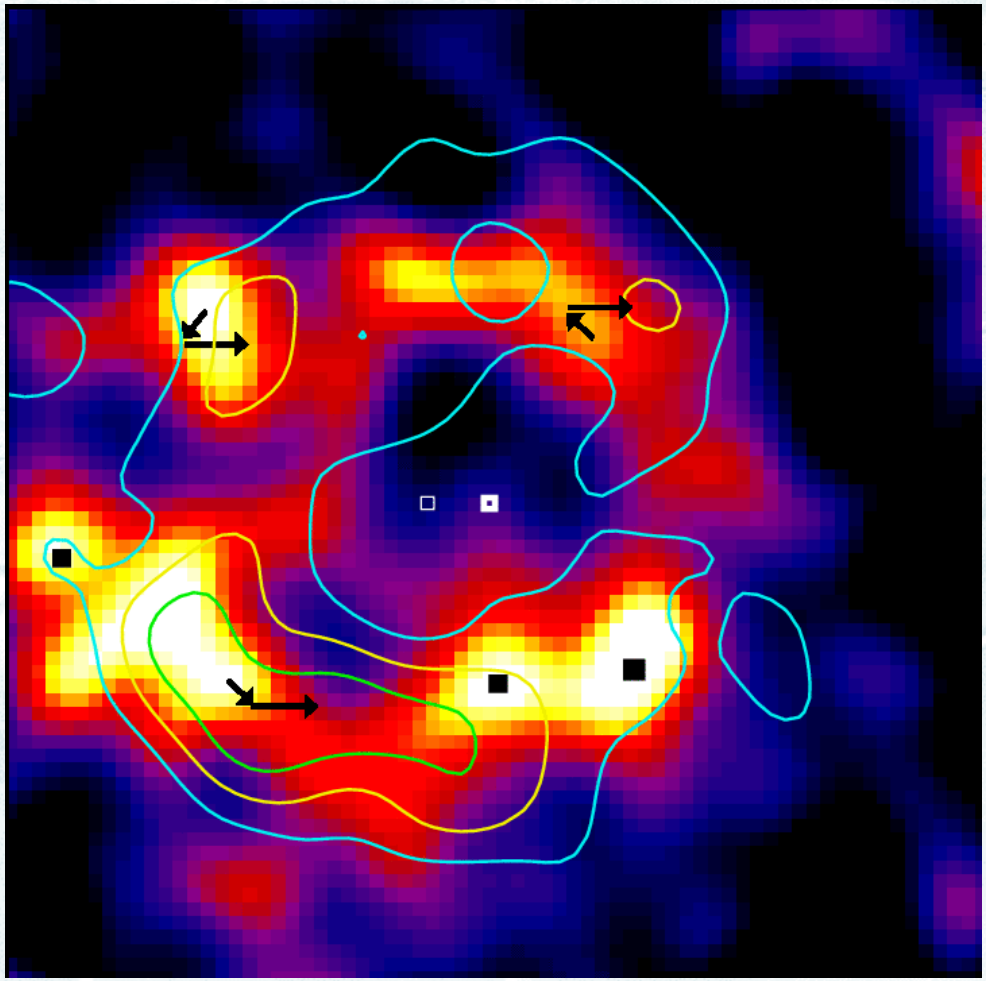


1. Early disk evolution
2. Vortices – precursors of planets?
3. Disk-planet interactions – gaps
4. Giant planets in Debris Disks

Hints of the future?

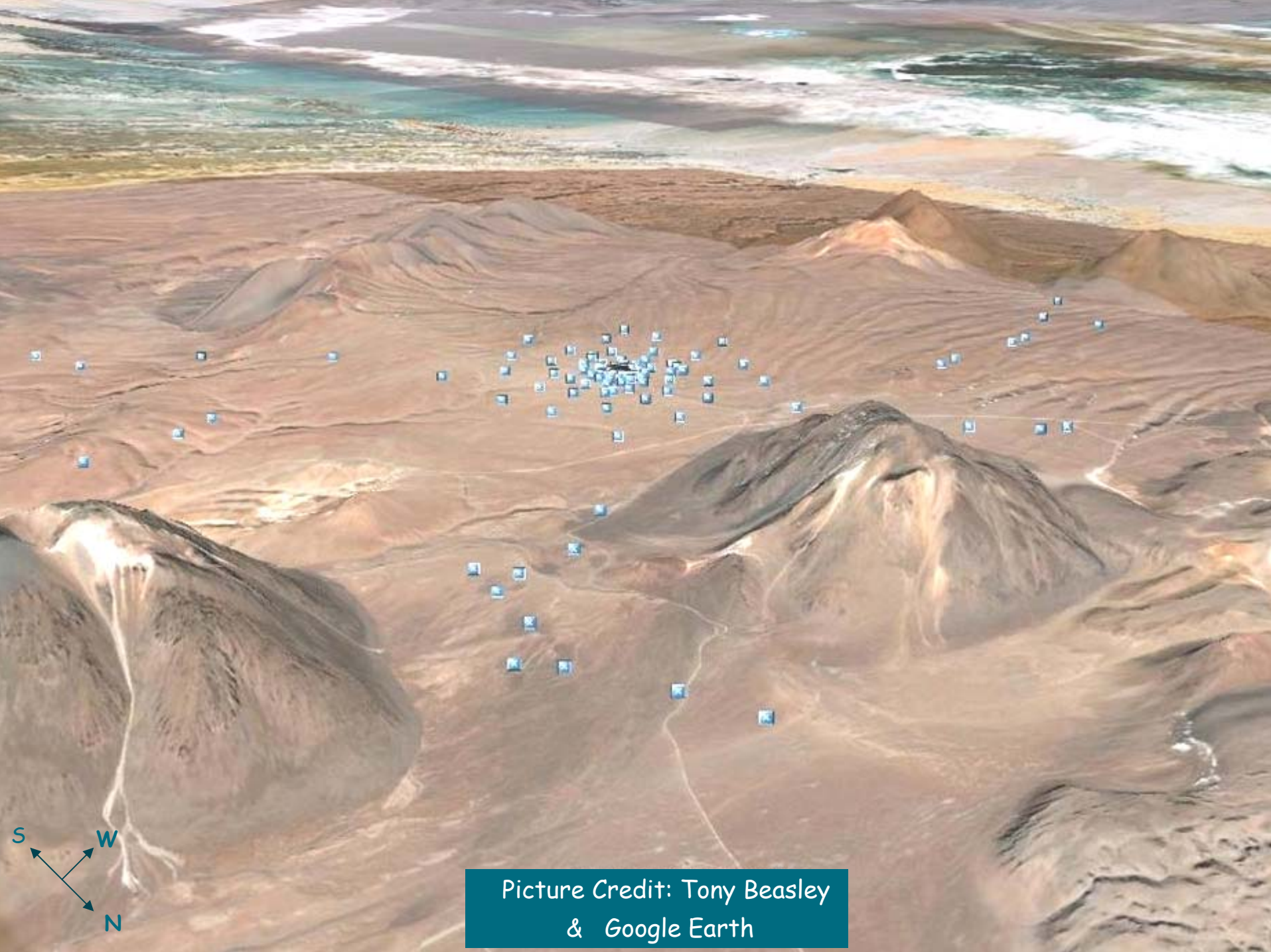
ALMA
ATACAMA LARGE MILLIMETER ARRAY

Debris Disks: J. Greaves



- Orbital motions
- JCMT observations 4 years apart
- ALMA – months?

Let the revolution begin!



Picture Credit: Tony Beasley
& Google Earth

detente

Authors names