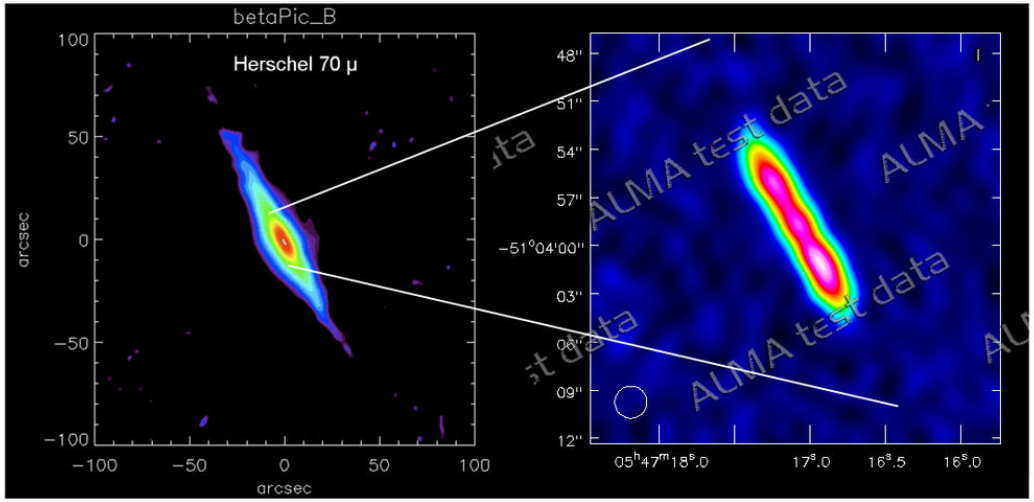

Cold Dust in Star Formation

Science ideas for Early-ALMA

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Adapted from U. Chile Early-ALMA Workshop
December 14-15 2010
www.das.uchile.cl/workshop_dec2010/

THE UNIVERSITY OF NEW SOUTH WALES

Early-ALMA assumptions

- 16 Antennae in “extended” configuration
  - 36-400m baselines
- 8 GHz bandwidth: <u>Continuum</u>
  - 4x128 channels of 15 MHz
- 4 Frequency Bands:
  - 3, 6, 7, 9 (100, 230, <u>345</u>, 690 GHz)
- Pointed Mosaics
  - 25-50 positions
- Cycle 1:
  - Linear Polarization

Resolution & Sensitivity

Freq (Band) (GHz)	FoV (arcsec)	Angular Resn. (arcsec)	Max Scale (”)	Point Source mK 5σ, 1hr	Ext. source over beam. mJy 5σ, 1hr	Linear Polarization mJy 5σ, 5%,1hr
100 (3)	62	1.6	11	8	0.14	3
230 (6)	27	0.7	5	11	0.20	4
345 (7)	18	0.5	3	21	0.37	7
690 (9)	9	0.3	1.5	200	3.5	70

16 Antennae x 8 GHz Bandwidth @ -50°

$$S \propto \frac{T_{sys}}{N\sqrt{\Delta v \bullet \tau}} \Rightarrow \sim 4 \times \text{ better for full - ALMA}$$

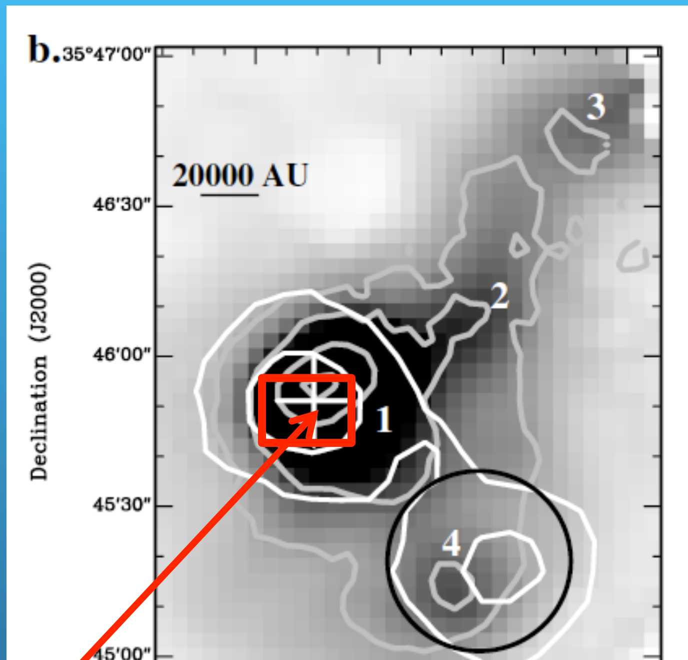
Four Suggested Projects

- Protostellar Initial Mass Function (IMF):
  - Mass spectrum of dust clumps within cold cores
- Earliest stages of Massive Star Formation (MSF):
  - Temperatures of the cold dust clumps
- Magnetic field structure within dust cores:
  - Linear polarization of dust clumps
- A very special source – the Central Molecular Zone:
  - Dust cores of Sgr A, Sgr B2, Sgr C & G1.3

1. Protostellar Initial Mass Function
Dust core structure on the arcsecond scale

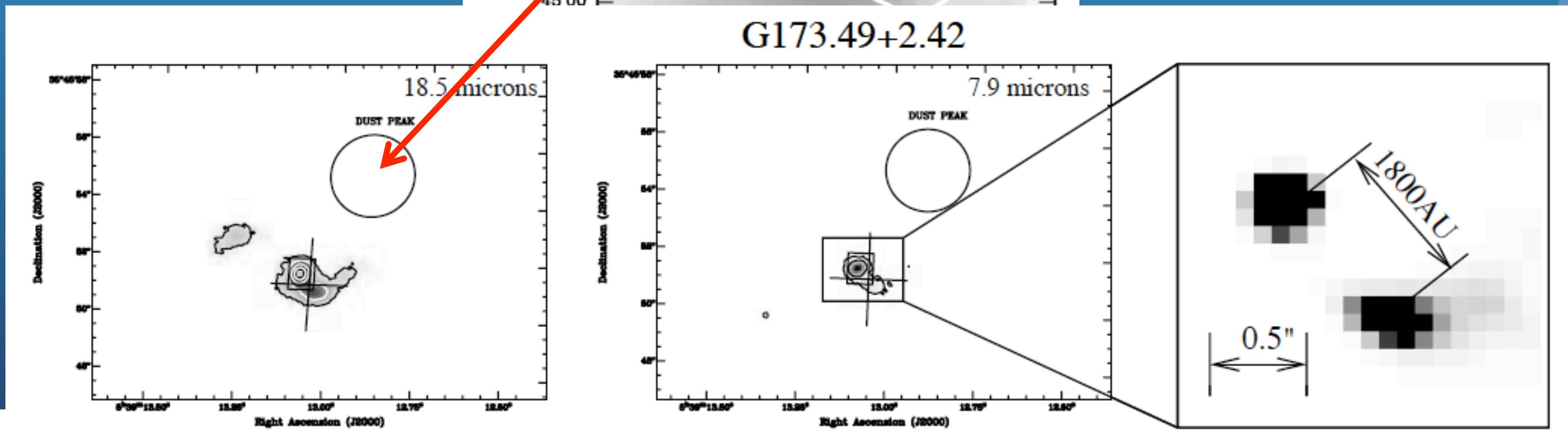
1 arcmin

Arcsec resn in mid-IR
Several 4-7 $M_{\odot}$ sources
Gemini 8 + 18μm
Longmore et al, 2006



Massive, cold dust core
in the sub-MM
M~100$M_{\odot}$, T~50K, L~50,000 $L_{\odot}$
SCUBA 450+850μm, MSX 21μm

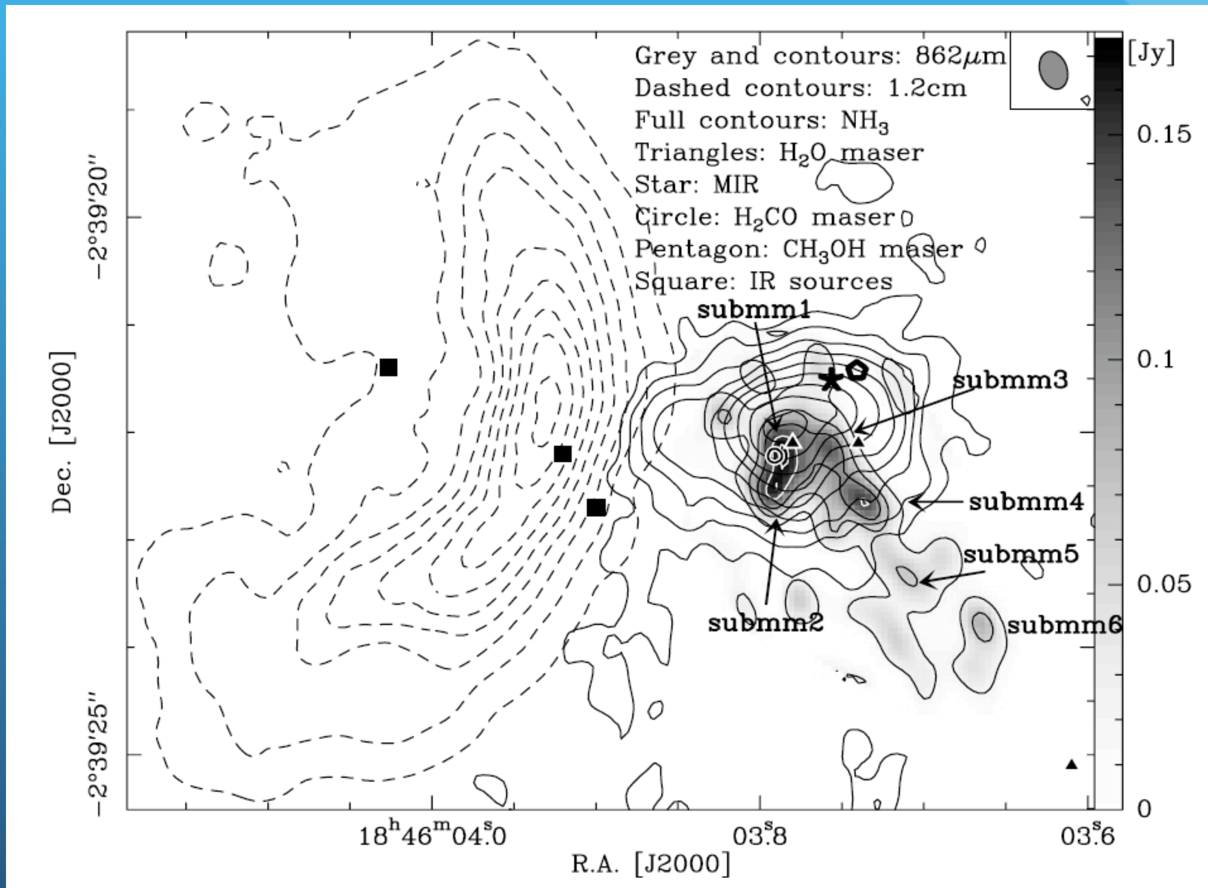
Minier et al. 2005



HMC G29.96 with SMA @ 345 GHz

Proto-Trapezium Cluster, ~100 mJy sources, 5-10 $M_\odot$

5 arcsec



5σ ~ 100 mJy

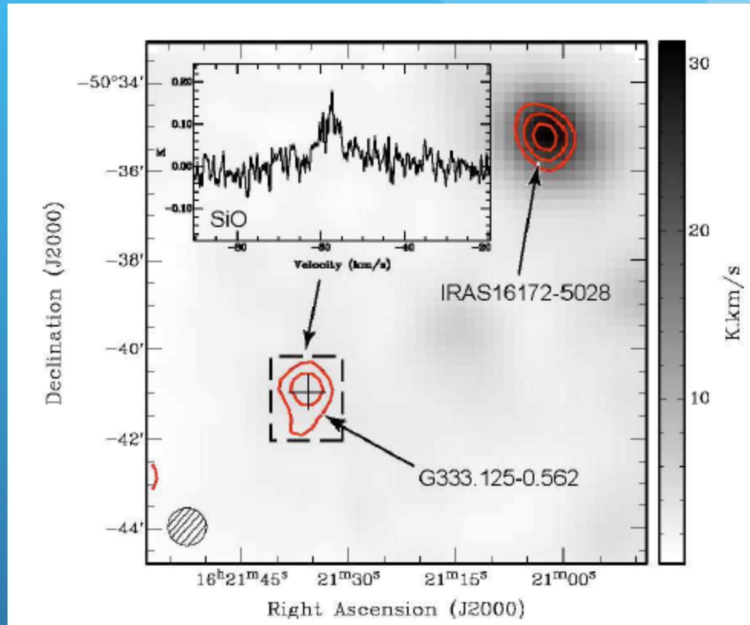
➔M(5σ) > 3 $M_\odot$

Early-ALMA is ~300 x better!

Beuther et al. 2007

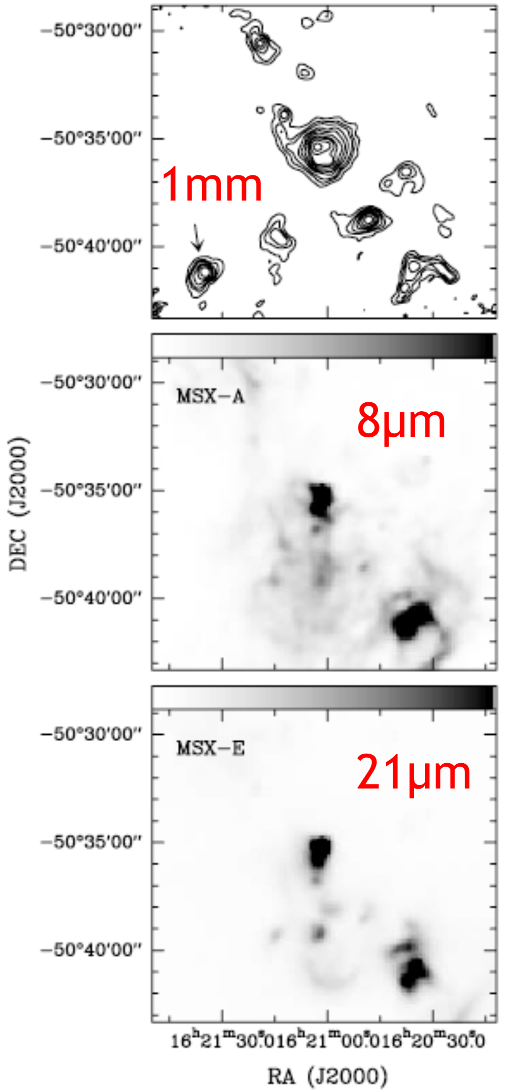
The cold, cold core in G333 (The 'DQS')

Lo et al. 2008



SiO contours
on CS image

M~1,800$M_\odot$,
T~19K,
L~10,000 $L_\odot$



Garay et al. 2004

Early-ALMA Sample Project I: Protostellar Initial Mass Function in the G333 cold core

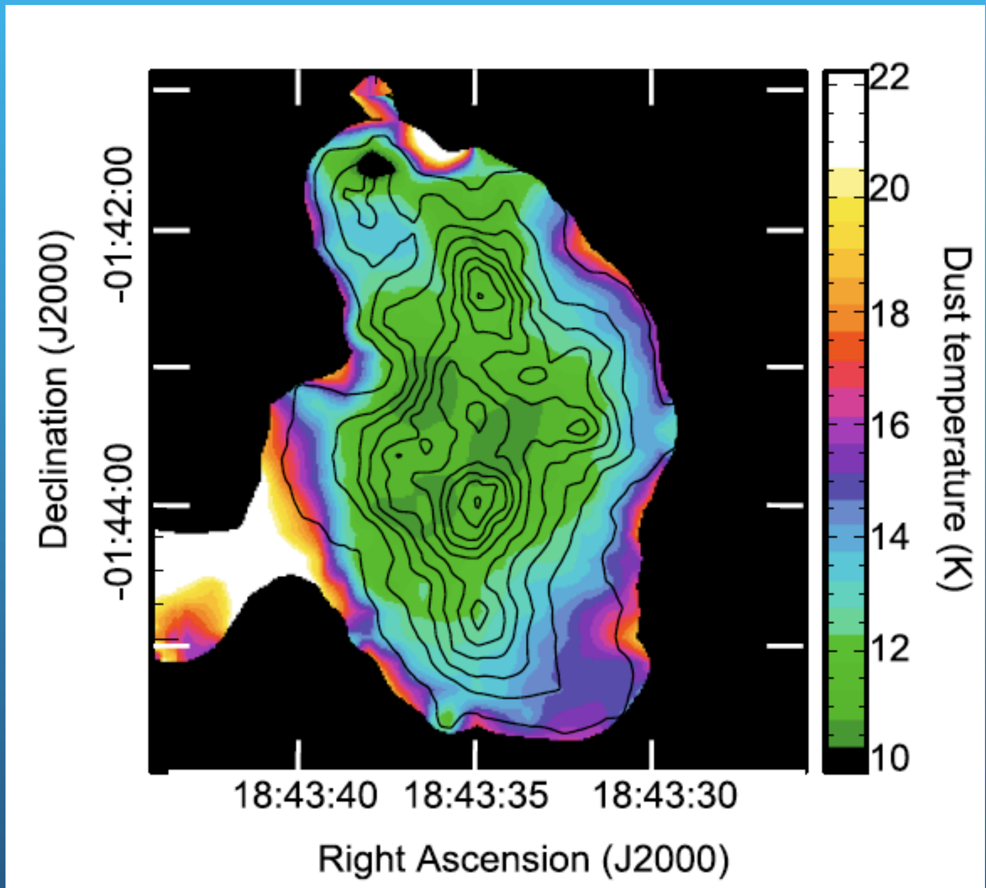
$$M_{gas} \approx \frac{F_\nu d^2}{\kappa_{dust} B_\nu(T_{dust}) R_{dust-gas}}$$

Frequency	5σ, 10min (mJy)	Mass $M_\odot$ @ 10K
100 (3)	0.44	10
230 (6)	0.63	0.3
345 (7)	1.2	0.1
690 (9)	11	0.2

G333: d=3,600pc, T=10K

To cover 1 arcmin requires 4 x 60/18 = 14 positions = ~3 hours

2. Earliest stages of MSF
Temperature structure of protostellar cores



Herschel SEDs of IRDC
Peretto et al. 2010

$$F_\nu \approx \Omega B_\nu(T)\varepsilon_\nu$$

and $\varepsilon_\nu \sim \nu^{-\beta}$

So that $F_\nu \approx \frac{\Omega T}{\nu^{2+\beta}}$ when $h\nu << kT$

$T = 10K$: 200 GHz

$T = 20K$: 400 GHz

$T = 50K$: 1 THz

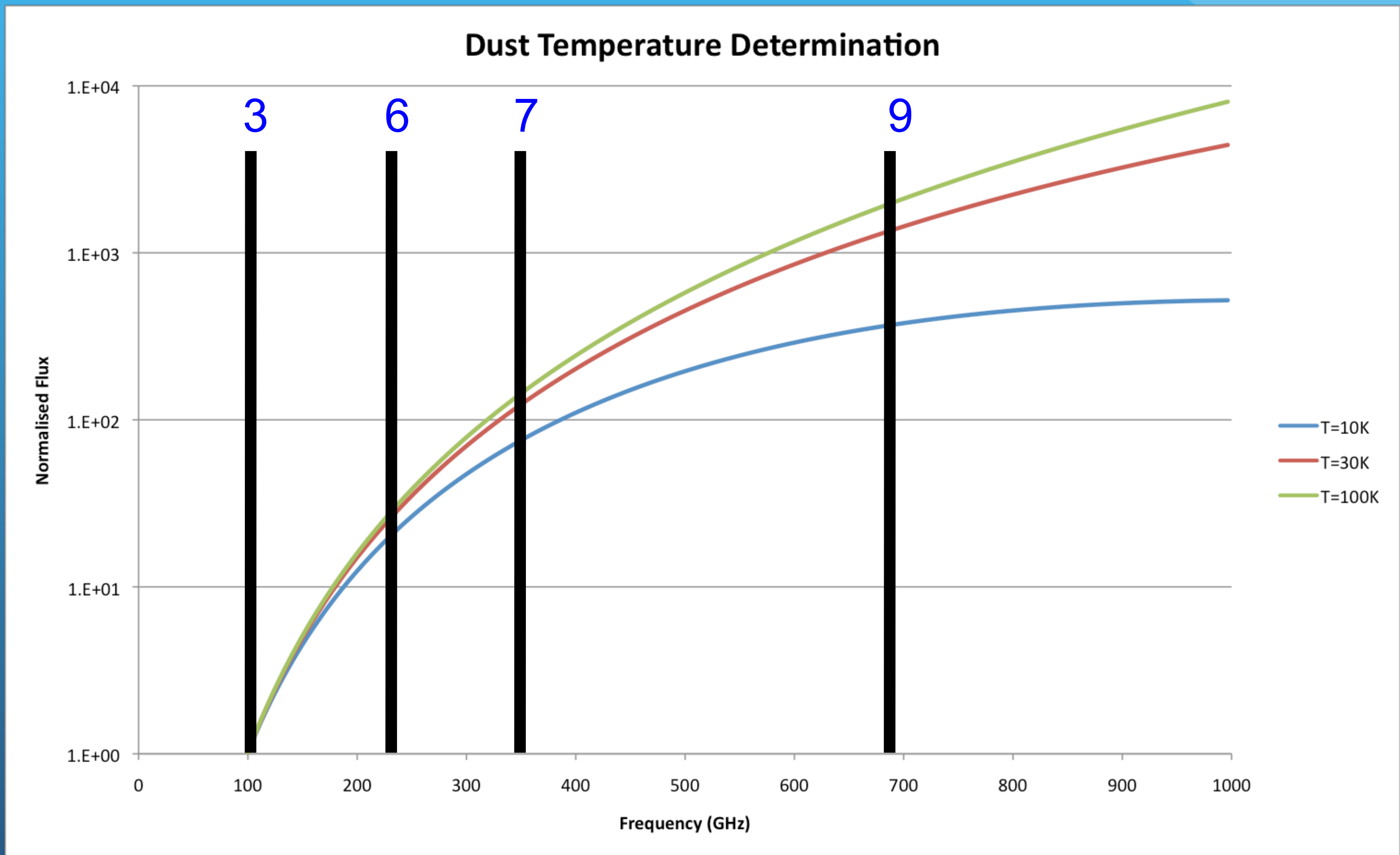
ALMA:

(i) Resolve sources gives Ω

(ii) SED give slope T

Dust Temperatures from SEDs

Caution: maximise frequency baseline to best constrain the Temperature

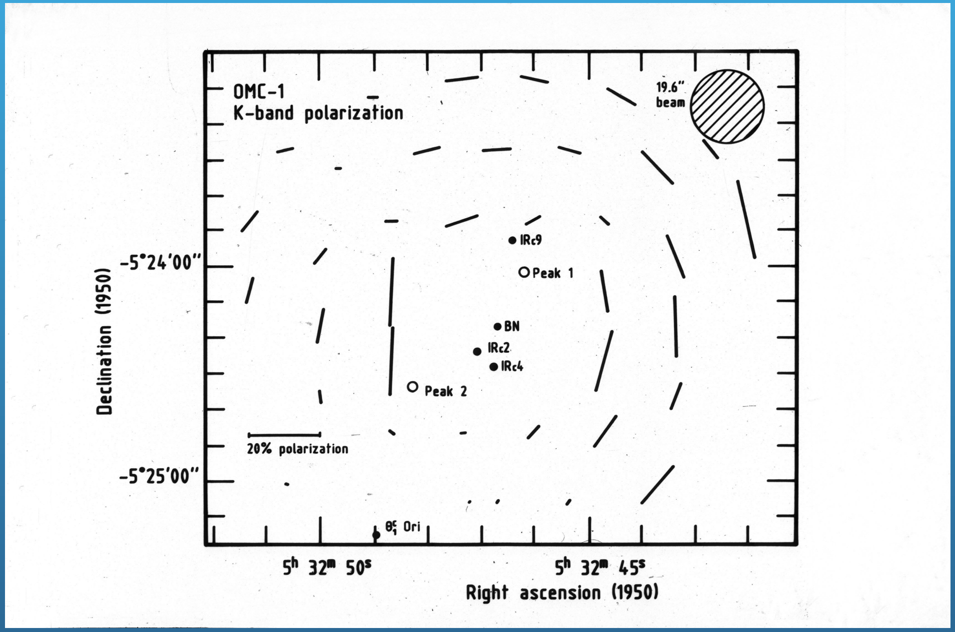


100 GHz band not sensitive to same mass range:

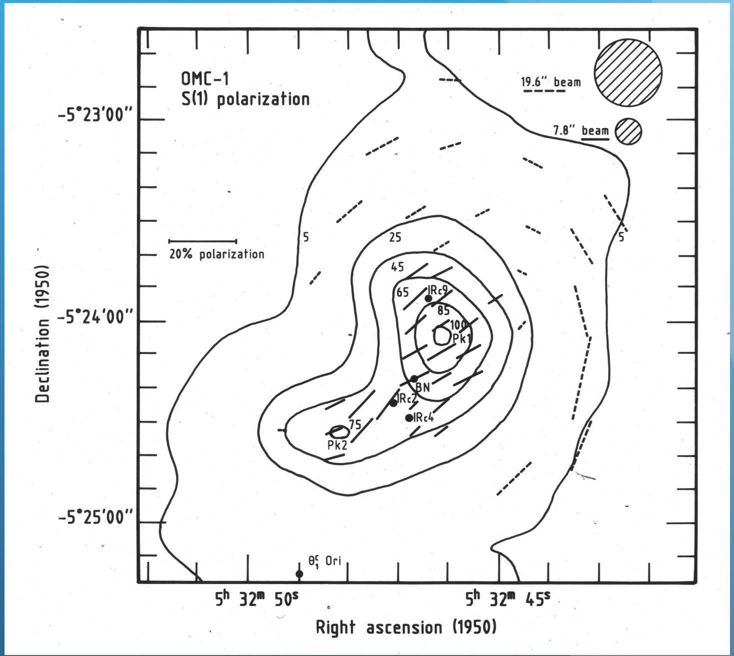
So, to determine T for M > 1 $M_\odot$ needs Bands 6-7-9 x 3/√3 hrs ~ 5 hours

3. Magnetic Fields through dichroic linear polarization of the dust grain emission

2μm Continuum



2.12μm H_2 Line

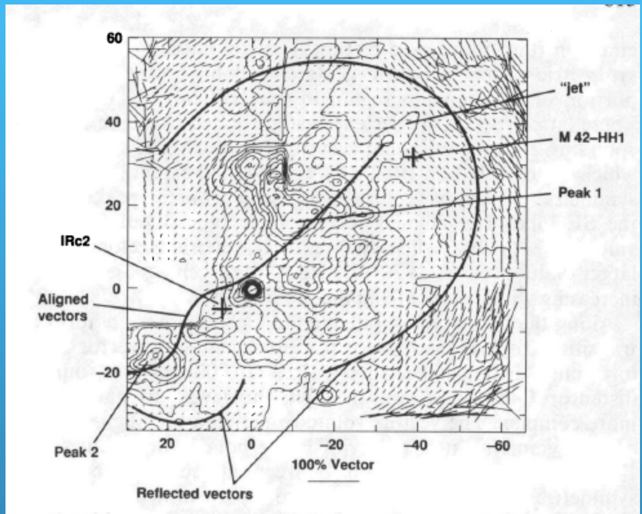


IR Reflection Nebula:
Location of Central Sources

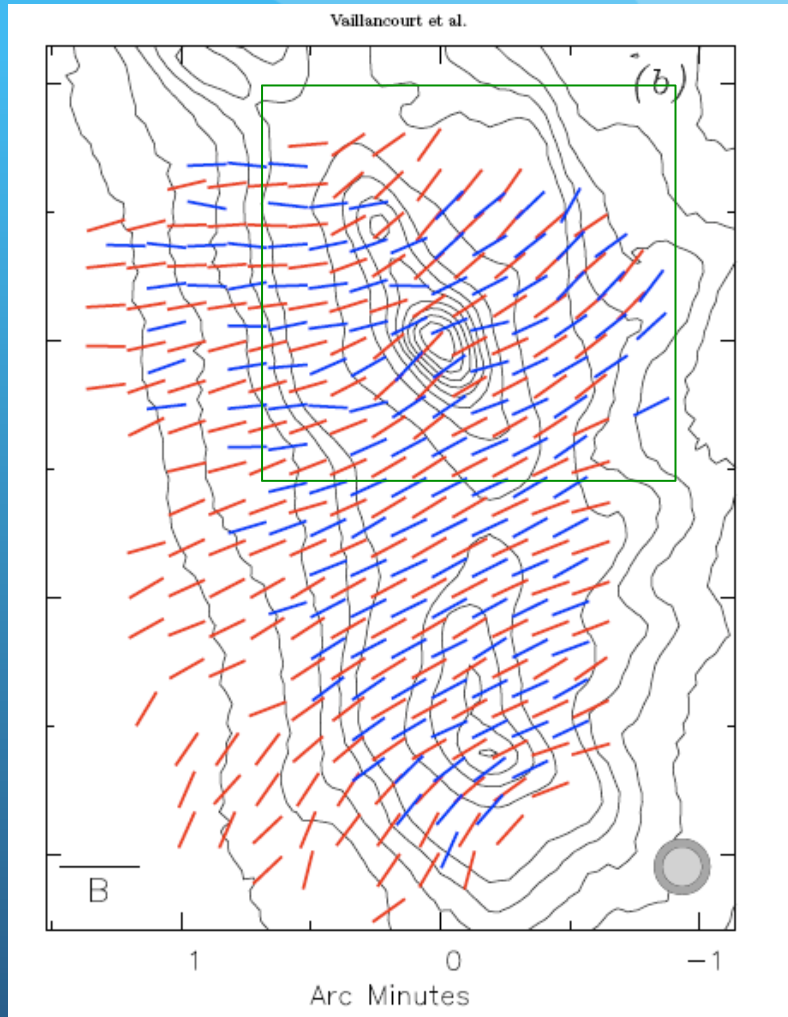
Reflection Nebula +
Dichroic alignment:
Direction of Mag. Field

Hough et al. 1986

Magnetic Fields in Orion

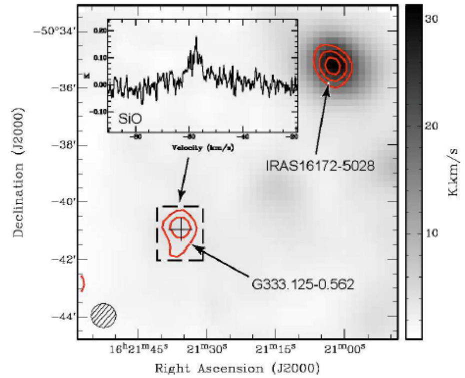


H_2 IR: arcsecond structure
Burton et al. 1991



Sub-mm: 450+850µm
10 arcsecond structure
Vaillancourt et al. 2008

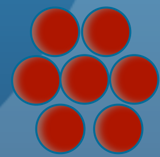
Sub-mm Linear Polarization in the G333 Cold Core



Lo et al. 2008

- 5% polarization requires photometry to 5% of source flux.
- Yields magnetic field structure on the arcsecond scale

Frequency (GHz)	Model Core Flux (19K, 1800$M_\odot$, 9000$L_\odot$) (Jy)	Knot flux @ 0.1% dilution (mJy)	Time for 5% polarization at 5σ (min)	Time to map 1′ (min)
100 (3)	0.2	0.2	12,000	12,000
230 (6)	6	6	27	240
345 (7)	24	24	6	75
690 (9)	200	200	7	200

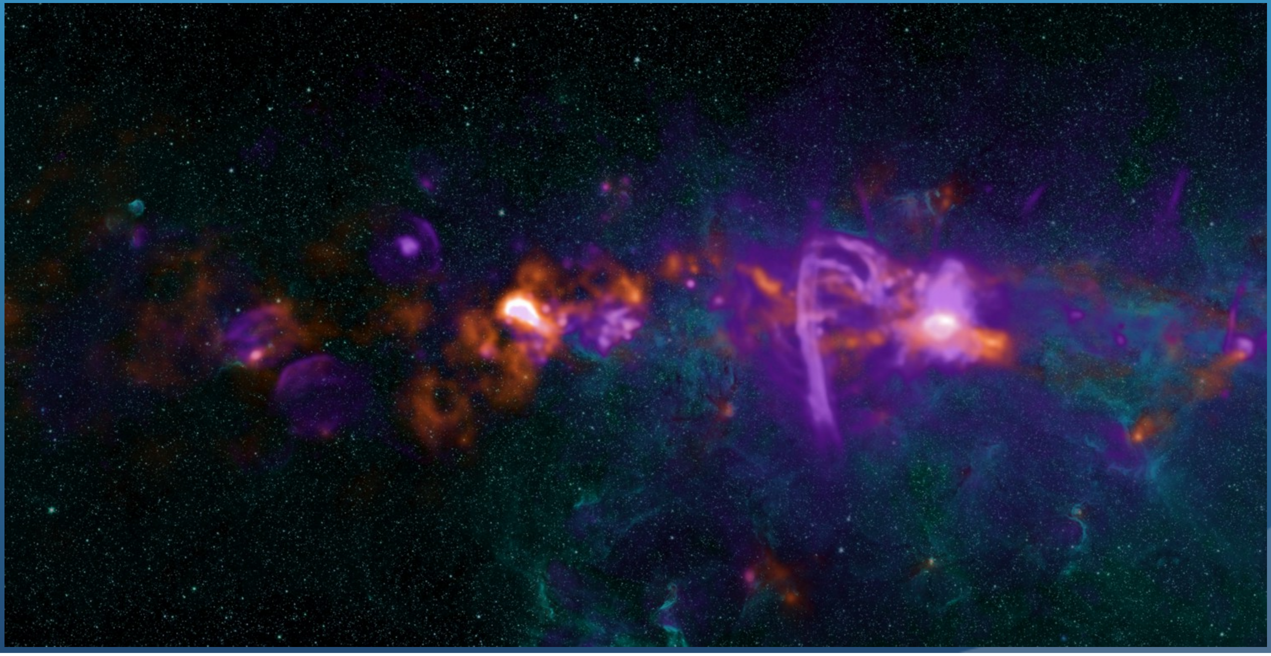


Needs just ~1 hour!
However Total Power measurements very important

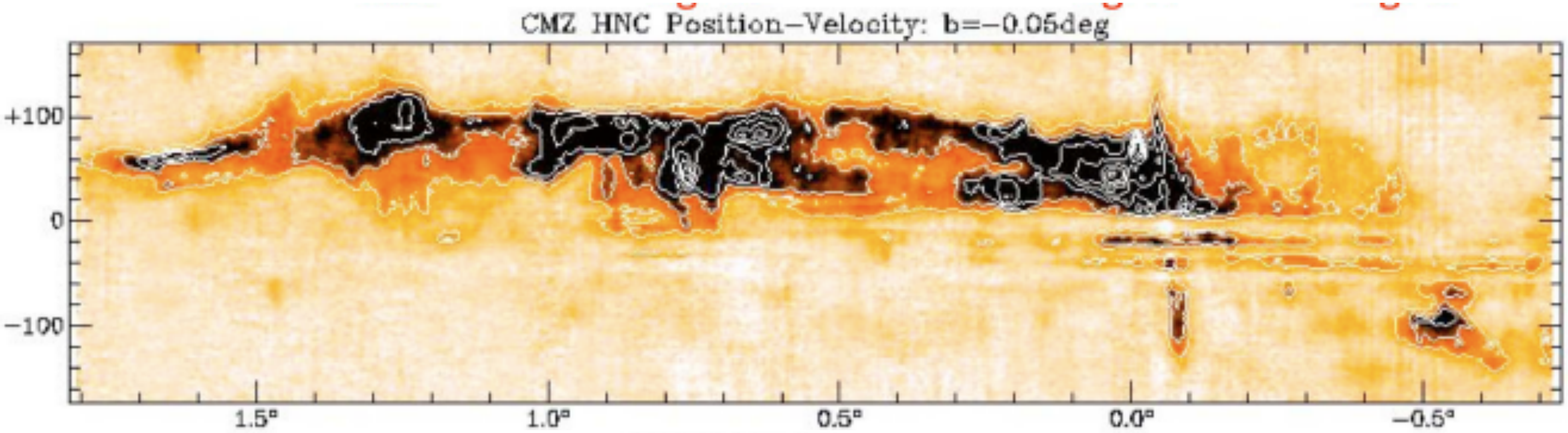
4. The Central Molecular Zone

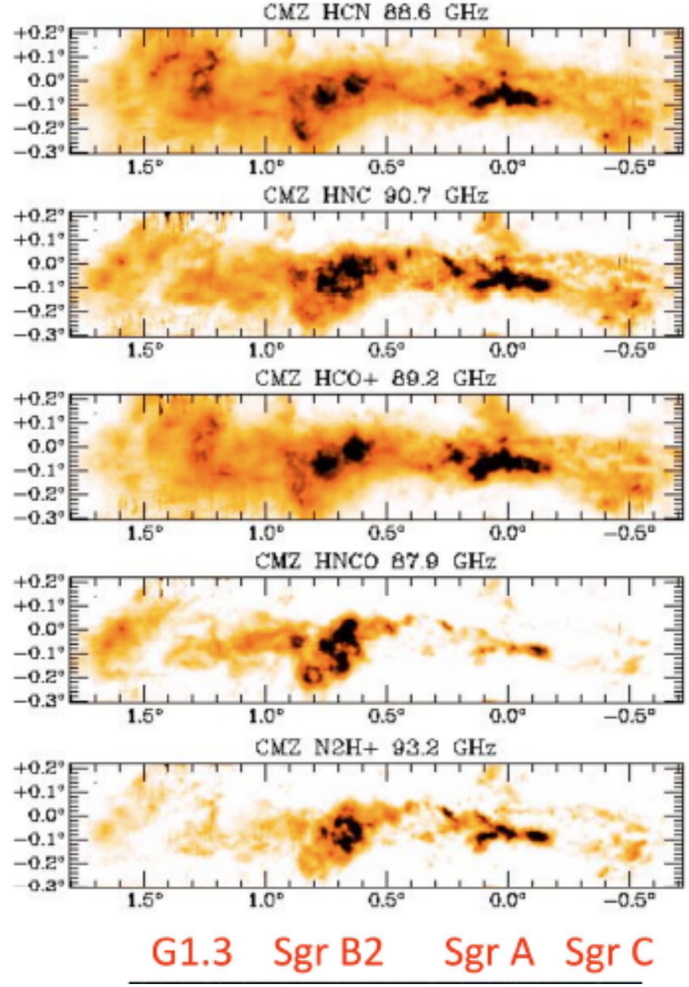
- ~300 x 50pc (3° x 0.5°)
  - ~10^7 $M_\odot$ extended organic emission
- A unique region of the Galaxy
- A proxy for extra-galactic nuclear star formation
  - 1″≡0.04pc; 0.1″≡0.004pc

Red: 1mm dust Green: 8μm stars Purple: 20cm non-thermal



NRAO





Every known molecule in space!

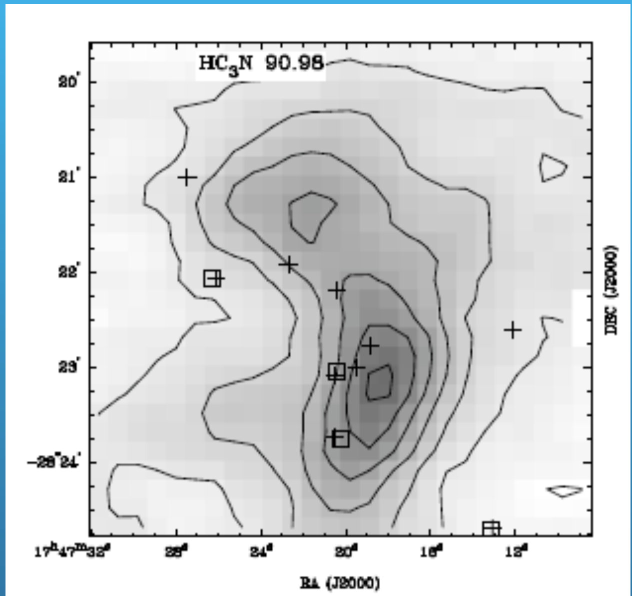
Warmer,
More turbulent
& Denser
than GMCs

Jones et al. 2011

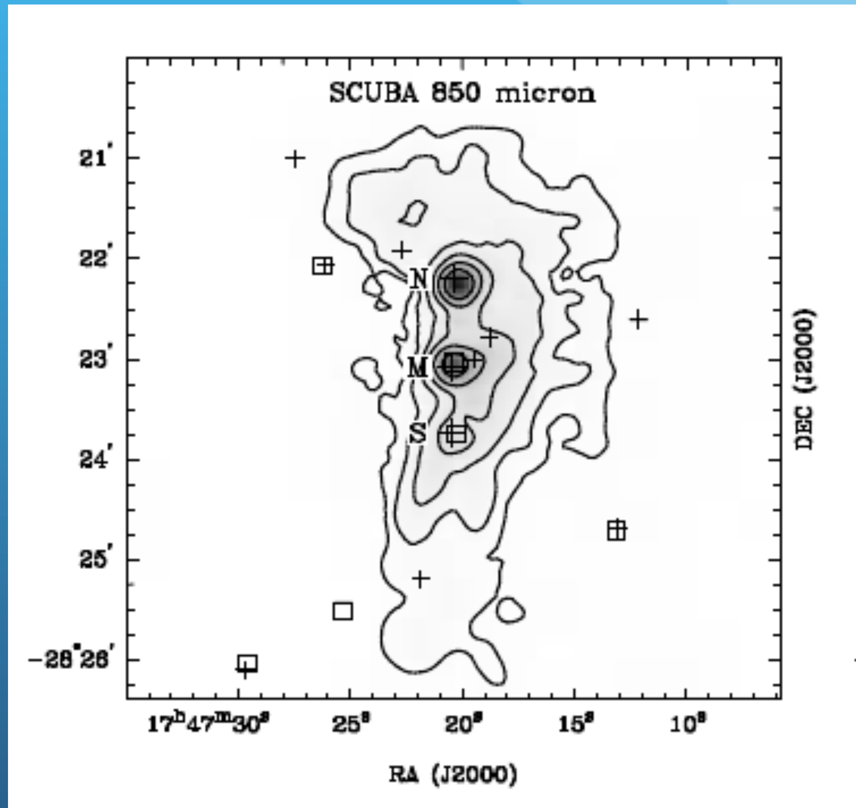
Early-ALMA and the CMZ

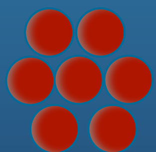
Image the 4 dominant dust cores in the 4 bands (3, 6, 7 & 9)

2'



Mopra HC_3N





- 4 bands
- 5 mins / beam

Needs ~4 x (1+9+13+27) x 5min ~ 200 min to image 1 arcmin for 4 cores

Jones et al 2008, 2010
Pierce-Price et al, 2000

Nanten2 to CCAT on the Pampa la Bola

Nanten2 yearly consortium meeting
at UNSW, May 20-21
See: www.phys.unsw.edu.au/~mgb/Meetings

Can support observing with Nanten2!