Quiescent High-Mass Cores in Orion

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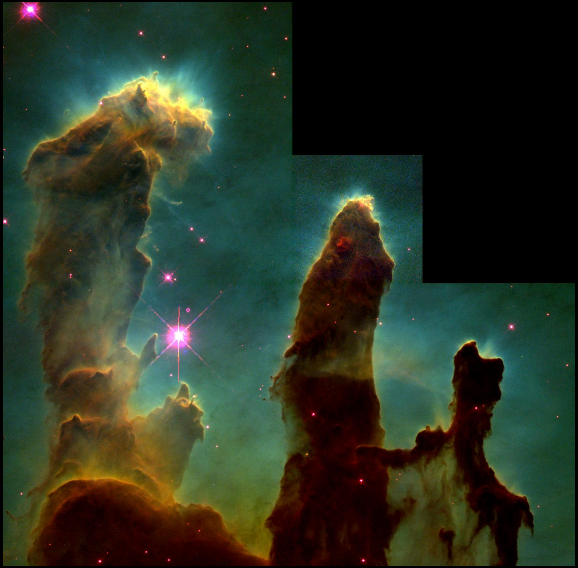
Star Formation

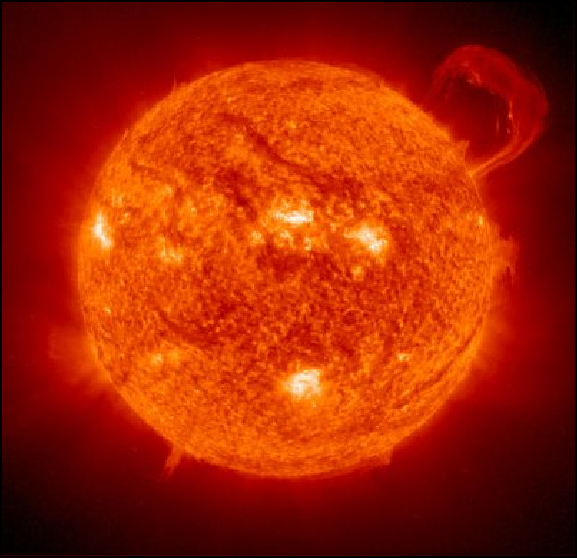
The general problem of star formation is how to turn something like this:



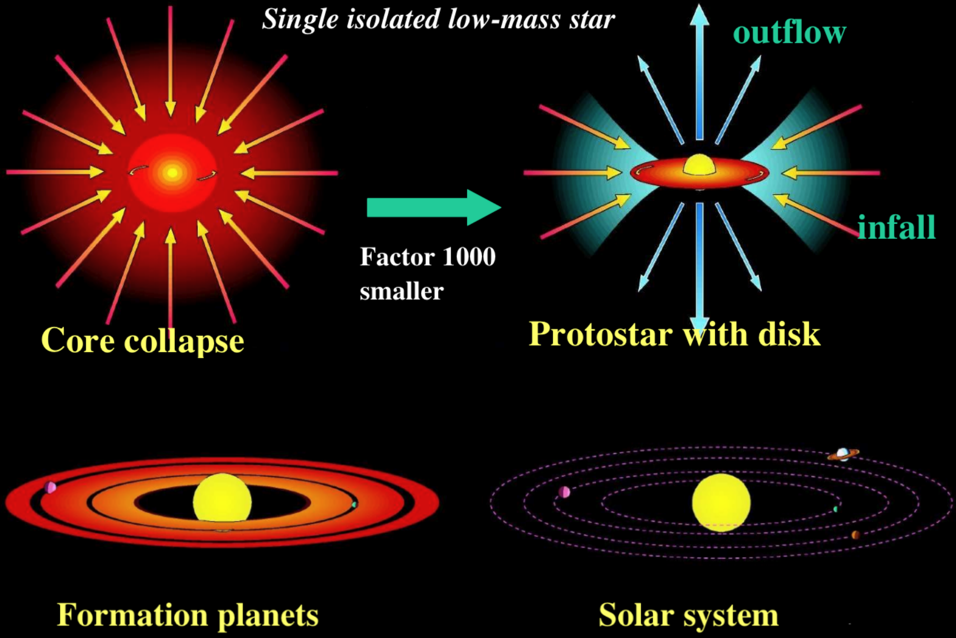
Hubble Image

Star Formation

Into something like this:

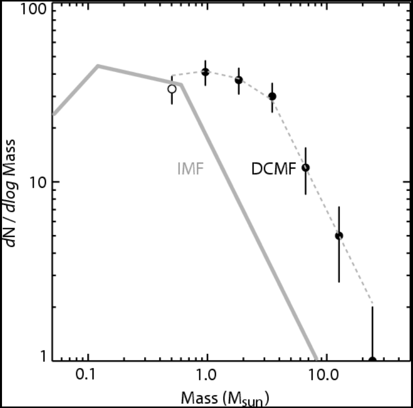


- diffuse and dense cores
- rich and complex structure


Single isolated low-mass star
outflow
infall
Factor 1000
smaller
Core collapse
Protostar with disk
Formation planets
Solar system

Why Study Cores

- Important for star formation
  - efficiency
  - mechanisms



Alves, Lombardi, & Lada (2007)

High-Mass Star Formation

- Historically a problem
  - Radiation Pressure
- Accretion via disks
- Turbulent fragmentation

Finding High-Mass Starless Cores important

  - IRDCs at kiloparsec distances
  - Identifying starless ones problematic
  - Orion (460 pc) is an appealing alternative

S. Carey MIPSGAL+GLIMPSE

Goal

Our goal is examine in more detail a previously determined sample of potential starless cores in Orion to see if they are truly candidate prestellar massive cores

- Improved mass estimates - collapsing?
- Evidence for fragmentation at higher resolution?

Outline

Orion Core Sample

- Quiescent Cores

Dust and Temperature modeling

- *Spitzer* MIPS SED

Spitzer Comparison with Cores

- Evolutionary State
- Dynamics

High-resolution chemistry of three selected cores

Spitzer Data

In this talk we make extensive use of photometry

- All *Spitzer* images from Megeath et al. (2010)
- Images created using Rob Gutermuth's cluster grinder
- In this talk, *Spitzer* images are made by combing IRAC1 (3.6 μm), IRAC2 (4.5 μm), and IRAC4 (8 μm)

Our spectral data is part of this work, and will be discussed later

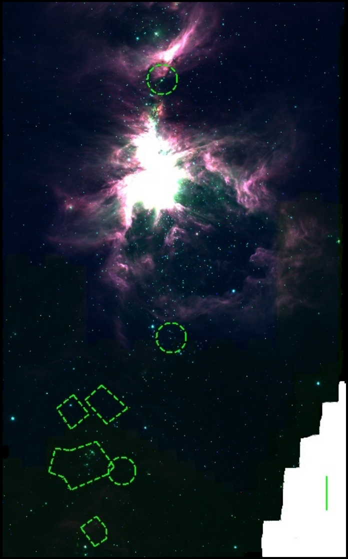
Orion Core Sample

Part of an ongoing program

- Li et al. 2003, 2007
- Velusamy et al. 2008

51 quiescent cores in Orion

- 350 μm Caltech Submillimeter Observatory
- 2+ parsecs from Trapezium
- Average mass: 9.8 $M_\odot$



Megeath et al. (2010)

What is a Quiescent Core?

From Li et al. (2003):

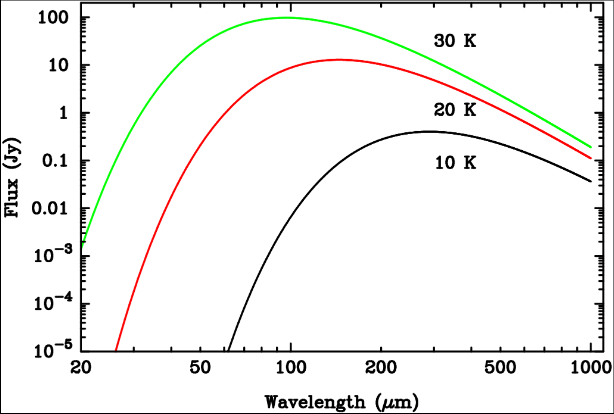
- No infrared point sources (IRAS)
- No known outflows
- 2+ parsecs from Trapezium cluster
- Turbulence dropping towards their centers (NH_3)

Based on existing data, all cores were believed to be starless

Temperature Fitting

Are the cores collapsing?

- Cores have evidence for external heating from NH_3
- This can have a large impact on derived masses from 350 μm dust emission
- Short wavelengths key for fitting temperature



MIPS SED Observations

MIPS SED is a low-resolution spectrometer on *Spitzer*

- covers $\sim 50 - 100\ \mu$m
- $\Delta\lambda = 1.7\ \mu$m

We observed 28 of the 51 cores with MIPS SED

11 objects detected

6 isolated enough to extract spectra

- $9.8''$ pixels

COREFIT

The Goal: Combine MIPS SED and submillimeter+millimeter data simultaneously to derive the density and temperature profiles for the cores.

- 350 μm, 450 μm - CSO
- 850 μm - JCMT Archive

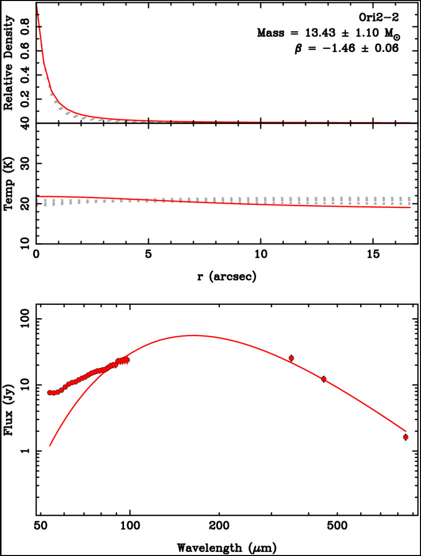
COREFIT

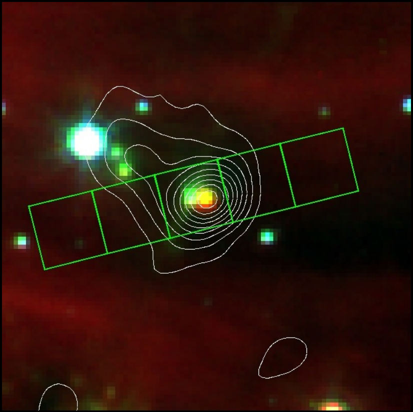
- Adapted from DISKFIT (Marsh et al. 2005)
- Parametric temperature and density profiles:

$$\rho(r) = \frac{\rho(0)}{1 + (r/r_0)^{\alpha}} \tag{1}$$

$$T(r) = T_1 + \frac{T(0) - T_1}{1 + (r/r_t)^2} \tag{2}$$

ORI2_2





Megeath et al. (2010)

Corefit Results

- None of the six cores are actually starless
- General properties (except for ORI1_13)
  - Central density $\sim 10^8$
  - Dust opacity index $\beta \approx -1.5$ ($Q(\lambda) \propto \lambda^\beta$)
  - SED underpredicts short wavelengths

Core Stability

- The cores are supercritical, meaning their masses are much larger than what could theoretically be supported
- This means they should be collapsing to form stars

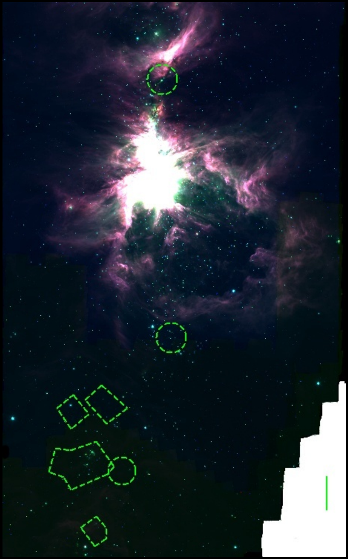
Recall: Orion Core Sample

From Li et al. (2003):

- No IRAS source
- No known outflows
- 2+ parsecs from Trapezium cluster
- Turbulence dropping towards their centers (NH_3)

51 quiescent cores in Orion

- 350 μm CSO
- 2+ parsecs from Trapezium
- Average mass: 9.8 $M_\odot$



Megeath et al. (2010)

Evolutionary State

What is the evolutionary state of these cores?

- Do they have embedded protostars?
- Infall motions suggesting collapse?

Are the cores starless?

51 cores in Li et al. (2007)
15 with a protostar/disk source within 5″ of the 350 μm peak

- some pointing inaccuracy in 350 μm data

86% of cores with stars (13/15) have $M_{350} \geq 4\ M_\odot$
44% of cores without stars(16/36) have $M_{350} \geq 4\ M_\odot$

- 7 with $M_{350} \geq 10\ M_\odot$

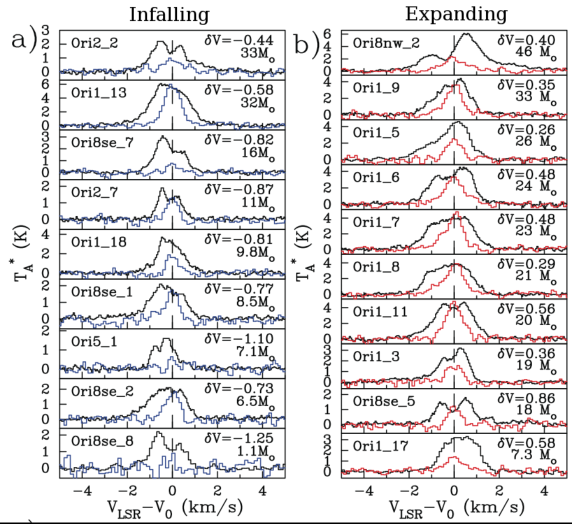
More massive cores do tend to have embedded protostars, but there are some exceptions

Red/Blue Asymmetry

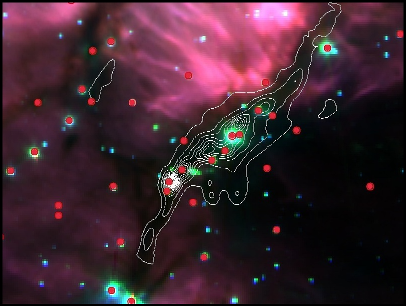
27 line profiles in Velusamy et al. (2008)

- 12 cores with stars - 5/4/3 red/blue/green
- 15 cores without stars - 5/5/5/ red/blue/green

No correlation between existence of stars and red/blue asymmetry



Multiplicity of Star Formation



Color Image - Megeath et al. (2010)

CARMA

The Combined Array for Research in Millimeter-wave Astronomy

- 23 dishes in three sizes
- jointly operated by Caltech, Maryland, Berkeley, Chicago, and Illinois
- Observes at millimeter wavelengths

High-Resolution with CARMA

N_2H^+ and HCO^+ are two commonly used tracers of high-density regions in low-mass cores.
Goal: Use the ~arcsecond resolution of CARMA to look for substructure below the resolution of the 350 μm data.

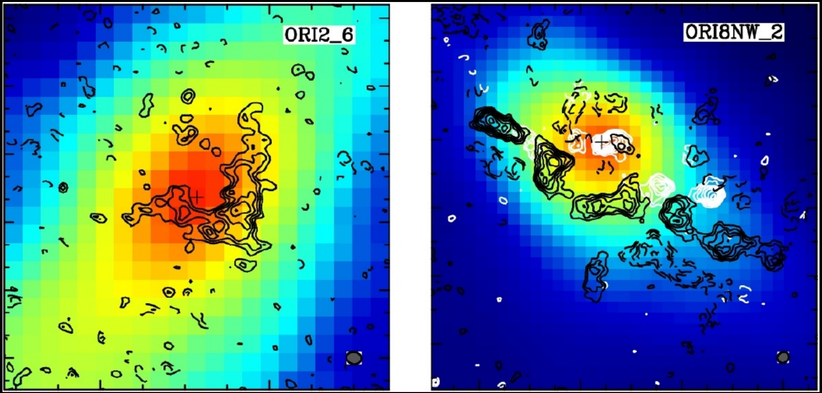
- How is a very massive core (ORI8NW_2) different from a slightly less-massive core (ORI2_6)?
- Are the cores fragmenting?
- Can we better estimate the core masses with gas tracers?

We observed:

- ORI2_6 - N_2H^+
- ORI8NW_2 - N_2H^+, HCO^+

Results - ORI2_6 & ORI8NW_2

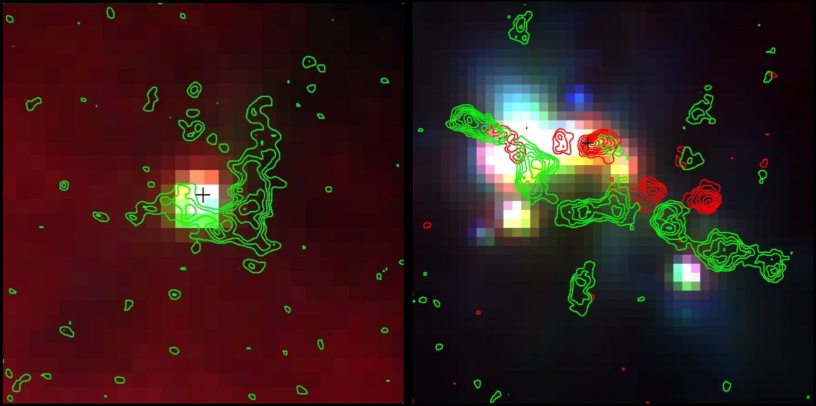
B and C Arrays (1″ and 2″)
N_2H^+ - Black
HCO^+ - White



Color Image - 350 μm CSO

Results - ORI2_6 & ORI8NW_2

N_2H^+ not detected in central regions with protostars



Color Image - Megeath et al. (2010)

Chemistry - Embedded Sources

The N_2H^+ does not peak at the continuum, while the HCO^+ does. This suggests the central protostars in each core have heated the dust and caused the following reaction (Zinchecko et al. 2009):

$$\mathrm{N_2H^+ + CO \rightarrow HCO^+ + N_2}$$

Ophiuchus A (Di Francesco et al. 2004):

- attributed to cold temperatures

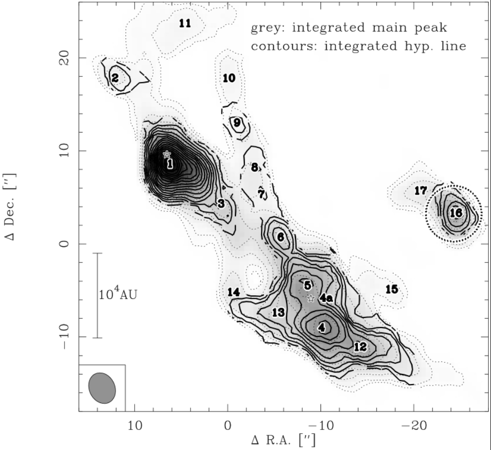
L483 (Jørgensen 2004)

- high CO abundance

Comparison with IRDCs

In IRDCs, the N_2H^+ does overlap with the continuum

- Beuther & Henning (2009)
- Beuther et al. (2005)
- Fontani et al. (2008)

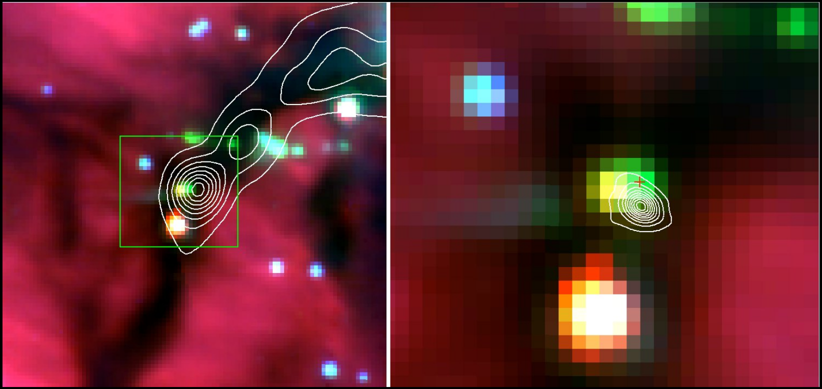


Beuther & Henning (2009)

Results - ORI1_13

Jorge Pineda is PI

- CARMA, Mopra, & CSO (2-1)
- Left is 350 μm CSO, Right is 3mm continuum CARMA

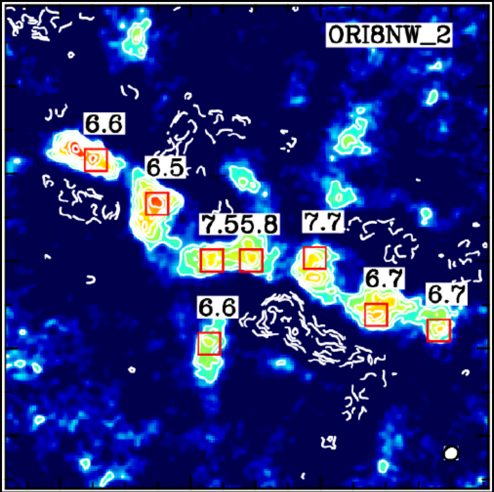


Color Image - Megeath et al. (2010)

Fragmentation

- N_2H^+ and HCO^+ suggest that ORI8NW_2 has fragmented into numerous subcores

- If we fit the N_2H^+ spectrum to each observed peak, we can obtain the velocity of that peak
  - 5.8 – 7.7 km/s



CARMA Summary

- The more massive core, ORI8NW_2, does appear to have fragmented while ORI2_6 has not.
  - The single core in ORI2_6 is the same spatial size as the multiple cores in ORI8NW_2
- Velocities support the conclusion that ORI8NW_2 is fragmenting

Conclusions

The Orion core sample not as starless as previously thought

- 16 starless cores with $M_{350} \geq 4\ M_\odot$
- 7 starless cores with $M_{350} \geq 10\ M_\odot$

Existence of protostars impacts the chemistry

- N_2H^+ and HCO^+
- But not the dynamics
  - no correlation with red/blue asymmetry

Future Work

- Improve COREFIT modeling
  - Add grain size distribution (currently 0.1 μm)
  - Better parametric models
    - Need to reproduce hot center
- Produce updated mass estimates for cores with COREFIT/CARMA data
  - N_2H^+ suggests some cores may have fragmented into sub-cores
  - This has implications for core mass function
- Simulate Orion cores at IRDC distances