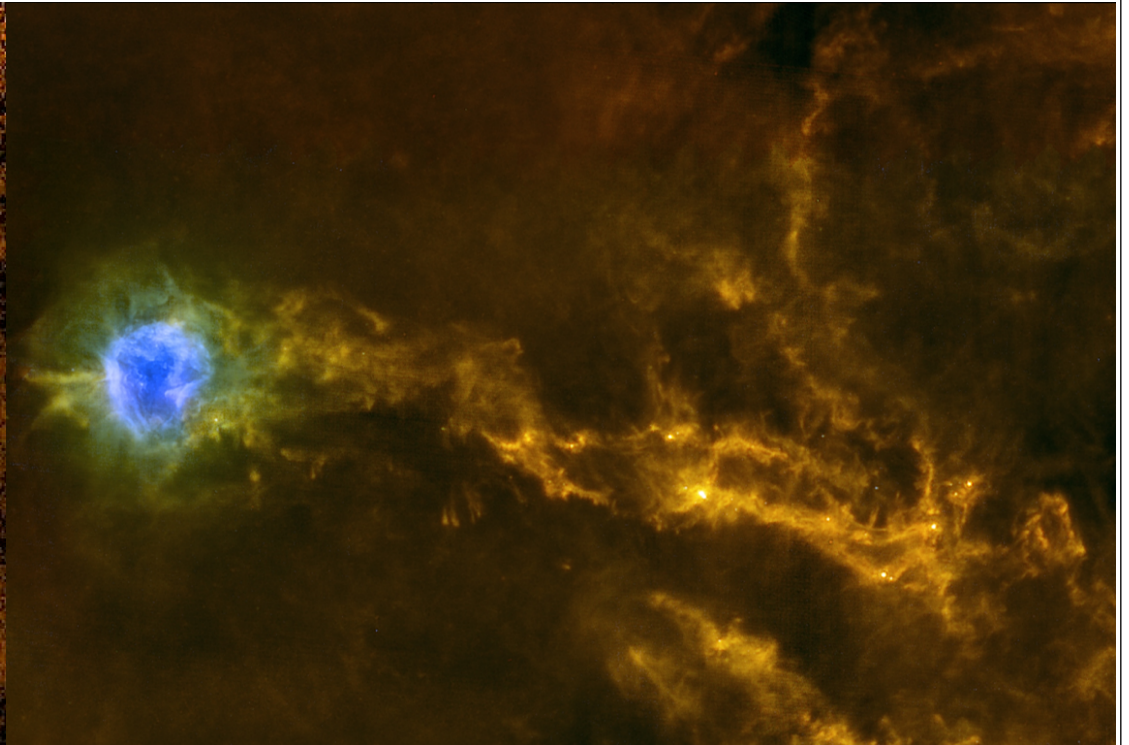
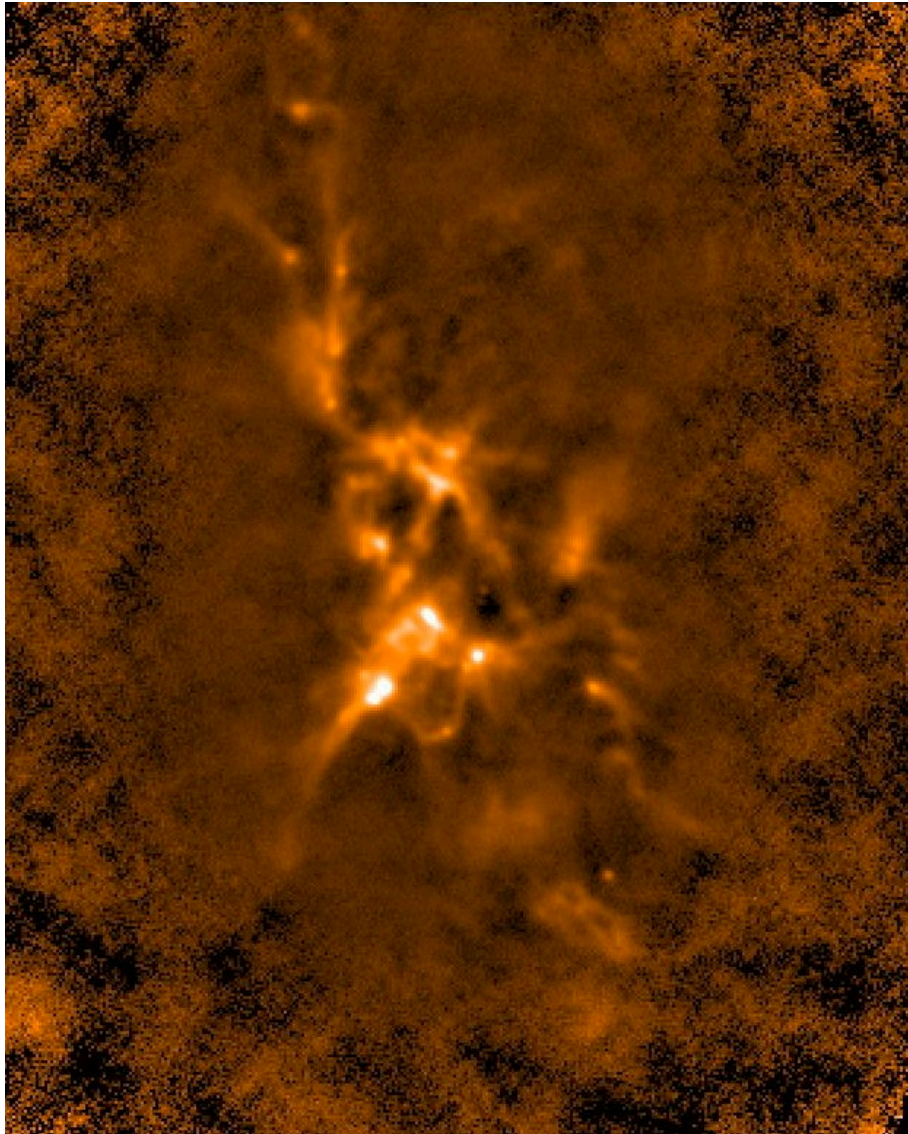


Low mass star formation



Mark Thompson
(with contributions from Jennifer Hatchell, Derek Ward-Thompson, Jane Greaves, Larry Morgan...)

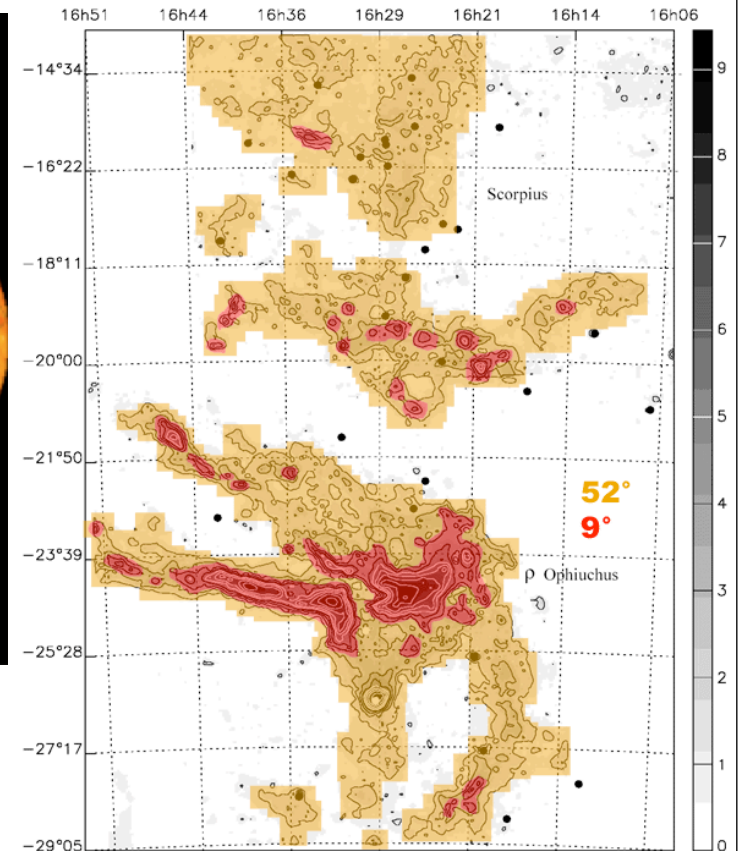
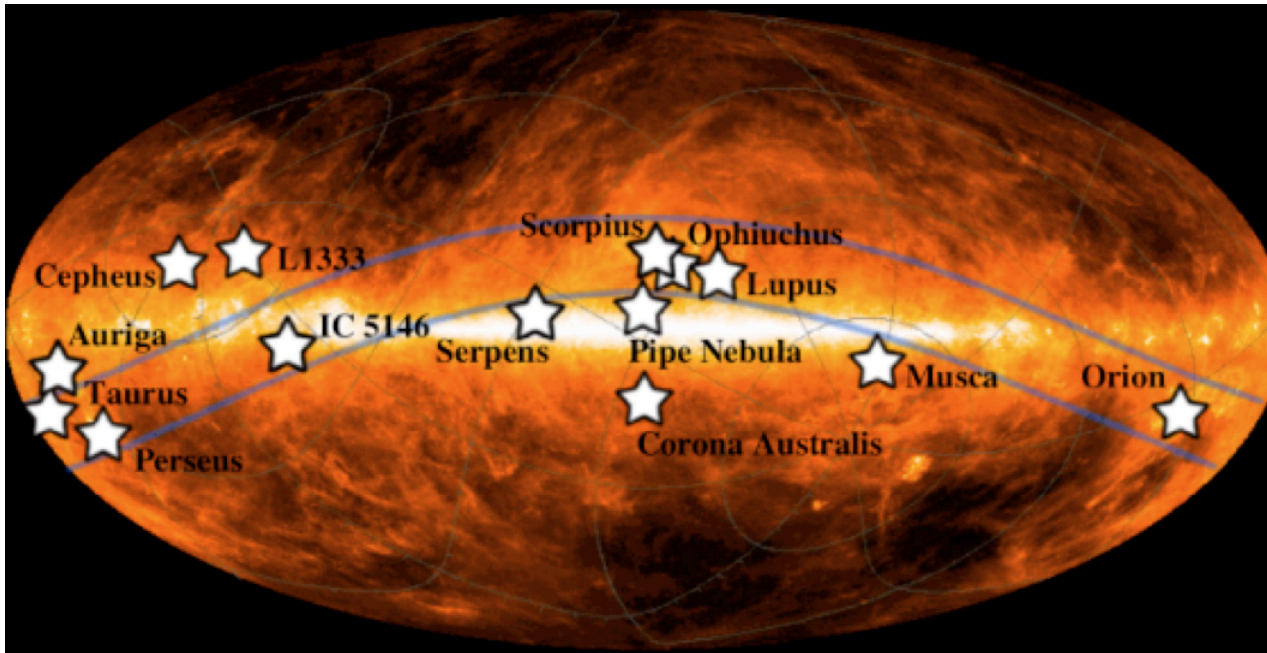
University of
Hertfordshire



The observational state of play

- Multiwavelength surveys are bringing about well-sampled statistical studies of YSOs and protostellar cores
- Focus placed on the Gould Belt clouds, but also on isolated clouds and at high latitudes
- SED coverage from mid-IR to sub-mm (*Spitzer, Herschel, & now SCUBA-2*)
- CO line maps from HARP
- ALMA poised to exploit subsets of the statistical samples

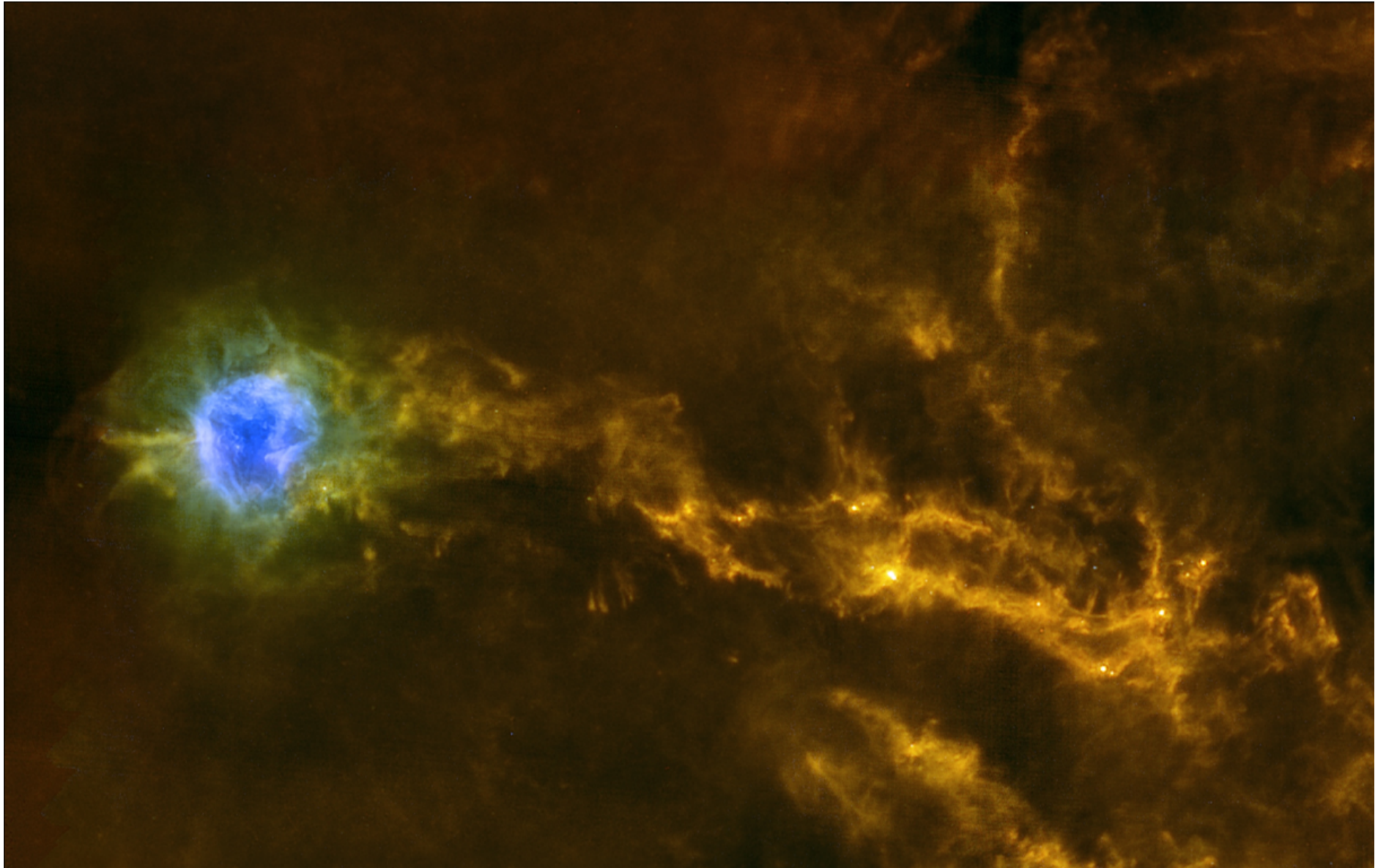
The Gould Belt



A ring of local ($\sim 300\text{-}400$ pc) O stars and star-forming clouds.

Some of the best and nearest places to study low mass star formation

The Gould Belt



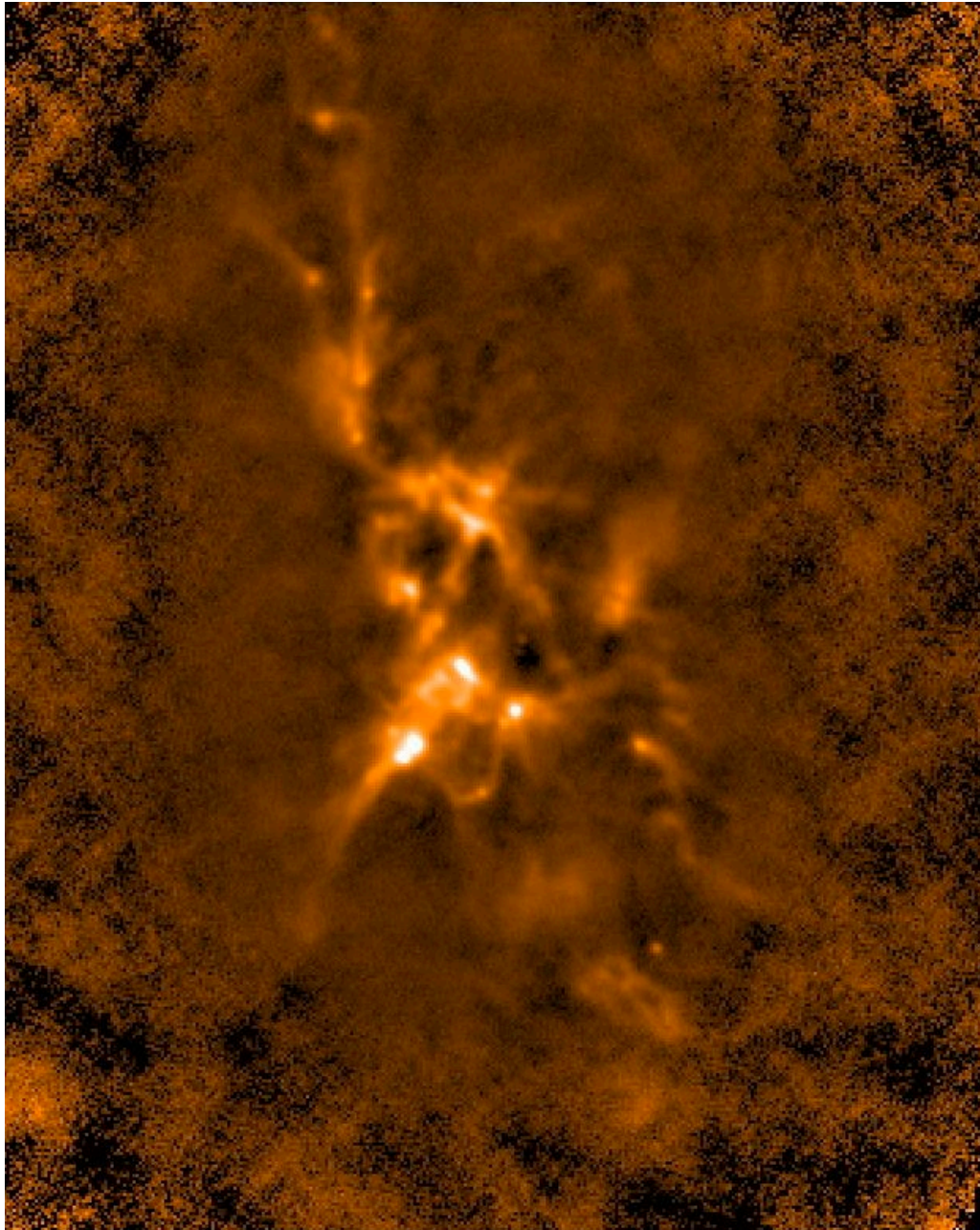
IC 5146 from Herschel (Herschel Gould Belt team)

The Gould Belt



IC 5146 from Spitzer (Spitzer Gould Belt team)

Early results from SCUBA-2



NGC 1333 at 850 μm with SCUBA-2

Thanks to Jennifer Hatchell & the
SCUBA-2 Gould Belt Legacy Survey Team

The theoretical state of play

- Traditional Shu-type inside-out collapse seems to explain the broad details of low-mass star formation, but...
- role of turbulence, magnetic fields, clustering, feedback is still unclear
- How does the observed core mass function translate to the Initial Mass Function?
- Protostellar luminosity function inconsistent with observations unless accretion is either slow or episodic

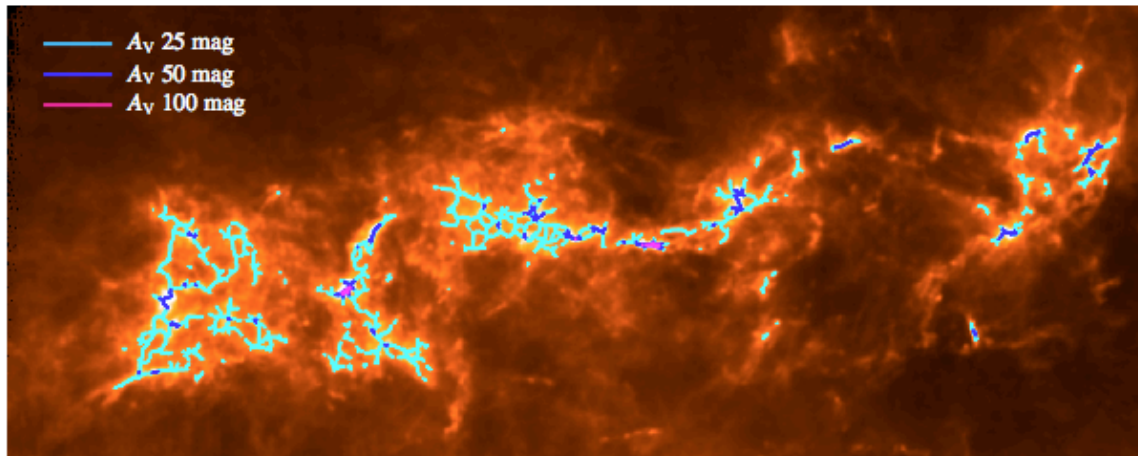
What we do know

- Stars form mostly in clustered environments
- Core mass function is similar to the IMF (confirmed by recent *Herschel* results), implies constant star formation efficiency, but caveats...
- Statistical timescales for Class 0/I are becoming well-determined (shorter than thought by *Spitzer*, thanks to *Herschel*)
- Star formation efficiencies are low in nearby clouds ($\sim 3\%$) but high in dense cores ($>25\%$)
- Local star formation rates (Σ_{SFR}) are higher than predicted by Kennicutt-Schmidt relations
- Possible surface density threshold for star formation (Lada+ 2010, Heiderman+ 2010)
- SFR per unit freefall time is a linear function of cloud mass (Krumholz 2011)

What we don't know yet

- How does gas assemble into dense cores?
- Turbulence, magnetic fields, environment?
- Filaments?
- Is there a (density) threshold for star formation?
- What sets the star formation rate?
- What sets the mass of stars?
- How do substellar objects form?
- Why is star formation so inefficient?

Filaments



What is the origin of the filamentary structure in molecular clouds?

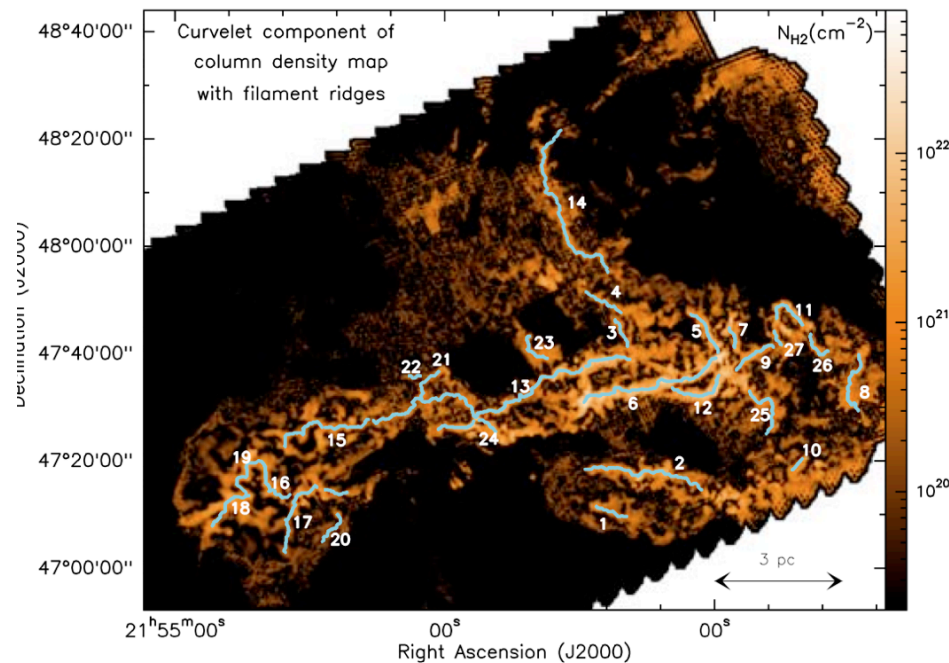
Turbulence-driven?
(consistent with width)

Magnetic fields?

No velocity or polarisation measurements...

Relation to SF?
(occurs along filaments & at junctures)

Vela C, Hill+ 2011



IC 5146, Arzoumanian+ 2011

Thresholds for star formation

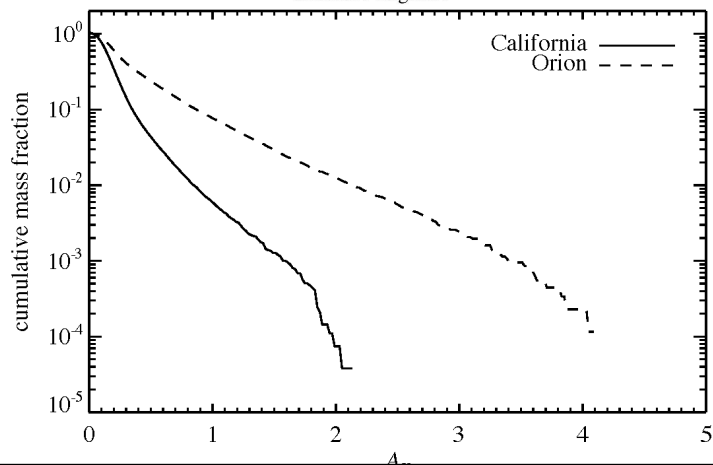
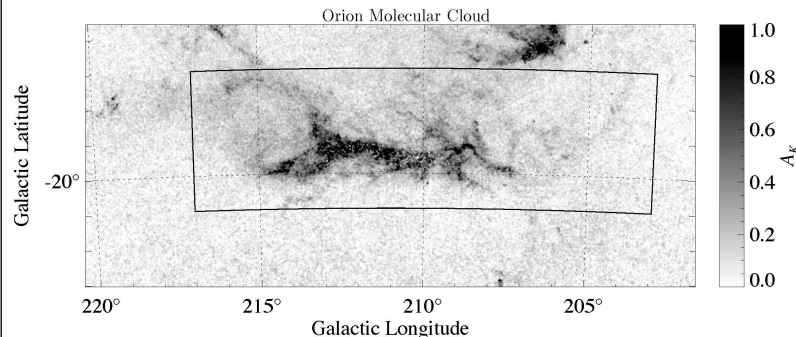
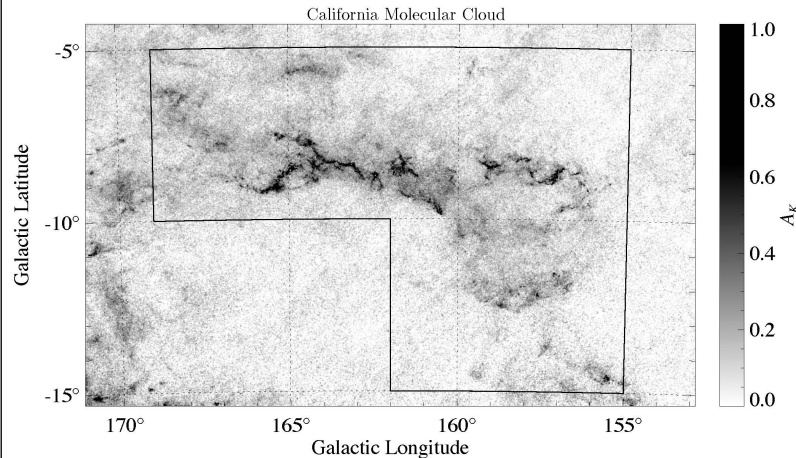
Lada+2010 & Heiderman+ 2011 results imply a surface density threshold for star formation

Implications for Kennicutt-Schmidt relation as gas traced by CO 1-0 includes material below the threshold

Does this surface density threshold translate into a real volume density threshold? (e.g. Krumholz+ 2011)

SFR per unit freefall time is constant fraction of molecular mass ($\sim 1\%$)

If so, shifts the question to how does dense gas form in molecular clouds...?



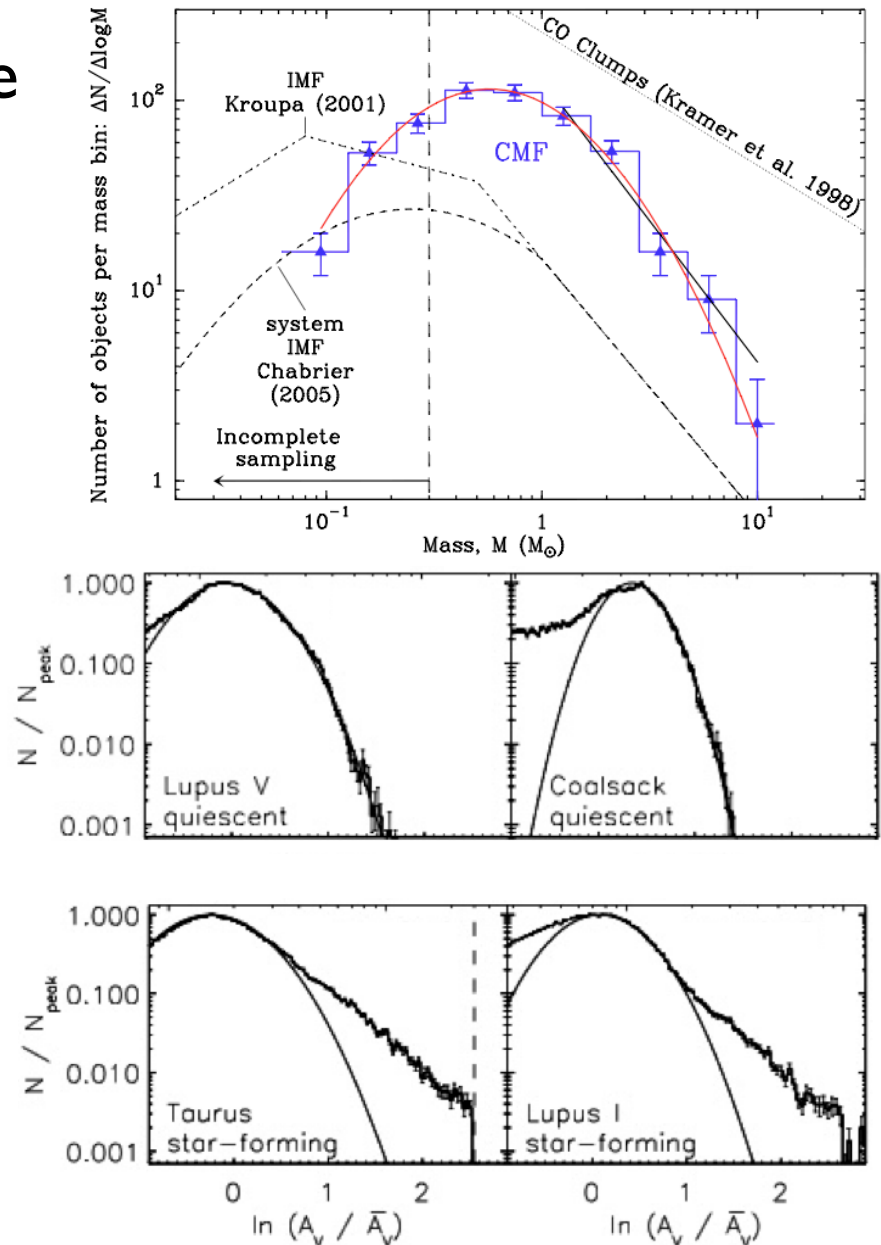
Origin of density enhancements

Close link between density structure of clouds & their resulting SF

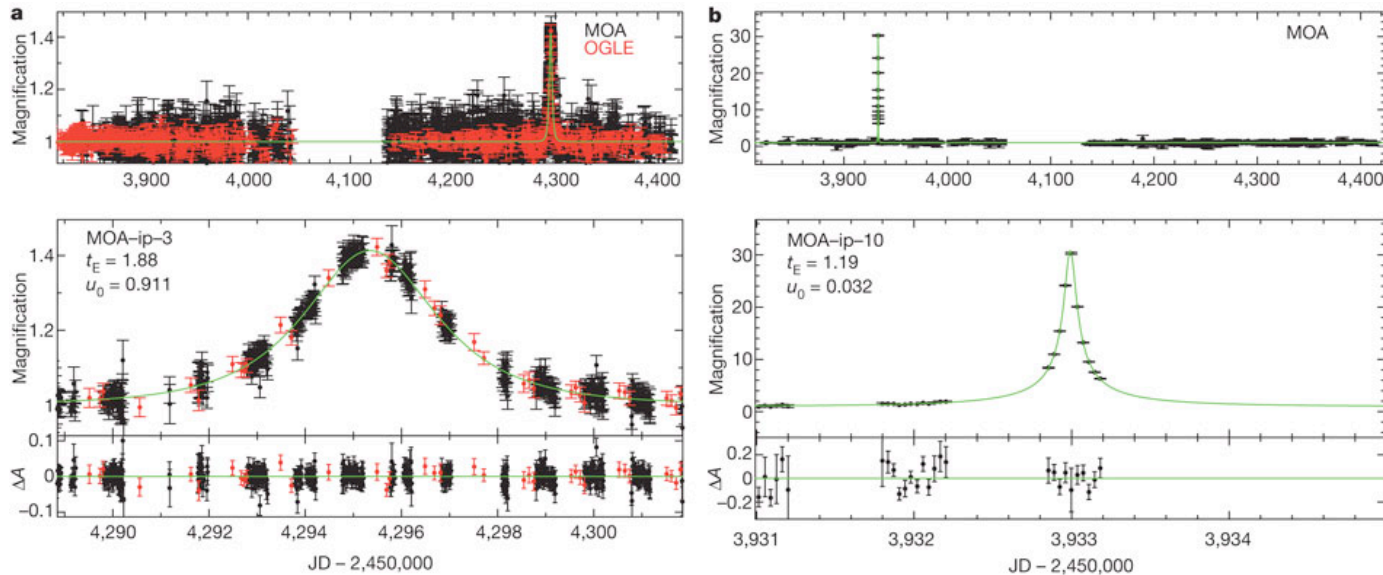
Dense core mass function follows the IMF

Likely that dense cores result from fragmentation of filaments (Andre+2010)

Understanding filaments and their evolution to cores is thus crucial to understanding the origin of the IMF



Substellar mass objects



Large population of brown dwarfs & even “free-floating planets” being discovered/inferred.

Formation mechanisms unclear but one relatively overlooked is gravoturbulent fragmentation (Padoan & Nordlund 2004) - can overcome the stringent density requirement for Jeans-type collapse

Needs sensitive continuum survey of clouds (ideally low A_v regions) to find low mass fragments

Summary

1. Statistics on YSOs/protostars we have already
(or will have with the completion of SCUBA-2 surveys)
2. What we don't have is a good picture of the cloud conditions
from whence they sprang
3. Continuum observations don't tell you about chemistry,
velocity, dynamics or turbulence (spectroscopy needed)
4. Are filaments formed by turbulence or magnetic fields?
(Polarimetry/spectroscopy needed)
5. How do filaments evolve to cores to YSOs to stars to the IMF?
6. Where does the dense gas come from?
(Spectroscopy of dense gas tracers will be key)