Star Formation & ISM. The Way Forward.

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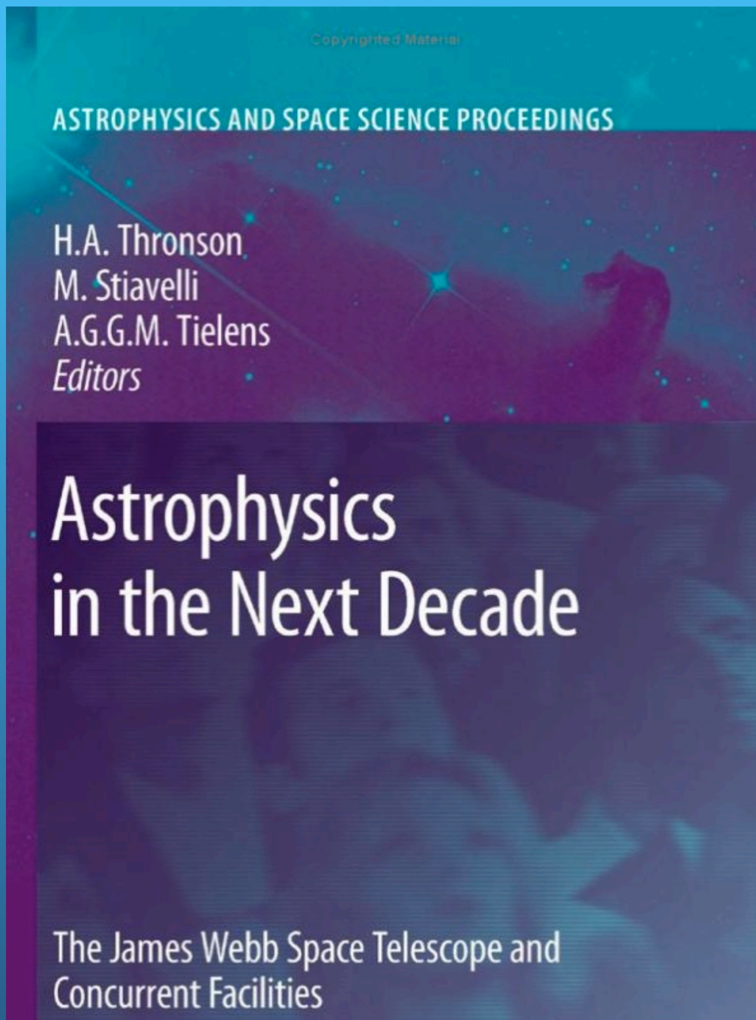
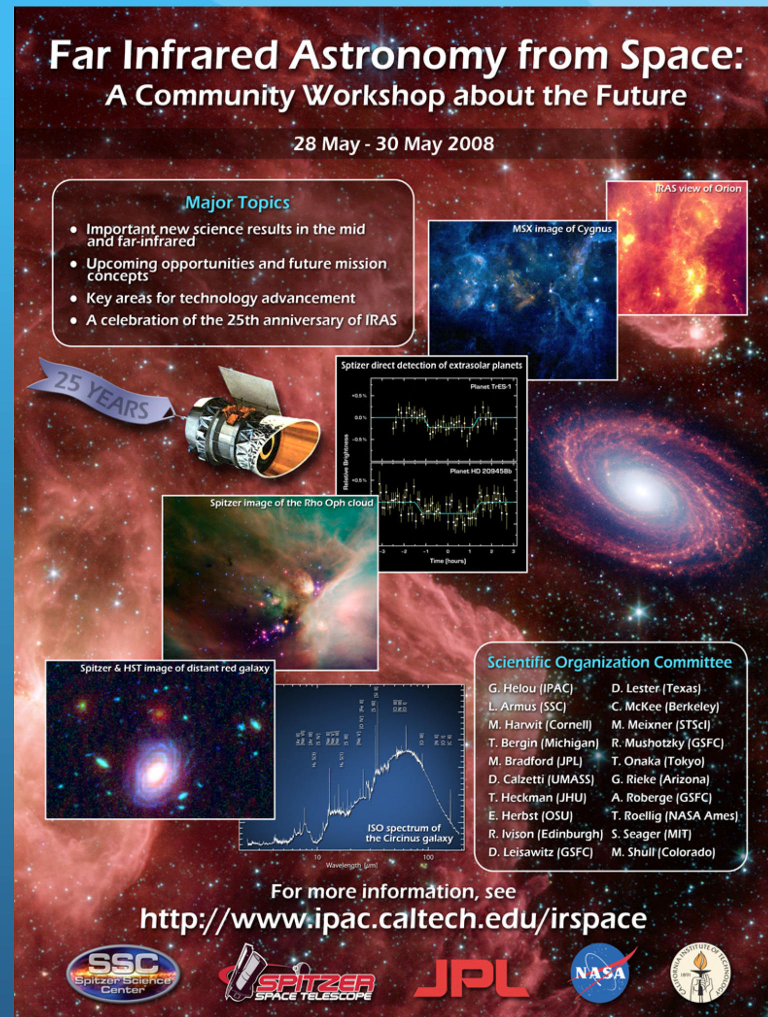
Preamble

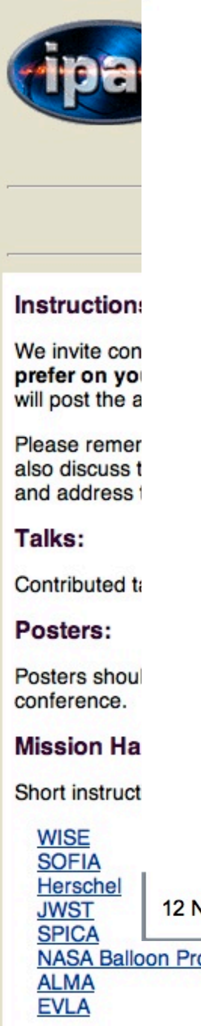


Tucson - Sep 2007

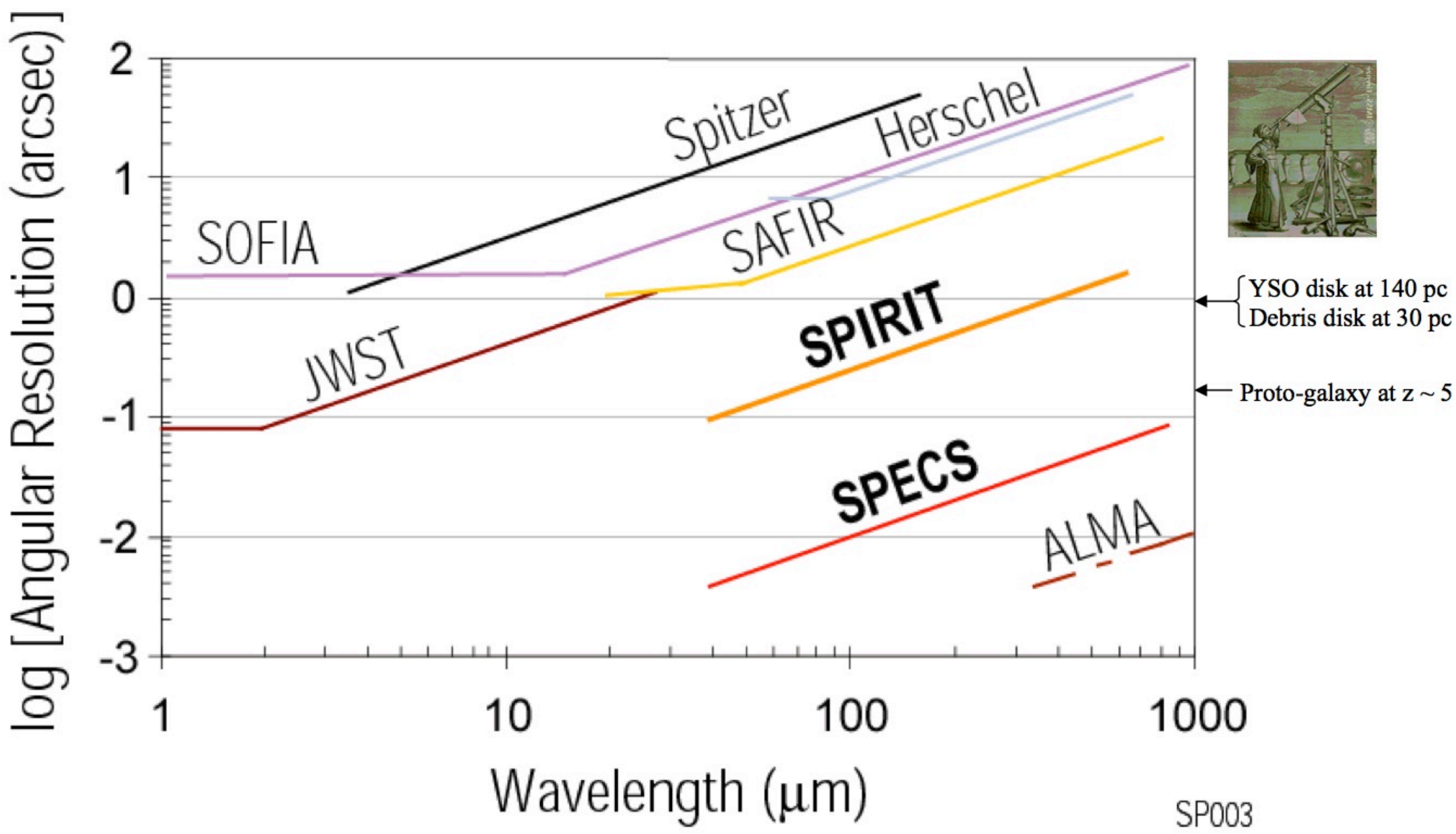


Pasadena May 2008

Pr



WANTED: Sub-arcsecond angular resolution



12 November 2007 Astrophysics 2020, STScI - D. Leisawitz 7

OUTLINE

- Introduction.
- Case Studies:
- Star Formation Rate in the Milky Way (HiGAL).
- Proto-Stellar Clusters (HiGAL).
- Structure of Filaments (HiGAL; HOBYS).

Higher angular resolution & sensitivity at Kpc distances.

- Waterfalls in Pre-stellar Cores & Proto-stars (WISH).
- Anomalous Microwave Emission (AME) by Dust

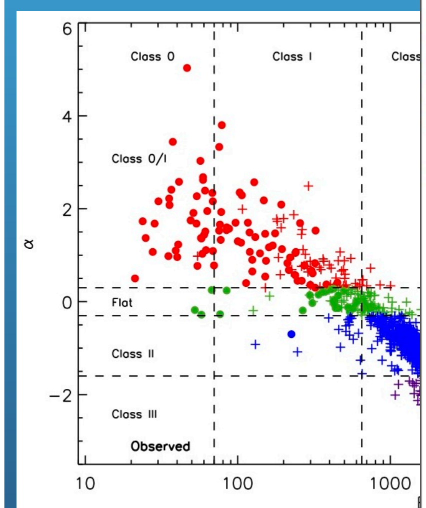
Introduction

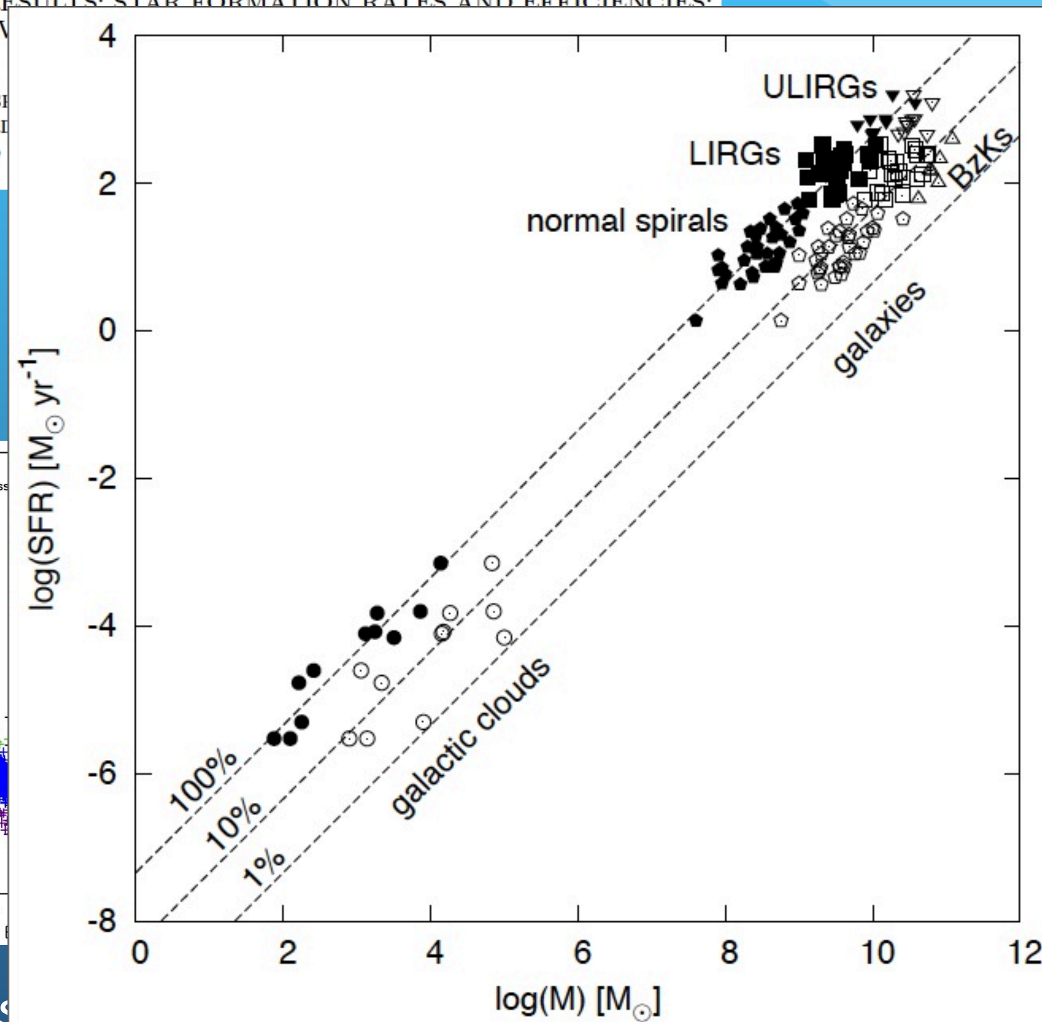
- A nearly "Impossible Task".
- Borrow the title from Xander Tielens on a recent (2013) meeting on DIBs (The Diffuse Interstellar Bands, IAU Symposium 297).
- The way forward involves (for the ISM) laboratory experiments, molecular physicists, astro-chemists, astrophysics, international collaboration & manageable expectations [i.e. not only higher spectral and angular resolution at all wavelengths] (well id DIBs at optical wavelengths).
- Large surveys (Legacy & Key programs): Taurus & MIPSGAL (Spitzer), HiGAL (Herschel): Low & High Mass SF
- *Distances & Velocities. Confusion along the line of sight (some our biggest problem).*

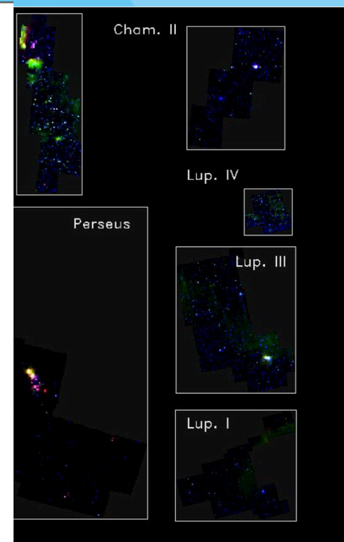
SFR in Nearby Clouds (C2d)

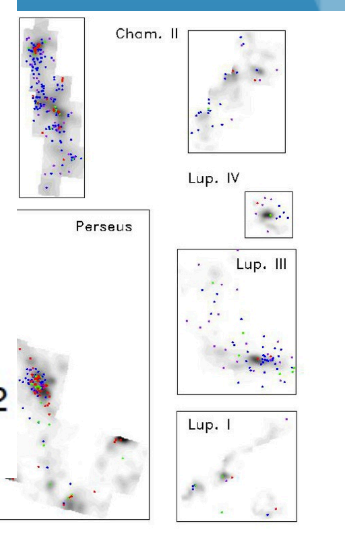

THE SPITZER C2D LEGACY RESULTS: STAR FORMATION RATES AND EFFICIENCIES;
EV

NEAL J. EVANS II[1], MICHAEL M.
MERÍN[5, 6], EWINE F. VAN DISH
STAPELFELDT[10], TRACY L. HUARI
GEOFFREY A. BLAKE[12], DAVID



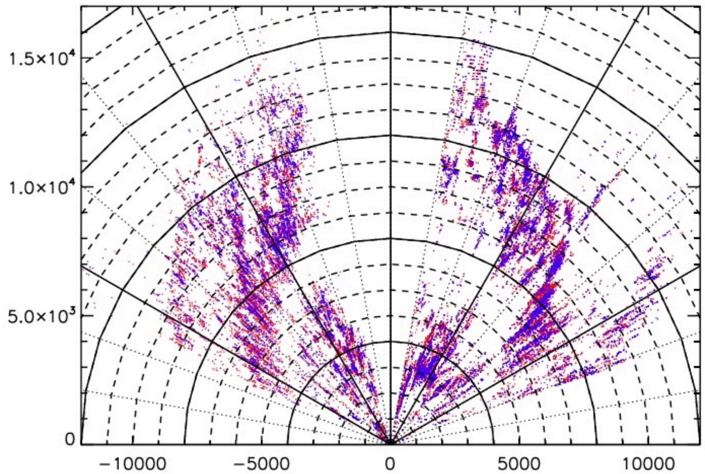






Evans

Star Formation Rate in the MW

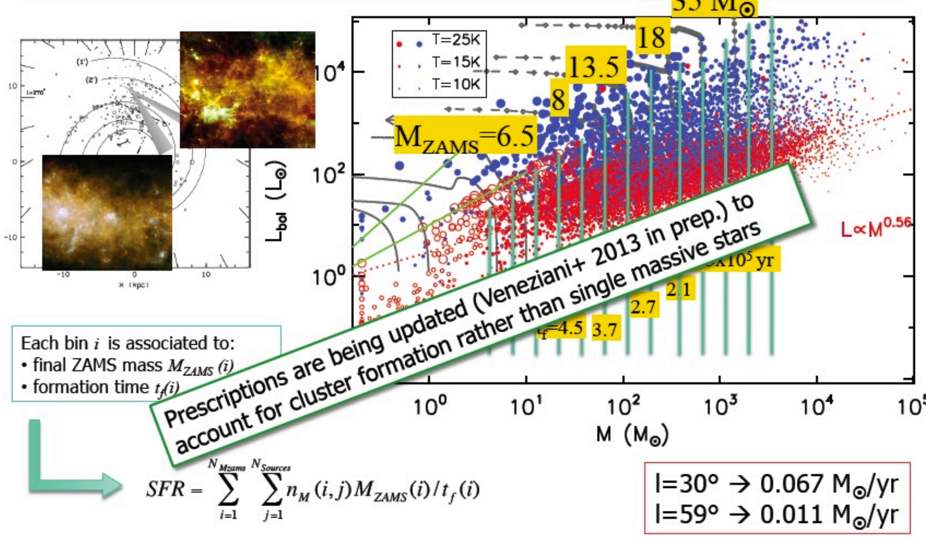


Initial sample of nearly 100,000 compact objects with counterparts in at least three adjacent bands and with a distance assignment: almost 60,000 are show here outside the CMZ and with first estimates on distances.

[Molinari+, photometric catalogues – Pestalozzi+ physical catalogue – Elia+ global science analysis]

Star Formation Rate from YSO counts

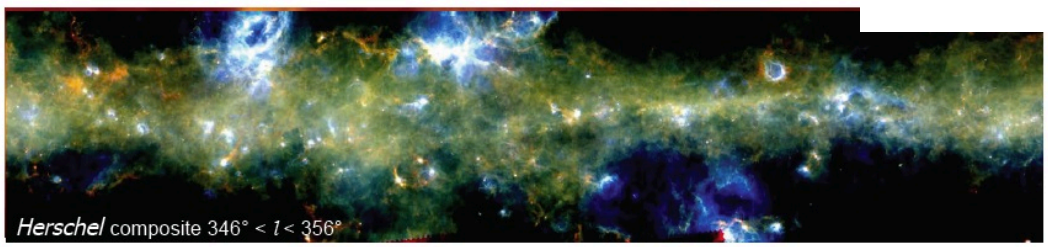
A first attempt in deriving the SFR in the two Hi-GAL SDP fields l=30° and l=59° (*Veneziani et al. 2012*), comparing YSO statistics for PROTOSTELLAR Clumps in the L *vs* M plot against evolutionary predictions (McKee & Tan 2003, Molinari+ 2008).



Each bin *i* is associated to:
- final ZAMS mass $M_{ZAMS}(i)$
- formation time $t_f(i)$

$$SFR = \sum_{i=1}^{N_{Mzams}} \sum_{j=1}^{N_{Sources}} n_M(i,j) M_{ZAMS}(i) / t_f(i)$$

l=30° → 0.067 M⊙/yr
l=59° → 0.011 M⊙/yr



Simultaneous 5-bands (*70-160-250-350-500μm*) continuum mapping of 720 sq. deg. of the Galactic Plane (|*b*|≤1°)

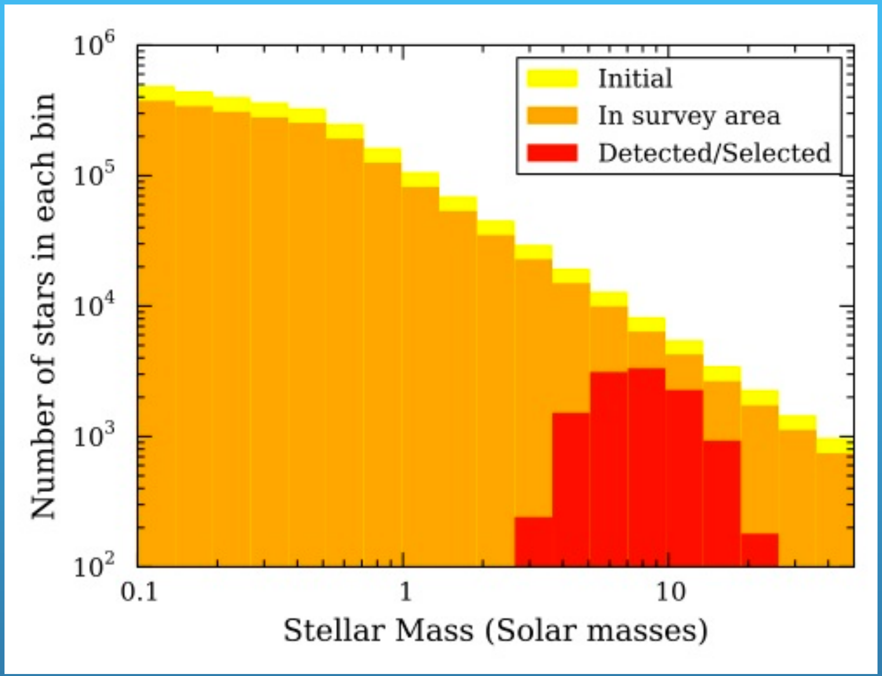
Plus IRAC+MIPS +WISE (SEDs)

SPIRE 500um beam ~ 36 arcsecs

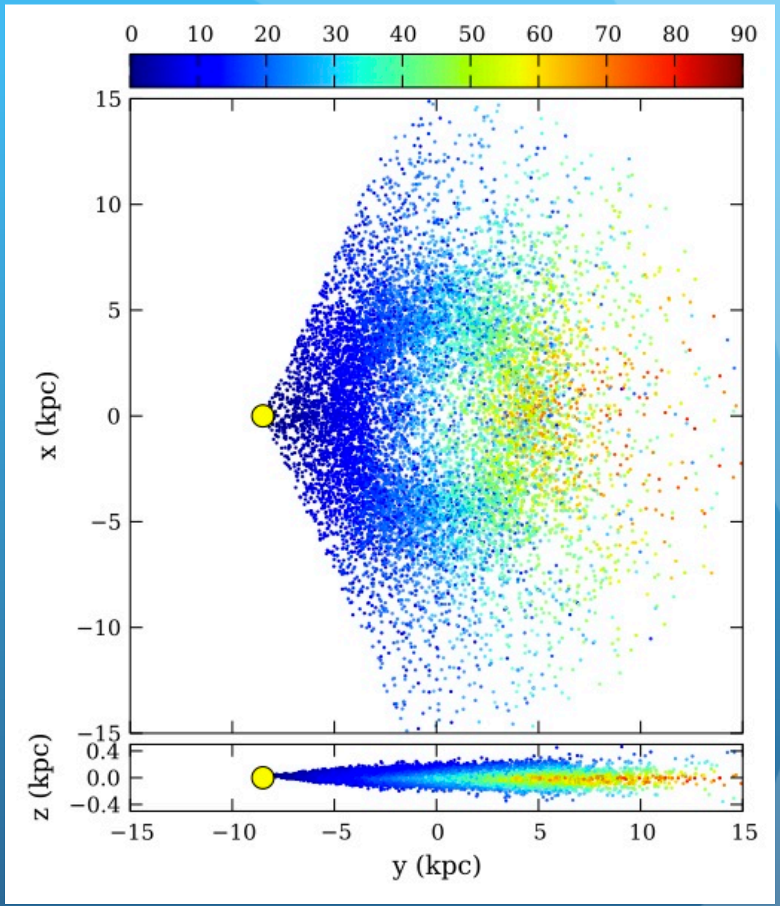
Molinari et al. 2014

SFR in the MW (II)

Population Synthesis models



From Robitaille & Whitney 2010



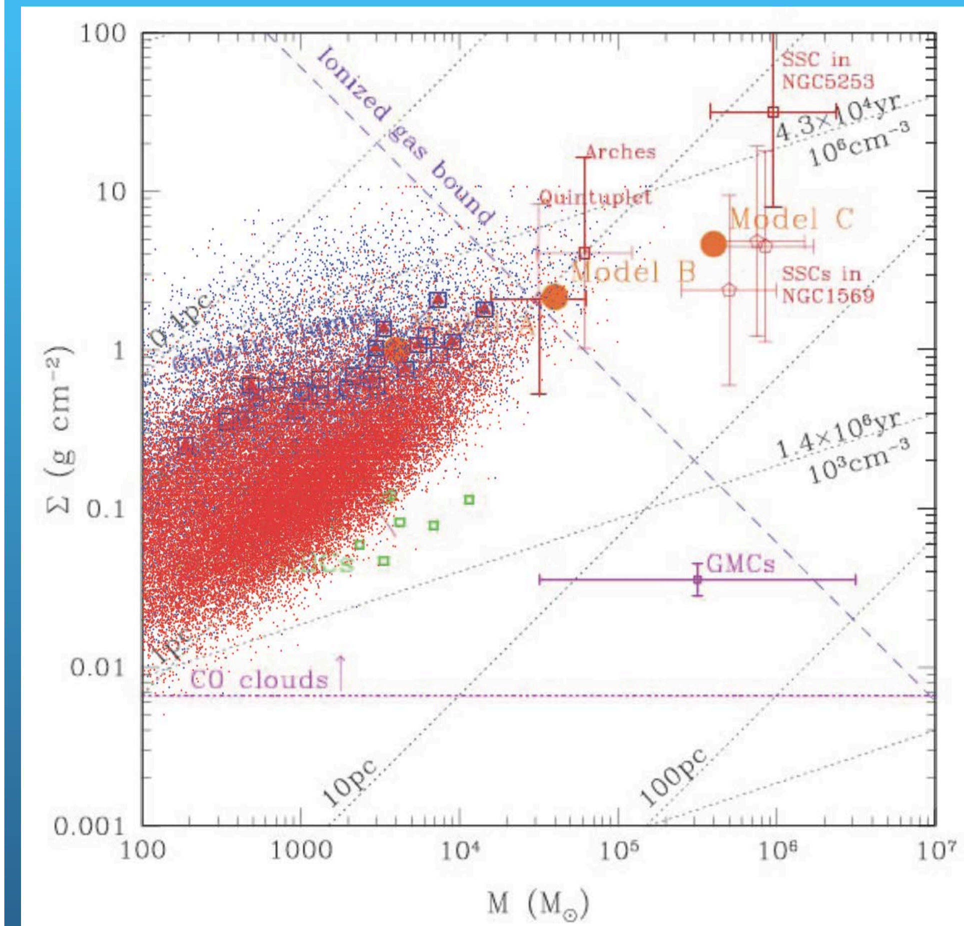
"Accurate method limited by sensitivity"

"2.7e+6 synthetic YSOs between 0.1 – 50 solar masses are required Galaxy Wide to explain the observed number (~12 000 YSOs). This represents less than 0.5% of all YSOs in the Galaxy"

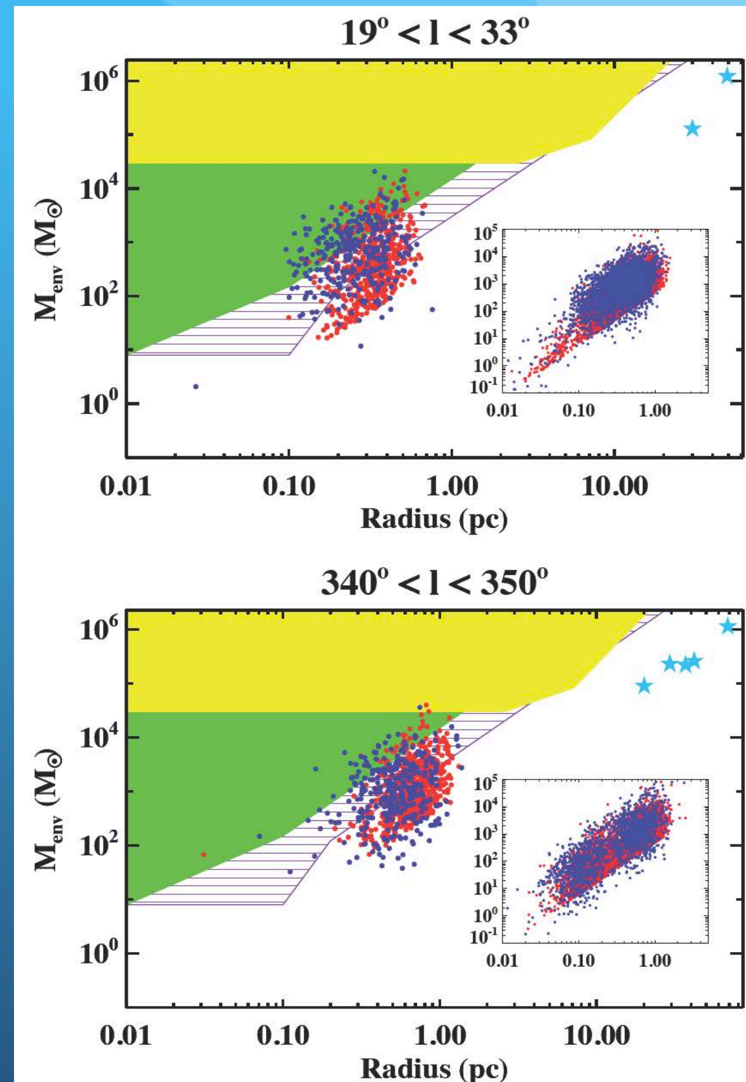
Based on IRAC + MIPS 24um

Proto-Stellar Clusters

Tips of the Bar

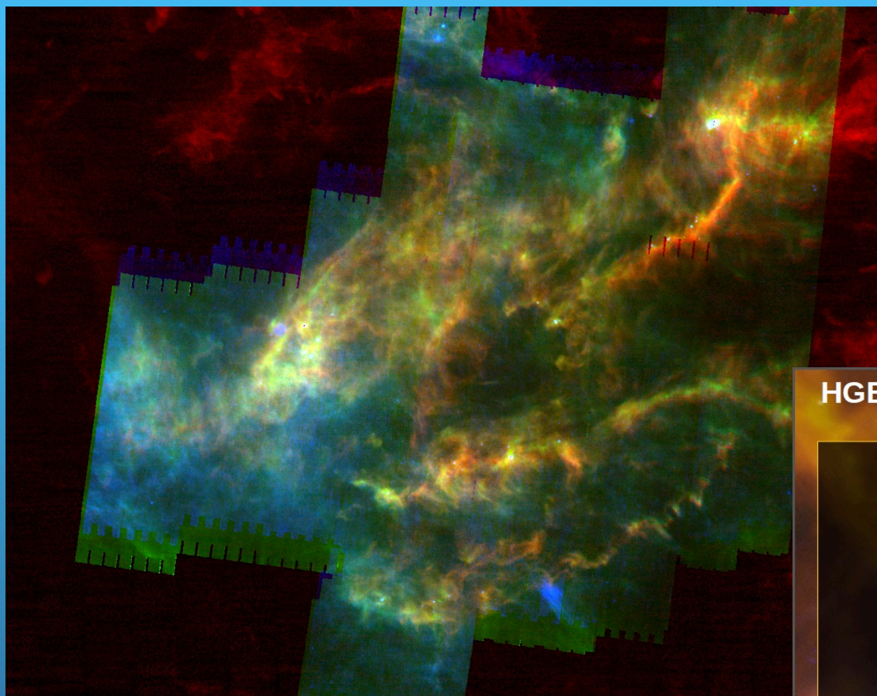


Molinari et al 2014



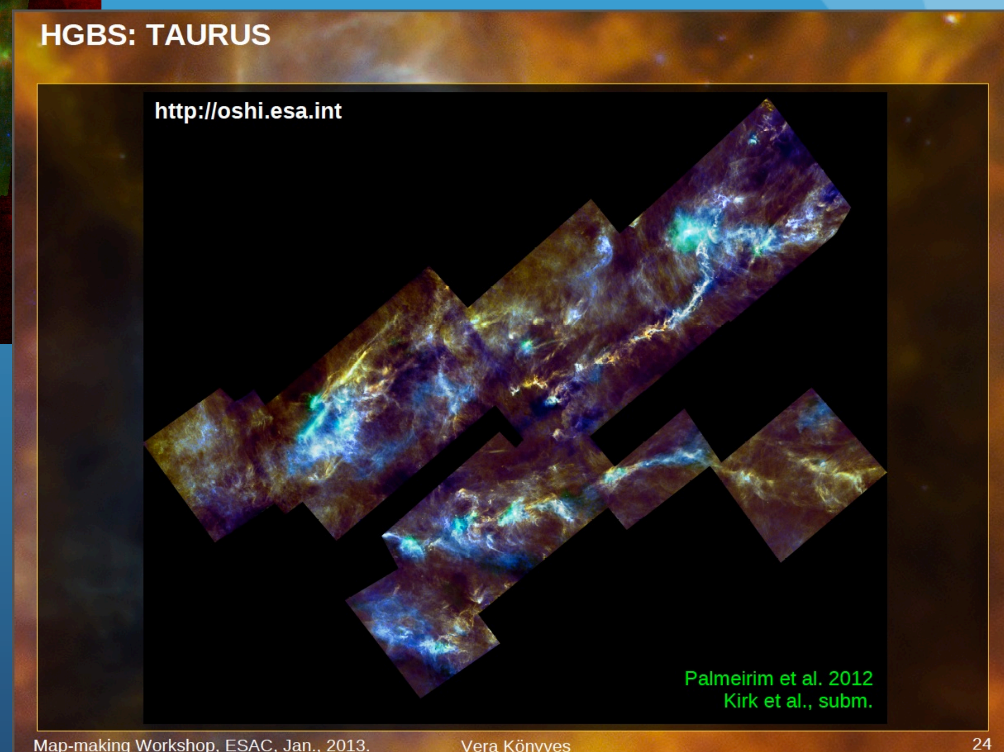
Veneziani et al. 2014

Structure of Filaments

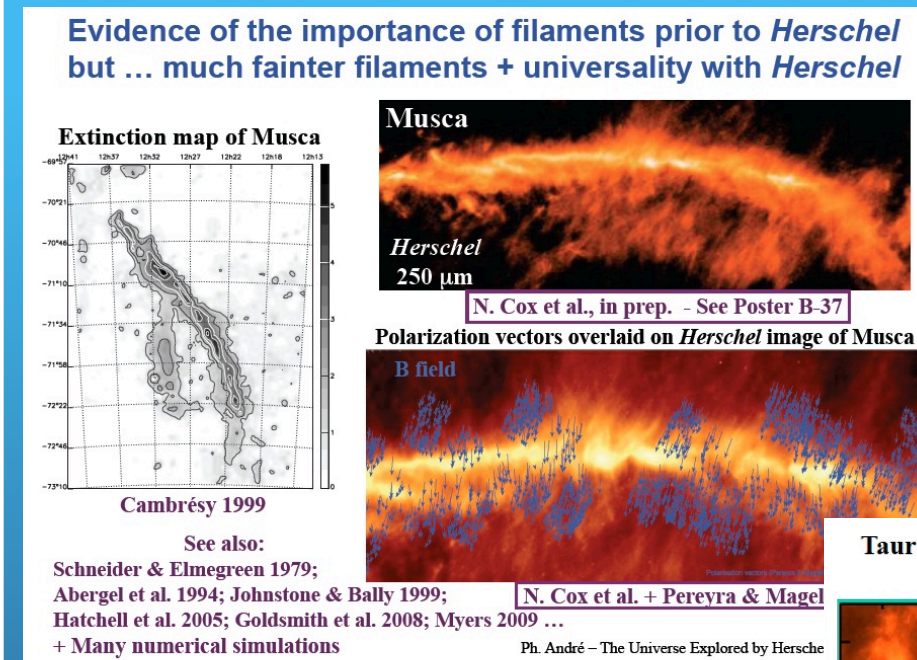


TMC [Spitzer 70, 160 plus CO (Goldsmith)]

TMC [Herschel 160, 250 and 350um]

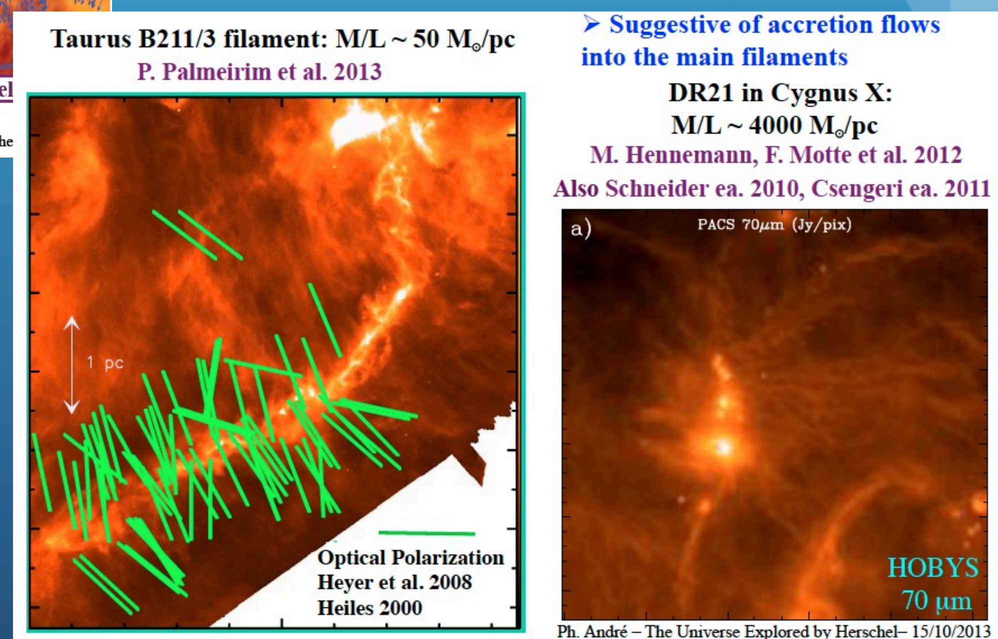


Structure of Filaments (II)

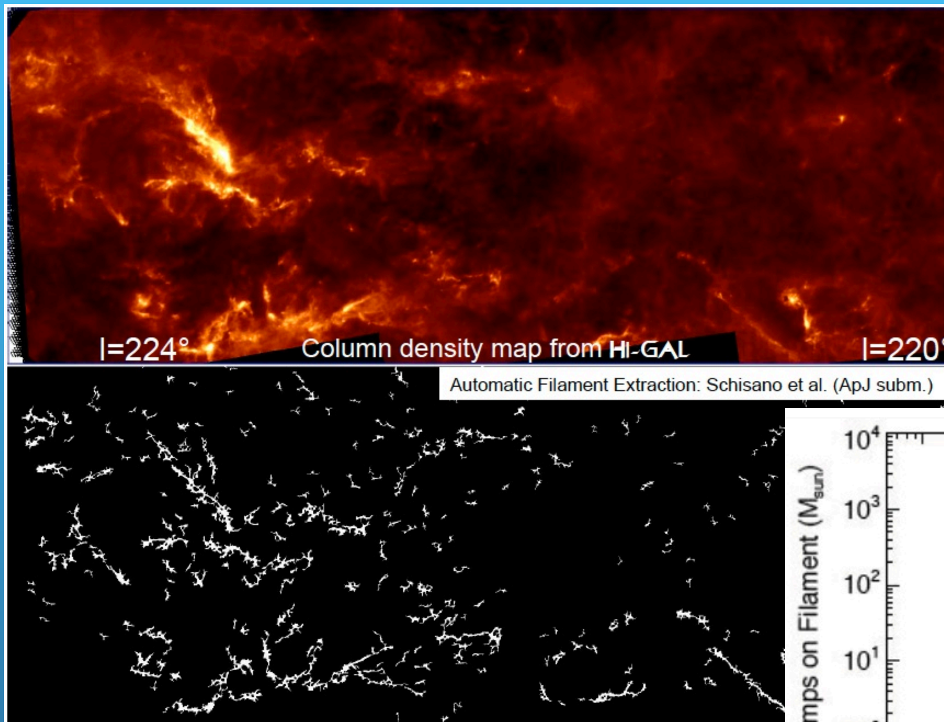


From Andre (2013)

In Nearby Clouds & the MW, SF is taking place along Filaments

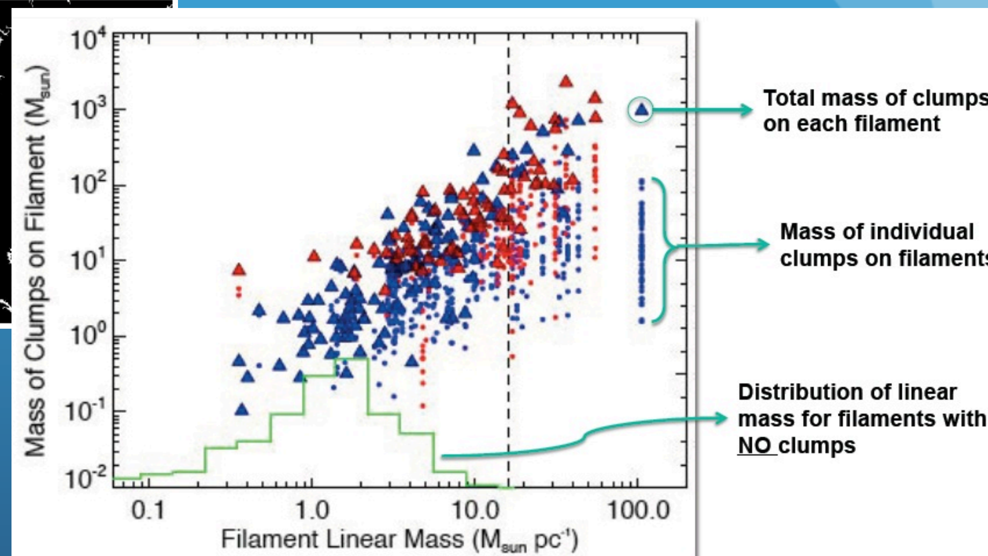


Structure of Filaments (III)



Filaments in the Outer Disk of the MW (Elia et al. 2013; Schisano et al. 2014)

From Molinari 2013



Do more massive clumps form on more massive filaments ?
Or do filaments grow mass from the surrounding environments and channel more mass to the clumps ?
No clear evidence for thresholds

Schisano et al. 2013, ApJ subm. (B4-P73)

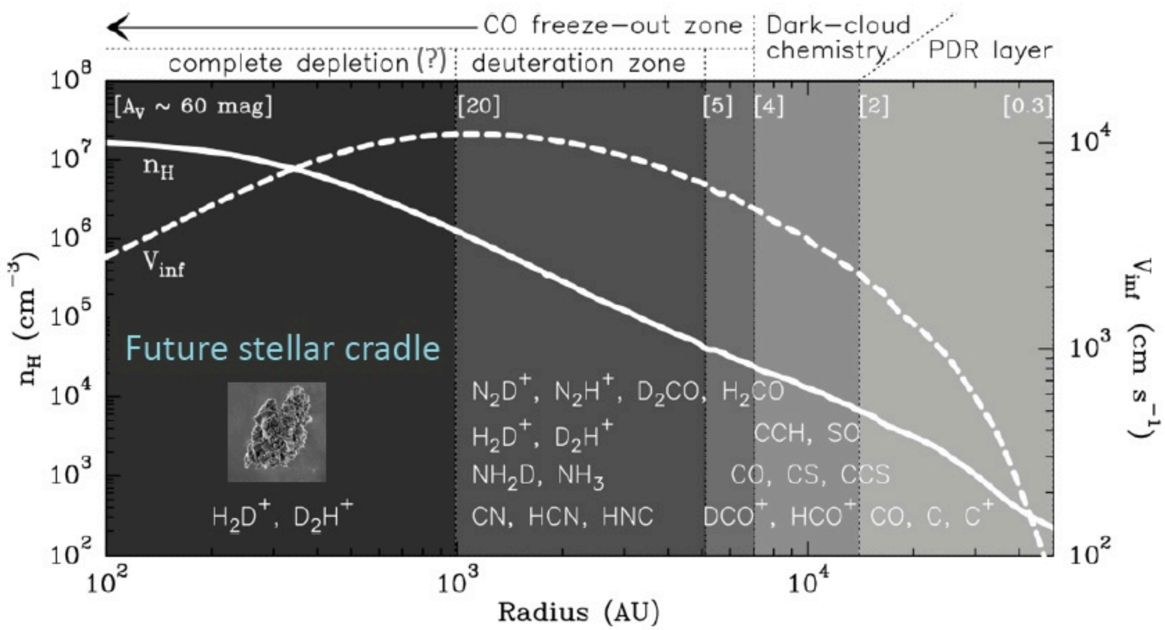
Waterfalls in Pre-stellar Cores & Proto-stars

"Pre-stellar Cores represent the initial conditions in the process of star & planet formation" (Caselli 2013)"
[Water from this stage to the solar system phase]

FIR Unique to penetrate 50/60 magnitudes of extinction.

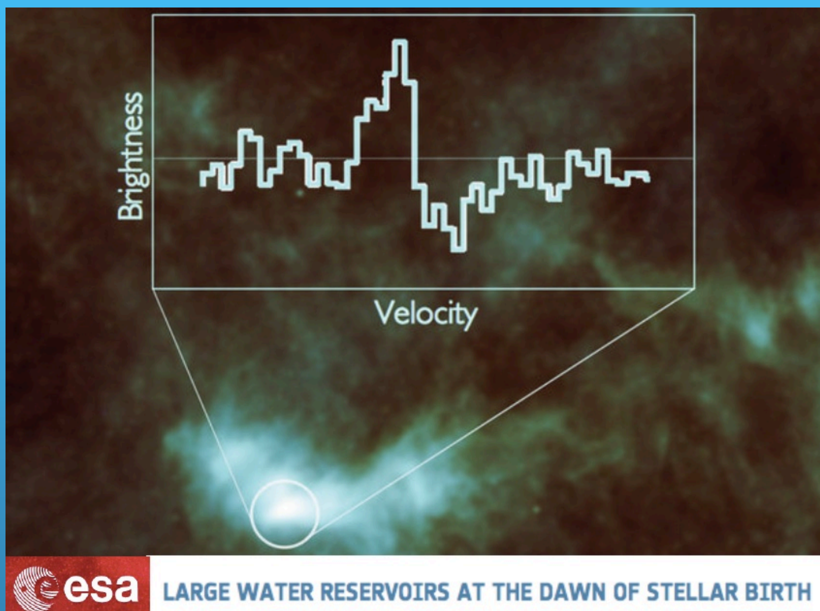
Caselli 2013

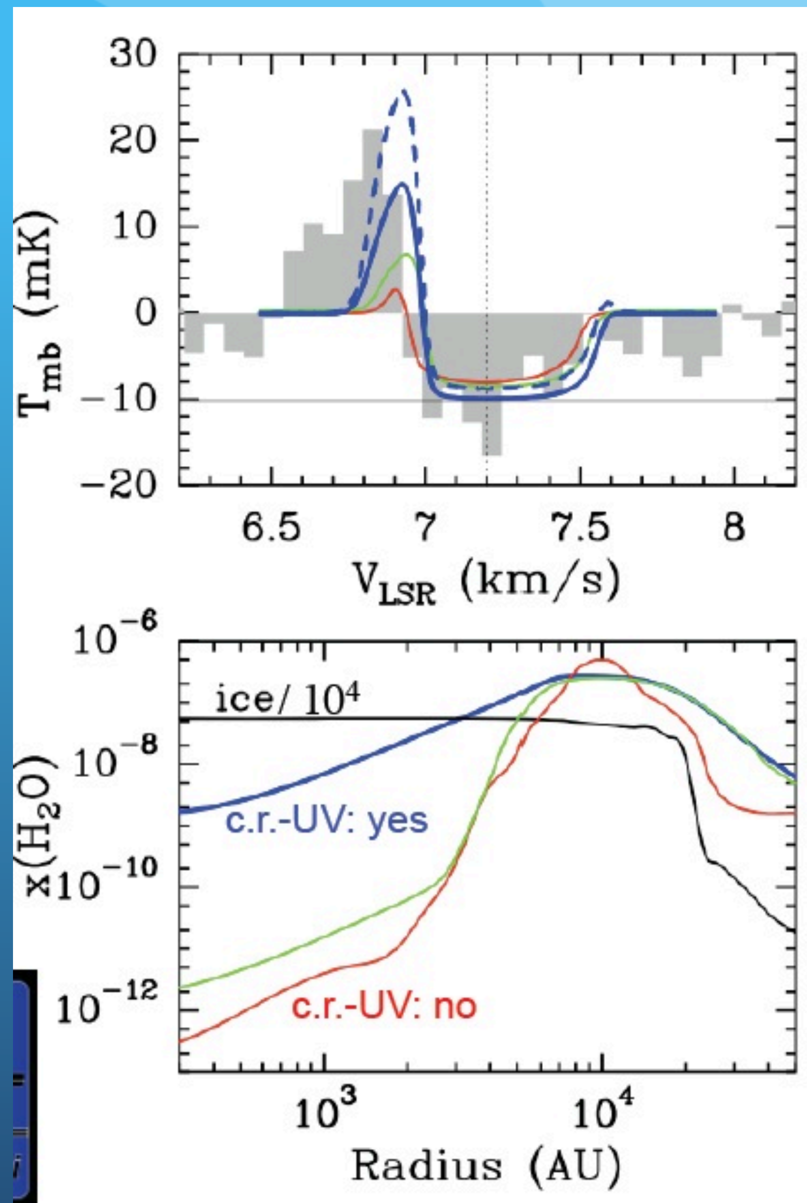
The pre-stellar core physical/chemical structure



Caselli et al. 1999, 2002, 2003; Vastel et al. 2006; Tafalla et al. 2006; Keto & Caselli 2008, 2010

Waterfalls (II)

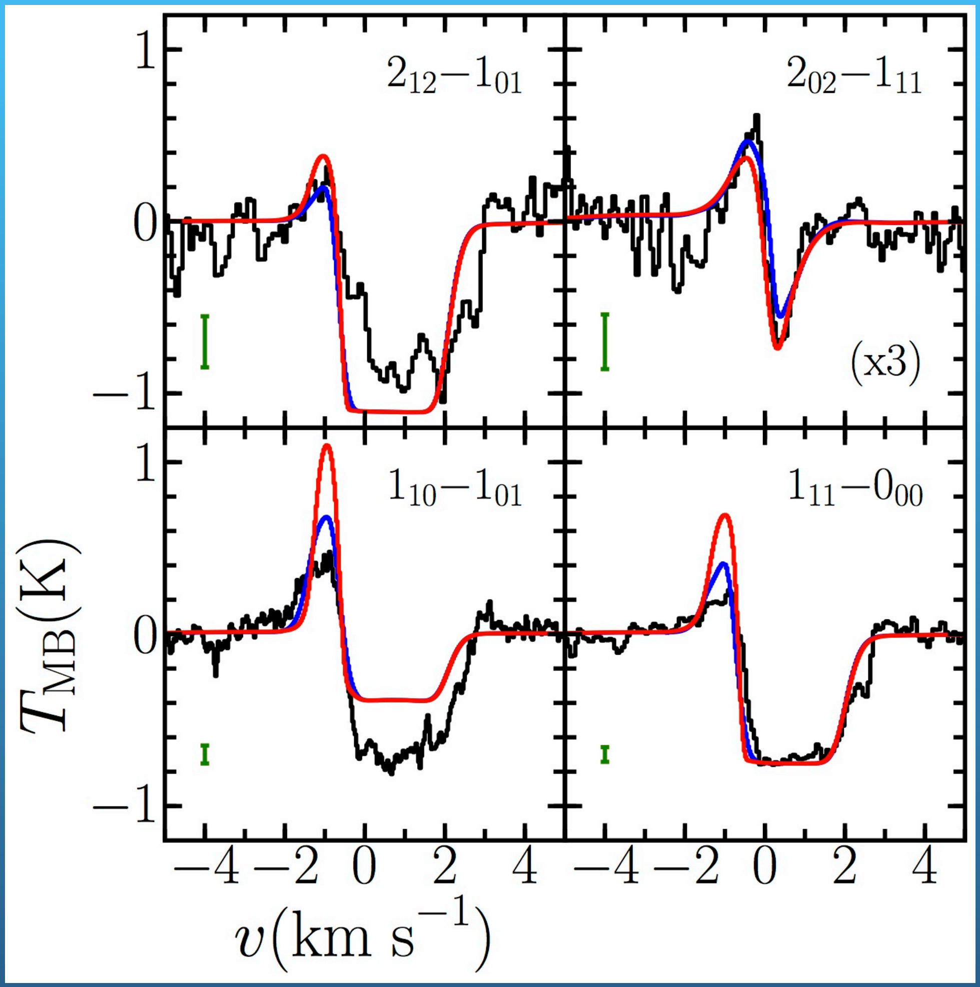


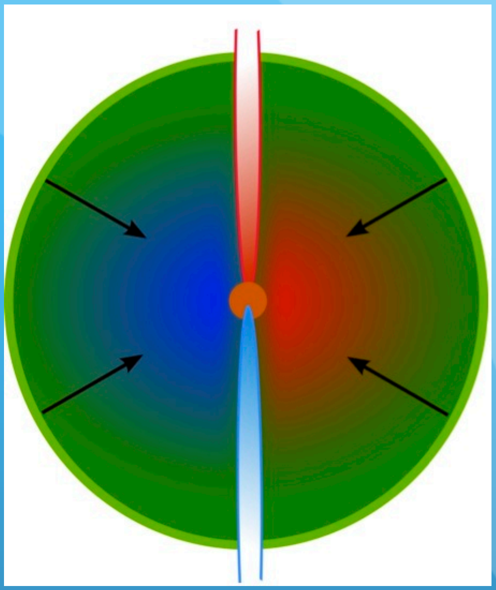


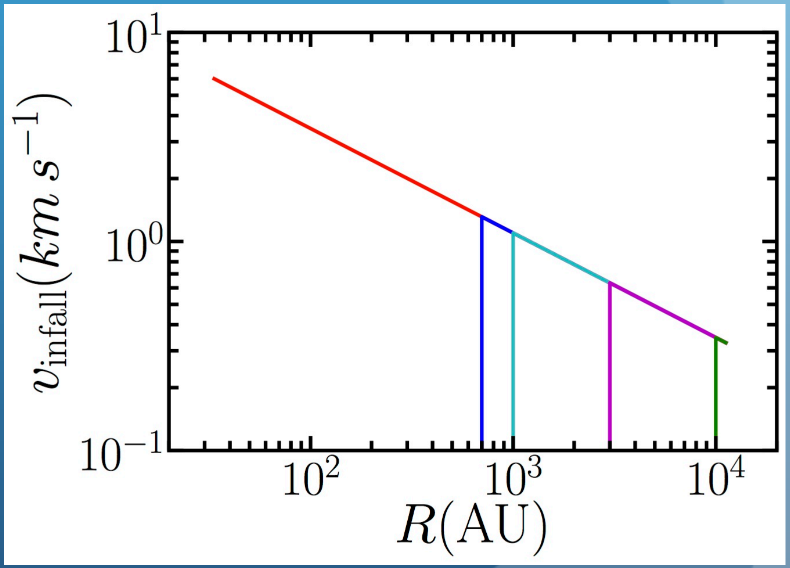
L1544 (in Taurus): HiFi observations of ortho Water (1_{10} -1_{01}) at 557GHz (~40 arcsec beam) in absorption against the IR background (Tdust~7K peak; ~300um)

40” ~ 5500 AU at 140pc

Waterfalls (III)







Mottram et al. 2013

NGC1333-IRAS4A

AME in RCW175

Excess emission at mm wavelengths. Perhaps related to Small spinning dust particles (PAHs). Perhaps at the interface Between the warm/cold dust (PDR).

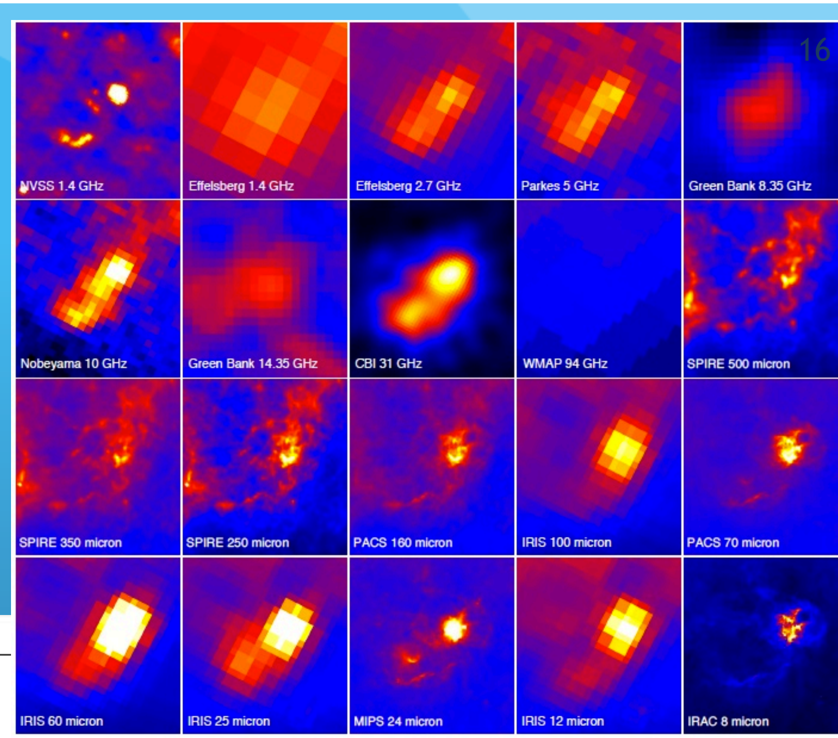
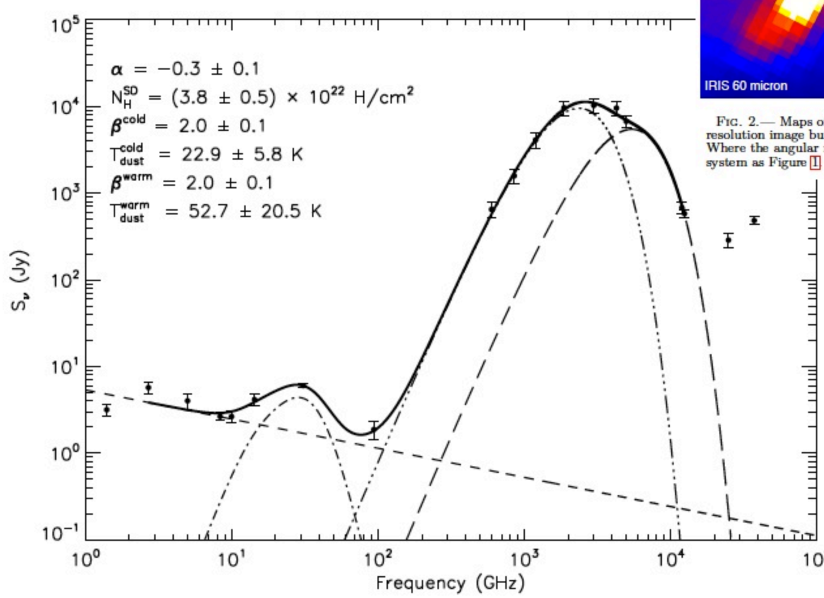


FIG. 2.— Maps of RCW175 all the way from the radio to the mid-IR. There are two maps at 1.4 GHz, as the NVSS map provides a high resolution image but, due to flux loss, it cannot be used to estimate the total flux density, and so we also have the Effelsberg 1.4 GHz map. Where the angular resolution is $\lesssim 5$ arcmin, it is possible to identify both G29.0-0.6 and G29.1-0.7. All maps are on the same co-ordinate system as Figure 1



Tibbs et al. 2011

FIG. 12.— Complete SED for RCW175 from the radio to the mid-IR. The data have been modeled using a power-law representing the free-free emission (*dashed line*), two modified blackbody curves representing the warm (*long-dashed line*) and cold (*dot-dot-dot-dashed line*) thermal dust emission components and a spinning dust curve for the warm ionized medium (*dot-dashed line*). The best fitting values for α, N_H^{SD}, β^{cold} and T_{dust}^{cold}, β^{warm} and T_{dust}^{warm} are displayed. It is clear that there is an excess over both the free-free and thermal dust emission present in RCW175.

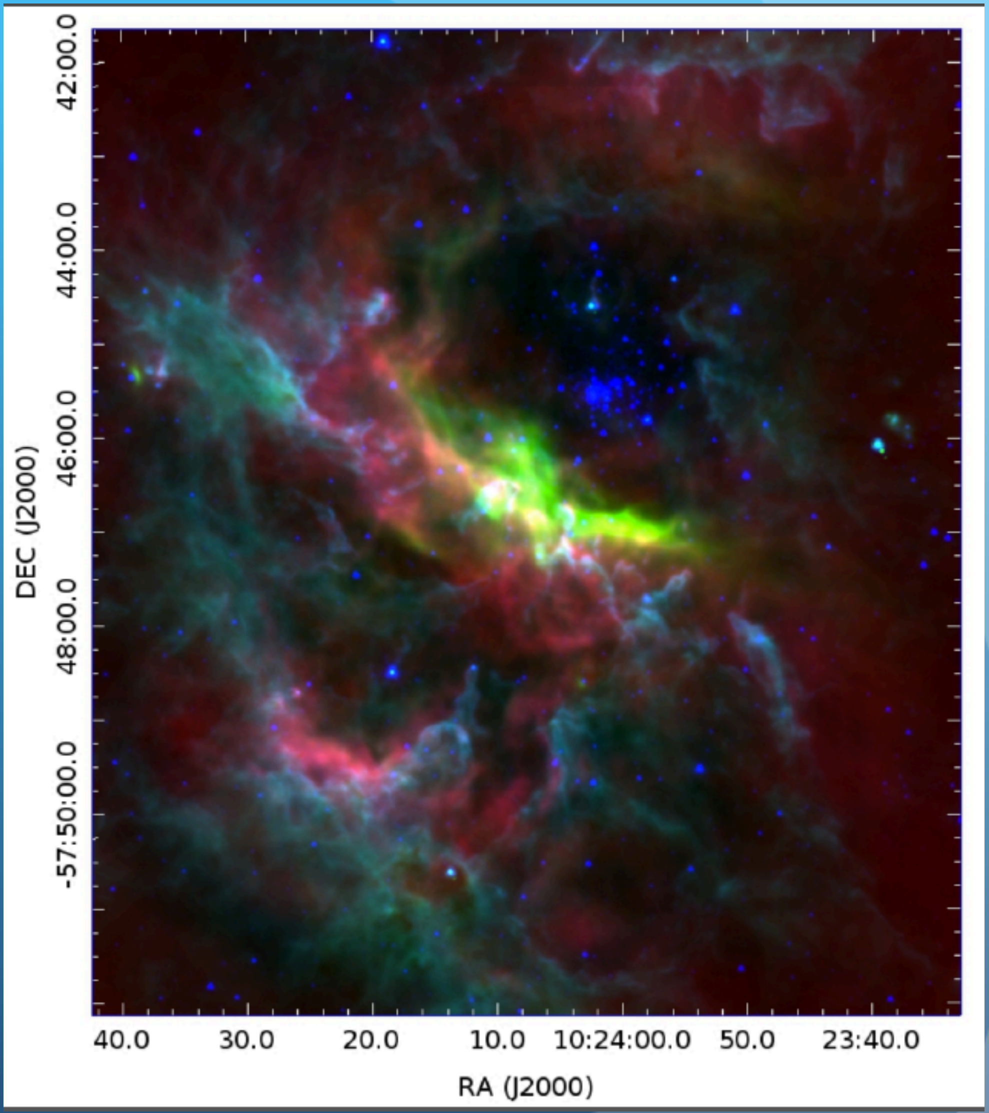
RCW 49 AME

RCW 49 AME from Caltech Background Imager at 31GHz (6'; 3sigma).

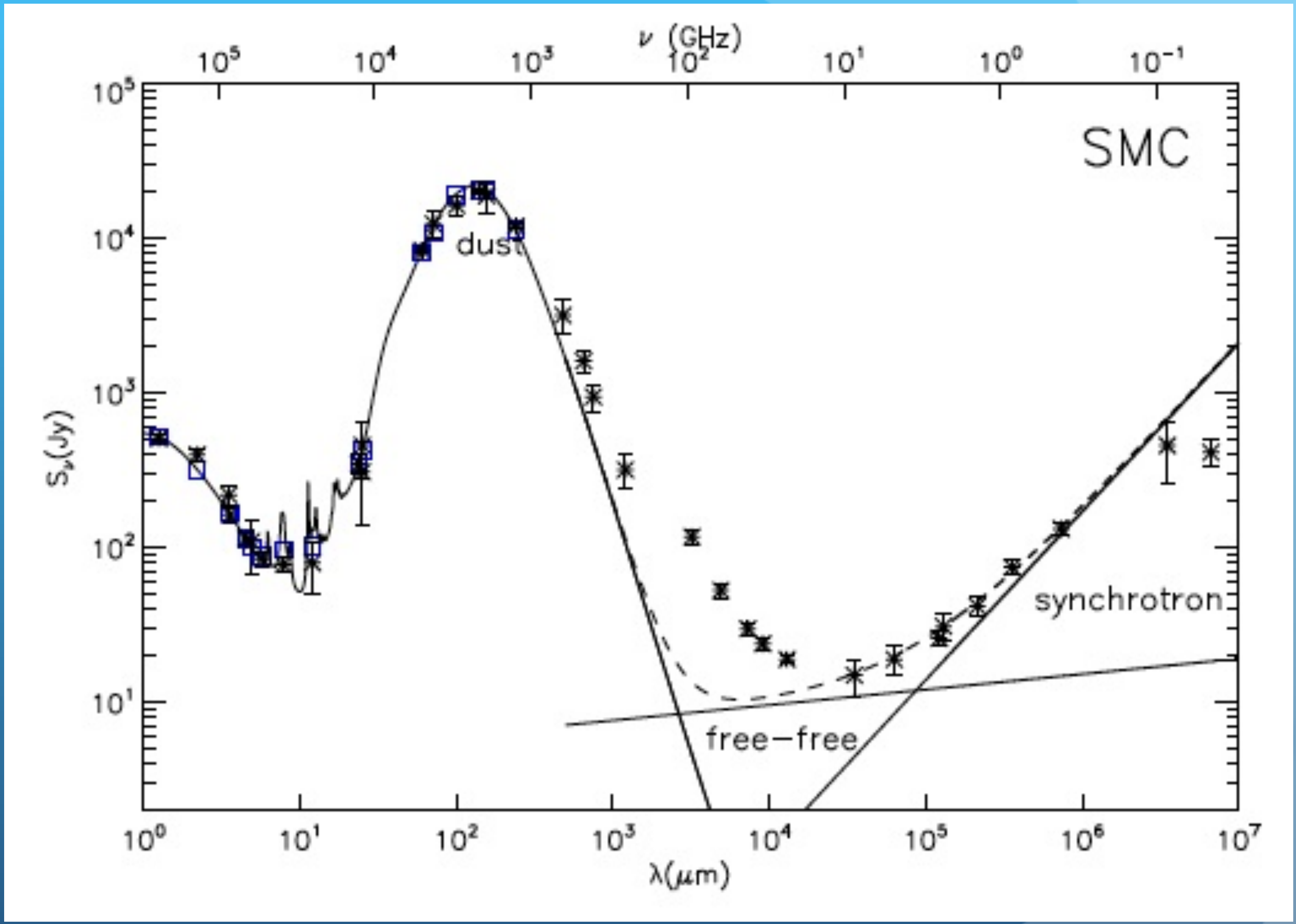
ATCA observations between 5, 19 & 34 Ghz (0.4 – 1 arcsec res) confirmed the excess, but the spectral index is consistent with strong shock & stellar winds *(Paladini et al. 2014)*

From Benaglia et al. 2013
ATCA 9Ghz (red)
IRAC 8um (green)
IRAC 3.6 (blue)

1-100arcsec scales w/ ATCA



AME in the Magellanic Clouds



Bot et al. 2010

Desired Measurement Capabilities

Parameter	Units	Value or Range
Wavelength range	μm	(3.6) 30 – 500um
Angular resolution	arcsec	Few arcsecs at long. wave
Spectral resolution, ($\lambda/\Delta\lambda$)	dimensionless	R=1.e+4 – 1,e+5
Continuum sensitivity	μJy	10^{-3}
Spectral line sensitivity	10^{-19} W m^{-2}	A few
Instantaneous FoV	arcmin	5
Number of target fields	dimensionless	The MW disk(imaging); few 100s for spectroscopy
Field of Regard	sr	

To study objects in the MW at few Kpc distances we still need higher angular resolution and sensitivity in the FIR