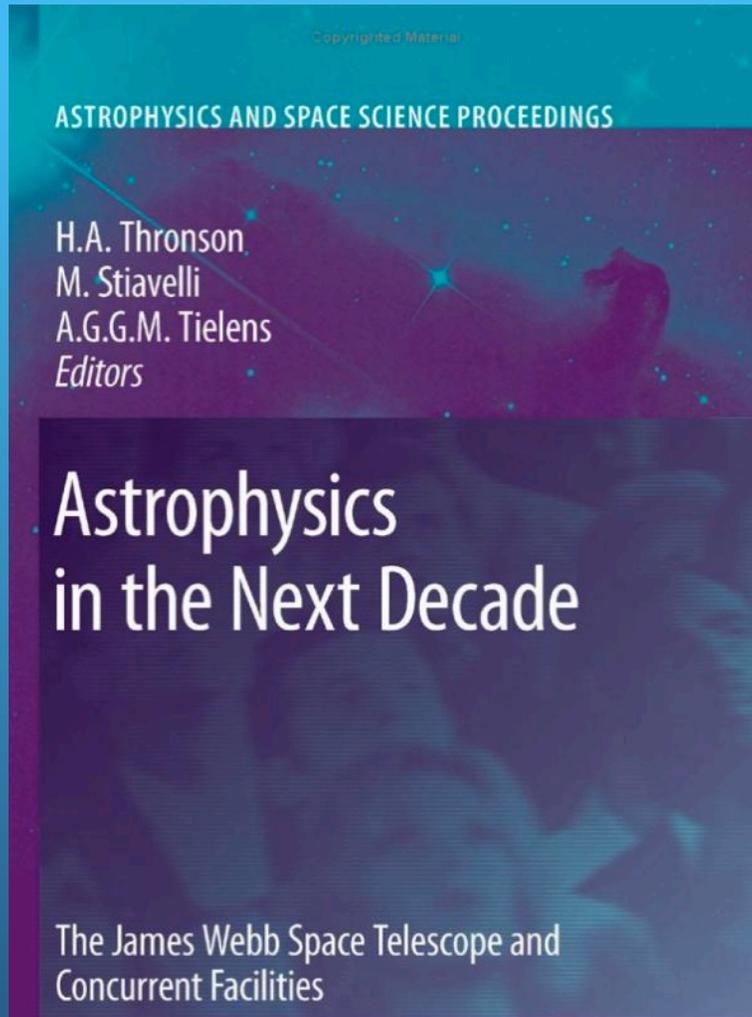


Star Formation & ISM. The Way Forward.

*Alberto Noriega-Crespo
Space Telescope Science Institute JWST*

Preamble



Tucson - Sep 2007

Far Infrared Astronomy from Space: A Community Workshop about the Future

28 May - 30 May 2008

Major Topics

- Important new science results in the mid and far-infrared
- Upcoming opportunities and future mission concepts
- Key areas for technology advancement
- A celebration of the 25th anniversary of IRAS

25 YEARS

IRAS view of Orion

MSX image of Cygnus

Spitzer direct detection of extrasolar planets

Planet TRAP-P
Planet HD 209458b

Spitzer image of the Rho Oph cloud

Spitzer & HST image of distant red galaxy

ISO spectrum of the Circinus galaxy

Scientific Organization Committee

G. Helou (IPAC)	D. Lester (Texas)
L. Armus (SSC)	C. McKee (Berkeley)
M. Harwit (Cornell)	M. Meixner (STScI)
T. Bergin (Michigan)	R. Mushotzky (GSFC)
M. Bradford (JPL)	T. Onaka (Tokyo)
D. Calzetti (UMASS)	G. Rieke (Arizona)
T. Heckman (JHU)	A. Roberge (GSFC)
E. Herbst (OSU)	T. Roellig (NASA Ames)
R. Ivison (Edinburgh)	S. Seager (MIT)
D. Leisawitz (GSFC)	M. Shull (Colorado)

For more information, see
<http://www.ipac.caltech.edu/irspace>

Pasadena May 2008

Pro



WANTED: Sub-arcsecond angular resolution



Instructions:

We invite you to contribute to the program. We prefer on your part that you will post the abstracts.

Please remember to also discuss the program and address the needs of the community.

Talks:

Contributed talks

Posters:

Posters should be presented at the conference.

Mission Highlights:

Short instructions

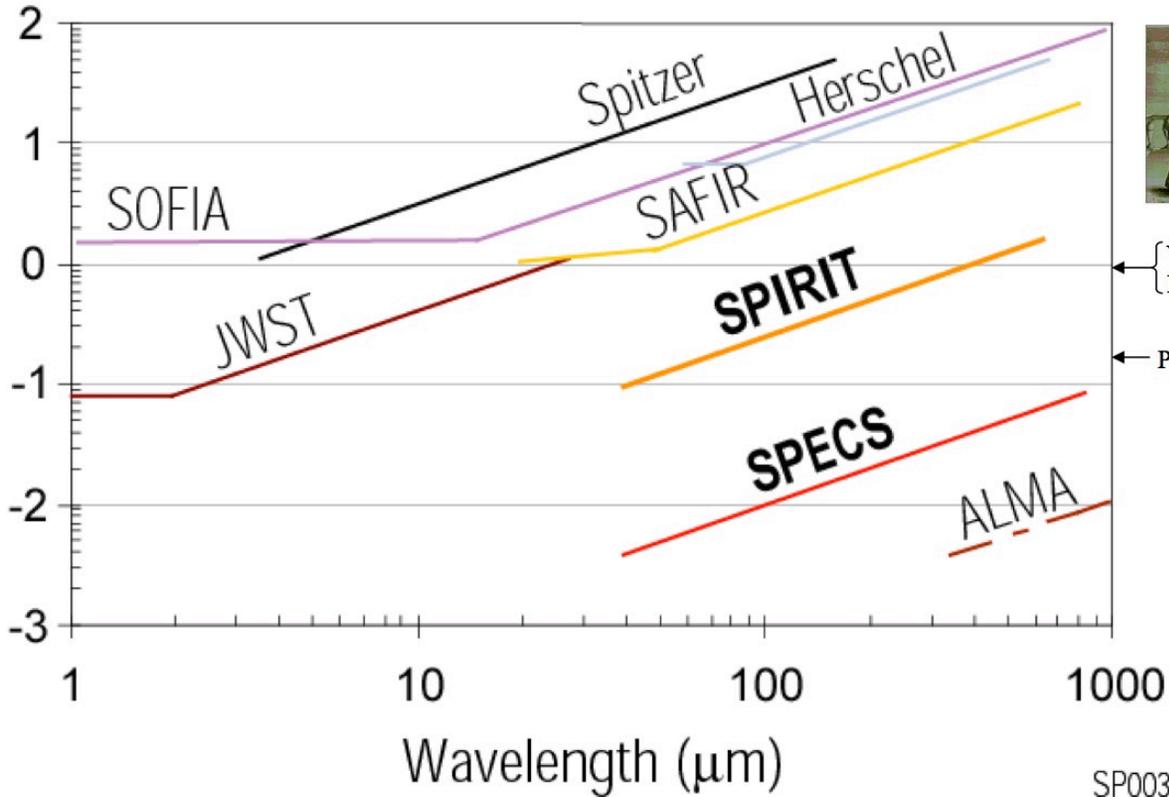
- [WISE](#)
- [SOFIA](#)
- [Herschel](#)
- [JWST](#)
- [SPICA](#)
- [NASA Balloon Program](#)
- [ALMA](#)
- [EVLA](#)

12 November 2007

Astrophysics 2020, STScI - D. Leisawitz

SP003

log [Angular Resolution (arcsec)]



{ YSO disk at 140 pc
 Debris disk at 30 pc
 ← Proto-galaxy at $z \sim 5$

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

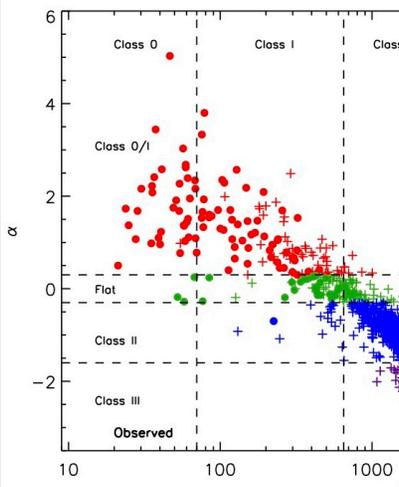
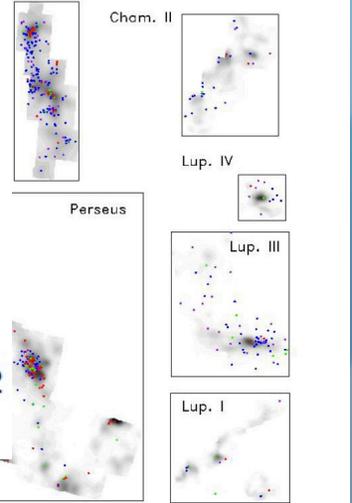
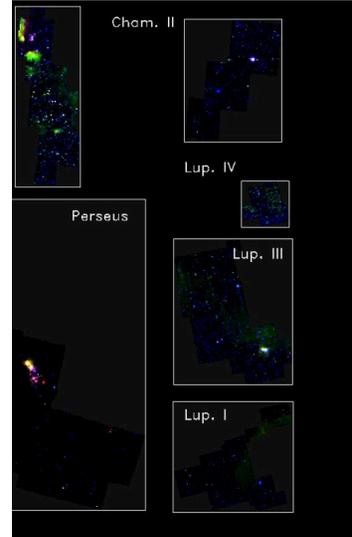
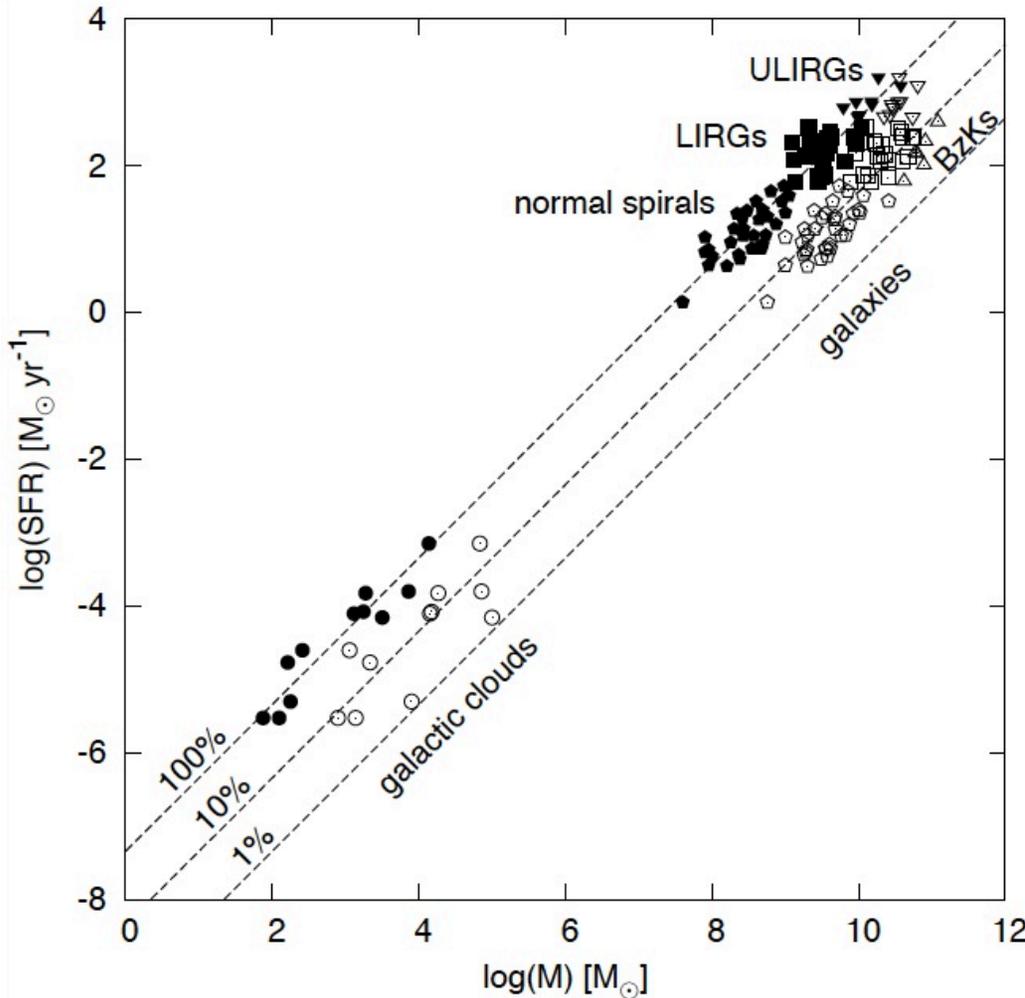
Introduction

- 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)

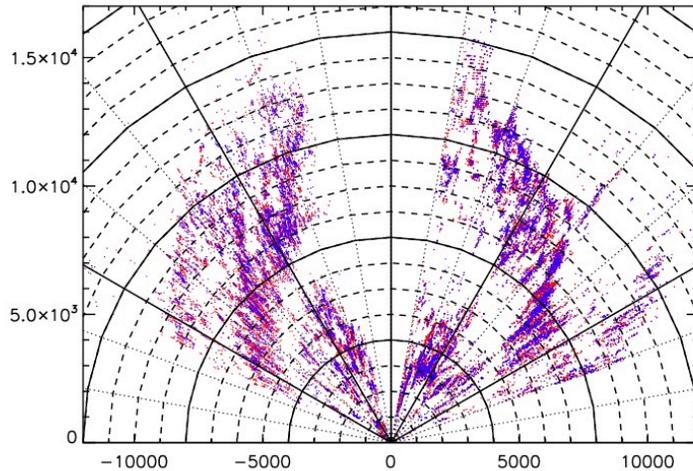
THE SPITZER C2D LEGACY RESULTS: STAR FORMATION RATES AND EFFICIENCIES

NEAL J. EVANS II¹, MICHAEL M. MERIN^{5, 6}, EWINE F. VAN DISSEL⁷, STAPELFELDT¹⁰, TRACY L. HUANG¹¹, GEOFFREY A. BLAKE¹², DAVID



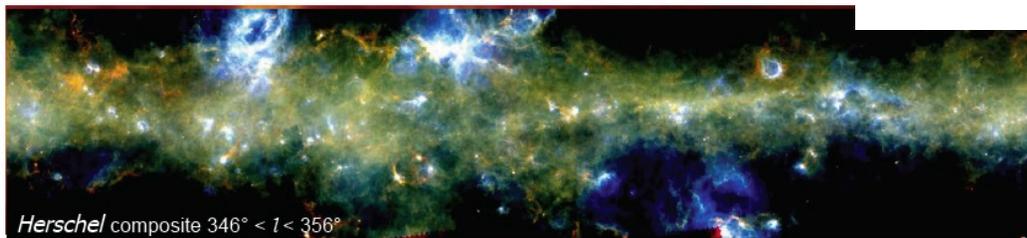
Evans

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 shown here outside the CMZ and with first estimates on distances.

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

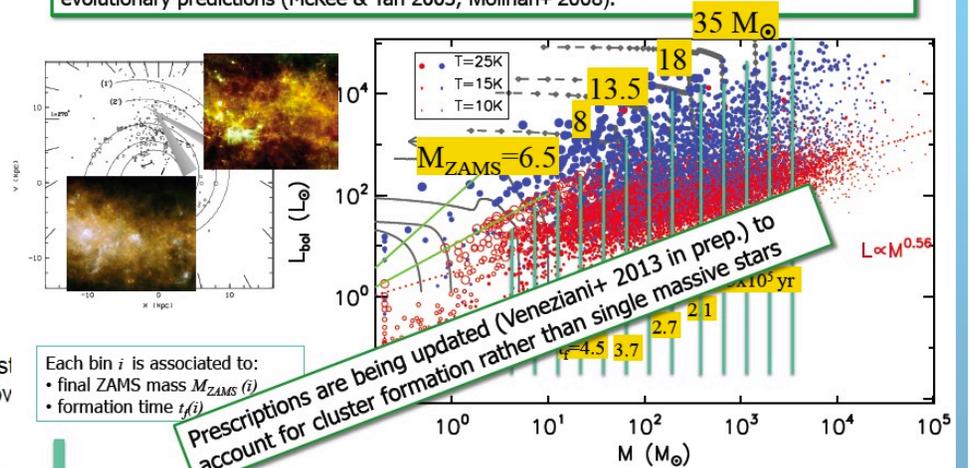


Simultaneous 5-bands (70-160-250-350-500 μ m) continuum mapping of 720 sq. deg. of the Galactic Plane ($|b| \le 1^\circ$)

Plus IRAC+MIPS +WISE (SEDs)

Star Formation Rate from YSO counts

A first attempt in deriving the SFR in the two Hi-GAL SDP fields $l=30^\circ$ and $l=59^\circ$ (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 $t_f(i)$

Prescriptions are being updated (Veneziani+ 2013 in prep.) to account for cluster formation rather than single massive stars

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

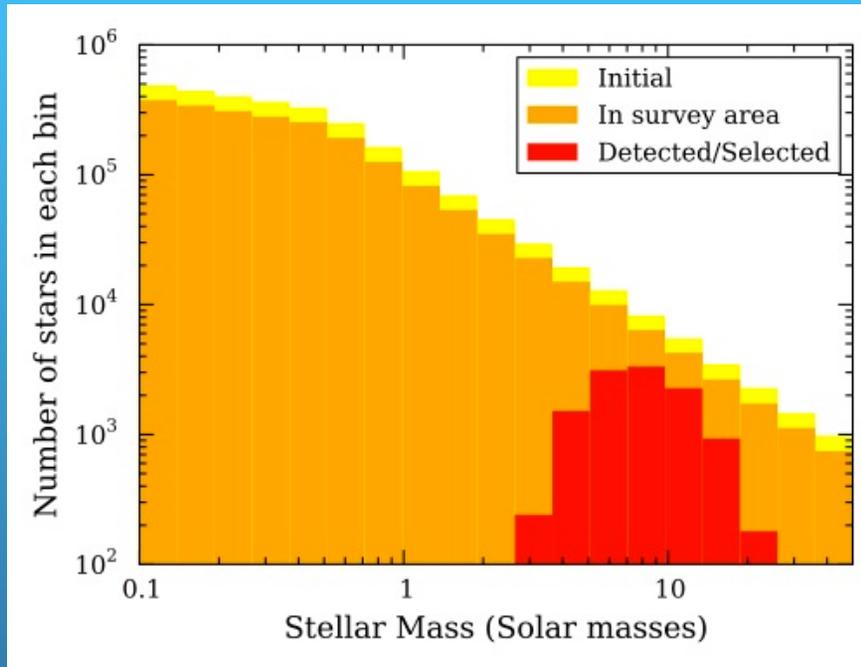
$l=30^\circ \rightarrow 0.067 M_\odot/\text{yr}$
 $l=59^\circ \rightarrow 0.011 M_\odot/\text{yr}$

SPIRE 500 μ m beam ~ 36 arcsecs

Molinari *et al.* 2014

SFR in the MW (II)

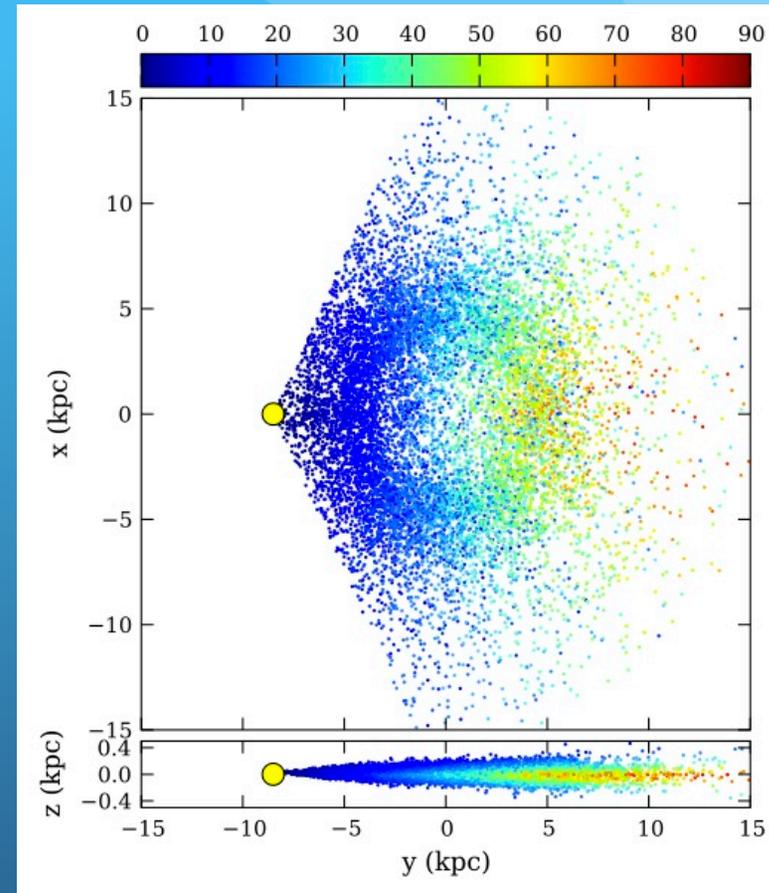
Population Synthesis models



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”

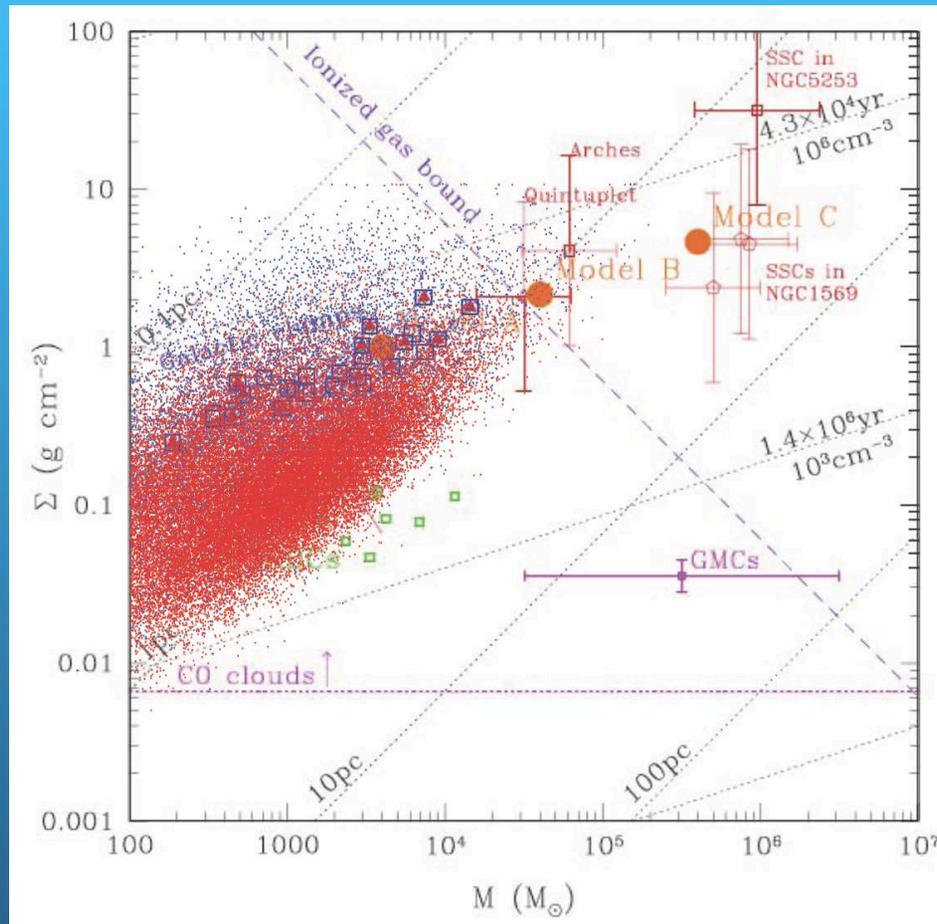


Av

*Based on IRAC + MIPS
24um*

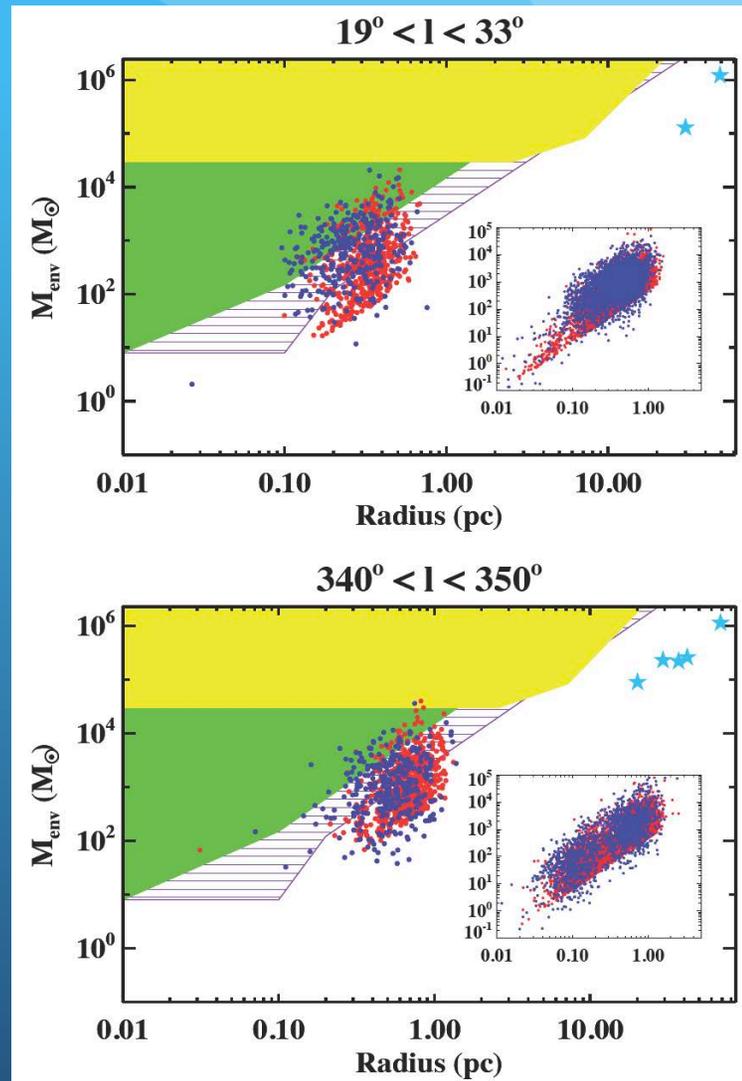
Proto-Stellar Clusters

Tips of the Bar

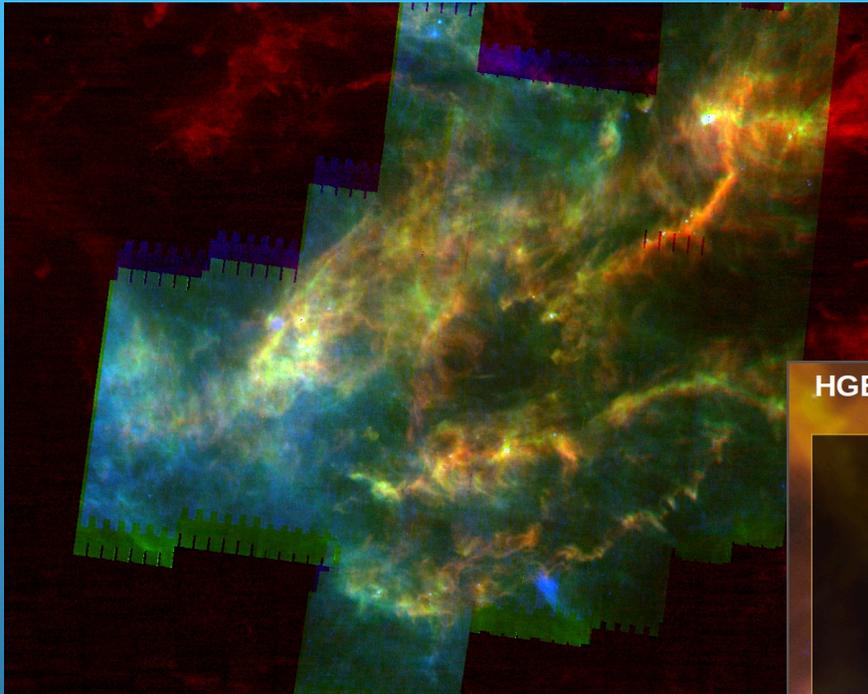


Molinari et al 2014

Veneziani et al. 2014



Structure of Filaments



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

*TMC [Herschel 160,
250 and 350um]*

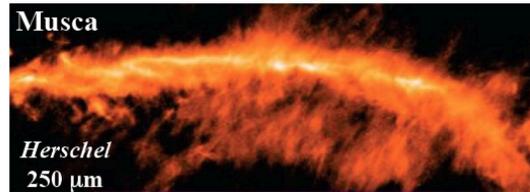
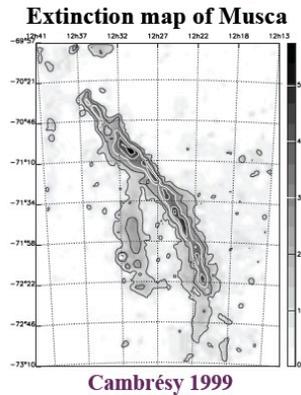
HGBS: TAURUS



Palmeirim et al. 2012
Kirk et al., subm.

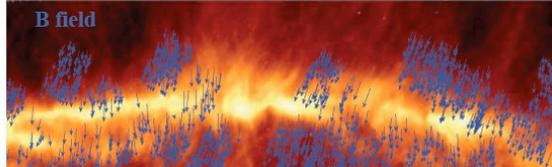
Structure of Filaments (II)

Evidence of the importance of filaments prior to *Herschel* but ... much fainter filaments + universality with *Herschel*



N. Cox et al., in prep. - See Poster B-37

Polarization vectors overlaid on *Herschel* image of Musca



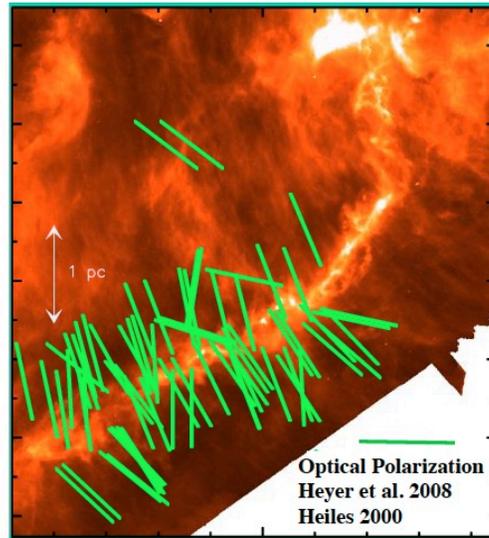
See also:
Schneider & Elmegreen 1979;
Abergel et al. 1994; Johnstone & Bally 1999;
Hatchell et al. 2005; Goldsmith et al. 2008; Myers 2009 ...
+ Many numerical simulations

N. Cox et al. + Pereyra & Magel
Ph. André - The Universe Explored by Herschel

From Andre (2013)

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

Taurus B211/3 filament: M/L $\sim 50 M_{\odot}/\text{pc}$
P. Palmeirim et al. 2013

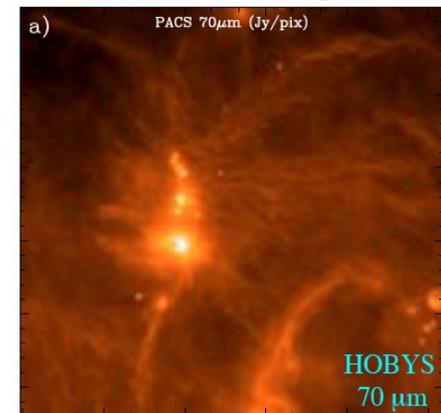


Suggestive of accretion flows into the main filaments

DR21 in Cygnus X:
M/L $\sim 4000 M_{\odot}/\text{pc}$

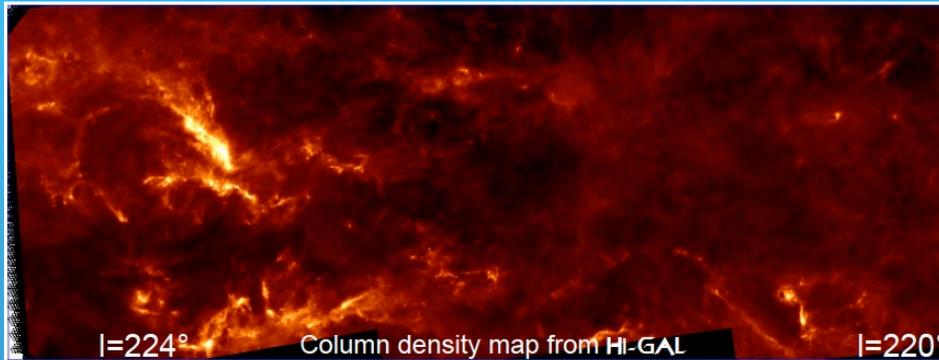
M. Hennemann, F. Motte et al. 2012

Also Schneider et al. 2010, Csengeri et al. 2011



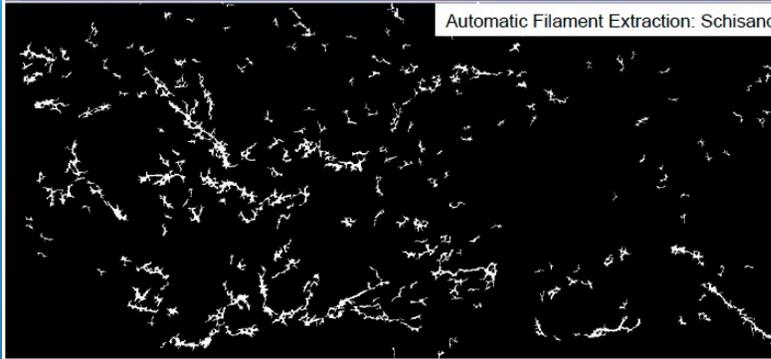
Ph. André - The Universe Explored by Herschel- 15/10/2013

Structure of Filaments (III)

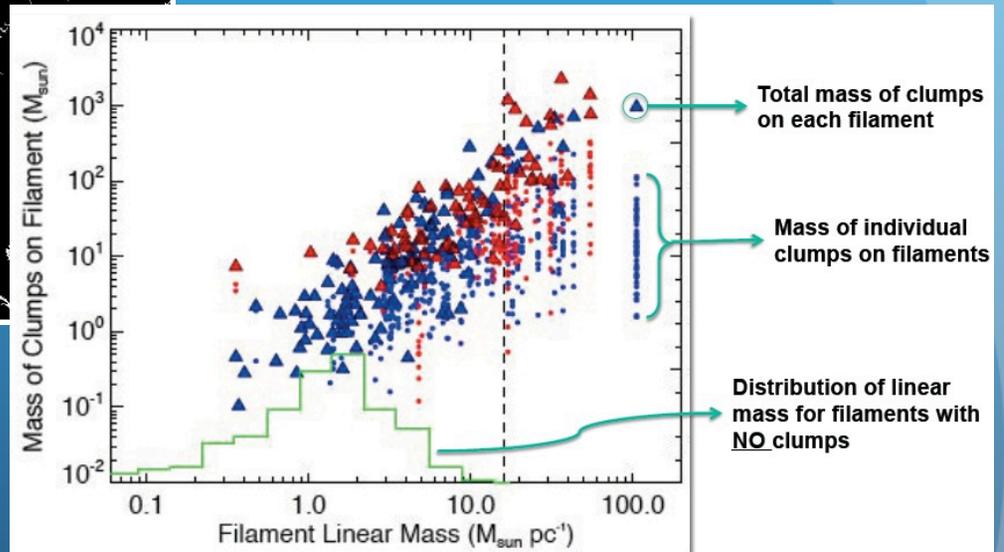


Filaments in the Outer Disk of the MW (Elia et al. 2013; Schisano et al. 2014)

Automatic Filament Extraction: Schisano et al. (ApJ subm.)



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

Waterfalls in Pre-stellar Cores & Proto-stars

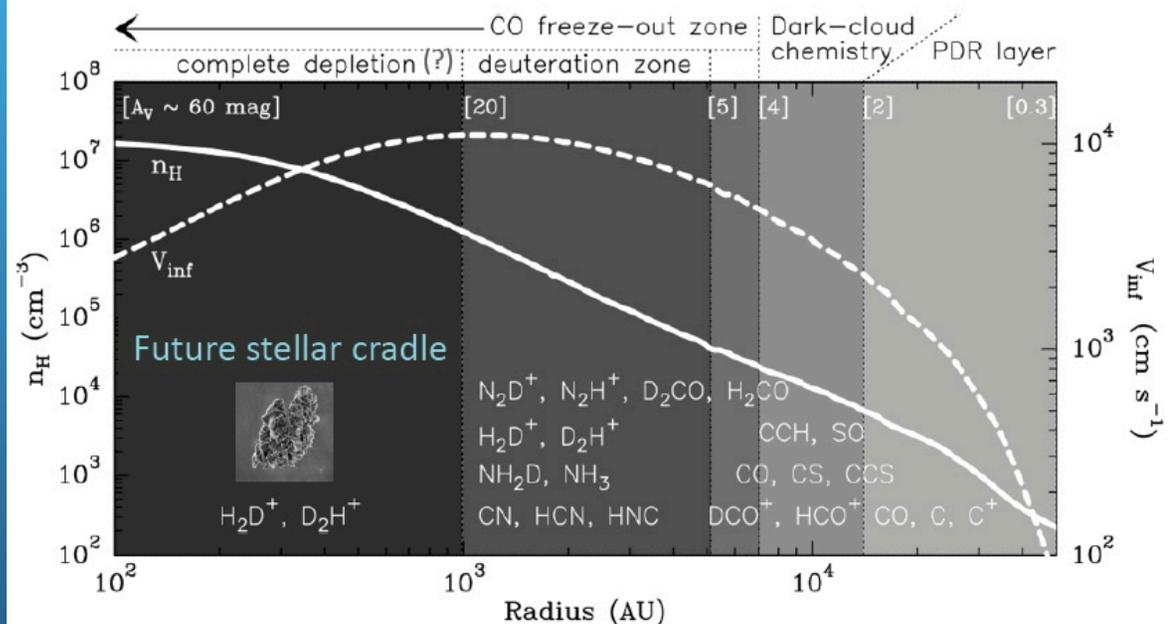
“Pre-stellar Cores represent the initial conditions in the process of star & planet formation” (Caselli 2013)”

[Water from this stage to the solar system phase]

FIR Unique to penetrate 50/60 magnitudes of extinction.

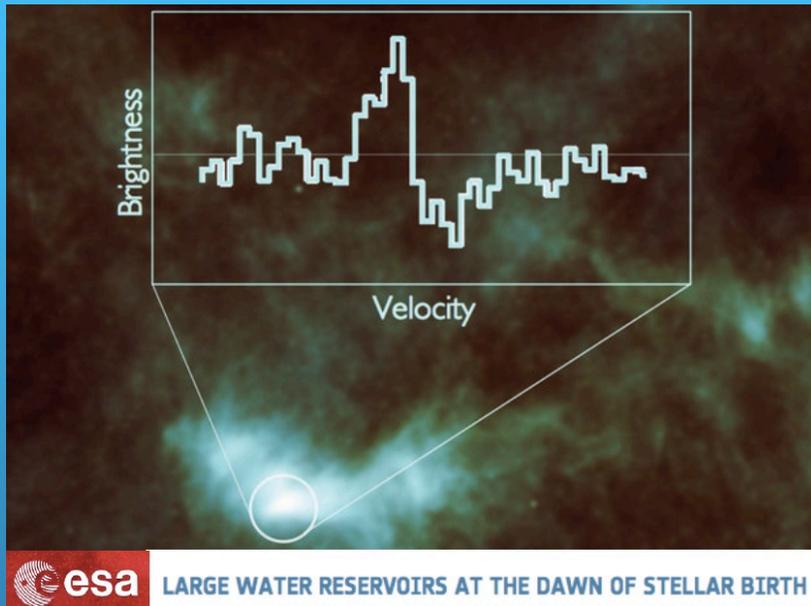
Caselli 2013

The pre-stellar core physical/chemical structure



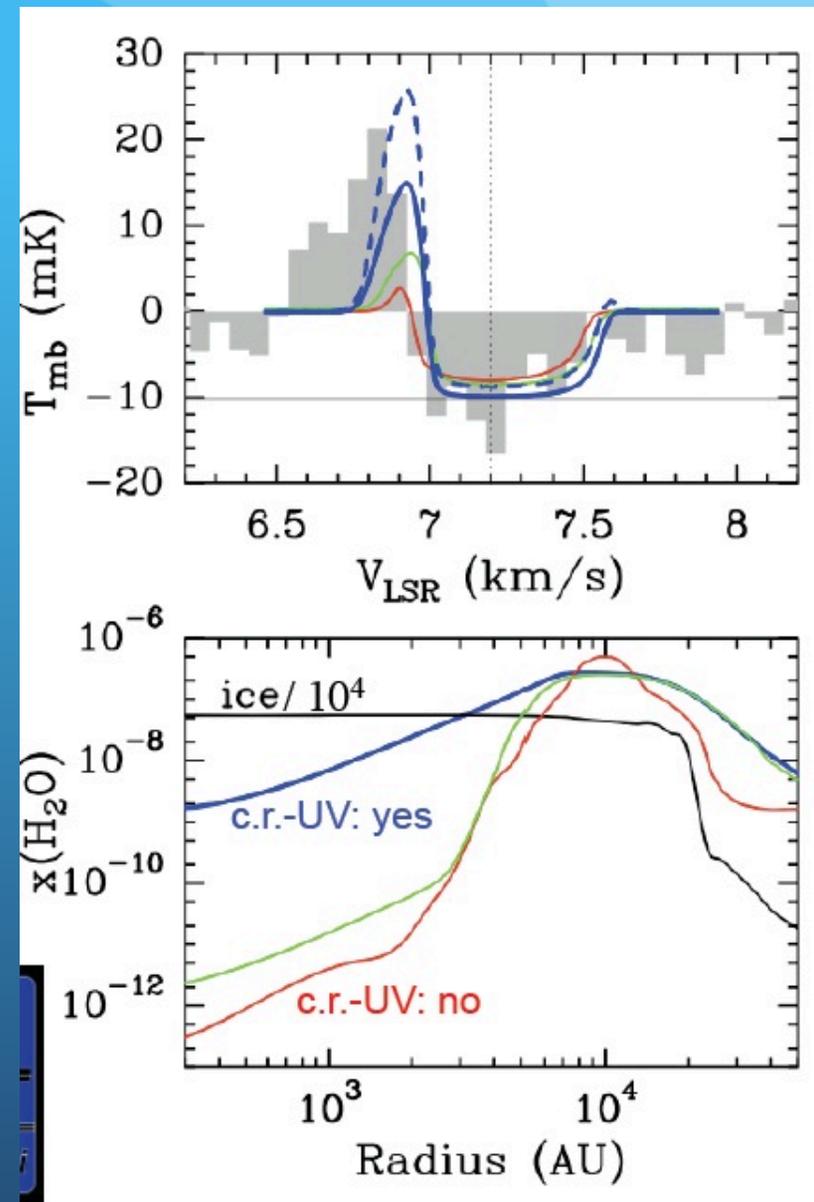
Caselli et al. 1999, 2002, 2003; Vastel et al. 2006; Tafalla et al. 2006; Keto & Caselli 2008, 2010

Waterfalls (II)

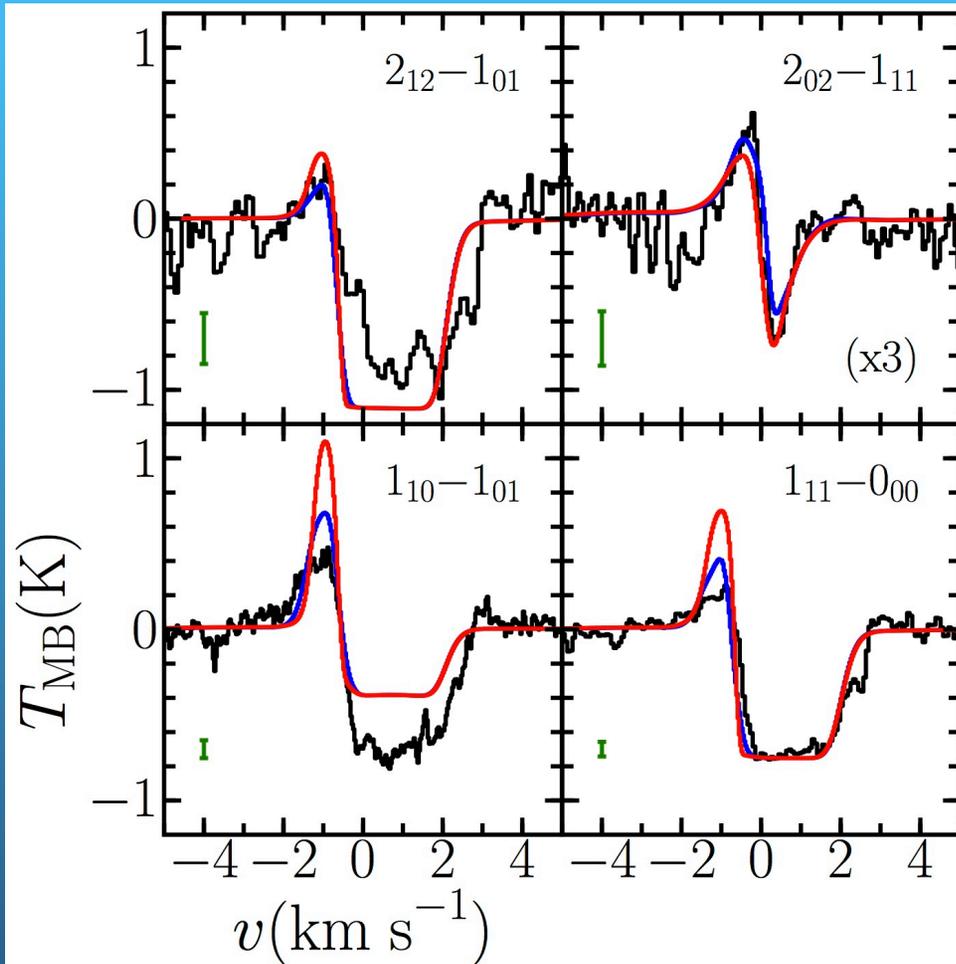


L1544 (in Taurus): HiFi observations of ortho Water ($1_{10}-1_{01}$) at 557GHz (~40 arcsec beam) in absorption against the IR background ($T_{\text{dust}} \sim 7\text{K}$ peak; $\sim 300\mu\text{m}$)

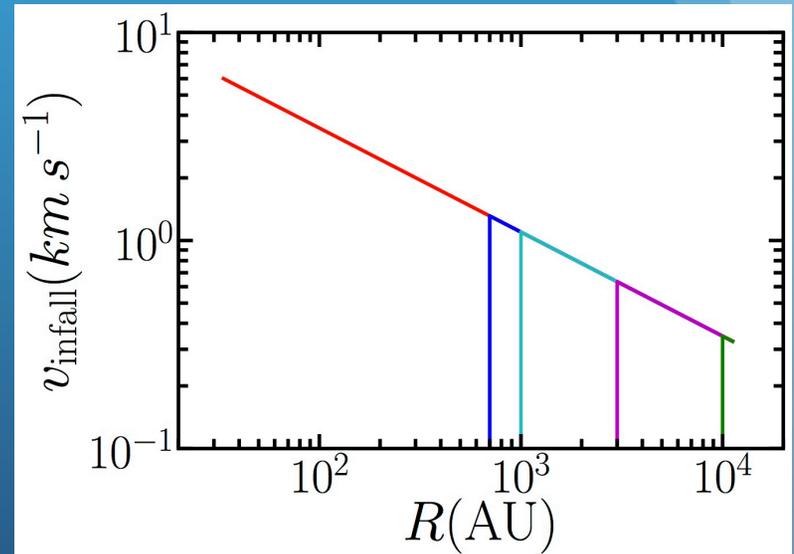
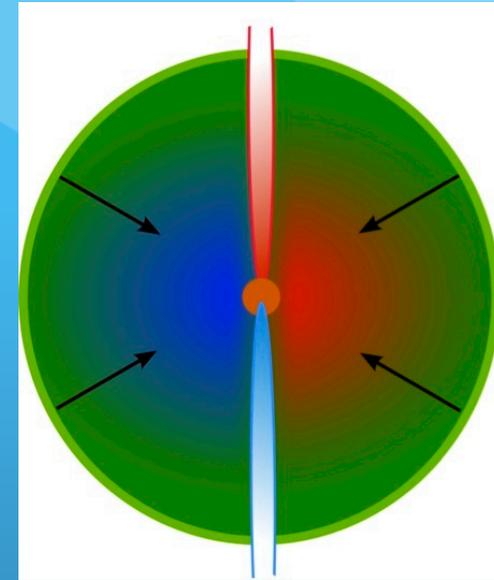
40" ~ 5500 AU at 140pc



Waterfalls (III)



Mottram et al. 2013



NGC1333-IRAS4A

FIR Community Wksp - Goddard

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).

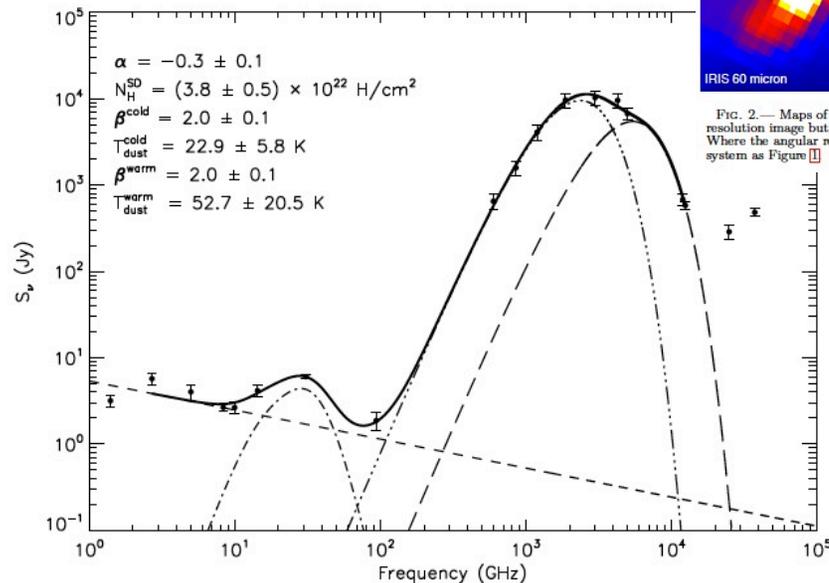


FIG. 12.— Complete SED for RCW175 from the radio to the mid-IR. The data have been modeled using a power-law representing the free-free emission (*dashed line*), two modified blackbody curves representing the warm (*long-dashed line*) and cold (*dot-dot-dashed line*) thermal dust emission components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

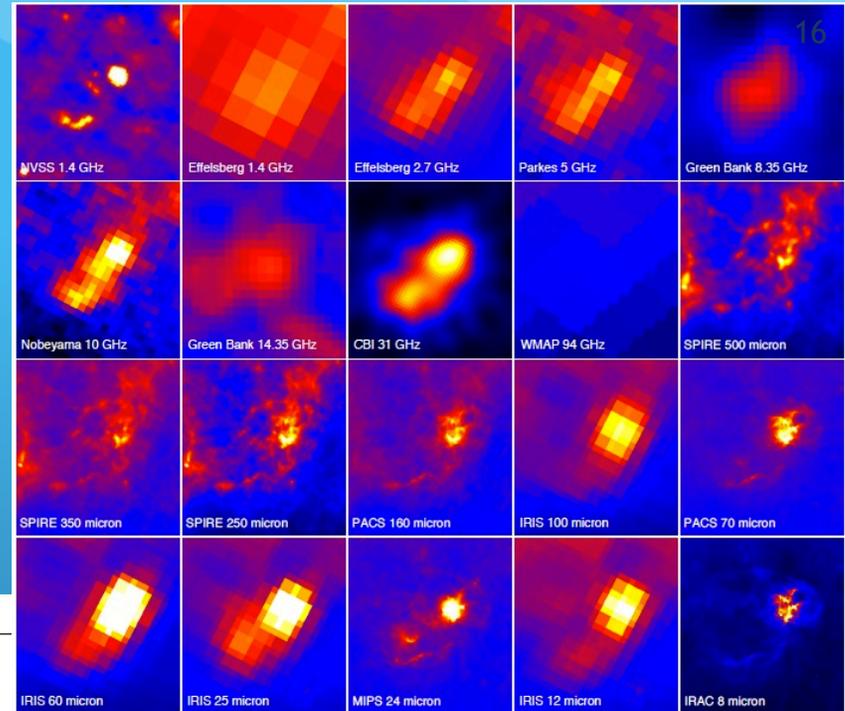


FIG. 2.— Maps of RCW175 all the way from the radio to the mid-IR. There are two maps at 1.4 GHz, as the NVSS map provides a high resolution image but, due to flux loss, it cannot be used to estimate the total flux density, and so we also have the Effelsberg 1.4 GHz map. Where the angular resolution is $\lesssim 5$ 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

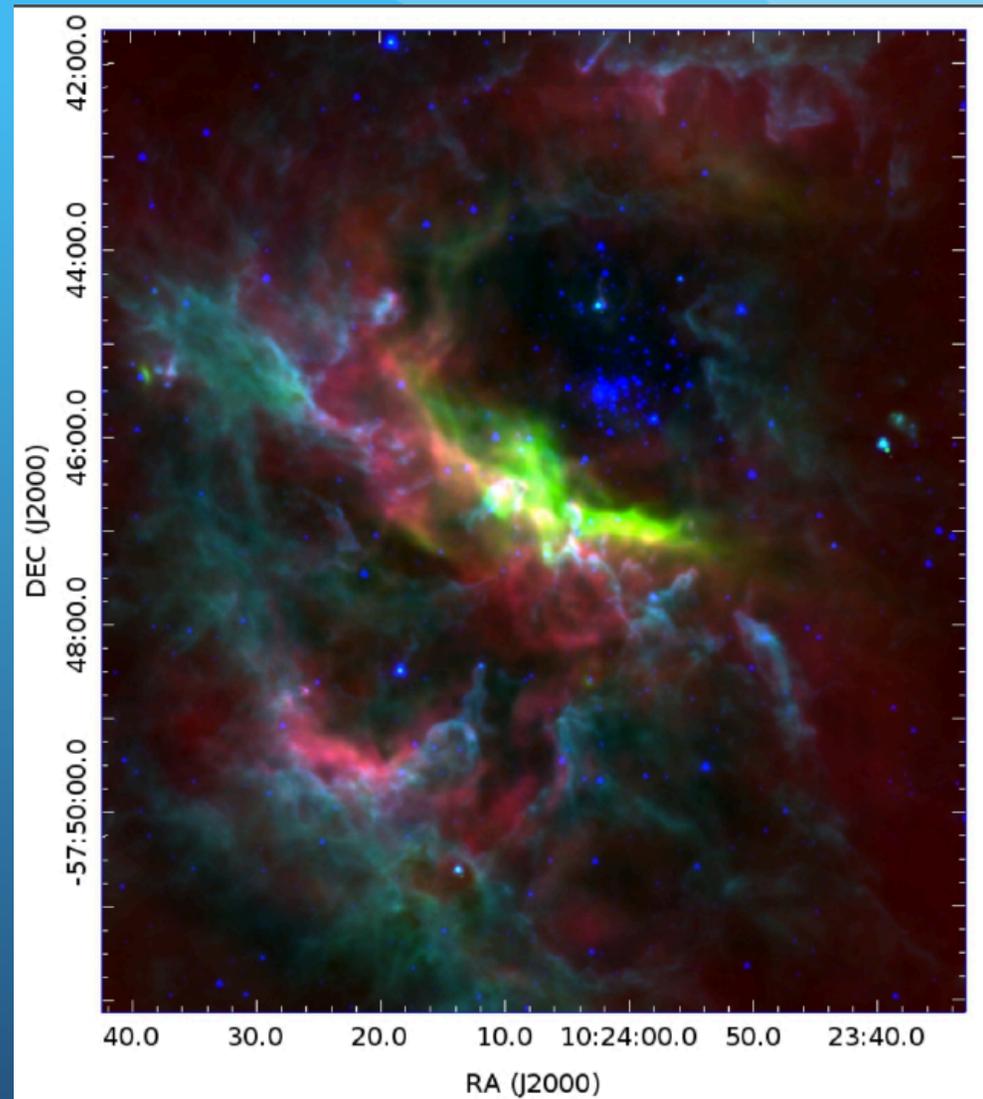
RCW 49 AME

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

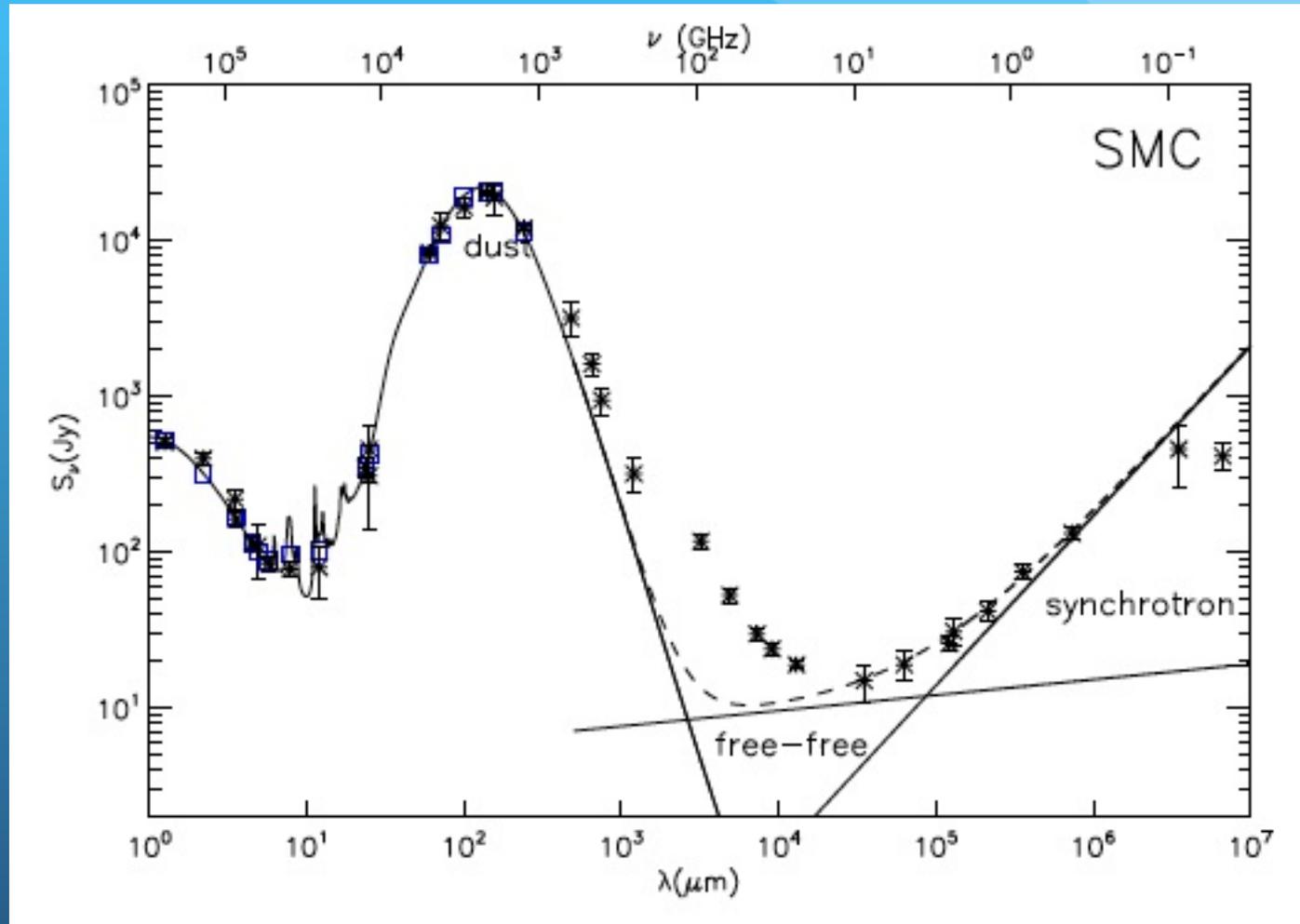
ATCA observations between 5, 19 & 34 GHz (0.4 - 1 arcsec res) confirmed the excess, but the spectral index is consistent with strong shock & stellar winds (*Paladini et al. 2014*)

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 - 500 μm
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	$10^{-19} \text{ W m}^{-2}$	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