Molecular gas at ALMA resolution in the Magellanic Bridge

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Universidad de Chile

The Soul of High Mass Star Formation, Puerto Varas, 20 March 2015

Outline

1. Motivation
2. Dark molecular gas
3. What we are learning from the submm emission of cold molecular gas in the Magellanic System

Collaborators: B Cornejo, A Rojas (DAS)
A. Bolatto (U. Maryland,
C. Verdugo, (Observatoire de Paris)

How can we measure H_2

- CO observations , $X=N(H_2)$)/ICO
- Virial mass determination, DV and size (R)
- Emission from dust

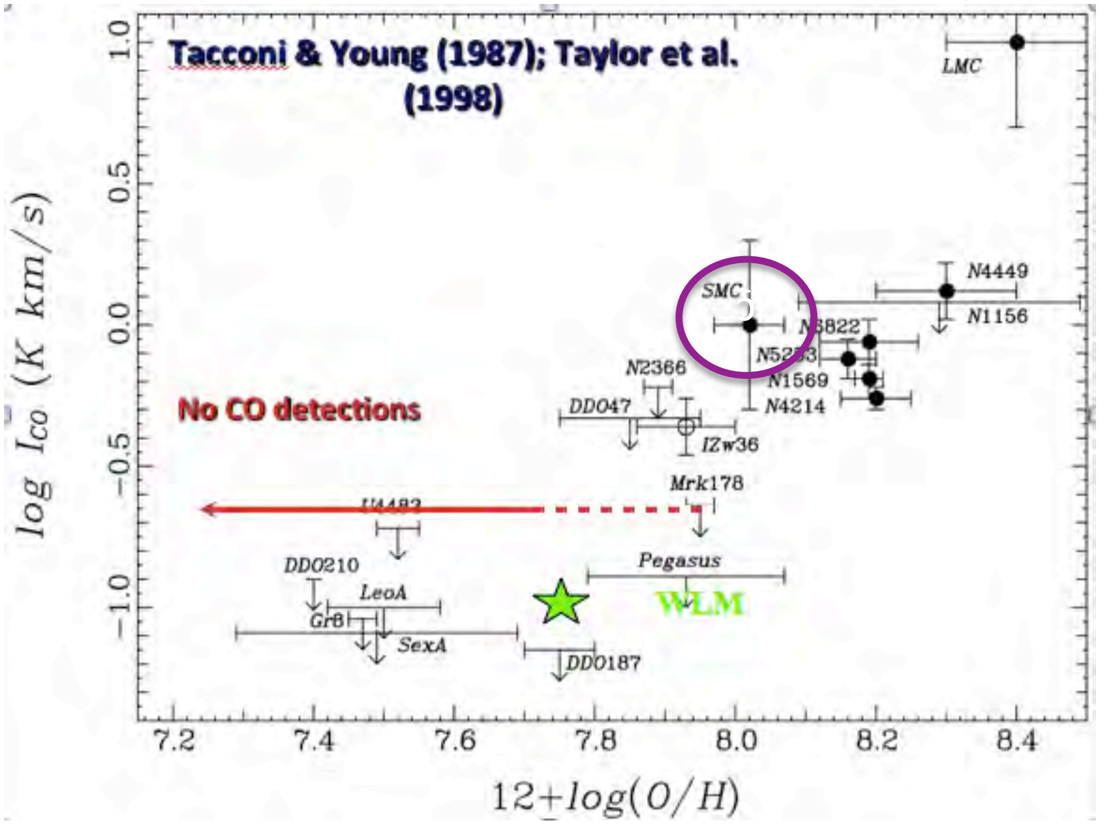
Easy in the Galaxy and similar systems,

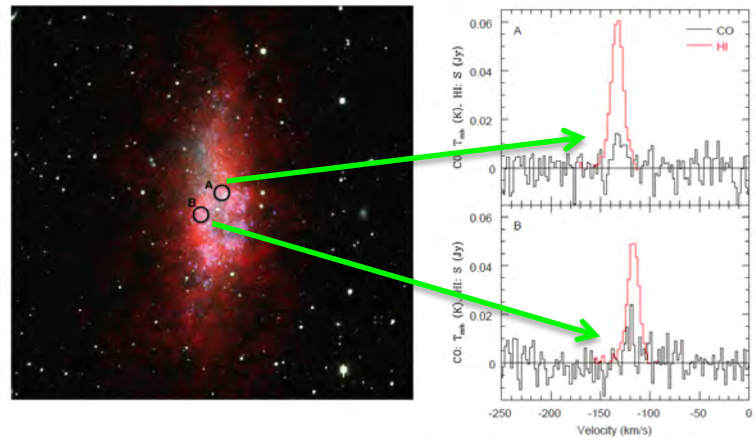
!!!Not the case elsewhere, low metallicity!!!!!

WLM

Breaking the metallicity barrier for CO detections!

13% of Solar





Only at a distance of 1 Mpc

Elmegreen, Rubio, Hunter, et al.2013

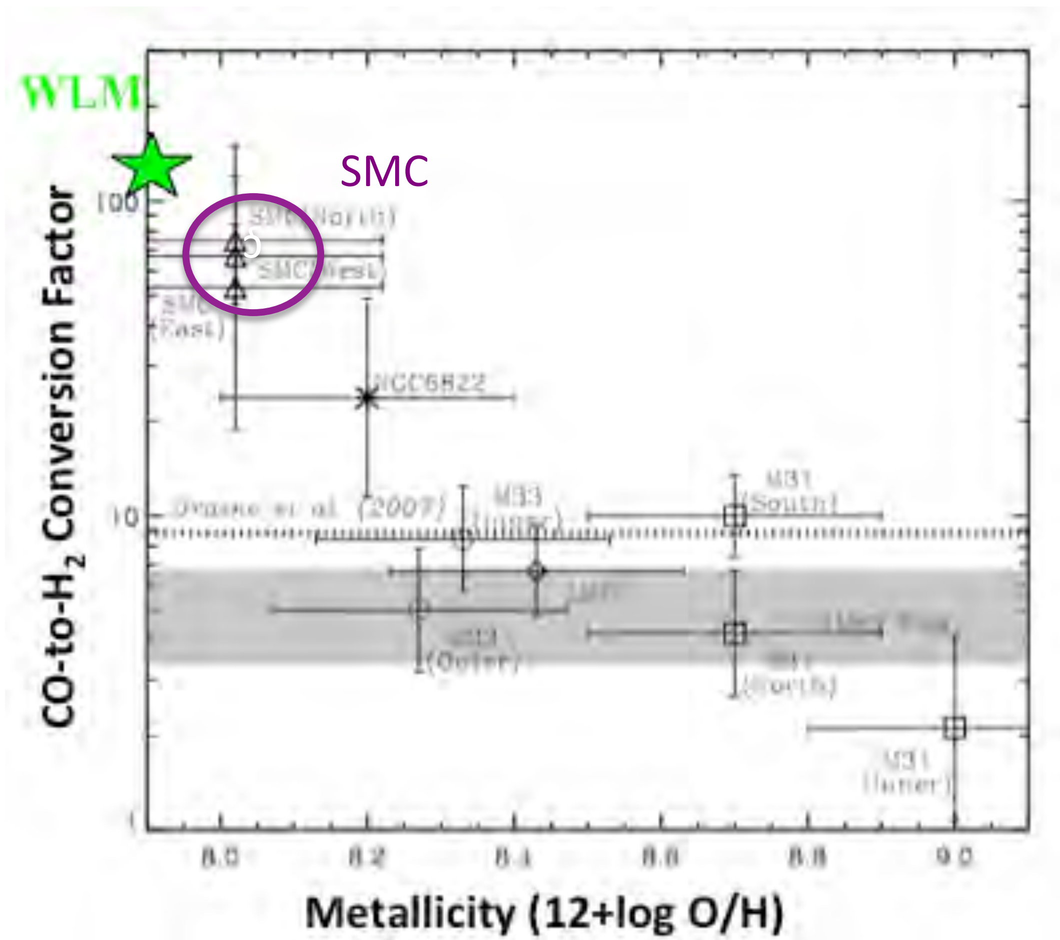
Nature 495,487

Conversion factor rises sharply at low metallicity.

LEROY+ 11:

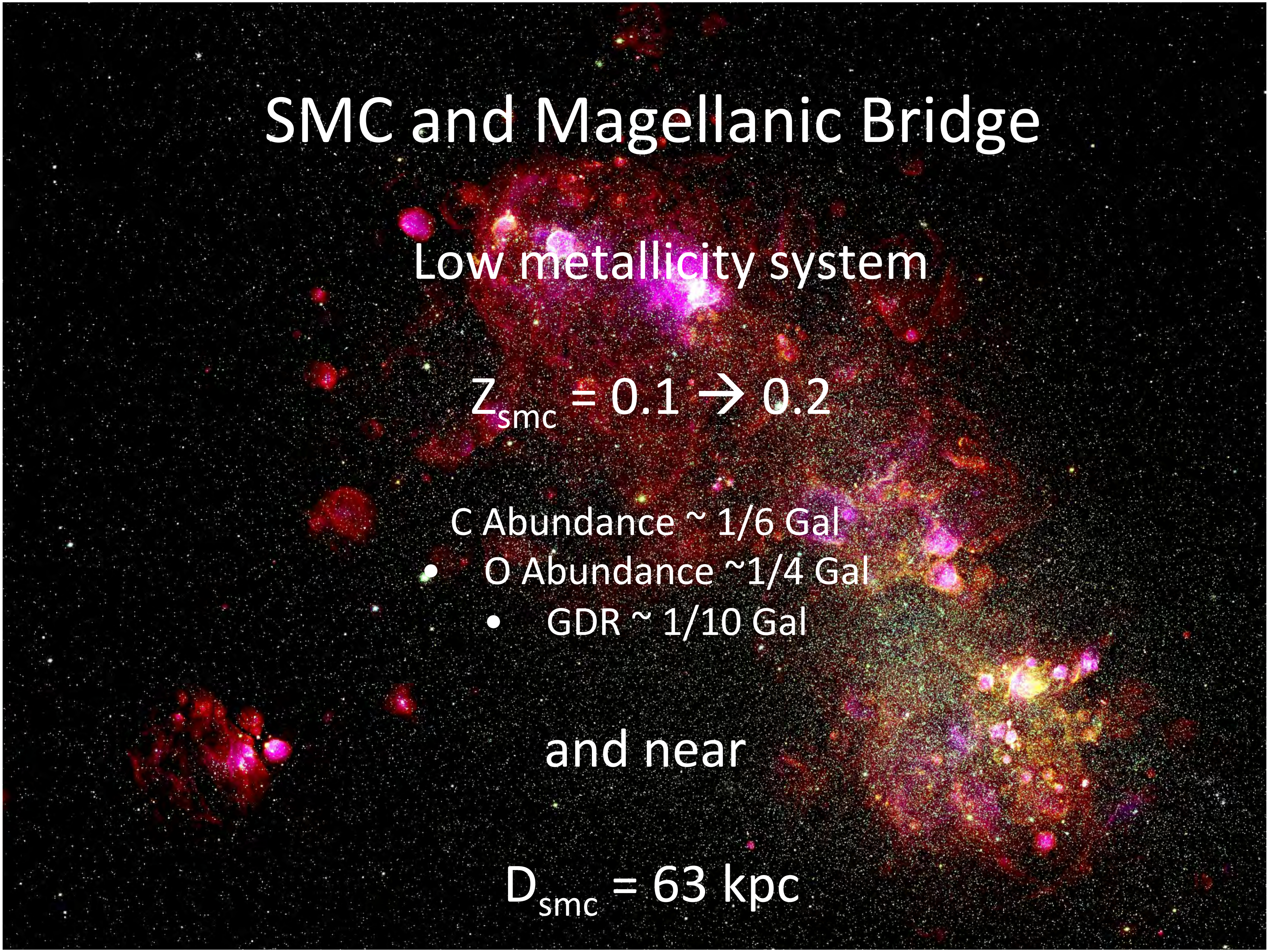
In WLM

α_CO = 124



Dust as an ISM Tracer

Points: *Dust-driven solutions for the conversion factor in parts of Local Group galaxies*



SMC and Magellanic Bridge

Low metallicity system

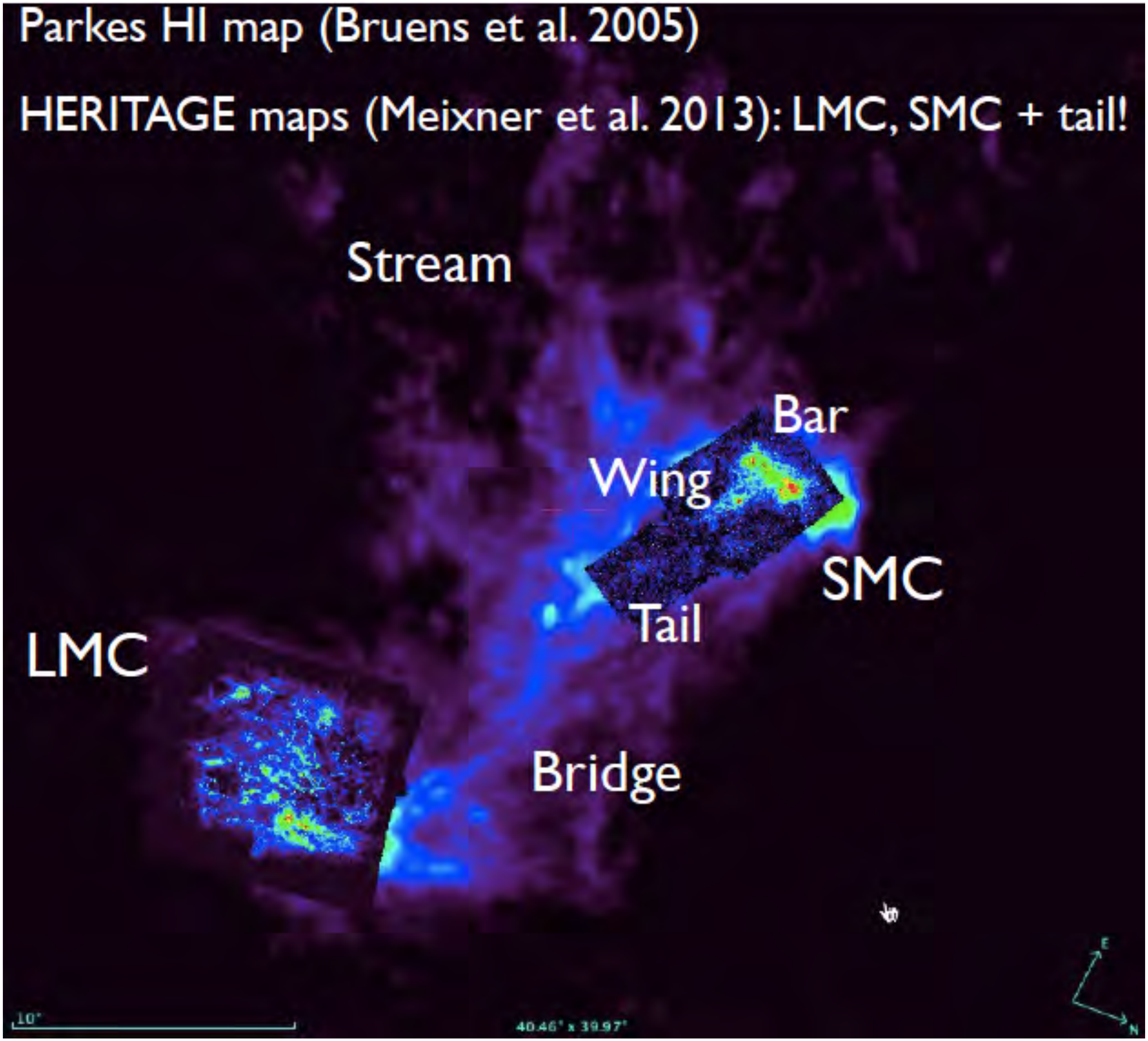
$Z_{smc} = 0.1 \rightarrow 0.2$

C Abundance ~ 1/6 Gal

- O Abundance ~1/4 Gal
  - GDR ~ 1/10 Gal

and near

$D_{smc} = 63$ kpc


Parkes HI map (Bruens et al. 2005)
HERITAGE maps (Meixner et al. 2013): LMC, SMC + tail!
Stream
Bar
Wing
SMC
Tail
LMC
Bridge
10°
40.46° x 39.97°
E
N

Submillimeter and FIR studies of the dust

An alternative way to measure the dark molecular mass

Survey in the Magellanic Clouds

- SIMBA bolometer @ SEST (2000)

- SPITZER 3.6, 4.5, 5.8, 8.0, 24, 70, 160 μm

- HERSCHEL, 160,250, 300, 500 μm

- 0.850 mm LABOCA bolometer @APEX (2007)

Assuming a universal opacity of dust grain properties and knowing the gas-to-dust ratio I_{mm}-> $N(H_2)$

LABOCA/APEX observations in the Magellanic Clouds

15 regions :10’x10’ to 20’x30’ maps
Res: 22” (~6 pc@SMC)

LMC 8
SMC 4
Mag Br 3

Total 29 sources

Before

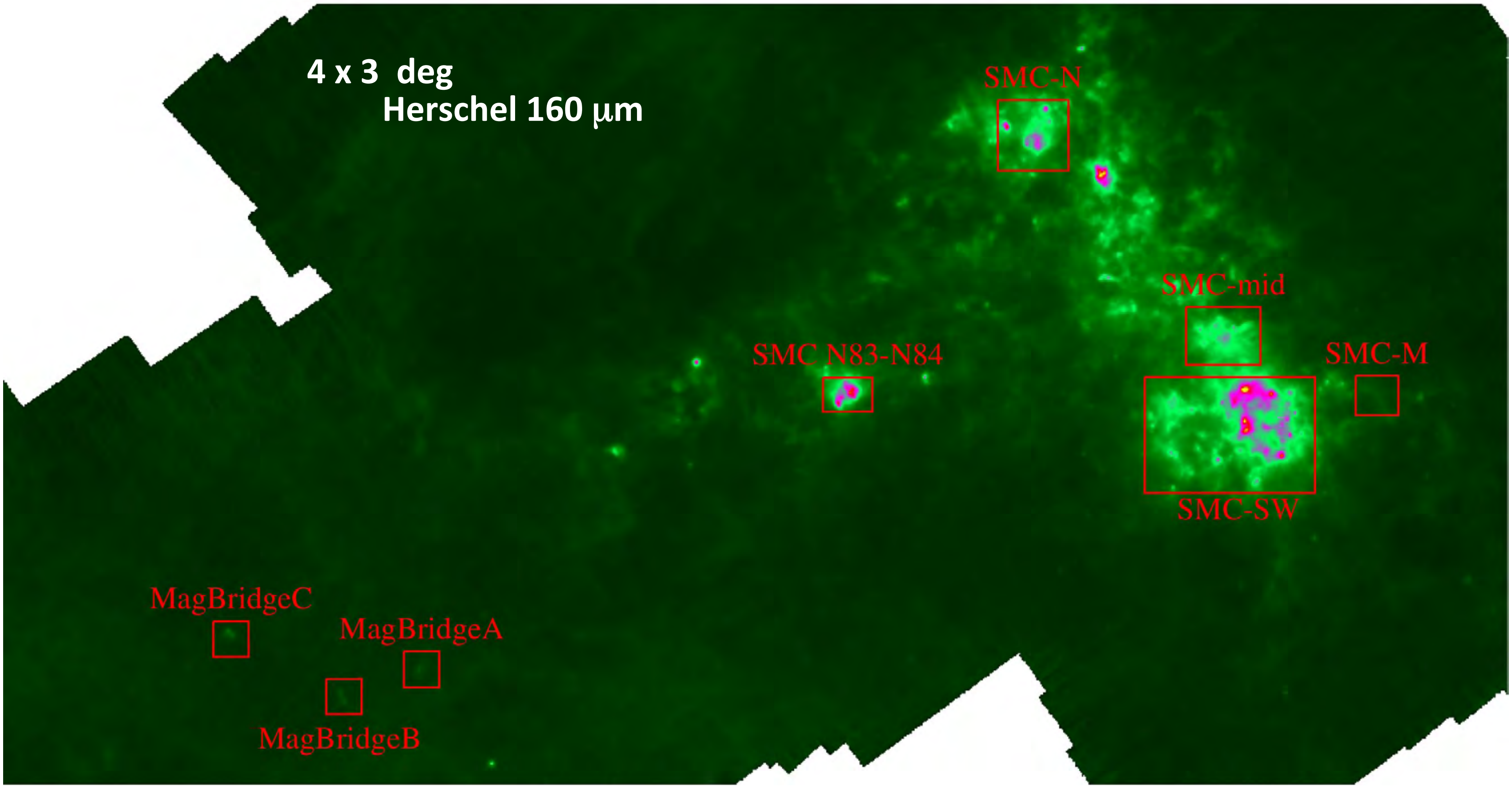
Caroline Bot (France)

Cinthya Herrera (Chile)
Viviana Guzman (Chile)

Celia Verdugo
MSc Thesis, 2012
DAS, UCHILE

SMC and Magellanic Bridge

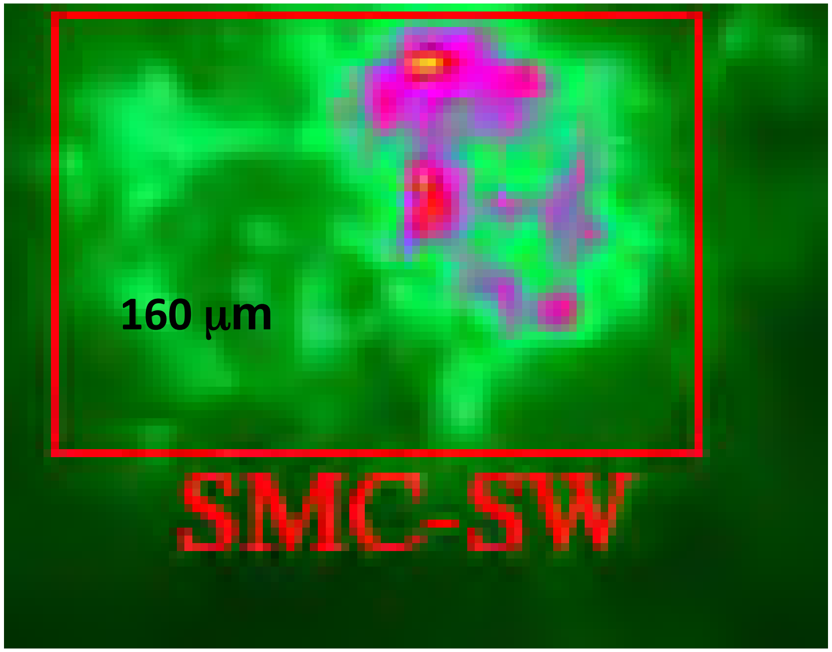
D=63 Kpc

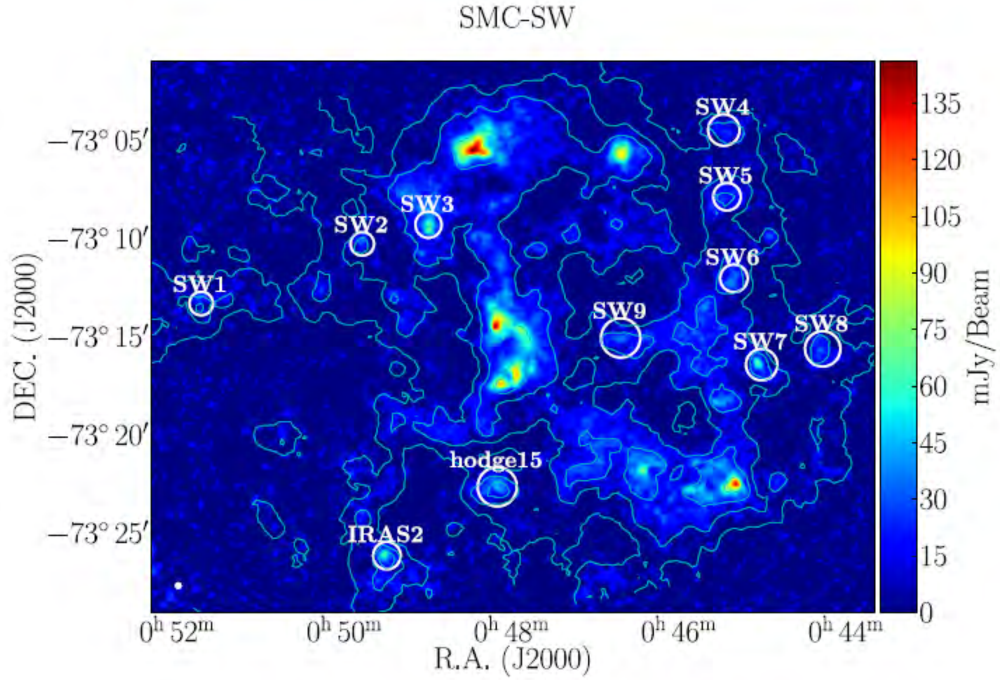


The Herschel Inventory of the Agents of Galaxy Evolution (Heritage) in the Magellanic Clouds

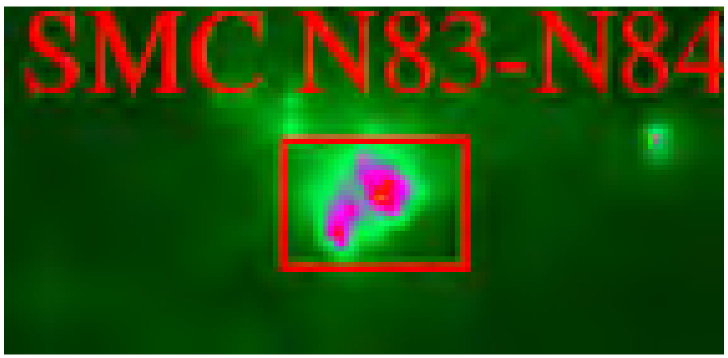
Meixner et al 2013

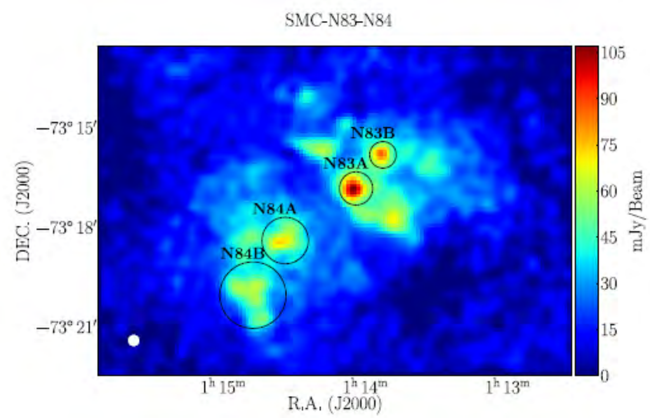
870 μm continuum emission with LABOCA





11 new sources in SMC_SW





SED fitting

Fit procedure $\rightarrow$ T, β, C

$$S_\nu = \tau_\nu B_\nu(T)\Omega$$

$$S_\nu = C \cdot \nu^\beta B_\nu(T_d)$$

$$\tau_\nu = \frac{S_\nu}{\Omega B_\nu(T_d)}$$

$$\tau_\nu = \frac{C\nu^\beta}{\Omega}$$

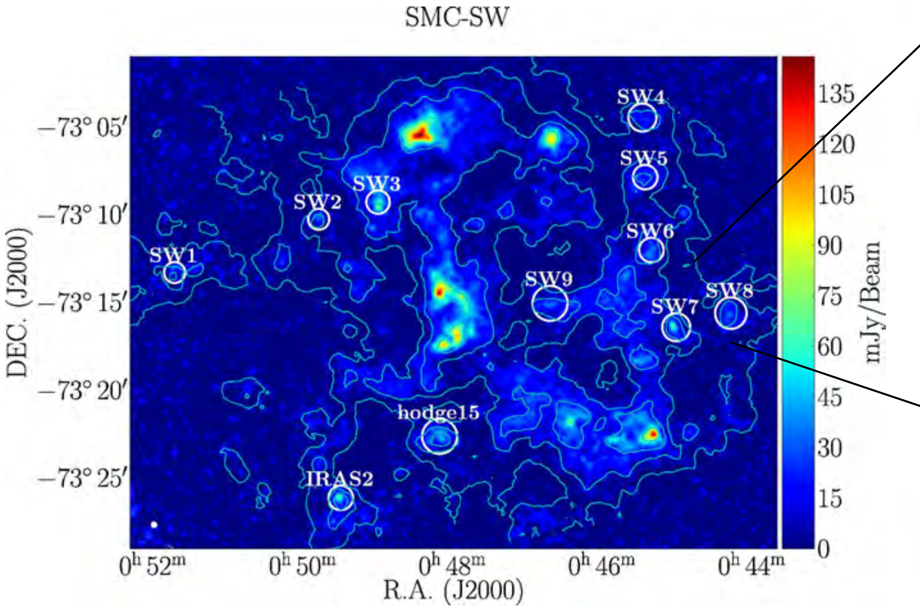
Results: T, β, τ

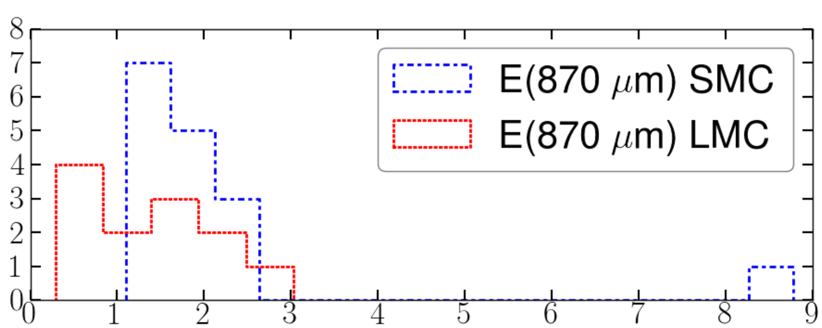
SMC: 22 K
LMC: 24 K
Bridge: 19 K

Determine Temperature opacity and emissivity index β

SMC Submillimeter Excess

Excess ~1.7





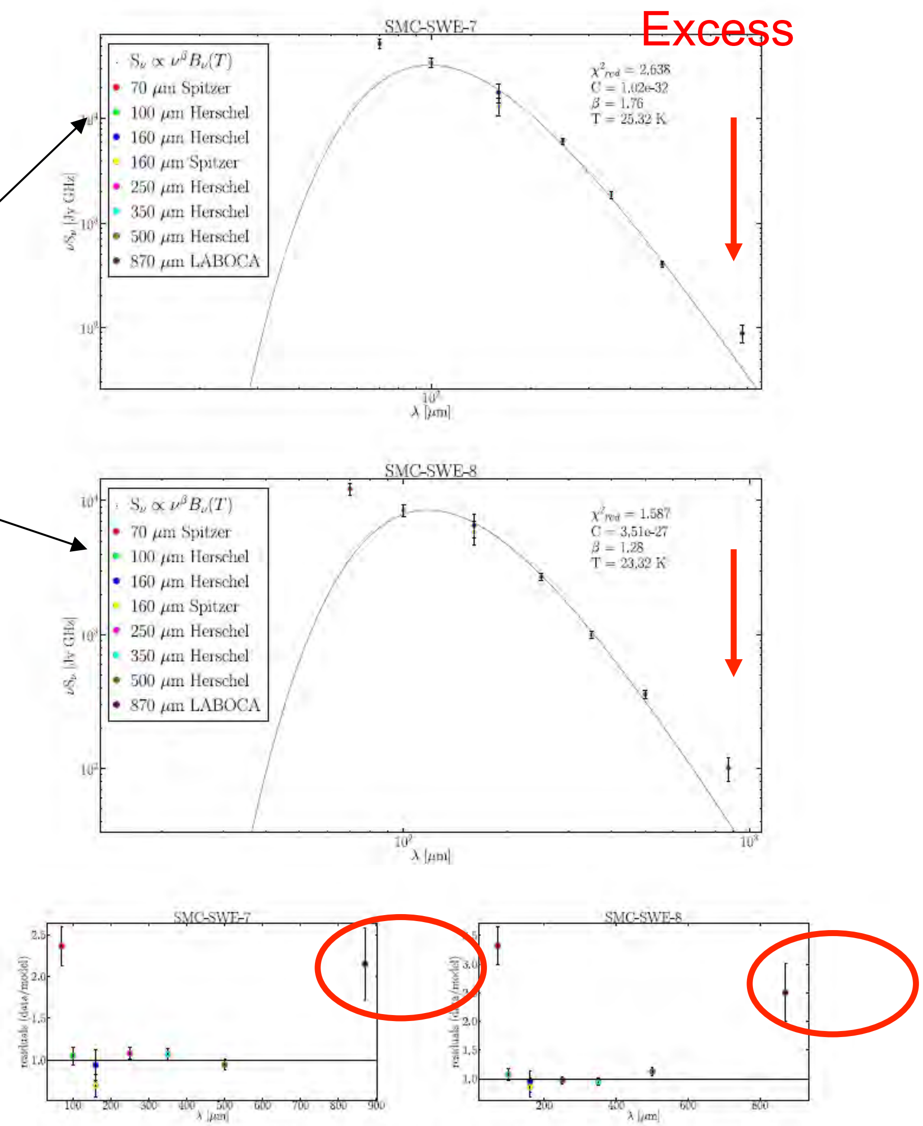
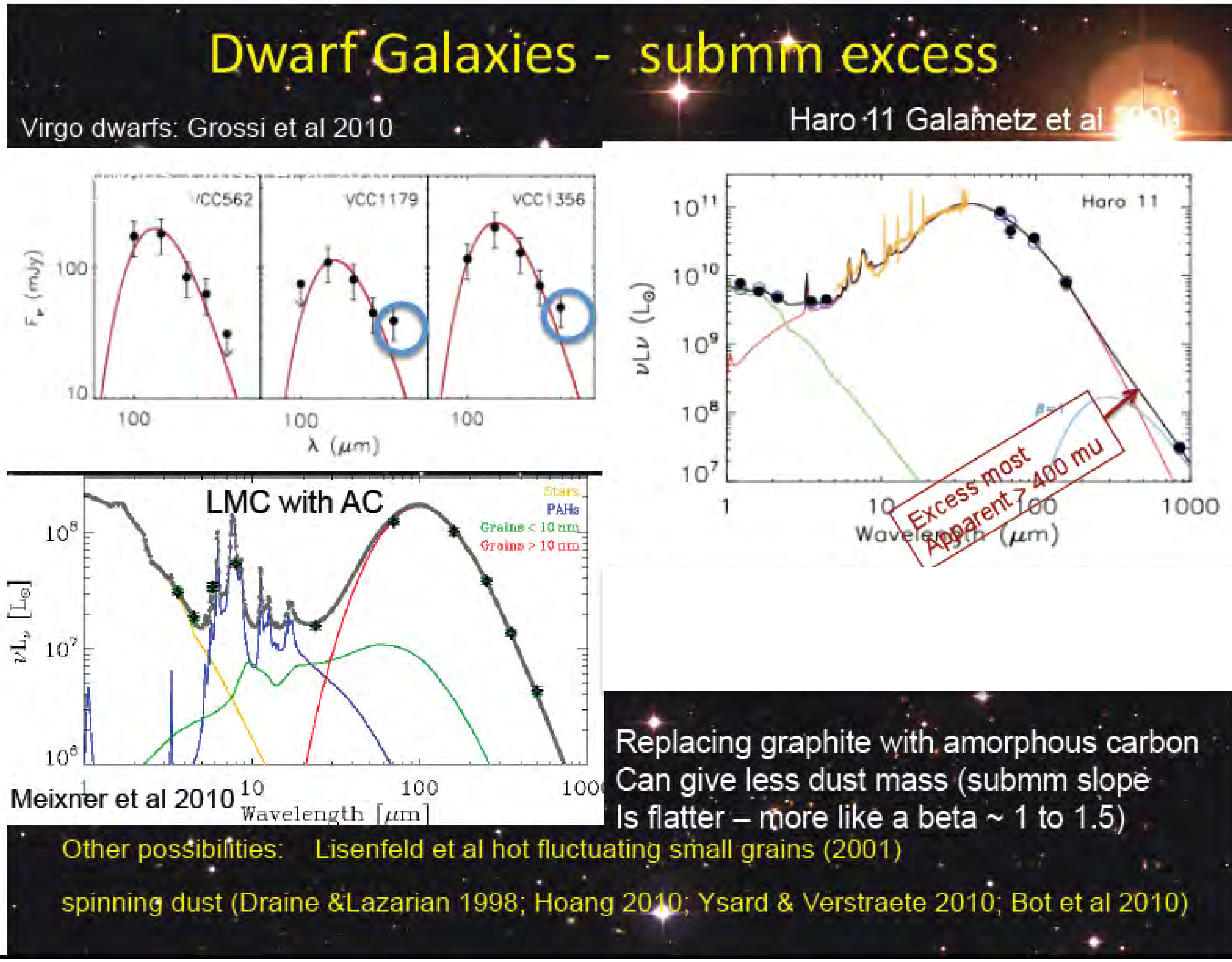


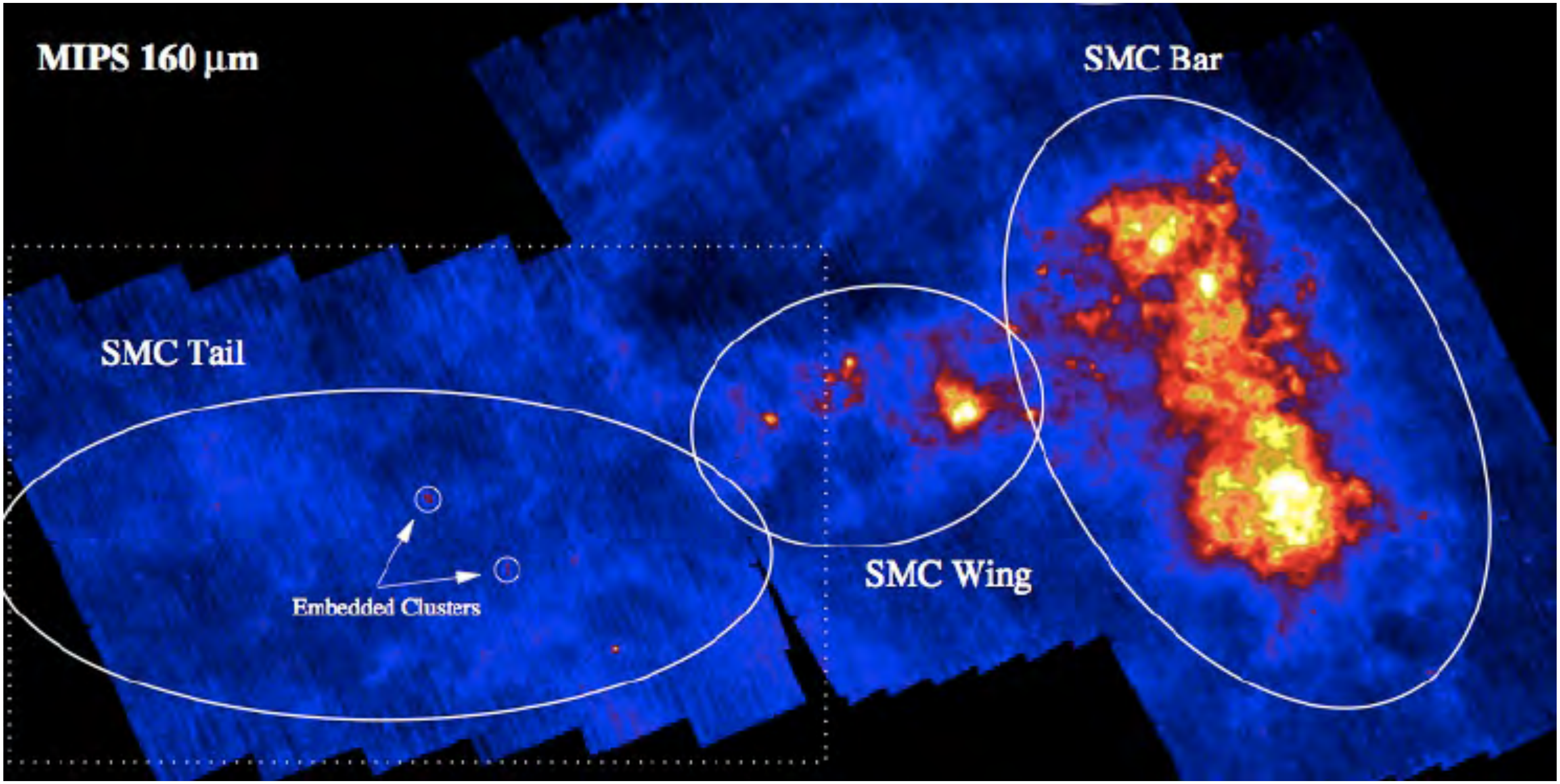
Figure 4.8: SED's for SMC-SWE-7 and SMC-SWE-8 with their corresponding residuals plots.

Verdugo et al 2014, Submitted

Submillimeter excess

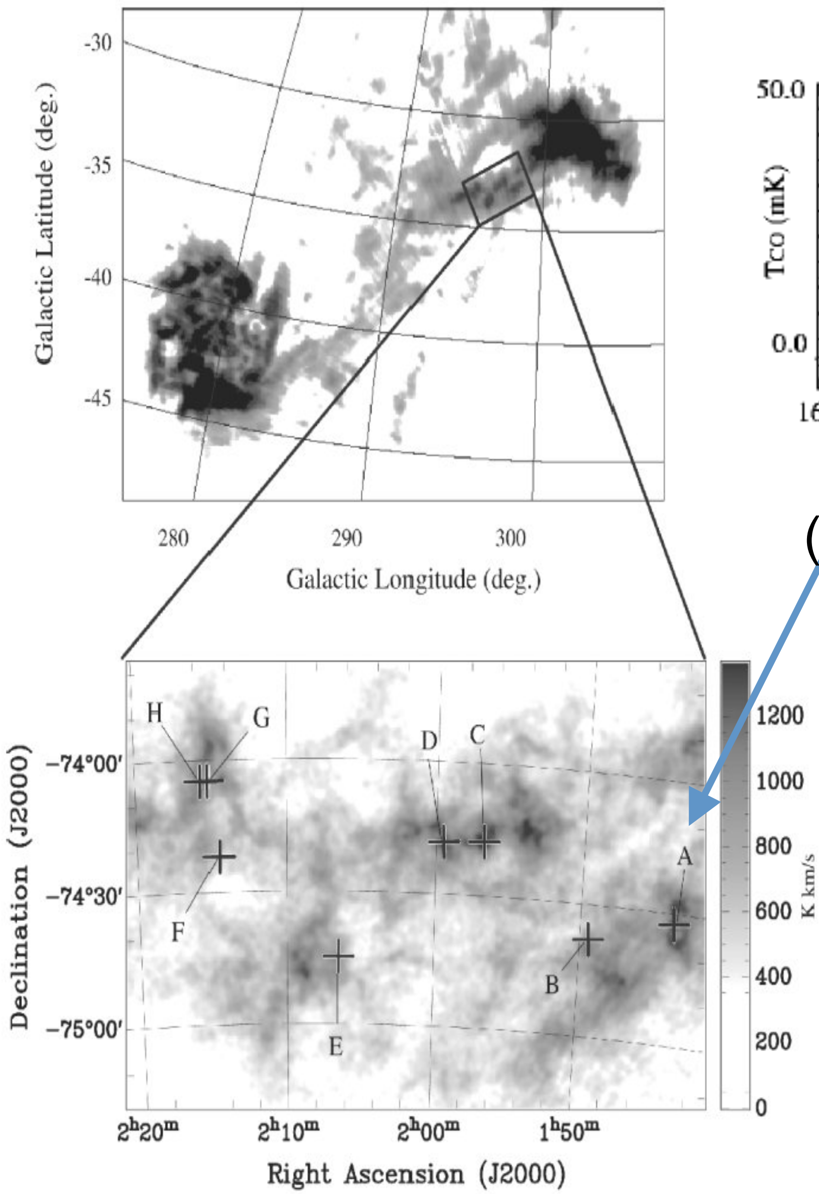


Madden et al , Galametz et al 2011

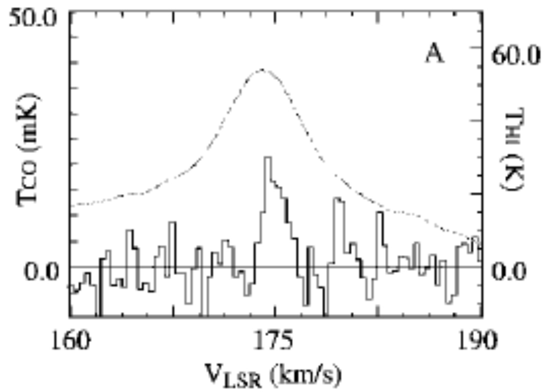


Gordon et al 2009
GDR ~ 1200 +- 350

Magellanic Bridge Source A



CO(1-0) Nanten observations



T_mb= 20 mK

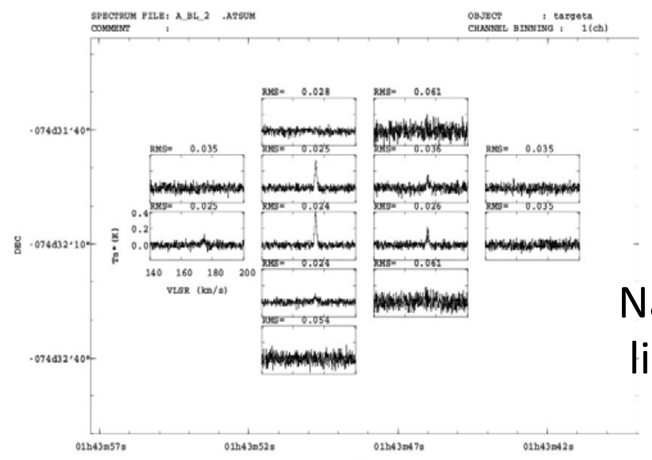
DV= 1.6 km/s

Ico= 30 +- 8 mK km/s

M= 1×10^{3} Mo

Using X_co = 7 X_gal

(Mizuno et al. 2006)

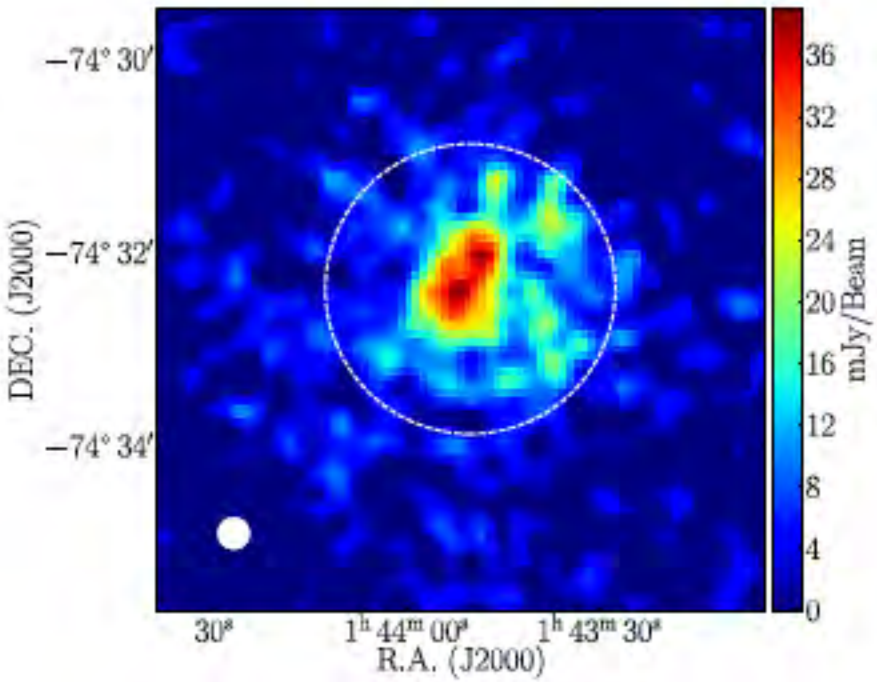


Narrow CO lines ~ 1km/s

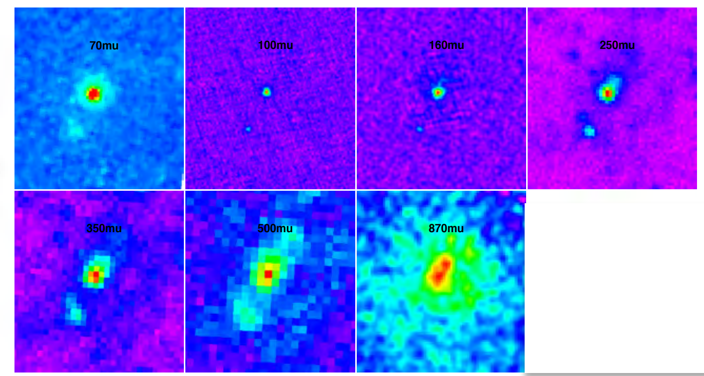
ASTE CO3-2

Muller et al. 2014 CO3-2 with ASTE

Continuum emission at 870 mu



S_870mm= 0.59 +- 0.12 Jy



Excess =8.8±1.8

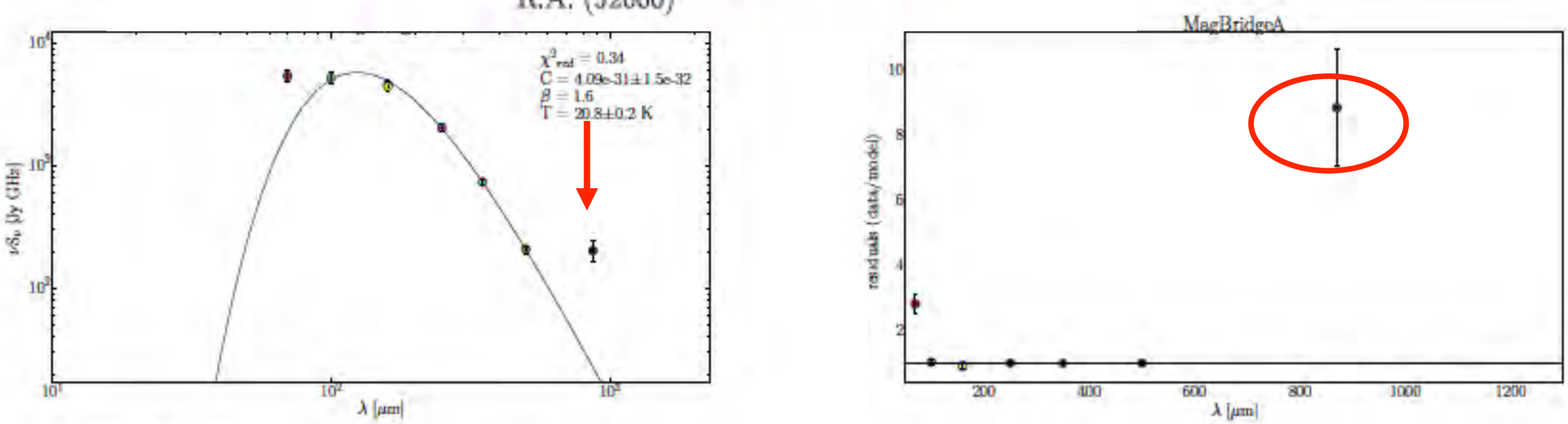


FIG. 11.— SEDs for LMC sources with their corresponding residual plots.

MONICA RUBIO 2012.1.00683.S

PROJECT TITLE:	Sub-millimeter excess in a low metallicity cloud in the Magellanic Bridge				
PRINCIPAL INVESTIGATOR NAME:	Monica RUBIO	PROJECT CODE:	2012.1.00683.S		
SCIENCE CATEGORY:	ISM, star formation and astrochemistry	ESTIMATED 12M TIME:	2.0 h	ESTIMATED ACA + TP TIME:	5.9 h
CO-PI NAME(S): (Large Proposals only)					
CO-INVESTIGATOR NAME(S):	Alberto Bolatto; Celia Verdugo; Norikazu Mizuno; Erik Muller				
EXECUTIVE SHARES[%]:	NA : 0 EU : 0 EA : 0 CL : 100 OTHER : 0	STUDENT PROJECT? (Yes/No)	No	RESUBMISSION? (Yes/No)	No

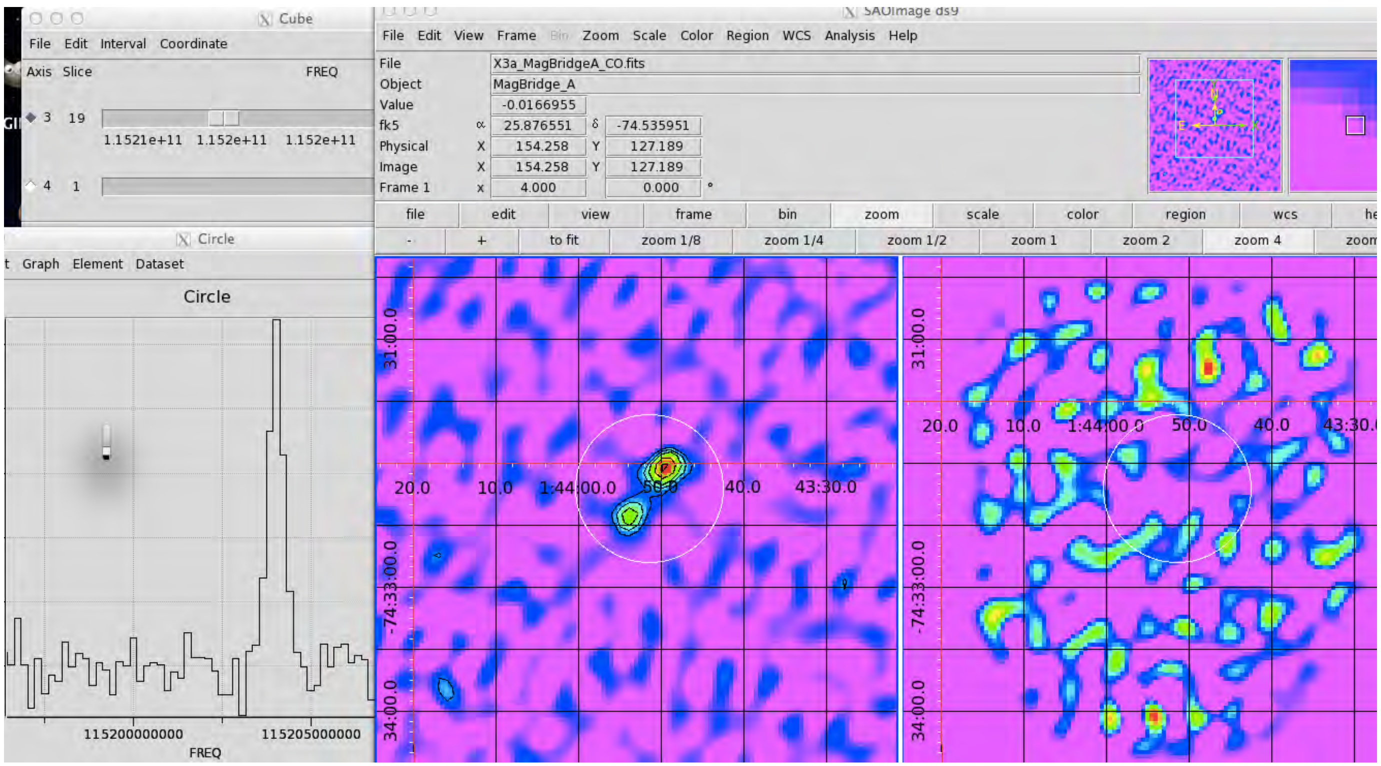
ABSTRACT

The Magellanic Bridge is a filamentary structure of about 15 to 21 kpc seen in neutral hydrogen (HI) lying between the LMC and the SMC. It represent the nearest tidally interaction between these two galaxies some 200 Myr ago. It has a lower metallicity than the SMC and therefore allow to study the ISM in extreme conditions. Recent studies have revealed the presence of young (< 200Myr) massive stars and CO molecular clouds. The latter are barely resolved in single-dish observations and are spatially related to warm dust emission sources, as recently established by the Spitzer SMC-SAGE and Herschel HERITAGE studies. We have obtained 870 micron images of one of these sources, Magellanic Bridge Source A. Surprisingly, its dust emission shows a large submillimeter excess, indicative of either very cold dust or a dramatically different submillimeter emissivity. We propose to study this source in CO(1-0) and (2-1) and the associated continuum at arcsecond resolution to determine the physical properties of the molecular cloud.

REPRESENTATIVE SCIENCE GOALS (UP TO FIRST 5)

SCIENCE GOAL	POSITION	FREQUENCY	BAND	ANG.RES.(")	ACA?
CO 1-0	J2000: 01:43:53.0000, -74:32:26.000	115.20199 GHz	3	5.0	Y
Continuum 1mm, CO 2-1	J2000: 01:43:53.0000, -74:32:26.000	217.26000 GHz	6	1.6	Y

Magellanic Bridge A
ALMA C1 1.3 mm continuum



Nº antennas = 12

1.3mm res= 1.34”

Continuum
rms = 5 mJy

CO (1-0)
ang res= 2.0 “
Vel res = 0.1 km/s

CO(2-1)
Ang res -1.3 “
Vel res= 0.5 km/s

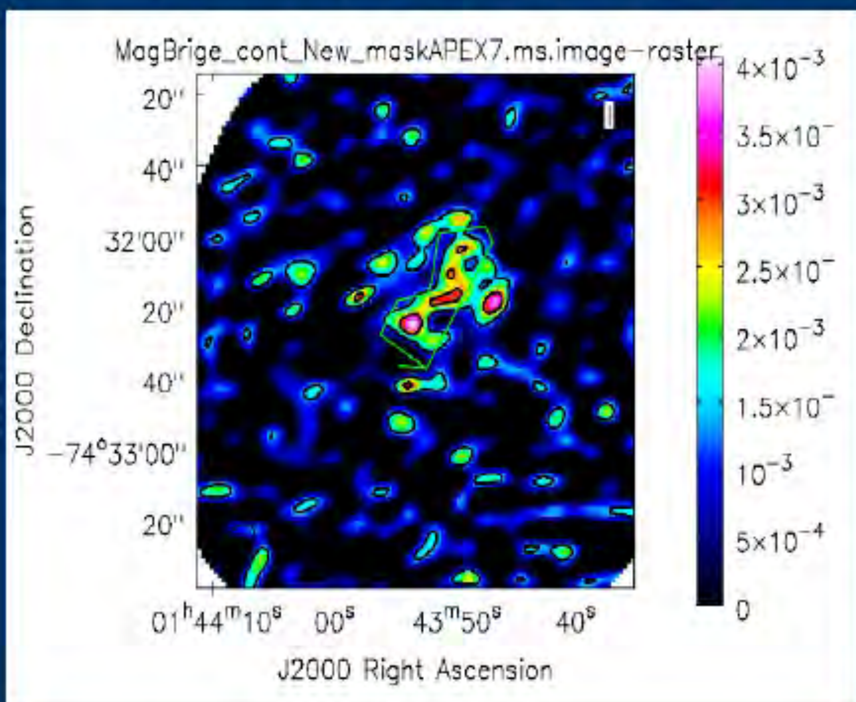
Data delivered showed no continuum emission

Magellanic_Bridge_A ALMA C1
1.3 mm continnum

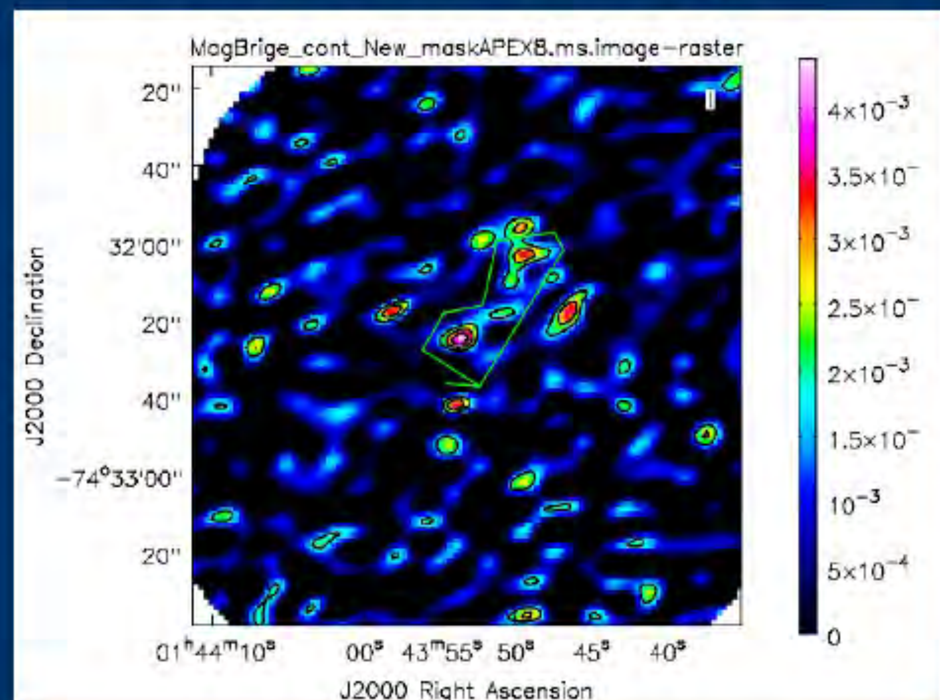
Student:
Byron Cornejo

MagBridge: Continuo 1mm

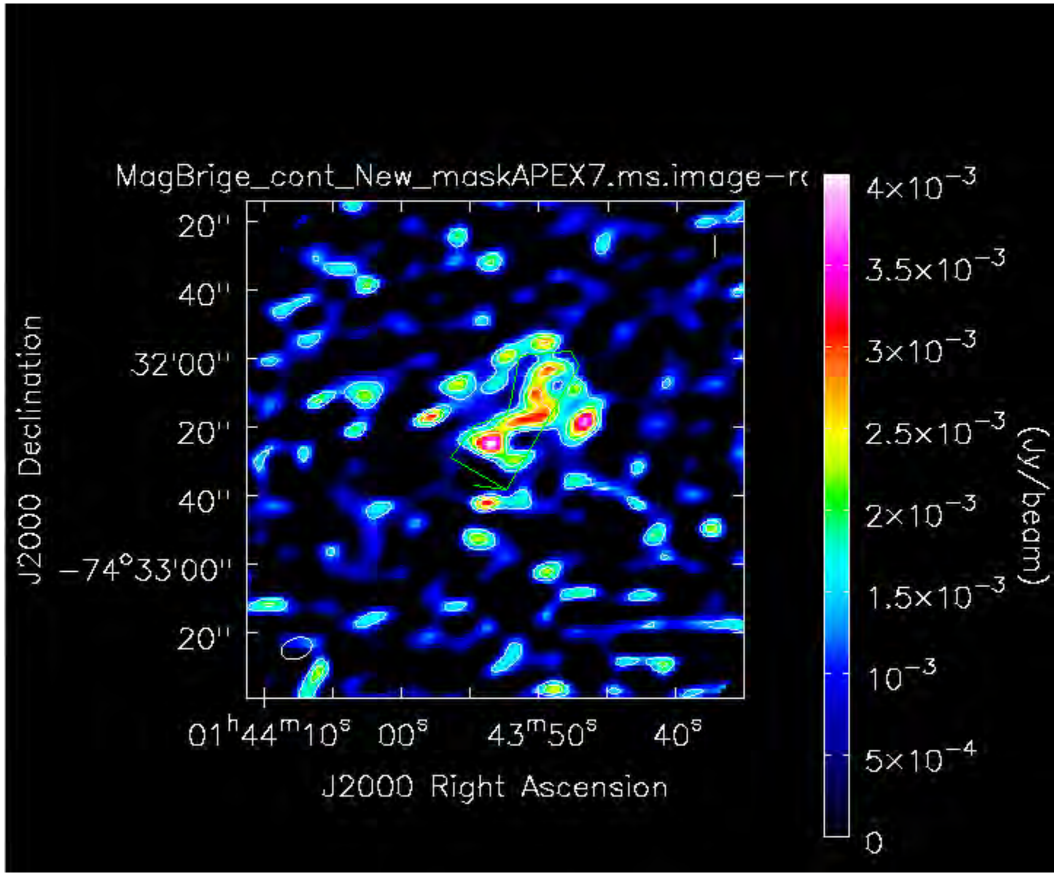
- Reducción usando Natural:



- Reducción usando Briggs:



Magellanic Bridge A
ALMA C1 1.3 mm continuum



S_1.3mm = 0.143+-0.007 Jy

➔

M_mm= 1.1 x10^5 Mo

M_co = 1x10^3 Mo

X_co =7 X_gal. (Mizuno et al.2006)
2.6arcmin beam (50pc)

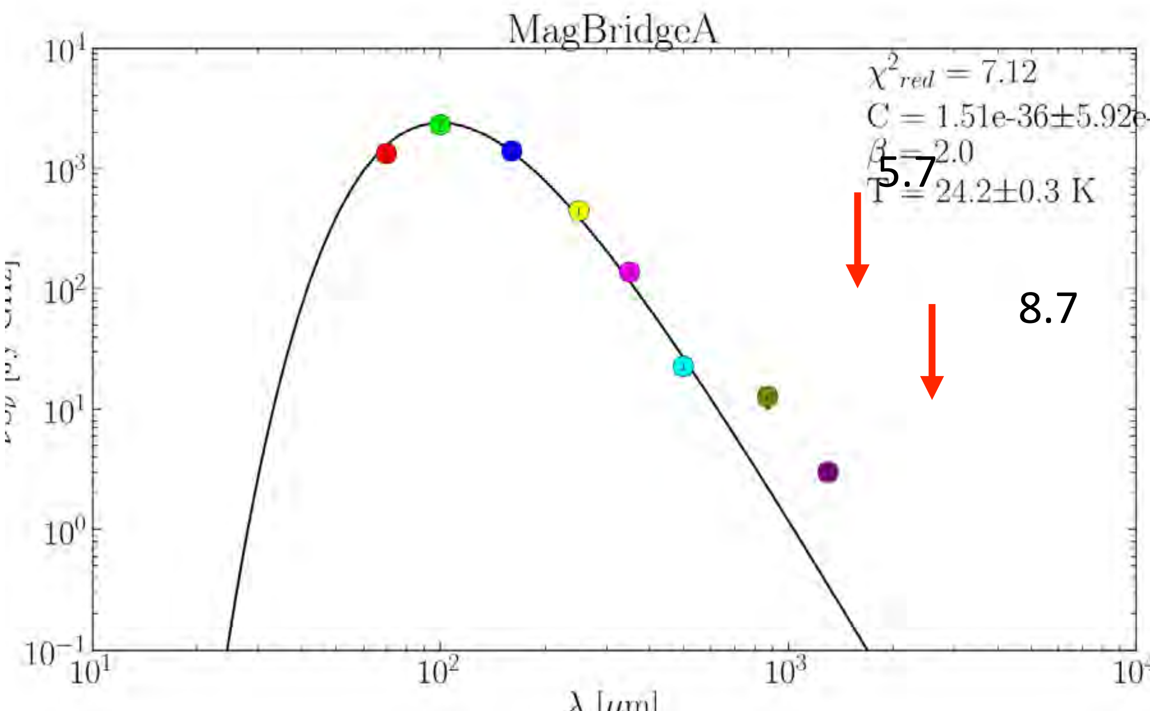
R~ 7 to 10 pc

M_virial_$_{CO_alma}$ =8.2x 10^3 Mo

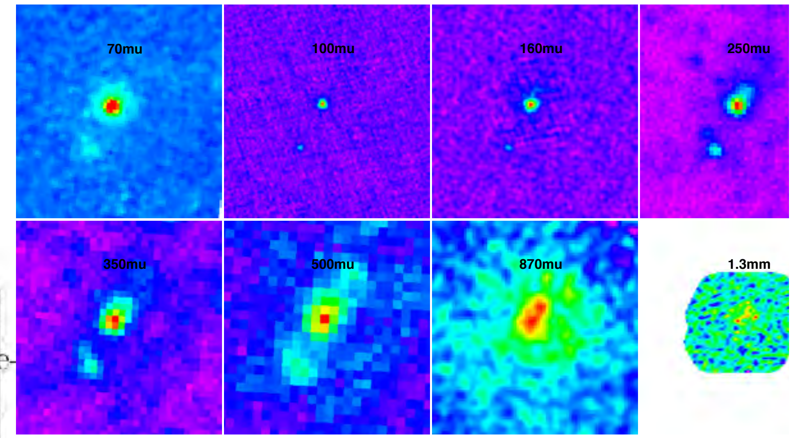
Magellanic_Bridge_A ALMA C1
1.3 mm continnum

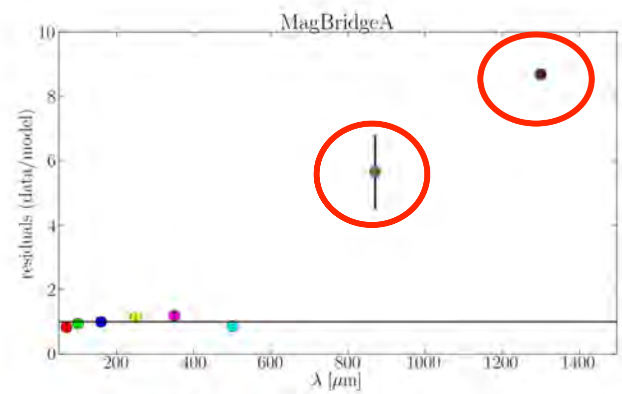
Submillimeter excess at 1.3 mm

@870mu = 5.7
@1.3mm = 8.7



Fit result: f beta=2, T=24.2 , C=1.51e-36,





Residuals to fit

Mmm=1.1x10^5 Mo

Rubio et al, In prep.

Results

- ALMA observation of the continuum dust emisssion confirms submillimeter excess

@ 1.2 mm excess is 5.7
@ 1.3 mm is 7.0

Larger excess as wavelength increases.

Caution to derive masses or $N(H_2)$ fr0m submm dust emission in these sytems

- The mass dust , M_mm ~ 1.1 x10^5 Mo

Assuming a gas to dust ratio scaling with metallicity and a dust emissivity with β=2

Larger than and larger that the mass derived from Nanten CO emission.
And larger than mass from ALMA CO10 observations 8x10^3 Mo

Important implications for star formation, star formation rates, etc.

Stay tuned!