ALMA studies of the Magellanic Bridge

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Dissecting Galaxies Near and Far, Santiago, 25 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)
N. Mizuno (JAO)

The search for H_2

- H_2 gas does not emit in the cold dense cloud where star formation is occurring

- Need to find other tracers

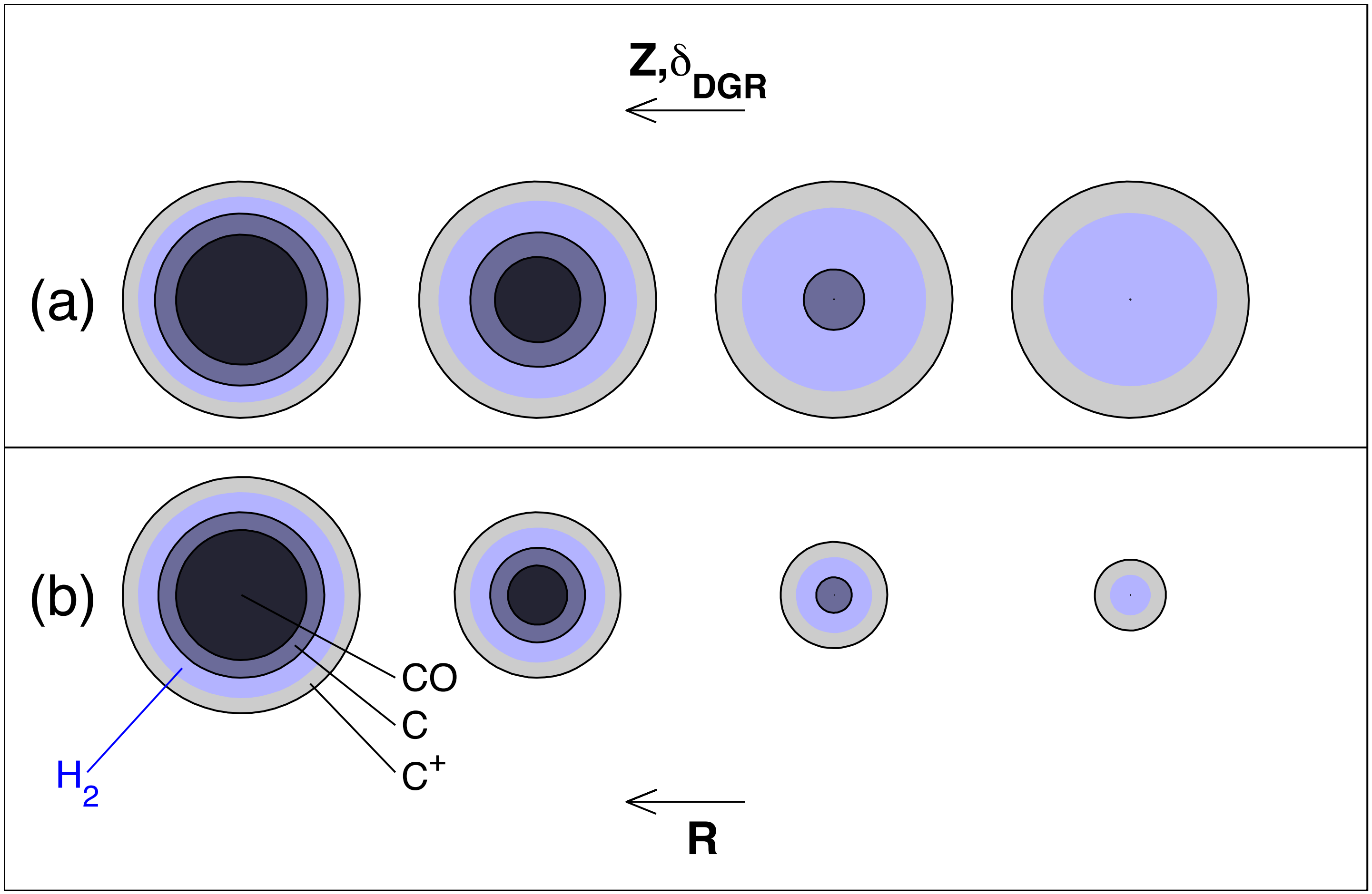
How can we determine H_2

- 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 everywhere,
low metallicity!!!!!

Metallicity effects



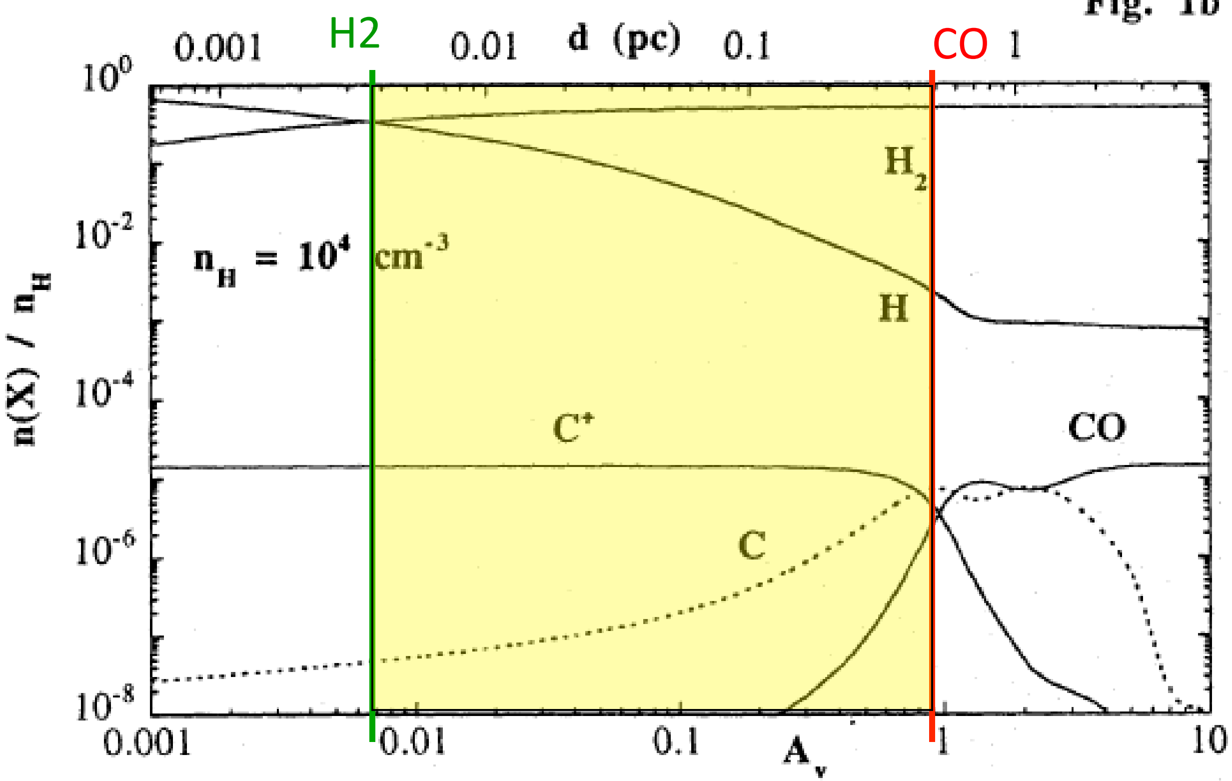
from Bolatto, Wolfire, & Leroy (2013), Bolatto et al. (1999)

see also Maloney & Black (1988), Lequeux et al. (1993)

In low metallicty systems , i.e, SMC and LMC it is well known that CO does not trace the total H_2 dark gas.

CO photo dissociated (Rubio, et al 93, Maloney and Black 98, Bolatto et al 99)

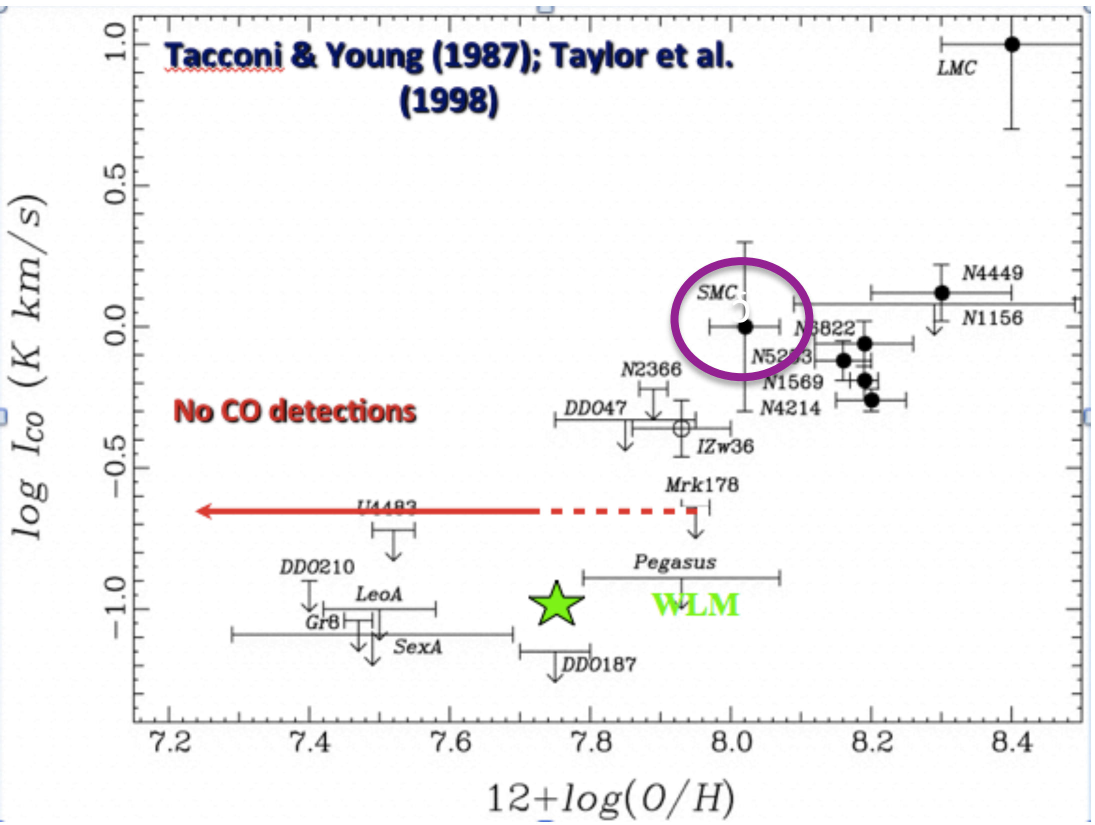
Fig. 1b

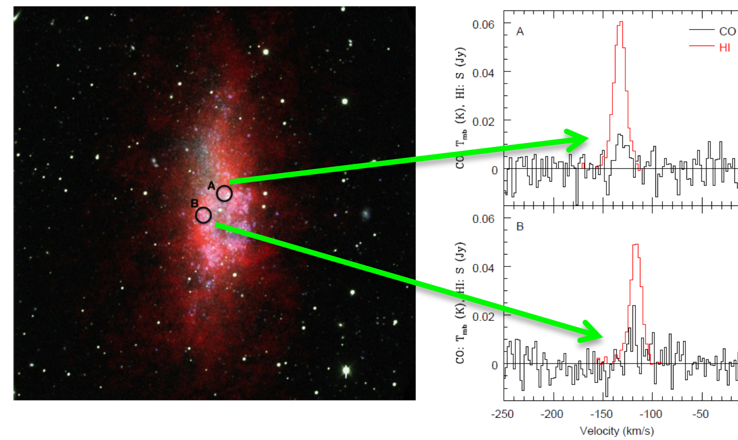


Abundances of several molecules and ions on a plane parallel uniform molecular cloud model illuminated from one side by a UV field =10 UV_gal, Z=0.1Zo (Lequeux et al 94)

WLM

Breaking the metallicity barrier for CO detections!
13% of Solar





Only at a distance of 1 Mpc

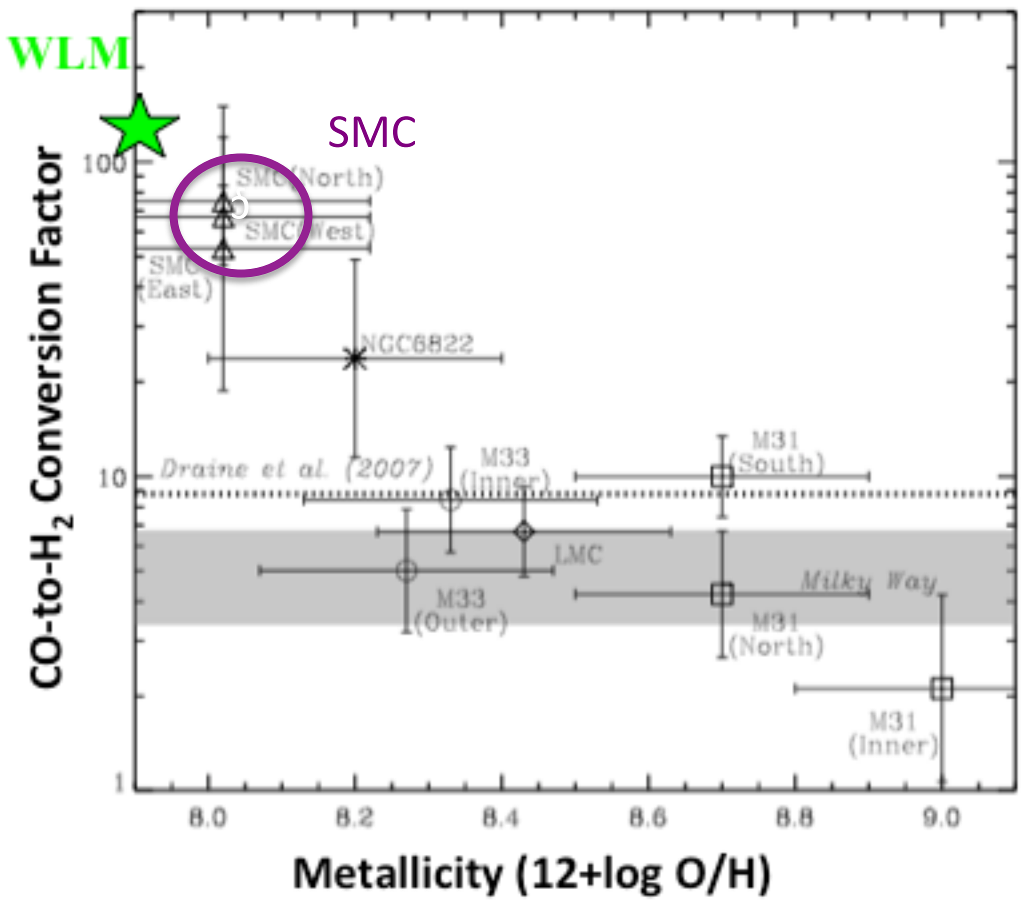
Elmegreen, Rubio, Hunter, et al.2013
Nature 495,487

Conversion factor rises sharply at low metallicity.

LEROY+ 11:

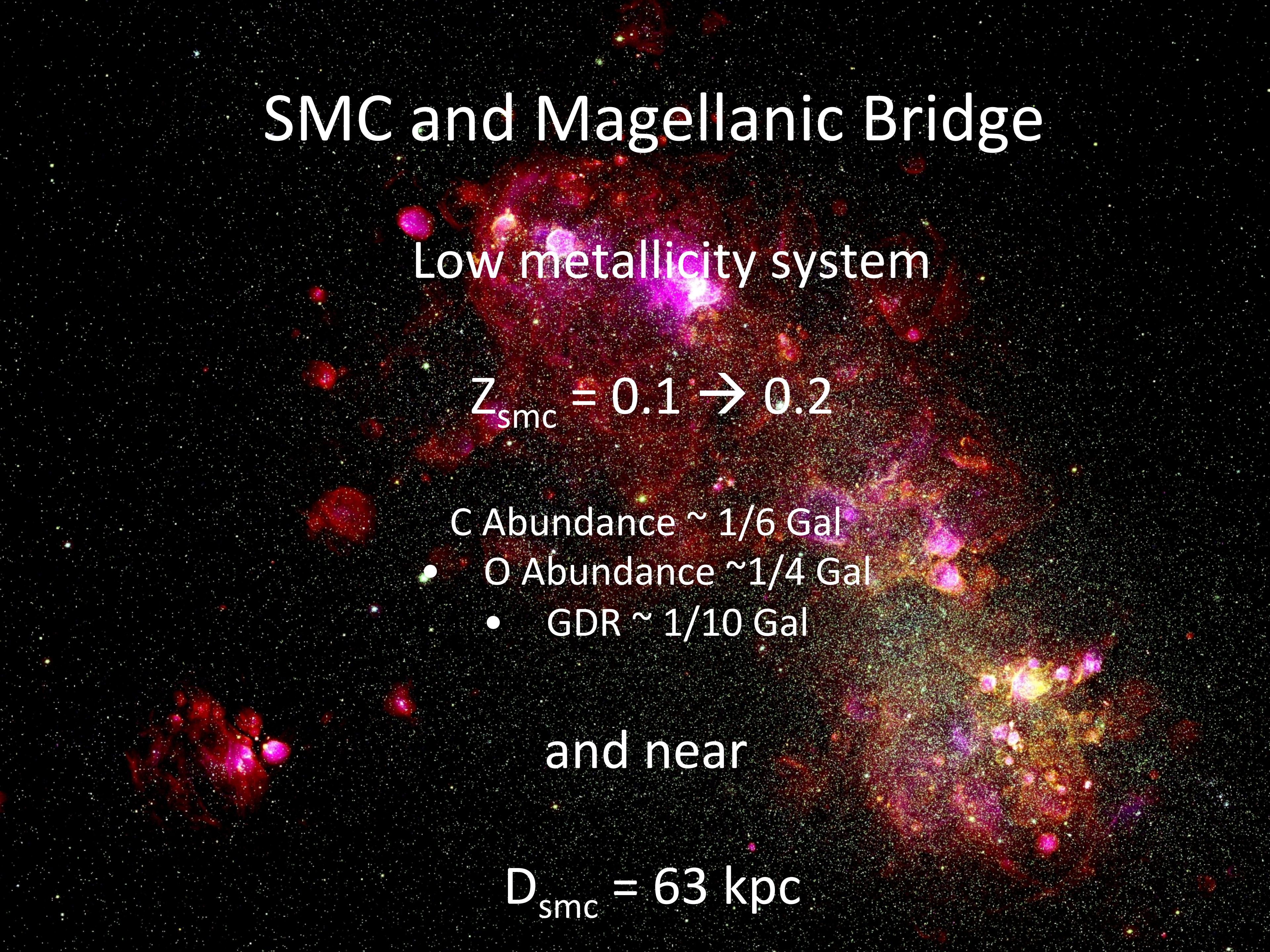
In WLM

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

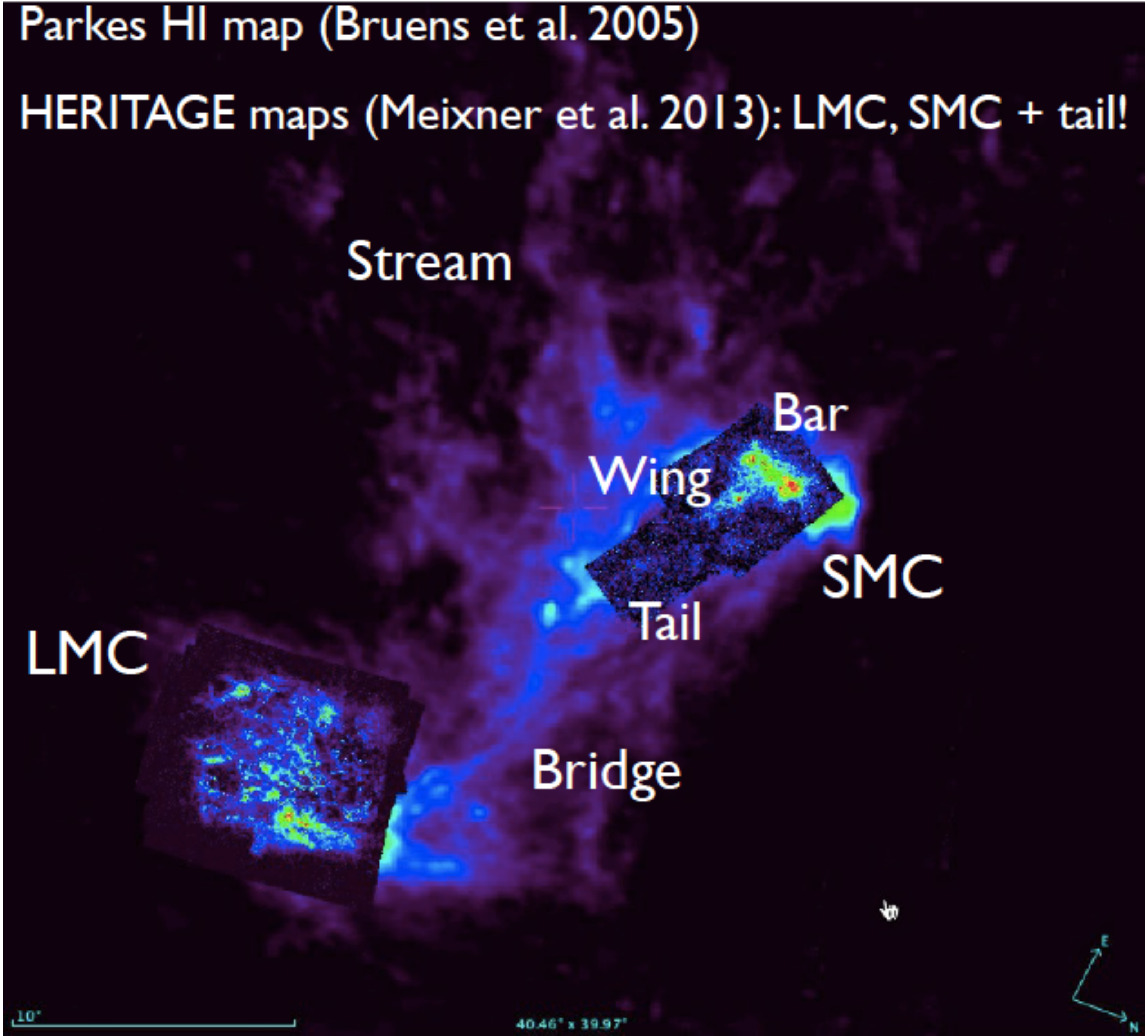
$Z_{smc} = 0.1 \rightarrow 0.2$

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

Celia Verdugo
MSc Thesis, 2012
DAS, UCHILE

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

LMC 8
SMC 4
Mag Br 3

Total 29 sources

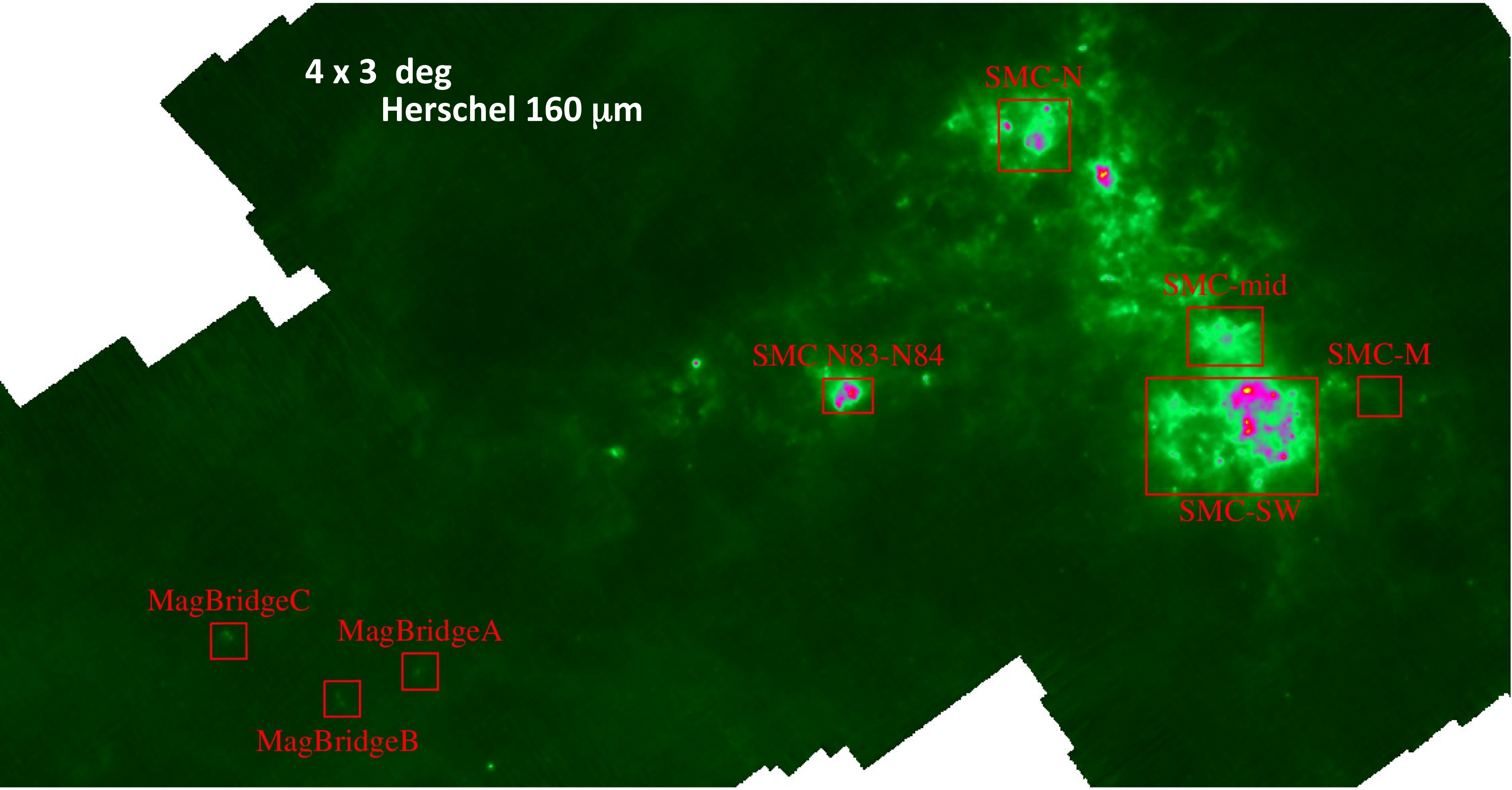
Before

Caroline Bot (France)

Cinthya Herrera (Chile)
Viviana Guzman (Chile)

SMC and Magellanic Bridge

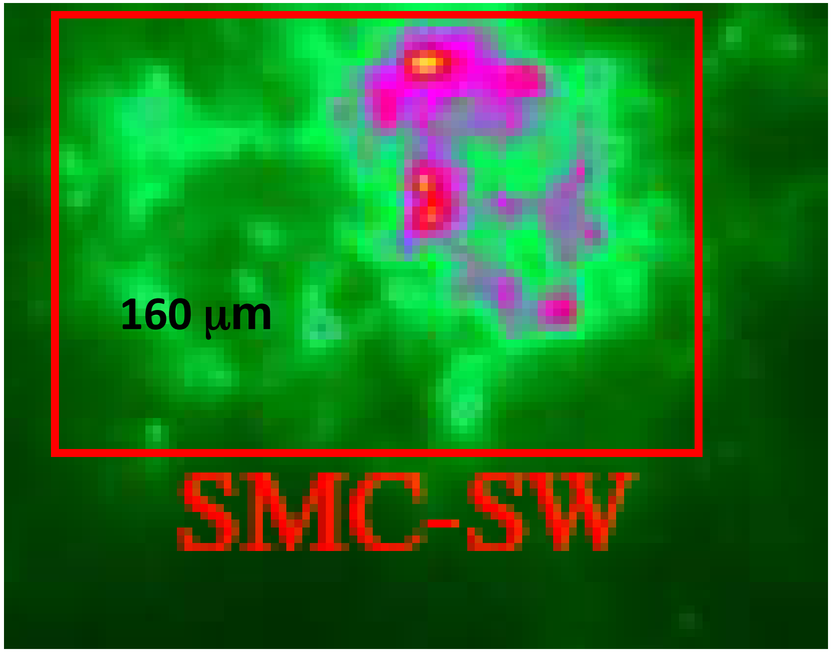
D=63 Kpc

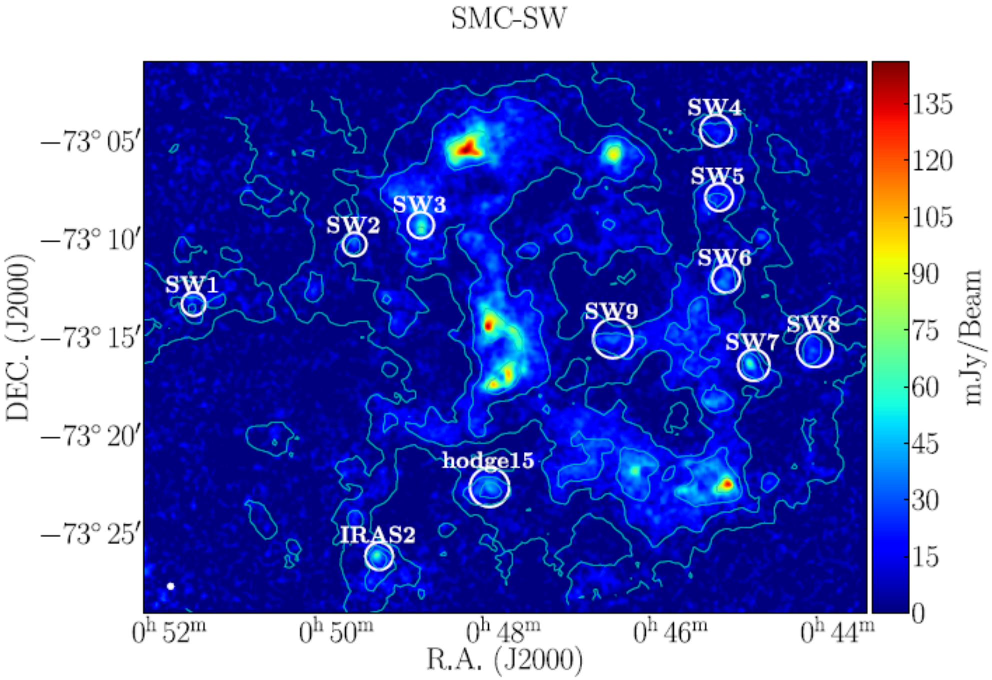


The Herschel Inventory of the Agents of Galaxy Evolution (Heritage) in the Magellanic Clouds

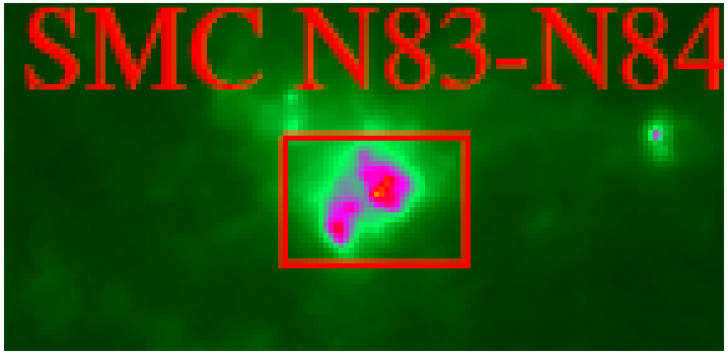
Meixner et al 2013

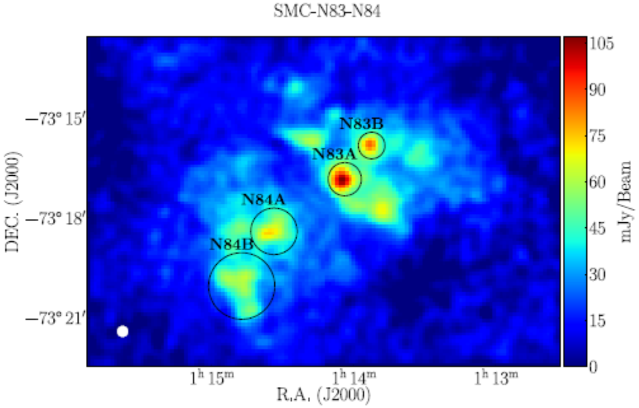
870 μm continuum emission with LABOCA





11 new sources in SMC_SW





SED fitting

Fit procedure $\rightarrow$ T, β, C

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

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

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

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

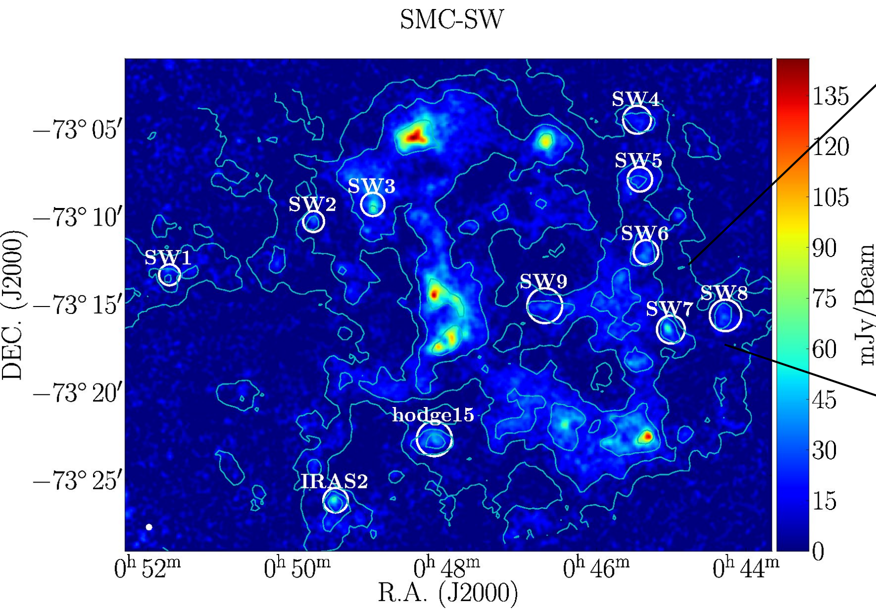
Results: T, β, τ

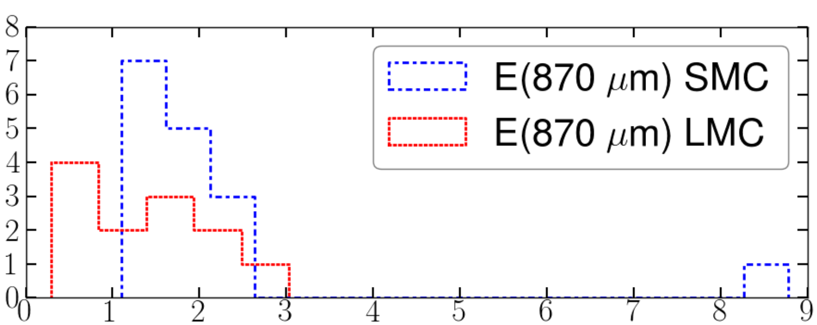
SMC: 22 K
LMC: 24 K
Bridge: 19 K

Determine Temperature opacity and emissivity index β

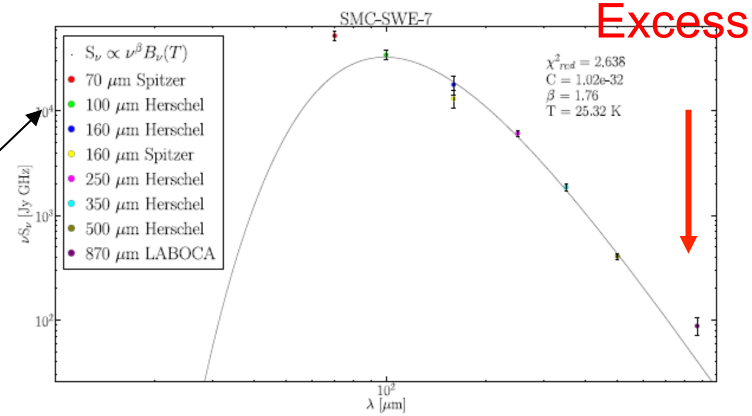
SMC Submillimeter Excess

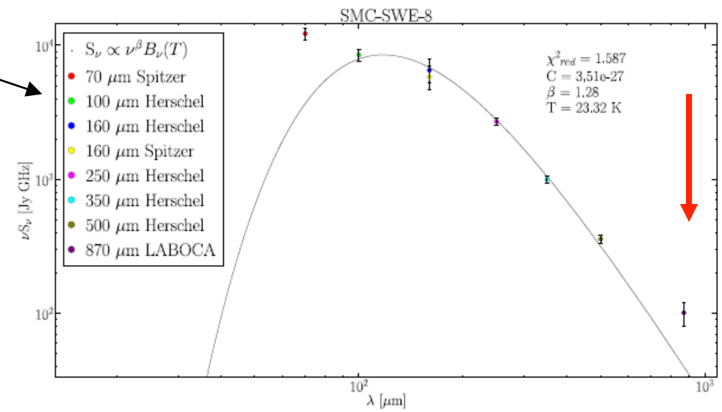
Excess ~1.7





Excess





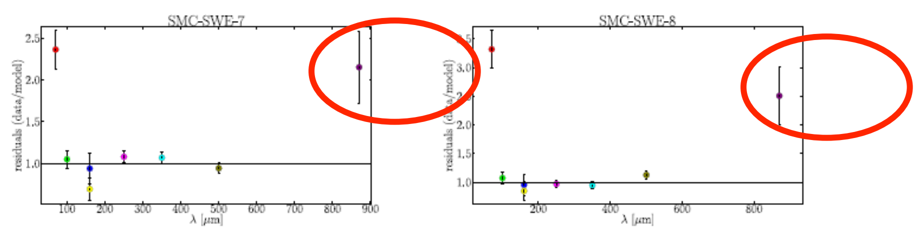
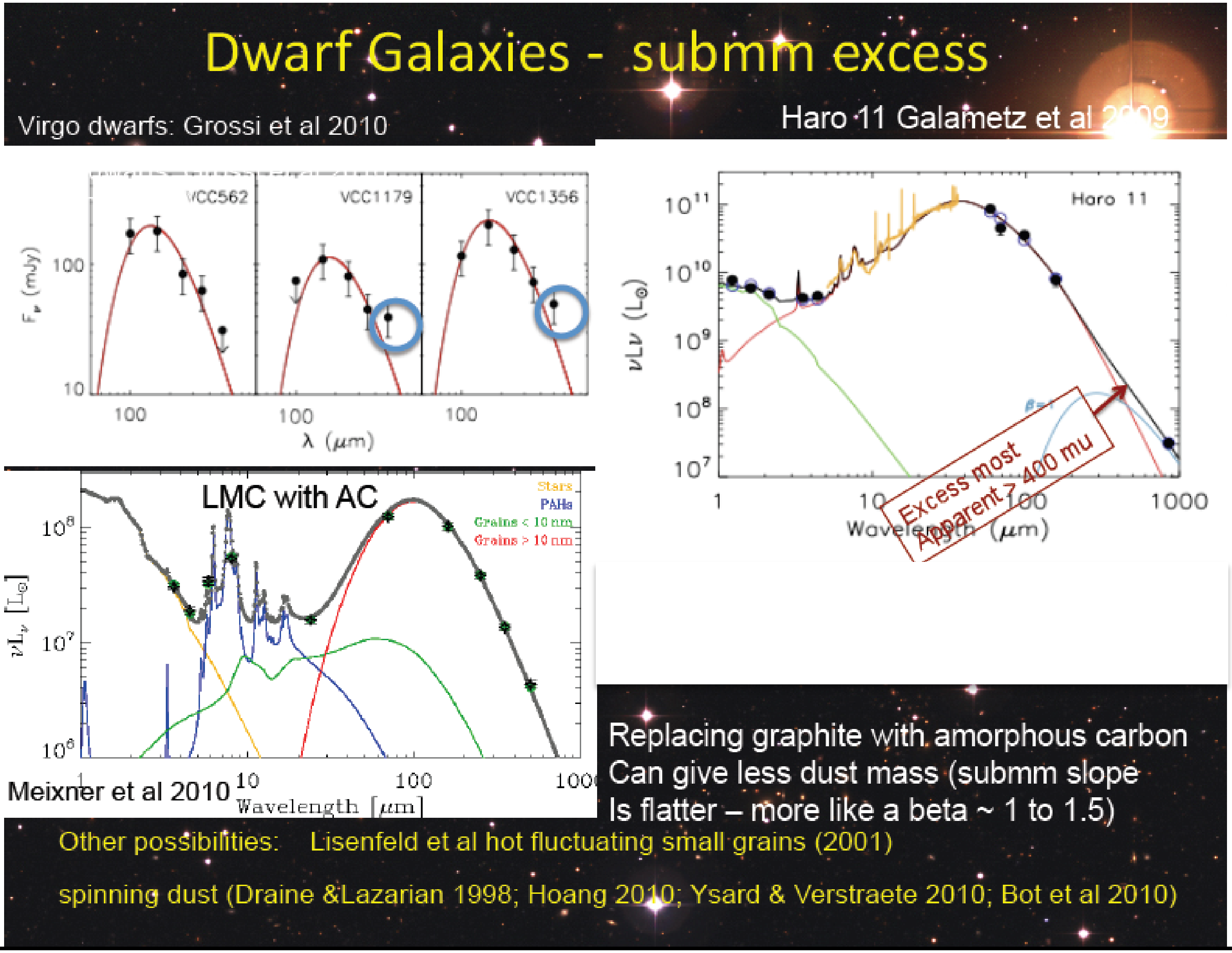


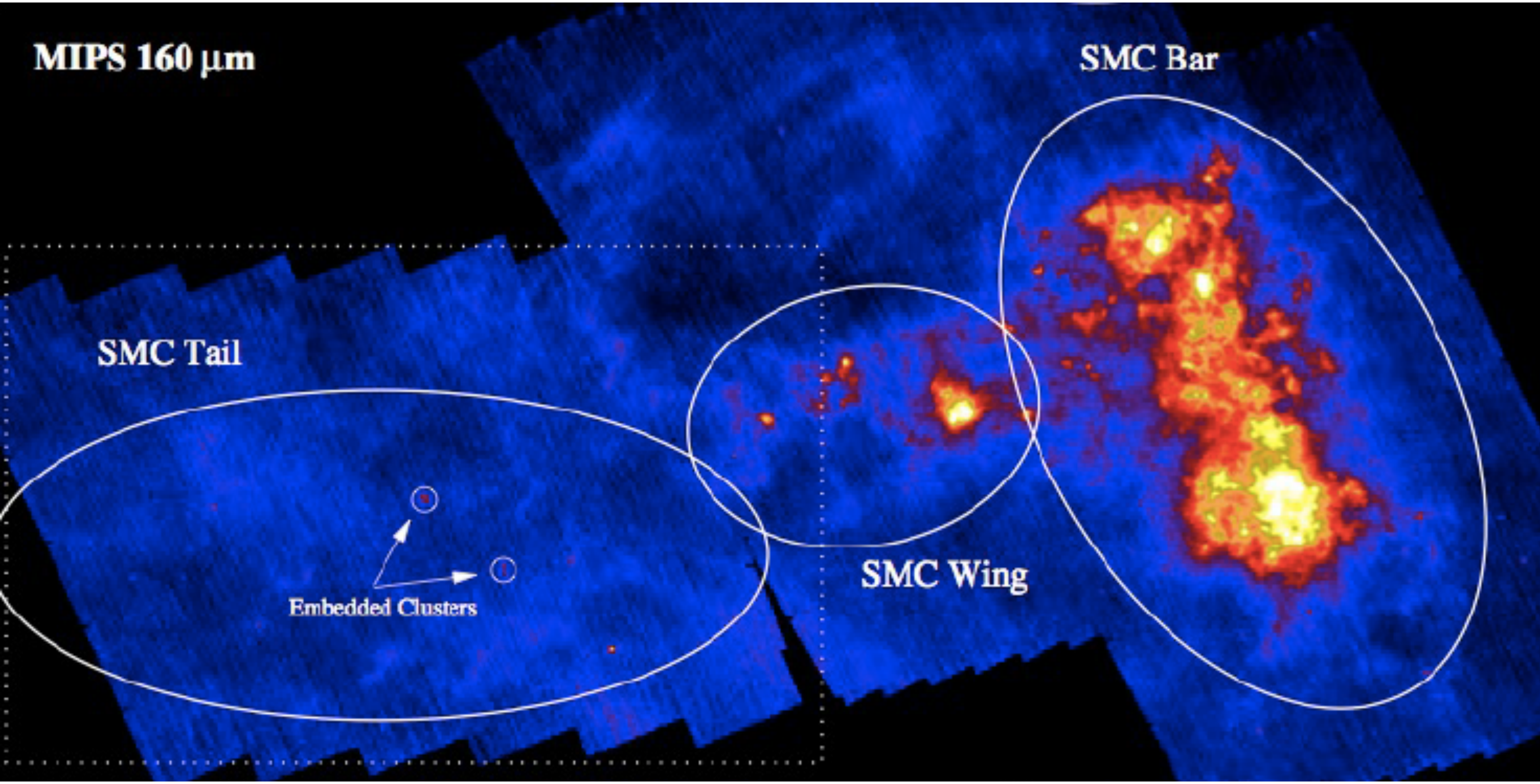
Figure 4.8: SED's for SMC-SWE-7 and SMC-SWE-8 with their corresponding residuals plots.

Verdugo et al 2014, Submitted

Submillimeter excess

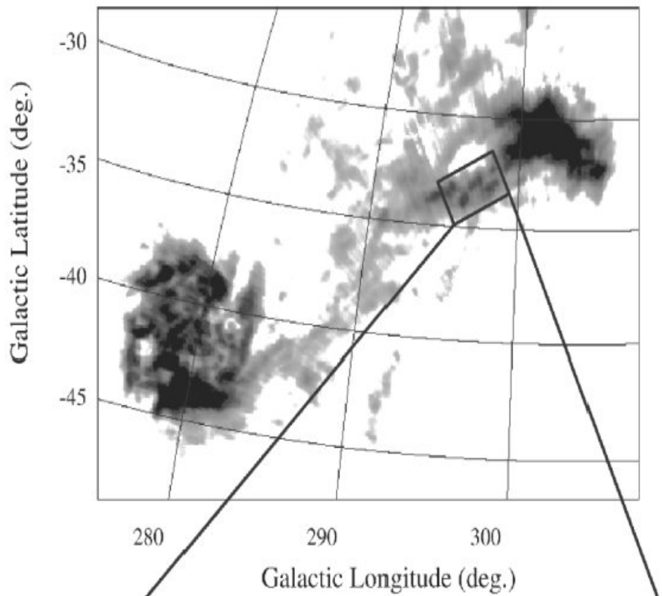


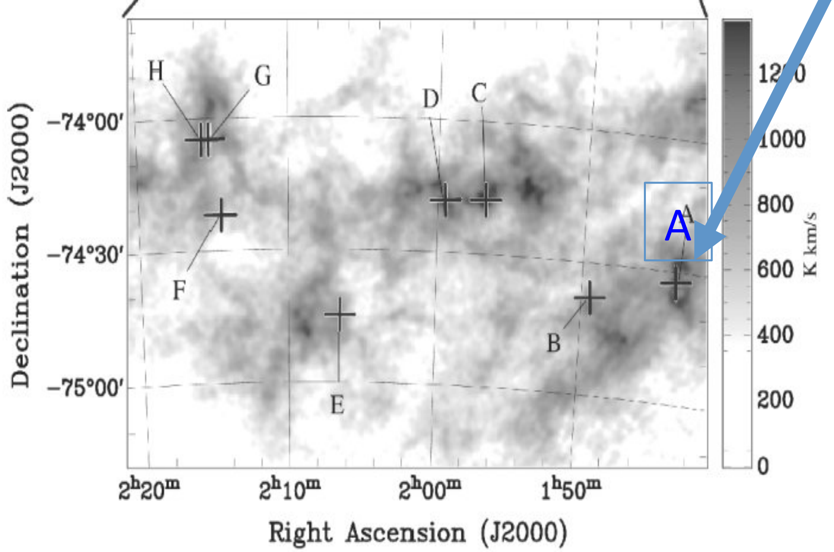
Madden et al , Galametz et al 2011



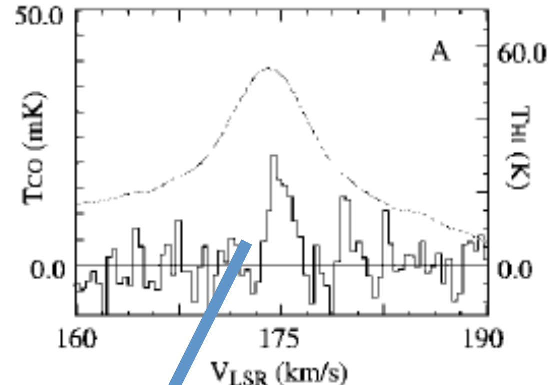
Gordon et al 2009
GDR ~ 1200 +- 350

Magellanic Bridge Source A





CO(1-0) Nanten observations



T_mb= 20 mK

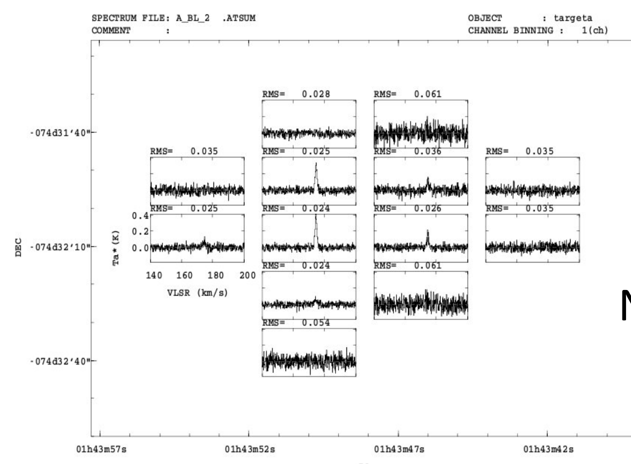
DV= 1.6 km/s

Ico= 30 +- 8 mK km/s

M= 1x10^3 Mo

Using X_co = 7 X_gal

(Mizuno et al. 2006)

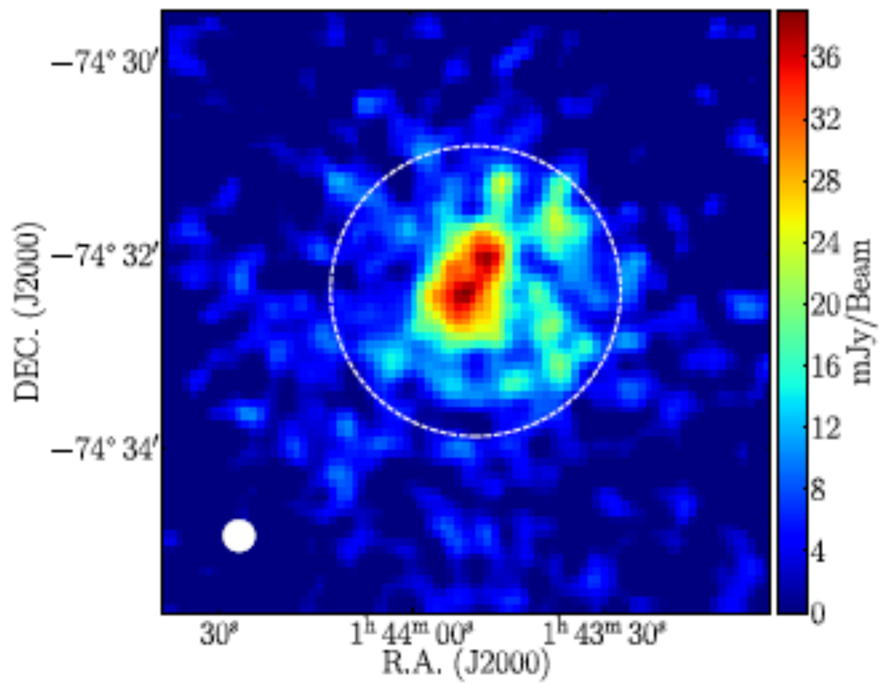


Narrow CO lines ~ 1km/s

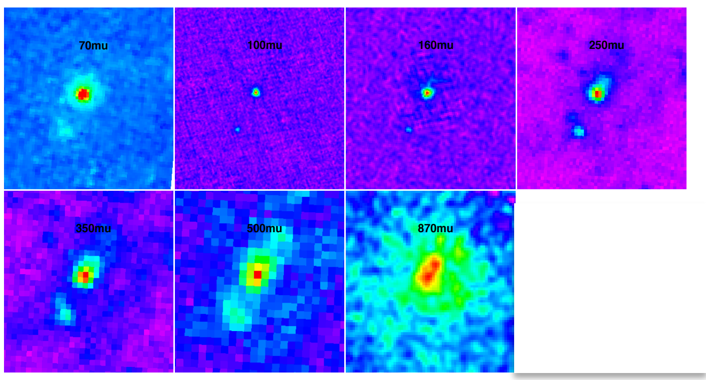
ASTE CO3-2

Muller et al. 2014 CO3-2 with ASTE

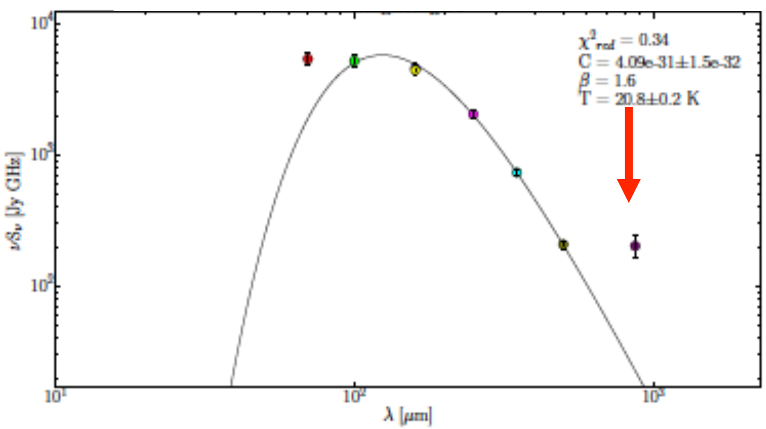
Continuum emission at 870 mu



S_870mm= 0.59 +- 0.12 Jy



Excess =8.8±1.8



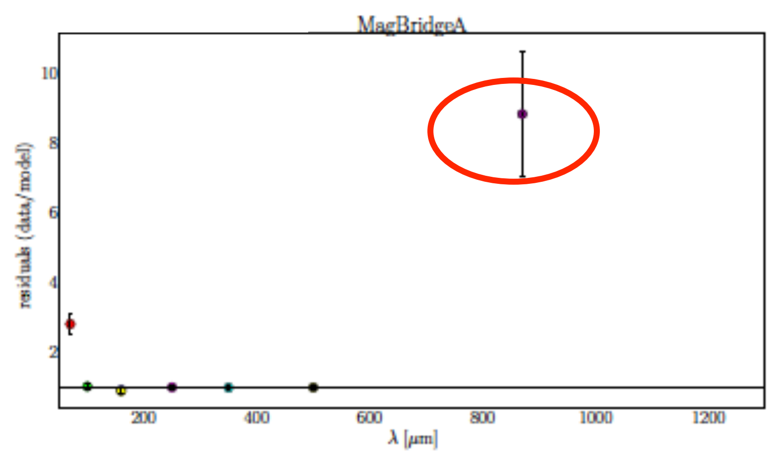


FIG. 11.— SEDs for LMC sources with their corresponding residual plots.

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 : EU : EA : CL : OTHER :	0 0 0 100 0	STUDENT PROJECT? (Yes/No) RESUBMISSION? (Yes/No)	No No	

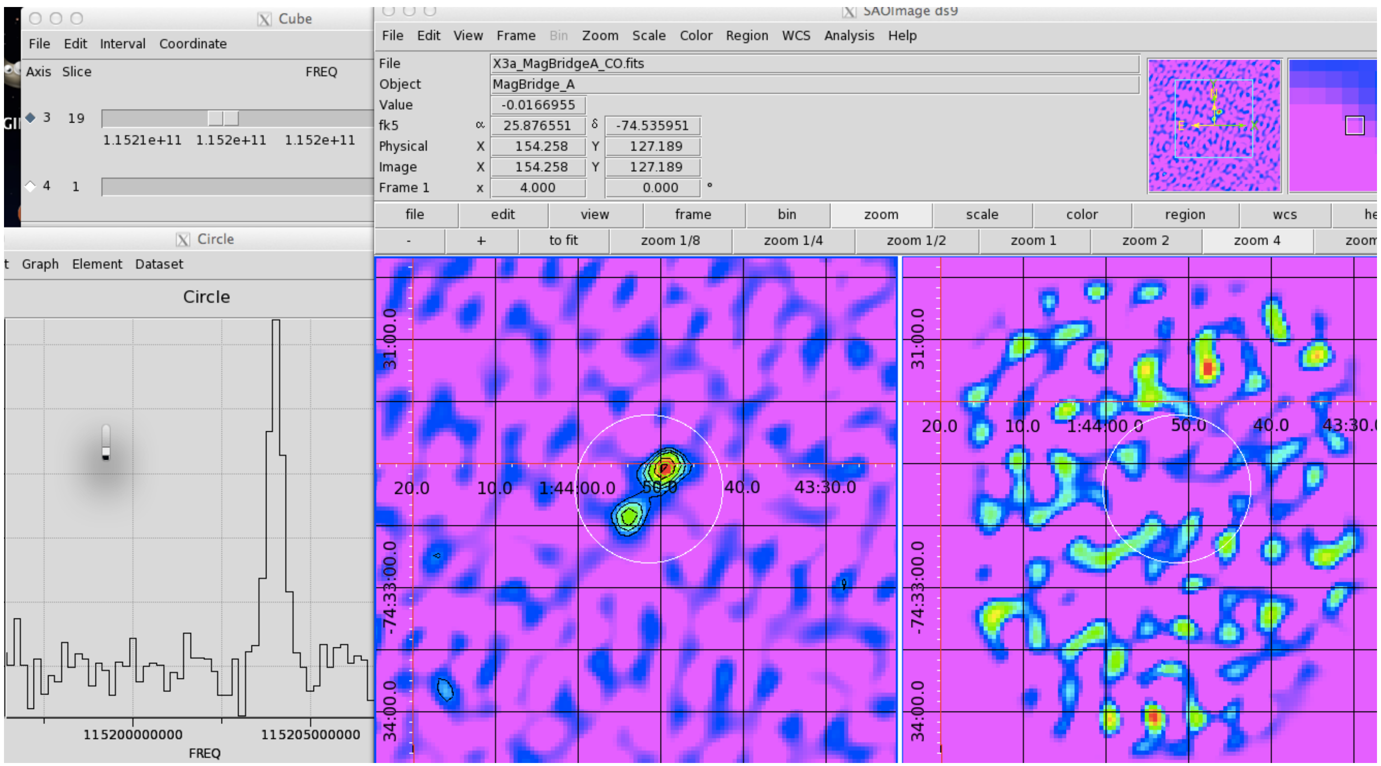
ABSTRACT

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



N° 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

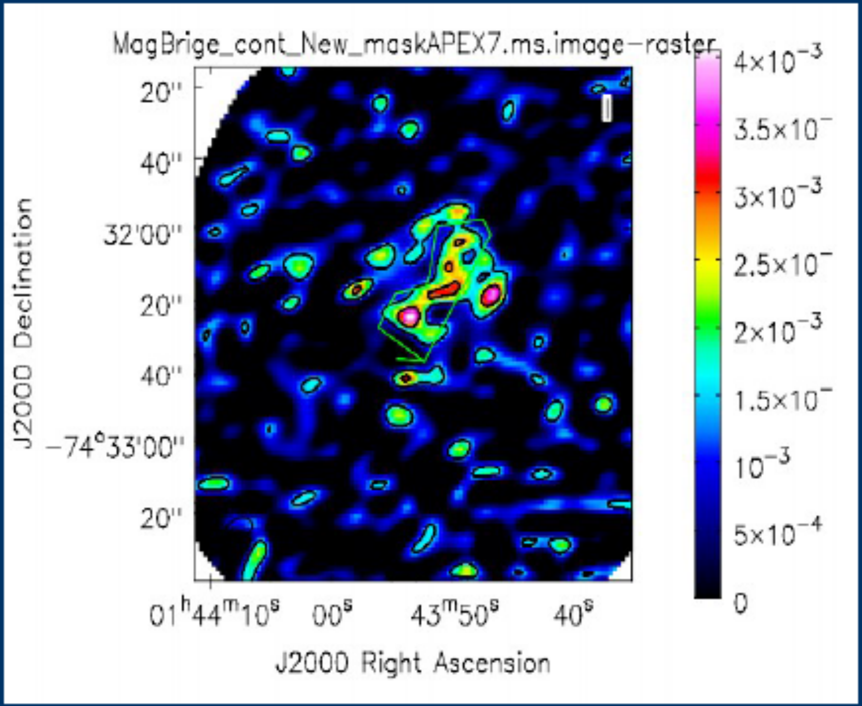
Data delivered showed no continuum emission

Magellanic_Bridge_A ALMA C1
1.3 mm continnum

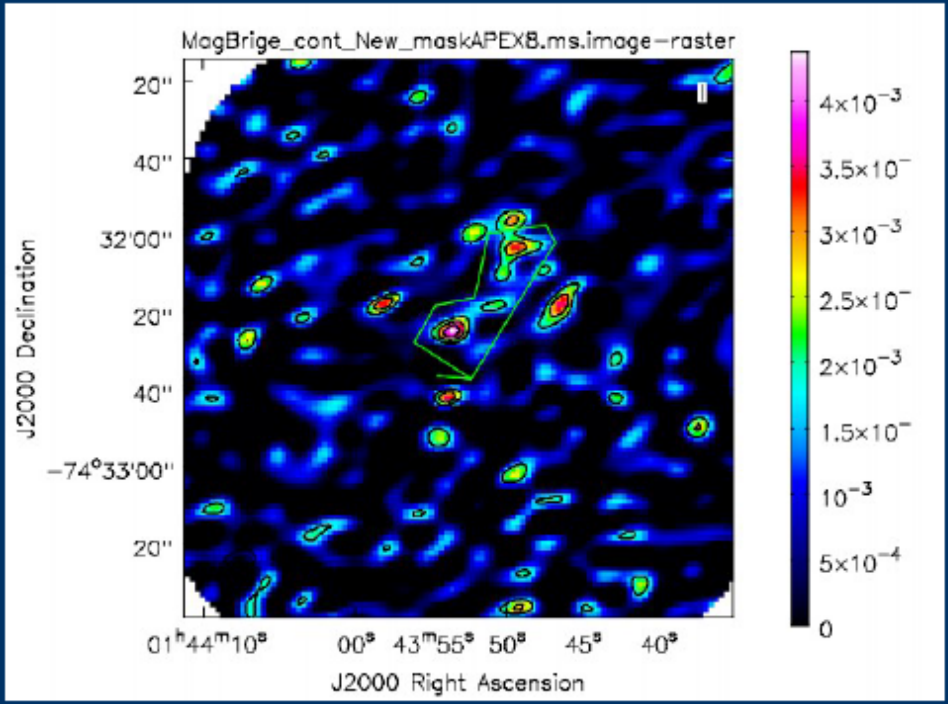
MagBridge: Continuo 1mm

Student:
Byron Cornejo

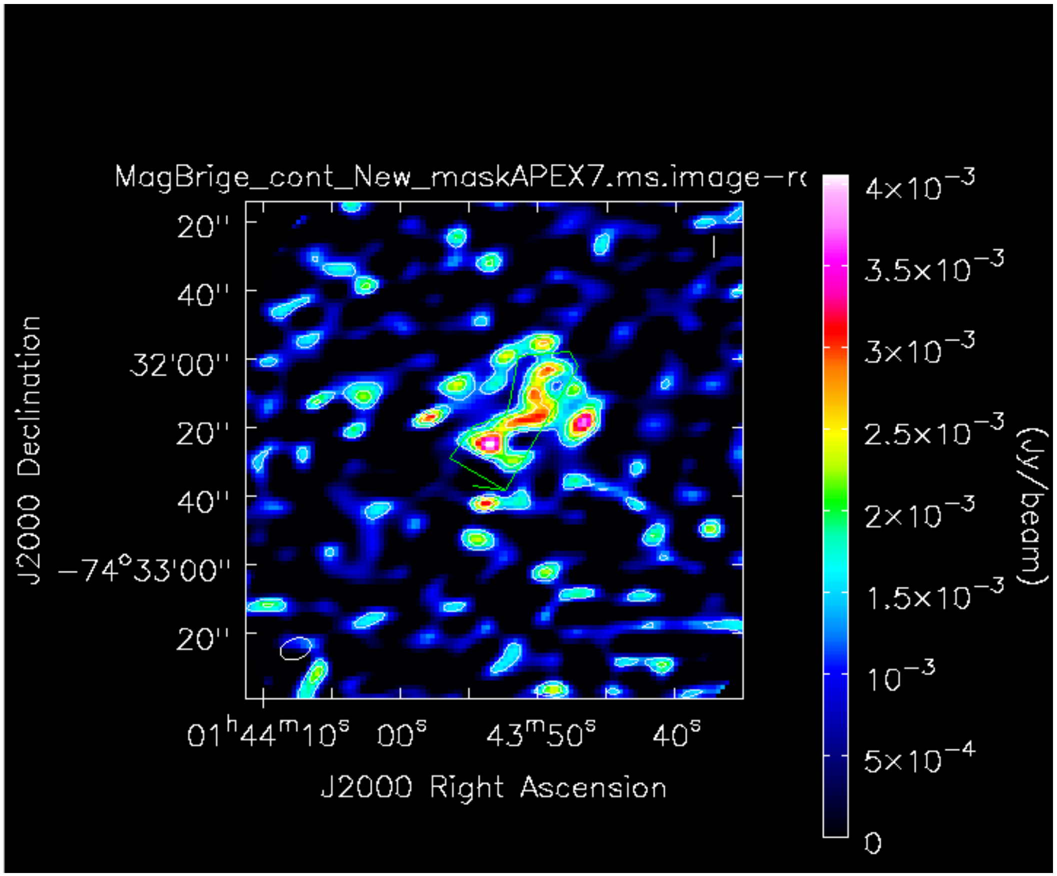
- Reducción usando Natural:



- 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)

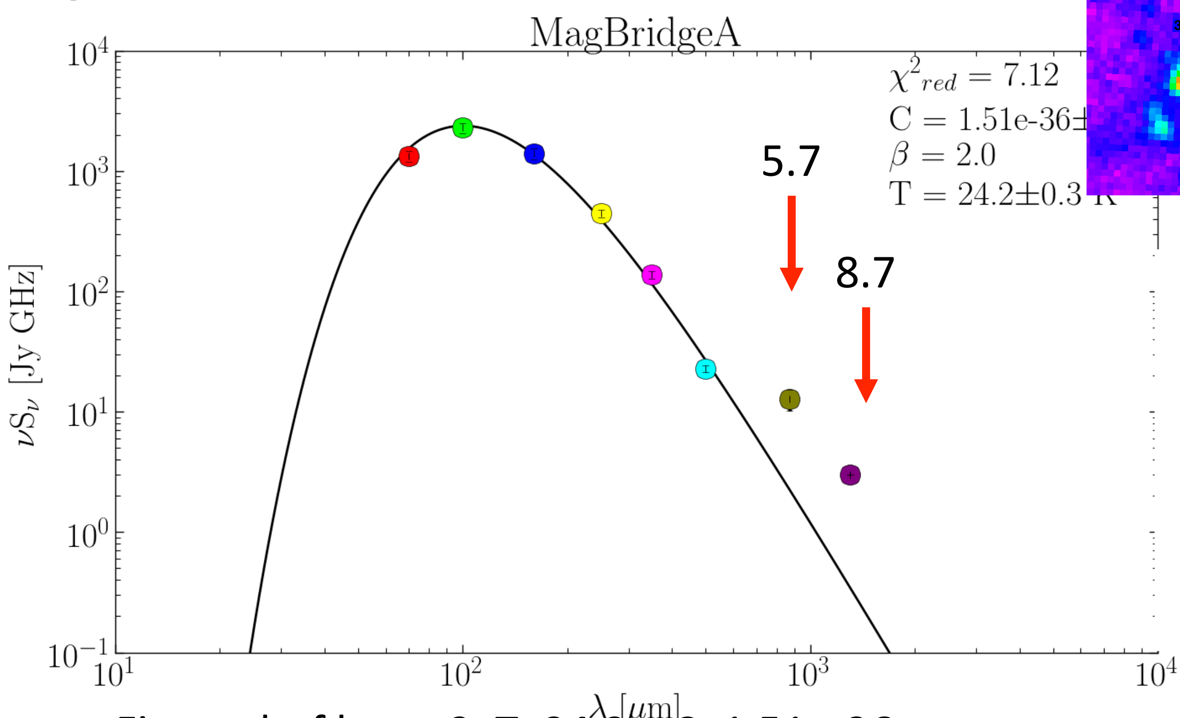
R~ 7 to 10 pc

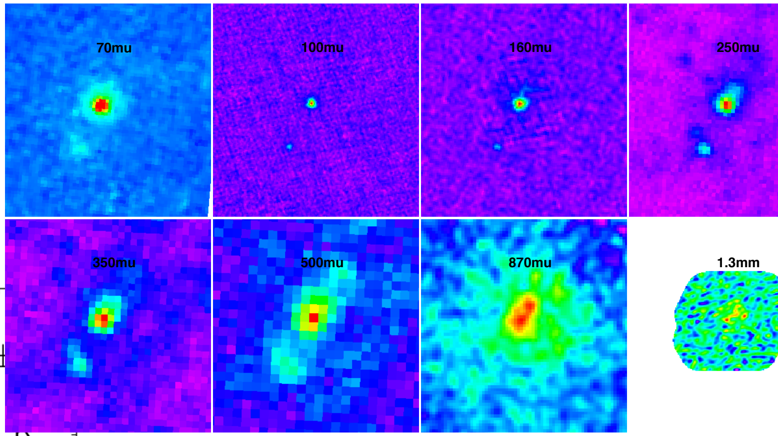
M_virial$_{CO_alma}$ =8.2x 10^3 Mo

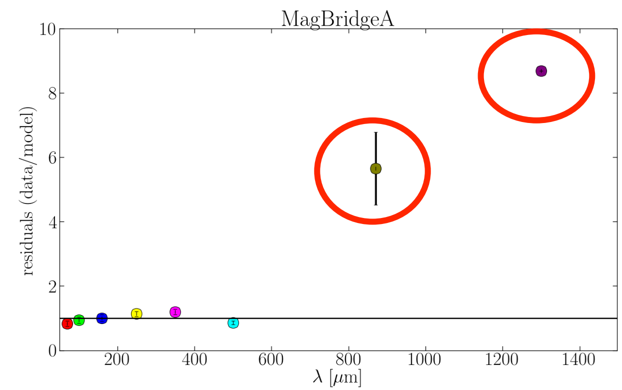
Magellanic_Bridge_A ALMA C1
1.3 mm continnum

Submillimeter excess at 1.3 mm

@870mu = 5.7
@1.3mm = 8.7







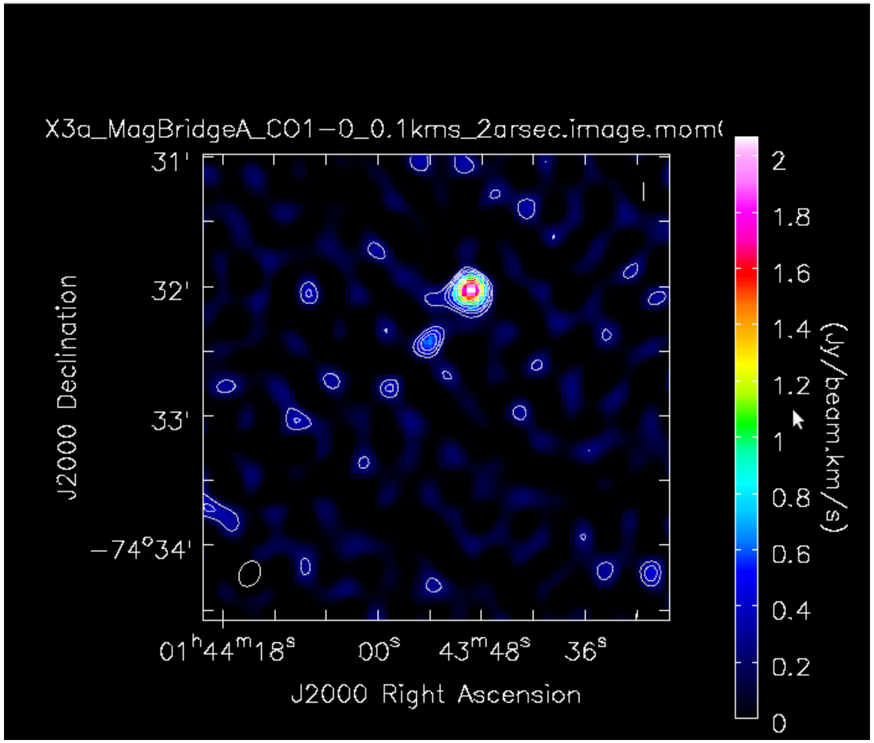
Fit result: f beta=2, T=24.2 , C=1.51e-36,

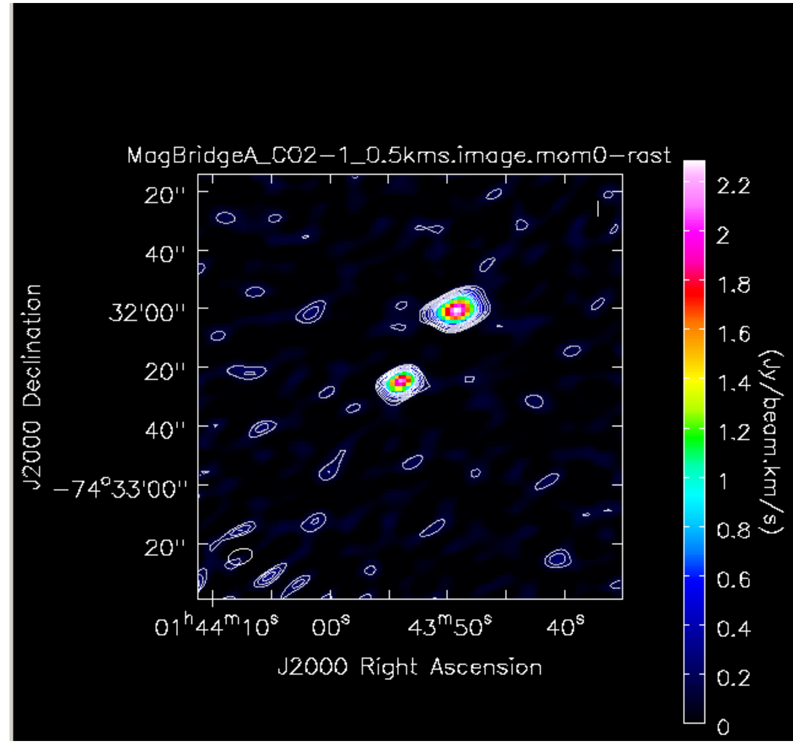
Residuals to fit

Mmm=1.1x10^5 Mo

Rubio et al, In prep.

Magellanic_Bridge_A ALMA C1
CO1-0, CO2-1

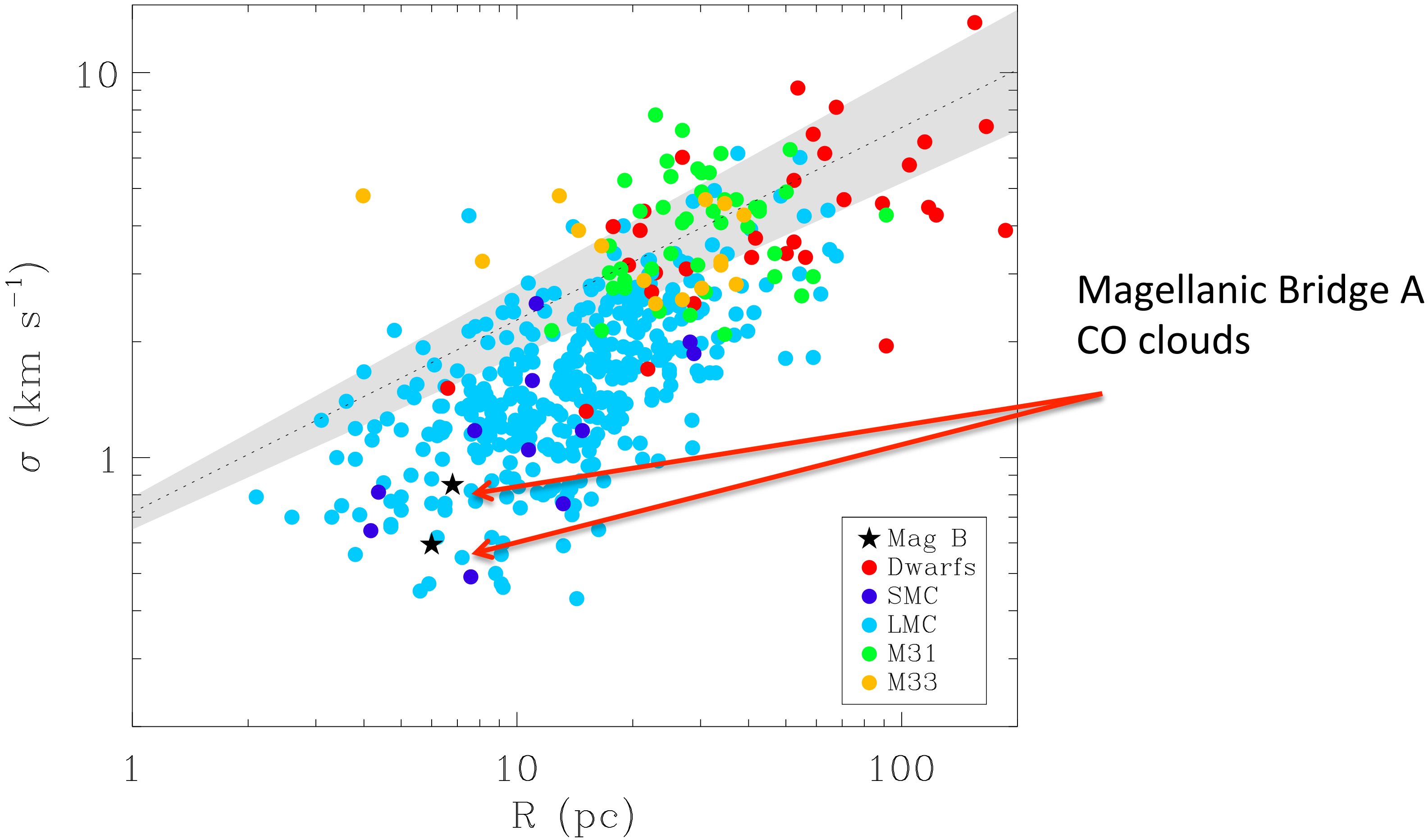




CO1-0

	Radius(pc)	FWHM (km/s)	Mvirial($M_\odot$)
Source 2	6.8	2.0 +- 0.223	5200 +/- 290
Source 1	5.5	1.4+-0.064	3000 +/- 99

Size-linewidth relation



Data from Bolatto et al 2013, added new APEX SMC data (Rubio et al, in prep)

Grey area is Solomon/s inner galaxy clouds

Conclusions

- 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 $N(H_2)$ from submm dust emission in these systems

- 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 virial mass determination from ALMA CO10 observations 8x10^3 Mo

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

Stay tuned!