高分解能観測で探るマゼラン雲の星形成

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(Nagoya University, Japan)

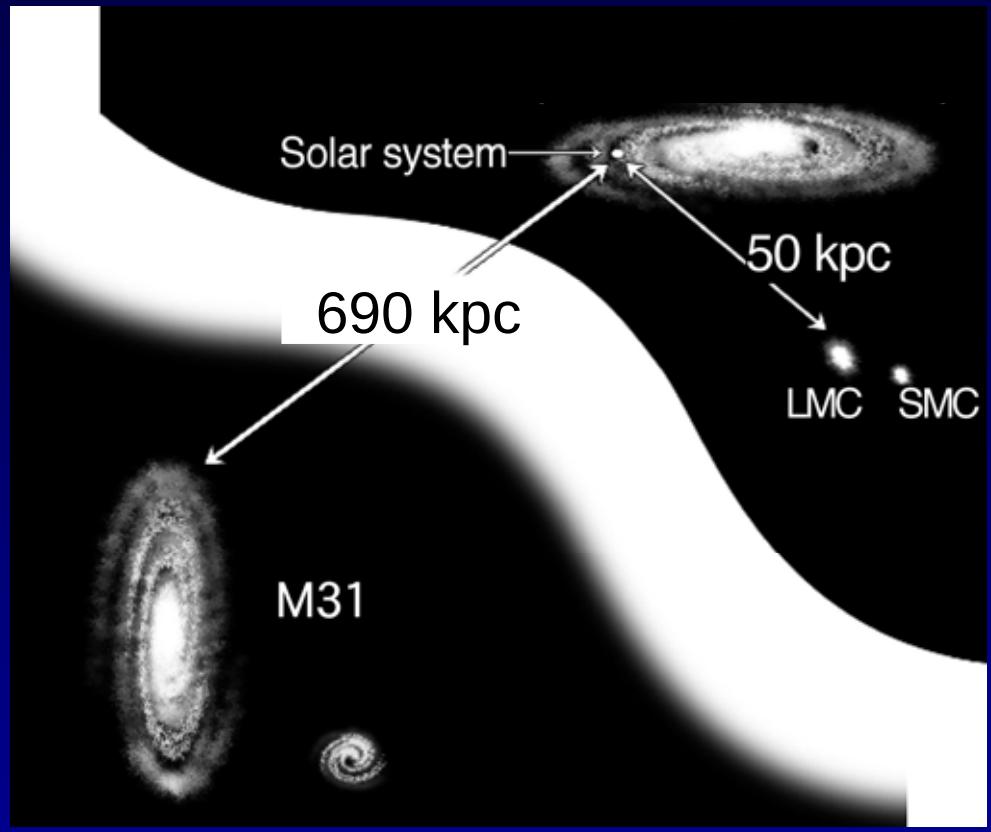
1. NANTEN results of Magellanic Clouds
2. SEST results of Magellanic Clouds
3. CO Observations towards Magellanic Bridge
3. Future prospects (NANTEN2, ASTE, ALMA)

マゼラン雲研究の特徴

- **一つの銀河全体の分子ガスの分布**
  - **同じ空間分解能、近い、**Face-on
- **星団形成の仕組み**
  - Populous Cluser**の存在**
- **原始銀河に近い環境下での星形成**
  - **重元素量：銀河系** > LMC > SMC > Bridge

- **現状：**GMC**の分布が明らかに->高分解能観測**

Why Magellanic Clouds ?



Nearest bigger galaxies, relative face-on location (LMC)

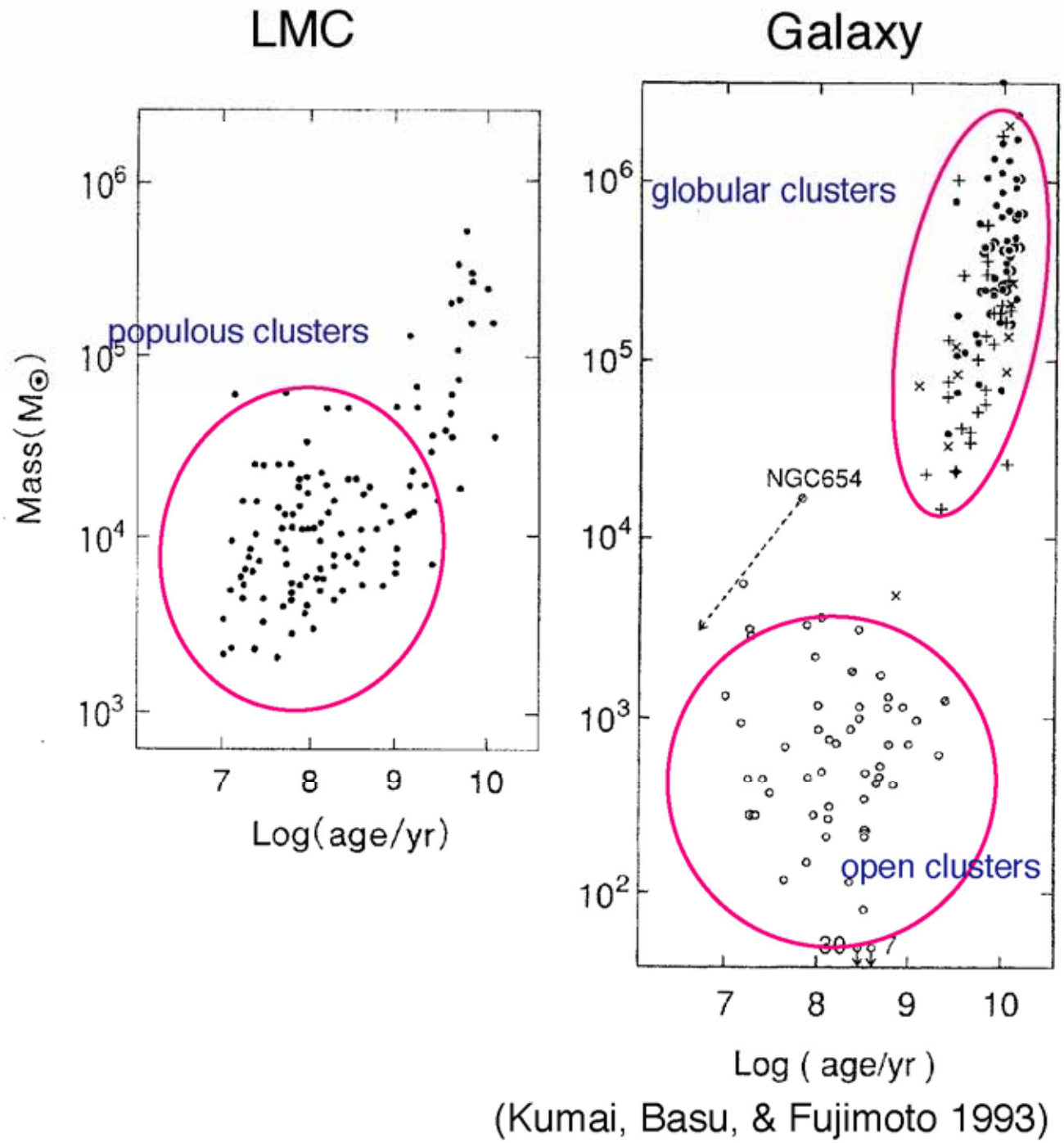
We can resolve individual GMCs!

Different interstellar environment

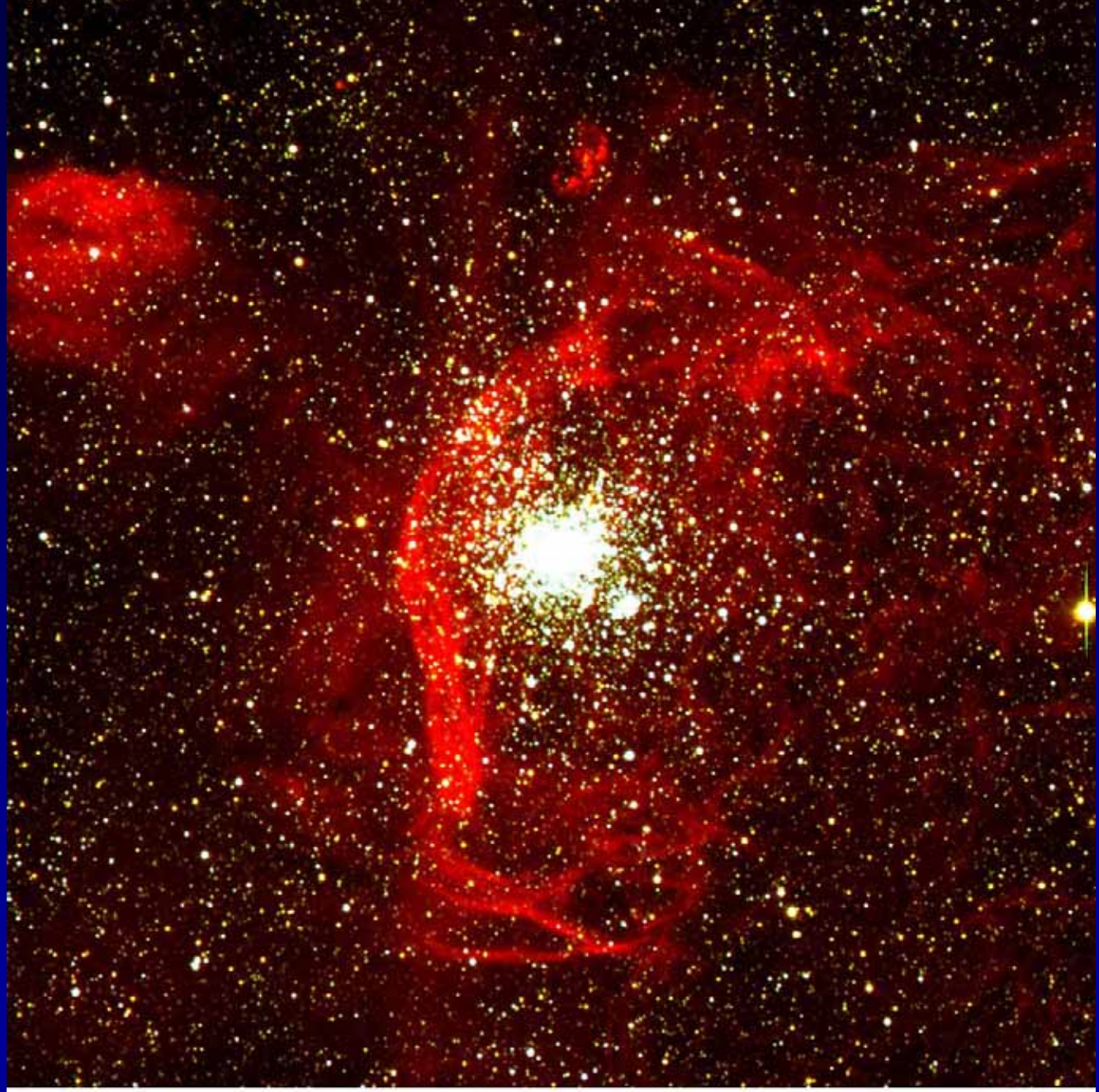
lower metallicity, higher gas to dust ratio, strong UV field

Active star formation

populous clusters, huge HII regions (e.g., 30Dor…)

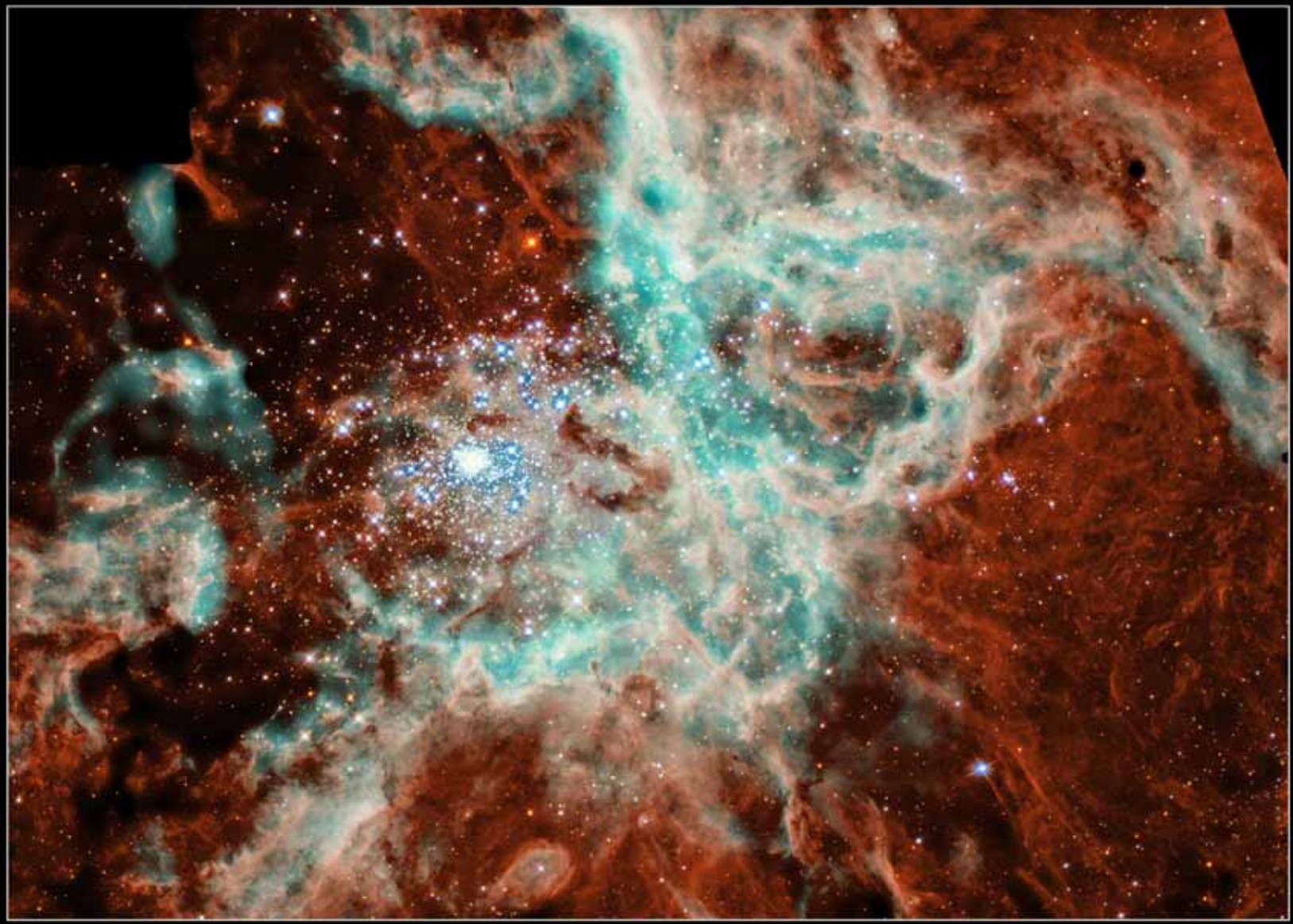


(Kumai, Basu, & Fujimoto 1993)



Stellar Cluster NGC 1850 in the LMC
(VLT UT1 + FORS1)

ESO PR Photo 15/99 (27 February 1999)



30 Doradus in the Large Magellanic Cloud
Hubble Space Telescope • WFPC2

NASA, N. Walborn (STScI), J. Maíz-Apellániz (STScI), and R. Barbá (La Plata Observatory, Argentina) • STScI-PRC01-21

NANTEN telescope in Chile

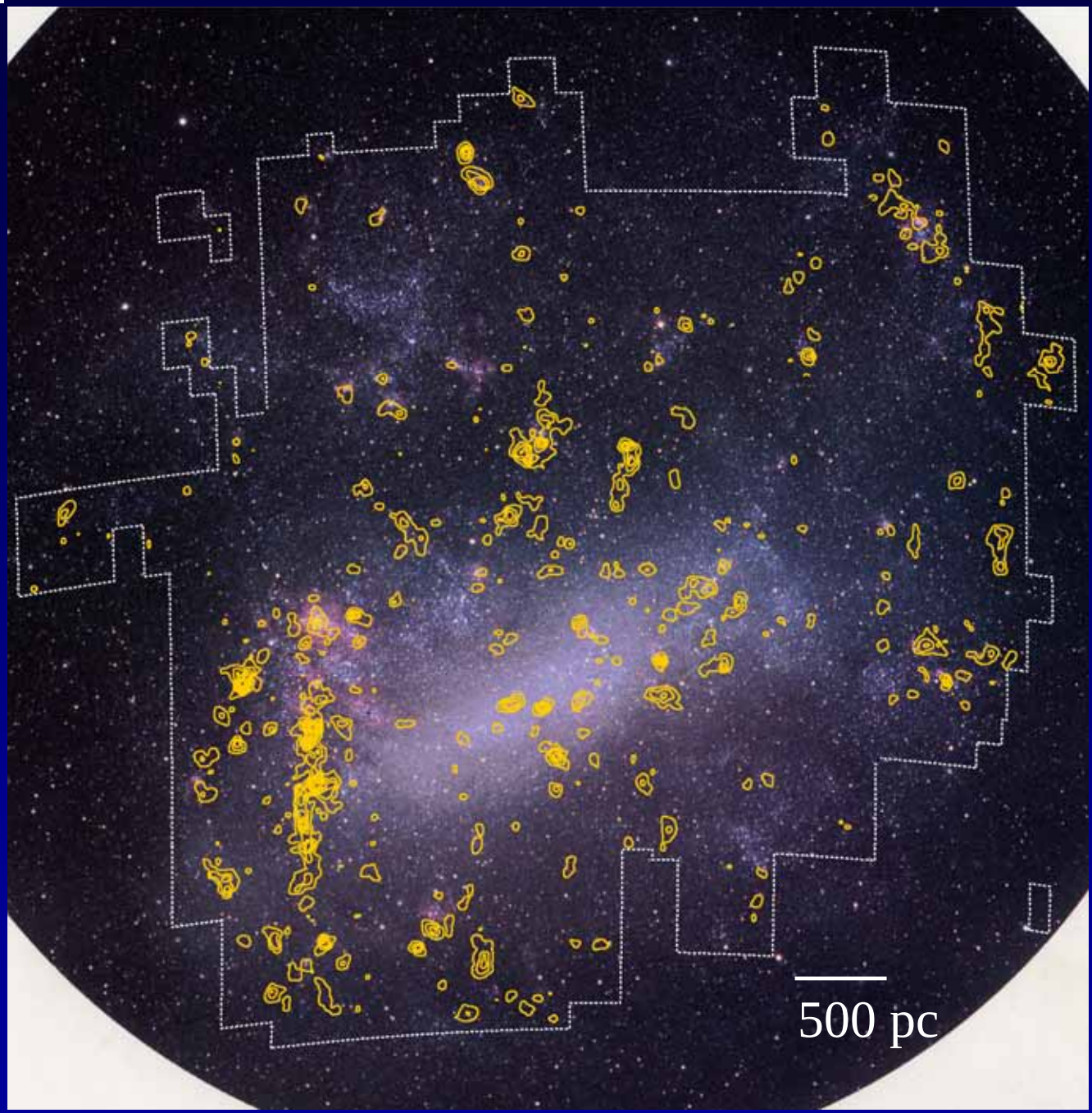
Since 1996

Las Campanas Observatory

- Diameter: 4m

  CFRP + conductive paint
- SIS receiver + AOS backend
- 85-115GHz, mainly CO(J=1-0)
- Beam size 2.6 arcmin (@115GHz)

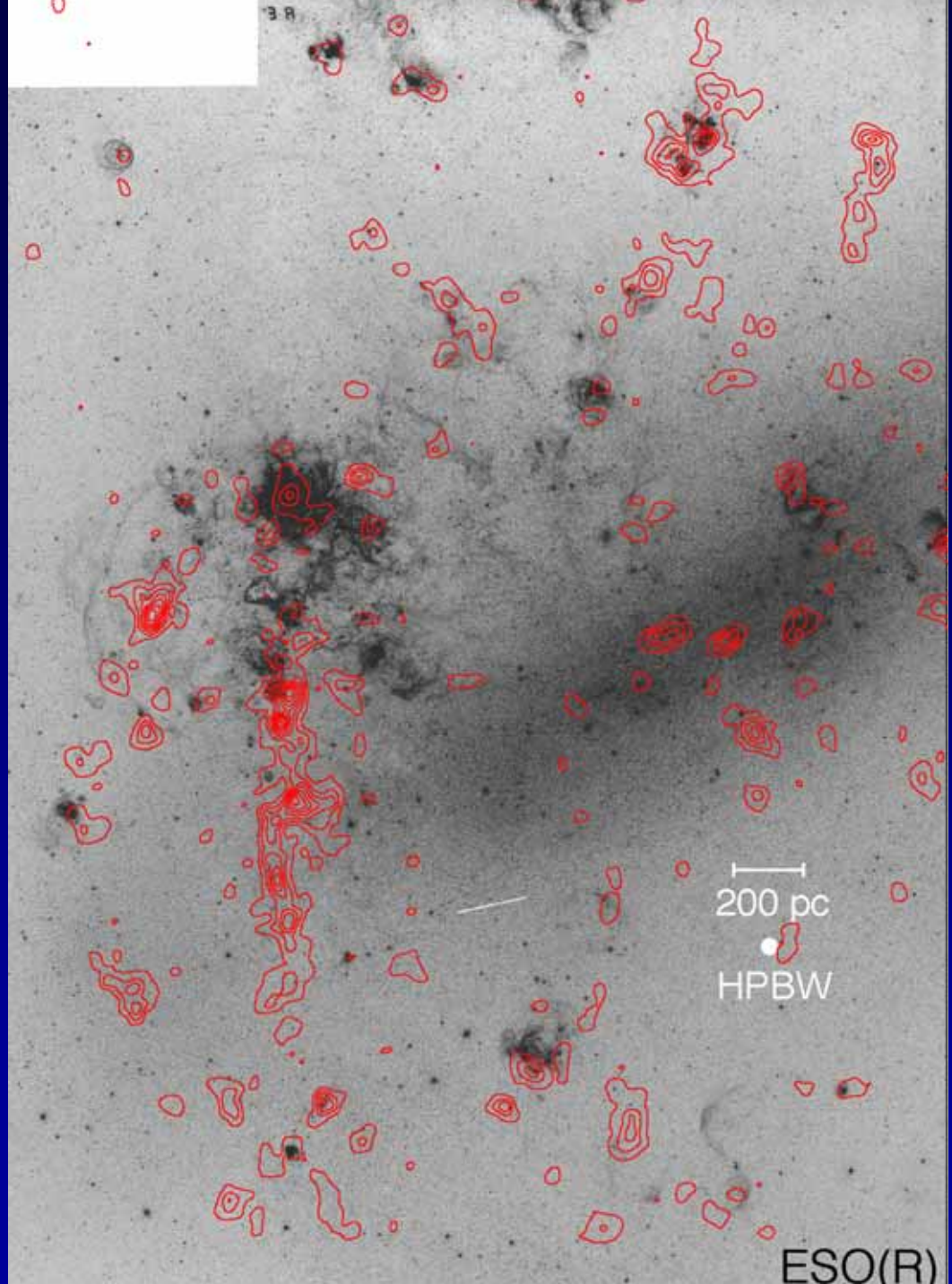
  ~ **40 pc@50kpc**
- Velo. Res. 0.1 or 0.6 km/s
- Band Width 100 or 500 km/s
- Tsys ~ 300 K (SSB)



270 CO clouds identified ($M > 10^4\ M_{sun}$)

Total molecular mass

$\sim 7 \times 10^7\ M_{sun}$


200 pc
HPBW
ESO(R)

Properties of giant molecular clouds

- 270 clouds identified
- 168 clouds (> 3 points) derived physical parameters

  Mass $4 \times 10^4 - 3 \times 10^6\ M_\odot$

  Size (radius) 30 – 120 pc

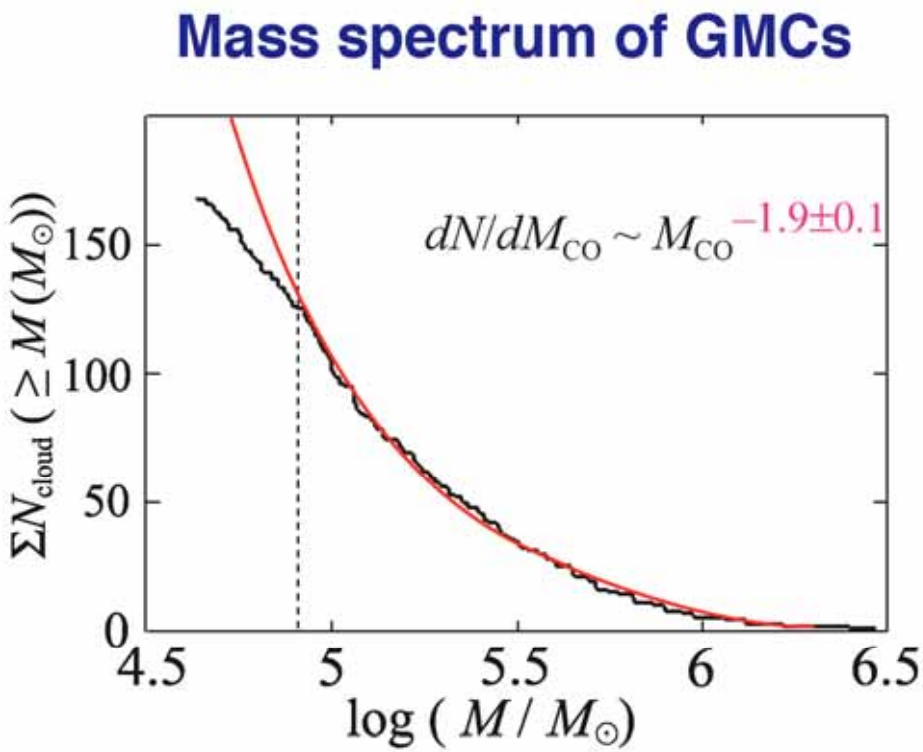
  Line width (FWHM) 3 – 14 km s^{-1}
- Mass Spectrum

  $dN/dM \propto M^{-1.9\pm0.1}$
- Size–Line width relation

  $\Delta V \propto R^{0.66\pm0.2}$
- $X = N(H_2)/I_{CO} = M/L_{CO}$

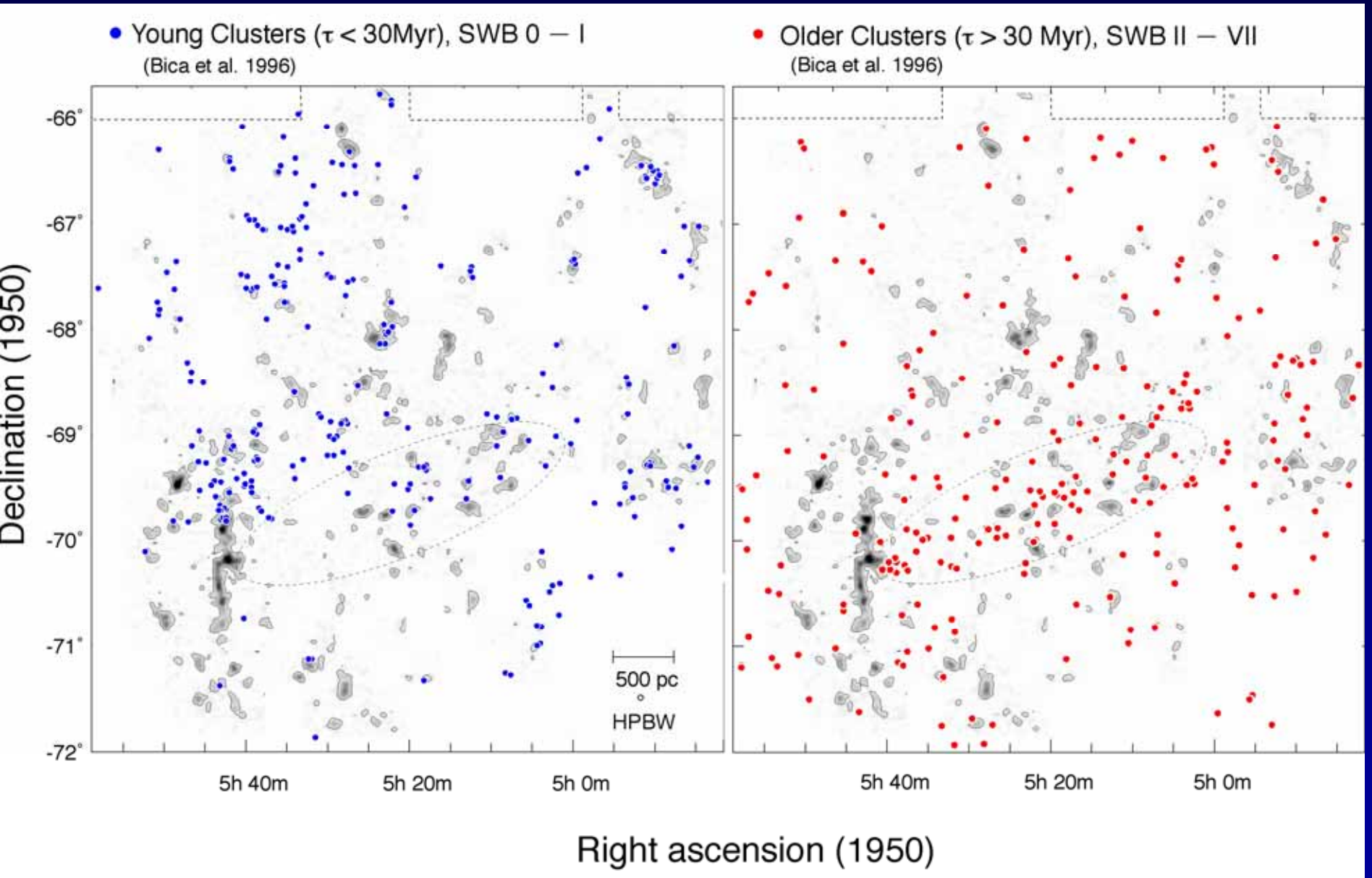
  $X_{LMC} \sim 9 \times 10^{20}$ cm^{-2} / (K km s^{-1})

  $\sim 3\ X_G$



c.f. for Galactic clouds
$dN/dM_{CO} \sim M_{CO}^{-1.5}$
(e.g., Solomon et al. 1987)

Distributions of clusters and CO clouds



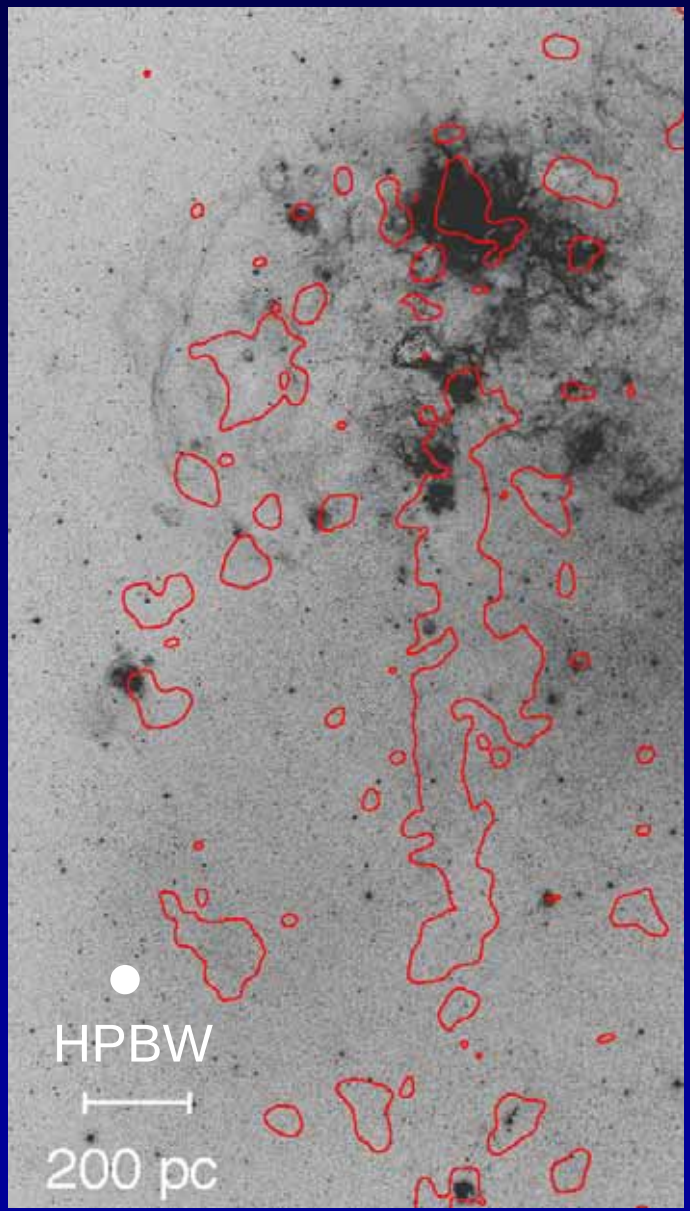
Youngest clusters (<10 Myr)

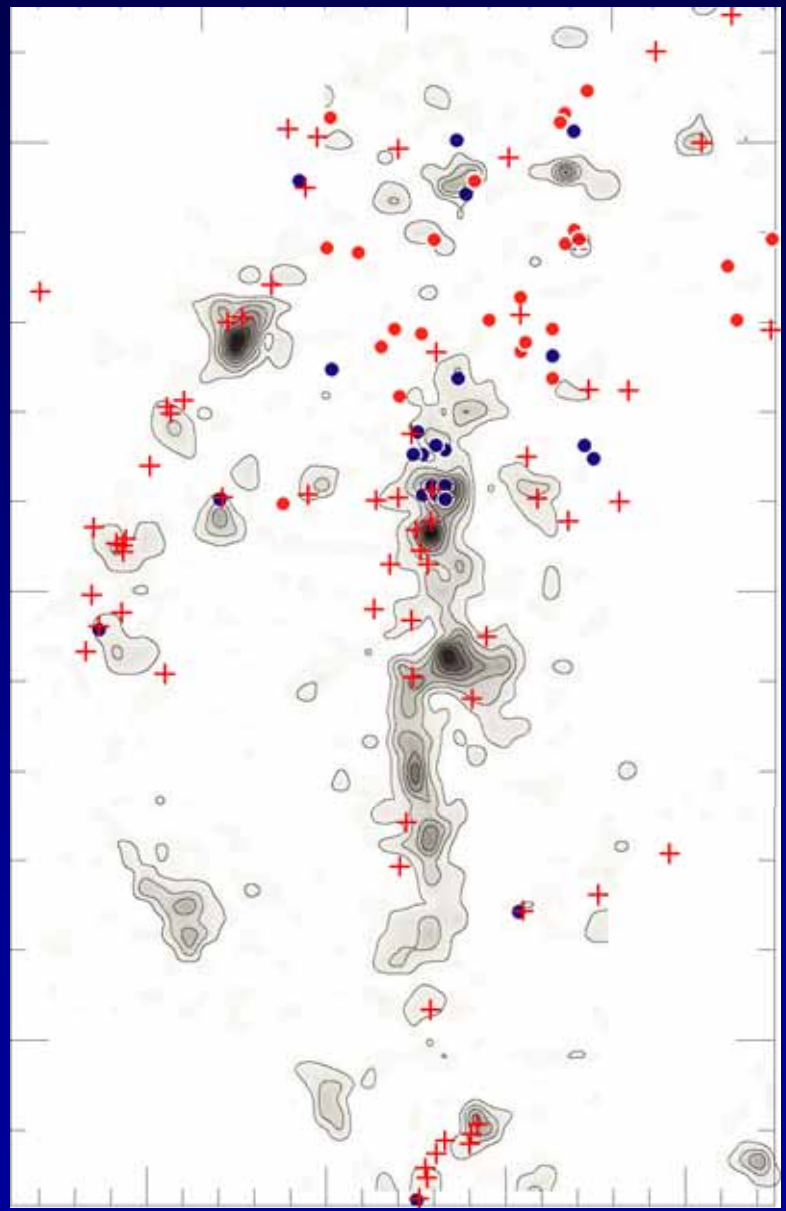
Young clusters (10Myr < 30Myr)

HII regions

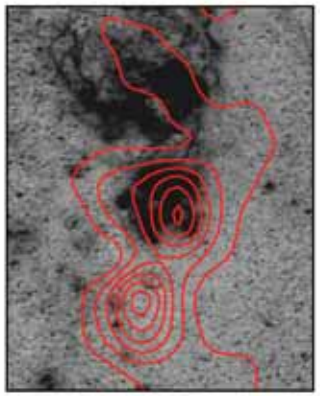
Bica et al. 1996

Davies et al. 1976



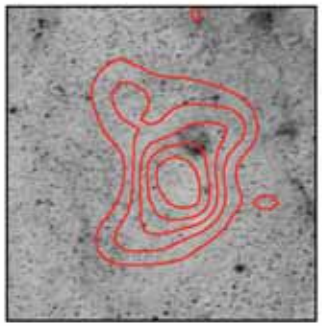


103 CO clouds (> $10^5 M_{sun}$)



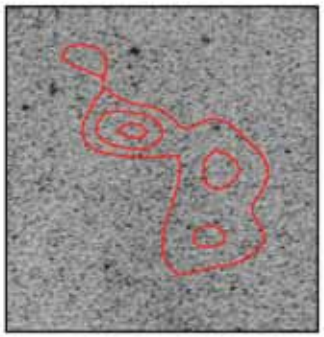
Clusters and HII region
(< 10 Myr)

32 (31 %)



Only HII regions

37 (36 %)



Nothing

34 (33 %)

300 pc

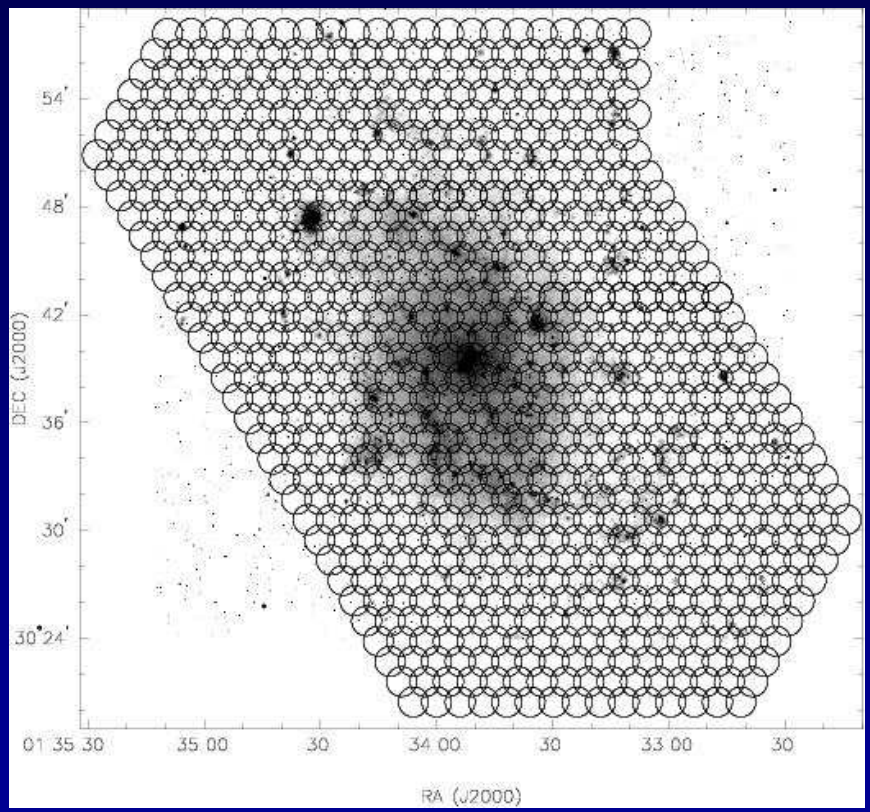
Evolutional time scale

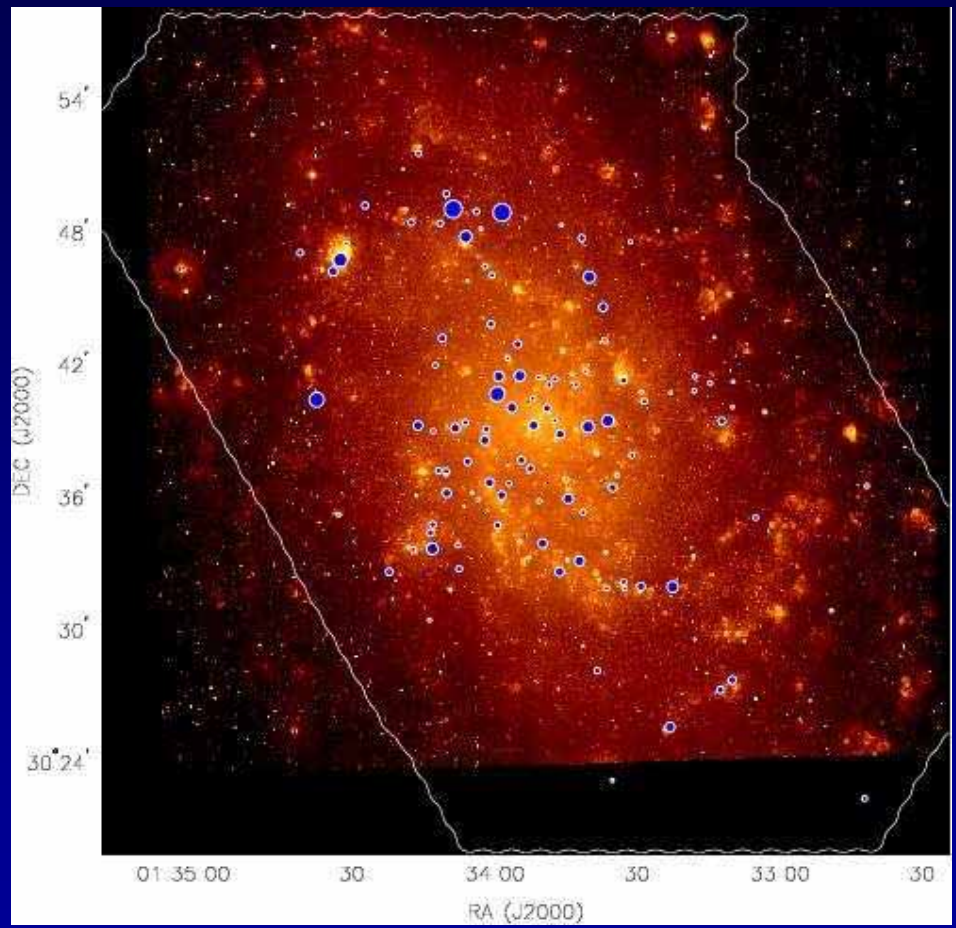
~ 3 Myr

~ 3 Myr

~ 3 Myr

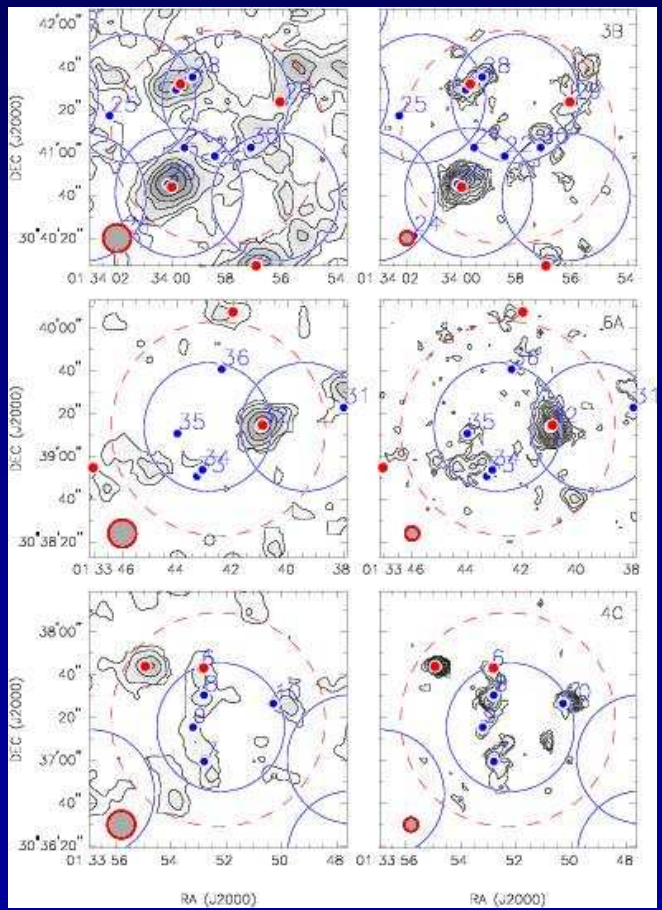
M33 BIMA Observations (linear resolution 50 pc)

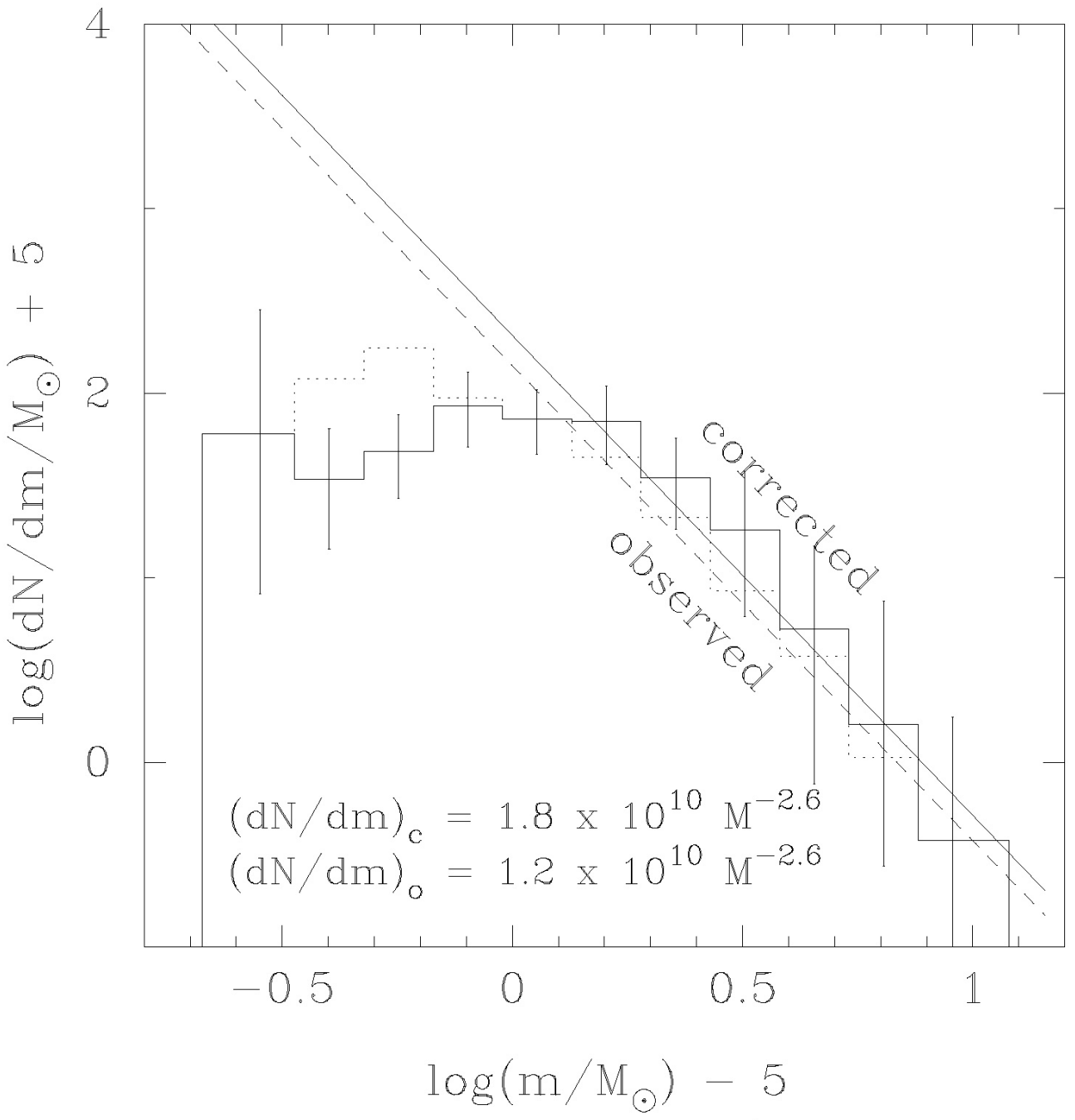




Engargiola et al. 2003
Rosokowsky et al. 2003

- **148 GMCs detected**
- **More than 2/3 of the GMCs have associated HII regions**
- **Steep index for mass spectrum ~ -2.6**




4
2
0
log(dN/dm/M⊙) + 5
corrected
observed
(dN/dm)c = 1.8 x 10^10 M^−2.6
(dN/dm)o = 1.2 x 10^10 M^−2.6
−0.5
0
0.5
1
log(m/M⊙) − 5

SEST observations for the LMC

Collaborators

L.E.B. Johansson, S. Nikolic, R.S. Booth, L.A. Nyman (OSO)

SEST 15 m

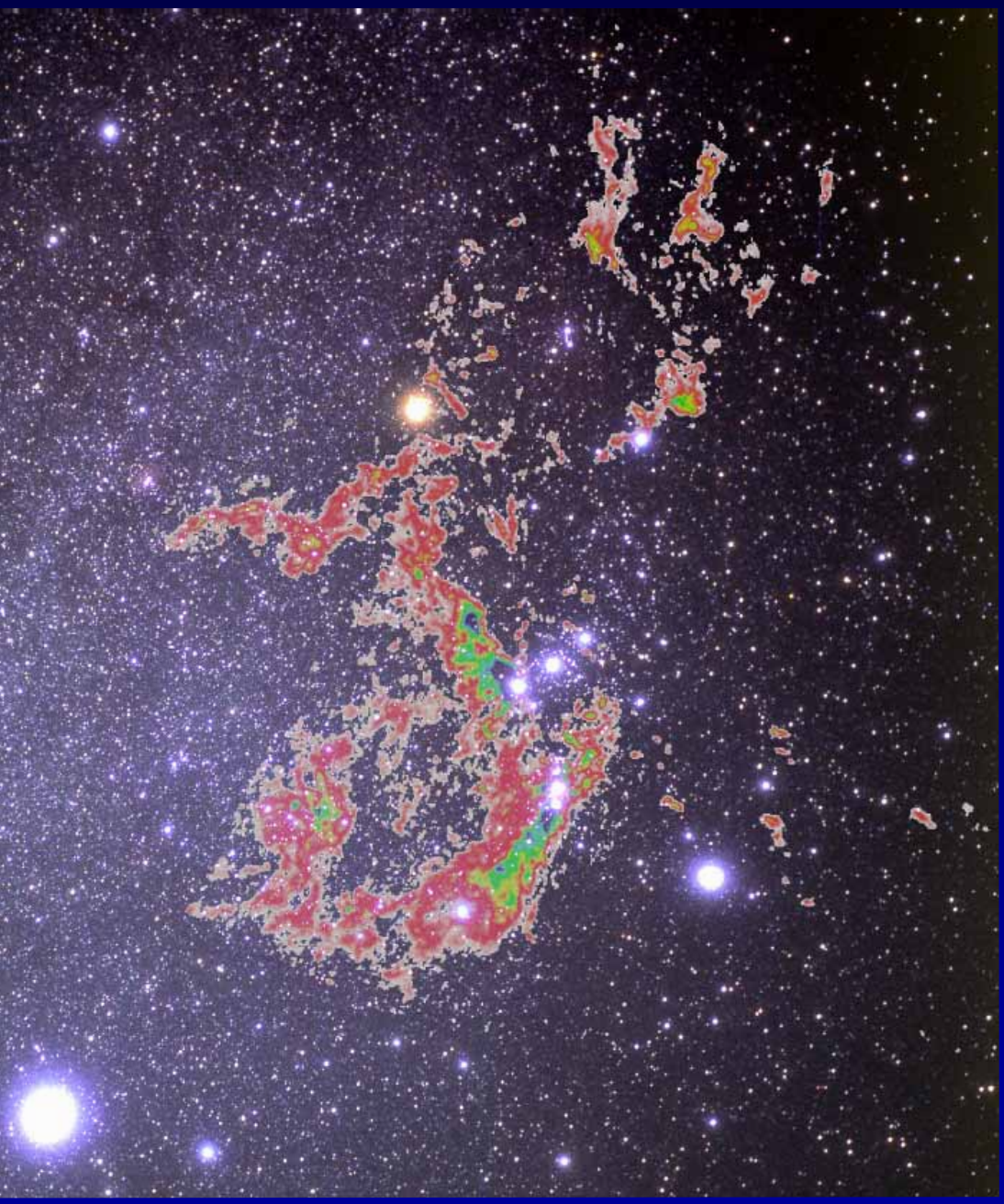
Beam size

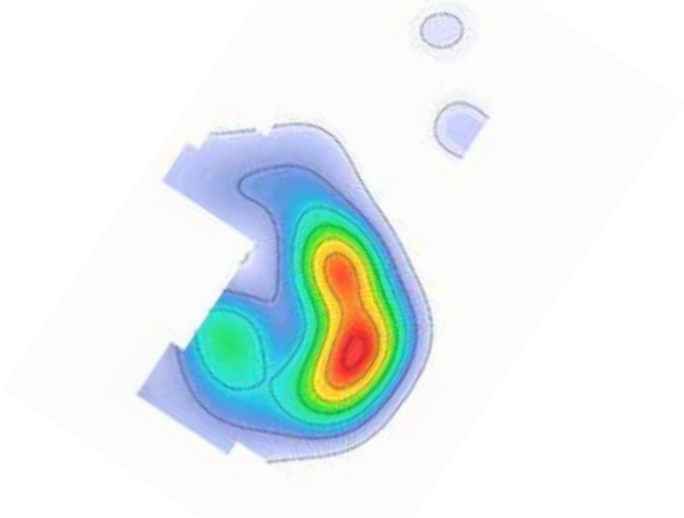
45" (10 pc) (115 GHz)
23" (5 pc) (230 GHz)

Mapping ^{12}CO (*J*=1-0/2-1)

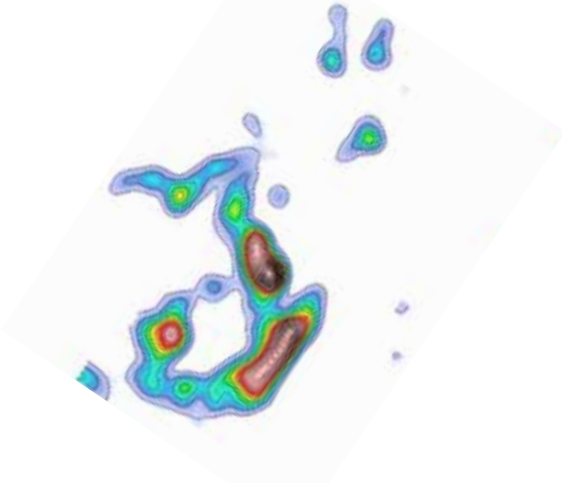
grid 40 " (cloud)
20 " (peak)

^{13}CO (*J*=1-0/2-1), C^{18}O(2-1), HCO^{+}, HCN, HNC, CS





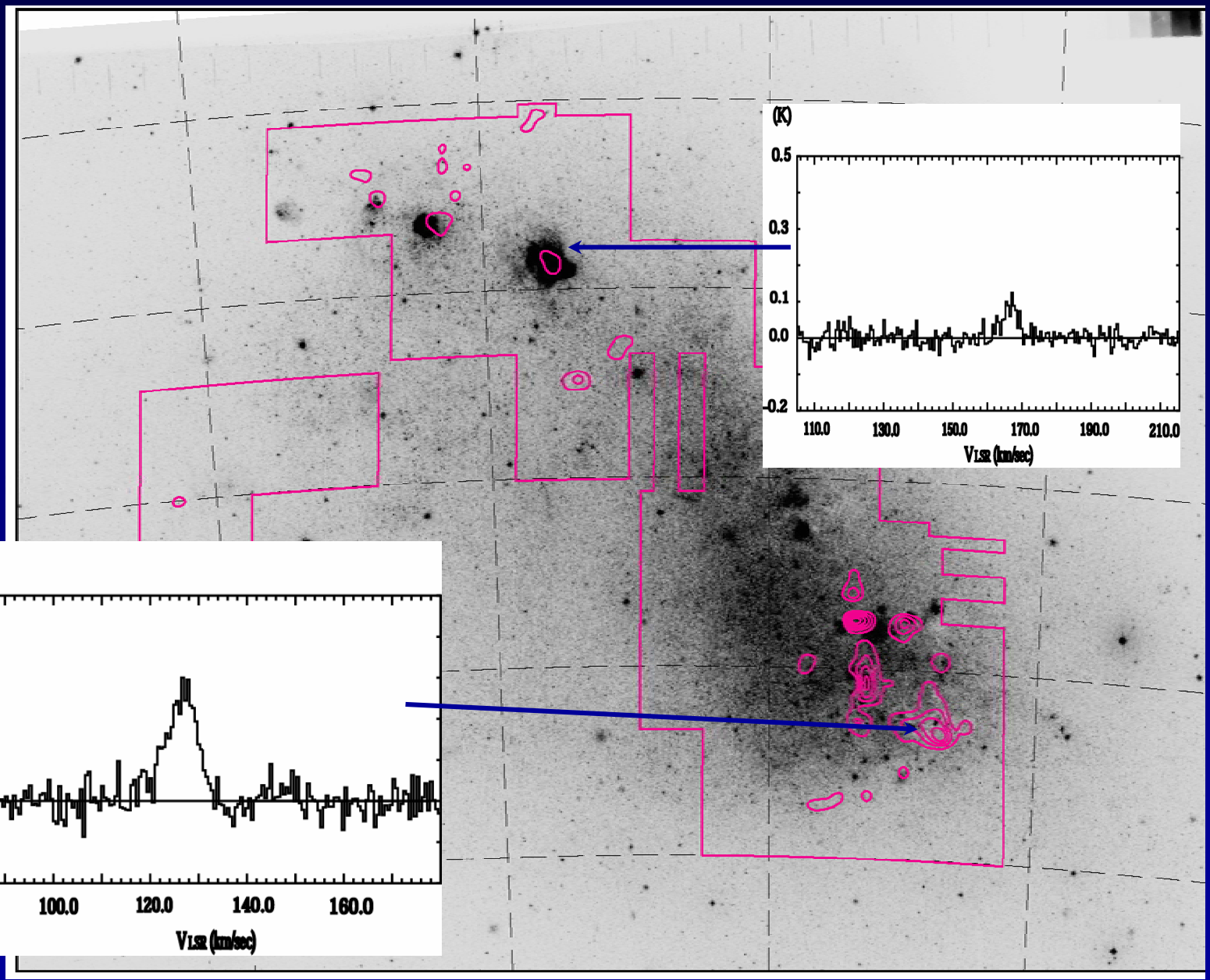
NANTEN (40 pc)



SEST (10 pc)

NANTEN results of the SMC

Mizuno et al. 2001

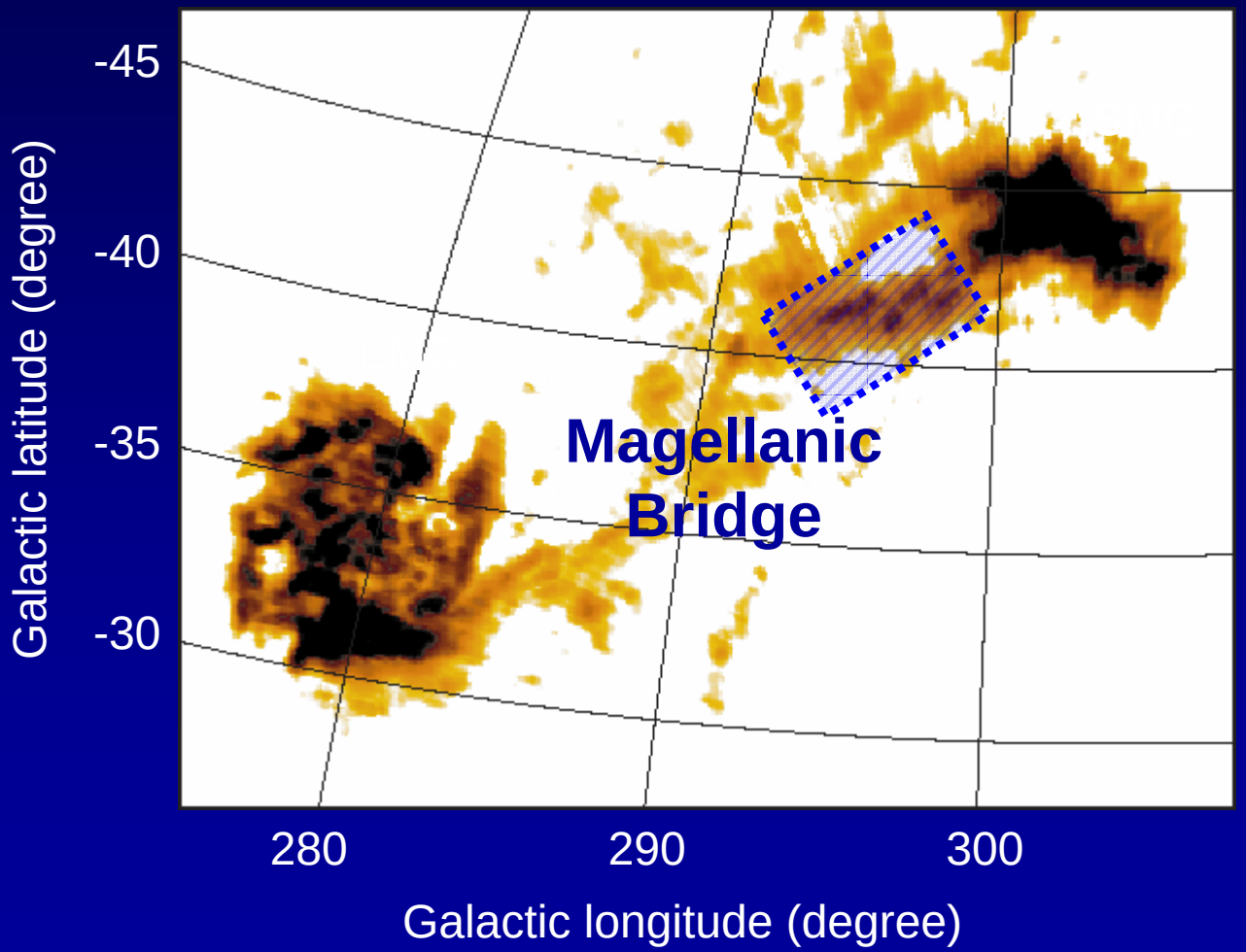


Search for CO in the Magellanic Bridge

Putman et al. 1998

マゼラニック・ブリッジ　~環境~

中性水素ガス（HI）で見たマゼラン銀河 (Putman et al.1998)



ブリッジ

質量は10^8太陽質量
Putman et al.（1998）

内部に星が存在している
Irwin et al.（1985）
Grondin et al.（1990）

分子雲中での
星形成？？？

観測諸元

名古屋大学「なんてん」電波望遠鏡

(@チリ・ラスカンパナス天文台)

口径：4m

観測ライン：^{12}CO(J=1-0)

周波数：115GHz

ビームサイズ：2'.6

⇒50pc@60kpc

システム雑音温度：220K

速度分解能：0.1km/s

rms:0.009K@0.1km/s

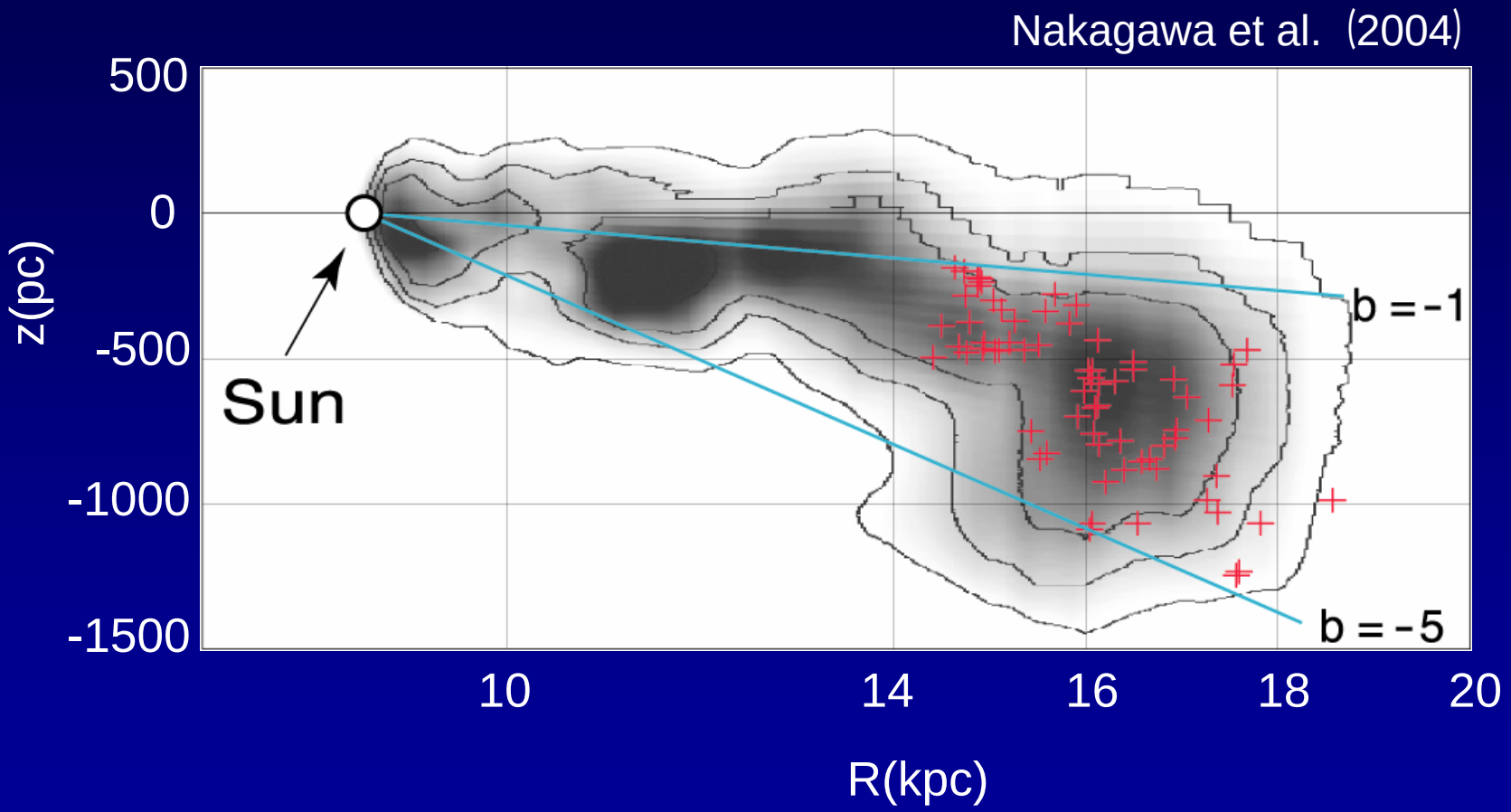
積分時間：約8時間/1点

観測時間：約20時間/1点

観測期間：

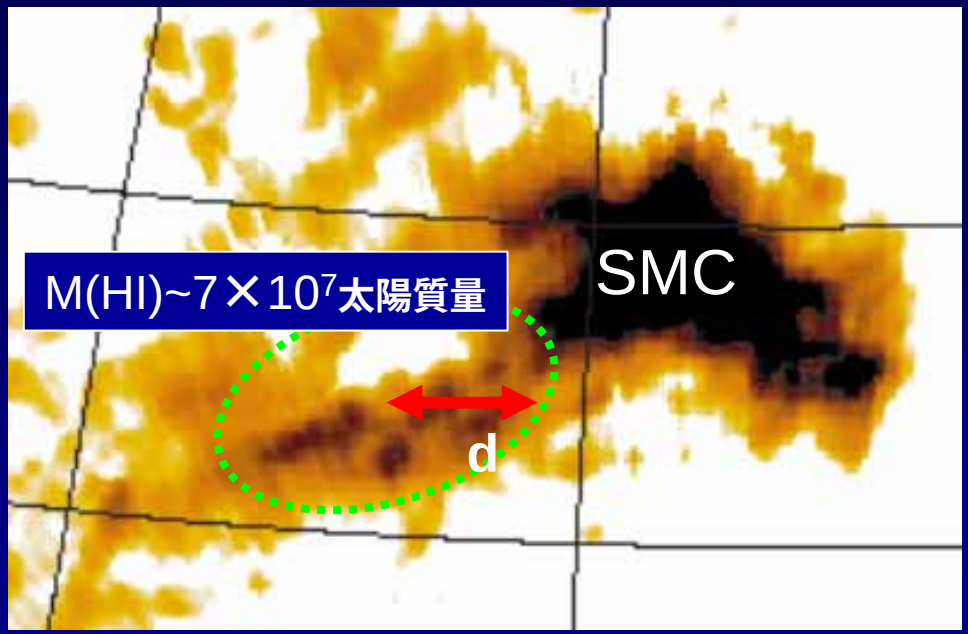
2002/10〜2003/7

Galactic Warp



銀河系の中では重力場が弱く、重元素量が低い

考察



Putman et al. (1998)

$$(\Delta V)^2 \approx \frac{GM_{total}}{d}$$

ΔV~15km/s、d~2kpc ⇒M(total)〜10^8**太陽質量**

Sub-millimeter observations of the Magellanic Clouds

- **Structure and evolution of GMCs in the metal poor environment**
  - CI observations
  - Comparison with the galactic GMCs
- **Reveal the properties (density, temperature, size) of dense clumps in the GMCs**
  - CO (J=7-6, 4-3, 3-2)

NANTEN2
ASTE

これからのマゼラン雲観測

- **高分解能観測**
  - 0.1 arcsec = 0.024pc
  - **銀河系内のGMCとの比較が可能**
  - 0.01arcsec**の分解能なら**Proto-cluster**形成の現場が見える。**
- YSOs**の探査**
  - **現状は極めて貧弱**
  - IRSF/SIRIUS, ASTRO-F, Spitzer

NANTEN→NANTEN2

- Large scale survey of interstellar gas
  in the Galaxy and Magellanic Clouds
  in CI ($^3P_1$- $^3P_0$), CI ($^3P_2$- $^3P_1$)
  and CO (J= 2-1, 3-2, 4-3, 7-6)
- Move NANTEN telescope to Atacama, Chile
  Alt. 4,800m starting from November 2003
- Replace the main-ref for higher-freq. operation
- Enclosed in a Dome

Summary

1. Giant molecular clouds in the Magellanic Clouds are similar to our own in mass etc., except for the apparent CO depletion.
2. The mass spectrum of GMCs in the LMC is steeper than that of the galactic disk.
3. Very young clusters have been identified by comparing with CO. The SFE is likely around several to a few %.
4. Starless GMCs have been identified.
5. Formation of stellar clusters is very rapid, and they are efficient in dissipating the parent molecular clouds.
6. CO was detected in the Magellanic Bridge.
7. CI observation has been started with ASTE.