Investigating AGN Black Hole Masses and the M_{BH}-σ_e relation for Low Surface Brightness Galaxies

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ABSTRACT

We present an analysis of the optical nuclear spectra from the active g
nuclei (AGN) in a sample of low surface brightness (LSB) galaxies. Using dat
the Sloan Digital Sky Survey (SDSS), we derived the virial black hole (BH)
of 24 galaxies from their broad Hα parameters. We find that our estimates of
BH masses lie in the range $10^5 - 10^7$ $M_\odot$, with a median mass of 5.62 x 10^6 M
bulge stellar velocity dispersion σ_e was determined from the underlying stellar s
We compared our results with the existing BH mass - velocity dispersion (M_{B}
correlations and found that the majority of our sample lie in the low BH mass
and below the $M_{BH} - \sigma_e$ correlation. We analysed the effects of any systematic
the M_{BH} estimates, the effects of galaxy orientation in the measurement of σ_e
increase of σ_e due to the presence of bars and found that these effects are insu
to explain the observed offset in M_{BH} - σ_e correlation. Thus the LSB galaxi
to have low mass BHs which probably are not in co-evolution with the host
bulges. A detailed study of the nature of the bulges and the role of dark ma
the growth of the BHs is needed to further understand the BH-bulge co-evolu
these poorly evolved and dark matter dominated systems.

Although we do not generally see AGN in LSB galaxies, a significant fraction of bulge dominated GLSB galaxies do show AGN activity (Sprayberry et al.1995; Galaz et al. 2011). Some of them are even radio bright and visible in X-rays .

Morelli et al. (2012) found that the stellar populations in the bulges of LSB galaxies have similar properties as that of the bulges of normal galaxies. They concluded that the formation and evolution history of bulges in LSB galaxies are similar to that of the bulges in normal galaxies.

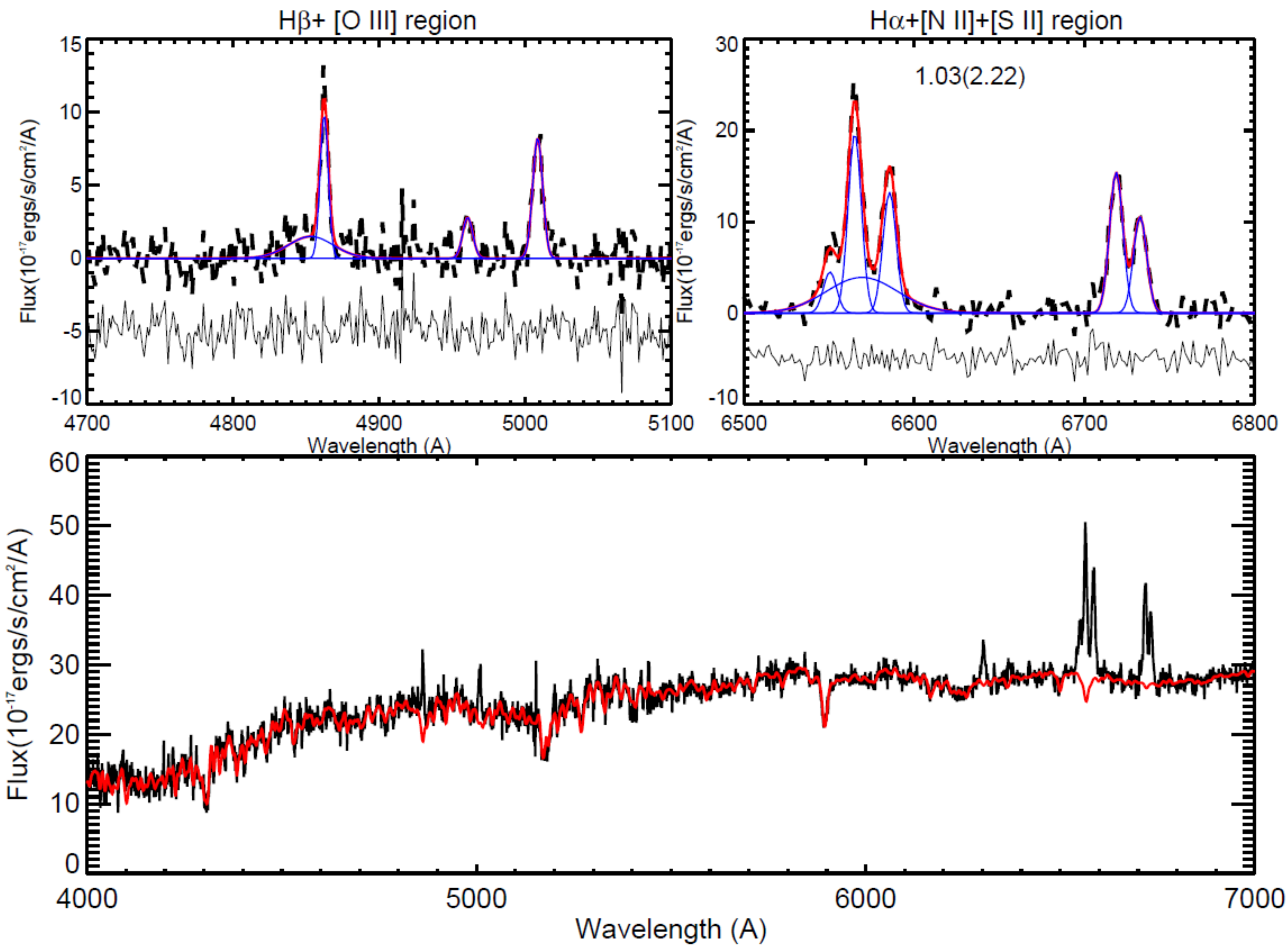

Figure 2. The bottom panel shows the pPXF fit for the galaxy, Malin 1 (identification number 13). The black line is the observed spectrum and the red line is the best fit optimal template for the underlying stellar population. The Gaussian fits to the different

- In this paper, we present a detailed analysis of 24 bulge-dominated LSB galaxies with signatures of type - I AGN (broad Hα component) identified from a large sample of 558 LSB galaxies to understand the AGN activity and to estimate the mass of the BHs present in their centers.
- The Sloan Digital Sky Survey (SDSS) Data Release 10 .

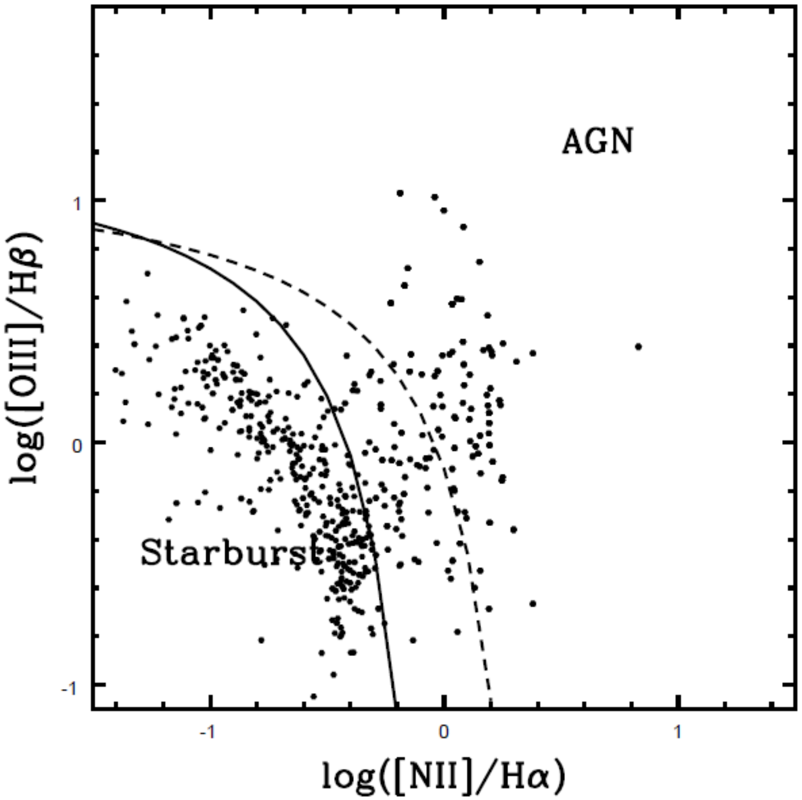

Figure 1. The BPT AGN diagnostic diagram,[OIII]/Hβ versus [NII]/Hα for the sample of 558 galaxies. The emission line fluxes for these sample galaxies are taken from the SDSS database. The

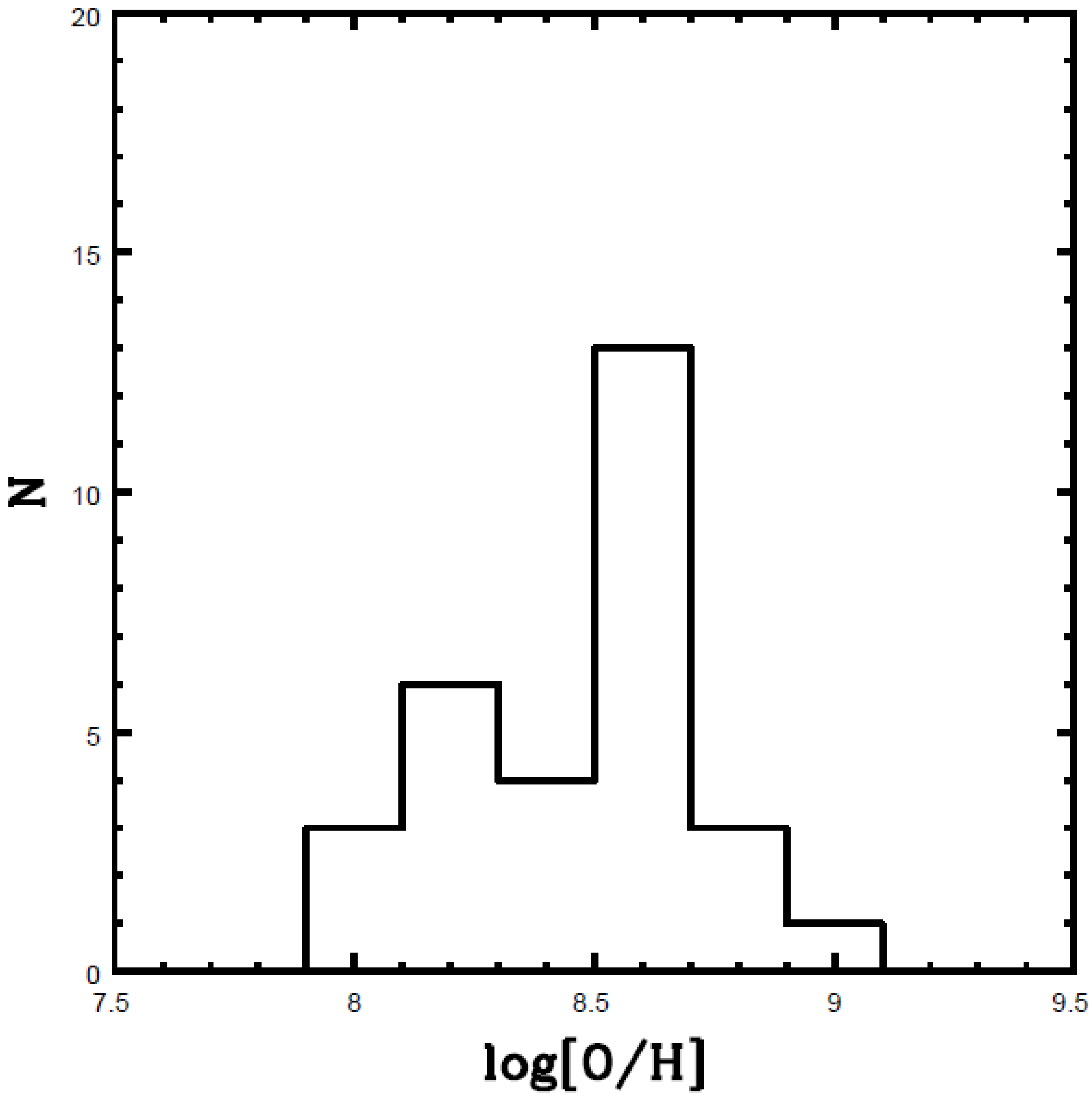

Figure 6. The gas phase metallicity distribution of 30 LSB galaxies.

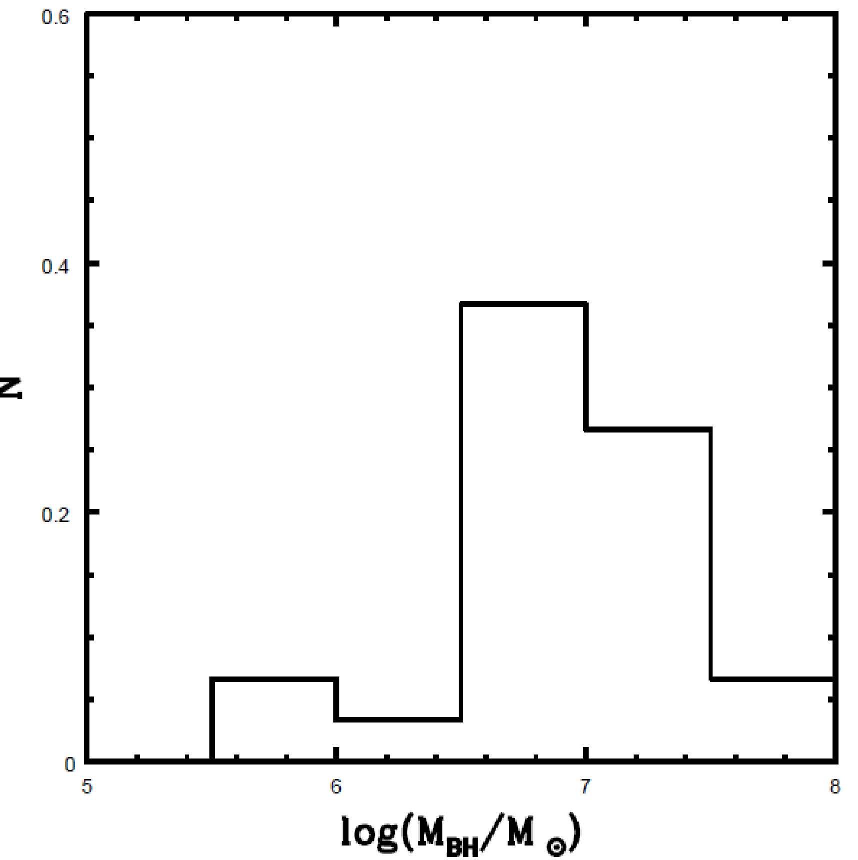

Figure 7. The M_{BH} distribution of 24 broad line AGN candidate LSB galaxies.

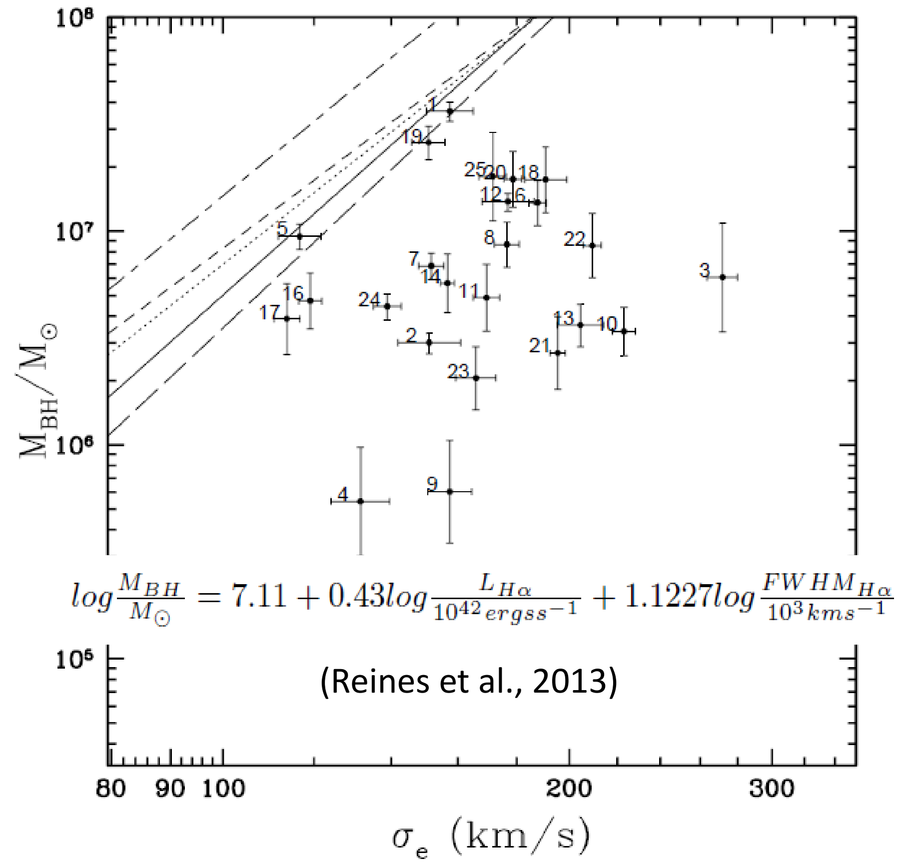

Figure 8. The M-σ_e plot with broad line AGN candidates. The linear regression lines given by (Tremaine et al. 2002), (Ferrarese & Merritt 2000), (Gültekin et al. 2009), (Kormendy & Ho 2013) relation for classical bulges/elliptical galaxies and (McConnell & Ma 2013) relation for late type galaxies (dashed, solid, dotted short-long dashed and long-dashed lines, respectively) for M_{BH} against σ_e are also shown.

tained the FWHM. The FWHM of Hα absorption line in our sample galaxies is less than 600 kms^{-1}, which is one of the criteria to identify the broad Hα component. For all our sam-

Основные выводы

- Большинство найденных LSB-галактик с активным ядром лежит ниже последовательности M_{bh}-σ_e для нормальных спиралей. При этом в большинстве случаев балджи – классические (индекс Серсика 2. 5)

Следовательно, в LSB- галактиках балджи и SMBHs развиваются независимо.

- The isolated and poorly evolved LSB galaxies are

good candidates to understand the evolution of heavy seed BHs.

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THE RELATIONSHIP BETWEEN MOLECULAR GAS, H I, AND STAR FORMATION IN THE LOW-MASS, LOW-METALLICITY MAGELLANIC CLOUDS

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ABSTRACT

The Magellanic Clouds provide the only laboratory to study the effect of metallicity and galaxy mass on molecular gas and star formation at high (~ 20 pc) resolution. We use the dust emission from HERITAGE *Herschel* data to map the molecular gas in the Magellanic Clouds, avoiding the known biases of CO emission as a tracer of H_2. Using our dust-based molecular gas estimates, we find molecular gas depletion times ($\tau_{\rm dep}^{\rm mol}$) of ~ 0.4 Gyr in the LMC and ~ 0.6 SMC at 1 kpc scales. These depletion times fall within the range found for normal disk galaxies, but are shorter than the average value, which could be due to recent bursts in star formation. We find no evidence for a strong intrinsic dependence of the molecular gas depletion time on metallicity. We study the relationship between gas and star formation rate across a range in size scales from 20 pc to ≥ 1 kpc, including how the scatter in $\tau_{\rm dep}^{\rm mol}$ changes with size scale, and discuss the physical mechanisms driving the relationships. We compare the metallicity-dependent star formation models of Ostriker et al. (2010) and Krumholz (2013) to our observations and find that they both predict the trend in the data, suggesting that the inclusion of a diffuse neutral medium is important at lower metallicity, but do not capture the full extent of the scatter in the relationship between gas and star formation.

Subject headings: galaxies: dwarf – galaxies: evolution – ISM: clouds – Magellanic Clouds

1. INTRODUCTION

Star formation plays a critical role in shaping how galaxies form and evolve. Understanding the molecular gas content of low-mass, low-metallicity galaxies and its relationship to the star formation rate is necessary to understand how the gas mass fractions evolve with redshift (e.g., Tacconi et al. 2010; Genzel et al. 2012) and how the star formation efficiency depends on galaxy mass and metallicity (e.g., Bolatto et al. 2011; Saintonge et al. 2011; Krumholz et al. 2011). Both are critical to understanding the "galaxy mass function" and drivers of the star formation history of the universe.

Our current knowledge of the extragalactic relationship between gas and star formation comes from studies of mostly high-metallicity, high-mass nearby galaxies that use ^{12}CO to trace the molecular gas. The original work to quantitatively compare the star formation rate to the gas density by Schmidt (1959) found a power law relationship, generally referred to as the "star formation law." More recent studies of the extragalactic star for-

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- Most of the resolved data for samples of galaxies achieve resolutions of several hundred parsecs to 1 kpc (Bigiel et al. 2008; Leroy et al. 2008; Bigiel et al. 2011; Rahman et al. 2012; Leroy et al.2013a) and all find similar values for the average molecular gas depletion time of τ_{moldep} ~2 Gyr. The weak dependence of $\tau_{mol\ dep}$ on the galactic properties and environment (Leroy et al. 2013a) suggests that star formation is a local process based on the conditions within giant molecular clouds (GMCs).
- Справедливо ли это для небольших галактик, бедных H2?

- БМО-ММО: масса молекулярного газа – через количество пыли по HERSHEL (в галактике много CO-silent газа).
- Наблюдения:

Clouds key project (HERITAGE; Meixner et al.2013). HERITAGE mapped both LMC and SMC at 100,

160, 250, 350, and 500 μm with the Spectral and Photometric Imaging Receiver (SPIRE) and Photodetector Array Camera and Spectrometer (PACS) instruments.

- Масса газа – по оптической толщине на 160 мкм (через спектр и интенсивность), калибровка – по HI.

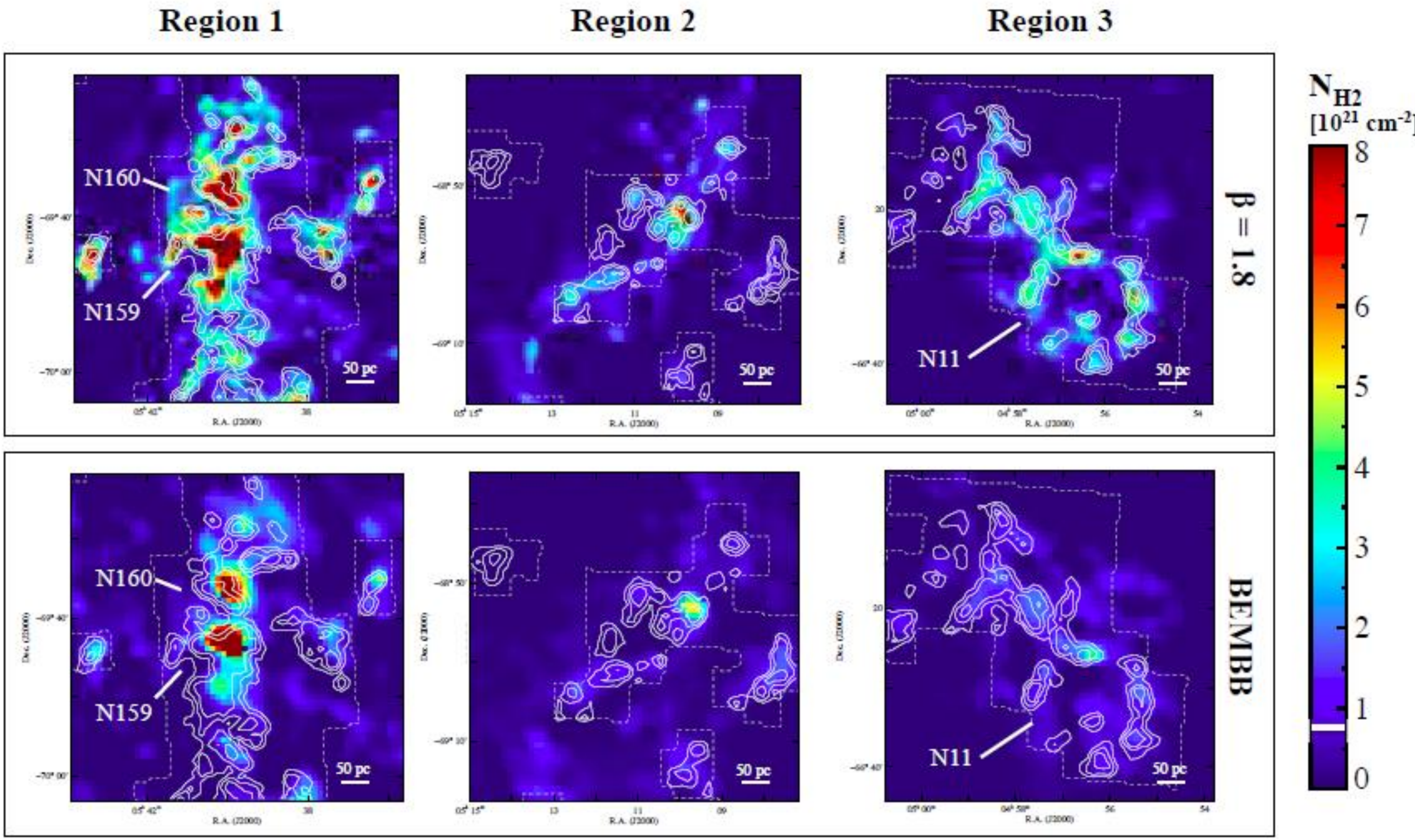


FIG. 3.— The top and bottom rows of images respectively show the enlarged regions of the N_{mol} maps (identified in Figure 2) for the dust modeling with $\beta = 1.8$ and the BEMBB model from Gordon et al. (2014) at the same color scale as show in Figure 2. The contours show the MAGMA ^{12}CO intensity at levels of 0.6 (3σ), 2, and 5 K km s^{-1} with the dashed grey line showing the survey coverage in the regions.

Зеленые крестики – по CO-линии с галактическим фактором конверсии
Звездочки – разрешение 1 кпк, серые точки – п200 пк, коричневый цвет – 200 пк.

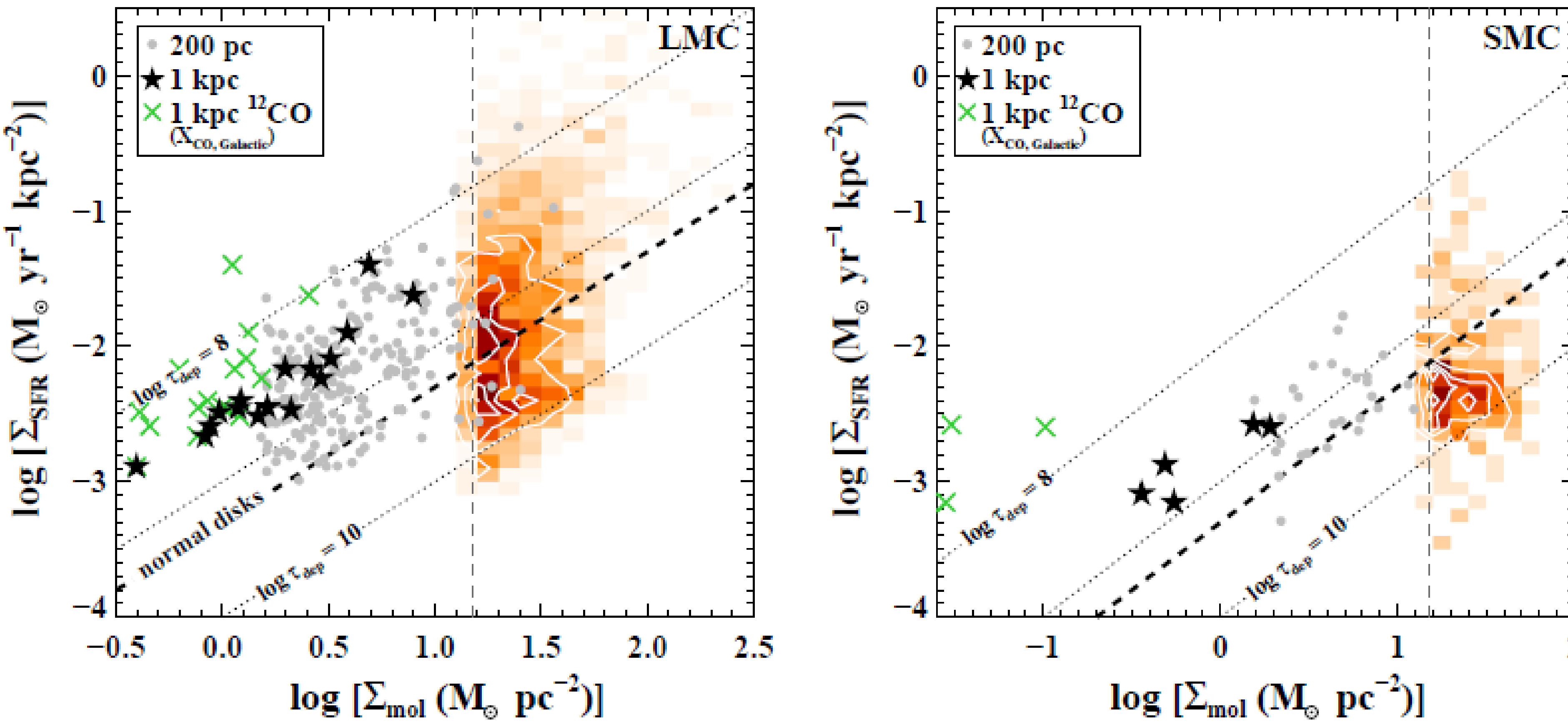


Fig. 4.— Σ_{SFR} as a function of Σ_{mol} for the LMC (left) and SMC (right) at various resolutions. The red color scale show
wo-dimensional distribution at a resolution of $r = 20$ pc with the white contours indicate levels that are 20%, 40%, 60%, and
f the maximum density of points. The vertical gray dashed line indicates the estimated 2σ sensitivity cut of the $r = 20$ pc
$\Sigma_{mol} \sim 15\ M_{\odot}\ pc^{-2}$). The grey circles and black stars show the data at resolutions $r = 200$ pc and $r = 1$ kpc, respectively. The
tars show Σ_{mol} derived from NANTEN CO data at a resolute of $r = 1$ kpc using a Galactic CO-to-H_2 conversion factor. Here we p

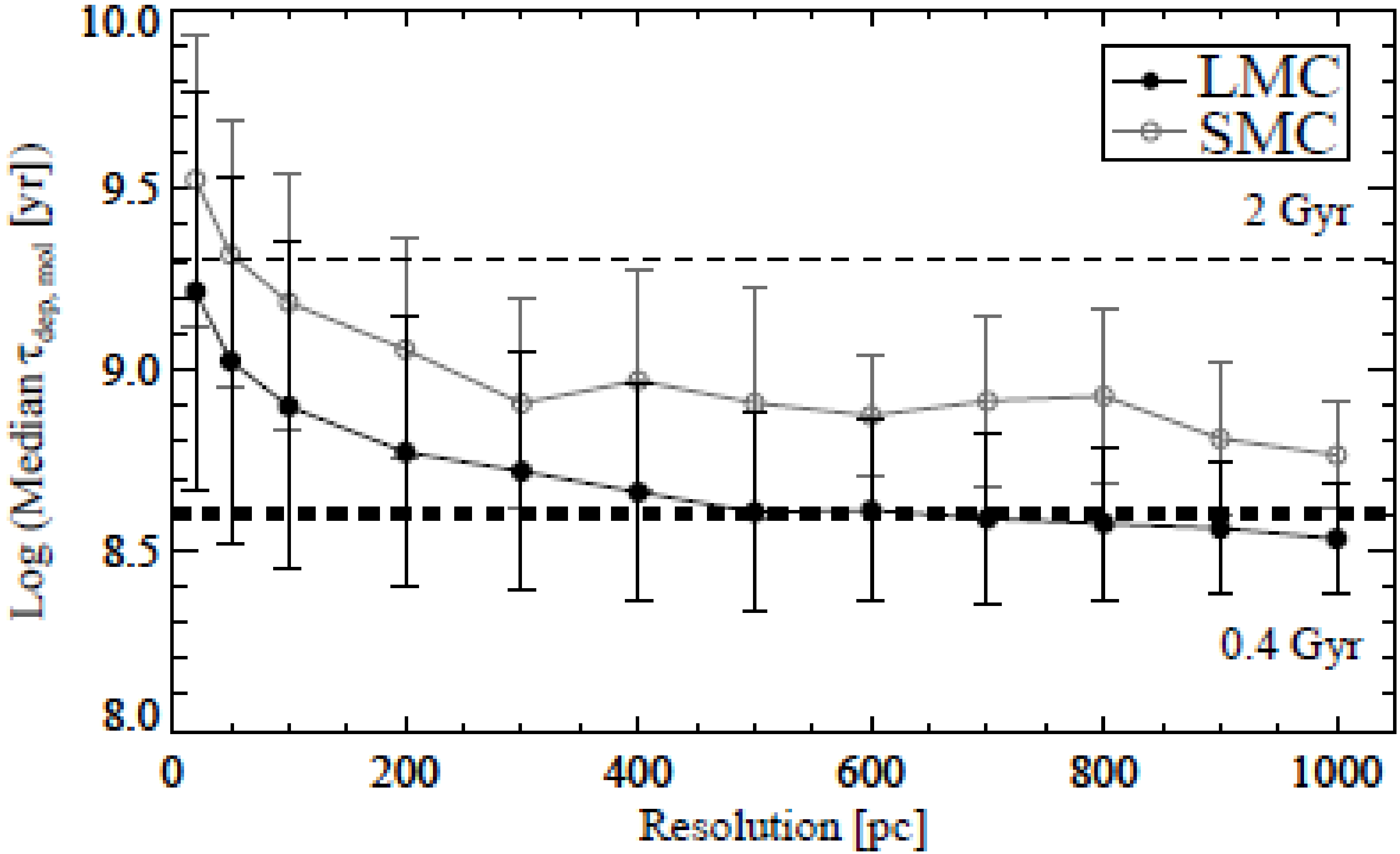


FIG. 6.— Median molecular gas depletion time as a function of resolution. Black filled and open grey circles show the data for the LMC and SMC, respectively. The error bars show 1σ on the mean. The upper dashed line shows $\tau_{\rm dep}^{\rm mol} = 2$ Gyr, the average for normal galaxies, and the lower dashed line shows $\tau_{\rm dep}^{\rm mol} = 0.4$

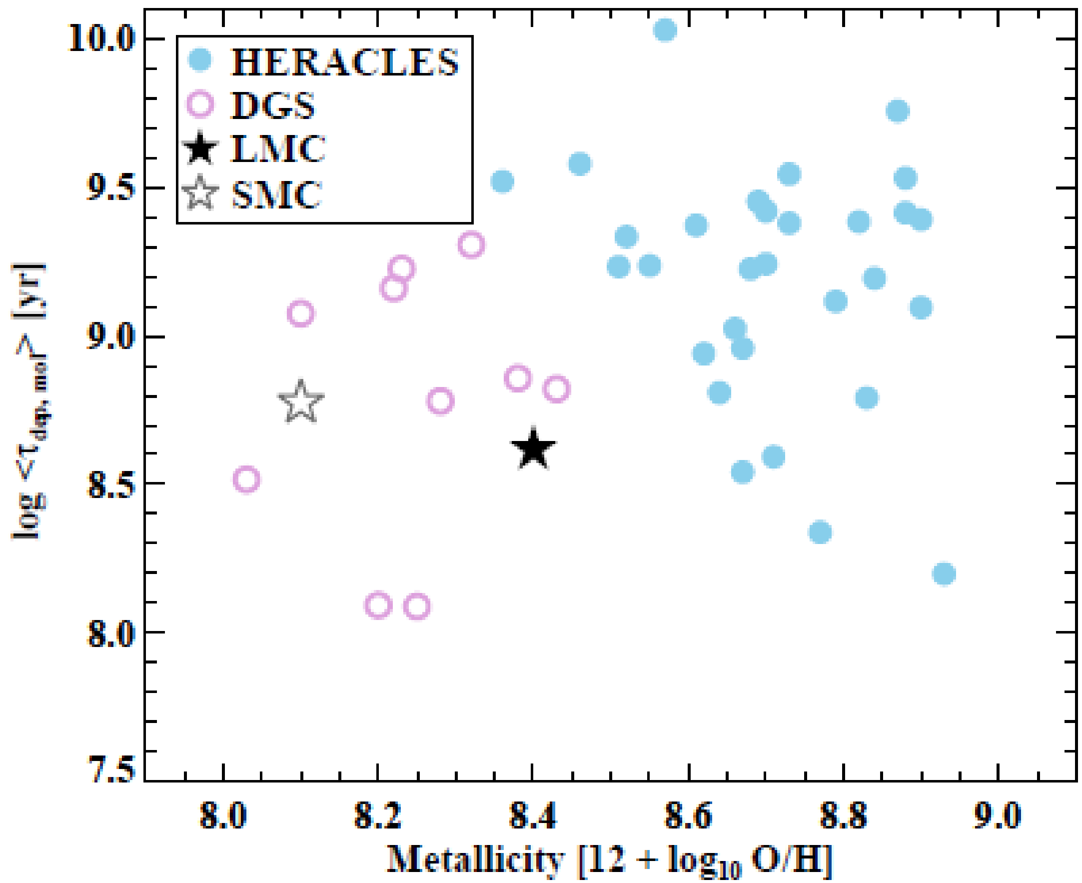
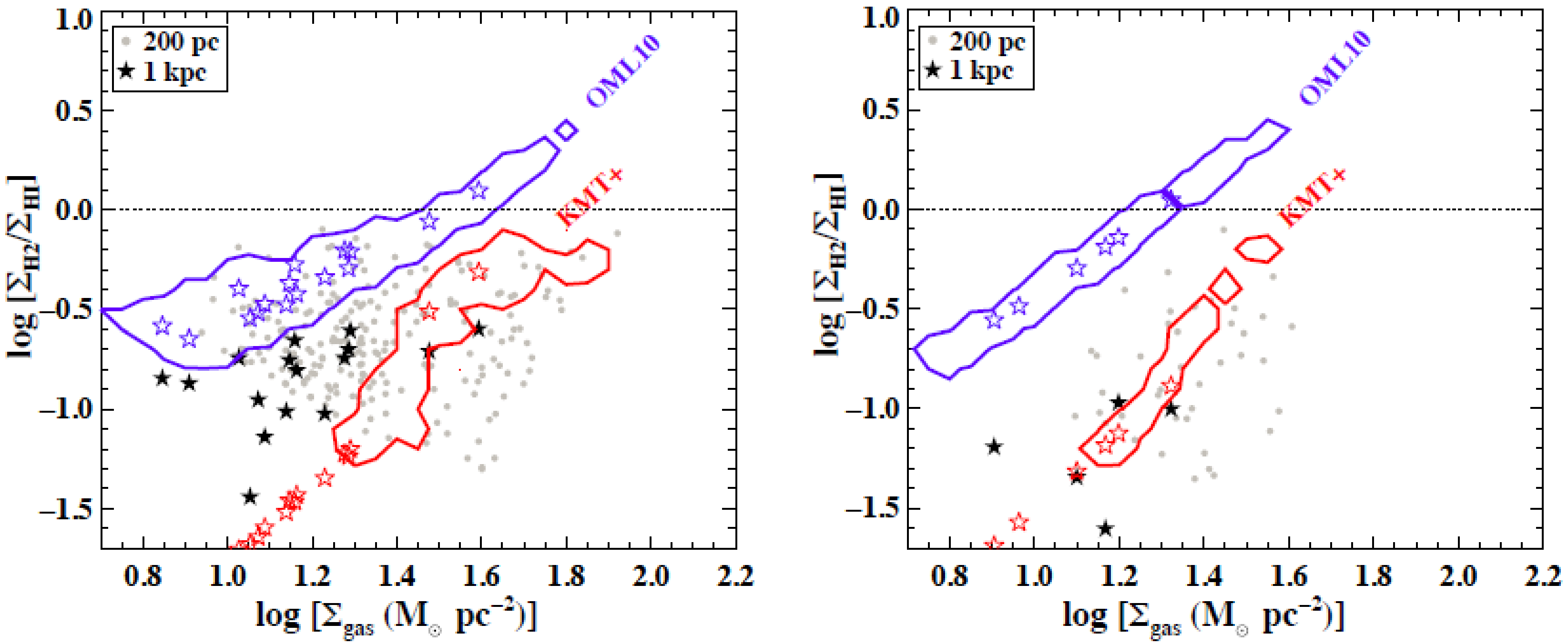


FIG. 8.— The galaxy-averaged molecular gas depletion time ($< \Sigma_{\rm mol} > / < \Sigma_{\rm SFR} >$) with metallicity for the HERACLES sample (light blue points), LMC (black filled stars), and SMC (grey open stars). We have taken the average $\Sigma_{\rm mol}$ and $\Sigma_{\rm SFR}$ of the 1 kpc LMC and SMC data, which are comparable measurements to the ~ 1 kpc resolution HERACLES data. We also include the integrated molecular gas depletion times ($M({\rm H_2})/SFR$) from the Dwarf Galaxy Survey (DGS) using a metallicity dependent CO-to-H_2 conversion factor from Cormier et al. (2014). While there is a large amount of scatter, there does not appear to be any trend with metallicity.



- Сравнение с теоретическими моделями (для заданной металличности и полной массы газа)
- OML 10= Ostriker, E. C., McKee, C. F., & Leroy, A. K. 2010
- KMT = Krumholz et al., 2009

Самые важные выводы

- Время исчерпания газа на масштабе 1 кпс ниже, чем для спиралей (0.4Gyr-LMC, 0.6Gyr-SMC). Нет явной свя зи с металличностью. Возможно – отражение недавнего всплеска SFR.
- Сравнение SFR-Mgas с теоретическими моделями – неважное, особенно в области низких масс газа