MOLECULAR GAS OF THE MOST MASSIVE SPIRAL GALAXIES I: A CASE STUDY OF NGC 5908

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ABSTRACT

We present IRAM 30m observations of molecular lines of CO and its isotopologues from the massive spiral galaxy NGC 5908 selected from the CGM-MASS sample. ^{12}CO $J = 1-0$, ^{12}CO $J = 2-1$, and ^{13}CO $J = 1-0$ lines have been detected in most of the positions along the galactic disk. The total molecular gas mass of NGC 5908 is $\sim 7\times10^9$ M$_\odot$ and the total cool gas mass adding atomic hydrogen is $\sim 1.3\times10^{10}$ M$_\odot$, comparable to the upper limit of the mass of the X-ray emitting hot gas in the halo. Modeling the rotation curves constructed with all three CO lines indicates that NGC 5908 has a dark matter halo mass of $M_{\rm vir} \sim 10^{13}$ M$_\odot$, putting it among the most massive isolated spiral galaxies. The ^{12}CO/^{13}CO $J = 1-0$, ^{12}CO $J = 2-1/J = 1-0$ line ratios and the estimated molecular gas temperature all indicate normal but non-negligible star formation in this fairly gas-rich massive isolated spiral galaxy, consistent with the measured star formation intensity and surface densities. The galaxy is probably at an early evolutionary stage after a fast growth stage with mergers and/or starbursts, with plenty of leftover cool gas, relatively high SFR, low hot CGM cooling rate, and low X-ray emissivity.

Subject headings: galaxies: individual: NGC 5908 - (galaxies:) intergalactic medium - galaxies: ISM - galaxies: spiral - galaxies: star formation - ISM: molecules

1. INTRODUCTION

The evolution of an isolated spiral galaxy is regulated by the cooling and accretion of the circum-galactic medium (CGM), the condensation of the cool gas in the disk and the follow-up star formation, as well as the feedback of energy and metal-enriched material by young stars and supernovae (SNe) back into the interstellar medium (ISM) and the CGM. In these processes, molecular gas in the galactic disk acts as a link for gas cycling between the CGM (via cooling and accretion) and the star formation (by providing fuel) (e.g., Kennicutt & Evans 2012; Bolatto et al. 2013 and references therein). Therefore, measuring the overall content and spatial distribution of molecular gas in an isolated spiral galaxy plays a key role in understanding how it builds up the stellar content of the galaxy.

ated with the disk and bulge respectively, with the disk component typically younger and with higher metallicity (e.g., Cezario et al. 2013). This bimodality in the age and metallicity of GCs indicates that the major part of the disk of these galaxies may form after the merger and starburst stage when the galaxy swallowed most of the companions and became dominant in the dark matter halo. This scenario is further supported by the discovery of superluminous ($M_* = 0.3-3.4\times10^{11}$ M$_\odot$) spiral galaxies with active star formation (SFR $= 5-65$ M$_\odot$ yr^{-1}), diverse environments and merger stages at $z \sim 0.1-0.3$ (Ogle et al. 2016). These galaxies may be the progenitors of the local massive, isolated, quiescent spiral galaxies which represent the cleanest cases to witness the gentle growth of galactic disks without major merger and extensive star formation.

- Работа – в рамках проекта изучения нескольких (6) наиболее массивных галактик Circum-Galactic Medium of MASsive Spirals (CGM-MASS) с Vrot > 300 km/s.
- . All the CGM-MASS galaxies have diffuse X-ray emission from hot gas detected above the background extending ∼(30−100) kpc from the galactic center.

NGC 5908

- Необычная галактика очень большой массы. Изолированная (скорее, широкая пара).
- Связь SFR с оставшейся массой газа – информация к истории формирования балджа и диска.

- NGC5908 0.5-1.25 keV XMM-Newton
  - *Jiang-Tao Li et al., 2018*

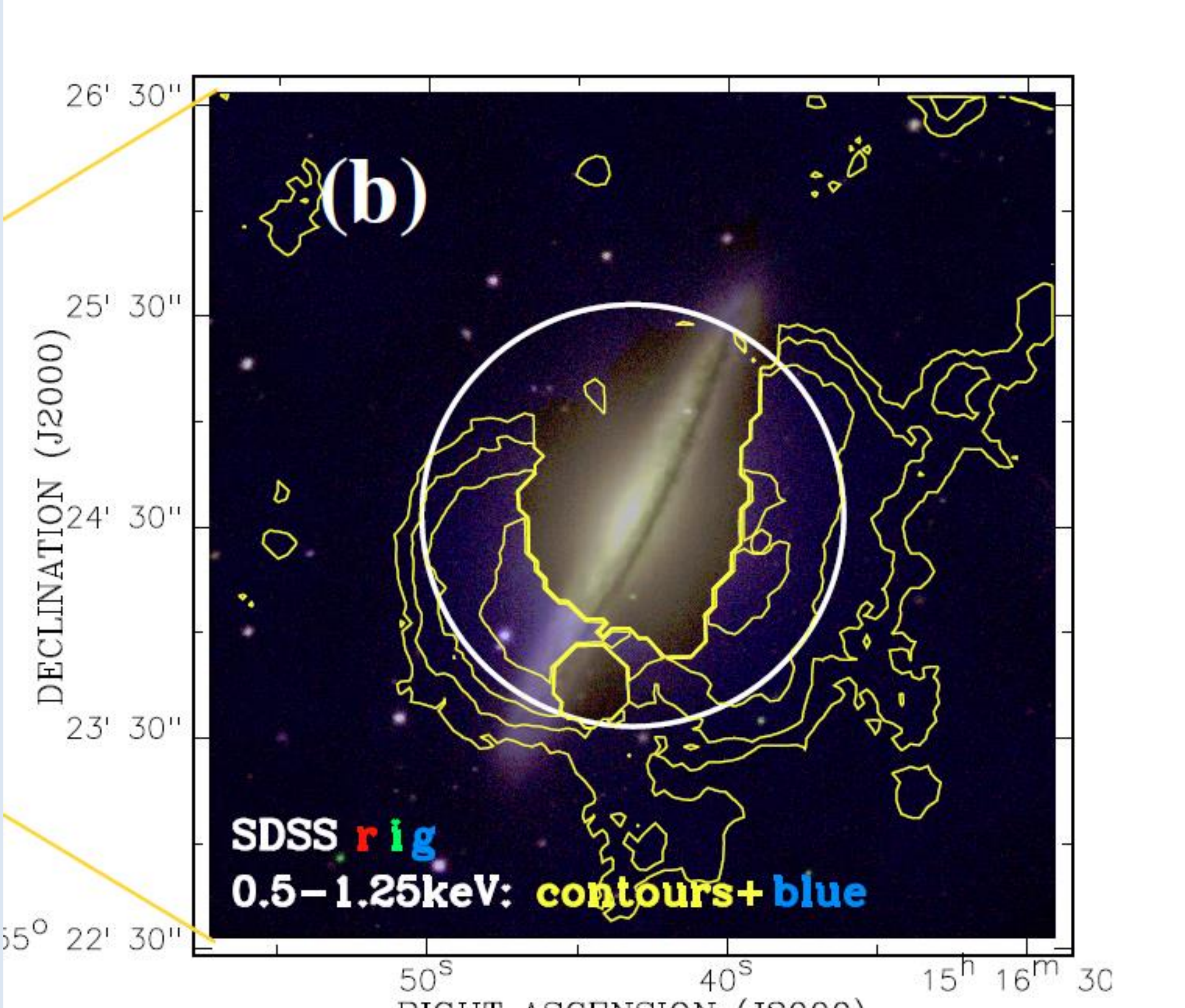

TABLE 1
PARAMETERS OF NGC 5908.

Parameters	Value
Type	SA(s)b
Distance	51.9 Mpc
redshift	0.011028
scale	$1'' = 0.252$ kpc
inclination	65.31°
$v_{\rm rot}$	347 km $\rm s^{-1}$
$M_{\rm HI}$	5.9×10^9 $\rm M_\odot$
M_*	$2.56^{+0.02}_{-0.15} \times 10^{11}$ $\rm M_\odot$
SFR	3.81 ± 0.09 $\rm M_\odot$ $\rm yr^{-1}$
M_{200}	8.1×10^{12} $\rm M_\odot$
r_{200}	417 kpc
kT	$0.38^{+0.64}_{-0.09}$ keV
$L_{\rm X,r<0.1r_{200}}$	$7.2^{+2.9}_{-2.3} \times 10^{39}$ ergs $\rm s^{-1}$
$r_{\rm cool}$	$13.9^{+4.9}_{-6.4}$ kpc
$\dot{M}_{\rm cool,r<r_{cool}}$	$0.37(< 1.55)$ $\rm M_\odot$ $\rm yr^{-1}$
$M_{\rm hot,r<r_{200}}$	$1.4^{+3.3}_{-0.6} \times 10^{10} f^{1/2}$ $\rm M_\odot$
$M_{\rm H_2,^{12}CO}$	$(8.3 \pm 0.4) \times 10^9$ $\rm M_\odot$
$M_{\rm H_2,^{13}CO}$	$(5.2 \pm 0.4) \times 10^9$ $\rm M_\odot$
$M_{\rm H_2,average}$	$(6.8 \pm 1.7) \times 10^9$ $\rm M_\odot$
$\mathcal{R}_{\frac{^{12}CO_{10}}{^{13}CO_{10}},{\rm median}}$	7.0 ± 1.7
$\mathcal{R}_{\frac{^{12}CO_{21}}{^{12}CO_{10}},{\rm median}}$	0.43 ± 0.11
$\tau_{\rm ^{13}CO,median}$	0.16 ± 0.03
$T_{\rm K,median}$	32 ± 9 K
$M_{\rm vir}$	$(1.4 \pm 0.1) \times 10^{12}$ $\rm M_\odot$
$\Sigma_{\rm H_2}$	5.4 ± 1.4 $\rm M_\odot$ $\rm pc^{-2}$
$\Sigma_{\rm H_2+HI}$	10.1 ± 1.4 $\rm M_\odot$ $\rm pc^{-2}$

- Наблюдения: IRAM 30m, 8 положений.
- ^{12}CO J = 1−0, ^{12}CO J = 2−1, and ^{13}CO J = 1 − 0 lines.

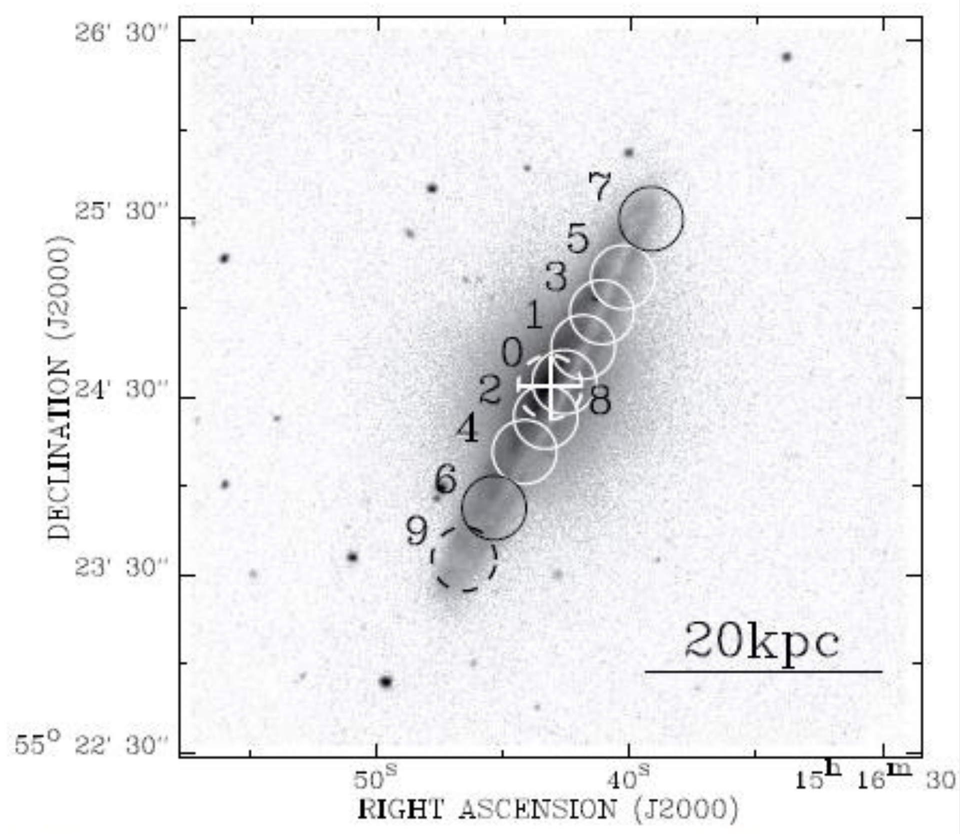

FIG. 1.— SDSS r-band image of the central 4′ × 4′ region of NGC 5908. The circles are the location of the IRAM 30m beams with the size indicating the beam size at ^{12}CO $J = 1-0$ band. The black solid circles have twice the exposure time as the white solid

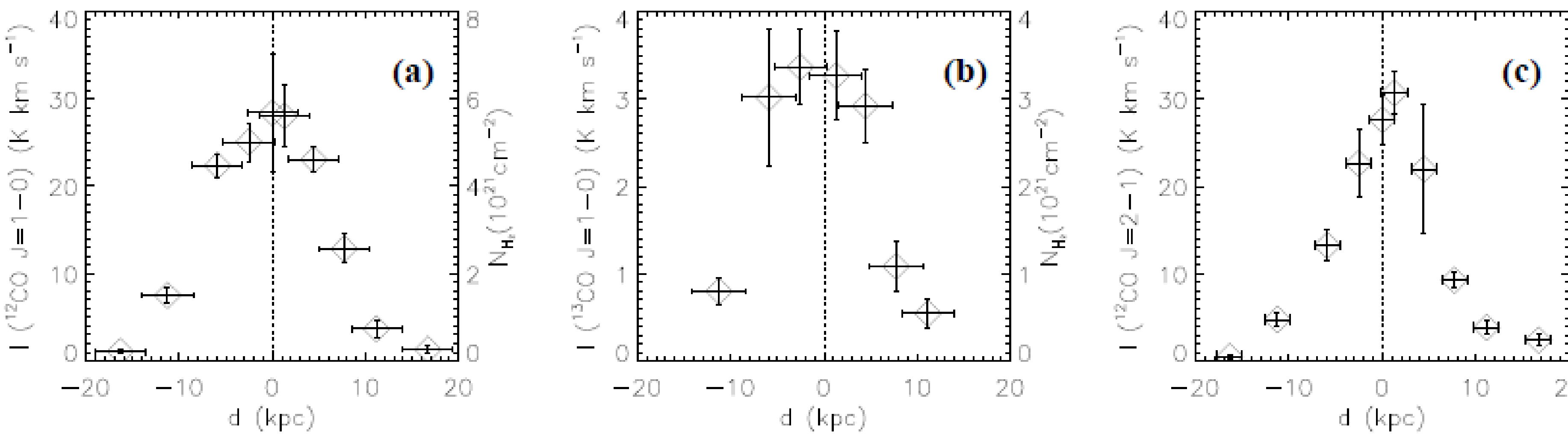

FIG. 2.— The main beam and forward efficiency corrected integrated line intensity of ^{12}CO $J = 1-0$ (a), ^{13}CO $J = 1-0$ (b), and ^{12}CO $J = 2-1$ (c) along the galactic disk. The x-axis is the distance along the galactic plane from the galactic center. The vertical line in each panel marks the location of the galactic center. We also convert the ^{12}CO $J = 1-0$ and ^{13}CO $J = 1-0$ intensity to the molecular gas column density $N_{\mathrm{H_2}}$ in (a) and (b).

Чем определяется отношение линий 12CO/13CO?

- Оптическая толщина газа (зависит от плотности газа, для DIG отношение выше).
- Соотношение обилий этих молекул (выше в более теплом газа) В starburst galaxies отношение выше.
- Отношение R =^{12}CO(2-1)/^{12}CO(1-0) зависит от температуры и структуры молекулярных облаков

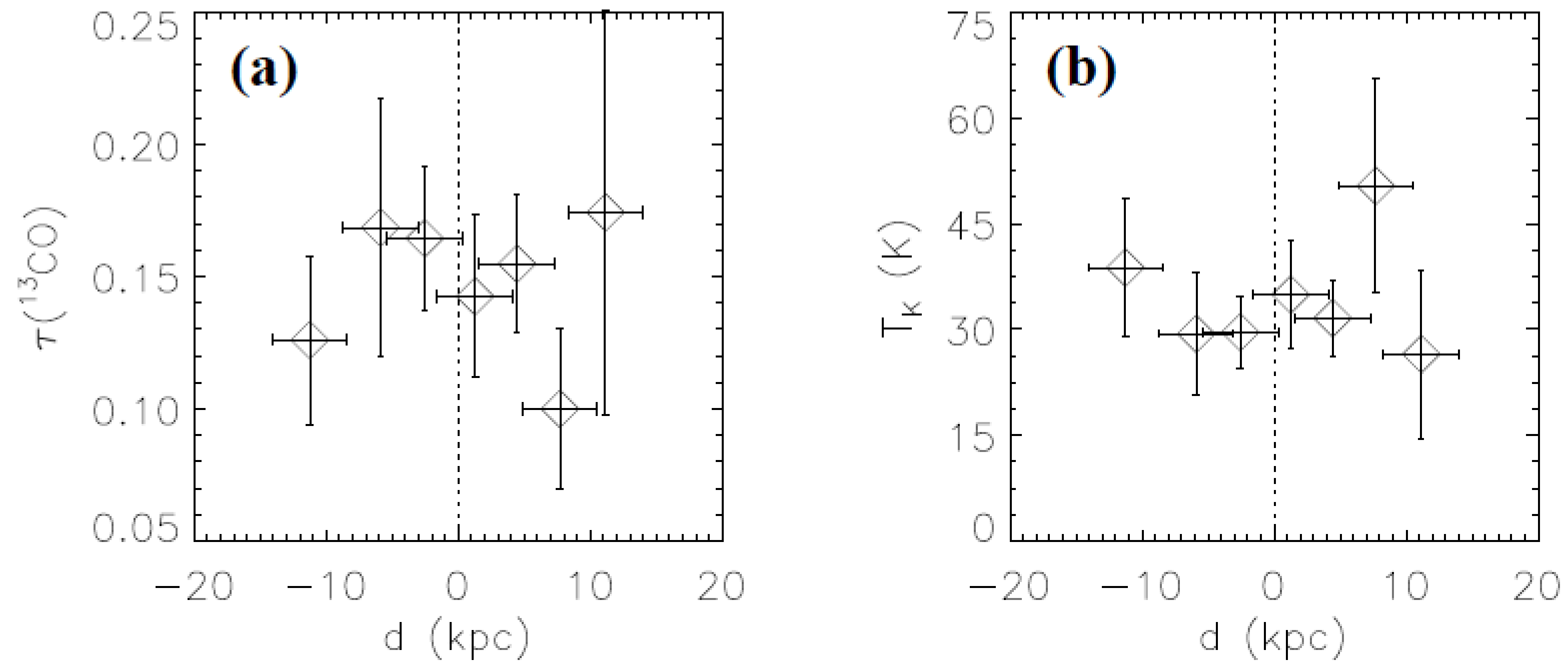

FIG. 4.— (a) Optical depth of ^{13}CO ($\tau_{^{13}CO}$). (b) Kinetic temperature (T_K) of the molecular gas under the LTE assumption. The x-axis is the distance along the galactic plane from the galactic center.

- The total mass of cold molecular and atomic gas of NGC 5908 is in general comparable to the mass contained in the extended hot CGM $M_{hot} = 1.4\ 9(+3.3-0.6) \times 10^{10}\ M_{\odot}$.

HI:

Vmax=347km/s.

Mvir = $1.4*10^{12}\ M_{\odot}$

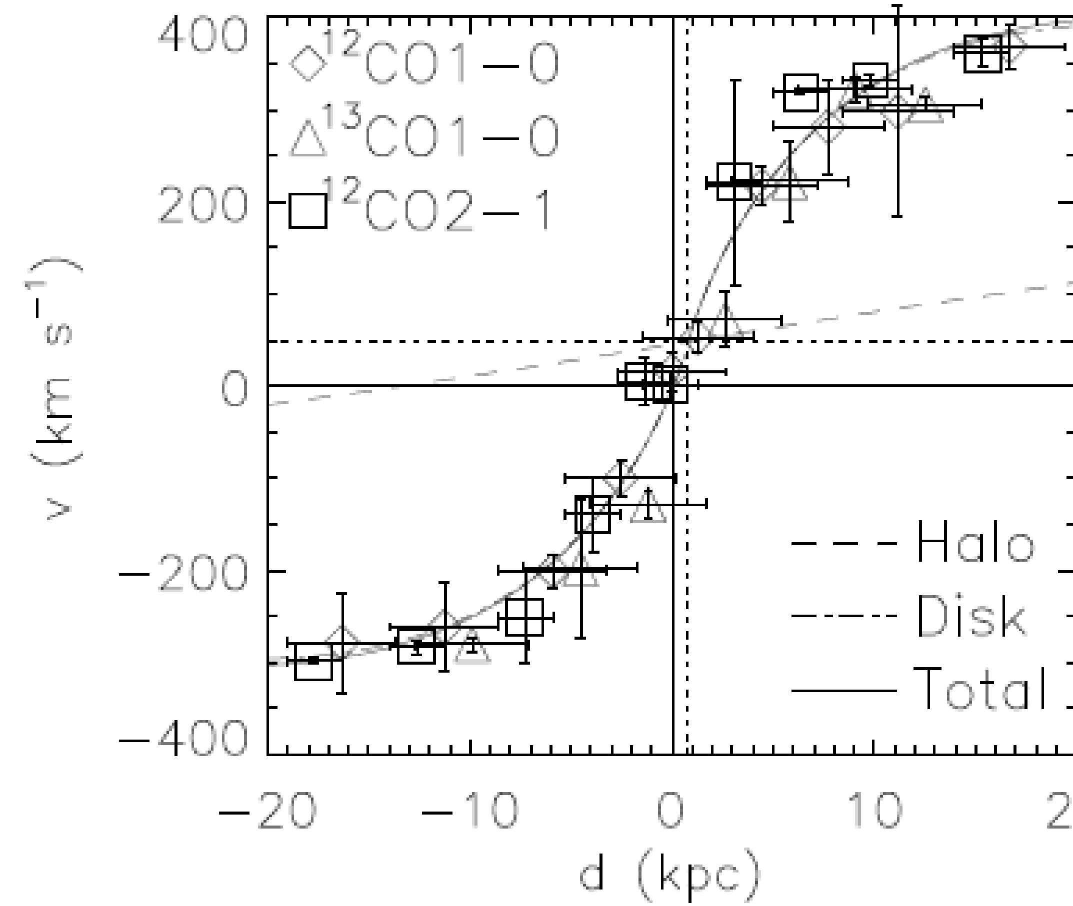

FIG. 5.— Rotation curves of the ^{12}CO $J = 1 - 0$ (diamond), ^{13}CO $J = 1 - 0$ (triangle), and ^{12}CO $J = 2 - 1$ (box) lines along the galactic disk. The x-axis is the distance along the galactic plane from the galactic center. Data points of the ^{13}CO $J = 1 - 0$ and ^{12}CO $J = 2 - 1$ lines are slightly shifted in the x-direction in order to avoid overlapping. The dotted vertical and horizontal lines show the best-fit shift from the optical center (+0.8 kpc) and the systematic velocity of NGC 5908 (+48 km s^{-1}). The best-fit inclination angle is 89.98°, significantly larger than the value determined in optical (65.31°, obtained from HyperLeda Makarov et al. 2014). The

Модельные оценки:

(dM/dt)cool = 0.37 (< 1.55) $M_{\odot}$ yr−1

- на порядок ниже, чем SFR.
- С учетом гигантской звездной массы

M*= 2.6*1011,в прошлом SFR был более чем на порядок более высокий.

ОСНОВНЫЕВЫВОДЫ

- The cool gas mass is comparable to the total mass of hot gas in the halo, so makes a significant contribution to the galaxy's gas budget, but is still far from sufficient to account for the "missing baryons".
- Comparison to the star formation law indicates that NGC 5908 is converting cool gas to young stars at a normal efficiency, with no significant suppression of star formation as often suggested in disk galaxies with a huge bulge.
- The radiative cooling of the hot CGM or any other external gas supply are probably insufficient to compensate the gas consumed in star formation. The galaxy must have a fast growth stage with mergers and/or starbursts in the past.