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Momose et al. 2010

Reference

¹Handa et al. 1991; ²Downes et al. 1996; ³Laine et al. 1999; ^{4,5}Sheth et al. 2000, 2002; ⁶Jogee et al. 2005; ⁷Muraoka 2008; ⁸Verley et al. 2010; ⁹Onodera et al. 2010; ¹⁰Ferrarese et al. 1996; ¹¹Koda & Sofue 2006; ¹²de Vaucouleurs et al. 1991; ¹³Kennicutt 1998; ¹⁴Calzetti et al. 2007

Abstract

We present new 12CO(J=1-0) observations of the barred galaxy NGC 4303 using the Nobeyama 45m telescope (NRO45) and the Combined Array for Research in Millimeter-wave Astronomy (CARMA). The H α images of barred spiral galaxies often show active star formation in spiral arms, but less so in bars. We quantify the difference by measuring star formation rate and efficiency at a scale where local star formation is spatially resolved. Our CO map covers the central 2.03 arcmin region of the galaxy; the combination of NRO45 and CARMA provides a high fidelity image, enabling accurate measurements of molecular gas surface density. We find that star formation rate (SFR) and efficiency (SFE) are twice as high in the spiral arms as in the bar. We discuss this difference in the context of the Kennicutt-Schmidt (KS) law, which indicates a constant star formation rate at a given gas surface density. The KS law breaks down at our native resolution (~250 pc), and substantial smoothing (to 500 pc) is necessary to reproduce the KS law, although with greater scatter.

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- 2. NAOJ (ALMA)

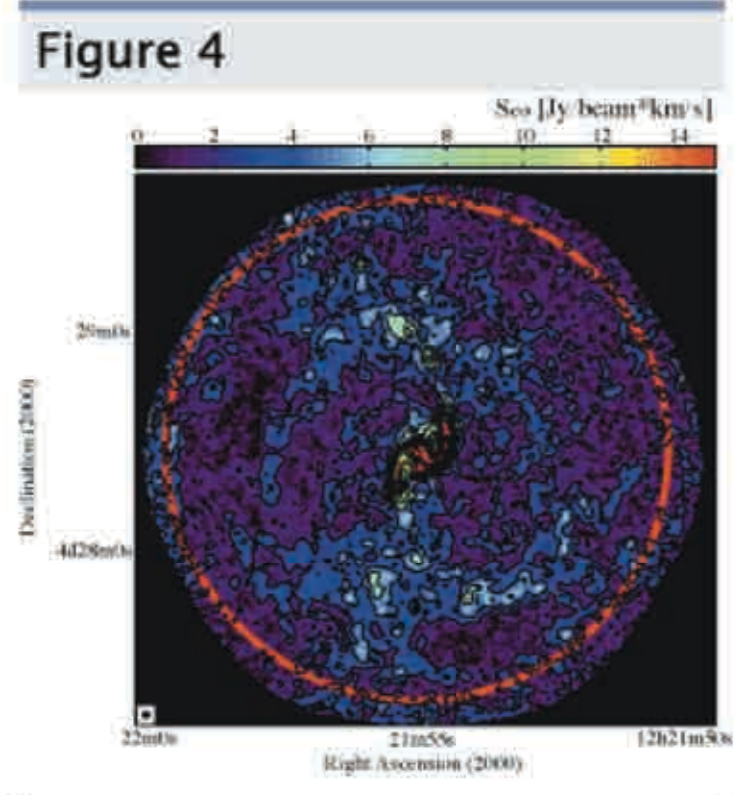


Figure 4: Combined CO map. Red circle; central 2.3 arcmin region.

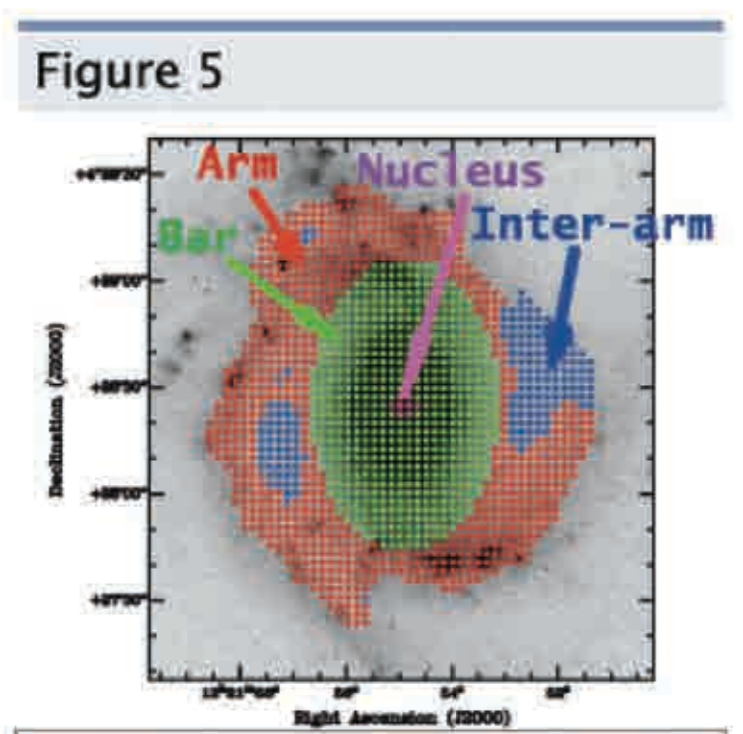


Figure 5: Local definitions with 300 grid. The nucleus, bar, arm and inter-arm are represented by pink, green, red and blue, respectively.

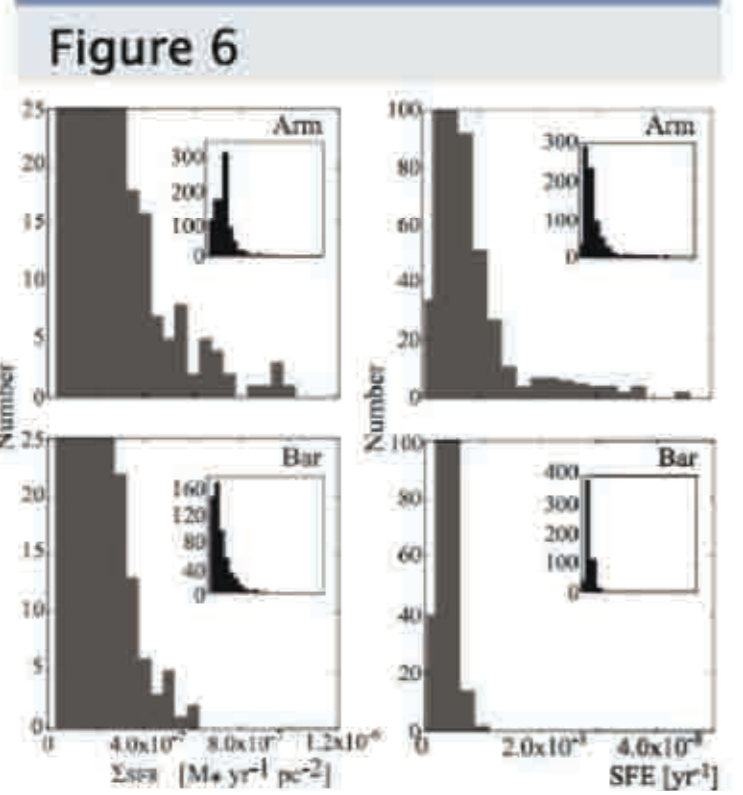


Figure 6: Histograms of (left) area averaged star formation rate ΣSFR , and (right) SFE. The insets are overall view of the histograms.

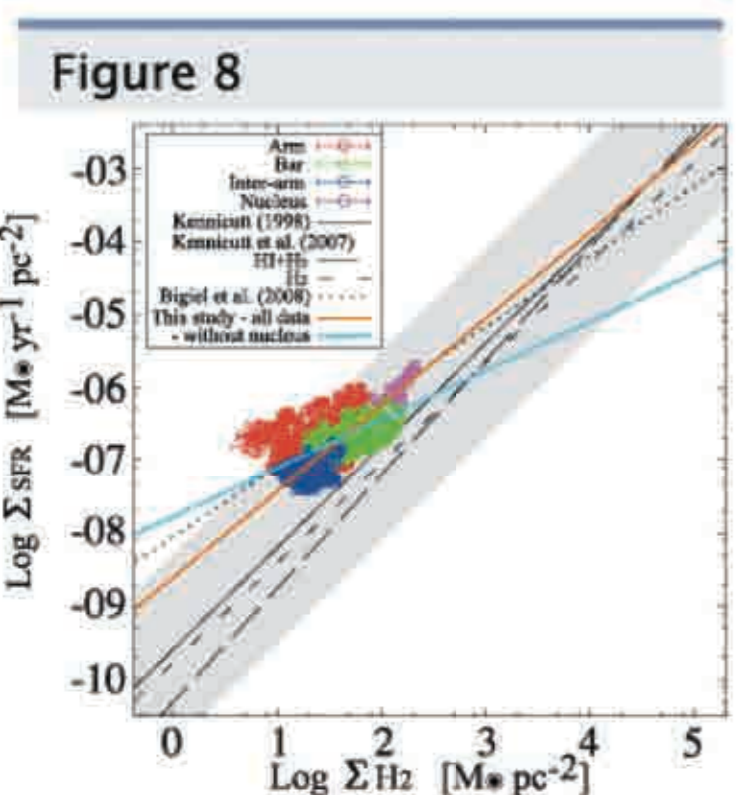
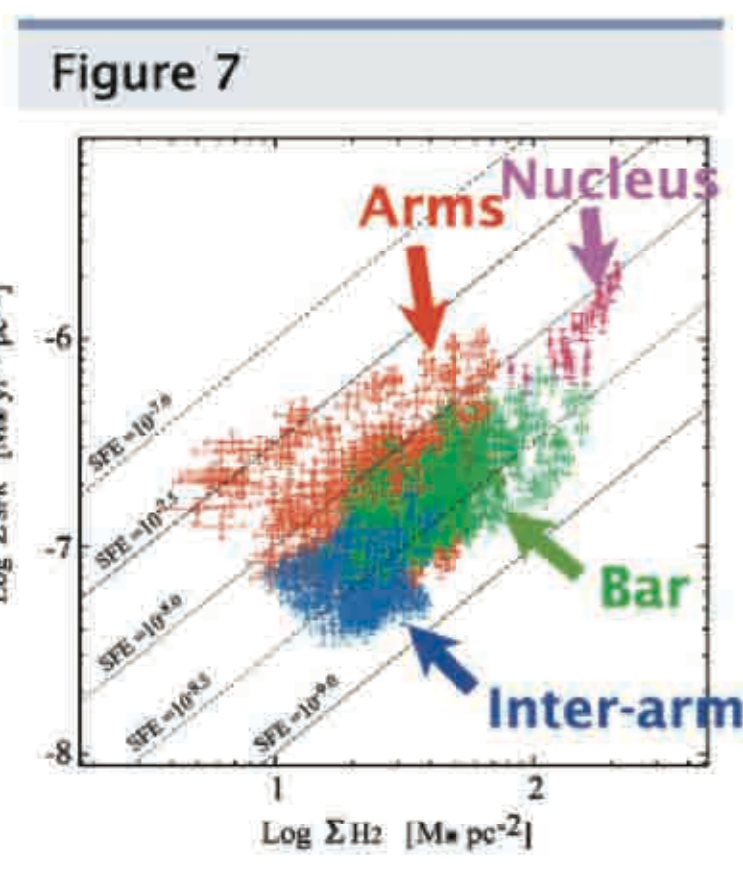
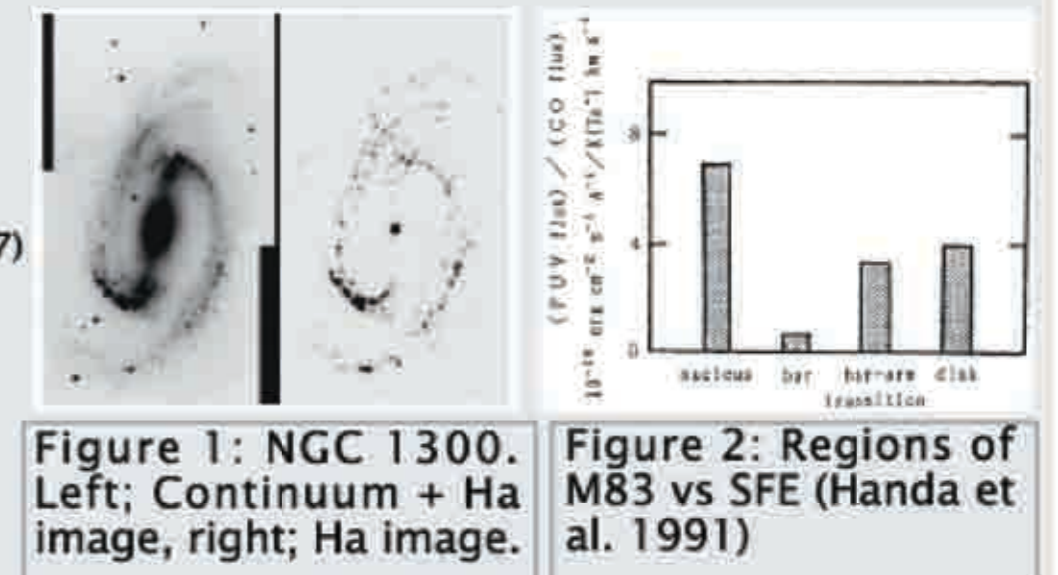


Figure 8: ΣH_2 vs ΣSFR at the resolution of 500 pc. Grey region is the scatter of Kennicutt's Figure 9 (1998)

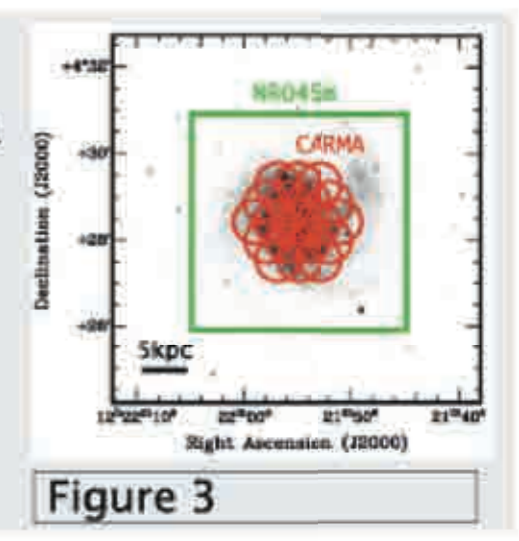
Introduction

- Star formation activities (SFAs) in barred spiral galaxies
 - * SFRs/SFEs seem to be different between bars and arms (Figure 1,2)
 - Higher in outer spiral arms, but not so high in inner bars
 - > There are less quantitative validations of this (Ref. 1, 2, 3, 4, 5, 6, 7)
 - * Another indicator of SFAs -- the KS relation --
 - The KS law breaks down with small scales in M 33 (Ref 8,9)
 - > More verifications are required using other galaxies
- Motivations
 - * Verifying SFAs over the galaxy at a Giant Molecular Association scale (~500 pc)
 - Accurate measurement of molecular gas distribution with high fidelity combined data
- Target -- NGC 4303 --
 - * Distance : 16.1 Mpc ($V_{lsr} = 1556$ km/s) (Ref 10,11)
 - * Position Angle : 312.2 deg
 - * Hubble type : SABbc (Ref 12)
 - * Inclination : 27.8 deg
 - * Nuclear region : Sy2, HII



Observations and Results

- Observations (Figure 3)
 - * Nobeyama 45m single dish telescope
 - Obs. region : 5' x 5'
 - Beam : 21" (~ 1.6 kpc)
 - sensitivity : $T_{mb} = 73$ mK
 - * CARMA
 - ~ 80" (19 pointing)
 - 3.1" x 2.5" (240 x 200 pc)
 - 43 mJy/beam
 - * Combined data
 - ~ 80"
 - 3.2" (240 pc)
 - 34 mJy/beam
- Results --> Figure 4



Analysis

- SFR/SFE (Ref 13, 14)
 - $SFR = L(H\alpha_{corr}) [erg/s] * 7.9 * 10^{-42} = (L(H\alpha) [erg/s] + (0.031 \pm 0.006) * L(24\mu m) [erg/s]) * 7.8 * 10^{-42} [M\odot/yr]$
 - $SFE = SFR / MH_2 [1/yr] (\approx X_{CO} = 2.0 * 10^{20} [cm^{-2} (K km/s)^{-1}])$
- Definition of the regions -- set 4 regions (Figure 5) --
 - Nucleus : $r = 3'' \sim 0.3$ kpc
 - Bar : 40" x 26" (3.1 x 2.0 kpc)
 - Arm/Inter-arm : Classified by eye, based on K-band image

Discussion I -- Local star formation in the bar and arms --

- Number histogram (Figure 6)
 - Both high SFRs and SFEs are appeared only in the arms, but absent in the bar
 - The averages -- The bar vs arms vs entire disk --
 - Both SFR and SFE in the arms are higher than those in the entire disk
 - Both SFR and SFE in the bar are lower than those in the entire disk
 - The bar vs arms : 30 % higher for SFR, twice higher for SFE in the arms than those in the bar
- >> SFAs are higher in the arms, but lower in the bar

Discussion II -- the KS relation of NGC 4303 --

- Distribution of data (Figure 7)
 - The arms data are distributed widely than other regions
 - The difference of SFE between the bar and arms (factor 2) causes of the scatter in the arms
 - The correlation begins to break down with small scale
 - One of this reason is the offset between CO and H α arms
- The same range as Kennicutt (1998) (Figure 8)
 - The index of the best fit : with the Nucleus ... $N = 1.22$, without the Nucleus ... $N = 0.67$
 - Comparison to Kennicutt 1998 : Almost all data exist within the scatter with systematically higher SFR
 - The correlation appears at 500 pc resolution, but breaks down with small scale (especial in the arms)