ASYMMETRIC GALAXIES: NATURE or NUTURE?

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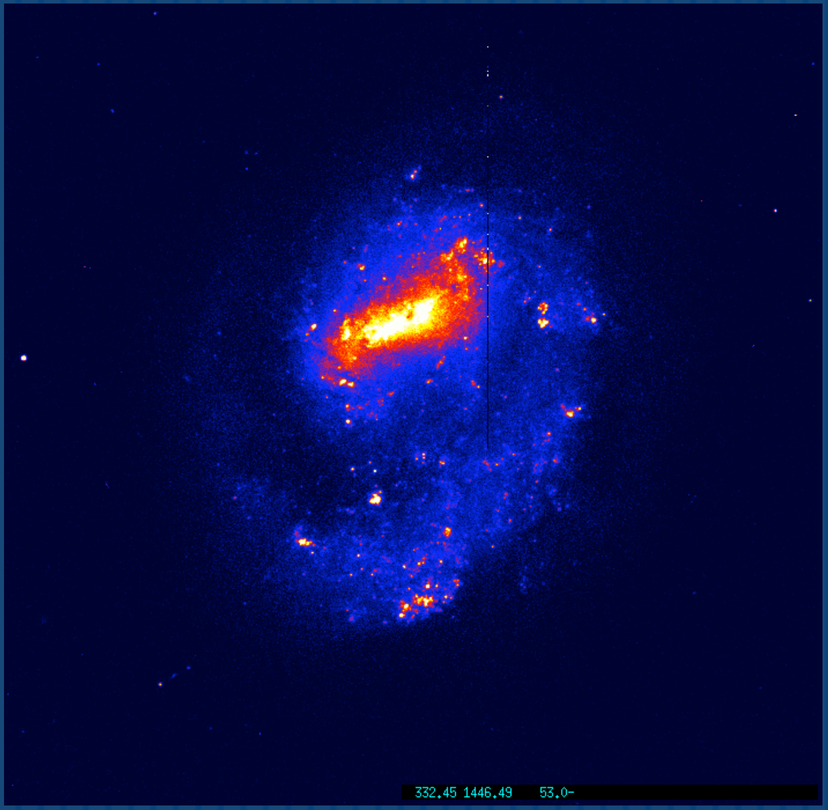
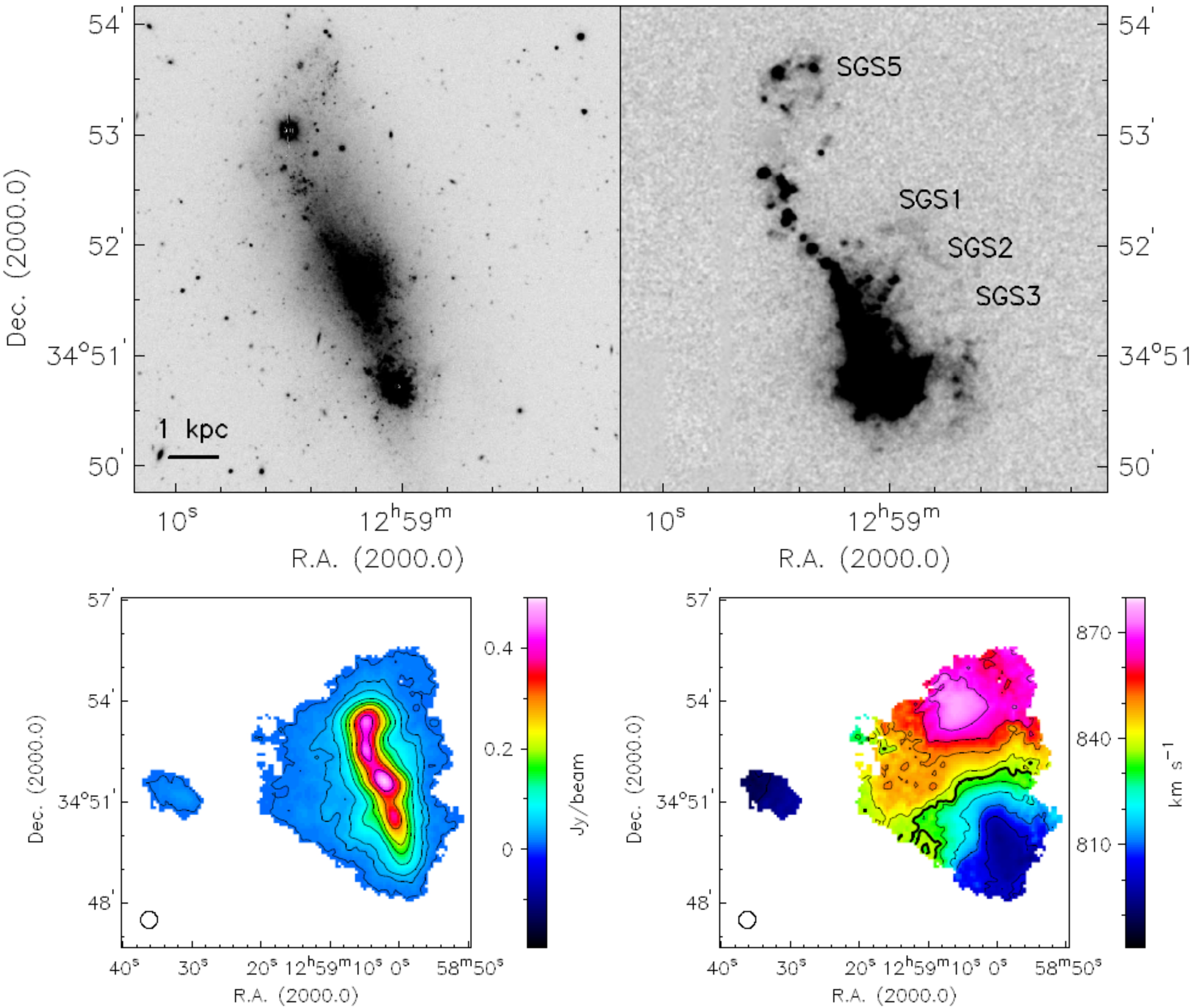
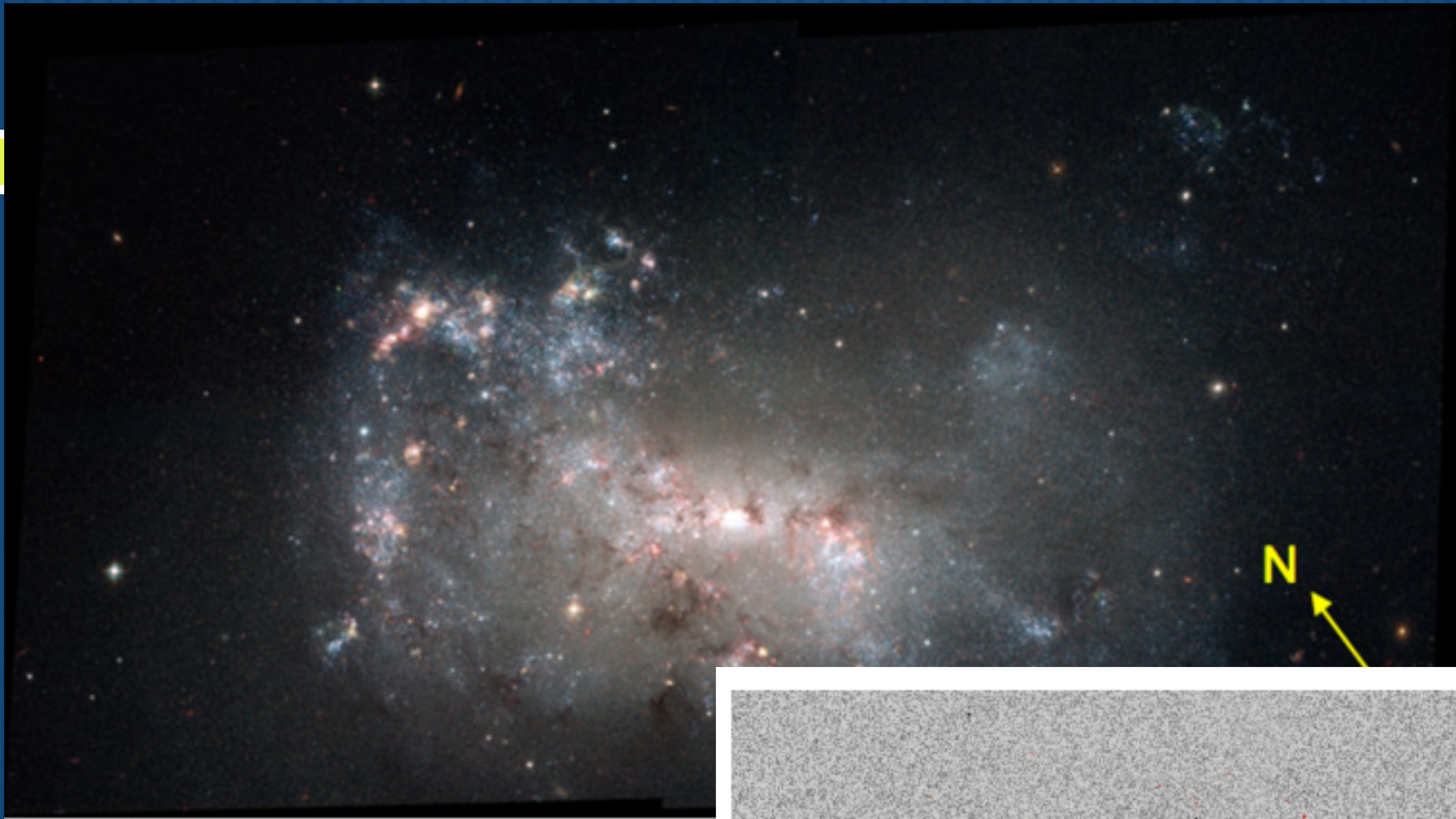
Prevalence of Asymmetry

- HI Profiles
  - 50% of “normal” galaxies are asymmetric (Richter & Sancisi 1994)
  - 75% of “late-type” spirals (Matthews, van Driel, Gallagher 1998)
- Stellar Distribution
  - At least 30% of spirals (Rix and collaborators)





SGS5
SGS1
SGS2
SGS3
1 kpc
Dec. (2000.0)
R.A. (2000.0)
54'
53'
52'
34°51'
50'
10s
12h59m
57'
54'
34°51'
48'
40s
30s
20s 12h59m10s 0s
58m50s
0.4
0.2
0
Jy/beam
870
840
810
km s-1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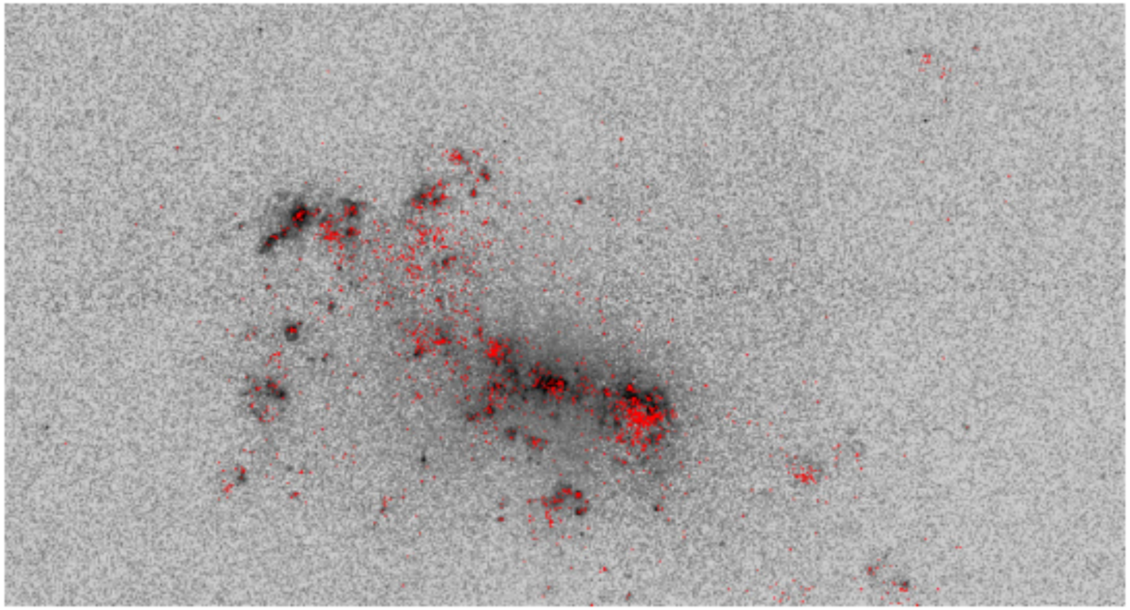


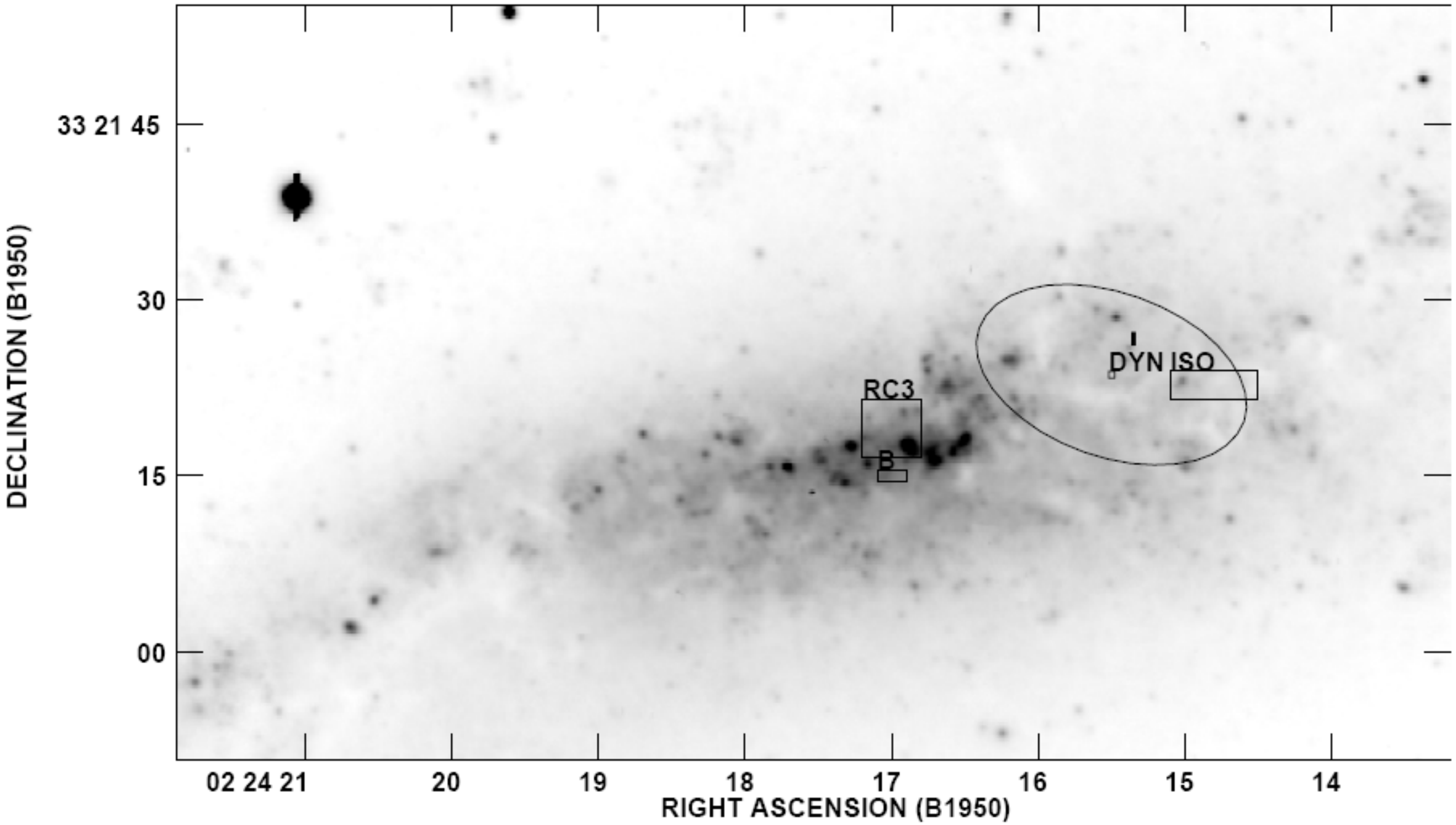
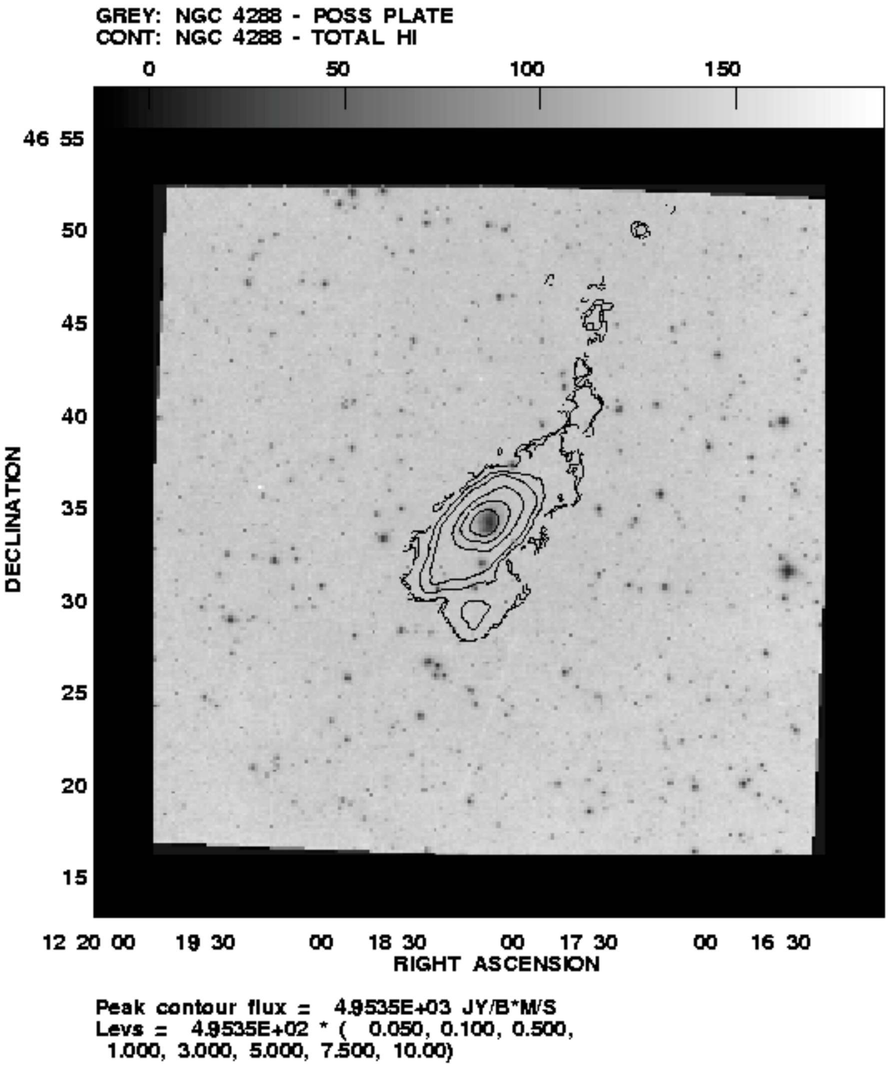


FIG. 5.—Four centers of NGC 925: the center of NGC 925 according to the RC3, the center of the bar (B), the center of the outer isophotes (ISO), and the dynamical center (DYN). The boxes represent the derived errors to the fitted centers. The ellipse is the FWHM of the beam from the H I observations in Paper I.

Causes of Asymmetry

- Differential precession (Baldwin, Lynden-Bell, Sancisi 1980)
  - Short timescales (<5 Gyr); hard to account for prevalence
- Minor mergers (Walker et al. 1996, Zaritsky & Rix 1997)
  - Most Magellanic spirals have companions (Odewahn 1992)
  - Lopsidedness/star-formation correlation (Rudnick et al. 2000)
  - Timescales are short
    - Asymmetries last only 10^9 yrs
    - "a few orbit times"
- Displaced disk (Levine & Sparke 2001, Noordermeer, Sparke & Levine 2001)
  - Disk offset from dynamical center of a dominant halo
  - Recreate asymmetric rotation curves (e.g. NGC 4395)

Minor merger ?



Wilcots, Lehman, Miller 1996

Causes of Asymmetry

- Displaced disk (Levine & Sparke 2001)
  - Disk offset from dynamical center of a dominant halo
  - Starts offset --> stays offset

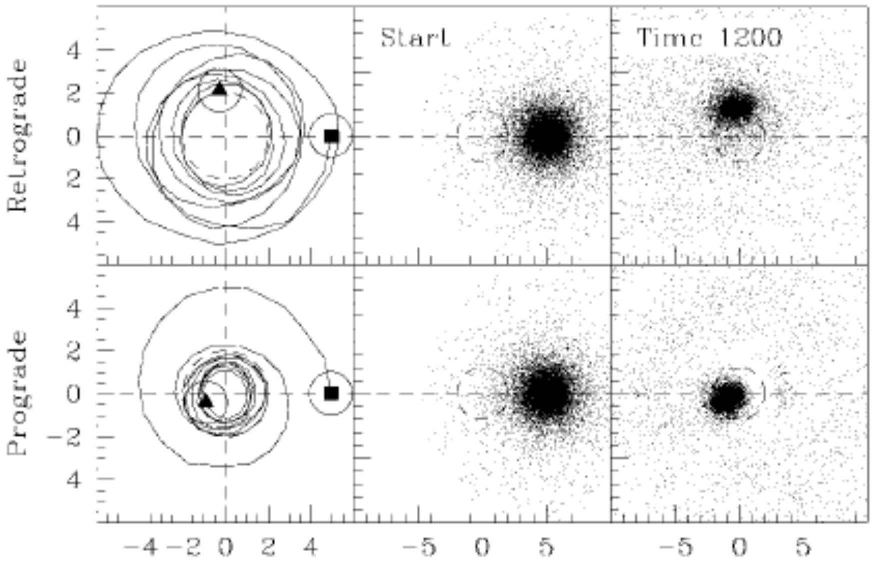


FIG. 2.—Path of the most tightly bound particles, from the start (*square*) to the finish (*triangle*) of a two-dimensional simulation beginning with the disk center at $x_0 = 5$; the solid circles show a radius of 1 disk scale length, and the dashed circle marks the halo core radius $r_c = 2$.

Let's look at really asymmetric galaxies…

- Magellanic-type spirals
  - Strong single spiral arm (m=1)
  - Stellar bar
  - Center of the stellar bar offset from the center of the outer isophotes
  - Often large star-forming complex at one end of the bar

TABLE 3

H I RESULTS

Galaxy	$M_{H\,I}$ ($10^7\ M_\odot$)	Size (H I) (arcmin)	Size (D_{25}) (arcmin)	Size (H I) (kpc)	V_{rot} (km s^{-1})	M_{tot} ($10^9\ M_\odot$)
UGC 655..........	82.2	6.7 × 5.1	2.5 × 2.5	16.4 × 12.6	56	14.6
UGC 2463.........	314.4	5.8 × 3.3	2.3 × 1.5	33.1 × 18.9	99	55.7
NGC 2537.........	21.2	8.5 × 7.3	1.7 × 1.5	11.4 × 9.8	47	11.4
IC 2233	18.3	7.2 × 2.6	0.7 × 0.6	9.5 × 3.4	77	7.4
UGC 5391.........	176.0	4.5 × 3.5	2.2 × 0.8	21.1 × 16.3	93	52.9
UGC 5391A......	13.1	2.7 × 1.8	...	12.5 × 8.4	31	2.5
UGC 5848.........	30.5	4.0 × 2.7	2.1 × 1.0	9.8 × 6.7	63	8.5
NGC 3659.........	213.7	5.7 × 2.4	2.1 × 1.1	21.8 × 9.2	108	35.7
NGC 3664.........	197.1	5.1 × 4.5	2.0 × 1.9	21.0 × 18.6	31	10.9
NGC 3664A......	44.7	3.0 × 2.6	0.8 × 0.8	12.0 × 10.4	30	5.1
NGC 3995.........	1197.0	4.1 × 2.3	2.8 × 1.0	40.2 × 22.6	64	27.8
NGC 3994.........	113.6	1.3 × 1.2	1.0 × 0.6	12.4 × 11.2	61	29.7
NGC 3991.........	551.1	3.0 × 2.1	...	28.5 × 19.8	81	41.9
UGC 6628.........	104.3	5.4 × 5.3	2.9 × 2.9	13.8 × 13.4	20	10.7
NGC 3846A......	70.6	3.2 × 2.2	1.1 × 0.8	13.4 × 9.1	66	12.6
IC 3476	9.5	2.7 × 1.9	5.3 × 3.7	2.1 × 1.8	54	3.4
NGC 4707.........	17.7	4.4 × 3.6	2.2 × 2.1	6.2 × 5.0	30	1.9
UGC 10310.......	66.2	5.2 × 3.9	2.8 × 2.2	11.1 × 8.3	43	5.3

Prescott & Wilcots 2004 – HI survey of Magellanic Spirals

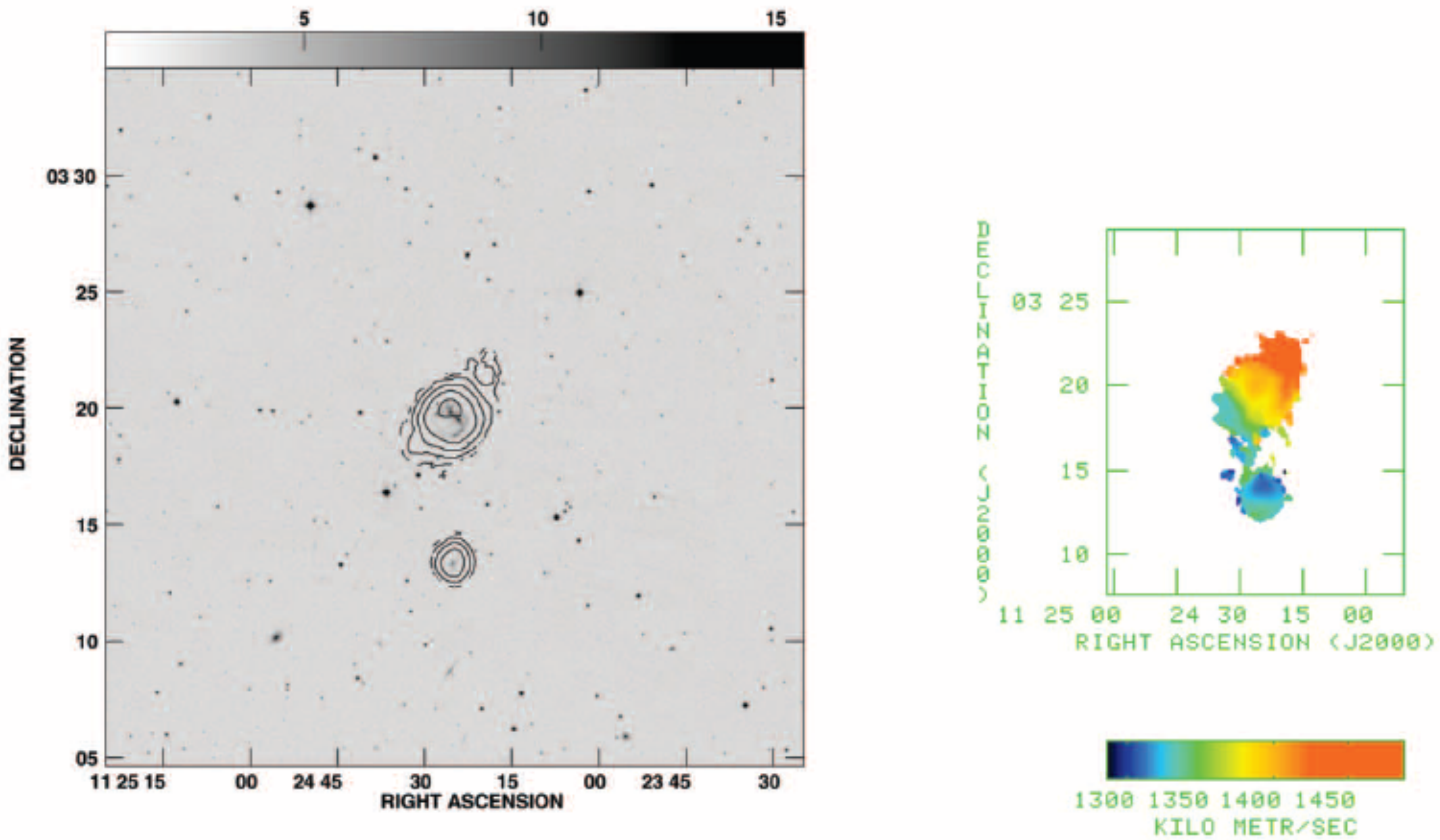


FIG. 2.—Same as Fig. 1, but for NGC 3664. The contours on the total H I maps are 2, 5, 10, 20, 40, and 80 times 1.5×10^{21} cm^{-2}.

Prescott & Wilcots -- NGC 3664 and its companion

Just How Asymmetric are Magellanic Spirals?

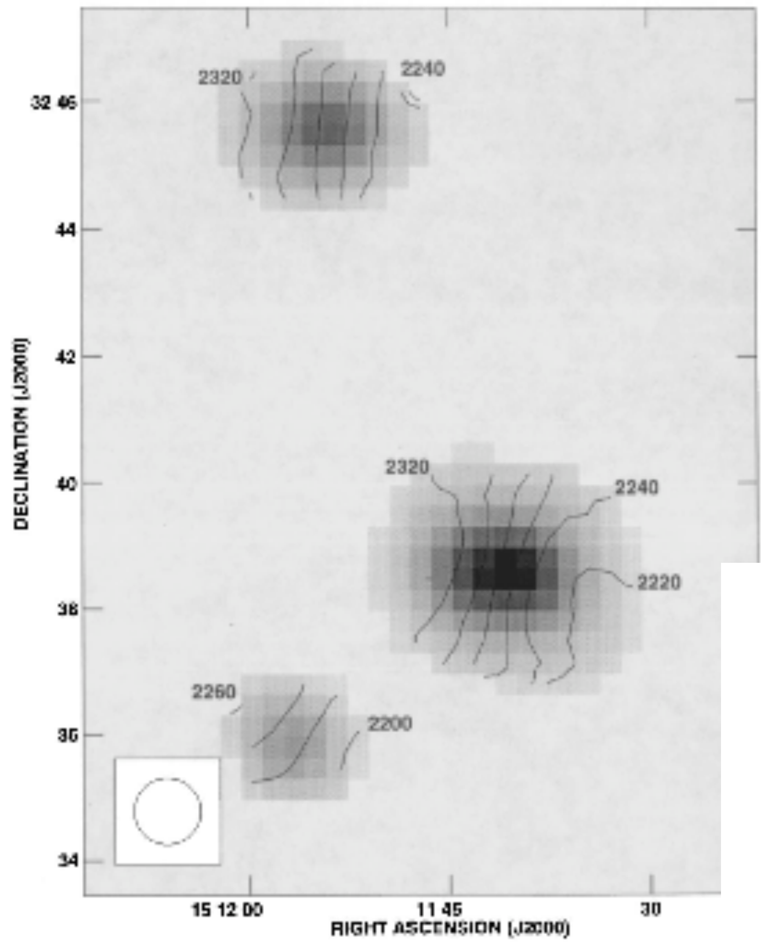
- Only 4/13 had real companions
- Existing interactions all quite weak (Q ~ 0.001) – unlikely to do much to the dynamics/structure
- HI profiles of interacting Magellanic spirals no more or less asymmetric than non-interacting Magellanic spirals, and
- HI profiles of Magellanic spirals in general are no more or less asymmetric than HI profiles of field galaxies
- Presence of a companion/recent interaction not required for structural asymmetry of Magellanic spirals

What about isolated galaxies?

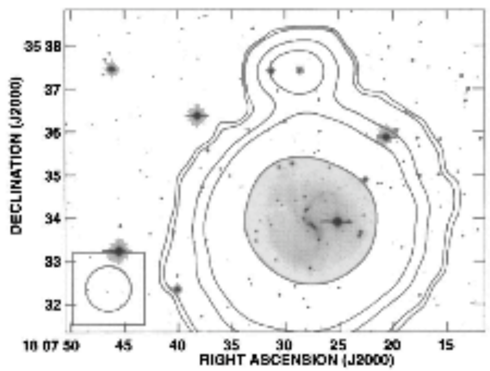
An HI Survey of Isolated Galaxies (Pisano & Wilcots '99, Pisano et al '02, '03)

- Sample (Tully 1988):
  - No known companions within 6 Mpc
  - Density < 0.1 Mpc^{-3} for M < -16
  - Equivalent to the Local Group with only the MWG and no irregulars/dwarfs brighter than IC 10
  - Velocities between 1500-2600 km s^{-1}
    - Sensitive to interactions within the past 1 Gyr for a single VLA pointing

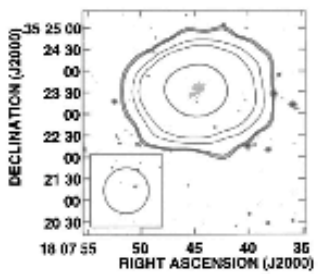
Isolated??



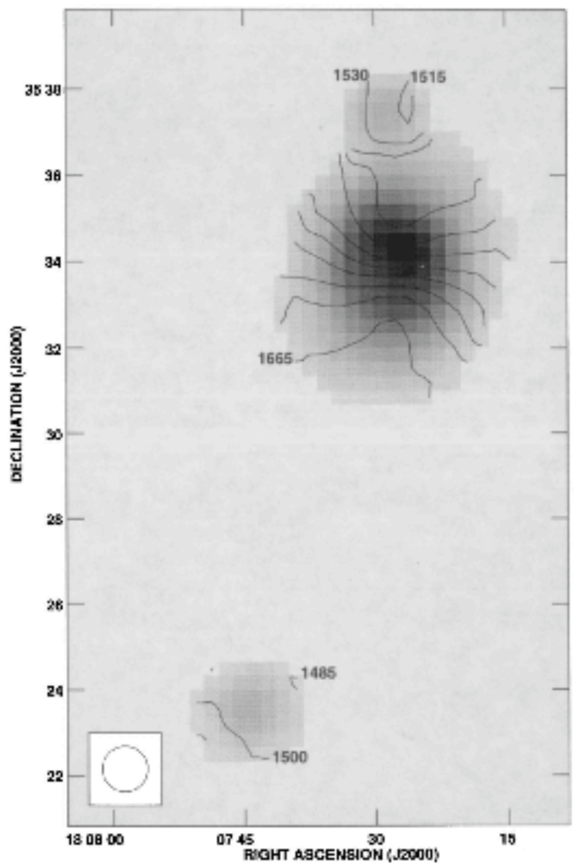
DECLINATION (J2000)
RIGHT ASCENSION (J2000)
32 46
44
42
40
38
36
34
15 12 00
11 45
30
2320
2240
2320
2240
2220
2260
2200



DECLINATION (J2000)
RIGHT ASCENSION (J2000)
35 38
37
36
35
34
33
32
18 07 50
45
40
35
30
25
20
15



DECLINATION (J2000)
RIGHT ASCENSION (J2000)
35 25 00
24 30
00
23 30
00
22 30
00
21 30
00
20 30
18 07 55
50
45
40
35



DECLINATION (J2000)
RIGHT ASCENSION (J2000)
35 38
36
34
32
30
28
26
24
22
18 08 00
07 45
30
15
1530
1515
1665
1485
1500

$$t_{\rm fric} = \frac{(2.5 \times 10^{14}) R^2 V}{M_{\rm comp} \ln \Lambda} \ {\rm yr} \ , \qquad (1)$$

where

$$\Lambda = \frac{R V^2}{M_{\rm comp} G} \ , \qquad (2)$$

TABLE 4

INTERACTION PARAMETERS

Galaxy	Projected Separation[a] kpc	R_{gal}	km s^{-1}	Projected V_{rot} (km s^{-1})	Maximum $V_{rot,gal}$ (km s^{-1})	ΔV (km s^{-1})	Q_D	t_{fric} (Gyr)	t_{orbit} (Gyr)
UGC 11124 N	24.7	1	70	139	116	23	5.6×10^{-3}	4.5	6.8
UGC 11124 S	90.2	3.6	90	178	116	62	6×10^{-3}	107	9.2
UGC 9762 N	78.4	3.8	5	36	144	108	1.9×10^{-3}	6.8	5.0
UGC 9762 S	44.8	2.1	40	124	144	20	1.6×10^{-3}	7.5	15

[a] Assuming companion is at same distance as galaxy.

Name	α (J2000)[a]	δ (J2000)[a]	Hubble Code[b]	D_{25}[b] (arcmin)	inc.[b] (deg)	M_B[c] (mag)	$V_{\odot}$[a] (km s^{-1})	Distance[d] (Mpc)	ρ[b] (Mpc^{-3})	Group[b]
UGC 260	00 27 02.9	11 35 03	Sc	2.9	82	−19.2	2131	33	0.07	64–0
UGC 328	00 33 22.2	−01 07 17	SBm	1.7	0	−16.6	1986	31	0.07	61–0
NGC 803	02 03 44.8	16 01 52	Sc	3.3	65	−19.6	2101	32	0.07	52–0
NGC 895	02 21 36.1	−05 31 14	Scd	3.9	49	−20.9	2288	35	0.07	51–0
NGC 918	02 25 50.7	18 29 46	SABc	3.4	56	−19.7	1507	23	0.06	52–0
VV 525	02 26 21.3	−09 50 27	SABm	3.3	78	−18.0	2109	32	0.08	51–0
NGC 986	02 33 34.3	−39 02 37	SBab	3.3	42	−20.9	2005	31	0.06	51–0
UGC 2463	03 00 37.5	40 15 06	SABm	2.9	50	−18.6	1901	29	0.07	18–0
UGCA 94	04 42 57.3	−08 05 29	Sm	2.0	49	−19.7	2522	39	0.08	34–0
UGC 3463	06 26 55.7	59 04 47	SABbc	2.6	48	−20.3	2692	41	0.06	20–0
ESO 124-G15	08 23 40.4	−60 52 33	Sc	1.7	65	−19.5	2591	40	0.09	33–0
NGC 2708	08 56 07.9	−03 21 38	Sb	2.9	67	−19.6	2008	31	0.09	31–0
UGC 5172	09 41 52.2	48 40 14	Sm	2.0	0	−18.2	2594	40	0.08	21–0
UGCA 195	10 03 18.9	−21 25 51	SABd	1.4	0	−19.3	3069	47	0.09	31–0
UGC 5518	10 14 10.9	39 27 06	Im	2.1	57	−16	2064	32	0.07	13–0
NGC 3246	10 26 41.8	03 51 43	SABdm	2.3	55	−19.6	2150	33	0.06	30–0
UGC 5707	10 31 14.3	43 08 14	SABcd	2.5	45	−19.2	2800	43	0.07	20–0
NGC 3321	10 38 50.6	−11 38 55	Sc	2.9	65	−19.2	2487	38	0.07	22–0
UGCA 217	10 43 36.1	−09 51 22	Sd	1.9	35	−18.3	2080	32	0.07	22–0
IC 2627	11 09 53.4	−23 43 35	Sbc	3.2	36	−20.4	2081	32	0.10	22–0
NGC 3882	11 46 06.5	−56 23 17	Sc	2.4	58	−20.9	1817	28	0.07	23–0
ESO 39-G2	11 50 21.7	−75 22 23	Im	2.4	60	−20.1	1830	28	0.08	53–0
NGC 4930	13 04 04.7	−41 24 44	SBc	5.4	54	−21.1	2587	40	0.09	23–0
NGC 5375	13 35 56.0	29 09 52	SBab	3.3	42	−20.5	2386	37	0.10	42–0
UGC 9242	14 25 20.9	39 32 20	Scd	5.0	90	−17.2	1440	22	0.09	43–0
NGC 5727	14 40 26.1	33 59 18	SABdm	2.3	61	−17.7	1491	23	0.09	43–0
UGC 9762	15 11 41.3	32 38 35	Sm	1.3	26	−17.3	2273	35	0.07	70–0
NGC 6339	17 17 06.7	40 50 40	SBcd	3.2	59	−19.3	2108	32	0.07	70–0
NGC 6368	17 27 11.6	11 32 33	Sb	3.7	84	−20.8	2764	43	0.07	70–0
UGC 11124	18 07 27.6	35 33 50	SBcd	2.6	31	−18.8	1613	25	0.08	70–0
UGC 11152	18 12 32.2	18 35 56	SBdm	2.1	60	−19.5	2727	42	0.08	73–0
UGC 11220	18 23 25.5	40 56 43	Im	1.5	0	−14.9	1449	22	0.07	70–0
UGCA 417	20 09 21.9	−06 17 07	Im	2.9	60	...	1425	22	0.09	66–0
UGC 11557	20 24 00.8	60 11 41	SABdm	2.4	26	−18.9	1390	21	0.08	40–0
ESO 187-IG35	20 56 56.3	−55 43 14	SBdm	1.5	61	−17.4	2092	32	0.07	61–0
UGC 11651	20 57 15.4	25 58 07	Sdm	3.3	81	−18.5	1525	23	0.06	64–0
IC 5078	21 02 31.9	−16 48 58	Sbc	3.7	79	−18.5	1474	23	0.06	60–0
NGC 7098	21 44 16.5	−75 06 44	SABa	3.9	55	−20.9	2357	36	0.07	55–0
UGC 11861	21 56 24.0	73 15 39	SABdm	3.6	45	−20.2	1525	23	0.07	40–0
NGC 7416	22 55 41.8	−05 29 43	SBb	3.3	86	−20.2	2857	44	0.07	63–0
NGC 7661	23 27 14.3	−65 16 14	Sc	1.9	54	−18.5	2047	31	0.07	55–0

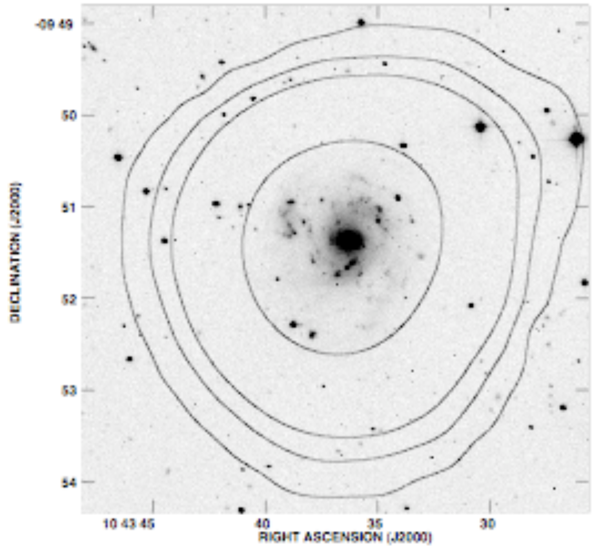


Fig. 22c

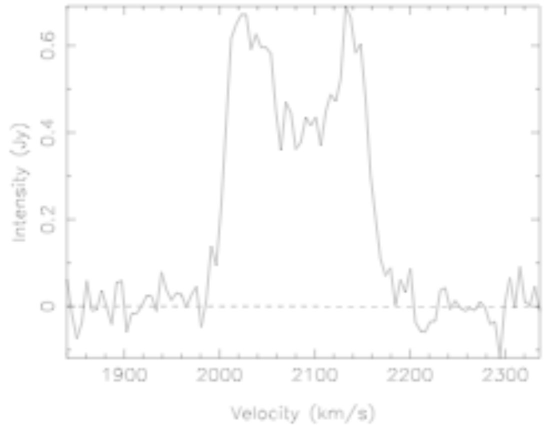


Fig. 22d

Fig. 22.—Same as Fig. 6, but for UGCA 217

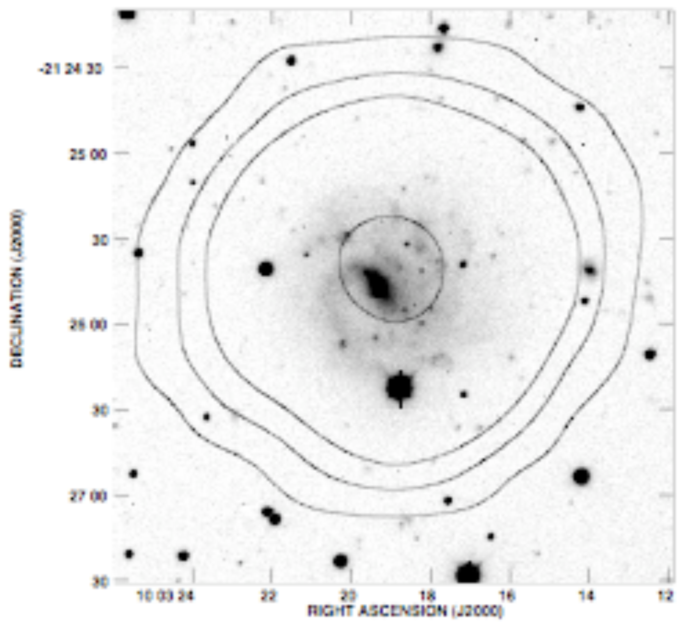


Fig. 17c

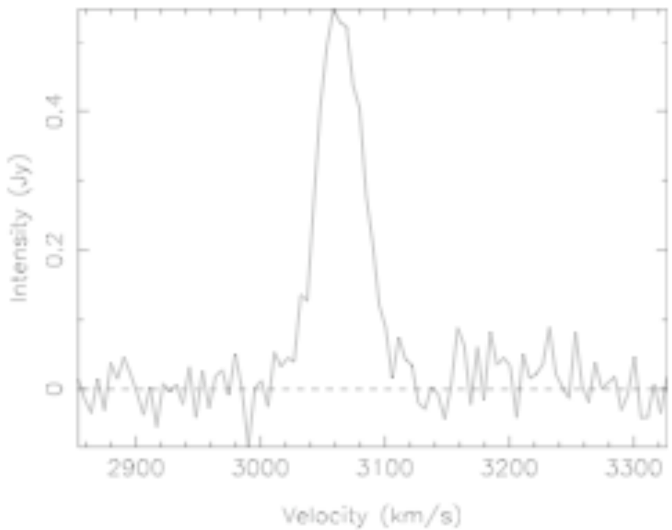


Fig. 17d

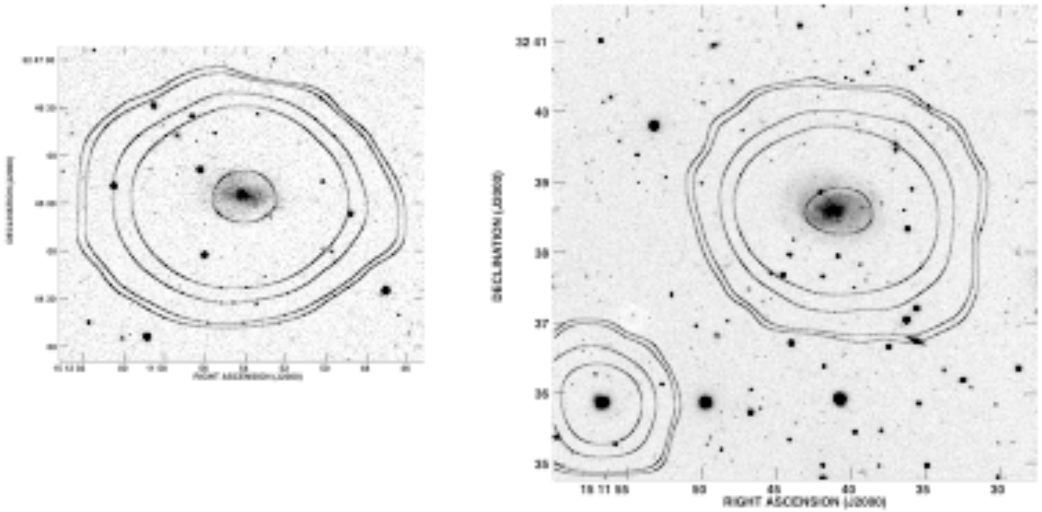


FIG. 30*c*

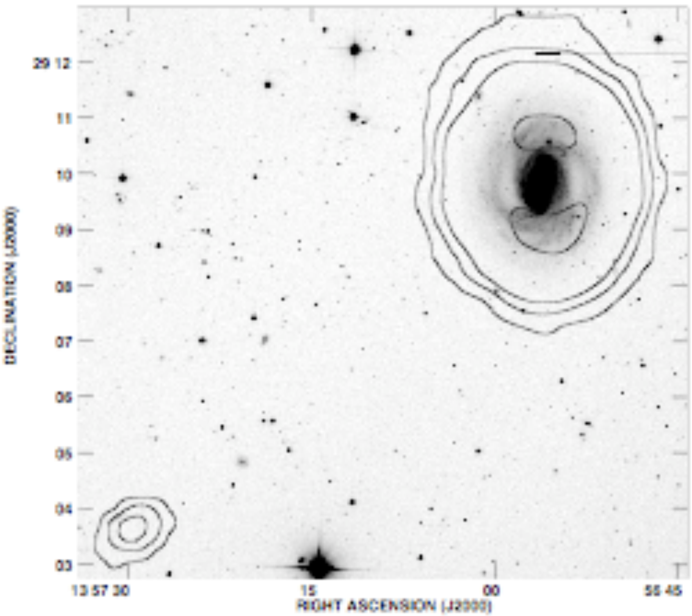


FIG. 27*c*

FIG. 27.—Same as Fig. 5, but for NGC 5375

Results

- 10/41 isolated galaxies have gas-rich companions; 13 companions in all

TABLE 2
INTERACTION PARAMETERS

Name	t_{orbit} (Gyr)	$t_{dyn.fric.}$ (Gyr)	Q_D ($\times 10^{-3}$)	r_J (kpc)	M_{int} ($\times 10^{10}\ M_{\odot}$)	M_{tidal} ($\times 10^{8}\ M_{\odot}$)
UGC 260A...........	2	4	20	3.4	2	30
ESO 124-15A	12	138	0.03	18	20	0.06
ESO 124-15B	5	53	0.2	3.2	4	30
NGC 2708A.........	10	8	0.2	28	8	0.5
NGC 3882A.........	14	84	0.03	16	7	0.9
ESO 39-2A...........	62	...[a]	2	8.9	0.03	0.06
NGC 5375A.........	5	12	3	24	40	3
NGC 5727A.........	115	...[a]	2	18	0.01	0.2
UGC 9762A.........	98	...[a]	2	25	0.04	5
UGC 9762B	7	6	2	7.8	2	4
UGC 11124A.......	2	7	1	3.0	3	2
UGC 11124B	6	136	0.01	8.7	20	0.08
UGC 11152A.......	5	3	40	8.6	0.7	50

[a] For this object, the dynamical friction timescale is unphysical.

Results

- 10/41 isolated galaxies have gas-rich companions; 13 companions in all
- Statistical analysis of the orbits – most circular

  orbit times are long (> 2 Gyr)

  dynamical friction timescales longer

  interactions are weak ($Q < 10^{-3}$)

Are they Asymmetric?

- HI Profiles
  - 75% quite symmetric – on average more symmetric than Magellanic spirals
  - 25% have companions
- Stellar Distribution (optical light)

$$A^2_{RMS} = \frac{(\Sigma(I_0 - I_\phi))^2}{(2I_0)^2}$$

  - 50% asymmetric – a symmetric HI profile is not always indicative of a symmetric optical morphology
  - But….we should really do this in the IR

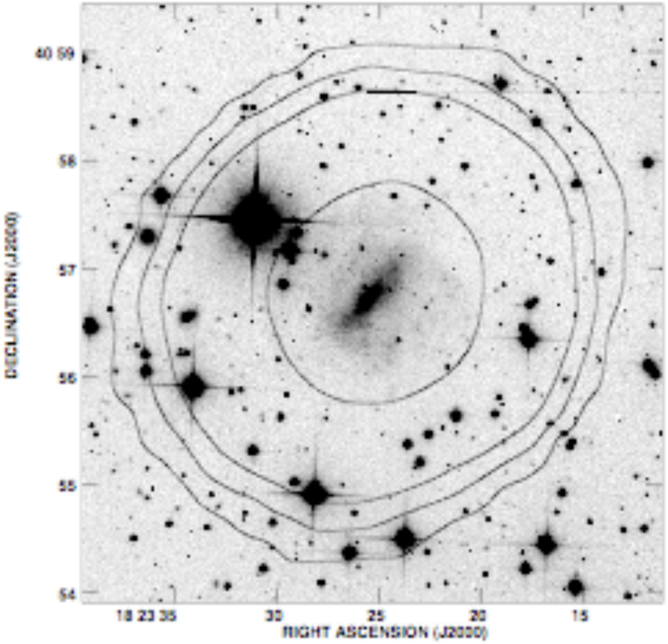


FIG. 35*c*

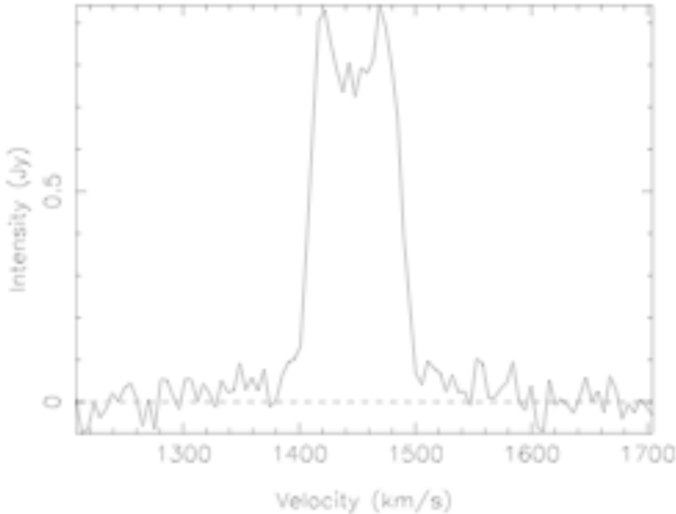


FIG. 35*d*

FIG. 35.—Same as Fig. 6, but for UGC 11220

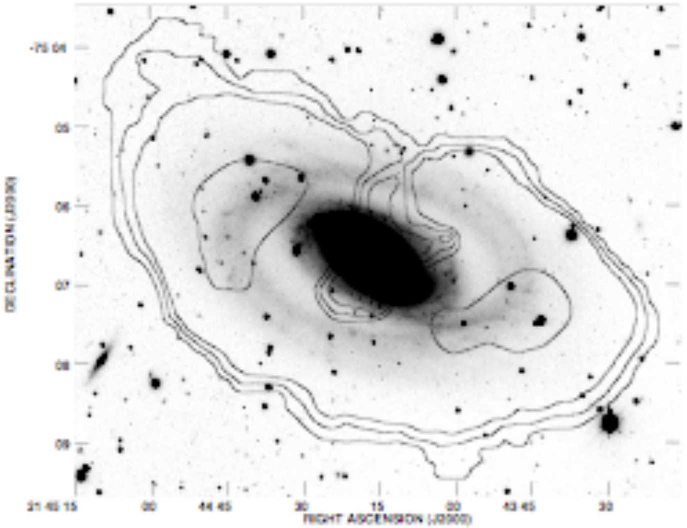


FIG. 41*c*

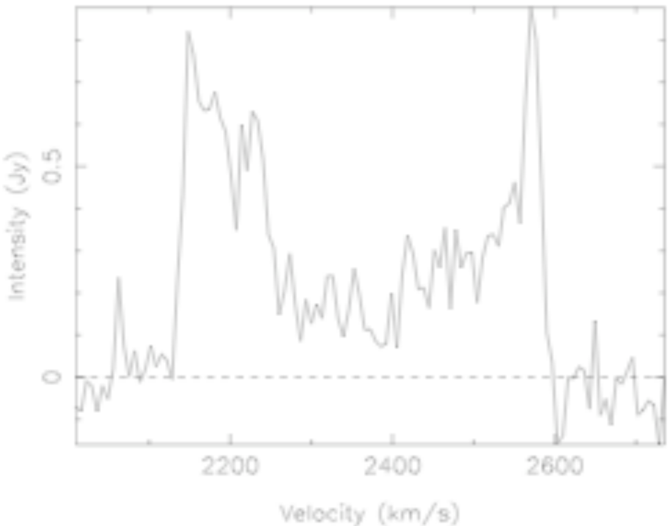


FIG. 41*d*

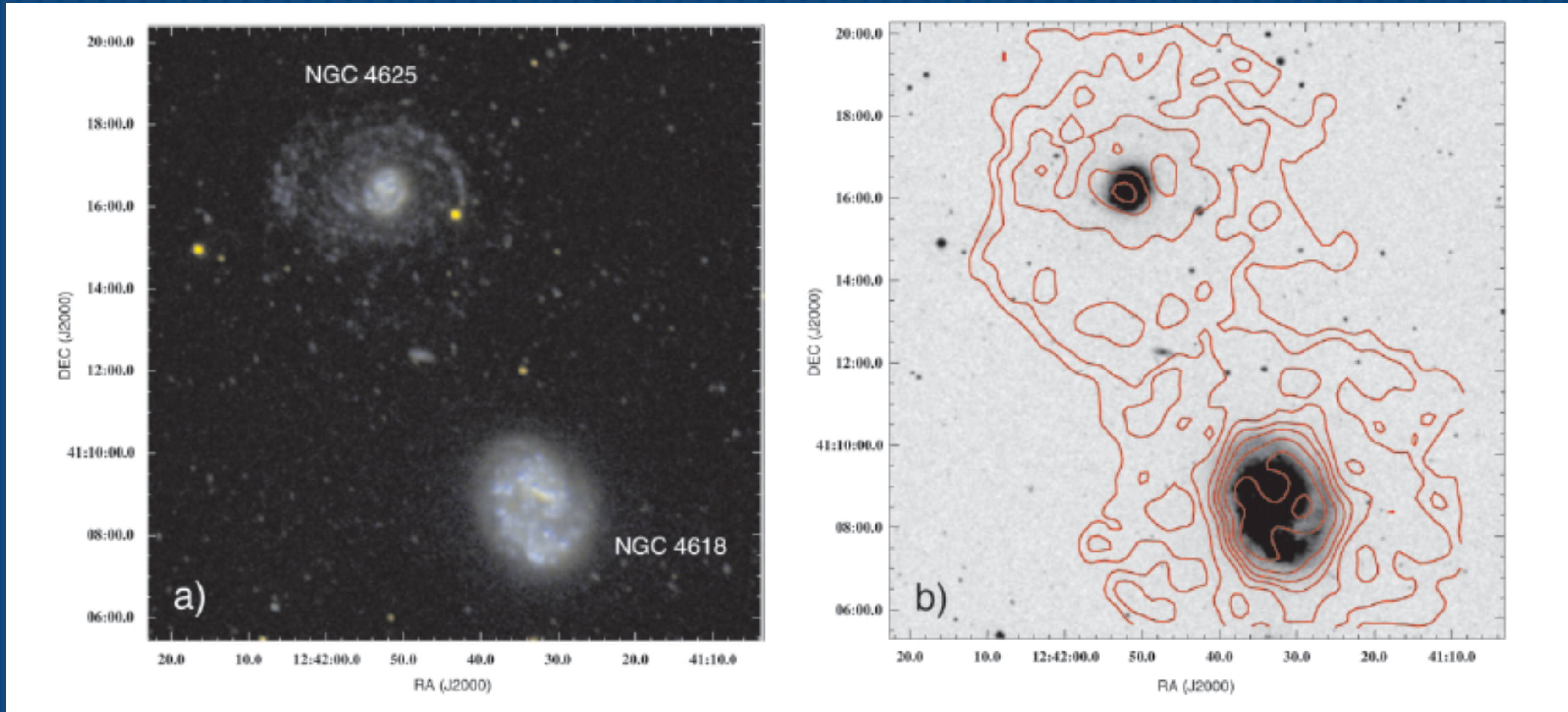
FIG. 41.—Same as Fig. 6, but for NGC 7098

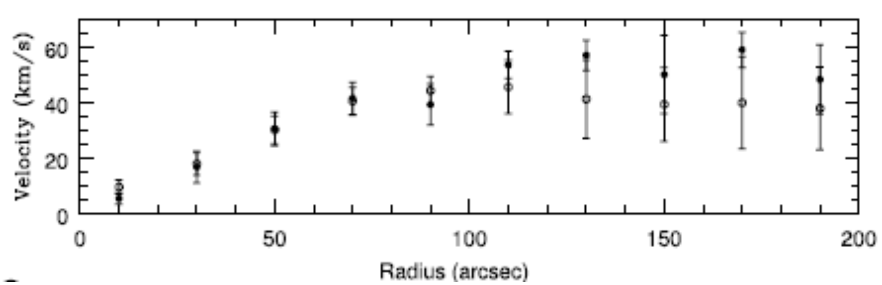
Some Closing Thoughts…

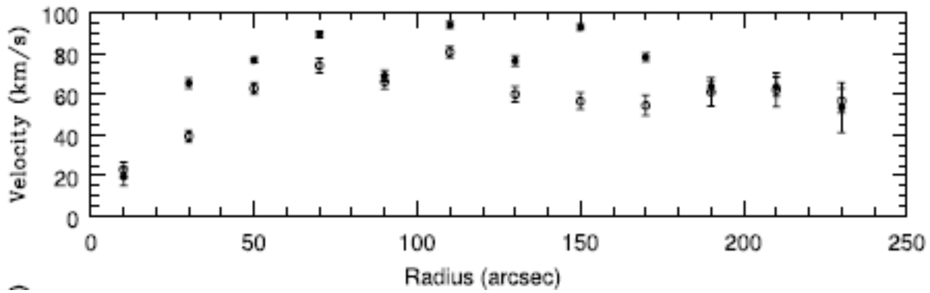
- HI profiles are an inexact measure of asymmetry
  - HI profiles of Magellanics aren't all that asymmetric
- What is the role of interactions in driving asymmetry?
  - How strong and how recent?
  - How long can a galaxy sustain its asymmetry? In gas? In stellar distribution?
- What do we really know about the distribution of satellites around otherwise "isolated" galaxies?

Impact of Interaction on Lopsidedness: A Case Study of NGC 4618/NGC 4625

NGC 4618/NGC 4625 – Interacting Magellanic Spirals



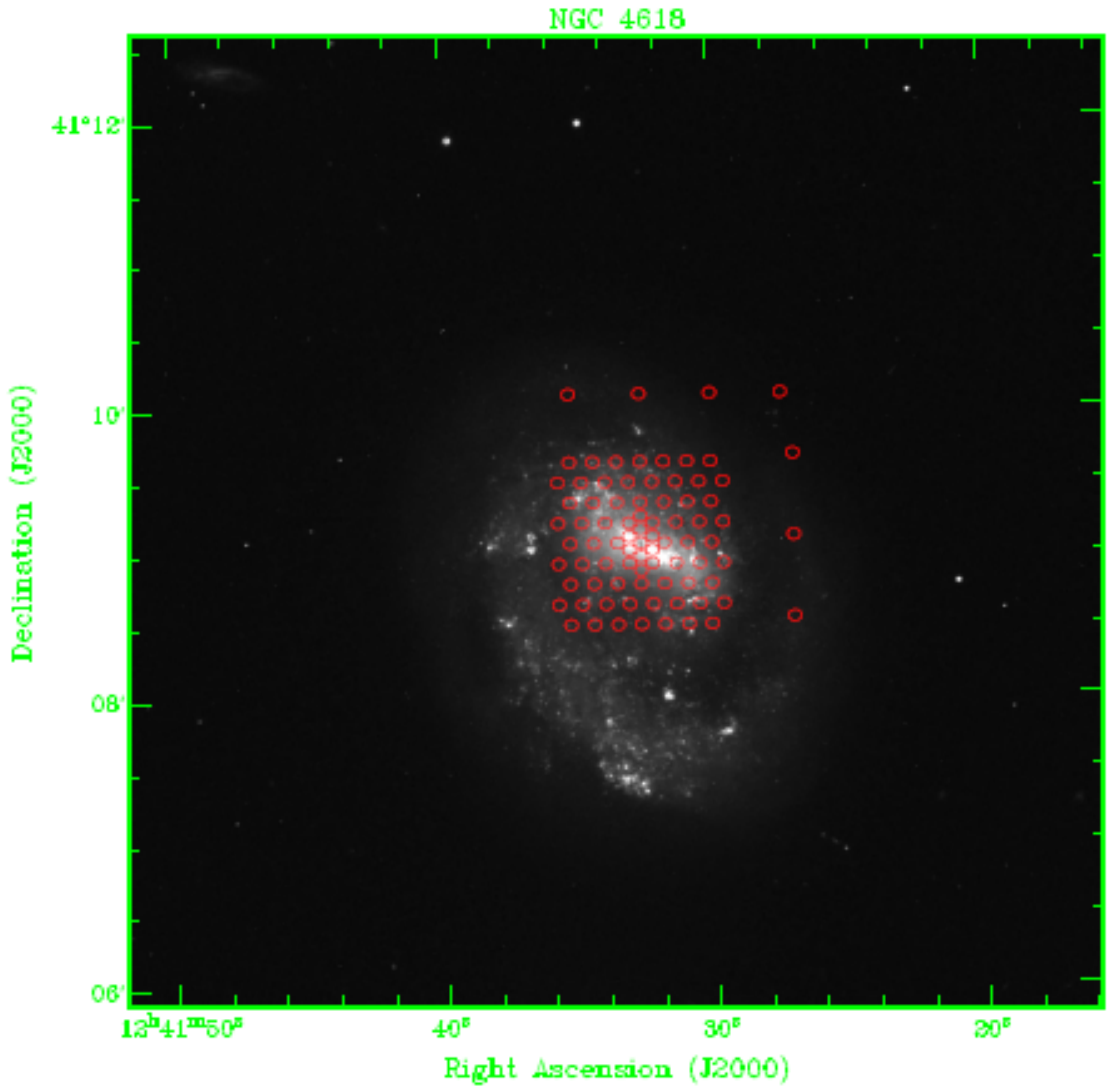




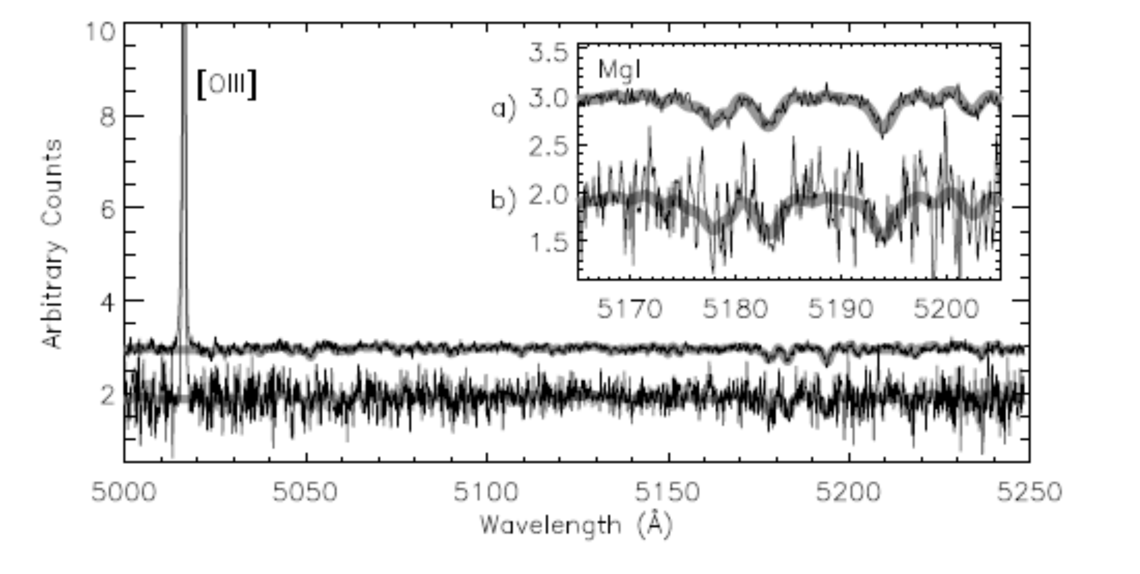
NGC 4618/4625

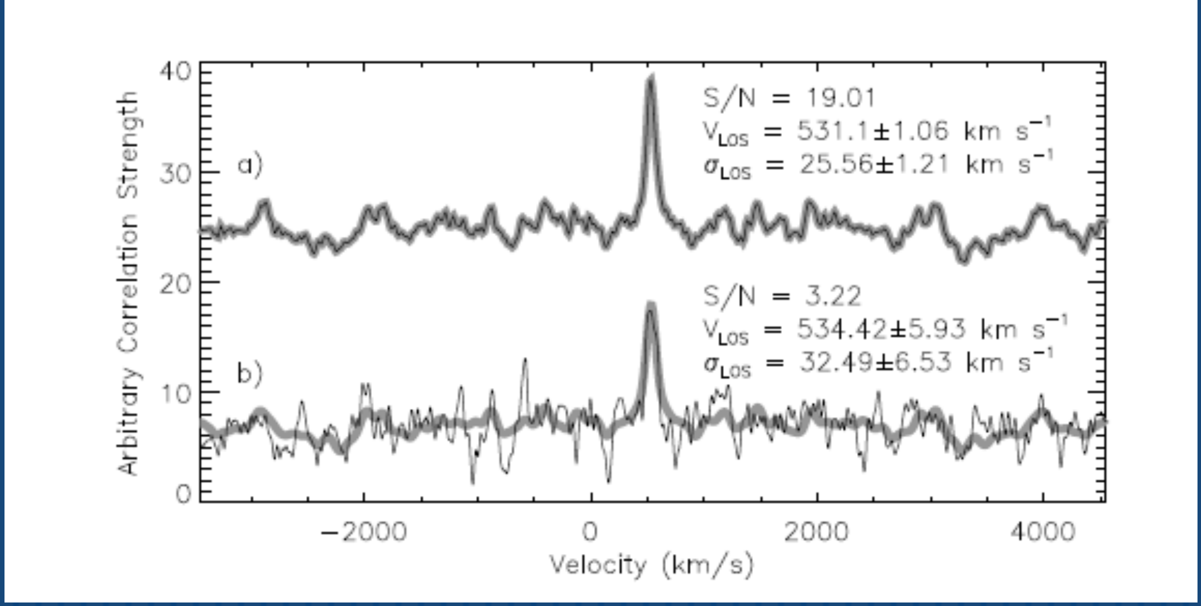
- Interaction timescales: 0.14 – 0.7 Gyr
- Masses
  - NGC 4618 – log M ~ 9.3
  - NGC 4625 – log M ~ 9.9

Extended HI disk of NGC 4625 is amazingly undisturbed; HI profiles/rotation curves not very asymmetric

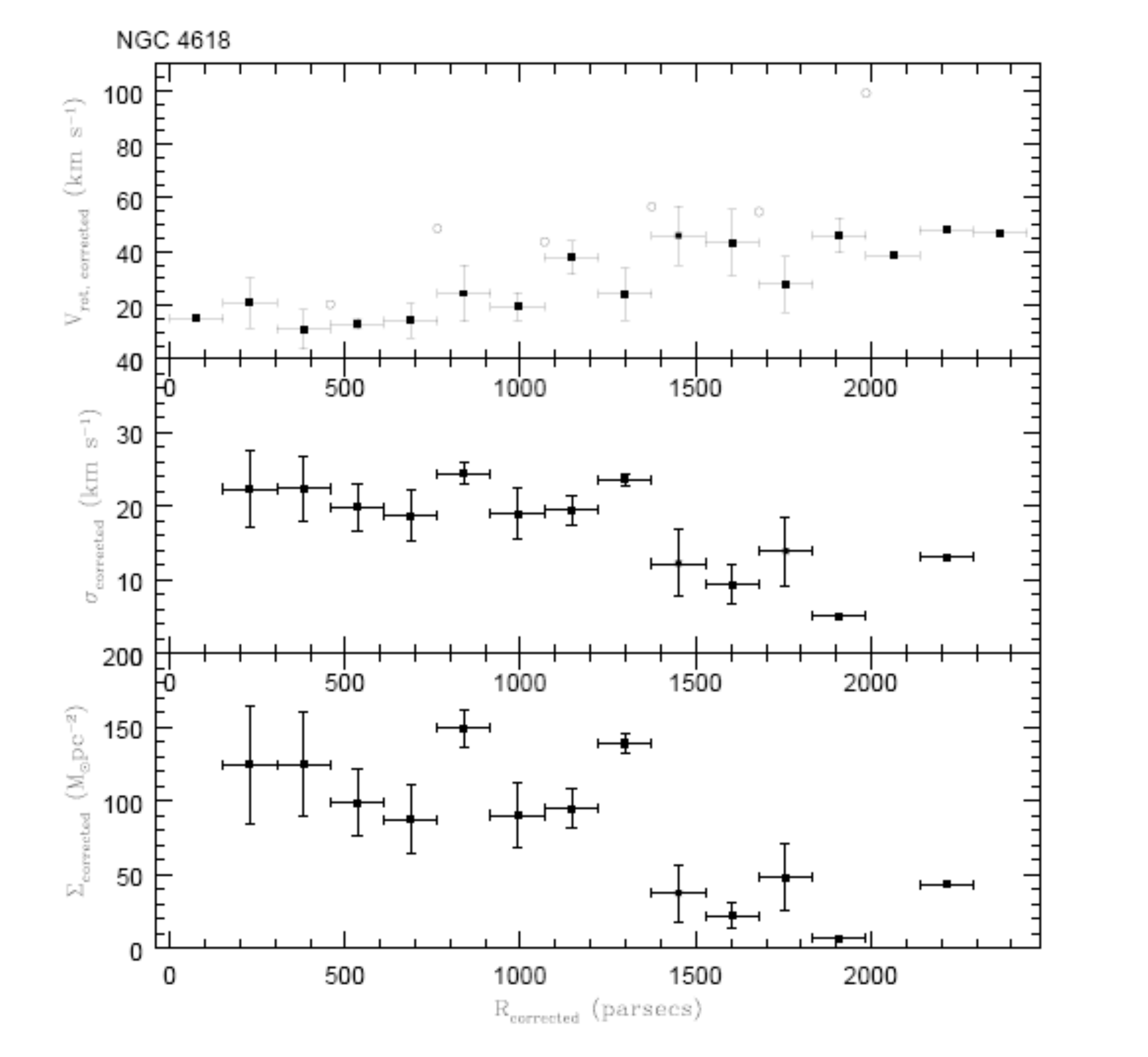


Prescott, Westfall, Wilcots, Bershady 2008



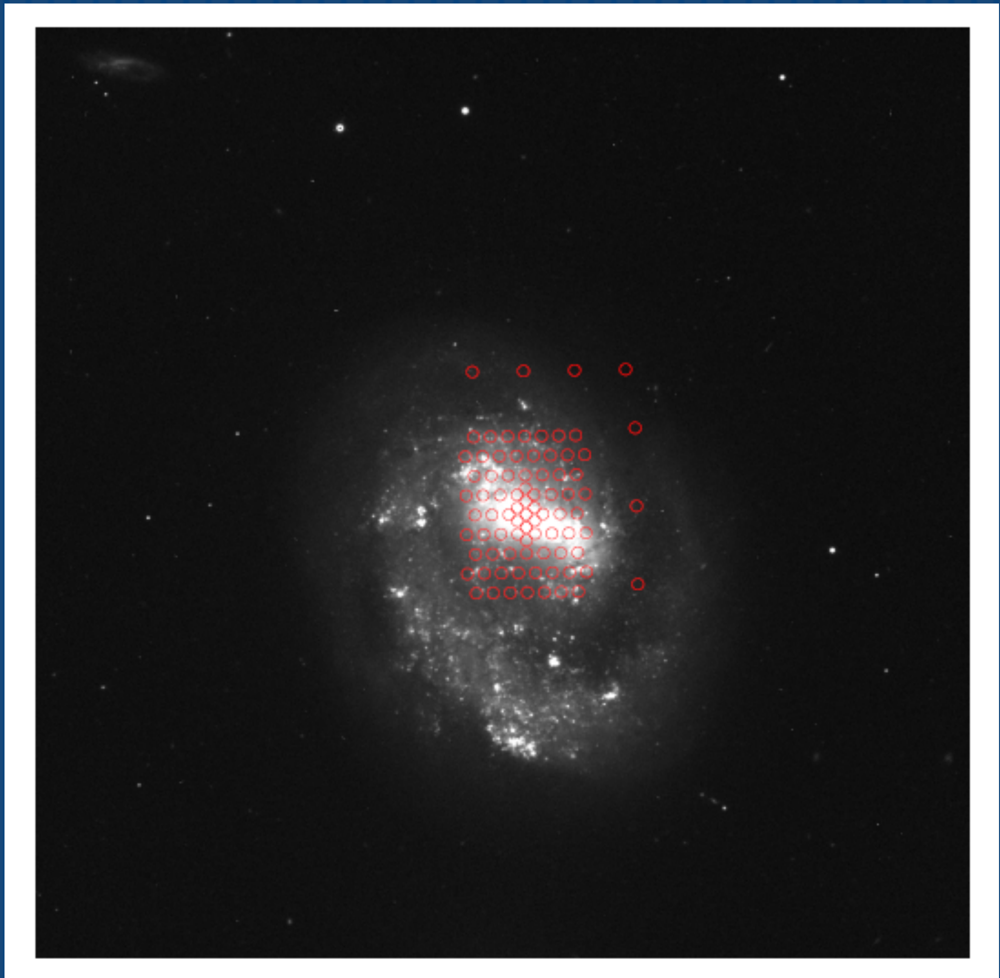


Prescott et al. 2008



NGC 4618
V_rot, corrected (km s^-1)
σ_corrected (km s^-1)
Σ_corrected (M_⊙pc^-2)
R_corrected (parsecs)
0
500
1000
1500
2000

Stellar kinematics of NGC 4618



- $V_{rot} \sim 55$ km s^{-1} (HI)
- $\sigma_z \sim 23$ km s^{-1} (stellar)
- $V/\sigma \sim 2.2$
- Log $M_{dyn} \sim$ 9.67 (HI), 9.25 (stellar disk) – 30% of total

Prescott, Westfall, Wilcots, Bershady (2008, in preparation)

The Mystery of Magellanic Bars

- Bar fraction decreases from Sa→Sc, then increases for later type disk galaxies (Abraham & Merrifield 2000)
- DM dominated systems – not likely to be globally unstable to bar formation
- Interaction -driven???
- Initially offset disk (Junqueira & Combes 1997)
- Secular evolution (Noguchi 2001) – curious enhancement in "concentration parameter" for extreme late-type disk galaxies