HI observations of galaxies in the southern filament of the Virgo Cluster with KAT-7 and WSRT

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September 4th, 2015

Outline

Galaxy evolution in dense regions

The evolutionary path of a galaxy is influenced by its environment (e.g. Dressler+ '80)

When a galaxy falls into a cluster:

- infall *usually* happens along filament
- mechanism(s) of gas stripping in play

In Virgo:

- several HI-tail galaxies observed
- curious case of NGC 4424: complex morphology

NGC 4424: complex galaxy in Virgo

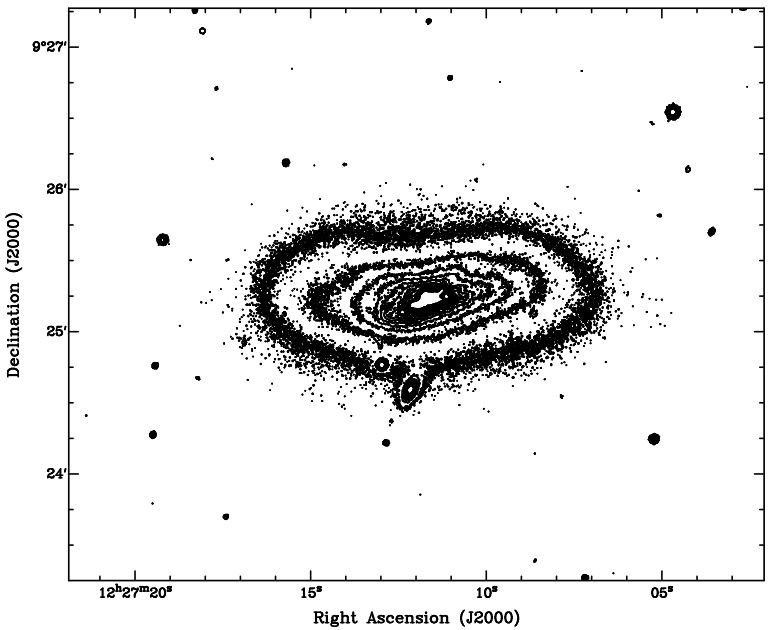
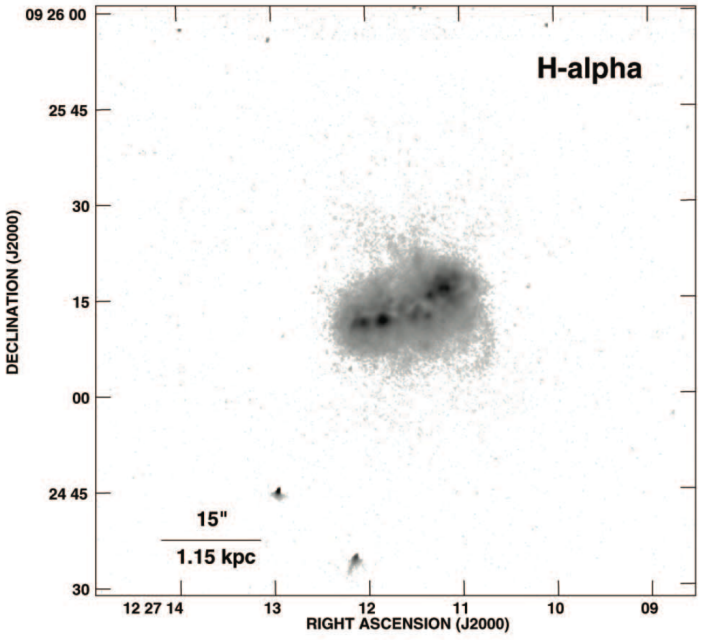
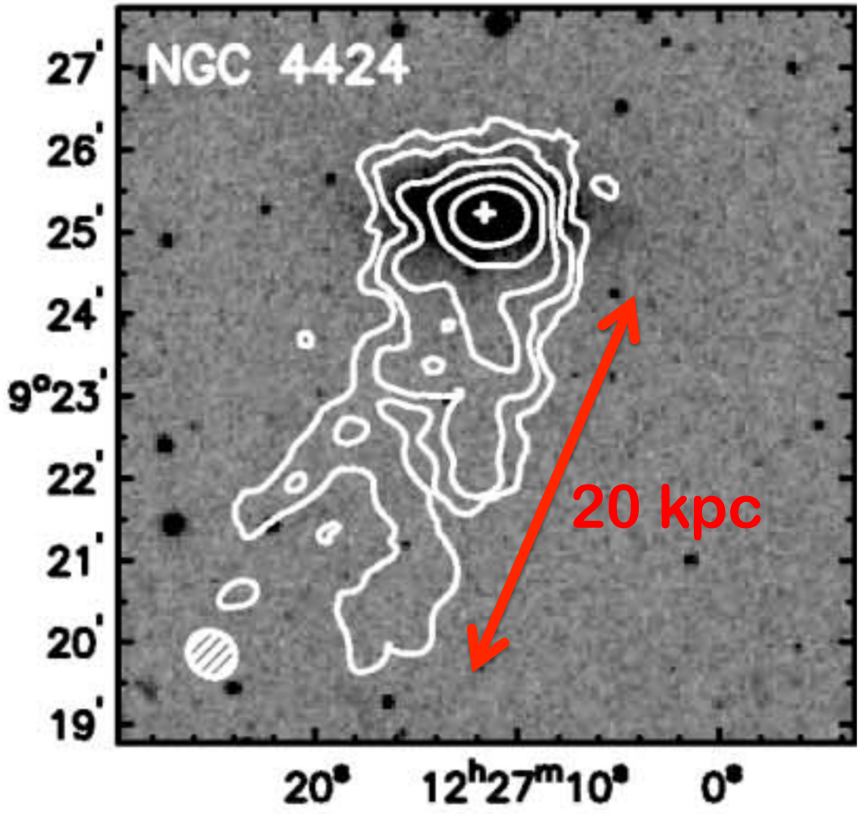


Figure: NGC 4424 in SDSS R-band contours.

- SBa galaxy (de Vaucouleurs)
- 3.1° away from from M87
- Banana-shaped isophotes
- Heavily disturbed stellar disk (Cortés+ '06)
- Small companion to the south

Previous HI observation (Chung et al. '07, VLA)





- HI tail length: 20 kpc
- Truncated disk: ram pressure happening?
- Complex $\mathrm{H}\alpha$ morphology: galaxy-galaxy interaction?
  (Kenney+ '96, Cortés+ '06)

In this work...

Challenge

- Achieve higher sensitivity (lower N_{HI}) and acceptable resolution
- Observe HI tail at an *unprecedented* extent
- Investigate causes of HI tail

Tools

- KAT-7: short baselines $\longrightarrow$ extended structures + high N_{HI} sensitivity
- WSRT: higher resolution

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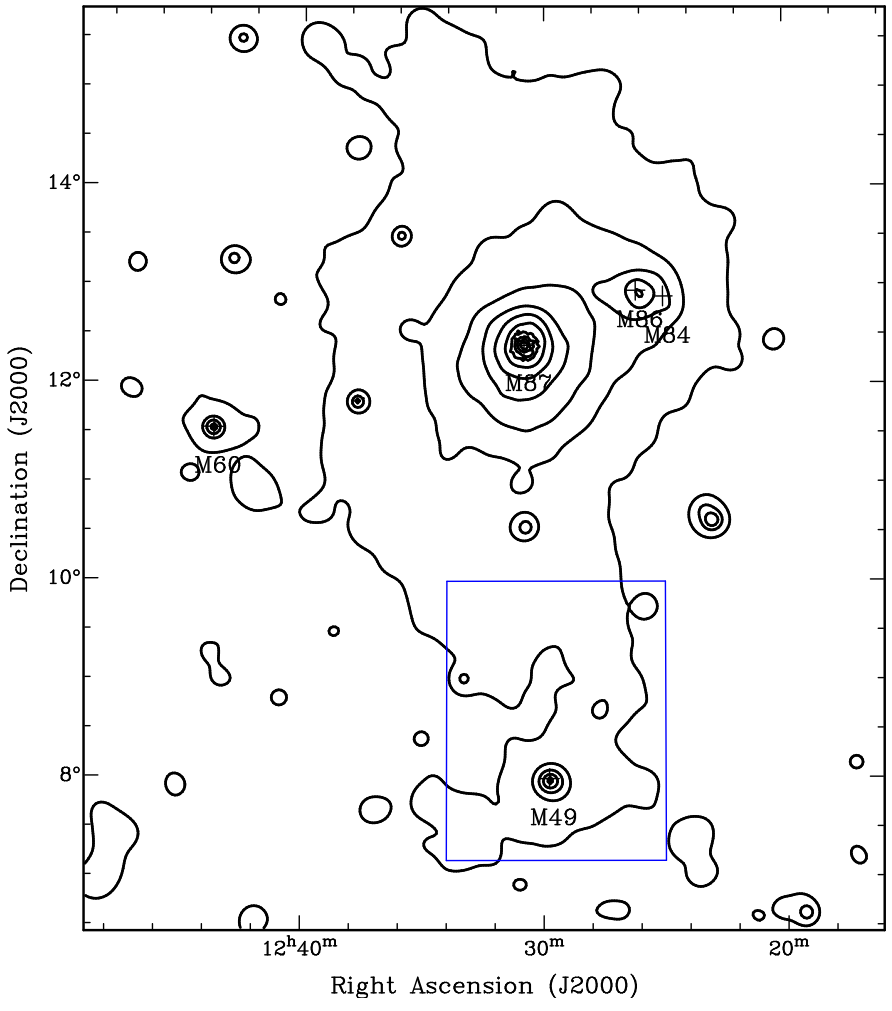
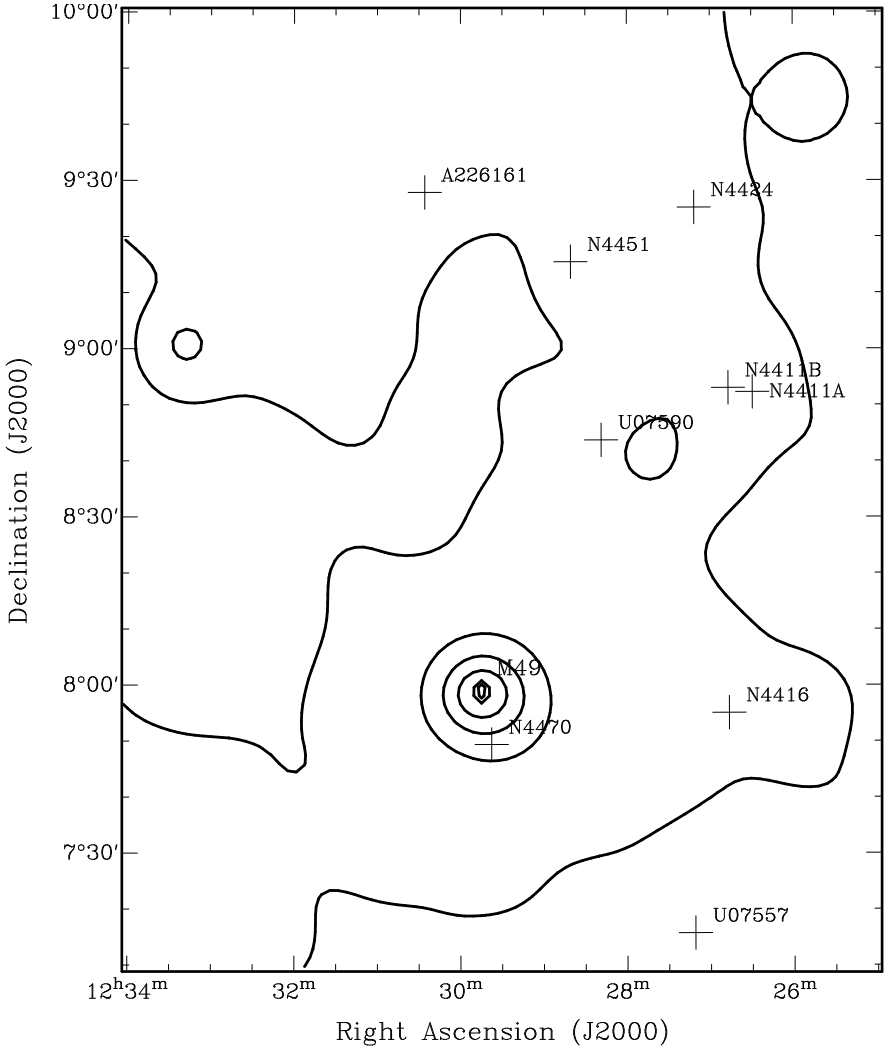
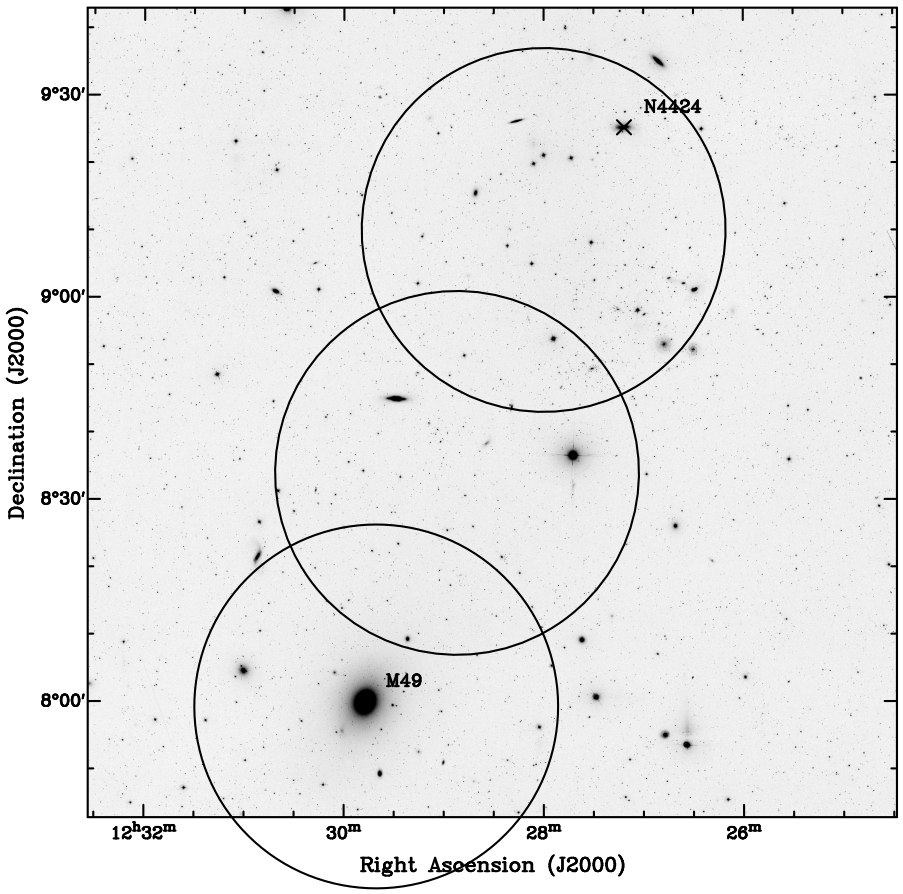
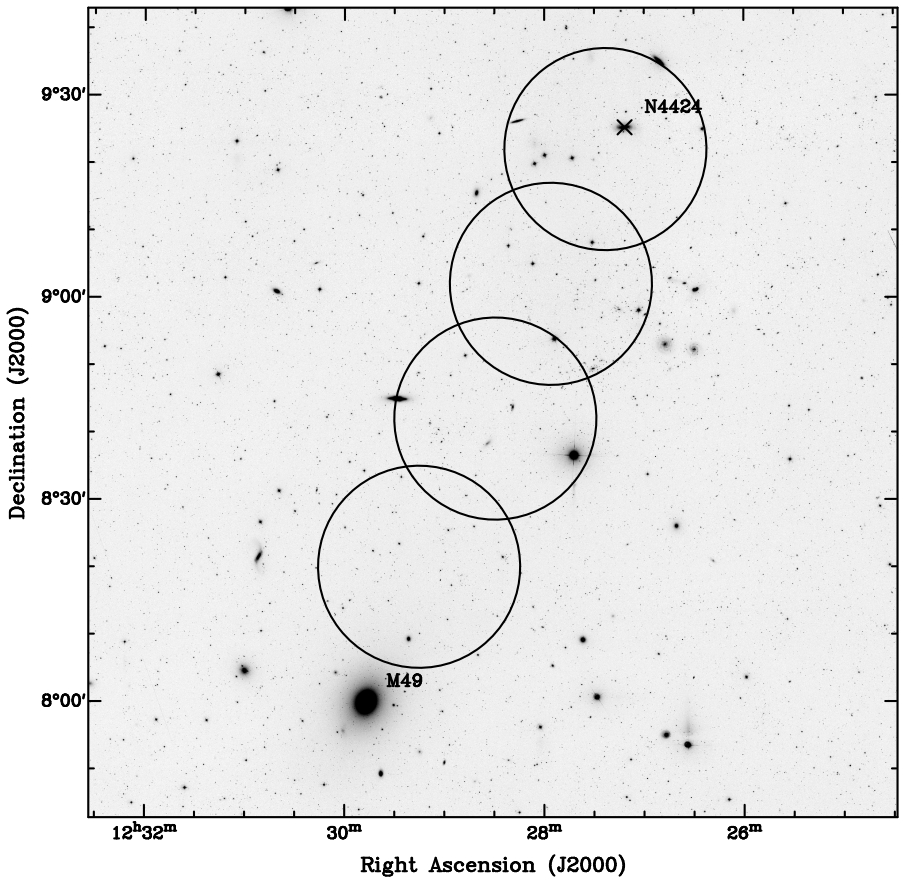
Observed field





Pointings


N4424
M49
9°30′
9°00′
8°30′
8°00′
Declination (J2000)
12h32m
30m
28m
26m
Right Ascension (J2000)


N4424
M49
9°30′
9°00′
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8°00′
Declination (J2000)
12h32m
30m
28m
26m
Right Ascension (J2000)

Summary of observations

Parameter	KAT-7	WSRT
Central frequency	1418.0 MHz	1415.6 MHz
Number of pointings	3	4
Total integration/pointing	30h & 24h & 24h	12h
Velocity range	$\sim$ -2115 $-$ 3179 $\mathrm{km\,s^{-1}}$	$\sim$ -1030 $-$ 2800 $\mathrm{km\,s^{-1}}$
Total bandwidth	25 MHz	20 MHz
Number of channels	4096	1024
Channel bandwidth	6.1 kHz - 1.28 $\mathrm{km\,s^{-1}}$	19.5 kHz - 4.13 $\mathrm{km\,s^{-1}}$
Synthesized beam	$\sim 4'$	$\sim 3' \times 0.5'$

Final cubes

KAT-7 & WSRT cubes

- Over $\sim 15\,\mathrm{km\,s^{-1}}$
  - $\sigma_{\mathrm{KAT7}} \sim 2.5\,\mathrm{mJy\,beam^{-1}}$
  - $\sigma_{\mathrm{WSRT}} \sim 0.35\,\mathrm{mJy\,beam^{-1}}$
- over $\sim 75\,\mathrm{km\,s^{-1}}$ and at 3σ
  - KAT-7 : $N_{HI} \sim 1.2 \times 10^{19}\,\mathrm{cm^{-2}}$
  - WSRT : $N_{HI} \sim 1.4 \times 10^{19}\,\mathrm{cm^{-2}}$

KAT-7 + WSRT?

- ~~Traditional combination in u,v plane~~
- New approach: combination in N_{HI}

$$I_c = \frac{1.26\,I_K + I_W}{2.26}$$

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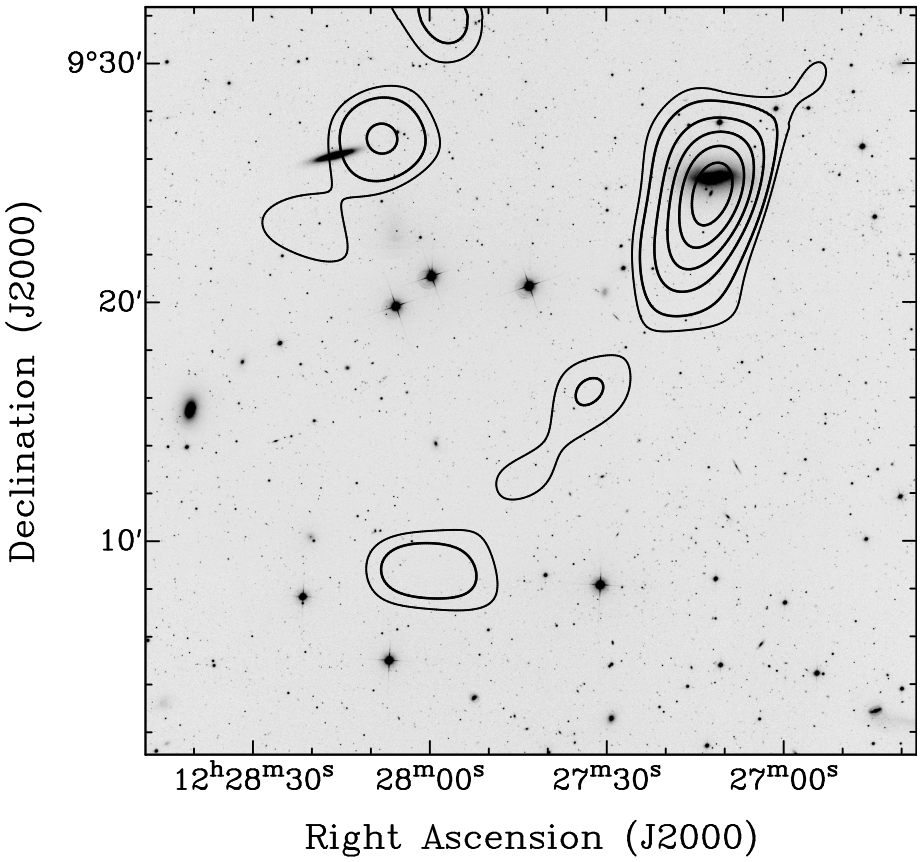
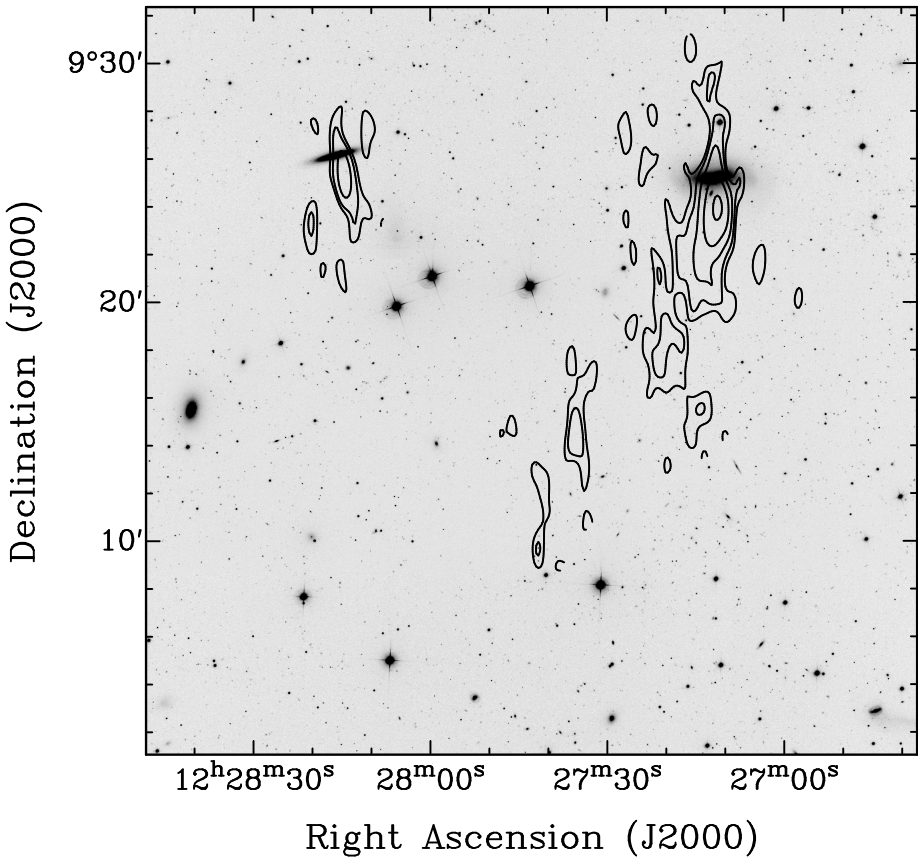
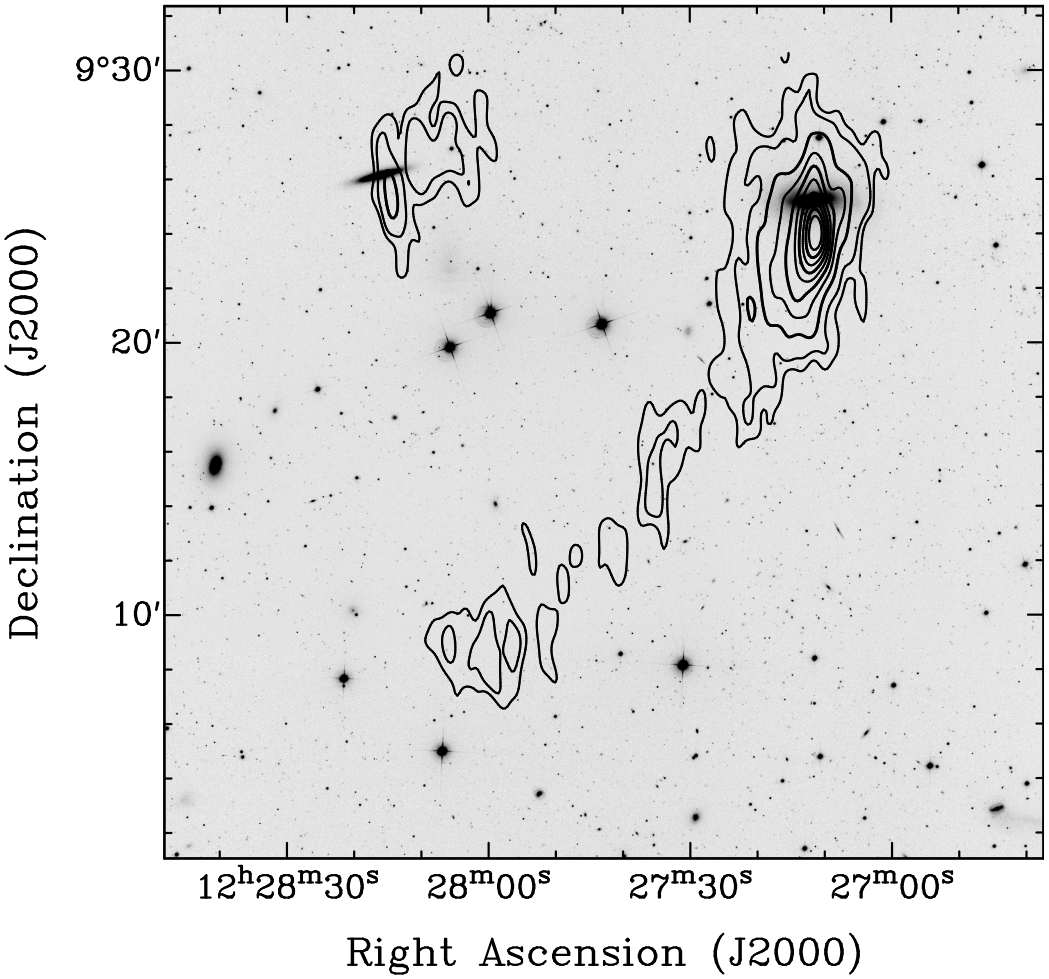
NGC 4424, KAT-7 & WSRT





NGC 4424, KAT-7 + WSRT



- contour levels: $5 \times 10^{18} - 10^{20}\,\mathrm{cm}^{-2}$
- Better sensitivity in combined map
- HI tail length: $\sim$ 60 kpc, i.e 3x VLA detection
- Tail contains 20% of galaxy's HI mass
- A tail detected in N4445 in opposite direction

Origin of the tail

What caused the HI tail?

Two most likely processes:

- ram pressure
- galaxy-galaxy interaction

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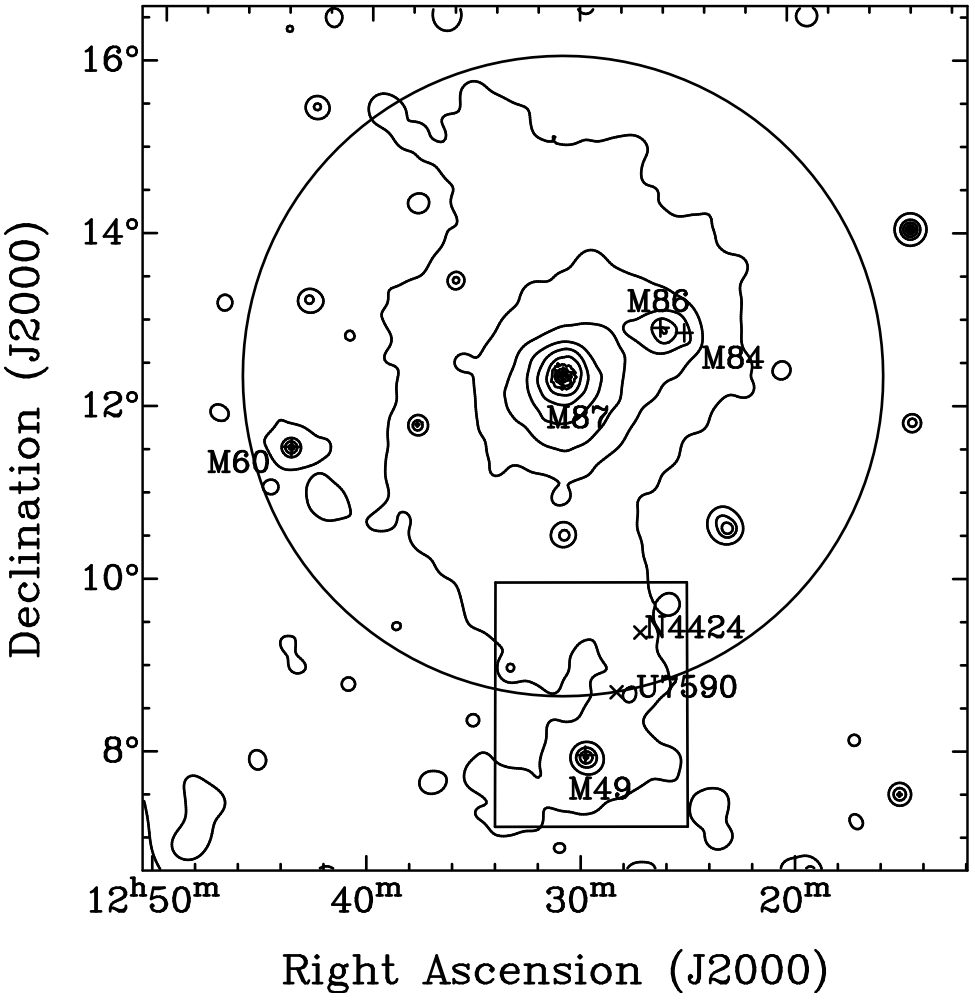
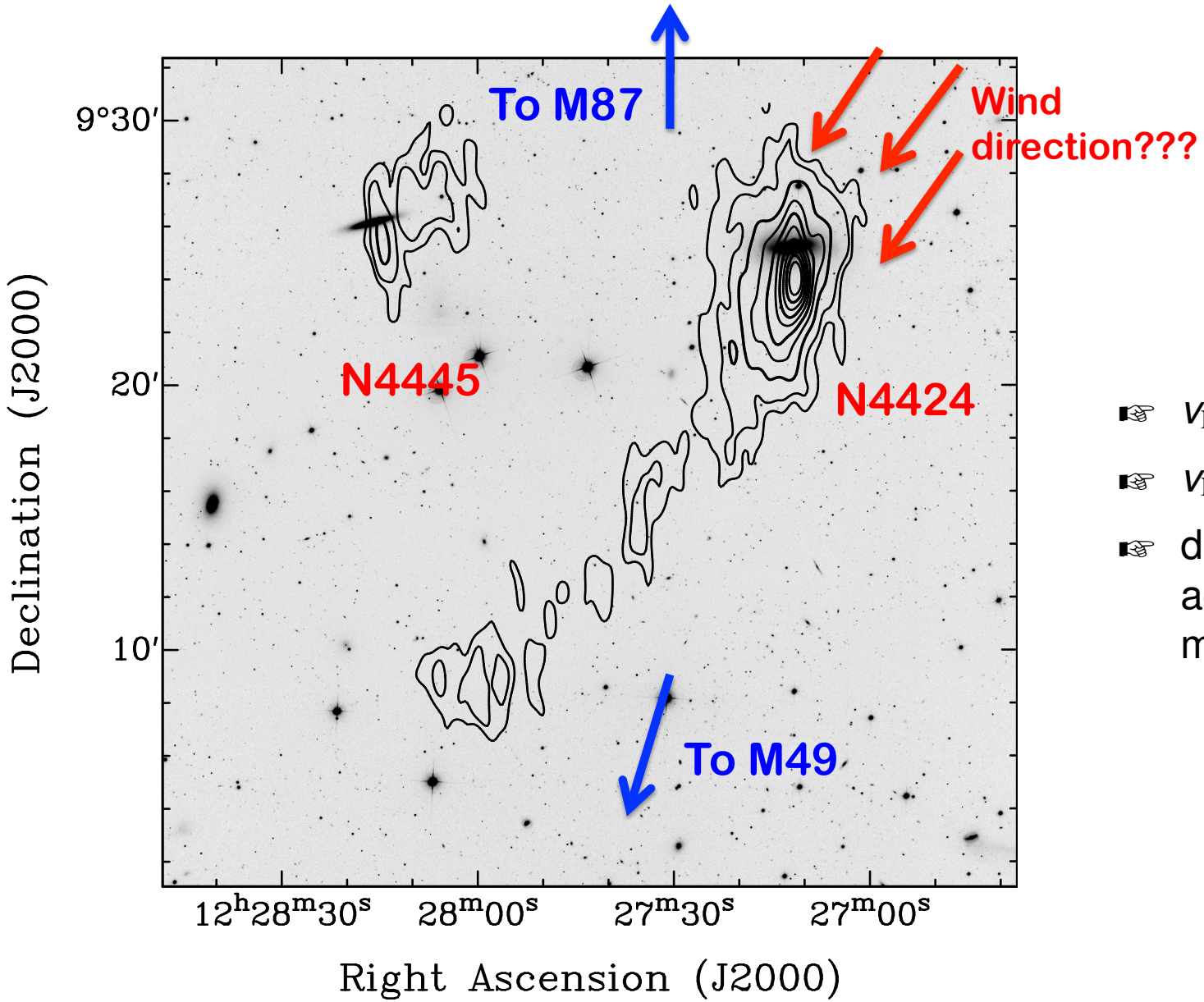
Ram pressure

- Very effective out to $1 - 2\, r_{\rm vir}$ (Kenney+ '04, Crowl+ '05, Tonnesen+ '07, Bahe+ '13)
- $p_{\rm ram} > f_{\rm restoring}$ possible (Chung+ '07)



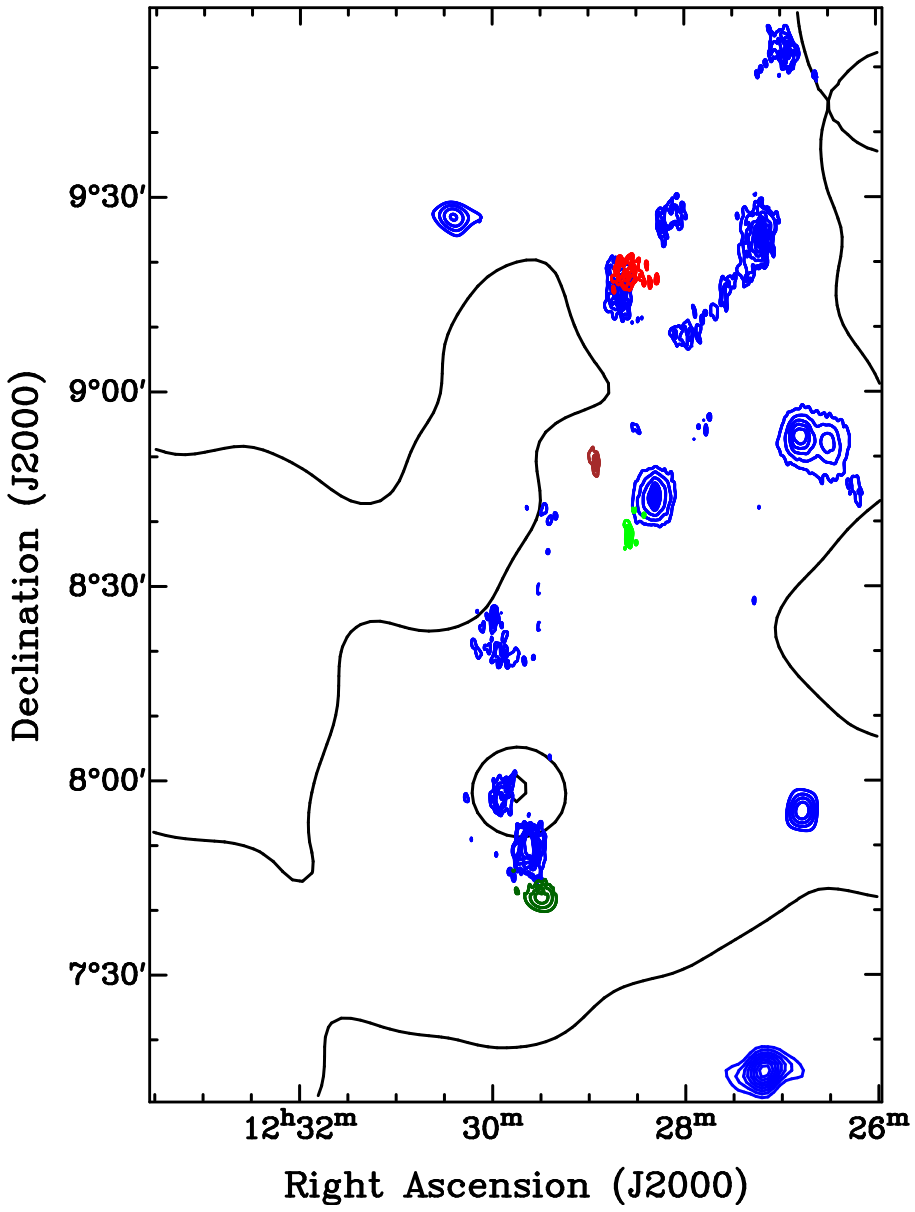
Ram pressure



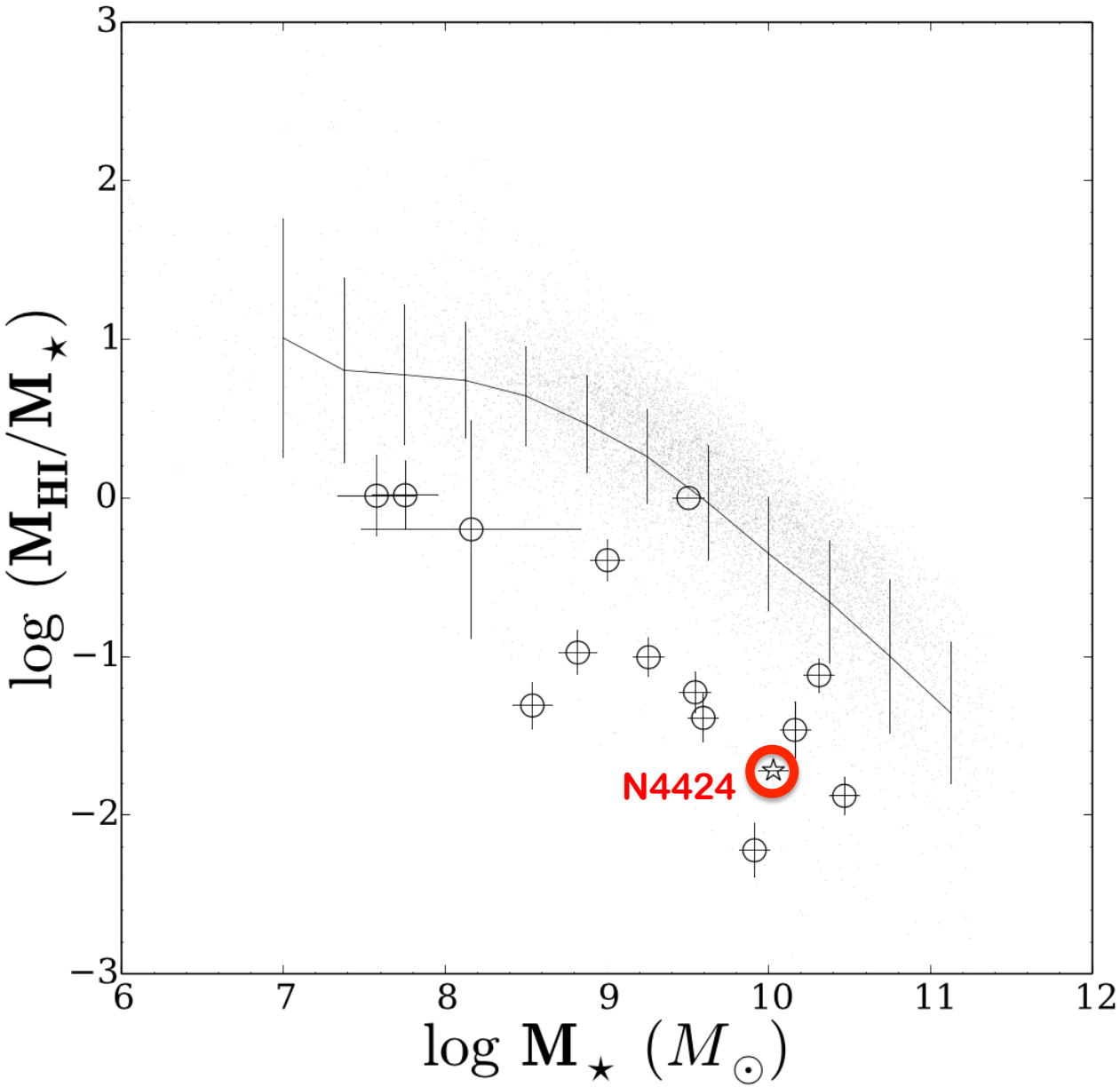
- $v_{\mathrm{N4424}} = 433\,\mathrm{km\,s^{-1}}$
- $v_{\mathrm{N4445}} = 418\,\mathrm{km\,s^{-1}}$
- direction of wind agree with infall motion

Ram pressure

- Black contours: *ROSAT* x-ray emission
- Other colours: HI
- Most galaxies on ‘filament’ present asymmetry
- A few HI clouds with no optical counterparts



Gas content



- Comparison of detected galaxies vs. ALFALFA sample (see Maddox+ '15 for description of sample)
- $M_\star$ of galaxies derived from *WISE* photometry
- ALFALFA sample represents 'upper limit'
- N4424 gas content is *typical* of environment

Is there room for galaxy-galaxy interaction?

Short answer: YES!

- Ram Pressure *only* cannot explain the complex $\mathrm{H}\alpha$ morphology of NGC 4424.
- NGC 4445 could be the interacting companion. Needs further investigation.

However...

- galaxy-galaxy interaction is NOT required to explain the tail
- the hot x-ray gas distribution matches with the morphology of the tail

Summary

- Combining HI data cubes in column density units might be an alternative to combining different arrays: technique to be tested with other arrays
- The extent of NGC 4424's tail is larger than previously thought: $\sim$ 60 kpc vs. $\sim$ 20 kpc previously detected
- Although galaxy-galaxy interaction is not ruled out, it is most likely that the tail is caused by ram pressure stripping

Thank You!

Summary

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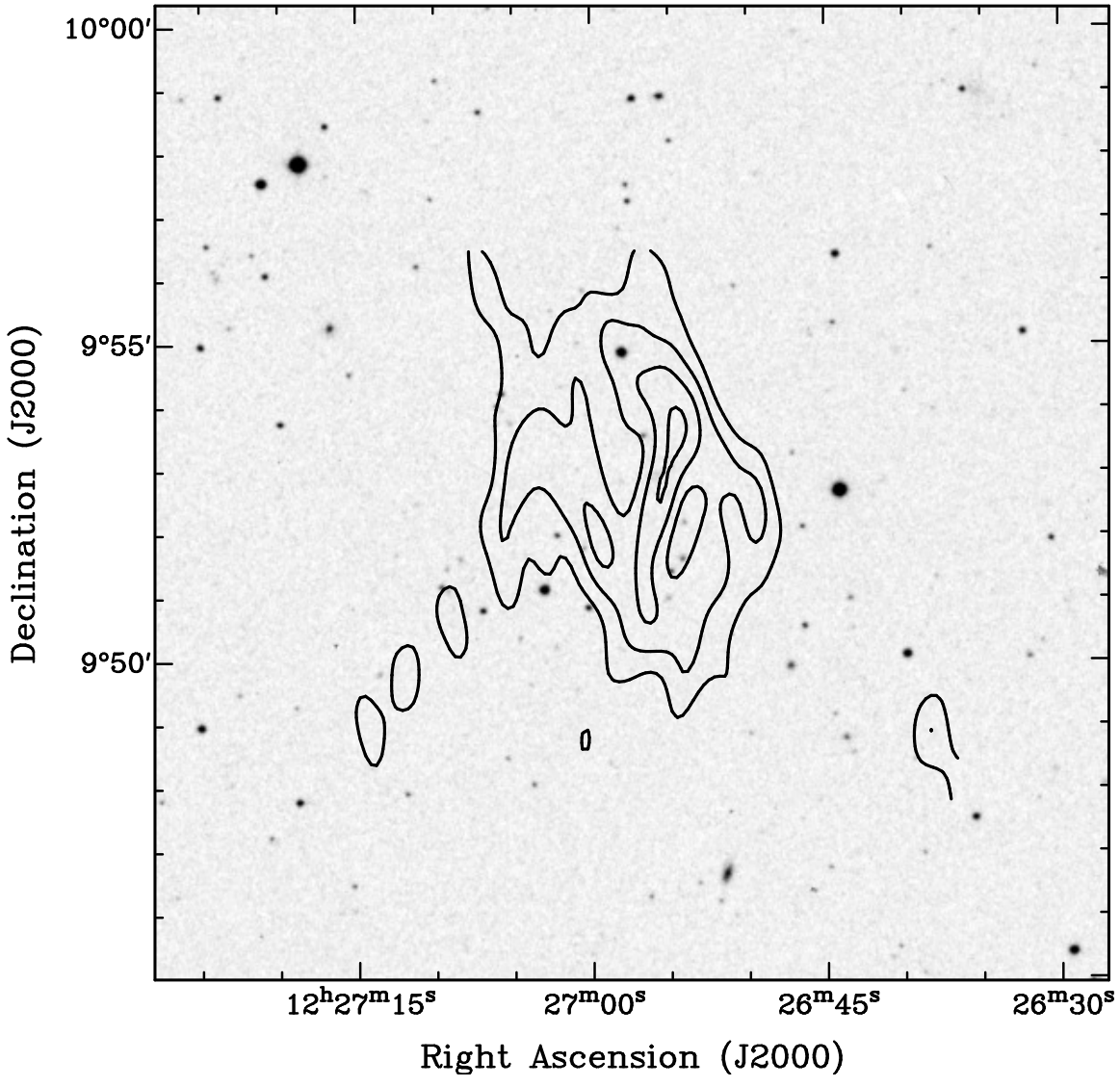
Thank You!

VCC 0952


10°00′
9°55′
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Declination (J2000)
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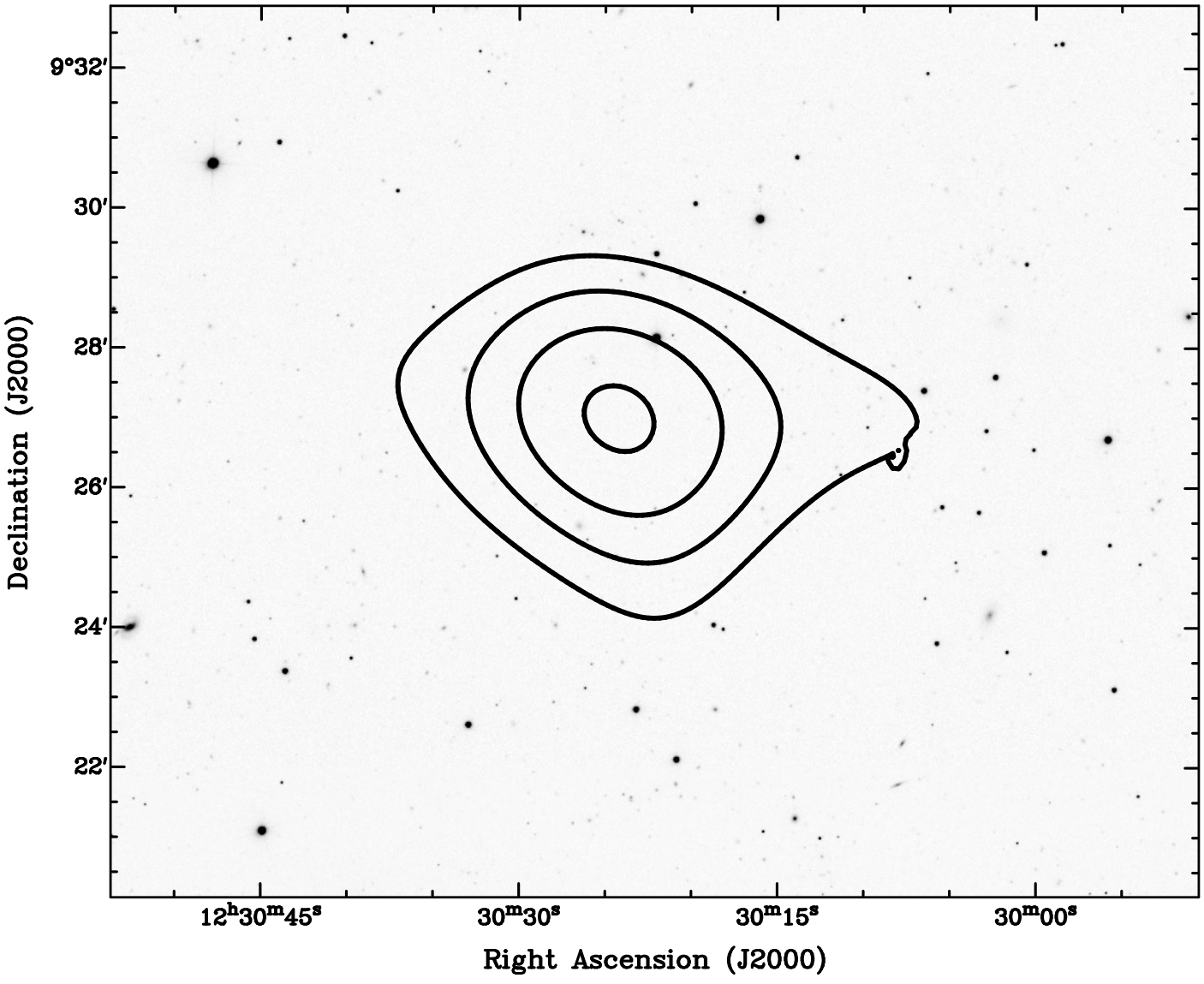
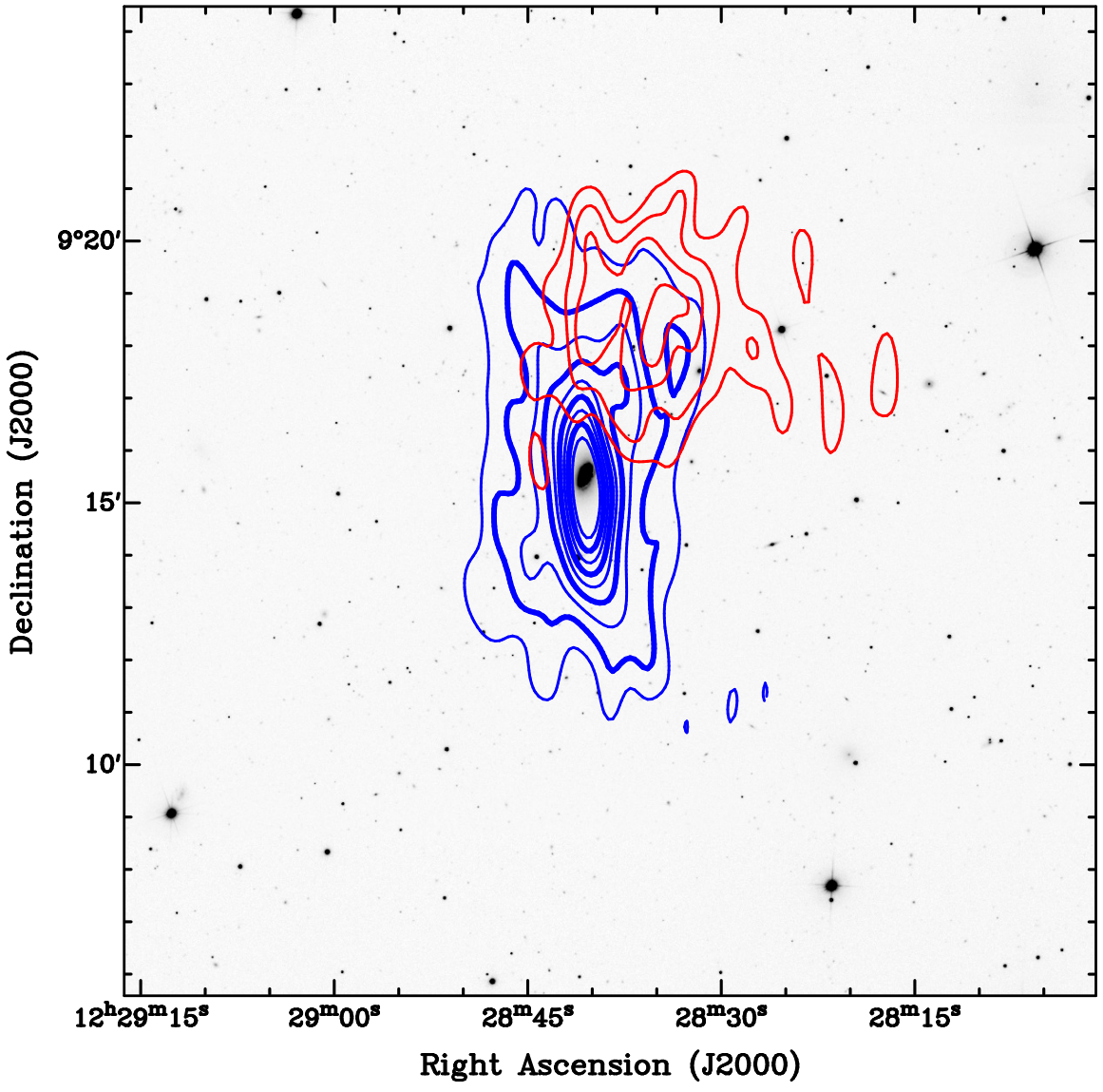
26m45s
26m30s
Right Ascension (J2000)

Cloud 7c aka AGC 226161



N4451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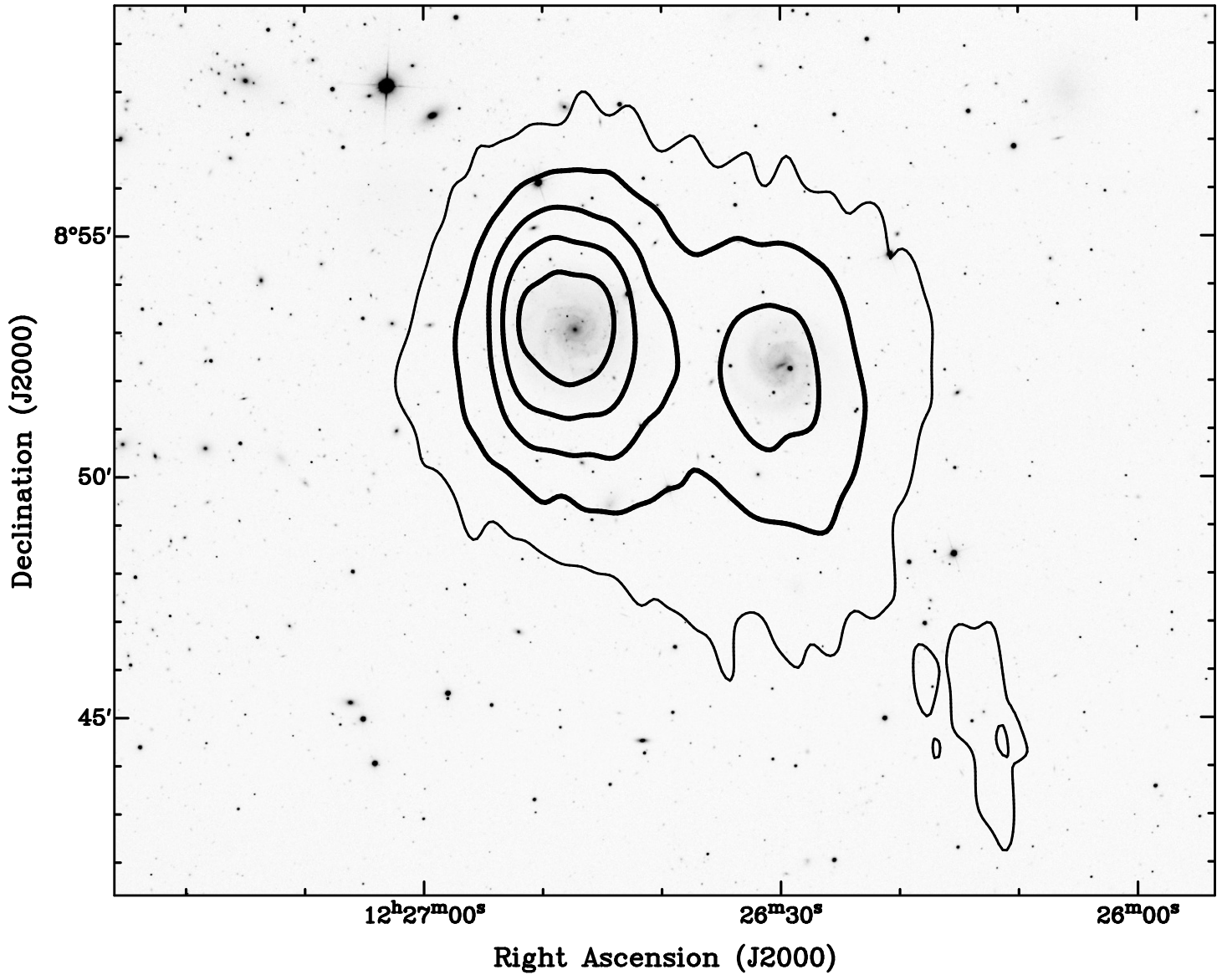
Right Ascension (J2000)

NGC 4411 A&B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45′
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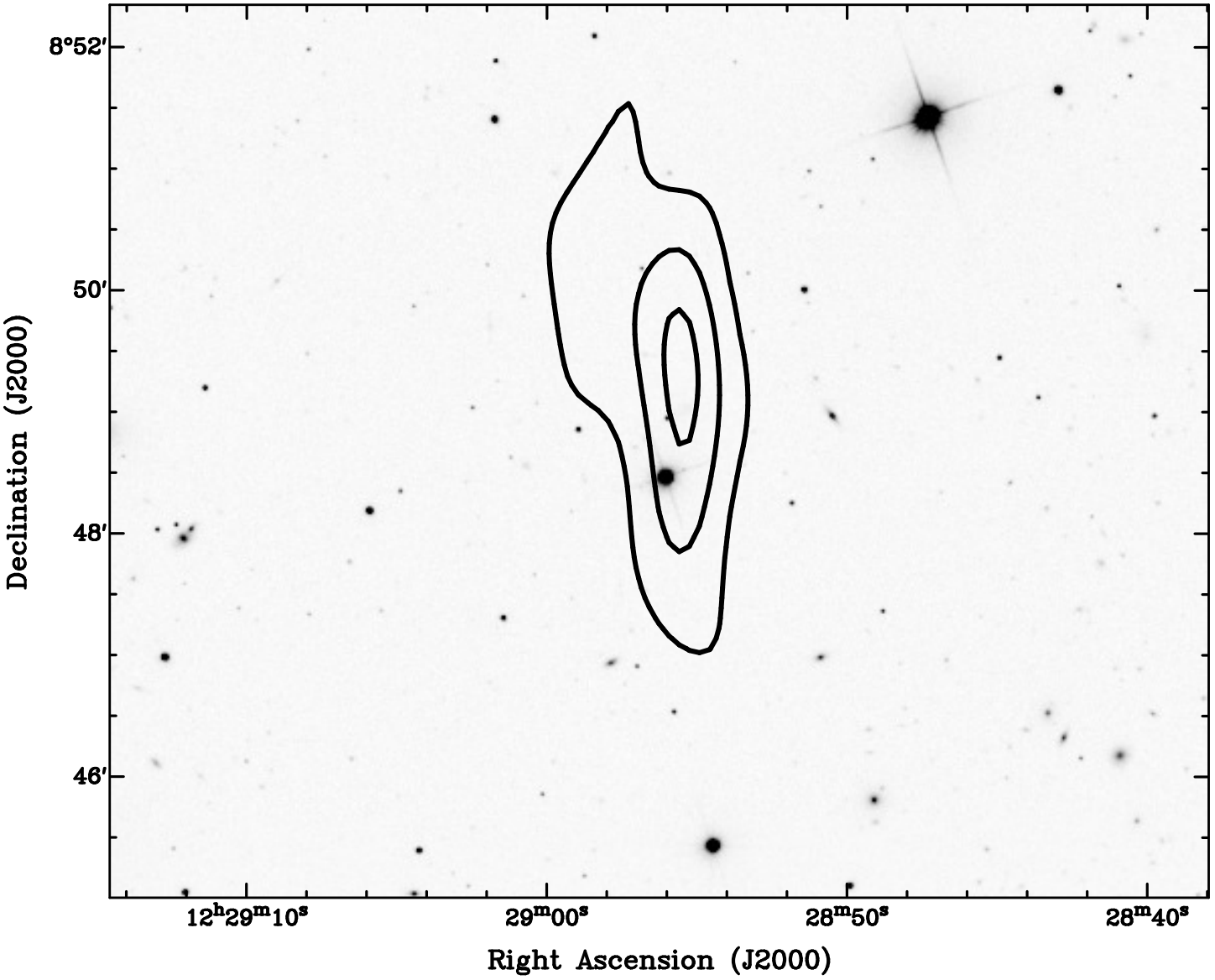
26m00s
Right Ascension (J2000)

VCC 1142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48′
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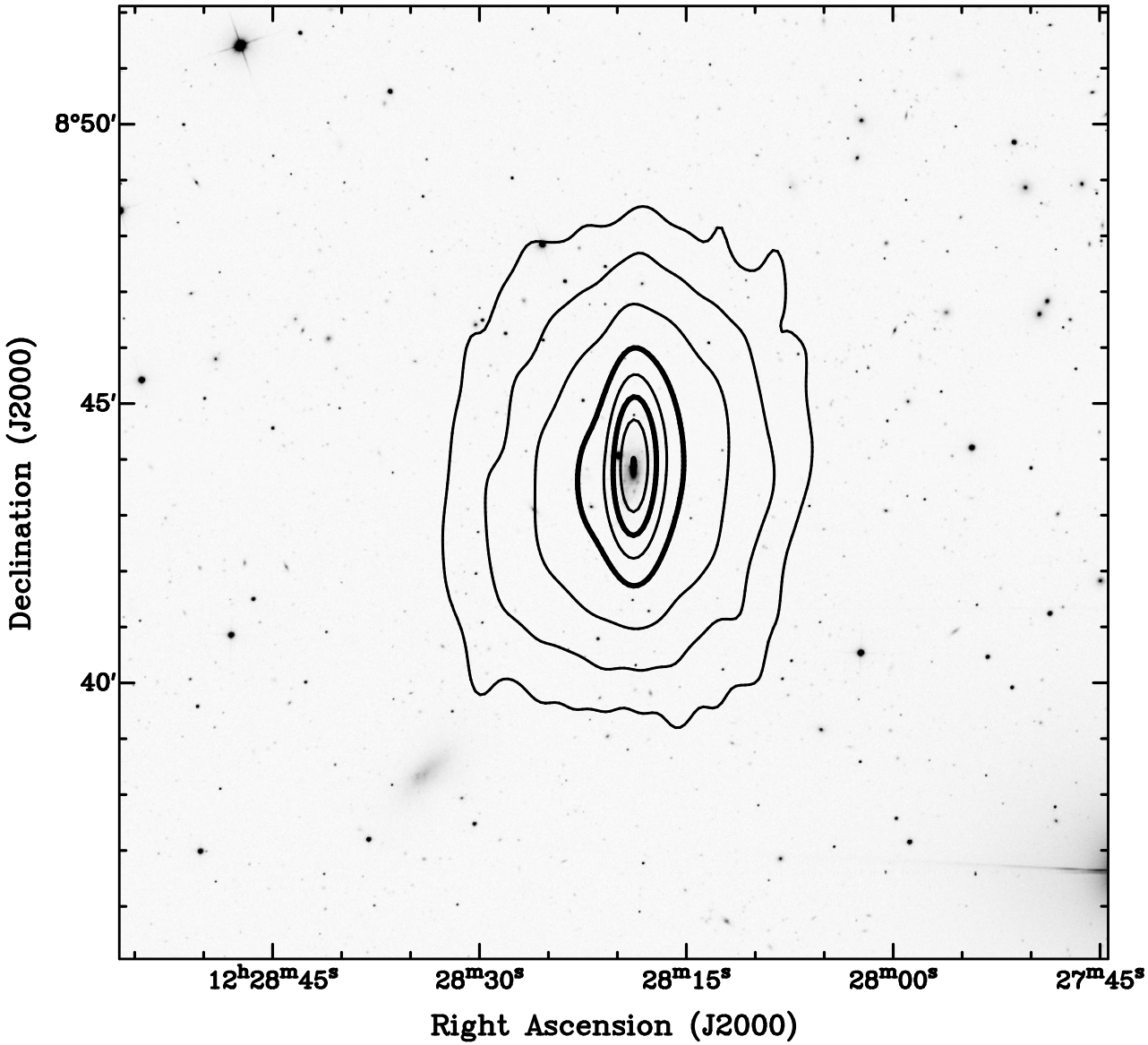
28m40s
Right Ascension (J2000)

UGC 7590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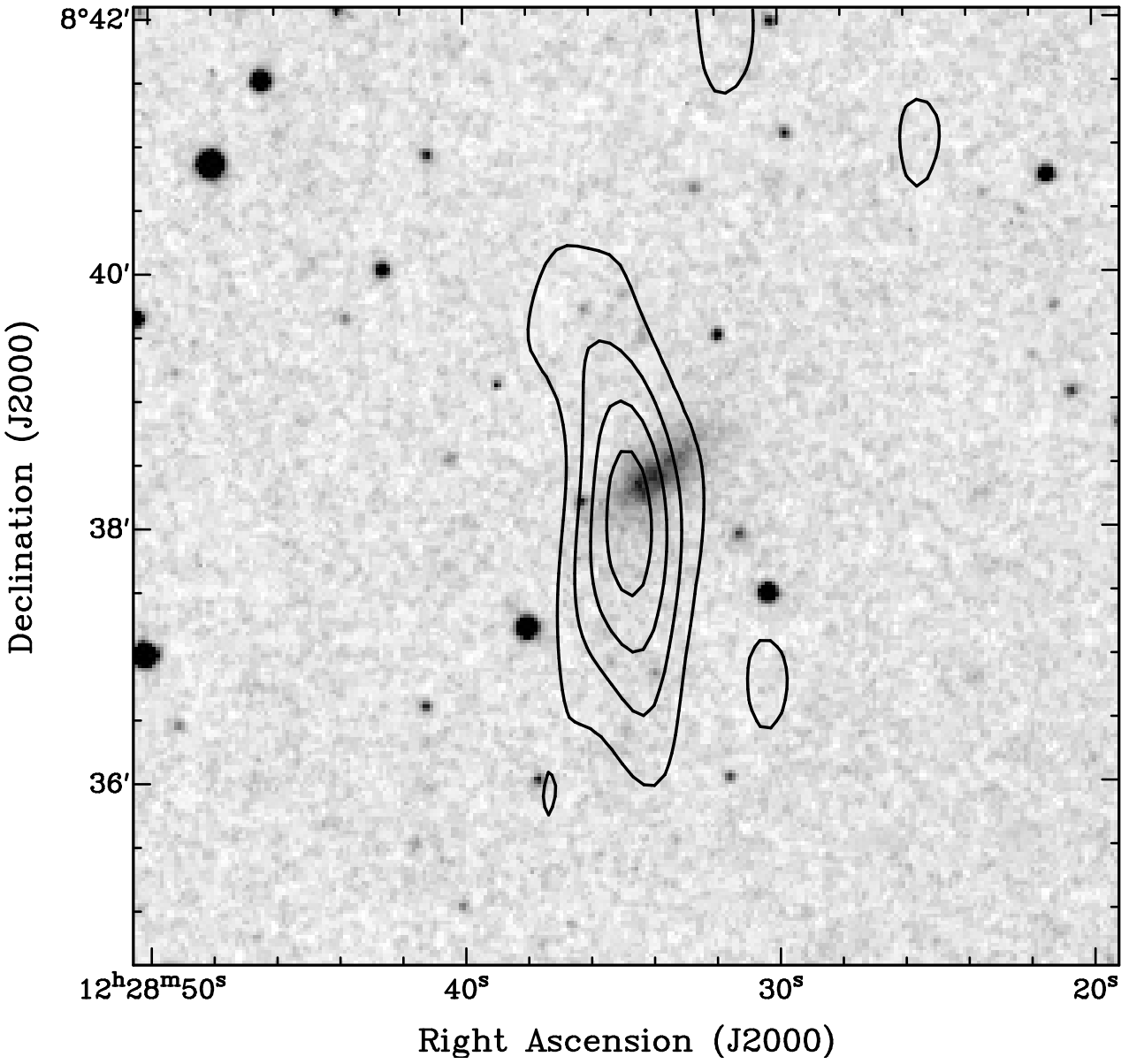
Right Ascension (J2000)

UGC 7596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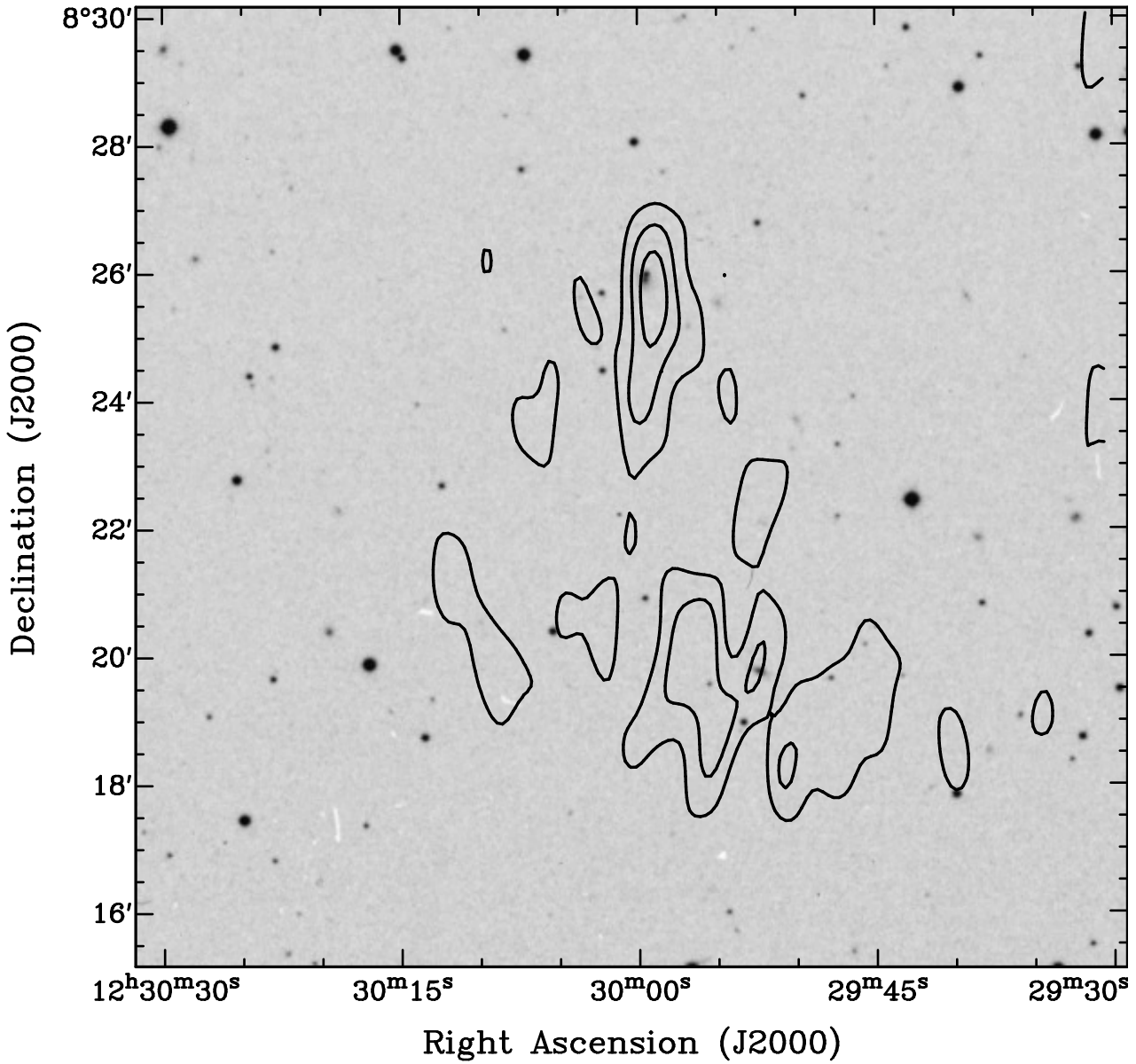
30s
20s
Right Ascension (J2000)

AGESVC1 293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22′
20′
18′
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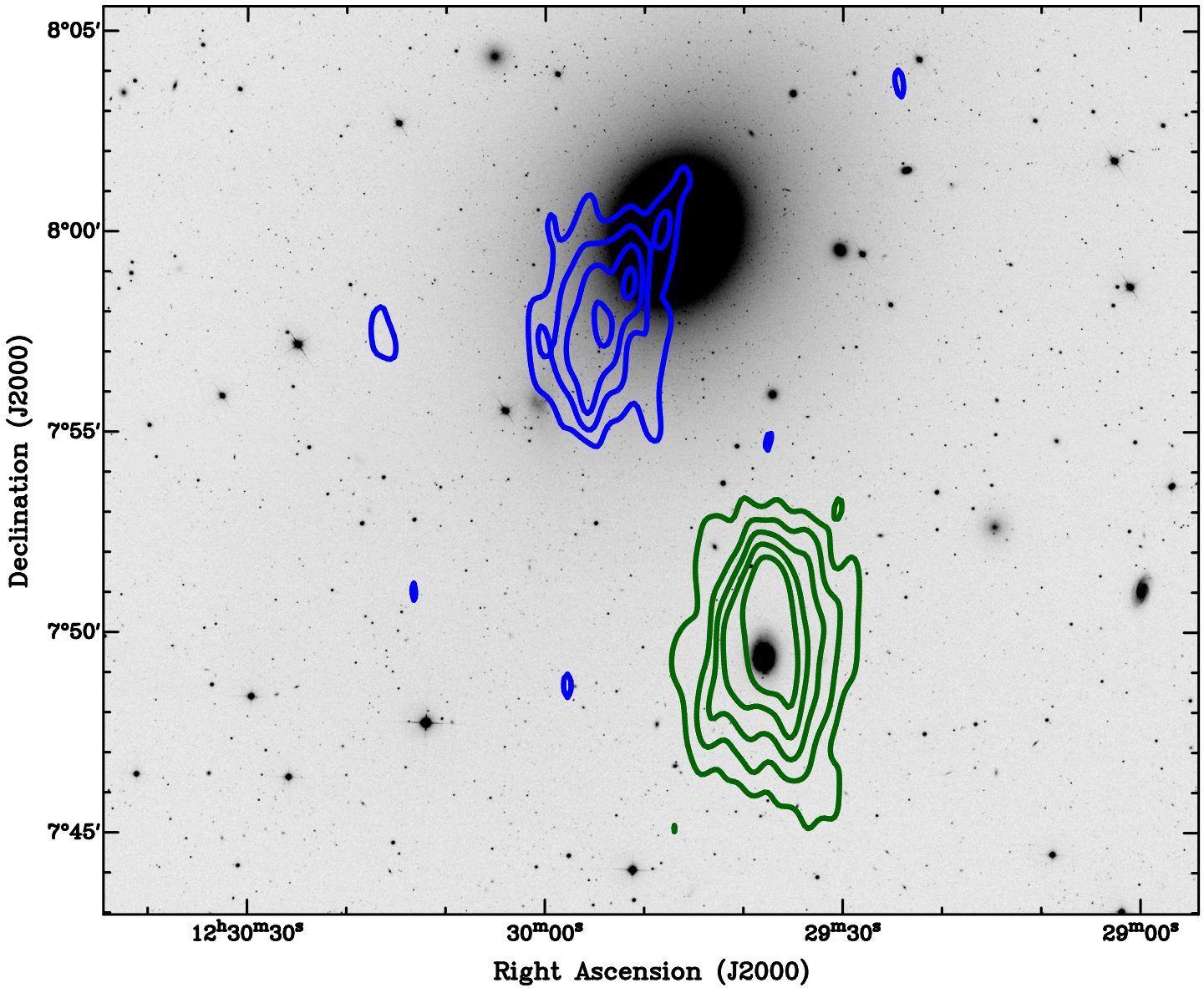
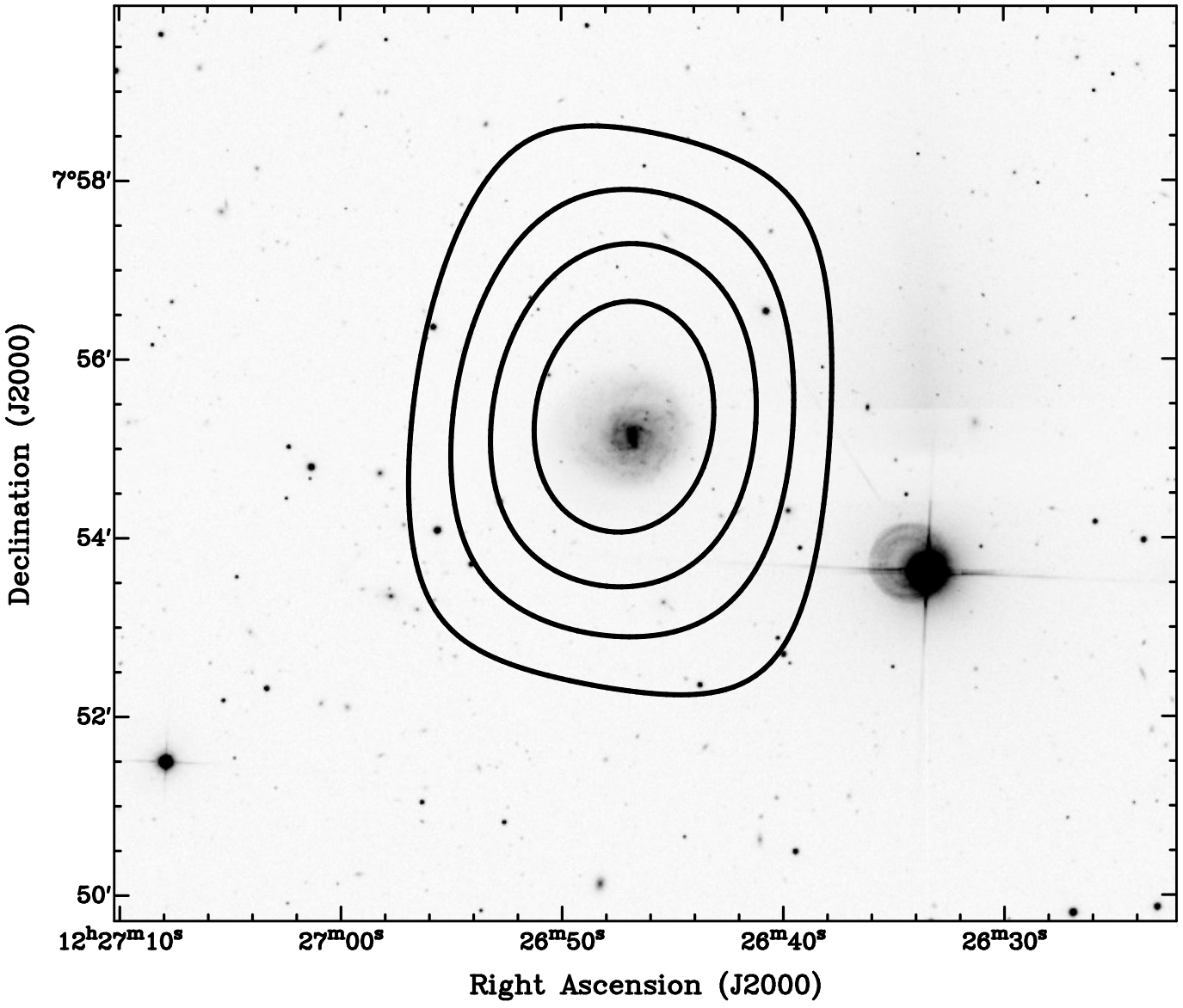
Right Ascension (J2000)

Gas cloud near M49



NGC 4416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56′
54′
52′
50′
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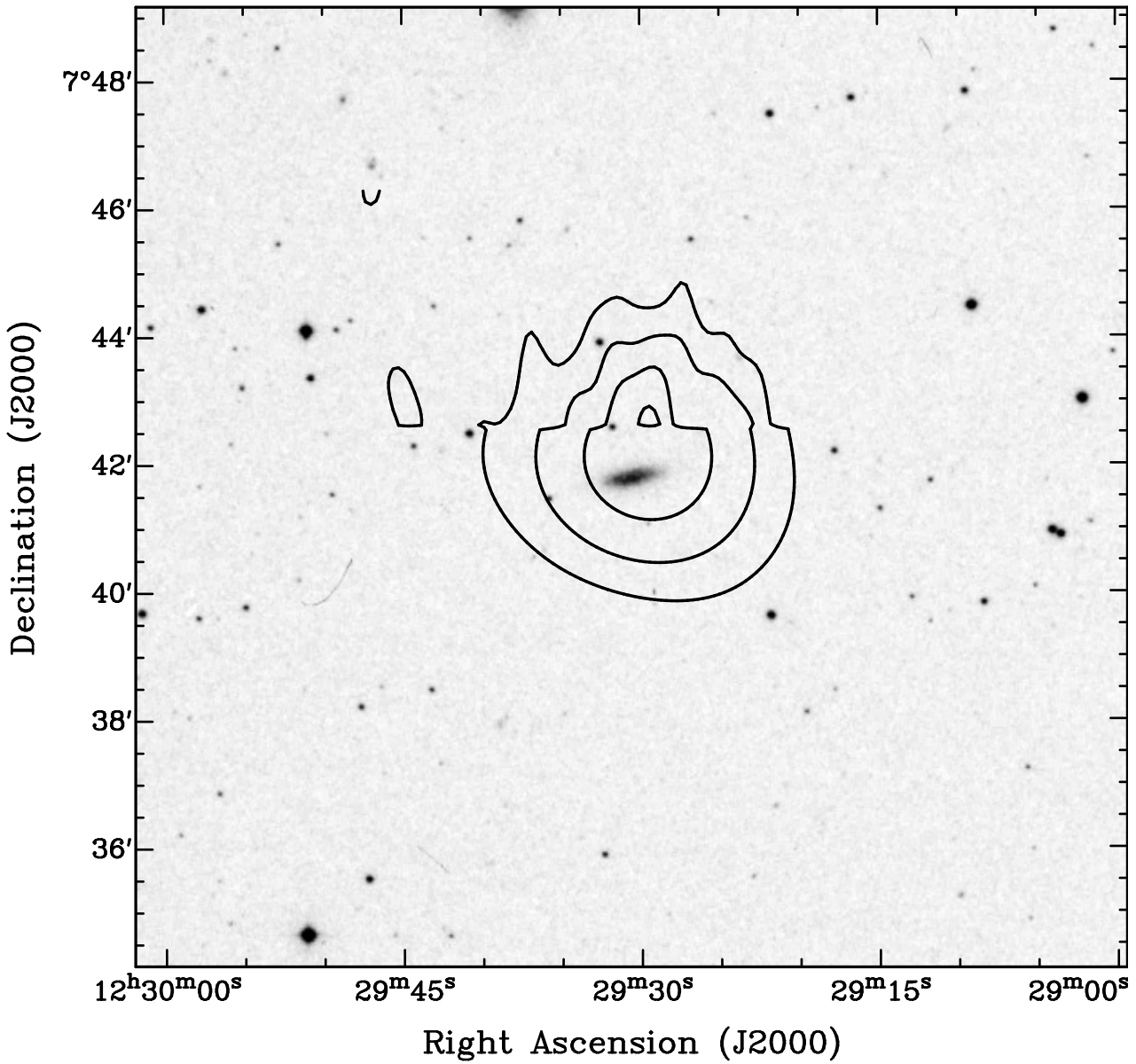
Right Ascension (J2000)

NGC 4466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44′
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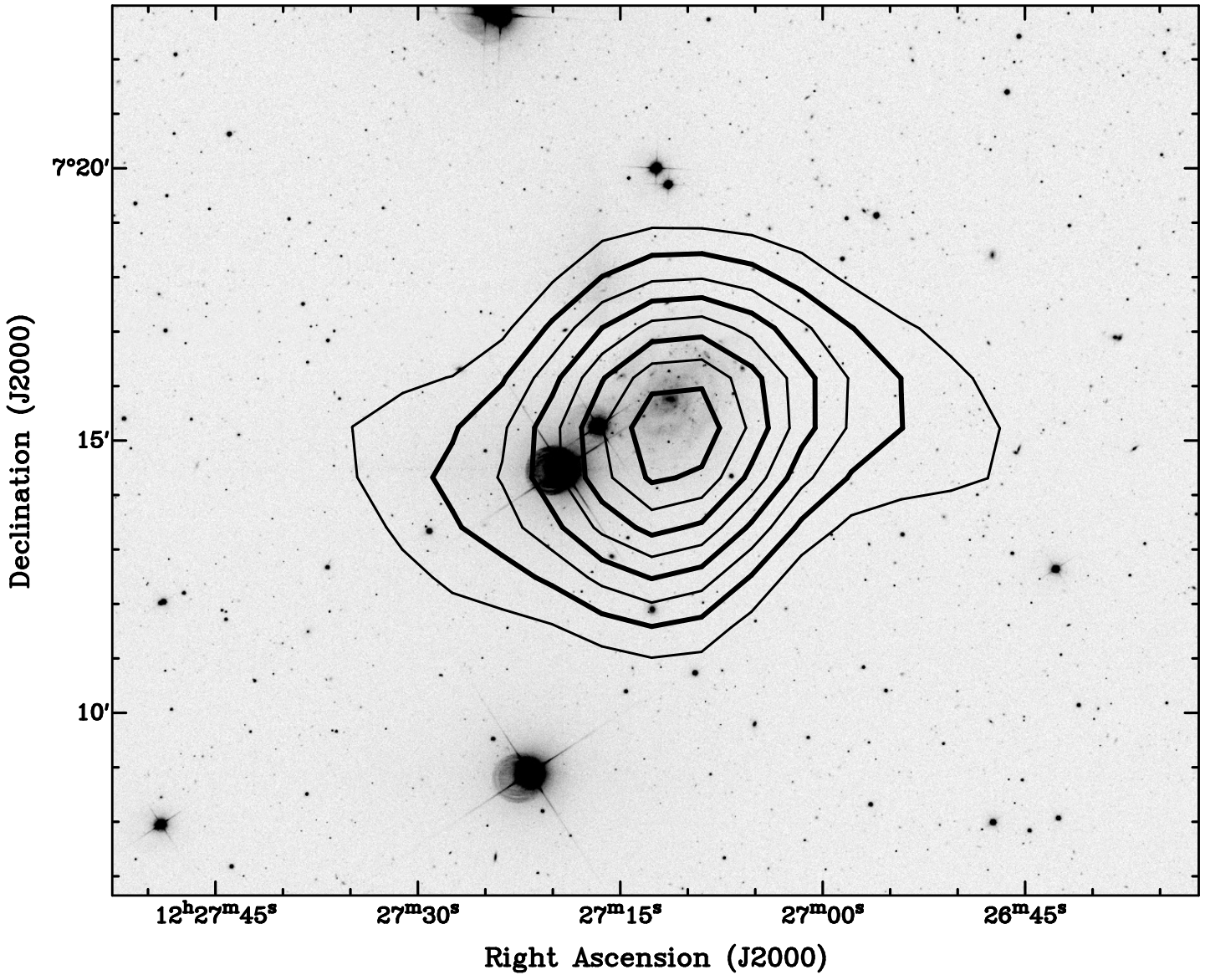
Right Ascension (J2000)

UGC 7557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15′
10′
Declination (J2000)
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27m30s
27m15s
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Right Ascension (J2000)

Galaxies properties

Table 2: Properties of detected galaxies.

Object	R.A	Dec.	Type	D_{25}	i	v_{sys}	W_{50}^c	M_{HI}	def_{HI}	d_{M87}
	J2000			(′)	(deg)	(km s^{-1})	(km s^{-1})	(10^8 M$_\odot$)		(deg)
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
NGC 4424	12 27 11.6	09 25 14	SBa	3.63	62.1	433	58.6	2.0 ± 0.4	1.14 ± 0.11	3.10
NGC 4451	12 28 40.5	09 15 31	Sab	1.48	51.2	864	255.8	5.0 ± 1.8	0.59 ± 0.20	3.18
NGC 4470	12 29 37.8	07 49 27	Sa	1.29	44.7	2321	135.7	1.6 ± 0.4	0.74 ± 0.16	4.58
UGC 7590	12 28 18.8	08 43 46	Sbc	1.35	76.6	1112	177.2	32.0 ± 11.0	-0.08 ± 0.20	3.71
Cloud 7c	12 30 25.8	09 28 01	HI cloud	–	–	496	74.0	0.6 ± 0.1	–	2.93
NGC 4411A	12 26 30.0	08 52 18	Sc	2.04	54.4	1271	105.2	1.8 ± 0.3	0.84 ± 0.11	3.68
NGC 4411B	12 26 47.2	08 53 04	Sc	2.51	26.7	1260	153.9	15.6 ± 1.6	0.52 ± 0.06	3.64
UGC 7557	12 27 11.1	07 15 47	Sm	3.02	21.3	924	245.2	4.1 ± 0.7	0.75 ± 0.10	5.21
NGC 4445	12 28 15.9	09 26 10	Sab	2.63	90.0	418	171.8	0.5 ± 0.2	1.73 ± 0.18	3.02
VCC 1142	12 28 55.5	08 49 01	dE	0.27	53.4	1334	52.0	0.4 ± 0.1	-0.09 ± 0.31	3.60
NGC 4416	12 26 46.7	07 55 08	Sc	1.70	24.0	1381	229.2	3.9 ± 0.7	1.10 ± 0.12	4.58
NGC 4466	12 29 30.6	07 41 47	Sab	1.32	74.9	797	185.9	2.1 ± 0.4	0.91 ± 0.12	4.71
UGC 7596	12 28 33.9	08 38 23	Im	1.66	71.9	595	59.5	0.7 ± 0.1	1.14 ± 0.10	3.79
VCC 0952	12 26 55.7	09 52 56	SABc	0.26	54.6	1024	100.3	0.9 ± 0.2	-0.06 ± 0.44	2.68
AGESVC1 293	12 29 59.1	08 26 01	?	0.57	41.8	615	87.3	0.2 ± 0.1	–	3.96
M49 Cloud	12 29 54.4	07 57 57	HI cloud	–	–	476	66.0	0.7 ± 0.1	–	4.43
KW Cloud	12 28 34.4	09 18 33	HI cloud	–	–	1270	73.2	0.7 ± 0.1	–	3.13