M84 Lunch Talk NRAO 4/11/86

systemic 1013 km/s
Virgo cen 1019 km/s

35mm

M84 NGC4374 — one of the 4 prominent E galaxies in Virgo. ~vel ≈ Virgo mean.
— 3C272.1, a low-power radio galaxy

$P_{1.4} = 1.4 \times 10^{23}$ W/Hz } small, weak low power source.
~3 arcmin diam ~ 13 kpc.

Well into the regime of edge-darkened, symmetrical jet structures. Robert Laing & I observed it originally with VLA at 20cm & 6cm to see if it led jets, jet collimation, B-field etc., ∴ nearby example of the low power radio galaxy phenomenon.

→ the surprise we got is what I want to concentrate on, not the details of the jets, etc. that we went for originally.

6cm map at 3".86 (290pc) resolution (~ 35mm?)
— double jet + cocoon, C shaped symmetry of ridge line
— inner lobe to S
— a major axis elongation in p.a. 32°.
— steeper towards gradients in lobes ~ NWest. (N) NWSE (S)

6cm color image at 1".2 resol. — (35mm)

Polarized emission — substantial. — 35mm slides (low)

Jets 0.15 to 0.3
Lobes 0.3 to 0.45
S lobe gradients 0.45 to 0.55

E vector orientations at 3'.86 resol.

Shown in (35mm slide) every 5" for clarity % χ.

Note the similarity of the 20cm & 6cm P maps – not much general depolarization.

But $\chi \rightarrow$ rotations. And here's where the surprise came in

Routinely make $\Delta\chi$ maps from 2-freq. data: they keep the fundamental 180° ambiguity of $\Delta\chi$ vector orientations. (Which way is which?). All unit vectors in 5σ blanking on P or both (35mm slide).

→ N.B. This is the only way you can display $\Delta\chi$ data without introducing any assumptions.

– see $\Delta\chi \neq 0$ over most of source
adjacent measures strongly correlated
something organises $\Delta\chi$ on >20" (1.5kpc) scales
"banded structure" is evident

See this clearly on color contour display of

minimum RM = $\dfrac{\Delta\chi}{\lambda^2_{1.4} - \lambda^2_{4.9}}$ (blanked 3σ)

Ambiguities depr. in here (red next to purple).
Range is −35 rad/m² to +25 rad/m², close to max you can map unambiguously between 20cm and 6cm.

Now superimpose this minimum RM on I. to look at relationships
This is 6σ blanked so highly reliable.

Steepest gradients in RM are along p.a. ~ 50°. (4 rad/m²/arcsec)
Largest ⊖ ⊕ RM's across the center of N lobe } in both lobes they are the steepest I gradients.
center of S lobe }

Could this be instrumental? χ depends only on Q/U
To pattern χ must pattern Q/U. Not easy when you observe in circular pol". → so no instrumental effect we could think of.

Is it a λ^2 law (needed to i) interpret whether it's ~~really~~ rotation in front source, or possibly mixing)

ii) resolve ambiguities.

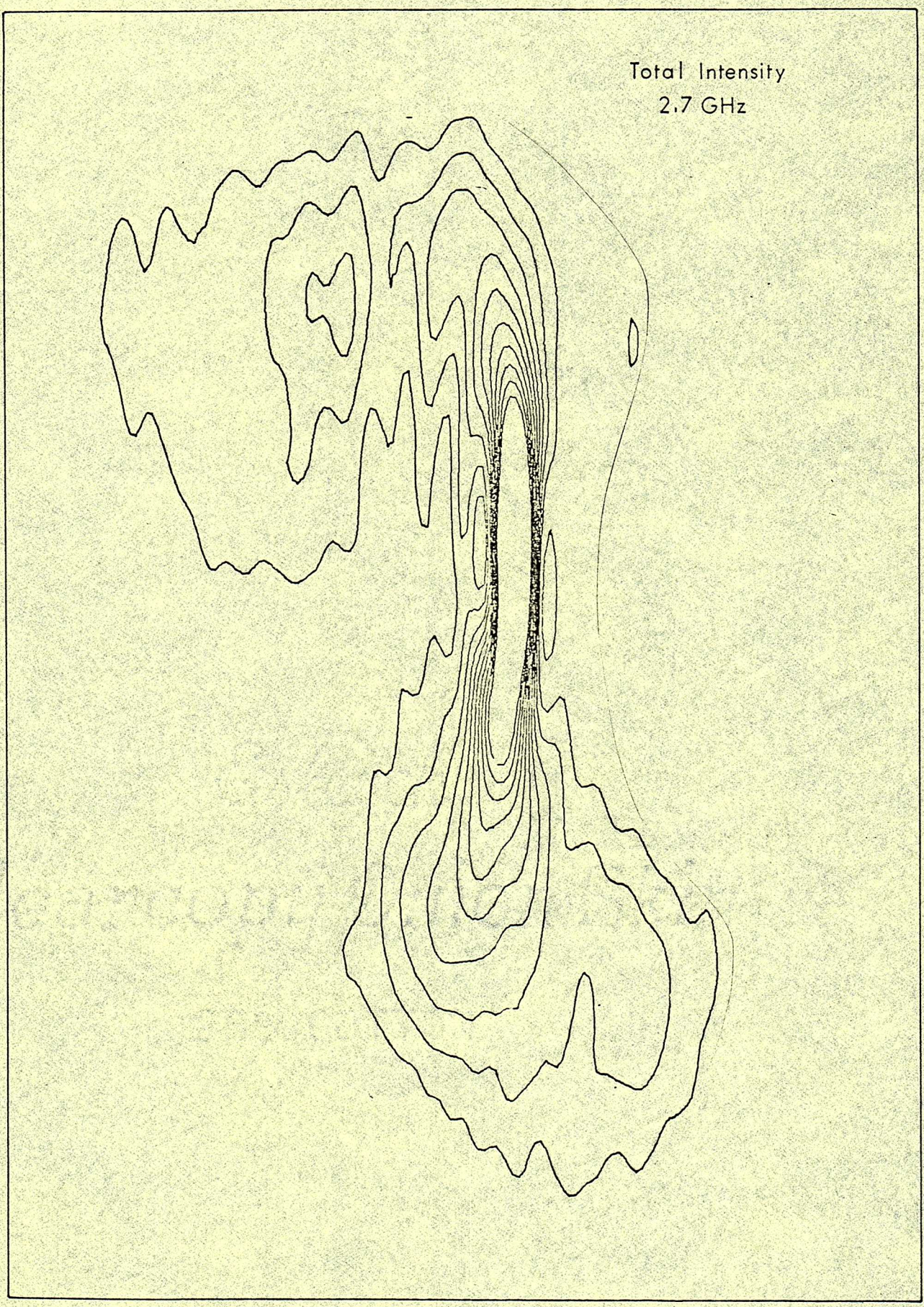
Need another freq. We didn't get other freqs at VLA
Only available data like ~ enough res': is Cambridge 11cm.
3".86 × 16".25 (δ).

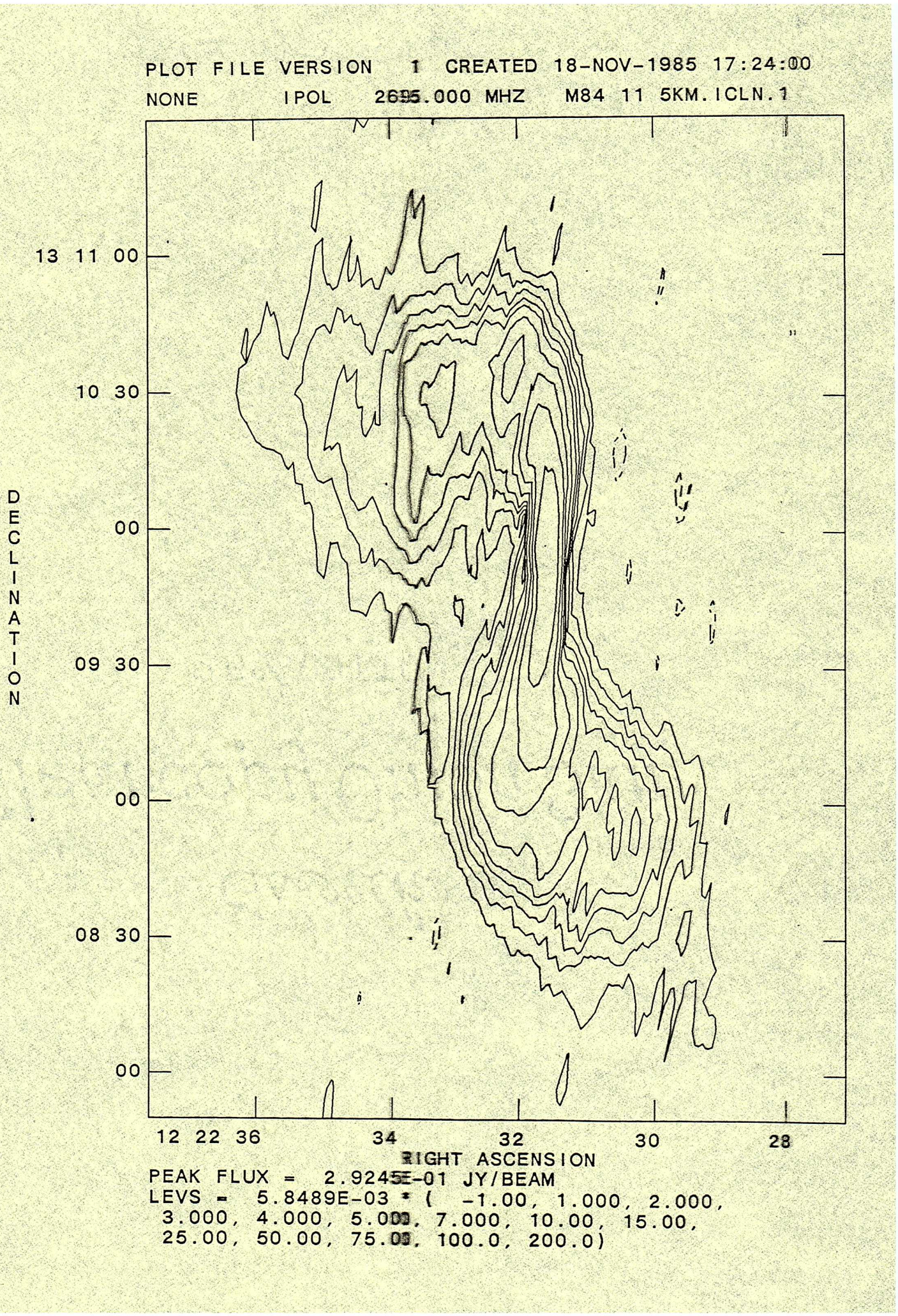
Unfortunately Cambridge δ beam ~ RM struct. scale, so heavily convolves the RM structure. Rather than convolve everything to Cambridge beam, adopt recipe:

i) ~~Combine~~ use observed 20cm/6cm VLA vectors to estimate 11cm pixels assuming $\Delta\chi \propto \lambda^2$ and no ambig.

2) Predict 11cm Q, U, then convolve
→ predict 11cm χ, cf. with observed χ.

AIPS could do.


Total Intensity
2.7 GHz


PLOT FILE VERSION 1 CREATED 18-NOV-1985 17:24:00
NONE IPOL 2695.000 MHZ M84 11 5KM.ICLN.1
13 11 00
10 30
00
09 30
00
08 30
00
DECLINATION
12 22 36
34
32
30
28
RIGHT ASCENSION
PEAK FLUX = 2.9245E-01 JY/BEAM
LEVS = 5.8489E-03 * (-1.00, 1.000, 2.000,
3.000, 4.000, 5.000, 7.000, 10.00, 15.00,
25.00, 50.00, 75.00, 100.0, 200.0)

→ 11cm $\Delta\chi_{obs-pred}$ map — should be near zero, is.

$\overline{\Delta\chi}$ is 2°.1, $\sigma_{\Delta\chi} = 6°.7$, $\sigma_{2.7} = 4°.0$ } Consistent with noise.

- identify pieces where little var. across Cambridge beam
- plot $\Delta\chi$ vs. λ^2 for these. (35mm slide).

CONCLUDE. Minimum RM is correct
$\Delta\chi \propto \lambda^2$ as well as we can tell }.
So the naive interpretation is reasonable..

Last check/caveat → B distrib. makes sense with these "small" RM's. (35mm)

→ note the B structure is not much correlated with RM structure

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What are we looking at with this RM?

3 main possibilities

1) Foreground, our Galaxy
2) Foreground, NGC4 related
3) Mixed into radio source

Arguments that it is not mixed in

1) If it was uniformly mixed, 35 rad/m² would →

$D = \frac{p1.4}{p4.9} \rightarrow 0.$

should see banded pattern in D and D correlating with RM.

D (35mm)

D vs RM (35mm). (IMVIM) } does not support mixed pcon.

2) If mixed, should not N see $\Delta\chi \propto \lambda^2$ (do)

may see B correlation with RM, though orthogonal components involved. (don't)

CONCLUDE → more likely foreground

Whose foreground, "their" or "ours"?

$l = 278°, b = -75°$ region of severely small negative RM's. $\overline{RM} = -2.4 \pm 3.9$ rad/m² for ten sources within 10° of M84.

Also, the fluctuations in RM on this scale would be unusual for galactic RM foreground, ~~etc~~ or these |b|.

Simonetti / Cordes structure fn. of galactic RM.

M84 structure fn: well above hi-b.

Finally, look at the symmetries.

(Slices). { Changes sign across nucleus of M84 ← coincidence if foreground
RM extrema on I gradients. ↙
Banded pattern near the galactic minor axis.

All suggests we are seeing RM pattern originating in M84 itself, with linear scales of the structure ~ few kpc. So we have ionised gas and magnetic fields outside the 3C272.1 radio source bar inside M84.

N.B. if the foreground RM is really ~0, then the fact that we have both signs of RM → large scale reversal of magnetic field direction in the magnetoionic M84 medium.

Other evidence for ISM in M84.

1960 - Dust lane (Gn Wade for Hubble plate)

1985 - Hansen et al. line-like Hα, [OII], [SII], [SII] in band ~1" to radio jet

1984 - Einstein — 0.5-3 keV gas emitting · 3×10^{40} erg/s

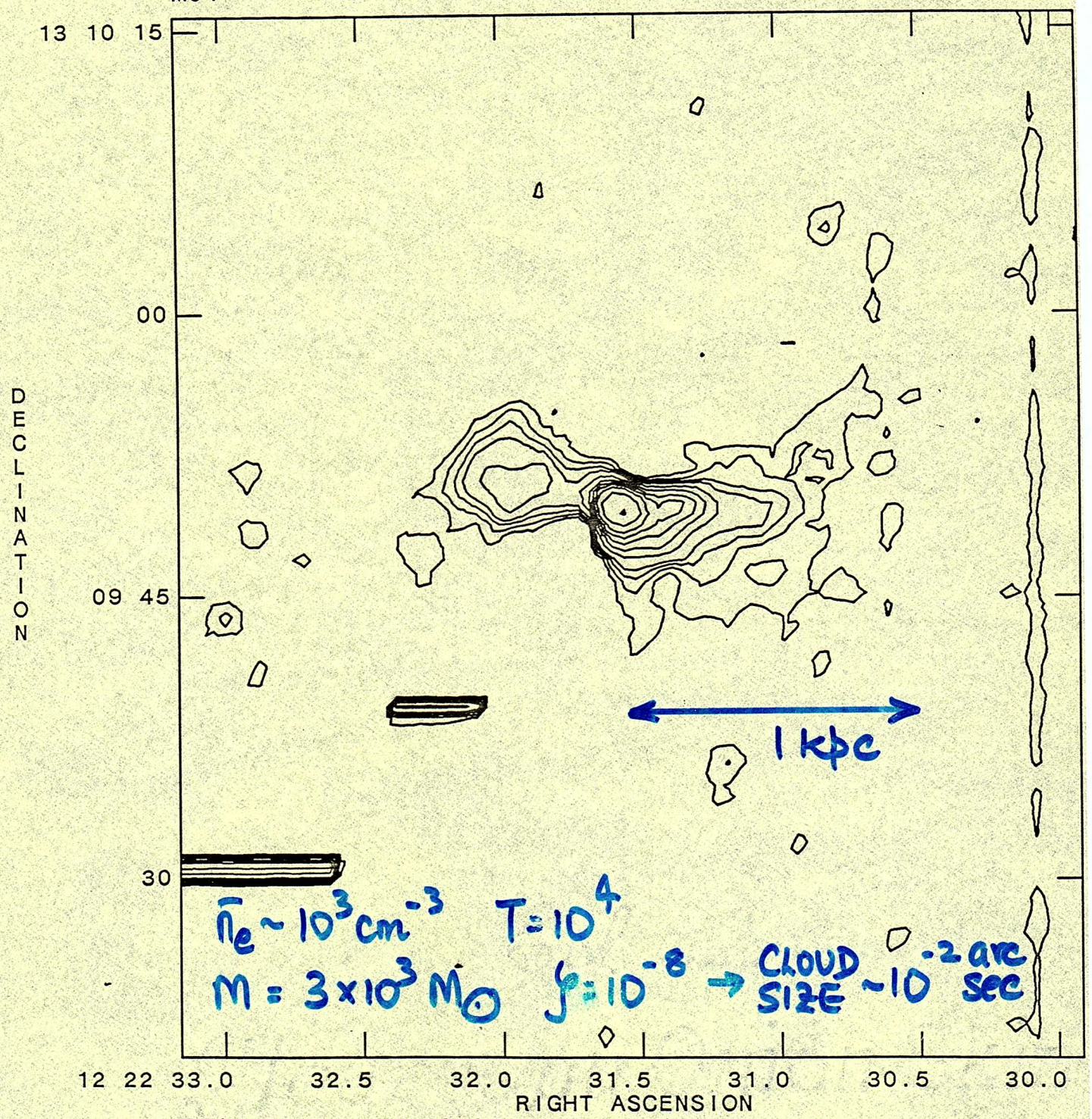
- unpublished HRI images combined in AAS

Hα + [NII] in M84

data of Hansen et al. AA 149, 442 (1985)

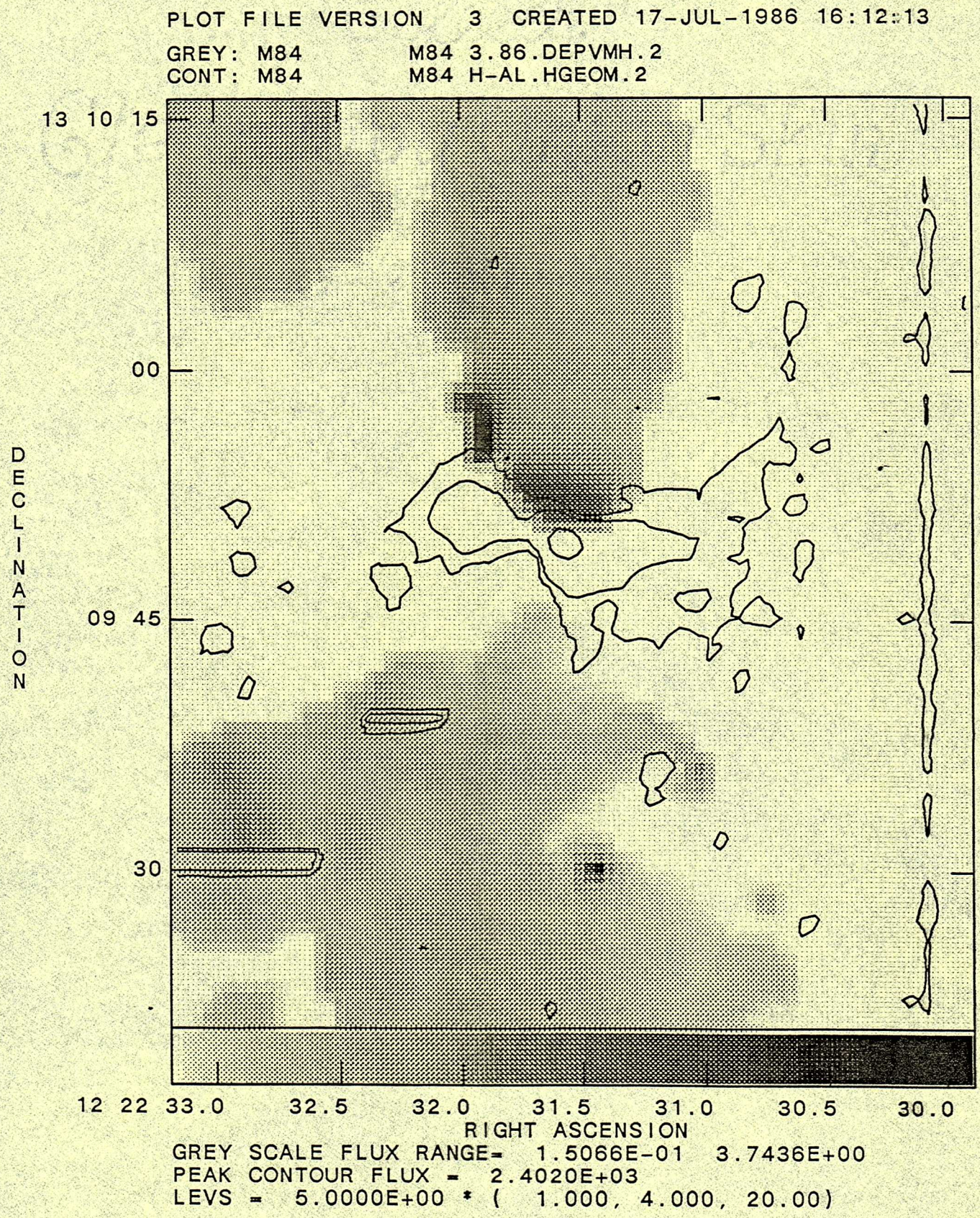
PLOT FILE VERSION 1 CREATED 17-JUL-1986 16:05:27

M84 M84 H-AL.HGEOM.2



PEAK FLUX = 2.4020E+03

LEVS = 5.0000E+00 * (1.000, 2.000, 3.000, 4.000, 6.000, 8.000, 10.00, 12.00, 15.00, 20.00, 30.00, 40.00)


PLOT FILE VERSION 3 CREATED 17-JUL-1986 16:12:13
GREY: M84 M84 3.86.DEPVMH.2
CONT: M84 M84 H-AL.HGEOM.2
13 10 15
00
09 45
30
DECLINATION
12 22 33.0
32.5
32.0
31.5
31.0
30.5
30.0
RIGHT ASCENSION
GREY SCALE FLUX RANGE= 1.5066E-01 3.7436E+00
PEAK CONTOUR FLUX = 2.4020E+03
LEVS = 5.0000E+00 * (1.000, 4.000, 20.00)

Hansen et al. inner 1.5 kpc.

$n_e \sim 10^3$ (from line ratios of SII)
$T \sim 10^4$
$\rightarrow \xi \sim 10^{-8}$,

$M_{gas} \sim 3 \times 10^3 M_\odot$ total.
Scale of clouds $\sim 10^{-2}$ arcsec.

$\sigma_v \sim 350$ km/s
no significant rotation (< 38 km/s)

→ 1) does not cover whole source
2) V. high local RM's if $\underset{\sim}{B}$ in here, but would
→ V. high depolarization & chaotic variation.

Possibly the few sources of v. high depol are this medium, but in general, it has all the wrong properties.

Ensslin Brightest NRI features anticorrelate with the radio echo (possibly dynamically significant.)
But evidence for a low-level diffuse X-ray source.

RM fluct. of 25 rad/m^2 RM = 810 $n_e B L$ rad/m^2

Need $n_e B L \sim 0.03 \mu$gauss.cm^{-3}.kpc

X-ray est $n_e \sim 10^{-2}$ cm^{-3} → B L 3 μgauss.kpc.

L? At least 2 kpc (bands), could be up to 10 kpc
$\underset{\sim}{B} \sim 0.3$ to 1.6 μgauss needed.
$\varepsilon_B \sim 1\%$ of $n_e kT$ in X-ray gas.
Seems plausible Beq in lobes ~ 20 μgauss

Note overall evidence for displacement of X rays down the C of the jets. — motion of M84 through the Virgo medium. So ~~edges~~ distribs? of the gas may be modified by medium. Is it infalling or stripping? Why does the radio source wermoreby flare across the "motion" and go up the optical minor axis? Why is the RM banding pattern ~ same as this axis. (What is the axis telling us? Something about n_e or something about $\underset{\sim}{B}$?) — $\underset{\sim}{B}$ must figure Because of I. Relation to I gradients → interaction with radio source?

RM's in other radio galaxies.

Jet traced, not 2-d in general

NGC 6251   120 rad/m² over ~15 kpc
$\Delta\chi \propto \lambda^2$ for $\Delta\chi \gg$ M84
→ must be foreground. Symmetry n.k.

→ 3C449   40 rad/m² over 15″ ≈ 3.5 kpc

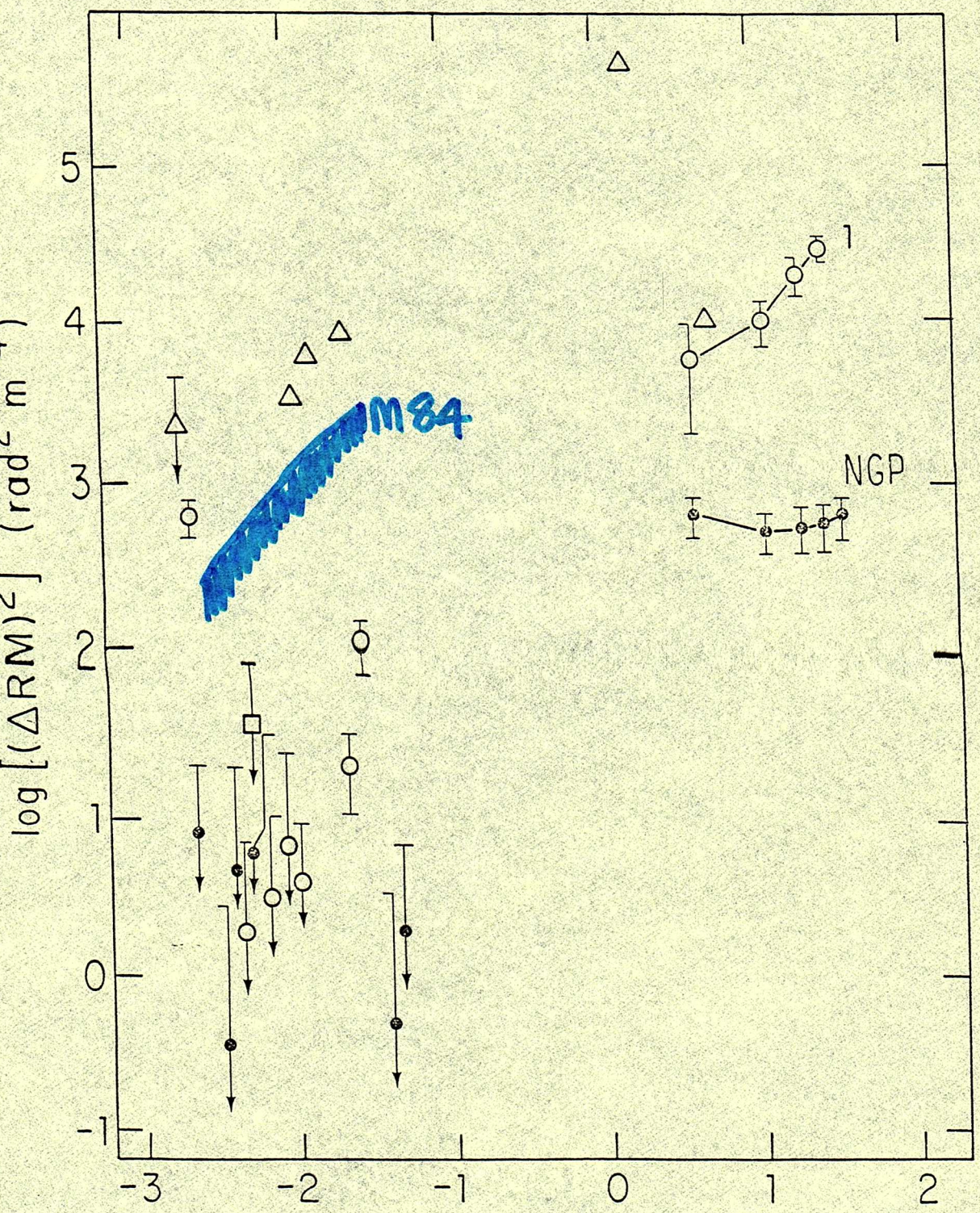
NGC 1265

lensing gal of 0957+561 (2pk QSO) $n_e B L \sim 0.1 \mu G\, cm^{-3}\, kpc$

3C66B   40 rad/m² over 6 kpc.

Don't know 2-D pattern in these galaxies.

Simonetti & Cordes
Ap.J. Nov 1 1986



Δ ⇒ l=90°, b=0°

1 ⇒ 85°<l<115°, -40<b<-10°, in Simard-Normandin Anomalous Region A (high Θ RM's)

So

- ∃ magnetoionic medium in NGC 4261 probably $n_e \sim 10^{-2}$, $B \sim 1 \mu$gauss.
- ∃ large scale bended structure in RBL origin unclear but symmetry relates to radio source field elongation & galaxy minor axis.
- need other 2-D cases to see how typical this is. — RM studies of other ellipticals with ext. X-ray emission and radio sources?
- sensitive X-ray imaging Vs → bend scale & distrib. of the extended X-ray emission.

need – Hansen et al contour image for overlay.

$M_{HI} < 10^8 M_\odot$ publ.
$< 10^7 M_\odot$ unpubl? JVG.

Ionized hi gas ~ $3 \times 10^3 M_\odot$ – for a warping disk. What the large T_V?

Dust coexisting with X-ray gas?

Gas structure + origin + excitation very unclear.

- Velocity dispersion > expected from shock excitation even rapid cooling behind X-ray corona
- needs covering factor of 0.05 if gas is photoionized from nucleus using IUE UV fluxes
  This doesn't make sense if filling factor is 10^{-8}