Magnetic Fields in Lensing Elliptical Galaxies

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XXIIIrd IAP Colloquium

From Giant Arcs to CMB Lensing:

20 years of Gravitational Lensing

In honour of **Bernard Fort : Giant Arcs**

July 4, 2007

Theme of the talk:
Elliptical Galaxies at high redshift have coherent kiloparsec–scale Magnetic Fields.

Faraday Rotation of the Plane of Polarization of Radiation is a probe to the magnetic field in galaxies and galaxy clusters.

When they form multiple images of background polarized sources, **Differential Faraday Rotation between the Images** can establish the presence of Magnetic Field in Lens Galaxy,

and separate out the effect due to Magnetic Field at the Source.

Plan of the talk

Polarized Source and Faraday Rotation of the Plane of Polarization

Multiple Images and Differential Faraday Rotation

Rotation Measure in some Gravitatioanl Lens Systems

Summary and Prospects for Cluster Magnetic Field

Why Magnetic Field in this conference?

Magnetic fields will leave their imprints in Gravitational Lensing from Galaxy to CMBR.

Origin of large scale coherent Magnetic Field in Galaxies and Galaxy–Clusters remains an unsolved problem.

Detection of Magnetic Field in High Redshift Galaxies and Galaxy–Clusters is important to the theory of Galaxy Formation and Evolution.

It also constrains models of the amplification of a seed magnetic field.

Magnetic Fields in Spiral Galaxies

Presence of coherent Magnetic Field in Spiral Galaxies well established.

The symmetry properties or the distribution not same.

Milky Way: Axisymmetric slowly decreasing $\sim 10\mu$Gauss field nearly aligned with the spirals. Sign change between spiral arms.

Magnetic Torus in M31

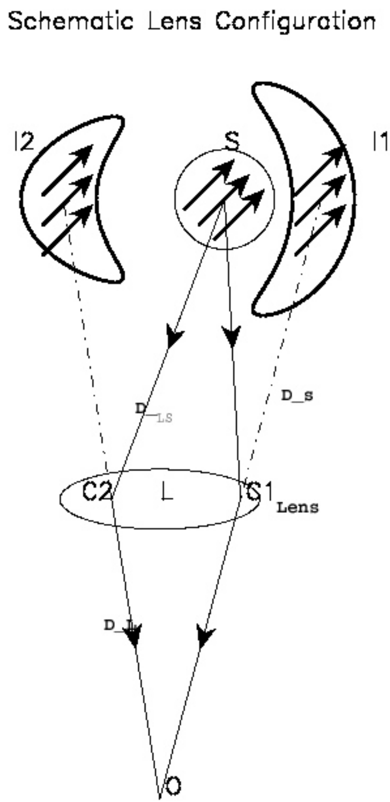
Direct Observations: Coherent fields of a few μGauss at kiloparsec scale between redshift of 0.4 and present

Additional random Smaller scale Fields

Magnetic Field in Galaxy–Clusters:
Synchrotron emission from Radio Halo
Diffuse X-ray Enhancements & Radio flux in Abell clusters
EGRET Gamm Ray excess in clusters
Excess Faraday Rotation measures in the field of clusters
Result: μGauss field with scale length of coherence:

$$\mathrm{B} = \mathrm{B}_o \sqrt{\frac{\ell}{10kpc}}^{-1}$$

Rudnick : Intrinsic RM in the source or from embedded radio source
Recent survey of clusters at high/medium redshift:
AGNs are hosted by more than 1/2 which is 20 times local value.
(cf. Eastman et al June 2007 ApJL astro-ph 0706.0209)
Is there large scale magnetic field in normal IntraClusterMedium? What is its origin?


Schematic Lens Configuration
I2
S
I1
D_s
D_LS
C2
L
C1
Lens
D_L
O

Faraday Rotation

Polarized Radiation from a source: Plane of Polarization should be same in all the images

Magneto–ionic Plasma in an intervening medium will rotate the Plane of Polarization

The angle of rotation of the plane of polarization:

$$\Psi_F = \frac{e^3}{2\pi m_e^2 c^4} \int B_{\|}(\ell) n_e(\ell) \lambda^2 d\ell$$

No Rotation at high frequencies

Huge Rotation (ambiguity of π^c at low frequencies.

Converting to what we observe on the earth:

Observed Rotation Measure:

$$RM \simeq 2.6 \times (N_e)_{19} < B_{\|} >_{\mu G} /(1+z)^2 \; rad \; m^{-2}$$

$(N_e)_{19}$ is the Electron Column Density in 10^{19} / cm^2

z is the redshift of the intervening galaxy

Rotation Angle of the Plane of Polarization:

$$\Psi = RM * \lambda^2$$

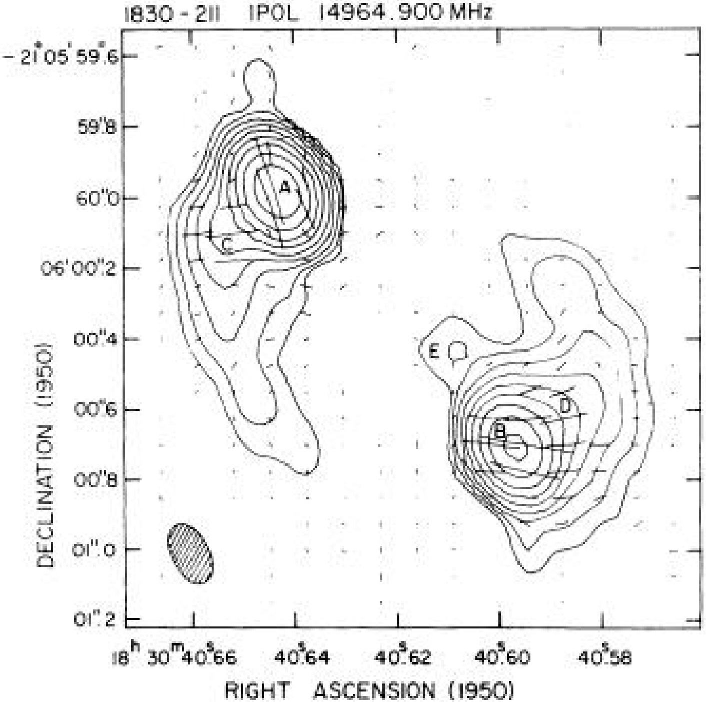
10^{21} /cm^2 Electron column density and 1 μG Magnetic field produces $\sim 50^o$ Faraday Rotation at 6 cm.

But Huge rotation at 18 cm and negligible at 1.3 cm.

Faraday Rotation could be caused at the Source, in the Lens or in Milky Way.
The source contribution will be same for all Images.
Milky Way contribution at arcsecond scale too.
$\longrightarrow$ Differential Faraday Rotation between images cancels many of these effects to a good extent

But Time–delay between Large–Separation Images is a drawback.

Estimate of the Magnetic Field strength from Differential Faraday Rotation with multiple epoch monitoring will establish that the observed magnetic field is in the **Intervening Medium** *rather than at the Source.*



1830 - 211 IPOL 14964.900 MHz
-21°05'59".6
59".8
60".0
06'00".2
00".4
00".6
00".8
01".0
01".2
DECLINATION (1950)
18h 30m 40s.66
40s.64
40s.62
40s.60
40s.58
RIGHT ASCENSION (1950)
A
B
C
D
E

Faraday Rotation in selected Lens Systems

System	Lens redshift	RM (rad m^{-2}) (lit.)	Diff RM (rad m^{-2}) (best fit)*	Excess P.A. (degree) (λ=0)	χ^2_{**}	no dof
Lens Spiral Galaxies						
B0218+357	0.684	A-8920 B-7920	AB: 913±31	-10	0.3	2
PKS1830–211	0.89	A -157 B 456	AB: 1480±83	24	7	2

System	Lens redshift	RM (rad m^{-2})	Diff RM (rad m^{-2})	Excess P.A.	χ^2_{**}	no of d o f
Lens Elliptical Galaxies						
Q0957+561	0.36	A-61±3	AB: 99± 2	-2	0.3	1
		B -160±3				
B1422+231	0.31	A -4230±60	AB: 125±125	4.7	16.1	2
		B -3440±88	AC: 20±70	3.4	5	2
		C -3340±90	BC: 105±77	-1.3	6.1	2
1938+666	0.878	A 665± 14	AB: 960±202	-26	27	1
		B 465± 14	BC1:85±39	-10.5	19	1
		C1 441± 3	C2C1: 56±4	-1.1	2.6	3
		C2 498± 3				

Data from

Patnaik et al, 1993, MNRAS 261, p435

Patnaik & Narasimha, 2001, MNRAS, 326, 1403.

King, L.J. et al, 1998, MNRAS, 289, 450.

Nair, S., 1994, Thesis, Mumbai University.

Nair, S., et al, 1993, ApJ 407, 46.

Subrahmanyan, R., et al, 1990, MNRAS 246, 263.

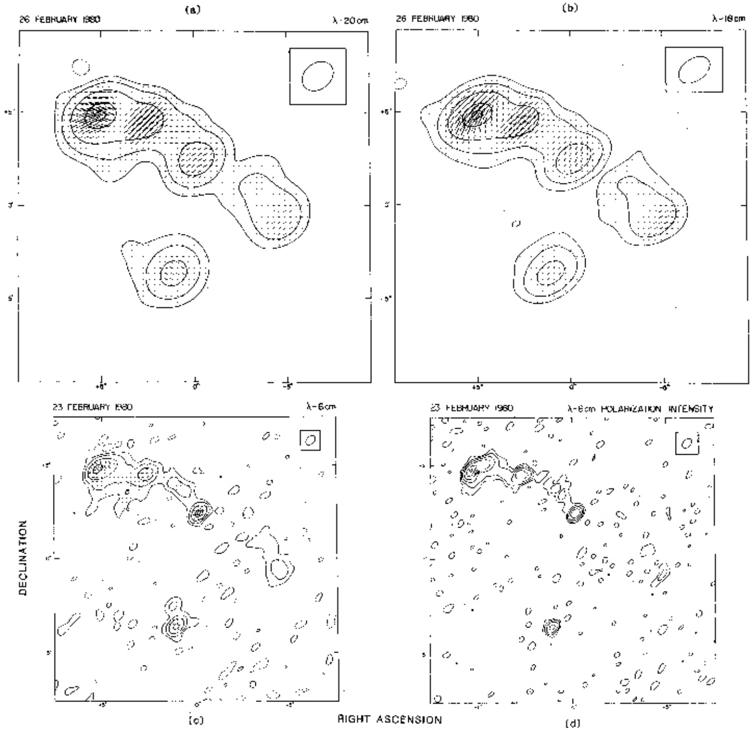


FIG. 3.—VLA maps of linear polarization of 0957+561. Contours are of total intensity at 95, 64, 16, 4, 1, −1% of map peak for (a), (b), and (c). The $\lambda = 6$ cm polarization intensity distribution is shown in (d), where the contours are 95, 64, 32, 16, 8, and 4% of peak value 4.3 mJy per beam.

Case Study: 0957+561

The first lens system, Q0957+561 has two images of a background quasar lensed by an Elliptical Galaxy and a Galaxy–Cluster at redhsift of 0.36

Extended highly polarized emission by a $\sim$10" feature along Image A only.

Both the AGN core and extended features are polarized in radio - 6 - 10 %. Hence analysis is not limited by statistical errors.

Faraday Rotation should be $zero$ at shortest wavelength. But it is non–vanishing for both images.

Differential Faraday Rotation has $zero$ excess angle at zero wavelength.

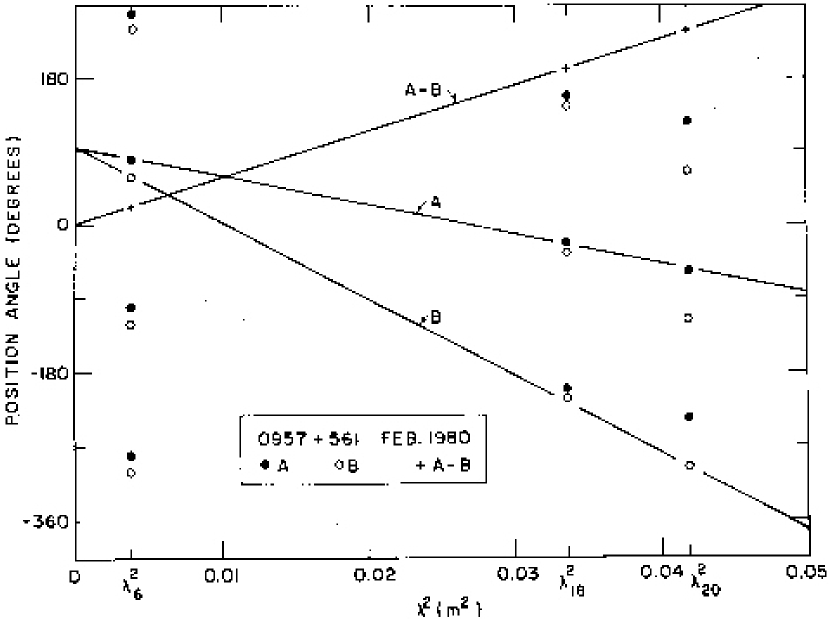
Interpretation: Faraday Rotation in the source.

Between Quasar Images: 99 rad/m^2 but nothing known about its symmetry.
$\rightarrow$ *At 30 kpc scale Rotation Measure of* $\sim$*100 rad/m*^{2} for the system 0957+561.

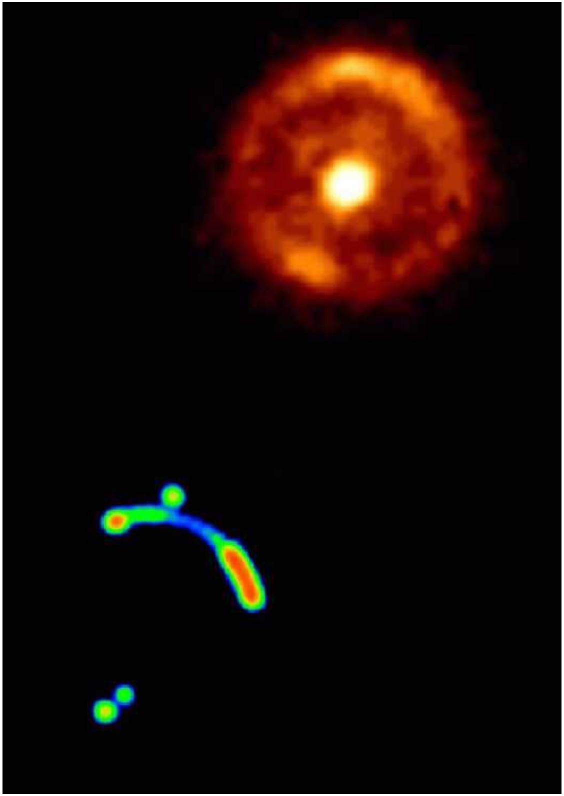
Kronberg's method for extended Polarized structure:
Quasar image A has structures extending over 10 arcsec (50 kpc at the lens).
No tabular data on polarization is available,

From the VLA maps of Greenfield et al(1985):
We could find only one region from the extended emission, having Rotation Measure 50 rad/m^2.

Since the source had internal RM:
Magnetic Field of Lens Galaxy or Cluster or Quasar Source?.



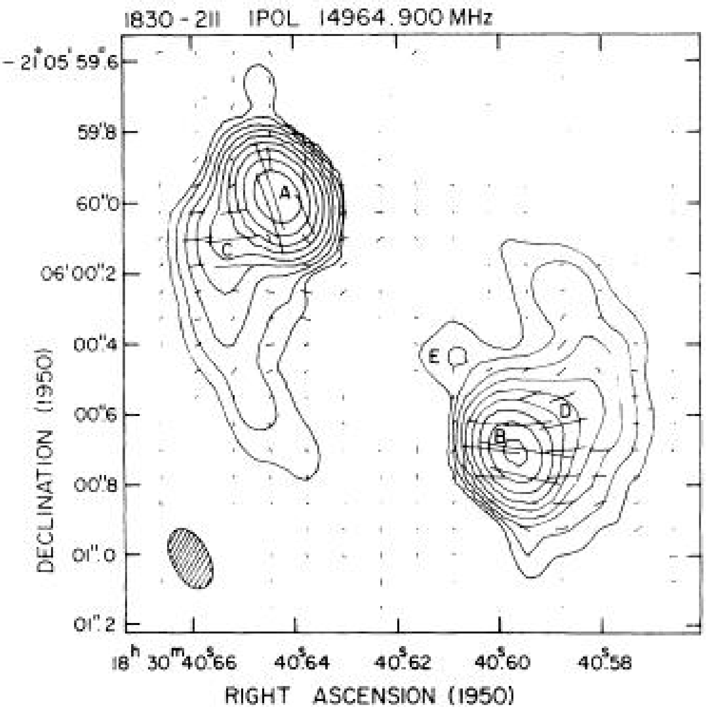
POSITION ANGLE (DEGREES)
180
0
-180
-360
A-B
A
B
0957 + 561 FEB. 1980
● A ○ B + A-B
0
0.01
0.02
0.03
0.04
0.05
λ^2_6
λ^2_{18}
λ^2_{20}
λ^2 (m^2)

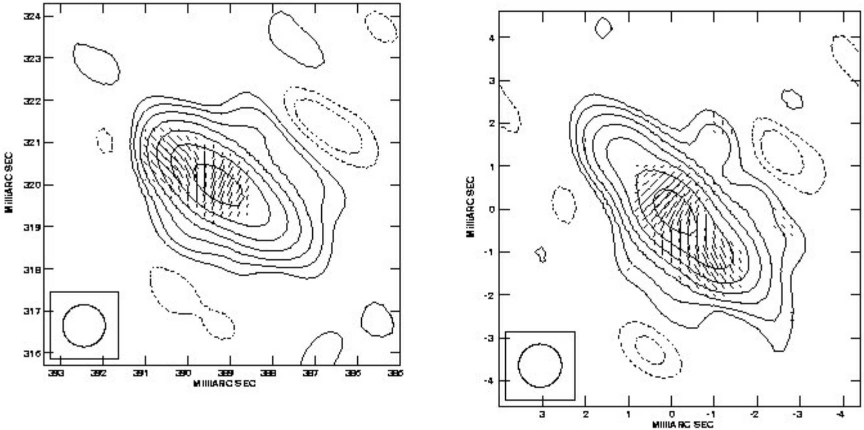


1938+666

Lens is an Elliptical Galaxy at redshift 0.88
Polarization of the Source is moderate,
but varies between images. (Depolarization)
4 Images of the AGN core,
Two of them (C1, C2) almost merging.
Only the merging image C1 C2 has similar polarization levels and hence RM is reliable.
Common RotationMeasure for all images: $\sim$500 rad m^2
Probably it is produced at the Source.

Differential Rotation Measure of 56 rad/m^2 between images C1 & C2 appears reliable.
$\rightarrow$ At $\sim$4 kpc coherence scale, Magnetic field comparable to that of 0957+561.


1830 - 211 IPOL 14964.900 MHz
DECLINATION (1950)
RIGHT ASCENSION (1950)
A
B
C
D
E


MilliARC SEC
324
323
322
321
320
319
318
317
316
393
392
391
390
389
388
387
386
385
MilliARC SEC
MilliARC SEC
4
3
2
1
0
-1
-2
-3
-4
3
2
1
0
-1
-2
-3
-4
MilliARC SEC

B1422+231

4 Images of a high redshift bright Quasar produced by an Elliptical Galaxy (+ Group?) at redshift 0.31.

At VLB scale, the core has high polarization,
but limited data

At VLA scale, very low polarization.
Only Close Pair of Images appear to be reliable for Polarization study.

Their Differential Rotation Measure is comparable to other Ellipticals, even though direct Rotation measure is high.

Summary

The lenses we studied had a range of common Rotation measure

But Differential Faraday Rotation was in a narrow range:

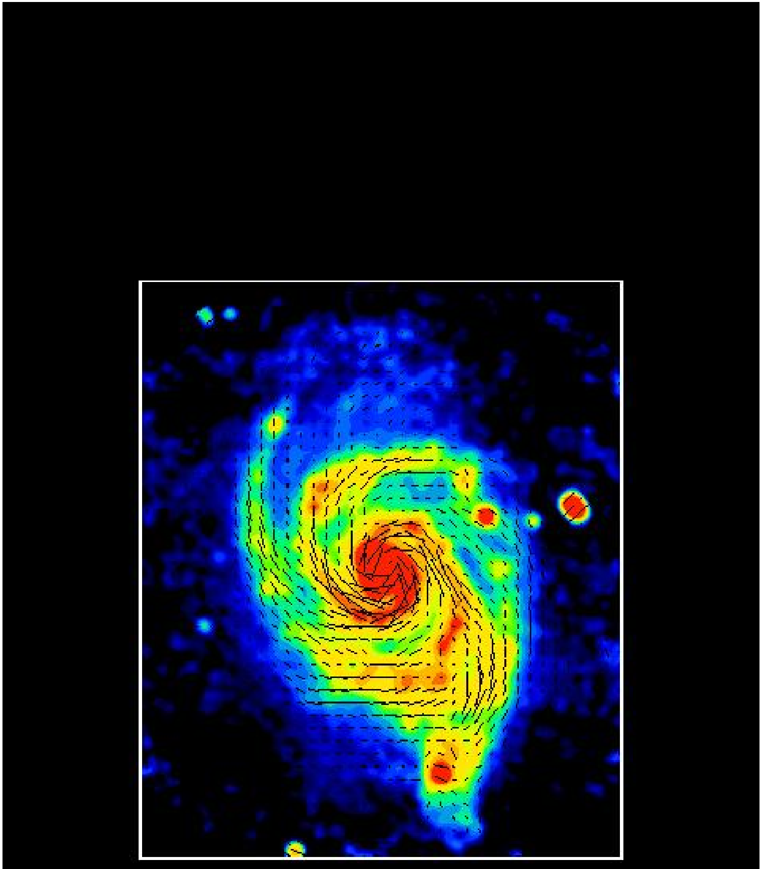
For Spiral Galaxies $\sim$ 1000 rad m^2

For Elliptical Galaxies $\sim$ 100 rad m^2

There is no obvious redshift evolution in the Rotation Measure between redshift of 1 and 0.3

Tracing the Rotation measure along extended features has not been successful for us so far:

1. Failure to get good polarization meausrements at multiple frequencies along the entire structure
2. Possible Faraday Rotation introduced at the source.



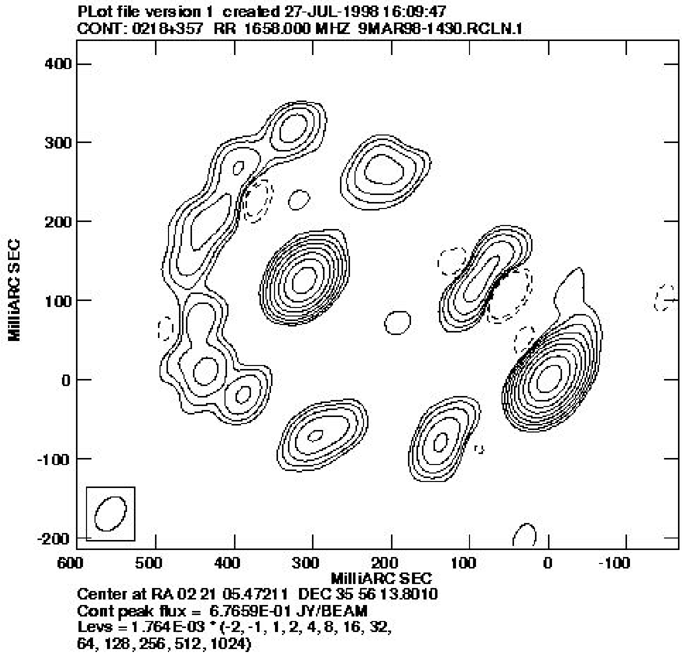
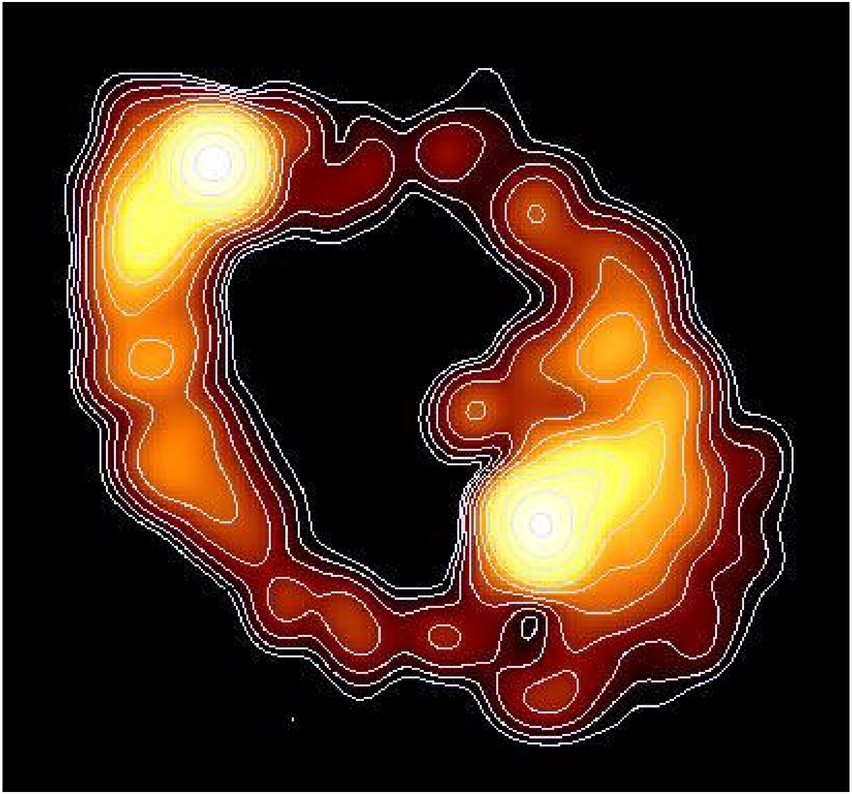


Figure 1. 1.7 GHz map of B0218+357 made combining data from EVN and MERLIN arrays. Contour plotted are 1.76 mJy/beam × (-2,-1,1,2,4,8,16,32,64,128,256). Peak flux density is 677 mJy/beam. The resolution is 47.3 mas × 33.7 mas at -35°.7 which drawn at bottom left hand corner.



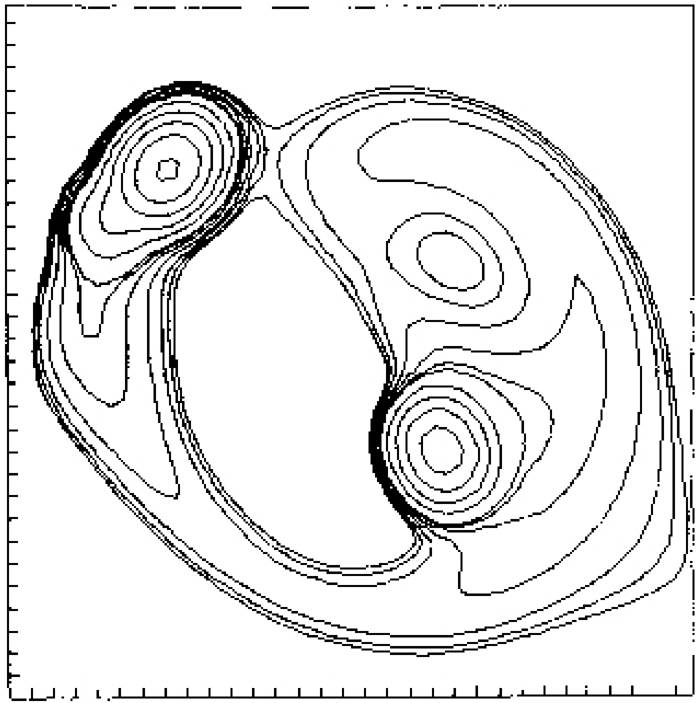


FIG. 6.—Simulation of possibly observable structure at a resolution of around $(0''.15)^2$ and a dynamic range of the order of 1000 or 2000. The extended structure shows a bridgelike feature that spans the ring between object E and the ring on the NE side.

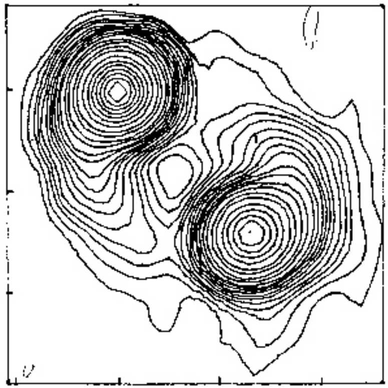


FIG. 1a

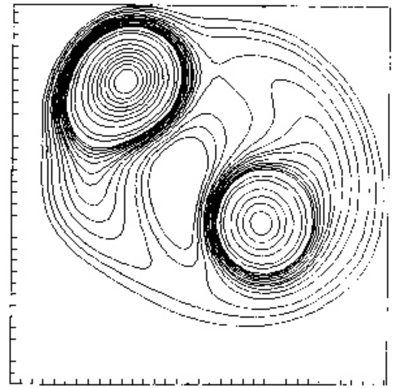


FIG. 1b

FIG. 1.—(a) VLA map at 8.41 GHz (from Jauncey et al. 1991b), which has a restoring beam of (0"25)². (b) Simulated map at the same frequency, convolved with a Gaussian beam of FWHM (0"25)² and contoured in a manner similar to that in (a).

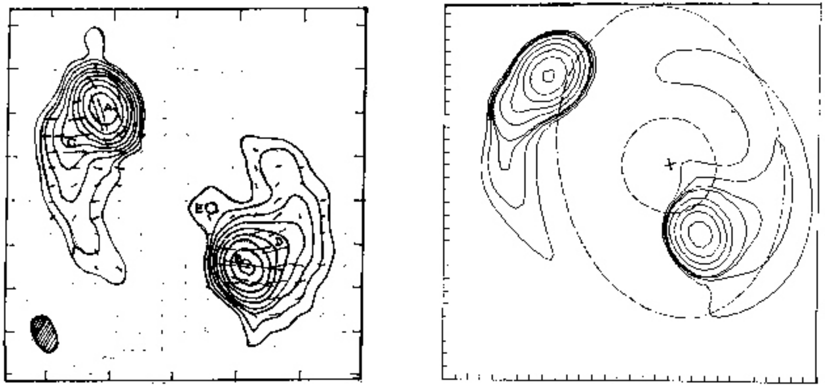


FIG. 2*a* FIG. 2*b*

FIG. 2.—(*a*) VLA map at 15 GHz (from Subrahmanyan et al. 1990), which has a beam of FWHM $0''.16 \times 0''.12$ and is contoured in powers of 2. (*b*) Simulated map using the lens model of § 2, convolved with a Gaussian beam of $(0''.15)^2$ and contoured as in (*a*). Superposed are the tangential (outer) and radial (inner) critical curves, at which the magnification is "infinite."