GRAVITATIONAL LENSING
LECTURE 21

Docente: Massimo Meneghetti
AA 2015-2016

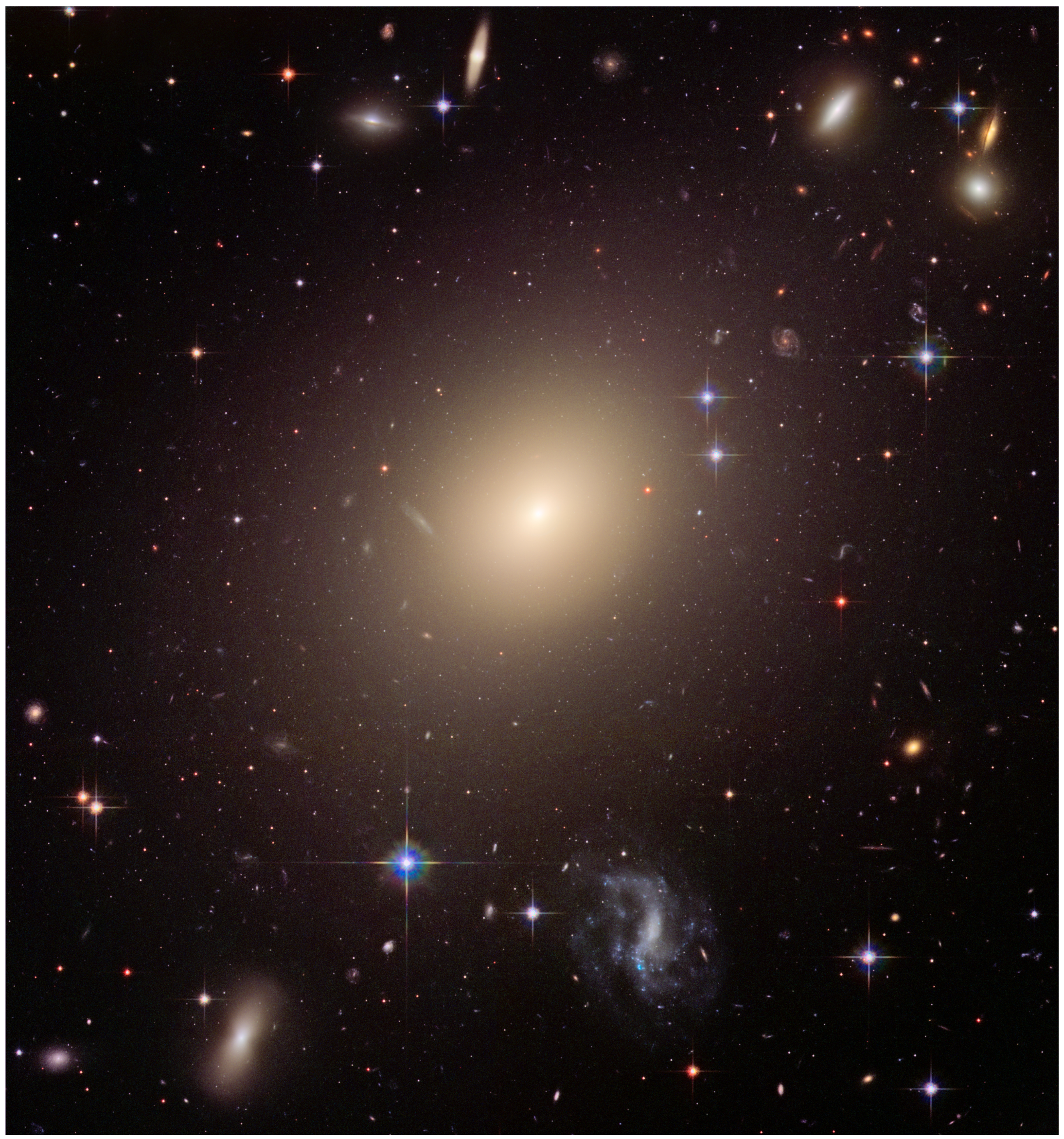
STRONG LENSING BY GALAXIES AND CLUSTERS

- Rethinking galaxies and galaxy clusters as strong lenses
- Finding strong lenses
- Applications:
  - the mass structure of galaxies and clusters
  - substructures
  - cosmography
  - cosmic telescopes

lens oriented   *source oriented*

GALAXIES AND CLUSTERS AS LENSES

Elliptical galaxies



ESO 325-G004

- ellipsoidal/spheroidal shape
- light follows Sersic profile with n=4 or larger
- sustained by velocity dispersion
- large range of masses: 10^7-$10^{13} M_\odot$
- poor gas content
- no or very limited star formation; old stellar populations
- red colors
- most frequent in dense environments

GALAXIES AND CLUSTERS AS LENSES

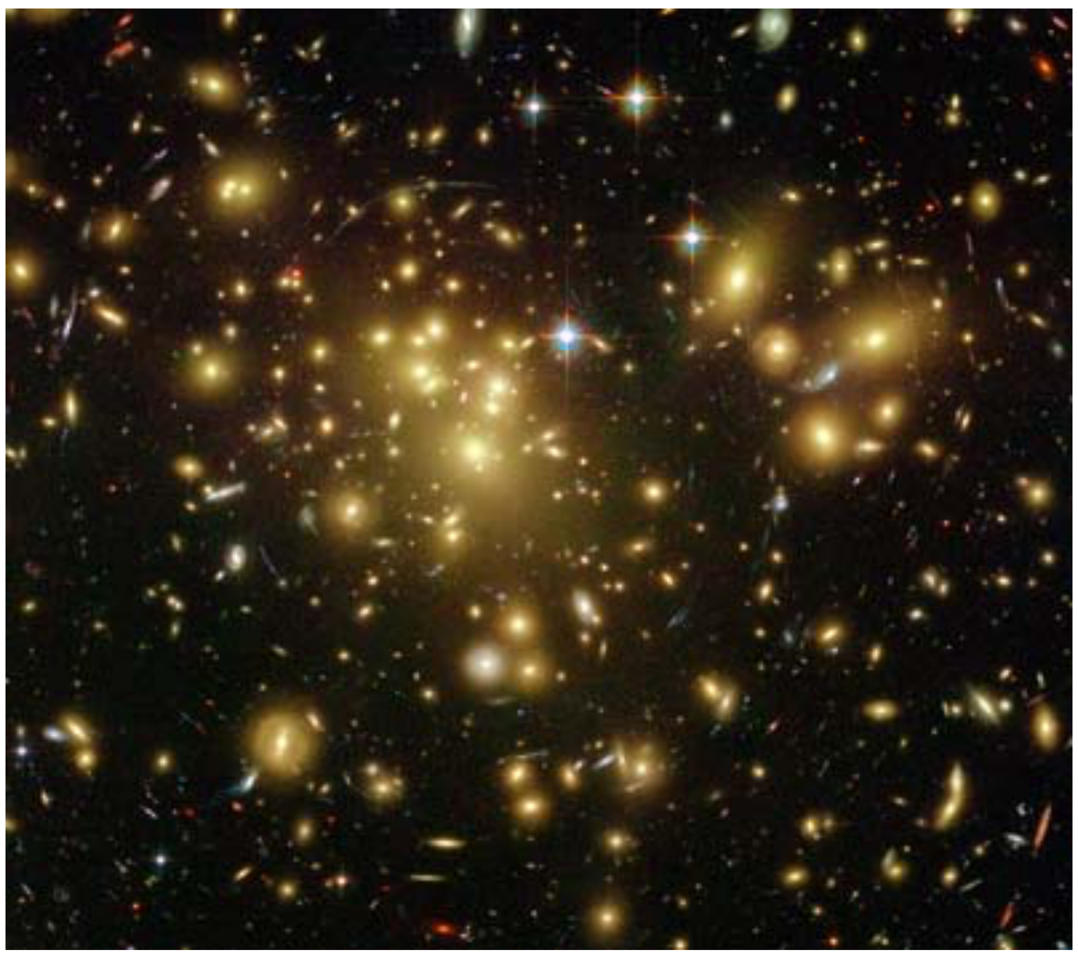
spiral galaxies

NGC 1300 / NGC 5457

- disk + bulge (+ bar)
- light follows Sersic profile with n=4 or larger in bulges; n~1 in disks
- disks sustained by rotation
- large range of masses: 10^9-$10^{12}M_\odot$
- rich of gas and dust
- active star formation in the disk
- red bulges/ blue disks
- most frequent in the field

GALAXIES AND CLUSTERS AS LENSES

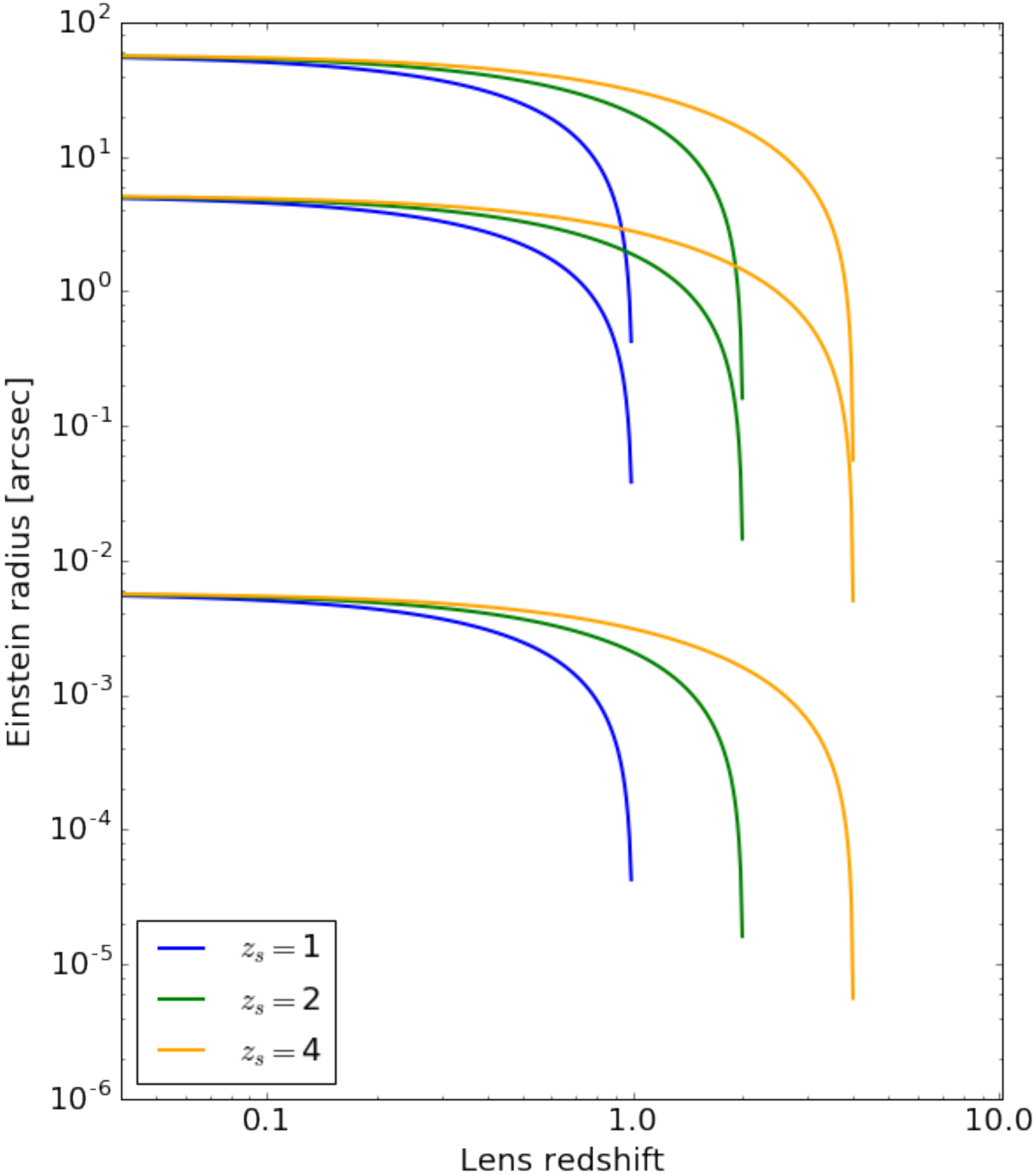
galaxy clusters



Abell 1689

- largest bound cosmic structures
- tail of the mass function: 10^{13}-$10^{15}M_\odot$
- 11-12% gas; ~1% stars
- contain thousands of galaxies
- red sequence of elliptical galaxies + blu cloud of spiral galaxies

SIZES OF THE EINSTEIN RADII



Galaxy cluster (1000 km/s)

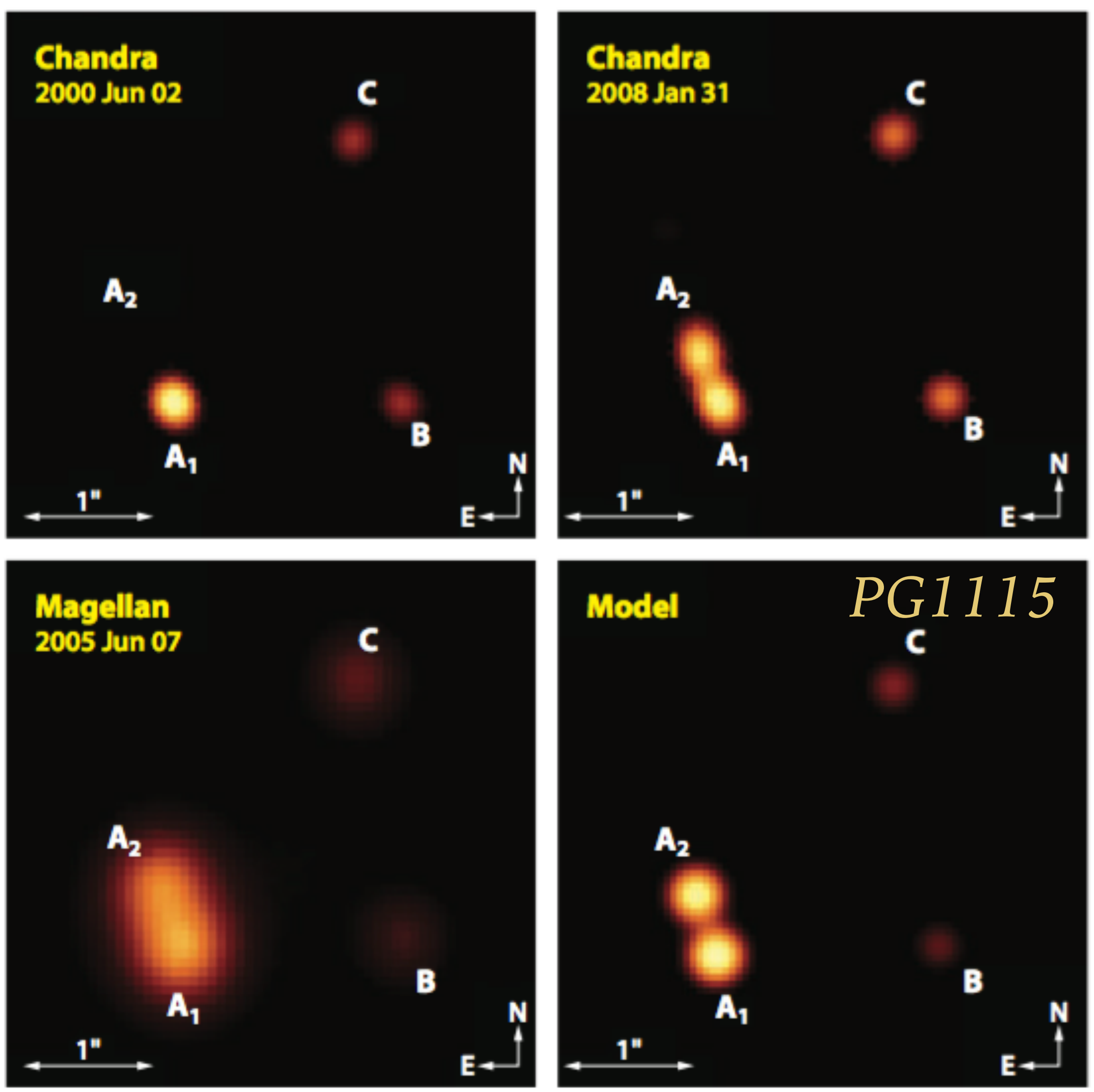
Massive elliptical (300 km/s)

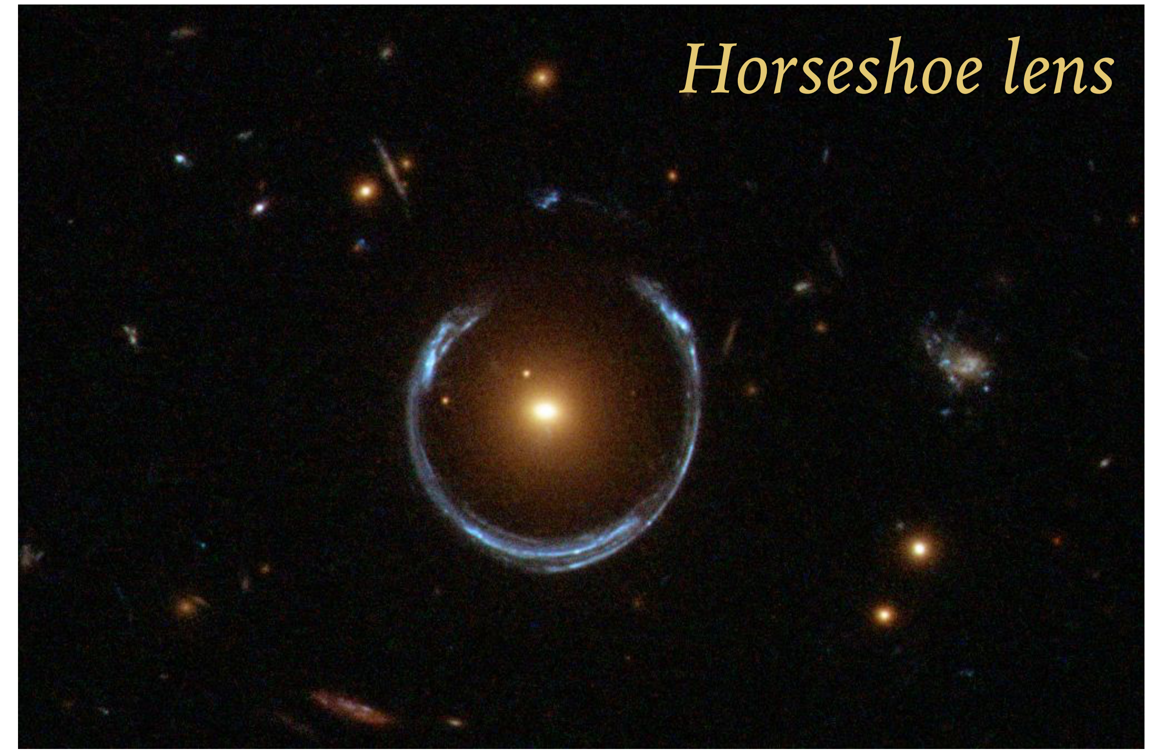
Dwarf satellite (10 km/s)

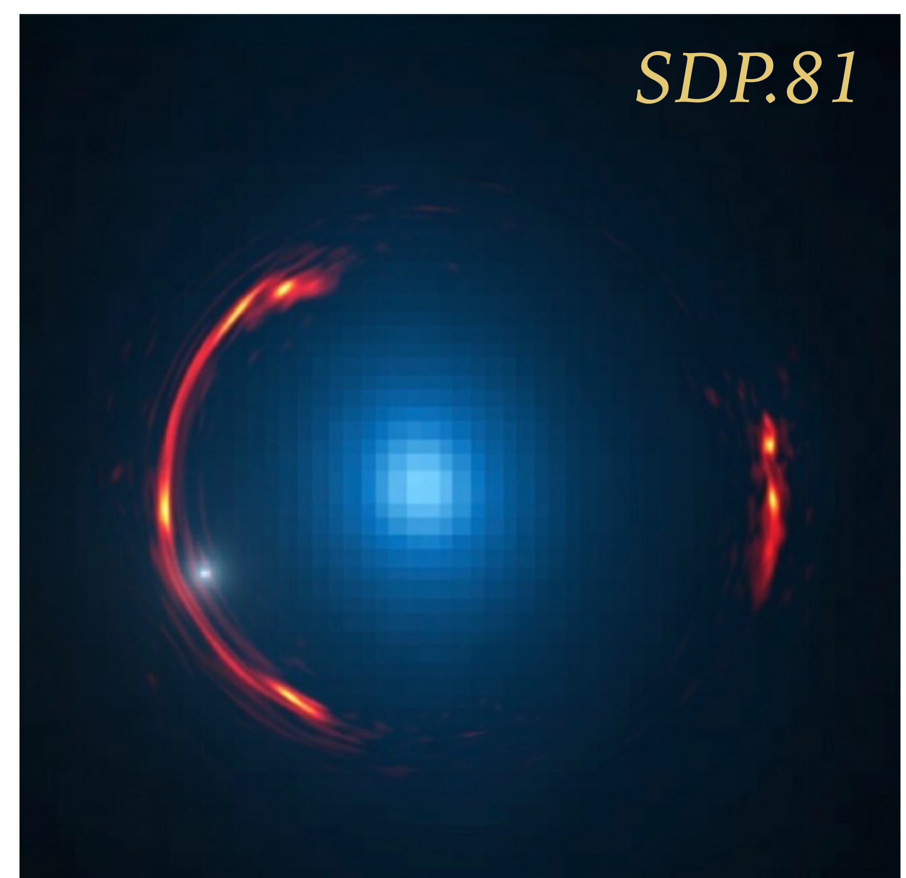
Stars

MULTIPLE COMPONENTS – MULTIPLE LENSING REGIMES

- macrolensing: the dark matter halo, galaxies
- millilensing: substructures in galaxies
- microlensing: stars in galaxies







LENSING OBSERVABLES

- multiple images [images with the same colors and the same spectra]
- parity inversion in multiple images
- image distortions
- time delays

SERENDIPITOUS DISCOVERIES

Discovery of the first galaxy-QSO lens system (1979)

0957+561 A, B: twin quasistellar objects or gravitational lens?

D. Walsh
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire, UK
R. F. Carswell
Institute of Astronomy, Cambridge, UK
R. J. Weymann
Steward Observatory, University of Arizona, Tucson, Arizona 85721

0957+561 A, B are two QSOs of mag 17 with 5.7 arc s separation at redshift 1.405. Their spectra leave little doubt that they are associated. Difficulties arise in describing them as two distinct objects and the possibility that they are two images of the same object formed by a gravitational lens is discussed.

SPECTROSCOPIC observations have been in progress for several years on QSO candidates using a survey of radio sources made at 966 MHz with the MkIA telescope at Jodrell Bank. Many of the identifications have been published by Cohen *et al.*[1] with interferometric positions accurate to ~2 arc s and a further list has been prepared by Porcas *et al.*[2]. The latter list consists of sources that were either too extended or too confused for accurate interferometric positions to be measured, and these were observed with the pencil-beam of the 300 ft telescope at NRAO, Green Bank at λ 6 cm and λ 11 cm. This gave positions with typical accuracy 5–10 arc s and the identifications are estimated as ~80% reliable.

The list of Porcas *et al.* includes the source 0957+561 which has within its field a close pair of blue stellar objects, separated by ~6 arc s, which are suggested as candidate identifications. Their positions and red and blue magnitudes, m_R and m_B, estimated from the Palomar Observatory Sky Survey (POSS) are given in Table 1 and a finding chart is given in Fig. 1. Since the images on the POSS overlap, the magnitude estimates may be of lower accuracy than normal, but they are very nearly equal and object A is definitely bluer than object B. The mean position of the two objects is 17 arc s from the radio position, so the identification is necessarily tentative.

Observations

The two objects 0957+561 A, B were observed on 29 March 1979 at the 2.1 m telescope of the Kitt Peak National Observatory (KPNO) using the intensified image dissector scanner (IIDS). Sky subtraction was used with circular apertures separated by 99.4 arc s. Some observational parameters are given in Table 2. The spectral range was divided into 1,024 data bins, each bin 3.5 Å wide, and the spectral resolution was 16 Å. After 20-min integration on each object it was clear that both were QSOs with almost identical spectra and redshifts of ~1.40 on the basis of strong emission lines identified as C IV λ1549 and C III] λ1909. Further observations were made on 29 March and on subsequent nights as detailed in Table 2. By offsetting to observe empty sky a few arc seconds from one object on both 29 and 30 March it was confirmed that any contamination of the spectrum of one object by light from the other was negligible.

Table 1 Positions and magnitudes of 0957+561 A, B

Object	RA	Dec (1950.0)	M_R	M_B
0957+561A	09 57 57.3	+56 08 22.9	17.0	16.7
0957+561B	09 57 57.4	+56 08 16.9	17.0	17.0

0028–0836/79/0279—0381$01.00

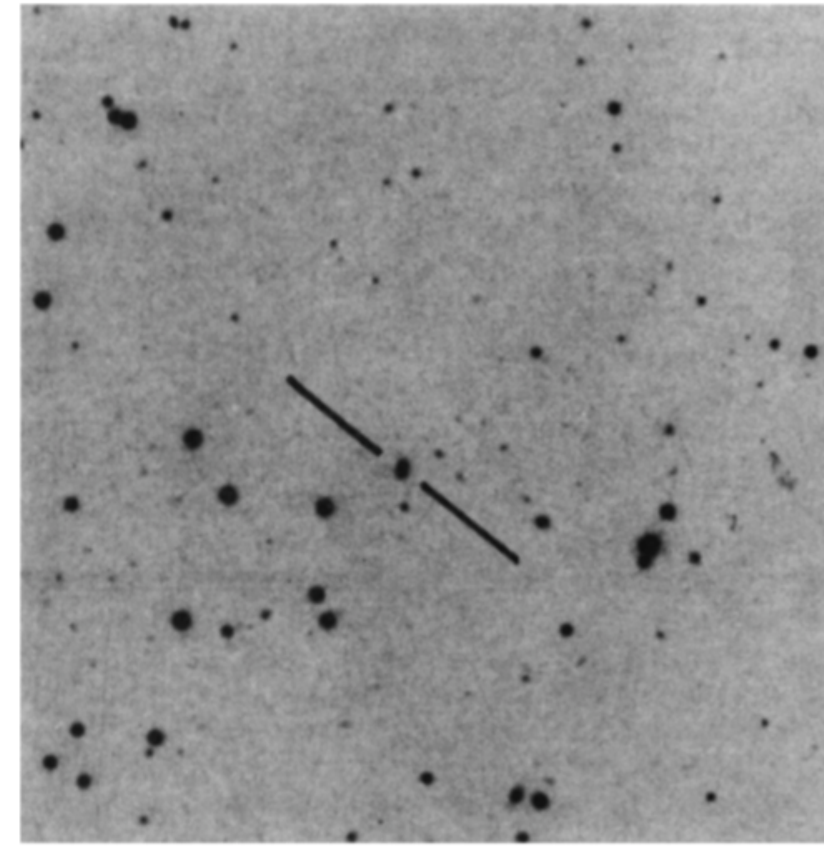


Fig. 1 Finding chart for the QSOs 0957+561 A and B. The chart is 8.5 arc min square with the top right hand corner north preceding and is from the E print of the POSS.

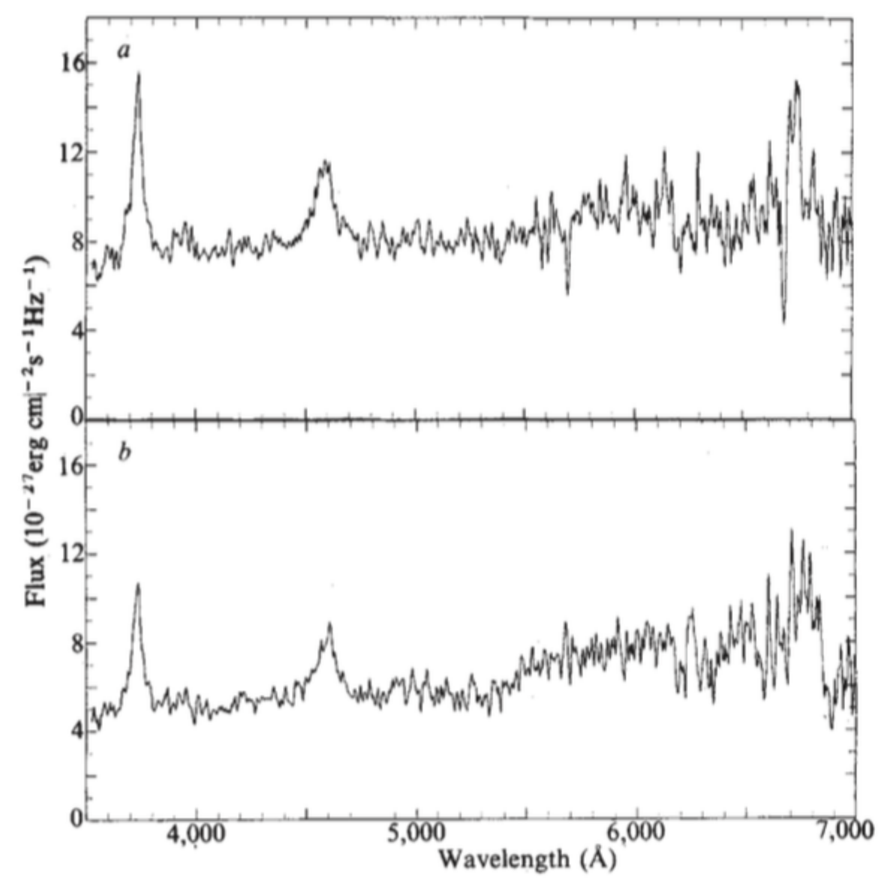


Fig. 2 IIDS scans of 0957+561 A(*a*) and B(*b*). The data are smoothed over 10 Å and the spectral resolution is 16 Å.

SE

. . . .

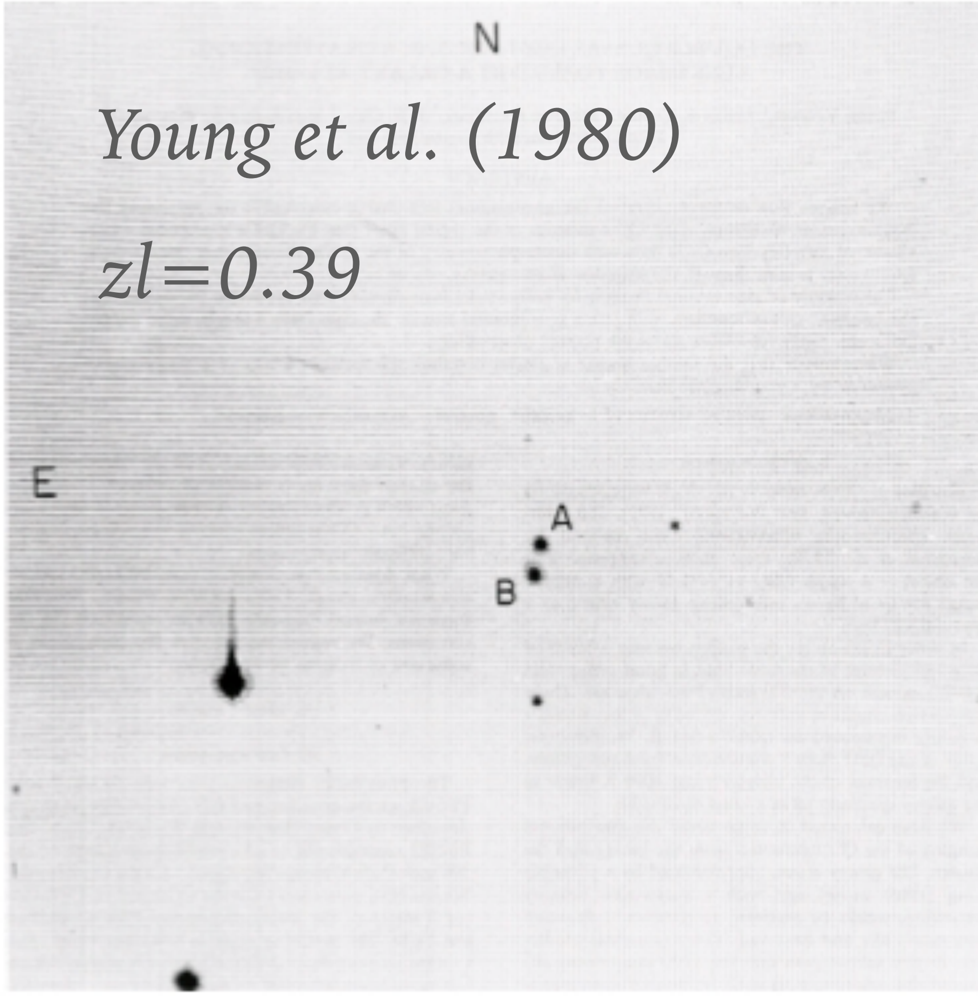
Disc

095'
obj

D. Wa
University o
R. F. (
Institute of
R. J. W
Steward Ob

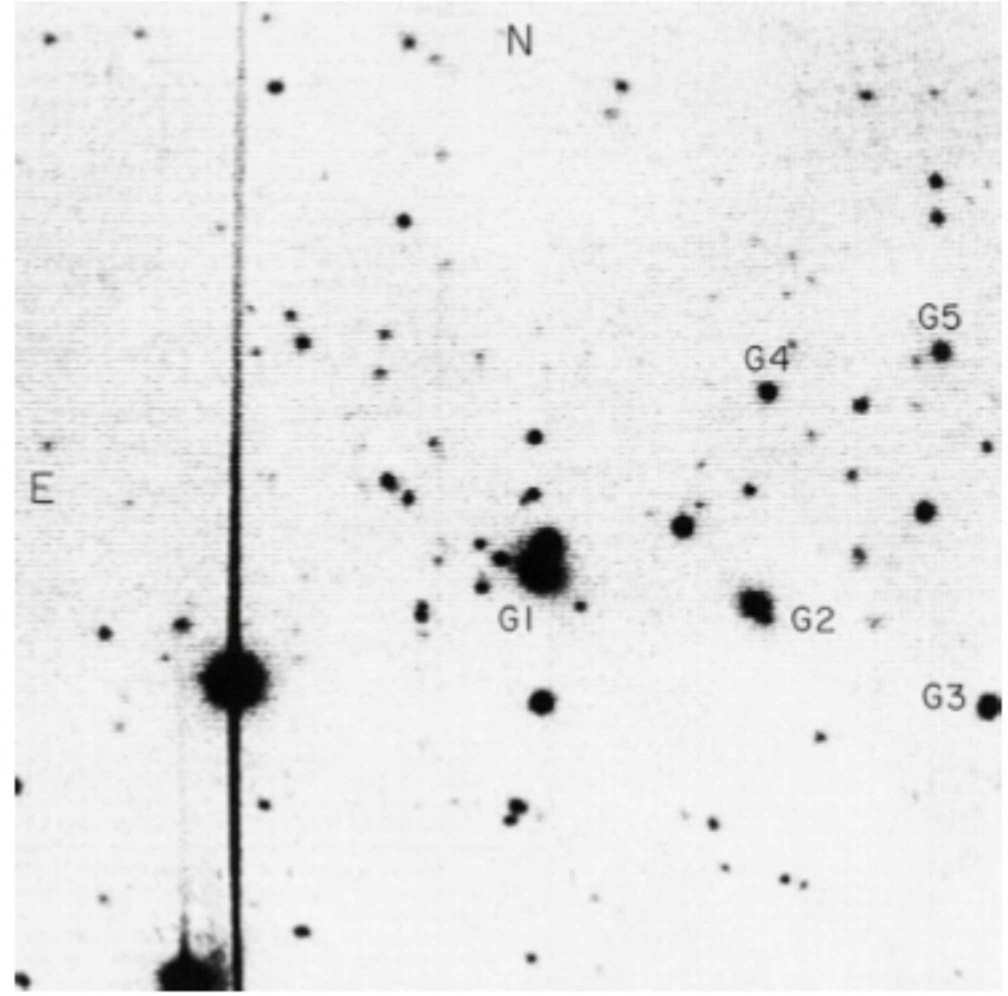
0957 + 56
separation
that they
them as tw
two image
lens is disc

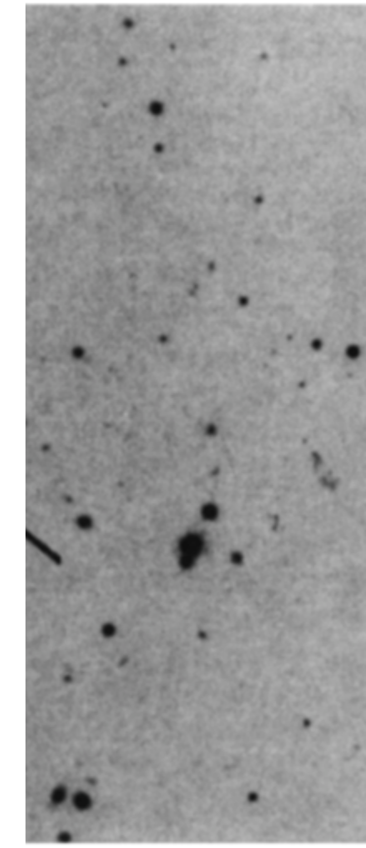
SPECTROS
several yea
made at 96
Many of the
with interfe
list has bee
sources tha
accurate in
were obser
NRAO, Gr
with typica
estimated a
The list o
has within i
by ~6 arc s
Their posit
estimated f
are given in
the images



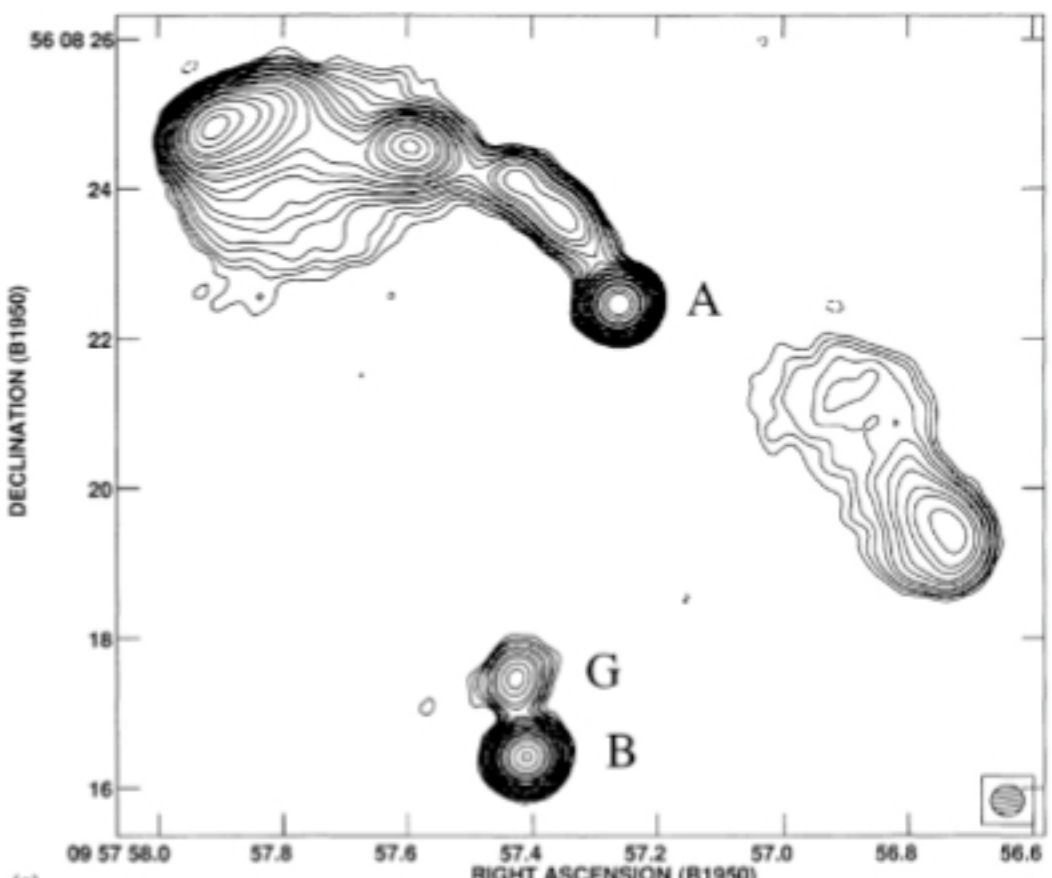
Young et al. (1980)

zl=0.39

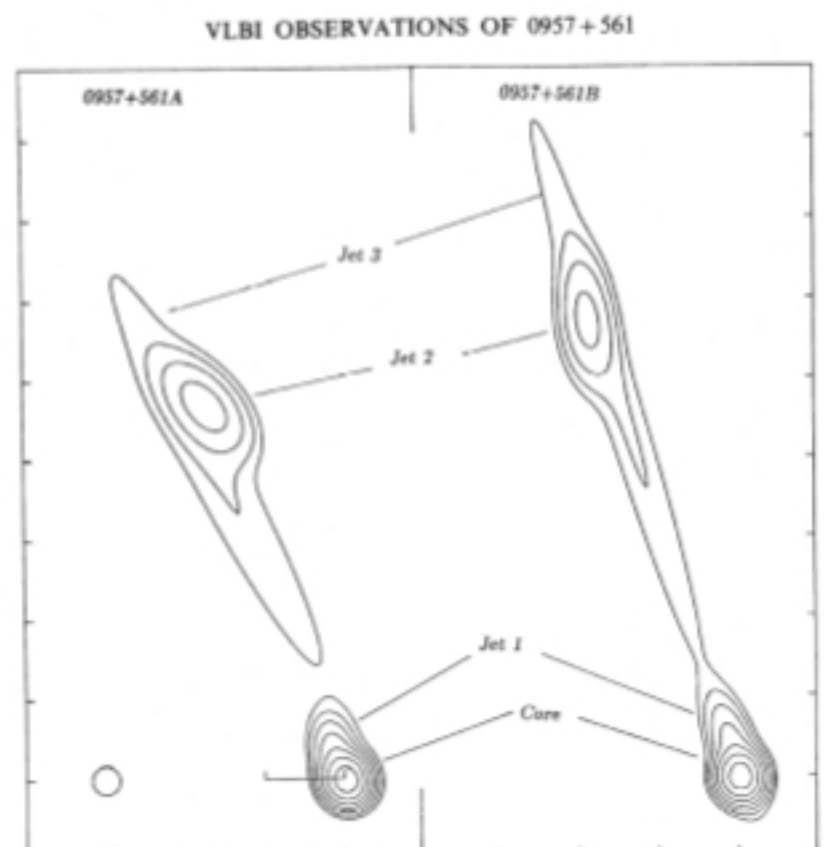




ı957 + 561 A and B. The chart
t hand corner north preceding
ıt of the POSS.



Gorenstein et al. (1984)



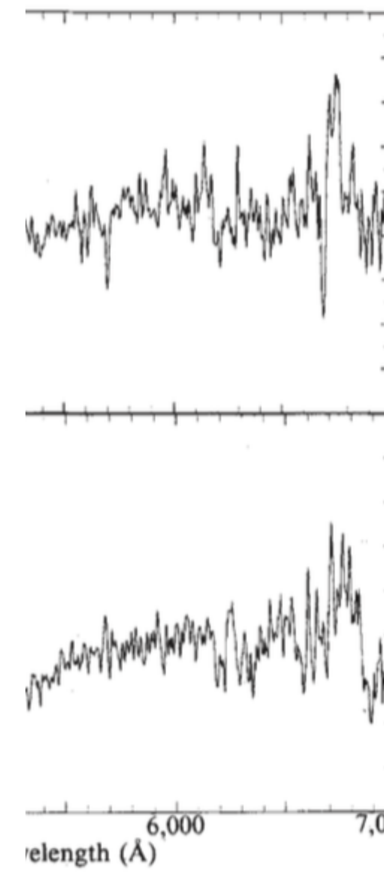


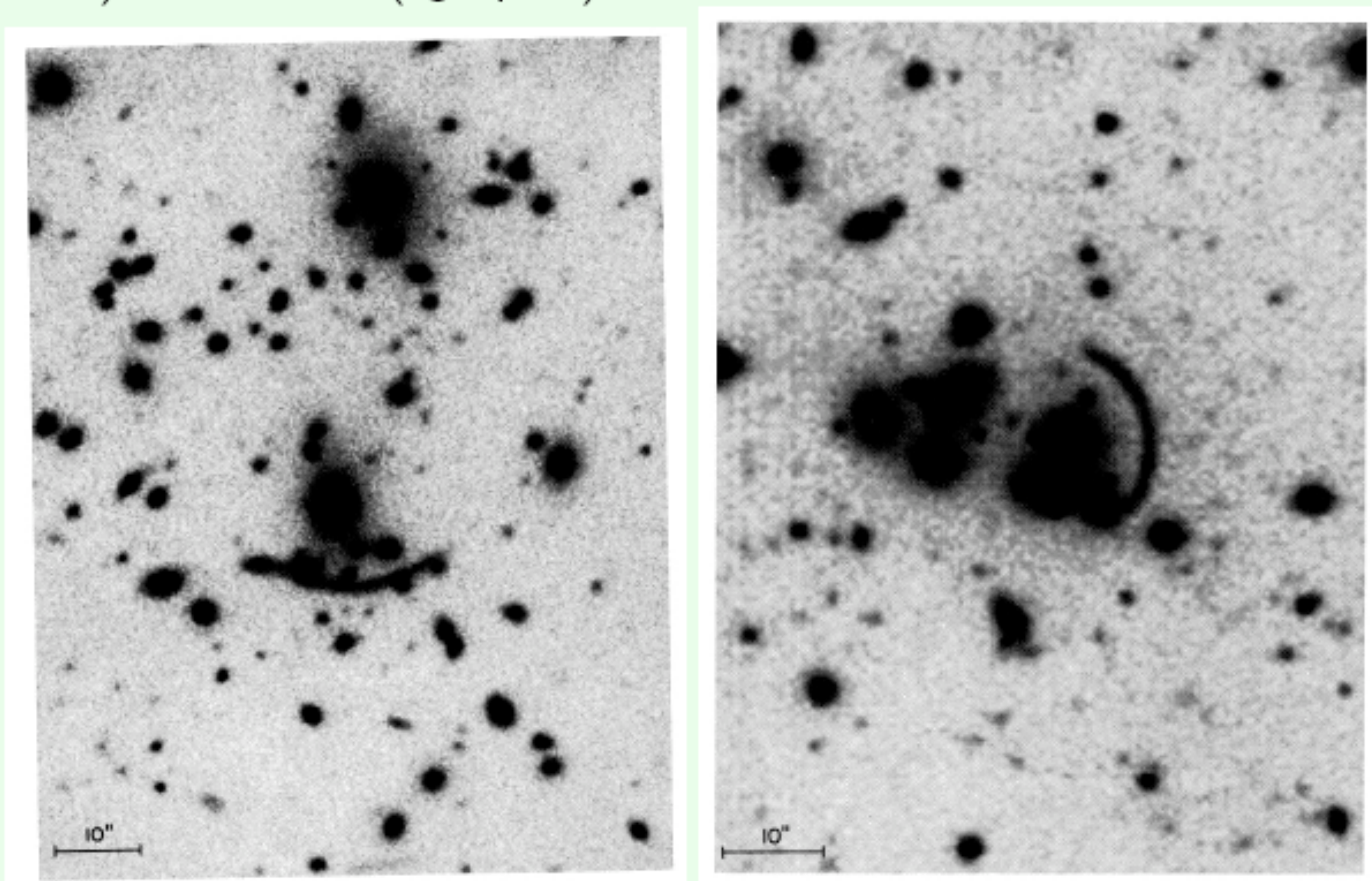
Fig. 2 IIDS scans of 0957 + 561 A(*a*) and B(*b*). The data are smoothed over 10 Å and the spectral resolution is 16 Å.

0028–0836/79/0279—0381$01.00

SERENDIPITOUS DISCOVERIES

Historical remark: The first gravitational arcs

The first detection of gravitational arcs in galaxy clusters is dated 1986. In this year, two groups independently discovered strongly elongated, curved features around two clusters of galaxies (Soucail et al., 1987; Lynds & Petrosian, 1989): A370 (left panel below) and CL2244-02 (right panel).



They were seen displaced from the cluster center and curving around it. Several hypothesis were put forward about the nature of these features, all proven wrong. The correct interpretation of these observations as gravitational lensing effects was made by Paczynski (1987), when the redshift of the arc in A370 was measured and discovered to be much larger than the redshift on the cluster. In particular, A370 is at redshift $z_{\rm d} = 0.374$, while the arc is at redshift $z_{\rm s} = 0.724$. The arc in CL2244-02 ($z_{\rm d} = 0.3$) is at redshift $z_{\rm s} = 2.24$. The figures below show color higher quality images