Galaxies and Extragalactic Astronomy

3. Galaxy Dynamics

3. Galaxy Dynamics

3.1 Introdution

- Galaxy dynamics is the study of the movement of the different galaxy components (stars and gas) and the potential responsible for these movements

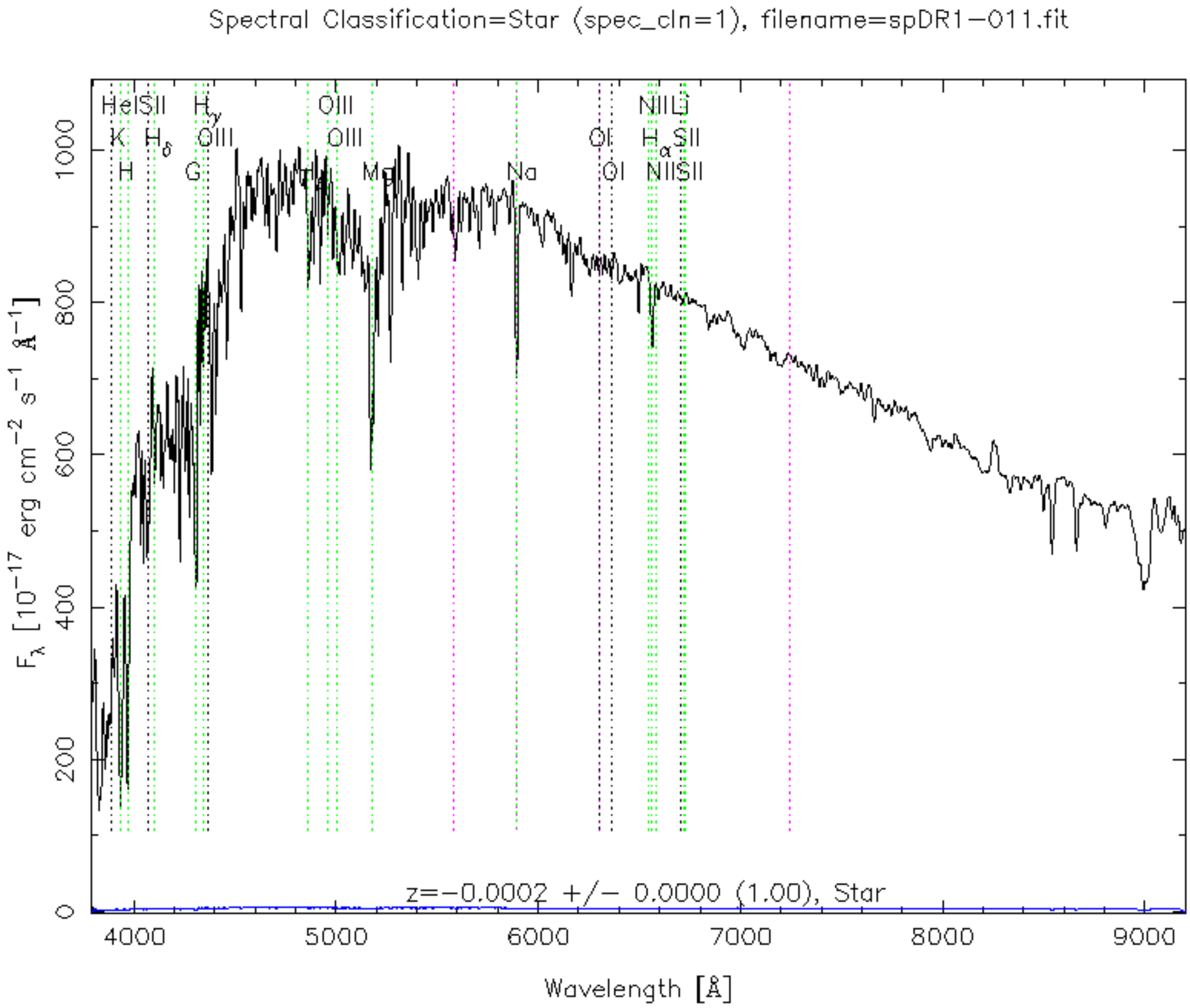
- the galaxy kinematics is determined by the phase space distribution function. In external galaxies it cannot be determined and the stars and gas kinematics is studied instead

- In the vast majority of galaxies individual stars cannot be resolved and only non-resolved stars mean movements can be studied

3. Galaxy Dynamics

3.2 Kinematics measurement

- Doppler effect => line-of-sight velocity v_{los}
- the observed spectrum of a particular location in a galaxy is the sum of all the stellar spectra in the line of sight along the galaxy. Each star has a different v_{los} and therefore the resulting spectrum have broadened lines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K
H
Hδ
Hγ
G
OIII
OIII
OIII
Mg
Na
OI
OI
NIILi
Hα SII
NIISII
z=-0.0002 +/- 0.0000 (1.00), Star
Fλ [10^-17 erg cm^-2 s^-1 Å^-1]
Wavelength [Å]
0
200
400
600
800
1000
4000
5000
6000
7000
8000
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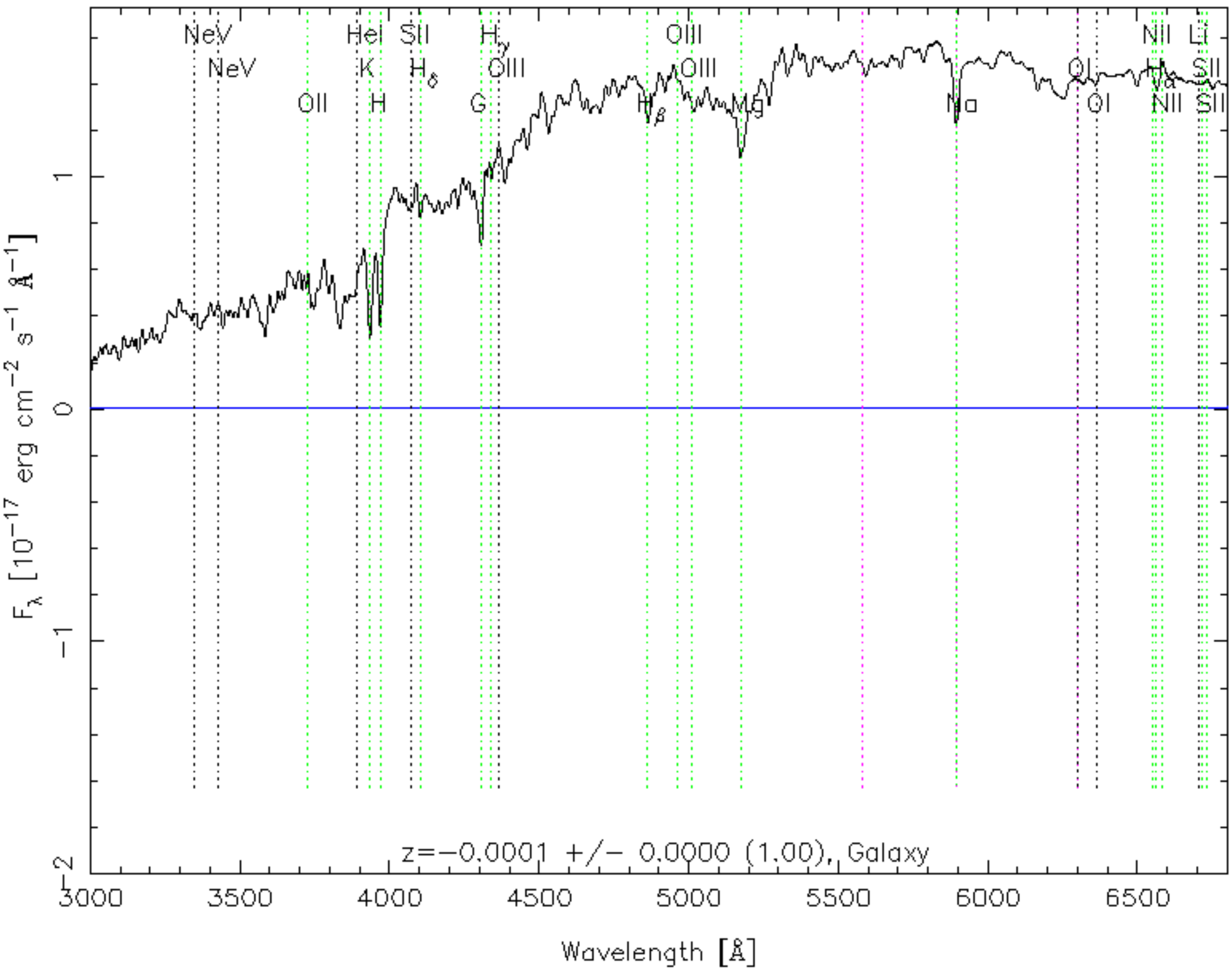


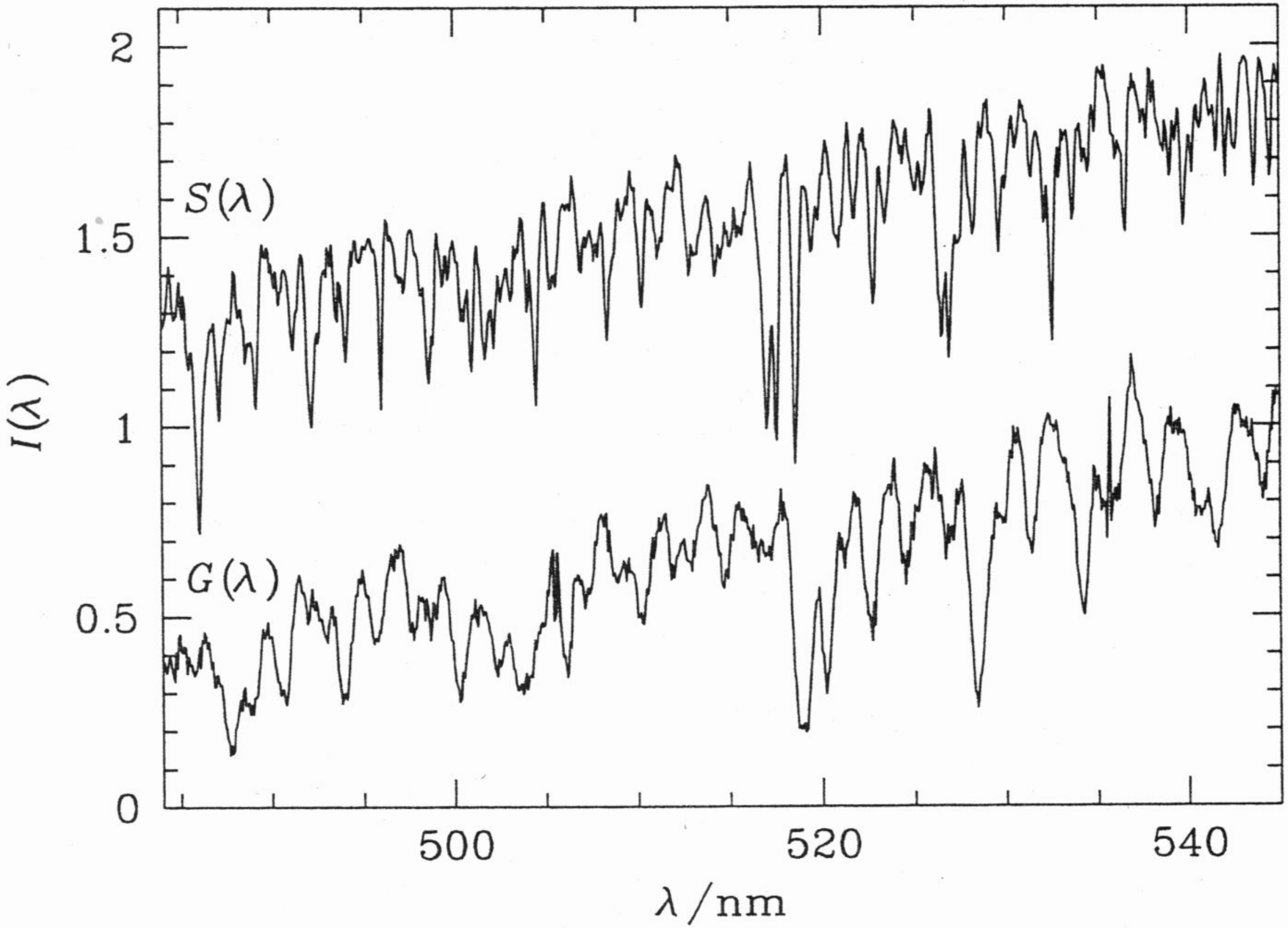


Figure 11.1 Spectra of a K0 giant star (S) and the center of the lenticular galaxy NGC 2549 (G). These data cover a small part of the optical spectrum around the strong Mg b absorption feature at 518 nm.

3. Galaxy Dynamics

3.2 Kinematics measurement

- to study quantitatively the shift and broadening of the spectral lines the line of sight velocity distribution (LOSVD) is defined, $F(v_{los})$, such that the fraction of stars contributing to the spectrum with line of sight velocities between v_{los} and $v_{los} + dv_{los}$ is $F(v_{los})dv_{los}$

- If we assume that all stars have the same spectrum $S(u)$, then the received intensity at a spectral velocity u of a star with line of sight velocity v_{los} is $S(u-v_{los})$. The observed spectrum is obtained summing all stars

$$G(u) \propto \int dv_{los} \, F(v_{los}) \, S(u-v_{los})$$

3. Galaxy Dynamics

3.2 Kinematic measurement

- In principle we can get $F(v_{los})$:

  $F(k) \propto G(k)/S(k)$

  but in practice it does not work well

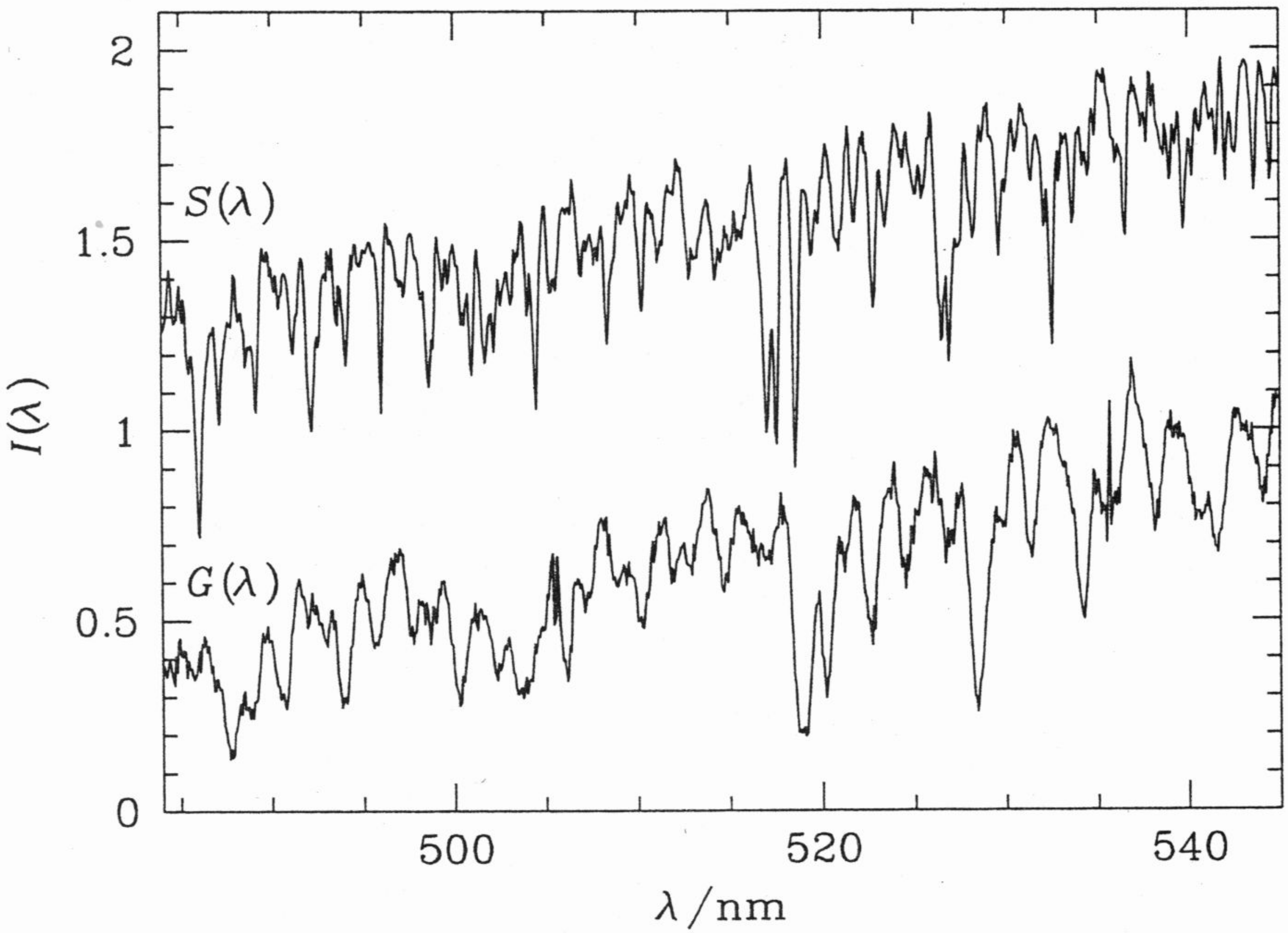


Figure 11.1 Spectra of a K0 giant star (S) and the center of the lenticular galaxy NGC 2549 (G). These data cover a small part of the optical spectrum around the strong Mg b absorption feature at 518 nm.

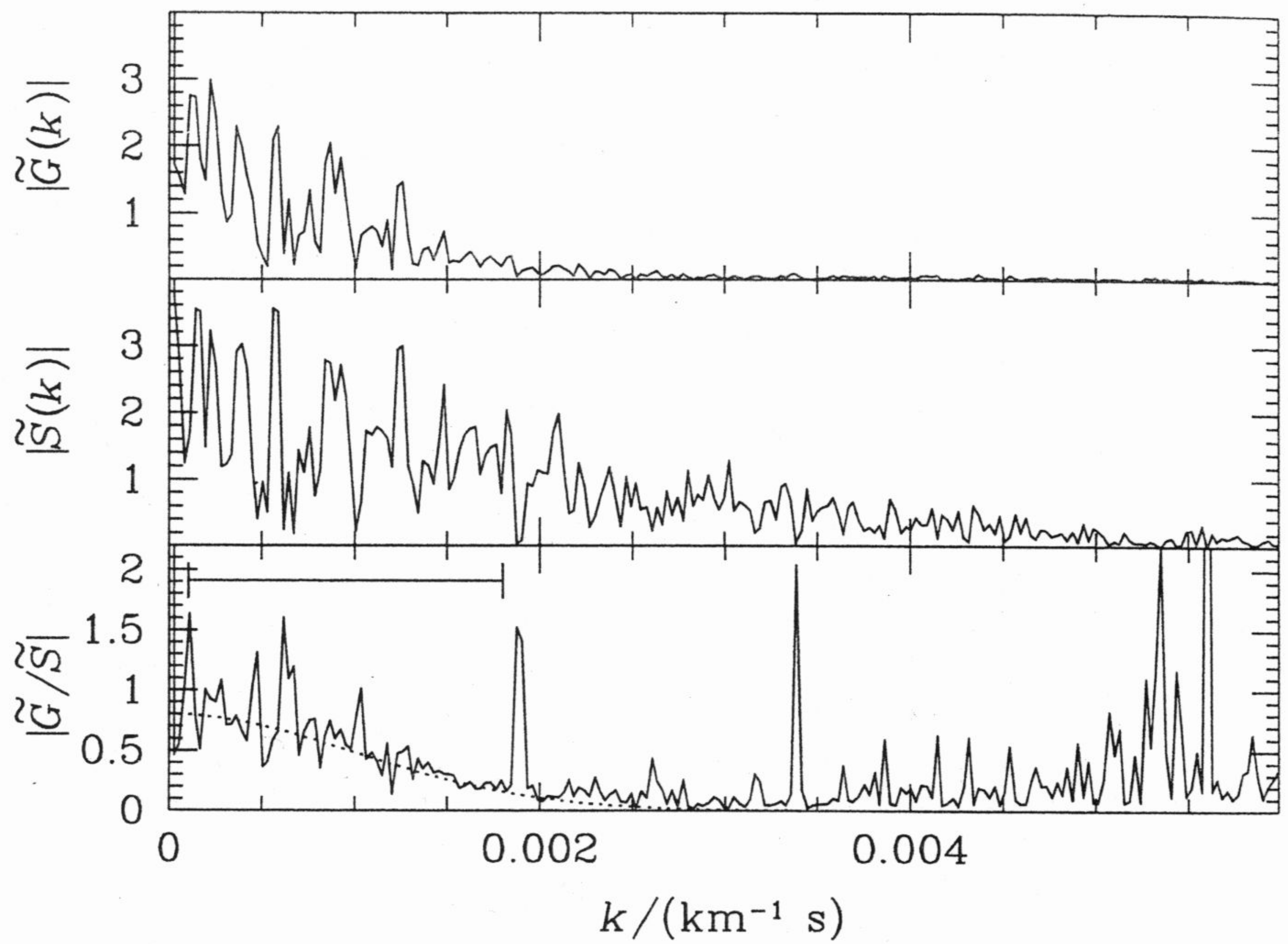


Figure 11.2 The amplitudes of the Fourier transforms of the spectra illustrated in Figure 11.1, and the amplitude of their ratio. The dotted line shows a model fit to the amplitude of equation (11.7), with $\gamma = 0.8$ and $\sigma_{\rm los} = 160\,\mathrm{km\,s^{-1}}$, and the horizontal bar indicates the range in k over which the fit was made.

3. Galaxy Dynamics

3.2 Kinematic measurement

- mean velocity: mean movement of the stars
- velocity dispersion: random motions of the stars averaged along the line of sight through the galaxy

3. Galaxy Dynamics

3.2 Kinematic measurement

- Methods to obtain: v_{los} σ_{los}
  - Direct fit method: assume that the distribution is Gaussian
  - Fourier Quotient method: assume that the distribution is Gaussian
  - Cross-correlation method

$$CCF(v_{los}) = \int du\, G(u)\, S\,(u-v_{los})$$

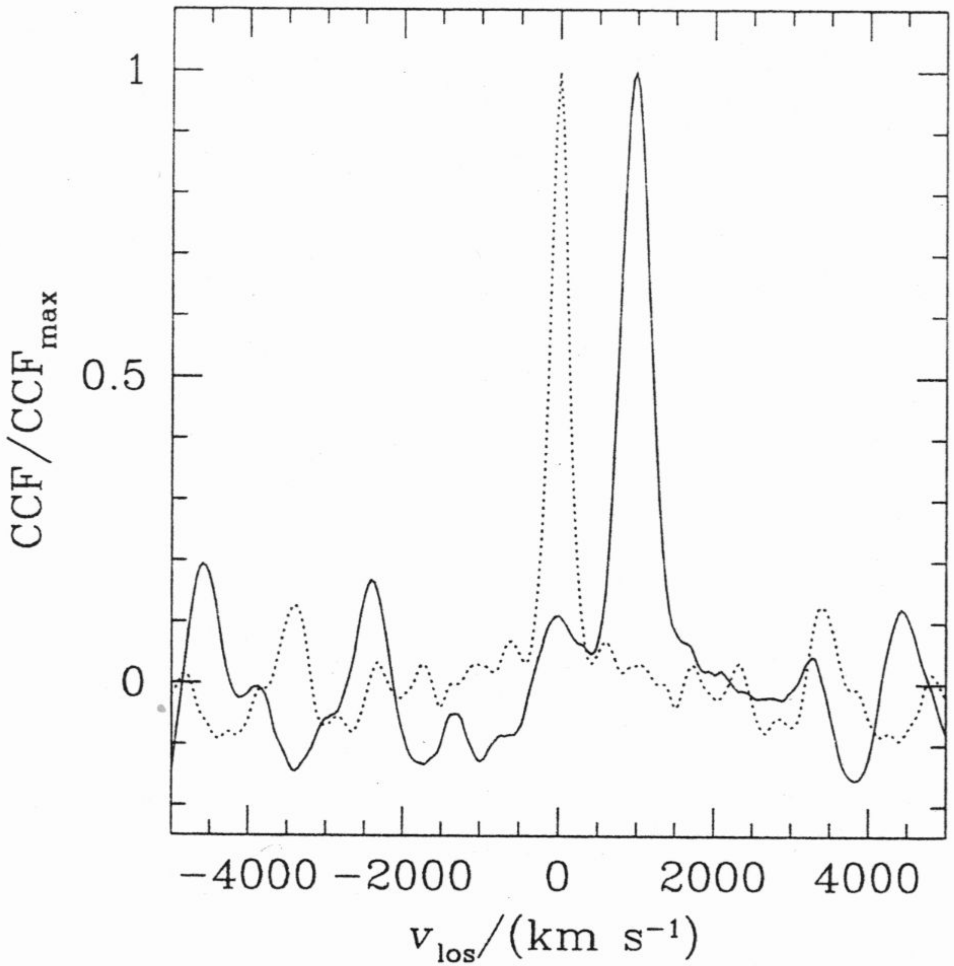


Figure 11.3 The cross-correlation function between the galaxy and star spectra shown in Figure 11.1. The dotted line shows the auto-correlation function of the star. The functions have been normalized by their peak values.

3. Galaxy Dynamics

3.2 Kinematic measurement

- Line profile analysis
  - Spectral smoothing with an optimal filter to reduce the noise
  - Correlation functions
  - LOSVD moments
  - truncated Gauss-Hermite series
  - Unresolved Gaussian decomposition
  - Position-velocity (PV) diagram
  - Data cubes: 3D spectroscopy

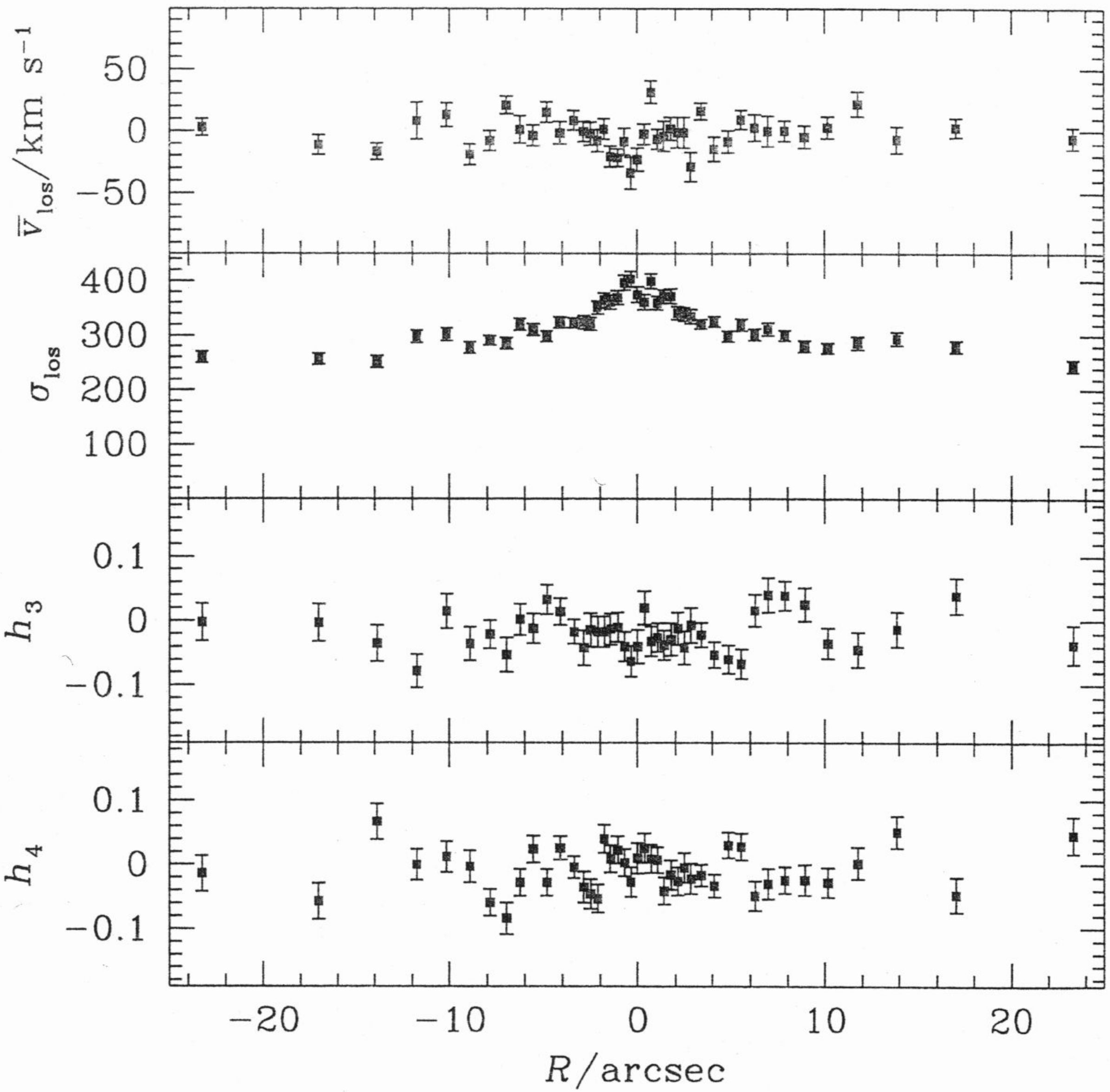


Figure 11.12 The variation in properties of the LOSVD derived by applying the truncated Gauss-Hermite algorithm (§11.1.2) to spectra obtained close to the center of M87. [From the data published in van der Marel (1994)]

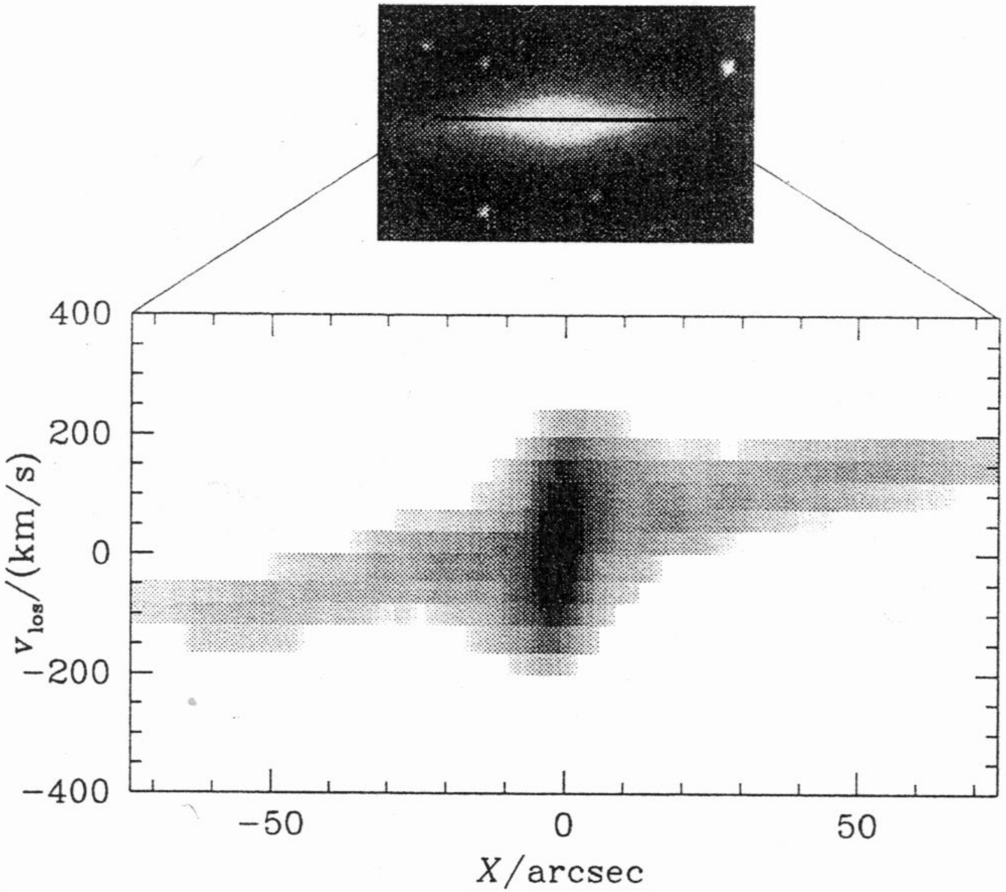


Figure 11.15 Stellar position–velocity diagram for the major axis of the edge-on S0 galaxy NGC 7332 (as shown in the top panel). The grayscale indicates the density of stars as a function of both line-of-sight velocity and position along the major axis. The kinematics were derived using the UGD algorithm. [DSS image from the Palomar/National Geographic Society Sky Survey, reproduced by permission; the kinematic data were obtained by M. Merrifield and K. Kuijken]

3. Galaxy Dynamics

3.3 Elliptical galaxies kinematics

- In general the velocity distribution of the stars is very similar to a Gaussian
- Symmetric distributions with respect to the photometric semiaxes
- As a first approximation the flattening of the ellipticals is due to rotation, although the rotation is smaller than the necessary value for the flattening
- Sometimes they present kinematic differentiated cores (KDC)
- Central black holes

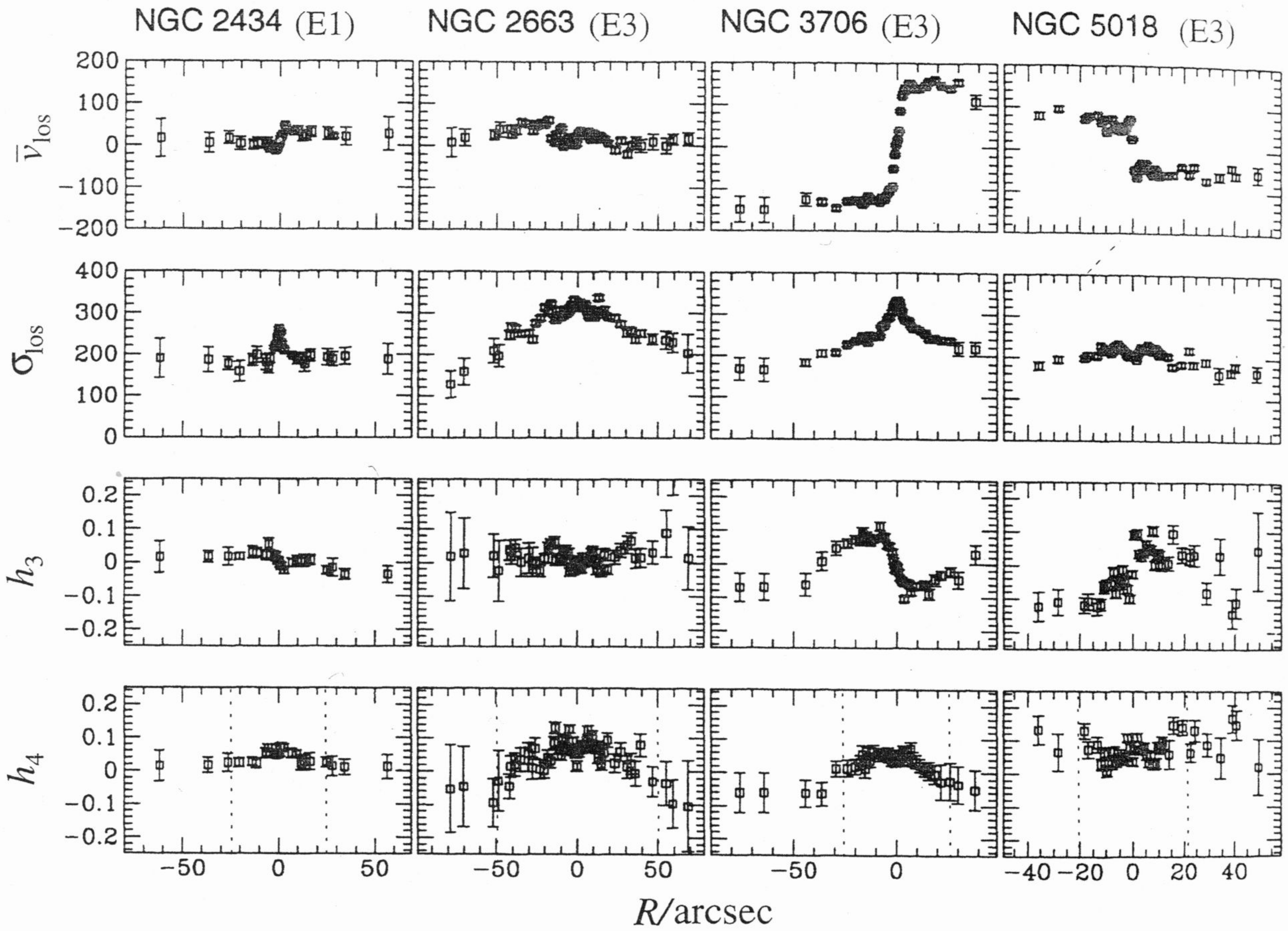
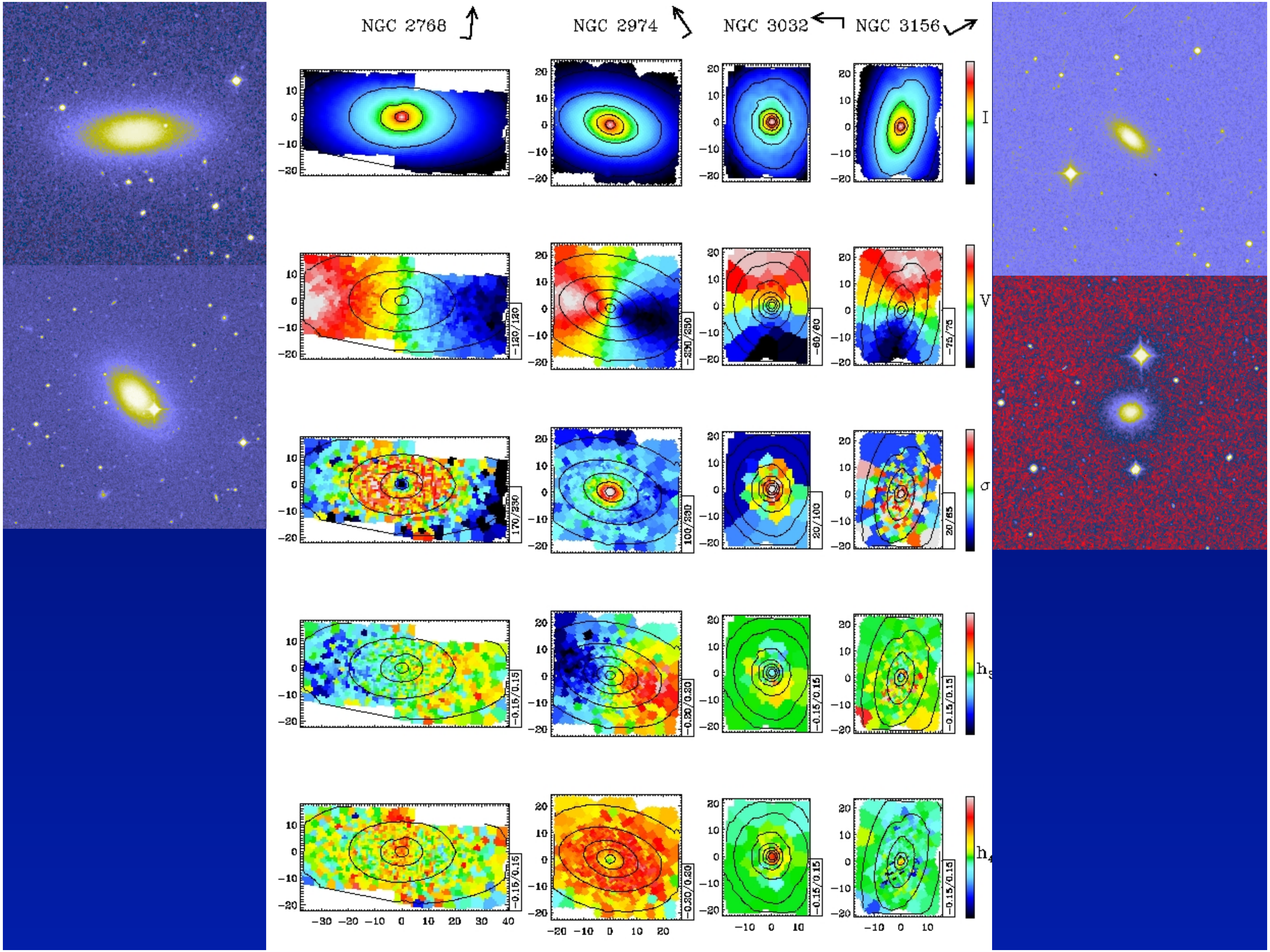
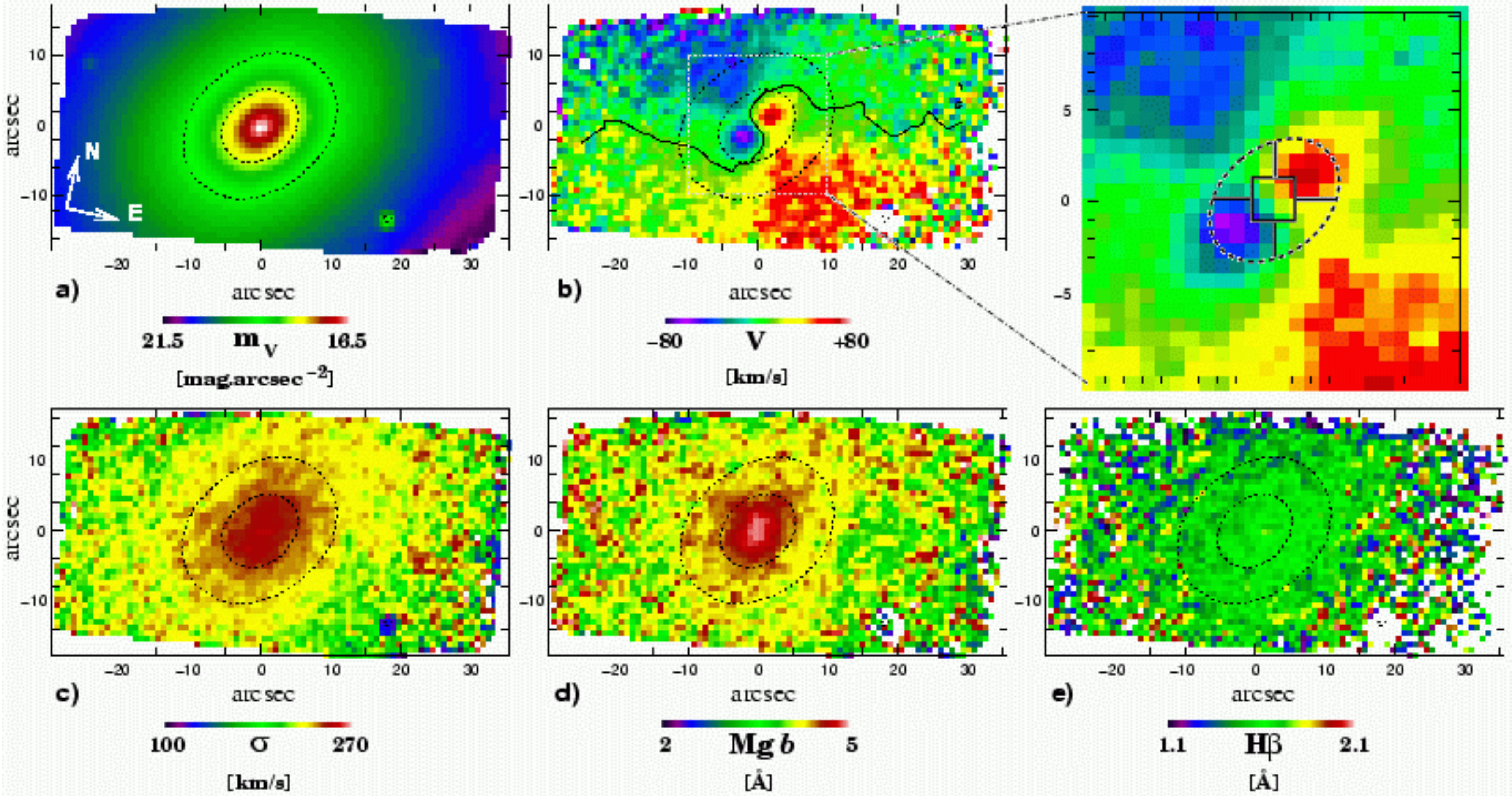


Figure 11.6 The large-scale major-axis kinematics for a sample of four giant elliptical galaxies. The LOSVDs of these systems have been parameterized using the truncated Gauss-Hermite expansion (§11.1.2). The dotted lines indicate the effective radius, $R_{\rm e}$, for each galaxy. The Hubble classification (shown in parentheses) is based on the galaxy's average ellipticity outside $R_{\rm e}/2$. [After Carollo *et al.* (1995)]


NGC 2768
NGC 2974
NGC 3032
NGC 3156
I
V
σ
h_3
h_4
−120/120
−250/250
−60/60
−75/75
170/230
100/250
20/100
20/85
−0.15/0.15
−0.30/0.30
−0.15/0.15
−0.15/0.15
−0.15/0.15
−0.30/0.30
−0.15/0.15
−0.15/0.15



a)
b)
c)
d)
e)
arcsec
N
E
21.5 m_V 16.5
[mag.arcsec^{-2}]
−80 V +80
[km/s]
100 σ 270
[km/s]
2 Mg b 5
[Å]
1.1 Hβ 2.1
[Å]

3. Galaxy Dynamics

3.4 Spiral galaxies kinematics

- complicated velocity distribution of the stars due to the existence of two components: bulge and disk that are difficult to separate

- Bulge:

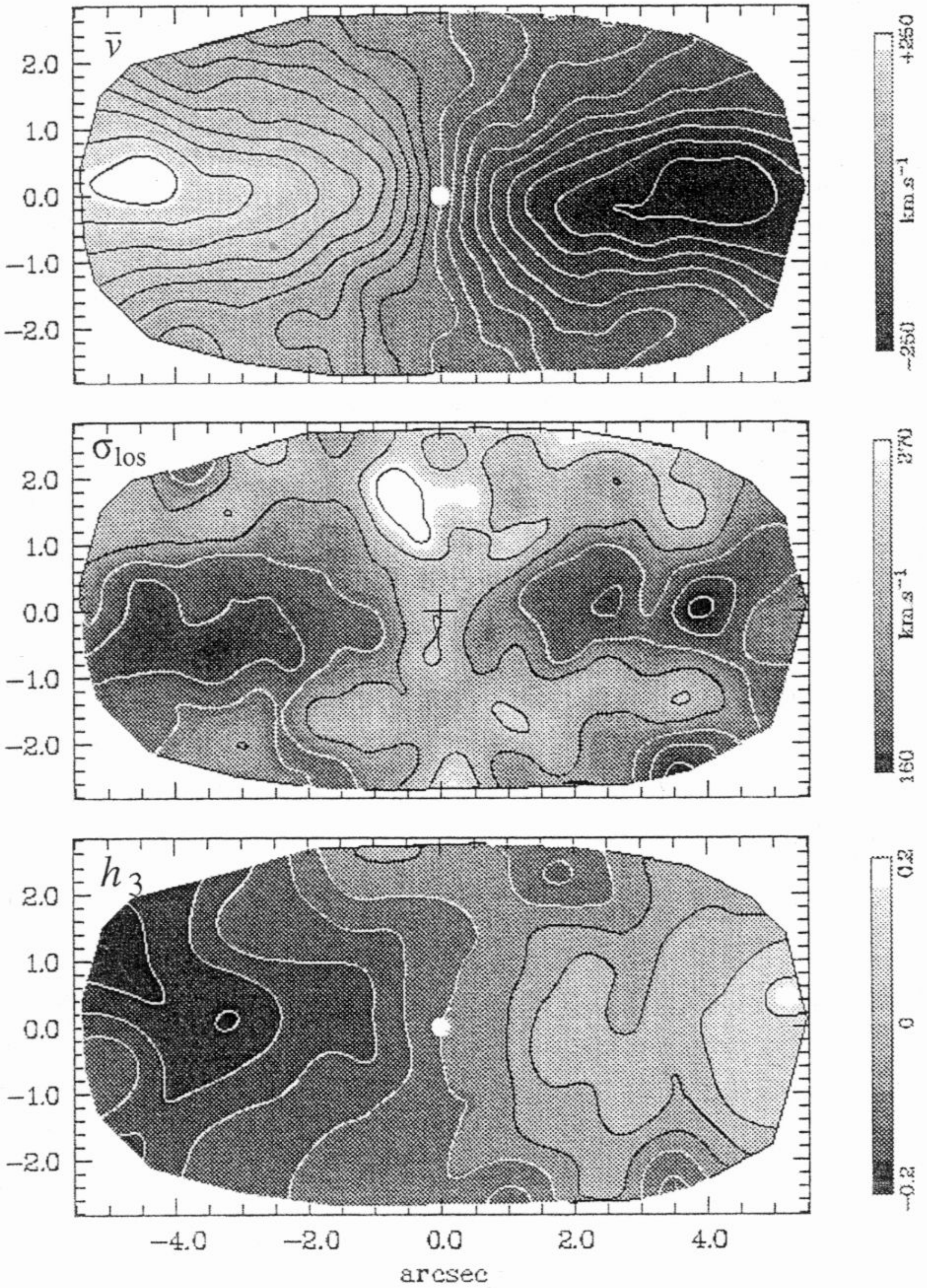
similar to elliptical galaxies where the principal component is σ

the flattening appears to be due to rotation

- Disk:

rotational component dominates ($\bar{v}_{los} > \sigma_{los}$) with little random movements

a maximum radial velocity is defined (the terminal circular velocity depends on the inclination angle: $v_c = v_{los} / \sin i$)



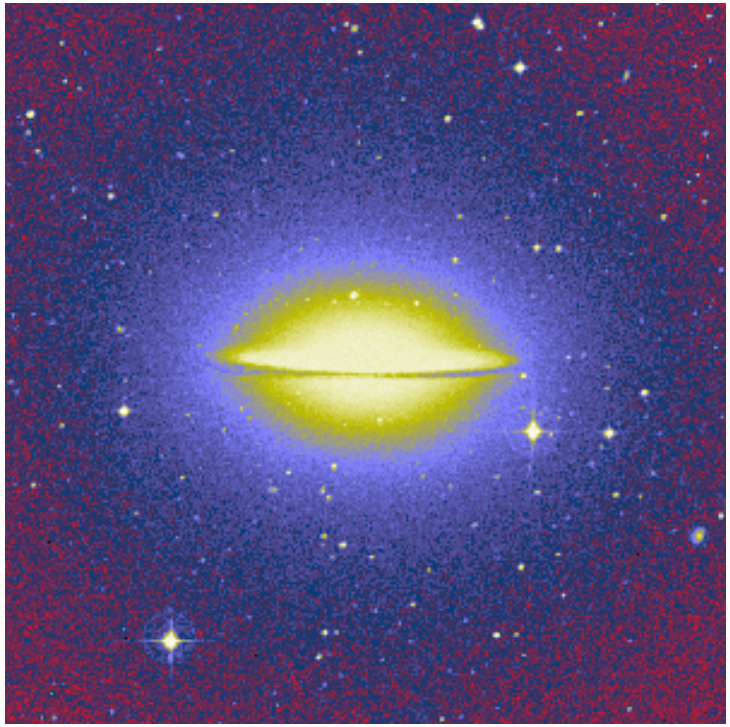
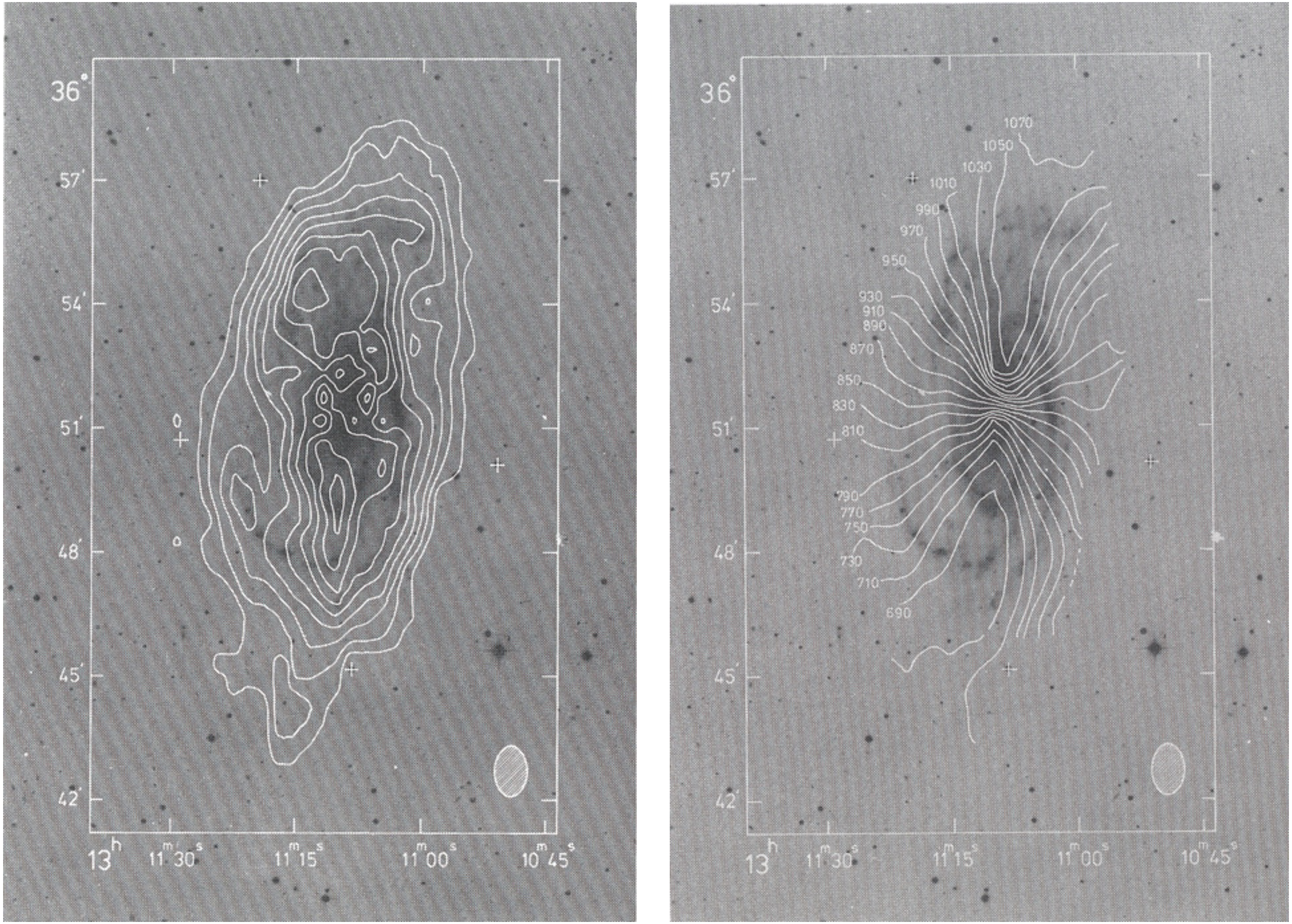


Figure 11.16 A kinematic map of the central region of M104 (the Sombrero Galaxy), showing the variation in mean velocity, line-of-sight dispersion, and skewness with position. The major axis of the system runs horizontally across each panel, with the photometric center of the galaxy indicated. The range of the grayscale is shown to the right of each panel. [After Emsellem et al. (1996) courtesy of E. Emsellem]

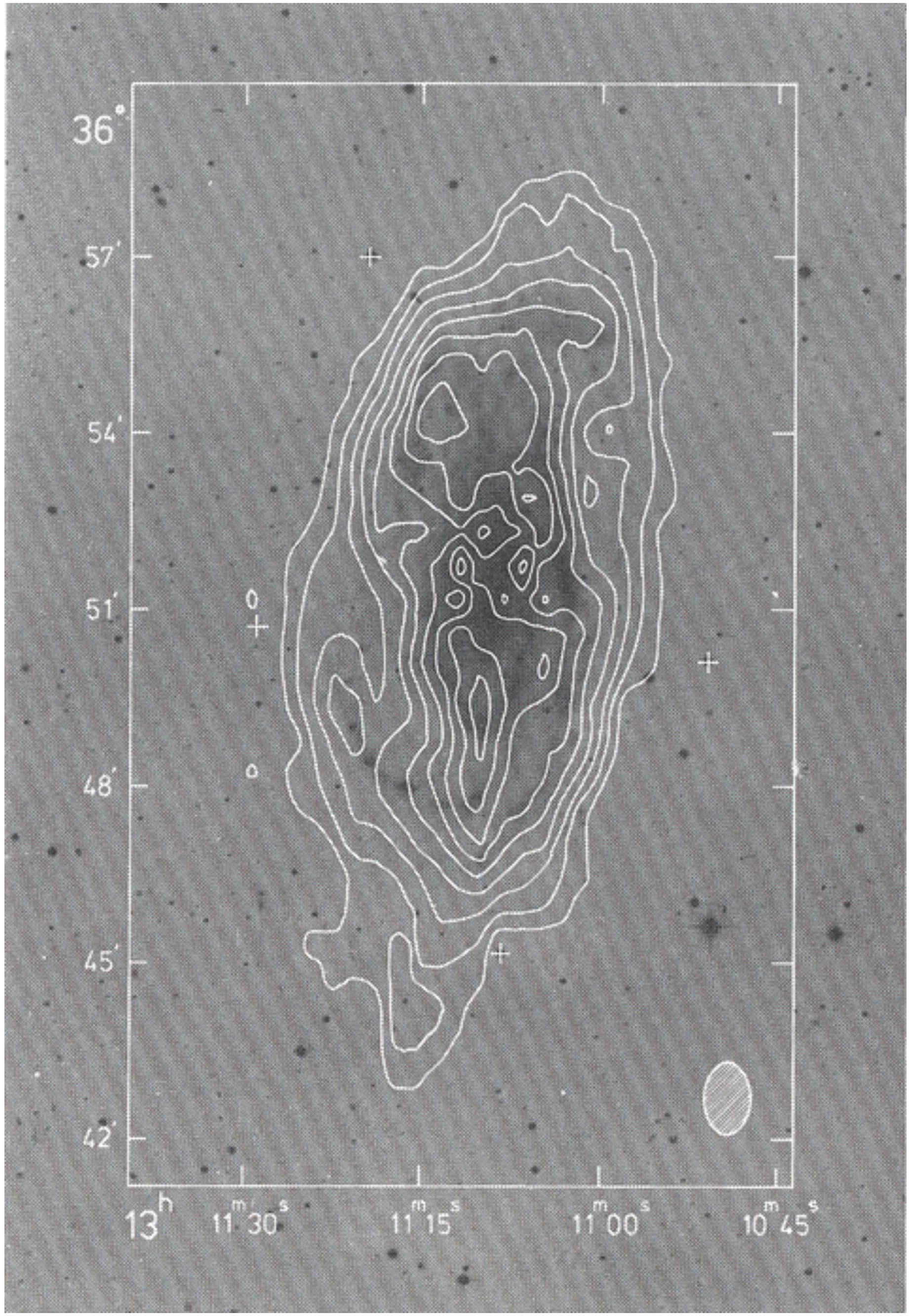
3. Galaxy Dynamics

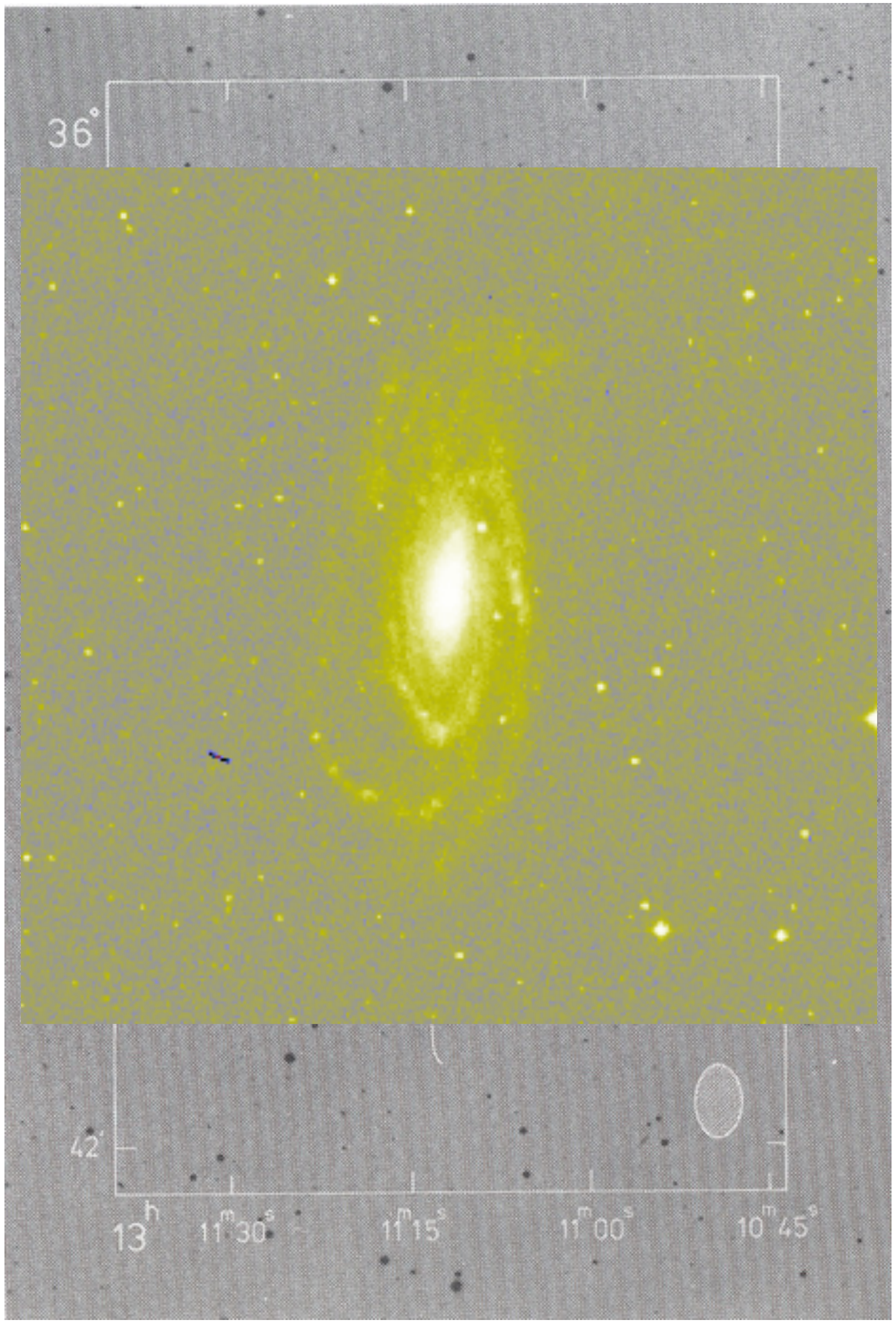
3.4 Gas kinematics

- The velocity distribution of the gas can be traced out to larger radii
- the ionized gas (visible), the neutral gas (radio) and the molecular gas (radio) can be studied
- HI measurements (21cm line: hydrogen hyperfine structure)
- resolved kinematics
- unresolved kinematics

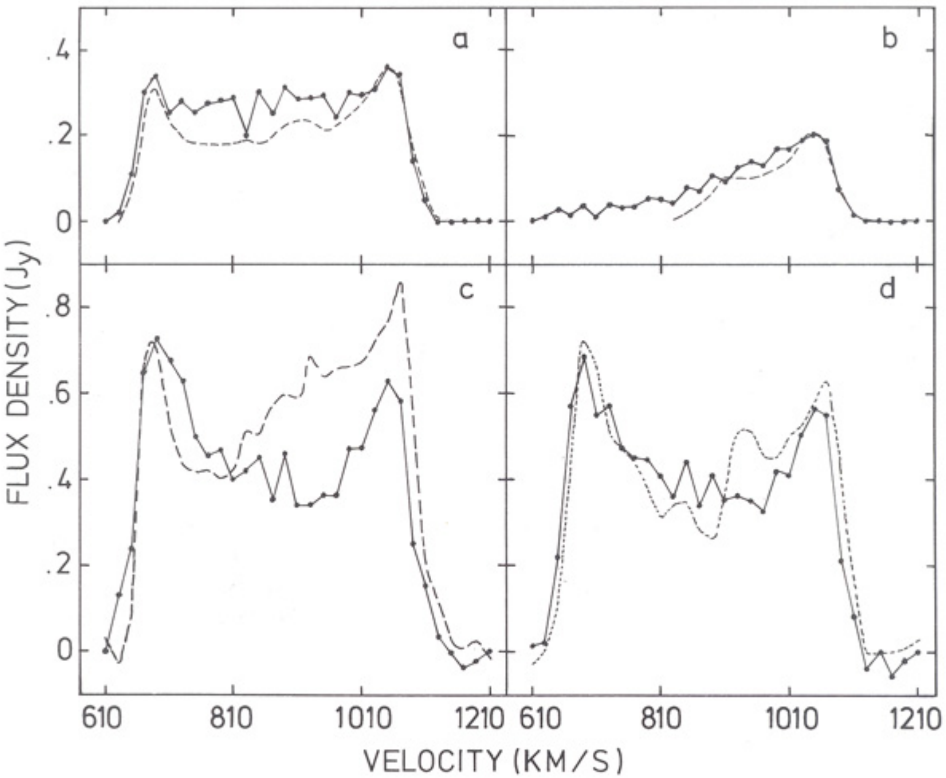

36°
57′
54′
51′
48′
45′
42′
13h 11m 30s
11m 15s
11m 00s
10m 45s
1070
1050
1030
1010
990
970
950
930
910
890
870
850
830
810
790
770
750
730
710
690

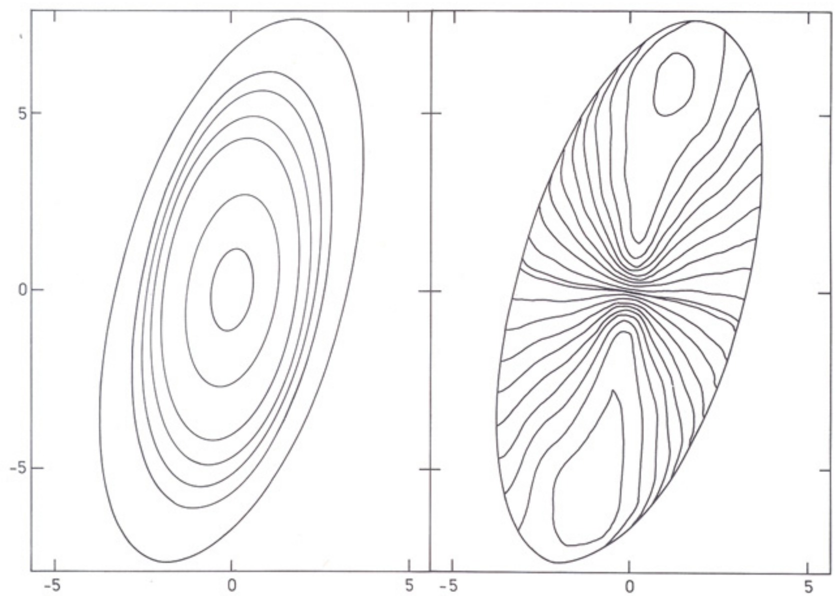
NGC 5033

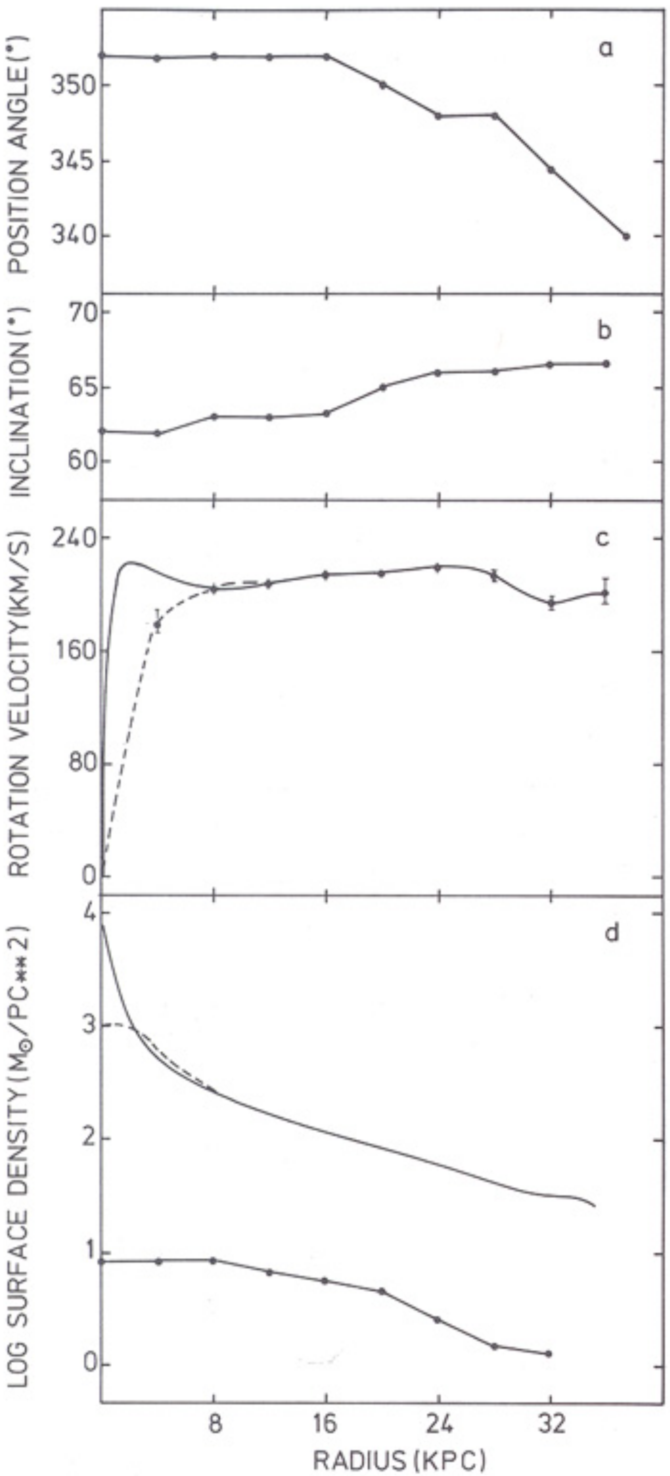

36°
57′
54′
51′
48′
45′
42′
13h 11m30s
11m15s
11m00s
10m45s


36°
42′
13h 11m30s
11m15s
11m00s
10m45s

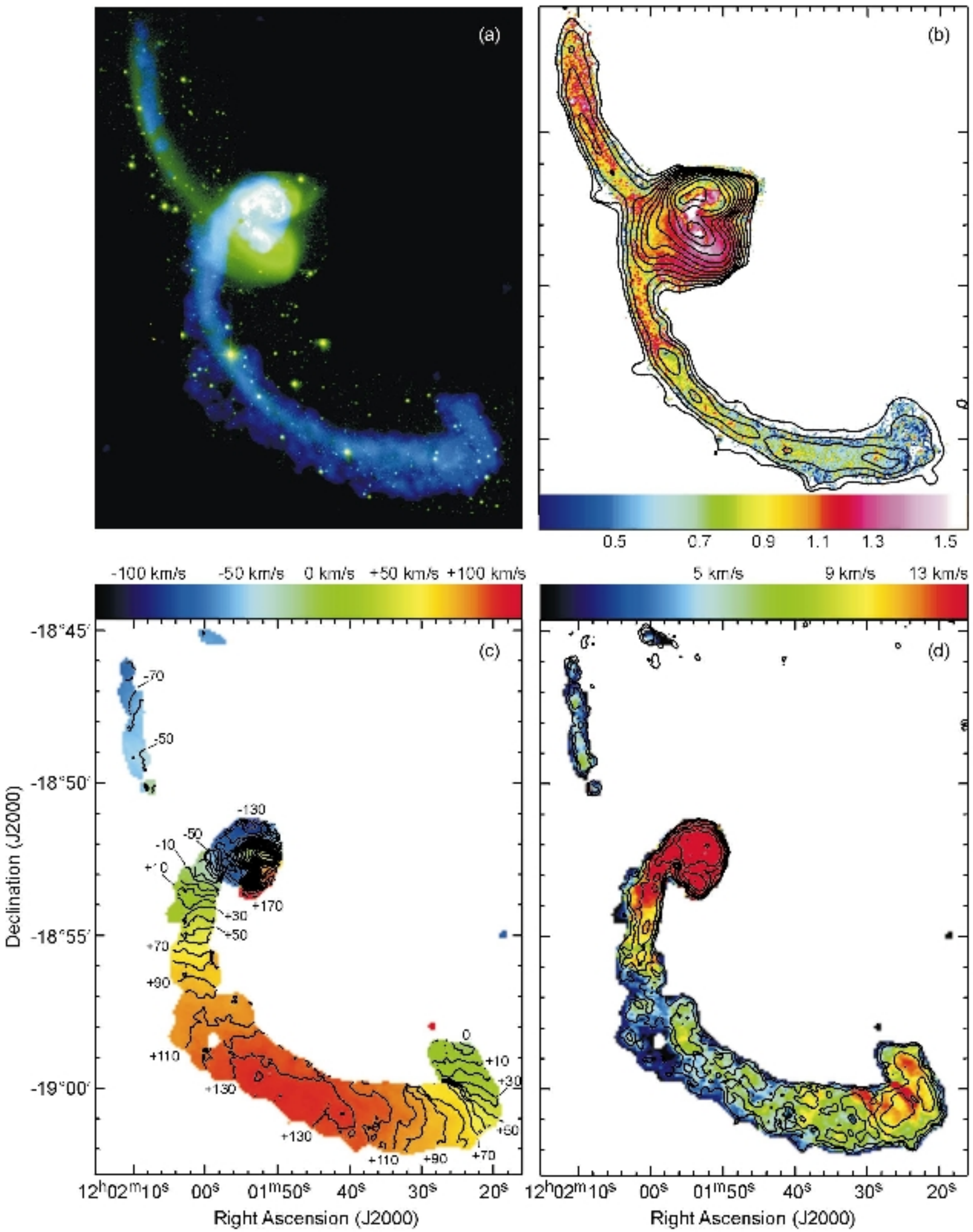
NGC 5033


a
b
c
d
FLUX DENSITY (Jy)
.4
.2
0
.8
.6
.4
.2
0
610
810
1010
1210
VELOCITY (KM/S)

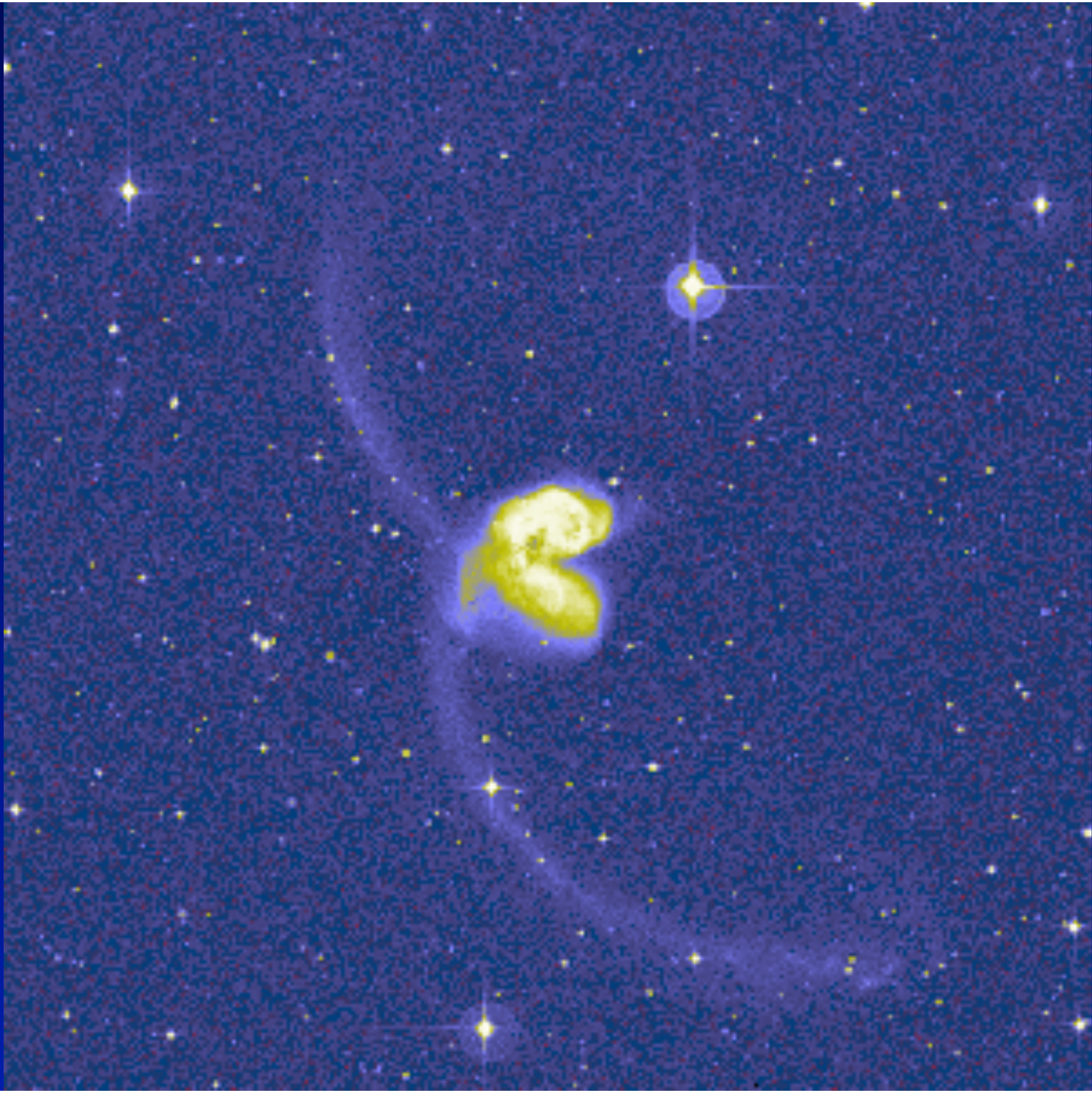

5
0
-5
-5
0
5

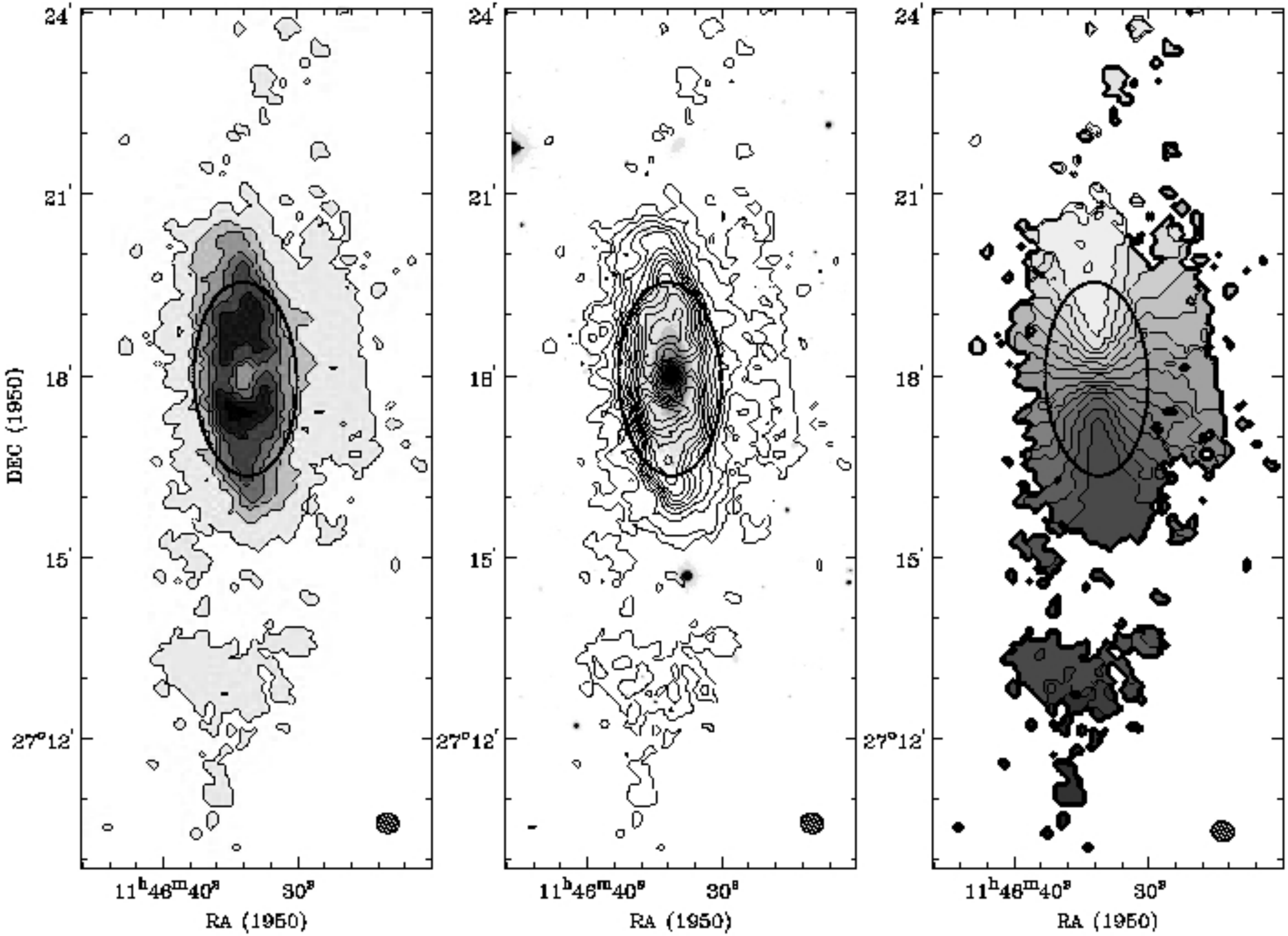

a
b
c
d
POSITION ANGLE (°)
350
345
340
INCLINATION (°)
70
65
60
ROTATION VELOCITY (KM/S)
240
160
80
0
LOG SURFACE DENSITY ($M_\odot$/PC**2)
4
3
2
1
0
8
16
24
32
RADIUS (KPC)

NGC 5033

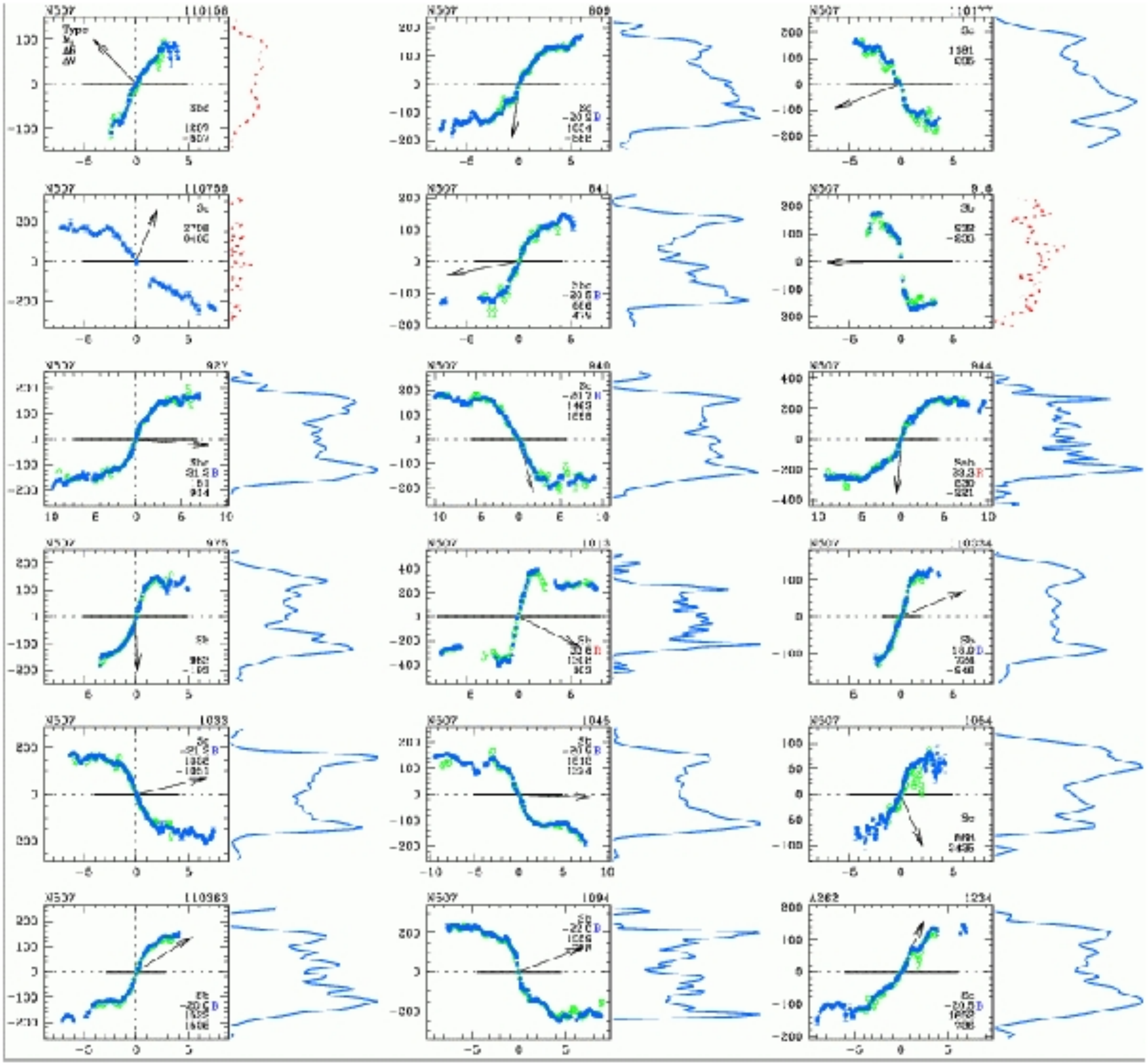


(a)
(b)
0.5
0.7
0.9
1.1
1.3
1.5
-100 km/s
-50 km/s
0 km/s
+50 km/s
+100 km/s
5 km/s
9 km/s
13 km/s
(c)
(d)
-18°45′
-18°50′
-18°55′
-19°00′
Declination (J2000)
-70
-50
-130
-50
-10
+10
+170
+30
+50
+70
+90
+110
+130
+130
+110
+90
+70
+50
+30
+10
0
12h02m10s
00s
01m50s
40s
30s
20s
Right Ascension (J2000)





24'
21'
18'
15'
27°12'
DEC (1950)
11h46m40s
30s
RA (1950)

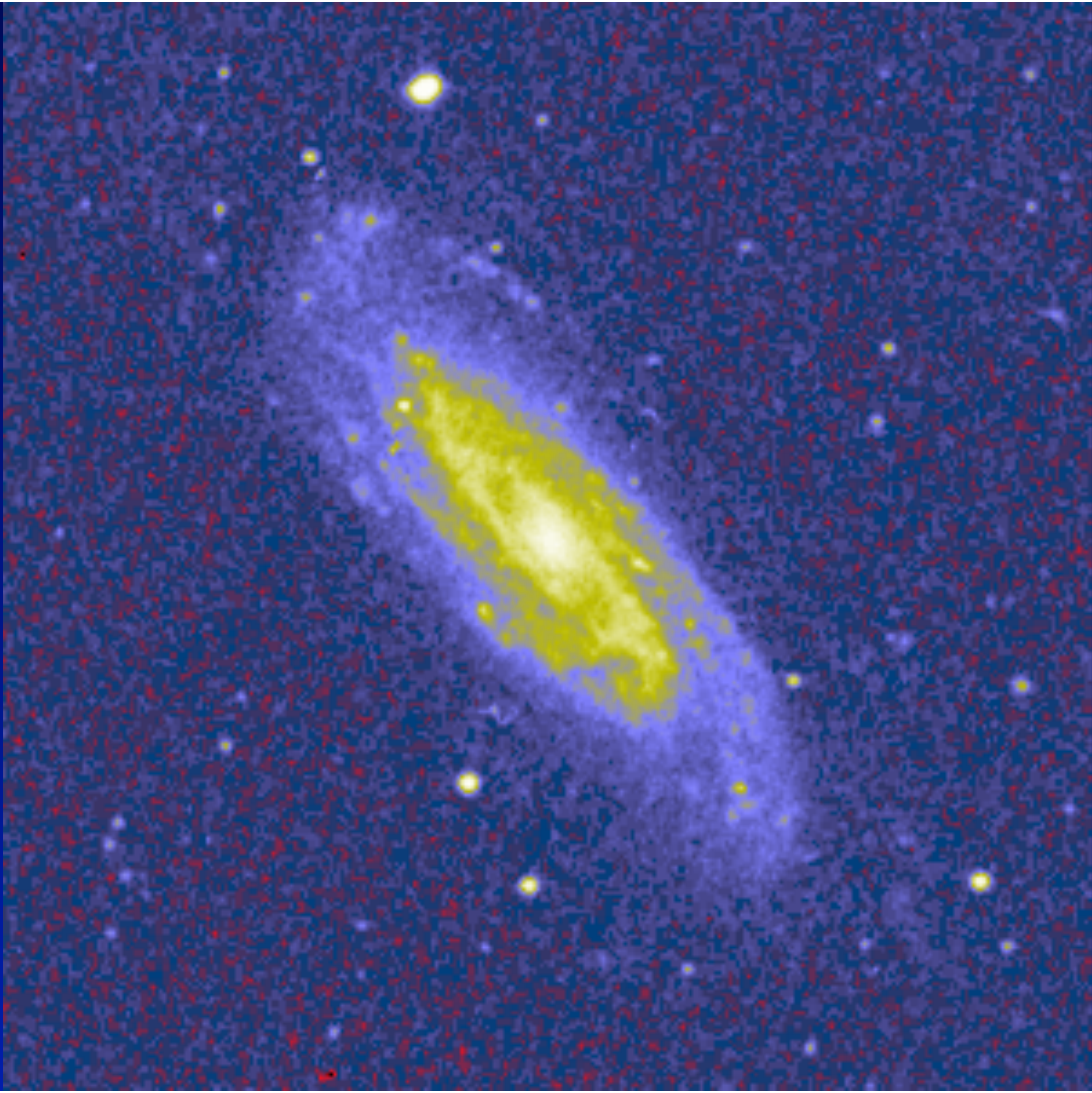


3. Galaxy dynamics

3.5 Mass determination

- the mass of a galaxy can be obtained from the kinematic data applying the Virial theorem
- ellpticals
- spirals
- M/L ratio
- dark matter

NGC
3198



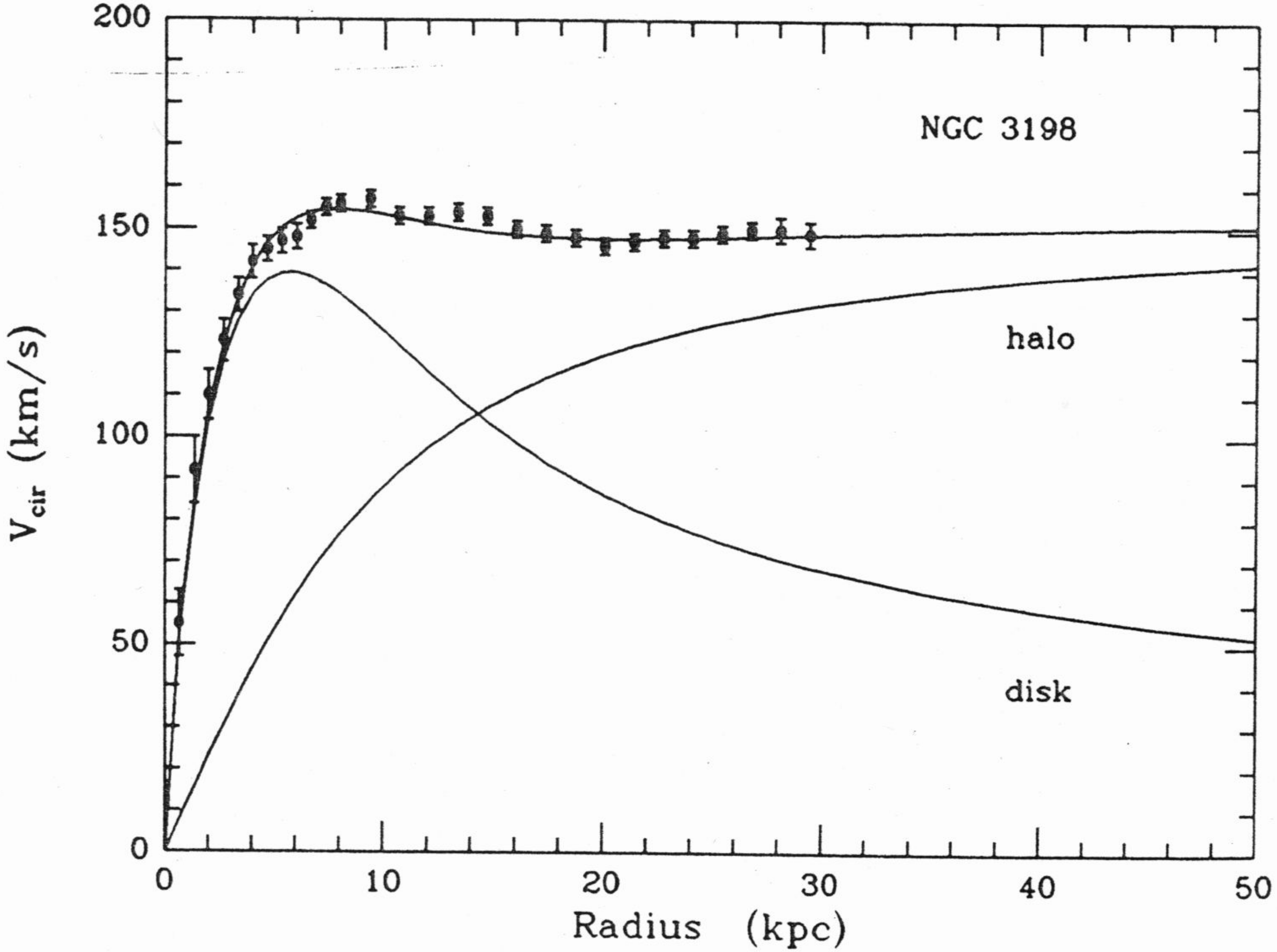


Figure 10-2. The Sc galaxy NGC 3198. Top: neutral hydrogen column density contours superimposed on an optical photograph. Bottom: circular-speed curve plus model fits using an exponential disk with constant mass-to-light ratio and the halo density profile (10-10). The model curve is for the maximum possible disk mass-to-light ratio. The horizontal scale assumes $h = 0.75$. Reprinted from van Albada et al. (1985), by permission of *The Astrophysical Journal*.