THE STELLAR POPULATIONS AND INTERNAL REDDENING OF SPIRAL GALAXIES

by

Roger Rouse

OUTLINE

- Motivation
- Goals
- Sample, Observations, and Calibration
- Subsample of Galaxies
  - Measurement of the magnesium b triplet, Mgb
  - Measurement of the optical-infrared color, B-K
  - Diagram used to analyze color and population gradients
  - Comparison to Stellar Population Synthesis Models
- Results
- Conclusions and Future Work

MOTIVATION

- Would like to understand the evolution of galaxies. Therefore, need to understand the current state and history of their contents: stars, gas, and dust.
- In the area of stellar populations spiral disks are not as well studied as bulges and ellipticals.
- In particular are color gradients in disks due to reddening or stellar population changes?

COLOR GRADIENTS

- Need a reddening independent measure of the population such as the magnesium b triplet, Mgb, at 5177Å.
- Need a color with large wavelength range such as B-K, an optical infrared color
- Need Mgb and B-K at same locations in a galaxy.
- Need spatial resolution in the spectroscopy.

GOALS

- To image disks in BVRI & JHK.
- To obtain long slit optical spectroscopy.
- To measure B-K gradients and Mgb gradients.
- To use B-K and Mgb to investigate the cause of the color gradients.

GALAXY SELECTION

- Galaxies were selected from the Aaronson (1982) Tully-Fisher sample.
- The criteria were
  - Size: Small enough to be observed with a $3'$ long slit.
  - Inclination: Less than 56^o
  - Color: Match another galaxy's $B_T - H_{-0.5}$.
- This resulted in 5 pairs of 10 spiral galaxies.

Name	Type	B_T	$Log(D_{25})$	$Log(R_{25})$	$B_T - H_{-0.5}$	$V_0(\frac{km}{s})$	A_B
NGC 3782	SAB(s)cd	12.8	1.22	0.19	1.13	739	0.01
NGC 5204	SA(s)m	11.4	1.70	0.22	1.17	204	0.01
NGC 4713	SAB(rs)d	11.9	1.43	0.20	1.53	653	0.00
NGC 2701	SAB(rs)dm	12.4	1.34	0.13	1.58	2326	0.05
NGC 3338	SA(s)c	10.9	1.77	0.21	1.98	1301	0.06
NGC 4654	SAB(rs)cd	10.7	1.69	0.24	2.01	1035	0.06
NGC 772	SA(s)b	11.1	1.86	0.23	2.63	2458	0.16
NGC 2268	SA(r)bc	12.2	1.51	0.21	2.63	2222	0.21
NGC 949	SA(rs)b	12.6	1.38	0.27	2.37	612	0.17
NGC 6384	SAB(r)bc	11.3	1.79	0.18	2.37	1663	0.41

OBSERVATIONS

- BVRI CCD images taken at the MDM 51″ McGraw Hill Telescope.
- JHK NICMOS images collected at the Steward Observatory 61″ at Catalina.
- 3600Å to 6000Å spectral images captured at MMT using the red channel spectrograph with 300l grating (18Å resolution). Spectral images with 600l grating (9Å resolution) were also obtained.

Galaxy	Pos1[a] 300l	Pos2 300l	Pos1 600l	Pos2 600l	B[b]	V	R	I	J[c]	H	K
NGC 772	2	2	2	0	2	3	3	3	4	4	4
NGC 949	2	2	1	1	1	1	1	2	5	5	8
NGC 2268	2	2	1	1	1	1	1	1	0	0	0
NGC 2701	2	2	1	1	2	2	2	2	5	4	6
NGC 3338	2	2	1	1	2	1	1	1	3	3	3
NGC 3782	2	1	2	1	2	3	2	1	3	3	7
NGC 4654	2	2	2	2	1	1	1	1	3	3	6
NGC 4713	2	1	1	1	1	1	1	1	3	3	4
NGC 5204	2	2	2	2	1	1	1	1	4	3	4
NGC 6384	2	2	3	2	2	1	3	1	9	5	9

[a]Columns marked Pos1 or 2 indicate the number of exposures at that slit position.

[b]Columns B, V, R, & I are the number of exposures taken in that filter.

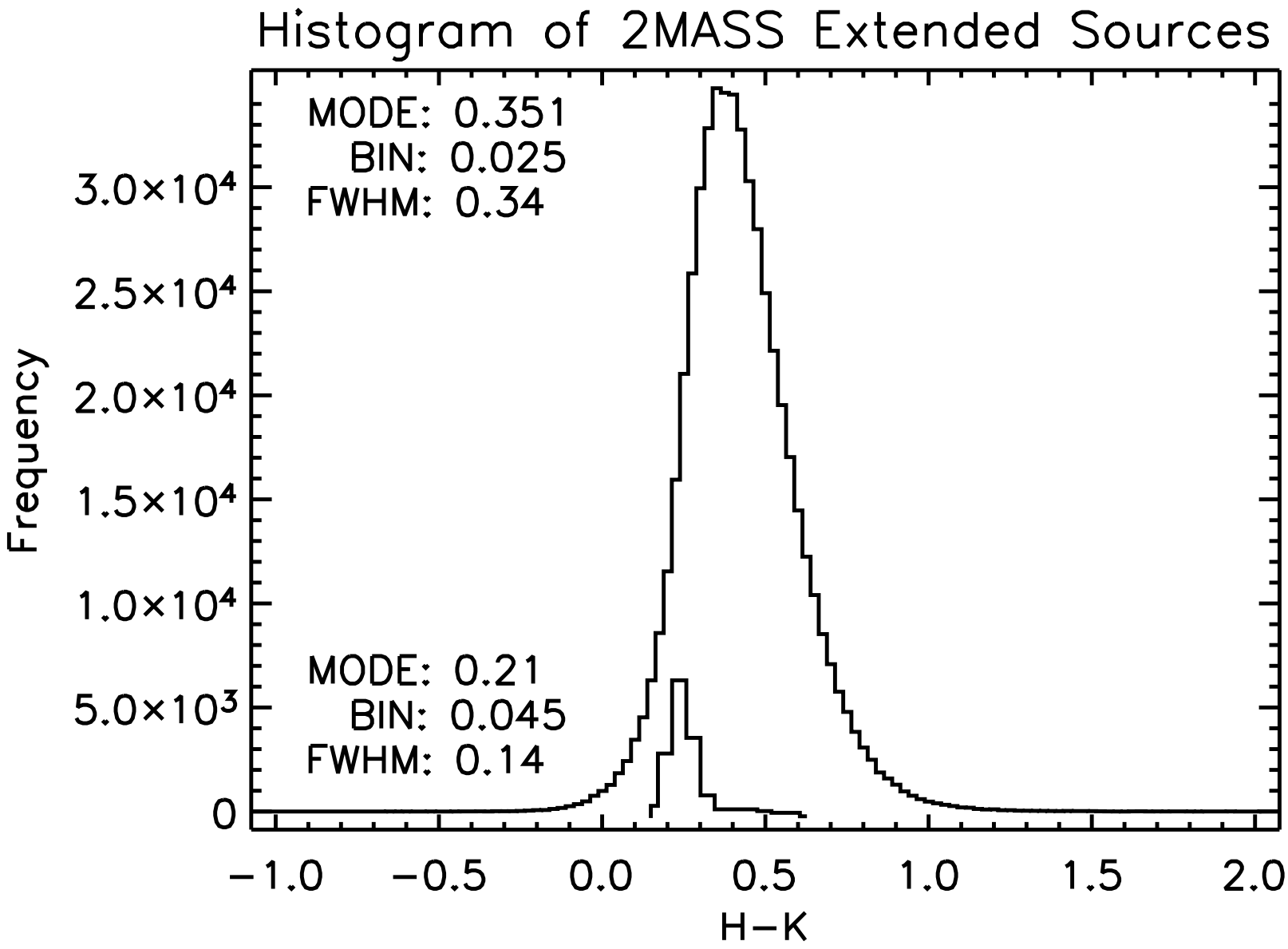
[c]Columns J, H, & K are the number of sequences of exposures taken in that filter.

CALIBRATION

- BVRI CCD images reduced in the standard way.
- Landolt standards at range of airmass, times, and colors used to determine photometric solution.
- JHK images collected and reduced in the usual way that accounts for large sky brightness.
- Not photometric so previous photometry of galaxies used to determine zero points.
- The spectral images reduced in standard way.
- IDS line standards used to confirm transformation to Lick System.

TRANSFORMING TO STANDARD MAGNITUDES

- To form B-K the B and K magnitudes must be on the standard system.
- The B imagery was obtained on a photometric run. The photometric solution is used to assign B magnitudes to galaxy measurements.
- Because the K data was not photometric comparison to previous photometry of the galaxies gives the zero points.
- However, previous photometry is in H. So a fiducial H-K is needed. That is provided by 2MASS.

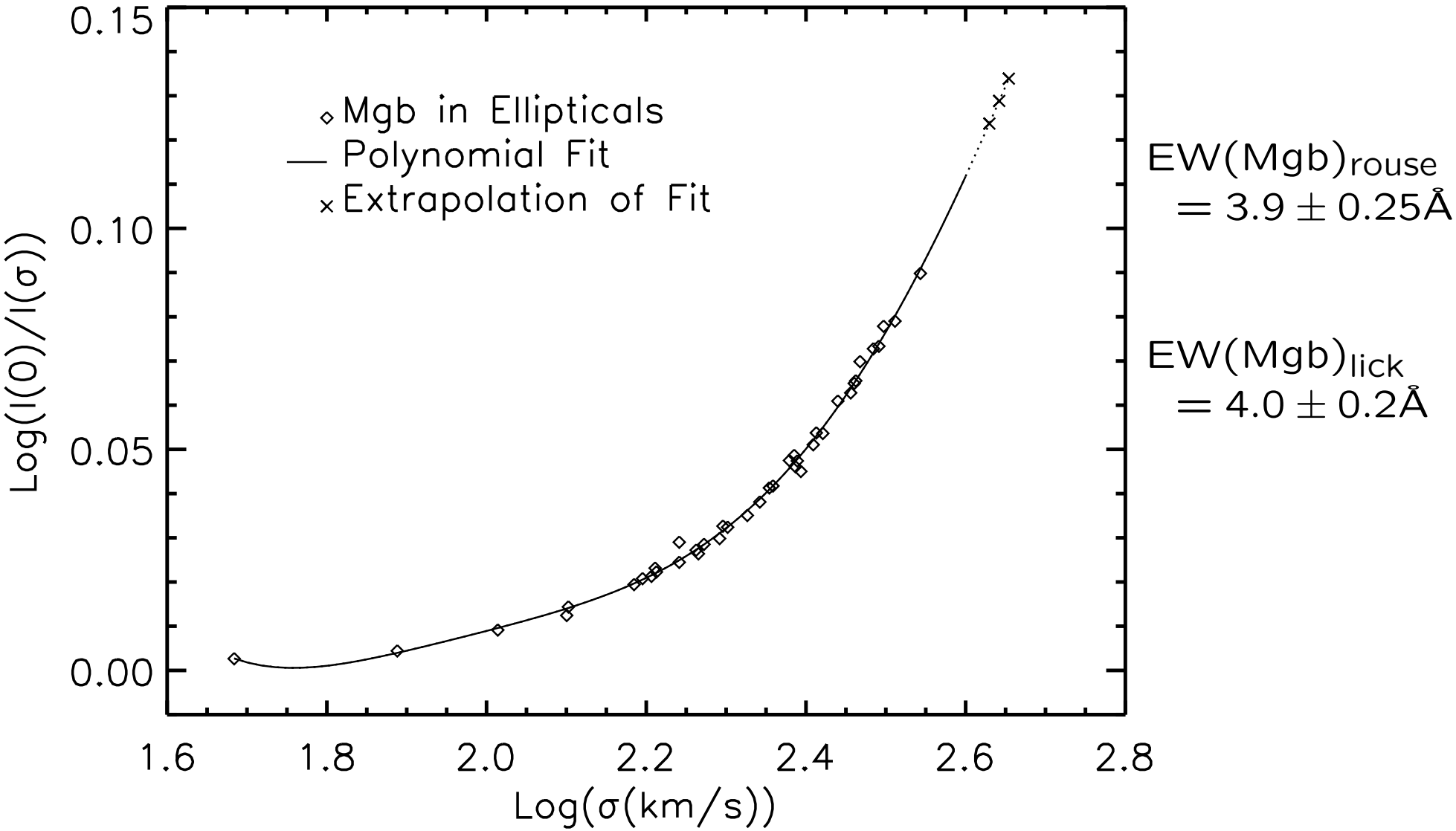

Histogram of 2MASS Extended Sources
MODE: 0.351
BIN: 0.025
FWHM: 0.34
MODE: 0.21
BIN: 0.045
FWHM: 0.14
Frequency
3.0×10⁴
2.5×10⁴
2.0×10⁴
1.5×10⁴
1.0×10⁴
5.0×10³
0
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
H−K

THE LICK SYSTEM

- A system of 21 standard line indices.
- Based on IDS observations of many line standard stars.
- The model outputs line indices on the Lick System.

TRANSFORMING TO LICK SYSTEM

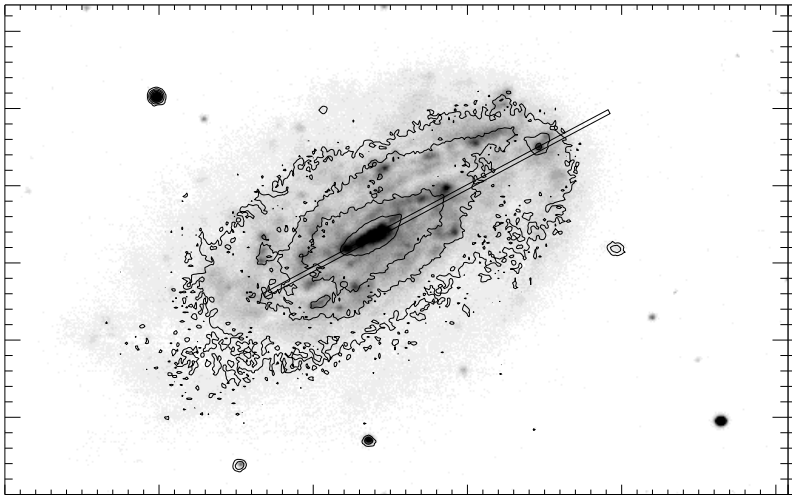
- The main difference between instrumental EWs and the Lick EWs is the difference in resolution between the MMT spectra and the IDS spectra.
- The effect of broadening on the EW has been determined by González (1993). I use this relationship to determine a scale factor that compensates for the difference in resolution.
- My corrected EW(Mgb), 3.9±0.25Å, differs insignificantly from the Lick value, 4.0±0.2Å (Worthey 1993) measured in the line standard SA103-95.
- No other corrections are applied.


0.15
0.10
0.05
0.00
Log(I(0)/I(σ))
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Log(σ(km/s))
Mgb in Ellipticals
Polynomial Fit
Extrapolation of Fit
EW(Mgb)rouse
= 3.9 ± 0.25Å
EW(Mgb)lick
= 4.0 ± 0.2Å

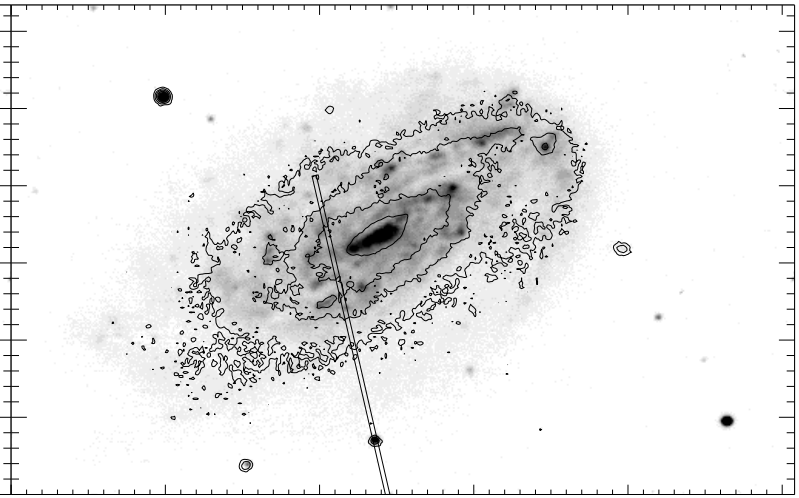
MODEL SELECTION

- Bruzual & Charlot, Worthey, and Bressan (Padova) models agree within 25-30% (Charlot et al. 1996).
- This work uses Worthey's (1994) evolutionary synthesis
- A wide range in age and metallicity is provided.
- Many basic observable quantities are provided such as standard magnitudes, colors, Lick line indices.
- Used successfully to analyze ellipticals (González 1993, Trager et al. 2000)

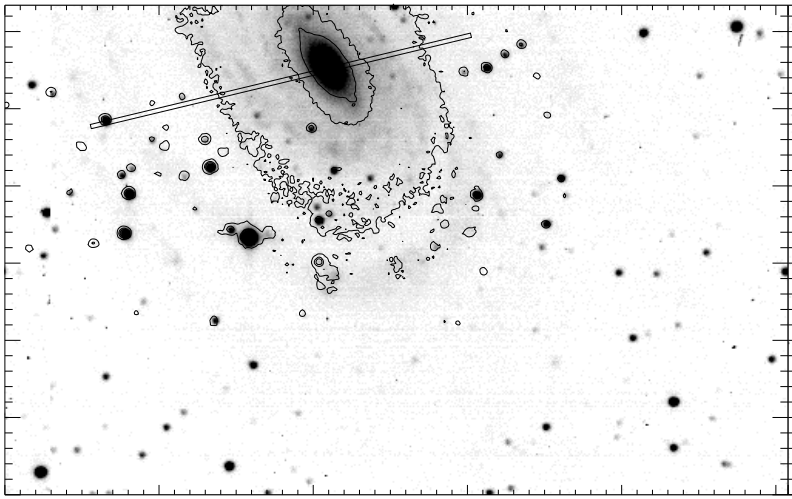
NGC4654 Pos. 1 (2.01)



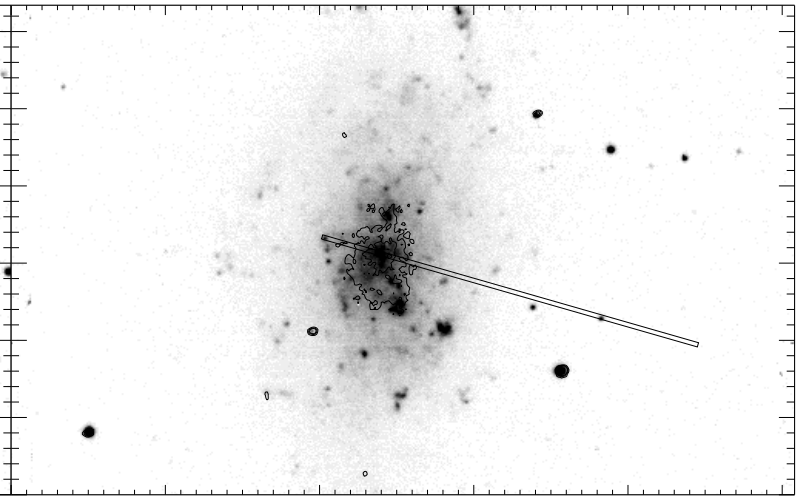
NGC4654 Pos. 2 (2.01)

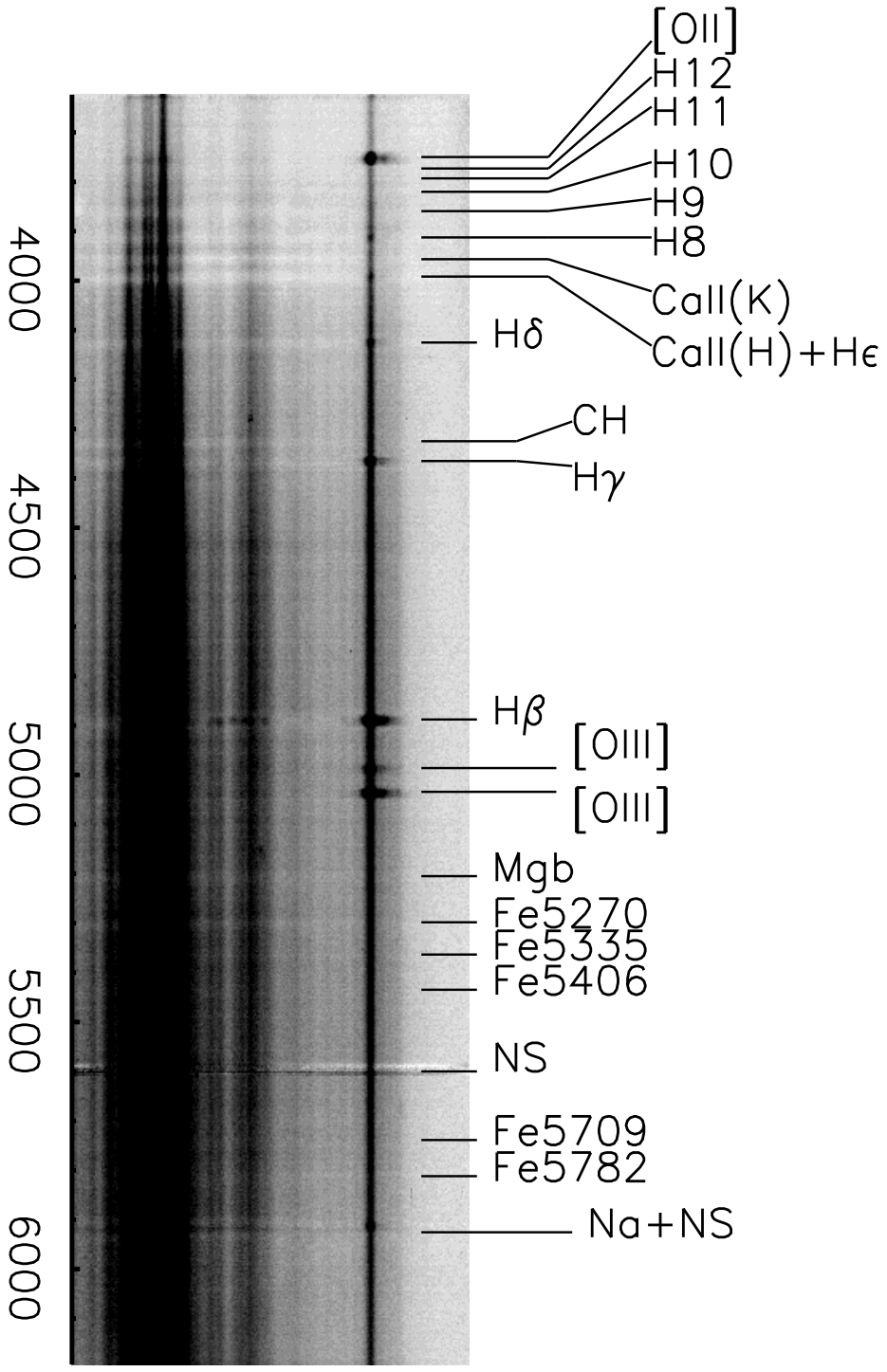


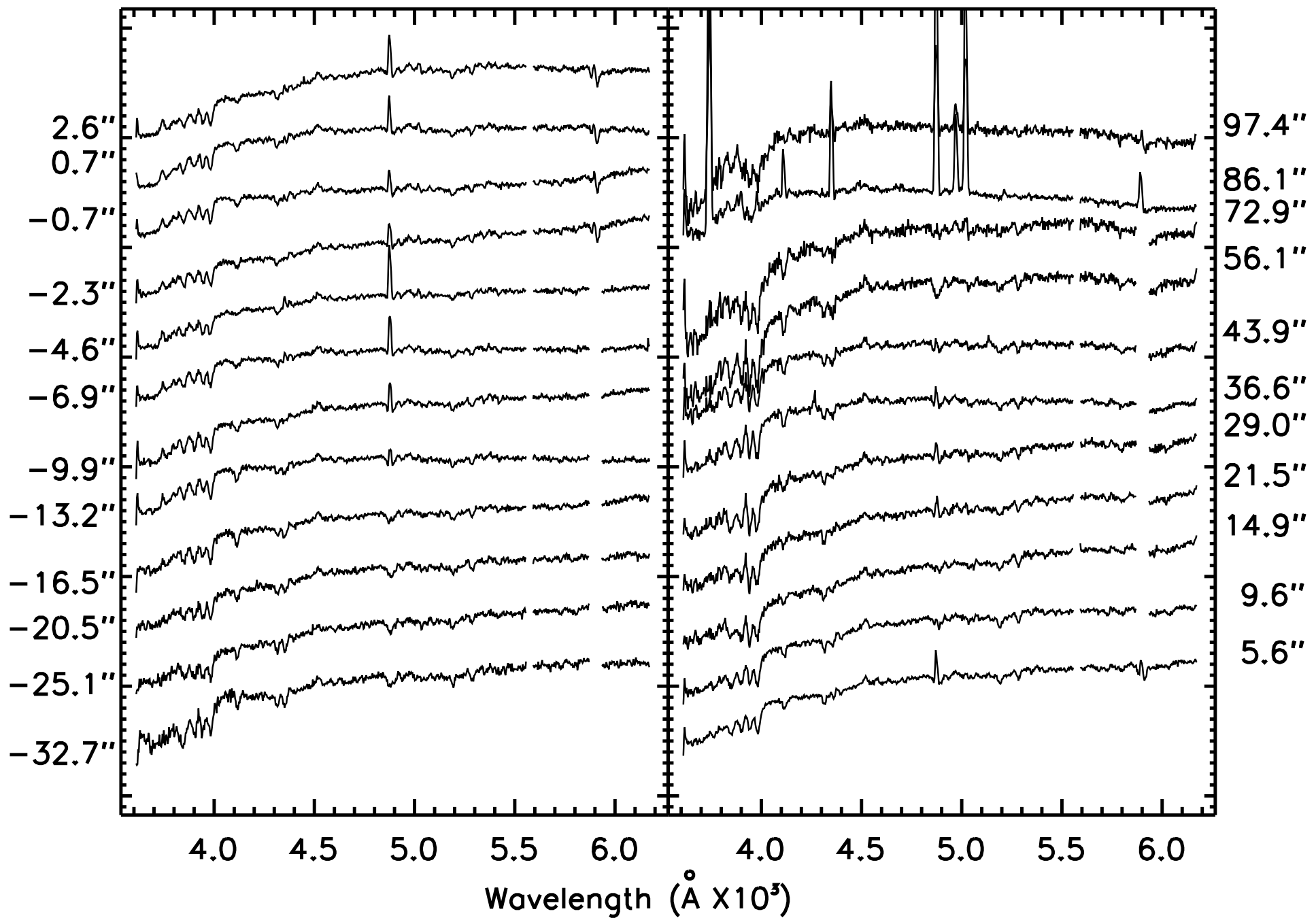
NGC6384 Pos. 1 (2.37)

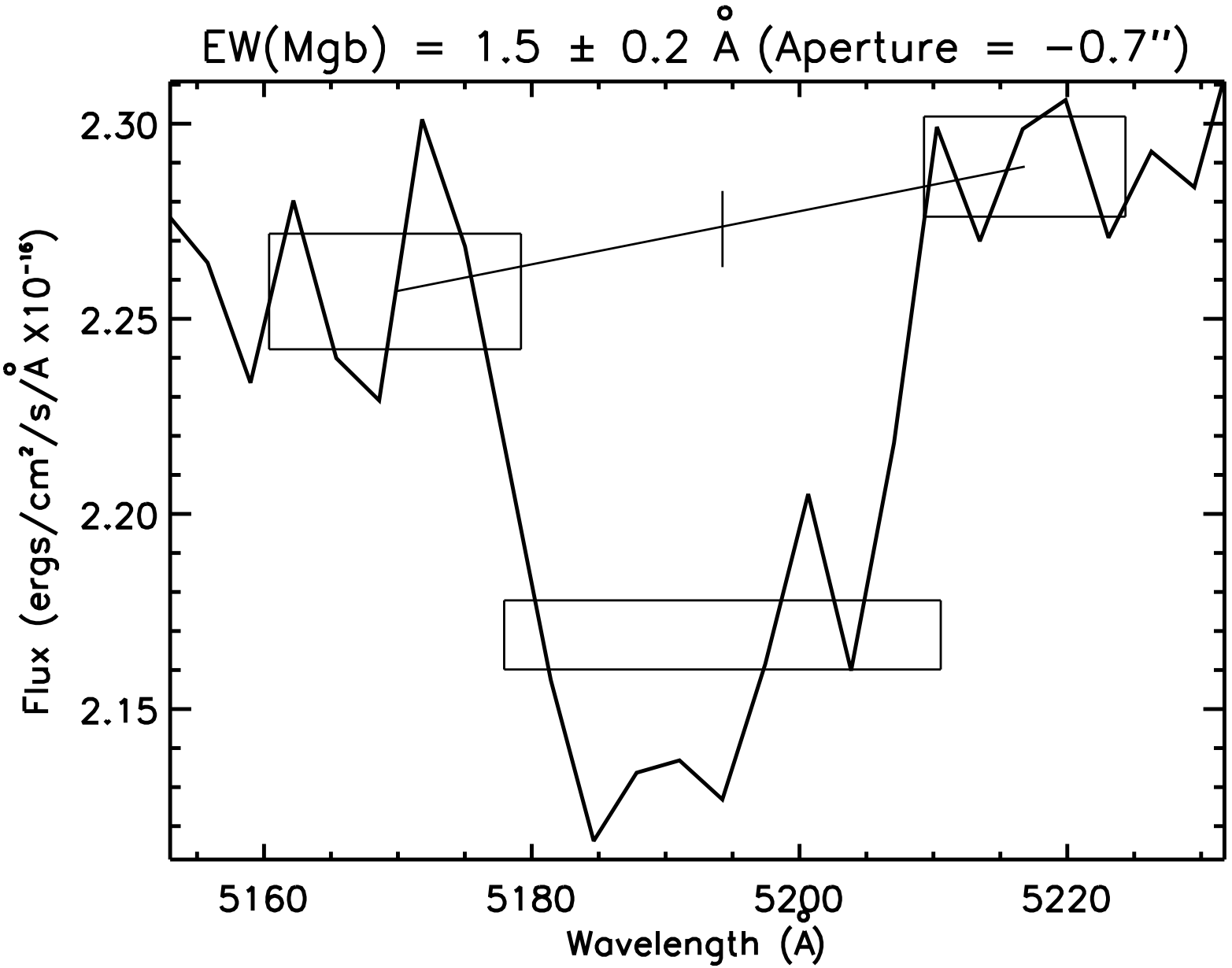


NGC5204 Pos. 1 (1.17)

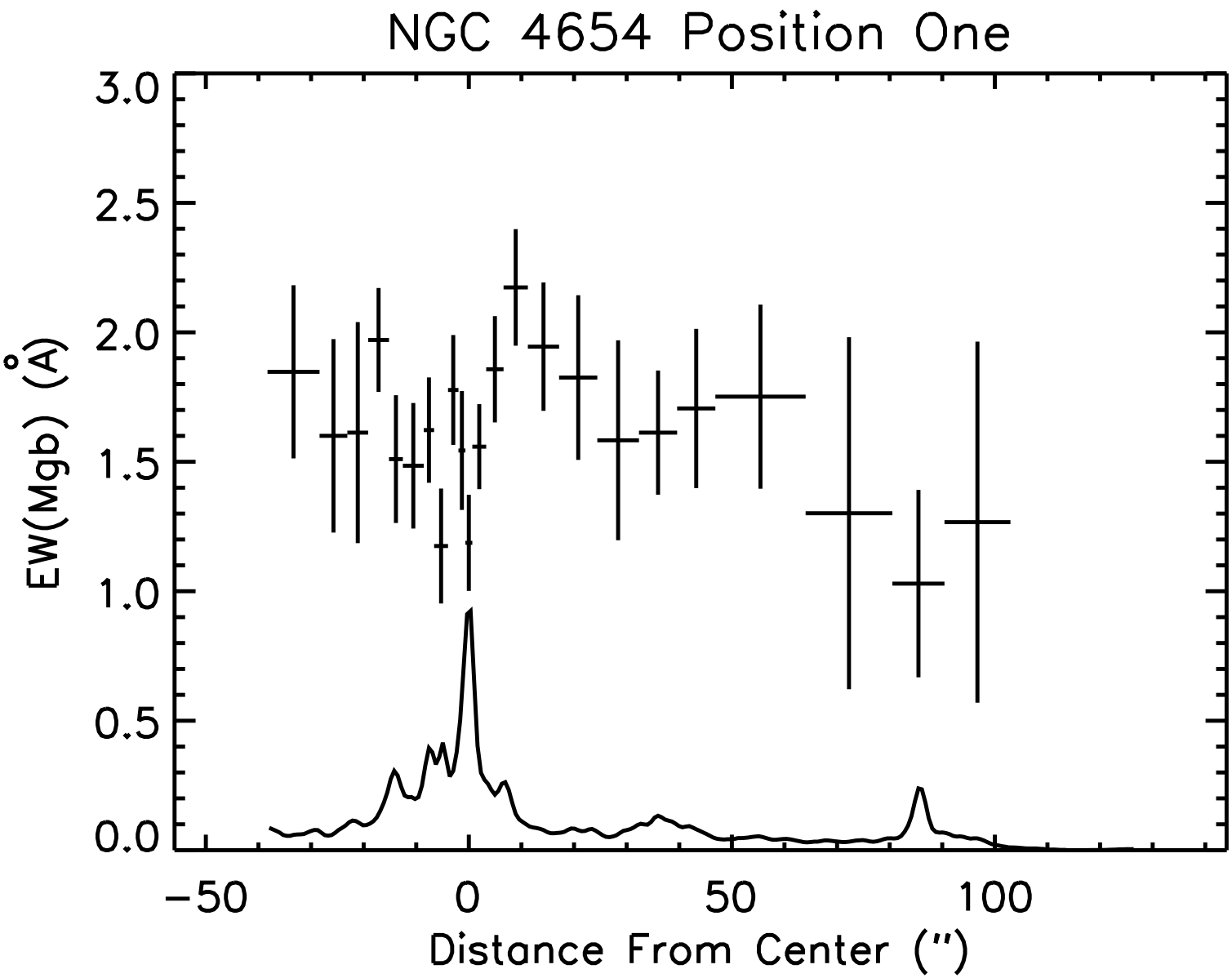



[OII]
H12
H11
H10
H9
H8
CaII(K)
CaII(H)+Hε
Hδ
CH
Hγ
Hβ
[OIII]
[OIII]
Mgb
Fe5270
Fe5335
Fe5406
NS
Fe5709
Fe5782
Na+NS
4000
4500
5000
5500
6000

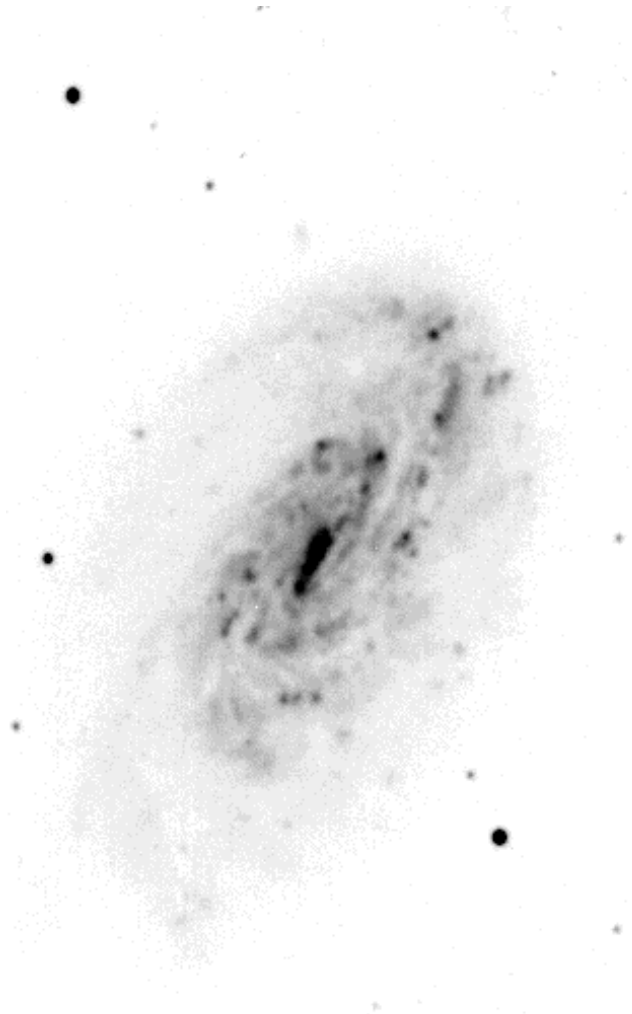

NGC4654 Extracted Spectra
2.6"
0.7"
−0.7"
−2.3"
−4.6"
−6.9"
−9.9"
−13.2"
−16.5"
−20.5"
−25.1"
−32.7"
97.4"
86.1"
72.9"
56.1"
43.9"
36.6"
29.0"
21.5"
14.9"
9.6"
5.6"
4.0
4.5
5.0
5.5
6.0
4.0
4.5
5.0
5.5
6.0
Wavelength (Å X10³)



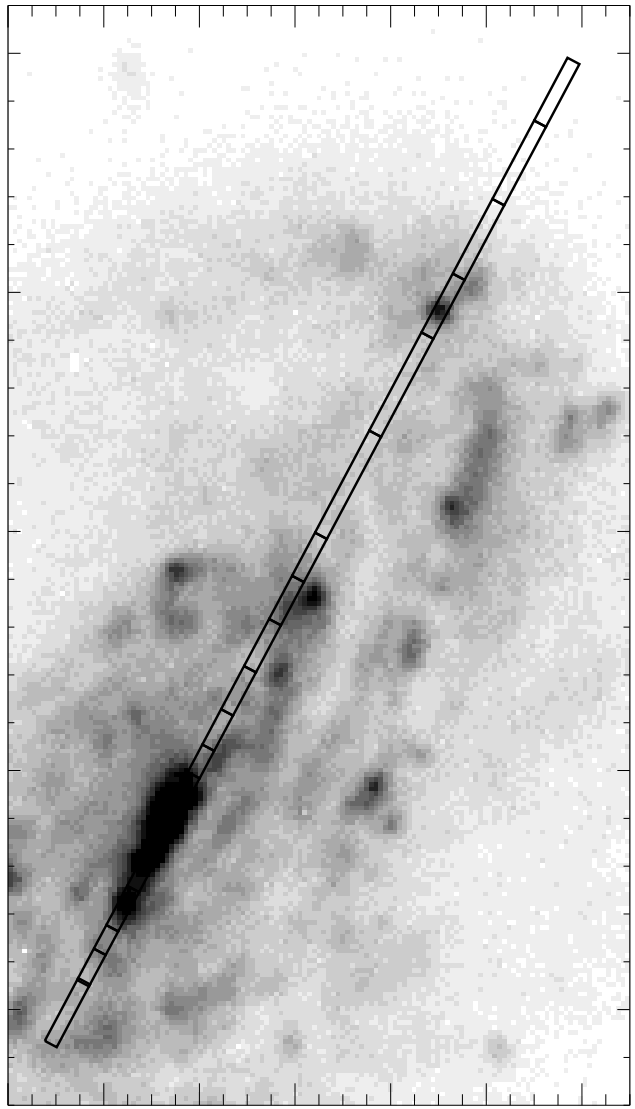
$$EW(Mgb) = \Delta\lambda(1 - F_I/F_C)$$

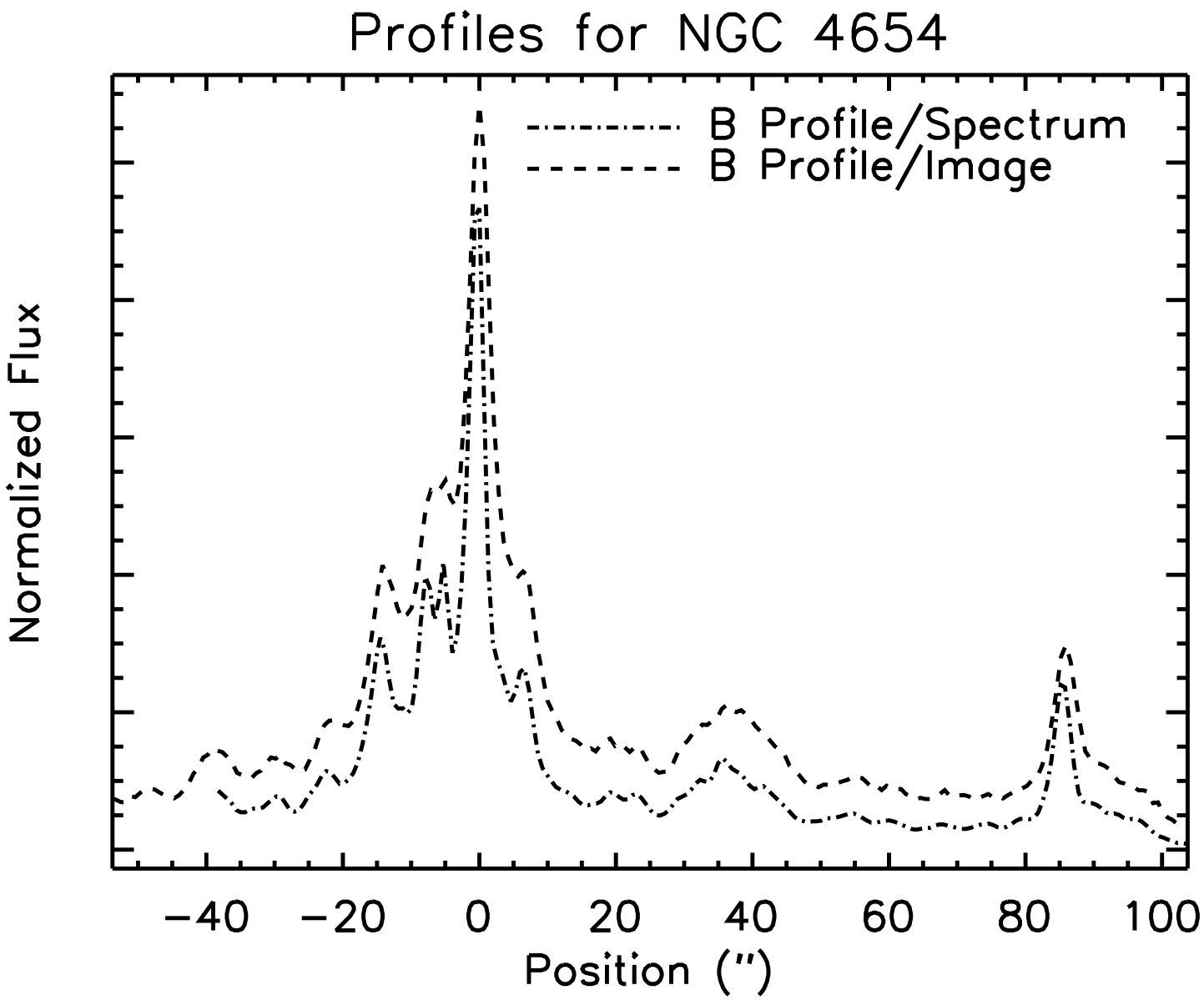

NGC 4654 Position One
EW(Mgb) (Å)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−50
0
50
100
Distance From Center (")

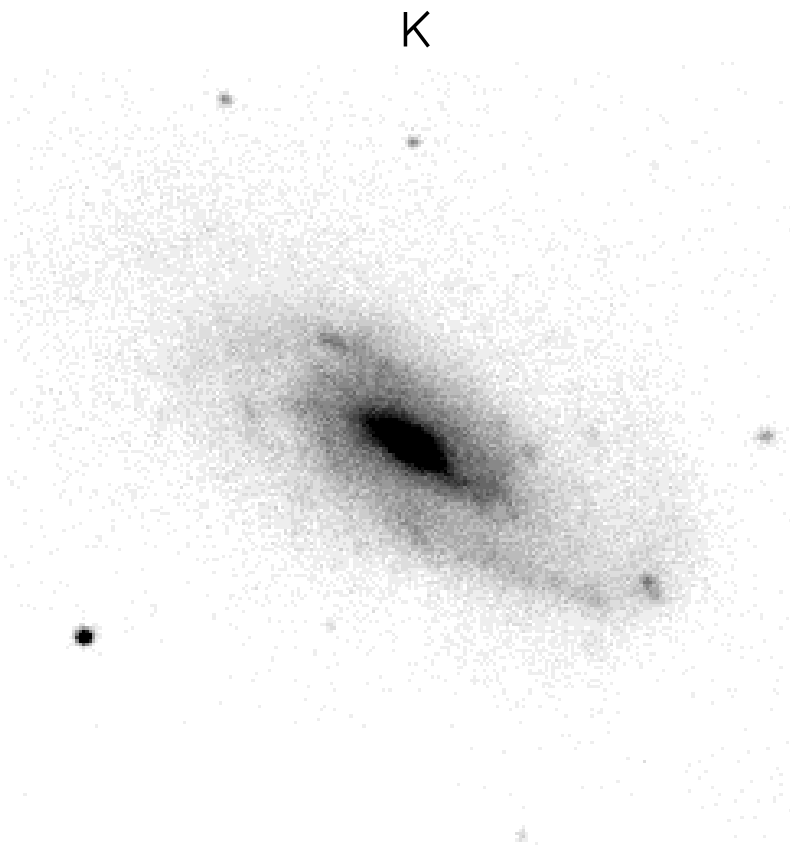
B

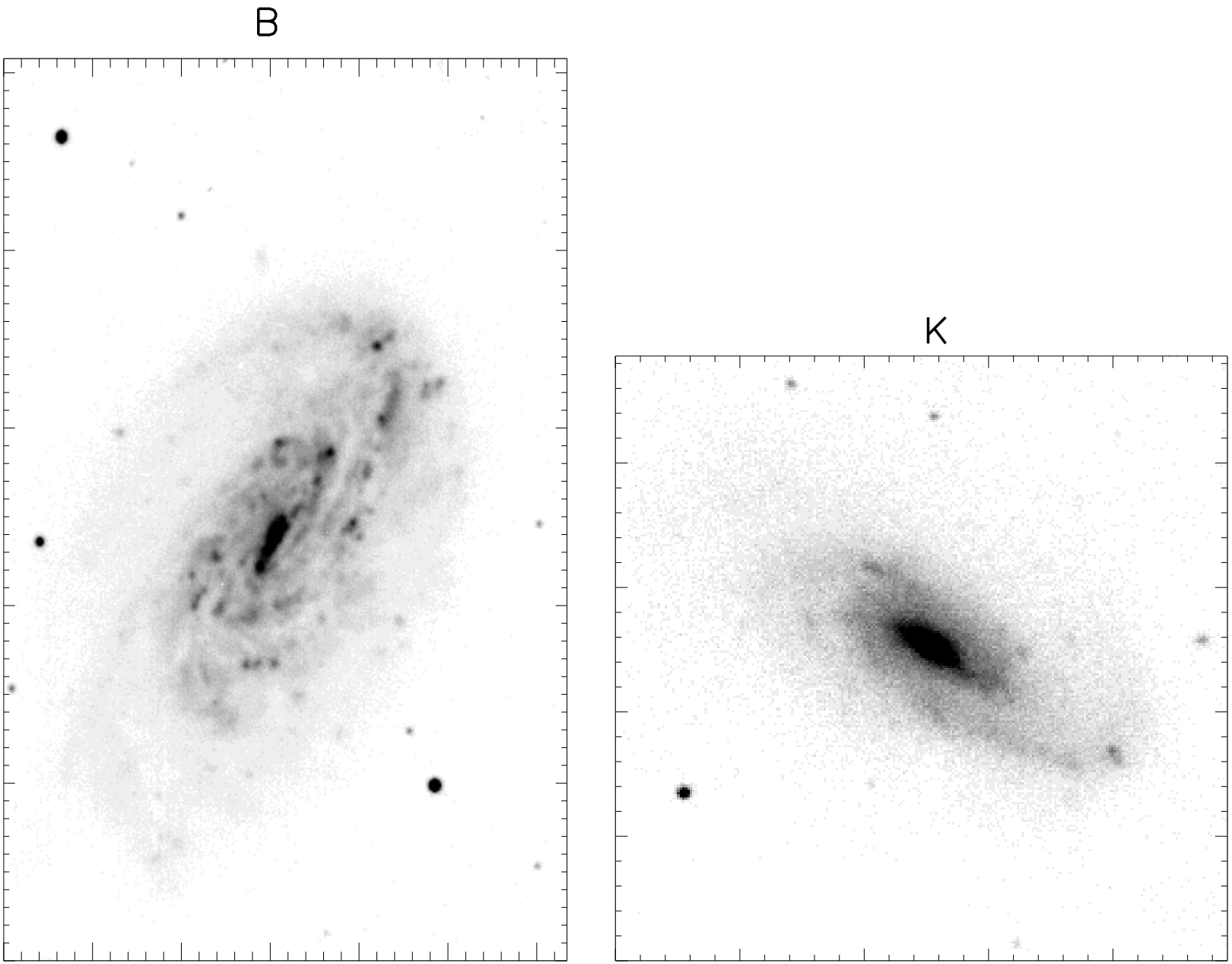


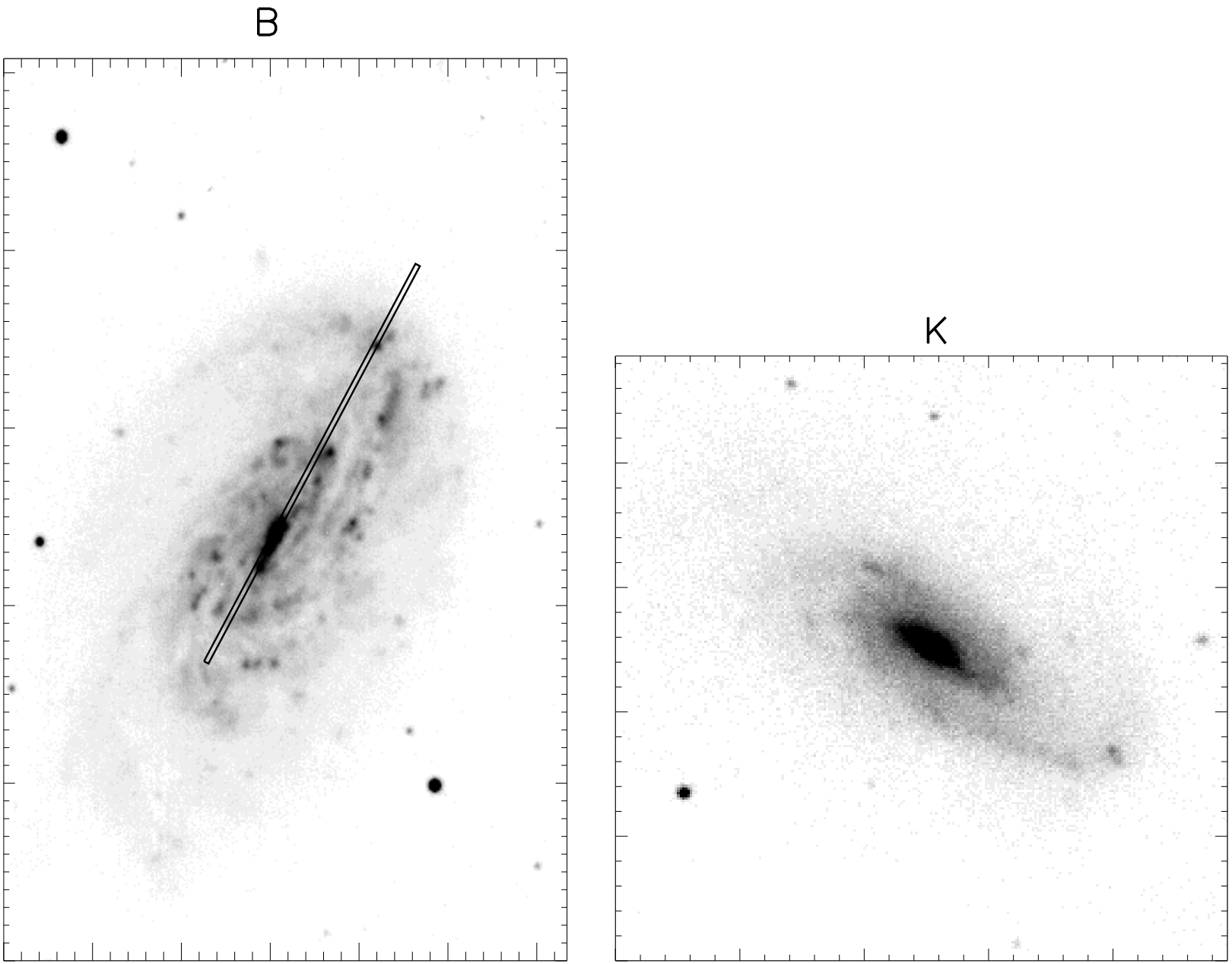
B

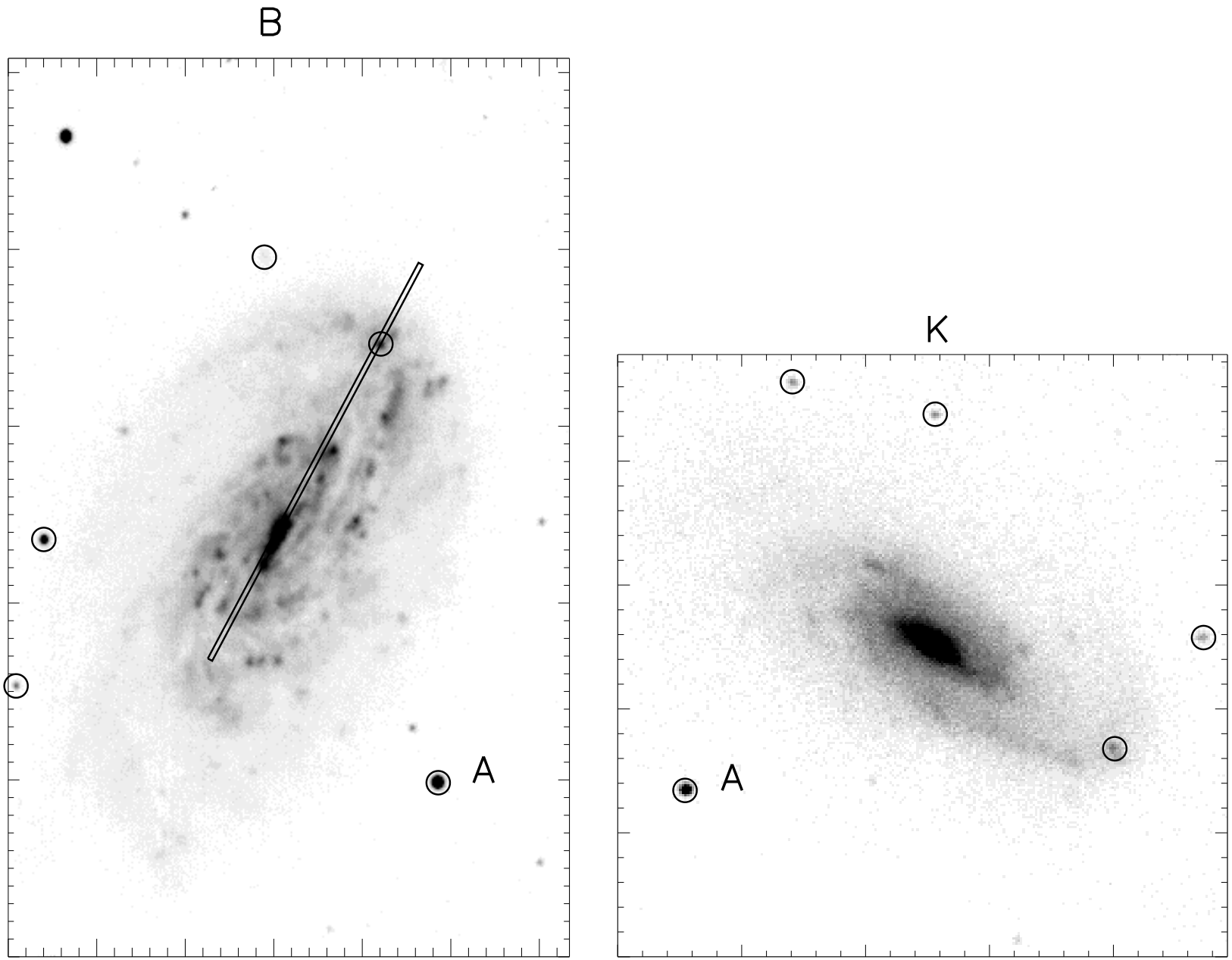


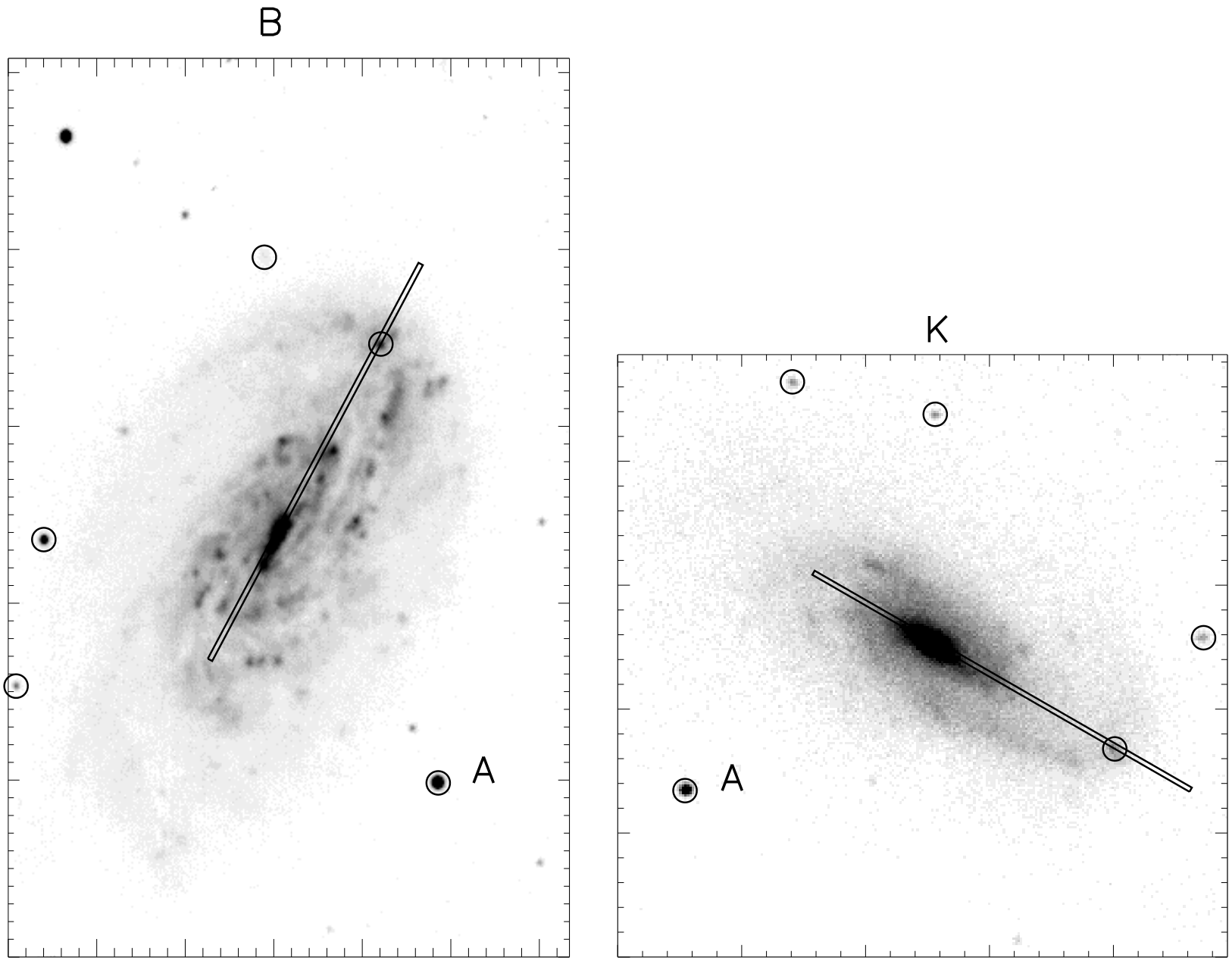

Profiles for NGC 4654
B Profile/Spectrum
B Profile/Image
Normalized Flux
−40
−20
0
20
40
60
80
100
Position (")

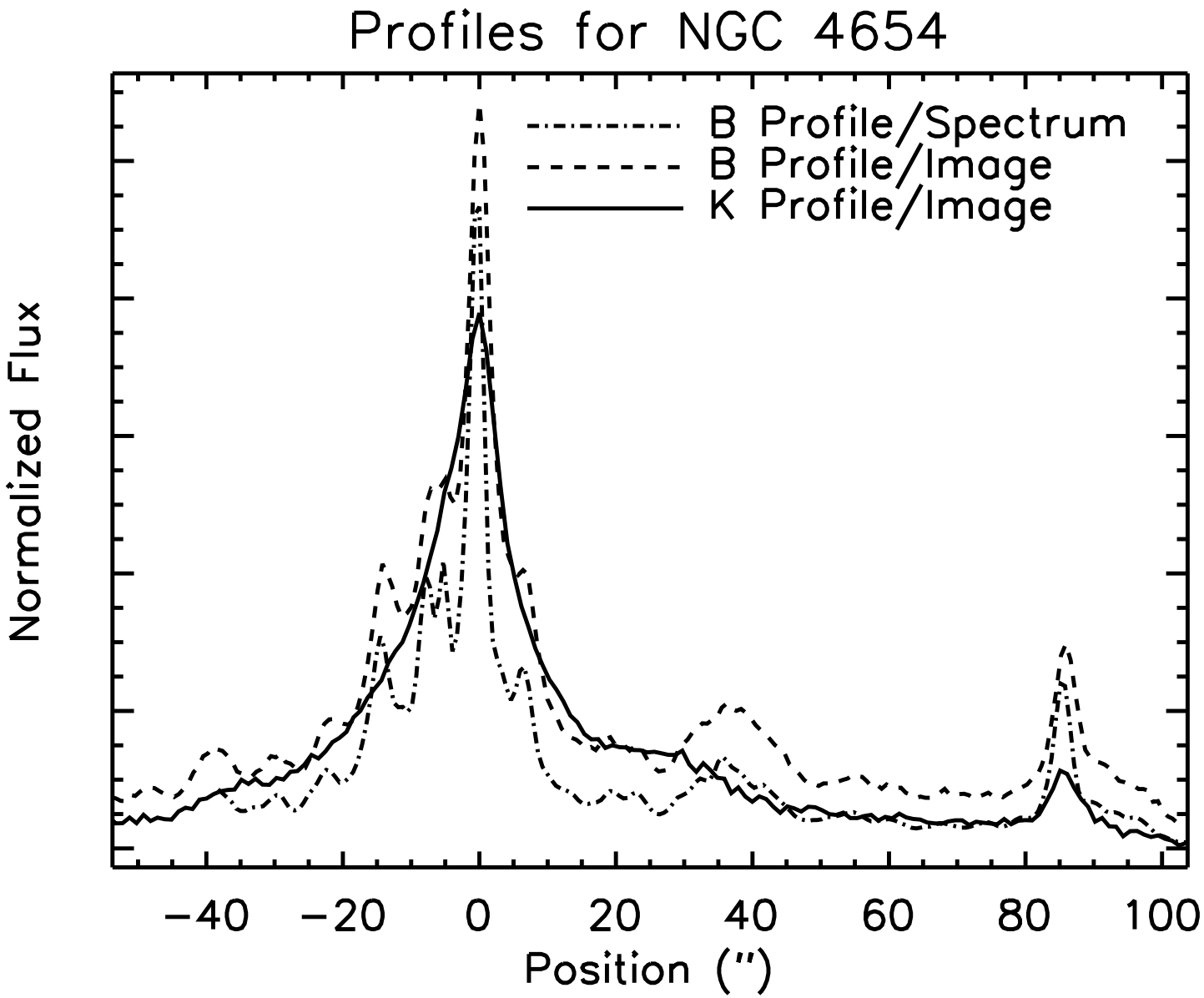

K

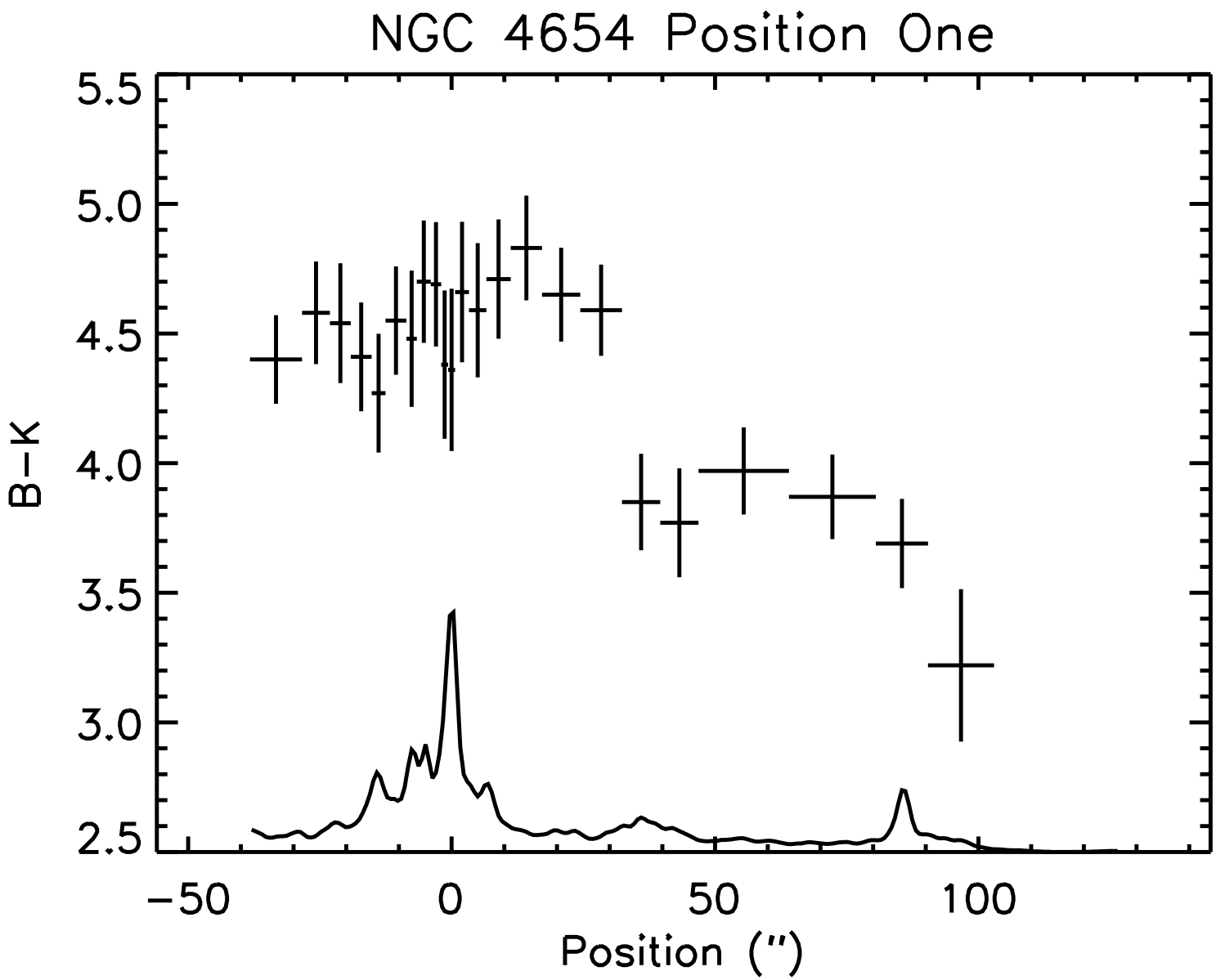

B
K

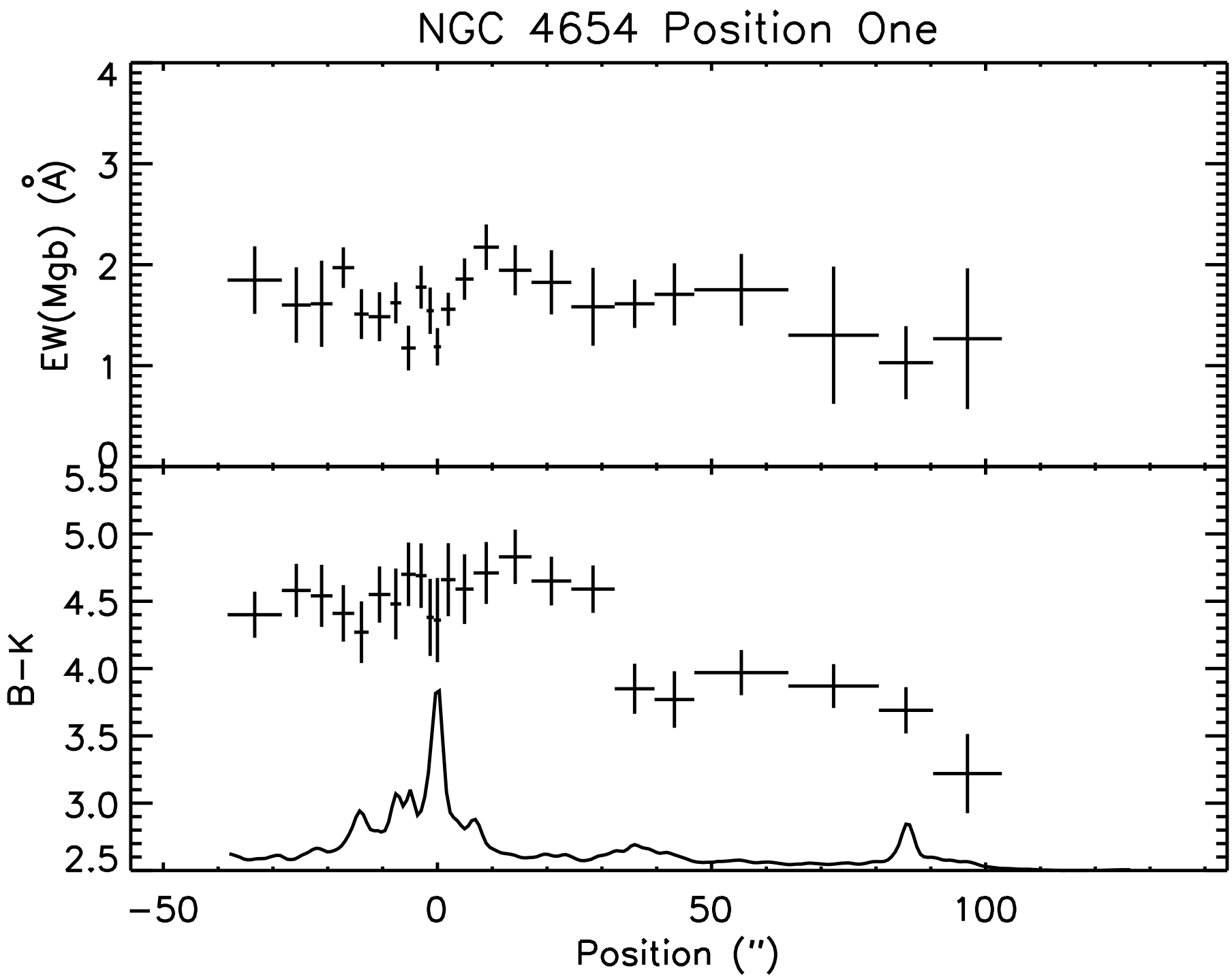

B
K

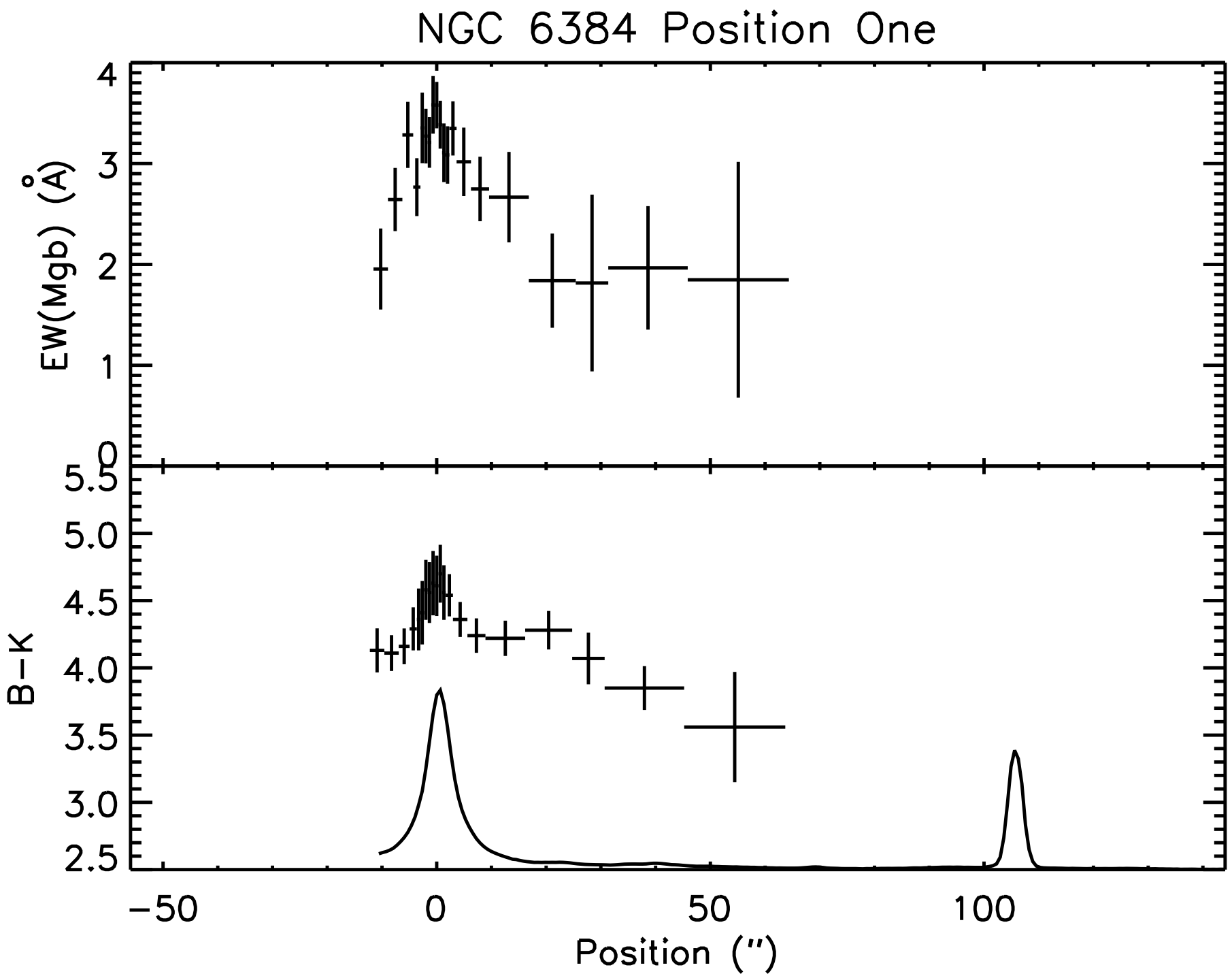

B
A
K
A

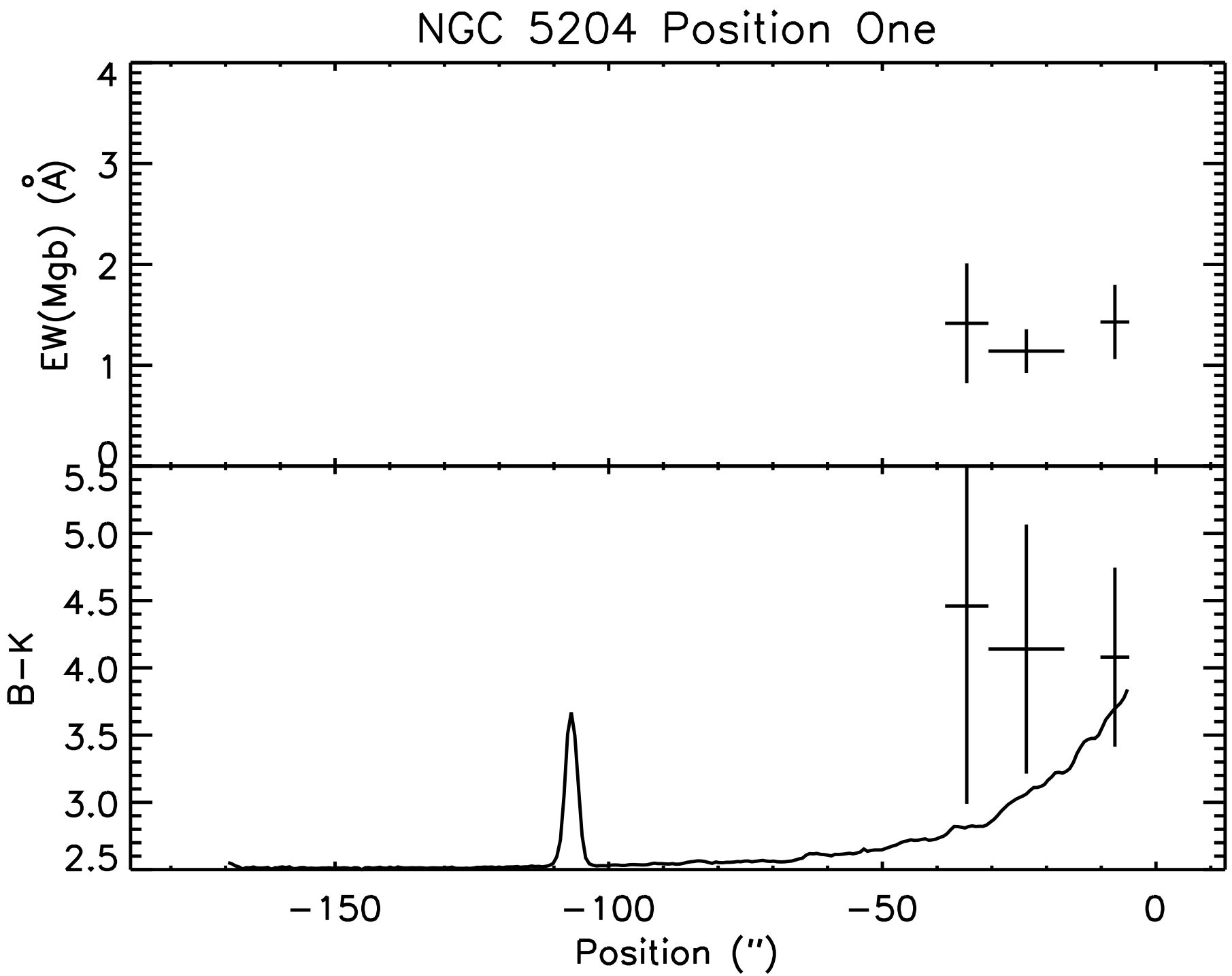

B
A
K
A

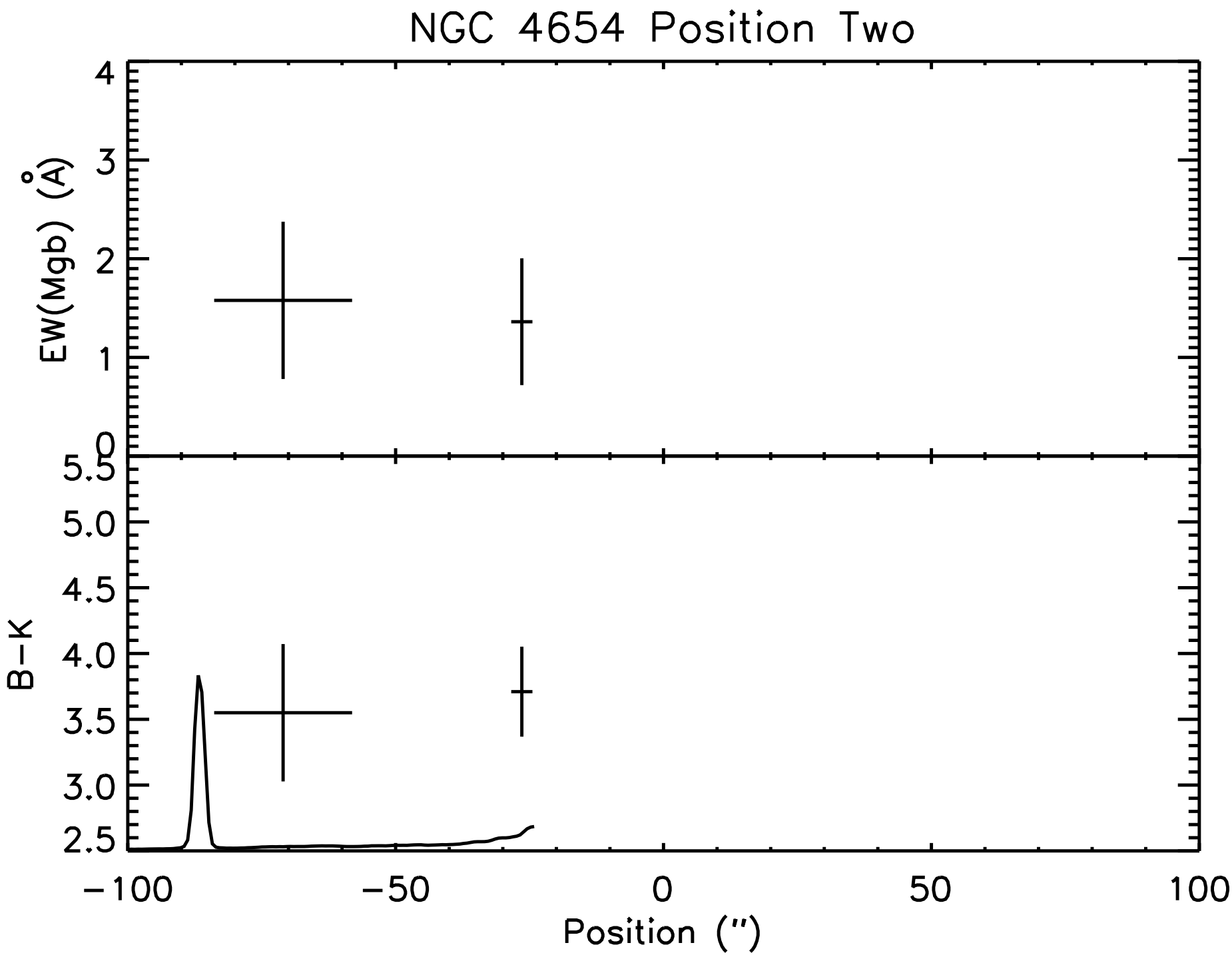

Profiles for NGC 4654
B Profile/Spectrum
B Profile/Image
K Profile/Image
Normalized Flux
−40
−20
0
20
40
60
80
100
Position (")

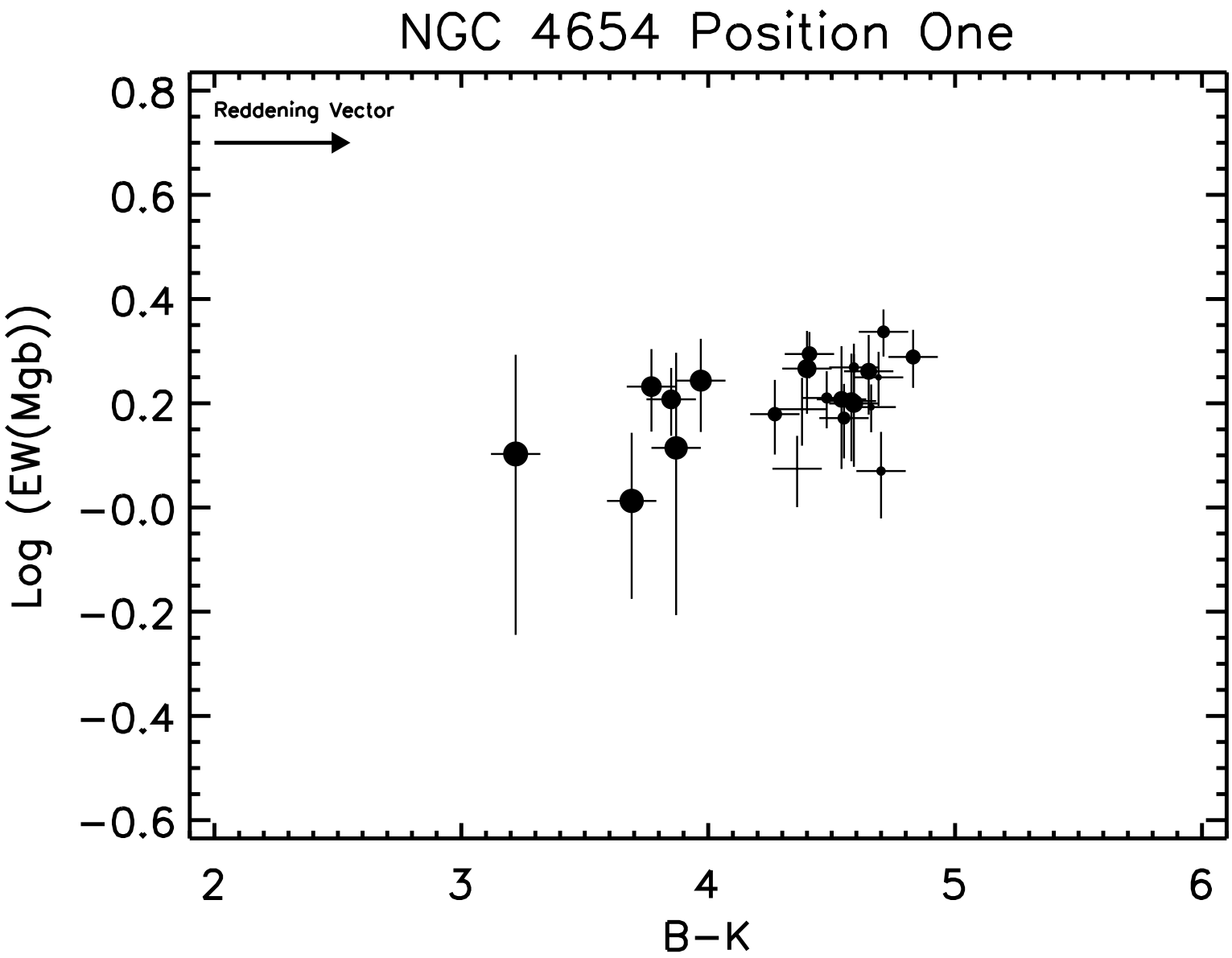

NGC 4654 Position One
B−K
5.5
5.0
4.5
4.0
3.5
3.0
2.5
−50
0
50
100
Position (")

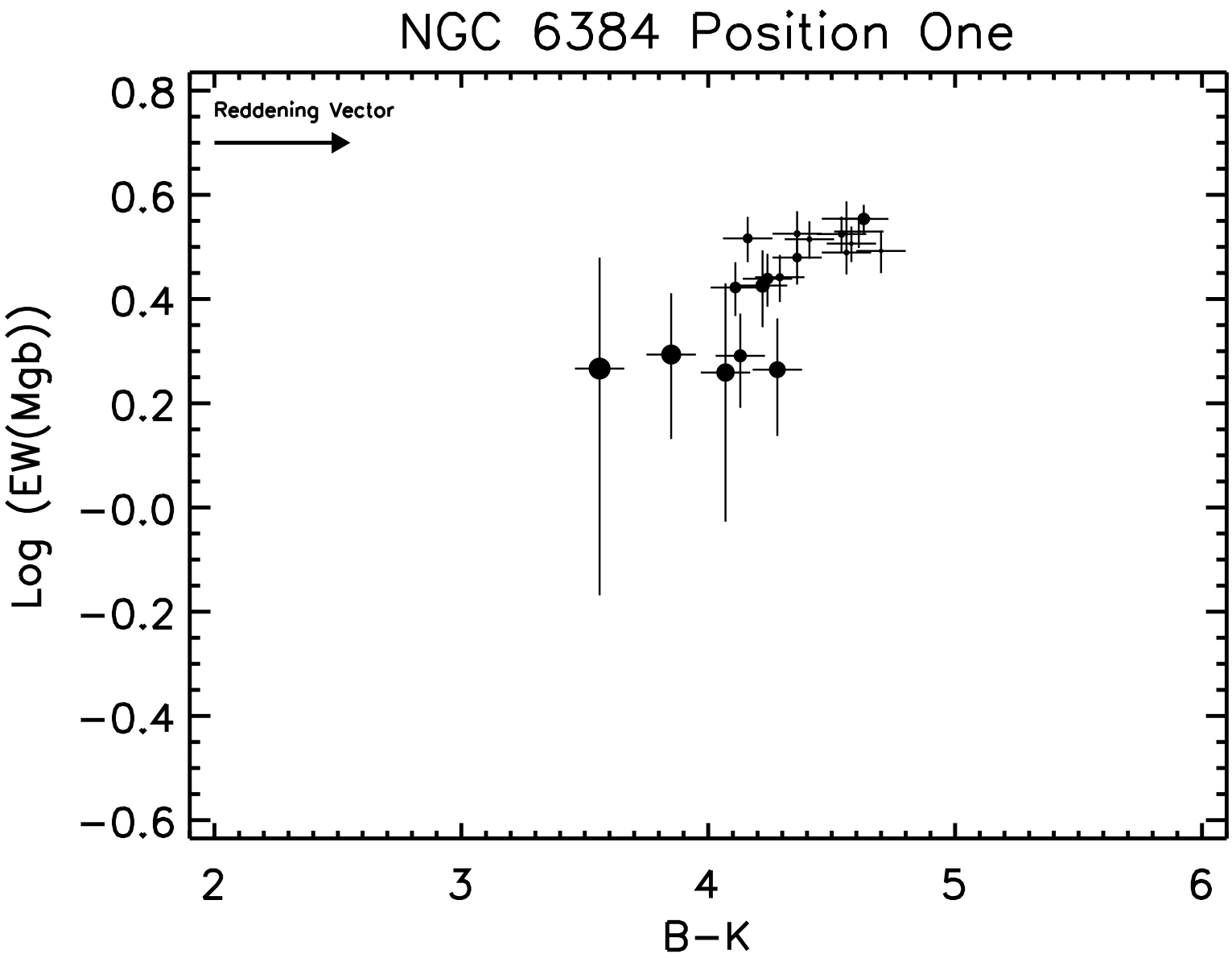

NGC 4654 Position One
EW(Mgb) (Å)
0
1
2
3
4
B−K
2.5
3.0
3.5
4.0
4.5
5.0
5.5
−50
0
50
100
Position (")

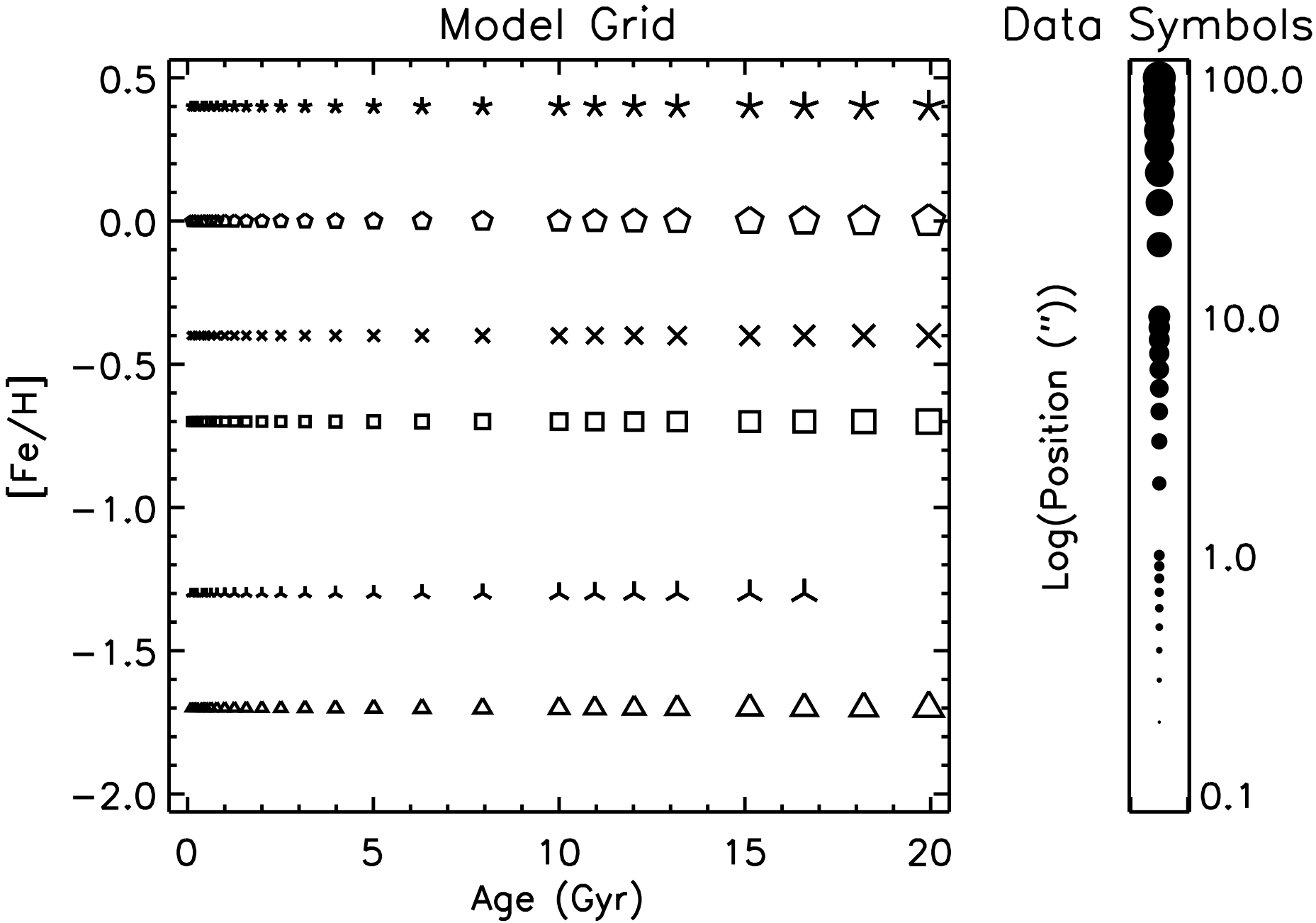

NGC 6384 Position One
EW(Mgb) (Å)
0
1
2
3
4
B−K
2.5
3.0
3.5
4.0
4.5
5.0
5.5
−50
0
50
100
Position (")

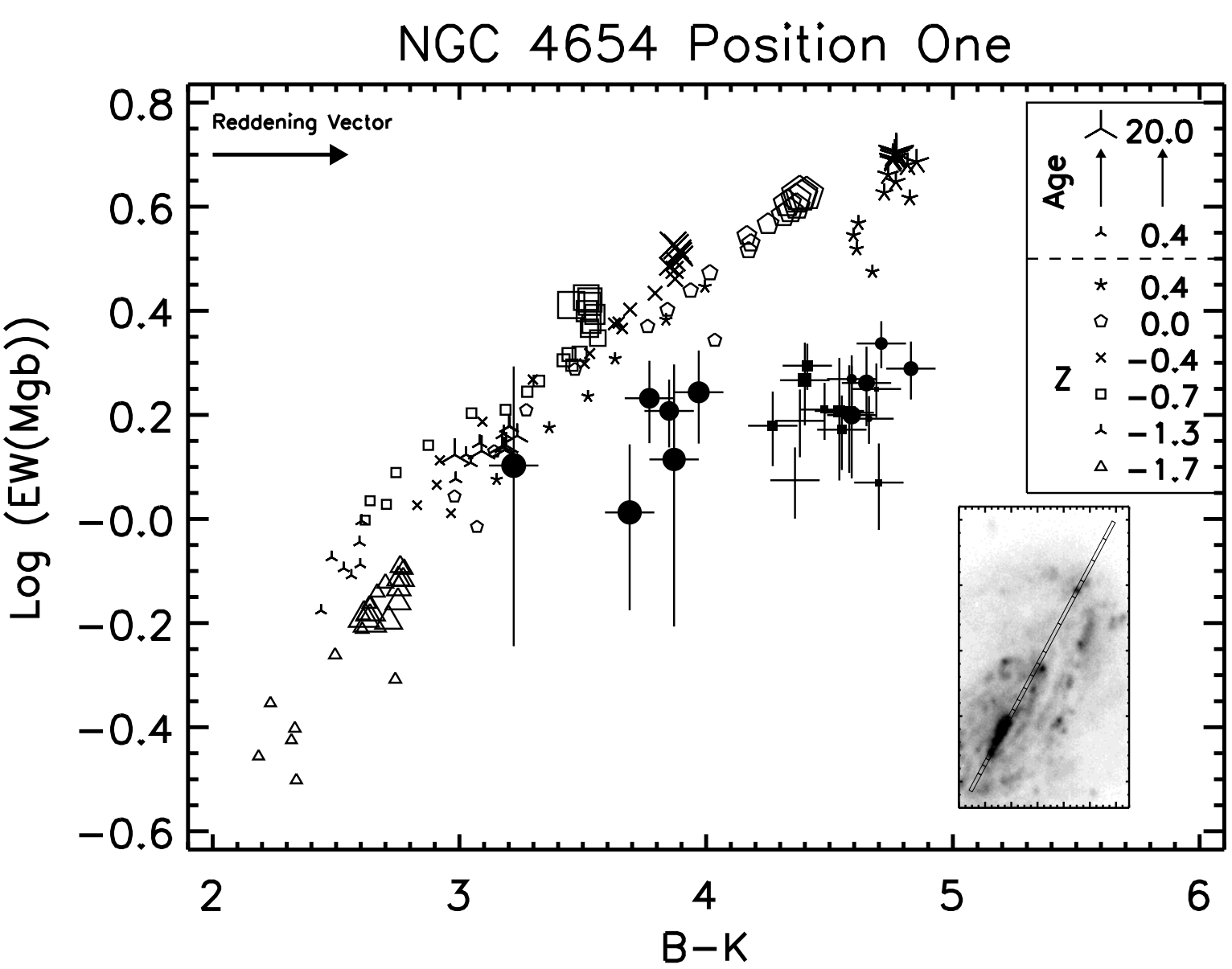

NGC 5204 Position One
EW(Mgb) (Å)
0
1
2
3
4
B−K
2.5
3.0
3.5
4.0
4.5
5.0
5.5
−150
−100
−50
0
Position (")

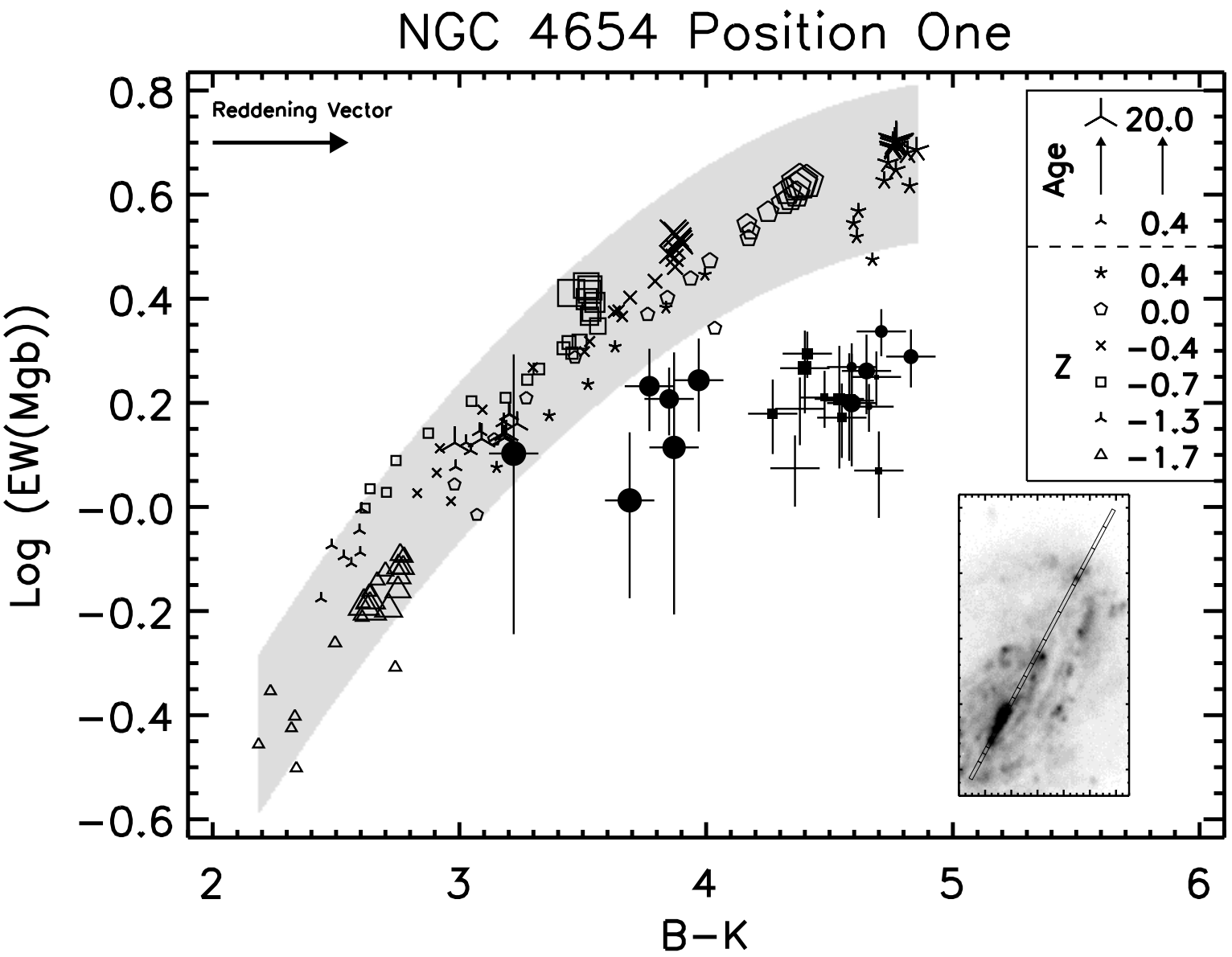

NGC 4654 Position Two
EW(Mgb) (Å)
0
1
2
3
4
B−K
2.5
3.0
3.5
4.0
4.5
5.0
5.5
−100
−50
0
50
100
Position (")

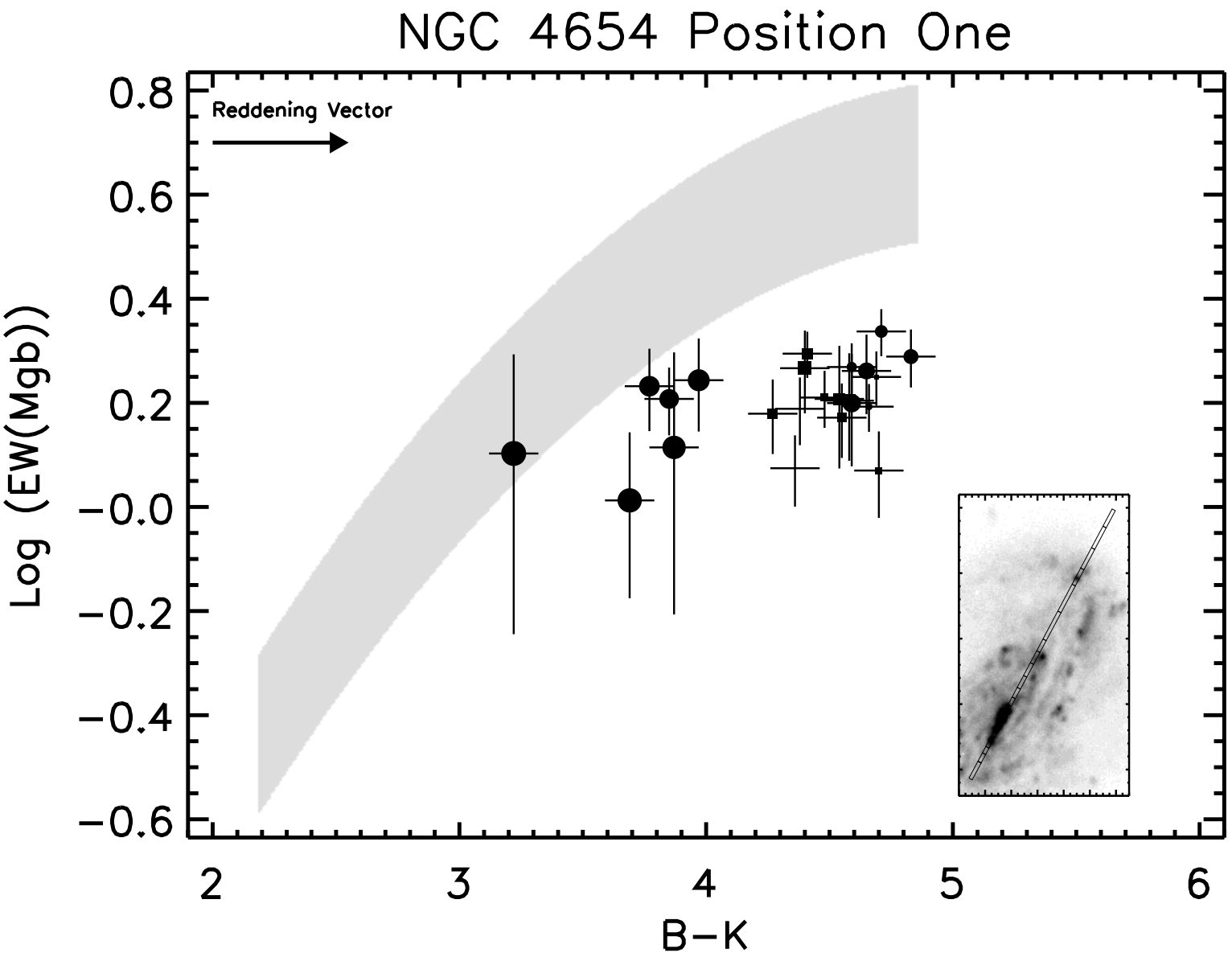

NGC 4654 Position One
Reddening Vector
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
Log (EW(Mgb))
2
3
4
5
6
B−K

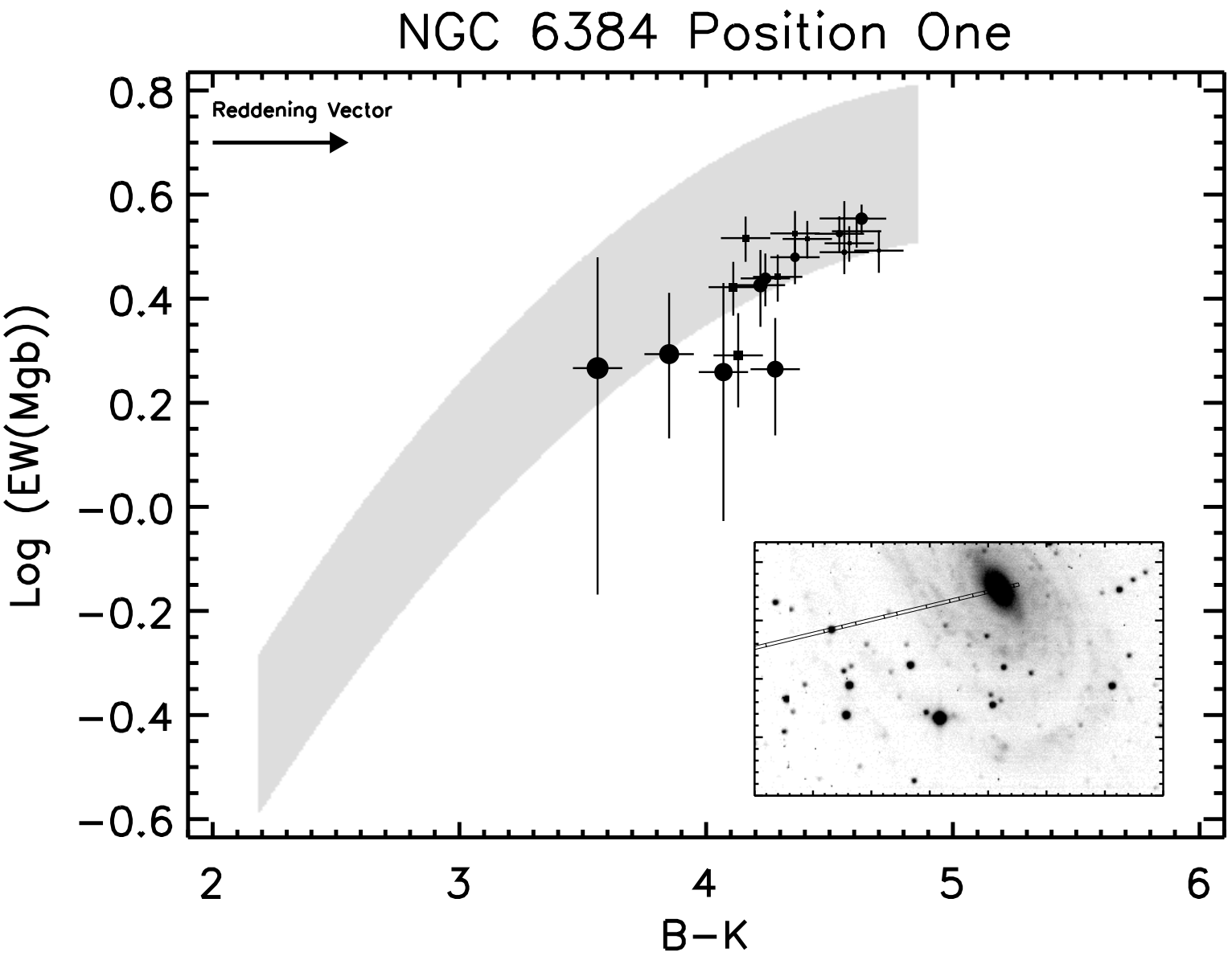

NGC 6384 Position One
Reddening Vector
Log (EW(Mgb))
B−K
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
2
3
4
5
6

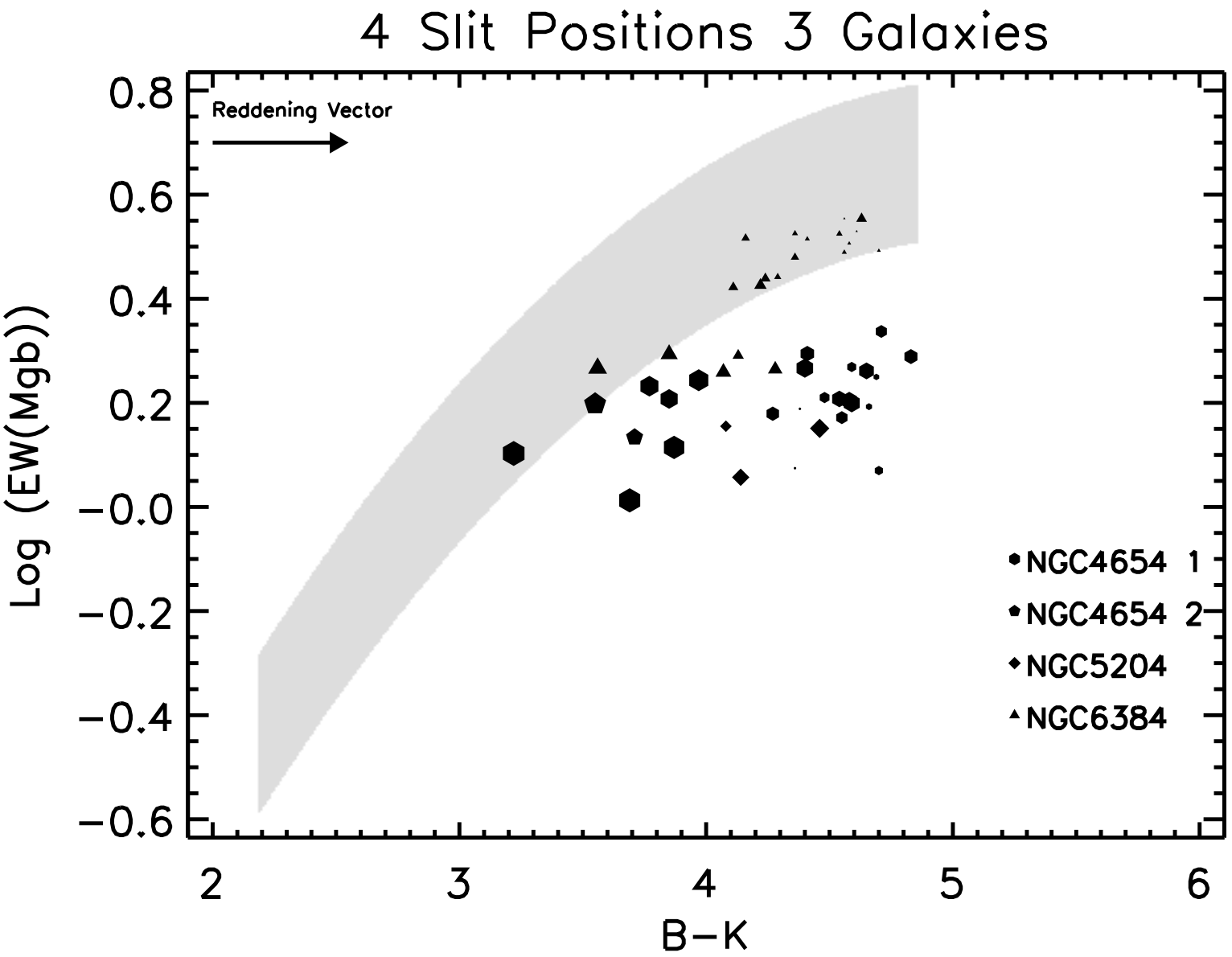

Model Grid
Data Symbols
[Fe/H]
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0
5
10
15
20
Age (Gyr)
Log(Position (″))
100.0
10.0
1.0
0.1


NGC 4654 Position One
Reddening Vector
Age
20.0
0.4
Z
0.4
0.0
−0.4
−0.7
−1.3
−1.7
Log (EW(Mgb))
B−K
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
2
3
4
5
6


NGC 4654 Position One
Reddening Vector
Age
20.0
0.4
Z
0.4
0.0
−0.4
−0.7
−1.3
−1.7
Log (EW(Mgb))
B−K
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
2
3
4
5
6


NGC 4654 Position One
Reddening Vector
Log (EW(Mgb))
B−K
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
2
3
4
5
6


NGC 6384 Position One
Reddening Vector
Log (EW(Mgb))
B−K
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
2
3
4
5
6


4 Slit Positions 3 Galaxies
Reddening Vector
Log (EW(Mgb))
B−K
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
2
3
4
5
6
NGC4654 1
NGC4654 2
NGC5204
NGC6384

CONCLUSIONS

- The faint regions of spiral disks have been observed in the optical bands, near infrared bands and spectroscopically with spatial resolution.
- This forms a very unique data set that has many uses.
- The galaxies analyzed were very different in their internal character.
- NGC 4654 shows a decrease in reddening outward with little or no population gradient.
- NGC 6384 shows a population gradient that increases in age and metallicity towards the center. There is a decrease in reddening outward in the outer disk.

CONCLUSIONS CONTINUED

- NGC 5204 resembles NGC 4654 although no gradients were detected.
- NGC 6384 is in the field. NGC 4654 and NGC 5204 are cluster galaxies.
- Perhaps the differences seen here are due to their different environments.
- Apparently one age or metallicity is not sufficient to describe NGC 6384.
- Simple stellar populations are very useful in analyzing the disks. However, they are insufficient to describe disks.
- Very old metal rich nor very metal poor populations of any age contribute to the integrated light of the three galaxies.

FUTURE WORK

- Look at the other slit positions & galaxies.
- Look at other colors to estimate the internal reddening law.
- Look at other lines to see if reddening is confirmed.
- Separation of emission from absorption in H to get better separation of age and metallicity
- Bulge-disk decompositions & surface brightness distributions
- Color distributions & true color images
- Test galaxy evolution models
- Are large Tully-Fisher residuals related to internal properties?