Measuring the Redshift of M104—The Sombrero Galaxy

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[2]

Abstract

Spectroscopic measurements of M104 were taken in the visible region. Spectral features were identified and the redshift of M104 was determined to be z =0.0057 corresponding to a velocity of 1720+/220 km/s, a figure well within an order of magnitude of the best accepted value. Based on the redshift, the distance to M104 was estimated using Hubble's relation.

Introduction

M104 is an 8th magnitude Sa-Sb type galaxy in Virgo with an apparent dimension of 9x4 arcmin [1]. In 1912 Vesto M. Slipher at the Percival Lowell Observatory observed and measured the redshift of the galaxy (now known to be 1024±5km/s [2]), and concluded the object must be extragalactic due to its extraordinarily high velocity [1].

The brightness and relatively large redshift of M104 make it an ideal target for basic spectroscopic measurements from the northern hemisphere. When reduced, these measurements can be converted into a spectrum, and atomic absorption lines can be identified to determine the redshift (by comparison with their known values from laboratory measurements), and hence velocity of M104. Such analysis is typical of measurements taken in the early 20^{th} century, and can be used to test the validity of Hubble's Law:

$$v = H_0 D$$

where v is the receding velocity of the galaxy, D is the distance to the galaxy, and H_0 is Hubble's constant. For our case of measuring a single red-

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[2]This image is under the public domain. Taken by the Hubble Space Telescope and available from the Space Telescope Science Institute Hubble Heritage Project.

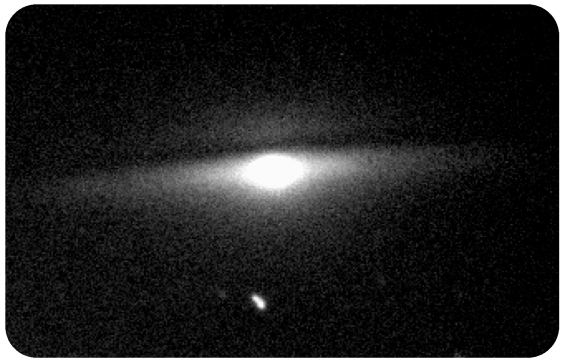


Figure 1: 60s processed exposure of M104

shift, Hubble's law can be used to determine the distance to M104.

Experimental Procedures

Observing was carried out on the Rice University Campus Observatory's 16" MEADE®LX200GPS Schmidt-Cassegrain telescope on April, 1 2004. Guiding was done automatically using a computer running TheSky™, with manual guiding correction during long exposures done with the aid of a separate guiding CCD.

Imaging was carried out on a 512x512 pixel CCD using a 3x focal reducer to increase the field of view. Spectroscopy was carried out with a single slit spectrometer (slit width 72μm) imaging onto a 765x510 pixel CCD.

After locating M104, a 60 second exposure was taken (including a 60s dark exposure automatically subtracted by the software). Three 0.1s flat field images of scattered incandescent lamp light were then taken (also with dark subtracted).

The spectrometer was then attached and a 60s exposure of scattered light from a Ne arc lamp was taken for calibration. This was followed by three sets of three 600s exposures of M104 with a Ne spectrum taken between each set to track any spectral drift. A 600s exposure of nearby sky was taken to estimate the background. An 8s exposure of μ-UMa was taken also for calibration purposes. Six hundred second duration dark exposures were then taken as well as a set of 40s Hg and Ne spectra. Finally, three 20s flat field spectra were taken.

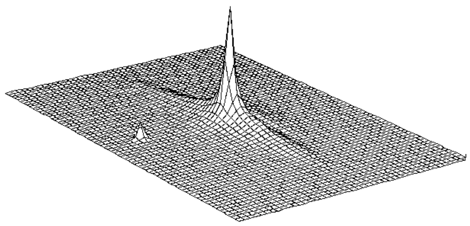
Data Reduction

All data processing was done using the Image Reduction Analysis Facility (IRAF).[3]

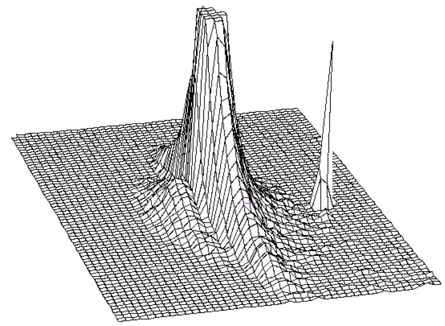
The image file was divided by an average of the three flat field exposures to remove any gradients in the CCD response. The average was first normalized to around unity by dividing by the mean of the central portion of the image. This image was then cropped and is displayed in **Figure 1**. Additionally, contour plots of the image were made using the *surface* command to emphasize the dark band caused by a lane of obscuring dust (shown in **Figure 2**).

Spectral analysis was conducted using the *apextract* package in IRAF. The three dark exposures

[3]IRAF is freely available from the National Optical Astronomy Observatory at `http://iraf.noao.edu`



Profile 1



Profile 2

Figure 2: 3D Profiles of **Figure1**

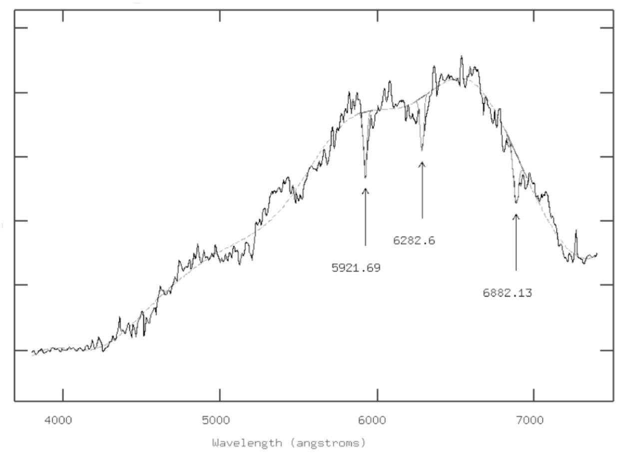
were first averaged and the resultant was subtracted individually from all nine spectra. The flat-field images were averaged and normalized as before (with the exception that the average was divided by a 21x21 "boxcar smoothed" image of the average instead of a constant). This normalized average was then divided into the individual spectra to equalize pixel response.

The *apall* task was used to extract one dimensional spectra from the two dimensional CCD image. Briefly, *apall* identifies an aperture on the CCD (i.e., the two-dimensional dispersed image of M104 in our case), tracks the aperture across the CCD to account for curvature or skewness in the spectrum image, subtracts the background from the spectrum based on a fit to surrounding background regions on the CCD, and finally outputs the one dimensional spectrum. This process was done on the first spectrum, and all subsequent spectrum used the first as a "reference" to define the aperture (to guarantee similarity for all the spectra in order to facilitate later averaging). All fitting was done with sixth order chebyshev polynomials, and the background was approximated using a 50 pixel wide region on either side of the spectrum. The Ne and Hg spectra were also extracted using the first spectrum as a reference.

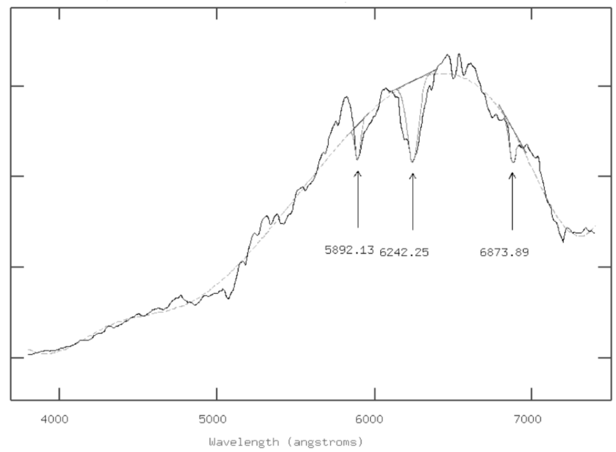
The extracted Ne and Hg spectra were then dispersion calibrated by identifying emission peaks with the *identify* command. The final mercury and neon spectra were combined into a single spectrum (since the emission lines do not overlap) to enhance accuracy. Chebyshev polynomials were then fit to the peaks to determine the dispersion across the CCD; this information was written out to a database by IRAF for later use. The goodness of fit for the various calibration

Spectrum	Order of Fit	RMS of Residuals (Å)
Ne-1	4	2.293
Ne-2	6	2.922
Ne-3	4	2.995
Ne-4	4	1.613
Hg+Ne	6	2.776

Table 1: Summary of Spectral Calibration Fits



M104



μ-UMa

Figure 3: Final Extracted Spectra

spectra are given in **Table 1**.

The *dispcor* task was then used to assign wavelengths to pixel numbers of the nine individual spectra based on the mercury and neon calibration references. The spectra were correlated with the calibration reference of closest temporal proximity. The nine individual spectra thus obtained were averaged using *scombine* to produce an averaged spectrum. This was then smoothed to remove noise producing the final spectrum shown in **Figure 3**.

Additionally, a spectrum of μ-UMa (aka Regulus) was taken for reference, also shown in **Figure 3**. The two spectrum are shown in-line in **Figure 4**.

Data Analysis

Spectral lines were identified using *spectool*. Ideally the maximum number of absorption lines should be identified, but due to the low resolution and relatively high noise, only the three most prominent lines could be identified with a high confidence level, leading to a decrease in the accuracy of the estimate for the redshift. Additionally, the absorption band around 6880Åis an atmospheric O_2 absorption line [3]

The difference in these lines is used as a basis for the estimate of the redshift of M104. The redshift z and velocity v of the galaxy were estimated using the relation:

$$z \approx \frac{v}{c} = \frac{\Delta\lambda}{\lambda}$$

Spectral Line	z	v
≈ 5900	0.005	1500 km/s
≈ 6260	0.0065	1940 km/s
average	0.0057	1720 km/s
accepted [2]	0.00342	1024 km/s

Table 2: Redshifts and Velocities of M104

derived from the Doppler shift. The determined values for v and z are given in **Table 2**.

The error of this measurement is estimated from the standard deviation σ of the two values from the average:

$$\sigma = 220 km/s$$

However, the small number of measurements make this estimate more of a minimum error. The actual value for the velocity of M104 is 1024±5km/s [2]. The determined value thus has a 68% error from the accepted value.

Finally, the distance to M104 can be estimated from Hubble's Law:

$$v = H_0 D$$

Using lower and upper bounds of $H_0 = 50\text{kms}^{-1}/\text{Mpc}$ and $H_0 = 100\text{kms}^{-1}/\text{Mpc}$ we estimate the distance to M104 to be between 17.2 and 34.4 Mpc.

Conclusions

The redshift and velocity of M104 were determined via spectroscopic measurements to be 0.0057 and 1720km/s respectively. These measurements are in 68% error from accepted values. This error, while large, is not unreasonable given the resolution of the spectrum and observing conditions.

References

[1] Students for the Exploration and Development of Space (SEDS)
"M104"
Dec. 9, 1999
http://www.seds.org/messier/m/m104.html
accessed April 29, 2004

[2] NASA/IPAC Extragalactic Database (NED)
"Messier 104"
http://nedwww.ipac.caltech.edu
accessed April 29, 2004

[3] Space Science Atmospheric Environment (SSAC) — Canadian Space Agency
"Fact Sheet 5: Absorption Lines in the Solar Spectrum"
http://www.space.gc.ca
accessed April 30, 2004

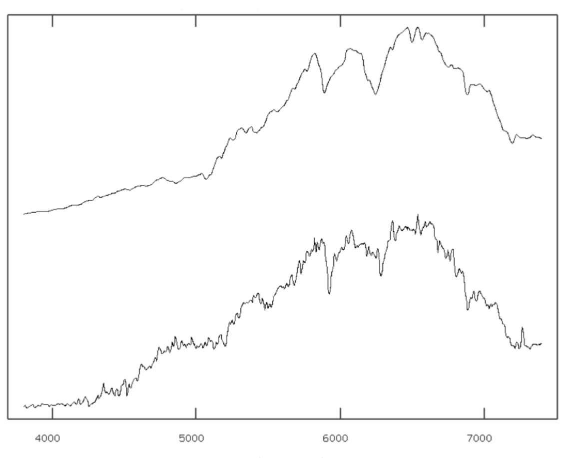


Figure 4: Combined Spectra