SPECTROSCOPY

I. INTRODUCTION

Spectroscopy provides information about the physical condition within the atmosphere of a star, nebula, or galaxy, and the intervening material between the source and the observer. This information includes the composition, temperature, density, ionization state, velocity (redshift), turbulence, magnetic field, etc. In some cases a spectroscopic observation provides detailed information about one or a few of these characteristics, and little or no information about the others. In the same spirit, no one spectrograph is well suited to the study of the full range of characteristics in a wide range of objects. In this experiment you will use a spectrograph to study the properties of ionized gas in a number of different sources including gas discharge tubes, planetary nebulae, HII regions, starburst galaxies, and/or Seyfert galaxies. The spectrograph uses the same CCD camera that you used in laboratory experiment, coupled with a spectrograph to disperse the light onto the CCD.

II. THE SPECTROGRAPH

A schematic diagram of the spectrograph is presented in Figure 1. Its basic elements are the entrance slit, the collimating mirror, the diffraction grating, the camera lens and finally the CCD. If you are not familiar with the function of each of these elements, read about grating spectrographs in a physics or optics text. The spectrograph has two viewing modes which are used to help the observer place the target image accurately on the slit. The **field viewing eyepiece** is used to recognize the target object, and to bring it's image close to the slit. The slit **viewing eyepiece/CCD** shows a magnified view of the slit, the target object, and the surrounding sky. See Figure 2. If the object is not centered on the slit, its light will be reflected by the back surface of the slit plate, and appear in the guider. (The slit plate is actually a mirror which has a narrow strip where the reflecting coating has been removed.) By moving the telescope, the object can be centered on the slit. When a star is centered on the slit, most of the light passes through the slit leaving just a hint of the star on either side of the slit. When an extended object is centered on the slit, the image is bisected by a dark band. Object light falling in the band is passed to the spectrograph. Once the object is correctly positioned, it is time to make an exposure. During the exposure the slit viewing CCD allows the observer to monitor the location of the object and to tweak the telescope pointing as needed.

Exposure Times:
The diffraction grating spreads the light coming through the slit across the CCD. Since the light is distributed over many more pixels than be in a direct image, the intensity of the light falling on any one pixel is greatly reduced. Therefore, much longer exposures are generally needed to record a spectrum than to obtain an image. For objects with smooth continuous spectra, stars for example, this ratio is about 100:1. On the other hand, if most of the light is contained in a few bright emission lines then the spectrum will require only a few times longer exposure. For this reason we will spend most of our time observing objects with

emission line spectra. There is another more fundamental reason for this choice as well; continuous spectra (normal stars) in general have only absorption lines which are difficult to see in the presence of a strong continuum unless rather high resolution is used. This further exacerbates the long exposure problem. Wolf-Rayet stars and Be stars are very massive young stars with emission lines, and they are an exception to the general rule. Close binary stars like, β Lyra stars, are transferring mass from one star to another. They are just one class of mass transferring stars which show emission lines.

Calibration Spectra:

When the flip-mirror (see Figure 1) is in the viewing position, it prevents the light from the sky from reaching the slit. However, if the calibration lamps are turned on, their light is reflected by the back of the flip-mirror to the slit. In this way one can quickly and conveniently obtain a calibration spectrum. Neon and mercury lamps are provided for this purpose. Unfortunately, neon has a very complex spectrum in the optical, and it is somewhat difficult to identify the lines. However, mercury has a very simple spectrum, therefore, it is useful for the initial stages of establishing a wavelength calibration. Lists of the wavelengths for neon, mercury are presented in the "Handbook of Chemistry and Physics". Be careful with these lists, they contain many very faint lines, and it is easy to get the wrong identification. Sample lamp and object spectra are presented in the Spectrograph three-ring binder in the lab.

III. OPTIONS and LABORATORY TESTING

There are a number of options that you can use in setting up the spectrograph to adapt it to the observations you have in mind. The first of these is the selection of the entrance slit. Two slits are available, wide and narrow. In general, the wide slit is used for low-resolution studies of extended sources, nebulae and galaxies, while the narrow slit is used for high-resolution studies of point sources, stars. There are two diffraction gratings: one with 600 lines/mm, and one with 1200 lines/mm. The former is for low dispersion, while the latter is for high dispersion. Finally, there are three camera lenses that can be used. Their focal lengths are 55, 105 and 135 mm. The longer the focal length the larger the image on the CCD. Since the longer focal length lens spreads out the light more than a shorter focal length, the resulting spectrum is fainter and requires a longer exposure time.

The configuration options and numbers:

Slit	Width (mm)	Projected width on the sky (arc seconds)
Wide	0.24	~ 6 arc seconds
Narrow	0.08	~ 2

****************** The following numbers are yet to be completely verified ******************************

	Wavelength	Monochromatic slit width

Grating	Lens	Dispersion	Range in one exp	Wide	Narrow
600 l/mm	55mm	3.8 A/pix	7600 A	1.4 pix	0.5 pix
600	105	2.2	3980	2.8	0.9
600	135	1.52	3040	3.5	1.2
1200	55	1.9	3800	1.4 pix	0.5 pix
1200	105	1.0	1990	2.8	0.9
1200	135	0.76	1520	3.5	1.2

Telescope plate scale = 24 arcsec/mm, collimator fl =225mm, and pixel size 13.5 μm

The monochromatic slit width should be at least two pixels to achieve Nyquist sampling. However, if the monochromatic slit width is ≥ 2 pixels the light is needlessly spread out without increasing the resolution. Pick the slit width and camera lens focal length accordingly. In some cases, it is desirable to choose a compromise configuration of the spectrograph that suits multiple observing programs. Changes to the configuration of the spectrograph require a complete set of new calibration data, so it is usually preferable to choose a compromise setting that need only be calibrated once.

The most common configuration use the wide slit, 600 l/mm grating and the 135 mm lens. This will give a wide range of wavelengths, the brightest images, and shortest exposures. Set the lens wide open (f/2.2) and to infinity focus. Screw it on the bottom of the CCD and then mount the CCD on the spectrograph. As a start, set the grating angle to 13 degrees using the grating rotary table. Turn on the Neon lamp, and with the flip mirror in the viewing position, take a 5 second exposure. You should see a mass of nearly emission lines on the right side of the image. In the standard configuration the right end of the spectrum are longer wavelengths.

The next task is to focus the spectrograph. This is done by loosening the four black thumb screws on the side of the spectrograph (marked FOCUS LOCKS) and successively adjusting the focus position, making short exposures and displaying them on the monitor. It is best to use a plotting routine to look at the brightness and sharpness of a close pair of lines. Once you have achieved a good focus, tighten the lock screws and recheck the focus. Like all refracting lenses, the camera lens has different focus positions for different wavelengths of light. Therefore, you will have to settle on a compromise focus position depending on the experiment you want to do. Be sure to record the dial setting for the best focus in your notebook!

Once the spectrograph is focused, you need to establish the wavelength calibration. Turn off the neon lamp and turn on the mercury one. Do a 5 second SNAP. There should be four prominent lines from the center of the image to the blue limit on the left. These are due to Hg and the wavelengths are:

Line	Wavelength (A)
Blue	4358
Green	5461

Yellow doublet	5770 & 5790

(Note: The yellow doublet may appear as a single fat line depending on the focus and resolution selected.)

IV. SETTING UP AND OBSERVING PROCEDURES:

If the spectrograph is not already mounted, mount the spectrograph on the back of the telescope while the telescope is pointing toward the zenith. Use the two clam-shell clamps and bolts to hold the spectrograph on the back of the telescope. Rotate the spectrograph until the field viewing eyepiece is pointed toward the East. Tip the telescope South to about 0 declination to make the CCD mounting face more or less horizontal. Now mount the CCD Dewar, with the selected camera lens attached, on the spectrograph. Note the North marking on the West side of the CCD mounting plate on the spectrograph. This is to be lined up with the North mark on the camera. (It has nothing to do with the direction North!) Return the telescope to the vertical, and install the counter weight holder and three “large” counterweights.

If the slit viewing CCD is not already installed, it needs to be installed, and focused on the slit.

Check that the telescope is balanced and adjust the weights accordingly.

Set, check, and record the grating angle setting. For convenience of calibration you may want to use the same angle as in the laboratory. However, you will still have to take one or more lamp spectra to make sure nothing has changed.

Start HBOC, and the Maxim/DL in the data room.

Find a medium bright, 4th to 8th magnitude, star and center it in the Field Viewing eyepiece. Flip the mirror to the spectrum position and look for the star on slit viewing CCD monitor. You may have to hunt around a bit to find it. (A star as faint as 8th magnitude is likely to smear across the CCD even on the shortest exposure.) Once found, center the star on the slit, and go back to the Field Viewer Eyepiece and adjust the micrometers until the star is in the center of the reticule. This will make setting up on faint objects very much easier. Record your micrometer settings for future reference.

Find a bright planetary nebulae, center it in the field viewing eyepiece, flip out the mirror and center the nebula on the slit.

Retire to the warm room and take a 10 second exposure. You should see at least four lines:

Line	Wavelength
H alpha	6563 A
OIII	5007

OIII	4959
H beta	4861

See Figure 3. The stellar continuum may or may not appear depending on whether or not the slit contains the central star. The vertical length of the nebular lines show the spatial extent of the nebula along the slit. The atmospheric night emission lines fill the entire length of the slit.

If the spectrograph is not well focused, you will not be able to split the OIII doublet! Once you have a recognizable spectrum you are ready to do some science. The first easiest experiment is to do a longer exposure on the planetary (100 seconds) and boost the gain on the plot to see many more lines. There is a table in Allen's Astrophysical Quantities that lists the lines in a typical planetary nebula and their typical intensities. A spectrum of NGC 7027 is shown in Figure 4 with an approximate wavelength scale and tentative identifications for the brighter lines. High resolution spectra of NGC 7027 show hundreds of likes from 36 different atoms and ions.

From here you can go to other PN's, and you will see which line ratios stay constant and which ones do not. Why are the lines from oxygen so bright when hydrogen is >10,000 times more abundant? What are the similarities and differences between the spectra of planetary nebulae and HII regions? What do the spectra of starburst galaxies and Seyfert 1 galaxies look like? Can you measure the redshift of a galaxy? How about a rotation curve?

Additional Observing Hints:

- Be sure to record the following in your notebook:
  Slit width (Broad or Narrow)
  Collimator focus
  Grating (600 or 1200 l/mm)
  Grating tip angle
  Camera lens focal length (55,105 or 135 mm)
  X-Y micrometer settings
  Slit orientation (E-W, N-S, or the angle E from N)

- Use the Configuration option in the CCD program to record your setup. For example WS 600l/mm_13 55mm represents the wide slit with the 600 line/mm grating at 13 degrees and the 55mm camera lens.

- You can never have too many notes!

- If exact wavelengths are important, consider taking a Hg and/or Ne spectrum immediately after your "keeper" spectra. Remember, everything bends; it's just a question of how much. If you are doing redshifts, then you want to know wavelengths as closely as possible. If line intensities are your objective then exact wavelengths are of lesser importance.

<u>SAVE AND KEEP THE RAW DATA SAFE!</u> <u>DON'T ERASE IT UNTIL AT LEAST THE END OF THE SEMESTER!</u>

V. CALIBRATION AND DATA ANALYSIS

There are two basic parts to the data analysis: wavelength calibration and flux calibration. The wavelength calibration was discussed above. Flux calibration involves finding the flux in physical units that is associated with a particular pixel number and DN value. While redshift measurements need only a wavelength calibration, the determination of electron temperature in a gas requires a flux calibration as well.

A. Wavelength Calibration:
The simplest wavelength calibration is usually done with a short exposure of the mercury lamp using the known wavelengths of the bright lines above.

B. Flux Calibration:
You cannot flat field a CCD frame in the same way as an image because there is no easy way of knowing the spectrum of the flat field lamp

However, a star of known spectrum and flux can be used as your calibrator. One such candidate is a main sequence A star, A0V. By convention these stars have a temperature of 10,000K. Unfortunately, they also have strong H Balmer absorption lines. You will have to interpolate across the absorption lines to produce. This can be done by a complex interpolation algorithm or by drawing a smooth connection across the H line and editing corresponding entries in the data file.

Once you have the wavelength calibrated A0V star spectrum with the H lines “removed” you are ready to establish the flux calibration.

$$R(\lambda) = \frac{I(\lambda)}{S(\lambda)} * B(\lambda, T)$$

Where:
R is the reduced spectrum
I is the wavelength calibrated input spectrum of your object
S is the wavelength calibrated spectrum of an A0V star with the H lines “removed”
B is the Planck function of wavelength and temperature T

For an A0V calibrator use T = 10000K

Since you are multiplying I by B/S, it is simplest to calculate B/S once and store it for later use. While this procedure provides a spectrum of the correct *shape* it hasn't yet gotten the *amplitude* right. To do this we need the absolute flux of the calibrator at some wavelength. In general this is hard to do. Vega the brightest A0V has been measured in absolute physics units. This calibration has been transferred to many other stars. This is getting into more detail than is needed for the determination of the physical parameters since it is only the ratios of line strengths that are needed. However, it you want to take the ratio of a line measured at HBO to a flux from Aercibo, then you have to take the next step and get to actual physical units.

As if this isn't enough already:
In principle you should do the wavelength and amplitude calibration for every pixel. This becomes a big job. As a first step one would have to positions the calibration star at many different places along the slit. The wavelength calibration is a much easier since the lamps fill the entire length of the slit. Enough is enough.

SPECTROPHOTOMETRIC CALIBRATION REFERENCES

Stone, R.P.S.(1977) ApJ 218, 767.
Oke, J.B. and Gunn, J.E. (1983) ApJ 266, 713.
Gunn, J.E. and Stryker, L.L. (1983) ApJ Supp. 52, 121.

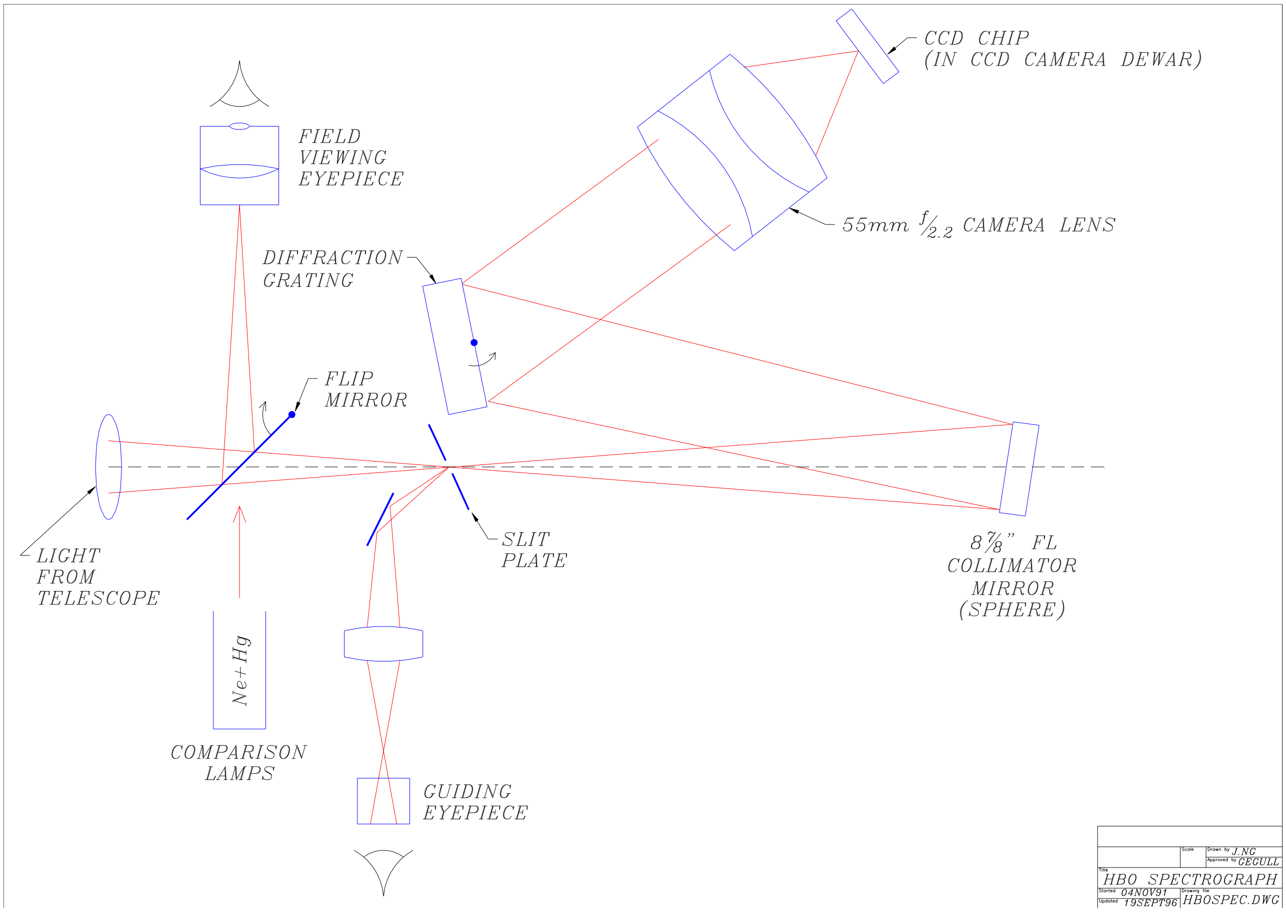


Figure 1. Schematic View of the Spectrograph

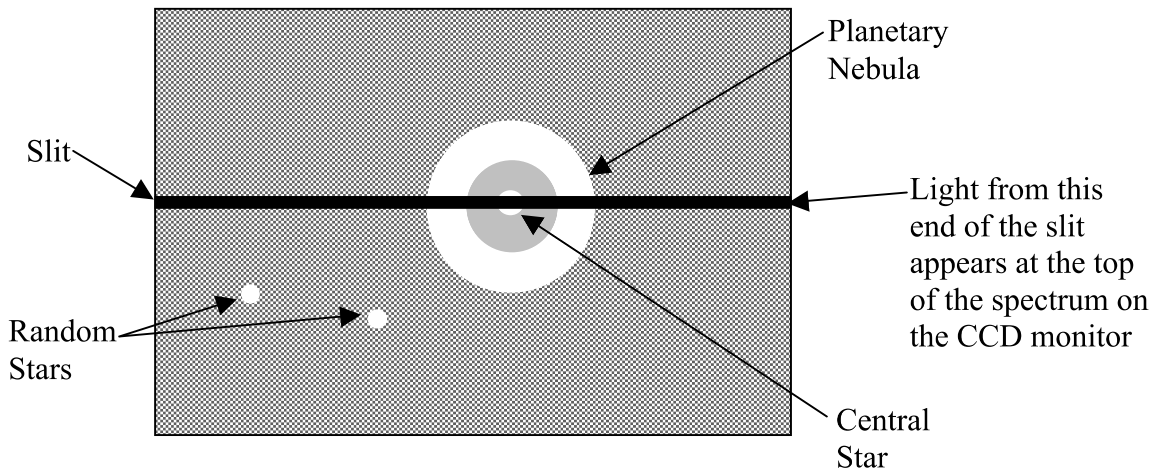


Figure 2. Cartoon View of the Slit Viewing Monitor.

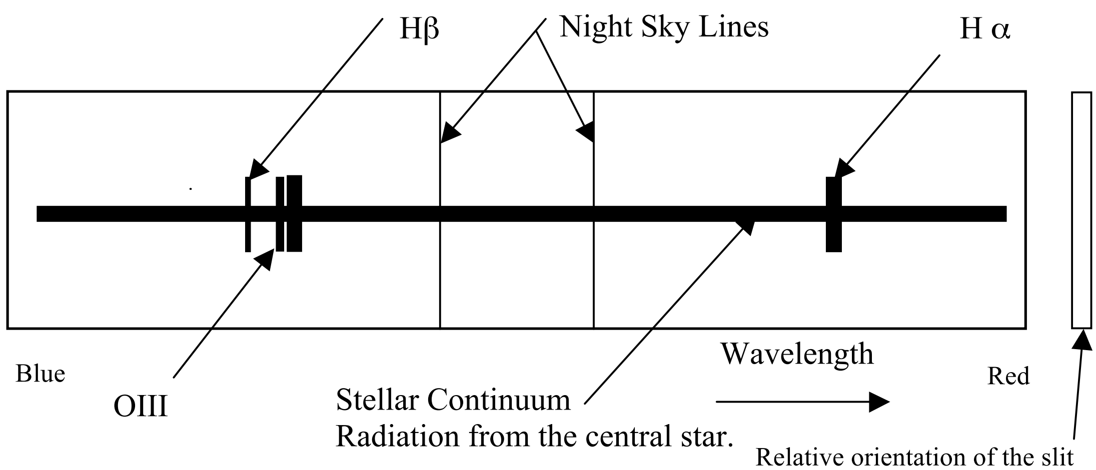


Figure 3. Cartoon View of a Planetary Nebula Spectrum on the CCD Monitor

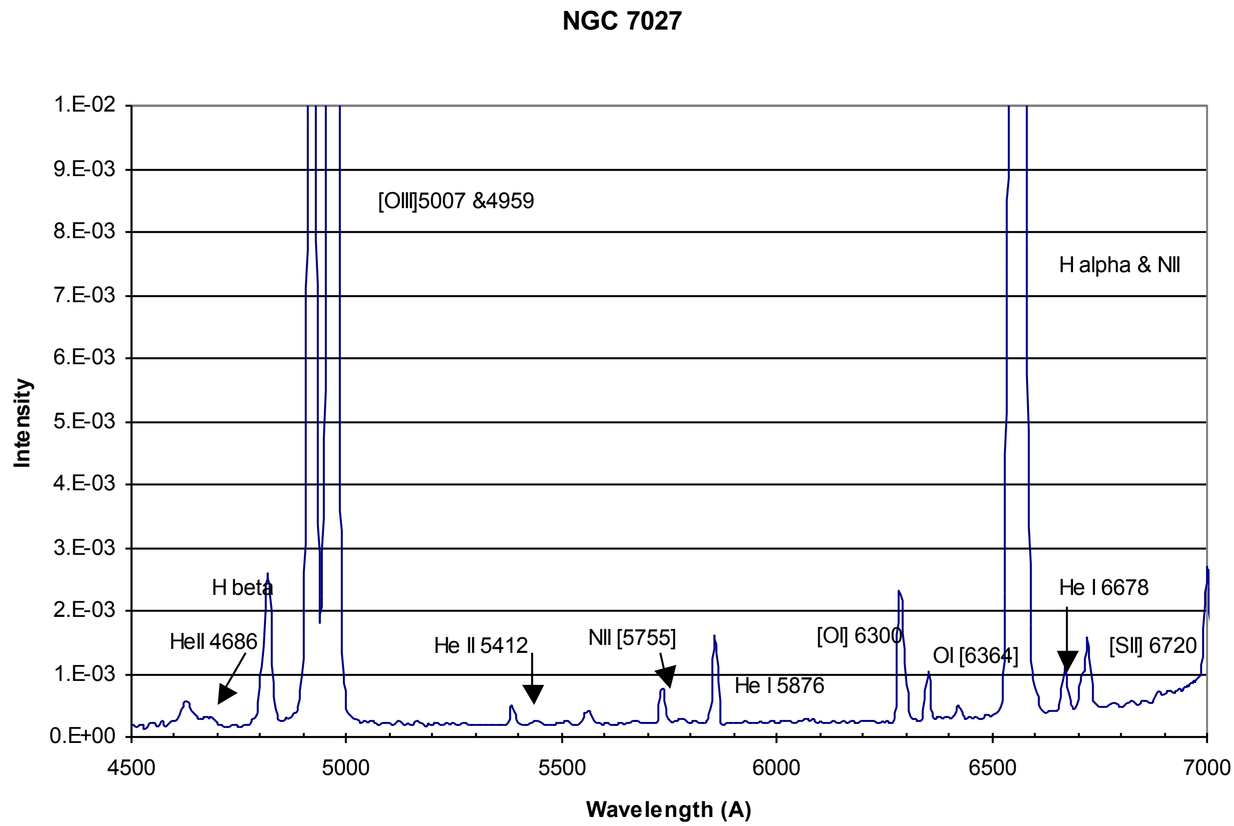
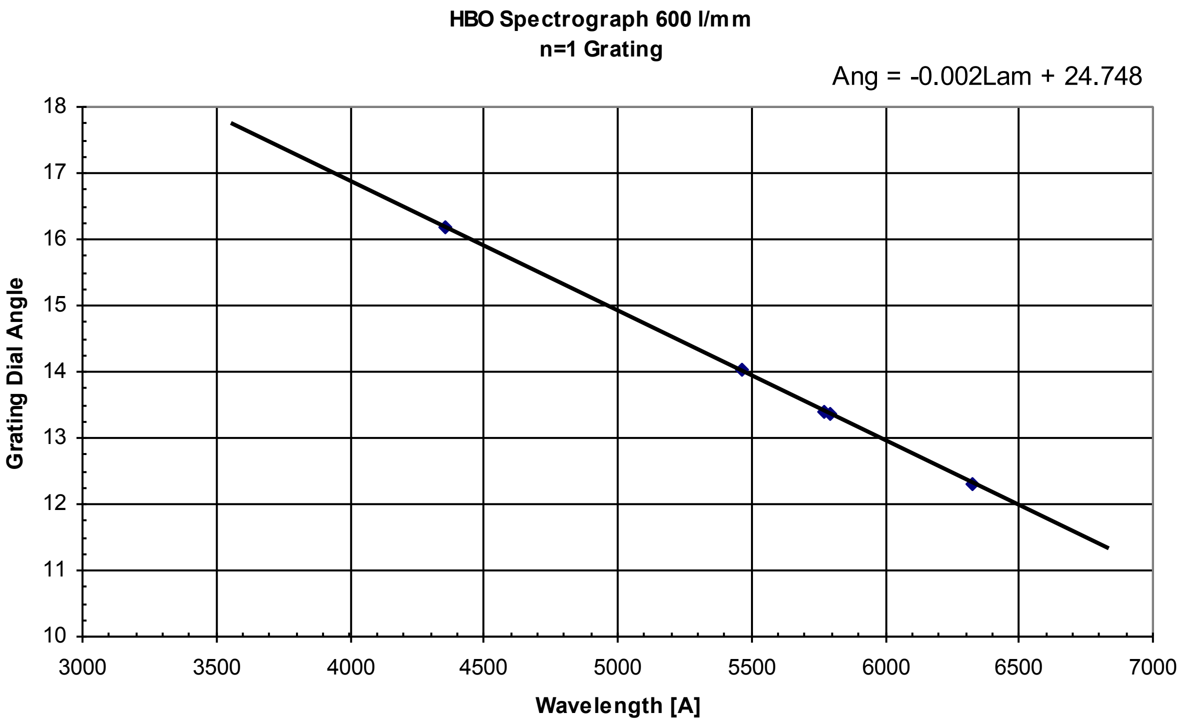
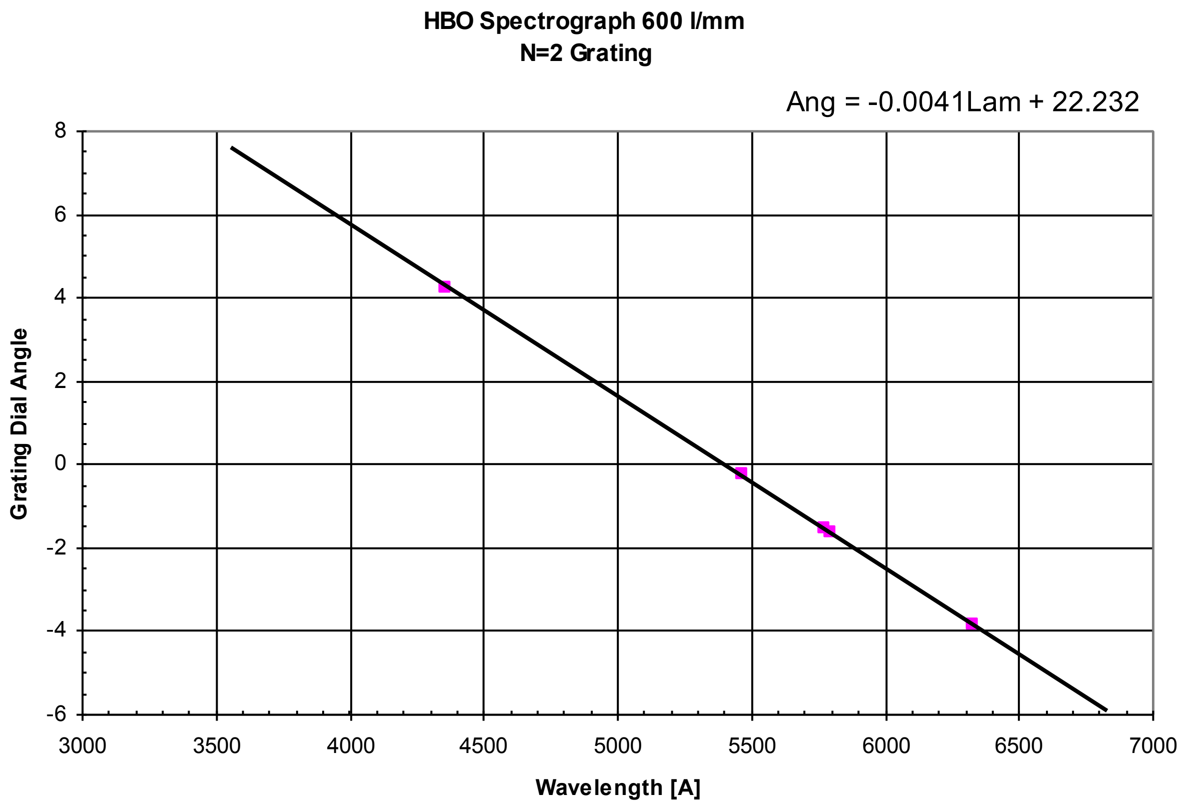


Figure 4. A Spectrum of NGC 7027 Taken at HBO. (~100 sec exposure)


HBO Spectrograph 600 l/mm
n=1 Grating
Ang = -0.002Lam + 24.748
18
17
16
15
14
13
12
11
10
Grating Dial Angle
3000
3500
4000
4500
5000
5500
6000
6500
7000
Wavelength [A]


HBO Spectrograph 600 l/mm
N=2 Grating
Ang = -0.0041Lam + 22.232
8
6
4
2
0
-2
-4
-6
Grating Dial Angle
3000
3500
4000
4500
5000
5500
6000
6500
7000
Wavelength [A]

LINE	(A)	NGC 7027 Intensity	Flux	ABS.	NGC 7026 Intensity	Flux	ABS
H8, He I	3889.0	9.72	21.53		11.96	23.65	
H7, [Ne III]	3969.0	34.26	71.84	...	33.60	62.76	
He I, He II	4026.0	1.31	2.63	...	2.27	4.13	
[S II]	4068.6	4.57	8.87	...	3.26	5.76	
[S II]	4076.2	1.53	2.95	...	1.35	2.37	
H6, He II	4101.7	18.07	34.19	...	19.21	33.17	
C III	4186.9	0.21	0.37	...	...	... ...	
He II	4199.9	0.69	1.20	...	...	... ...	
C II	4267.3	0.40	0.66		0.78	1.19	
H gamma	4340.5	36.16	55.87	...	35.60	51.69	
[O III]	4363.2	18.87	28.57	...	3.70	5.27	
He I	4387.9	0.29	0.43		0.75	1.06	
He I	4471.5	1.51	3.46	...	4.25	5.60	
He II	4541.6	1.45	1.88	...	0.41	0.51	
Mg I	4571.1	0.56	0.71	...	...	... ...	
N III	4634.1	1.43	1.71	...	1.26	1.47	
N III	4640.6	2.97	3.54	...	2.82	3.27	
C III	4647.4	0.67	0.79	...	1.01	1.17	
C IV	4658.3	0.72	0.85	...	0.50	0.57	
He II	4685.7	43.03	49.40	...	13.66	15.38	
[Ar IV]	4711.3	3.49	2.92	...	2.67	2.96	
[Ne IV]	4725.0	1.58	1.76		...	... ...	
[Ar IV]	4740.2	8.34	9.17	...	2.54	2.75	
H beta	4861.3	100.00	100.00	...	100.00	100.00	
He I	4921.9	0.95	0.91	...	1.63	1.57	
[0 111]	4958.9	504.48	469.67	...	339.35	319.33	
[0 111]	5006.9	1533.83	1381.98	...	1026.75	938.45	
?	5131.0	0.18	0.15	...	...	... ...	
[Fe VI]	5145.8	0.31	0.25	...	...	... ...	
[Fe VII]	5158.9	0.22	0.18	...	...	... ...	
[Fe VI]	5176.4	0.27	0.22	...	...	...	
[Ar III]	5191.8	0.37	0.30		...	... ...	
[N I]	5200.4	0.64	0.51	...	1.47	1.21	
[Ca v]	5309.2	0.52	0.39	...	...	... ...	
[Cl IV]	5323.3	0.15	0.11				
[Fe vi]	5335.2	0.25	0.18	...	...	... ...	
?	5345.0	0.34	0.25	...		... ...	
He II	5411.5	6.15	4.34	...	1.64	1.21	
[Fe VI]	5423.9	0.22	0.45	...	...	... ...	
[Fe VI]	5484.8	0.12	0.08				
[Cl III]	5517.7	0.32	0.21	...	1.06	0.75	
[Cl III]	5537.8	1.04	0.69	...	1.33	0.94	
[0 I]	5577.4	0.38	0.25	...	0.72	0.50	
O III	5592.4	0.21	0.14	...	...	... ...	

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Mg I	4571.1	0.56	0.71	...	...	... ...	
N III	4634.1	1.43	1.71	...	1.26	1.47	
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H beta	4861.3	100.00	100.00	...	100.00	100.00	
He I	4921.9	0.95	0.91	...	1.63	1.57	
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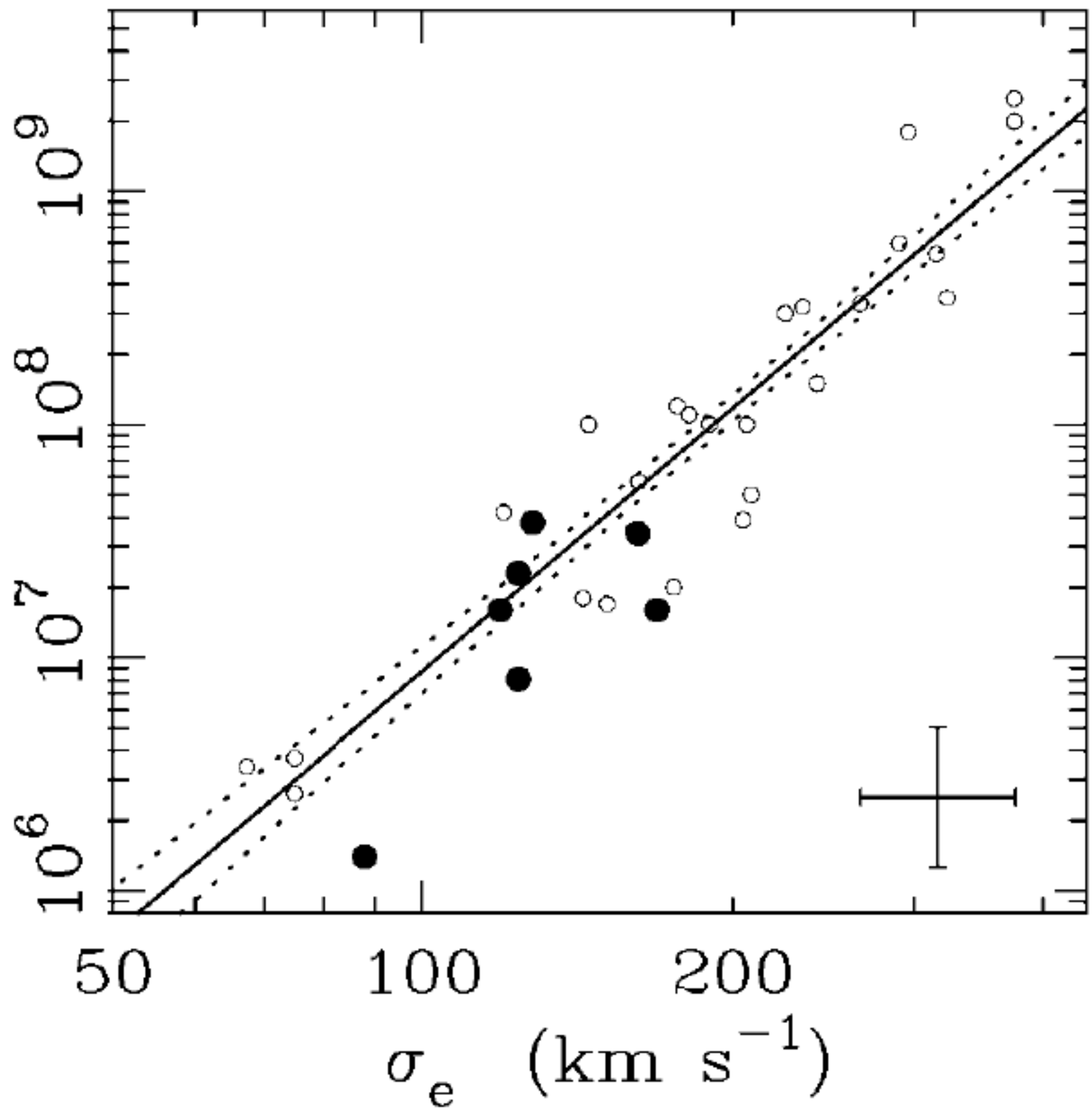
[0 111]	5006.9	1533.83	1381.98	...	1026.75	938.45	
?	5131.0	0.18	0.15	...	...	... ...	
[Fe VI]	5145.8	0.31	0.25	...	...	... ...	
[Fe VII]	5158.9	0.22	0.18	...	...	... ...	
[Fe VI]	5176.4	0.27	0.22	...	...	...	
[Ar III]	5191.8	0.37	0.30		...	... ...	
[N I]	5200.4	0.64	0.51	...	1.47	1.21	
[Ca v]	5309.2	0.52	0.39	...	...	... ...	
[Cl IV]	5323.3	0.15	0.11				
[Fe vi]	5335.2	0.25	0.18	...	...	... ...	
?	5345.0	0.34	0.25	...		... ...	
He II	5411.5	6.15	4.34	...	1.64	1.21	
[Fe VI]	5423.9	0.22	0.45	...	...	... ...	
[Fe VI]	5484.8	0.12	0.08				
[Cl III]	5517.7	0.32	0.21	...	1.06	0.75	
[Cl III]	5537.8	1.04	0.69	...	1.33	0.94	
[0 I]	5577.4	0.38	0.25	...	0.72	0.50	
O III	5592.4	0.21	0.14	...	...	... ...	

LINE	(A)	NGC 7027 Intensity	NGC 7027 Flux	NGC 7027 ABS.	NGC 7026 Intensity	NGC 7026 Flux	NGC 7026 ABS
[Fe VI]	5630.9	0.15	0.09	...	...	... ...	
[Fe VI]	5677.0	0.22	0.14	...	...	... ...	
[Fe VII]	5721.1	0.56	0.34	2			
[N II]	5754.6	10.20	6.11	...	3.90	2.51	
C IV	5801.3	0.72	0.42	...	...	... ...	
C IV	5812.0	0.41	0.24	...	...	... ...	
He I	5875.6	18.71	10.65	2	28.02	17.29	
He II	5913.0	0.15	0.08	10	...	... ...	
He II	5932.0	0.18	0.10	28	...	... ...	
He II	5953.0	0.12	0.07	...	...	... ...	
He II	5977.0	0.13	0.07	12	...	... ...	
He II	6004.0	0.16	0.09	3	...	... ...	
He II	6037.2	0.21	0.11	...	...	... ...	
He II	6074.3	0.23	0.12	...	...	... ...	
[Ca v], [Fe VII]	6086.9	1.15	0.60	...	...		
[K IV]	6101.8	1.01	0.53	...	...	... ...	
He II	6118.3	0.27	0.14	...	...	... ...	
[O I]	6300.3	28.43	13.70		12.22	6.54	
He I, [S III]	6312.0	9.69	4.65		5.09	2.72	
[0 I]	6363.8	10.09	4.75		4.19	2.20	...
Si II	6371.4	0.44	0.21	...	...	...	...
He II	6406.4	1.06	0.49	...	...	...	...
[Ar v]	6435.1	4.56	2.09		...	...	
?	6527.0	0.75	0.33	...		...	...
[N II]	6548.1	70.08	30.84	20	109.34	54.12	6
H lpha	6562.8	665.52	291.50	...	613.17	302.30	2
[N II]	6583.4	208.16	90.34	2	320.66	156.80	2
He I	6678.2	7.28	3.05	...	10.11	4.80	...
He II	6683.3	1.01	0.42	...	0.26	0.13	...
[S II]	6716.4	4.27	1.77	...	22.66	10.63	...
[S II]	6730.8	9.93	4.08	...	37.67	17.63	...
He ii	6890.9	1.44	0.56	...	...	...	...
[Ar v]	7005.7	12.22	4.55	15	...	...	...
He I	7065.3	20.34	7.40	10	14.00	5.88	...
[Ar III]	7135.8	63.67	22.54		76.95	32.63	...
[Ar IV]	7170.6	1.55	0.54	30	...	...	...
He II	7177.5	1.19	0.42	50	...	...	...
C II	7230.0	0.52	0.18	5	...	...	...
C u, [Ar IV]	7237.0	2.25	0.77	36	...	...	...
[Ar IV]	7262.8	1.67	0.56	23	...	...	...
He I	7281.4	2.85	0.96	20	2.35	0.92	20
[0 II]	7319.9	51.17	16.94	7	8.28	3.21	18
[0 II]	7330.2	42.57	14.05	13	7.94	3.06	3
[Cl IV]	7530.9	1.76	0.54	...	0.88	0.32	...
He II	7592.7	2.61	0.78	...	0.60	0.21	...
[S I]	7726.5	1.23	0.35	...		...	...
[Ar III]	7751.1	18.84	5.31	...	19.76	6.68	...
He I	7816.2	0.26	0.07	...	...	...	...
[P 11]	7876.0	0.31	0.08	2	...		
[Cl IV]	8046.1	4.74	1.21	5	2.11	0.65	2
?	8196.0	1.33	0.32	11			
He II	8236.8	5.14	1.23	25	1.50	0.47	18
Pa 28	8298.8	0.50	0.12	...	...		

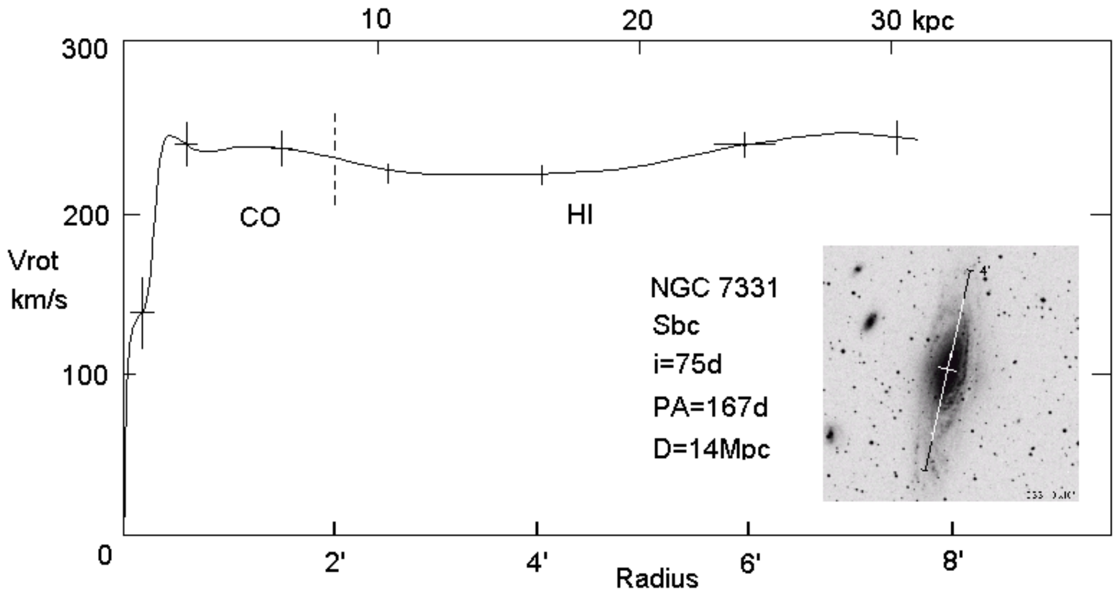
LINE	(A)	NGC 7027 Intensity	NGC 7027 Flux	NGC 7027 ABS.	NGC 7026 Intensity	NGC 7026 Flux	NGC 7026 ABS
Pa 27	8306.1	0.51	0.12	2	...	...	...
Pa 26	8314.3	0.61	0.14	6	...	...	...
Pa 25	8323.4	0.65	0.15	...		...	...
Pa 24	8333.8	0.77	0.18	10	1.26	0.36	15
Pa 23	8345.6	1.01	0.23	...	1.22	0.35	
Pa 22, He I, He II	8360.0	1.13	0.26	6	1.87	0.53	3
Pa 2l	8374.5	1.01	0.23	5	1.46	0.41	3
Pa 20	8392.4	1.13	0.26	...	0.78	0.22	
Pa 19	8413.3	1.21	0.27	...	0.87	0.24	...
Pa l8	8438.0	1.32	0.30	...	1.14	0.32	...
O I	8446.5	0.81	0.18	...	0.66	0.19	...
Pa17	8467.3	1.34	0.30	...	1.47	0.40	...
Pa 16, [Cl III]	8502.5	1.96	0.43	...	1.52	0.42	...
Pa 15	8545.4	2.79	0.61	4	1.88	0.51	...
[Cl 11]	8579.0	1.74	0.38	...	1.03	0.28	...
He I	8582.0	0.61	0.13	...	0.50	0.14	...
Pa 14	8598.4	3.59	0.77	...	2.66	0.71	...
Pa 13	8665.0	4.62	0.97	...	3.32	0.87	...
[C I]	8727.0	1.02	0.21	...	...	...	...
Pa l2	8750.5	4.77	0.98	...	3.80	0.99	...
Pa 11	8862.8	6.64	1.33	...	4.89	1.24	2
Pa 10	9014.9	9.43	1.83	5	7.38	1.82	35
[S 111]	9069.0	126.02	24.20	37	231.69	56.30	25
Pa 9	9229.0	14.46	2.69	10	11.52	2.73	8
[S 111]	9530.9	572.90	100.83	30	506.71	114.52	30
Pa 8	9546.0	21.35	3.76	30	7.70	1.73	30

Reference: Kingdom, J. and Ferland, G.J. ApJ, 1995, 442, 714



This is a graph of the mass of the presumed black hole in the center of the galaxy, in units of solar masses, vs. the velocity dispersion, FWHM, of spectral emission lines in Active Galactic Nuclei - Seyfert galaxies, etc. The qualitative explanation is that the greater the mass the faster things are orbiting around the center. The figure was copied from a short paper by Gebhardt et al. 2000, ApJ, 543, L5. The URL is http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=2000ApJ...543L...5G&db_key=AST&high=3adcdfb02924029. Hint: go to ADS and search under the author's name.

For this particular graph the authors measured the mass by measuring the random motions of stars in the vicinity of the nucleus to get a measure of the mass. They then plotted this kinetic mass as a function of the width of the emission lines. The stellar motion will not be influenced by magnetic feeds, but the gas motion might be.


10
20
30 kpc
300
200
100
0
Vrot
km/s
CO
HI
NGC 7331
Sbc
i=75d
PA=167d
D=14Mpc
4'
2'
4'
6'
8'
Radius


The spiral galaxy NGC 7331
2MASS
2 MICRON ALL-SKY SURVEY
Two Micron All Sky Survey
– Northern Facility –
2MASS Atlas Image
Infrared Processing and Analysis Center & University of Massachusetts