CORRECTING SPECTRAL DATA FROM EXTRAGALACTIC STAR-FORMING REGIONS FOR ATMOSPHERIC DISPERSION

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ABSTRACT

The calculation of star-formation rates for one hundred and forty-eight star-forming regions from sixteen low-redshift galaxies uses thirty-three thousand three hundred spectra from the SuperNova Integral Field Spectrograph (SNIFS) on the University of Hawai‘i’s 2.2-meter telescope on Mauna Kea. This requires the correction of atmospheric dispersion to allow for the required calculations of the light extinction in the regions studied to take place after calculating the Hydrogen alpha and Hydrogen beta line fluxes and the generation of images from these values. Then the star-formation rates can be calculated and comparisons can be made between low and high-redshift objects.

INTRODUCTION

In collaboration with my mentor, I investigated the effect of atmospheric dispersion on data from one hundred and forty-eight regions of star-formation across sixteen nearby galaxies from the SuperNova Integral Field Spectrograph on the University of Hawai‘i’s 2.2-meter telescope. Then the images can be corrected for atmospheric dispersion and the star-formation rate (SFR) of the region can be calculated. To calculate the star-formation rates of these regions involves the calculation of the Hydrogen alpha and Hydrogen beta line fluxes as these are used to calculated the amount of light lost due to dust in the star-forming region. Once the amount of light extinction has been calculated, the true flux of the Hydrogen alpha line can be calculated and then in conjunction with the redshift of the region, the Hydrogen alpha luminosity of the region can be calculated. From this the star-formation rate can be determined using equation two (Kennicutt, 1998) (Eq. 1).

\[
SFR \left( M_\odot \, yr^{-1} \right) = 7.9 \times 10^{-42} \, L(H\alpha) \, (erg \, s^{-1}) = 1.08 \times 10^{-53} \, Q(H^{0}) \, (s^{-1})
\]

Equation 1. The Kennicutt Hydrogen alpha luminosity relation to the local star-formation rate of the star-forming region where \( L(H\alpha) \) is the luminosity of the Hydrogen alpha line.

The atmospheric dispersion must be calculated to determine the star-formation rate as it causes the same spaxel for the red and blue channels to not be spectra of the same region of the sky. This is caused by that fact that the atmosphere refracts incoming light from a star, galaxy, or other celestial object much like a prism. The net effect is that the light is dispersed along a straight-line known as the parallactic angle, the angle between the azimuthal and equatorial coordinate grids at the location of the object (Figure 1). This dispersion causes the data from the telescope to shift depending on the wavelength with images at shorter wavelengths closer to the zenith when compared those with longer wavelengths (Figure 2). This means that the
atmospheric dispersion must be corrected before the calculation of the extinction values can occur. Otherwise the spaxel being calculated will give erroneous extinction values.

Figure 1. Example of how the parallactic angle is measured from North through East. The dashed lines represent the equatorial coordinate grid and the solid lines represent the azimuthal coordinate grid.

Figure 2. Example of how the atmosphere refracts and disperses incoming light. When traced backwards the dispersed data has bluer images closer to zenith compared to red images. Solid black line represents incoming light before interacting with the atmosphere, the dark grey lines represent blue light with the solid being light as it travels and the dashed being how it would look on the sky when traced straight back. This is the same for the light grey lines that represent red light.
METHODS

To calculate the effect of atmospheric dispersion on the data, both the magnitude and direction of the dispersion must be calculated. The magnitude of the atmospheric dispersion is calculated using equations two and three (Szokoly 2005) (Eqs. 2 & 3). The information required for this calculation is the outside temperature in Kelvin, atmospheric pressure in Pascals, both wavelengths that are being used (in this case Hydrogen alpha (0.6563 μm) and Hydrogen beta (0.4861 μm)), the reciprocal of the wavelengths (σ), and the angle at which the object is from zenith.

\[
10^8(n_{as} - 1) = \frac{5792105 \mu m^{-2}}{238.0185 \mu m^{-2} - \sigma^2} + \frac{167917 \mu m^{-2}}{57.362 \mu m^{-2} - \sigma^2}
\]

Equation 2. Szokoly 2005 relation for calculating the index of refraction \(n_{as}\) for a given wavelength, where \(\sigma\) denotes the reciprocal of the wavelength being studied.

\[
\Delta R(\lambda) \approx (n_{as}(\lambda) - n_{as}(\lambda_0)) \tan(z_a)
\]

Equation 3. Szokoly 2005 relation for calculating the magnitude of atmospheric dispersion for a given wavelength compared to another wavelength. This requires using equation two to calculate both indices of refraction, knowing the atmospheric temperature in Kelvin and pressure in Pascals at the time of observation, the zenith angle, and the standard values for both the temperature and pressure at sea level.

The calculation of the magnitude of the atmospheric dispersion requires knowledge of both the local atmospheric temperature and pressure. While the temperature is recorded in the data, the pressure is not. To solve this problem, thirteen years of pressure data from the nearby Canada-France-Hawai'i Telescope were averaged to create a value that would be used in for these calculations.

The calculation of the direction of the atmospheric dispersion involves calculating the parallactic angle of the object using equation nine (Filippenko 1982) (Eq. 4). This formula requires the hour angle (h) and zenith angle (z) of the object in addition to the latitude of the observatory (\(\phi\)). All of this information was recorded and included in the data files at the time of observation.

\[
\frac{\sin(\eta)}{\sin(\frac{\pi}{2} - \phi)} = \frac{\sin(h)}{\sin(z)}
\]

Equation 4. Filippenko 1982 relation for calculating the parallactic angle (\(\eta\)) of an object based on the hour angle (h) and zenith angle (z) of the object and the latitude at which the observation to place (\(\phi\)) with all angle in radians.

Once the parallactic angle of the object and the magnitude of atmospheric dispersion have been calculated, the values for the fluxes of each spaxel are calculated using the Pyraf
routine splot to calculate the local continuum level around the Hydrogen alpha and Hydrogen beta lines thus allowing for the calculation of the line fluxes and the generation of new images from these fluxes. Once these new images have been created the Hydrogen beta image is shifted by the amount calculated in the direction of the parallactic angle and new values are generated using a fast Fourier transform to accommodate for the sub-spaxel shift amounts. Finally, to determine if the shift was successfully calculated, the point spread function of the Hydrogen alpha, Hydrogen beta, and shifted Hydrogen beta images is calculated and visually inspected.

**DATA AND RESULTS**

Using thirteen years of weather data from the Canada-France-Hawai‘i Telescope, an average for the atmospheric pressure near to the University of Hawai‘i’s 2.2-meter telescope was calculated to be $\sim 61583$ Pa for use in the calculation of the amount of atmospheric dispersion for the data in addition to the values for standard temperature and pressure at sea level 288.15 K and 101325 Pa. This allowed for the calculation and shift of the original images but it was determined after calculating their point spread functions that the shift caused the image to become more offset than it was originally (Figure 3). This lead to using the calculated fluxes from a previously compiled database where it was determined that the fluxes needed to be recalculated as the Hydrogen beta fluxes were in some cases orders of magnitude higher than the Hydrogen alpha fluxes.

![Figure 3. Point spread function of one column of an image of the center of NGC 6946 showing that the peak of the shifted Hydrogen beta image is more offset from the Hydrogen alpha peak than the initial Hydrogen beta image.](image-url)
When the fluxes where recalculated it was found that the fluxes were now in accordance with the requirement that the Hydrogen beta line be at least 2.8 times less then the Hydrogen alpha line allowing for the generation of new flux based images.

**DISCUSSION AND FUTURE RESEARCH**

The recalculated Hydrogen beta fluxes lead to a large number of non-detections of the Hydrogen beta line notably reducing the number of usable values for the fluxes to be used in the shifting procedure (Figure 4). This leads to additional difficulty in determining whether or not the shift that is undertaken allows for the determination of new valid flux values as well as determining if the shift is successful or not.

Figure 4. Hydrogen beta flux image created from the calculated fluxes. All white squares represent non-detections of the hydrogen beta line whereas the black squares represent actual flux values on the order of $10^{-16} - 10^{-17}$ ergs except for the top left, top right, and the two adjoining pixels to the top right pixel that are bad pixels on the detector and thus read as zero.

These new flux based images will be used to try and determine the source of the large offsets seen in the shifted images. Once the cause is determined, fluxes can be generated for the shifted image that can be used to determine the extinction values for each spaxel. This will allow for the calculation of the star-formation rate for the region.
CONCLUSION

Despite setbacks due to the as yet undetermined cause of why the original image shifts appear to move the image too far as well as problems with flux values, new flux based images have been created for future use in the correction of the atmospheric dispersion in the data from which star-formation rates for the studied regions will be determined. This in conjunction with star-formation rate at higher redshifts comparisons can be made between these nearby galaxies and those much farther away and will allow for the creation of a timeline of galactic evolution from the early universe to now.

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REFERENCES

