Yale Observing Proposal *Standard proposal* **Semester:** *2014B*
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Low Surface Brightness Observations of Galaxy Disk Truncation with Different Obliquities

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:

Many disks of spiral galaxies have a truncated edge that form the periphery of the galaxy. This common phenomenon is not well understood, and various theories exist to explain the origins of truncation. Prior observations of the edge-on galaxies NGC 4565 and 5907 have found strong presence of truncation within their galactic disks, making each galaxy a prime candidate for further study. In addition to NGC 4565 and 5907, we propose to study M64, a face-on galaxy which will give us the opportunity to obtain information about disk truncation in two spatial axes rather than one! We propose to do this study in the Dragonfly Telescope because of its abilities to take deep, low surface brightness images. A better understanding of disk truncation will lead to more insight into galaxy formation and dynamics.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Min. Nights	Moon	Optimal months	Accept. months
1	Dragonfly	G, R	1	1	dark/grey	April-May	
2							
3							
4							
5							

Scheduling constraints and non-usable dates *(up to four lines).*

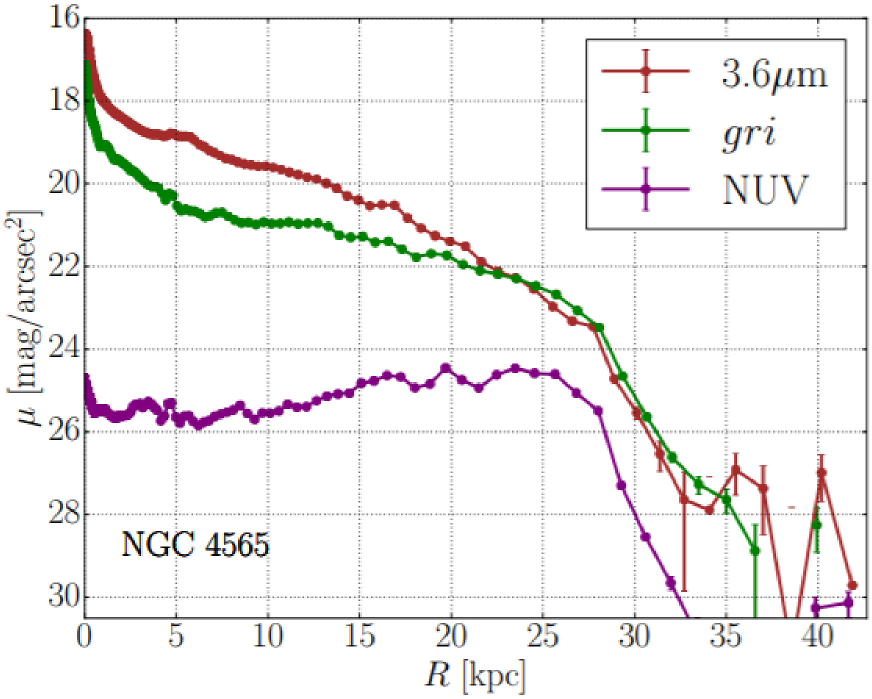
Scientific Justification *Be sure to include overall significance to astronomy. Limit text to one page with figures, captions and references on no more than two additional pages.*

Background: How does a galaxy end? This question is at the low surface brightness frontier of current astrophysical studies, and the answer will shed light on the formation and behavior of galaxies. The outskirts of galaxies have diverse, and often not much studied, structure. This proposal aims to study one particular kind of galaxy "edge," known as the truncation of the galactic disk. This is found in many disks of spiral galaxies, and which has been suggested to occur in 3 out of 4 galaxy disks (van der Kruit and Freeman 2011).

Why truncation? The exact origin of disk truncation is currently unknown. Some theories suggest that it forms when the density of gas (which collisionally settles to the galactic plane) falls below the critical value required to form stars (Kennicutt 1989). Other authors believe truncation reflects the location of stars that carried the largest angular momentum at the moment of collapse of the protogalaxy (van der Kruit 1987). However, more recent studies have shown that galaxy truncation occurs at the same galactic radius for all ages of stars (de Jong et al. 2007). This stellar density drop off is independent of height above the disk, but is sharpest in the galactic midplane. This suggests that the truncation effect is unlikely to be caused by a star formation threshold alone, as the threshold would have to maintain the same relative radius over a large period of cosmic time. This is unlikely when we consider the addition or removal of star forming material from the outskirts of the galactic disk. These findings suggest a dynamical approach to explain the relatively constant truncation radius over a galaxys lifespan, either through angular momentum redistribution by galactic density waves, or by the heating or stripping of stars by bombardment of dark matter subhalos (de Jong et al. 2007).

The proposal: We select three galaxies in order to characterize truncation at lower surface brightness levels than has been done before. The Needle Galaxy, NGC 4565, and the Splinter Galaxy, NGC 5907, are excellent candidates for studying galactic truncation for two main reasons: They are very large, covering an angular scale of more than $\sim$12 arcmin; and they are some of the most nearby edge-on spiral galaxies, with steep vertical inclines larger than 85 deg. As a result, NGC 4565 and 5907 are not only sufficiently visible, but also possess enough spatial resolution to derive radial and vertical surface brightness profiles. NGC 4564 and 5907 were the first galaxies in which truncation in the galactic disk was observed (van der Kruit 1979; van der Kruit and Searle 1981a,b). More recent observations (see figures) have confirmed traces of truncation in their galactic disks with better precision, and have allowed astronomers to place an upper limit to the present-day growth rate of galactic disks for the first time (Martnez-Lombilla et. al. 2018). The Black Eye Galaxy, M64, is not as obvious as a candidate for truncation. It is also large and bright, but it does not belong to the category of edge-on spiral galaxies, given its inclination of 63^o. This provides a unique comparison: most truncation studies have been limited to edge-on galaxies. Observing the profile of M64 will allow us to acquire information in two spatial dimensions, rather than the combined light seen in edge-on galaxies. The Dragonfly telescope will allow us to image at sufficiently low brightness to see the dim edge of the disk.

The instrument: Dragonfly is an excellent telescope for this study, because of its ability to reach very low surface brightness levels (Abraham, van Dokkum 2014). Recent studies with Dragonfly have reached to $\sim$ 32-34 mag arcsec^{-2}, and have already proved a valuable comparison in the case of stellar halos (Merrit et al., 2016). See figure below for examples of proposed analysis.



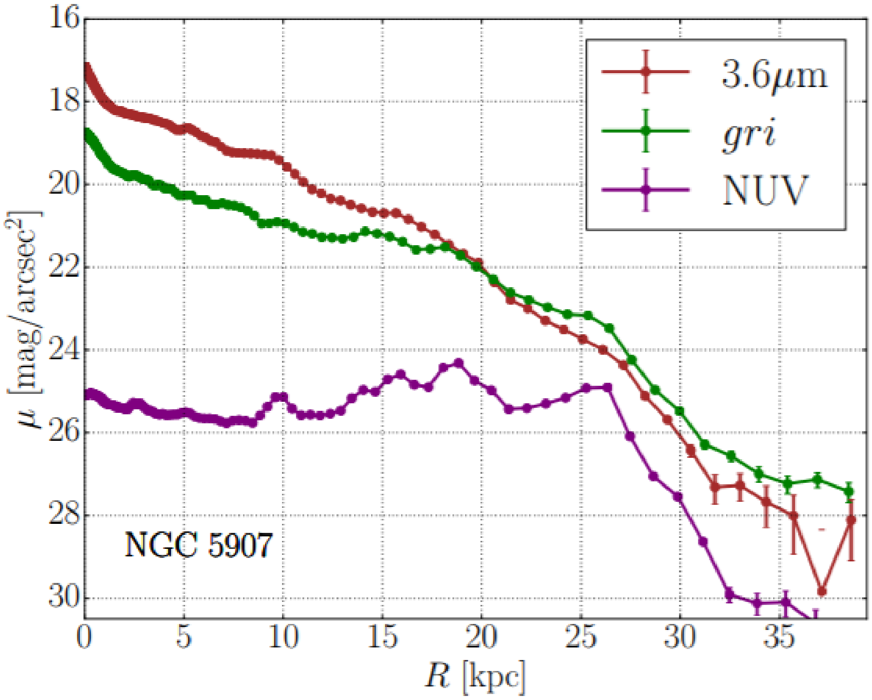


Figure 1: Profiles of NGC 4565 and NGC 5907 from Martinez-Lombilla et. al. 2018

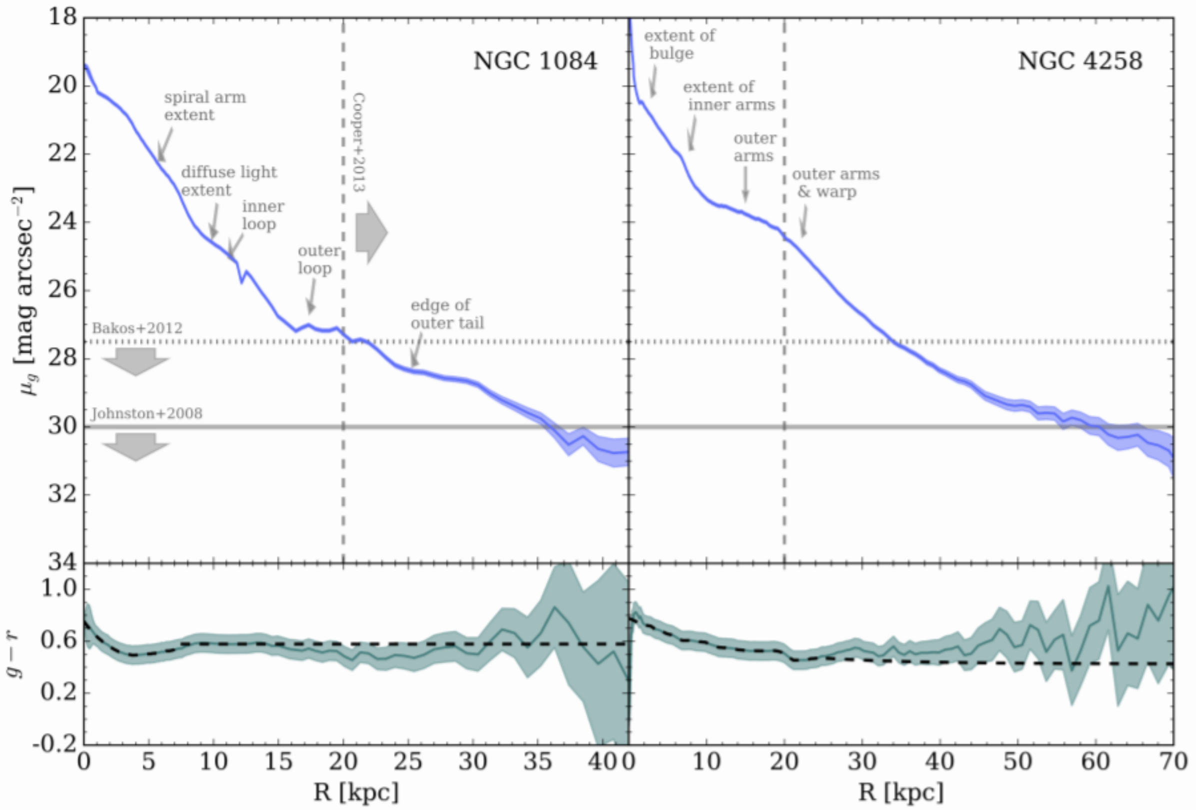


Figure 2: Past data from Merritt et al., 2016, similar to what is proposed here.

Impact to Yale Astronomy *Describe how this program fits into the Yale astronomy program. Will the data analysis and resulting papers be based at Yale? If the project is led by a faculty member, does the project involve students? What is the role of the PI viz-a-viz other non-Yale co-Is. Are the resources in place to analyze the data and come to a timely publication? (limit text to one page)*

This work builds on previous Dragonfly work at Yale, including the Dragonfly Nearby Galaxy Survey as part of Allison Merritts thesis, and follow-up Hubble Space Telescope program (PI: van Dokkum). The analysis will be led by Arina Bykadorova, Dominic Eggerman, Nathaniel Kerman, and Osase Omoruyi, who are Yale College students.

Previous Use of Yale Facilities and Publications *Please list previous use of Yale observing facilities and any publications resulting from these data in the past 3 years. If this is a long term project, please state this here and describe the overall strategy of the project.*

N.A.

Observing Run Details for Run :

Technical Description *Describe the observations to be made during the requested observing run. Justify the specific telescopes, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section.*

Instrument Setup We will make simultaneous use of all 48 lenses in the Dragonfly Array located at the New Mexico Skies facility. All of these 400mm f/2.8 refractors will be imaging using cooled CCDs. 24 will image through SDSS-G filters. The other 24 will image through SDSS-R filters (Doi et al., 2010). They will both integrate for equal amounts of time, on the order of 1,000 seconds.

Integration time and strategy We aim to get an SNR of 7 at a surface brightness of 27 mag arcsec^{-2}. In order to calculate SNR as a function of integration time, we used the exposure calculator for the La Silla Wide Field Imager telescope (ESO). This calculator assumes the following: f-number of f/8, a Quantum Efficiency of 92%, binning of 1x1, a lunar illumination of 50%, and an airmass of 1.3; whereas for our observation, we have observe at f/2.8 (+3 stops), and a Quantum Efficiency of 50% (-0.9 stops). An additional factor of 1/24 enters the time conversion from the WFI calculator to Dragonfly exposure time because of the 24 linearly added telescope-detector pairs. Therefore, the conversion factor is found to be $T_{dragonfly} = [[T_{(WFI,V-Band)}+T_{(WFI,R-Band)}]/2]$ x 2.34E-3. Because the WFI calculator has Johnson-Cousins filters rather than Dragonflys SDSS, we convert using an average of the two nearest filters in wavelength space: V and R. For an SNR of 6.9, we decide on a total integration time of 120 minutes subdivided into 10 minute exposures. Assuming a read time of 10 seconds/exposure, and a slew time of 120 seconds/source, we need a total of 368 minutes. This is just over 6 hours, and fully encompassed by a single night in late April.The observation order was chosen to maximize altitude and minimize airmass for each source. To that end, we will observe first NGC 4565 starting at 21:30 local (New Mexico) time, then M64 at 23:45, then NGC 5907 at 2:00.

Table: Integration time needed to achieve a given Signal to Noise Ratio (SNR)

S/N	WFI V (s)	WFI R (s)	Dragonfly (avg, s)	Dragonfly (avg, min)
1	7.80E+04	6.80E+04	170.82	2.847
3	7.25E+05	6.20E+05	1573.65	26.2275
5	2.00E+06	1.70E+06	4329	72.15
7	4.00E+06	3.30E+06	8541	142.35
10	8.00E+06	6.90E+06	17433	290.55

R.A. range of principal targets (hours): 12.5 to 15.2

Dec. range of principal targets (degrees): +21 to +56

Instrument Configuration

Filters: SDSS Scheme - G, R	Slit: NA	Fiber cable: NA
Grating/grism: NA	Multislit: NA	Corrector: NA
Order: 1	λ_{start}: NA	Collimator: NA
Cross disperser: NA	λ_{end}: NA	Atmos. disp. corr.: NA

Yale observing proposal LaTeX macros v1.0.