Finding LSB Galaxies in SDSS

Low Surface Brightness Galaxies in the Sloan Digital Sky Survey. I. Search Method and Test Sample
Kniazev et al. AJ 127 2004

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March 31, 2010
Low Surface Brightness (LSB) Galaxies

- Variety of forms: dwarf ellipticals, spirals, irregulars, etc
- Low central surface brightness
  - $\mu_0(B) \geq 23\text{(ish)} \text{mag arcsec}^{-2}$
- Of astronomical interest across many topics
- Population poorly characterized even locally
  - Intrinsically difficult to detect
Two Questions

1. Does the SDSS pipeline effectively identify LSB galaxies?

2. If not, how can we do better?
Test Sample

- Subsample from Impey et al 1996 catalog
  - Photographic plate survey
  - Selected 92 galaxies of varying types (dE, dEn, spirals, Im, dIrr)
  - and brightnesses: $26.4 \geq \mu_0(B) \geq 18.2$
  - Sample lies in 93 SDSS fields (some of the galaxies lie near edge of fields and were covered twice)
Does the SDSS Pipeline Effectively Identify LSBs?

- Did query recover much of the sample?
  - No.
- Standard SDSS procedures tend to split extended sources into many sources. Especially sources with knots (from HII)
  - “Galaxy Shredding”
- Many dim sources missed, up to 30% of sample
- Lowering detection threshold leads to many false positives
- Can’t make use of photometric catalog
Try to do better

Gigi sez:
“Lemme giv dis astromonee a shot…”
Analyzing LSBs

- Need to work with SDSS images and use own algorithms
- 8 step procedure to identify and analyze LSBs
Step 1

- Alignment and combination
- Need to combine g, r, i, images to enhance S/N
- Three images aligned using 100 brightest unsaturated stars from SDSS photometric catalog
- Images averaged with weighting based on S/N

\[ w_k = \frac{S_k \sigma_g^2}{S_g \sigma_k^2} \]
Step 2

- Filtering combined image

- Need to decrease background noise to detect galaxies with low central surface brightness
  - Without filtering, 90% of sources with $\mu_{\text{eff}}(r^*) \geq 24$ mag arcsec$^2$ undetected

- Filtering criteria: want to detect most of test sample, minimize false detections, and be computationally simple enough to do ~7000 fields in ~1 month

- Settled on two step filtration with windows of 27 pixels (10.5")
  - Smooth-and-clip (SAC)
  - Median-smoothing in circular aperture

(Shergin, Kniazev, Lipovetsky, ArXiv, 1996)
Step 3

- Object detection

- Search for objects above $3\sigma$ noise level with at least 2900 connected pixels ($R \sim 12''$)
  - Compare potential detections with SDSS’s list of 50 brightest stars
  - If positions match, it’s a star (save its location for a mask)
  - If not, save it as a detection*

- This is done on both the smoothed image from step 2 and the unsmoothed image from step 1 (though the unsmoothed image mostly reveal stars and HSB galaxies)

- Objects within 40 pixels (16") of frame edge are rejected as ghosts

*It still may be a very bright star which the SDSS pipeline misclassified as a galaxy
Step 4

- Integrated Photometry
- Extract subimages from ugriz images around objects
  - Subimages are 1.5 x as big as object masks for background determination.
- All stars from photometric catalog subtracted
- Previously unrecognized background galaxies and foreground stars can be masked out by hand
- AIP sky background code used to determine and subtract sky background

![Images showing subimages and background subtraction process]
Step 5

- Creation of surface brightness profiles
- Measured magnitudes in circular apertures with 1” step sizes
- Determined some parameters:
  - $R_{\text{eff}}$ radius containing half the flux
  - $\mu_{\text{eff}}$ mean SB inside $R_{\text{eff}}$
- Also found major axis PA and axis ratio
Step 6

- Rejection of false detections
  - Bright stars SDSS identified as galaxies
  - Ghosts
  - Extended halos around bright stars
  - Satellite tracks

- Automatically rejected based on very unusual colors or very bright $\mu_{\text{eff}}$
  - Inspection by eye shows 80% of false detections caught

- Further by-eye inspection needed
Step 7

- Fitting surface brightness profiles
  - Interactive fit
    - Two components (disk + bulge)
    - Each component fit with a Sersic profile
      \[ \mu(R) = \mu_0 + 1.086 \left( \frac{R}{\alpha} \right)^n \]
    - With n=1 (exponential)
    - OR
      - free n parameter but only a single component
Step 8

- Total Magnitudes
- After step 4 we can already integrate to find magnitude, but this just accounts for the flux above our limiting threshold.
- Number of ways to deal with this see “Intro to Photometry” Feb. 17

\[
\frac{F_{\text{lim}}}{F_{\text{tot}}} = 1 - (1 + N_\alpha) e^{-N_\alpha}
\]

\[
N_\alpha = \frac{\mu_{\text{lim}} - \mu_0 - 10 \log(1 + z) - k(z)}{1.086}
\]

If \( n=1 \) (exponential fit)  
\[
m_{\text{tot}}^{\text{Sersic}} = m_{\text{tot}}^d - 2.5 \log \left[ \frac{1}{n} \Gamma \left( \frac{2}{n} \right) \right]
\]

If \( n\neq1 \) (Sersic fit)
Detection Results

- 141 objects detected after rejecting false detections
- After removing non-LSB objects and double detections (on adjacent fields) 129 unique objects remain.
- 87/92 sample objects detected
- Out of the missing 5 galaxies, follow up observation has revealed nothing in the location of the 2 dimmest (IE they are probably photographic artifacts.)
- The other 3 missing sources were missed due to nearby bright stars or galaxies
- Real detection rate: 87/90 (96.5%)
- Additional 42 objects detected
- Yes, LSB detection seems to work
Detection Results

- Estimated limiting surface brightness isophotes:
  - $\mu_{\text{lim}}(g^*)=26.5$ mag arcsec$^{-2}$
  - $\mu_{\text{lim}}(r^*)=26.2$
  - $\mu_{\text{lim}}(i)=25.9$

- $\Rightarrow \mu_{\text{lim}}(B) \sim 26.9$
- About a magnitude deeper than sample survey
Photometric Results

- Weighted RMS $\Delta B(\text{our-NED}) = 0.25$
- Four extreme sources probably due to incomplete foreground subtraction in NED
  - Without them, $\Delta B(\text{our-NED}) = 0.18$
Conclusions

- The SDSS pipeline is not suited to finding LSB galaxies
- The quality of SDSS images is suited to finding LSB galaxies
- The authors outline their procedure for identifying and analyzing LSB objects
  - Requires AIPs and some by-eye analysis
    - Procedures described in detail, but no downloadable code/software
  - Successfully identified ~96.5% of initial sample and found 42 additional objects
- Capable of excellent photometry
Interesting Finds
(epilog)

- SDSS J140831-00073
- Stepped Disk
- SBP fit with two exponentials (IE two disk components)
- Inner spiral seen along with newly discovered faint outer spiral with distinct spiral arms
Interesting Finds (epilog)

- Morphological type, concentration index correlation
- $R_{90}$ radius containing 90% of flux
- $C = R_{90}/R_{\text{eff}}$

![Graph showing the relation between color index $(g^*-i^*)$ and concentration index $C(r^*)$. Open squares denote E galaxies. Asterisks denote early-type galaxies (S0–Sa). Crosses indicate galaxies of "intermediate"-type (Sab–Sc). Open circles stand for late-type galaxies (Sd–lrr and dl). Filled lozenges denote dEs. Filled triangles denote interacting galaxies. The values of the concentration index for classical de Vaucouleurs profiles (5.5) and for pure exponential disks (2.3) are shown by dashed lines.](image)
Interesting Finds (epilog)

- Giant spiral LSB galaxies
- Big, dim, diffuse, clear spiral structure, rare (16 known)