DISTANCE MEASUREMENT VIA SURFACE BRIGHTNESS FLUCTUATIONS
Baade-Wesselink 50 kpc

Andromeda 750 kpc
Legend: The image shows 2MASS galaxies color coded by the 2MRS redshift (Huchra et al. 2011); familiar galaxy clusters/superclusters are labeled (numbers in parentheses represent redshift). Graphic created by T. Jarrett (IPAC/Caltech).
BASIC IDEA
FUZZINESS AS A DISTANCE INDICATOR

Smoother galaxy (less “mottling”)

Greater distance

Contributing stars: giants.
Need to know stellar luminosity function (stellar population, metallicity, etc.)

M32 image: Tonry & Schneider (1988)
Background image: Shane & Wirtanen (1954)
BASIC IDEA
FUZZINESS AS A DISTANCE INDICATOR

\[ N_\star \]

depends on distance!
not observable :(

\[ N_\star + \Delta_\star(N_\star) \]

depends on distance!
yes observable :)\n
\[ \sqrt{\text{var}(\Delta_\star)} \propto 1/d \]

Contributing stars: giant stars.
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(stellar population, metallicity, etc.)

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**BASIC IDEA**

**THE PROCEDURE**

- Subtract model
- Get residuals
- Take power spectrum

\[
\sqrt{\text{var}\left(\Delta \hat{f}\right)} \propto 1/d
\]

Stronger fluctuations = closer! 

Far left M89 image: adapted from SDSS
BASIC IDEA

THE ACTUAL PROCEDURE

Images adapted from Cantiello et al. (2018)

original image

image minus galaxy model

image minus everything

power spectrum (and fit)

Luminosity function fit (to identify other sources)

Images adapted from Cantiello et al. (2018)
BIGGEST PITFALLS

Extra junk on galaxy (foreground/background objects)

Shot noise

Detector varying

IDEAL CASE:
100% of residuals are due to $N_*$ fluctuations

M87: J.-C. Cuillandre (CFHT)

Misty Bentz (ASTR6100 L10)
WHAT IT’S GOOD FOR

- Best precision:
  - Good seeing
  - High S/N
  - Low photometric noise

- Early-type galaxies or clean parts of spirals (no star formation)
- Don’t need to resolve individual sources!
- Relies on phenomenon that is present in all galaxies (unlike SN Ia or H₂O masers)
- Uses stellar population observables to calibrate it

- not empirical scaling law nor assumed universal luminosity function

1988 limit: ~20 Mpc with 20% precision
2018 limit: ~40 Mpc with 5% precision
3-D structure of galaxy clusters: Virgo (nearest)
See Mei et al. (2007)
- 84 early-type galaxies
- 5 in W’ cloud, 79 at $d = 16.5 \pm 0.1 \pm 1.1$ Mpc

Next Generation Virgo Cluster Survey (NGVCS)
Cantiello et al. (2018)
- 89 galaxies brighter than $B_T \approx 13.0$ mag
- SBF distances compared to literature
- Calibrating SBF relations w.r.t. color

Next step: fainter and bluer galaxies!

"Great Attractor"?
Getting $H_0$ as accurately, precisely as possible:

- $H_0$ = expansion rate today (≠ 13 billion years ago!)
  
  Depends on geometry, composition, etc.

- Strategy: Sample velocities from regimes when universe was youngest (fewest big structures influencing motion)

  - Get distances and velocities for furthest galaxies
  
  Use these to calculate $H_0$

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1929 - 1999: $H_0$ values ~50 km/s/Mpc - 100 km/s/Mpc

- HST Key Project: $H_0$ to better than 10%

- Blakeslee et al. (2002) SBF survey of 170 galaxies gets $H_0 = 73 \pm 4 \pm 11$ km/s/Mpc

- Inhomogeneous Malmquist bias:
  
  Obs errors keep galaxies out of high-density regions

  Sol’n: Correct statistically (with math)

- Poor quality distances too low (seeing × CMB frame velocity)

  Sol’n: Exclude galaxies (weakens statistics?)

- Different values for $H_0$ depending on calibrator:

  Cepheids vs. IRAS density field

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Next step: Space-based observations!
SUMMARY

SMOOTHER = FURTHER AWAY

WORKS BEST FOR SIMPLE GALAXIES

GETS DISTANCES FAR ENOUGH FOR CLUSTER STRUCTURES
SELECTED REFERENCES
IN CASE YOU WANT TO KNOW EVEN MORE

• Shane & Wirtanen 1954, AJ, 59, 285:
(Fig 2 = these slides’ background image) Isodensity contours from nebula counting suggest that clusters group into superclusters.

★ Tonry & Schneider 1988, AJ, 96, 807:
Seminal paper describing the principle and process of using SBFs as a distance indicator. This paper is really well written and friendly — if you read only one paper on SBF, this is it! ★★★

• Freedman & Madore 2010, ARA&A, 48, 673:
Review discussing measurements of the Hubble constant, including measurements made via SBF distances in context of other distance ladder methods.

Calibration of SBF distances in Virgo. Their introduction provides a great modern overview of the SBF method.

Comparison of Fundamental Plane and SBF methods.