HIERARCHICAL MODELING OF THE RESOLVE SURVEY

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with input from Katie Eckert, David Stenning, Amanda Moffett, Andreas Berlind, Victor Calderon, and other helpful people in Working Groups 1&4
Galaxy groups/clusters share dark matter “halos” in the cosmic web

- galaxy mergers lag halo mergers
- some halos still merging
- some “groups” of one
- physics of galaxy growth (e.g. star formation and black hole growth) tied to physics of dark matter halo growth – *how much?*
REsolved Spectroscopy Of a Local VolumE

http://resolve.astro.unc.edu

- volume-limited, unusually complete census of dynamical, stellar, and gas mass, plus star formation and merging, from dwarf galaxy to cluster scales
- >50,000 cubic Mpc
- >1500 galaxies
- stellar+gas mass limit \( \sim 10^9 \, M_{\odot} \)
- 1” = 0.3-0.5 kpc
- volume-limited design enables robust group finding
- perfect for hierarchical Bayesian modeling (HBM)
Cosmic Variance and Completeness

**ECO:** “Environmental COntext catalog” (~10x larger, stellar mass and group metrics match RESOLVE; Moffett+ 2015)
Contains RESOLVE-A; enables calibration of cosmic variance.
More complete than SDSS.

**RESOLVE-B:**
Stripe 82: extra deep; hyper-complete – cz campaign for galaxies lost by SDSS (dwarfs, pairs, shredded spirals)
Empirical completeness corrections larger than predicted by Blanton+ 2005 (Eckert+ 2016).
TWO PROJECTS

(NOTE IN ASTRO JARGON: “FUNCTION” = FREQUENCY DISTRIBUTION)

1. HBM of the ECO group velocity dispersion function (demo using mock ECO built on a dark matter simulation)

   observable: \( \sigma_{\text{gal}} \) = “dispersion” in projected galaxy orbital velocities; proxy for \( \sigma_{\text{true}} \) = metric of halo mass if halo is virialized (meaning \( M \leftrightarrow \sigma \))

2. HBM of RESOLVE galaxy stellar mass function and star formation history distribution (model grid design/interpolation challenge)

   observables: spectra or filter fluxes; indicative of \( M_\star \) and SFH (+metallicity, dust)

Popescu et al. 2011
1. HBM of the ECO group velocity dispersion function (demo using mock ECO built on a dark matter simulation)

Restrict mock ECO to groups with N≥3

Q: Can HBM improve $\sigma_{gal}$ accuracy?

Step 1: Semi realistic

- central galaxy not ID’d, but biases $\sigma$ low with true velocity zero
- 3D information is lost because velocities are only along line-of-sight
- groups need not be virialized, so even well-measured $\sigma_{gal}$ may exceed value expected from halo mass $\sigma_{true}$
- low-mass groups have lower N

Step 2: Fully realistic

- add friends-of-friends group finding

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(DEMO USING MOCK ECO BUILT ON A DARK MATTER SIMULATION)

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**Step 2: Fully realistic**
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**Step 1 compared to:**
- **Gapper** – traditional robust metric akin to standard deviation around mean velocity
- **Halo Abundance Matching (HAM)** – monotonic mapping from “observed” cumulative group \( X \) function to theoretical cumulative halo mass function at equal space density, plus \( M_{HAM} \leftrightarrow \sigma_{HAM} \) (assume virialized)
- **Simple Bayesian** – separate fit to each group’s distribution of velocities using Student’s \( t \), \( \nu=8 \)
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HAM

\[ X = \text{tracer of collapsed mass (} M_\star, M_{\text{gas}}, \text{light)} \]

but expect diversity in ratio of hot group gas to collapsed mass \( \rightarrow \) not monotonic

\( \Rightarrow \) by design, \( \sigma_{\text{HAM}} \) matches theoretical \( \sigma_{\text{true}} \) better than \( \sigma_{\text{gal}} \) does for overall distribution, but only \( \sigma_{\text{gal}} \) can probe real diversity

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RESULTS

• HBM seems to work – see shrinkage at low $\sigma$ (low mass $\Leftrightarrow$ low $N$ $\Leftrightarrow$ broadest posteriors)

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HBM OF RESOLVE STELLAR MASSES AND SFHs
(MODEL GRID DESIGN/INTERPOLATION CHALLENGE)

Problem: severe degeneracies (e.g. age-metallicity-dust reddening)

Q: Can HBM achieve consistent results within/across galaxies?

0: create/interpolate model grid

1: within galaxies
   • model annuli as if distinct galaxies
   • add HBM to enforce consistency
   • test on fake data with noise

2: across galaxy population
   • complete subsets within groups, all groups of same mass, etc.
   • full survey subject to universal SFH

3: nested HBM within & across galaxies
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RESULTS (step 0)

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- singular value decomposition on grid of model UV-NIR filter fluxes ⇒ too few SVD components!
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NEXT STEPS
• remove reddening from grid?
• or add more information (optical spectra, ISM model)?
• Gaussian Process model interpol’n
• test simple Bayesian MCMC vs. brute force integration

Model parameters (free or in grid sims):
1. total stellar mass formed in both young & old components combined $M$
2. fraction of mass in the younger component $f_y$
3. reddening of each component (free/grid)
4. metallicity of each component, 6 options
5. SFH parameters (when and for how long star formation occurred) – real # values
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   status: paper demonstrating HBM and applying to ECO expected this summer

2. HBM of RESOLVE galaxy stellar mass function and star formation history distribution (model grid design/interpolation challenge)
   status: model grid completion and simple Bayesian test expected this summer