WHAT CAN THE OCCULT DO FOR YOU?

DUST EXTINCTION MEASURED IN OVERLAPPING GALAXY PAIRS.

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B.W. Holwerda, ESA IDSW, 21-11-2013
MOTIVATION

• Interstellar dust reprocesses 30-50% of the stellar light from a spiral galaxy.

• Spectral Energy Distribution models of spiral galaxies need to know dust geometry.

• Distance measurements (Tully-Fisher, SNIa) need a prior assumption about dust in the host spirals.

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OCCULTING GALAXY TECHNIQUE

Background Galaxy

Foreground Galaxy

$F'$

$F + Be^{-\tau}$

$B'$

$e^{-\tau'} = \_\_\_\_\_\_\_\_\_\_\_\_\_ -$

Keel & White

1993

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REAL PAIRS

• Real pairs all types of galaxies

• Galaxy asymmetry remains a problem.

• Only a few pairs known and in literature by 2001.

Domingue et al 1999,2000
White et al. 2000
Keel et al. 2001a,b
Elmegreen et al 2000
FIRST RESULTS

These were all the occulting pairs known 10 years ago. How to get more?

- There is dust extinction up to $R_{25}$


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ONE MAN’S TRASH...

• Occulting (overlapping) pairs are interlopers in:
  • Strong lensing surveys.
  • Weak lensing surveys.
  • Group catalogs.
  • Redshift surveys.

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GALAXY PAIRS IN SLOAN

- SDSS spectra.

- Gravitational lenses; late-type spectra (lens) with high-redshift emission lines (lensed spiral).

- Rejects: Late-type spectra with emission lines at lower redshifts.

Holwerda et al., 2007c AJ, 134, 2385, astro-ph/0708.1119

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MUCH BETTER TO CROWDSOURCE IDENTIFICATION
Galaxy zoo project: Chris Lintott, Anze Slosar, Alex Szlalay, Daniel Thomas, Kevin Schawinski, Kate Land, Bob Nichol, Bill Keel and a cast of many thousands
GALAXYZOO SAMPLE

• Mostly nearby pairs (z<0.1)
• All types of galaxies, many spiral-spiral pairs
• Foreground disks at any inclination
• WIYN, KPNO and WHT follow-up: redshifts!
• GALEX UV (spiral-spiral)
• HST follow-up.

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OCCULTING PAIR WITH HST

\[ z = 0.06 \]

2MASX J00482185-2507365
HST ACS/WFC

ACS Nearby Galaxy Survey Treasury
Holwerda et al., 2009, AJ, 137, 3000
EXTINCTION MAPS

- Extinction in three filters measured independently
- HST pro: high photometric stability and resolution

Holwerda et al., 2009, AJ, 137, 3000
DISTRIBUTION OF OPTICAL DEPTH

- Optical depth distribution in overlap region.
- Exponential distribution with scales of 0.3, 0.15 and 0.1 mag.
- SN Ia prior? SED model constraint?

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EXTINCTION LAW

- Three filters allow two separate estimates of extinction law.
- Much spread due to structure in both galaxies.
- Mean $A_x/A_y$ values very close to the Milky Way value.

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IFU OBSERVATIONS

• Reap the benefit of both spatial and spectroscopic information.

• Match fibers to construct maps of extinction and slope of the extinction curve.

• Drawback: typical spatial sampling is greater than a Giant Molecular Cloud in the foreground galaxy.
HST PAIR

VIMOS R=720

Holwerda et al., 2013a, MNRAS, 433, 47

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EXTINCTION CURVE

Holwerda et al., 2013a, MNRAS, 433, 47
R_v AND A_v MAPS

Holwerda et al., 2013a, MNRAS, 433, 47
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UGC3995

- Another occulting pair with HST data
- Known interaction though
- Part of the CALIFA DR1

Holwerda et al., 2013b, A&A,
$A_V$ VALUES

- Low extinction values relatively under-represented.
- Interaction causing asymmetry?
- Or shocking dust into opaque structures.

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IFU $A_V$ AND $R_V$ MAPS

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UV-OPTICAL EXTINCTION LAW

Fig. 1.— Montage of NGC 2207/IC 2163 as seen in ugriz and XMM-OM UV bands. Some bright stars have been patched by interpolation in the optical images. The display uses no set logarithmic intensity mapping, similar to the sinh mapping recommended by Lupton et al. (2004), to retain detail over a wide dynamic range. The area shown spans 254 × 110 arcseconds, with north at the top.

Fig. 15.— Comparison of our mean data, as in Fig. 13, to the Calzetti et al. form, using their analytic expression. The assumed value of $R_V$ affects both normalization and slope, since our technique measures grey extinction as well as reddening. The best-fit value assuming no grey component is $A_V=4.0$, close to their value of 4.06 from SED fitting.

Keel et al. 2014, accepted
CONCLUSIONS

• Backlighting a galaxy is a good way to explore the small-scale dust structures and resulting extinction law in galaxies.

• No longer data-starved. Pairs pairs pairs!

• Distributions of extinction values vary strongly from galaxy to galaxy.

• Extinction law is a flat CCM ($R_V < 3$) or Calzetti (UV +opt).

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WHAT THE OCCULT CAN DO FOR YOU

- What is the chance a line-of-sight through a spiral galaxy has a certain amount of dust extinction?

- What is the typical extinction law seen through a spiral disk (as a function of spatial sampling)?

- How does dust geometry depend on luminosity, Hubble type, etc?

- How far out do dust disks extend?
FOLLOW-UP

Measure the dust content, extinction law and composition from galaxies backlit by a more distant galaxy.

Science Goals:
I. A probability function of extinction in a galaxy, \( P(A_V) \).
II. Typical scale-length and -height of dust in galaxies (and as a function of redshift).
III. The fractal number and mach number of the dusty Interstellar Matter (ISM).
IV. The composition of the dusty ISM; the extinction law and features, sub-mm excess.

I am very grateful to the reviewers for their encouraging and positive feedback. In general, the reviewers wanted more detail on how the four main science goals would be achieved with the available samples of occulting galaxies, i.e., on the biases and systematics in the samples and different analyses, and what can be achieved from existing data and which goals require follow-up observations.

Target Samples
The main current sample is 1993 pairs identified by the Galaxy Zoo [1]. Our "Gold" sub-sample (Elliptical background galaxy, good redshift separation) is currently 297 galaxies. Pairs can also be identified from blended spectra [2]. An updated sample will come from SDSS DR9 and the GAMA survey. Both selections are applied to high redshift samples (Table 1).

The two selection methods complement each other: close pairs (separation < 3", both galaxies in the fiber) through blended spectra and wider pairs by the human eye in Zoo campaigns. The current samples and data can address goal I. partly and II completely. Targets can be selected for HST and ALMA follow-up to address goals III and IV.

Analysis
Fig. 1 illustrates the possible analyses for a single pair, UGC 3559. SDSS aperture photometry can provide a mean extinction in the overlap region (e.g. \( A_V \approx 0.3 \)). Combined with all the other Sa galaxies in the Zoo sample this will give a probability function but over physical scales corresponding to SDSS resolution (~1-10 kpc), good enough to constrain general SED models but not enough for SNIa (Goal I). HST observations provide \( P(A_V) \) for just this pair (Fig. 2) and a wealth of detail on dust structure (Goal III). Integral Field Unit (IFU) observations yield extinction curves for every resolution element in the overlap region (3" or 9 kpc) and the slope of the extinction curve (\( R_V \)) is indicative of the dust grain size distribution and composition (Goal IV).

Sample Biases

<table>
<thead>
<tr>
<th>Survey</th>
<th>Partial overlap</th>
<th>Preference</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>GalaxyZoo</td>
<td>Partial overlap</td>
<td>Preference</td>
<td>All types, SDSS info</td>
<td></td>
</tr>
<tr>
<td>SDSS spectra, GAMA survey</td>
<td>Close pairs, late-types only</td>
<td>Good redshift separation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>zCOSMOS</td>
<td>Luminous</td>
<td>Rainy</td>
<td>Redshift separation, spec type.</td>
<td></td>
</tr>
<tr>
<td>GalaxyZoo 3</td>
<td>Same selection</td>
<td>Low- and high-z</td>
<td></td>
<td></td>
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</tbody>
</table>

CALIFA IFU Observations

Fig.1 UGC 3559, an interacting and occulting galaxy pair (Holwerda et al., in prep) identified in the Zoo. HST observations (right) of the overlap region show remarkable detail of the dust structures and provide a \( P(A_V) \) function (Fig. 2). CALIFA IFU observations provide spectra in the overlap region as well as reference spectra of the background counterpart. The extinction curve occasionally shows a non-Milky Way extinction Law (\( R_V=4 \)).
WILLIAM HERSHEYEL TELESCOPE

- Deeper Imaging Campaign (Dec 2012).
- Long-slit spectroscopy
  - redshift
  - spectral class
  - extinction curve
- GOAL: a clean sample of occulting dwarf galaxies.

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WHAT’S NEXT?

• Compare dust surface densities to Herschel fluxes in SDSS (e.g. in Stripe 82).

• HST snapshots.

• GAMA Southern Hemisphere Occulting Pairs

• More IFU data (e.g., CALIFA DR2)

• High-redshift pairs in HST deep fields.

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THANK YOU!

www.hubblesite.org
www.heritage.stsci.edu
www.stsci.edu