

### WHAT CAN THE OCCULT DO FOR YOU? DUST EXTINCTION MEASURED IN OVERLAPPING GALAXY PAIRS.

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### 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.



### 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<sub>25</sub>

White et al. 2000, ApJ, 542, 761

### ONE MAN'S TRASH...

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



### GALAXY PAIRS IN SLOAN



- SDSS spectra.
- Gravitational lenses; latetype 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* 





### LATEST NEWS: The Galaxy Zoo Forum is now online: | My Galaxies is now online

Welcome to **GalaxyZoo**, the project which harnesses the power of the internet - and your brain - to classify a million galaxies. By taking part, you'll not only be contributing to scientific research, but you'll view parts of the Universe that literally no-one has ever seen before and get a sense of the glorious diversity of galaxies that pepper the sky.

### Why do we need you?

The simple answer is that the human brain is much better at recognizing patterns than a computer can ever be. Any computer program we write to sort our galaxies into categories would do a reasonable job, but it would also inevitably throw out the unusual, the weird and the wonderful. To rescue these interesting systems which have a story to tell, we need you.

GZ is now live! Go ahead and sign up to start classifying galaxies right away.

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

**User Name** 

Password

Register

Forgot Password

Remember me next time.

Log In



# 1993 pairs!

Keel et al., 2013, PASP, 125, 3

### GALAXYZOO SAMPLE

- Mostly nearby pairs (z<0.1)</li>
- 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.

# OCCULTING PAIR WITH HST

· halo12

NA

### z = 0.06

F606W V

### 2MASX J00482185-2507365 HST ACS/WFC

100,000 light-years 30.7 kiloparsecs 27

NGC0253 halo11 halo8 halo2 de1 wide2 wide3 wide4 wide5 halo18 halo17. ACS Nearby Galaxy Survey Treasury

SW, 21-11-2013



### 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.
- SNIa prior? SED model constraint?



# EXTINCTION LAW

- Three filters allow two separate estimates of extinction law.
- Much spread due to structure in both galaxies.
- Mean A<sub>x</sub>/A<sub>y</sub> values very close to the Milky Way value.

### V band

### 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.











# Another occulting pair with HST data Known interaction though

• Part of the CALIFA DRI

Holwerda et al., 2013b, A&A,



### A<sub>V</sub> VALUES

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



### IFU AV AND RV MAPS



### UV-OPTICAL EXTINCTION LAW



### 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<sub>V</sub> < 3) or Calzetti (UV +opt).</li>

# 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? B.W. Holwerda, ESA IDSW, 21-11-2013

galaxies only spec type.

partial overlap

preference

occasionally shows a non-Milky Way extinction Law

GalaxyZoo 3 (SDSS + HST) same selection low- and high-z

### FOLLOW-UP

GAMA

0.0

4000

4500

5000

5500

Wavelength (Å)

6000

6500

7000

**CALIFA IFU Observations** 15'00.0 54 ( Dec (J2000) 48.0" 42.0 Av Map (HST 1.0 **Overlap Region** +29°14'36.0 Background Galaxy 08.50s 08.00s RA (12000) **Extinction Curve** Fig.1 UGC 3559, an interacting and occulting galaxy CCM fit  $R_V = 4.04$ ,  $A_J = 0.15$ 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

B.W. Holwerda, GAMA Team Meeting, 11-9-2013

(R<sub>v</sub>=4).

# WILLIAM HERSCHEL TELESCOPE

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

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

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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.

### Overlapping Galaxies • 2MASX J00482185-2507365



### THANK YOU!

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

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • HST/ACS • STScI-PRC08-33