WHAT CAN THE OCCULT DO FOR YOU?

DUST EXTINCTION MEASURED IN OVERLAPPING GALAXY PAIRS.

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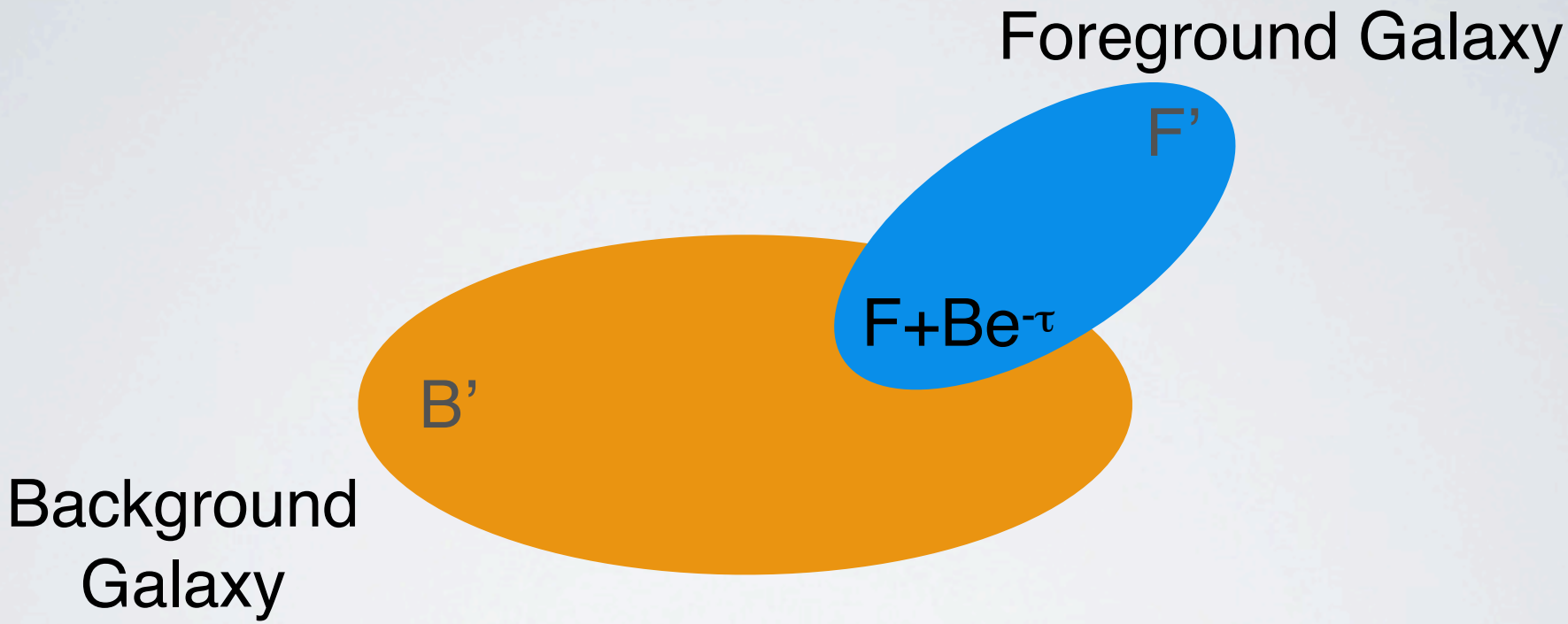
OUTLINE OF TALK

- Motivation
- Occulting Galaxies
- SDSS spectra & zoo
- A pair with HST
- IFU observations
- Conclusions
- Future Outlook

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.

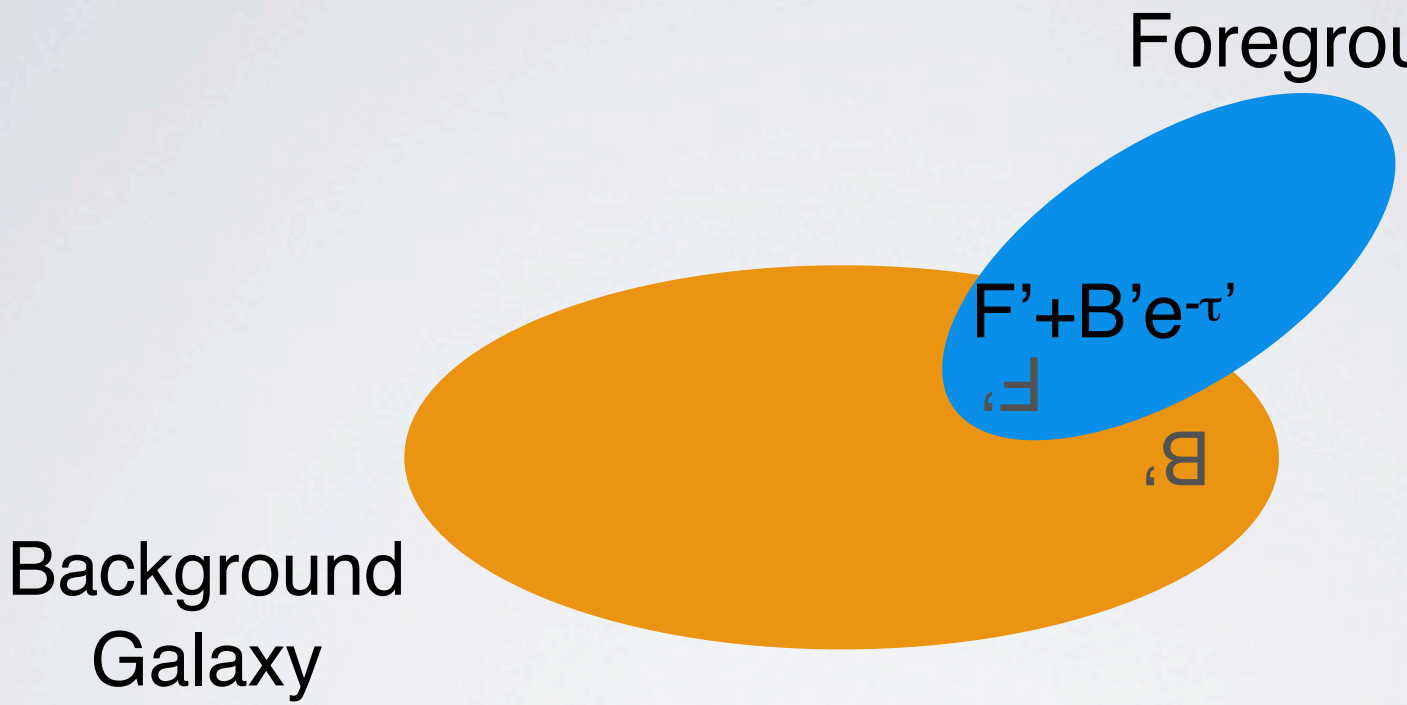
OCCULTING GALAXY TECHNIQUE



$$e^{-\tau'} = \frac{[F+Be^{-\tau}] - F'}{B'}$$

Keel & White 1995

OCCULTING GALAXY TECHNIQUE



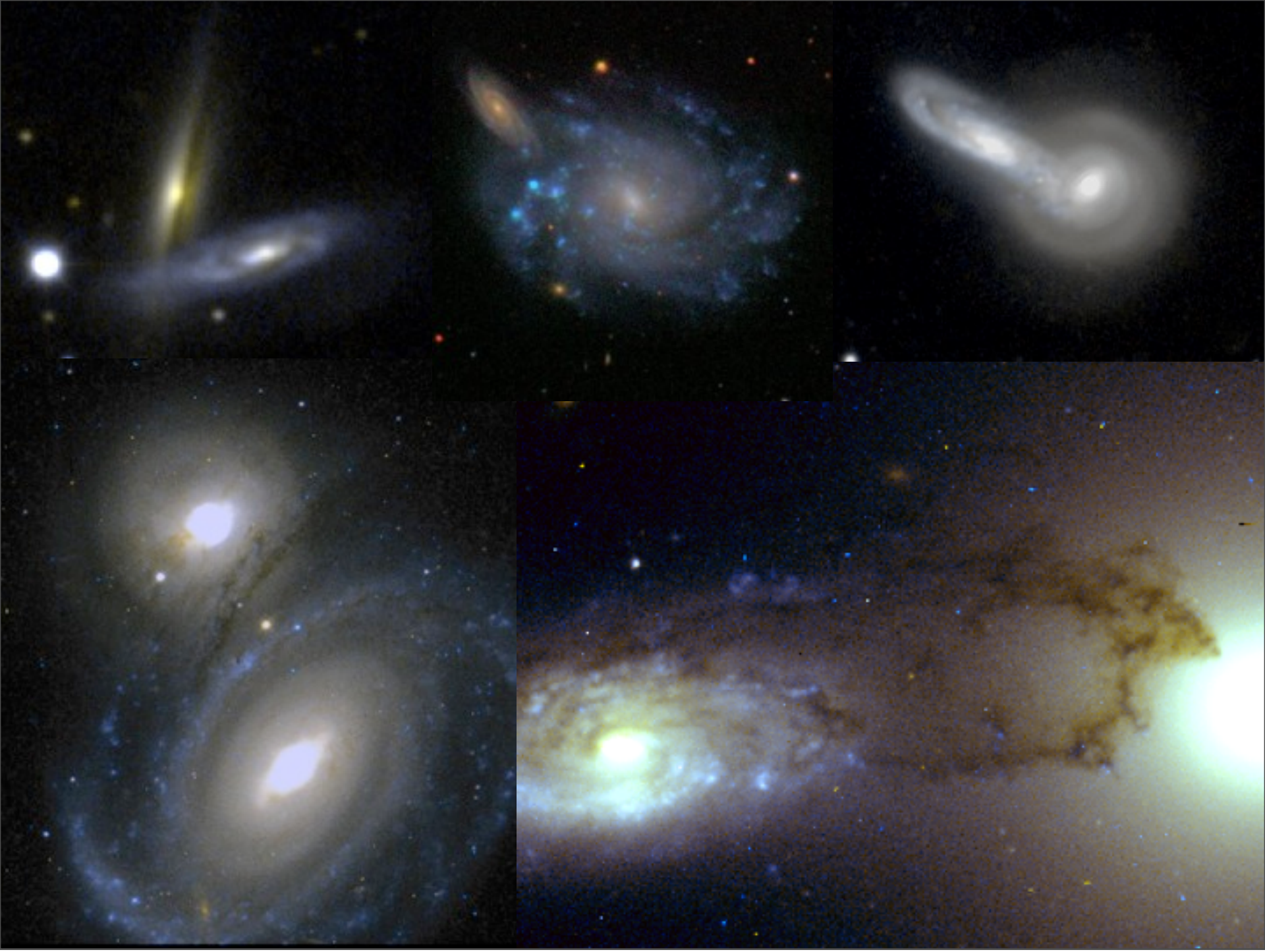
$$e^{-\tau'} = \frac{[F+Be^{-\tau}] - F'}{B'}$$

Keel & White 1995

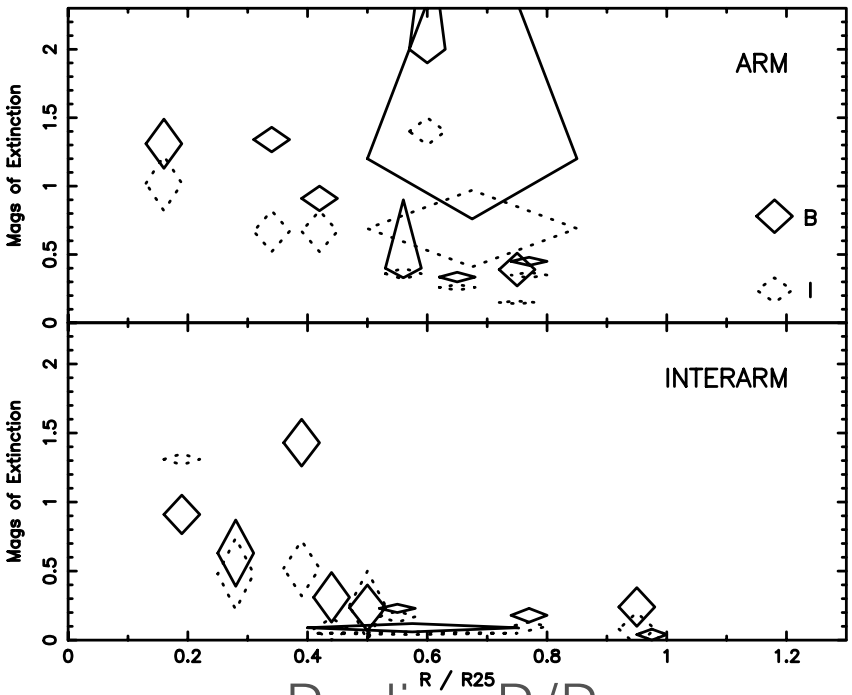
REAL PAIRS

- 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



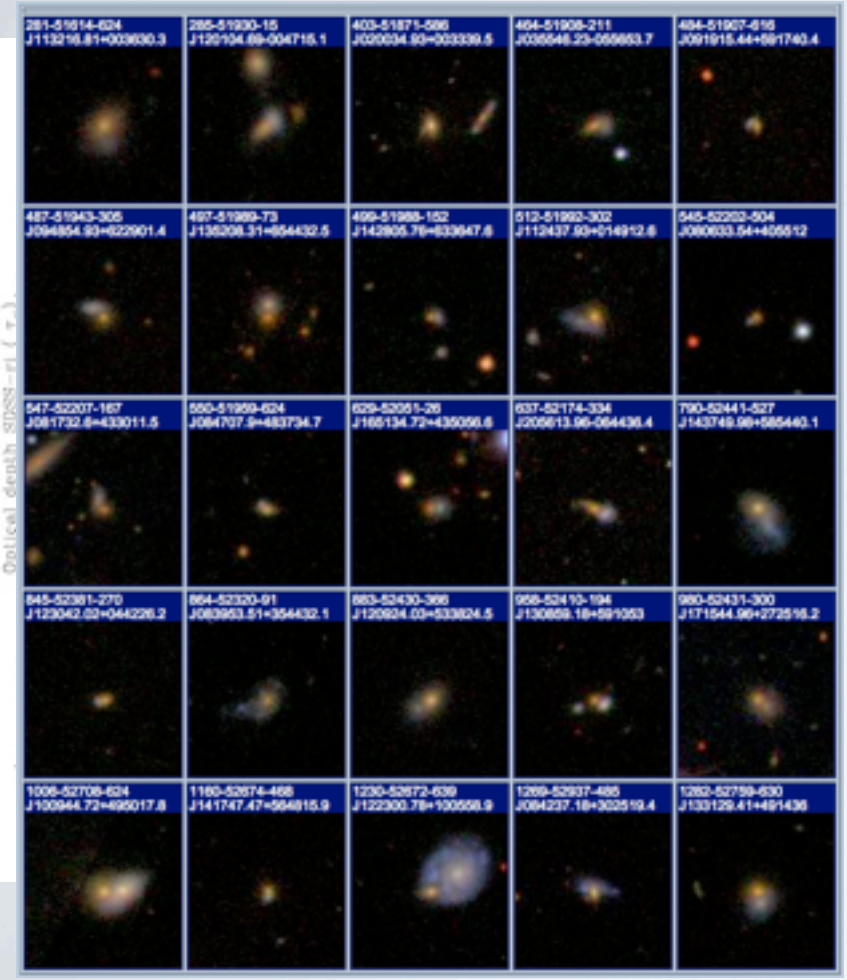
FIRST RESULTS



- Spiral arms are more opaque than the rest of the disk.
- There is dust extinction up to R_{25}
- Extinction law depends on size of sampling area.

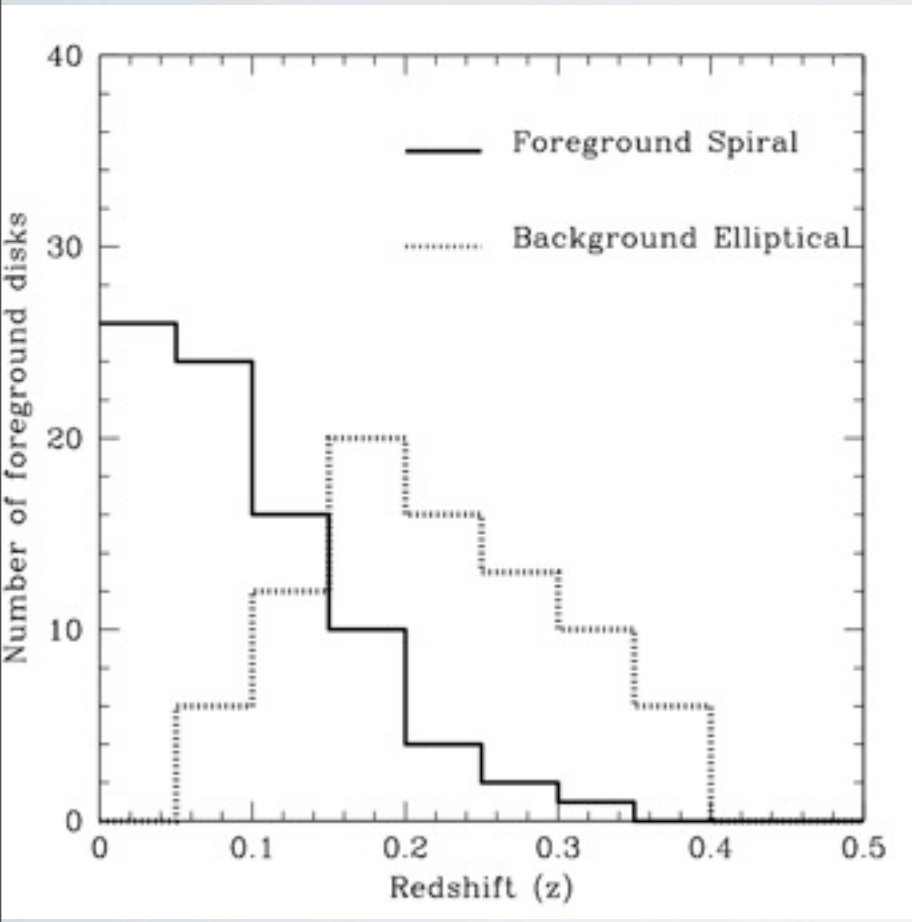
White et al. 2000, ApJ, **542**, 761

OCCULTING GALAXIES 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.

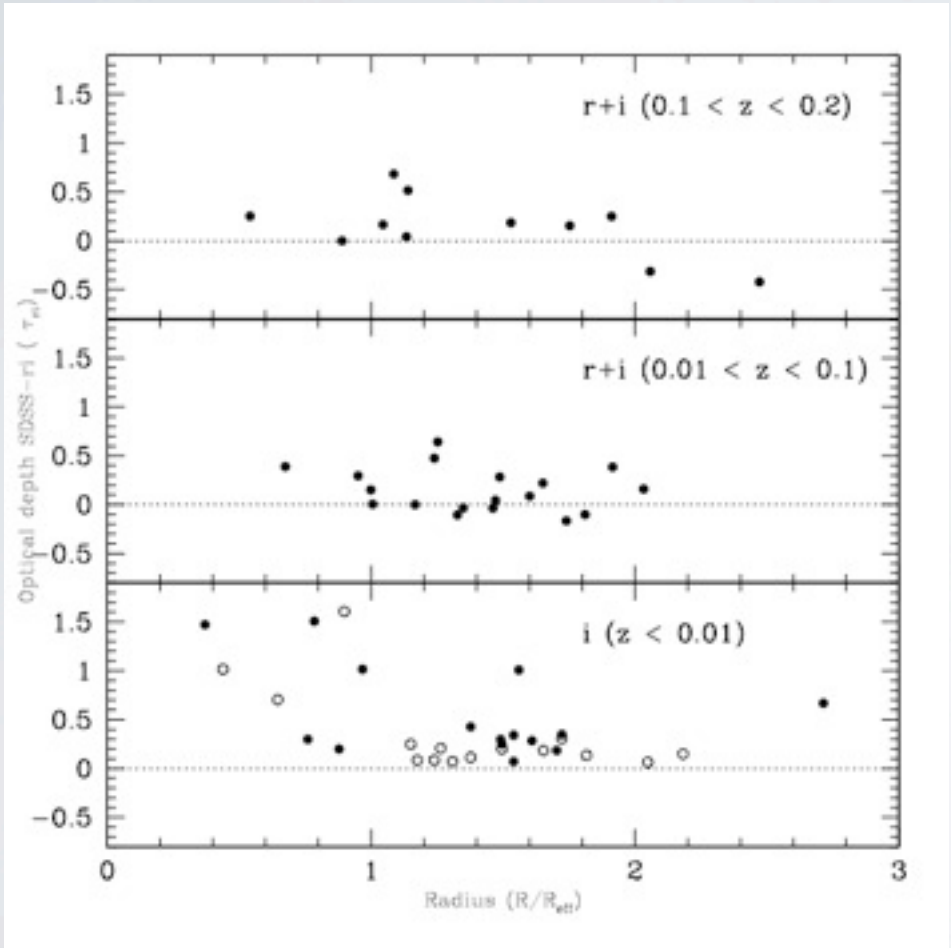
THE SLOAN SAMPLE



- Spectral type selection together with visual check: 86 occulting pairs.
- Selection from spectra limits to $z = 0.4$.
- Most of foreground spirals $z < 0.2$

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

GALAXY PAIRS IN SLOAN



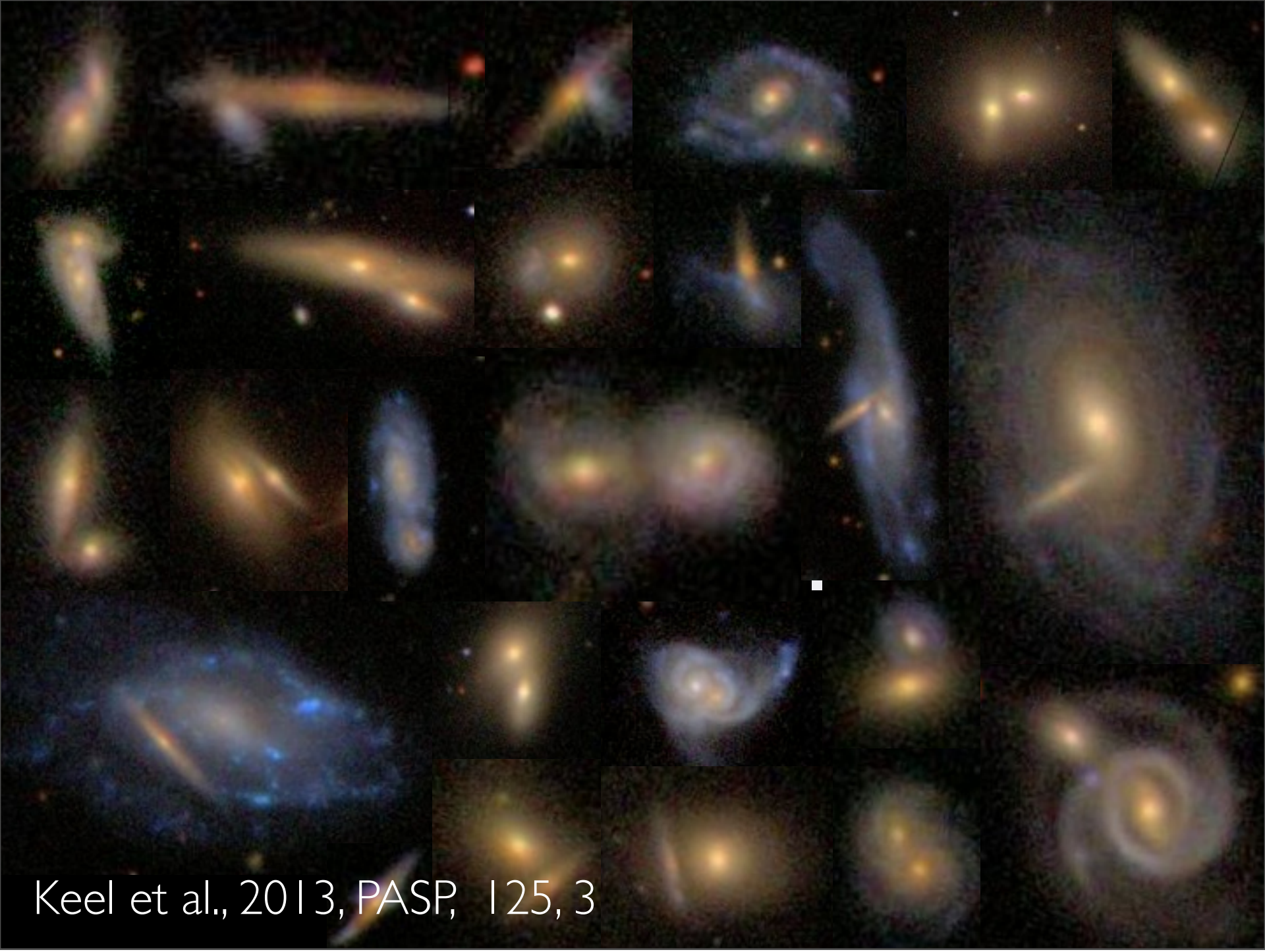
Optical Depth (τ)

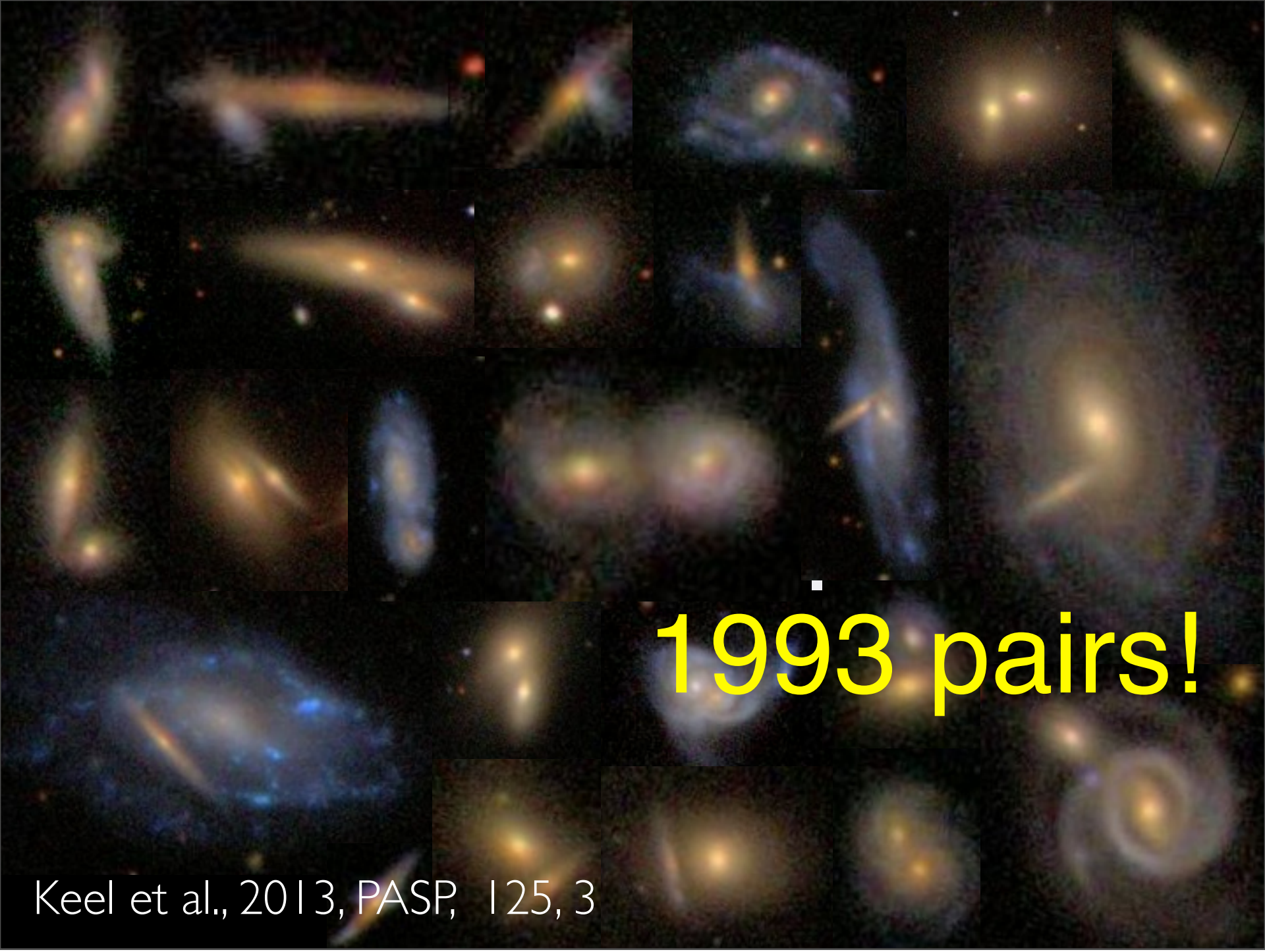
Distance from centre (R/R_{25})

- Radial opacity plot as a function of redshift.
- Compare to local results.
- Mix of arm/disk and Hubble types.
- More pairs!

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

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


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


1993 pairs!
Keel et al., 2013, PASP, 125, 3

GALAXYZOO SAMPLE

- Mostly nearby pairs ($z<0.1$)
- All types of galaxies, many spiral-spiral pairs
- Foreground disks at any inclination
- Subsamples:
  - WIYN, KPNO and WHT follow-up, deep imaging
  - GALEX UV (spiral-spiral)
  - HST GO and SNAP proposals

OCCULTING PAIR WITH HST

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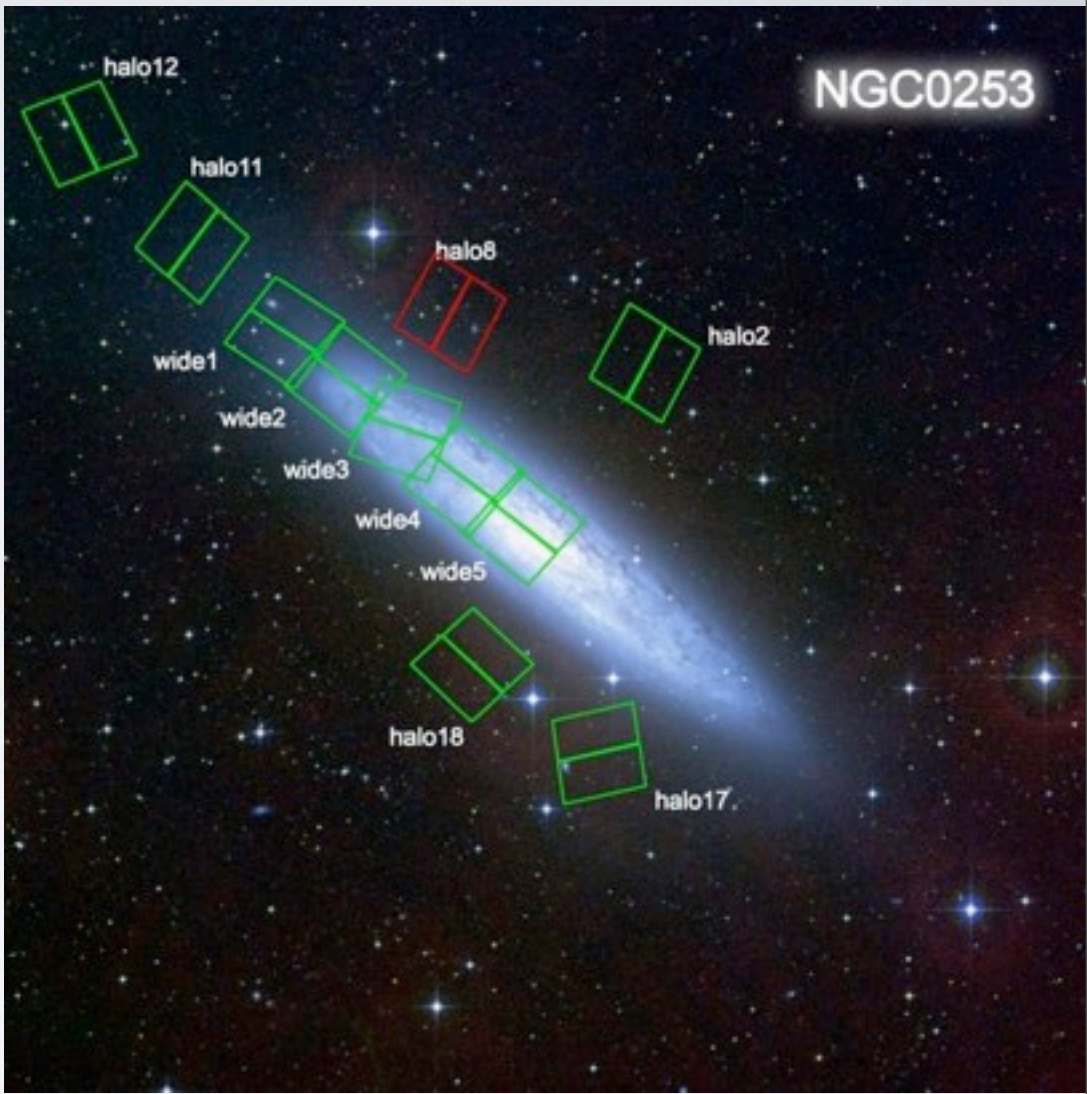
OCCULTING PAIR WITH HST



ACS Nearby Galaxy Survey Treasur

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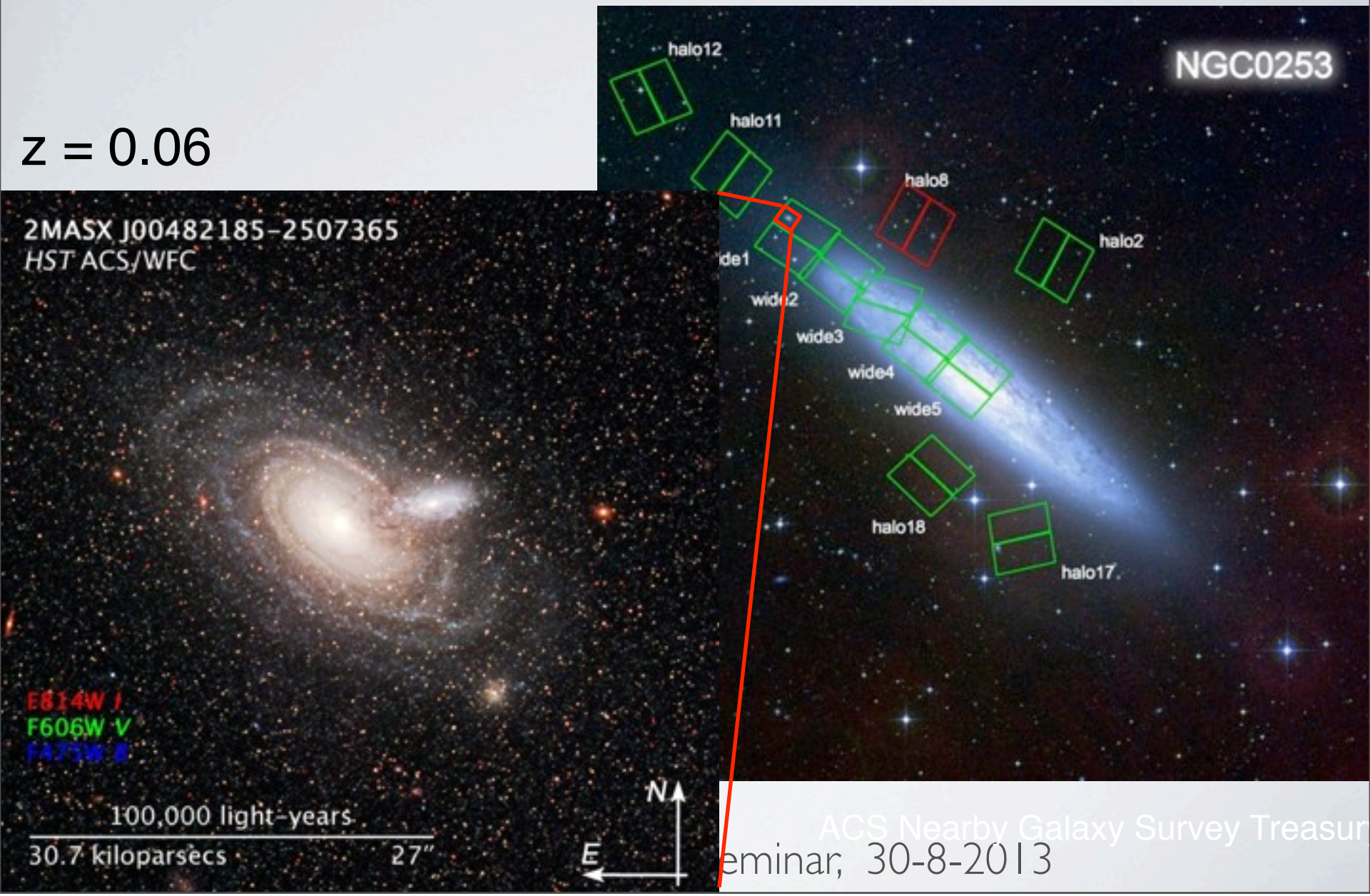
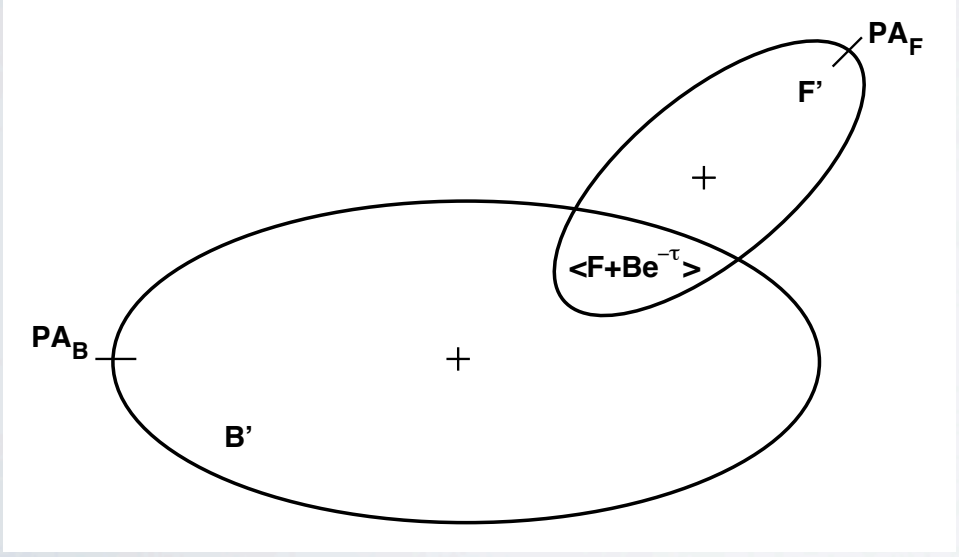
OCCULTING PAIR WITH HST

z = 0.06



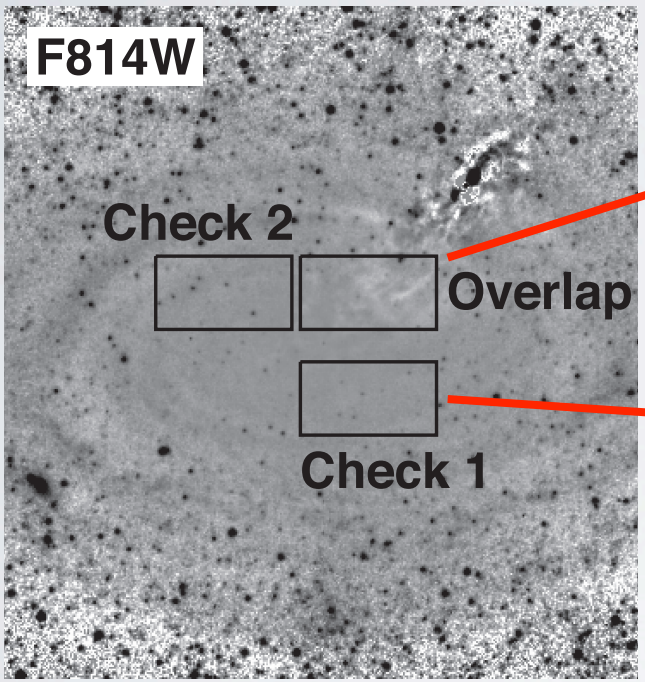
ANALYSIS

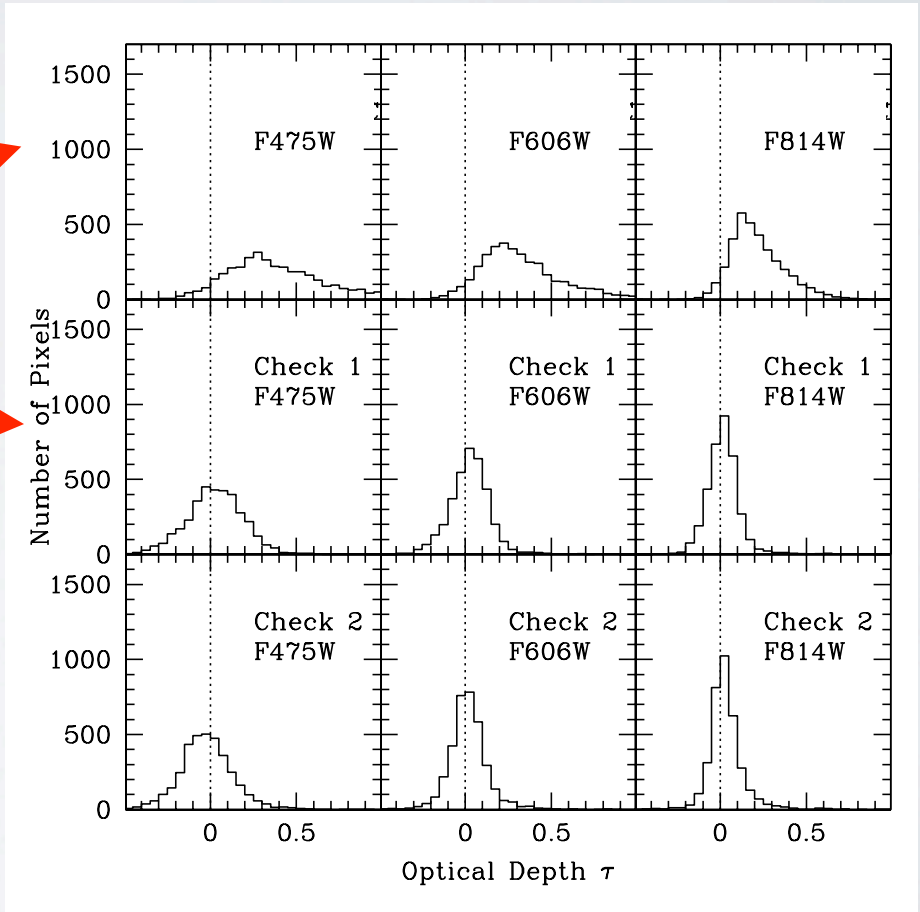


- Method A: Fit rotated galaxies
- Method B: flip background galaxy
- Method C: isophotal models of both galaxies.

ZERO-POINT CHECK

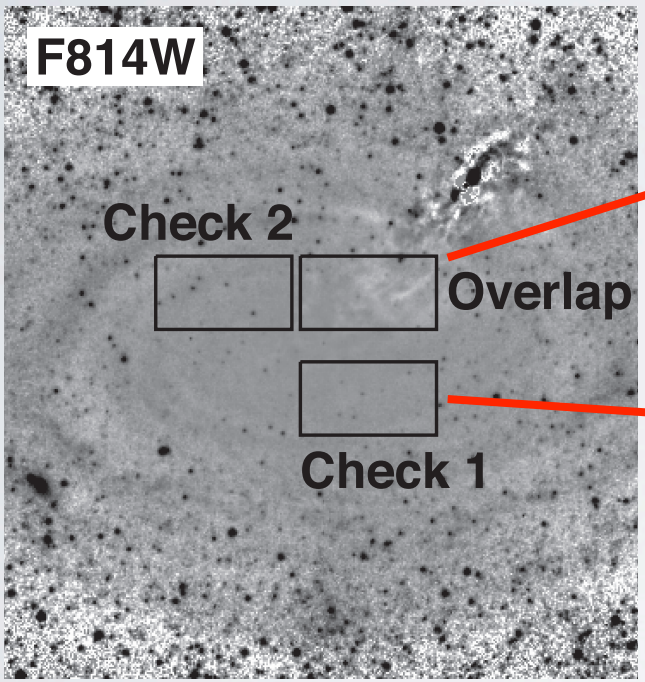
Method A: rotate both galaxies

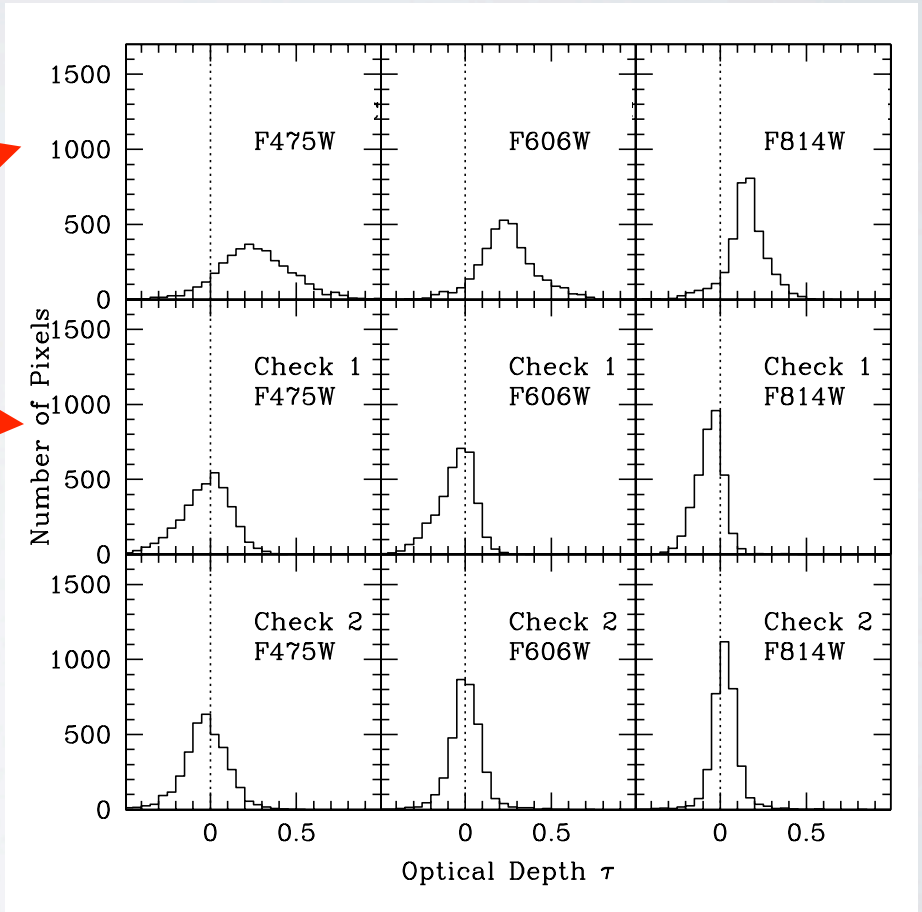




ZERO-POINT CHECK

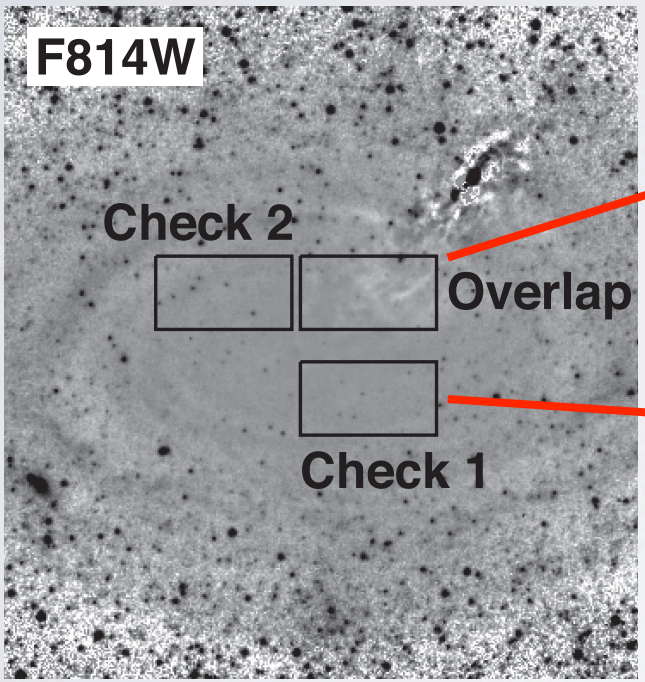
Method B: flip background galaxy

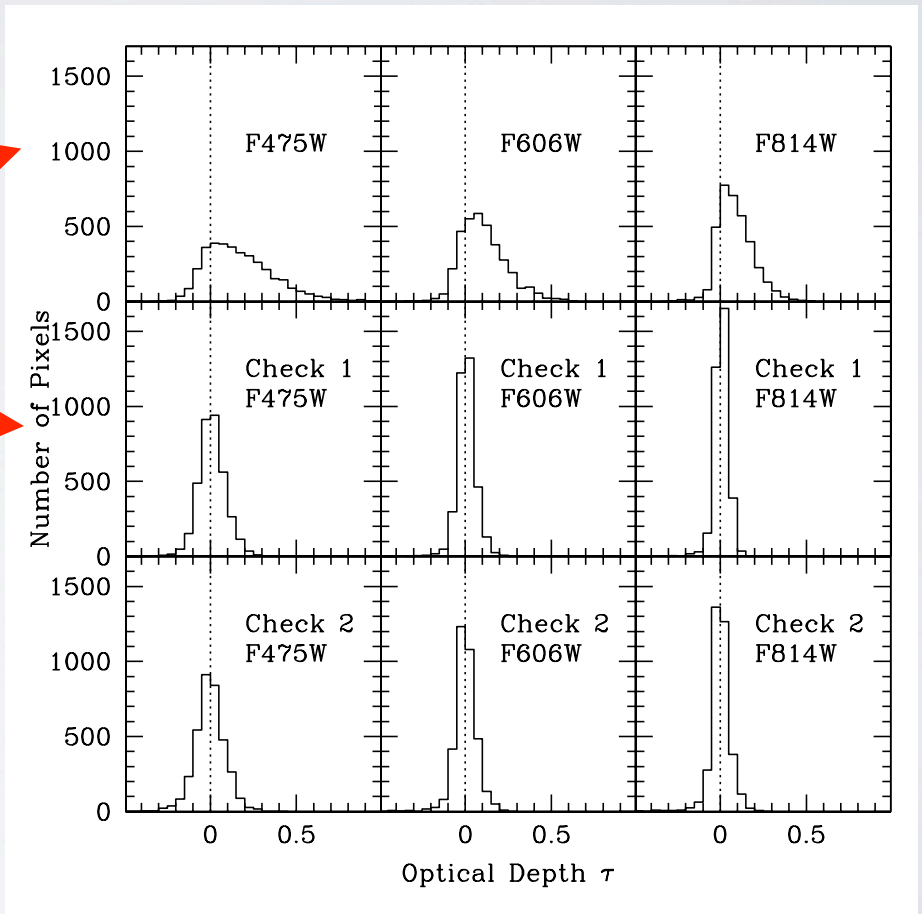




ZERO-POINT CHECK

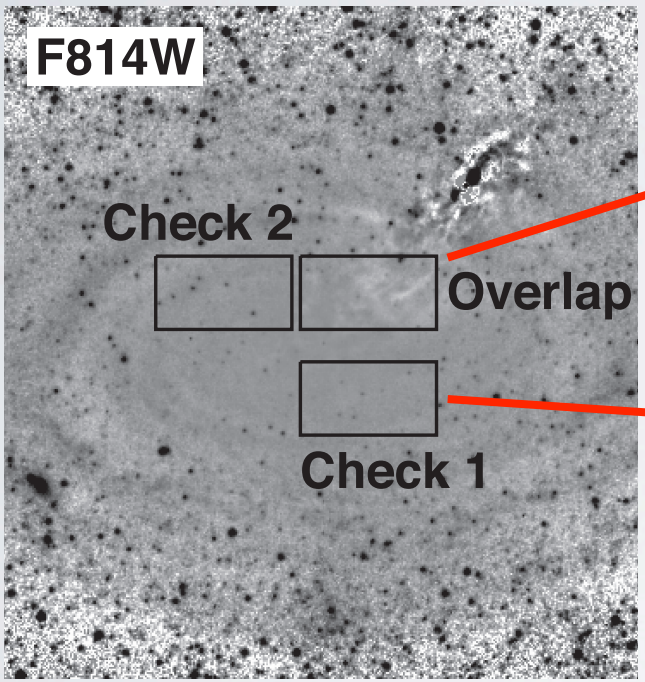
Method C: model both galaxies

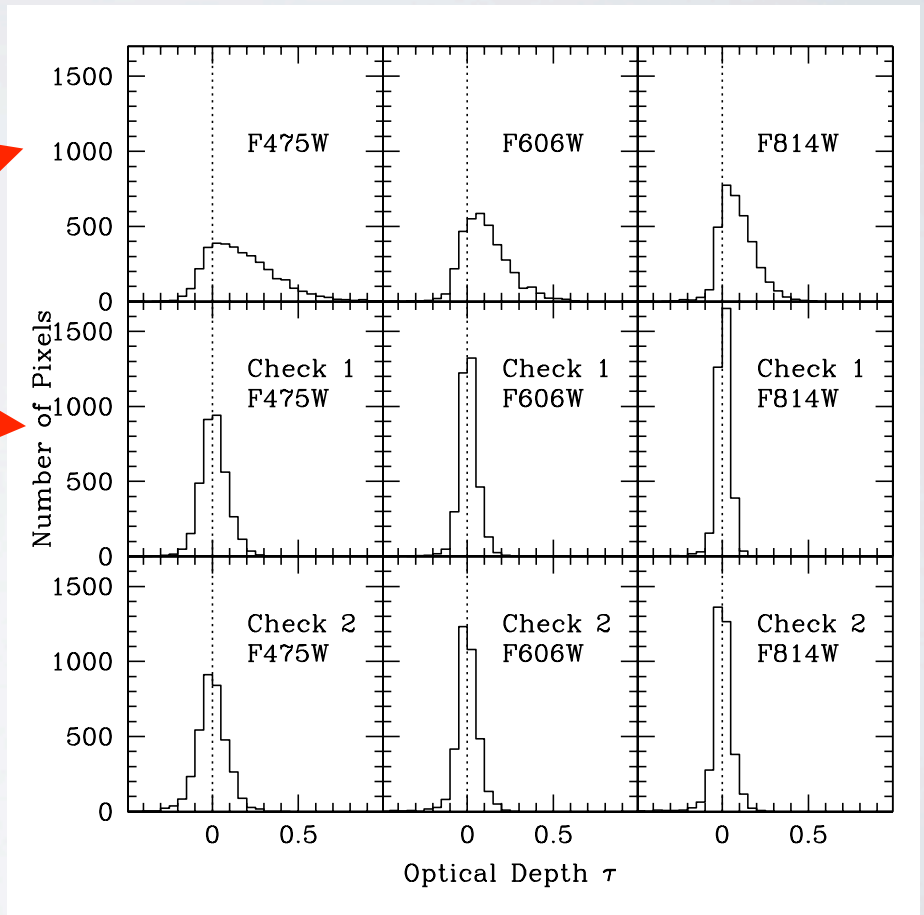




ZERO-POINT CHECK

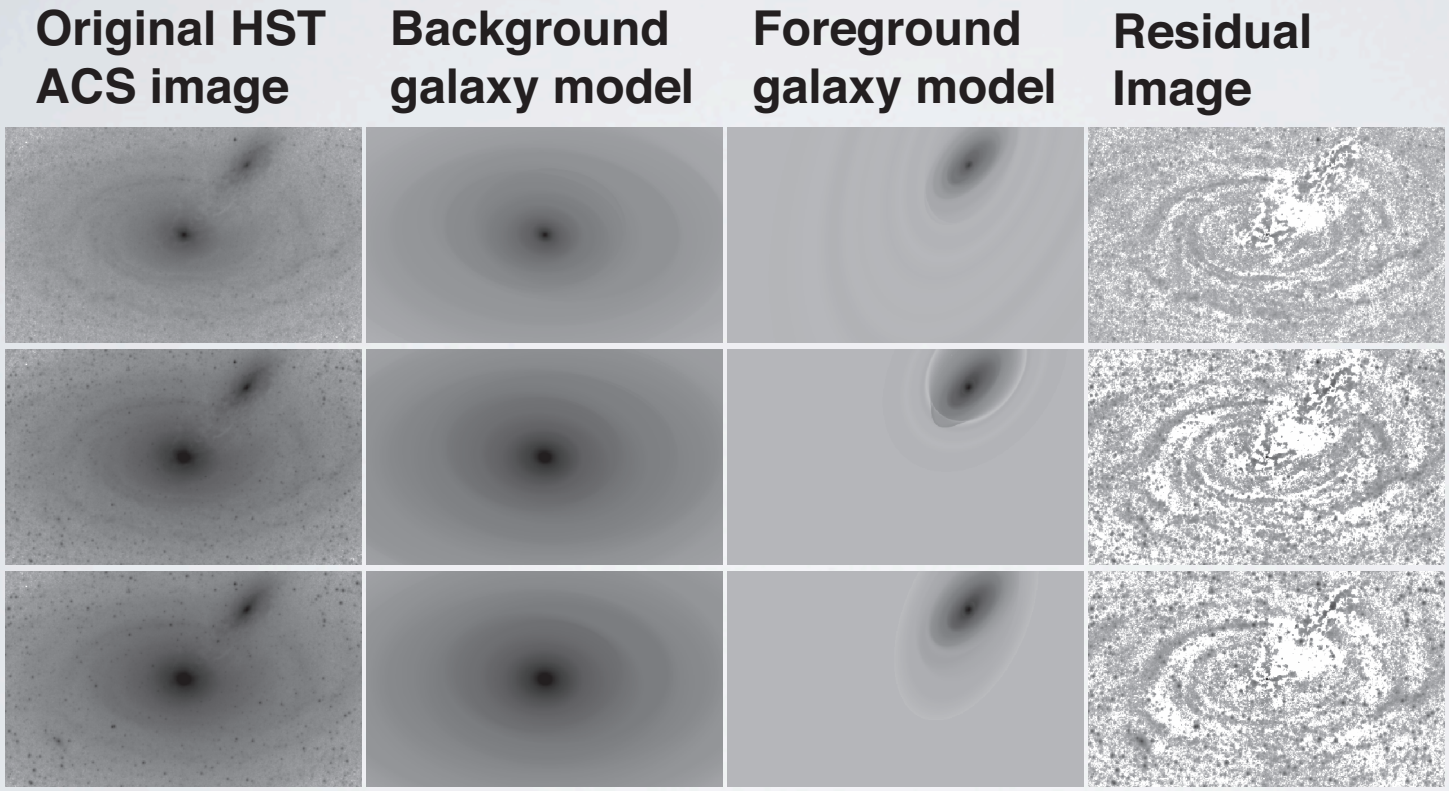
Method C: model both galaxies





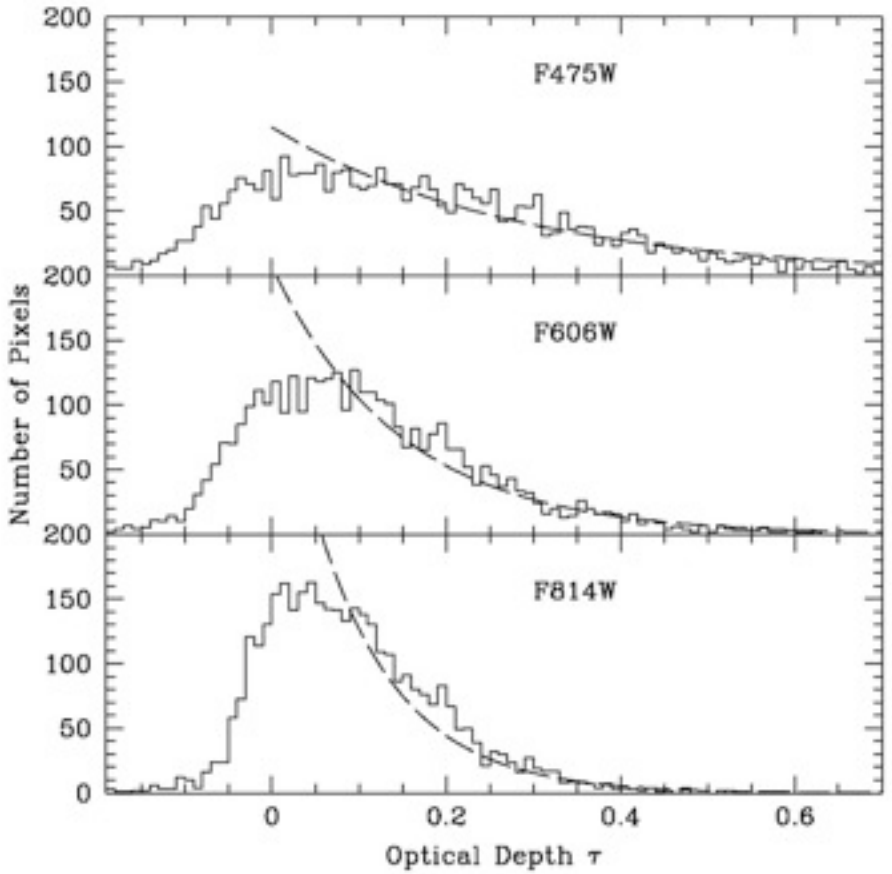
Winner!

METHOD C



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.
- SN1a prior? SED model constraint?

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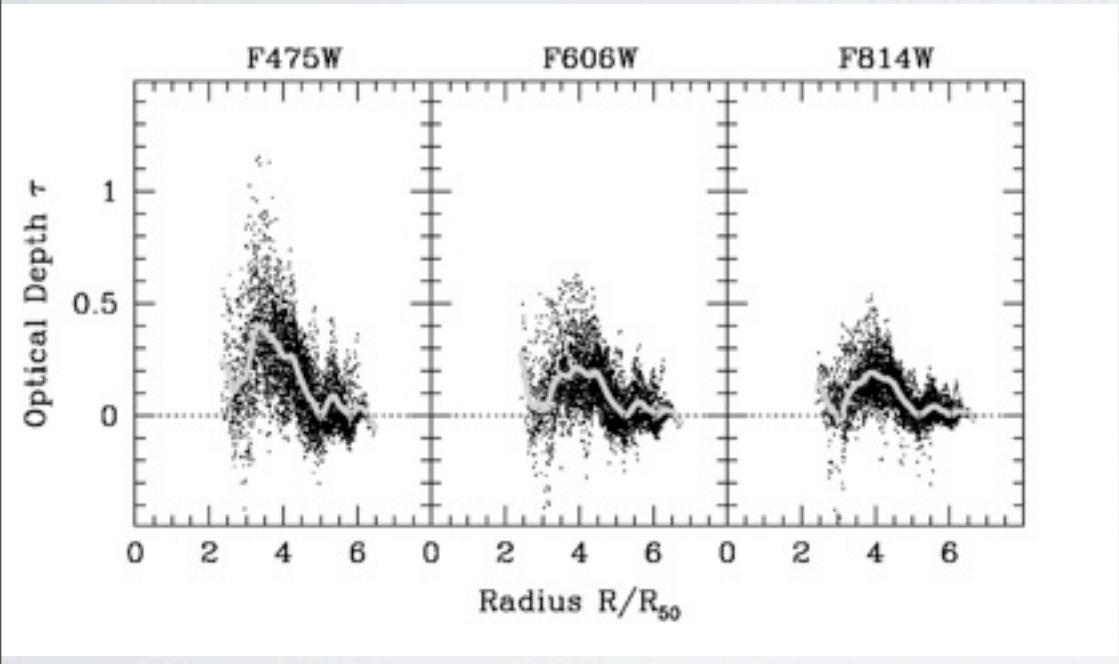
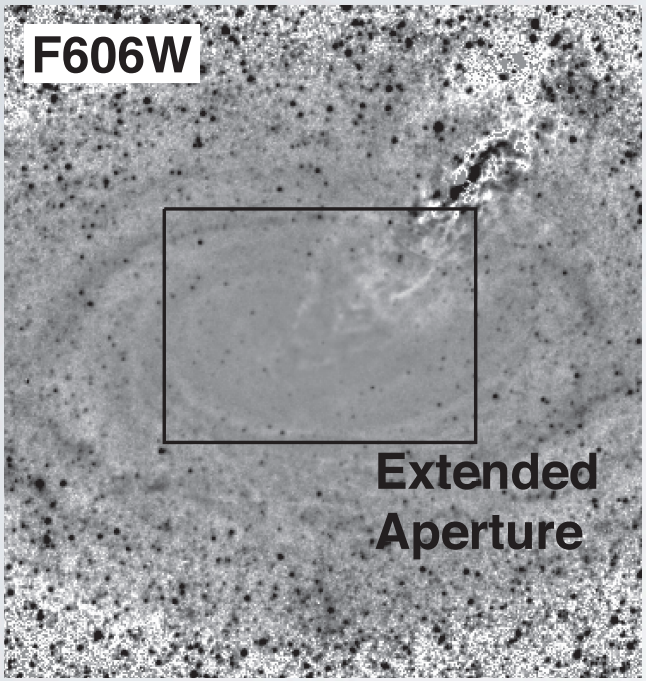
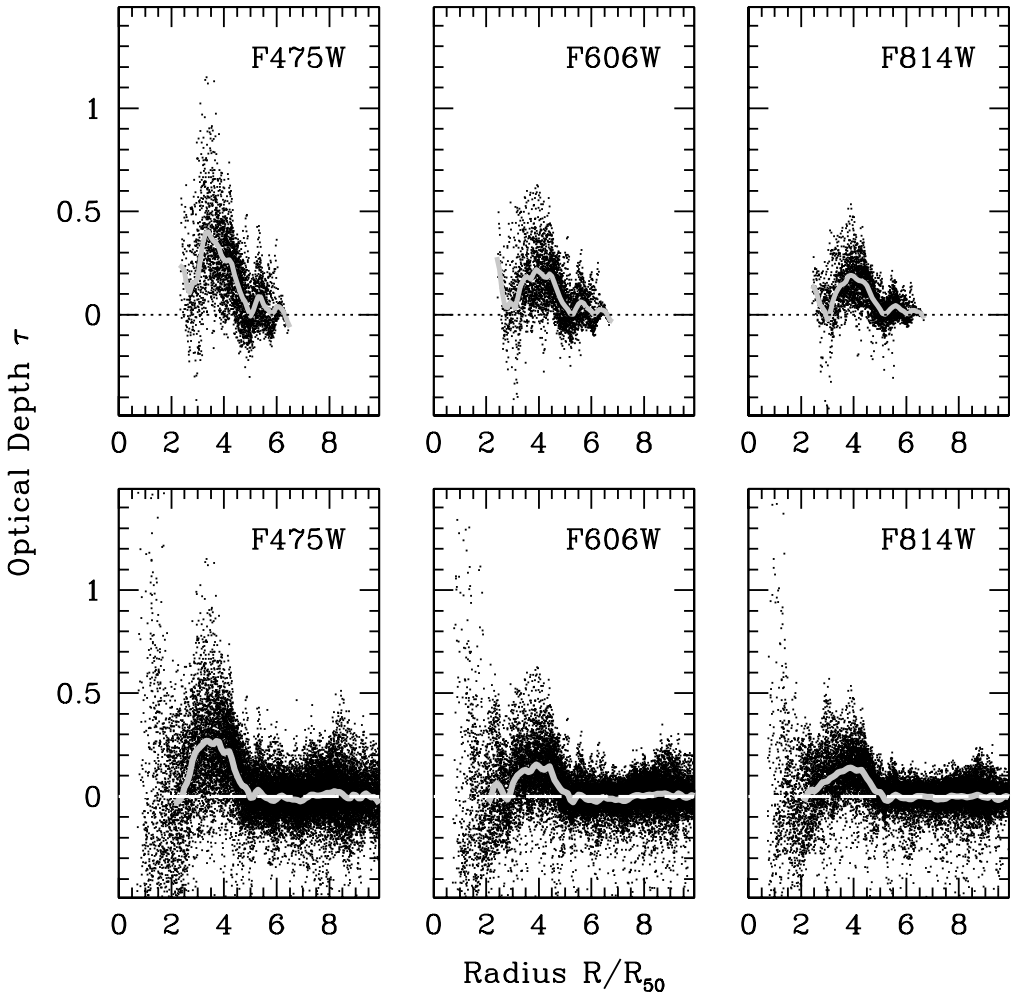
RADIAL DISTRIBUTION



- Effects of dust extinction extends up to 6 R_{50} or almost twice the R_{25}.
- The spiral arms are clear bumps in the mean optical depth.

EXTENDED RADIAL PROFILE





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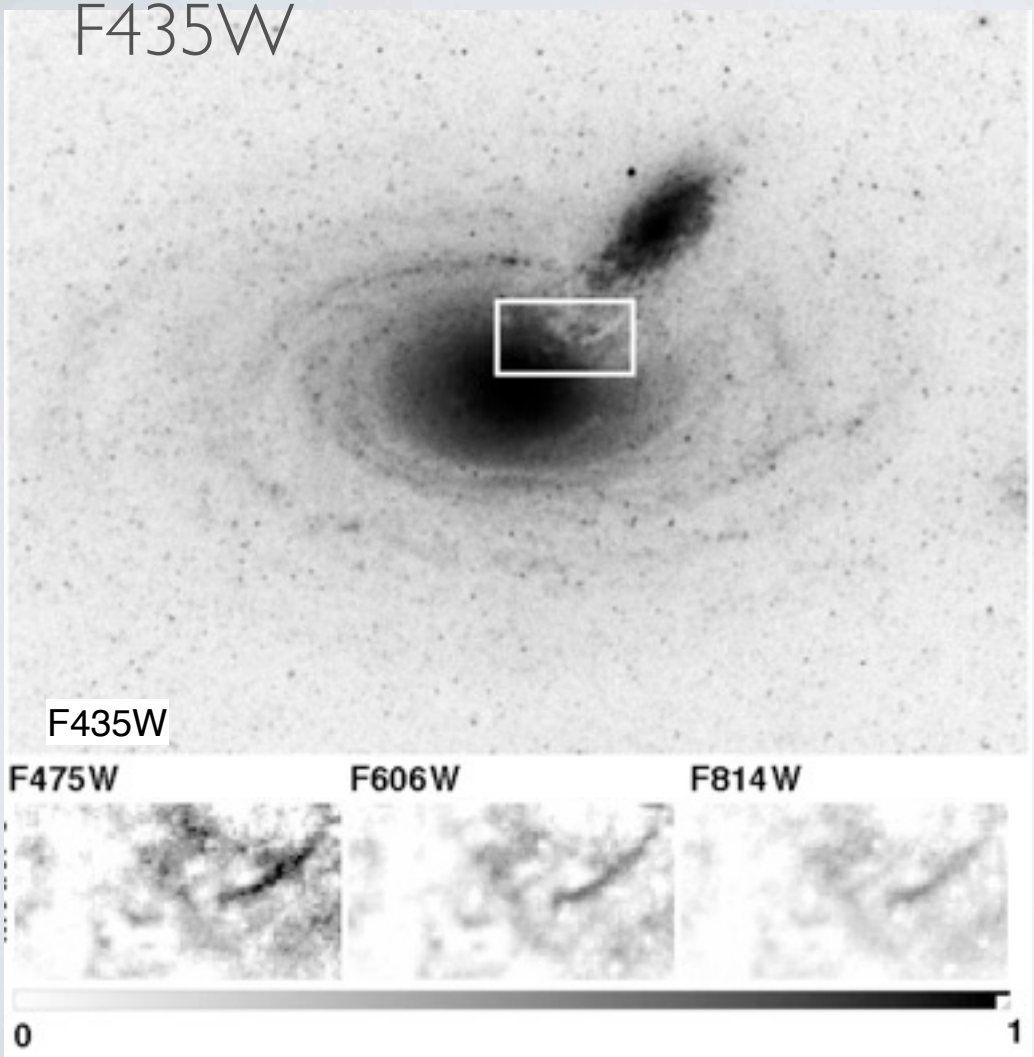
EXTINCTION MAPS

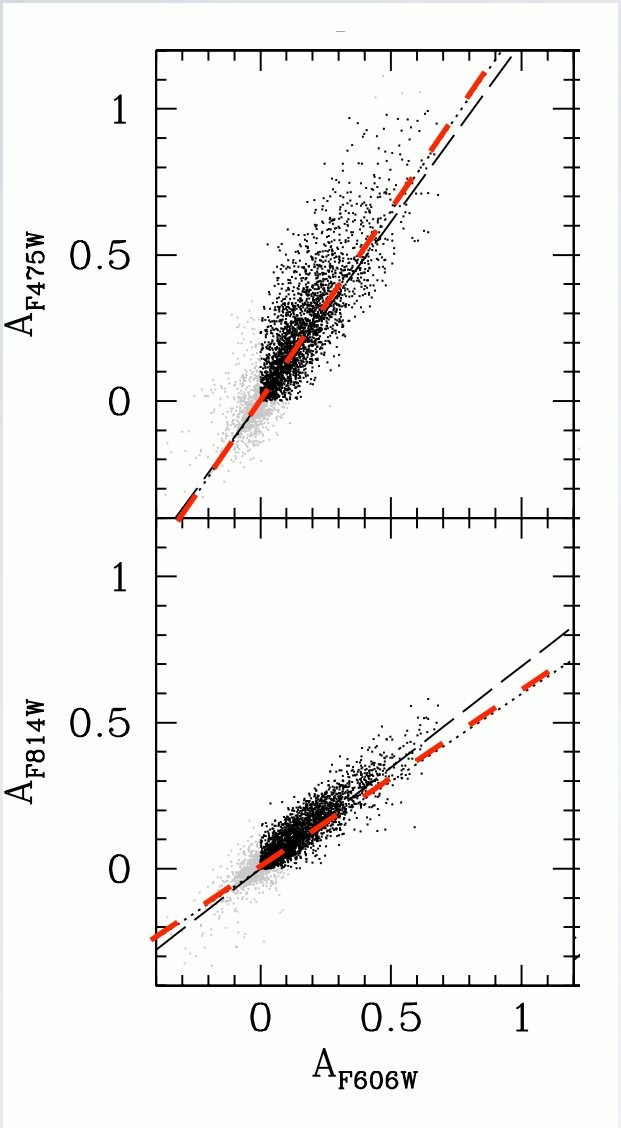


Optical Depth

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

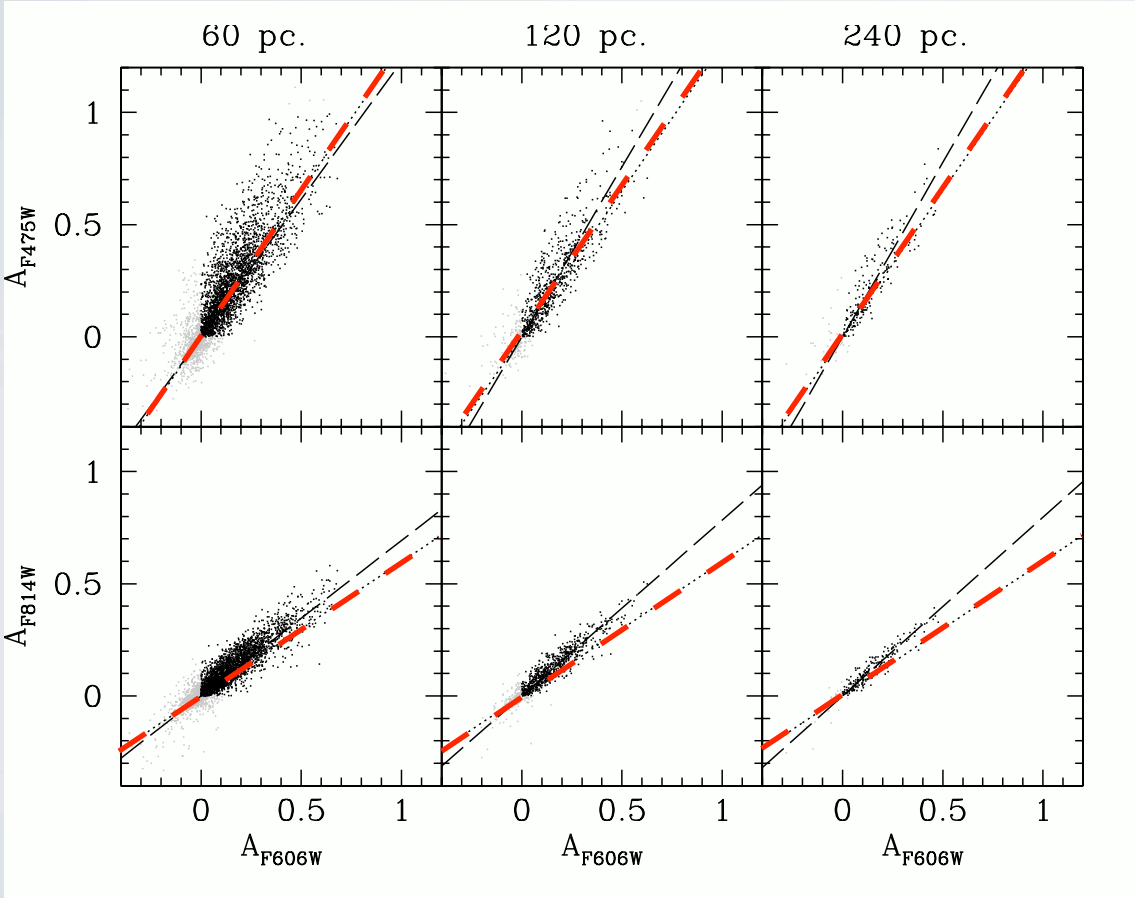
Holwerda et al., 2009, AJ, 137, 3000

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.

EXTINCTION LAW AND SAMPLING



- Extinction Law depends on the physical sampling scale.
- Taken over larger areas, the law becomes grayer.

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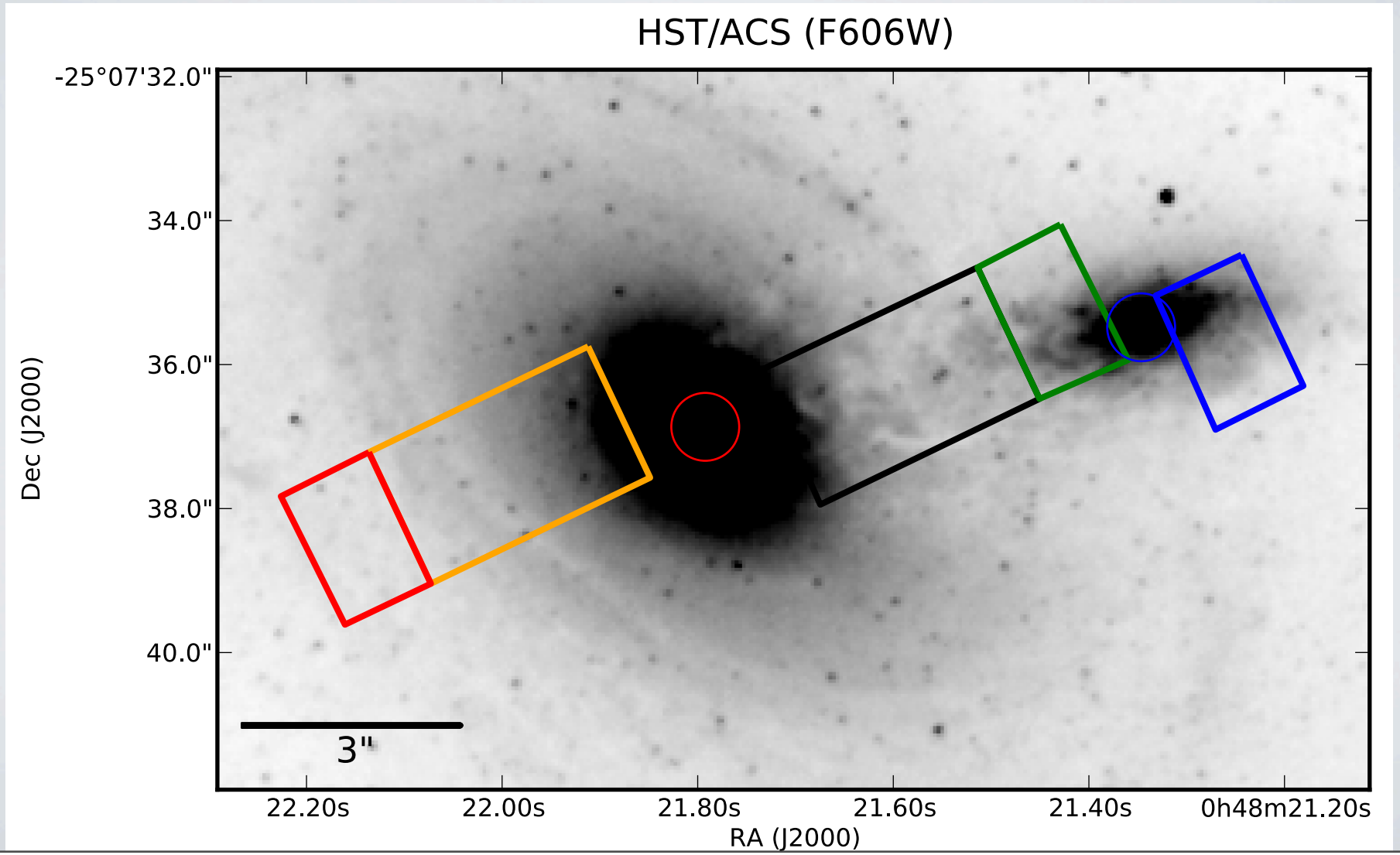
DUST IN DWARFS

- Stacked Herschel fluxes indicated lots of cold dust in smaller galaxies but relatively little extinction (e.g. Bourne et al. 2012).
- One way that could happen if a large fraction of the dust is in a more extended disk.
- **How common is it for dwarf spirals to have the dust spread out so much?**

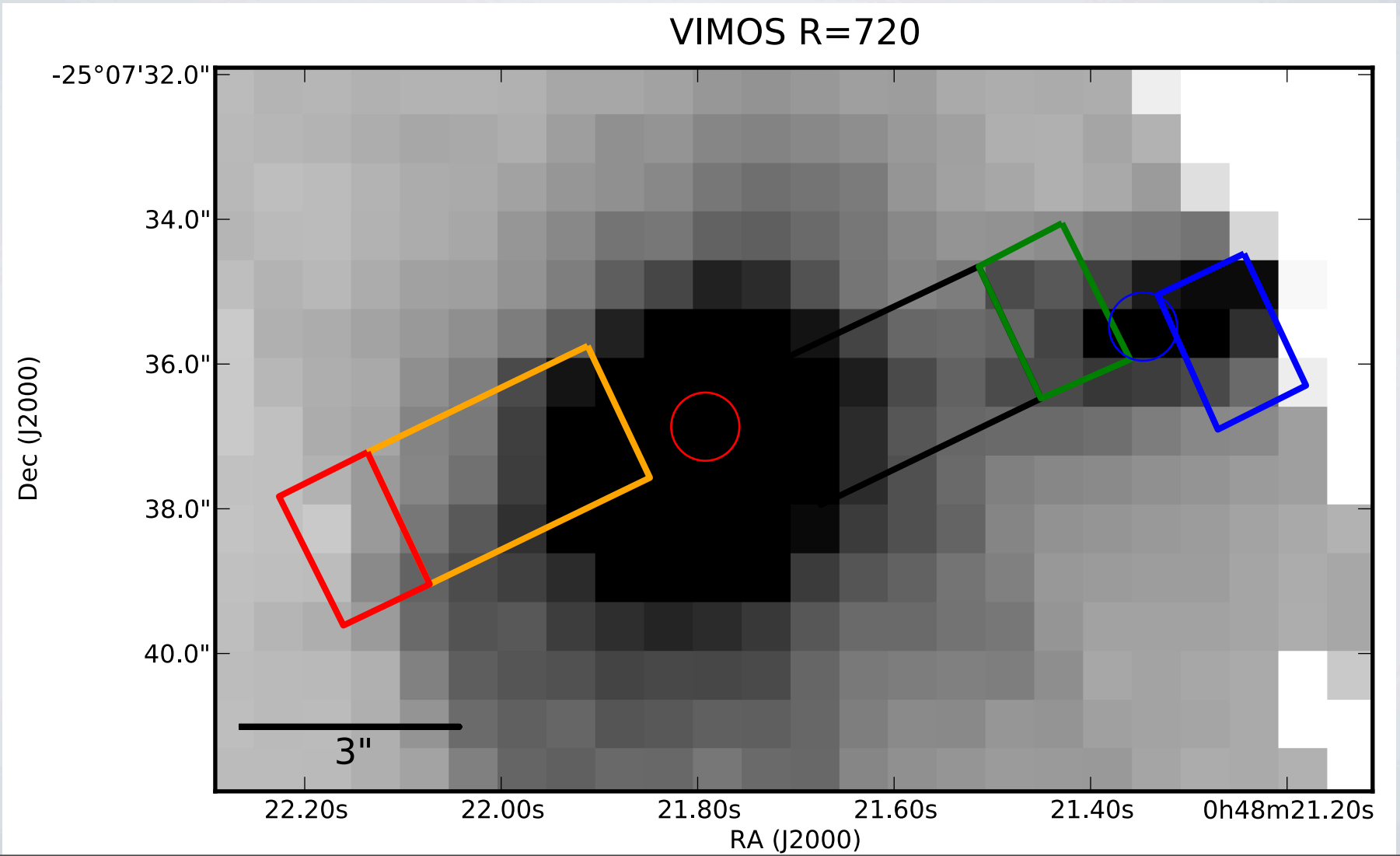
IFU OBSERVATIONS

- 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.

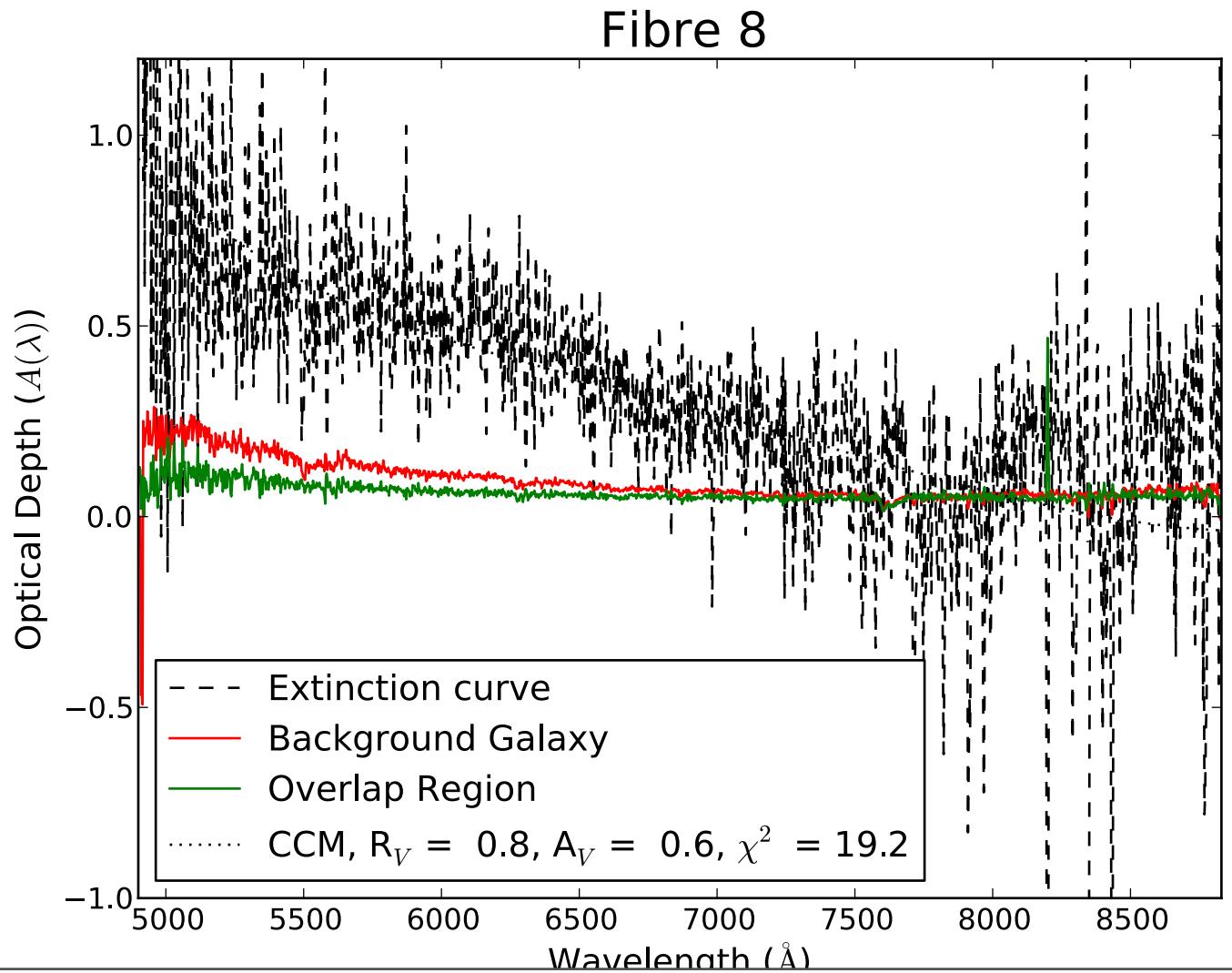
HST PAIR


HST/ACS (F606W)
-25°07'32.0"
34.0"
36.0"
38.0"
40.0"
Dec (J2000)
3"
22.20s
22.00s
21.80s
21.60s
21.40s
0h48m21.20s
RA (J2000)

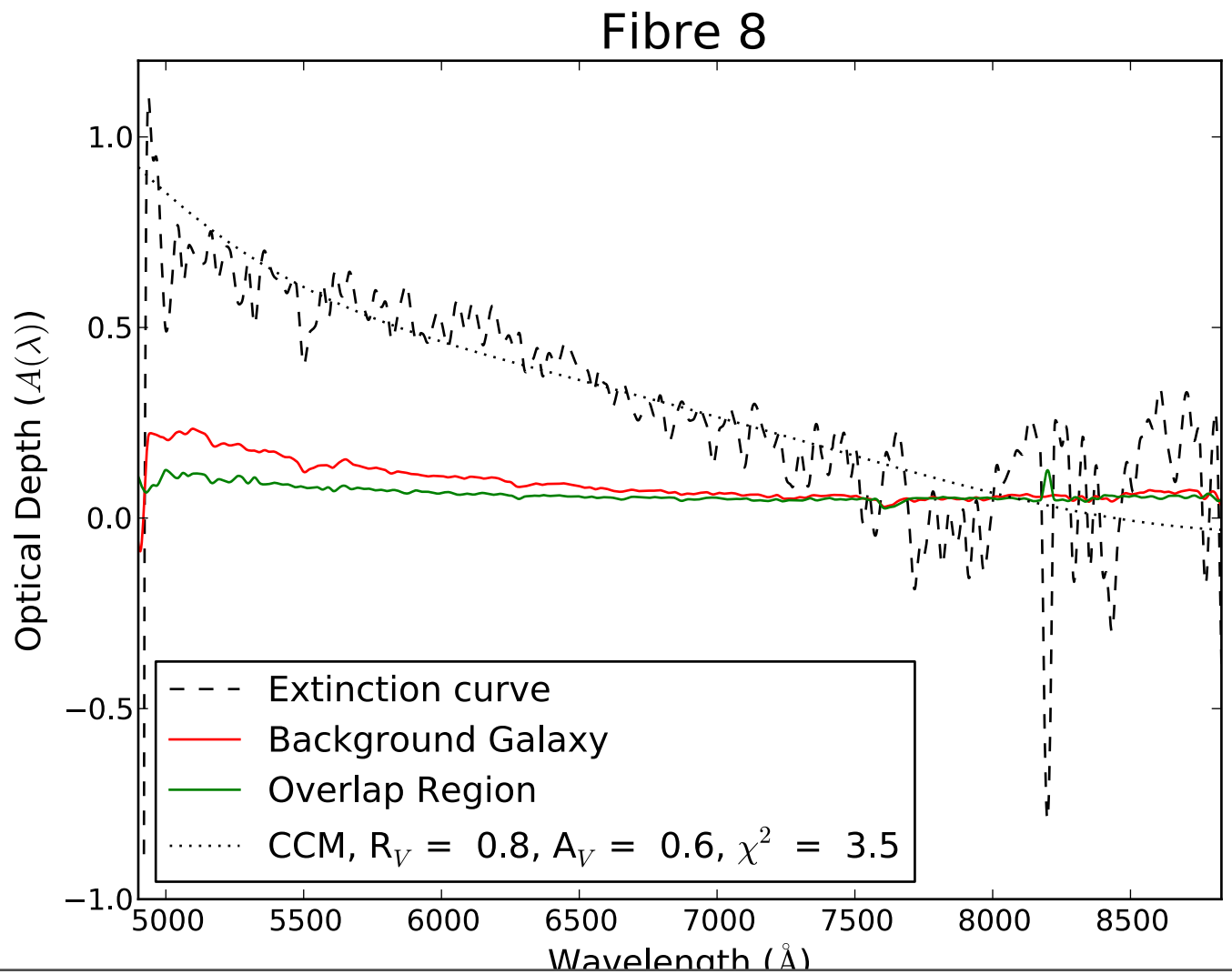
HST PAIR


VIMOS R=720
-25°07'32.0"
34.0"
36.0"
38.0"
40.0"
Dec (J2000)
3"
22.20s
22.00s
21.80s
21.60s
21.40s
0h48m21.20s
RA (J2000)

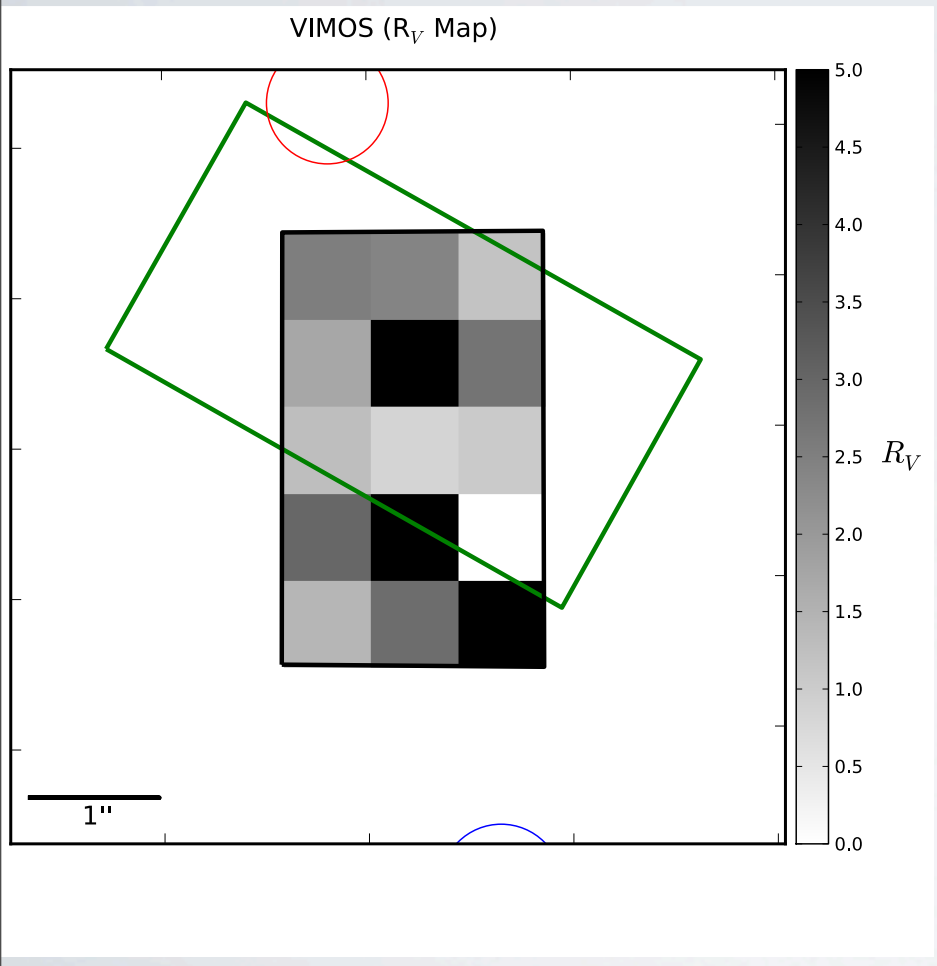
EXTINCTION CURVE

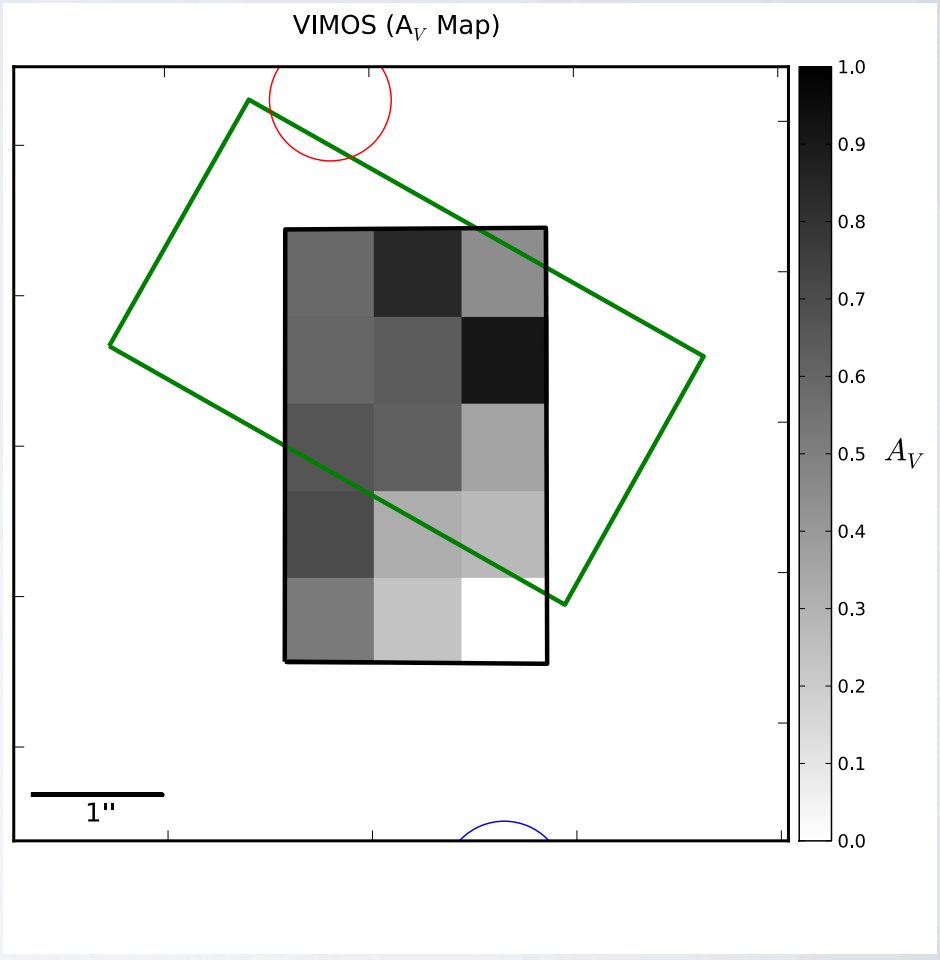


EXTINCTION CURVE



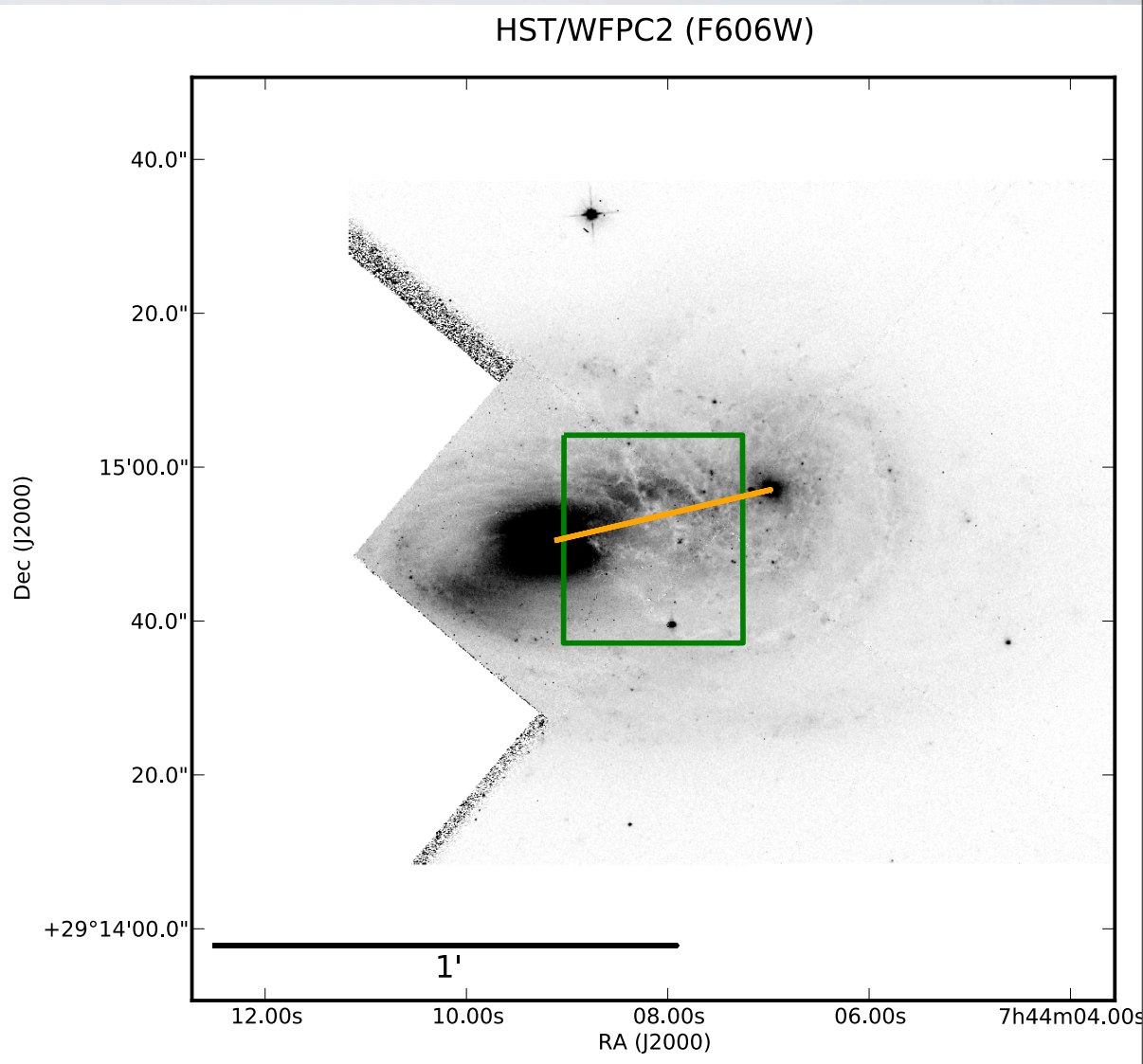
R_V AND A_V MAPS





UGC3995

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



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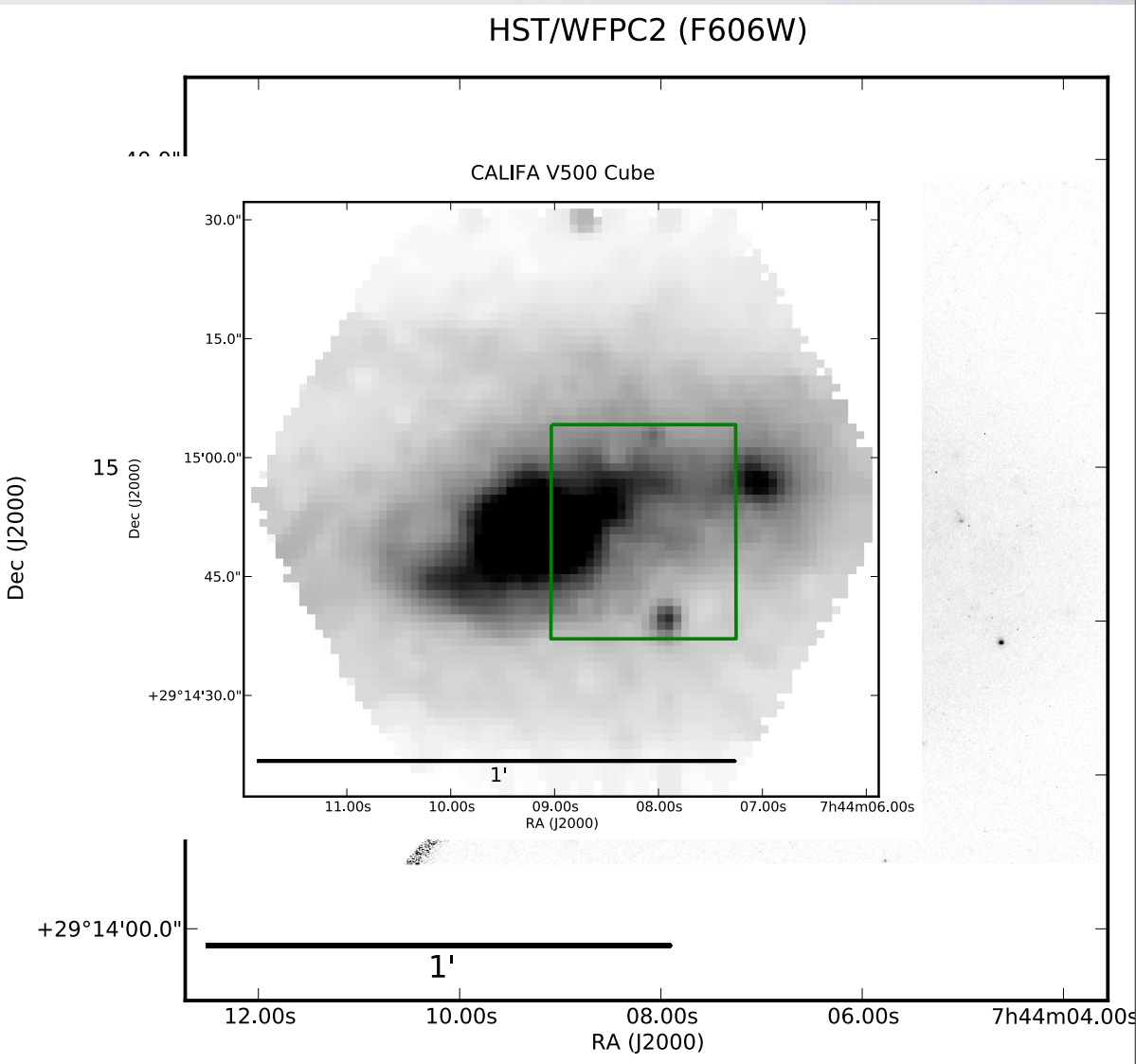
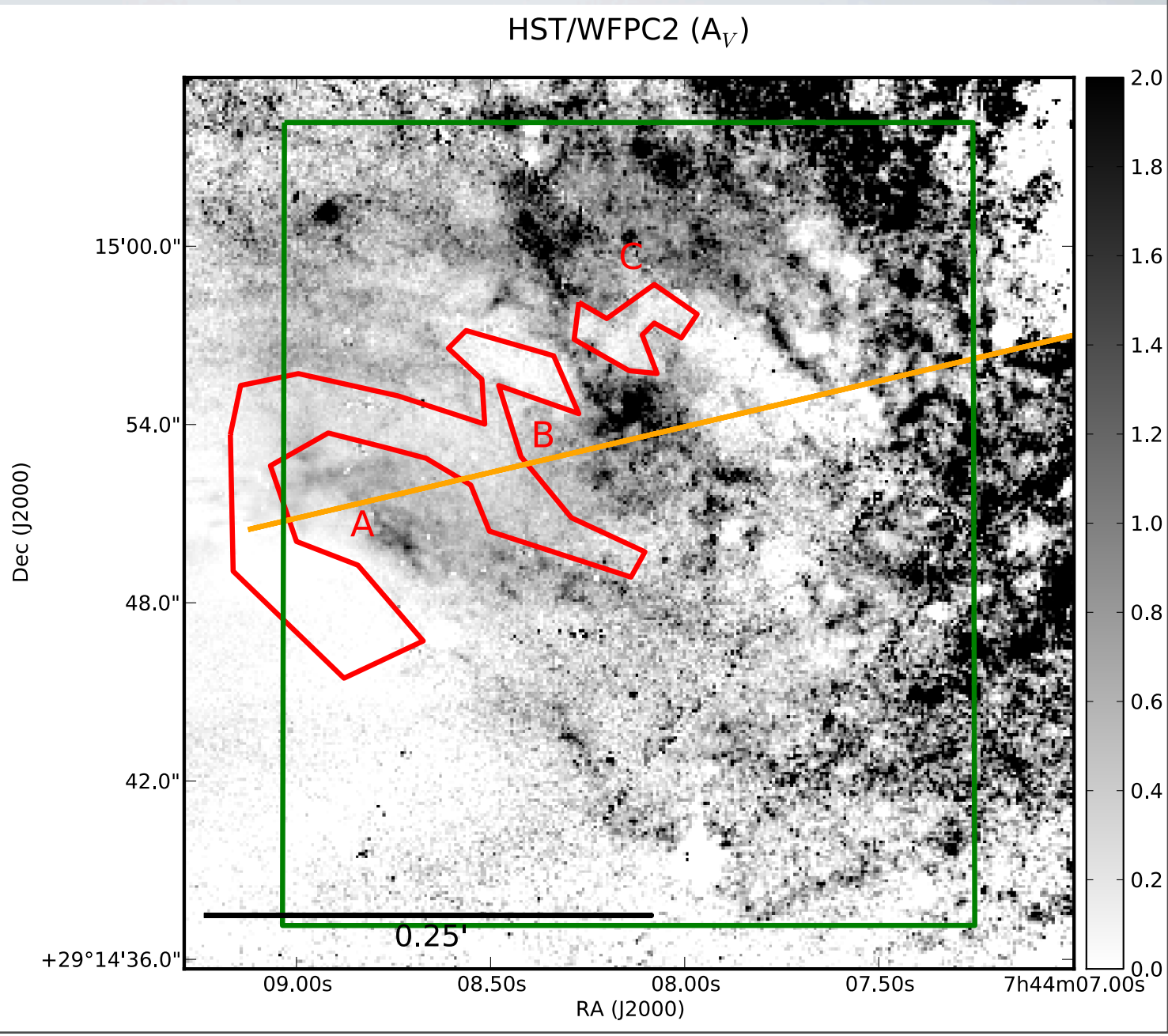
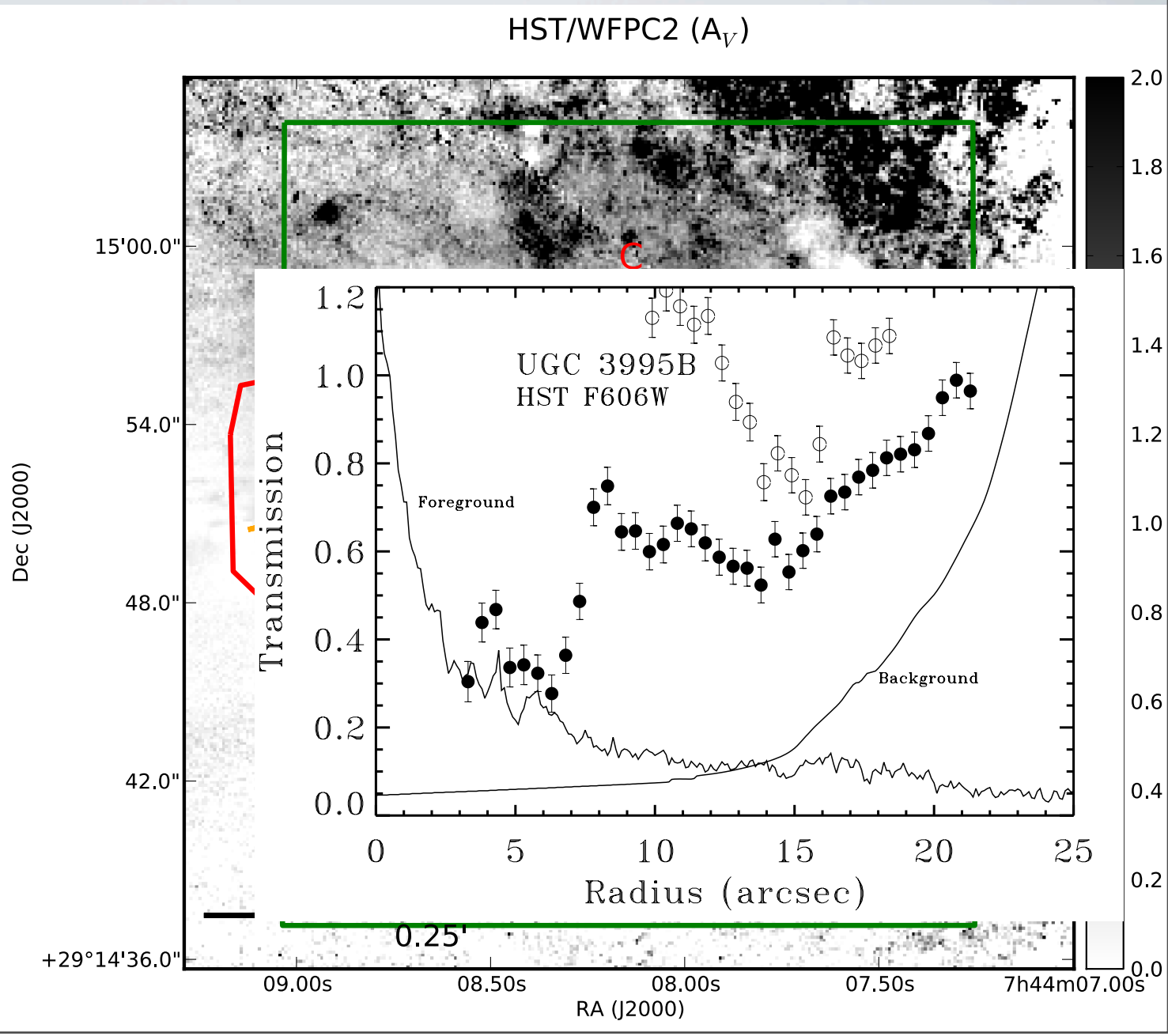


HST MAP


HST/WFPC2 (A_V)
15'00.0"
54.0"
48.0"
42.0"
+29°14'36.0"
Dec (J2000)
09.00s
08.50s
08.00s
07.50s
7h44m07.00s
RA (J2000)
A
B
C
0.25'
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

HST MAP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15'00.0"
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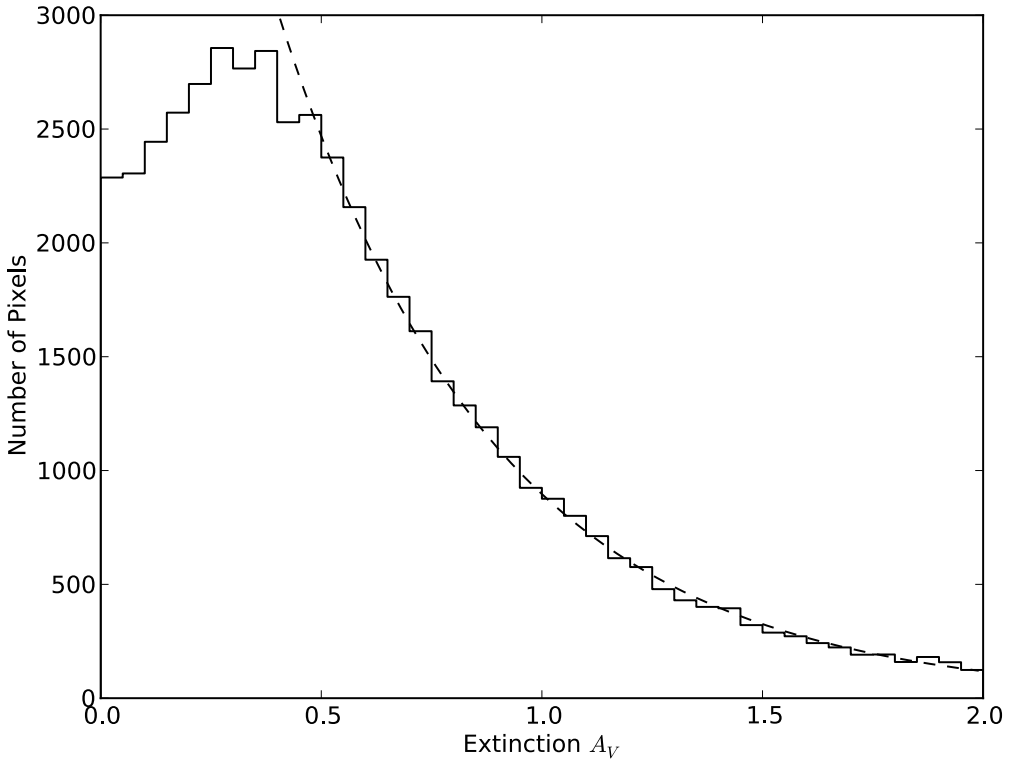
Dec (J2000)
09.00s
08.50s
08.00s
07.50s
7h44m07.00s
RA (J2000)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
UGC 3995B
HST F606W
Foreground
Background
Transmission
Radius (arcsec)
0.25'

A_V VALUES

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



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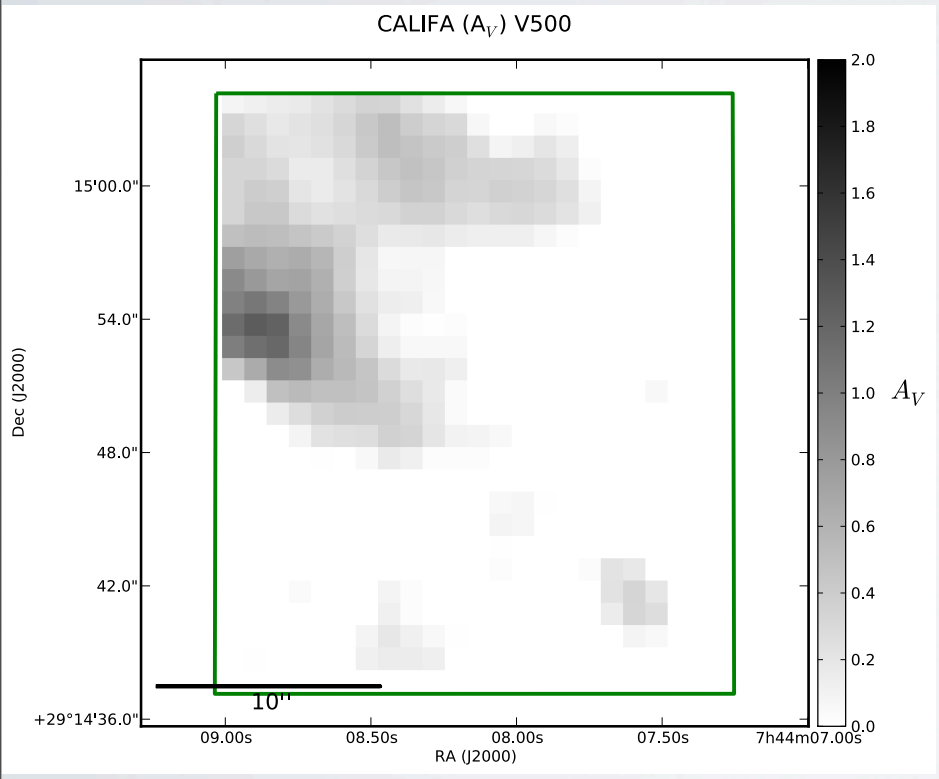
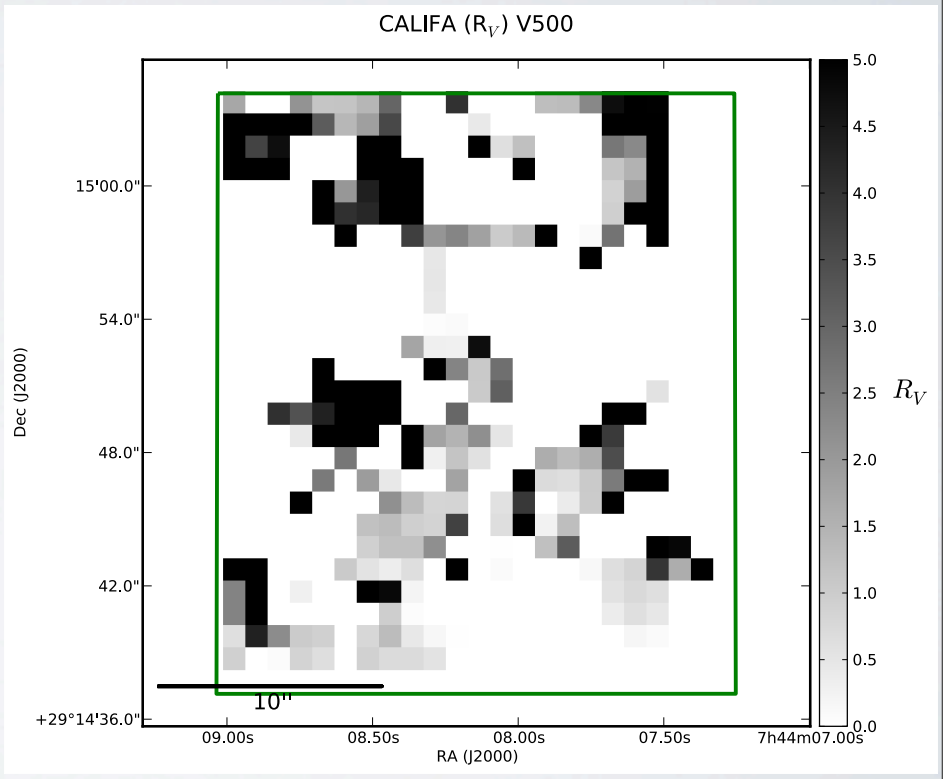
IFU A_V AND R_V MAPS





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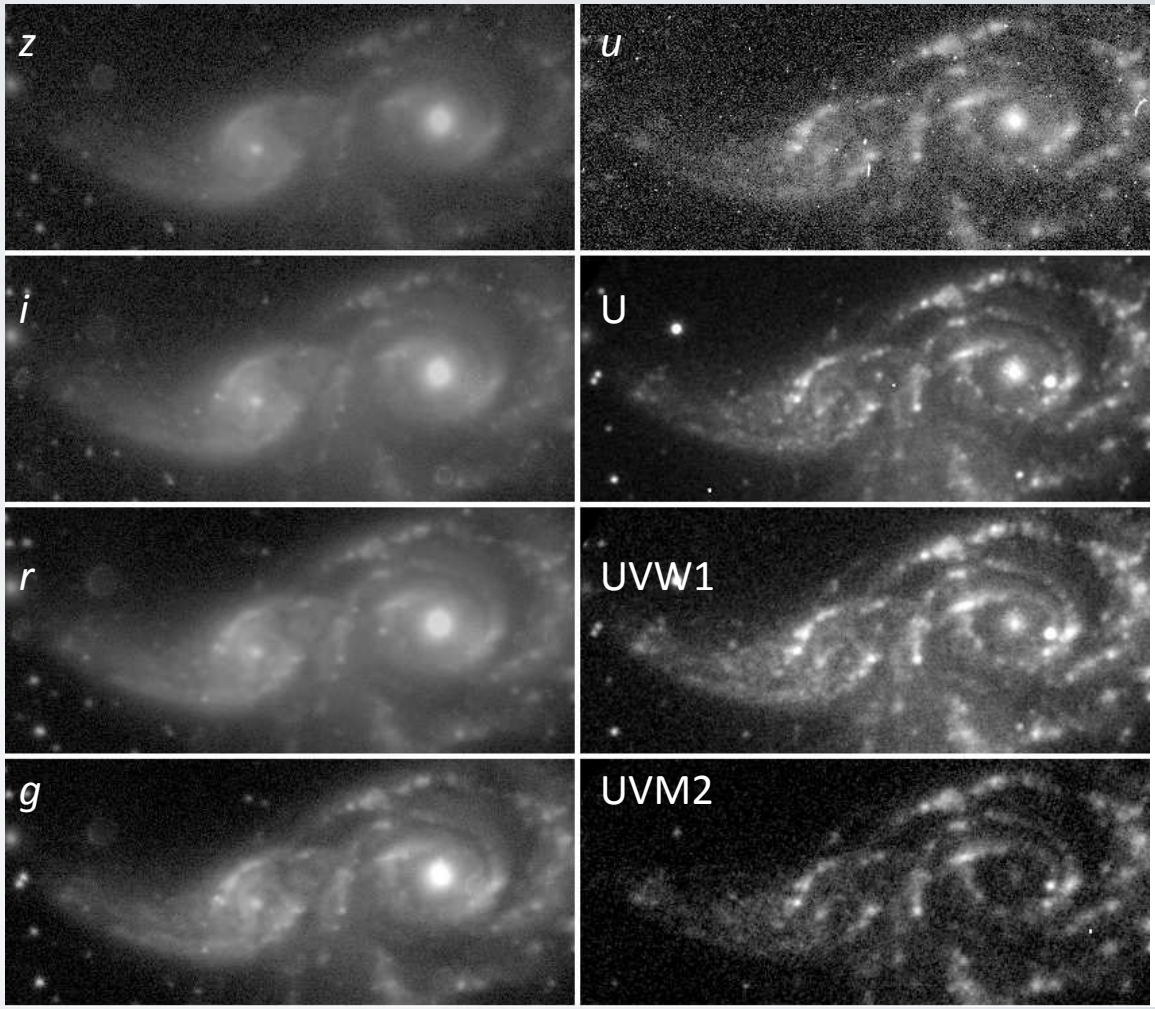
UV-OPTICAL EXTINCTION LAW



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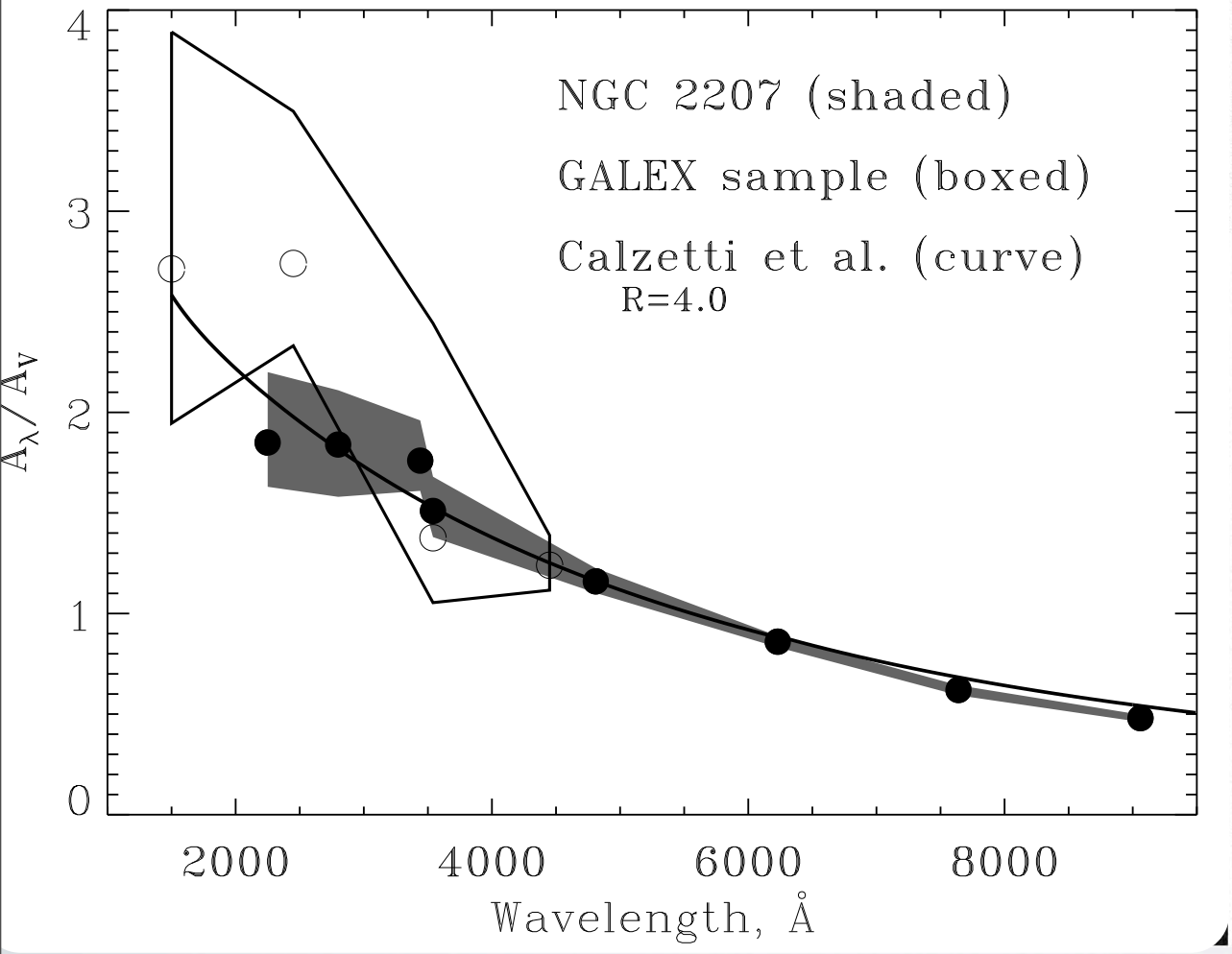
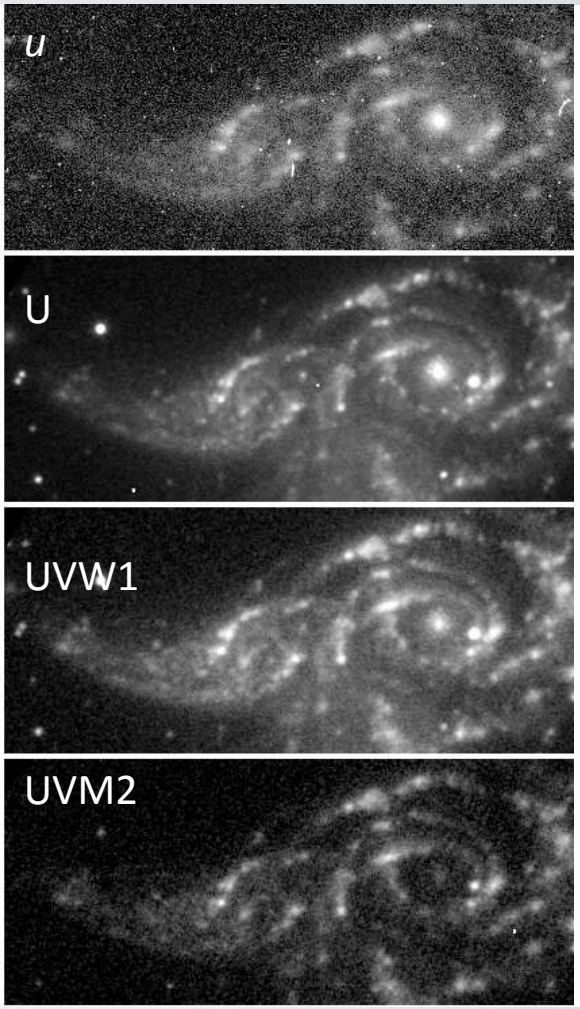
UV-OPTICAL EXTINCTION LAW





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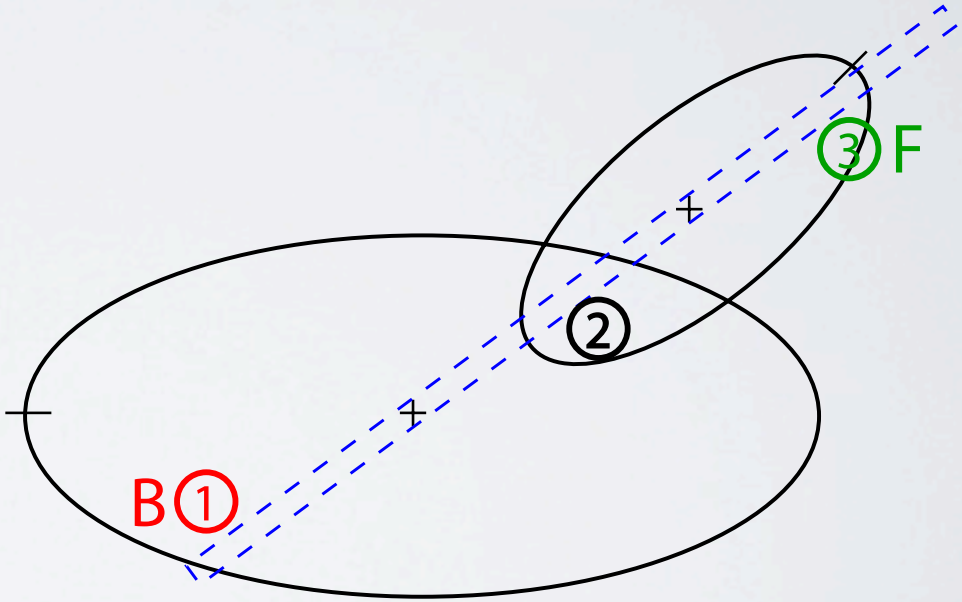
WILLIAM HERSCHEL TELESCOPE

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



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.
- Distributions of extinction values vary strongly from galaxy to galaxy.
- Extinction law is a flat CCM ($R_V < 3$) or Calzetti (UV+opt).

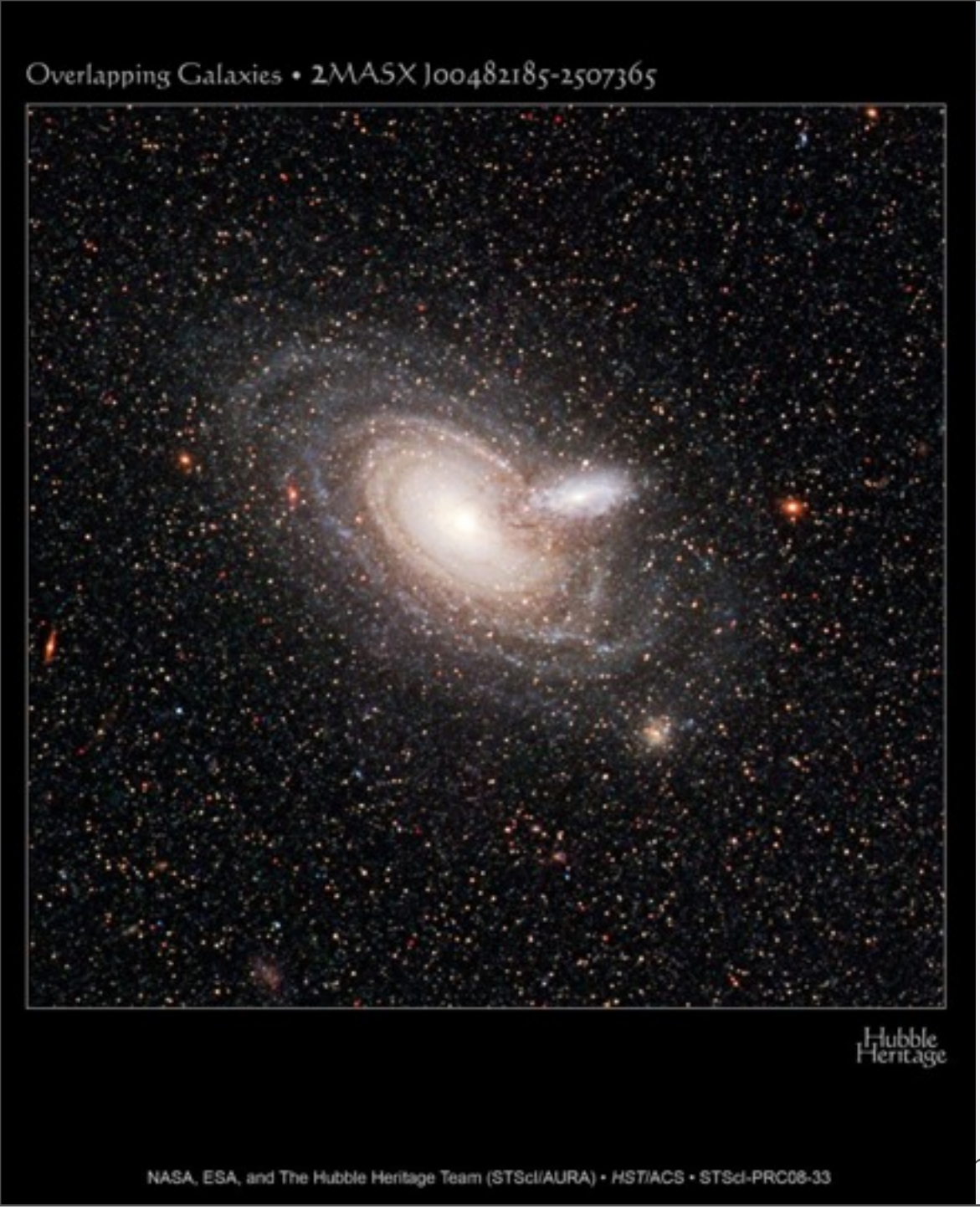
WHAT'S NEXT?

- 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.

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 does the dust disk extend?

B.W. Holwerda, ING Seminar, 30-8-2013



THANK YOU!

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