Tracing Cosmic Evolution with Void Galaxies

Anca Constantin & Chris Castillo (James Madison University)

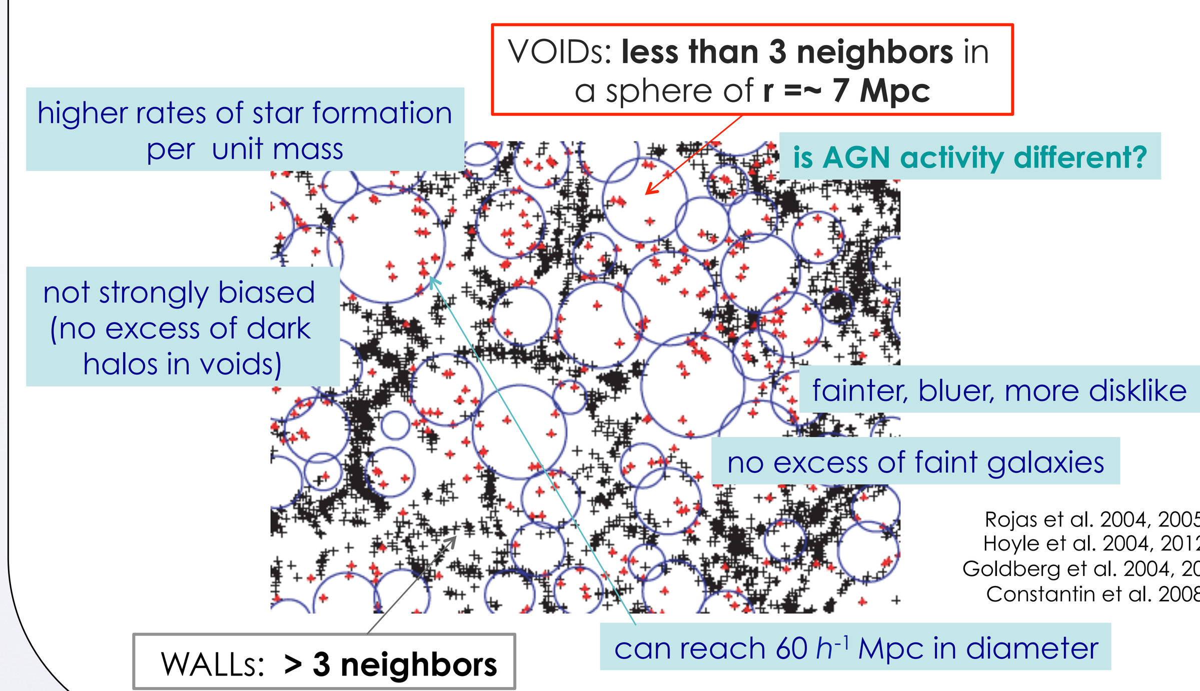
JAMES MADISON UNIVERSITY.

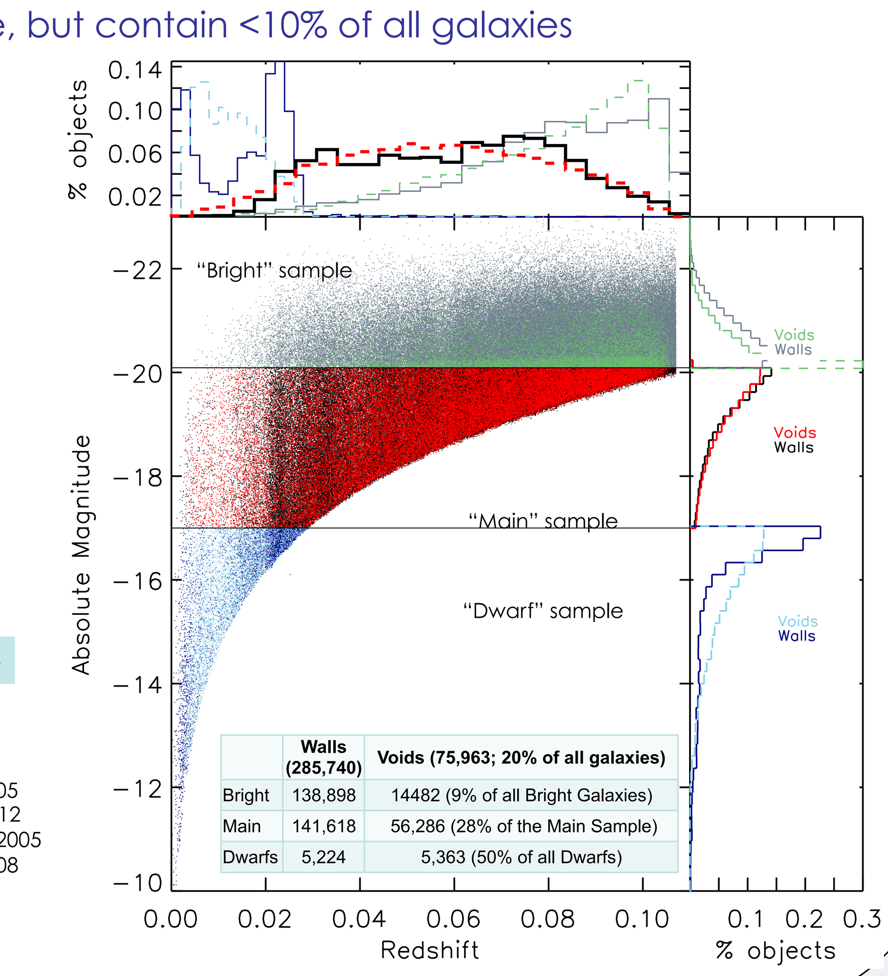
BACKGROUND: Given the standard cosmological paradigm in which structure in the present-day universe formed through hierarchical clustering, galaxies in the currently most underdense regions, the cosmic voids, must be the least "evolved" ones, as they must have formed at later times than those in the dense regions. Void and cluster galaxies must therefore follow different evolutionary paths, that probe a distinct mix of "nature versus nurture" drivers (e.g., galaxy interactions) of the coevolution of galaxies and their central black holes. The void galaxies are then the arguably best test-bed for constraining the currently elusive coupling between the central accretion and star-formation activities, along with its cosmic evolution.

THIS WORK: We present an in depth optical (SDSS) + mid-IR (WISE) investigation of the void galaxies, with novel constraints for the previously proposed evolutionary sequence sequence HII → Seyfert → Transition Object → LINER → Passive Galaxy in which galaxies transform from star-forming via AGN to quiescence, along with possible concrete ways in which ALMA observations of key examples of void systems could be exploited to map more directly the galactic duty cycle and its environmental dependence.

THE VOIDs SAMPLE: Voids occupy ~50% of the whole universe, but contain <10% of all galaxies

- Void finder algorithm from Hoyle & Vogeley 2002
- Implemented with SDSS, DR7 by Pan et al. 2012 => largest sample of voids.
- Voids are dynamically distinct (radial profiles match the predictions of void growth by gravitational instability), not simply smaller scale underdense environments.

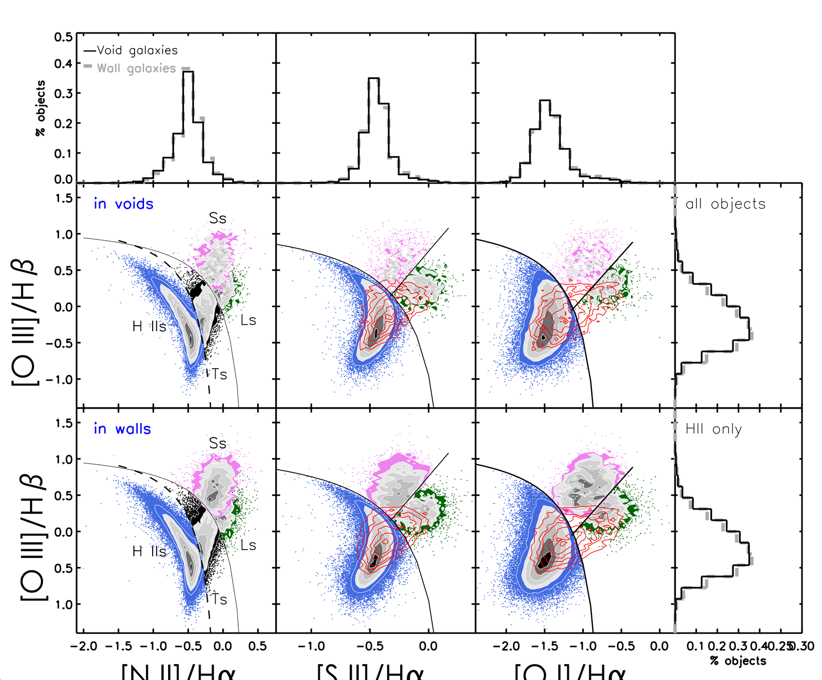




	Walls (285,740)	Voids (75,963; 20% of all galaxies)
Bright	138,898	14482 (9% of all Bright Galaxies)
Main	141,618	56,286 (28% of the Main Sample)
Dwarfs	5,224	5,363 (50% of all Dwarfs)

- Work with the "Main" samples of void and wall galaxies: well matched in BOTH r-band absolute magnitude & redshift.
- Stellar masses and spectral line measurements are from MPA/JHU catalogs (http://www.mpa-garching.mpg.de/SDSS/)
- Optical spectral classification is based on criteria of Kewley et al. 2006

Optical Spectral Signature for Nuclear Activity in Void and Wall Galaxies:



	Walls		Voids	
Emission line	93 866 (66%)		43 059 (77%)	
Seyferts	2 272	2.5%	895	2%
LINERs	2 245	2.5%	845	2%
Transitions	12 681	14%	4 974	12%
HII's	71 066	75%	33 817	79%

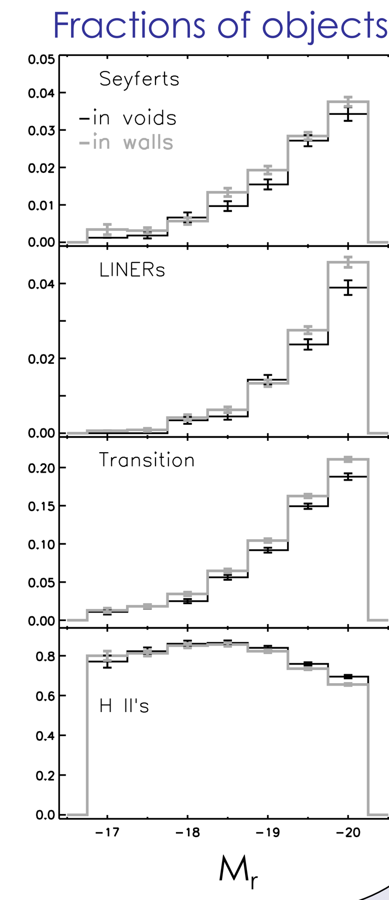
Compare at fixed brightness →

- Lower overall AGN (Seyferts, LINERs, Transition Objects) activity occurrence rate

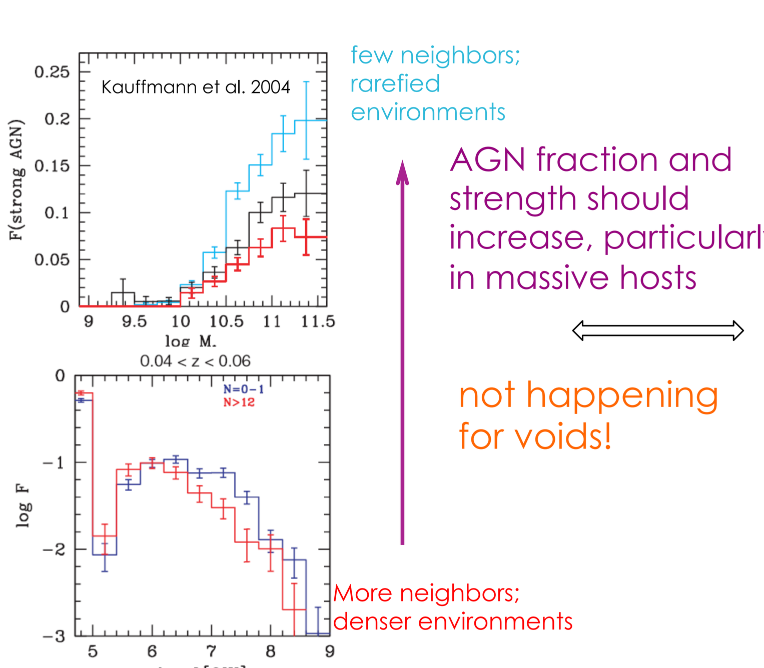
  → Difference more pronounced for LINERs, especially in brighter (L>L*) void galaxies

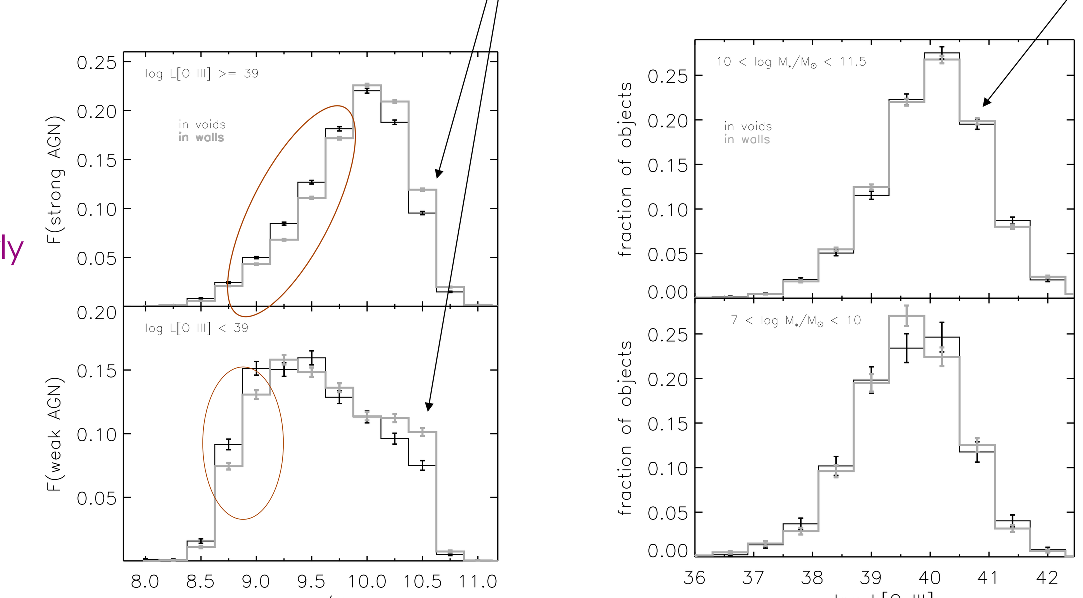
- HII's more ubiquitous at all (but the faintest) M_r

Fractions of objects



Optical AGN FRACTION: There is no excess of AGN activity in massive ($M_* > 10^{10} M_\odot$) void galaxies





Both weak and strong AGN are more frequent in voids than in walls, only among medium & small mass galaxies

A FIRST *WISE* TAKE ON THE VOID GALAXIES: mid-IR observations discover optically hidden AGN via color-color cuts (SEDs clearly distinguishable from normal SF galaxies).

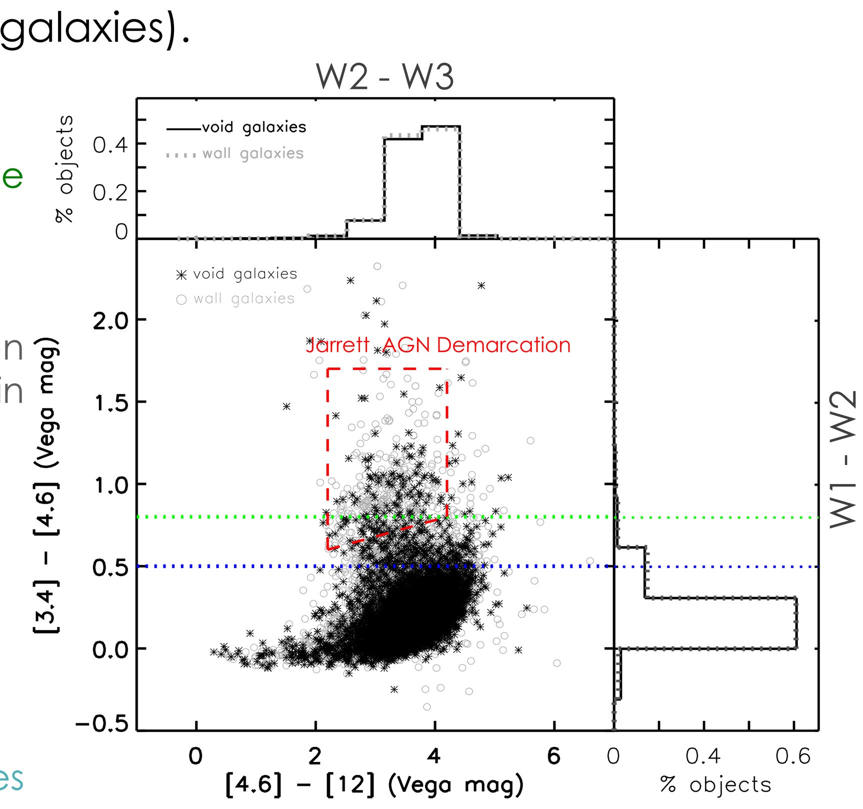
- WISE color-color distributions are indistinguishable in voids and walls
- WISE AGN candidate selection reveals similar OVERALL fractions in voids and walls:

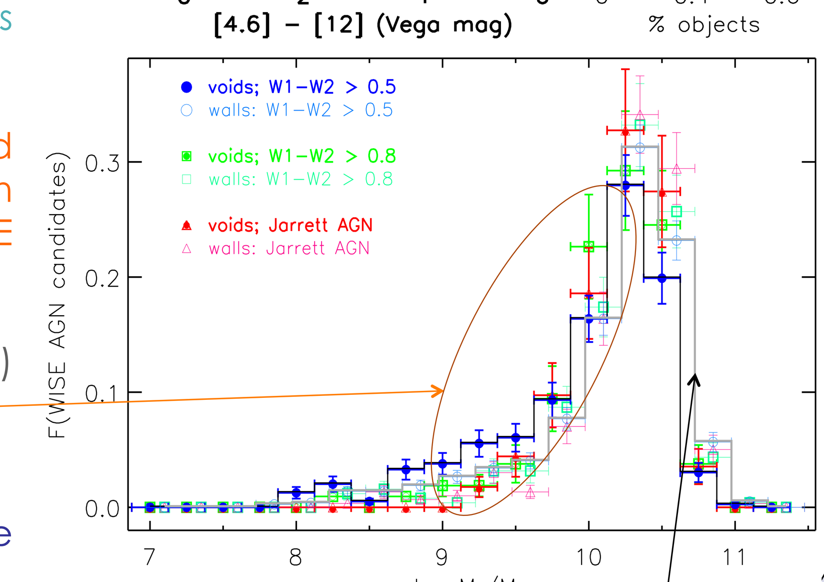
	Walls (56,705; 40% of all wall galaxies)	Voids (26,074; 46% of all void galaxies)
Jarrett Demarcation	299(0.5%)	113 (0.4%)
W1-W2 > 0.8	253 (0.4%)	253 (0.4%)
W1-W2 > 0.5	794 (1.4%)	397 (1.5%)

- => higher fraction of void galaxies detected in bluer WISE colors.
- Different WISE-AGN fractions in void and wall galaxies of low and high stellar mass M*, regardless of the WISE color cuts:

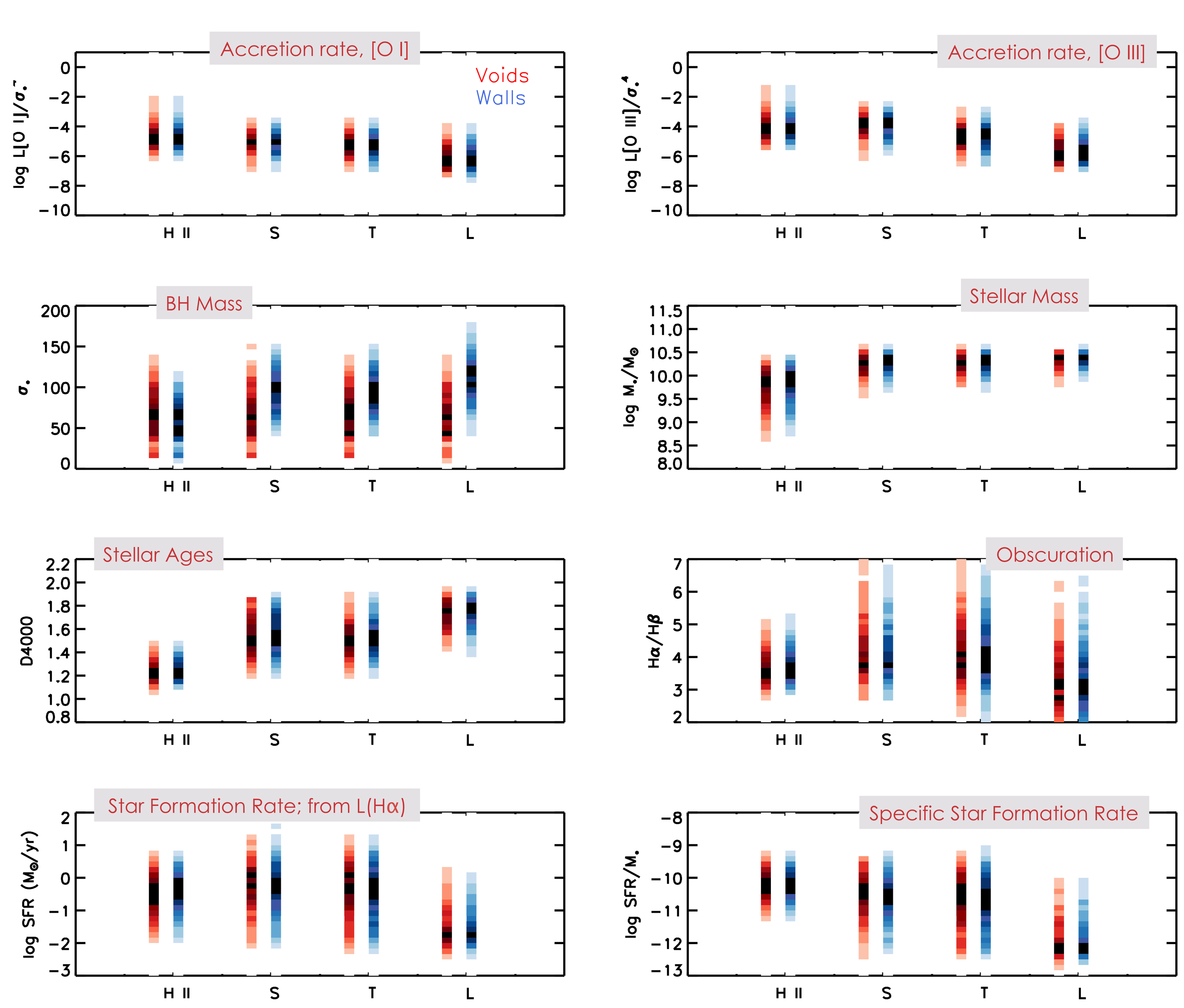
  → Higher fraction of red (hidden) AGN activity only in low mass ($M_* < 10^{11} M_\odot$) void galaxies.

  → No excess of red AGN in massive ($M_* > 10^{11} M_\odot$) void galaxies





A (secular) AGN EVOLUTIONARY SEQUENCE? Slower in VOIDS?



At 10% accretion efficiency → e-folding time in M_{BH} = Hubble time; $L/L_{edd} < 0.005$

At 0.001% accretion efficiency → e-folding time in $M_{BH} = 10^2 / (L/L_{edd})$ = few Myrs!

I. HII's - circumnuclear starburst, high accretion but obscured (more massive seed BHs; younger in voids)

II. Seyferts - waning SF, brief breakout of accretion emission (weaker accretion in voids; fuel still used for forming stars)

III. Transition obj's - aging stellar pop, accretion weaker

IV. LINERs - older stellar pop, minimal accretion, fuel exhausted (less massive in voids; larger fraction of void galaxies not here yet!)

V. Passive Galaxies –no accretion, no SF.

Learned from nothing:

- All types of AGN are found in voids, though 20% fewer AGNs and slightly higher fractions of HII's.
- Higher fractions of accreting systems in ~L* void galaxies, in striking contrast to expectations for excess of AGN in bright void hosts.
- Possible lower accretion rate in void AGN, linked to (=> probably due to) less fuel availability, as it is more efficiently used for SF.
- Are void AGN (and their hosts) at an earlier stage in an evolutionary sequence?

FUTURE DIRECTIONS:

1. Investigate the chemical abundances of the optical and WISE AGN candidates in void and wall galaxies, as a function of host galaxy mass and absolute brightness, in order to assess or dismiss the possibility that the red colors might originate from hard radiation fields produced by extreme star formation in low-metallicity environments (e.g., Campbell et al. 1986).
2. Test potential differences (& outliers) in the optically and mid-IR probed SFR – M_* Main Sequence Scaling Relation between voids and walls.
3. Provide the first tests of dwarf galaxy properties in voids: accretion fraction as a function of stellar mass of the host, location in the SFR – M_* Main Sequence Scaling Relation.

WITH ALMA:

1. Investigate and compare properties of the molecular gas that should constrain the onset of star-formation and connection to H I -to- H_2 conversion, and thus with the potential fueling mechanisms for nuclear accretion in the most underdense regions of the universe.
2. Populate the Main Sequence Scaling Relation with exotic void galaxies to provide independent constraints for its nature and possible environmental effects.

We gratefully acknowledge support by the 4-VA Collaborative at James Madison University.

JAMES MADISON UNIVERSITY PHYSICS AND ASTRONOMY