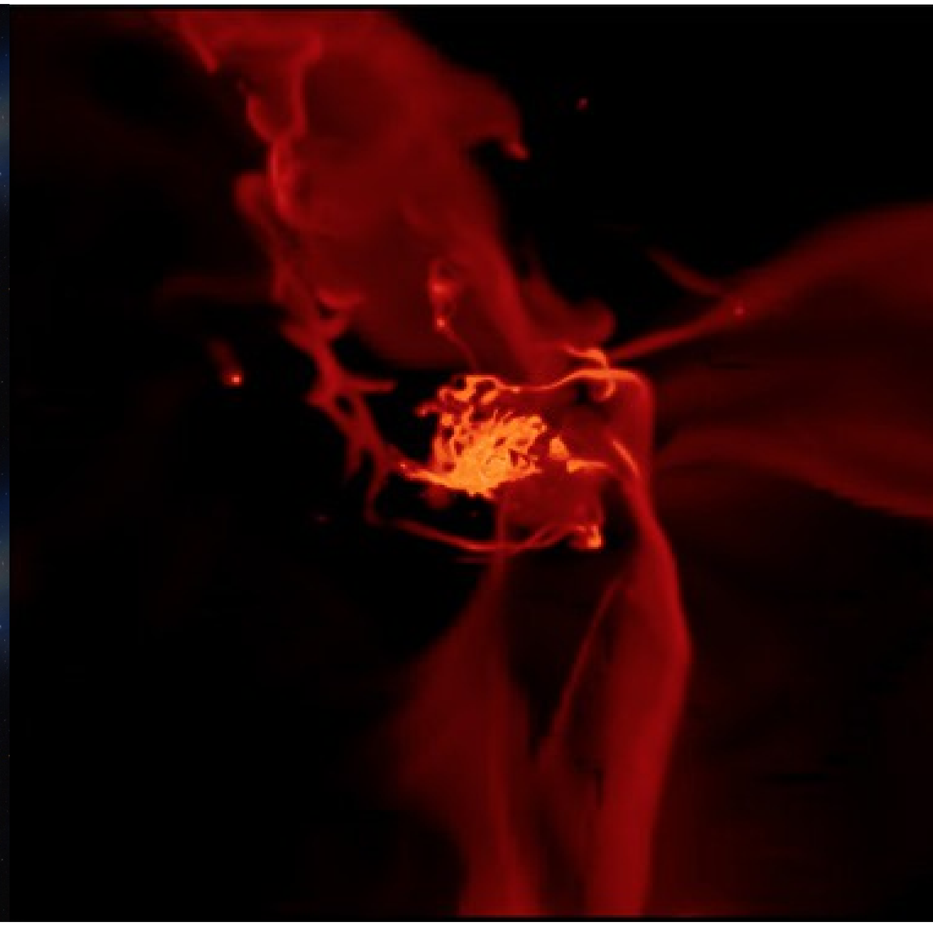
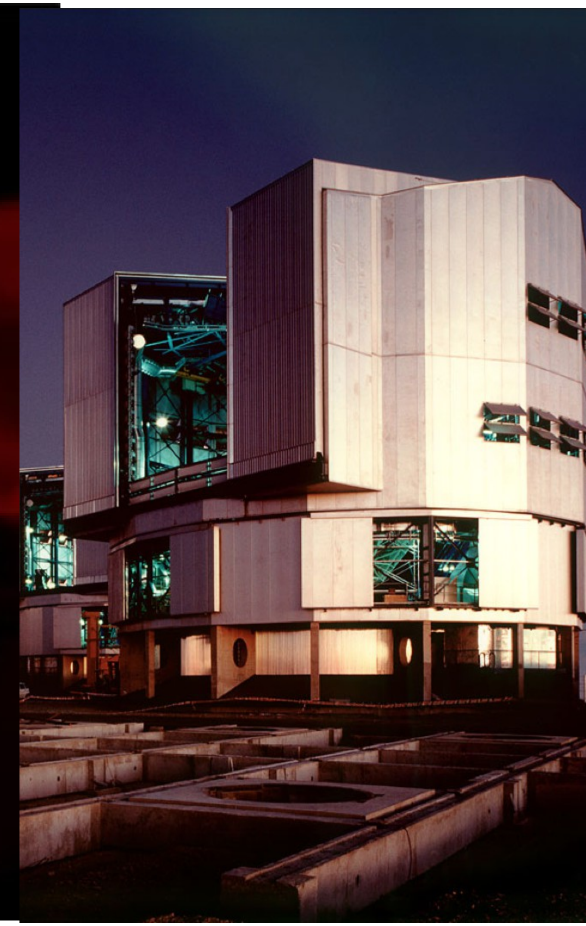
# ATLAS search for Lyman Limit Systems in quasar pairs





With Joe Hennawi, Tom Theuns, Rob Perry et many others & the ATLAS team?

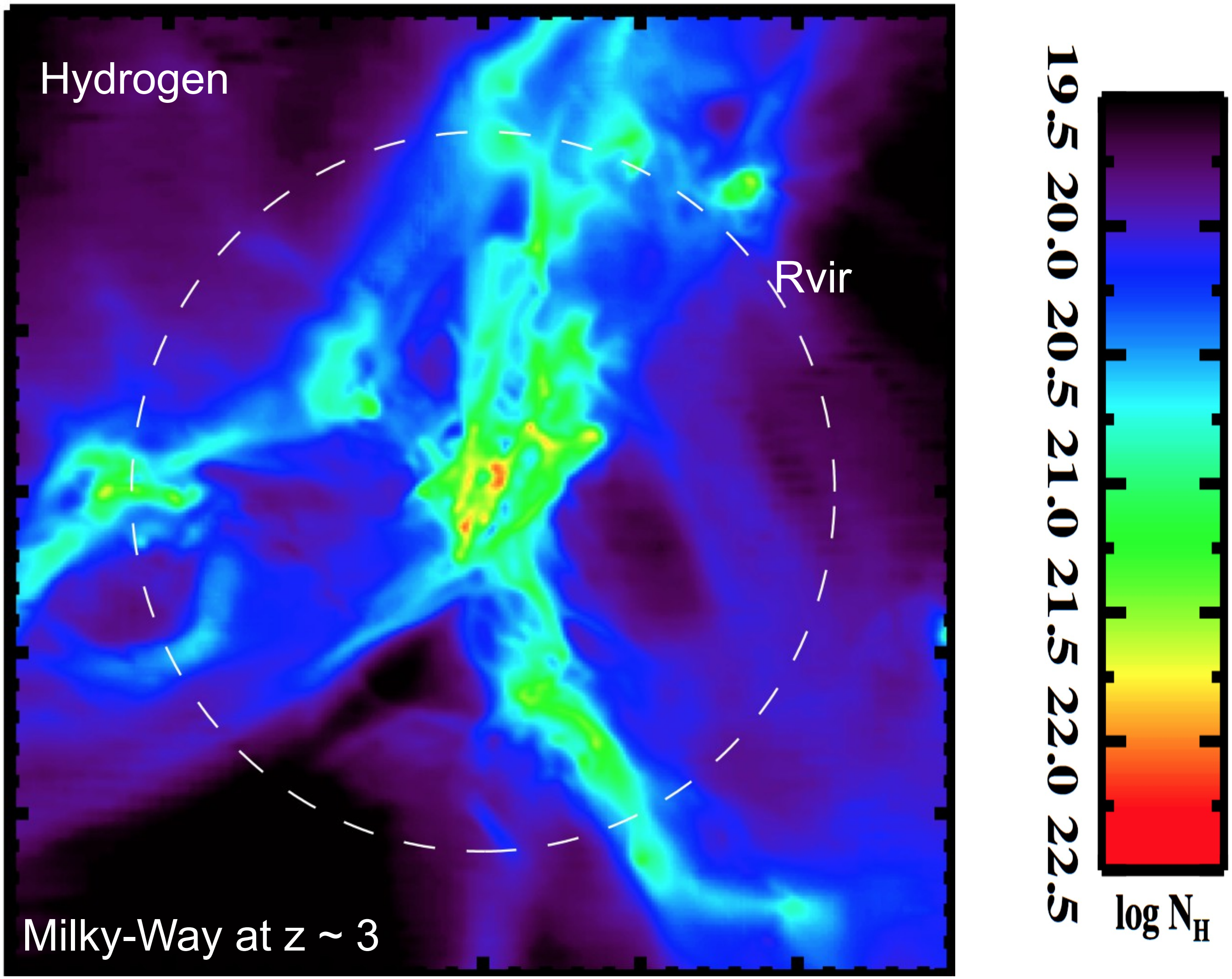
Durham University

Michele Fumagalli
Durham University
Carnegie Observatories

# Why Lyman Limit Systems?
# And why quasar pairs?

# The goal: gas around galaxies

The circumgalactic medium encodes the echos of two key processes for gas evolution: gas inflows and outflows



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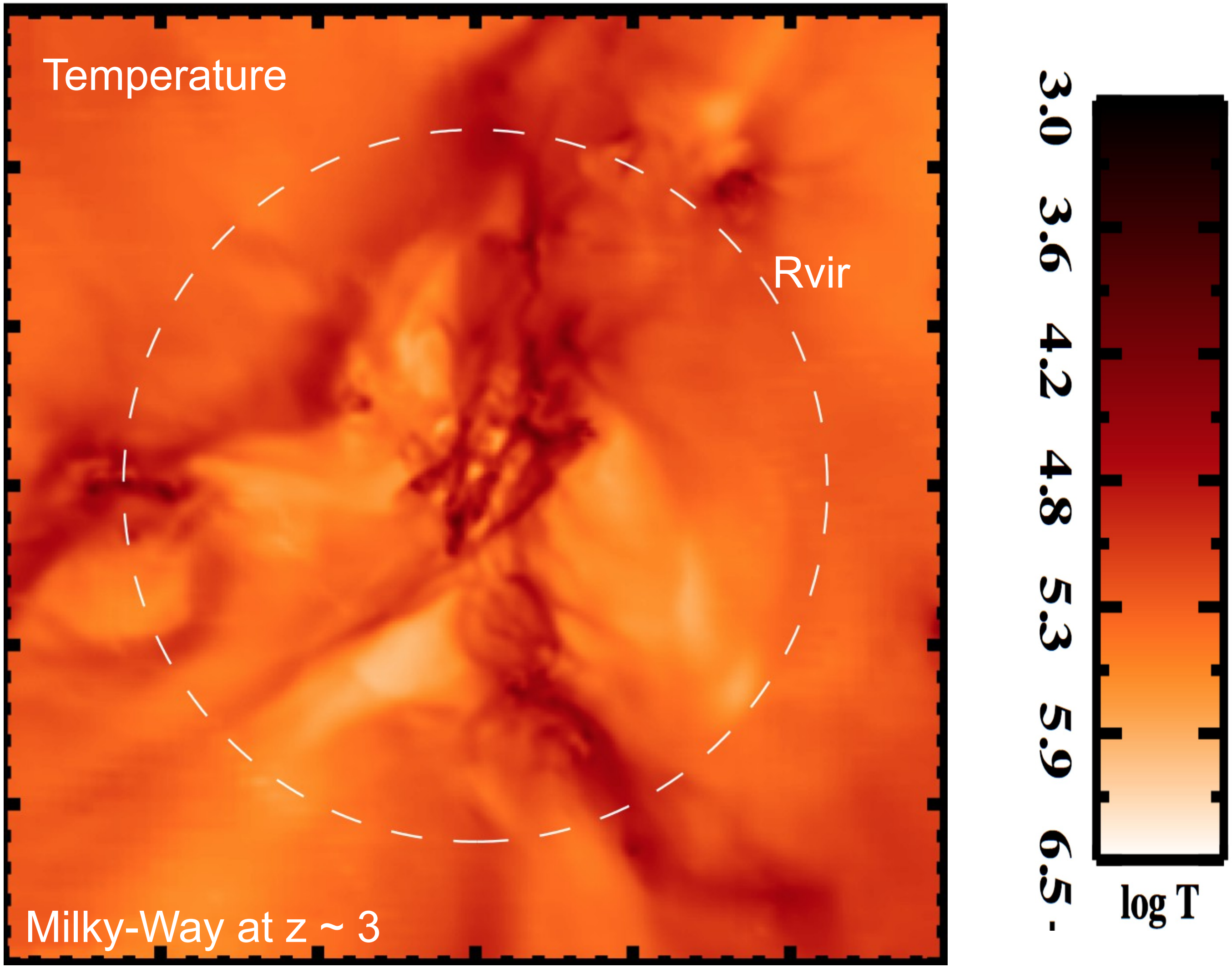

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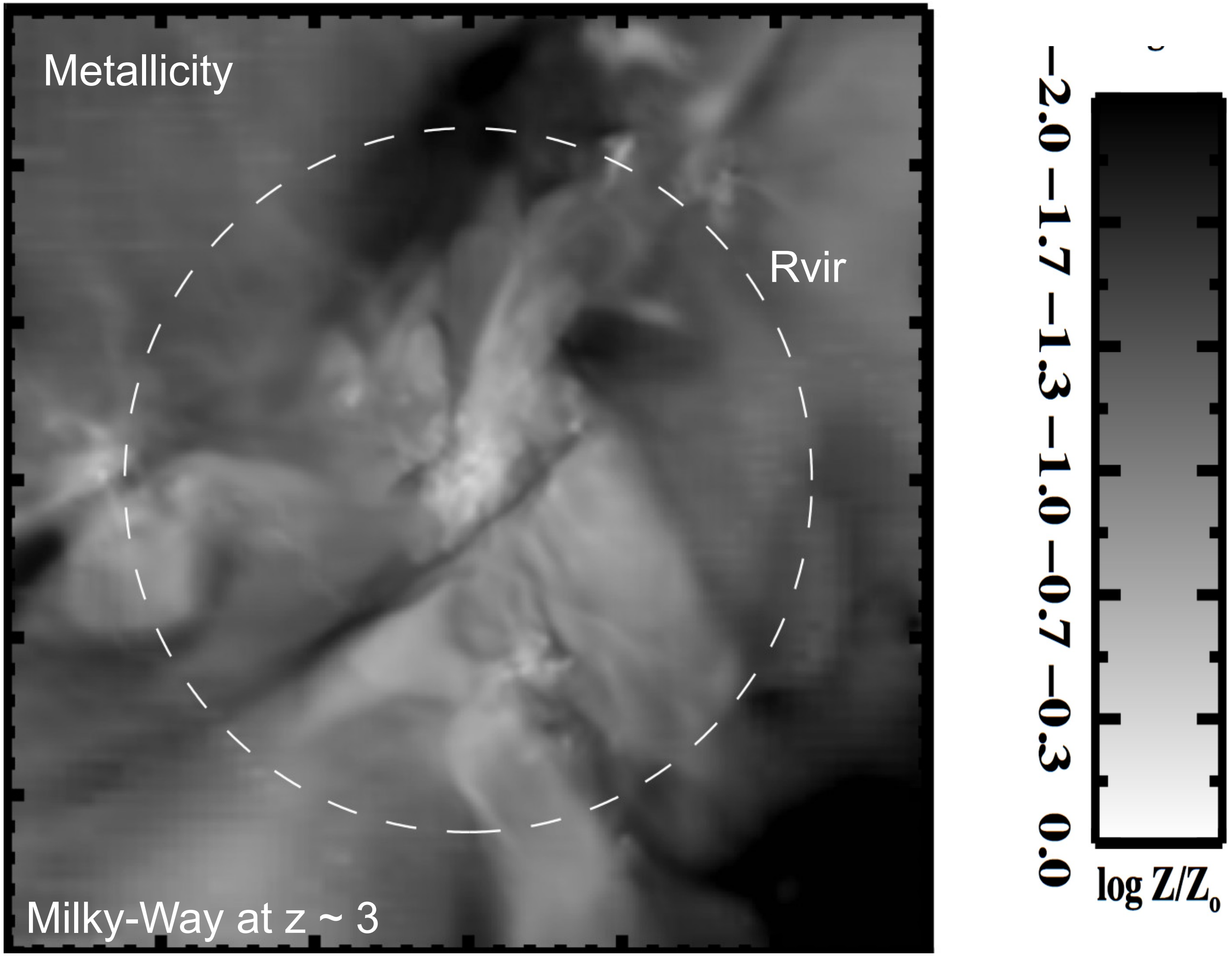
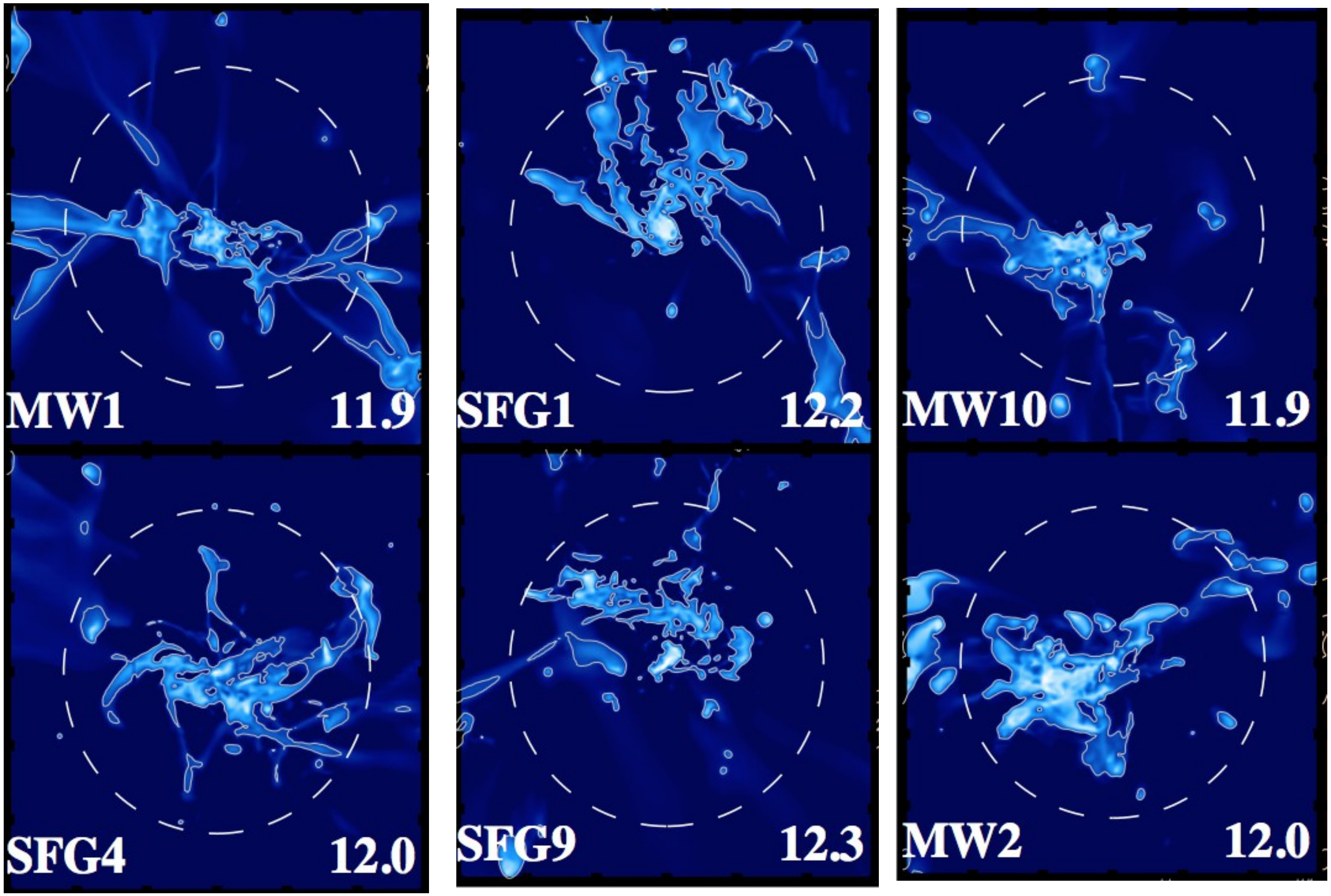
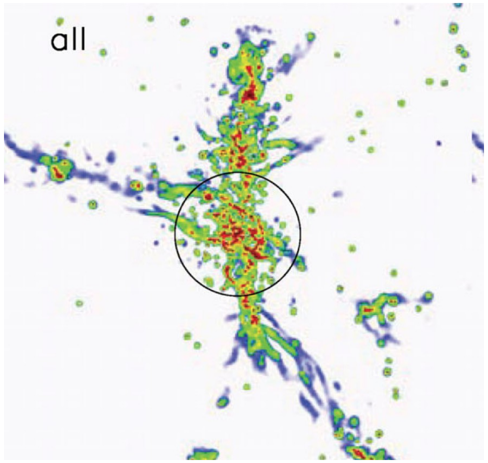


# CGM, Absorption Lines, and LLS

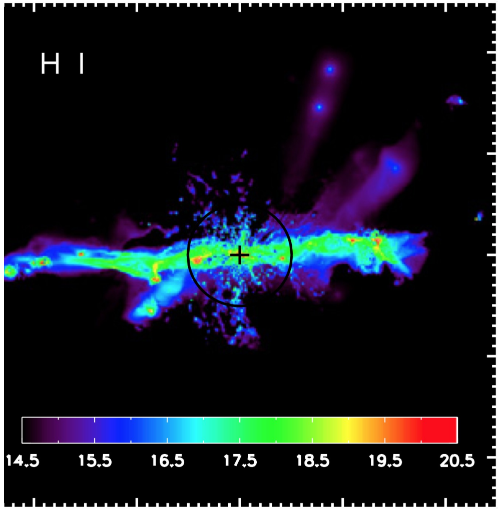
Absorption lines offer a powerful tool to investigate the properties of the CGM, and in particular LLSs




MF et al. 2011,2014




van de Voort et al. 2012




Shen et al. 2013

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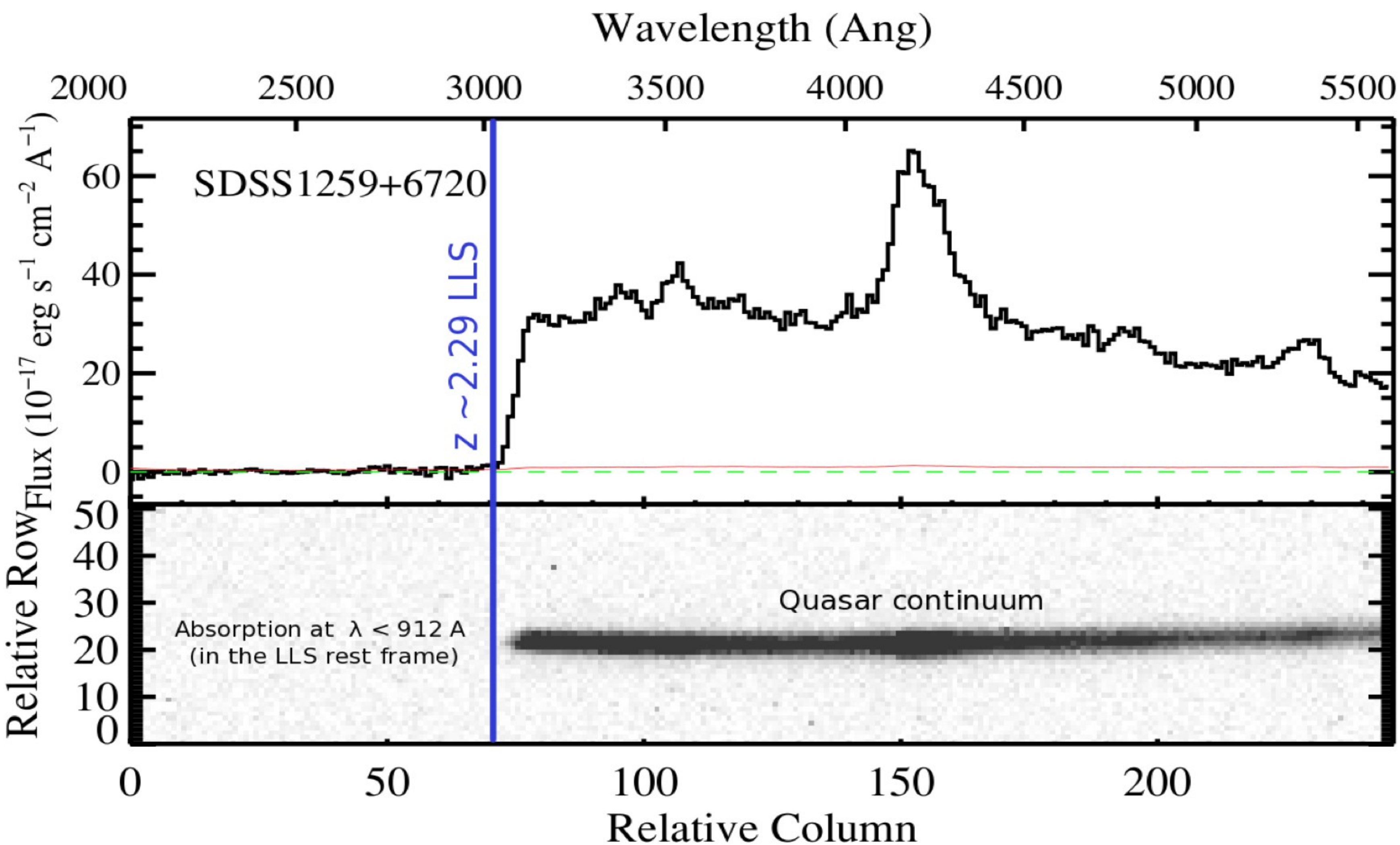


O'Meara et al. 2012

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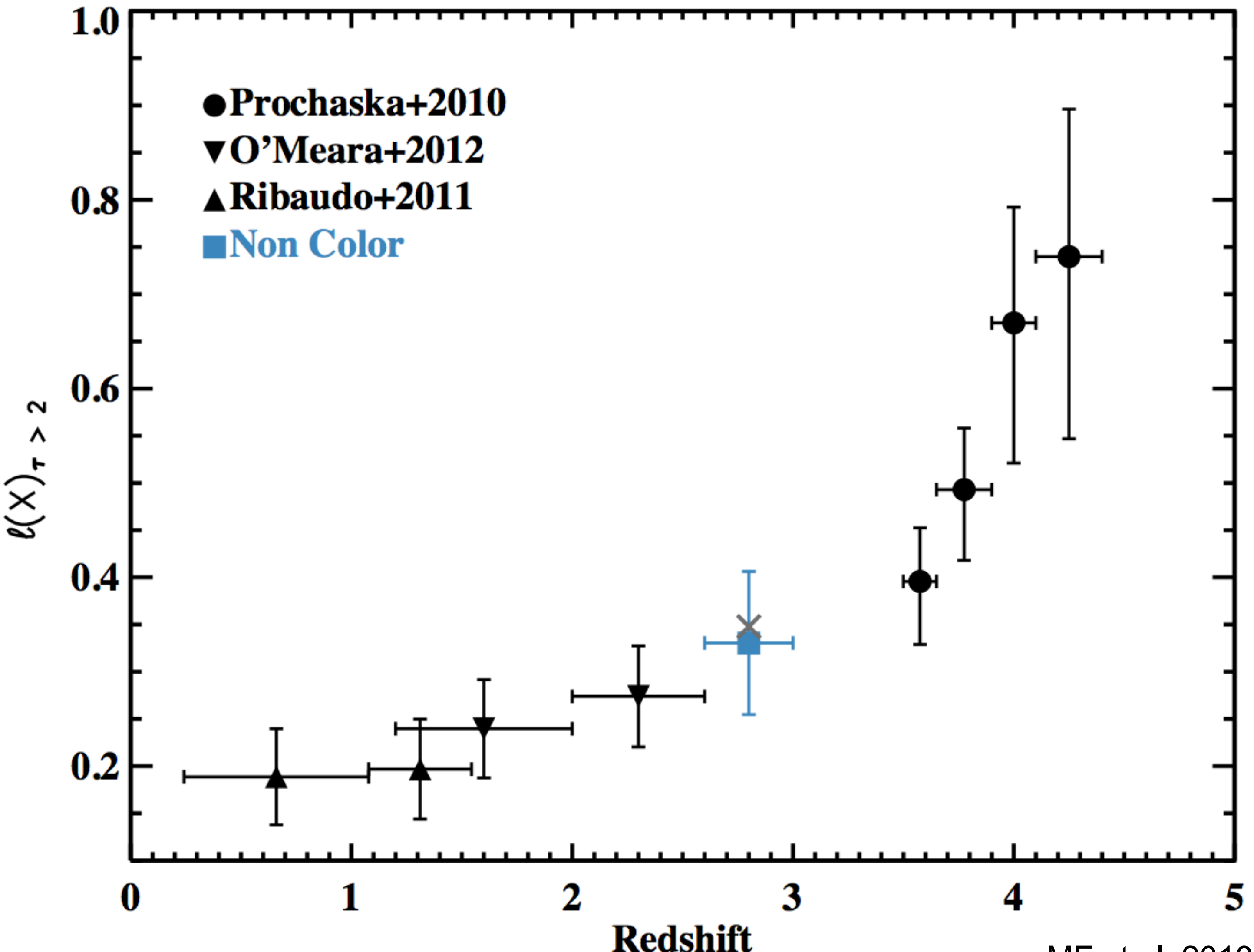
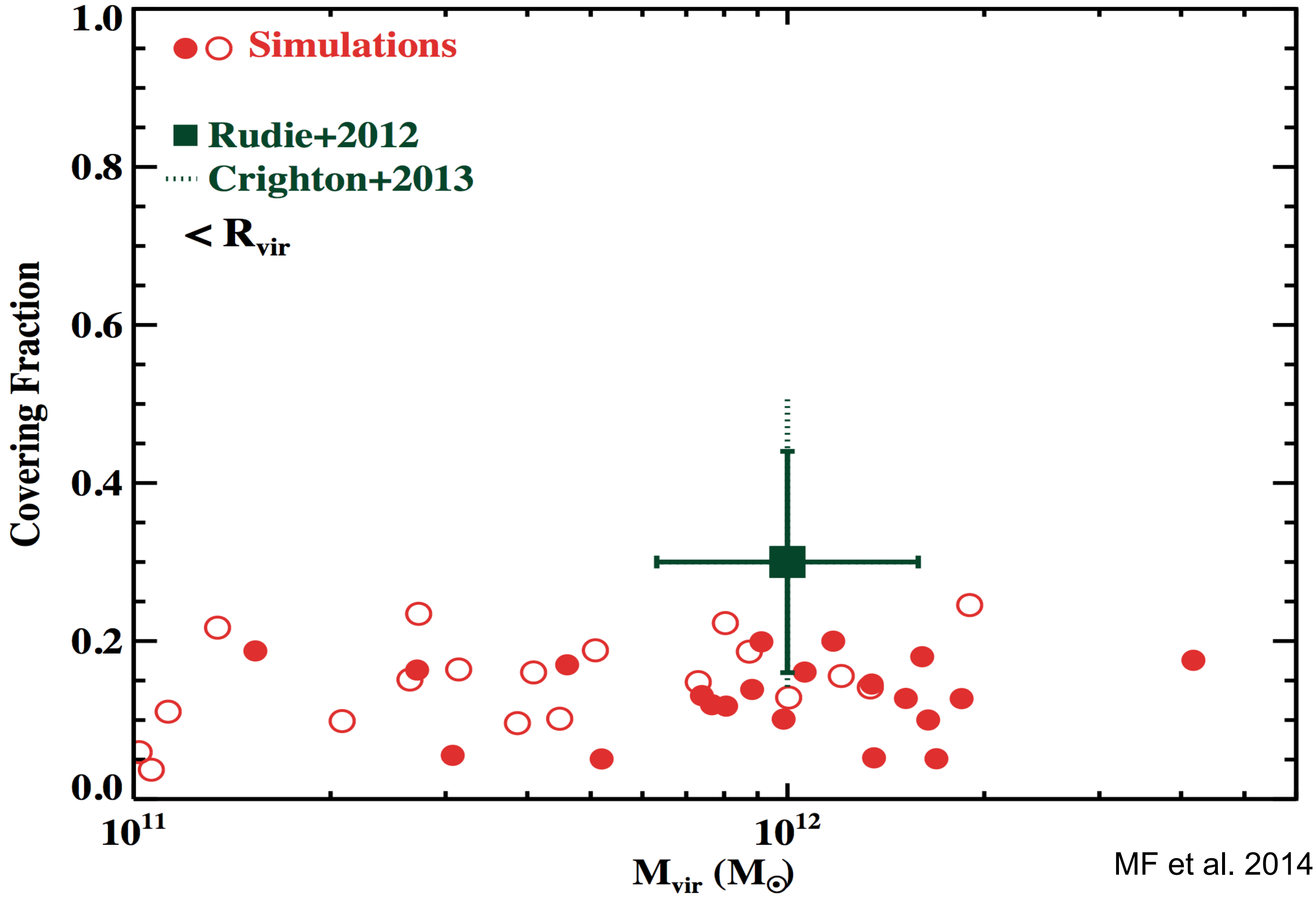



MF et al. 2013

# Ok, but why quasar pairs?

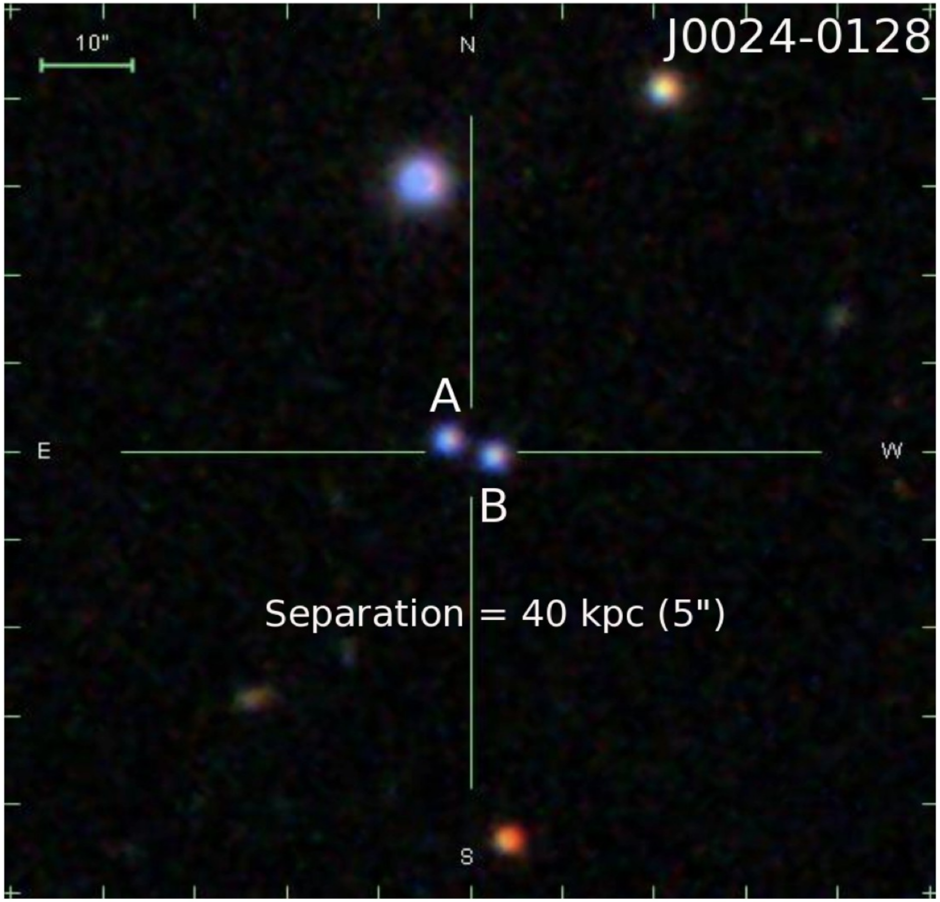
Our knowledge of the distribution of optically thick gas around z~2-3 galaxies is limited by the number of quasar/galaxy pairs

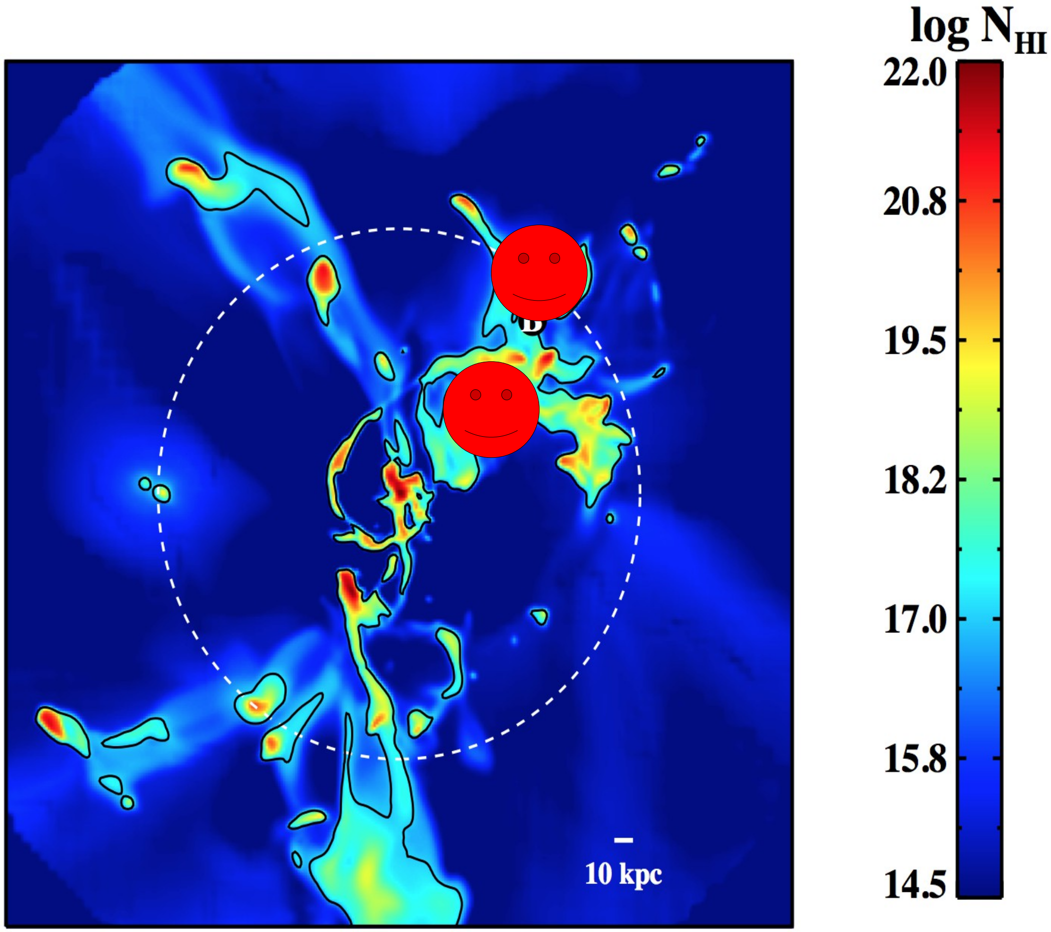



MF et al. 2014

# Ok, but why quasar pairs?

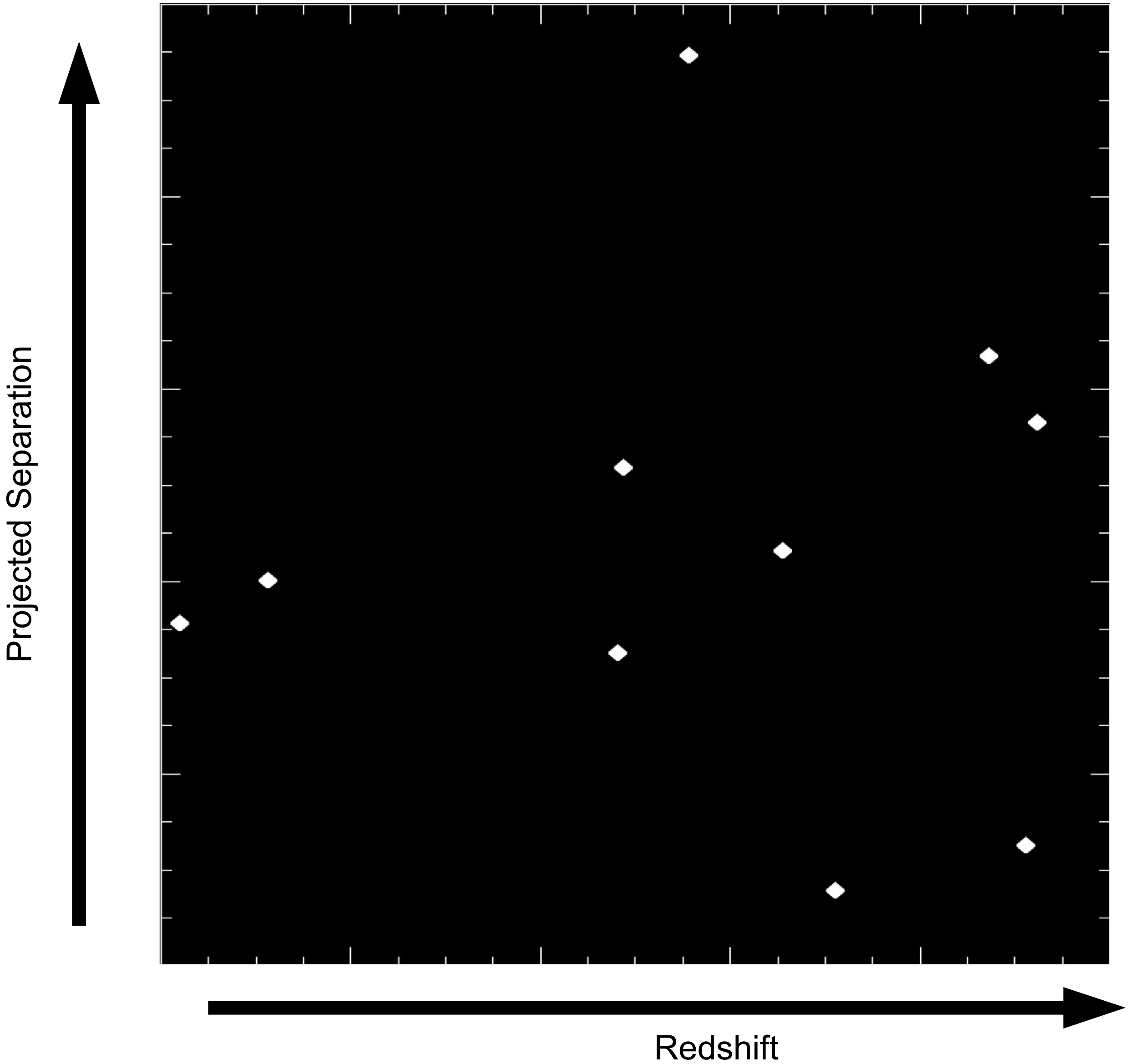
It would be easier to observe brighter quasars!



# The LLS autocorrelation function

The LLS autocorrelation function measured along quasar pairs is an effective way to map gas around galaxies



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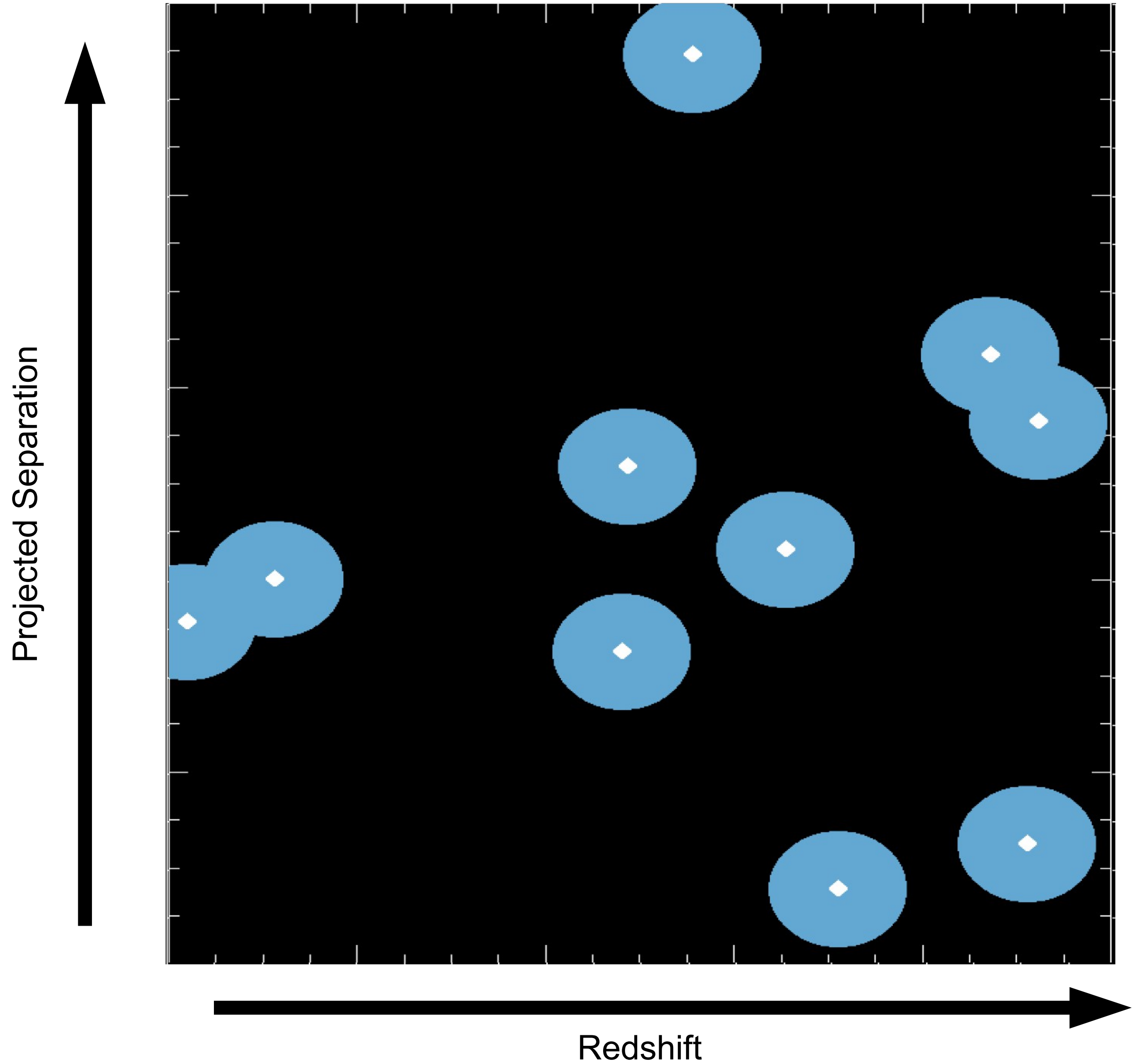

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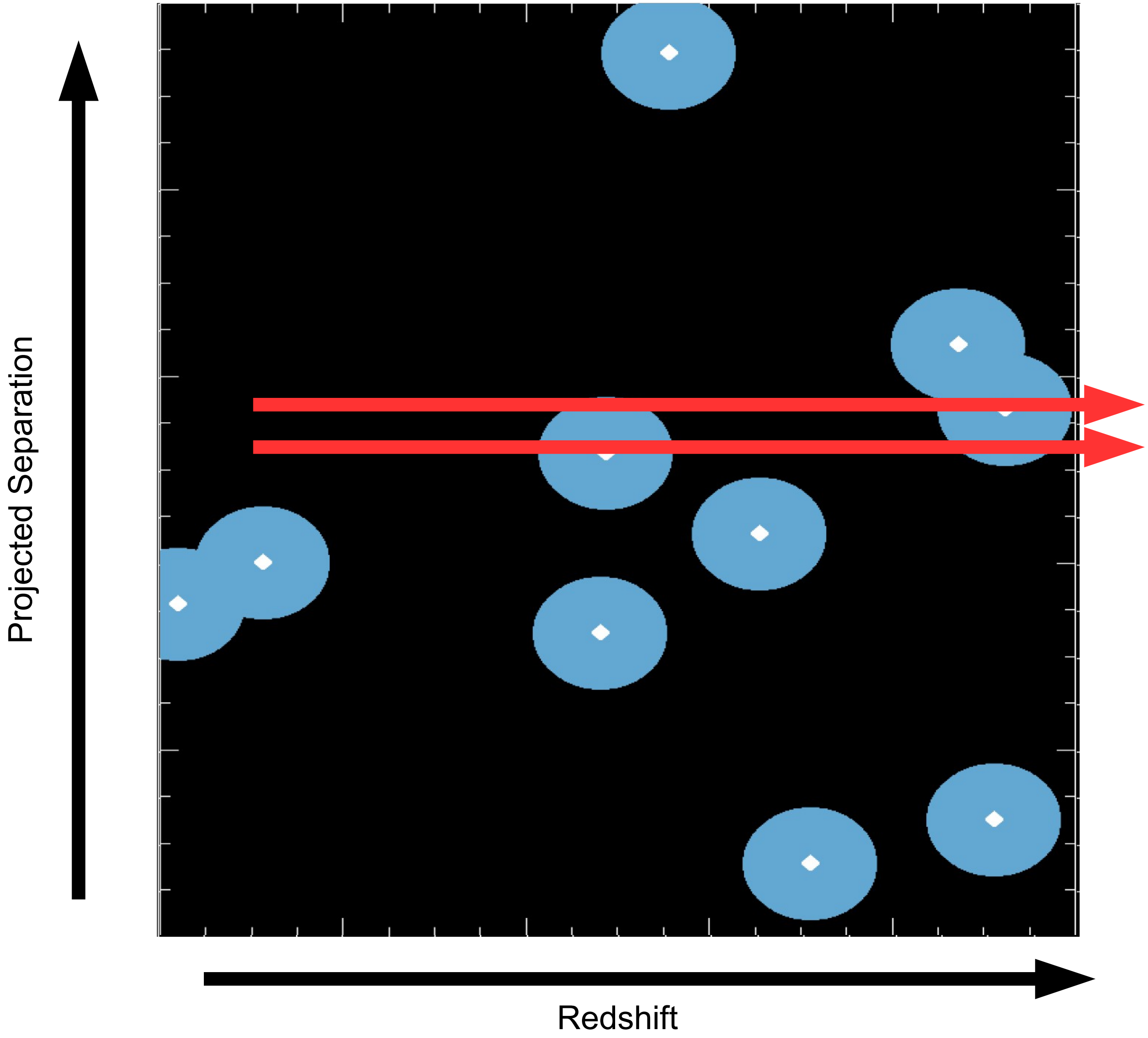


1-halo term:

$R < R_{CGM}$

$P\,(LLS,LLS) \sim f_C$

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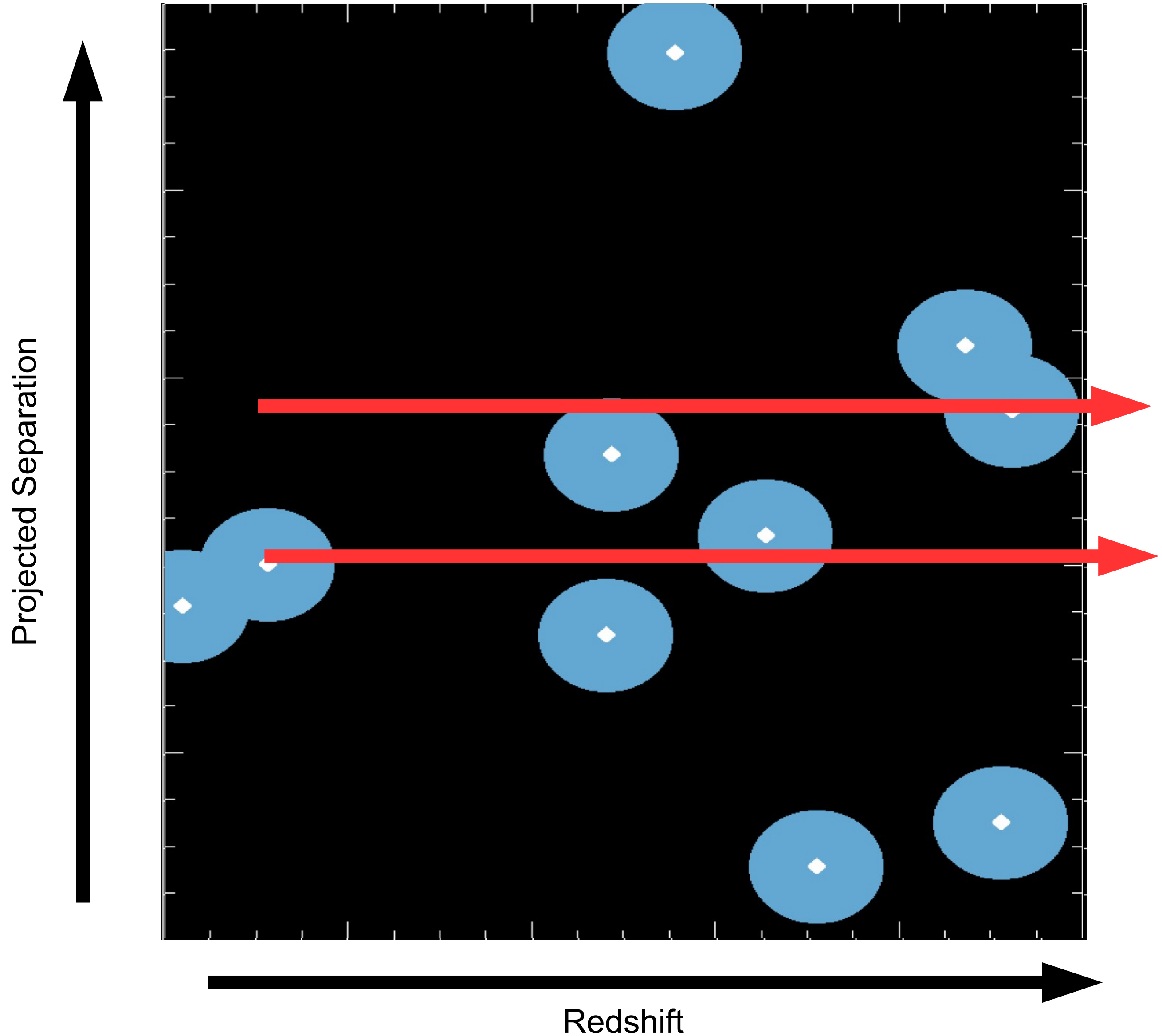


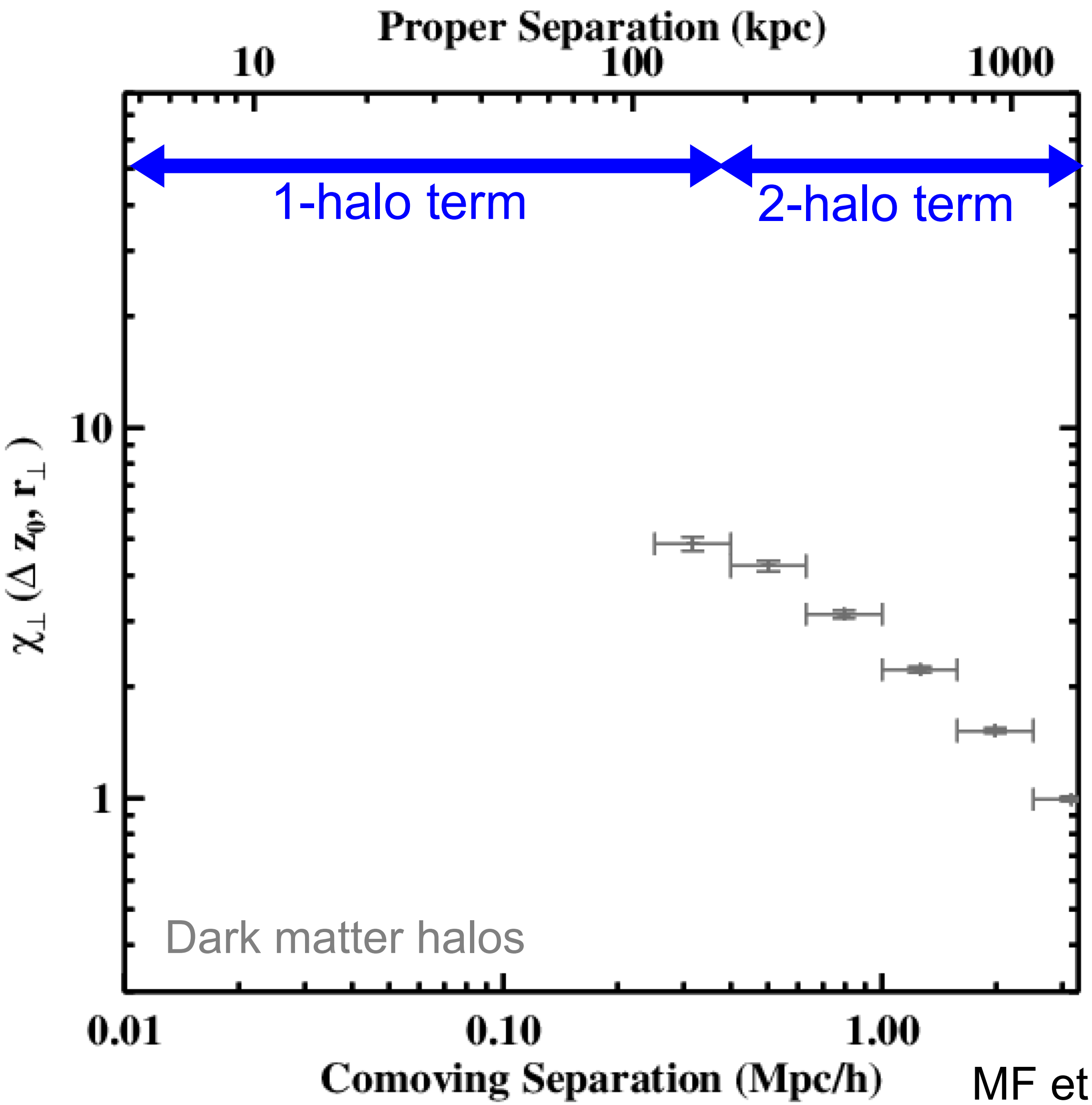

2-halo term:

$R > R_{CGM}$

$P\,(\mathrm{LLS,LLS}) \sim f_C \times \mathrm{DM}$

# The LLS autocorrelation function

## The LLS autocorrelation function measured along quasar pairs is an effective way to map gas around galaxies




MF et al. 2014

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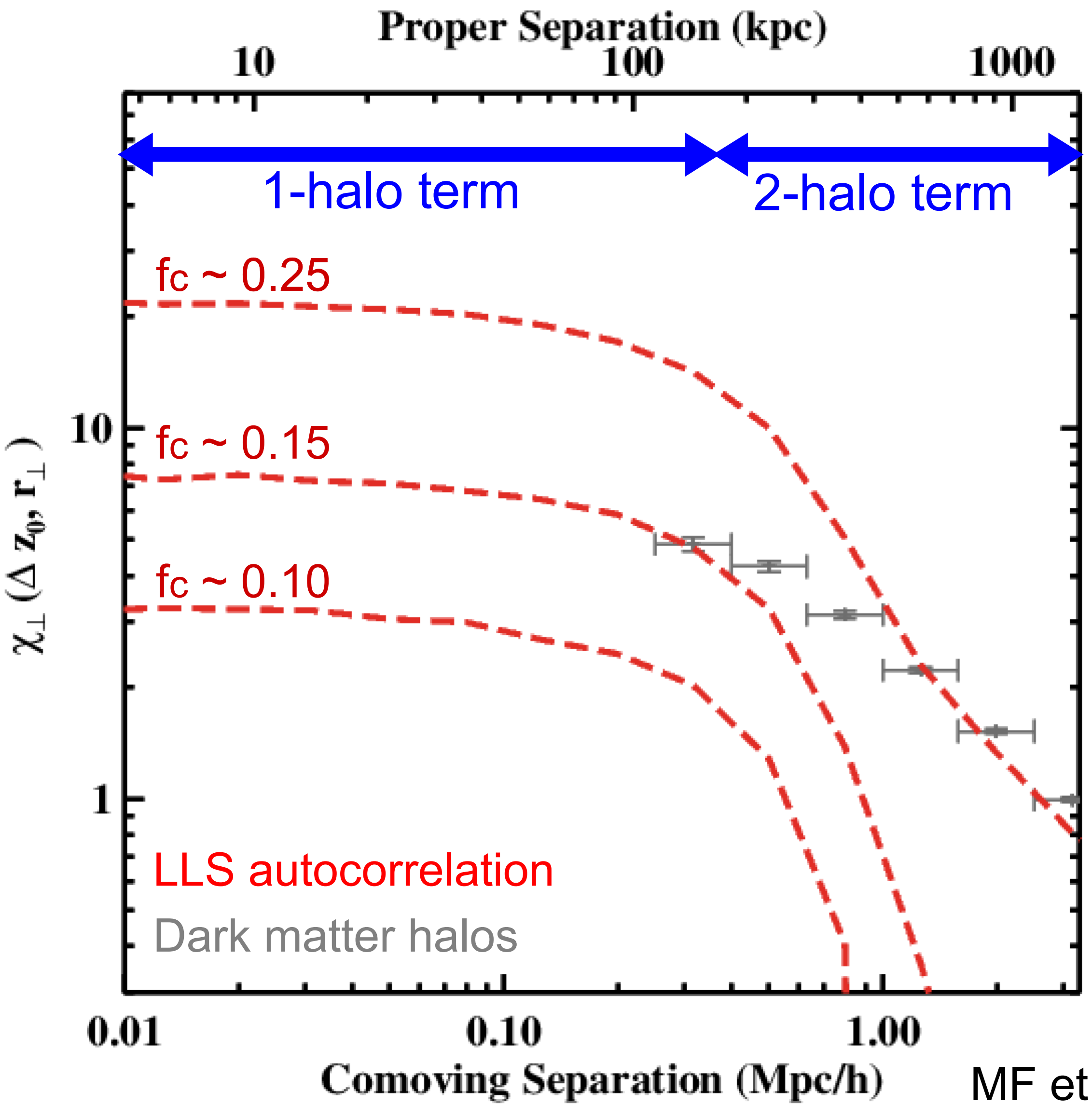


MF et al. 2014

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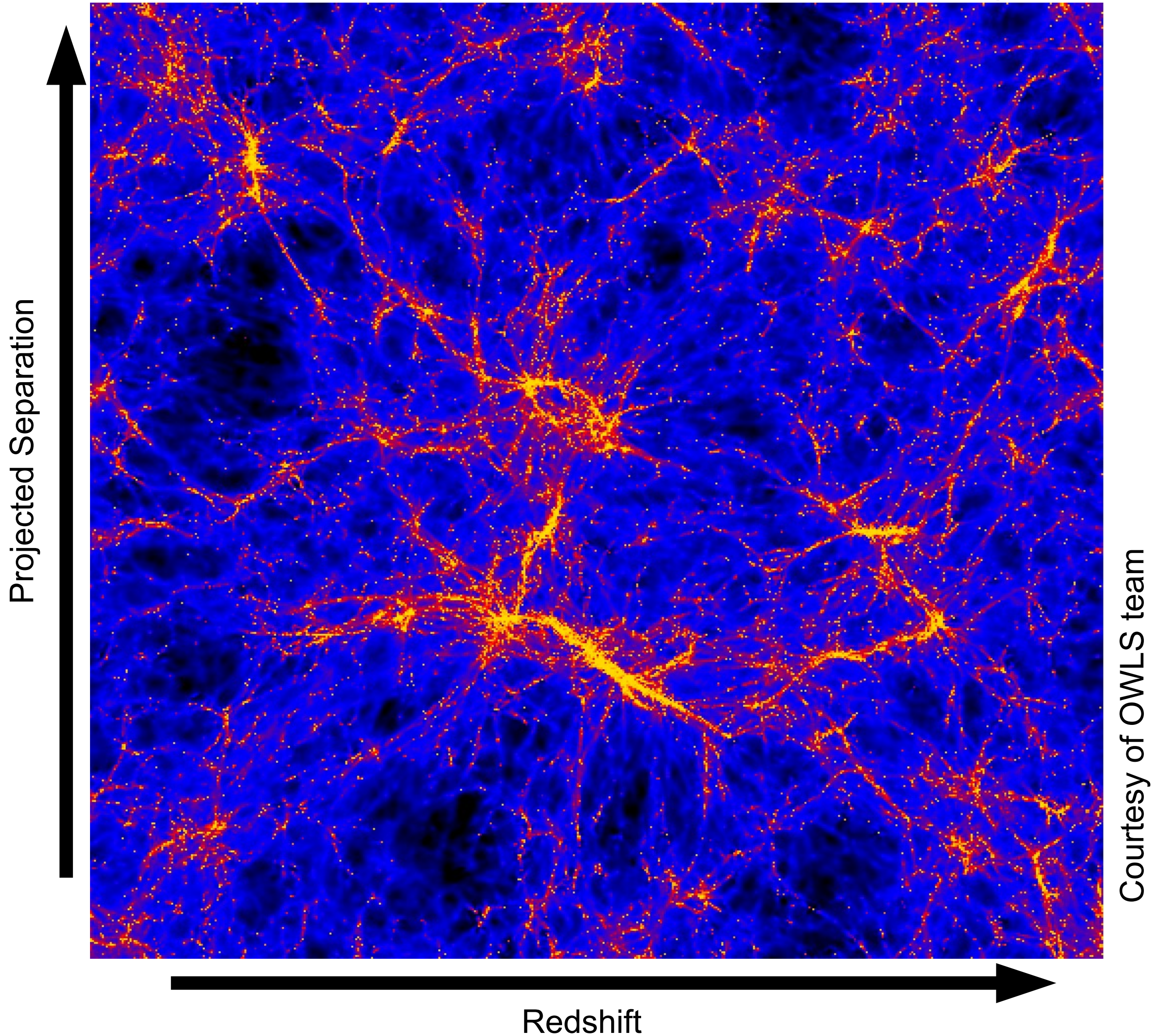

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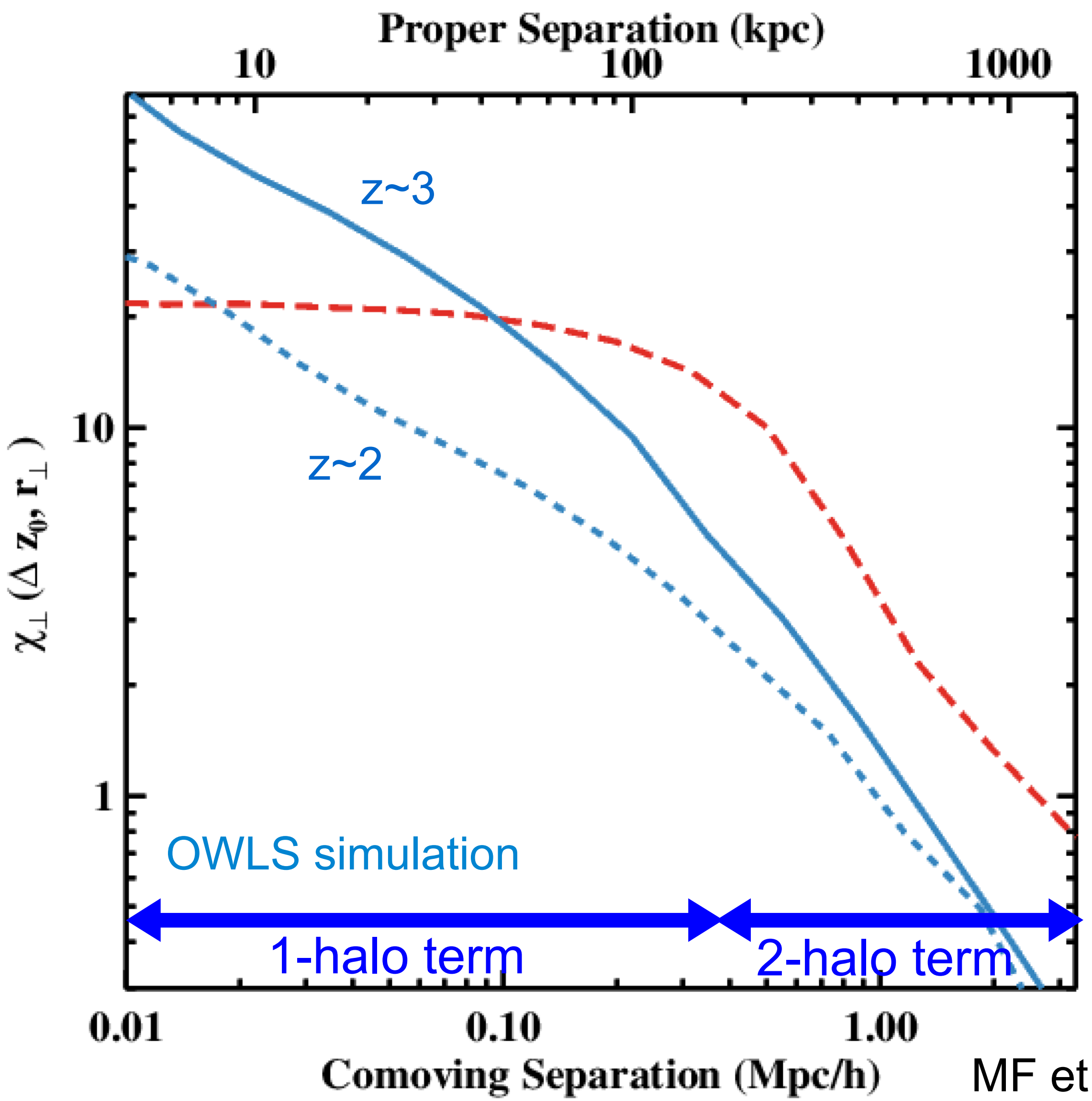
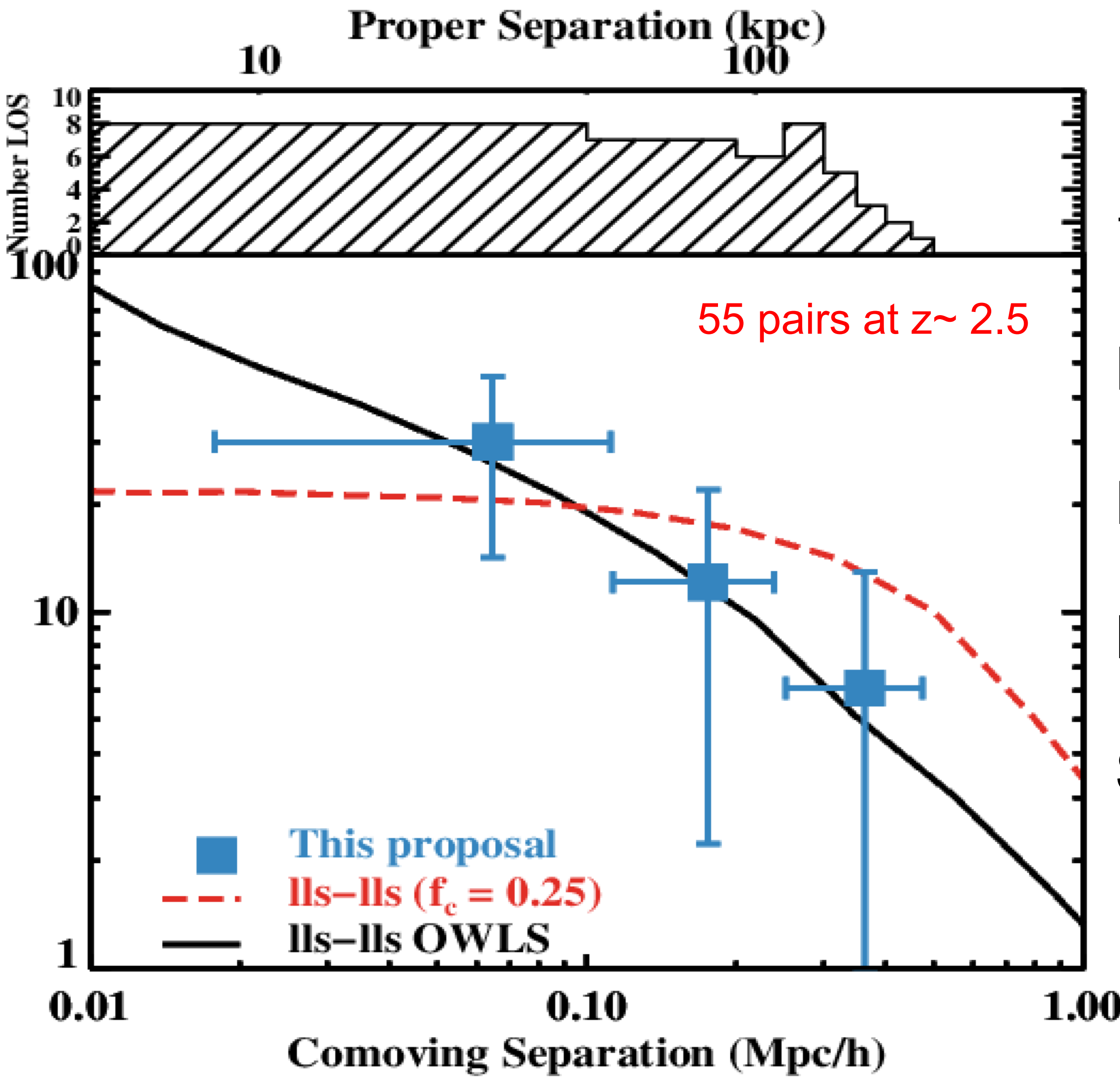



MF et al. 2014b

# The need for VST ATLAS

Currently, we are limited by sky coverage to search for QSO pairs




<u>Quasar Pair Wish List:</u>

Redshifts: z > 2 || z > 3

Redshift difference: < 0.1

Magnitudes: g<21

Separations: 1-20”

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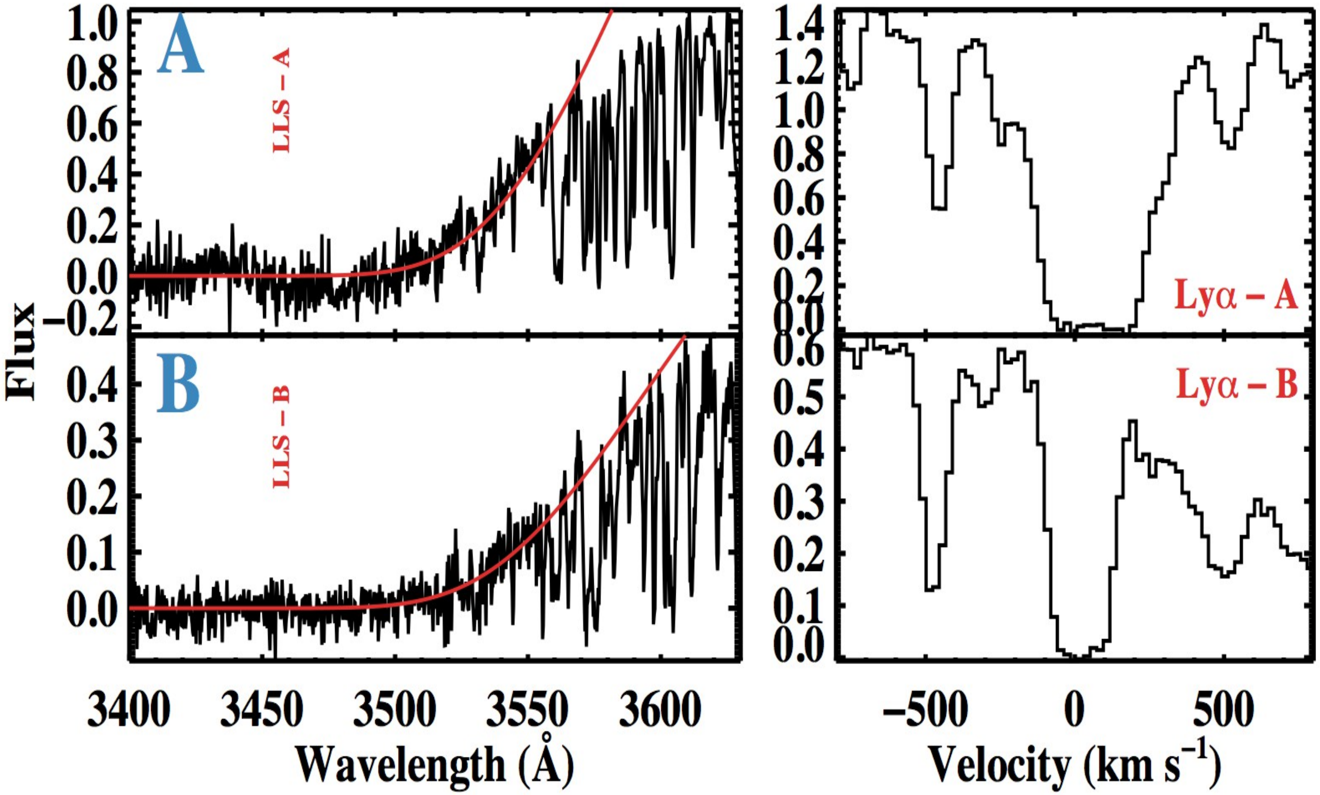



Separation of ~ 8″ ~ 65 kpc at z ~ 3

<u>The holy grail:</u>

Redshifts: z ~ 3.2-3.4

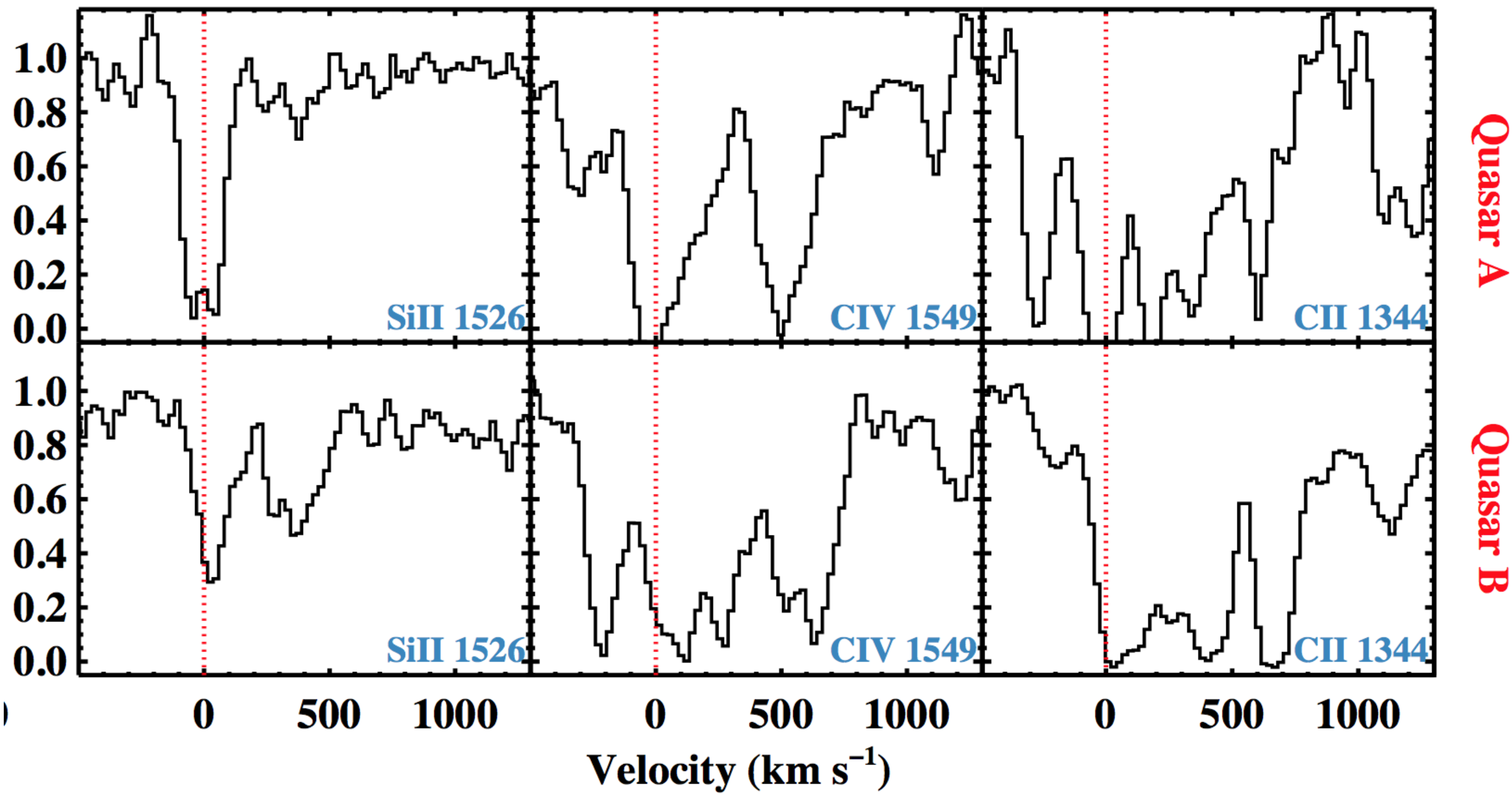
Redshift difference: < 0.1

Magnitudes: g<21

Separations: 1-20”

# The need for VST ATLAS

Provided bright enough quasars, we can study the projected velocities within the CGM of distant galaxies

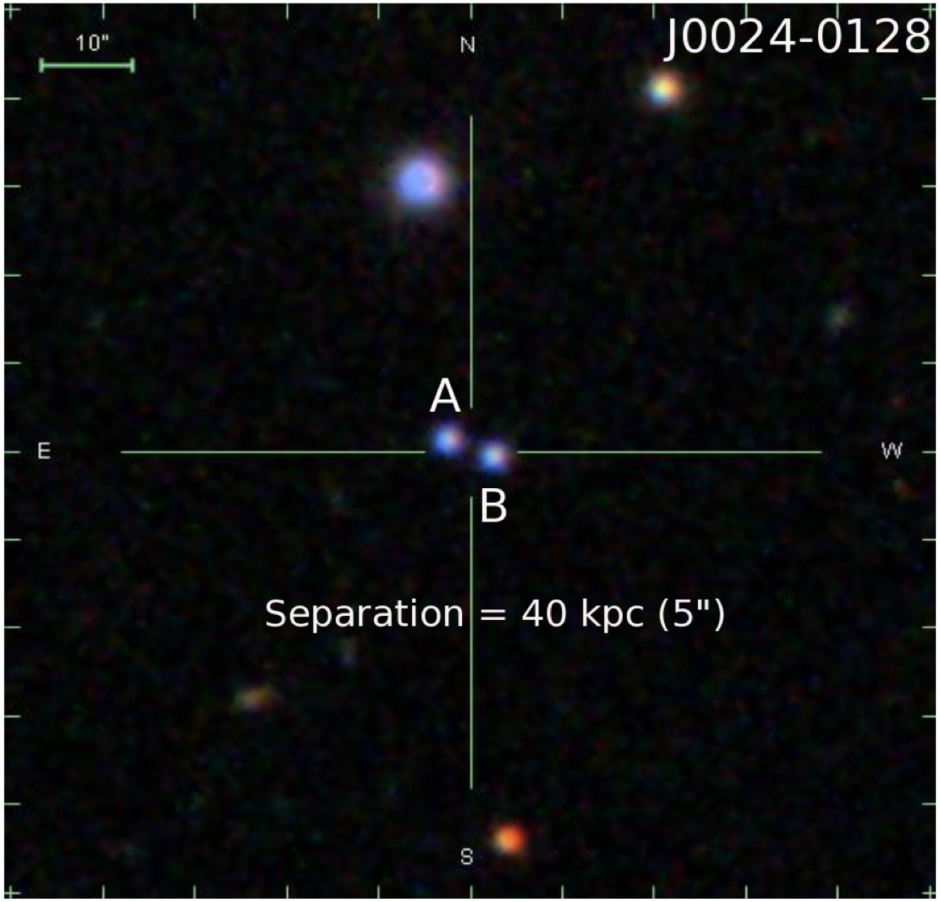


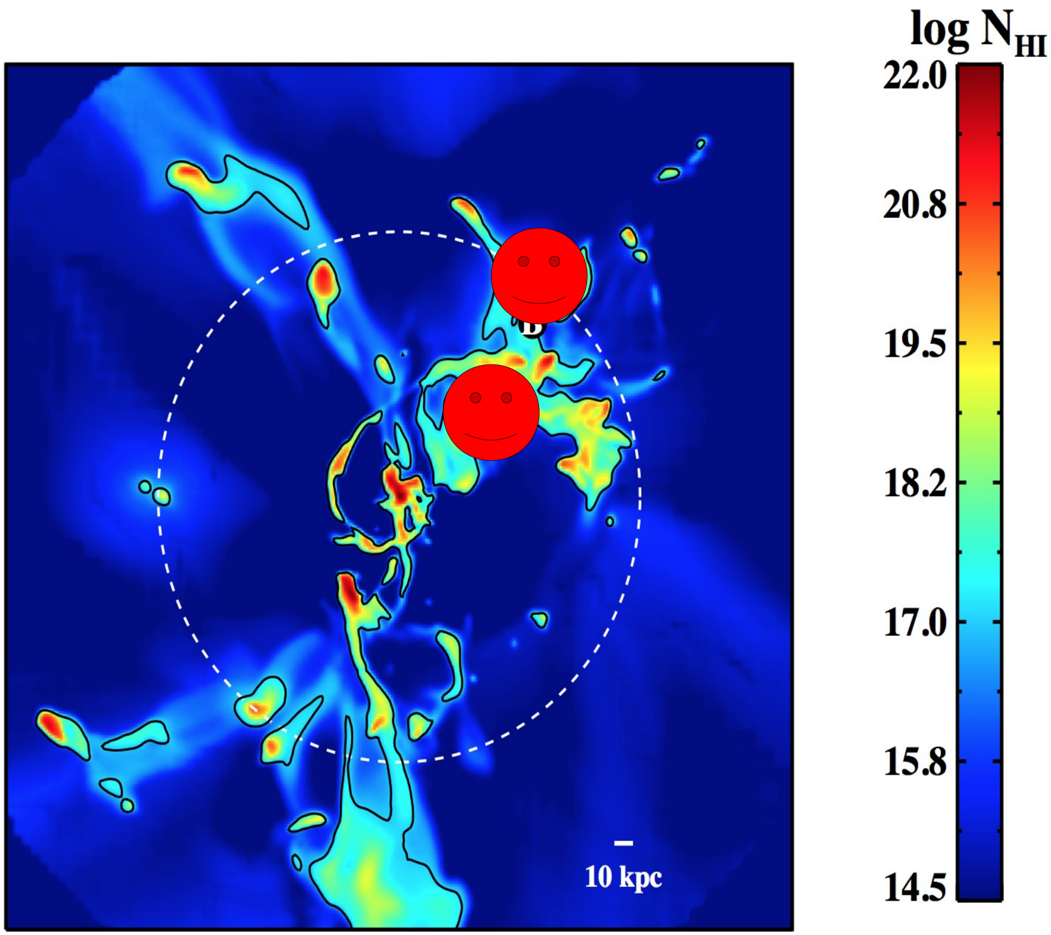
# The need for VST ATLAS

## Currently, we are limited by sky coverage to search for QSO pairs

| Quasar | RA | DEC | $z_{b/g}$ | $z_{f/g}$ | $R_{com}$ | $g_{b/g}$ | $g_{f/g}$ |
|---|---|---|---|---|---|---|---|
| SDSSJ1254+2235A | 12:54:19.054 | +22:35:35.96 | 3.6489 | 3.6489 | 55.6 | 21.69 | 20.73 |
| BOSSJ1400+3134A | 14:00:12.769 | +31:34:54.14 | 3.3230 | 3.3150 | 58.9 | 20.31 | 19.84 |
| BOSSJ1053+5001A | 10:53:20.042 | +50:01:47.85 | 3.0780 | 3.0500 | 67.3 | 21.04 | 21.18 |
| BOSSJ1240+4329A | 12:40:25.150 | +43:29:16.53 | 3.2639 | 3.2490 | 104.3 | 21.06 | 20.57 |
| BOSSJ0953+5249A | 09:53:07.604 | +52:49:54.03 | 4.2830 | 4.2709 | 194.4 | 21.89 | 22.80 |
| BOSSJ1541+2702A | 15:41:10.401 | +27:02:31.26 | 3.6320 | 3.6210 | 222.7 | 21.62 | 21.51 |
| BOSSJ1420+2831A | 14:20:23.772 | +28:31:06.59 | 4.3049 | 4.2900 | 405.7 | 22.22 | 23.04 |
| BOSSJ1000+4421A | 10:00:26.730 | +44:21:03.65 | 2.9879 | 2.9820 | 311.2 | 20.82 | 21.22 |
| BOSSJ1251+2715A | 12:51:22.737 | +27:15:23.61 | 3.6700 | 3.6400 | 487.5 | 21.82 | 21.31 |
| BOSSJ1116+4118A | 11:16:10.682 | +41:18:14.45 | 3.0039 | 2.9430 | 439.0 | 19.47 | 18.55 |
| APOJ0956+2643A | 09:56:25.920 | +26:43:21.67 | 3.0829 | 3.0820 | 537.4 | 20.84 | 19.50 |
| BOSSJ1451+3913A | 14:51:20.652 | +39:13:50.52 | 3.3840 | 3.2539 | 590.3 | 20.85 | 22.11 |
| BOSSJ1006+2607A | 10:06:09.761 | +26:07:32.47 | 3.0220 | 2.9610 | 740.7 | 20.54 | 20.81 |
| APOJ1431+3427A | 14:31:05.486 | +34:27:16.98 | 4.5760 | 4.2890 | 1073.0 | 24.39 | 22.55 |
| APOJ1614+2510A | 16:14:08.454 | +25:10:36.79 | 3.3269 | 3.0309 | 822.5 | 20.95 | 20.09 |
| BOSSJ0927+4507A | 09:27:04.277 | +45:07:15.74 | 3.5960 | 3.5820 | 1027.3 | 22.43 | 21.19 |
| BOSSJ1039+5026A | 10:39:00.013 | +50:26:52.83 | 3.2370 | 3.1324 | 964.3 | 20.60 | 19.52 |
| BOSSJ1414+3955A | 14:14:04.157 | +39:55:43.55 | 3.2149 | 3.1700 | 1012.6 | 18.73 | 21.31 |
| BOSSJ1150+4659A | 11:50:52.353 | +46:59:39.42 | 3.0000 | 2.9879 | 1117.5 | 21.25 | 20.61 |
| APOJ1026+4614A | 10:26:16.115 | +46:14:20.83 | 3.4210 | 3.3340 | 1250.0 | 20.50 | 20.20 |
| BOSSJ1011+5739A | 10:11:11.845 | +57:39:12.59 | 3.1340 | 3.1329 | 1266.9 | 21.27 | 20.07 |
| BOSSJ1427+5246A | 14:27:23.595 | +52:46:32.05 | 3.8740 | 3.7470 | 1519.6 | 21.62 | 23.01 |
| BOSSJ0829+2927A | 08:29:07.713 | +29:27:54.73 | 3.0699 | 3.0330 | 1298.0 | 21.12 | 21.29 |
| BOSSJ1117+6339A | 11:17:16.657 | +63:39:31.02 | 3.0130 | 2.9679 | 1331.4 | 21.45 | 19.87 |
| BOSSJ1024+5303A | 10:24:26.398 | +53:03:08.53 | 3.3590 | 3.2070 | 1416.4 | 20.57 | 21.02 |
| BOSSJ2307+2508A | 23:07:49.107 | +25:08:05.64 | 3.0720 | 3.0530 | 1365.4 | 20.92 | 20.36 |
| BOSSJ0823+4138A | 08:23:55.814 | +41:38:10.19 | 3.0160 | 2.9010 | 1311.9 | 21.70 | 19.57 |
| BOSSJ1546+5134A | 15:46:10.541 | +51:34:29.44 | 2.9340 | 2.9300 | 1341.0 | 20.53 | 19.43 |
| BOSSJ1239+3613A | 12:39:37.161 | +36:13:22.00 | 3.2179 | 3.1150 | 1418.3 | 21.85 | 19.85 |
| SDSSJ1330+6234A | 13:30:45.223 | +62:34:12.62 | 3.5260 | 3.4502 | 1568.2 | 20.77 | 21.20 |
| BOSSJ1138+3505A | 11:38:12.309 | +35:05:59.71 | 3.1800 | 3.1610 | 1499.7 | 21.57 | 20.82 |
| BOSSJ1136+4414A | 11:36:24.040 | +44:14:53.74 | [illegible] | 3.1050 | 1487.8 | 20.87 | 21.60 |

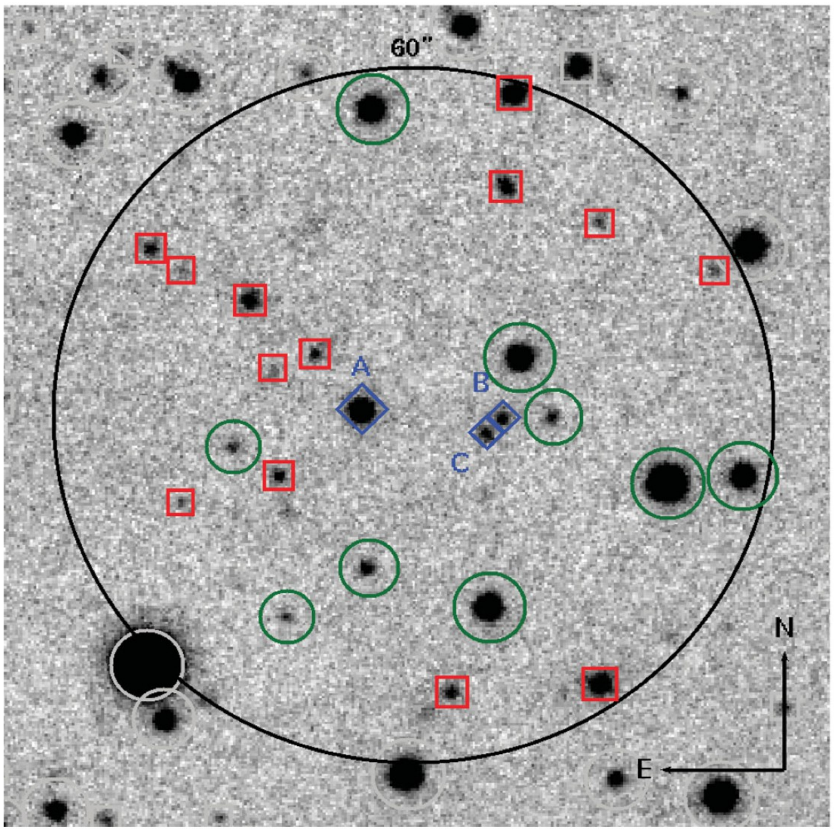
# More pairs, please!

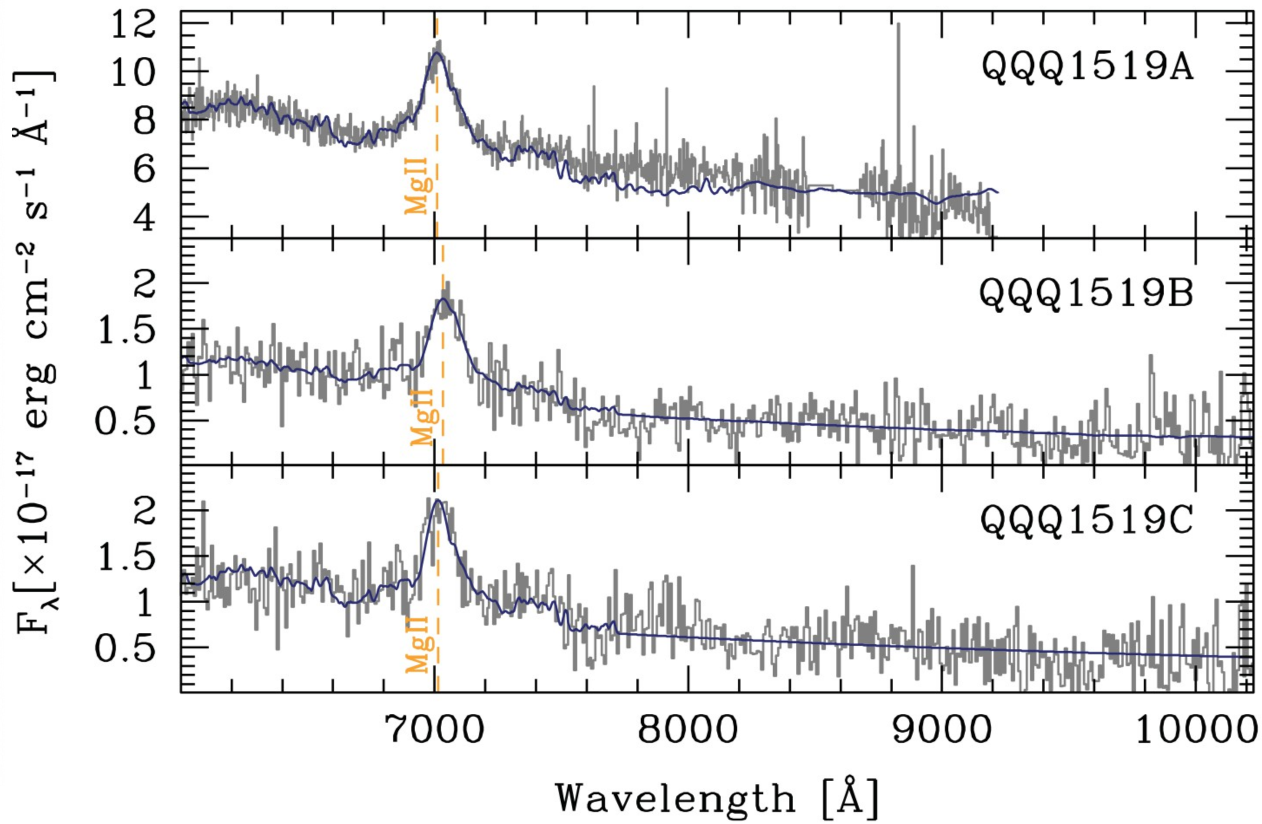


# And how about triplets?

## Sometimes, we stumble upon unexpected rarities




Farina et al. 2013