A statistical method for detecting gravitational recoils of SMBHs in AGNs

Peter Raffai[1,2]

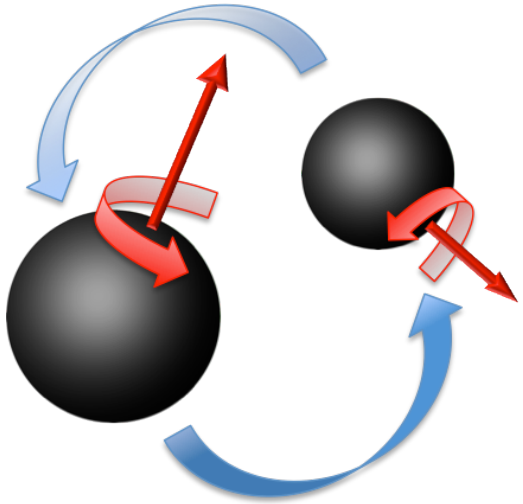
Bence Bécsy[1,2], Rafael de Souza[1,2], Zsolt Frei[1,2]

Bradley Greig[3], Zoltan Haiman[4], Andrei Mesinger[3]

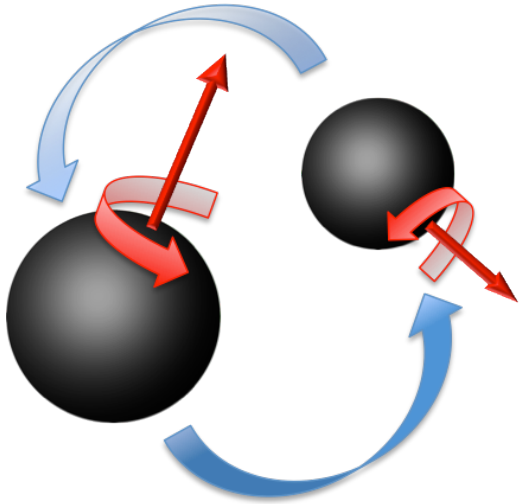
[1]Institute of Physics, Eötvös University, Budapest, Hungary
[2]MTA-ELTE EIRSA "Lendület" Astrophys. Res. Group, Budapest, Hungary
[3]Scuola Normale Superiore, Pisa, Italy
[4]Dept. of Astron., Columbia University, New York, USA

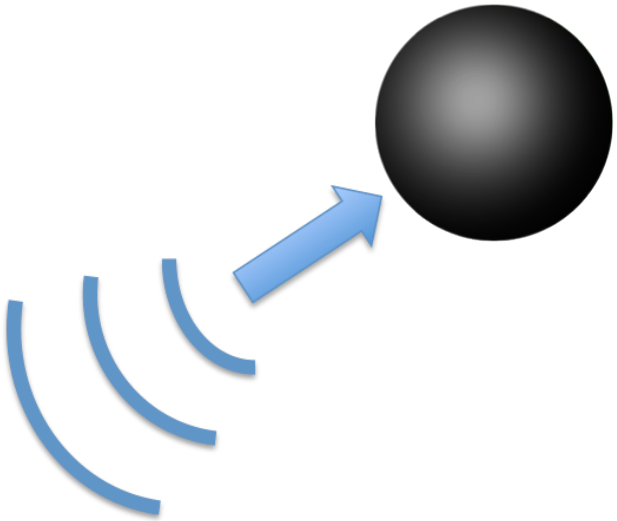
Galaxy mergers, recoiling SMBHs & AGNs

Galaxy mergers, recoiling SMBHs & AGNs

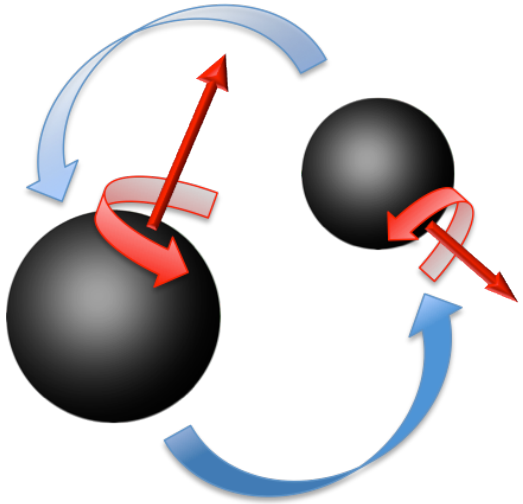


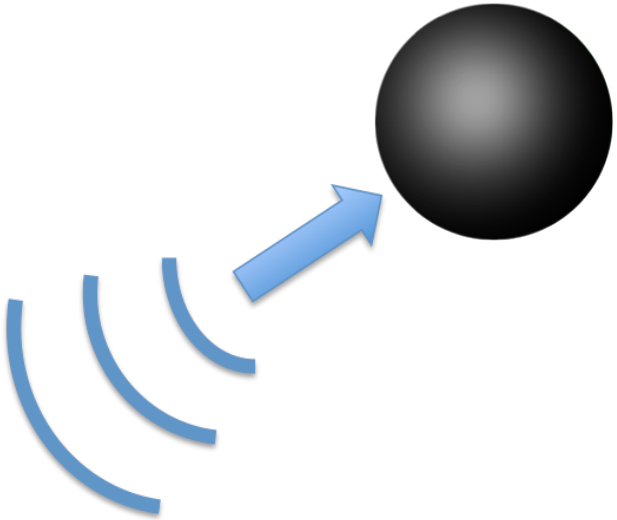
Galaxy mergers, recoiling SMBHs & AGNs



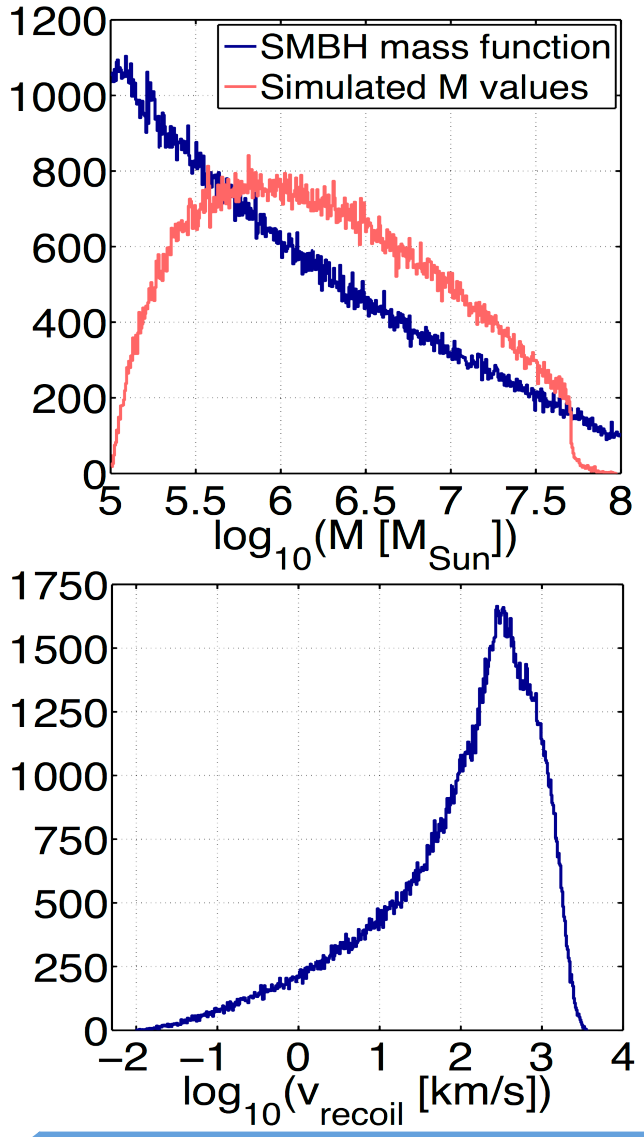


Galaxy mergers, recoiling SMBHs & AGNs





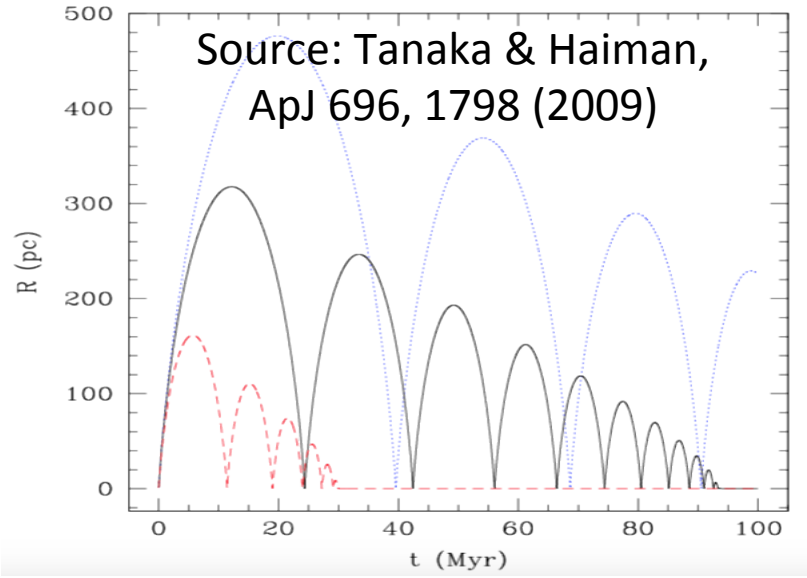
Recoil dynamics



- To calculate v_{recoil} magnitudes, we adopted the analytical formulae given in **Baker+ 2008**
- Masses of merging SMBHs randomized from mass function given in **A&R 2002**
- Spins isotropically oriented with magnitudes randomized from observationally inferred distribution given in **Reynolds 2013**
- v_{recoil} orientations were chosen to be isotropically distributed

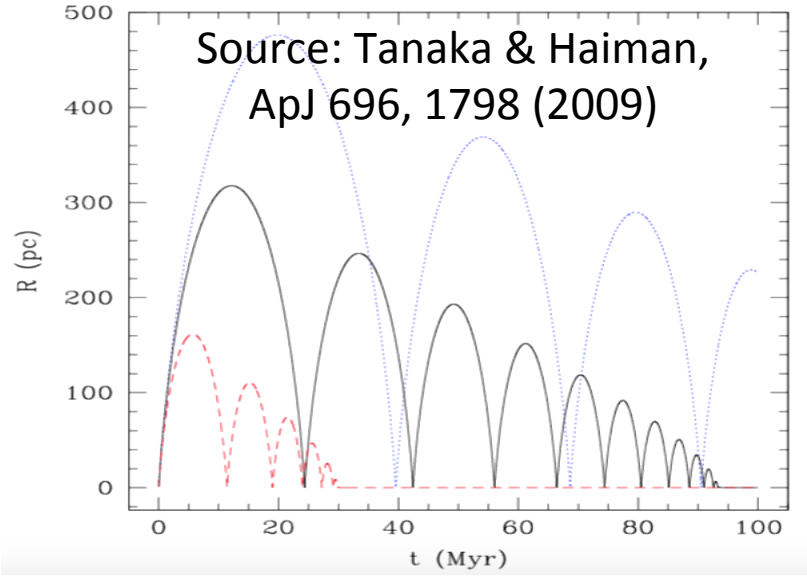
SMBH trajectories

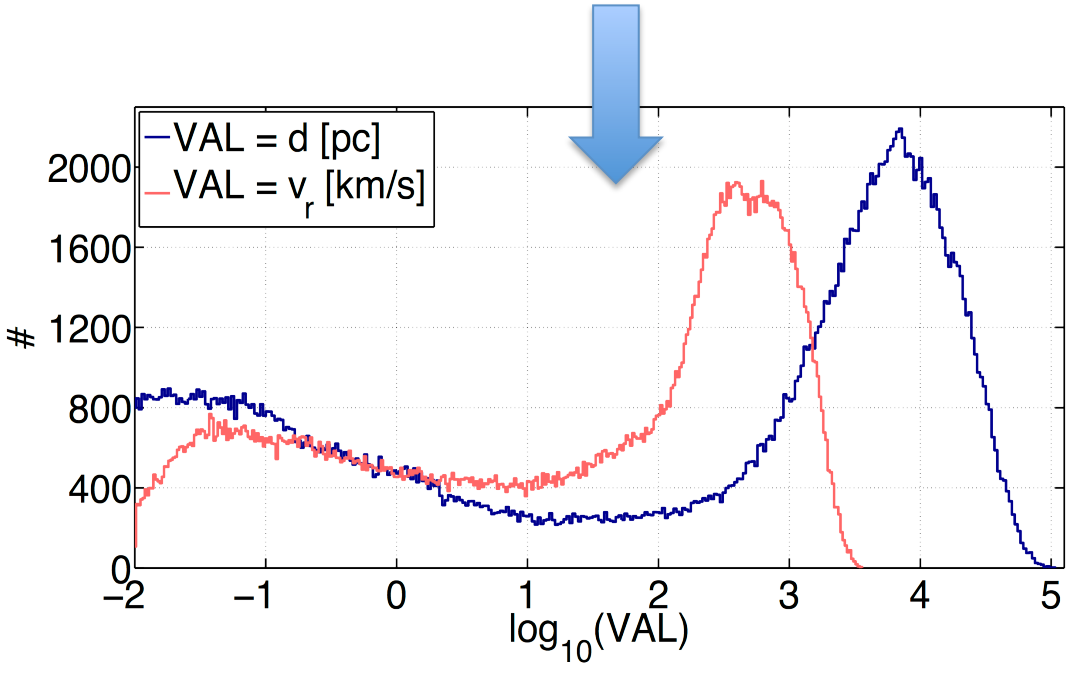
- We adopted the analytical model by **M&Q 2004**
- Dynamical friction due to SIS mass distribution with $\sigma \sim M^{1/4}$

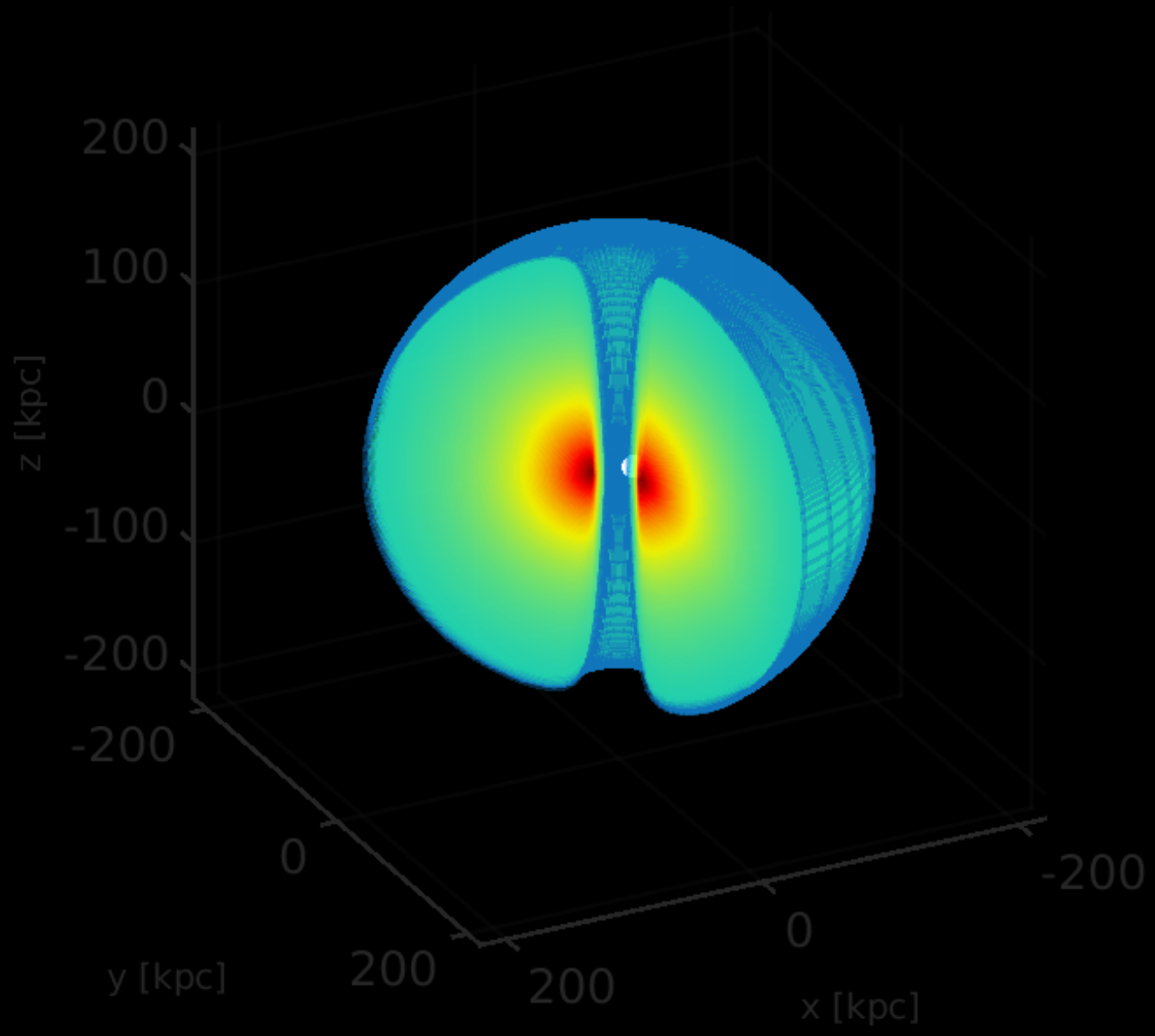


SMBH trajectories

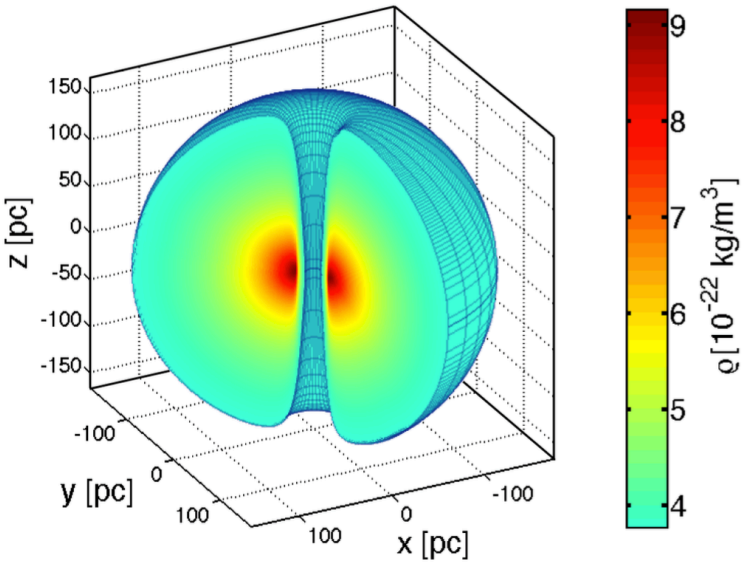
- We adopted the analytical model by **M&Q 2004**
- Dynamical friction due to SIS mass distribution with $\sigma \sim M^{1/4}$
- Only parameters: M, v_{recoil}
- Radial distances and velocities at random times

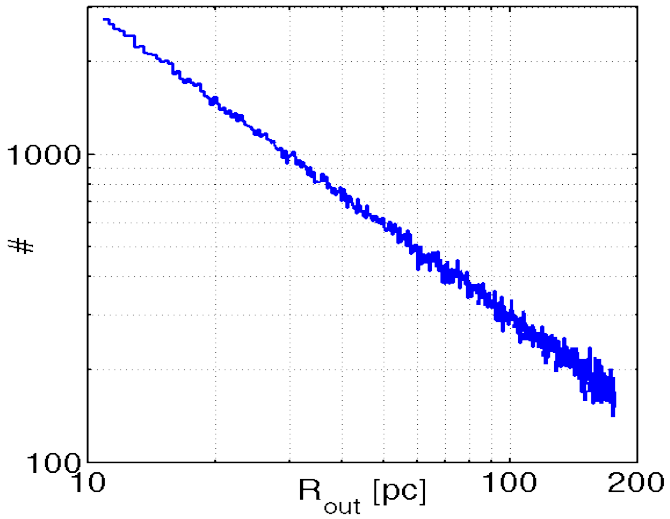





200
100
0
-100
-200
z [kpc]
-200
0
200
y [kpc]
200
0
-200
x [kpc]

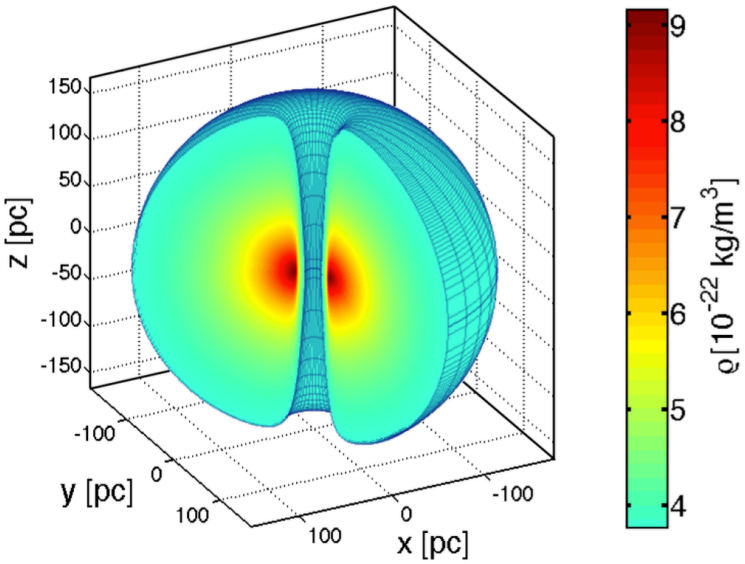
Dusty torus model



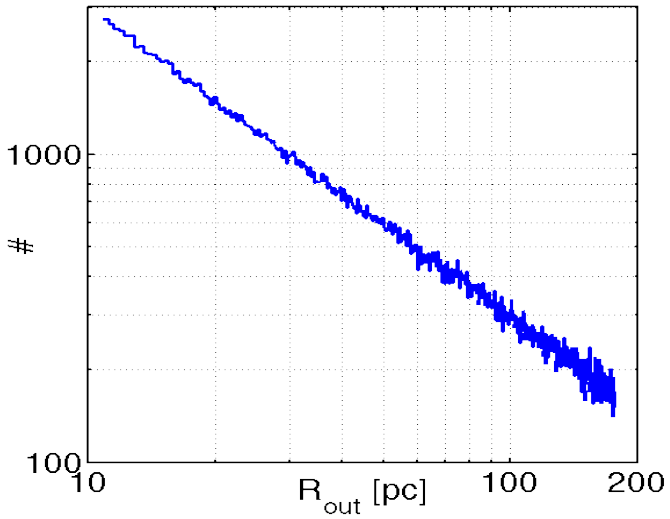


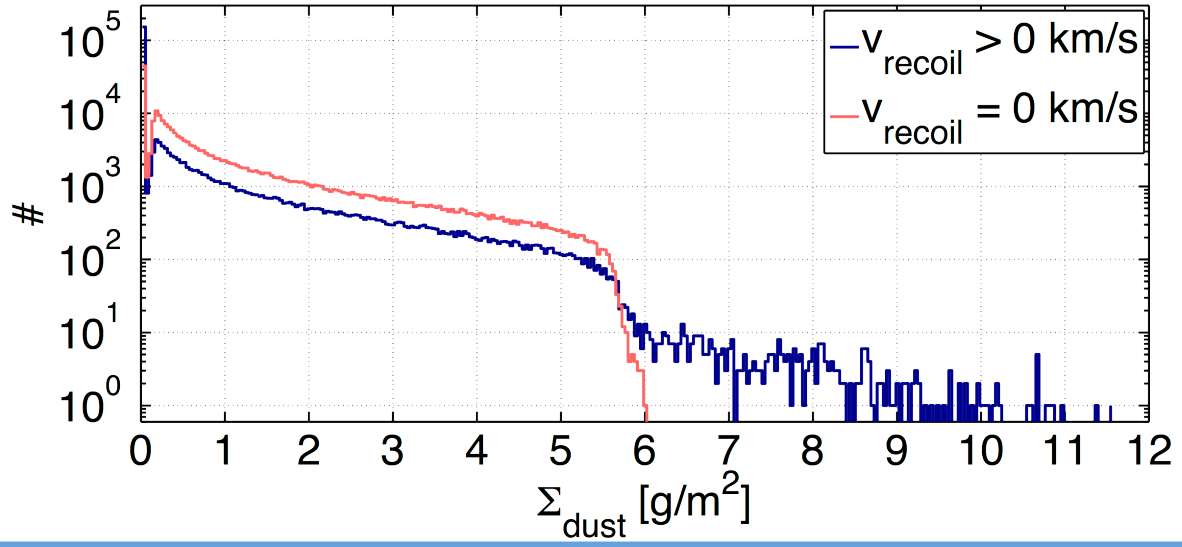
- Smooth dust torus model by **Schartmann+ 2005**
- Torus is the result of stellar winds and ejection of planetary nebulae by nuclear star cluster
- Only parameters: M and M_*

Dusty torus model

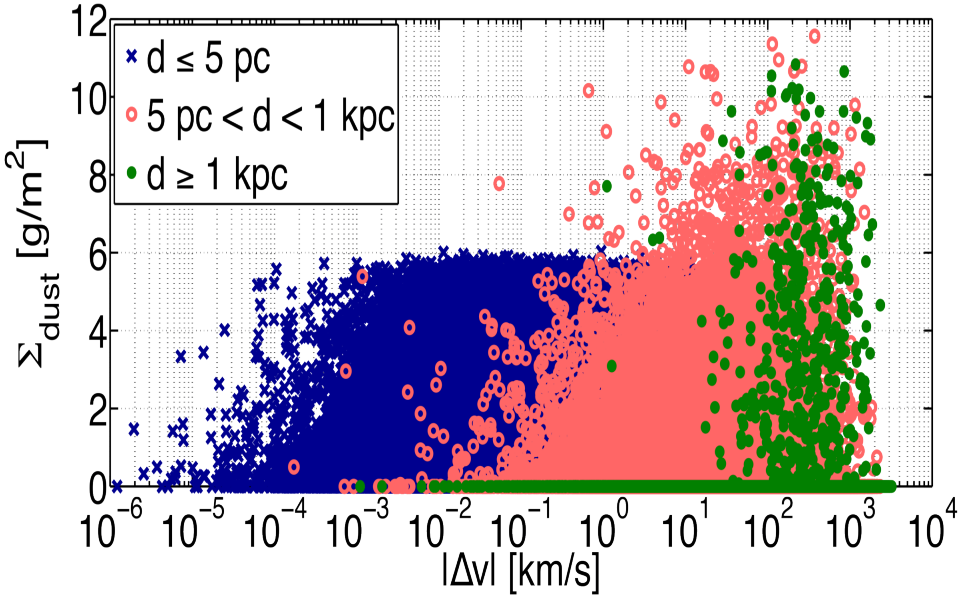


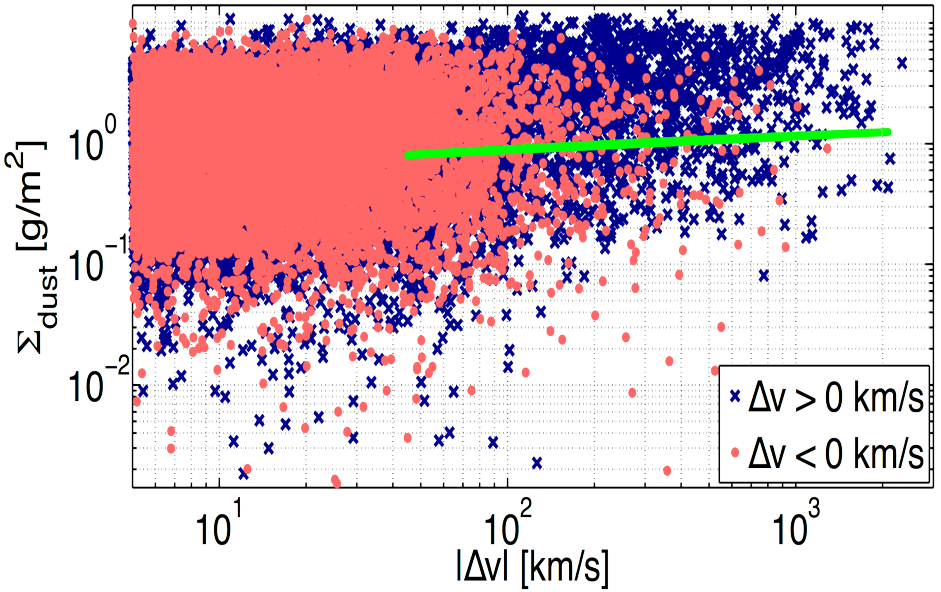
- Smooth dust torus model by **Schartmann+ 2005**
- Torus is the result of stellar winds and ejection of planetary nebulae by nuclear star cluster
- Only parameters: M and M_*



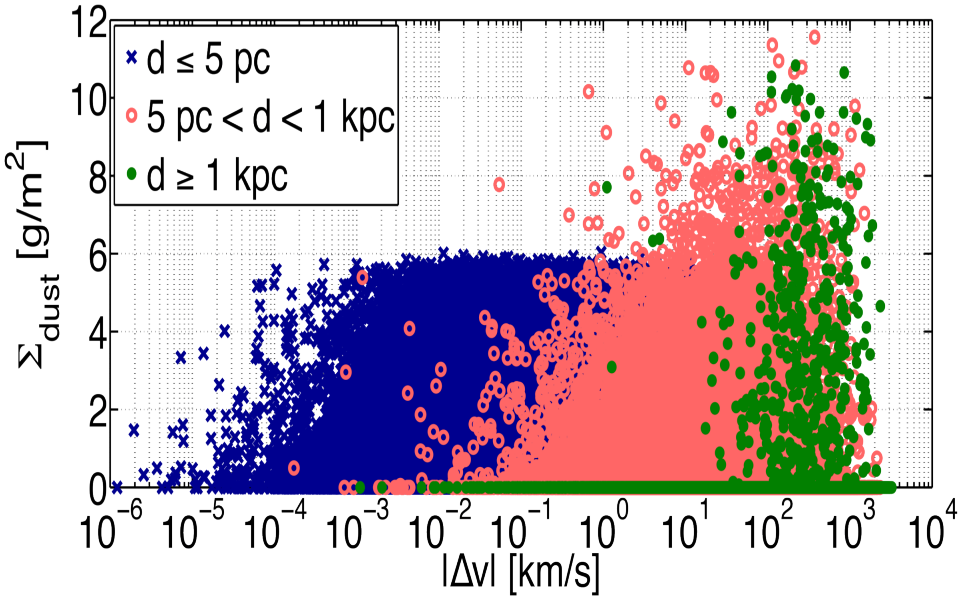


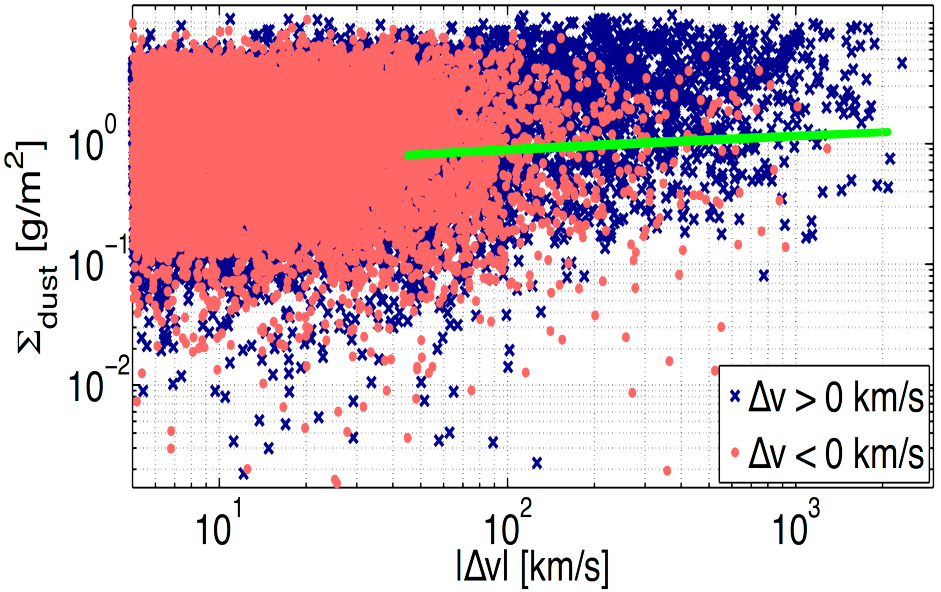
Observational tests

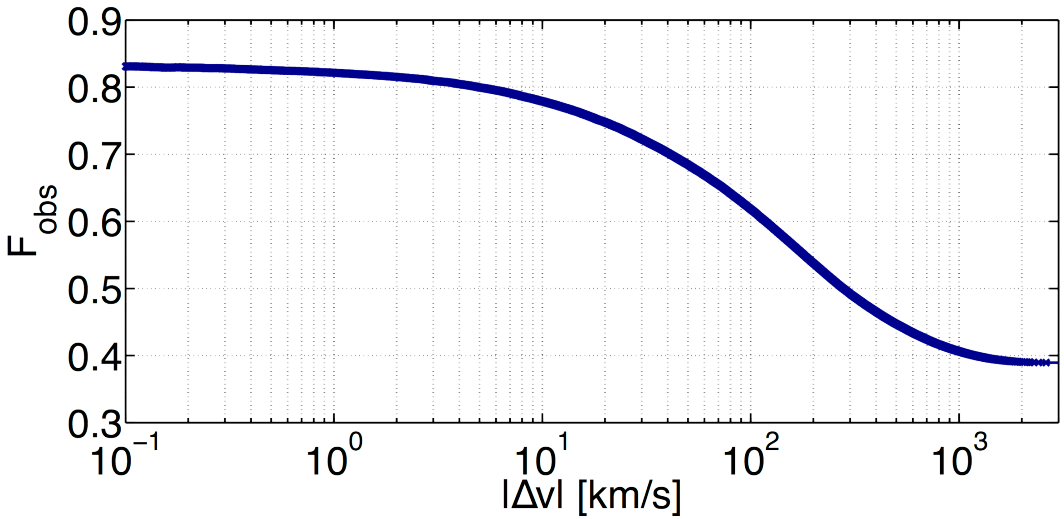




Observational tests

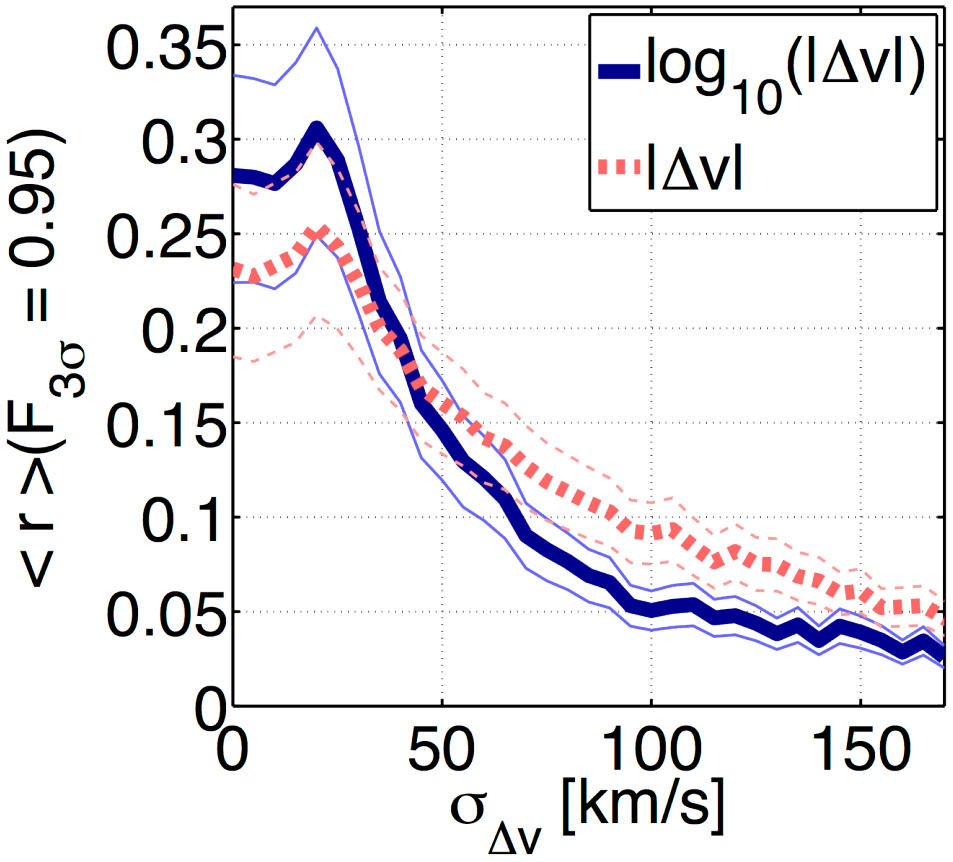


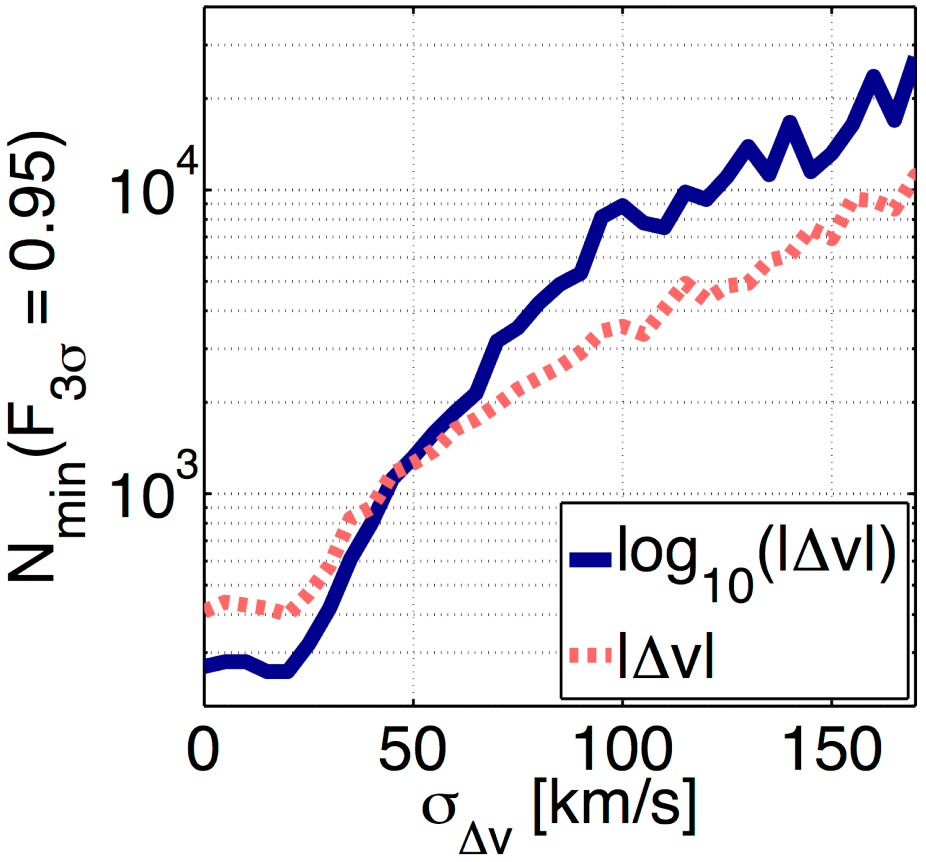




The effect of random Gaussian errors

Realistic σ_Σ values have minor effect on the Σ_{dust}-$|\Delta v|$ correlation





Ongoing work

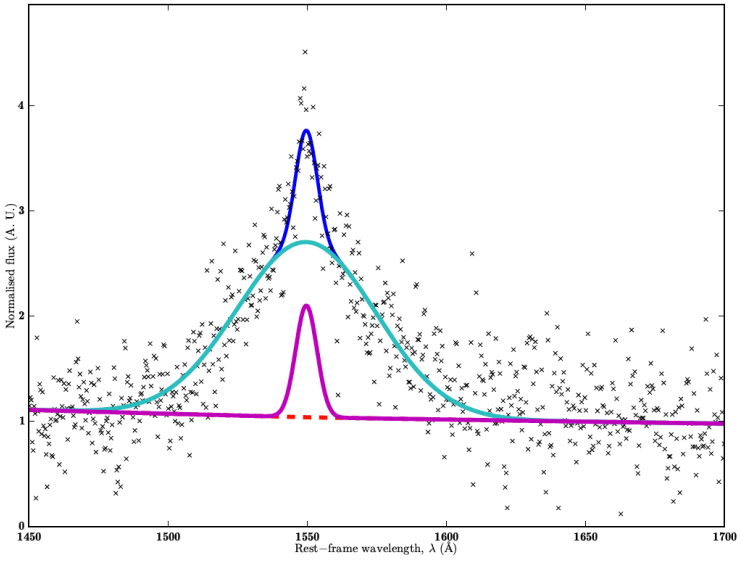
- Using SDSS DR12 catalog of ~300,000 QSOs
- SDSS-BOSS spectra publicly available
- Dust column density measure (Ledoux+ 2015):

$$\Sigma_{\rm dust} \propto \Delta(g-i) \equiv (g-i) - \langle (g-i) \rangle_z$$

- Peculiar velocity measure (Bonning+ 2007):

$$\Delta v = \frac{z_{\rm B} - z_{\rm N}}{1 + z_{\rm N}} c$$

- Spectral lines we use: narrow and/or broad CIV 1549, Hβ 4863, OIII 5007



STAY TUNED!

References

Raffai, P., Haiman, Z., & Frei, Z.: *"A Statistical Method to Search for Recoiling Supermassive Black Holes in Active Galactic Nuclei"*; Mon. Not. Roy. Astron. Soc., Vol. 455, p. 484 (2015) arXiv:1509.02075

SMBH Dynamics:

- [A&R 2002] Aller, M.C., & Richstone, D., AJ 124, 3035 (2002)
- Baker, J.G., et al., ApJ 682, 1, L29 (2008)
- Reynolds, C.S., CQG 30, 244004 (2013)
- [M&Q 2004] Madau, P., & Quataert, E., ApJ 606, L17 (2004)

Torus model:

- Schartmann, M., et al., A&A 437, 861 (2005)

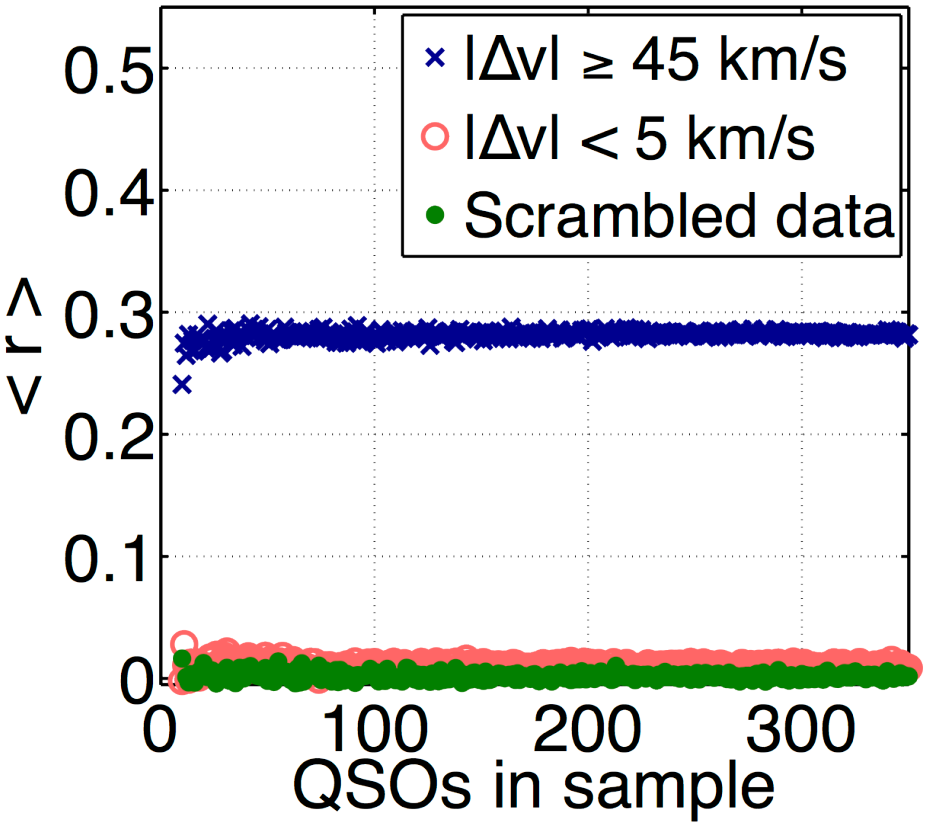
Observational proxies:

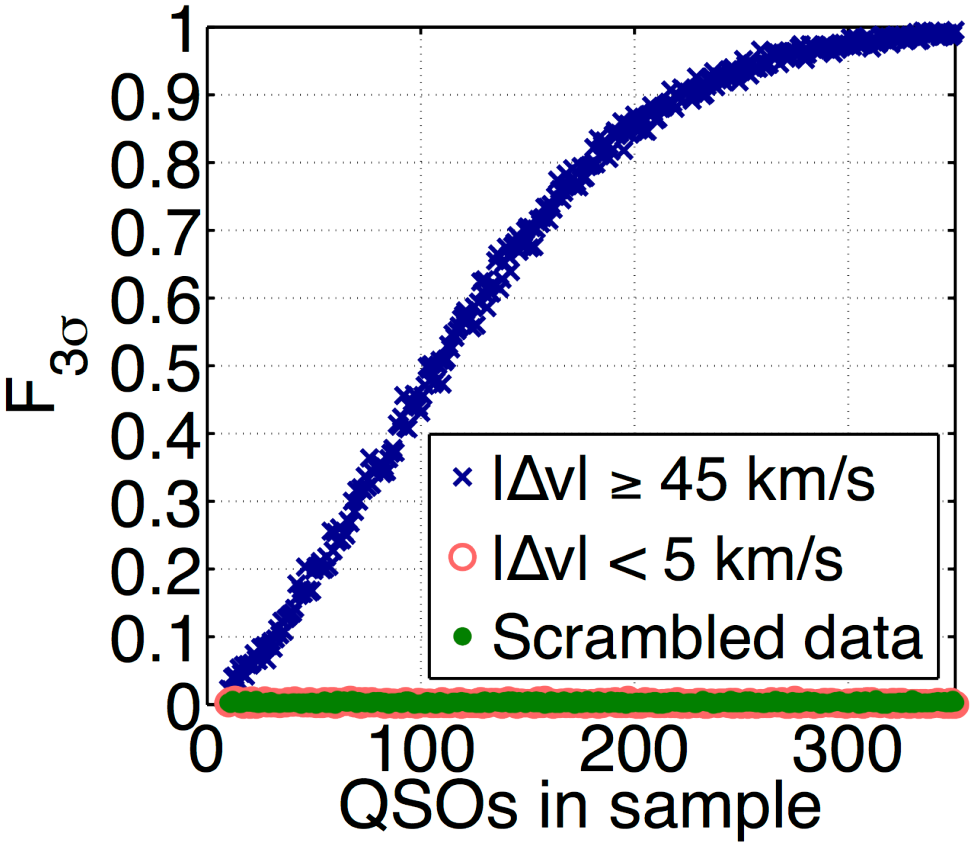
- Bonning, E.W., Shields, G.A., & Salviander S., ApJ 666, L13 (2007)
- Ledoux, C., et al., A&A 580, A8, p. 15 (2015)

Thank you for your attention!

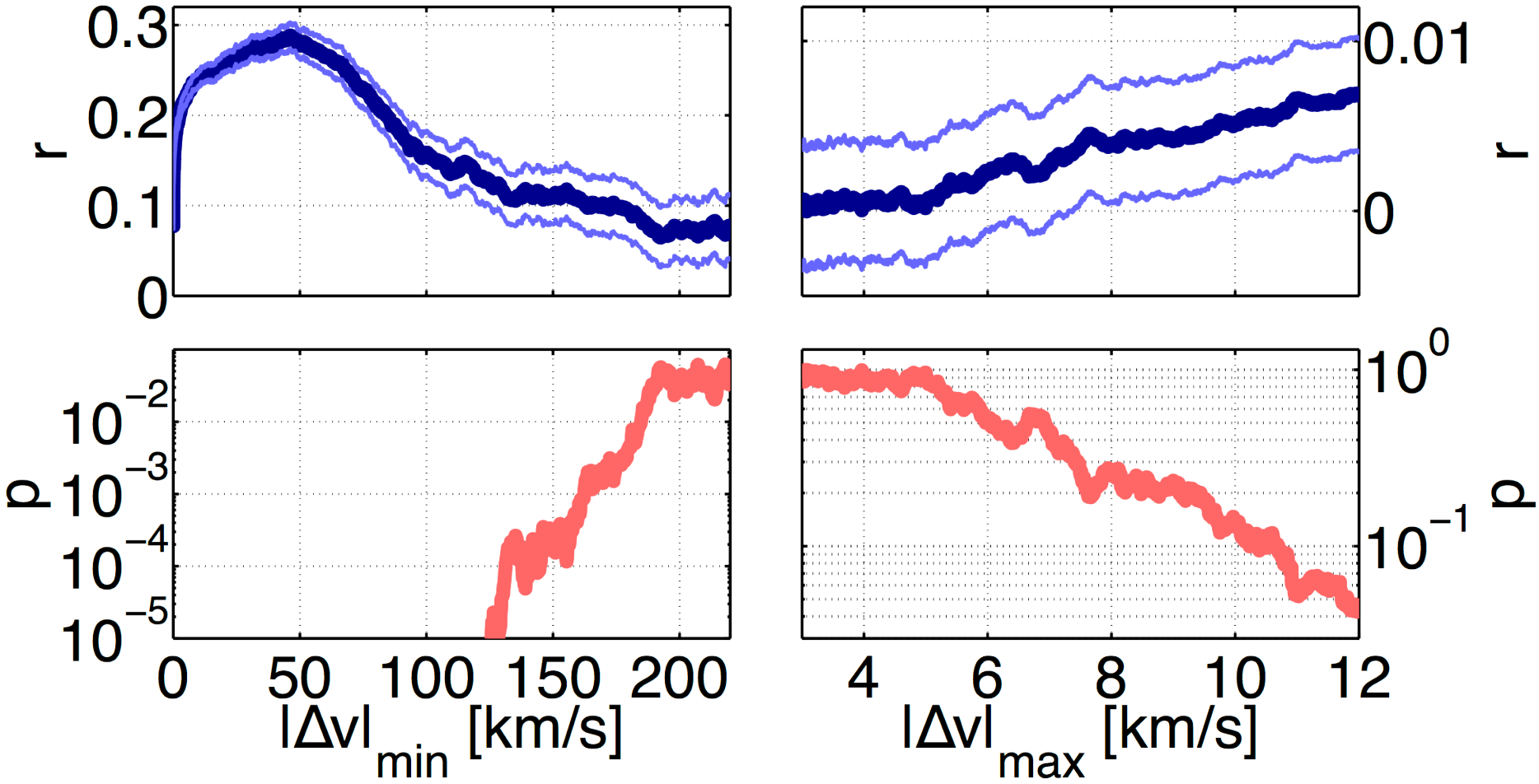
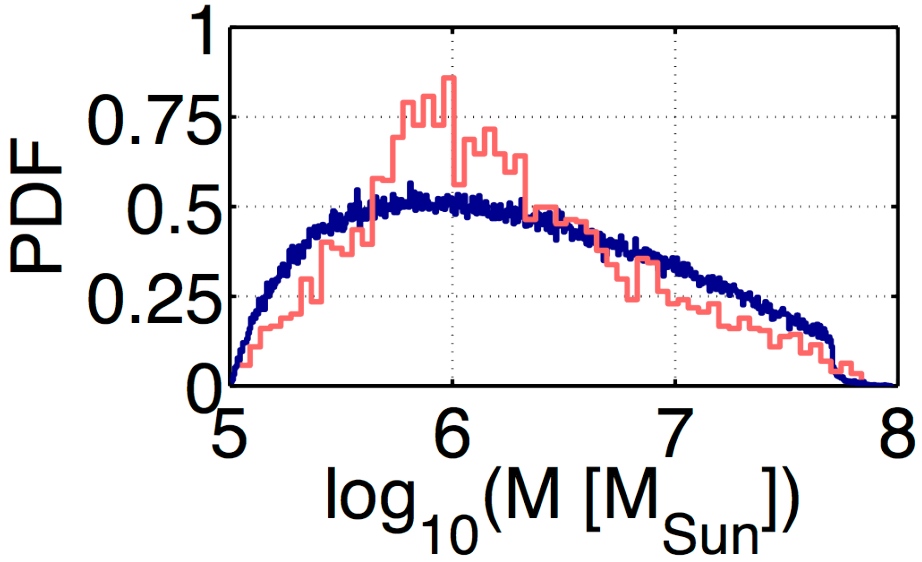
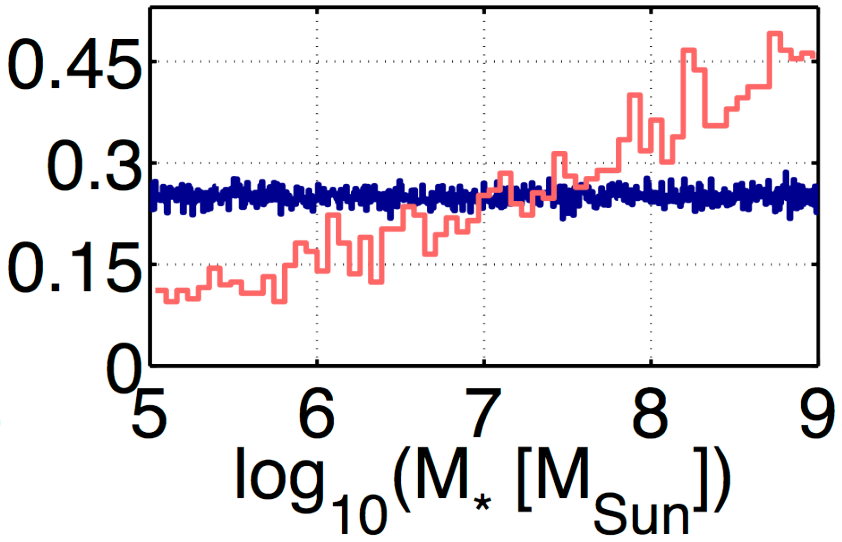
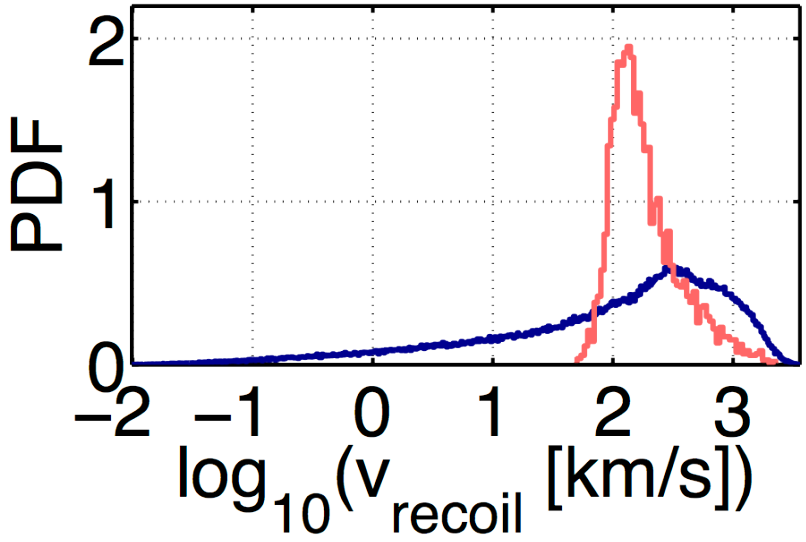
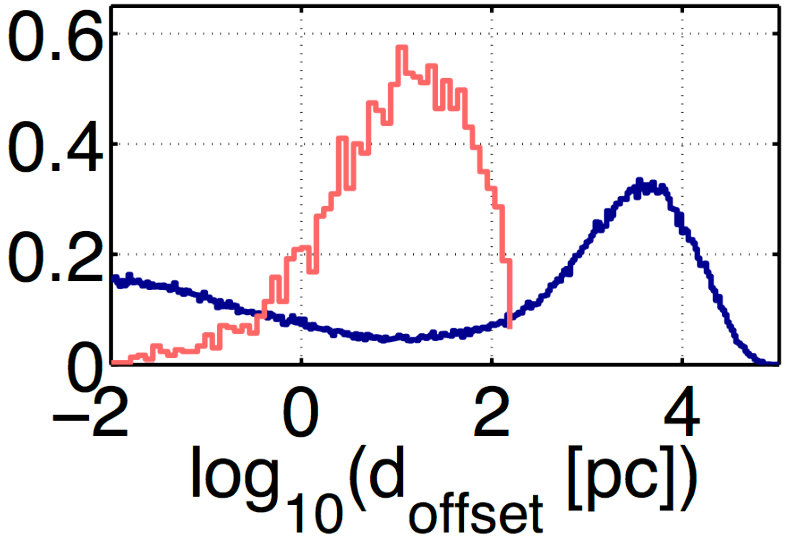
Extra slides

Number of QSOs required for rejection of no-correlation hypothesis with 3σ





Applying velocity cuts



Characteristics of QSOs showing the correlation