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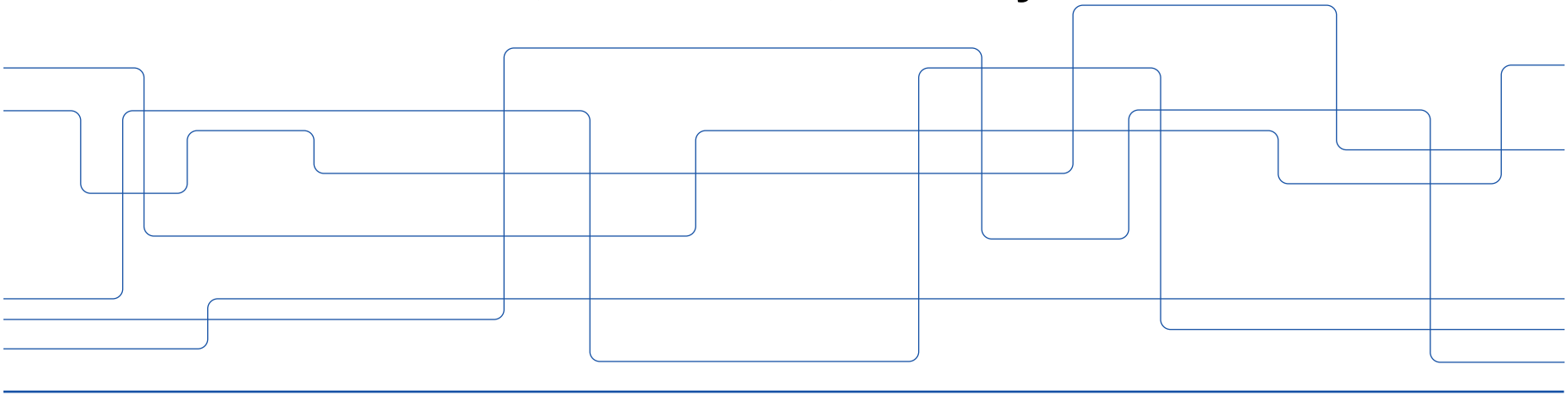
Re-analysis of limb anomaly detections in three HST/STIS transit images of Europa: No evidence for plumes

Gabriel Giono, Lorenz Roth, Nickolay Ivchenko et. al.



Introduction

This presentation is a summary of the following article:

An analysis of the statistics and systematics of limb anomaly detections in HST/STIS transit images of Europa

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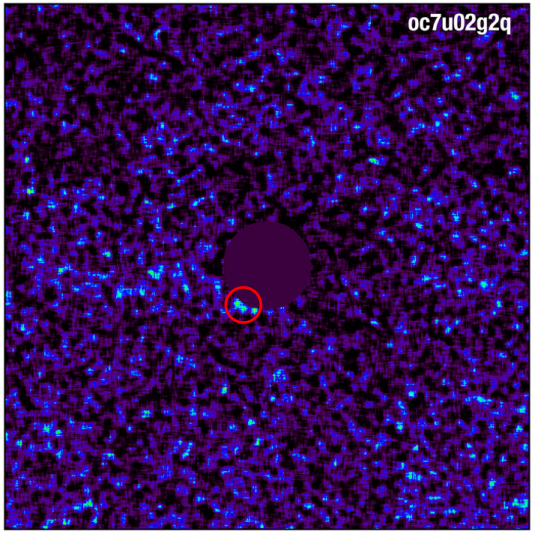
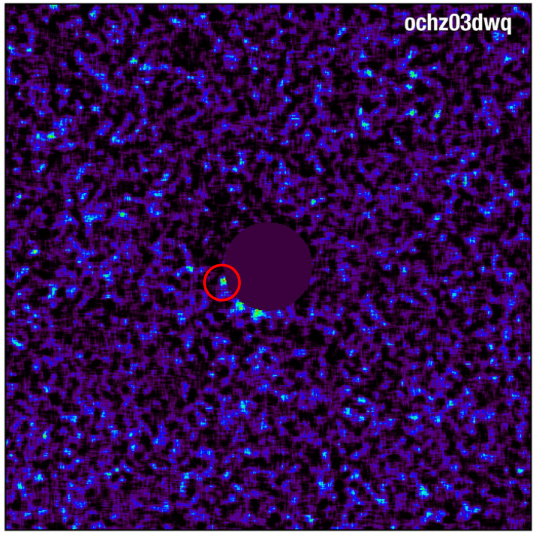
Published in the Astrophysical Journal in 2020.

The article reproduces the results from Sparks et al. (2016), discusses several potential issues with the method used which lead to a different conclusion.

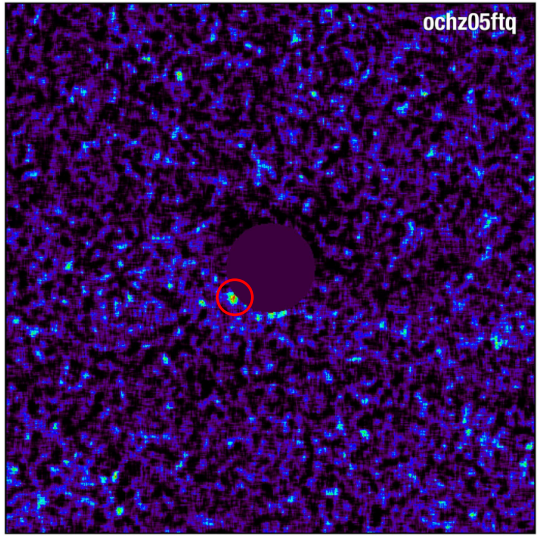
Sparks et. al. (2016) results



$\sigma = 3.9$



$\sigma = 4.4$



$\sigma = 4.5$

Only negative outliers are shown in the p-statistic.
Negative outliers correspond to absorption outside the limb (observation dimmer than model) which could be due to water vapor.

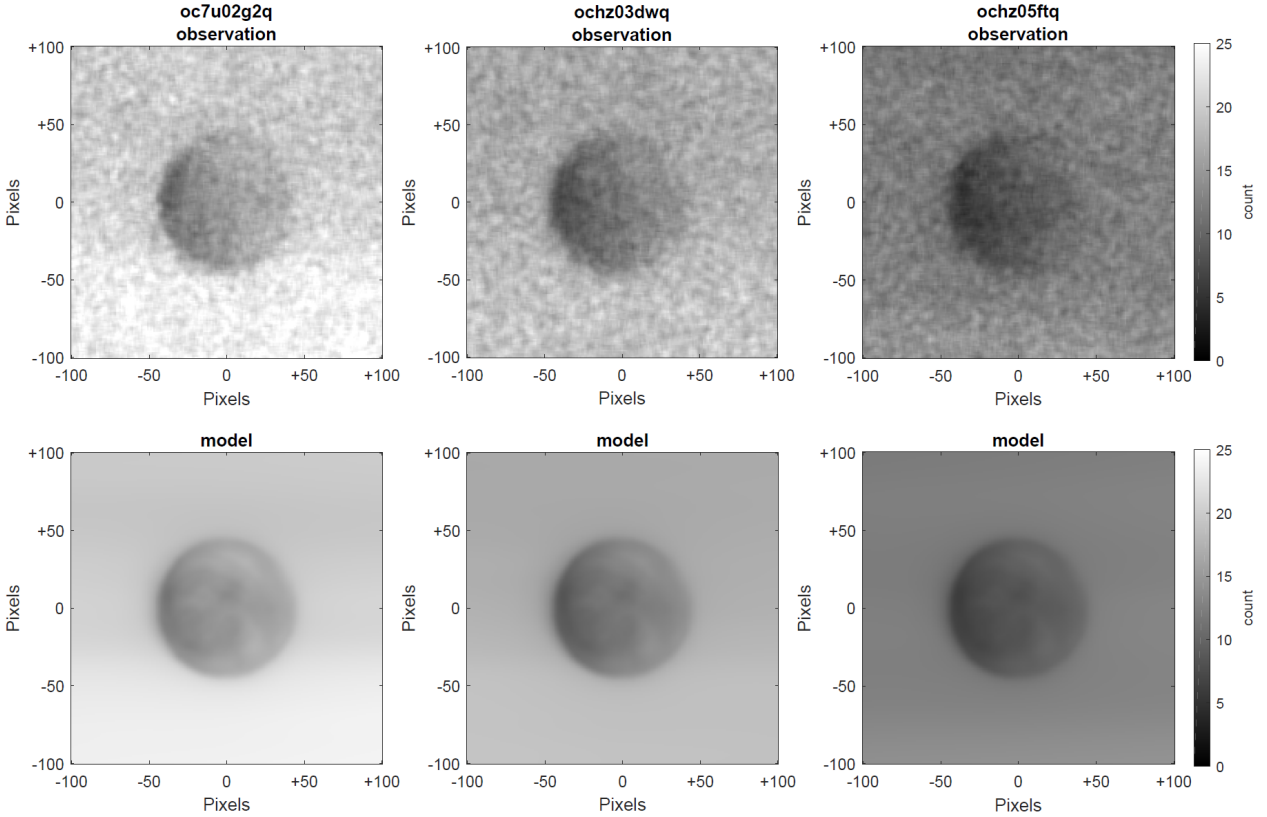
Reproducing Sparks et. al. (2016) results

The method looks for statistical differences between the HST/STIS measurement and a model of the observation using a z-test:

$$z = \left(\frac{\text{Observation}}{\text{Model}} - 1\right) \Big/ \sigma$$

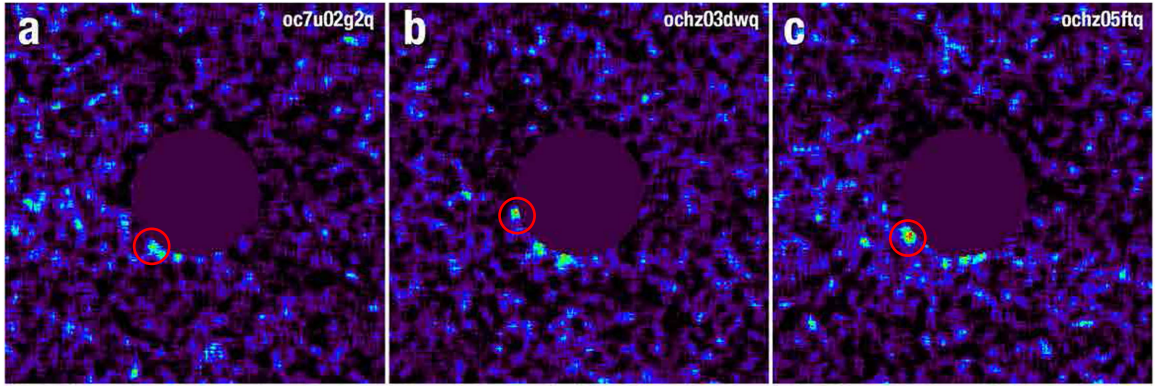
The p-statistic is also used for the comparison:

$$p = -\log\left(0.5 \times (1 - \text{erf}(-z/\sqrt{2})\right)$$

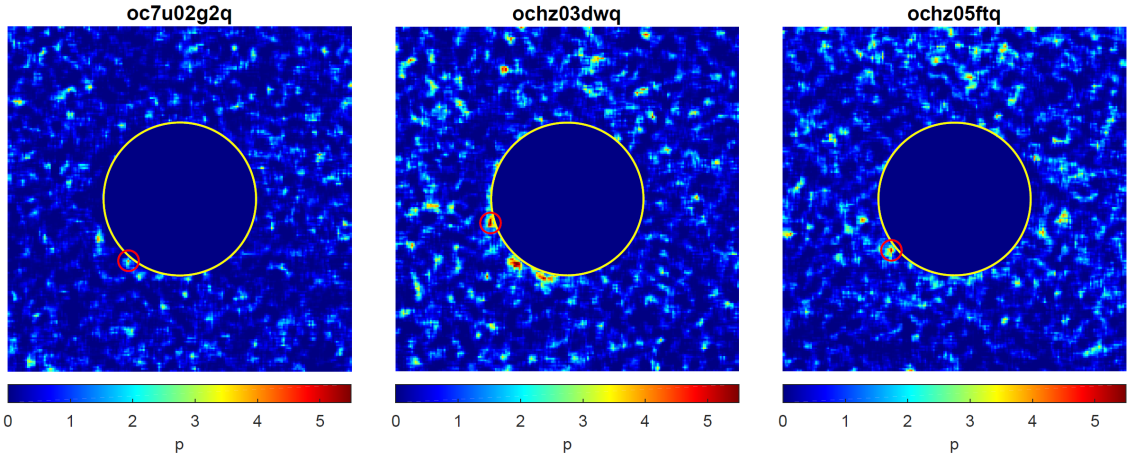


Comparing to Sparks et. al. (2016) results

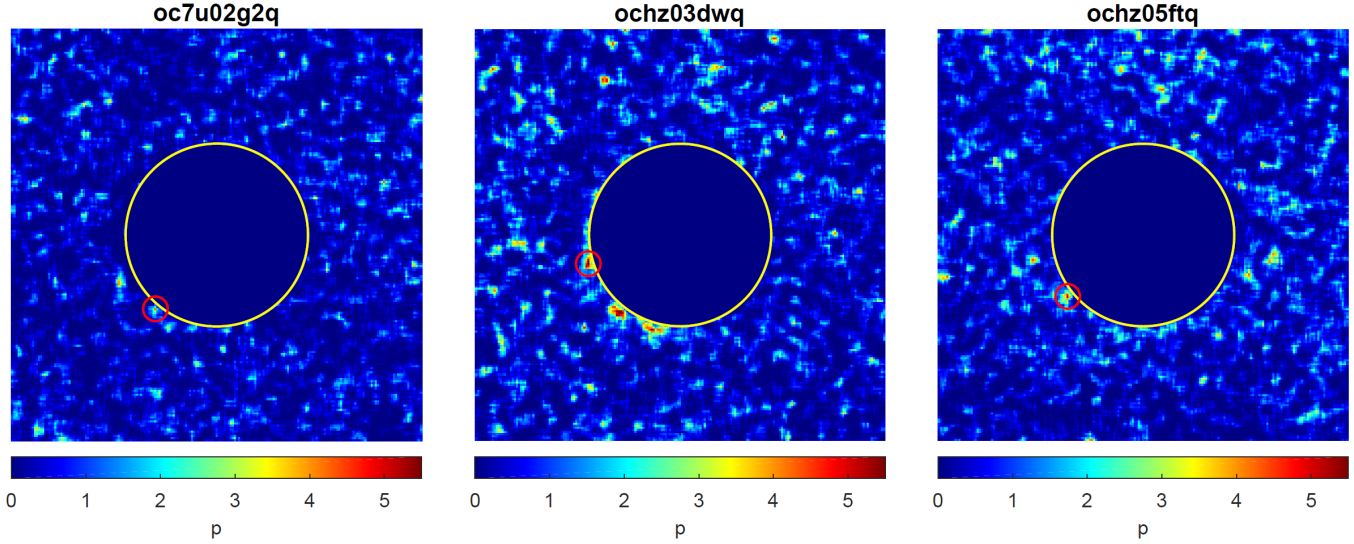
Sparks et al. (2016)



Giono et al. (2020)



Reproducing Sparks et. al. (2016) results



	Observation	Sparks et al. (2016)	Reproduction
Negative outlier	oc7u02g2q	3.9σ	3.8σ
	ochz03dwq	4.4σ	4.6σ
	ochz05ftq	4.5σ	4.3σ

Issues with the results

Reproducing Sparks et. al. (2016) results uncovered serveral issues

I. Positive outliers **should be discussed**.

II. The **exact position of Europa** in the observation is **not known** (due to HST absolut pointing error). Misalignment between observation and model can affect the resulting z-statistic significantly.
In case of Sparks et. al. (2016), the position of Europa was adjusted by hand. (and similiarly in our reproduction)

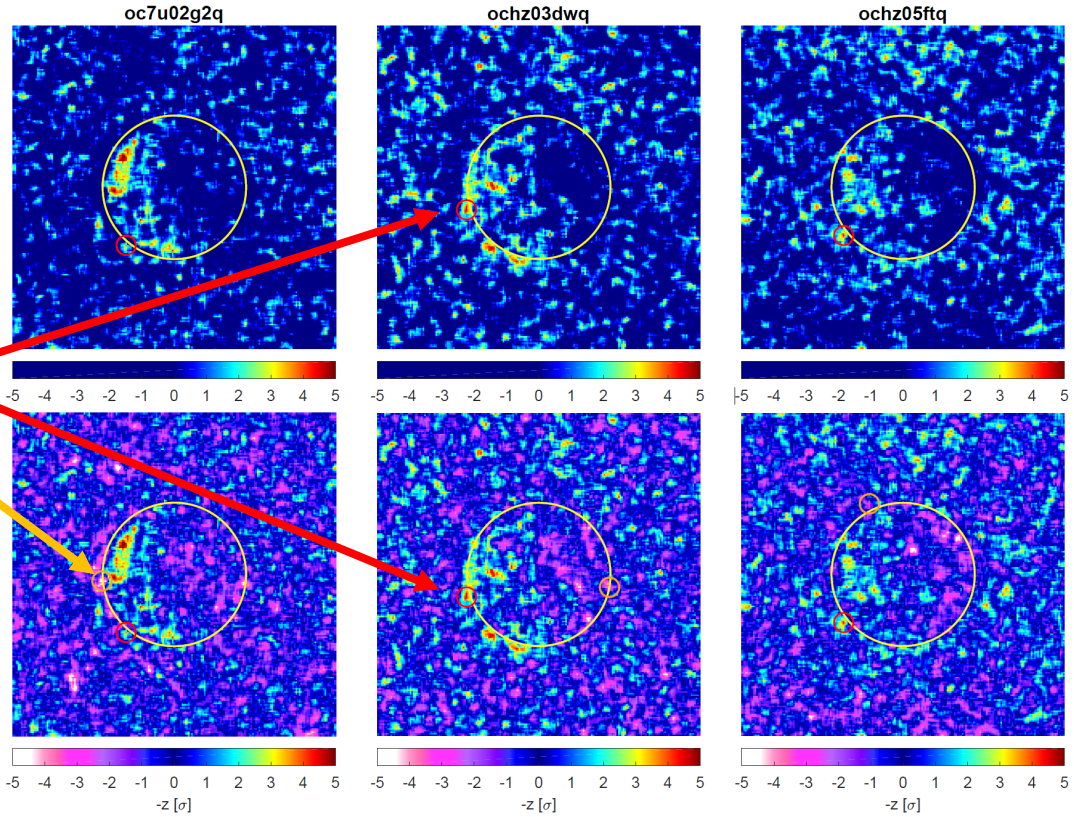
III. The **normalization of the z-statistic** can be affected by uncertainty in the model.

(I) Positive outliers

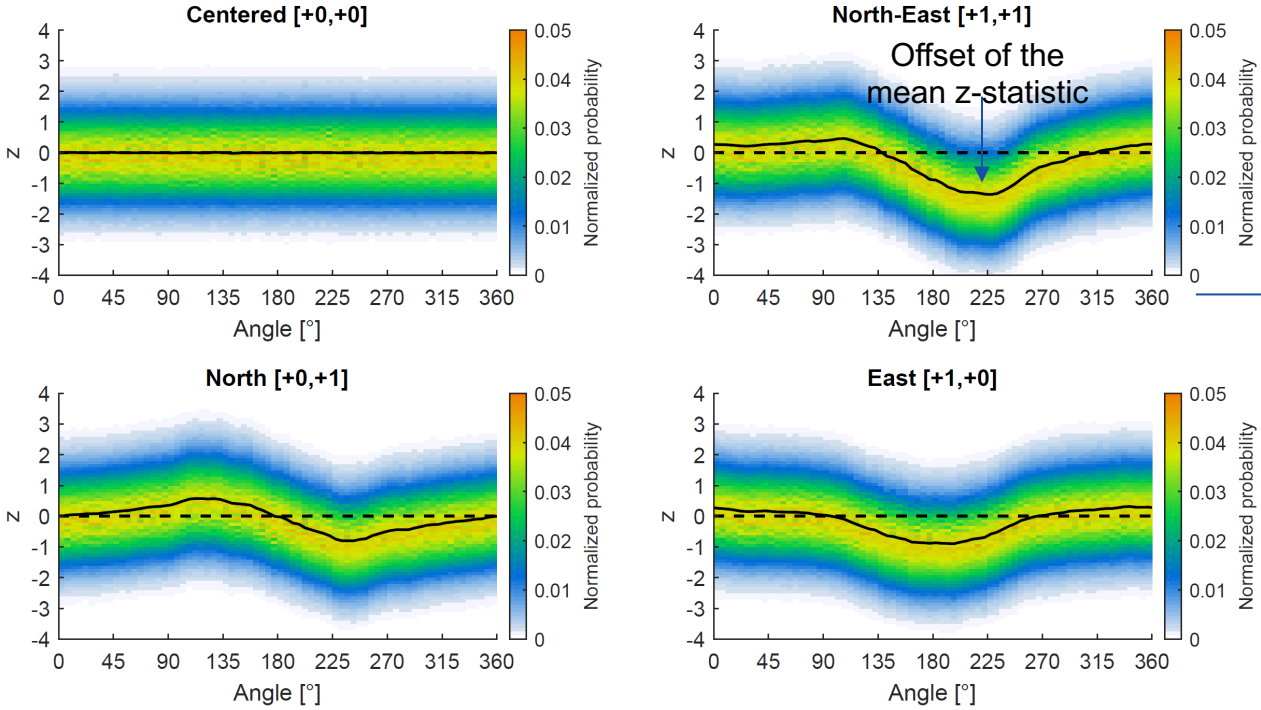
-z statistic is used instead of p-statistic: similar visually but directly in unit of σ.

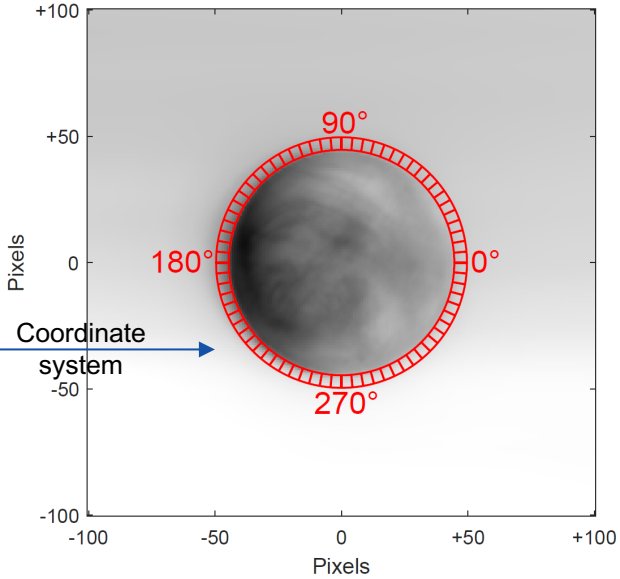
	Observation	Sparks et al. (2016)	Reproduction
Negative outlier	oc7u02g2q	3.9σ	3.8σ
	ochz03dwq	4.4σ	4.6σ
	ochz05ftq	4.5σ	4.3σ
Positive outlier	oc7u02g2q	N/A	-5.4σ
	ochz03dwq	N/A	-4.0σ
	ochz05ftq	N/A	-3.3σ

The largest positive outliers have similar significance as the largest negative outliers.



(II) Misalignment effect on the z-statistic





Monte-Carlo test with 10.000 trials. Artificial observation creates by adding Poisson noise to the model.

Misalignment (even a single pixel, as shown in the figure above) offsets the distribution of the z-statistic from zero.

(II) Results after adjusting the position

We developed a robust method to find the disk center. The best alignment for all three observations was offset by one or two pixels from the location used to reproduce Sparks et al. (2016) results. Adjusting the position brings the significance of the largest positive and negative outliers to similar level, i.e. recentering of the z-statistic dostribution.

	Observation	Sparks et al. (2016)	Reproduction	Position adjustment
Negative outlier	oc7u02g2q	3.9σ	3.8σ	4.3σ
	ochz03dwq	4.4σ	4.6σ	3.4σ
	ochz05ftq	4.5σ	4.3σ	3.9σ
Positive outlier	oc7u02g2q	N/A	-5.4σ	-4.2σ
	ochz03dwq	N/A	-4.0σ	-3.6σ
	ochz05ftq	N/A	-3.3σ	-2.9σ

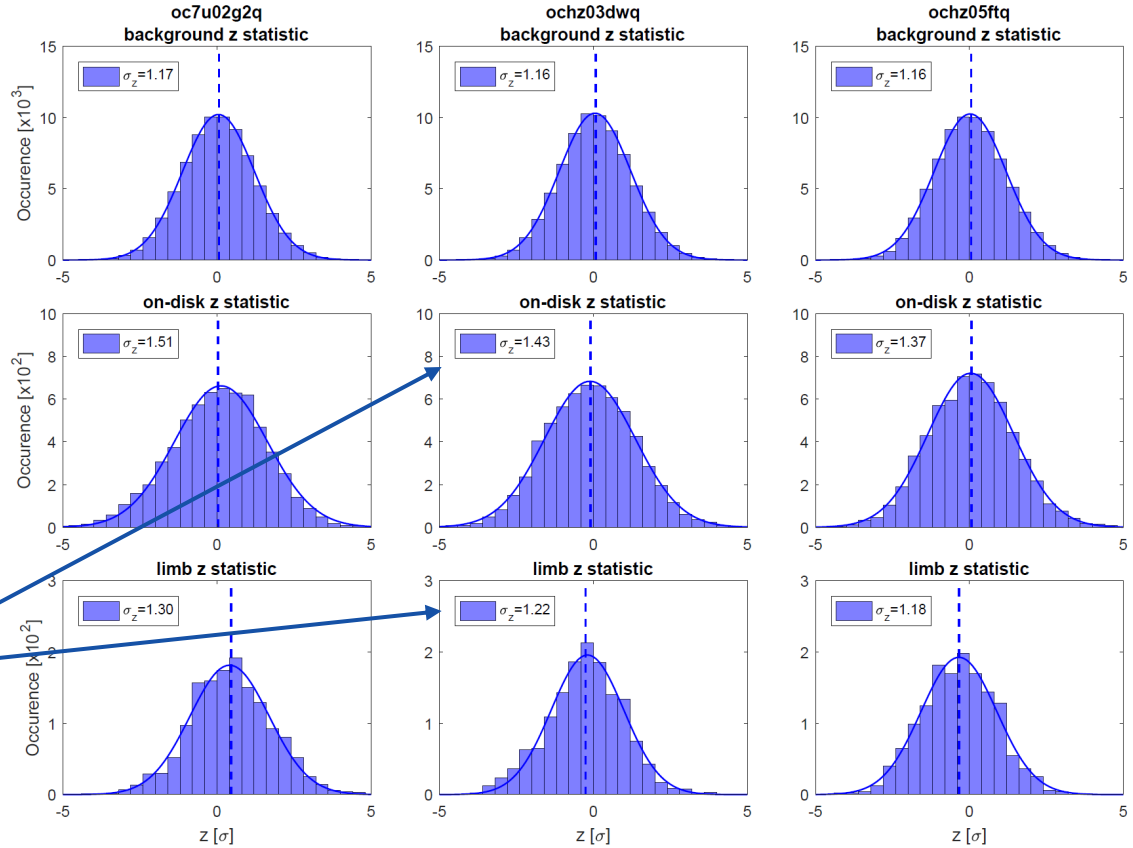
Note that in case of oc702g2q the significance of the negative outlier increased due to the shift direction. The positive outlier decreased to more reasonable level.

(III) Normalization of the z-statistic

If properly normalized by the observation noise, the z-statistic should be in unit of σ. This means the width of the z-statistic distribution σ_z should be unity.

This can be checked by taking a sample of enough pixels (e.g. in the Jovian background). However:

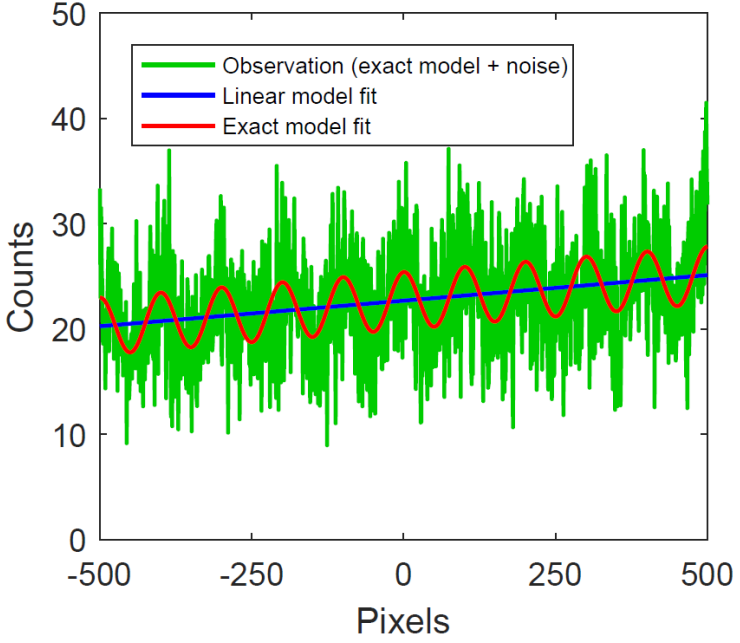
$$\sigma_z > 1$$

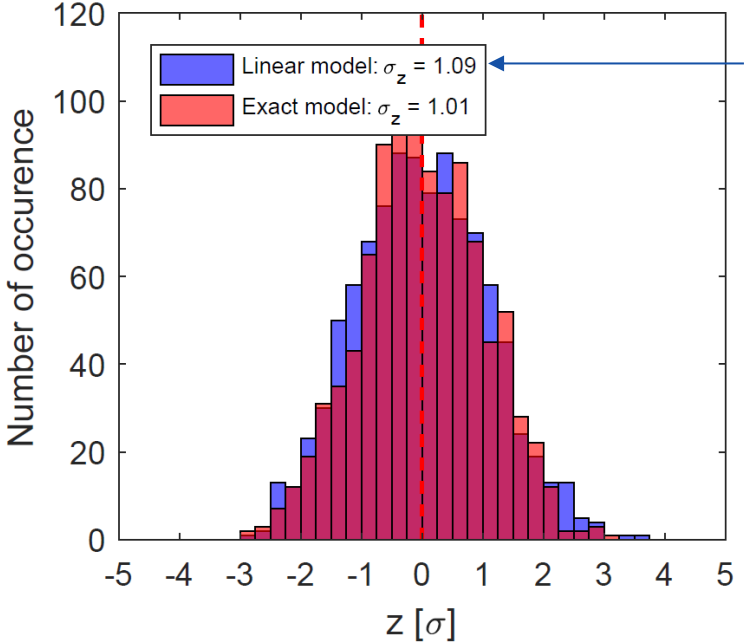


(III) Reason: model mismatch

Difference between the model and the observation can led to improperly normalized z-statistic.

Example with a simple model





Wrong model gives a 10% larger σ_z as the model mismatchs cannot be normalized away.

(III) Renormalizing the z-statistic

σ_z in the background is smaller (1.17) than σ_z on-disk (1.40): the model of the Jovian background is better than the model on-disk. The limb parts lies in-between, as both model meet at the limb.
One can re-normalize* the z-statistic using σ_z to obtain a better representation of the significance of the outliers, leading to negative outlier around 3.3σ.

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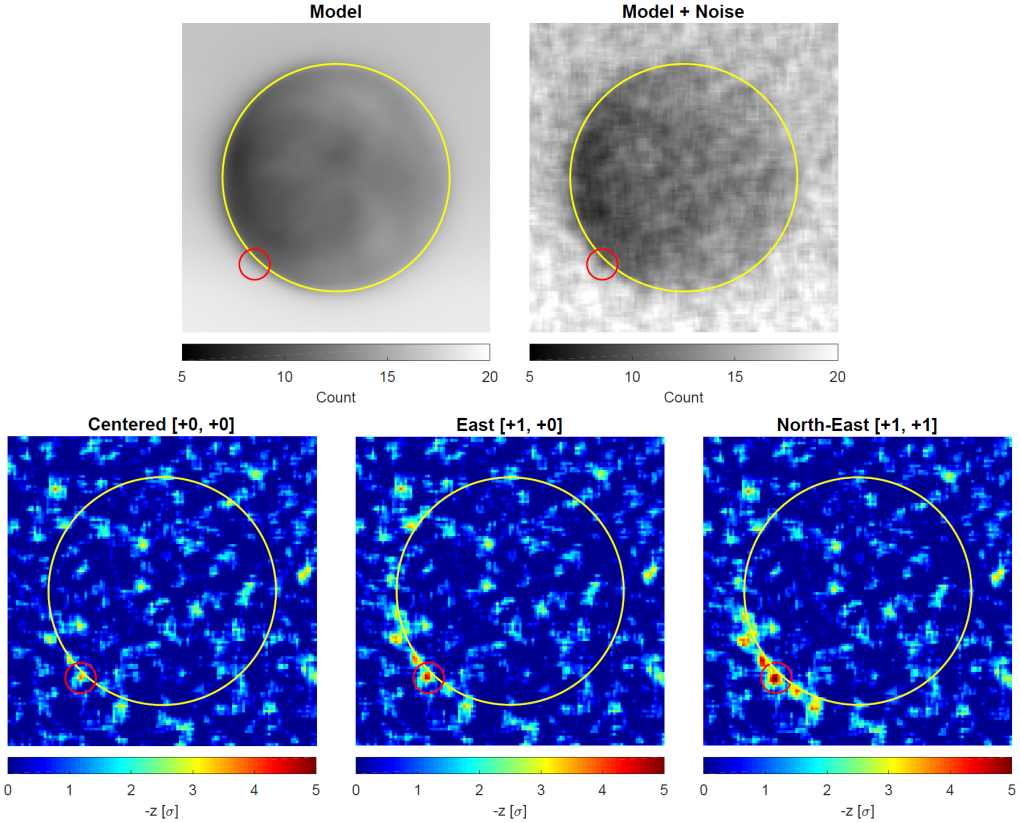
	Observation	Sparks et al. (2016)	Reproduction	Position adjustment	σ_z correction
Negative outlier	oc7u02g2q	3.9σ	3.8σ	4.3σ	$3.3^{+0.4}_{-0.5}\sigma$
	ochz03dwq	4.4σ	4.6σ	3.4σ	$2.8^{+0.1}_{-0.4}\sigma$
	ochz05ftq	4.5σ	4.3σ	3.9σ	$3.3^{+0.1}_{-0.5}\sigma$
Positive outlier	oc7u02g2q	N/A	-5.4σ	-4.2σ	$-3.2^{+0.4}_{-0.4}\sigma$
	ochz03dwq	N/A	-4.0σ	-3.6σ	$-3.0^{+0.5}_{-0.1}\sigma$
	ochz05ftq	N/A	-3.3σ	-2.9σ	$-2.5^{+0.4}_{-0.0}\sigma$

*although this is not valid in a purely mathematical sense. Yet it gives a better representation of the real significance of the outliers.

Discussion: significance of the results.

The region around the limb is composed of about 1500 pixel. In every image, one expect to find at least one negative outliers with 3.2σ significance.

Outliers with **3.3σ** significance are therefore expected in **1.4 images**.
Outliers with **4.0σ** significance can occurs in **1 out of 22 images**.



Right: Negative outlier seen outside the limb in an artificial observation (i.e. model+Poisson noise). Significance is 3.8σ , 4.6σ and 5.4σ from left to right.

Conclusion

The significance of the negative outliers seen in Sparks et. al. (2016) was found to be comparable to the expected occurence rate from a random distribution.

Misalignment and mismatch between the model and the observation can affect the z-statistic significantly and should be accounted for.

Positive outliers with similar significance level as the negatice ones were also observed. This seriously undermine the water plume hypothesis suggested by the original article.

In conclusion, the nature of the negative outliers seen in the observation seem to be purely statistical, with misalignment possibly increasing the significance in the darker trailing hemisphere by offseting the mean of the z-statistics.