1 INTRODUCTION

2 METHOD

2.1 Pan-STARRS1

4800

$10\mu m$

g_{P1}

z_{P1}

y_{P1}

z_{P1}

w_{P1}

g_{P1}

3π

g_{P1}

z_{P1}

y_{P1}

3π

3π

w_{P1}

z_{P1}

y_{P1}

3π

2.2 Convolutional Neural Network

3π

$h(x)$

x

$P(real)$

≤ 0.436

$h(x)$

~ 5.2

2.3 Citizen Science Platform

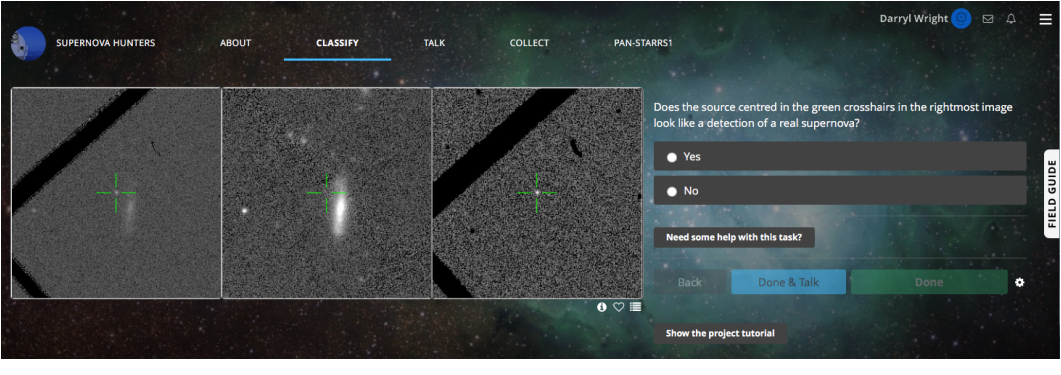

Figure 1. The classification interface presented to citizen scientists. The left most image is the *target* image taken during the previous week. In the centre is the equivalent 3π *reference* image and on the right is the *difference* image. Volunteers are asked to decide whether or not they think the detection in the green crosshairs in the difference image is a detection of a real transient.

~ 5200

1

~ 23000

~ 8300

$P(real) > 0.8$

3 PERFORMANCE

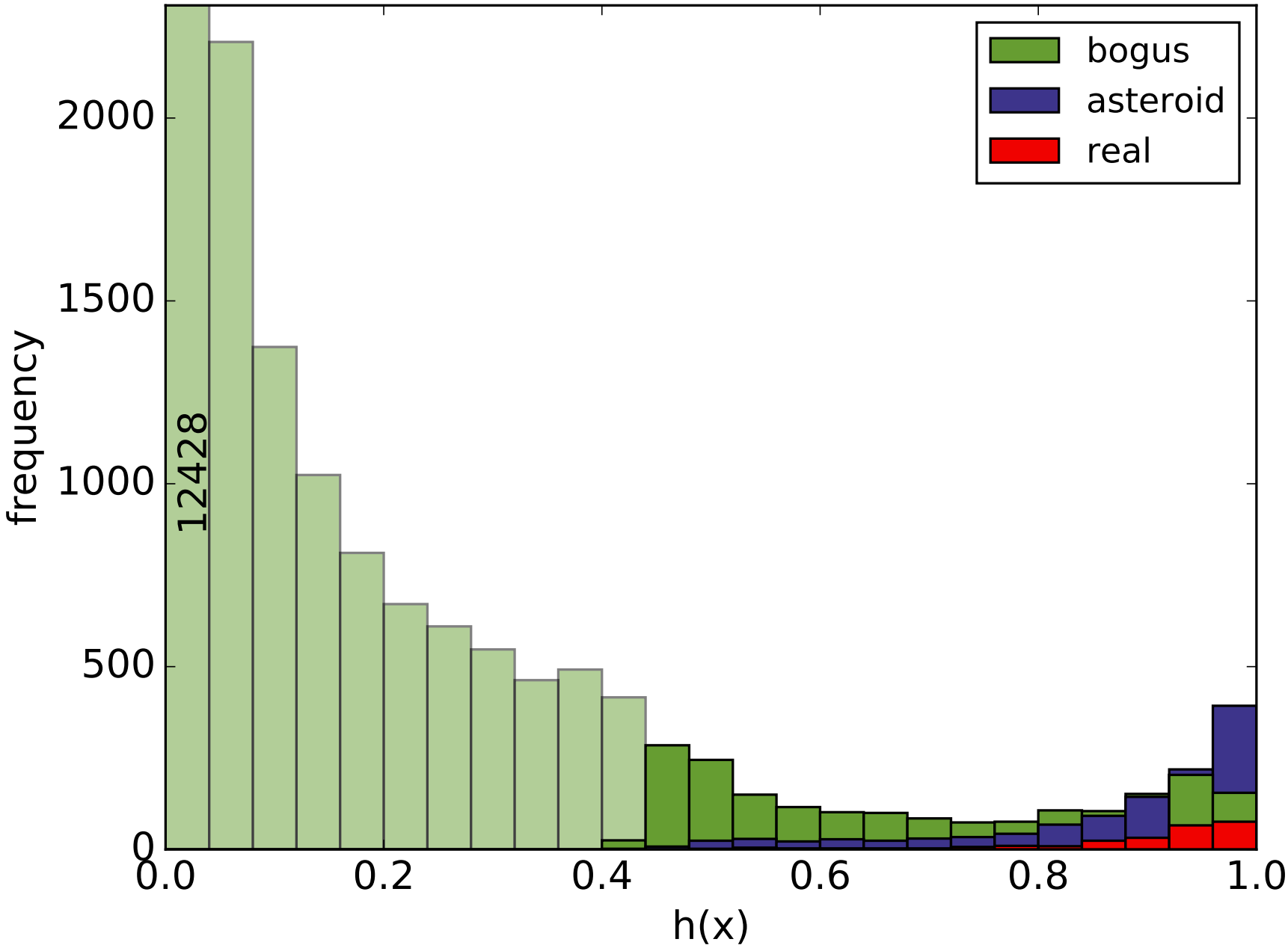

Figure 2. The distribution of hypotheses, $h(x)$ from the current 3π machine classifier for detected objects between MJD 57570 and MJD 57586. The light green shows the distribution of objects with $h(x) \leq 0.436$ which are automatically rejected. The remaining objects promoted for human screening even at high values of $h(x)$ contains many false positives. The first interval has a frequency of 12428, but the plot is truncated for clarity.

$h(x) = 0.436$

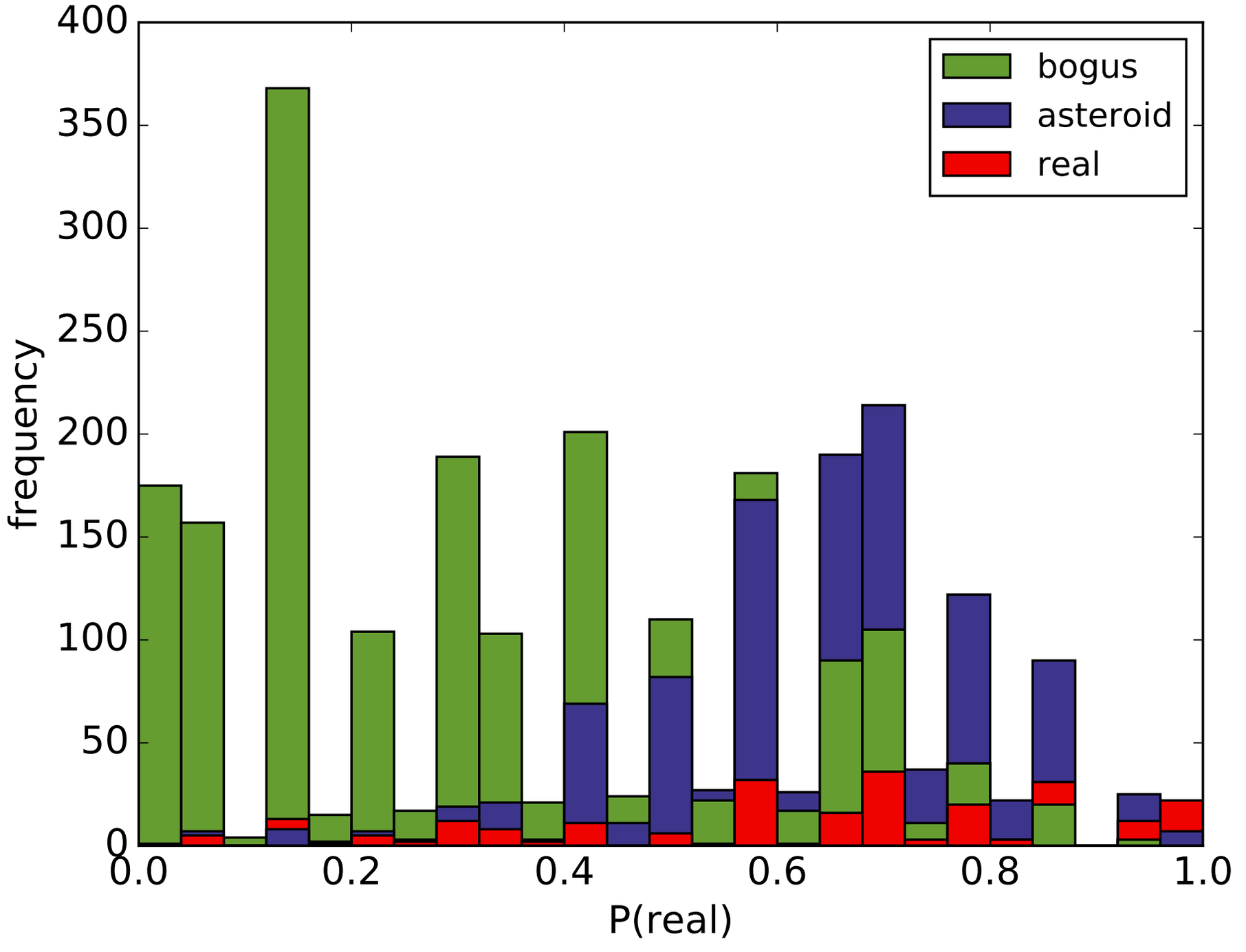

Figure 3. The distribution of $P(real)$ from Supernova Hunters for objects detected between MJD 57570 and MJD 57586. Compared with the machine $h(x)$ in Figure. **??** the objects at the extremes are pure. There are very few real detections with $P(real) < 0.04$ and few bogus detections above 0.92.

$P(real)$

$P(real) < 0.04$

3.1 Combining human and machines

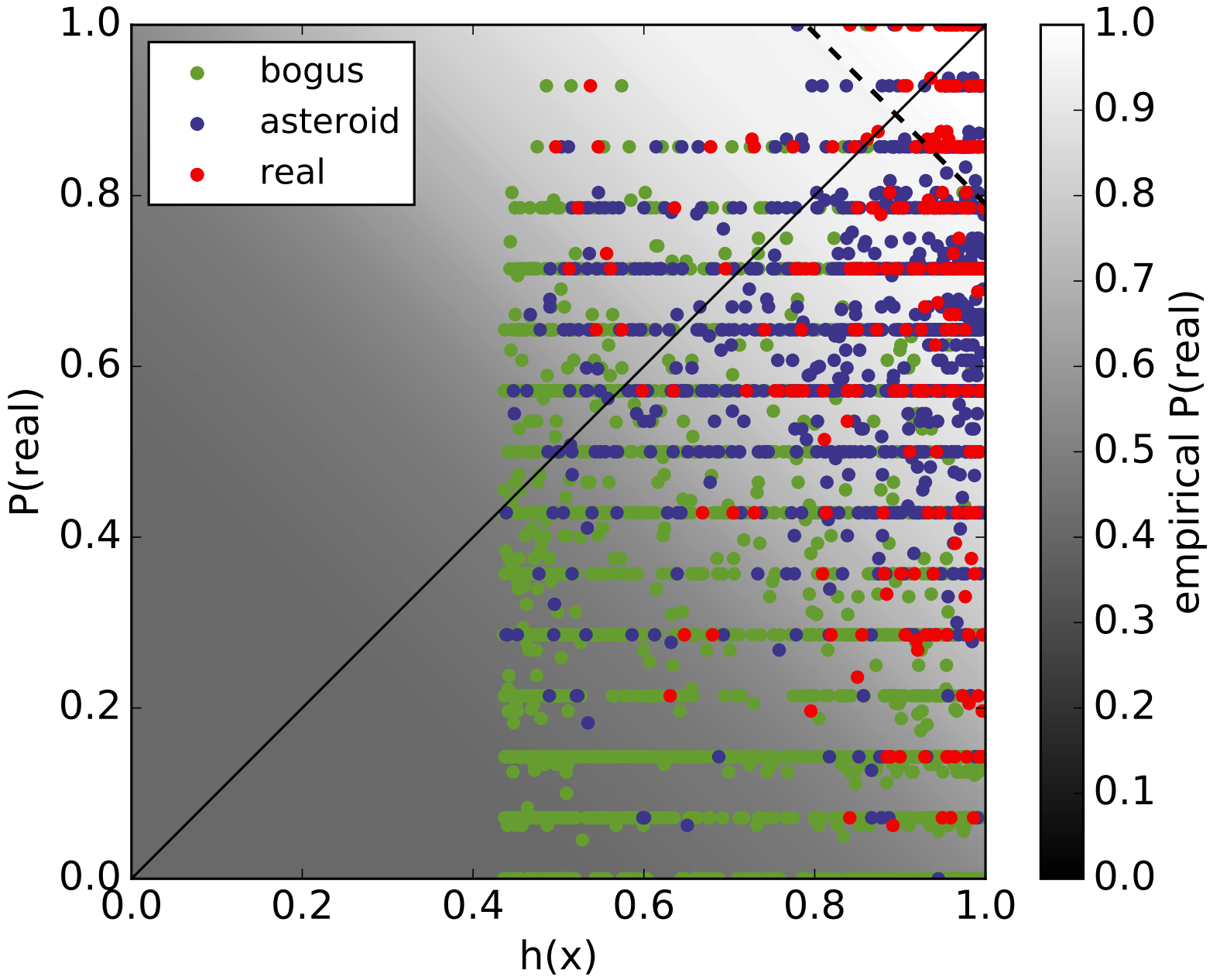

Figure 4. The $P(real)$ from Supernova Hunters against the machine $P(real)$ for detected objects between MJD 57570 and MJD 57586. $P(real)$ and $h(x)$ are combined by projecting the data onto the solid black line in the euclidean sense. For a given value of τ the background colour map shows the probability that an example chosen at random with combined score above τ will be real; an empirical measure of P(real) for our combination method. The dashed black line shows the 90% probability contour.

$\tau = (x + y)/2$

$0 \leq \tau \leq 1$

τ

$[h(x) + P(real)]/2 <= \tau$

$$P(real) = h(x)$$

$h(x)$

$h(x)$

$P(real)$

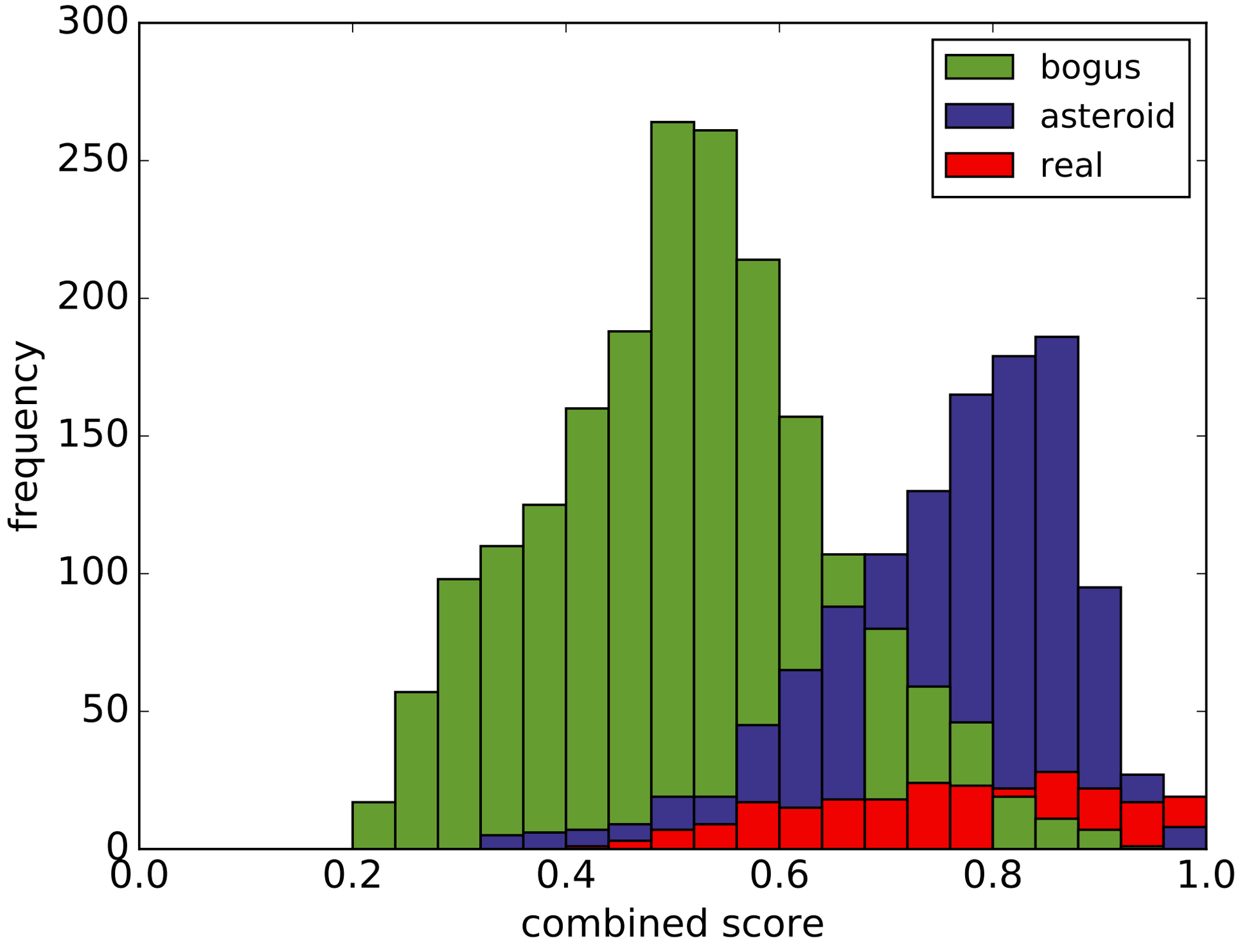

Figure 5. Histogram showing the distribution of data resulting from the combination of human and machine classifications.

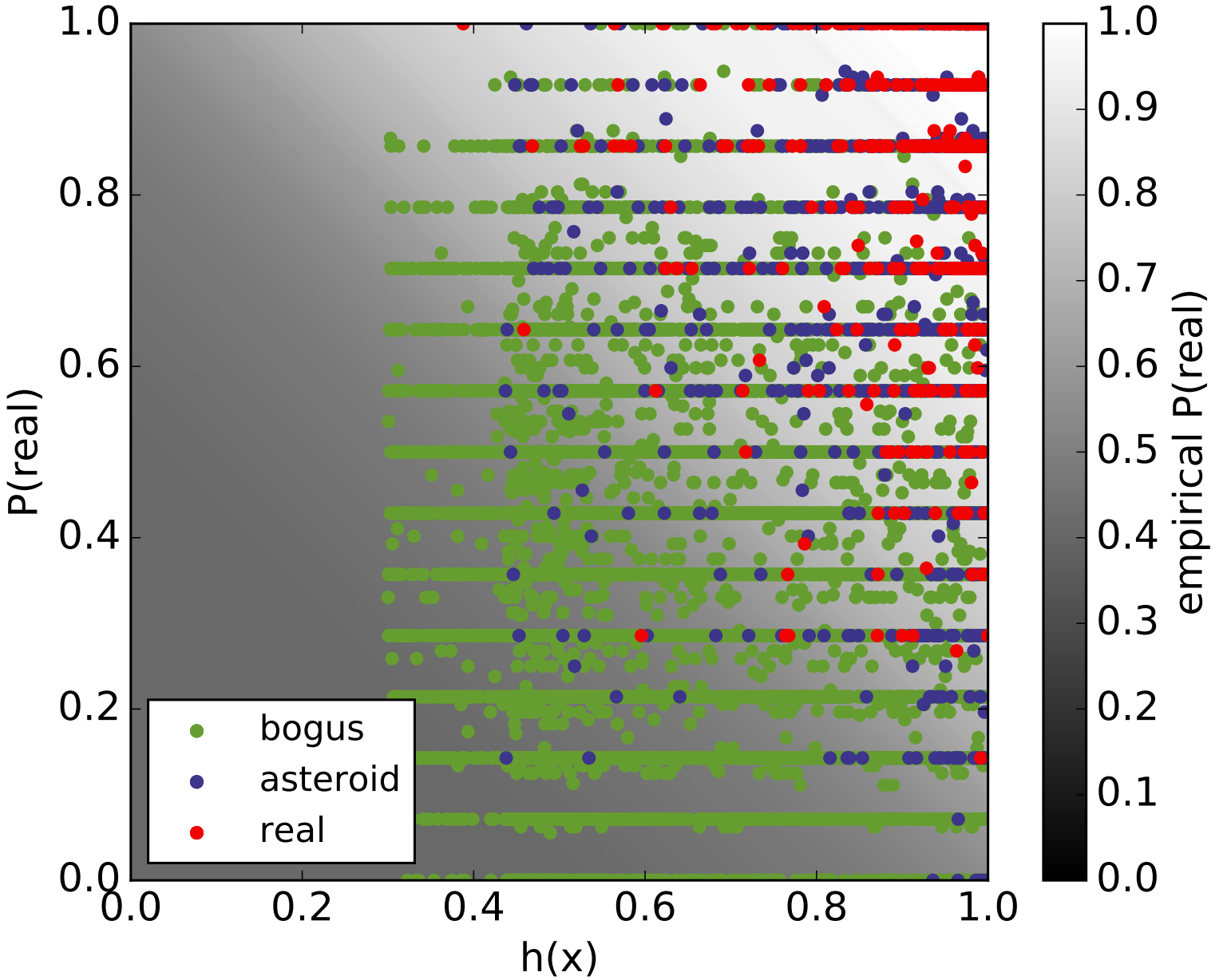

Figure 6. The same as Figure. **??** but on a new sample of 10908 objects detected between MJD 57587 and MJD 57627. For one week during this period we relaxed our cut on $h(x)$ to 0.3 which allowed us to recover a supernova with $h(x)$=0.39, but which achieved a $P(real)$=1.0 from Supernova Hunters. The background colour map is the same empirical $P(real)$ as Figure. **??** but underestimates the probability at each value of τ for this data set, perhaps suggesting an improvement in the classification ability of volunteers over time.

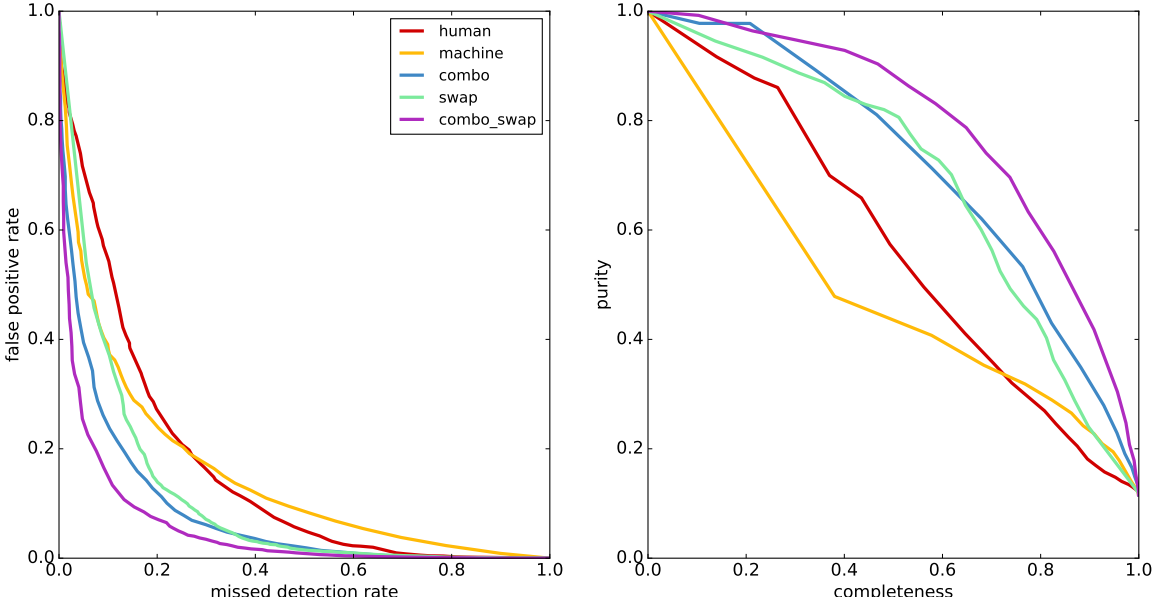

Figure 7. Left: ROC curve showing performance measured on data in Figure. **??** for human (red), machine (yellow) and the combination of human and machine classifications (blue). Right: The equivalent Purity-Completeness curve. Both plots show that the combination always outperforms humans and the machine individually. SWAP (green) makes more efficient use of the human classifications and allows a significant improvement over the simplest method of combining volunteer votes. Combining this improved SWAP score with the machine once again leads to better performance.

FPR	Human	Machine	Combination	SWAP	Combined SWAP
1%	73.9%	90.1%	58.7%	59.9%	48.3%
5%	56.3%	69.7%	35.8%	34.6%	24.3%
10%	45.6%	46.7%	23.8%	26.2%	15.3%

Table 1. Missed detection rate recorded for a choice of false positive rates, based on expert classifications.

MDR	Human	Machine	Combination	SWAP	Combined SWAP
1%	92.5%	85.9%	69.3%	100%	59.6%
5%	75.1%	52.8%	41.8%	100%	25.5%
10%	53.8.8%	39.1%	26.5%	40.9%	16.5%

Table 2. False positive rate recorded for a selection of missed detection rates, based on expert classifications.

$P(real)$

$h(x)$

2

ρ_0

$$\boldsymbol{M}^{i} = \begin{bmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \end{bmatrix}$$

$P(real)$

$P(real)$

$h(x)$

~ 10

4 CONCLUSIONS

3

$P(real)$

~ 10

$P(real)$

$P(real) > 0.5$

~ 30000

$\sim 10^6$

~ 750000

$\sim 10^6$

5σ

ACKNOWLEDGMENTS