Detection of Rotational Variability in Floofy Objects at Optical Wavelengths

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Background

The viewing geometry of an observation determines the amount of reflected light detected from an object

The measurement of optical light curves has been particularly well used in the study of small solar system bodies

Determining the properties of exoplanets is challenging

- Hot Jupiters: short circular orbits
- Longer orbits?

Background

Difficulties: noise, background source contamination and misclassification of observed objects

Solution: use color and a variety of filter combinations

- Low or high density?

"Floofy" Objects or UFOs

- Potentially rotationally variable objects with tentative variable reflectivity as a function of viewing angle
- Authors confident these objects will provide an unending amount of joy as astronomers work to understand their unique peculiarities

Data Collection

Solicited catstronomers through social media

Image criteria: floofy object rolling around, interest in floofy objects with different colored belly and non-belly regions, wanted images to be used for research

- Additional information: well-lit observations (large SNR, minimal contamination), observations from different angles, transiting and eclipsing objects

Overwhelming community response

Methods

Frame color-correction to account for differing seeing conditions and remove nearby colorful companions

- Prior research: frame center has relatively constant flat field and gain components
- Each object is highly resolved and not rotationally symmetric
- Remaining colorful backgrounds are removed manually
- Visual classifications

White balancing: account for variations in lighting across images of the same object

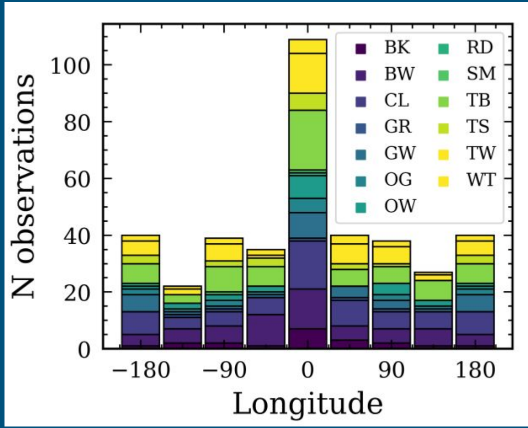
- Normalize image in each channel
- Determine average brightness in each channel

Data Analysis

Visual sub-type classifications attempt to follow previously identified color trends

Different sub-types were added as necessary throughout the classification process

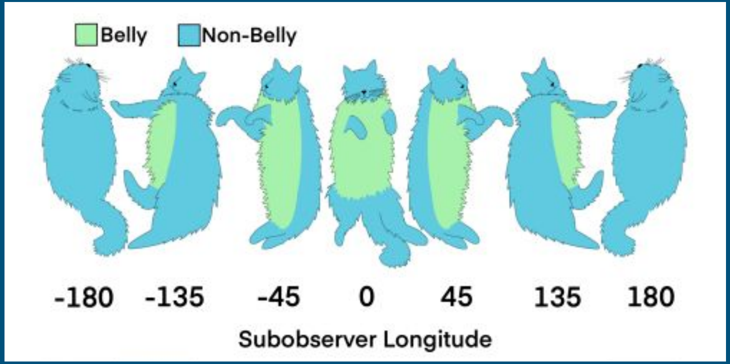
Sub-Type	Description	# Observed	% Used	# Frames	± 180	-135	-90	-45	0	45	90	135
BK	Black	25	28.0	17	0	2	2	1	6	3	2	1
BW	Black & White	54	48.15	56	4	5	6	11	14	5	5	6
GR*	Grey	9	11.11	5	0	1	1	0	1	1	1	0
GW*	Grey & White	18	50.0	24	5	1	1	1	8	4	3	1
OG	Orange	19	42.11	14	2	1	2	1	5	0	2	1
OW	Orange & White	24	41.67	21	1	2	2	2	8	0	4	2
WT	White	12	50.0	18	2	1	2	2	5	3	2	1
TB	Tabby	105	45.71	66	7	3	9	7	21	6	6	7
TW*	Tabby & White	–	–	43	5	2	6	1	14	7	6	2
CL	Calico	40	57.5	61	8	4	5	6	17	9	6	6
TS	Tortie	14	57.14	17	3	0	2	3	6	2	1	0
RD	Rag Doll	6	16.67	2	1	0	0	0	1	0	0	0
SM	Siamese	1	100.0	2	0	0	1	0	1	0	0	0
	TOTALS	328	45.12	346	38	22	39	35	107	40	38	27



Data Analysis

Longitudinal coordinate system shown

Latitude coordinate system: head = 90°, tail = -90°



Row 1: raw images of object CL1

Row 2: background subtracted images

Row 3: white balanced images

- Significant balanced images near -45°
- Added blue tint to images near +/-180°

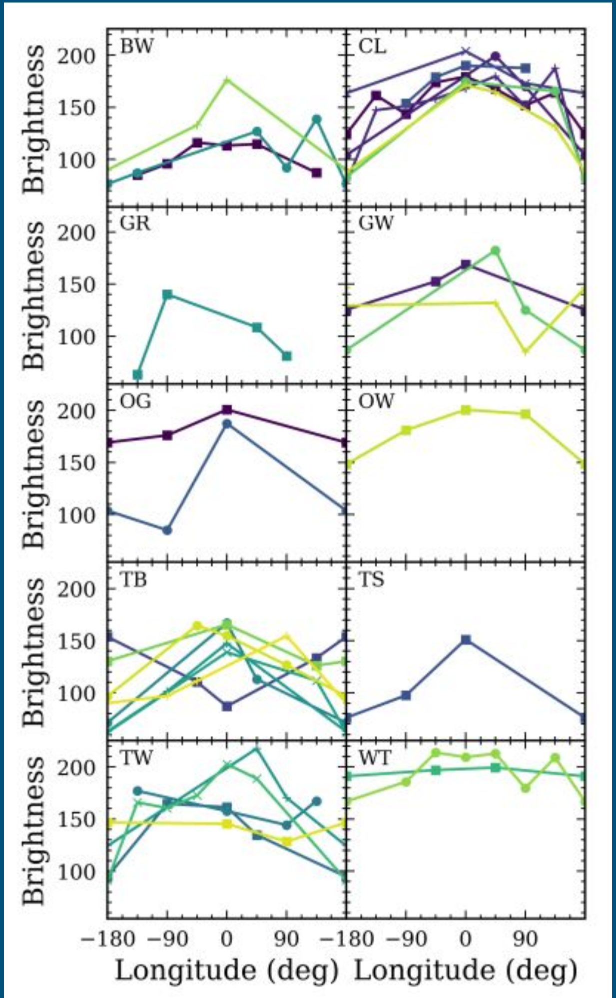
Results

Figure 3: white light rotation curves of objects with 4+ longitudes

- Each panel = different sub-type
- Each colored line = different object

Objects tend to be whiter and brighter at 0°

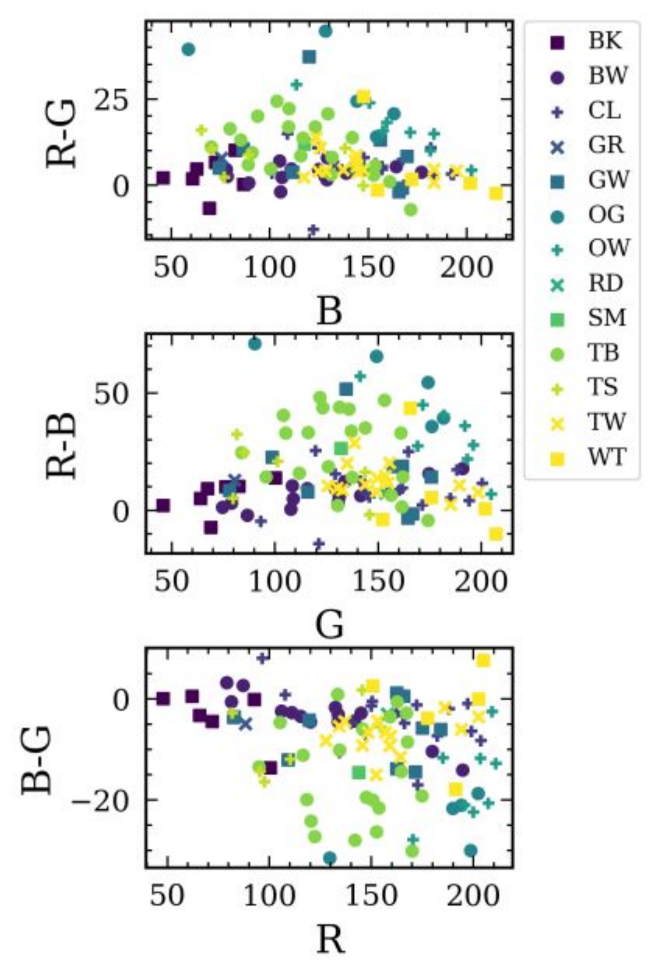
- Exception: WT is roughly constant with longitude



Results

Figure 4: color-magnitude diagram for all sub-type observations at 0°

- BK and BW trend into TW and WT across 0° in all plots
- The R−G vs. B plot is the most symmetric
- TB and OG objects stray from 0° the most in all three plots



Results

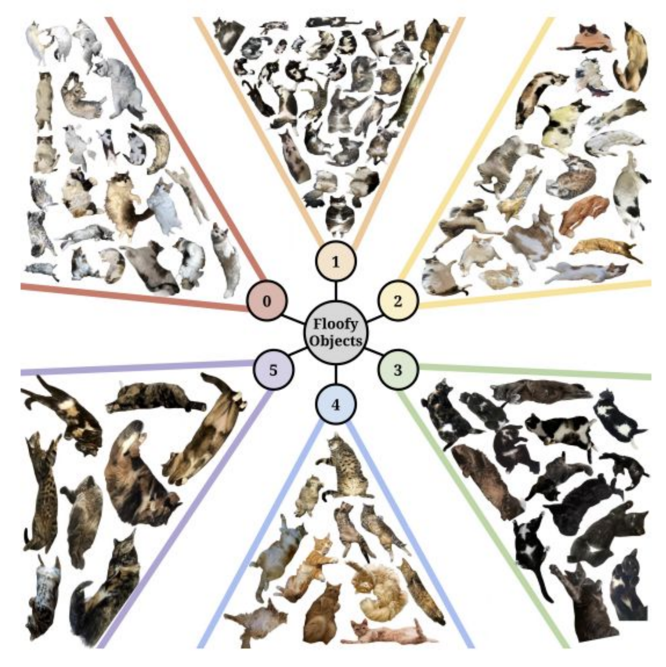
Figure 5: cluster membership based on 0° images

Clusters 0, 1, and 2: predominantly bright at 0°, with differing colors visible on limbs

- Cluster 0: many WT and CL objects with lighter limbs
- Cluster 1: many BW objects with darker limbs
- Cluster 2: limb colors lighter than cluster 1, but darker than cluster 0

Cluster 3: mostly BK sub-types, dark near 0° and on limbs

Clusters 4 and 5: mostly TB and OG sub-types, with cluster 4 being lighter and cluster 5 darker



Clusters 0, 1, and 2 are more rotationally variable

Clusters 3, 4, and 5 are more homogeneous

Shape and Rotation Rate

Resolved observations of floofy objects show that spatial inhomogeneities are the main cause of brightness variation

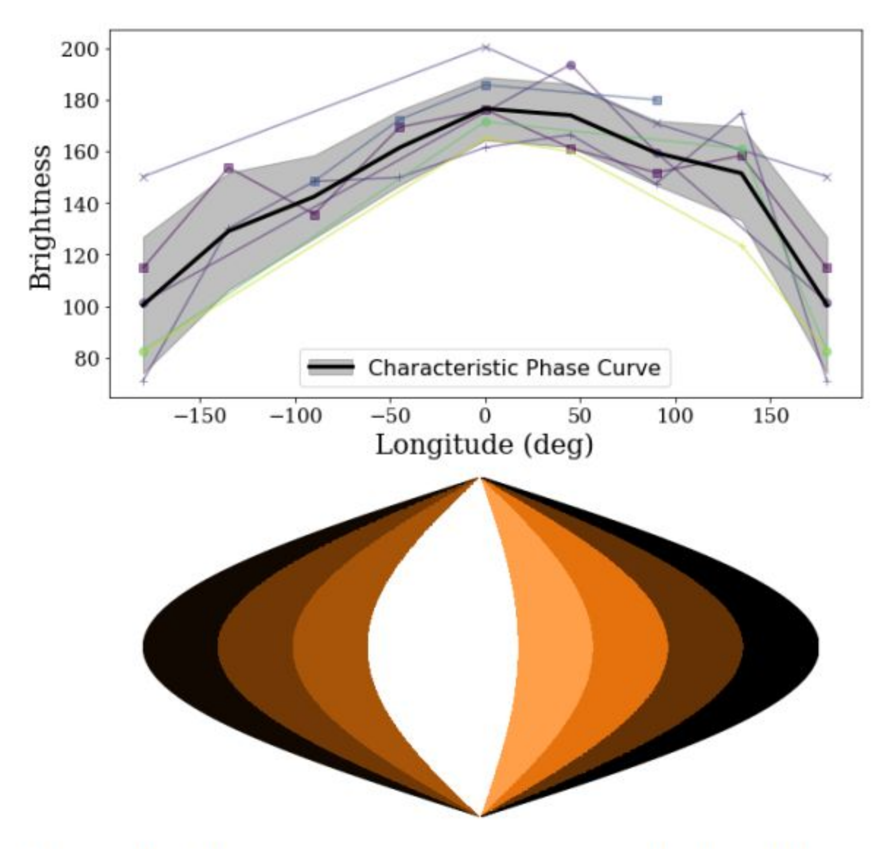
- Can apply mapping utilities as developed for planetary objects
- Determining size requires observing other objects for reference and comparison

A representative UFO can be created given a relatively large sample size

Results

Figure 6: rotation curve and longitudinal map for CL objects

- Rotation curve: strong brightness peak near 0°, and drop near 180°
- Longitudinal map: each colored slice indicates the mean brightness of CL objects at the given longitude



Conclusions

The best observational targets are tidally locked, zero-obliquity Hot Jupiters

Light phase curve observations enable comparison with known light curves

- Tidal locking and lack of rotational obliquity allow determination of the planet side at any given point in time

Further study of floofy objects is warranted as a function of temporal phase

Summary

328 floofy objects, 346 frames

- 13 different subcategories
- 32 different UFO rotation curves

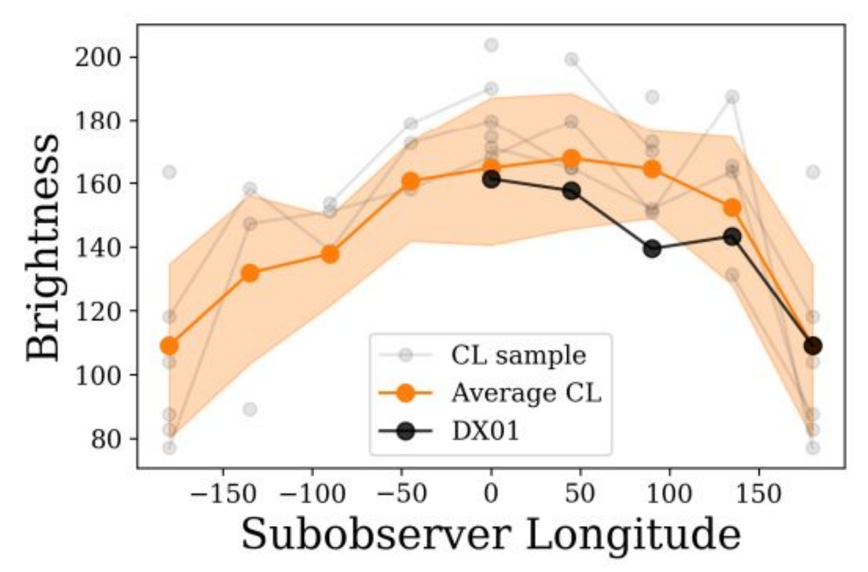
Trends: UFOs are typically brighter and whiter at 0°

Cluster analysis determined that 0° observations were best represented by 6 subcategories

False Pawsitives

WOOF (Wagging tails On Objectively Friendly) objects: potential confusion with non-spatially resolved floofy objects

Figure 7: comparing the partial DX01 (WOOF Object) rotation curve to the average CL rotation curve



4/5 observations of DX01 fall within 1σ of the average CL sub-type rotation curve

- The DX sub class is indistinguishable from the mean CL type object in unresolved observations

It is important to obtain resolved observations to differentiate between objects