Light Curves Produced by Starspots

Silvia Miramontes and Gibor Basri Ph.D.,
Department of Astronomy, University of California, Berkeley
Berkeley, CA

University of California BERKELEY Department of ASTRONOMY

Introduction

Because of the concentration of magnetic currents on the Sun, we are able to observe sunspots on its surface. This causes variability in the total brightness of the star. During the study of neighboring stars by the *Kepler* mission, scientists collected very precise measurements of the brightness of many stars every thirty minutes for four years. Some of the data comes from more magnetically active stars, which do not look like the light curves produced by the Sun's activity. To understand what these light curves tell us about spots on other stars, we wrote a program that produces light curves from spots with specified characteristics such as their position, size, and rotation period. Because the Sun rotates with different periods from the equator to the pole, we would also like to know if other stars behave the same way, and more about when and how it occurs. As a first step in this project, we have modeled certain situations to understand more their light curve behavior.

Differential Rotation

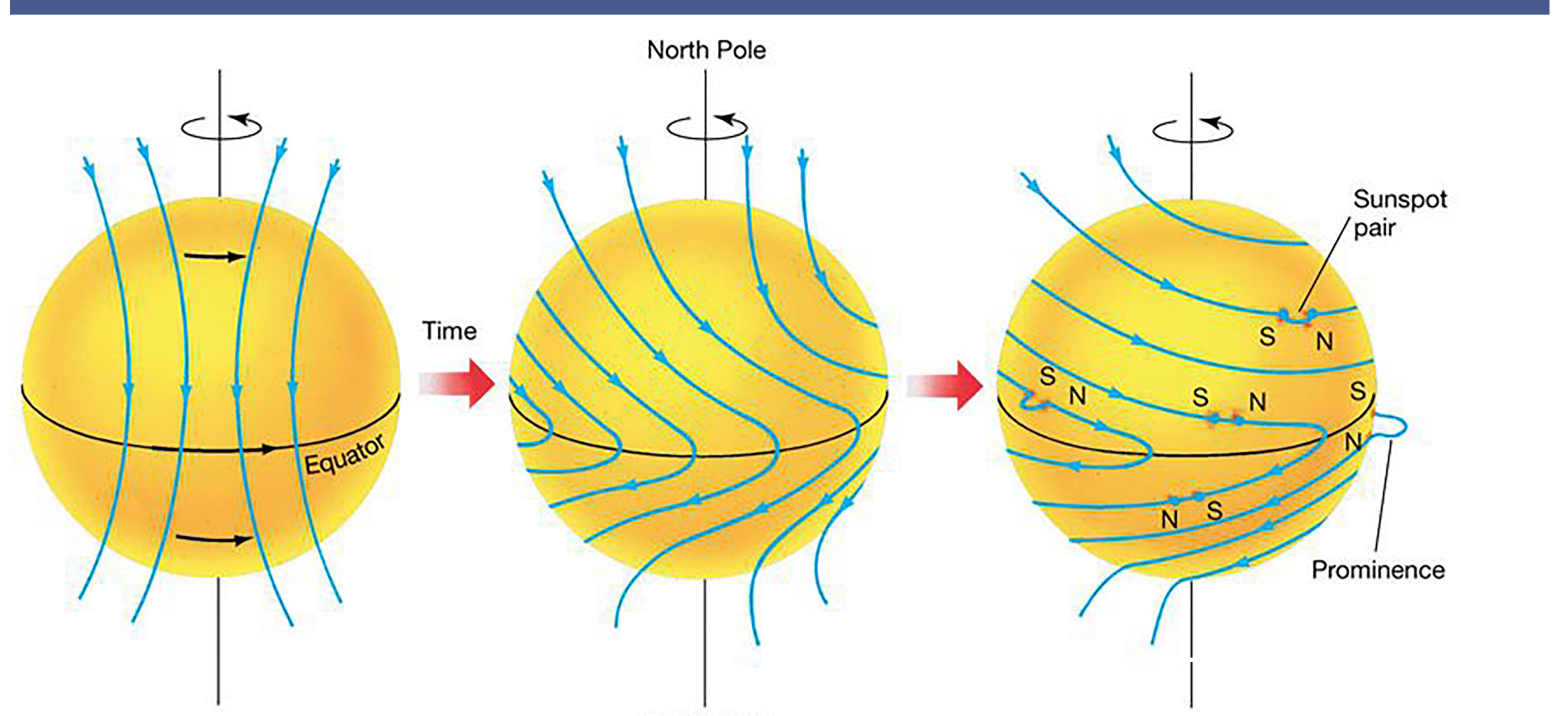

Fig. 1 *Differential Rotation*

- Because the sun is not a solid, different parts spin at different speeds.
- The rotation is faster at the equator (every 25 days) and slowest at the poles (every 31 days).
- Differential rotation can distort solar magnetics field lines.
- Promotes the development of active regions

Sunspots

- They originate when magnetic field lines are distorted by the Sun's differential rotation.
- Dark blotches that are not completely black; they have a temperature of about 4200K, making them cooler than the sun's photosphere (5800 K) and therefore dark in contrast.
- Strong tendency to form in groups.
- The number of starspots visible at any moment changes with time, varying from none to several hundred.

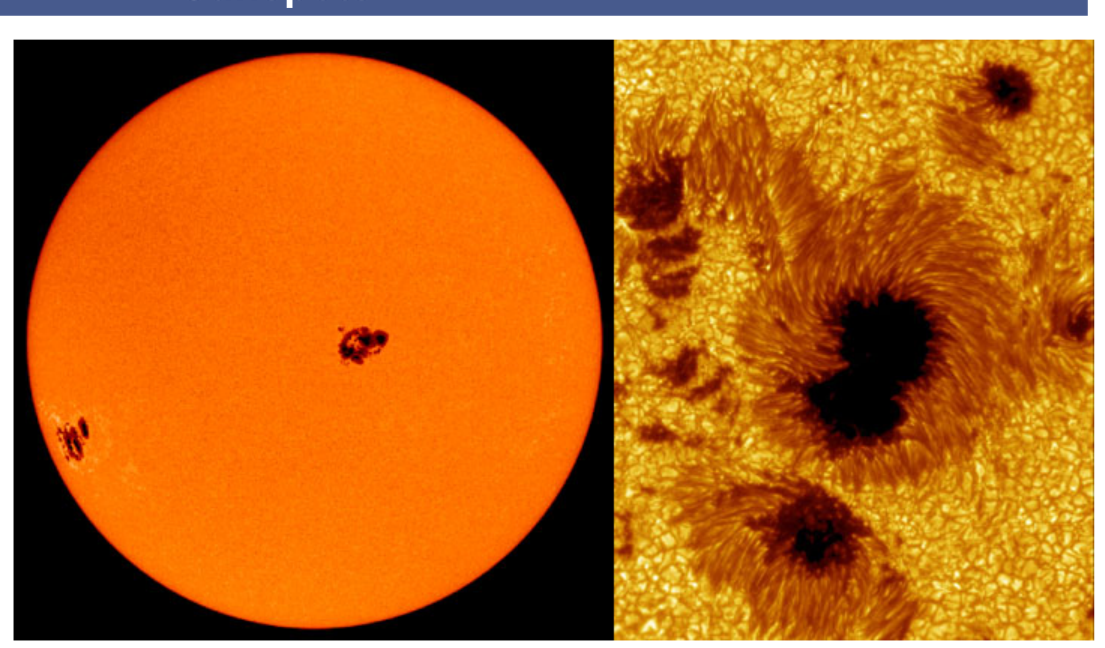

Fig. 2 *Sunspots on the Sun's surface*

Methodology

Analyzing the Appearance of Starspots

Our model allows the placement of spots to specified latitudes, longitudes, size and different periods. We used this for simulations to reveal the relationship of the number of spots placed evenly around the equator to the corresponding light curve amplitude. As a result, we determined the maximum number of spots one could place on a belt until their variability could no longer be detected by Kepler. We also began our study of differentially rotating spots, and the complexity of their light curves (which resemble some *Kepler* light curves).

Kepler Light Curve

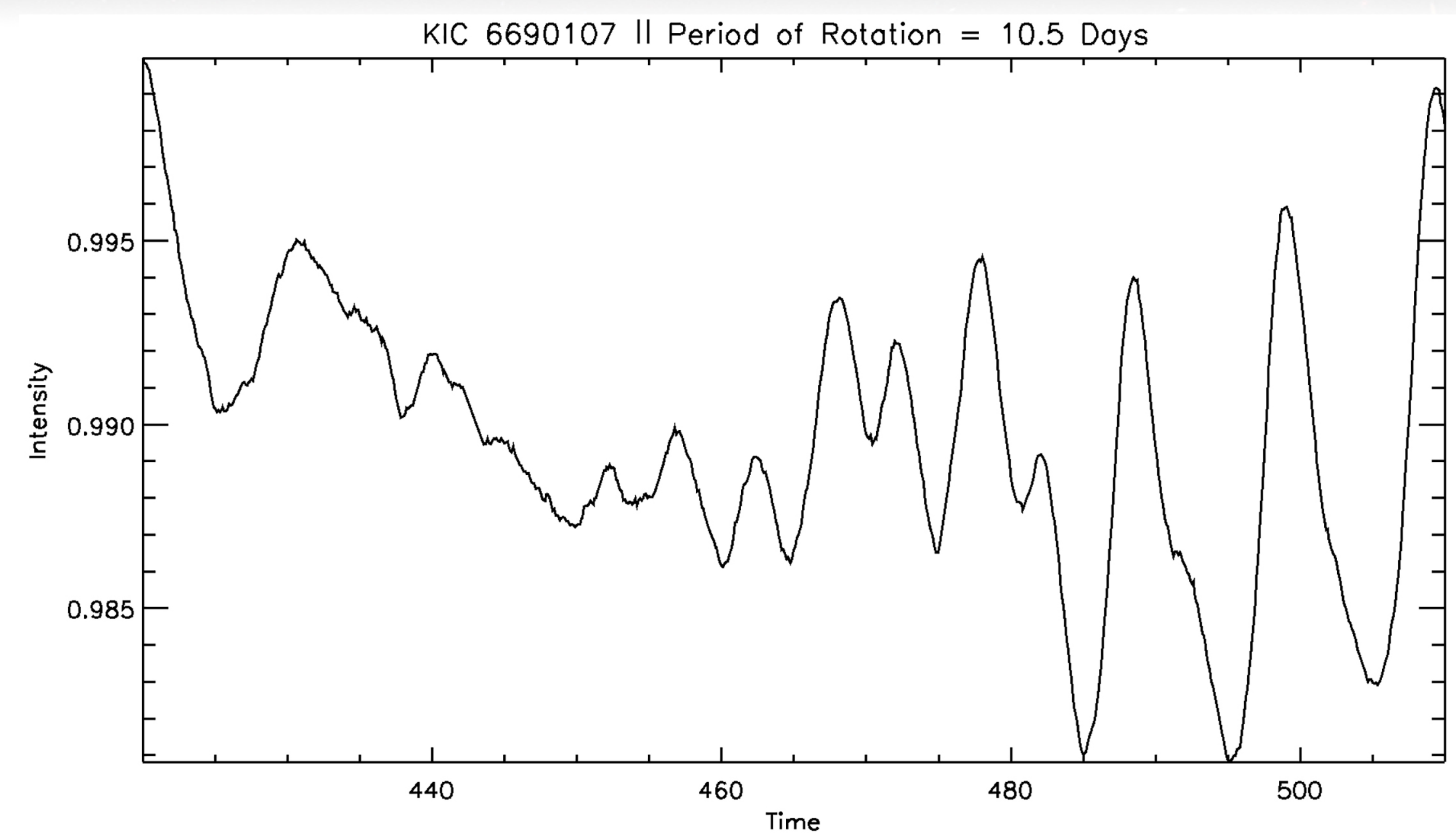

Fig. 3 *Close analysis of the characteristics of one of Kepler's light curves*

Starspots at the Equator

To better understand the interaction of the spots at different latitudes, we began by placing all the spots at a zero-degree latitude on a simulated star.
No relevant results were found when we placed two starspots on the star's surface. The puzzling results were revealed once we continued to place an even and odd number of spots. The amplitudes for a given number of spots oscillated depending on whether the number of spots was odd or even. This allowed us to find the maximum number of spots one could place on a belt until its variability could no longer be detected. That is, *Kepler* could no detect light curve amplitudes below 10^{-4} and no more than 4 spots at a fixed latitude.

Comparing Even vs Odd Number of Spots

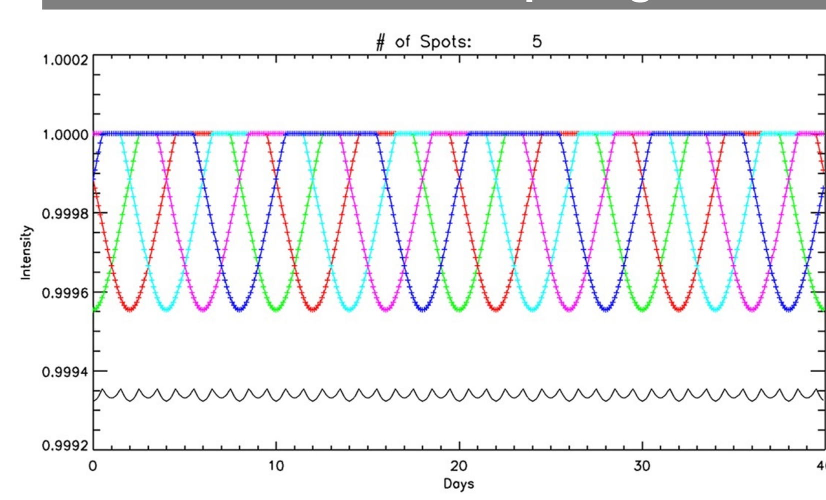

Fig. 4 *Light curve with 4 evenly spaced spots at the equator.*

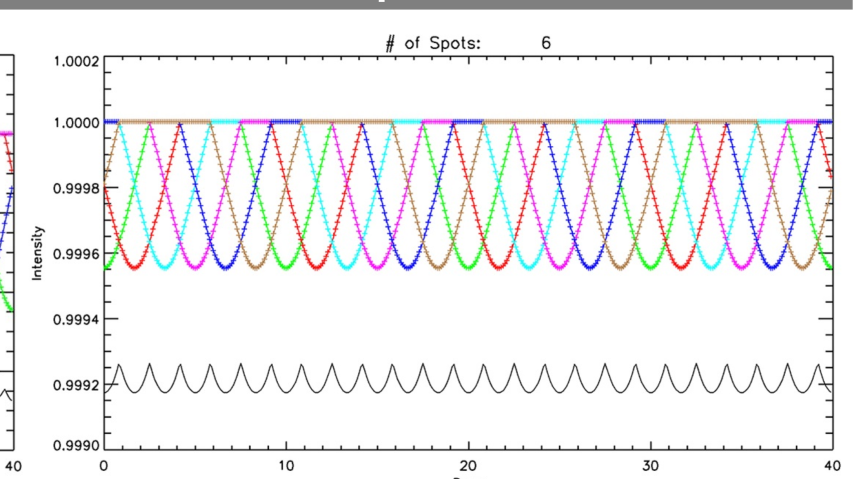

Fig. 5 *Light curve with 5 evenly spaced spots at the equator.*

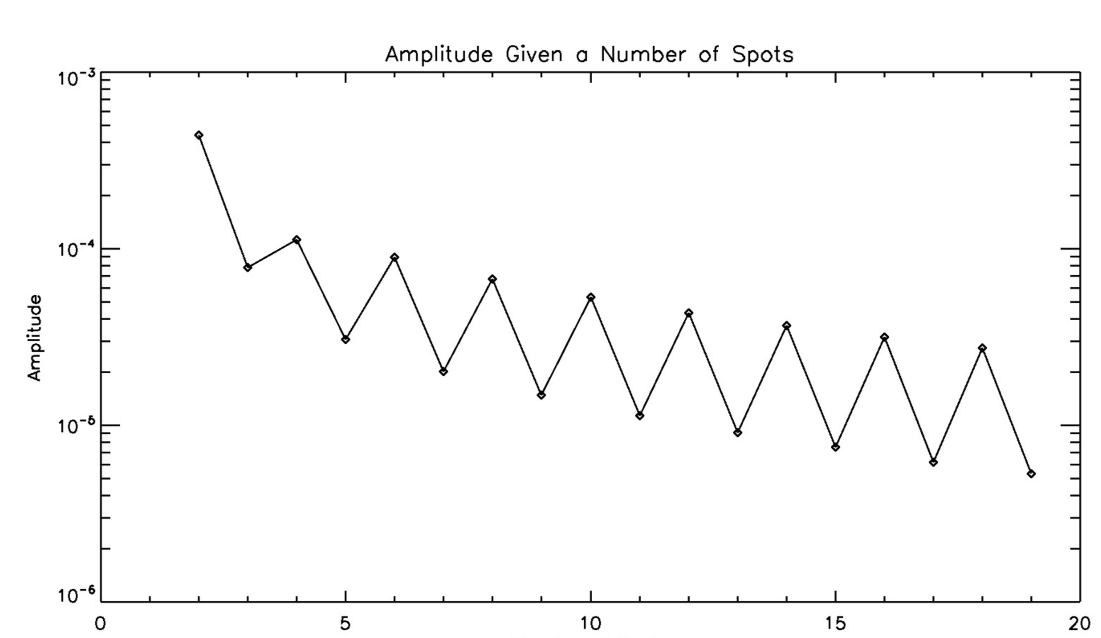

Fig. 6 *Relationship of the number of spots placed evenly around the equator to the corresponding light curve amplitude.*

Spot Number	Max	Min	Difference
2.00000	0.999994	0.999553	0.000440955
3.00000	0.999632	0.999553	7.82609e-05
4.00000	0.999548	0.999435	0.000112414
5.00000	0.999354	0.999324	3.06368e-05
6.00000	0.999263	0.999174	8.95858e-05
7.00000	0.999084	0.999064	2.02060e-05
8.00000	0.998983	0.998916	6.74725e-05
9.00000	0.998816	0.998801	1.47820e-05
10.0000	0.998709	0.998655	5.33462e-05
11.0000	0.998549	0.998537	1.13845e-05
12.0000	0.998437	0.998394	4.34518e-05
13.0000	0.998282	0.998273	9.11951e-06
14.0000	0.998168	0.998131	3.67761e-05
15.0000	0.998016	0.998009	7.51019e-06
16.0000	0.997899	0.997867	3.15309e-05
17.0000	0.997750	0.997744	6.19888e-06
18.0000	0.997631	0.997604	2.74181e-05
19.0000	0.997485	0.997479	5.30481e-06

Fig. 7 *Maximum value, minimum value, and their difference in light curves.*

Differential Rotation Application

To improve the simulation of differential rotation on a sphere and accomplish modeling a light curve with the characteristics observed in the *Kepler* mission's data, we randomized the latitudes for starspot placement, and applied the law of differential rotation to the modeled star. The results of this procedure produced a light curve that model the double and triple dips seen in the *Kepler* light curves.

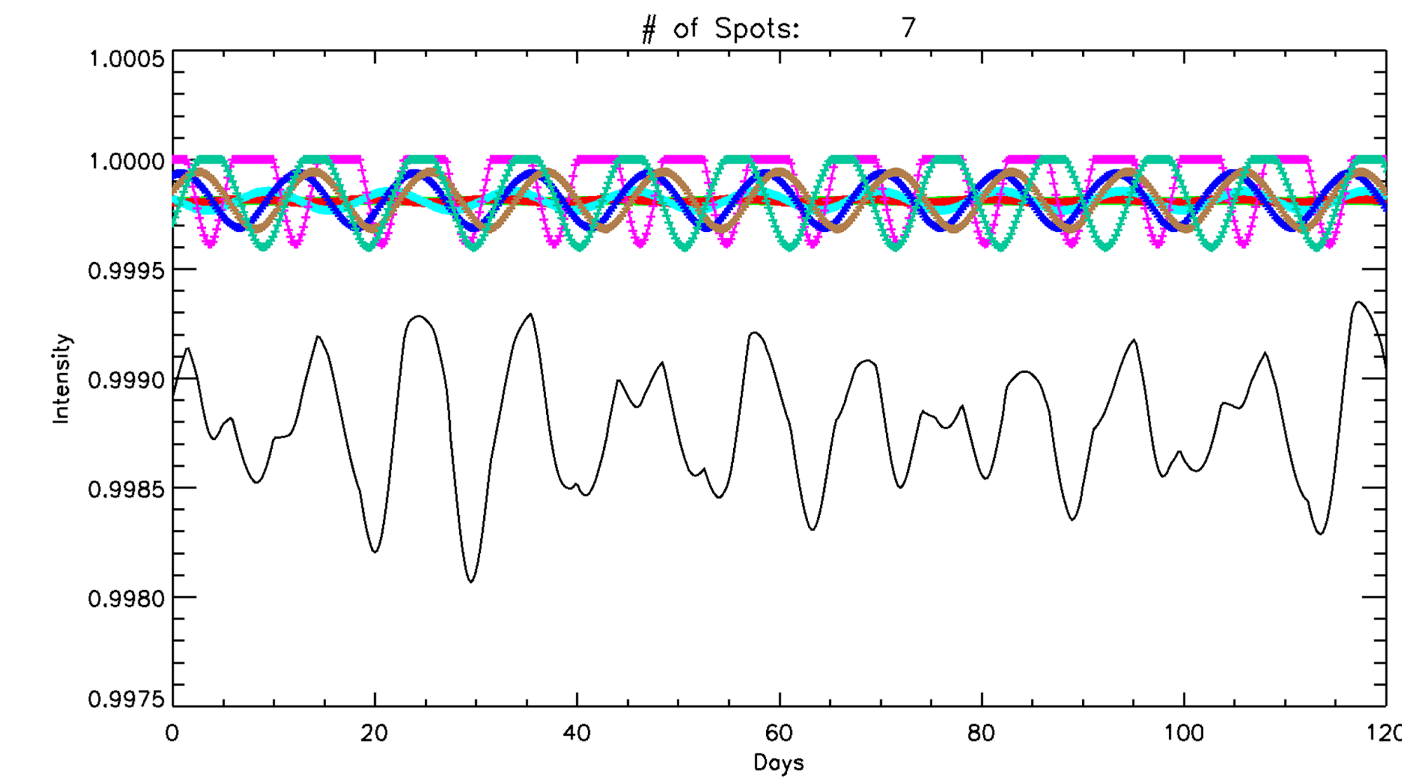

Fig. 8 *Light curve generated after the randomization of latitudes and application of differential rotation.*

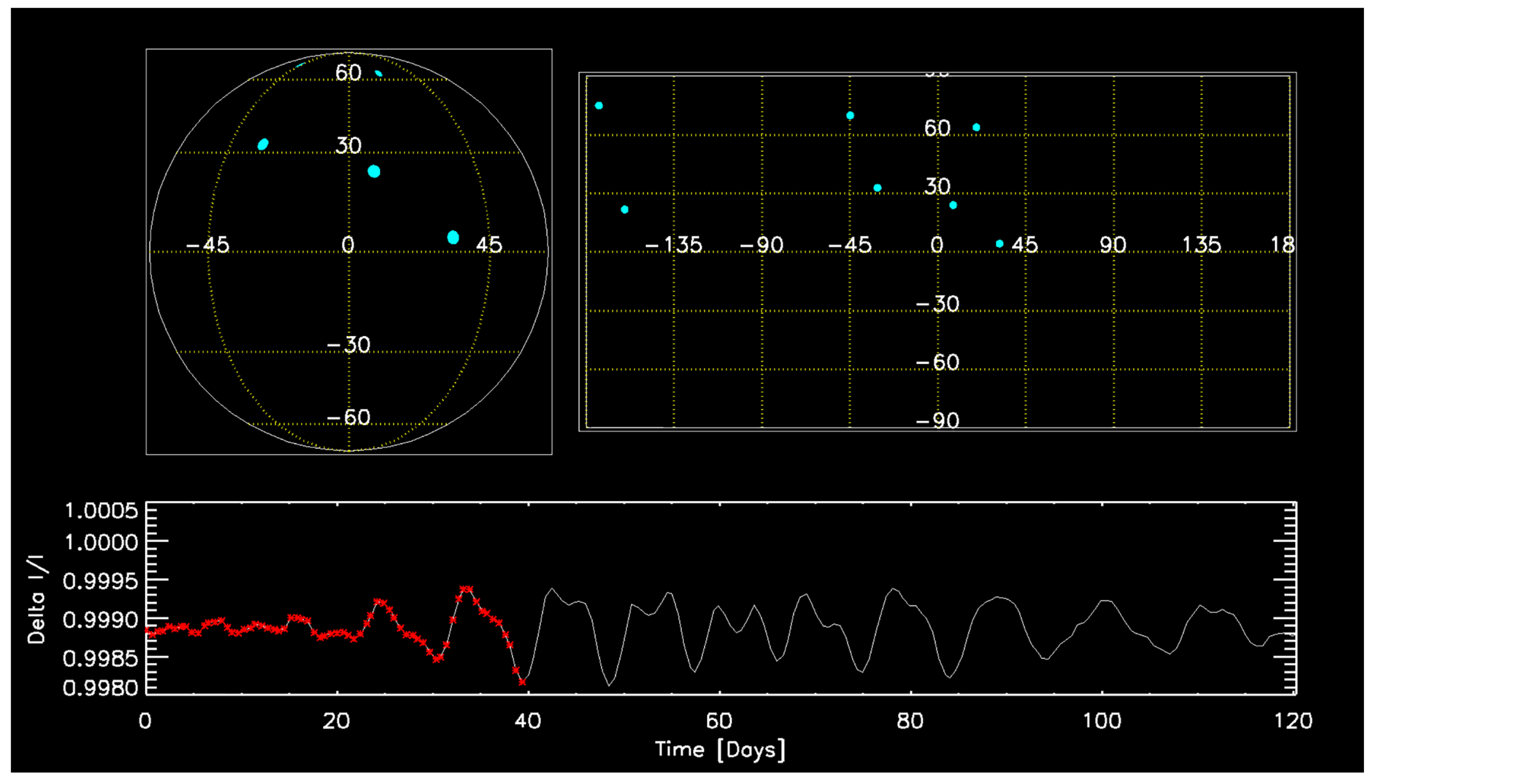

Fig. 9 *Animation of modeled star with starspots placed at random latitudes.*

Conclusions and Future Work

After the successful application of the differential rotation law with the randomization of latitudes, we conclude that our current approach is certainly giving us the results we need to continue with this project. Having seen the relationship between the even and odd number of spots placed at the equator gave us valuable information we can later utilize in this project. Additionally, by knowing the maximum number of spots *Kepler* can detect on a belt, we are able to establish a threshold in our forthcoming developments to improve *Kepler* light curve modeling.

Acknowledgements

Special thanks to professor Gibor Basri for his mentoring and mentoring in the development of this project. Also to Diana Lizarraga, Chris Noble and the Cal Nerds for their support and for letting me be part of UC Leads.

This project was funded by CAl NErDs UC LEADS

Literature Cited

(1) Cite some papers.
(2) You do not want to heavily cite your introduction
(3) Only include those papers that are important for a unique method that people could not easily find elsewhere.
(4) These should be so handy that people will actually stop and write them down! These can be small as people will be getting in close to write it all down.