Variable Stars: Action in the Sky!

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Outline

- Variable stars: history/introduction
- Types of variable stars
- Methods of observation
- Data mining and analysis
- The power of visual observations
- My current research projects

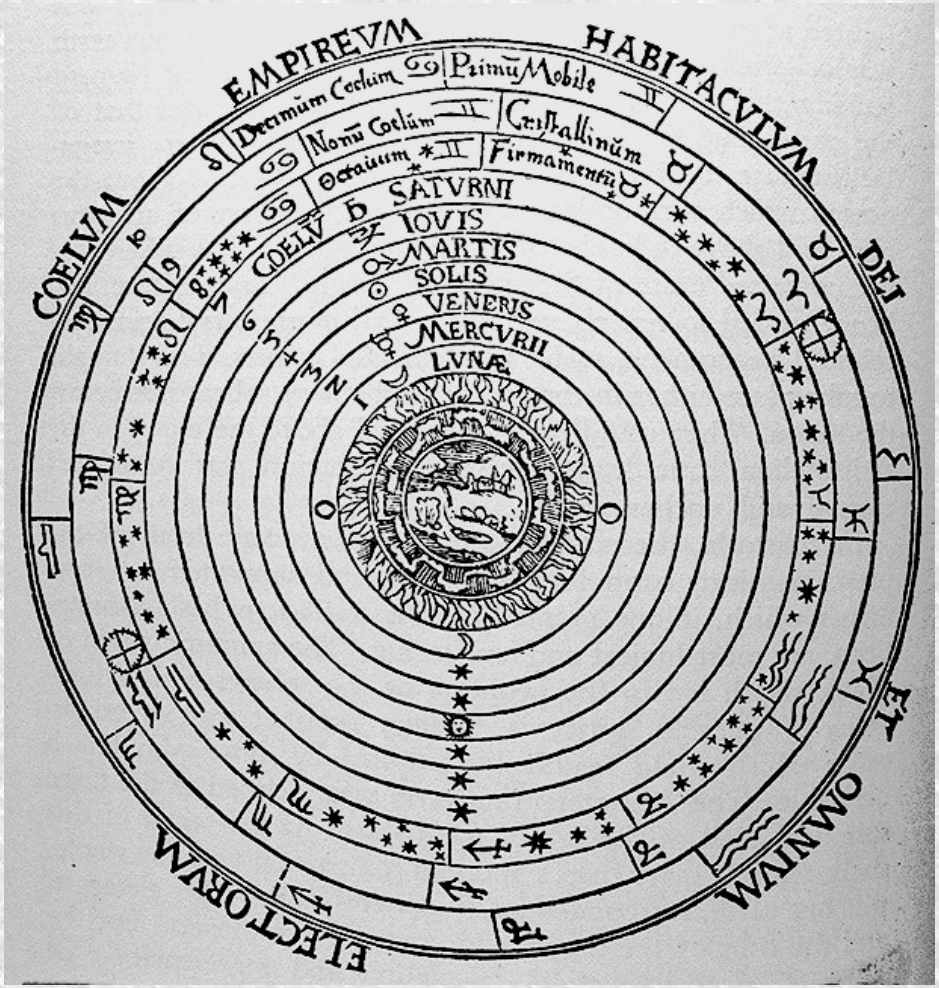
Why It Matters

Almost all stars (including the sun) are variable at some level

Variable stars provide unique and important information about the nature and evolution of the stars

They are “action in the sky”

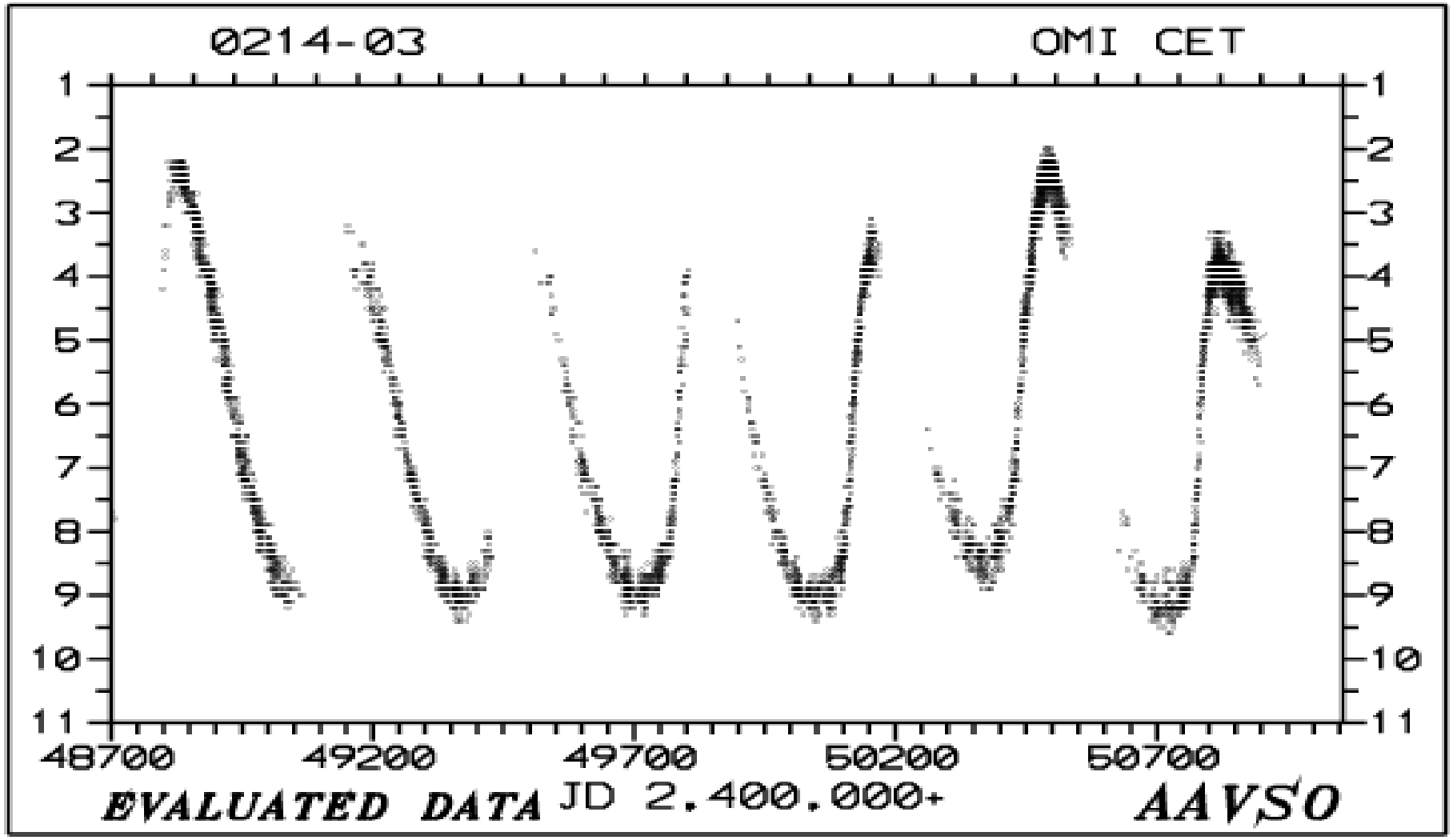
Aristotle's Universe



- Earth at the centre, made of “base elements” -- earth, water, air, fire
- Stars were made of “quintessence” which was perfect and unchanging

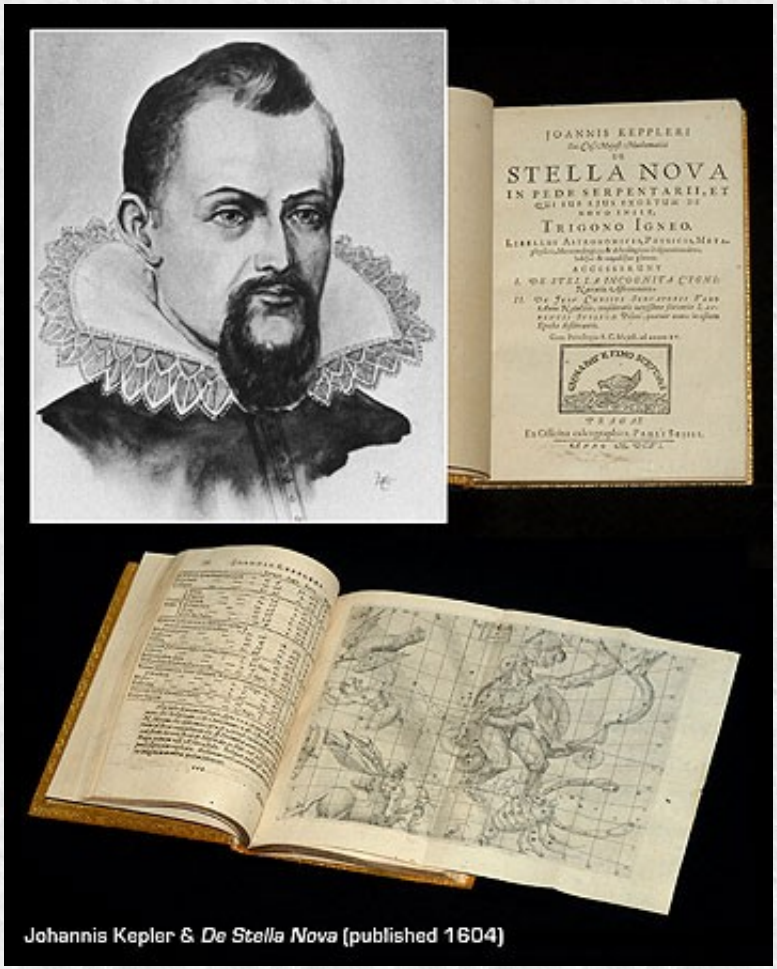
Variable Stars – Stars that Vary

Below: the light curve (magnitude versus time) of Mira; this may have spurred the Copernican revolution (1596)

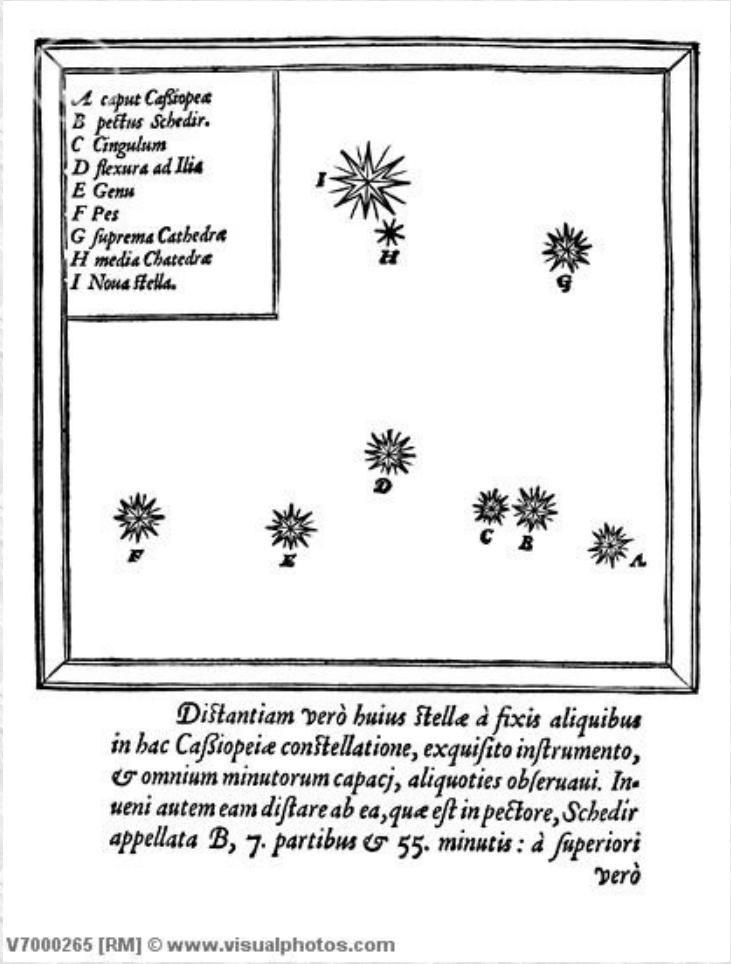


Historical Supernovae

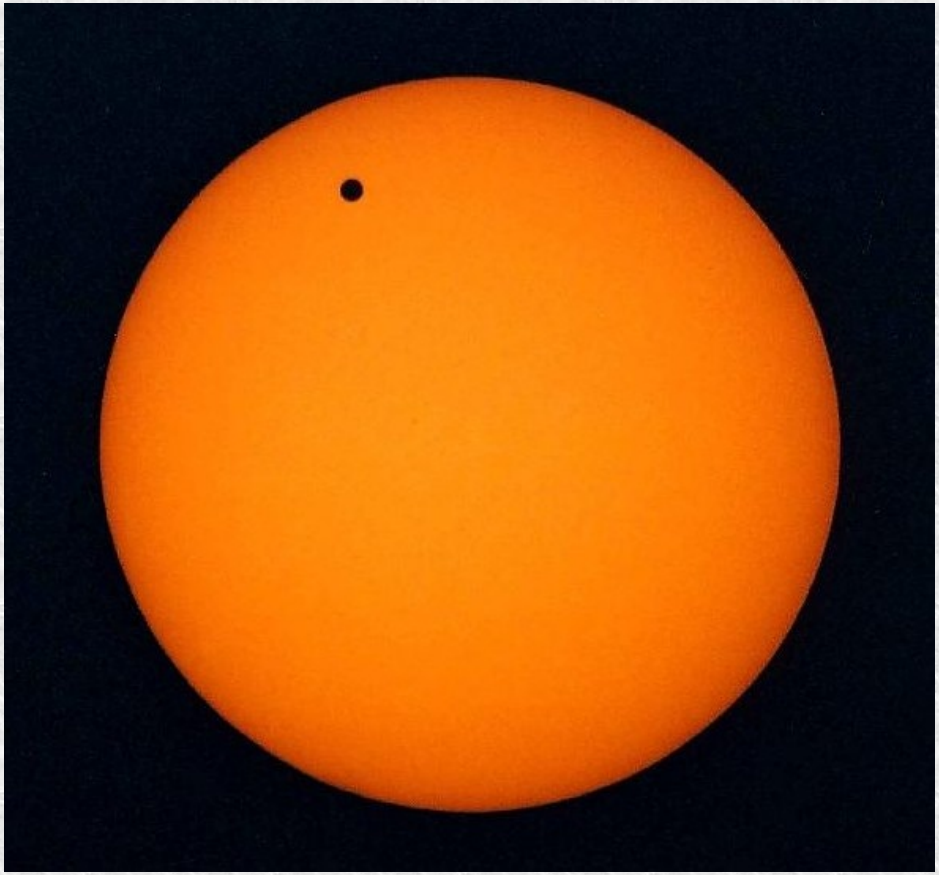
Tycho's (1572) and Kepler's (1604) supernovae *certainly* helped overcome Aristotle's cosmology



Johannis Kepler & *De Stella Nova* (published 1604)



The Sun as a Variable Star



- The sun is a ...
- ...pulsating variable star (helioseismology)
- ... flare star
- ... “eclipsing variable star” (left: transit of Venus)
- ... rotating variable star

AAVSO

American Association of Variable Star Observers

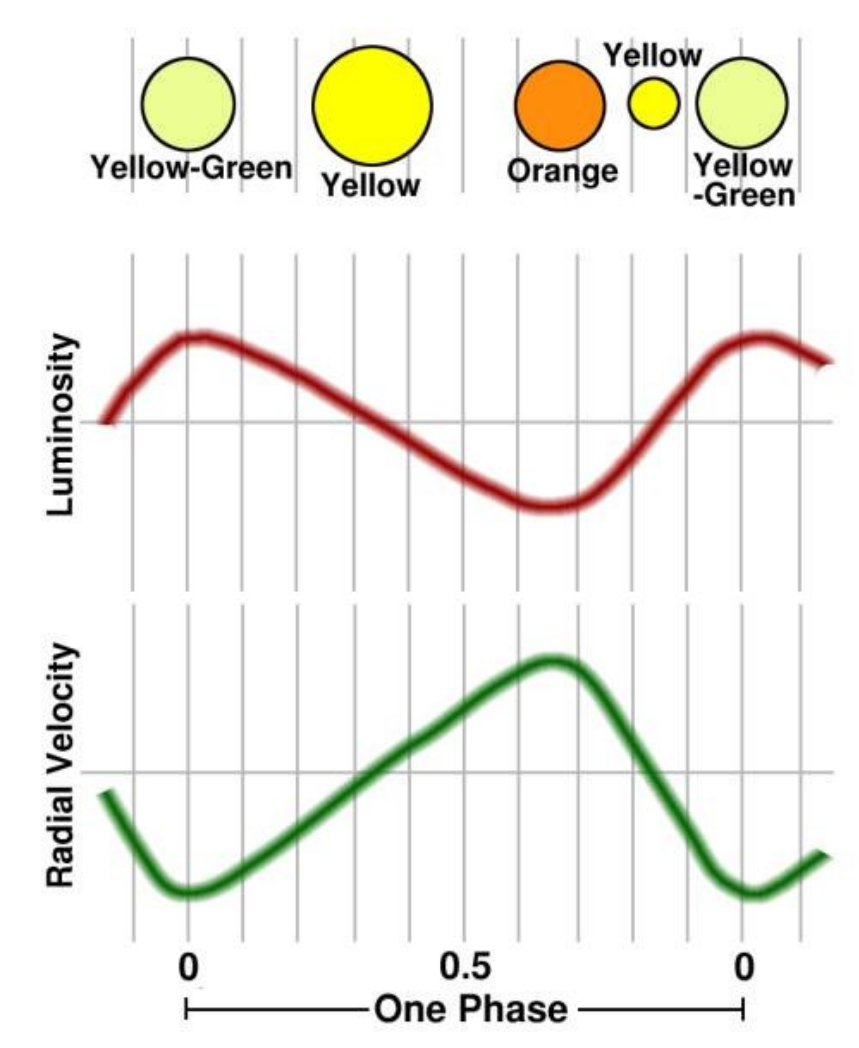
- Founded 1911; centennial in 2011
- Most significant organization through which skilled amateurs can contribute to research: “citizen astronomy”
- Website www.aavso.org contains a wealth of data and resources

AAVSO Data Are Used For ...

- Real-time, up-to-date information on unusual stellar activity
- Scheduling and coordinating variable star observing programs
- Simultaneous optical observations of program stars during ground-based or space observing programs
- Correlation of AAVSO optical data with data from other techniques or wavelengths
- Collaborative statistical analysis of stellar behaviour

Types of Variable Stars
or
Why Stars Are Variable

Pulsating Variable Stars
expand and contract rhythmically

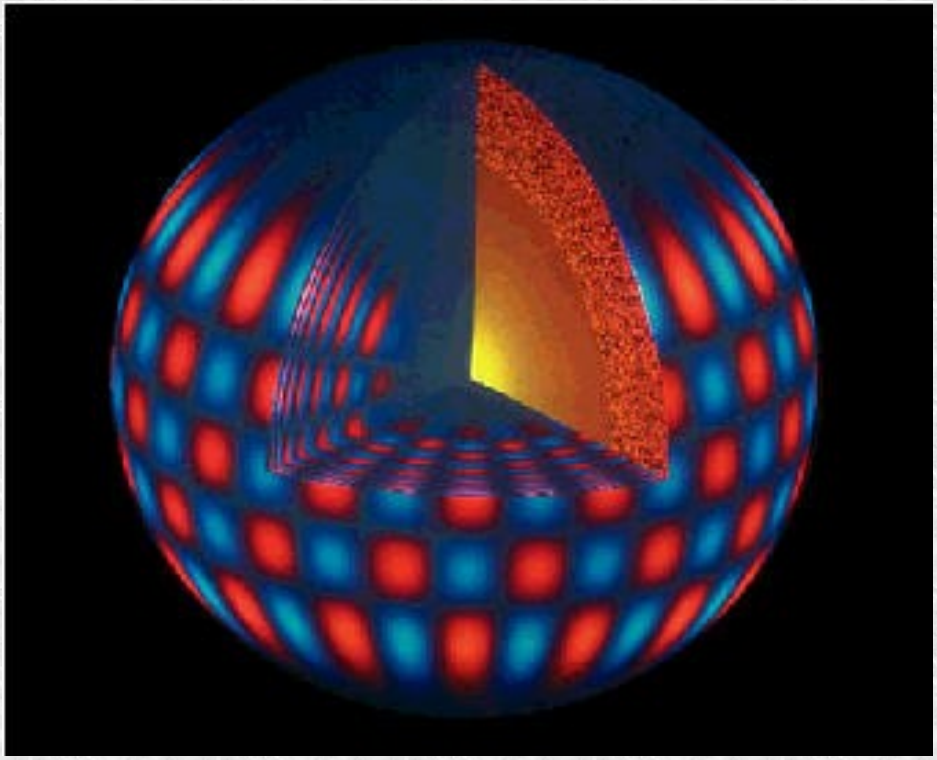


- Periods range from seconds (white dwarfs) to years (supergiants)
- Period → luminosity; the Leavitt Law
- Multiple periods → mass and interior structure; asteroseismology
- Period changes → rate of evolution; other processes

Why Do Stars Pulsate?

- Most large-amplitude pulsators like Cepheids: due to hydrogen and helium ionization zones, which thermodynamically drive the pulsation – like a car engine.
- Sun and orange and red giants: stochastic excitation of the pulsation by the random convective motions in the outer layers of the star.

Helioseismology



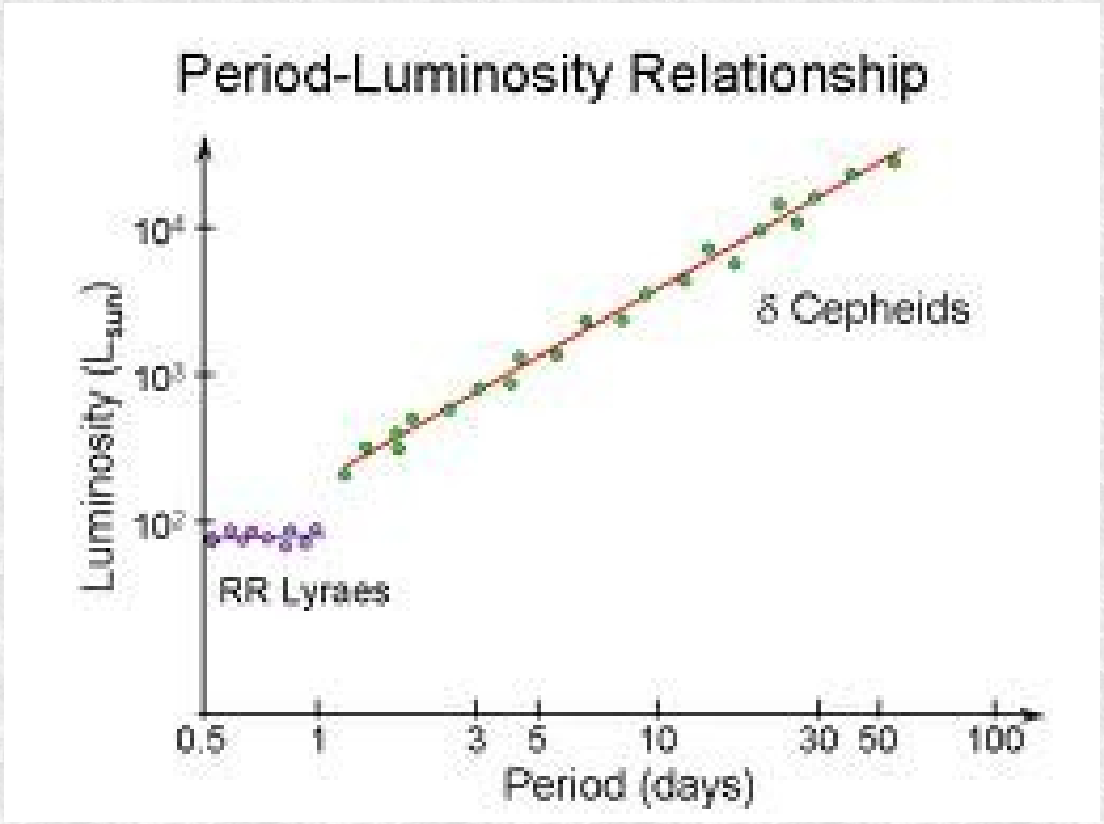
One of thousands of pulsation modes in the sun.

- The sun is pulsating in thousands of low-amplitude non-radial modes, stochastically excited by convection
- It takes specialized equipment to detect and measure them

The Leavitt Law for Cepheids

the period-luminosity relation

Henretta Leavitt (1868-1921)

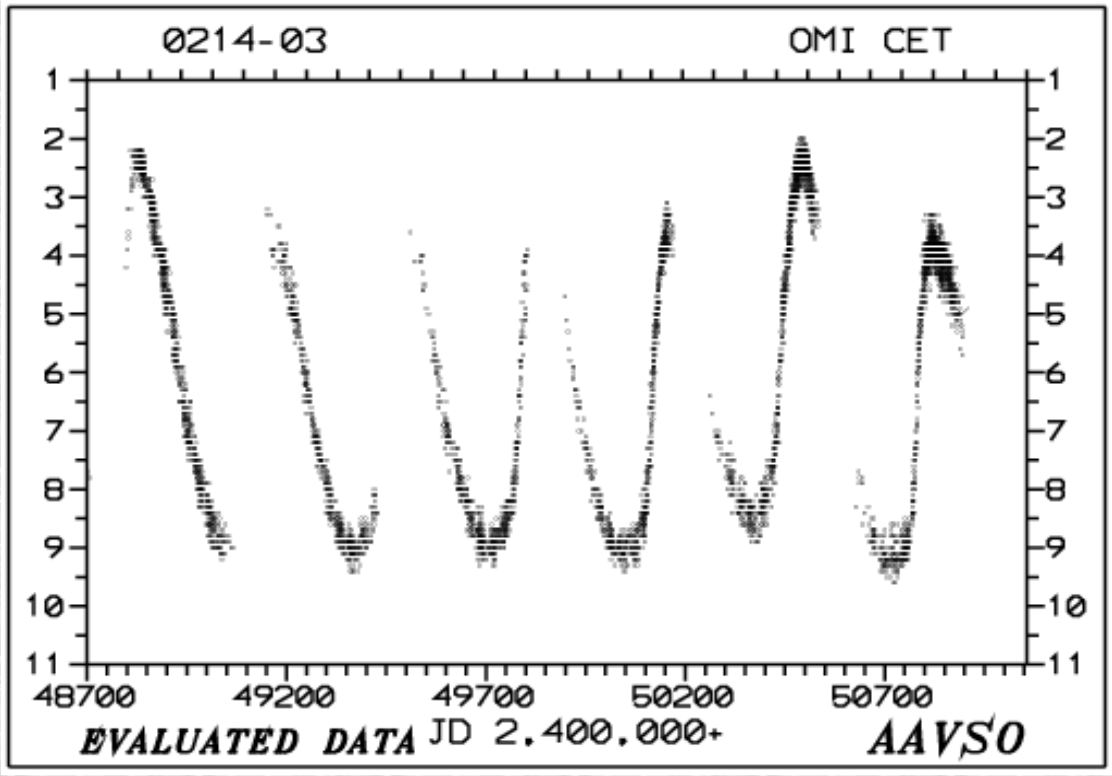


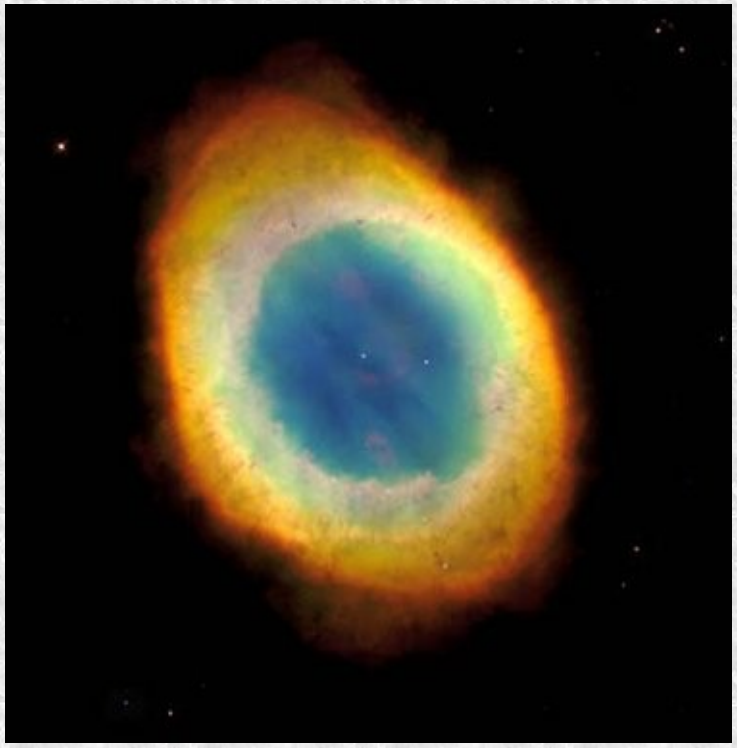
Polaris: An Unusual Cepheid

- Cepheid pulsating variable; period 3.9696 days
- Period slowly increasing; enables us to measure the star's evolution
- Amplitude has decreased to near-zero
- Is it brightening over the centuries?

Pulsation and Mass Loss

Sun-like stars, at the ends of their lives, swell to become red giants, begin to pulsate, eventually become Mira stars. The pulsation drives off the outer half of the star, leaving a planetary nebula and a white dwarf core





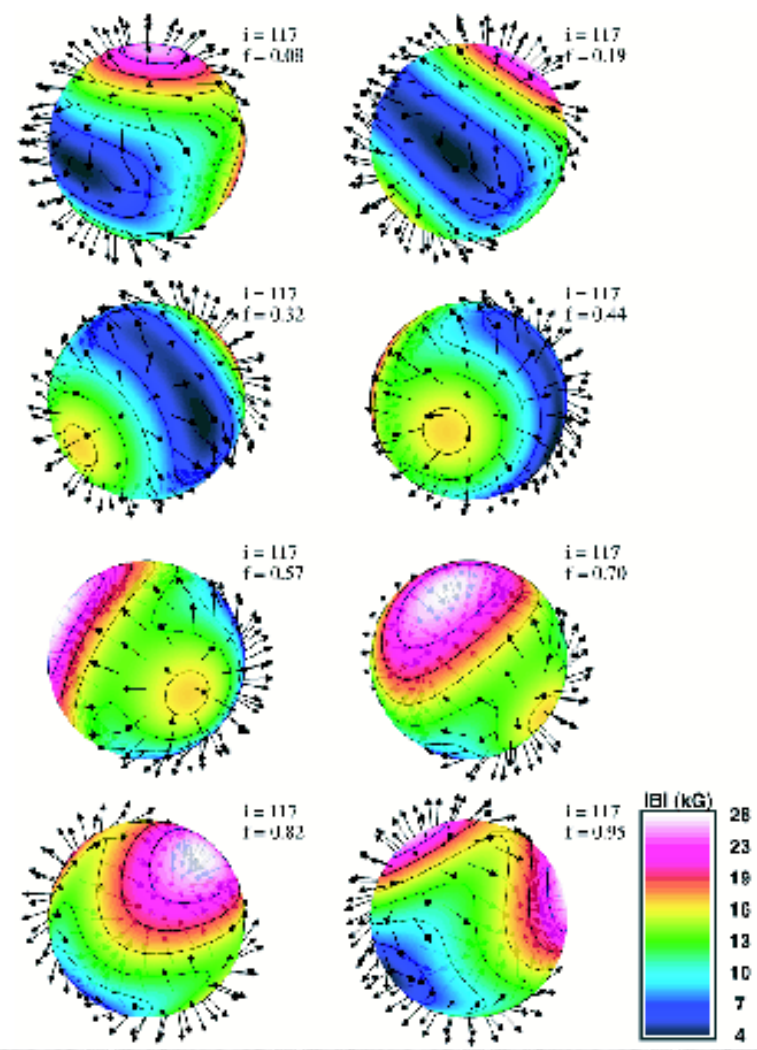
NASA

Rotating Variable Stars

NASA

- Rotating stars (axis not pointed at us) with non-uniform surfaces; small amplitudes
- Variability period is the rotation period
- (1) Sun-like stars with spots
- (2) “Peculiar A stars” with strong global magnetic fields

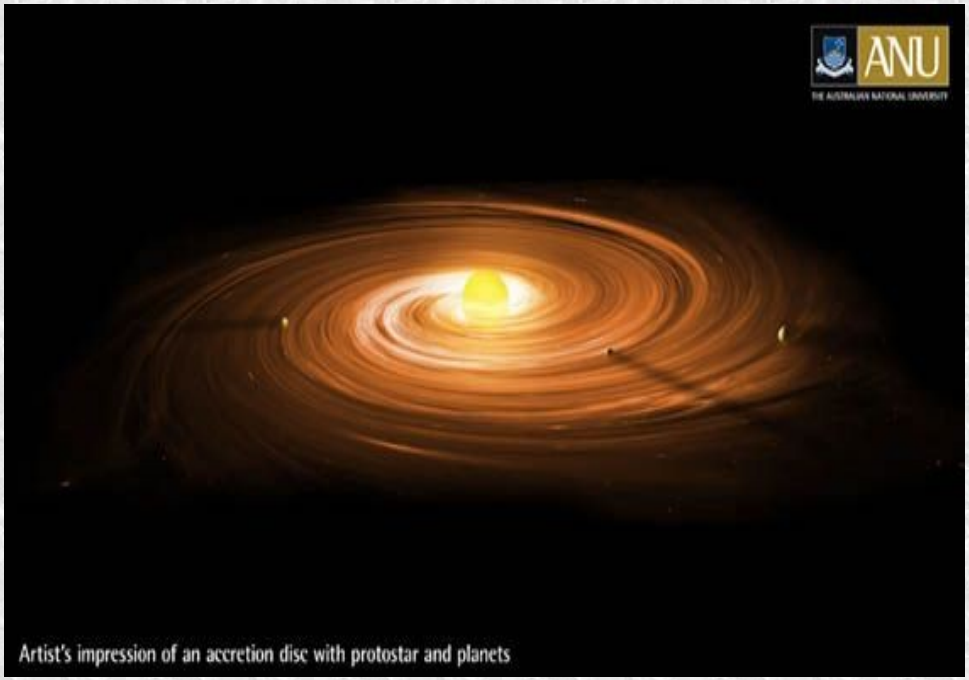
Peculiar/Magnetic A Stars



53 Cam: University of Bonn

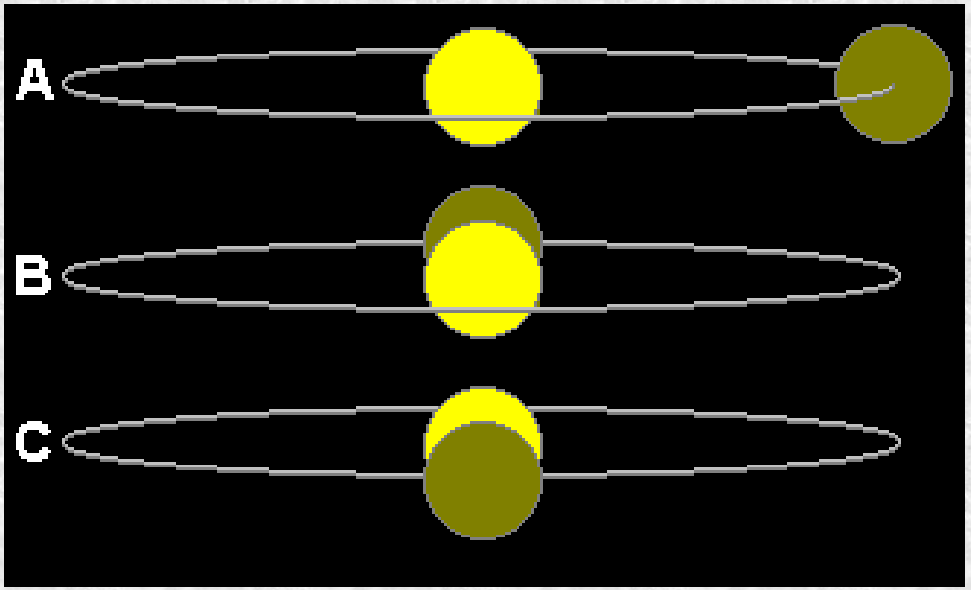
- Global magnetic fields of up to 20 KGauss!
- Brightness is slightly variable
- Spectra are bizarre and *highly* variable! Why?
- Variability period is rotation period

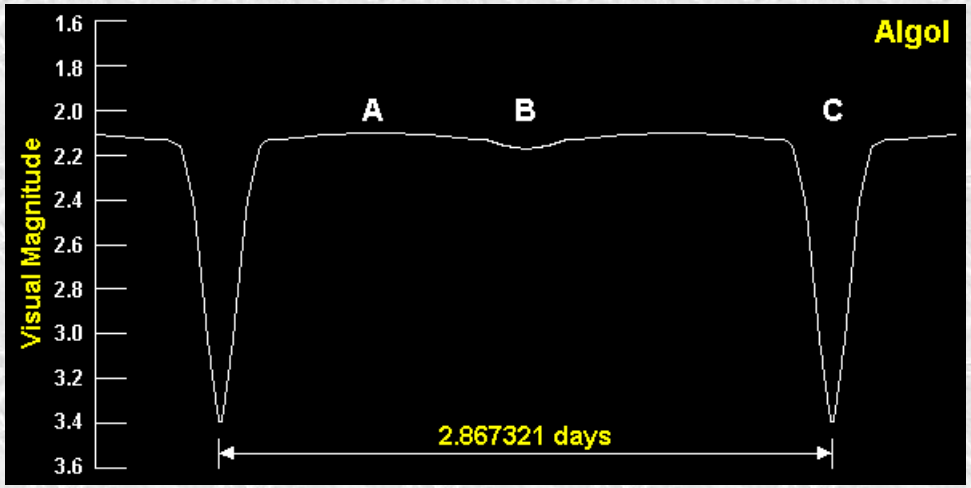
Pre-Main Sequence Variables
T Tauri Stars and their Relatives



- Sun-like stars in the last stages of formation
- Star undergoes rotational variability
- Large, irregular variations due to variable accretion from the disc
- Also variability due to absorption by disc

Eclipsing (Binary) Variable Stars

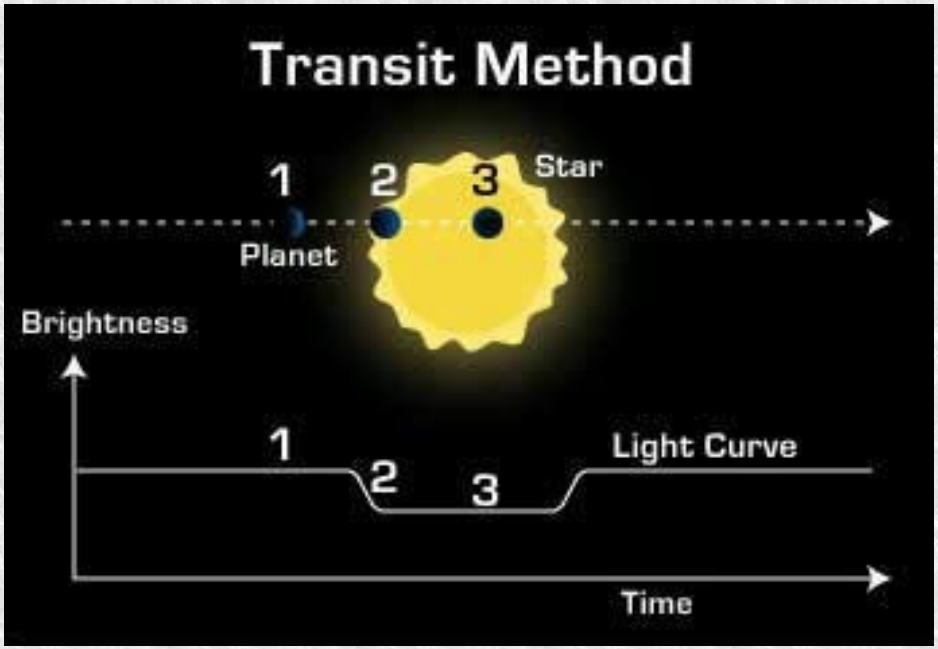




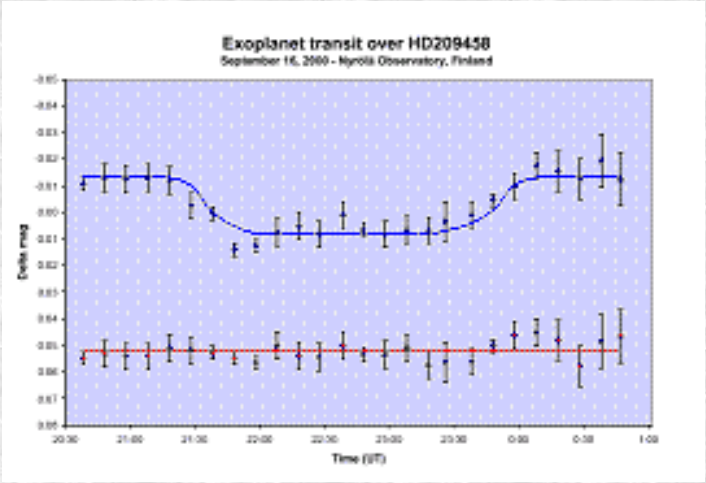
Algol: RASC Calgary Centre

- Period and light curve (plus spectroscopic observations) → mass, radius, luminosity
- Period changes → mass transfer or loss; these can be measured by timing eclipses accurately

Exoplanet Transits



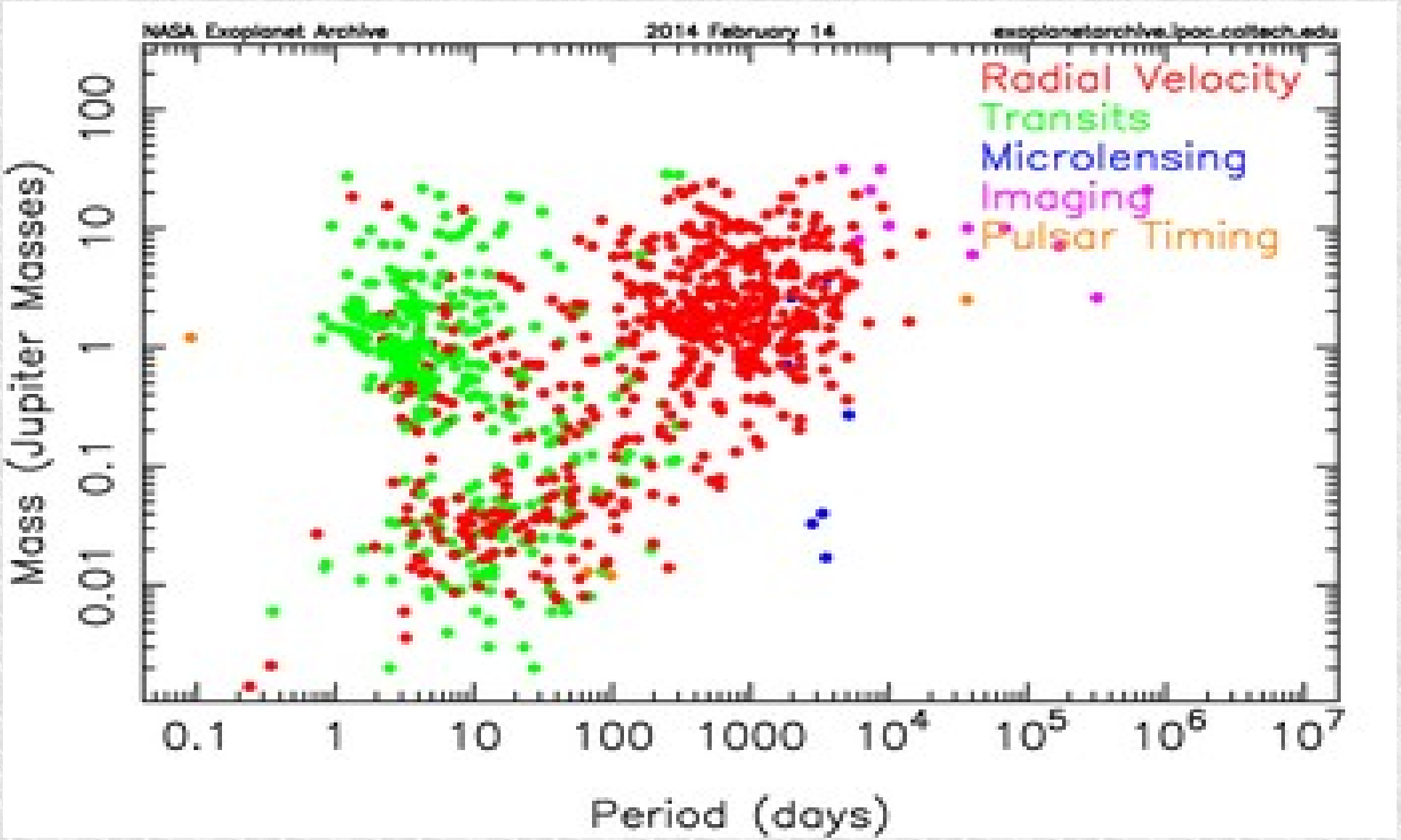
NASA



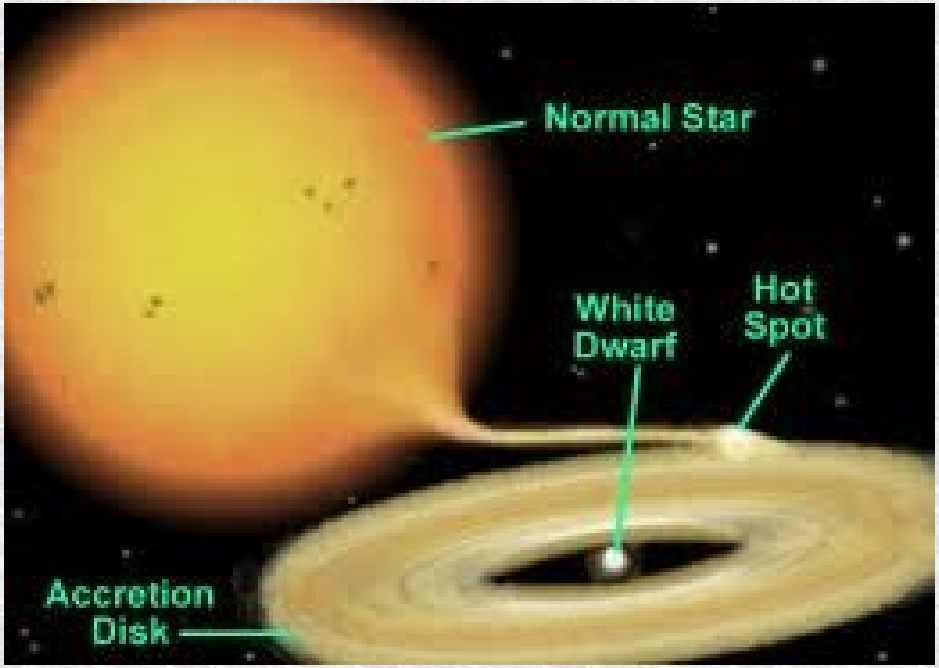
AAVSO

- Transit dims the star by ≤ few percent
- Transit light curve → period, radius of exoplanet (and mass and density if spectroscopic observations are also available)
- Multicolour light curves → atmosphere

Exoplanet Statistics



Erupting (Cataclysmic) Variable Stars



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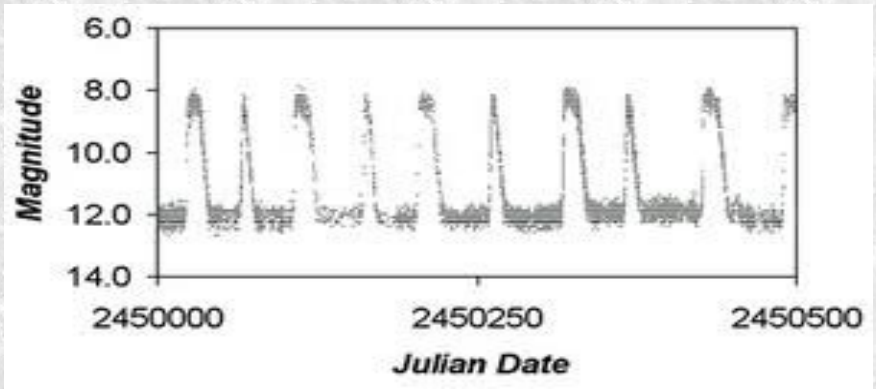
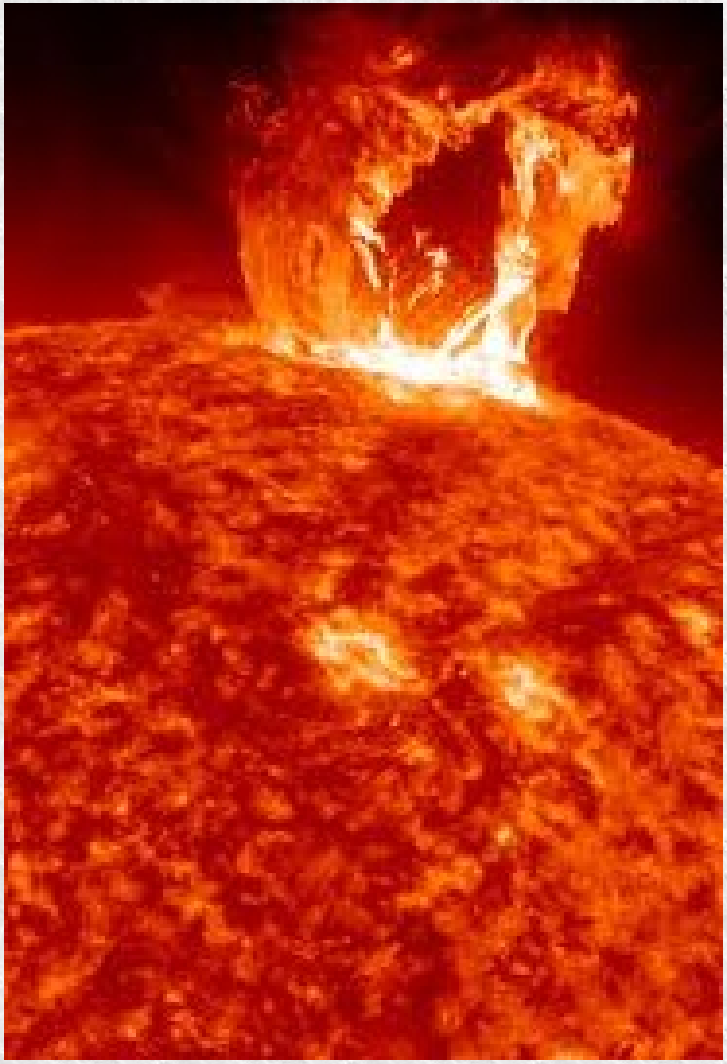


SS Cyg: AAVSO

- Flickering from hot spot
- Dwarf nova outburst from collapse of accretion disc
- Nova from runaway thermonuclear fusion on the surface of the white dwarf
- Supernova from detonation of the white dwarf if its mass exceeds 1.44 suns

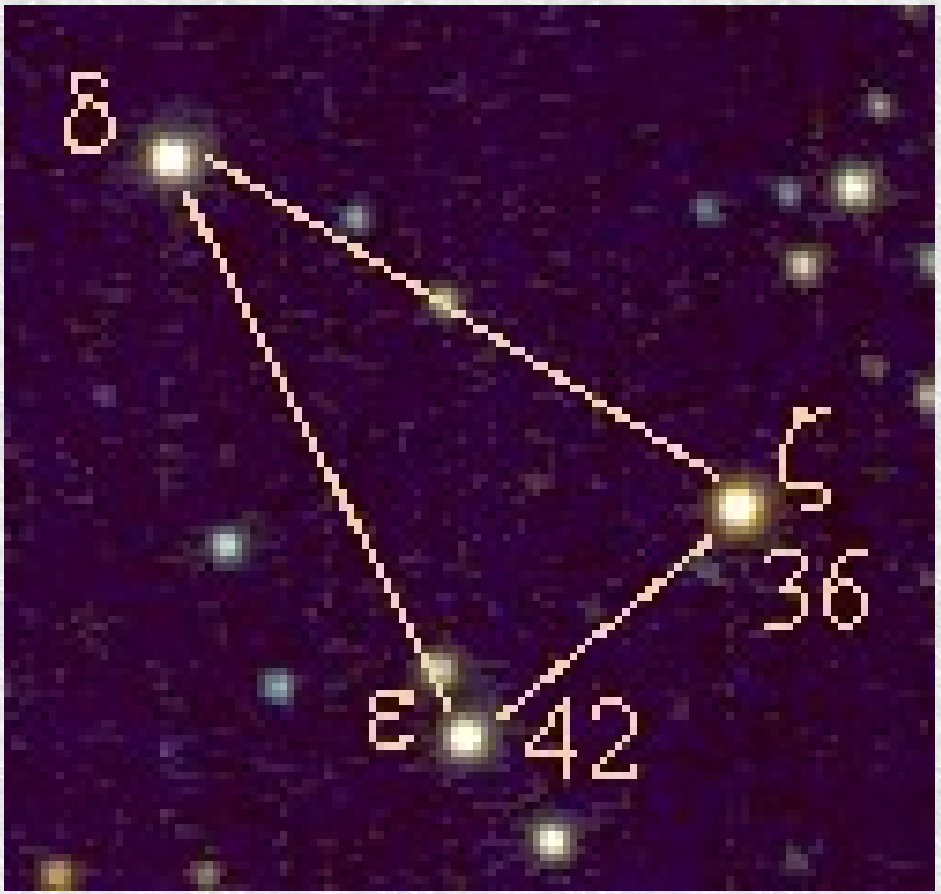
Flare Stars



- Sudden release of energy, due to short-circuit of the magnetic field
- Ultimately caused by rotation
- Almost all red dwarfs – the most common stars in the universe – are flare stars

Methods of Observation

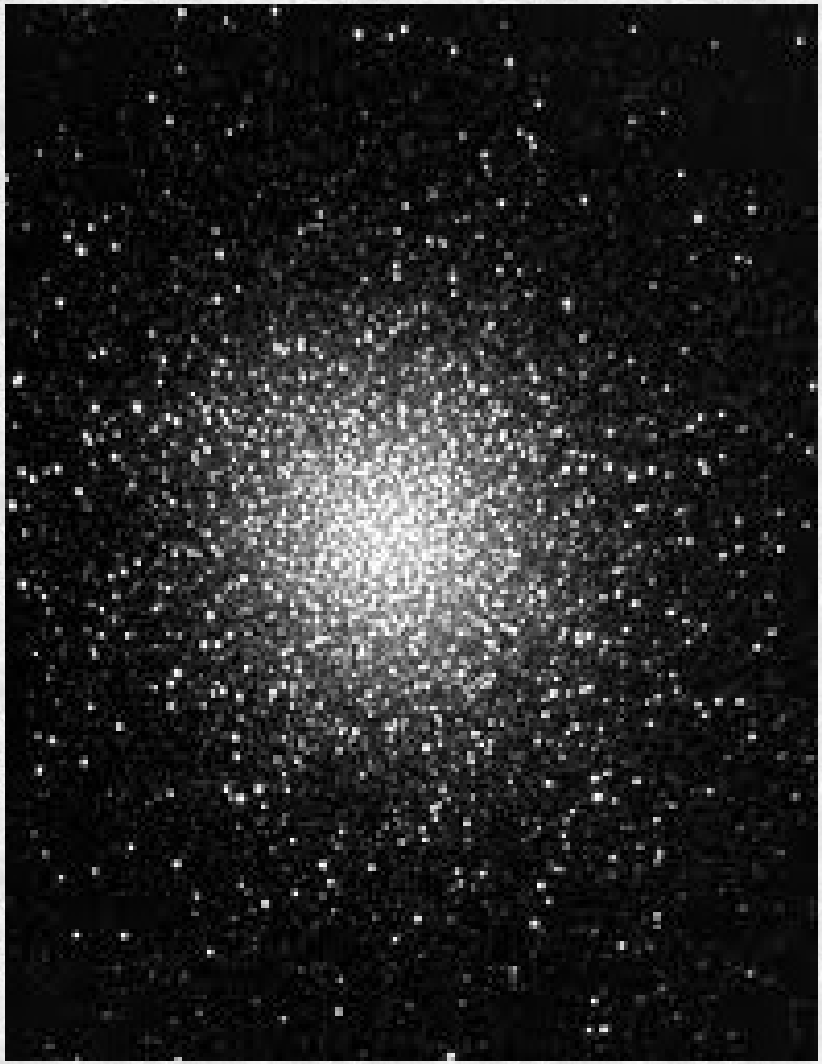
Visual Observation



Delta Cephei

- Simple
- Quick
- ... but prone to some low-amplitude spurious effects
- And accuracy is only 0.15-0.30 mag
- But still useful!

Photographic Observation



Kitt Peak National Observatory

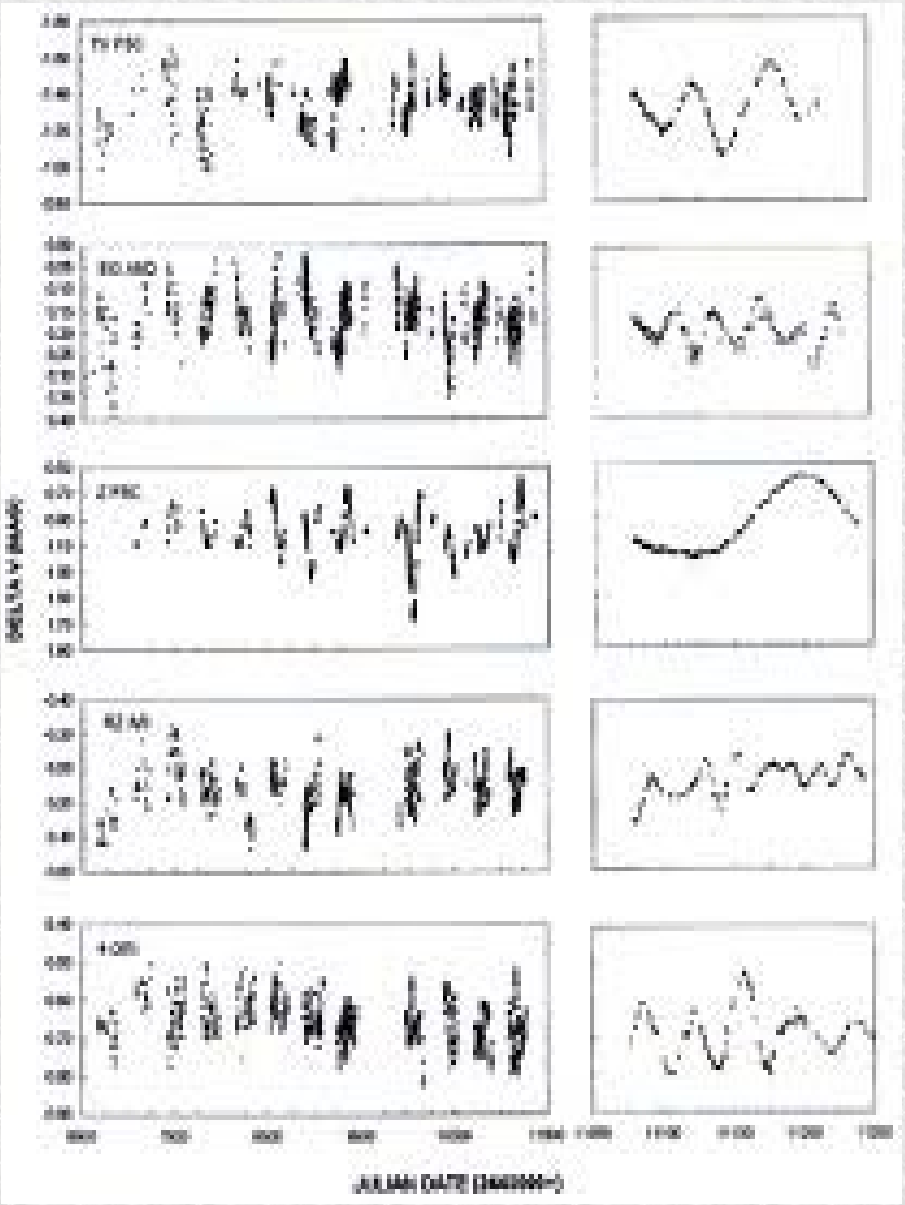
- Permanent; objective
- Panoramic
- Time exposure possible
- Sensitivity about 0.01; emulsions are very inefficient!
- Accuracy 0.02-0.10 mag, depending ....

Photoelectric Photometry (PEP)

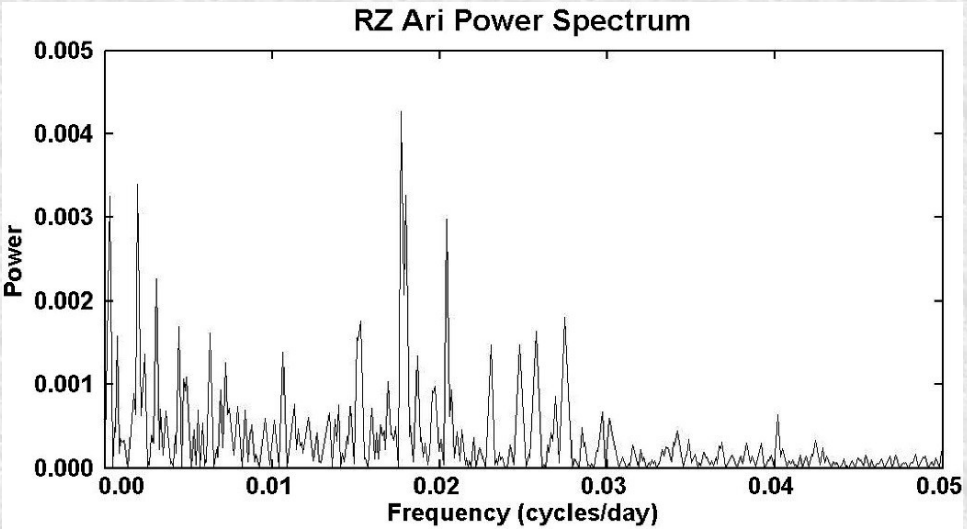
Optec SSP3 photometer

- Based on photoelectric effect: photomultiplier tube, or photodiode
- Developed around 1910 but amateur PEP blossomed after 1980
- Star-by-star observation
- Accuracy 0.005-0.02 mag
- Especially good for brighter stars

An Example of PEP Research

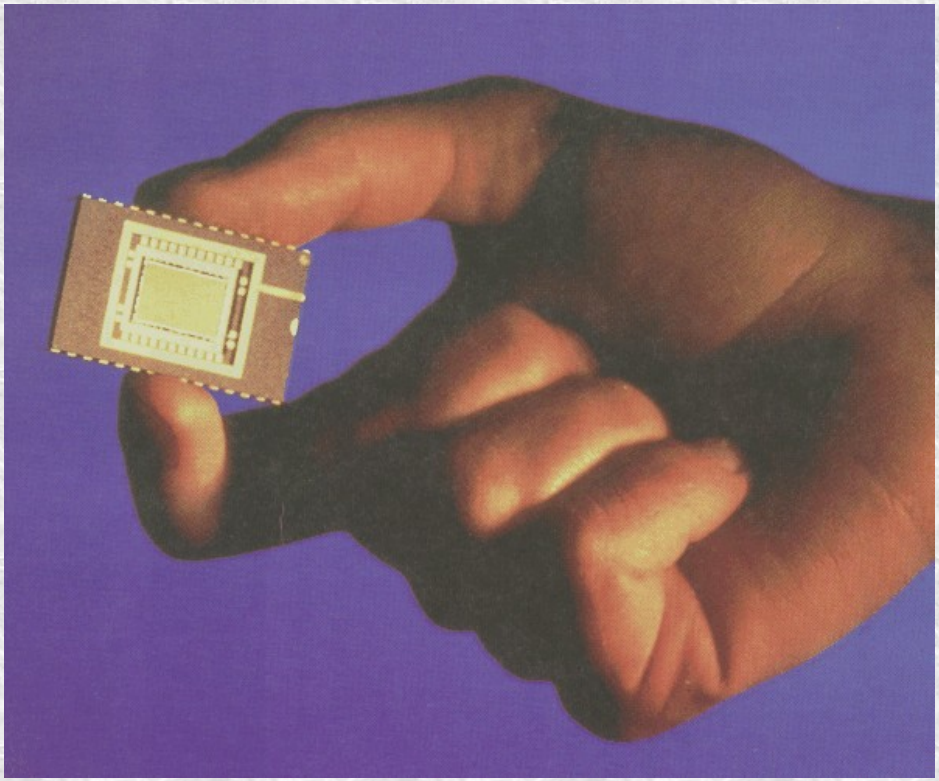


- Light curves of 5 small-amplitude pulsating red giants, showing short- and long-term variability
- Below: power spectrum, showing short- and long-term periods



Percy, Wilson, and Henry 2001

CCD Photometry
Charge-Coupled Device

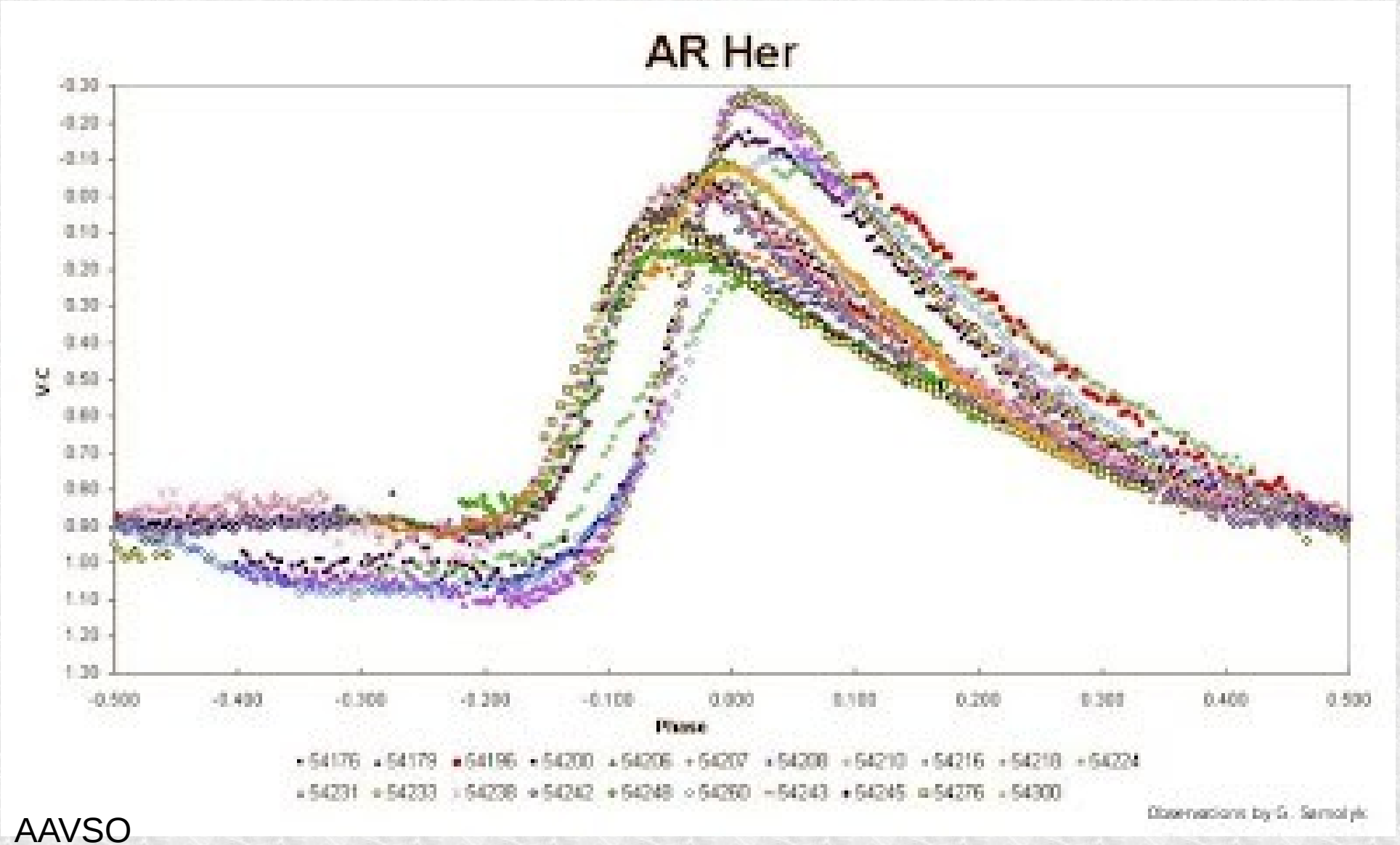


Smithsonian Astrophysical Observatory

- Digital; panoramic
- Co-developed by Canadian, Willard Boyle (Nobel Laureate)
- Sensitivity close to 100%
- Accuracy 0.005-0.02
- Not so good for brighter stars

An Example of CCD Research

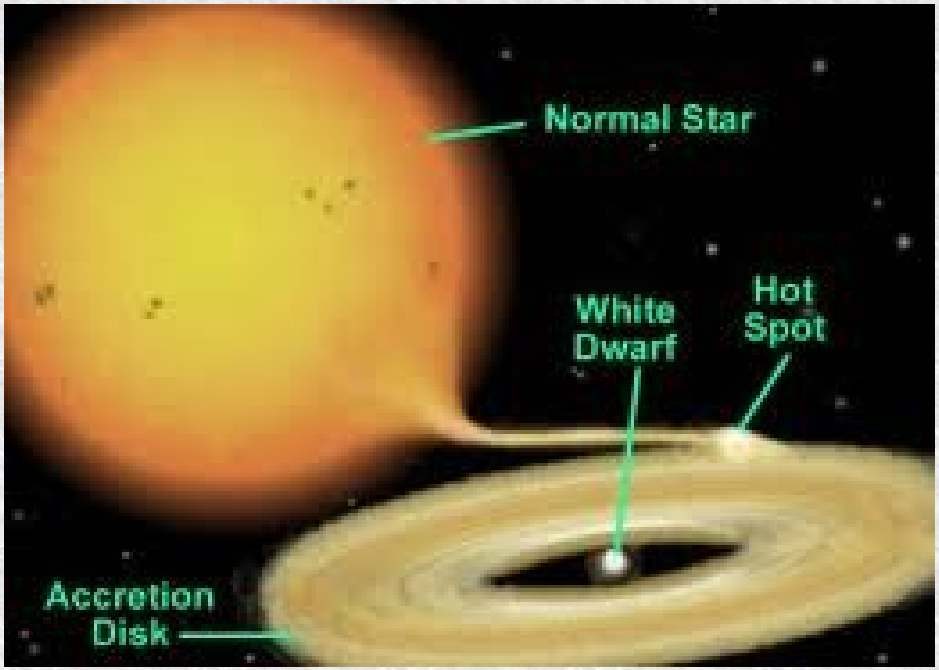
time series:variable maxima of RR Lyrae stars



AAVSO

Other CCD Photometry Projects

see *JAAVSO* and www.aavso.org/aavso-print



NASA

- Photometric monitoring of various aspects of cataclysmic variables: at quiescence (flickering, pulsation) and in dwarf nova, nova, and supernova eruption
- And short-period pulsators

Variable Star Data Mining and Analysis

- There are data on the AAVSO website, and many other places, which have not been fully analyzed
- There is a variety of time-series analysis software on the AAVSO website
- Also: useful instructions, tutorials, examples of research papers by amateurs and students
- Personal advice by AAVSO staff and members

Period Analysis

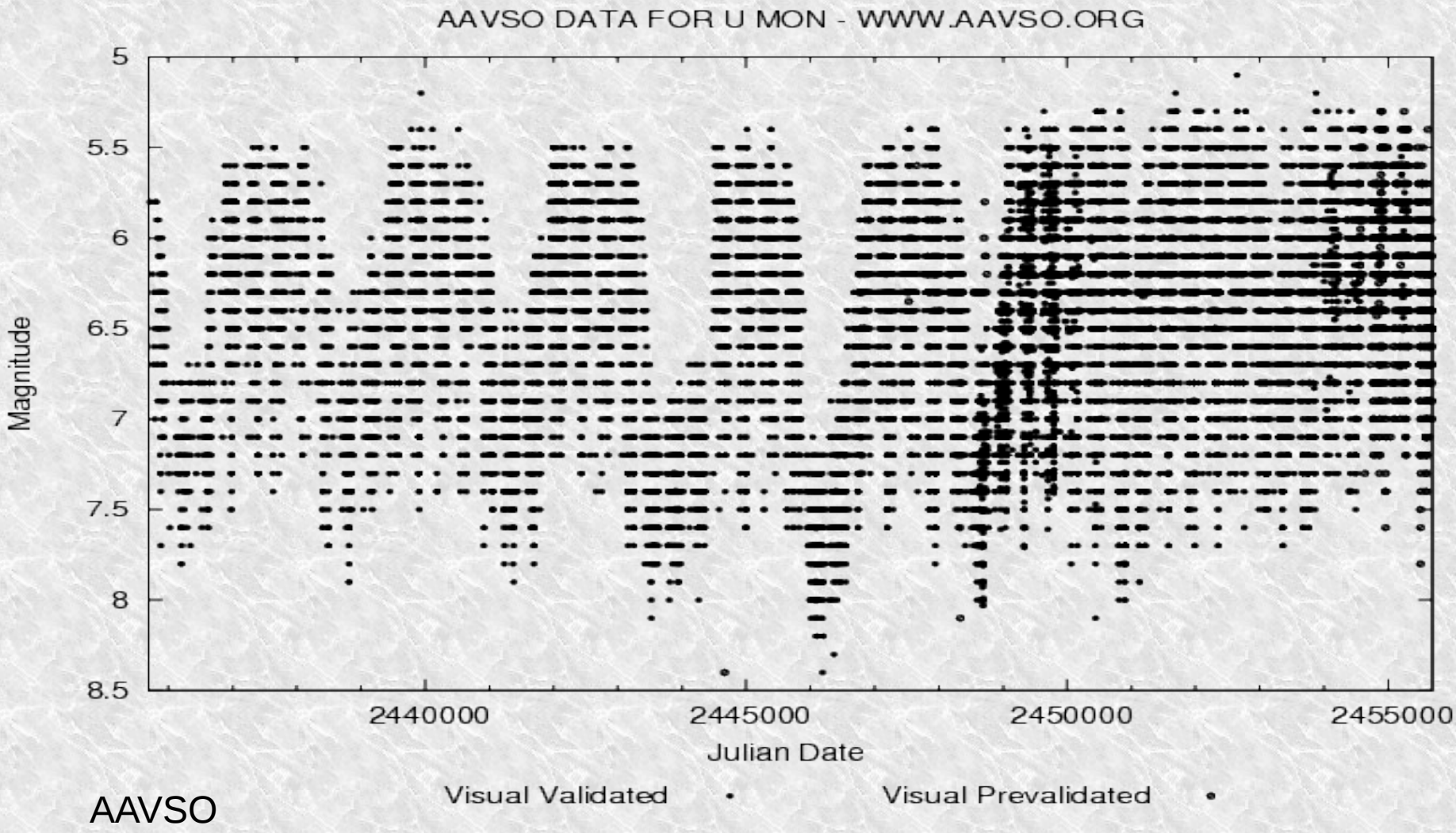
- Light curve: always the best place to start
- Fourier Analysis: determines periods present, and their average amplitudes
- Wavelet Analysis: gives change of period and amplitude with time.
- O-C Analysis: precision analysis of period changes over time

Visual observations of variable stars in modern astrophysics

Long-Term Light Curve of U Mon

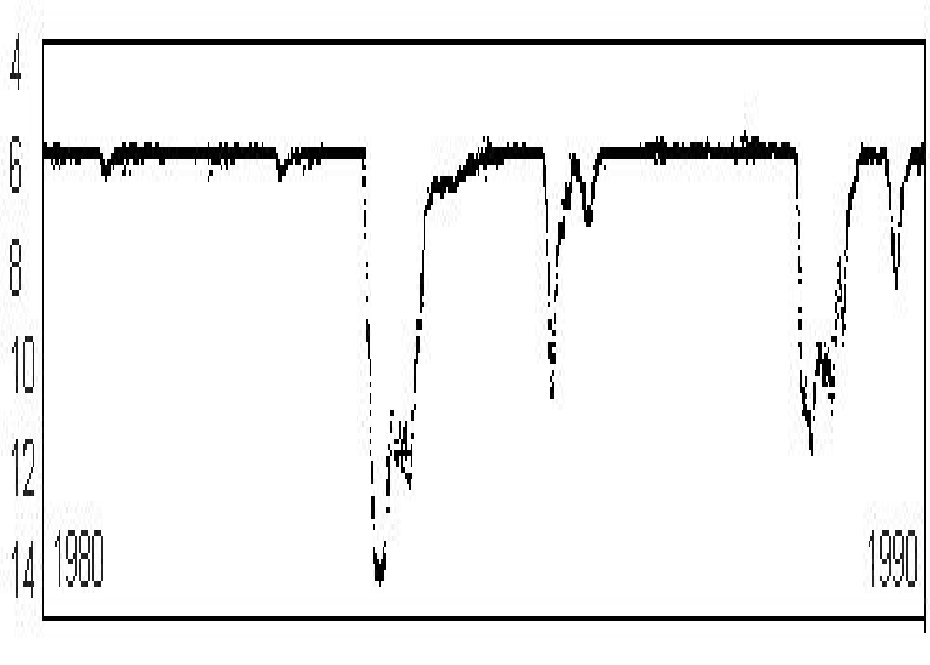
AAVSO visual data: numerous, sustained, standardized

20,000 days of observations of U Mon, an RV Tauri star



AAVSO

Timing Significant Events:
1. Unpredictable: Fadings of R CrB Stars

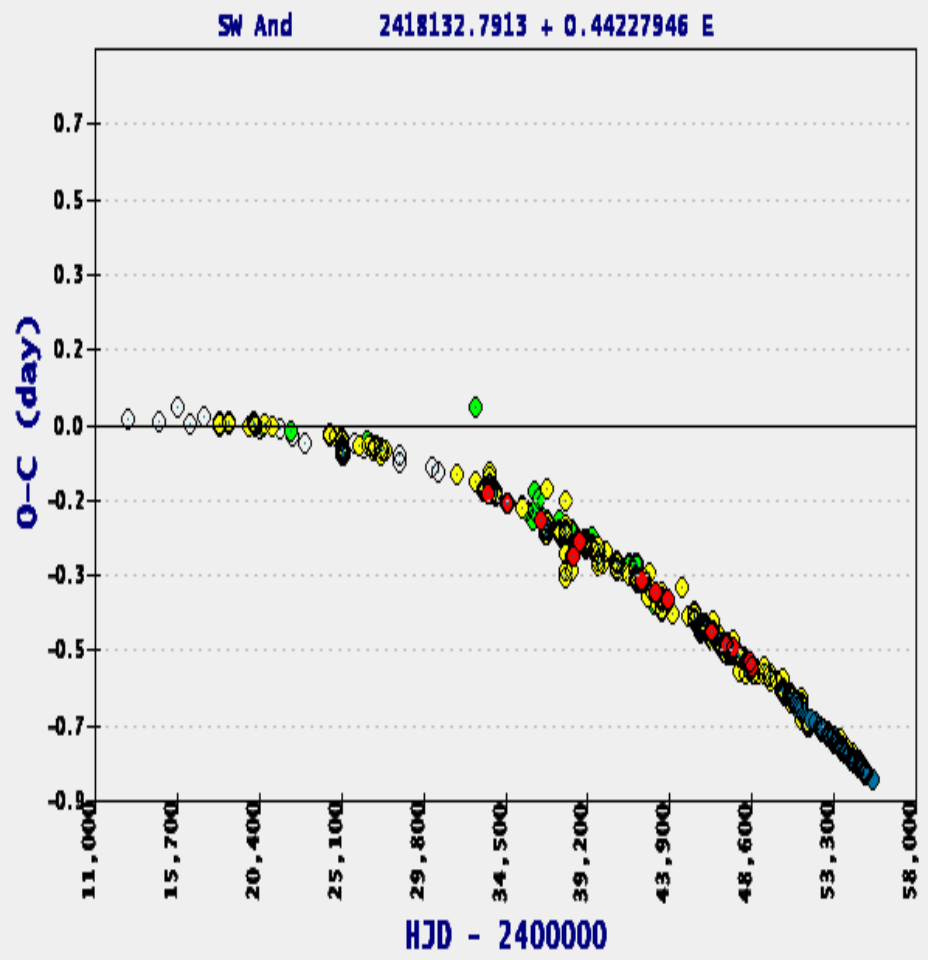


AAVSO

- Fadings are caused by ejected, obscuring, carbon-rich dust clouds
- Many (most? all?) RCrB stars are pulsating
- Are the fadings random, or tied to a period e.g. of pulsation?

Timing Significant Events

2. Semi-Predictable: Maxima of RR Lyrae Stars

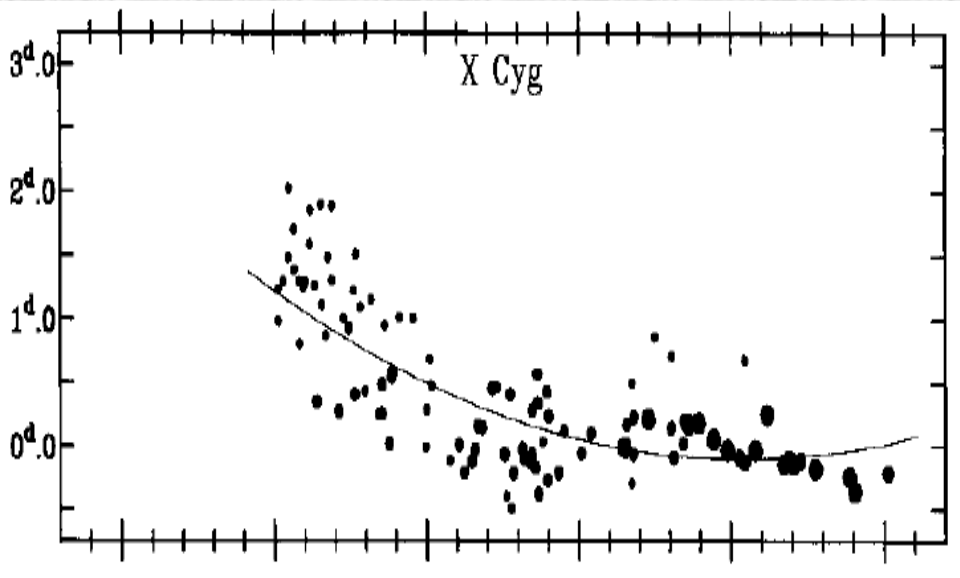


GEOS RR Lyrae database

- RR Lyrae: helium-burning horizontal-branch pulsating (0.3-0.6 day) stars
- Parabolic (O-C) diagrams reveal period changes, presumably due to evolution; can be compared with models
- But some (O-C) diagrams are not parabolic!

Timing Significant Events

3. Semi-Predictable: Maxima of Cepheid Variables

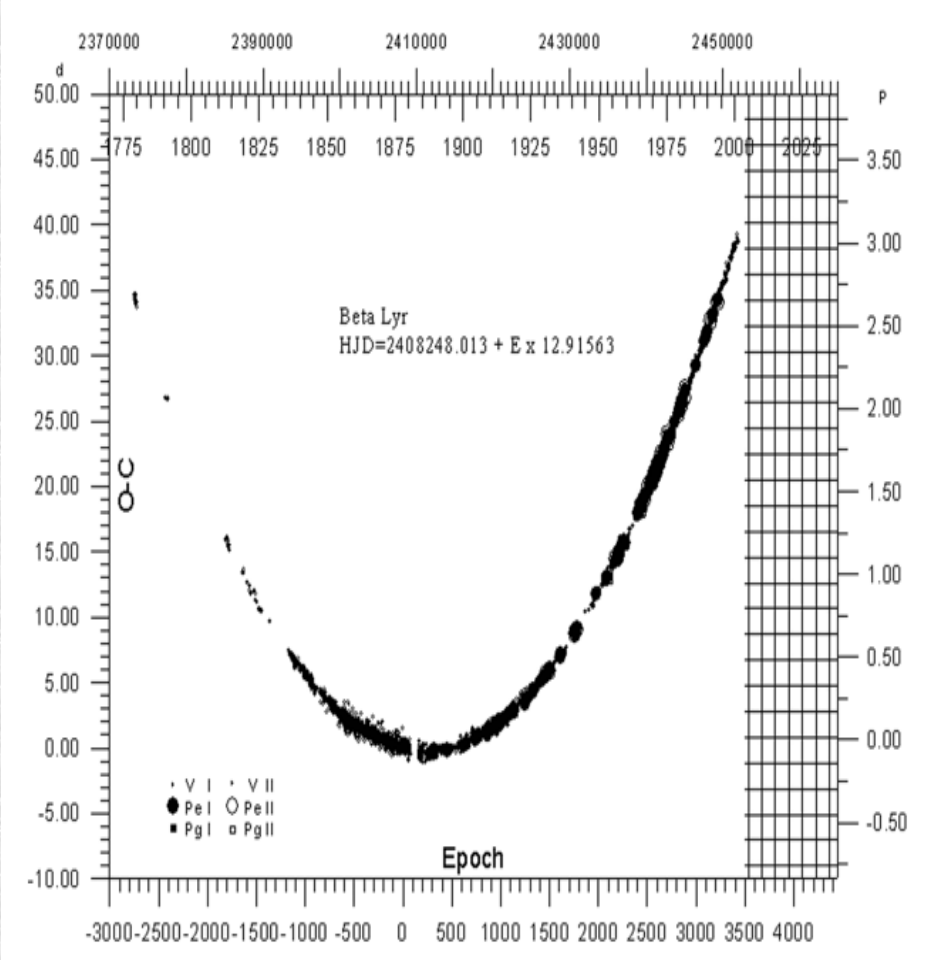


Malatesta 2002 September, AAVSO VSotS

- Cepheid variables: pulsating (1-100 days) yellow supergiants
- Used for determining distances, and the properties, structure, and evolution of the stars
- Even visual observations can reveal the period, and period change, especially with 200 years of data!

Timing Significant Events

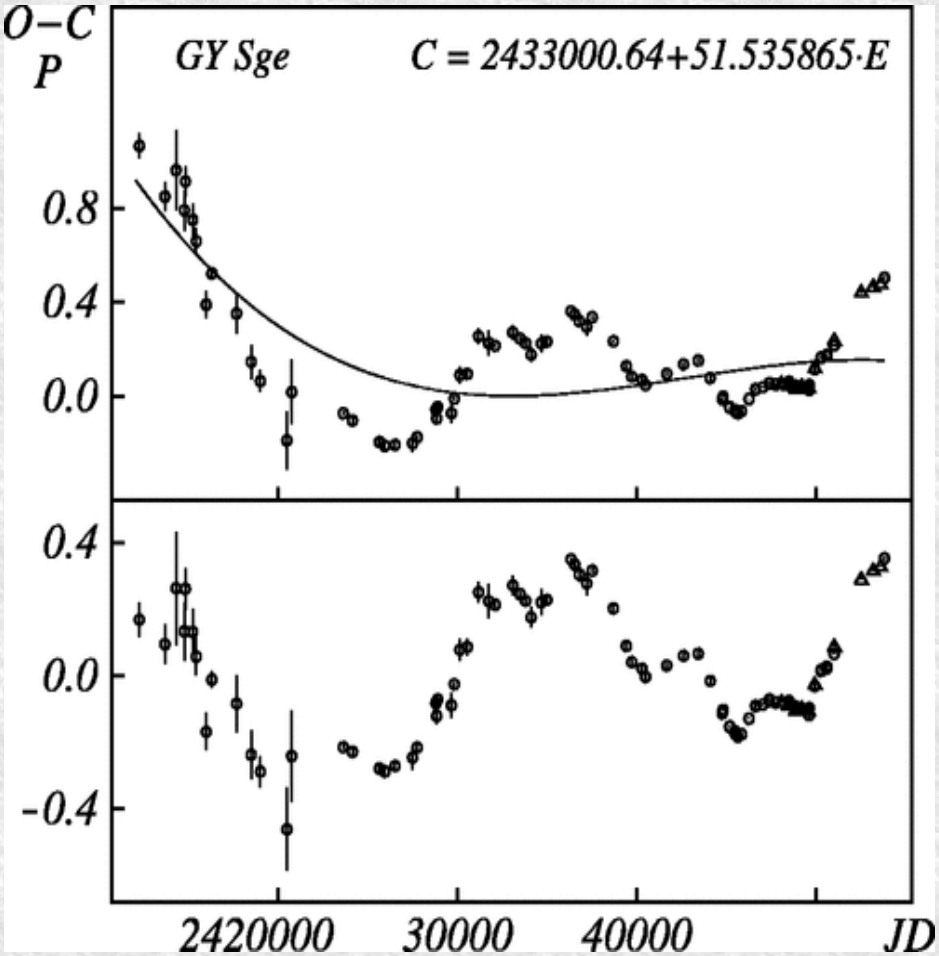
4. Semi-Predictable: Minima of Eclipsing Variables



- Beta Lyrae is perhaps the most bizarre of the thousands of known interacting close binary stars
- The period change reflects mass transfer and loss
- Further insight into this star is still needed!

AAVSO

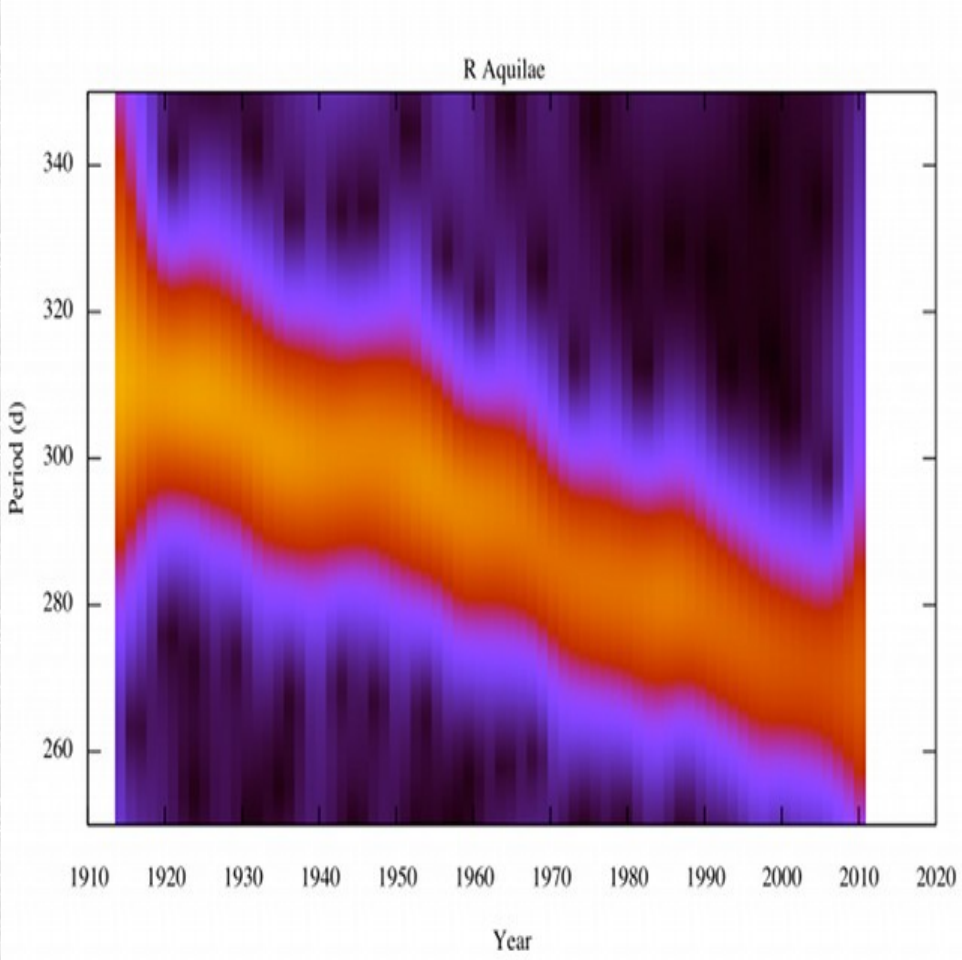
Period Changes: Systematic and Random



Berdnikov et al. 2007, PASP 119, 82;
GY Sge is a classical Cepheid

- (O-C) diagrams are not always linear (constant period) or parabolic (constant rate of period change)
- “random walk” (O-C) diagrams reflect random cycle-to-cycle period fluctuations
- These are found in Mira, RV Tauri, and some Cepheid variables

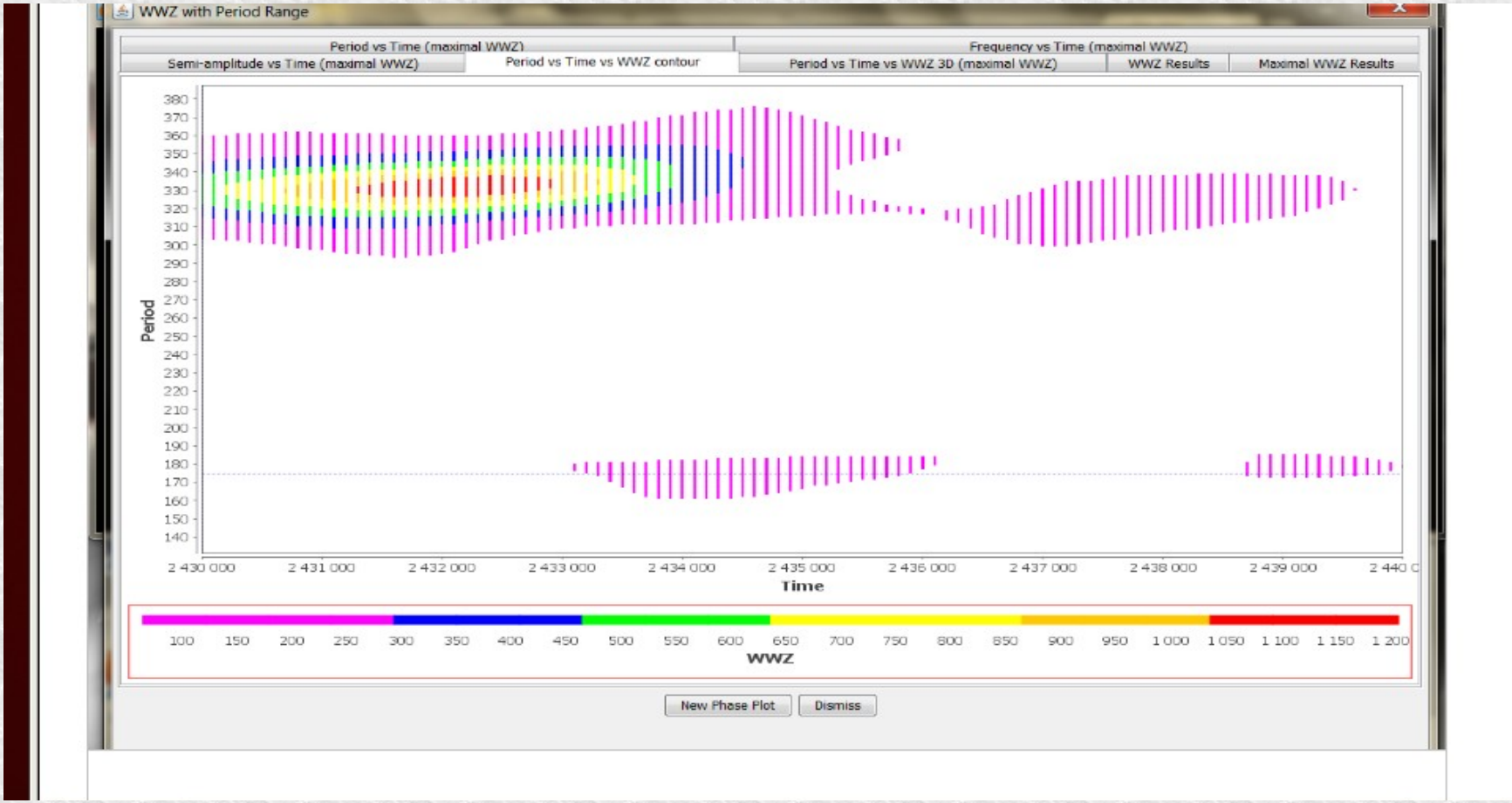
Period Changes
True Period Changes in Mira Stars



- The curvature of the (O-C) diagram is statistically too large to explain by random fluctuations
- This may reflect rapid evolution of the Mira star, such as a helium flash
- Wavelet analysis (left) can show this well

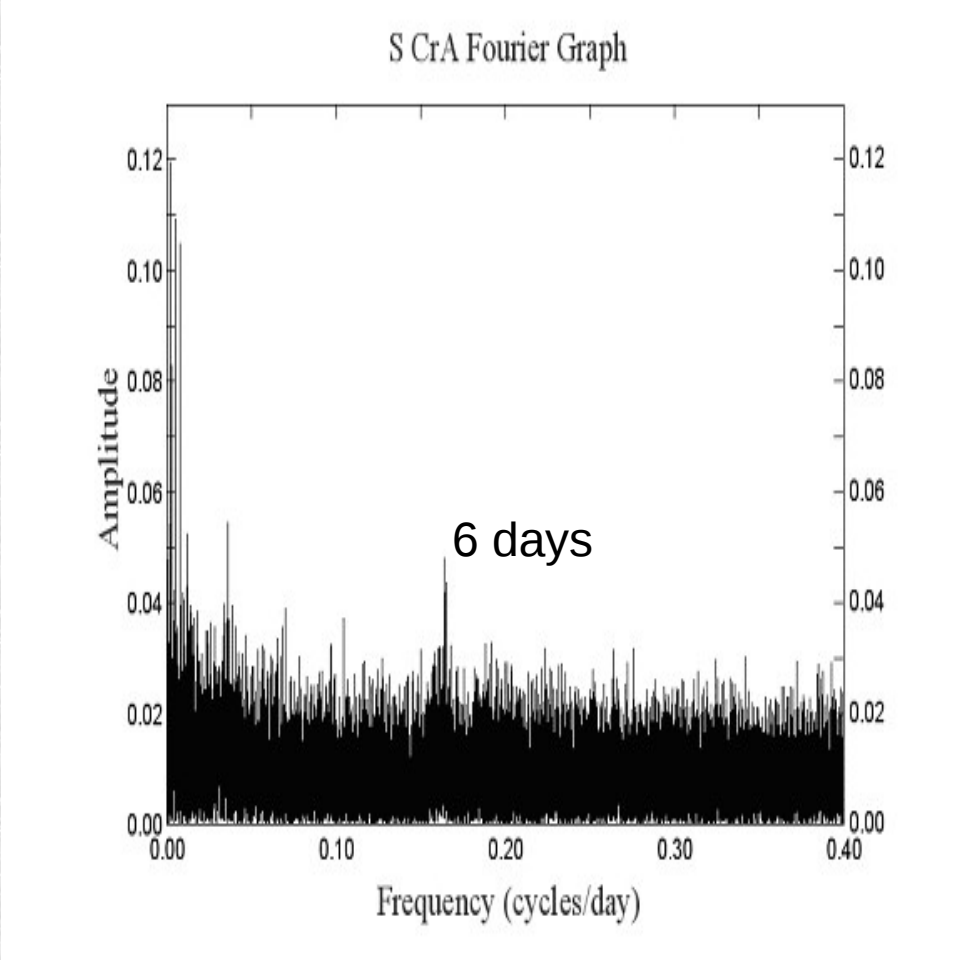
VSTAR Software

Fourier and wavelet analysis of pulsating red giant; other types of time-series analysis



Power versus period versus time for R Dor; www.aavso.org/vstar-overview

Beating Down the Error
Coherent Periods in T Tauri Stars



Percy, Palaniappan 2006, JAAVSO 35, 290

- T Tauri stars: young, spotted, rotating sun-like stars; coherent rotational variability; period: days; amplitudes small
- AAVSO visual observations, thought to have little value
- Danger: visual observations have small spurious one-year and one-month signals!

My Current Research

My Current Research

Studies of pulsating red giants and supergiants, especially their long-term behaviour

Systematic, sustained data from the AAVSO database, spanning many decades

Time-series analysis using the AAVSO VSTAR package

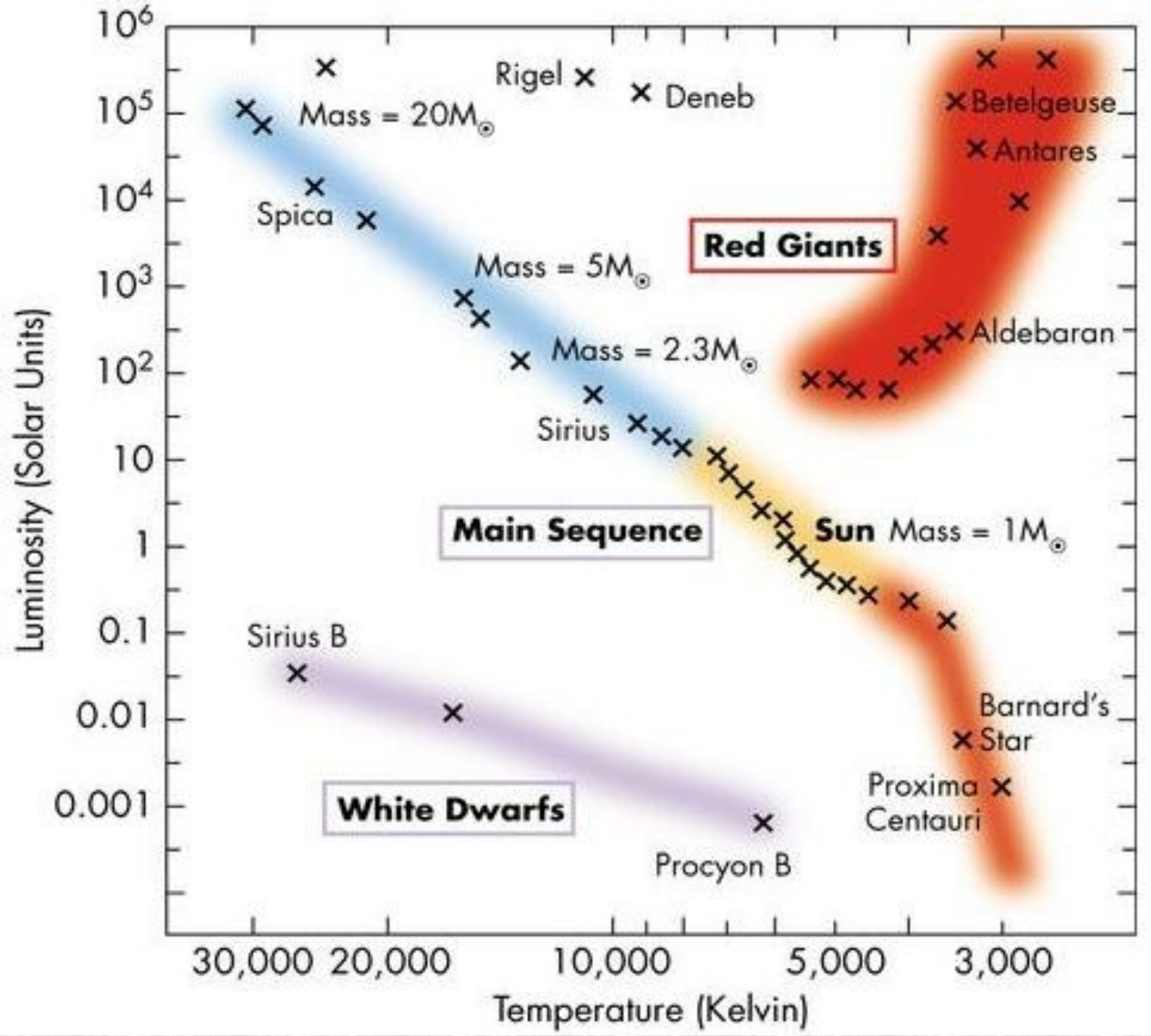
Undergraduate students develop and integrate their science and math skills by doing real science with real data

Results are published in the JAAVSO with students as co-authors; a win-win-win situation

The Role of My Students

- Undergrads and outstanding senior HS students
- Enhance math, science, and computing skills
- Are motivated by doing real research, with real (AAVSO) data
- Results presented and published, contributing to science, and providing feedback and motivation to AAVSO observers

Pulsating Red Giants (PRGs) and Supergiants (PRSGs)

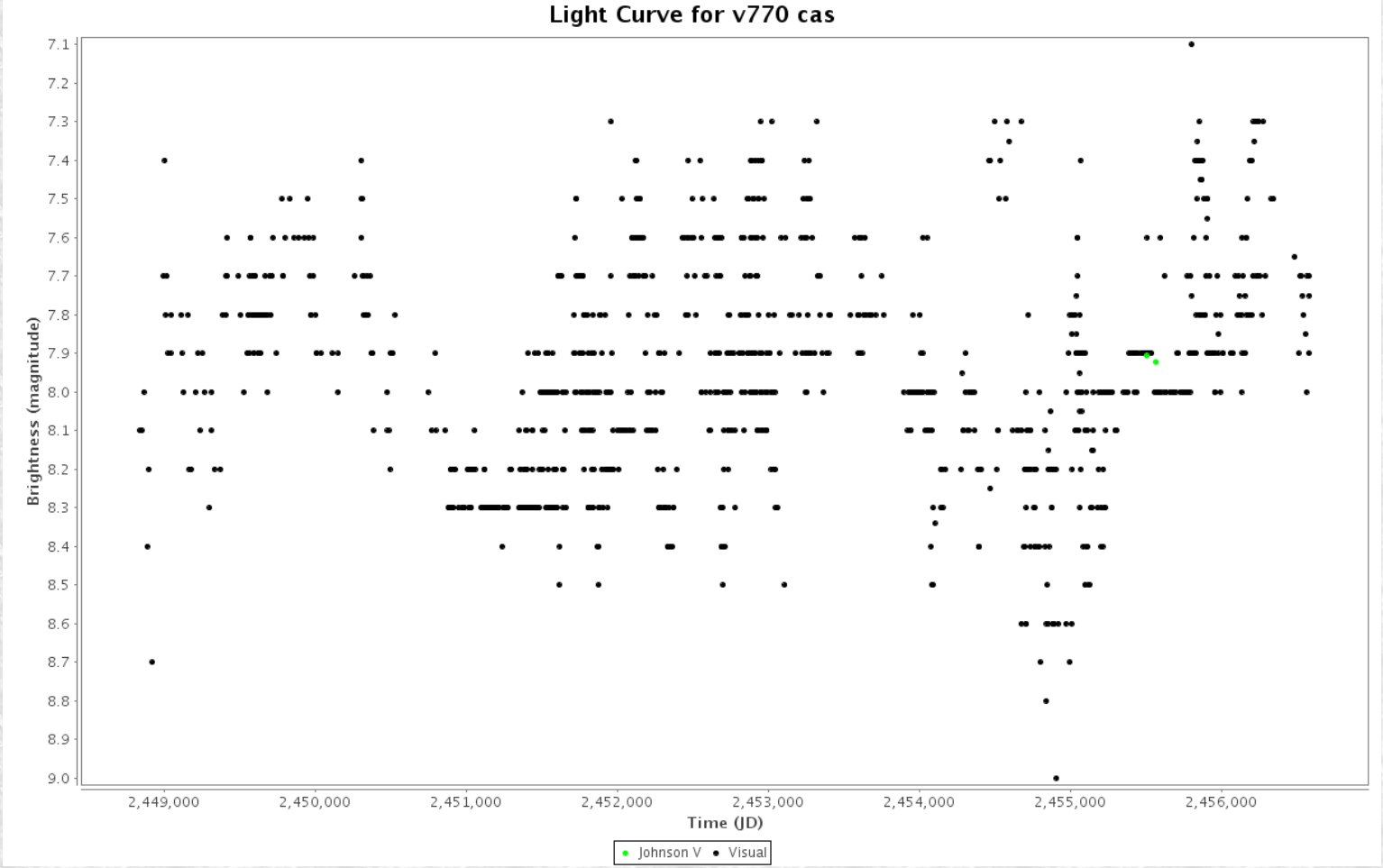


The Nature of “Irregular” PRGs

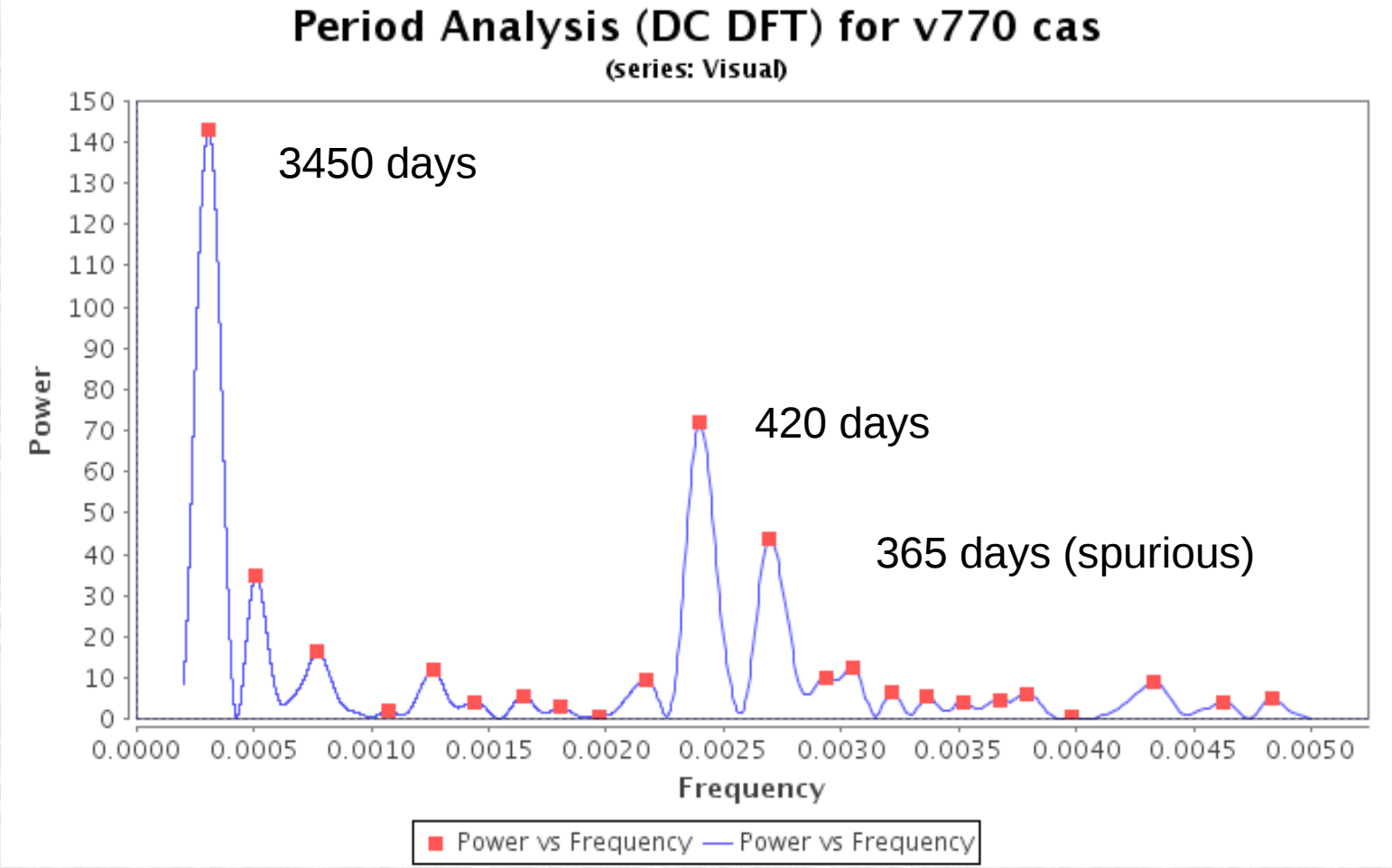
Percy & Terziev 2011

www.aavso.org/ejaavso3911

note the “long secondary period”



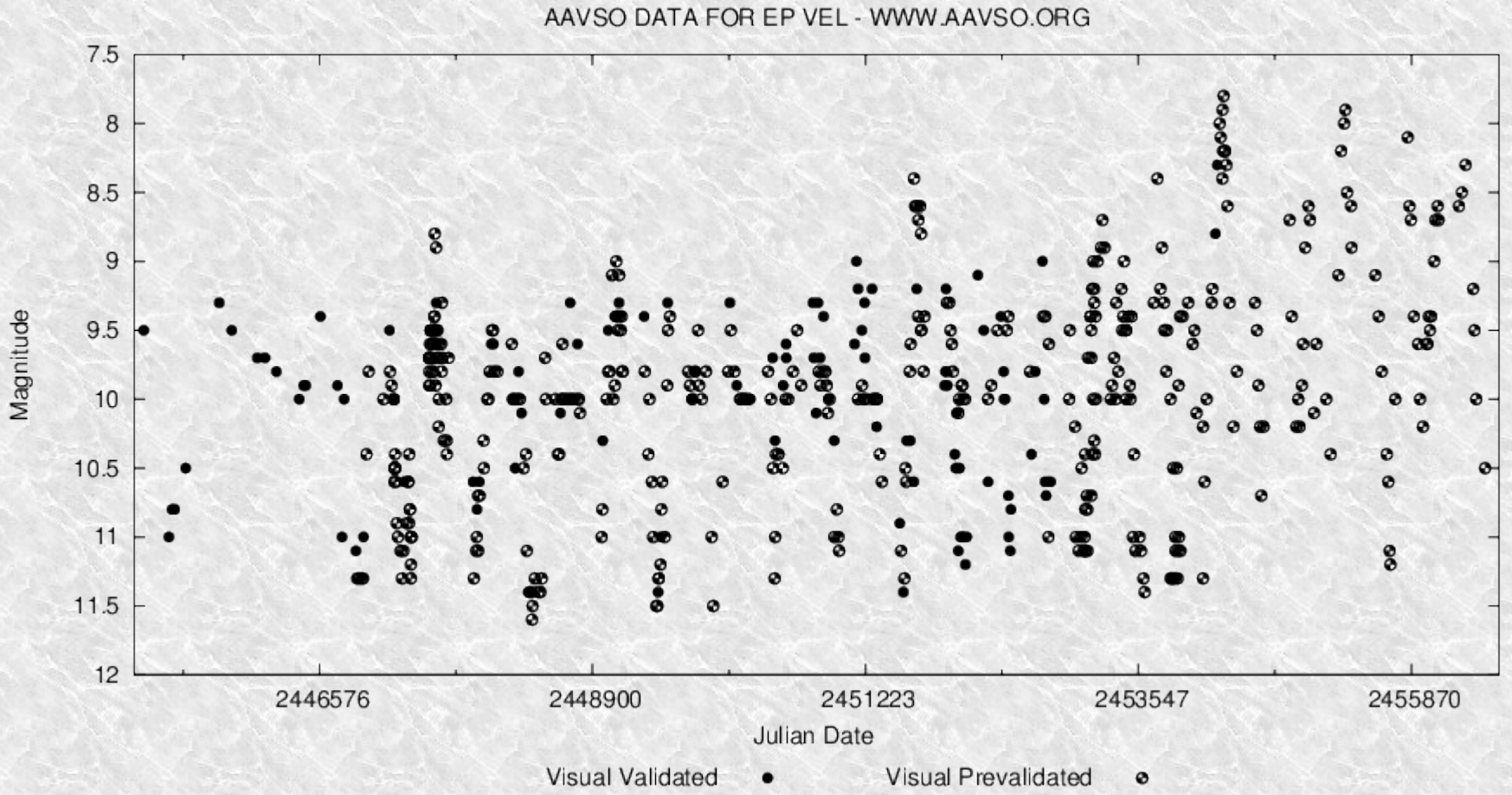
V770 Cas Power Spectrum, showing period of about 370 and possibly 3400 days: many "irregular" variables have one or more periods; two pieces of info is better than one, or none!



Frequency =1/period

Semi-Regular (SR) PRGs

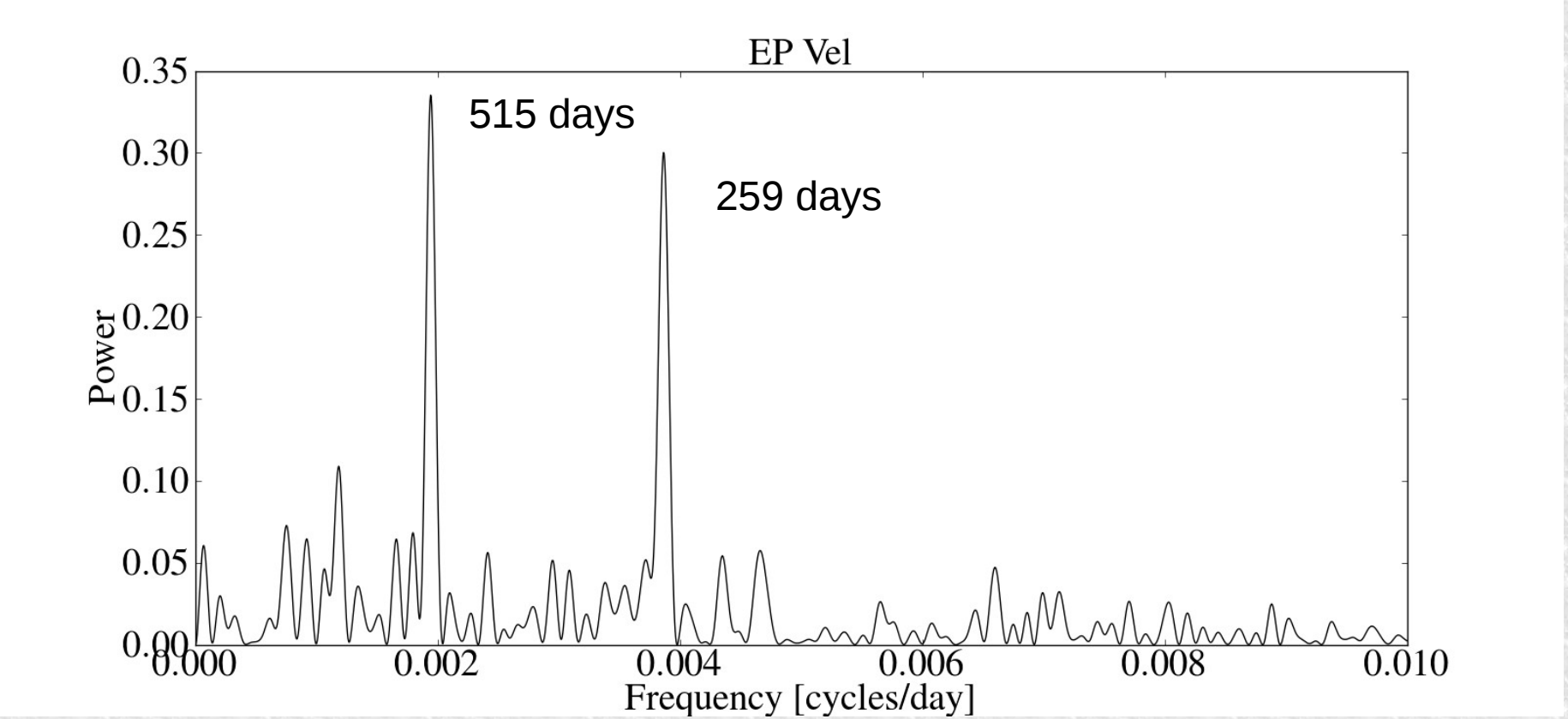
Percy & Tan 2013, www.aavso.org/ejaavso411001



Semi-Regular (SR) PRGs

Percy & Tan 2013, www.aavso.org/ejaavso411001

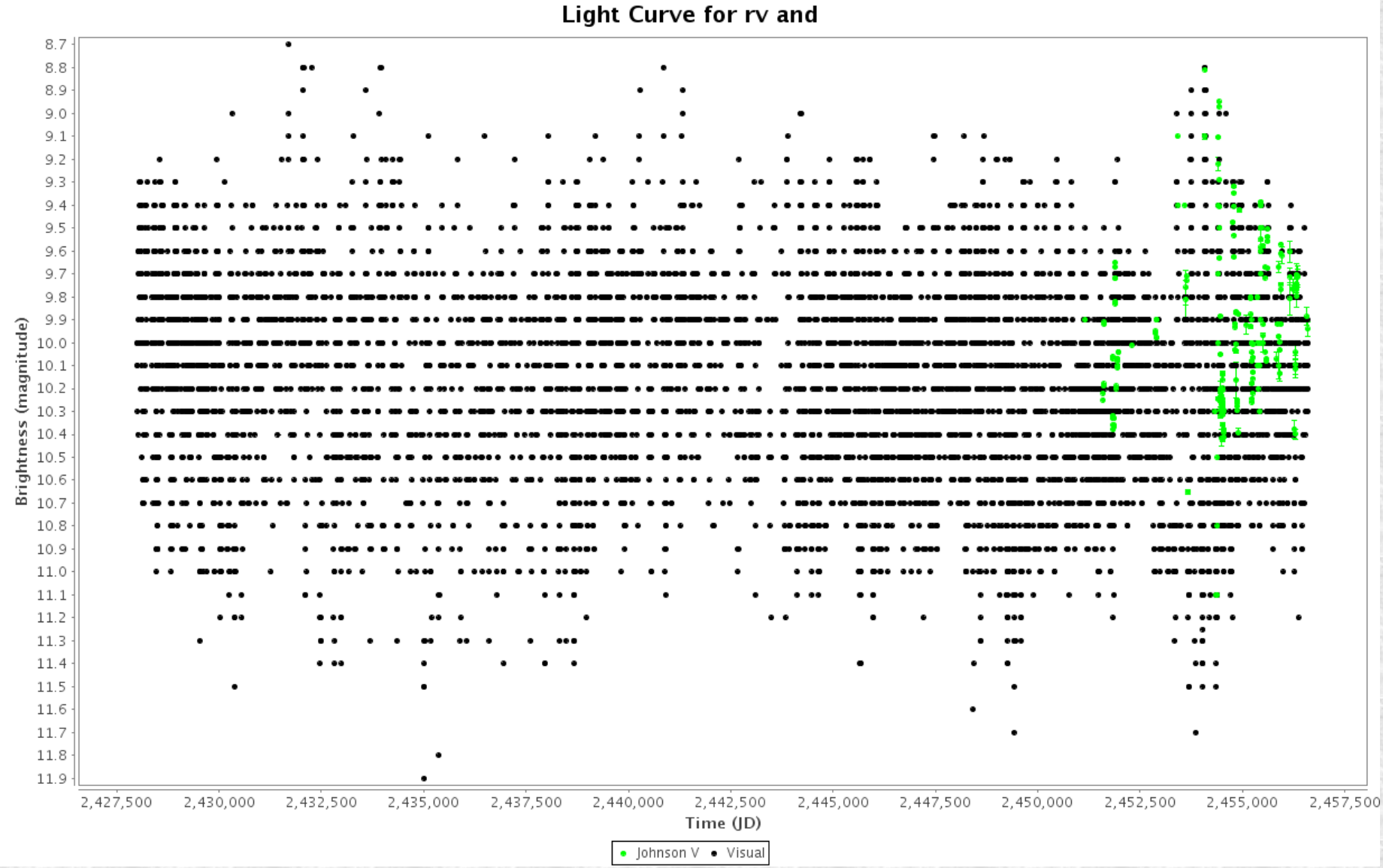
EP Vel, and many other SRs, pulsate in two modes; very useful! Twice as much info!



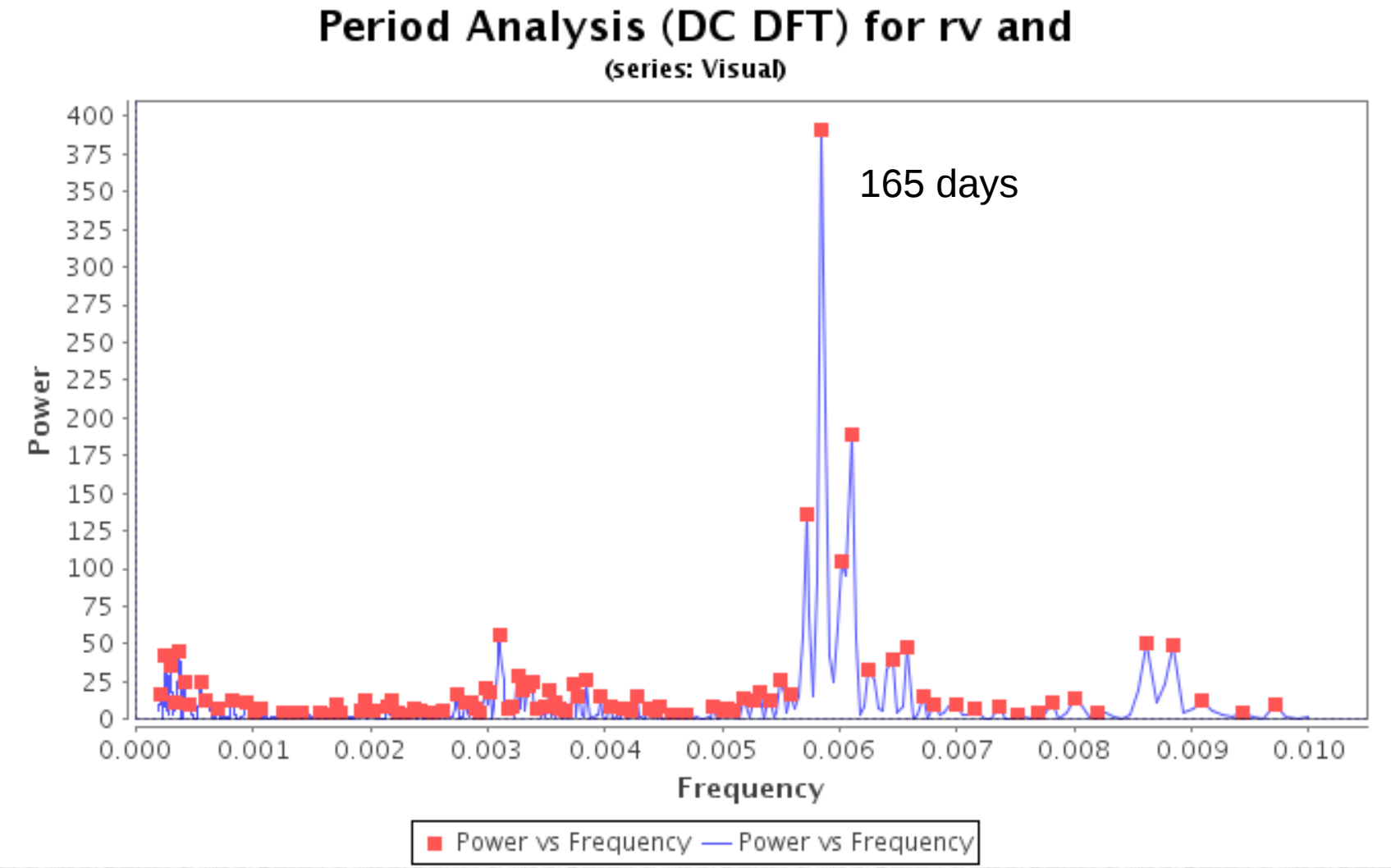
Frequency = 1/period

Amplitude Variations in PRGs

Percy & Abachi 2013, www.aavso.org/ejaavso243

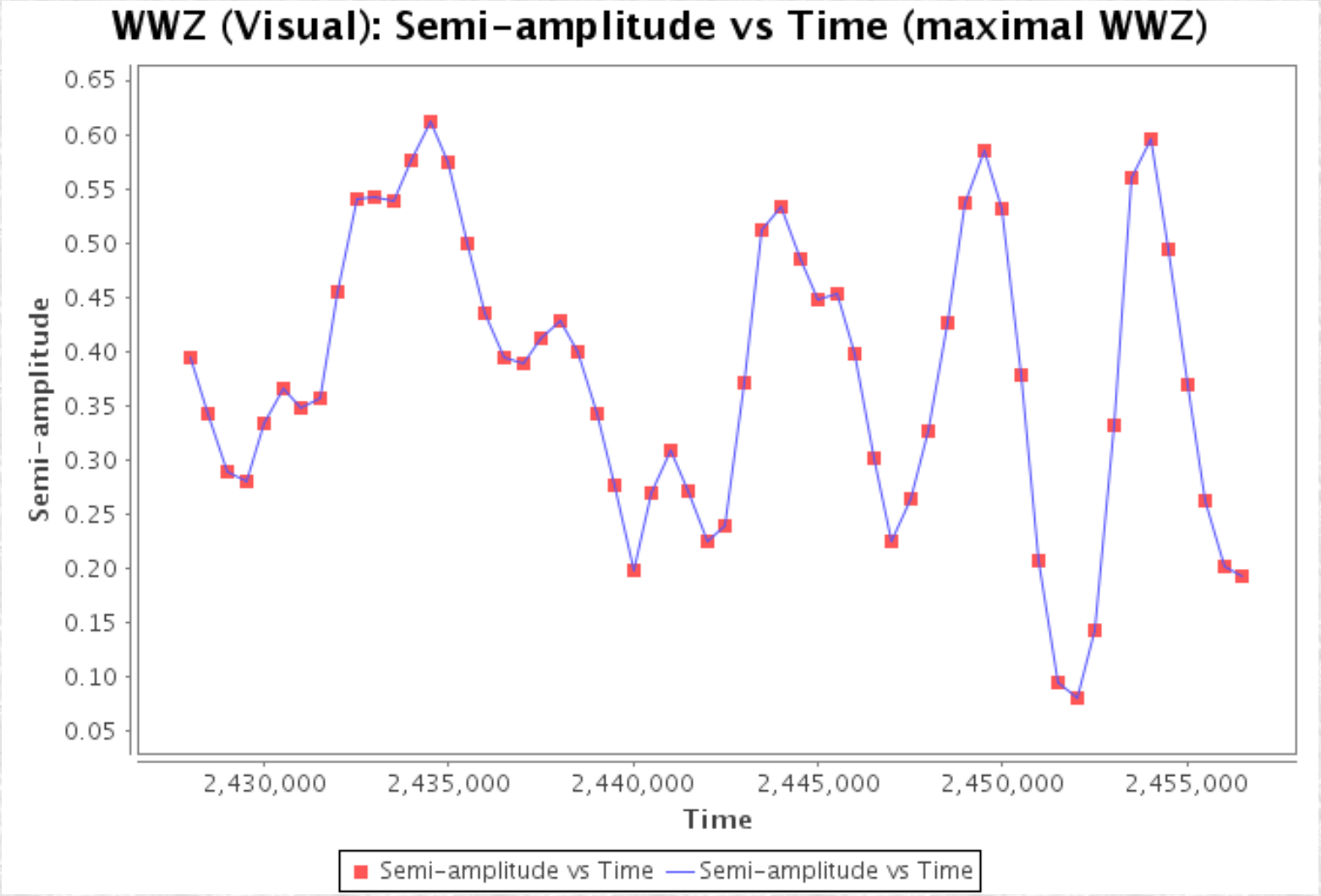


RV And power spectrum analysis, showing 171-day period



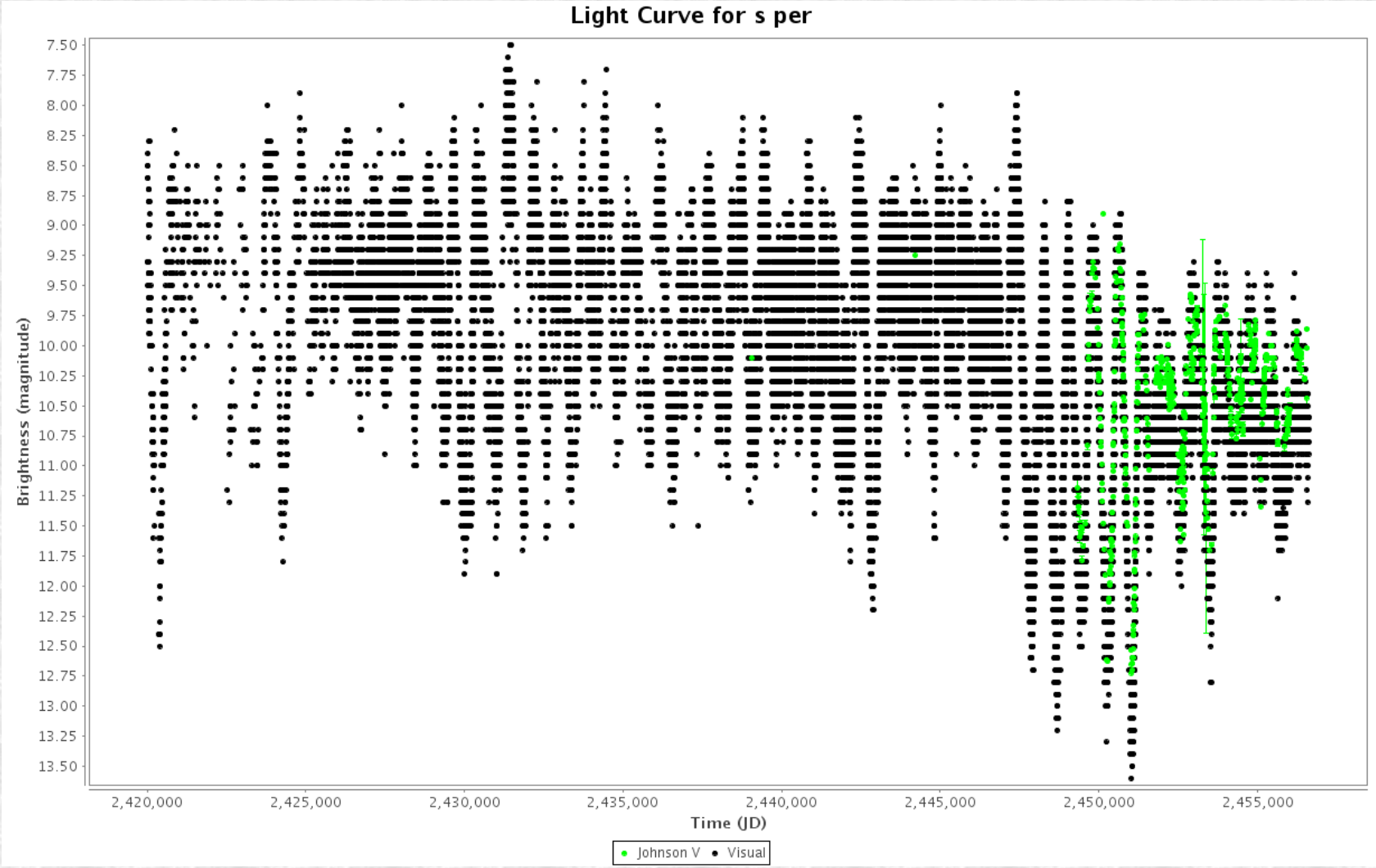
Frequency = 1/period

RV And: variation of pulsation amplitude with time; almost all pulsating red giants vary in amplitude; why?

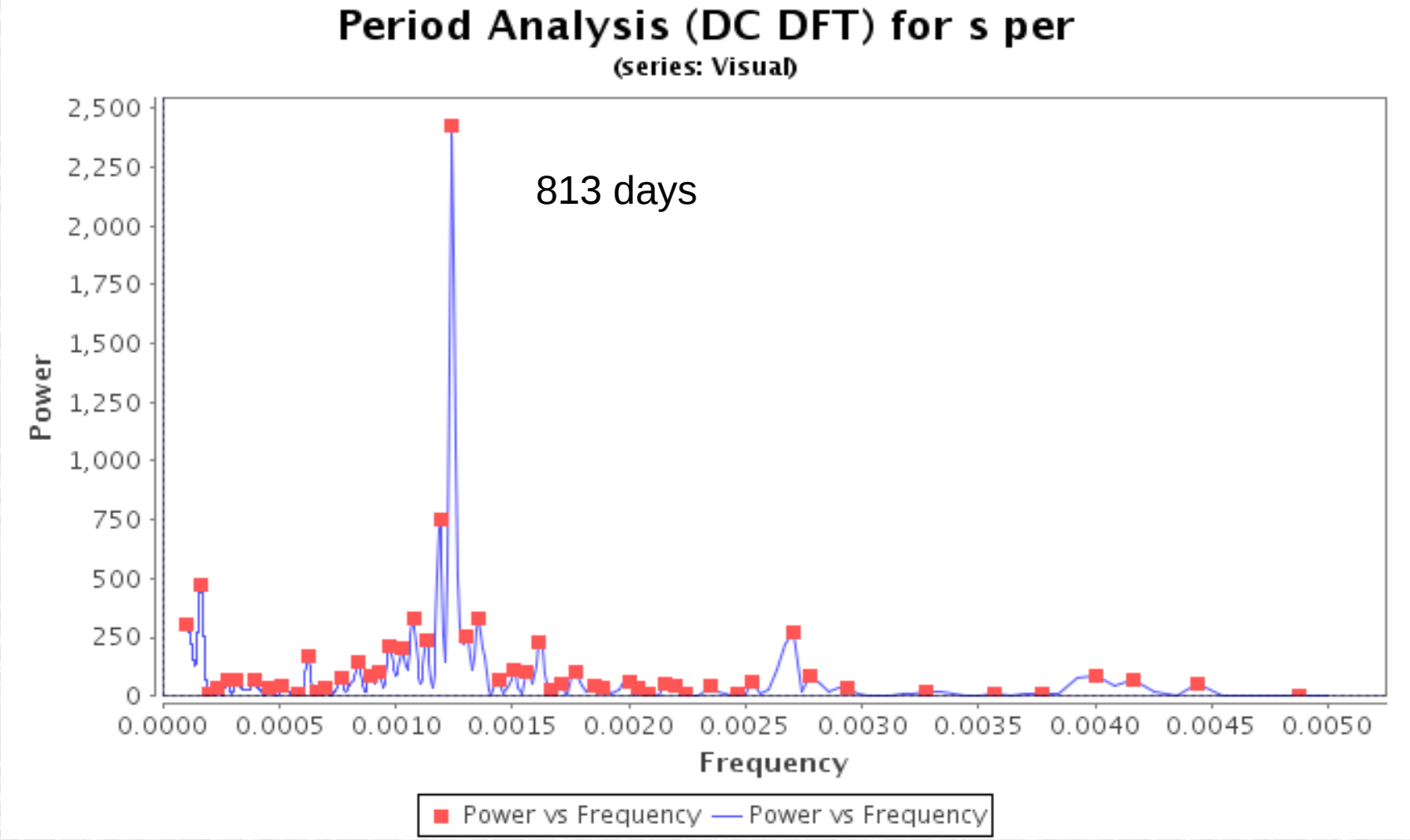


Amplitude Variations in Pulsating Red Supergiants

Percy & Khatu 2013, arxiv.org/abs/1310.6306

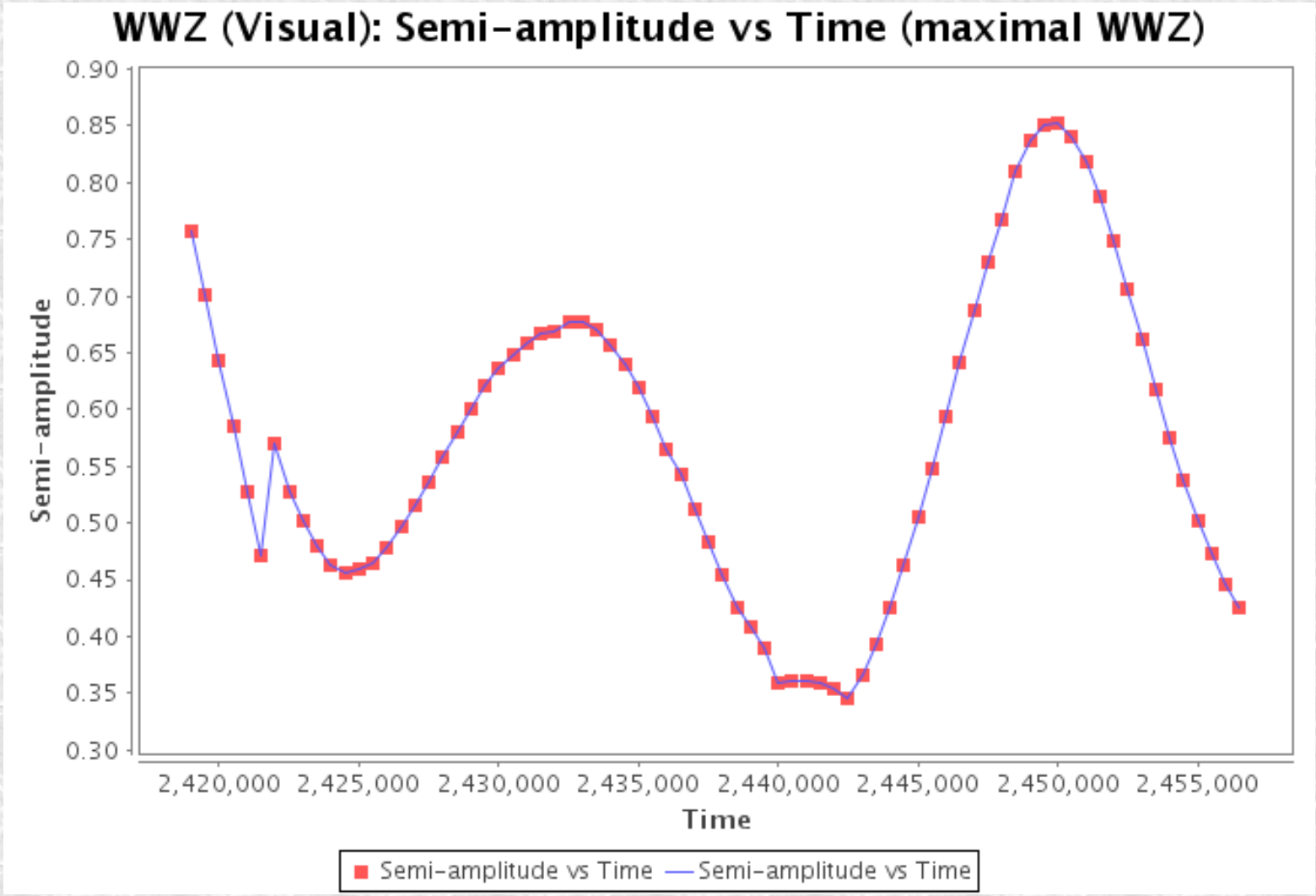


S Per: power spectrum analysis, showing 813-day period

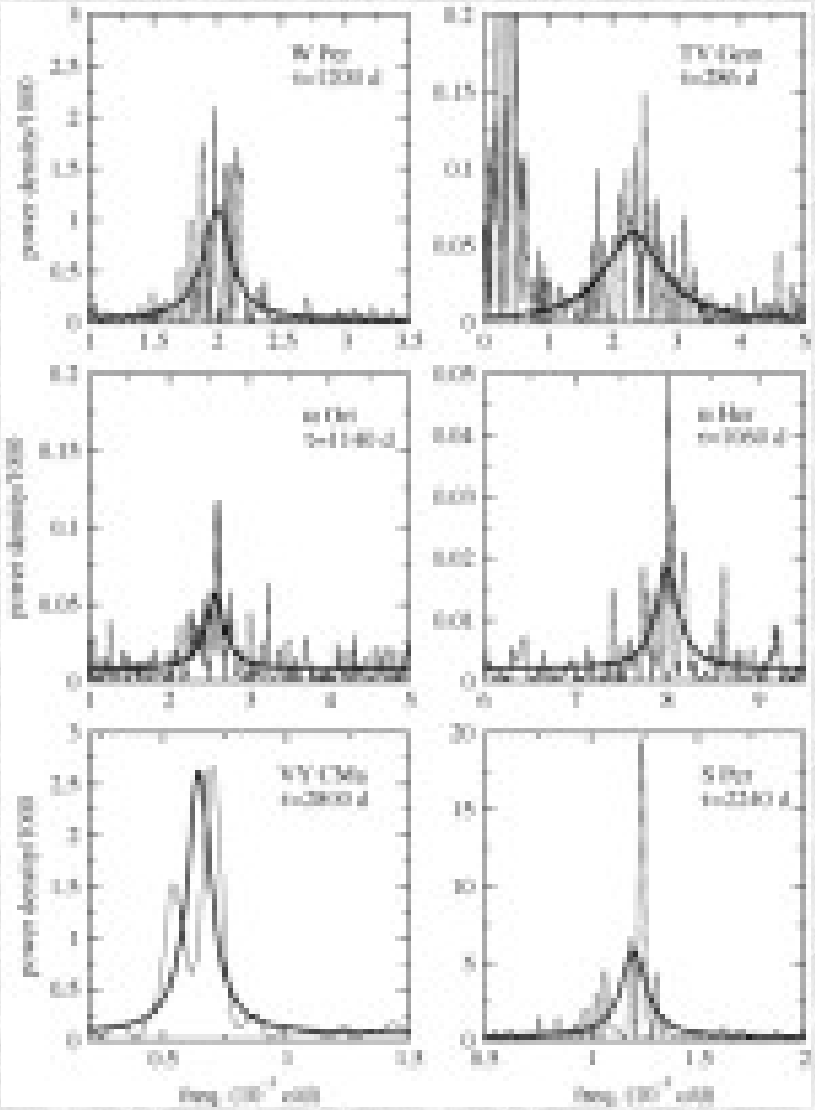


Frequency = 1/period

S Per: pulsation amplitude versus time; amplitude varies in this and other pulsating red supergiants; why?



Pulsating Red Supergiants: A Clue

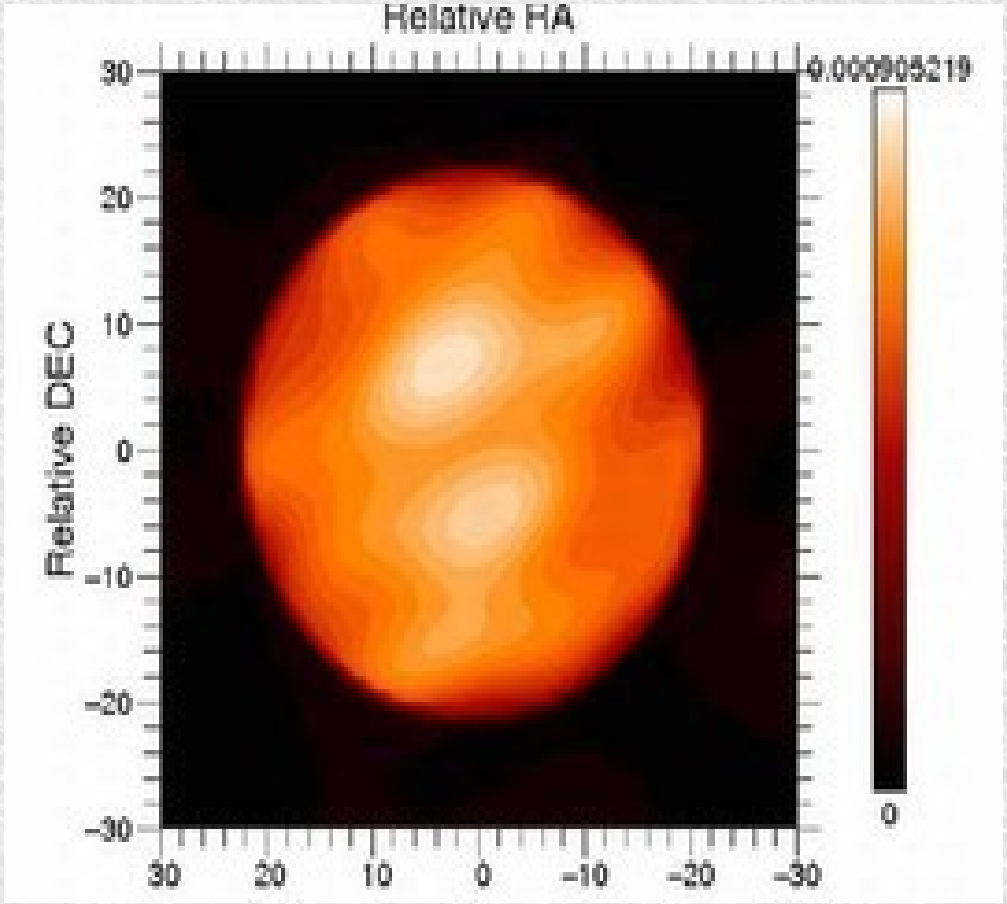


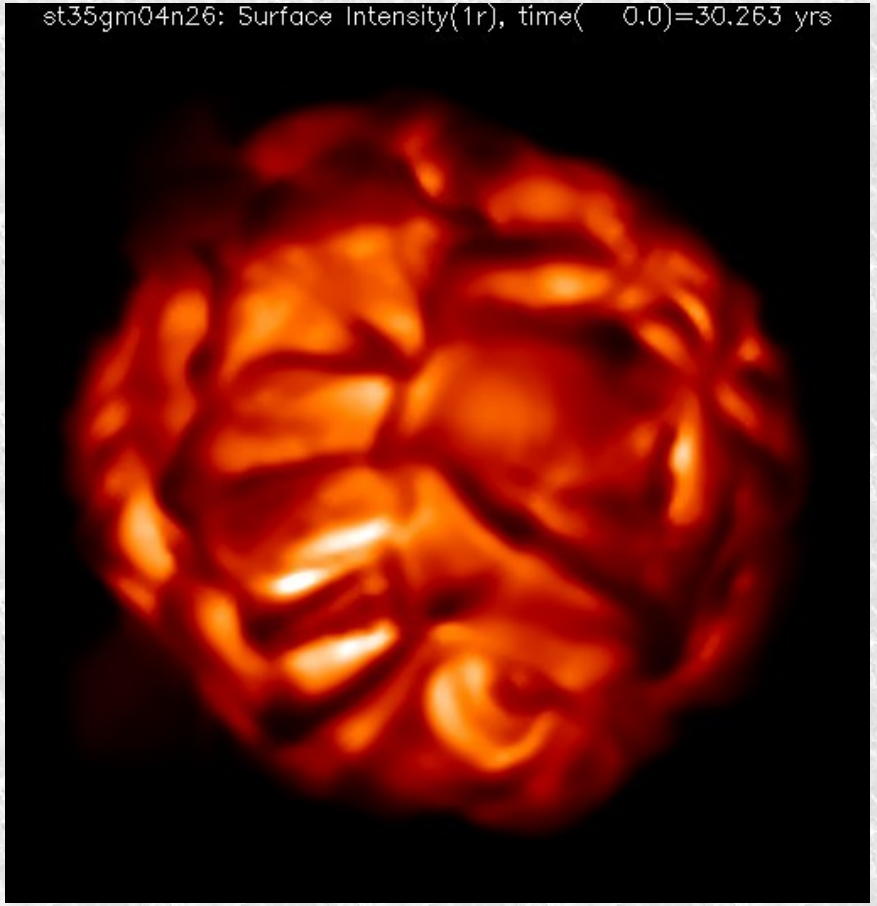
- The detailed power spectrum shows multiple peaks under a Lorentzian envelope
- This is interpreted as evidence for stochastic oscillations, caused by interplay between convection and pulsation
- We may be seeing their growth and decay

Kiss, Szabo, Bedding 2006, MNRAS 372, 1721

Betelgeuse

Image (left); model (right): red supergiants have deep convection zones; huge convective cells; non-uniform!





Current Projects 2013-2014

1. Some pulsating red giants pulsate in both the fundamental and first overtone mode. Do any also pulsate in the second overtone? In progress

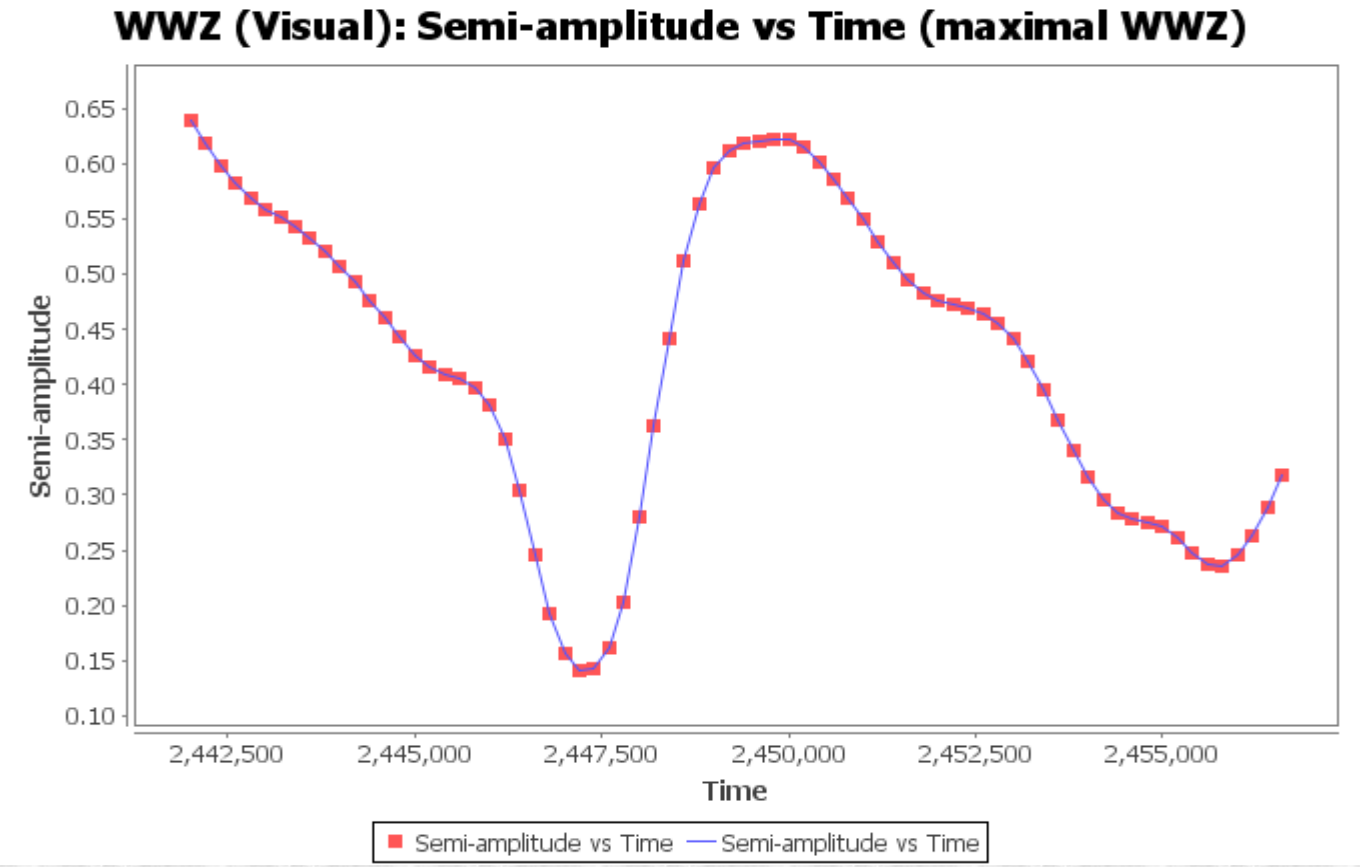
2. Do yellow supergiants such as RV Tauri stars and SRd stars vary in pulsation amplitude? Yes!

3. Following on Galileo: if the pulsation amplitude increases, does the pulsation period increase also? It seems to, in many cases

DE Her, Yellow Semi-regular (SRd) Variable

Amplitude as a function of time

Results by Rufina Kim (2014)



Reflections

- Despite decades of dire predictions, visual observation is not dead
- There is a steady stream of research papers, using visual data
- For many applications, including period determination and study of long-term variability, the longer the dataset, the more secure the results
- To reiterate: AAVSO visual observations are numerous, sustained, and standardized

Rewards of Variable Star Observing

- Contributing to science/astronomy – including forefront astronomy; seeing your name in the AAVSO database, or on a paper
- Knowing that your work also contributes to education; being able to share your knowledge and work with others
- Constantly learning about astronomy, variable stars, and observing techniques, from sources such as AAVSO
- Being part of an international community of “kindred spirits”, including those who have gone before us
- Being in touch with the universe

Acknowledgements

- A century of AAVSO (and other) visual observers
- AAVSO HQ staff who have standardized, guided, and archived the observations
- My students for their work and inspiration
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Resources for VSOers