# TIME-DOMAIN ASTRONOMY

## Science Case 3: Variable Stars

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# THE SKY CHANGES!

## MIRA CETI

- David Fabricius discovered "omicron ceti" in 1596:
  - It brightened from the 3rd to the 2nd magnitude, then disappeared. Actually, it disappeared from view since it faded beyond the detection limit.
  - It was re-observed in 1609 by Fabricius, and re-discovered in 1631 by Johann Fokkens Holwarda who determined a 11 month period.
  - Johannes Hevelius observed it in 1639 and 1642, and named the star "Mira" – *The Wonderful.*

- Earlier ancient discovery records unclear. Hipparchus may have discovered Mira in 134 BC.

# THE SKY CHANGES!


## ALGOL

- Geminiano Montanari discovered “beta Persei” in 1667:
  - Brightness varies from 2.1 to 3.4 magnitude in 2.87 days.
  - Period of less than 3 days credited to John Goodricke in 1782-83.
  - In 1881 Edward Pickering theorized (correctly) that it was an eclipsing binary star system.

- European, Arab, and Chinese cultures knew its variability and considered it evil:
  - “Demon’s Head” – Arab
  - “Mischief-maker” – Arab
  - “Satan’s Head” – Hebrew
  - “Lilith” – Adam’s legendary demonic first wife – Babylon/Hebrew
  - “The  Spectre’s Head” - Europe
  - “Piled-up Corpses” - Chinese

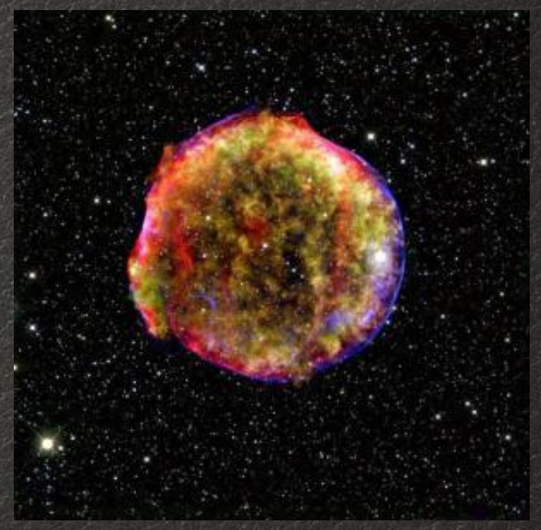
# THE SKY CHANGES!

# SUPERNOVA

HST Image of SN 1054

- Chinese astronomers have been the first (maybe…) to record a supernova:
  - Over 20 historical candidates identified over the past 2000 years.
  - Confirmed dates include 185, 393, 1006 (brightest and also recorded in Egypt, Iraq, Italy, Japan and Switzerland), 1054 (Crab nebula remnant shown above).

- In 1572 Tycho Brahe observed SN 1572 and argued it was very far from Earth.



X-ray Image of Tycho SN

# A RICH ZOO!

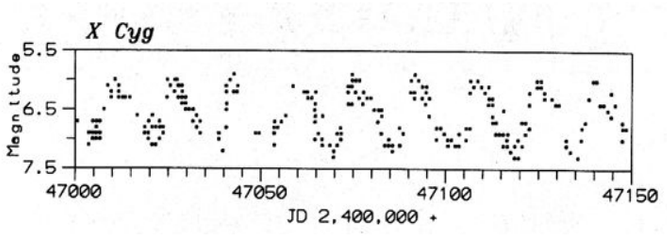
- Pulsating Variables:
  - Periodic expansion and contraction of their structure (Cepheids, RR Lyrae, RV Tauri, Long Period, Semi-regular, etc.).
- Eclipsing Variables
- Eruptive Variables:
  - Supernovae, novae, dwarf novae, cataclysmic variables, etc. (we don't discuss them here).

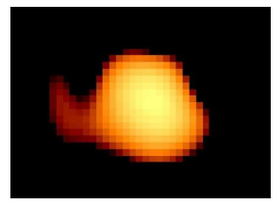
# CLASSIFICATION OF VARIABLE STARS

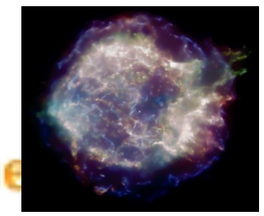
GROUP | CLASS | TYPE

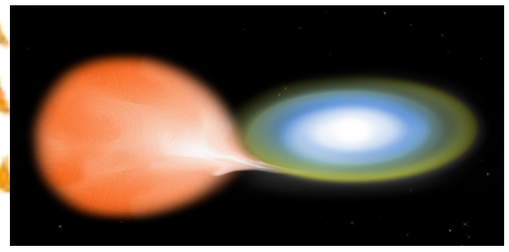
VARIABLE STARS

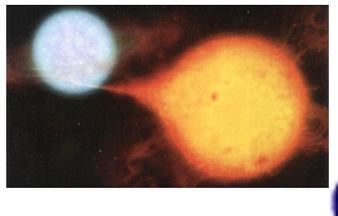
- INTRINSIC
  - I. PULSATING STARS
    - *Cepheids*
    - *RR Lyrae*
    - *RV Tauri*
    - Long-period variables
      - *Mira* type
      - Semiregular
  - II. ERUPTIVE (Cataclysmic stars)
    - Supernovae
    - Novae
    - Recurrent novae
- EXTRINSIC
  - III. ECLIPSING BINARIES
  - IV. ROTATING VARIABLES



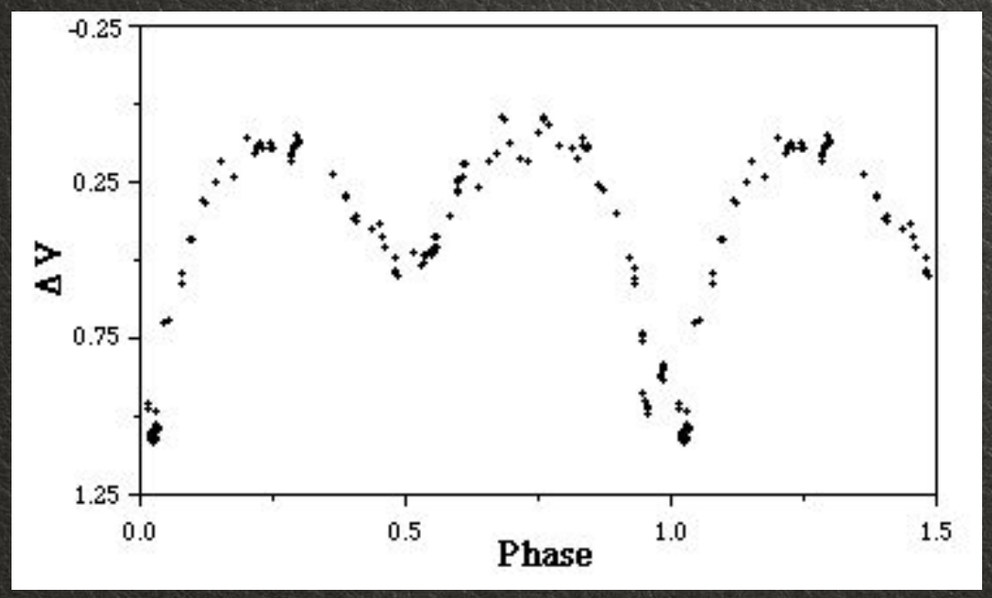


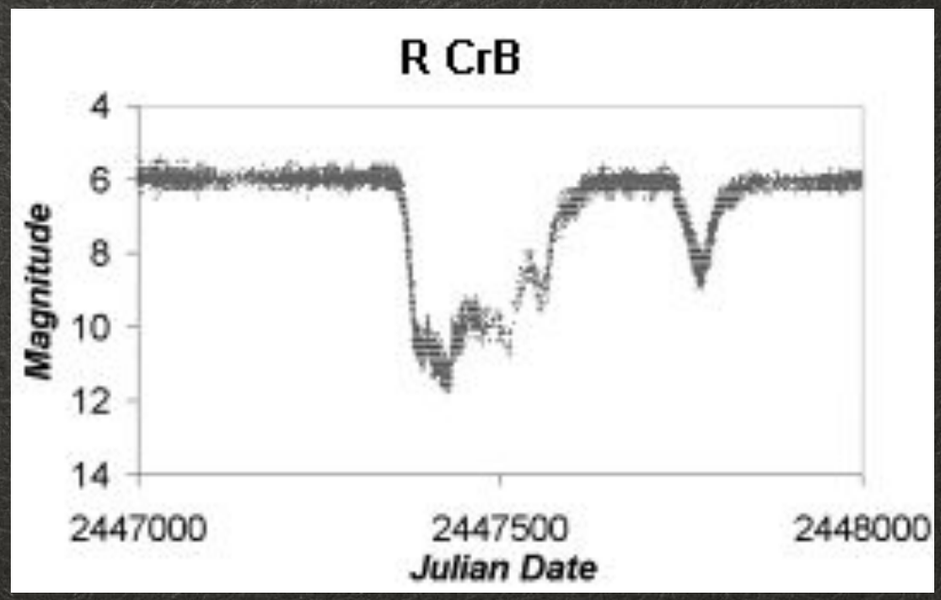




# PROPERTIES OF VARIABLES

- Light curves are used to track the luminosity of a variable star with time.
  - Measure period and amplitude
- Some stars are very regular, while others are irregular.

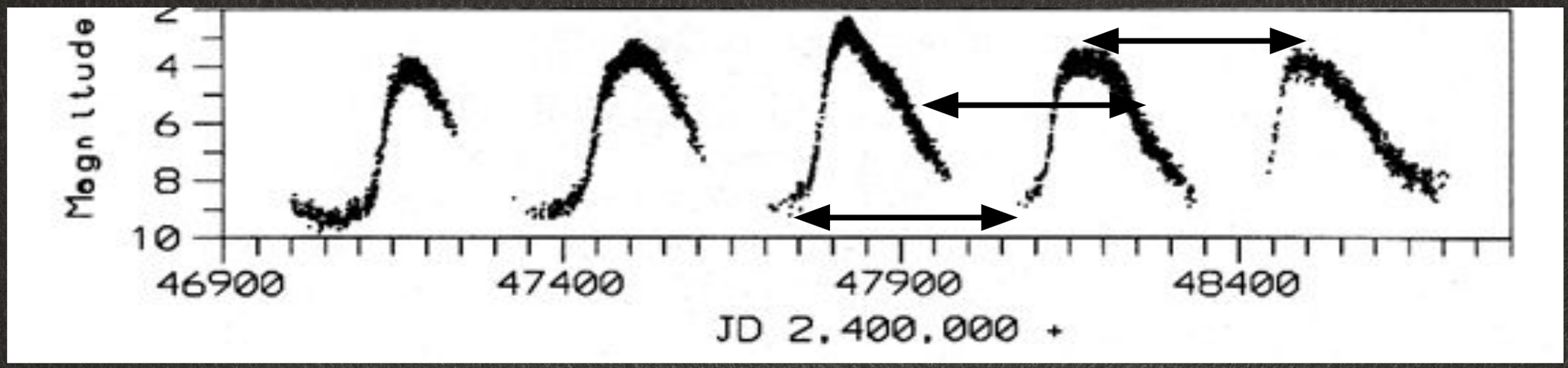


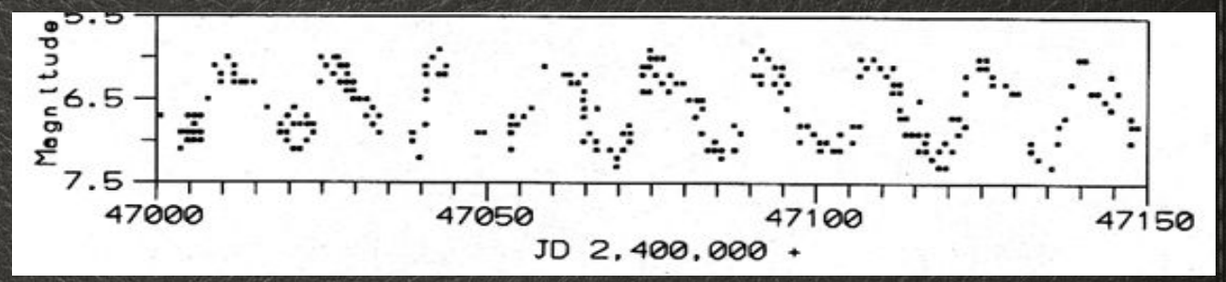
# Light Curves – Variation over Time

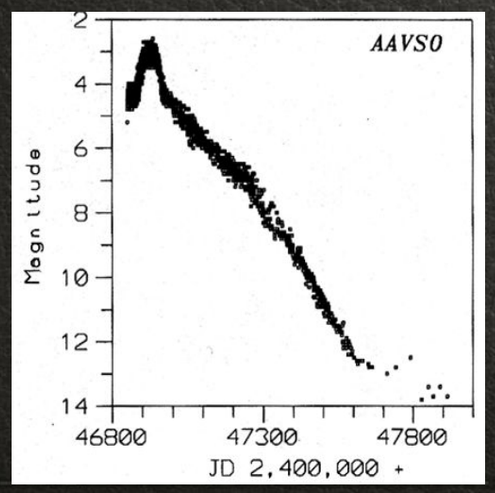
**Maximum (Maxima)**

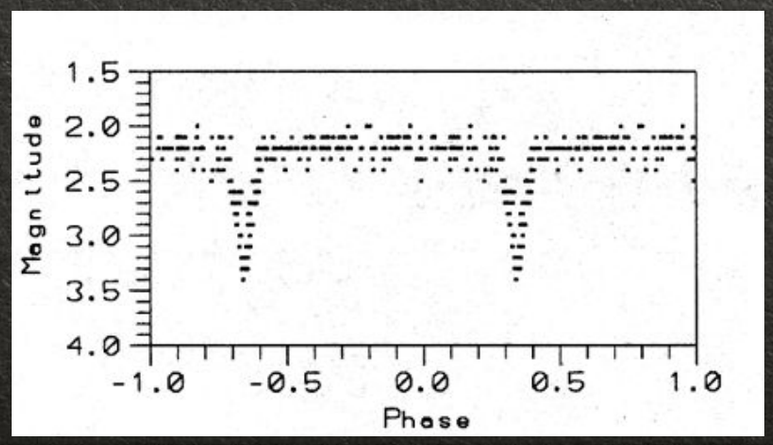
**Minimum (Minima)**

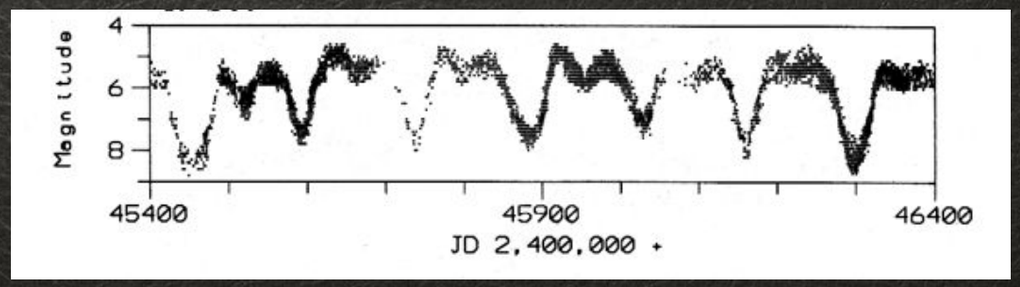



# Apparent Magnitude vs Julian Day

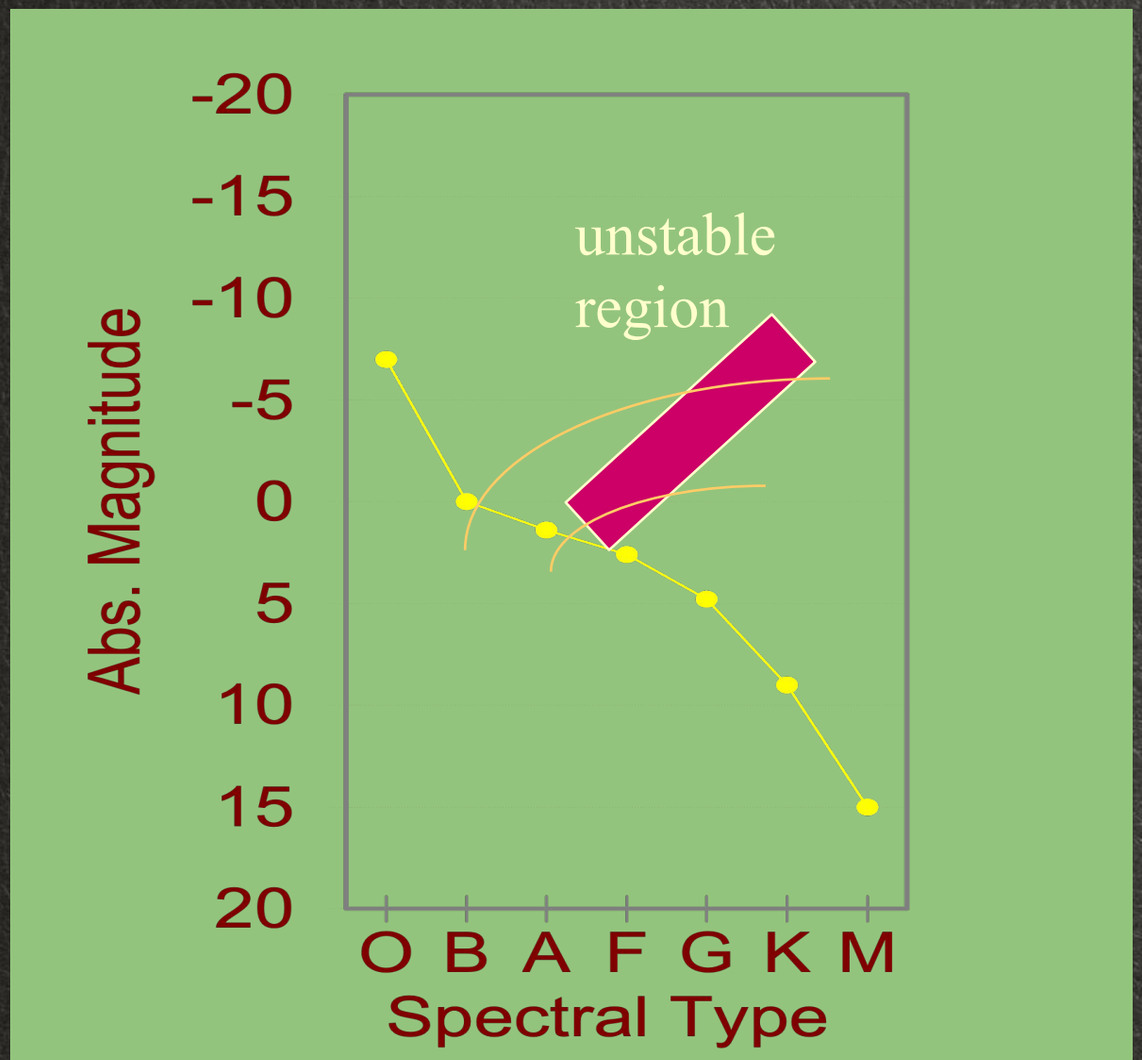



# INTRINSIC VARIABLES




- As giants, stars can become unstable.
- The temperature and luminosity fluctuate as the gas expands and contracts.
- These are *pulsating variables*.

Temperature (Kelvin)

30,000 10,000 5000 3000

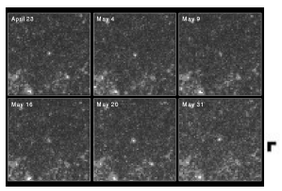
Absolute Magnitude

-10 -5 0 +5 +10 +15

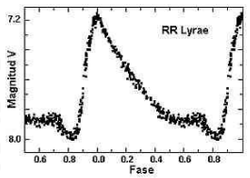
Luminosity (Sun = 1)

10,000 100 1.0 0.01

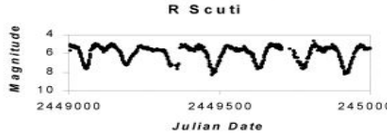
Cepheid Instability Strip



RR Lyrae



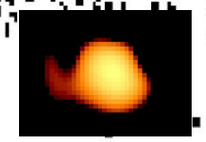

RV Tauri

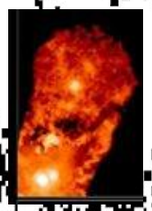



Supergiants

Semiregular

Giants





Mira

Main sequence

T-Tauri

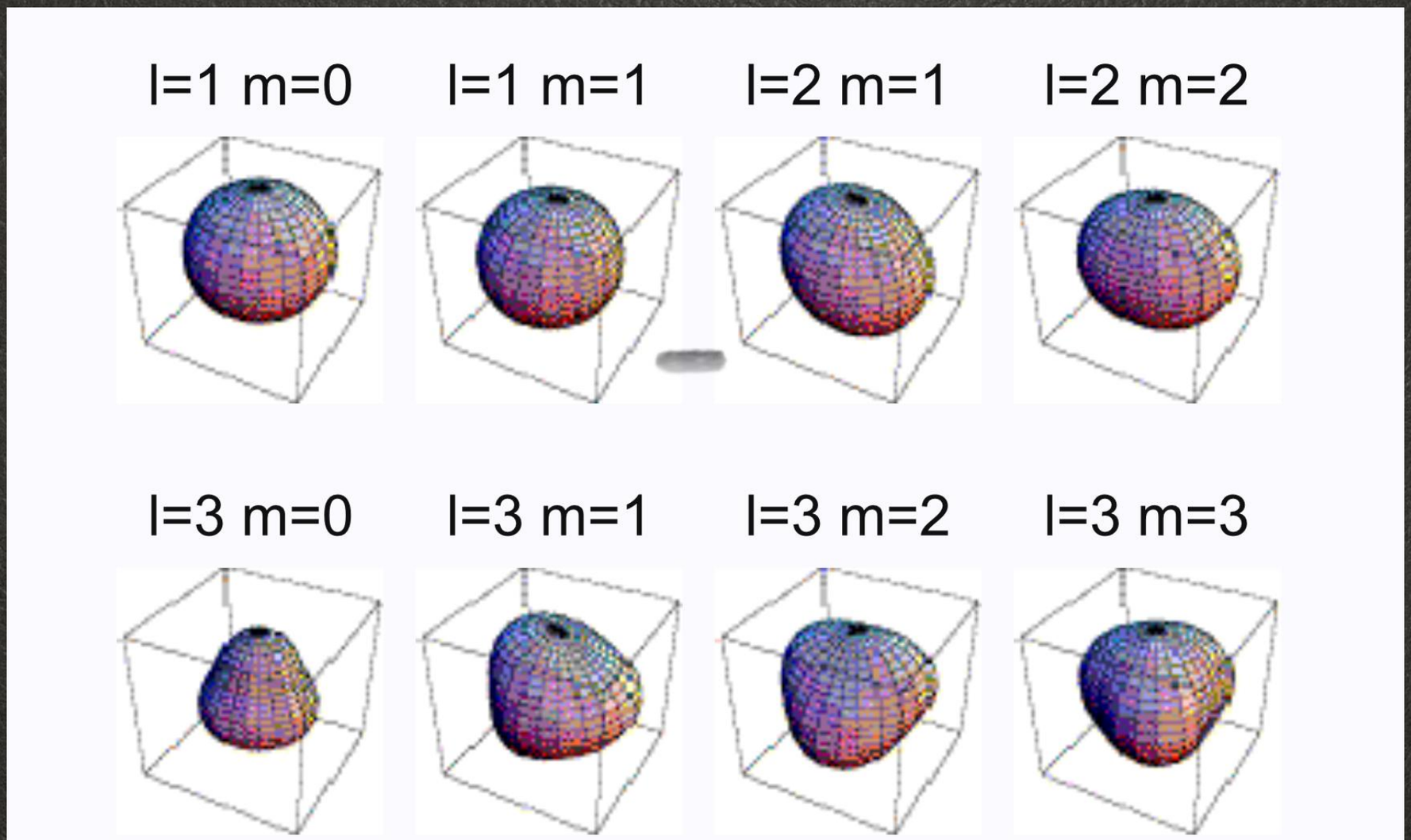
Instability Strip

White dwarfs

O B A F G K M

Spectral Class

# PULSATING VARIABLES
## RADIAL AND NON-RADIAL MOTION



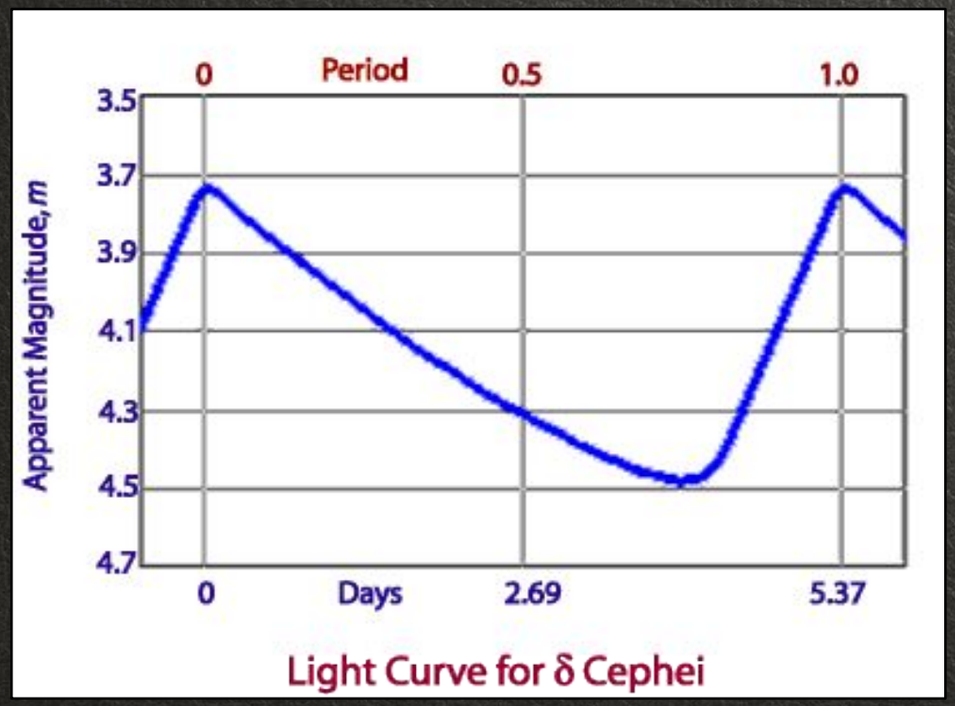
# EXAMPLES OF DIFFERENT TYPES OF PULSATING VARIABLES

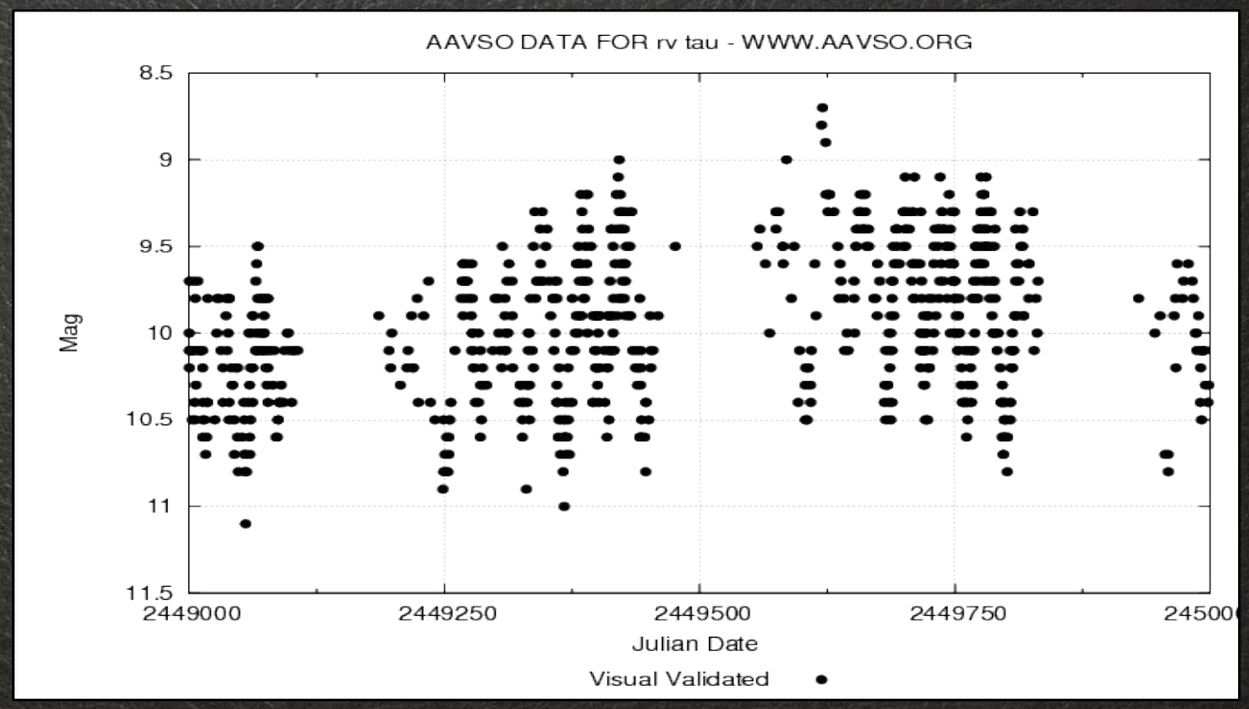
Cepheids Period 1-70 day

Henrietta Leavitt

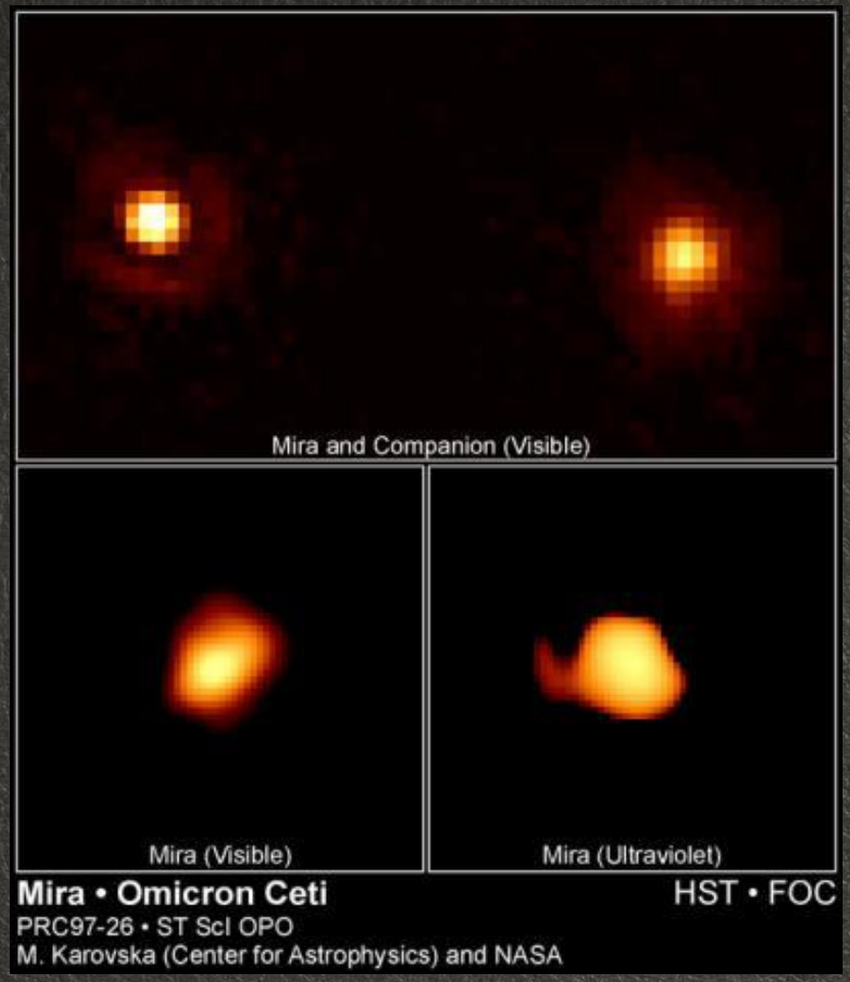
RV Tauri – Period up to 100 days

1000 days

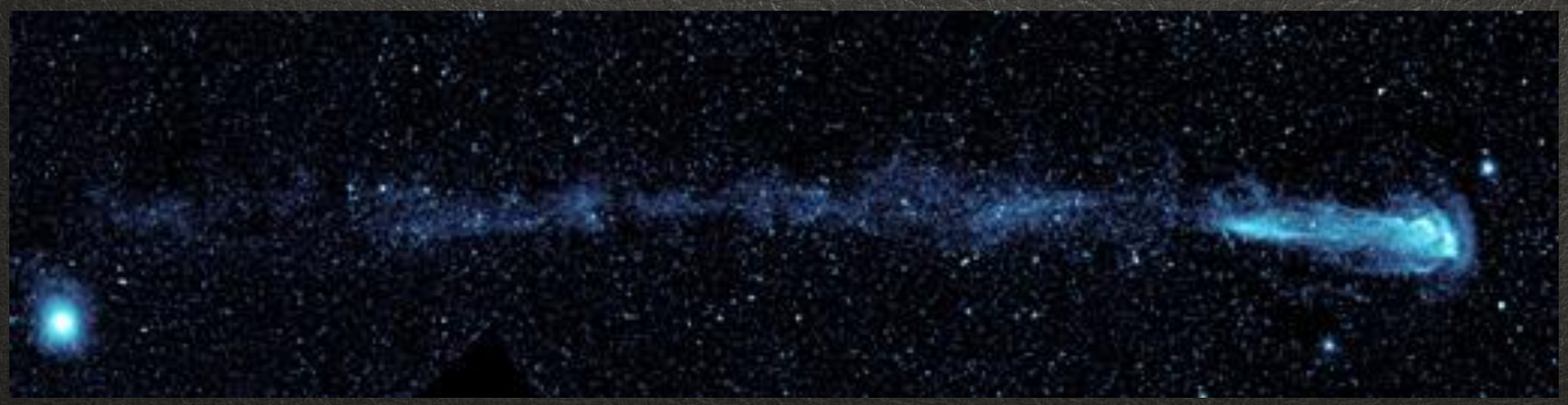


# MIRA, THE "FIRST" LPV, CONTINUES TO AMAZE



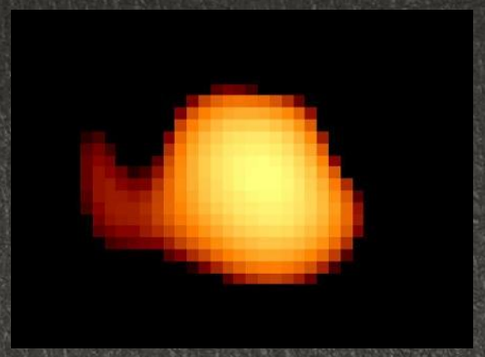

In 1997 Hubble Space Telescope resolved the binary star in Mira, and detected matter either being swept from its surface by its companion or having its atmosphere heated by the companion

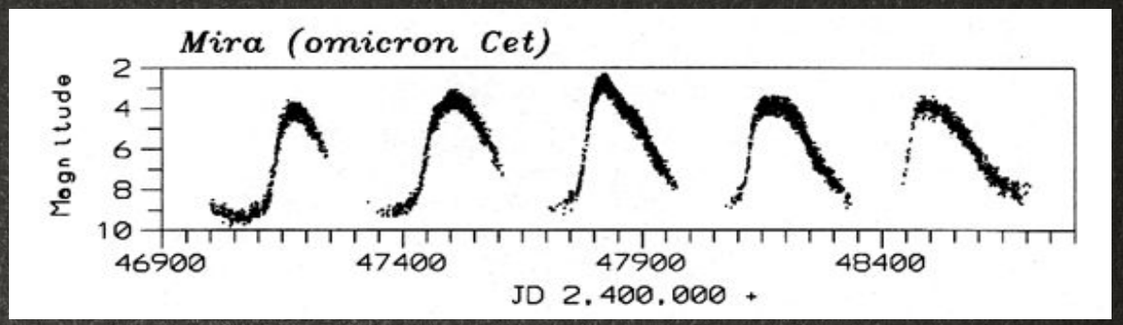


GALEX Ultraviolet Images detected a 13 light-year long "tail" in 2006.

# A. Pulsating Variable Stars;
## 1) Long Period Variables (LPVs)

### a) Miras
### Omicron Ceti (Mira)

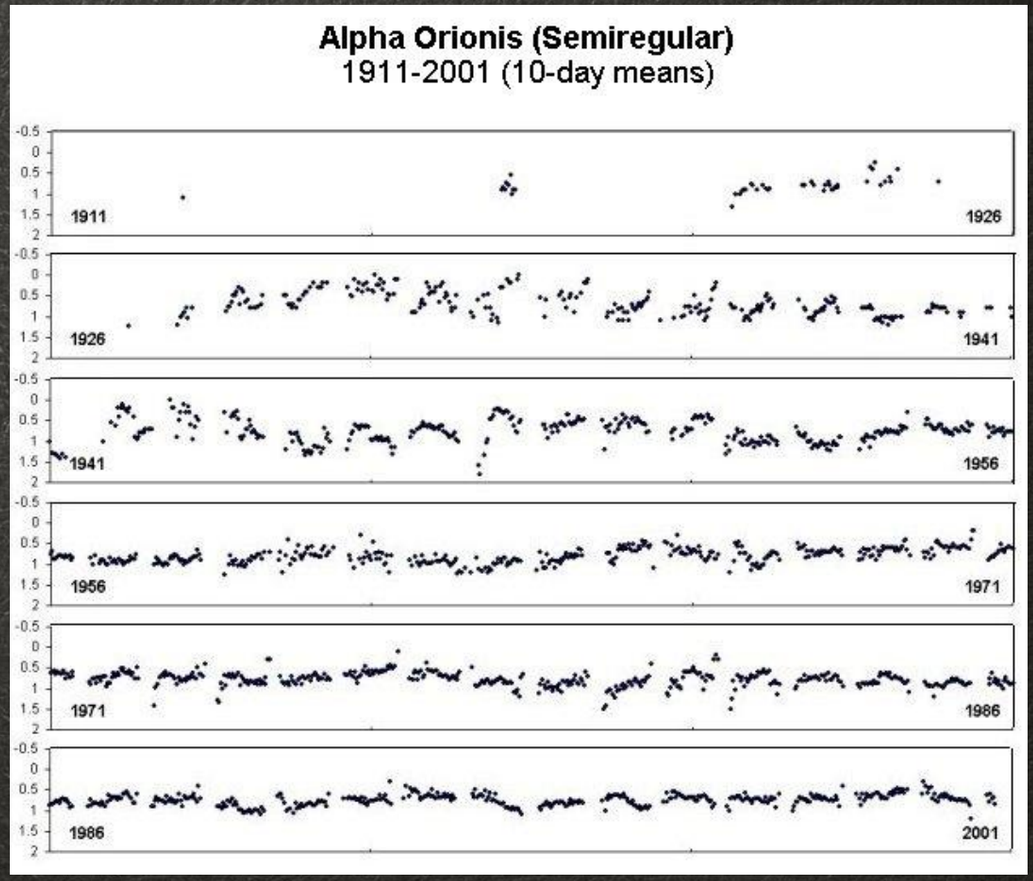





80 – 1000 days, 2.5 – 5.0 mag

### b) Semiregular Variables

### Betelgeuse
### (Alpha Orionis)


30 – 1000 days, 1.0 – 2.0 mag

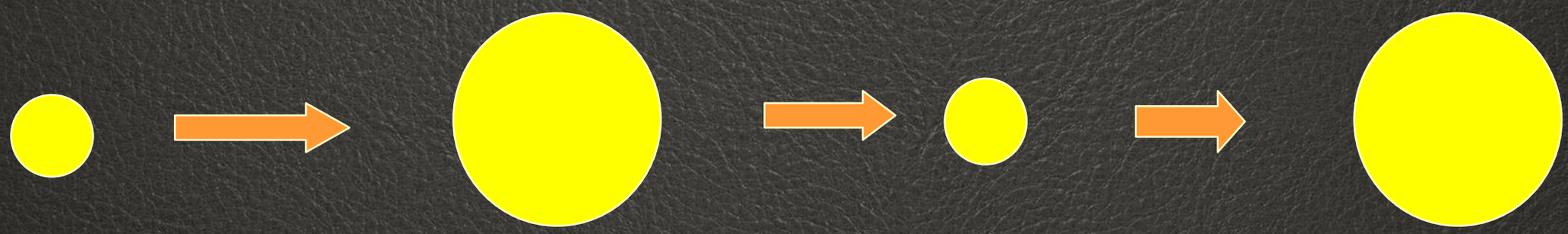
# STANDARD CANDLES

The best measure of large distances are variable stars.

Pressure and radiation precisely oscillate

Luminosity directly related to the period

The apparent magnitude and period give the distance.



Pressure increases as helium heats up

Pressure decreases as helium ionizes and cools

Process repeats

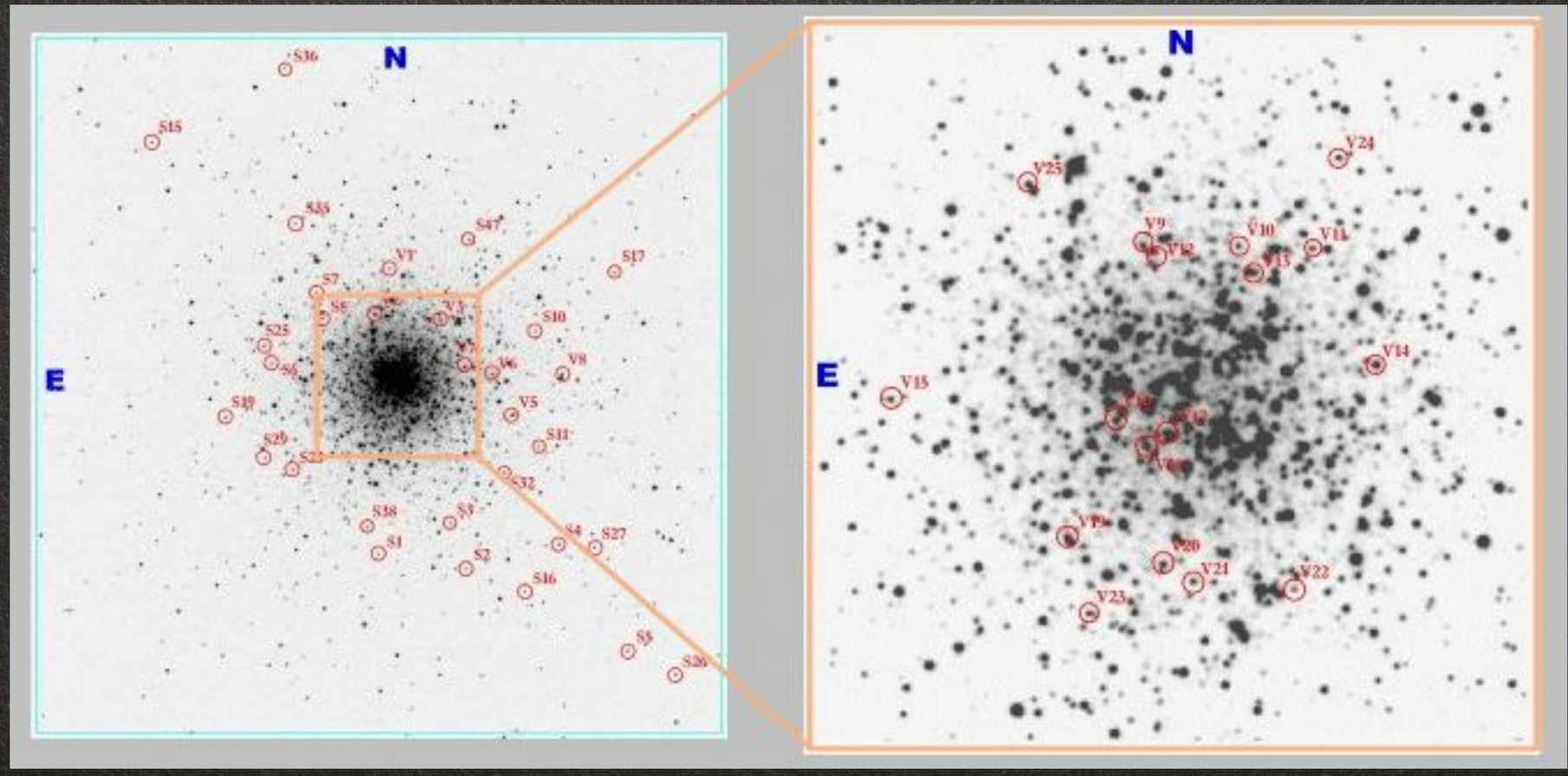
# RR-LYRAE

*RR-Lyrae* stars are low mass pulsating variables.

About 1 $M_{\odot}$

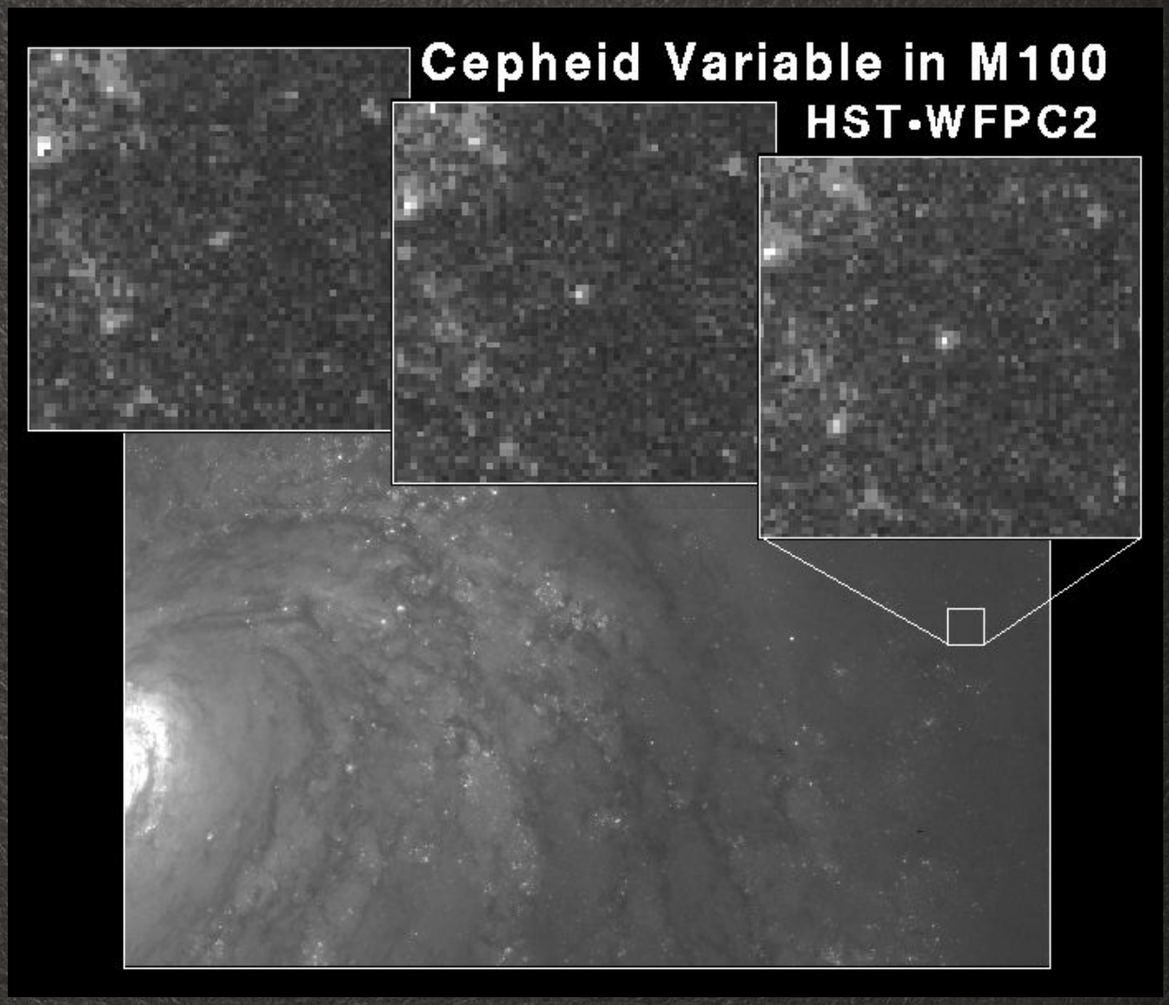
Period less than a day

Used for cluster distances

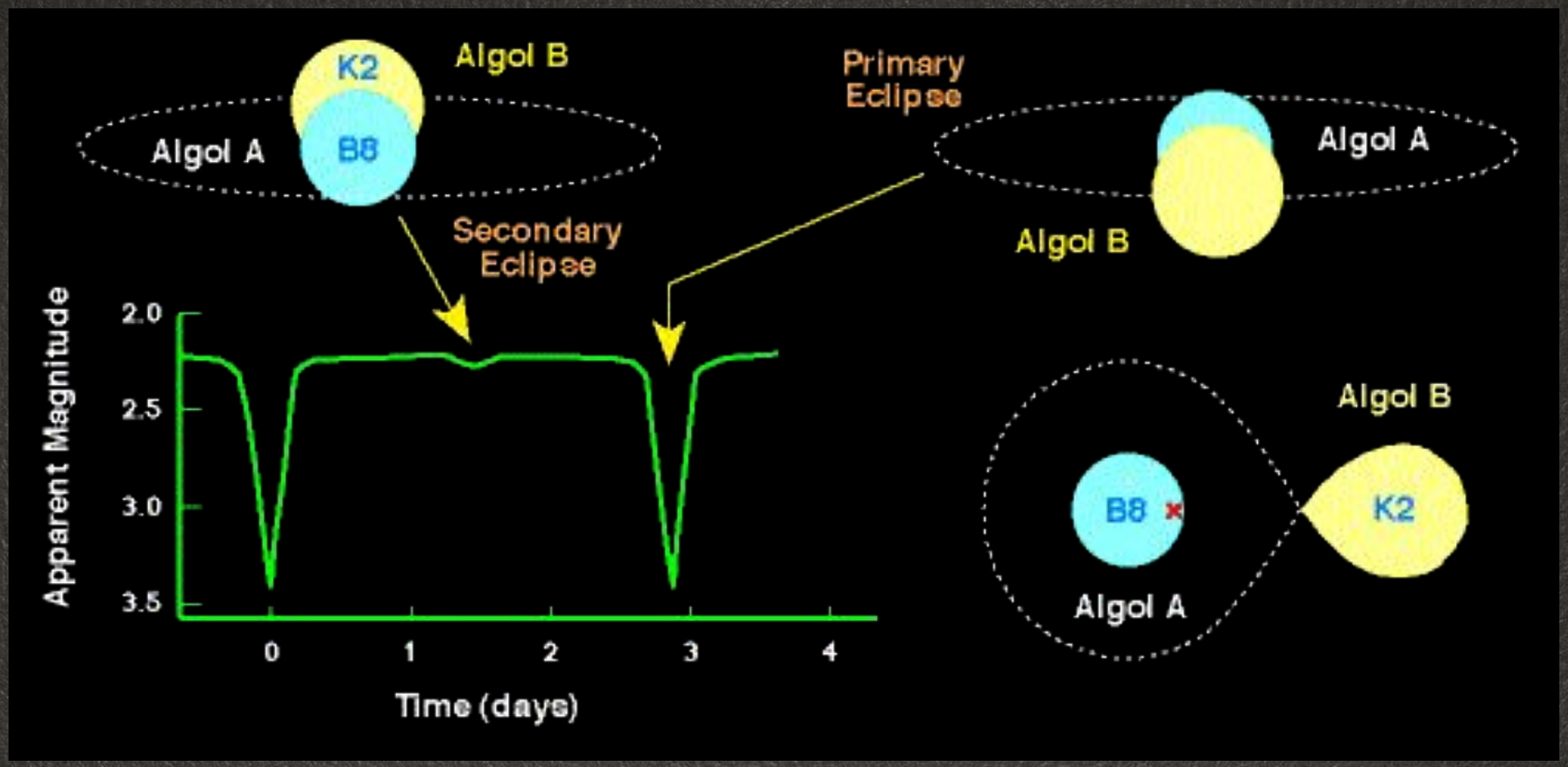


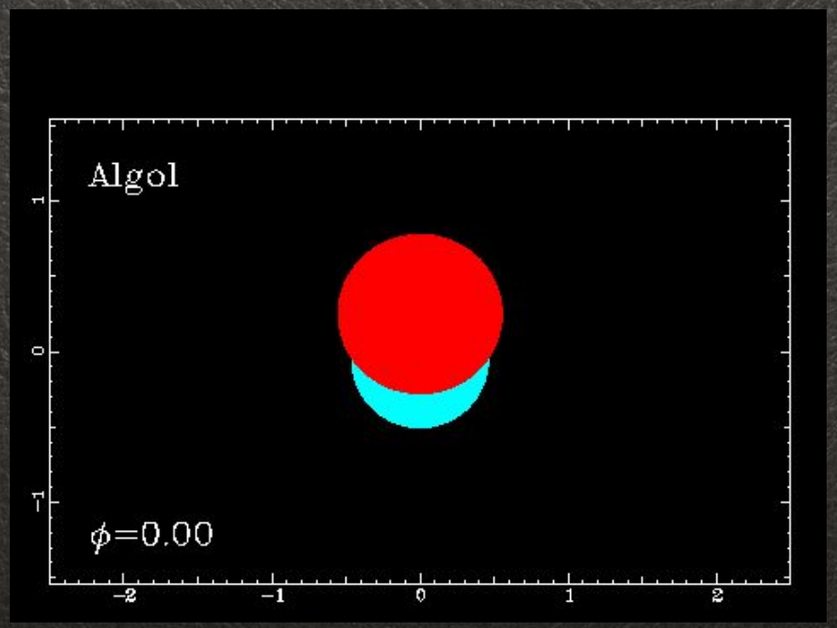
# CEPHEIDS

- Large mass stars that pass through the unstable region are known as *Cepheid variables*.
- From 5 $M_\odot$ to 20 $M_\odot$
- Period of 1 to 100 days
- Cepheids are important to measure distances to other galaxies.
- In star's interior $He^+$ looses $e^- \rightarrow He^{2+}$. As soon the star expands, it becomes brighter and cooler, and $He^{2+} + e^- \rightarrow He^+$.
- And the cycle repeats.

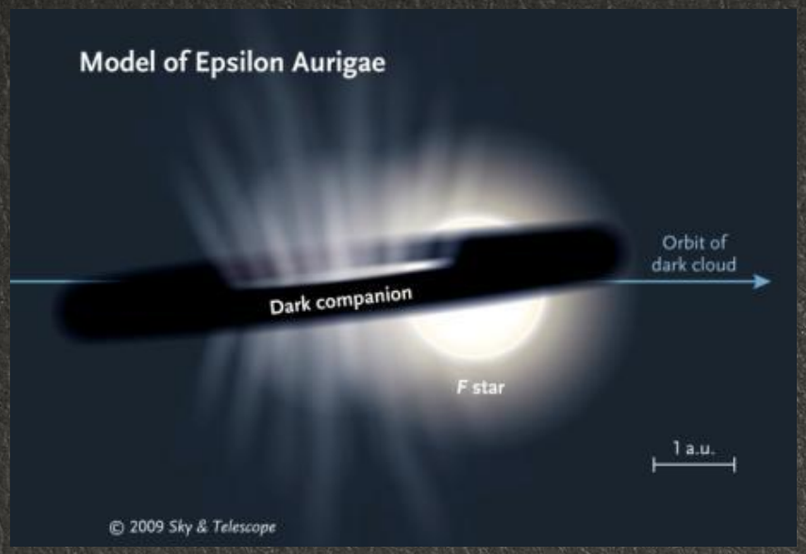


# ECLIPSING BINARIES

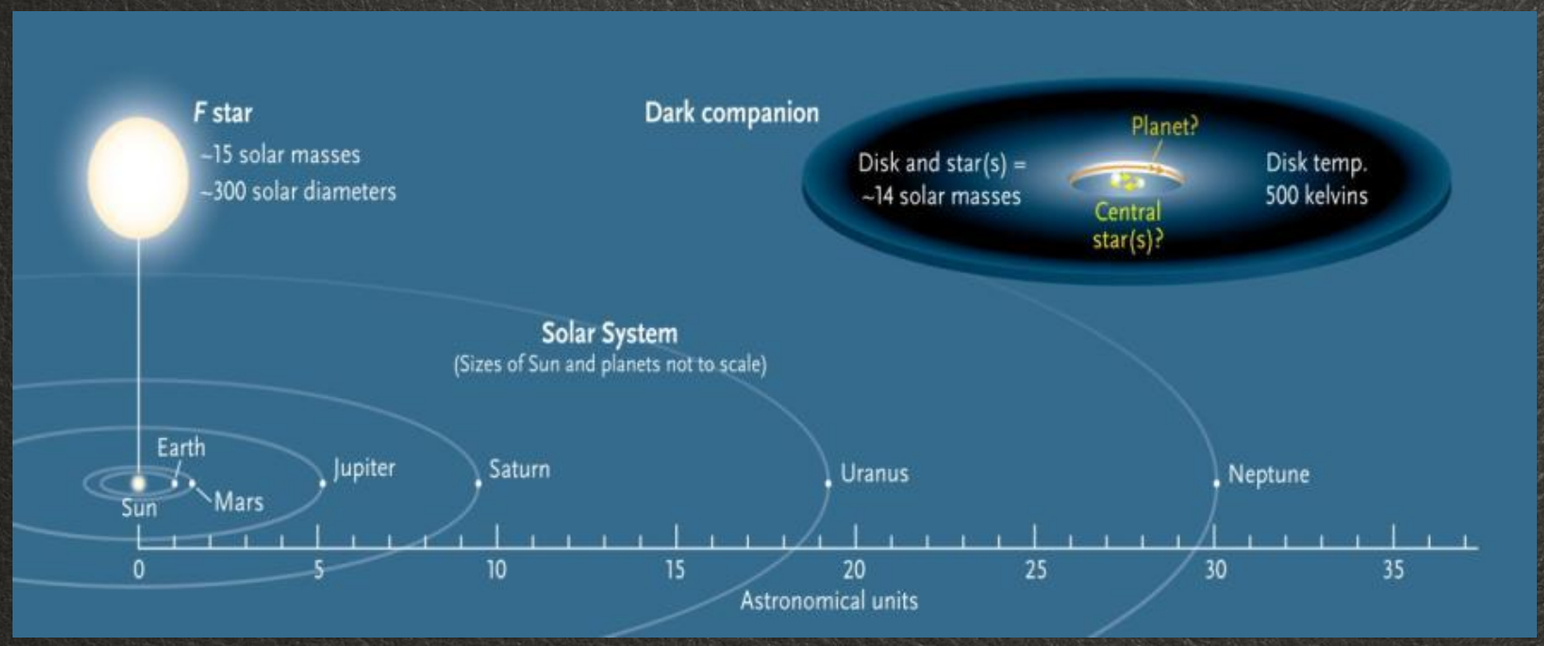


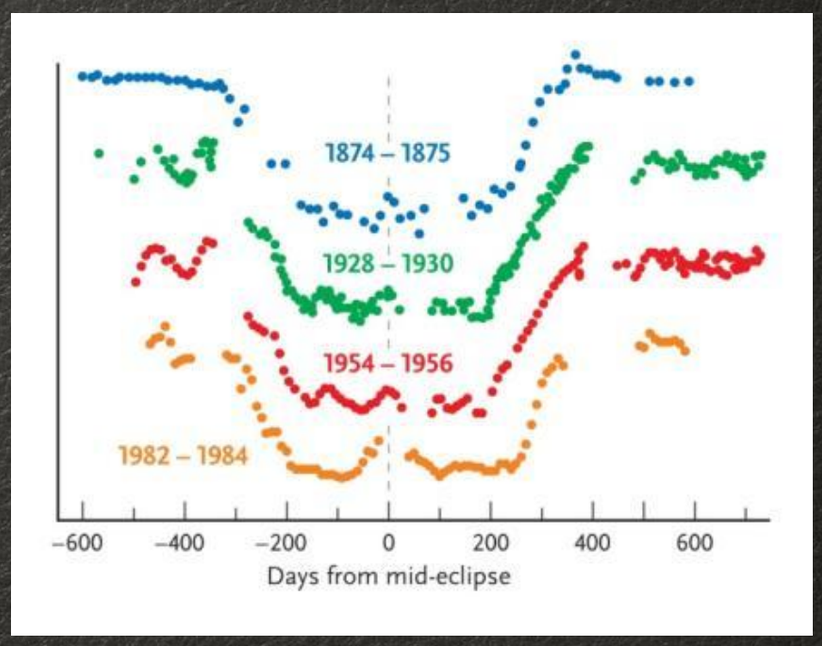



# EPSILON AURIGAE




- Eclipse begins Aug. 11, 2009
- Minimum light begins Dec. 19, 2009
- Mid-eclipse Aug. 4, 2010
- Minimum light ends Mar.19, 2011
- Eclipse ends May 13, 2011



# ERUPTING VARIABLES

Erupting variables are - *stars that have occasional violent outbursts caused by thermonuclear processes either in their surface layers or deep within their interiors*

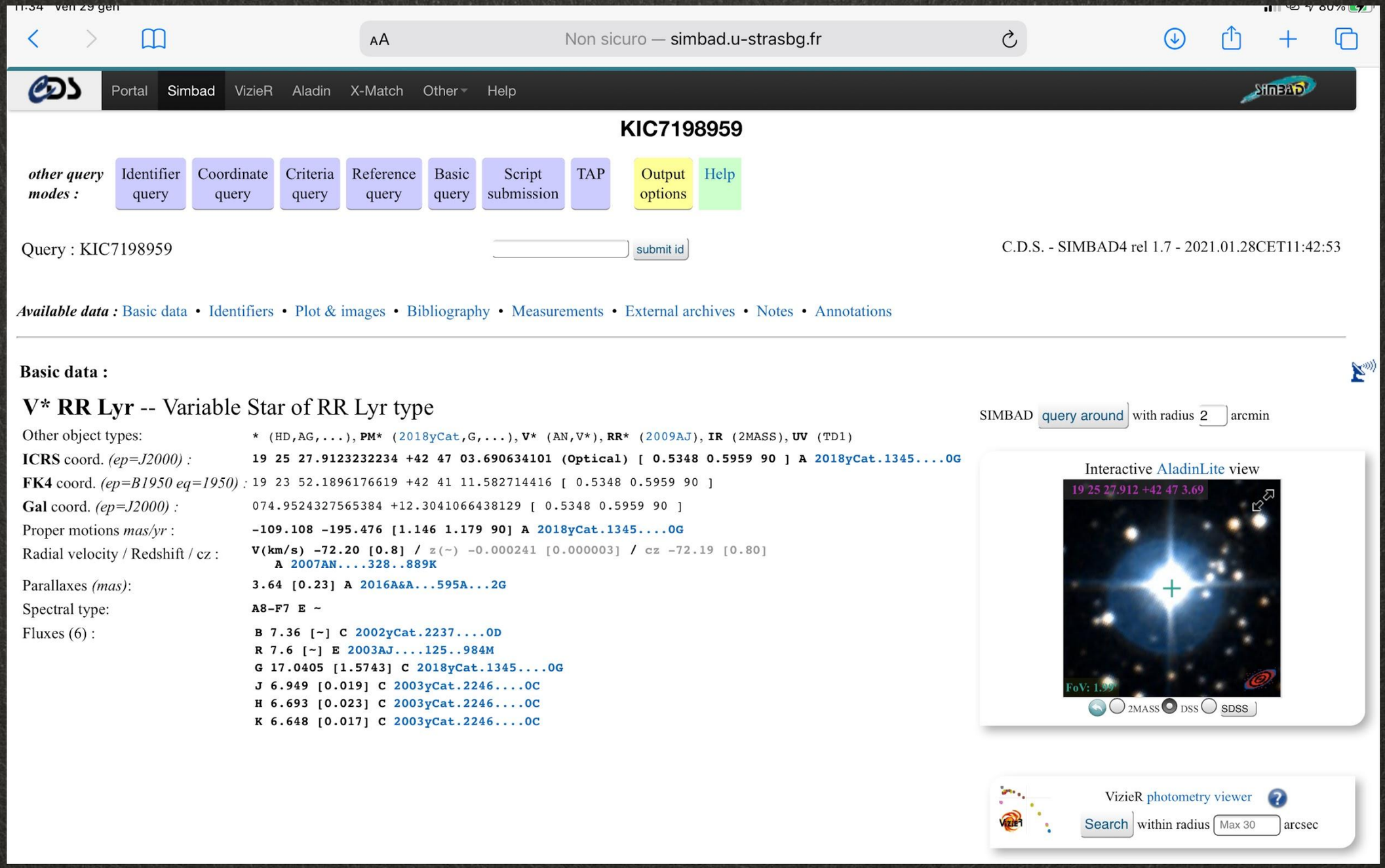
- Major Types
  - Supernovae
  - Recurrent Novae
  - Cataclysmic Variables

# CATACLYSMIC VARIABLES

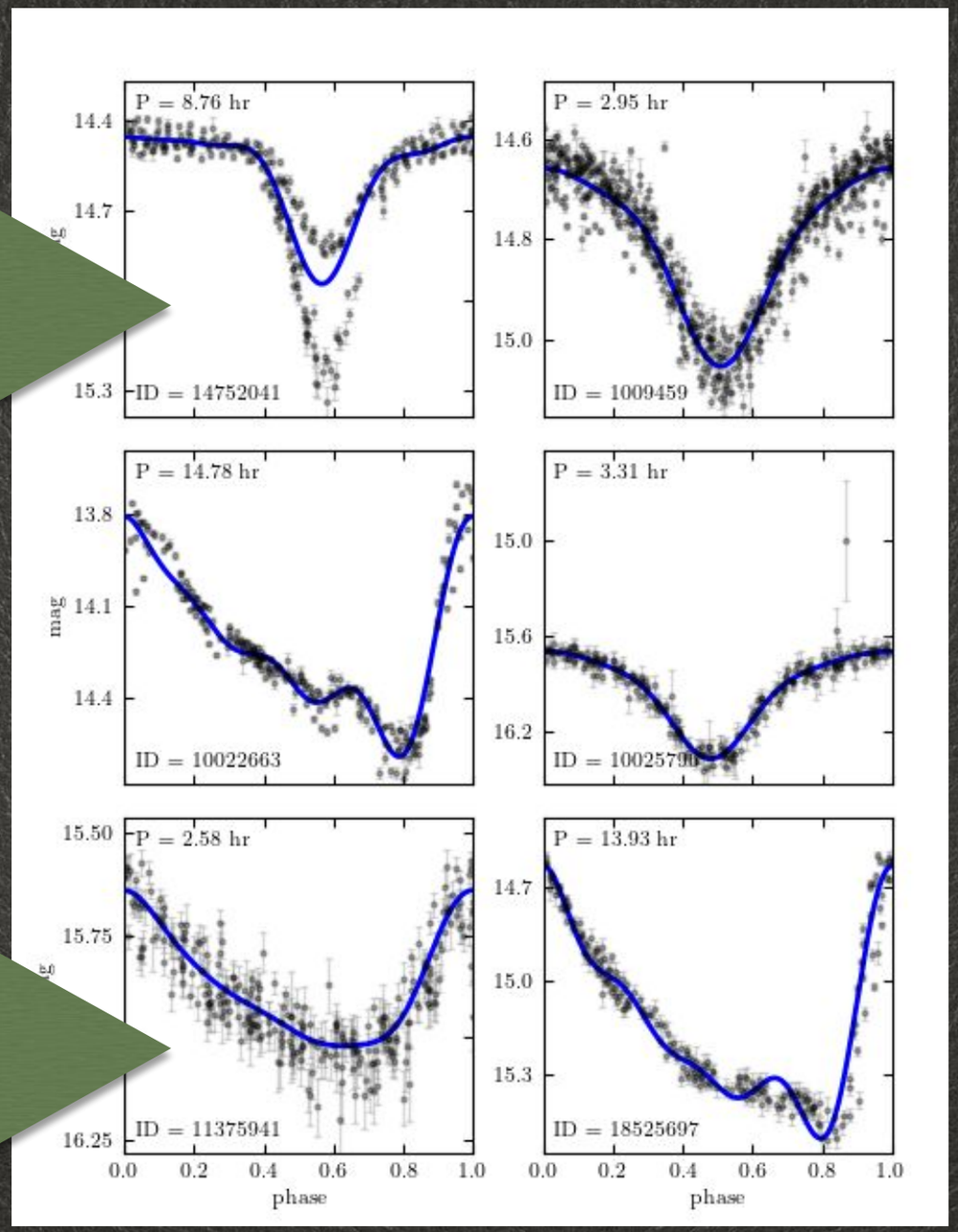
Key Properties:

- Binary Star System
  - Stellar Material Flows from red dwarf star onto accretion disk surrounding white dwarf companion
  - Flow stops and starts
  - Orbital period 78 minutes up to around 10 hours
  - "Hot spot" where stream hits accretion disk is often hotter and brighter than either star

# Notebook: Kepler



# Notebook: LINEAR



# REFERENCES AND DEEPENING

Lovro Palaversa

EXPLORING THE VARIABLE SKY WITH LINEAR. III. CLASSIFICATION OF PERIODIC LIGHT CURVES


Lovro Palaversa[1], Željko Ivezić[2,3,4], Laurent Eyer[1], Domagoj Ružđjak[4], Davor Sudar[4], Mario Galin[5], Andrea Kroflin[3], Martina Mesarić[3], Petra Munk[3], Dijana Vrbanec[3], Hrvoje Božić[4], Sarah Loebman[2], Branimir Sesar[6], Lorenzo Rimoldini[1,7], Nicholas Hunt-Walker[2], Jacob VanderPlas[2], David Westman[2], J. Scott Stuart[8], Andrew C. Becker[2], Gregor Srdoč[9], Przemyslaw Wozniak[10], and Hakeem Oluseyi[11]

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## ABSTRACT

We describe the construction of a highly reliable sample of ∼7000 optically faint periodic variable stars with light curves obtained by the asteroid survey LINEAR across 10,000 deg$^2$ of the northern sky. The majority of these variables have not been cataloged yet. The sample flux limit is several magnitudes fainter than most other wide-angle surveys; the photometric errors range from ∼0.03 mag at $r = 15$ to ∼0.20 mag at $r = 18$. Light curves include on average 250 data points, collected over about a decade. Using Sloan Digital Sky Survey (SDSS) based photometric recalibration of the LINEAR data for about 25 million objects, we selected ∼200,000 most probable candidate variables with $r < 17$ and visually confirmed and classified ∼7000 periodic variables using phased light curves. The reliability and uniformity of visual classification across eight human classifiers was calibrated and tested using a catalog of variable stars from the SDSS Stripe 82 region and verified using an unsupervised machine learning approach. The resulting sample of periodic LINEAR variables is dominated by 3900 RR Lyrae stars and 2700 eclipsing binary stars of all subtypes and includes small fractions of relatively rare populations such as asymptotic giant branch stars and SX Phoenicis stars. We discuss the distribution of these mostly uncataloged variables in various diagrams constructed with optical-to-infrared SDSS, Two Micron All Sky Survey, and *Wide-field Infrared Survey Explorer* photometry, and with LINEAR light-curve features. We find that the combination of light-curve features and colors enables classification schemes much more powerful than when colors or light curves are each used separately. An interesting side result is a robust and precise quantitative description of a strong correlation between the light-curve period and color/spectral type for close and contact eclipsing binary stars ($\beta$ Lyrae and W UMa): as the color-based spectral type varies from K4 to F5, the median period increases from 5.9 hr to 8.8 hr. These large samples of robustly classified variable stars will enable detailed statistical studies of the Galactic structure and physics of binary and other stars and we make these samples publicly available.



*Key words:* binaries: eclipsing – blue stragglers – catalogs – Galaxy: halo – stars: statistics – stars: variables: general