Light curve modeling of eclipsing binary stars

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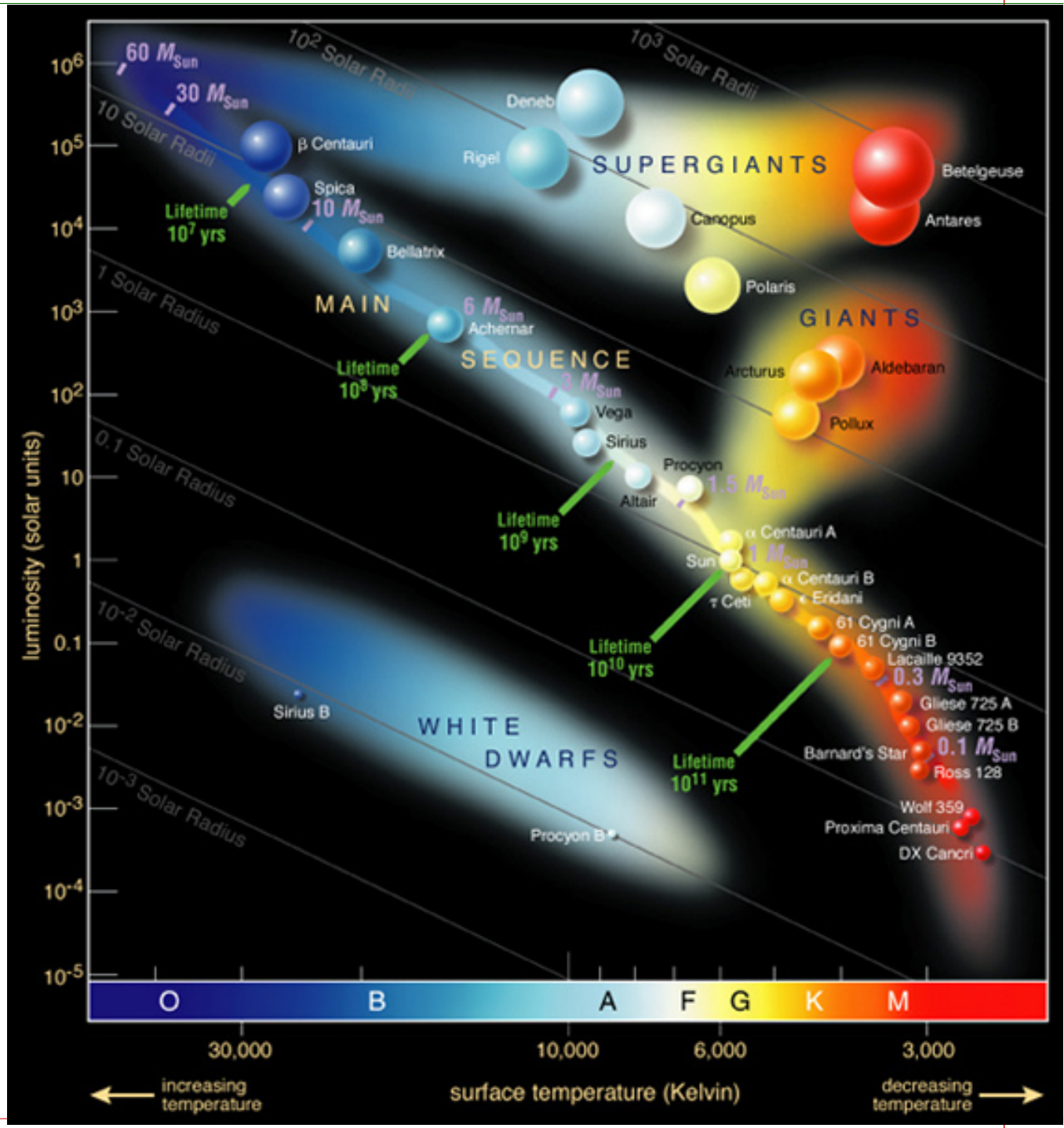
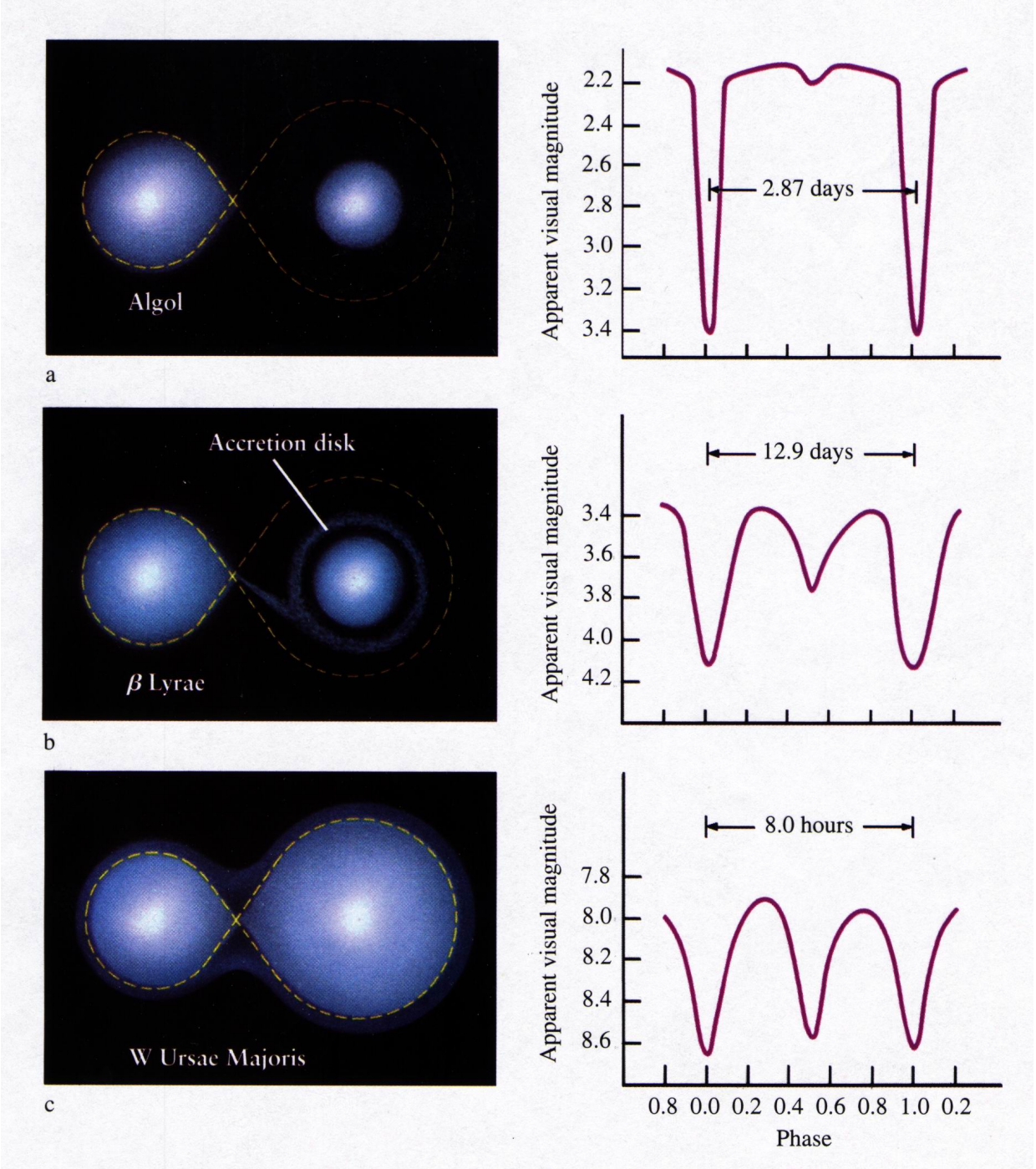
Binary stars

- physical variables
  - pulsating stars
  - mass, radius, temperature
- optical variables
  - binary stars (↔ visual binaries)
  - multiple stellar systems
  - (exoplanets)



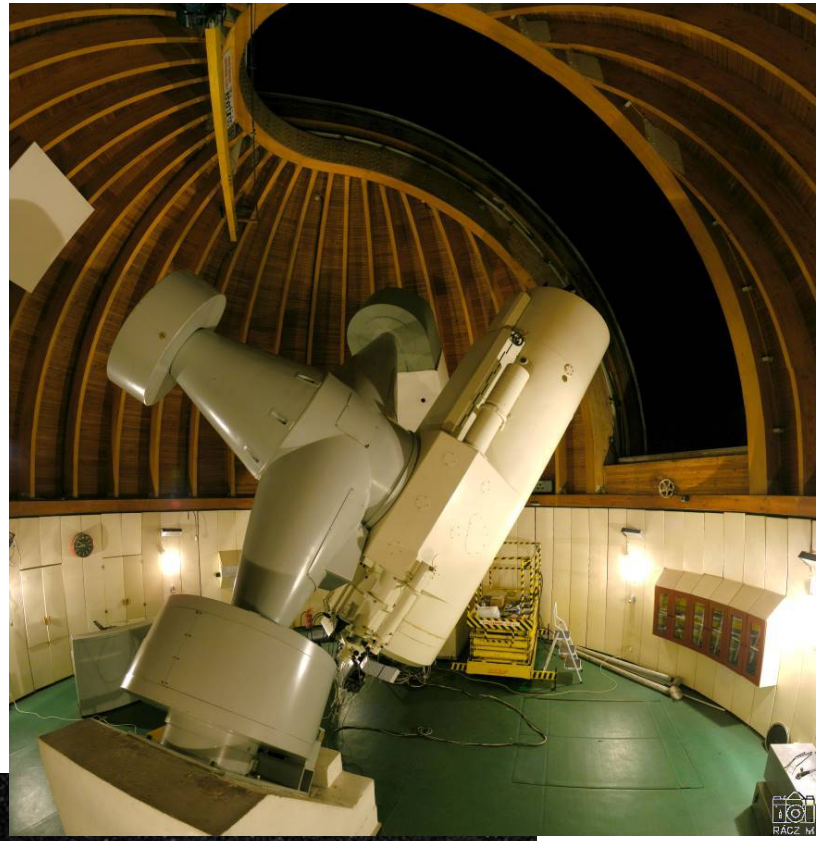
Binary stars

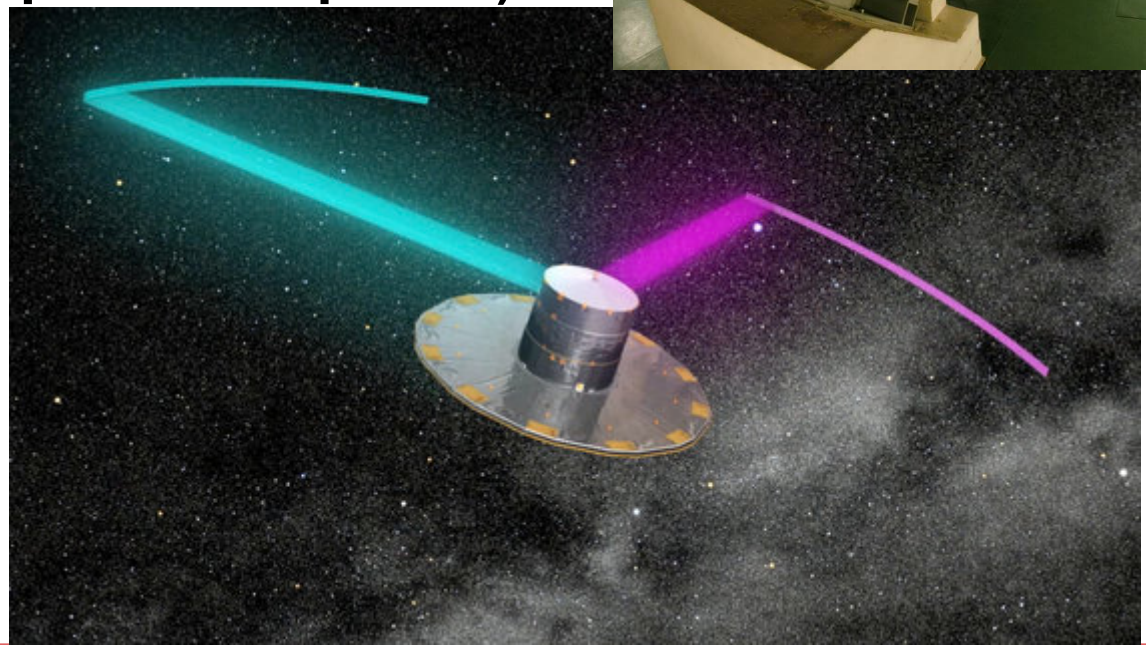
- primary
  - star, minimum
- secondary
  - star, minimum
- orbits
  - circular
  - eccentric
- distance
  - close
  - detached
  - semi-detached
- physical parameters
  - mass, radius, temperature



Observing binaries

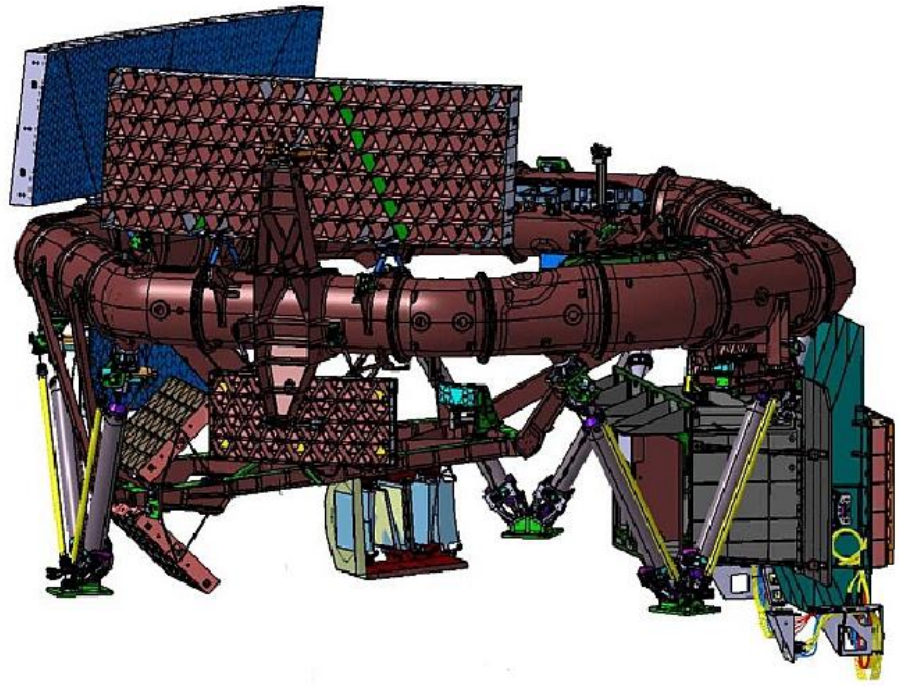
- ground based observations
  - MTA CSFK KTM CSI – Piszkéstető
  - ELTE GAO - Szombathely
- space missions
  - GAIA (petabytes of data during 5 years operational period)
  - Kepler (K2)
  - CoRoT





Observing and modeling binaries

- there are a lot of space missions
- there are a lot of binary and multiple system
- → we get a lot of data
- this requires automated light curve modelling and analysing packages
  - Phoebe (Wilson-Devinney code)
  - binary → multiple systems
  - paralelization (CPU, GPU).



Complex Analysis of Today's and Future Space Photometry of Multiple Stellar and Planetary Systems

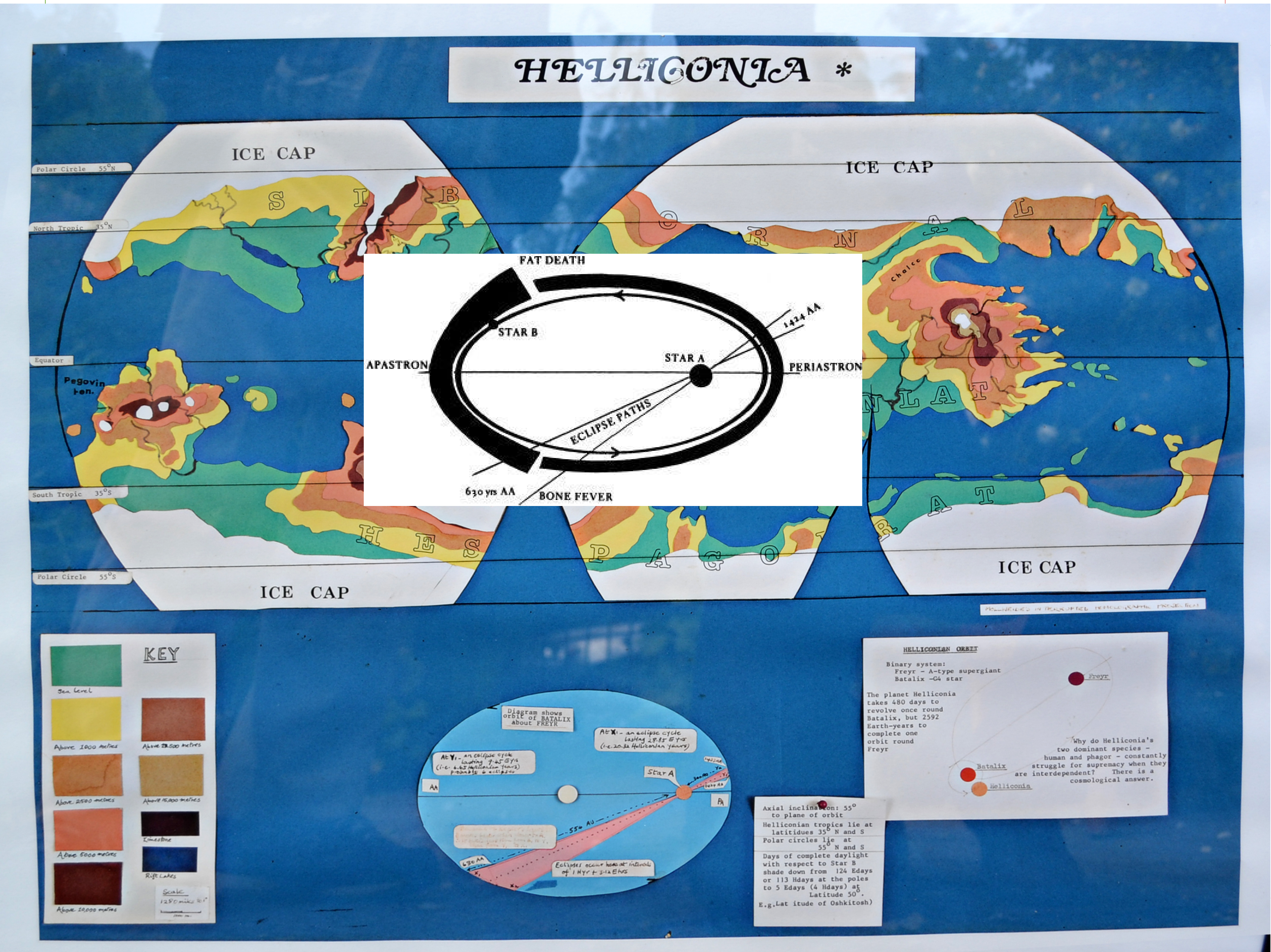
- PI: Dr. Tamás Borkovits
  - 15 years development (binary and triple stellar systems)
- Dr. Emese Forgács-Dajka, senior researcher
  - N-body on GPU, CPU/GPU development
- János Sztakovics
  - the next speaker, will talk about *Fast determination of some orbital elements of eclipsing binary stars on GP*
- Tamás Hajdú
  - will talk about *Eclipse Timing Variation analysis of binary stars with CUDA*

Modelling binary stellar systems

- Now we have Tamás Borkovits's code for modelling binary and triple stellar systems
  - We would like to
    - refine some parts of it
    - change some algorithms for more accurate ones
    - standardize, modularize the different parts of the code for mutual interoperability
    - accelerate computation by means of GPU paralelization
    - involving multiple stellar systems and exoplanet systems also

Modelling binary stellar systems

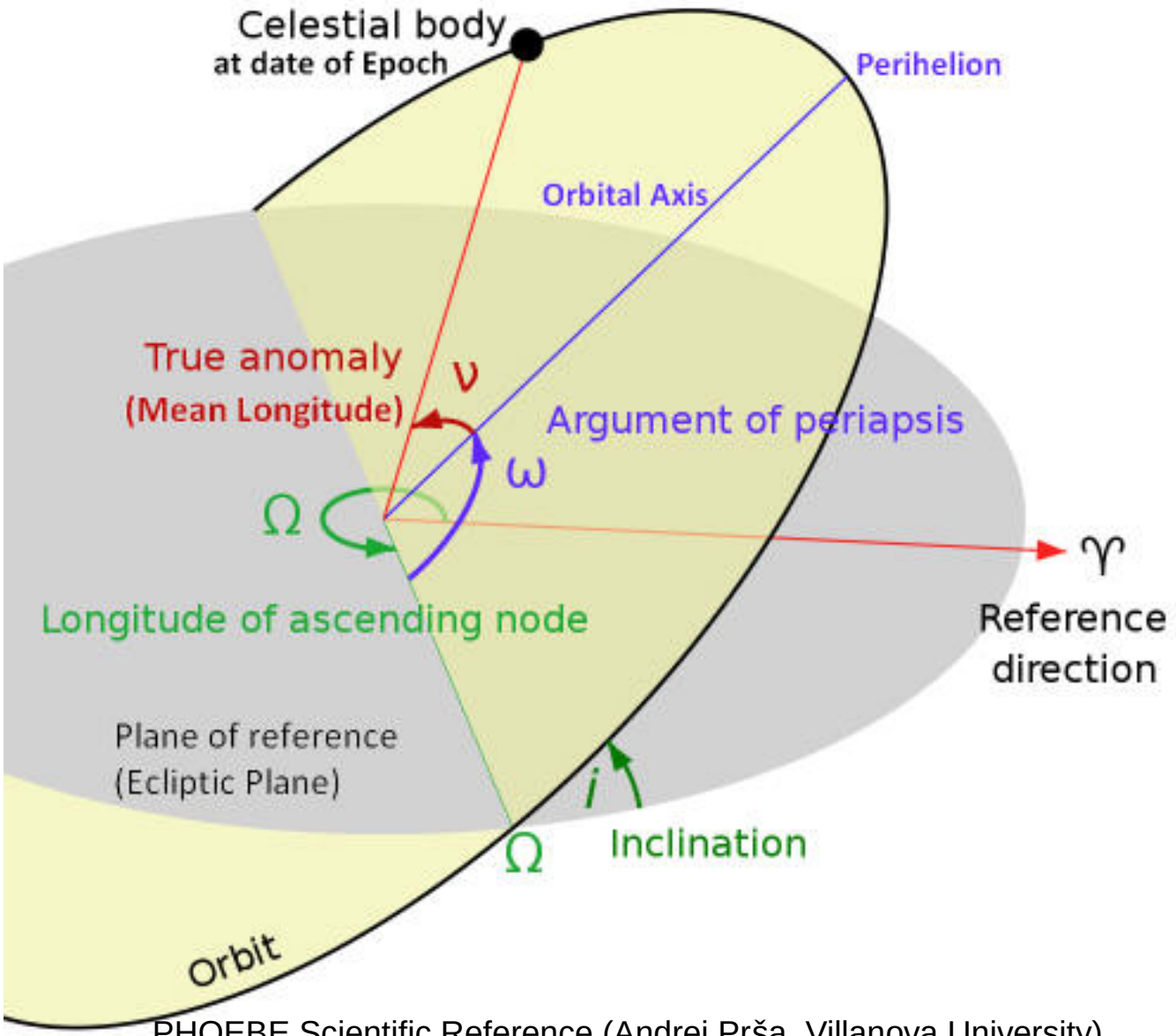
- Why it is useful to modelling binary and multiple stellar systems?
  - to determine the stars' physical parameters
    - masses (generally only an upper limit of them)
  - potential field → inner structure of the star
    - star evolution
  - orbital elements (like as semi-major axis) and stellar type define the habitable zone



HELLICONIA *
ICE CAP
Polar Circle 55°N
North Tropic 35°N
Equator
South Tropic 35°S
Polar Circle 55°S
Pegovin Fen.
Chalce
FAT DEATH
STAR B
APASTRON
STAR A
PERIASTRON
1424 AA
ECLIPSE PATHS
630 yrs AA
BONE FEVER
KEY
Sea Level
Rift Lakes
Diagram shows orbit of BATALIX about FREYR
Star A
HELLICONIAN ORBIT
Binary system:
Freyr - A-type supergiant
Batalix -G4 star
The planet Helliconia takes 480 days to revolve once round Batalix, but 2592 Earth-years to complete one orbit round Freyr
Freyr
Batalix
Helliconia
Why do Helliconia's two dominant species - human and phagor - constantly struggle for supremacy when they are interdependent? There is a cosmological answer.
Axial inclination: 55° to plane of orbit
Helliconian tropics lie at latitidues 35° N and S
Polar circles lie at 55° N and S
Days of complete daylight with respect to Star B shade down from 124 Edays or 113 Hdays at the poles to 5 Edays (4 Hdays) at Latitude 50°.
E.g.Lat itude of Oshkitosh)

Orbital elements

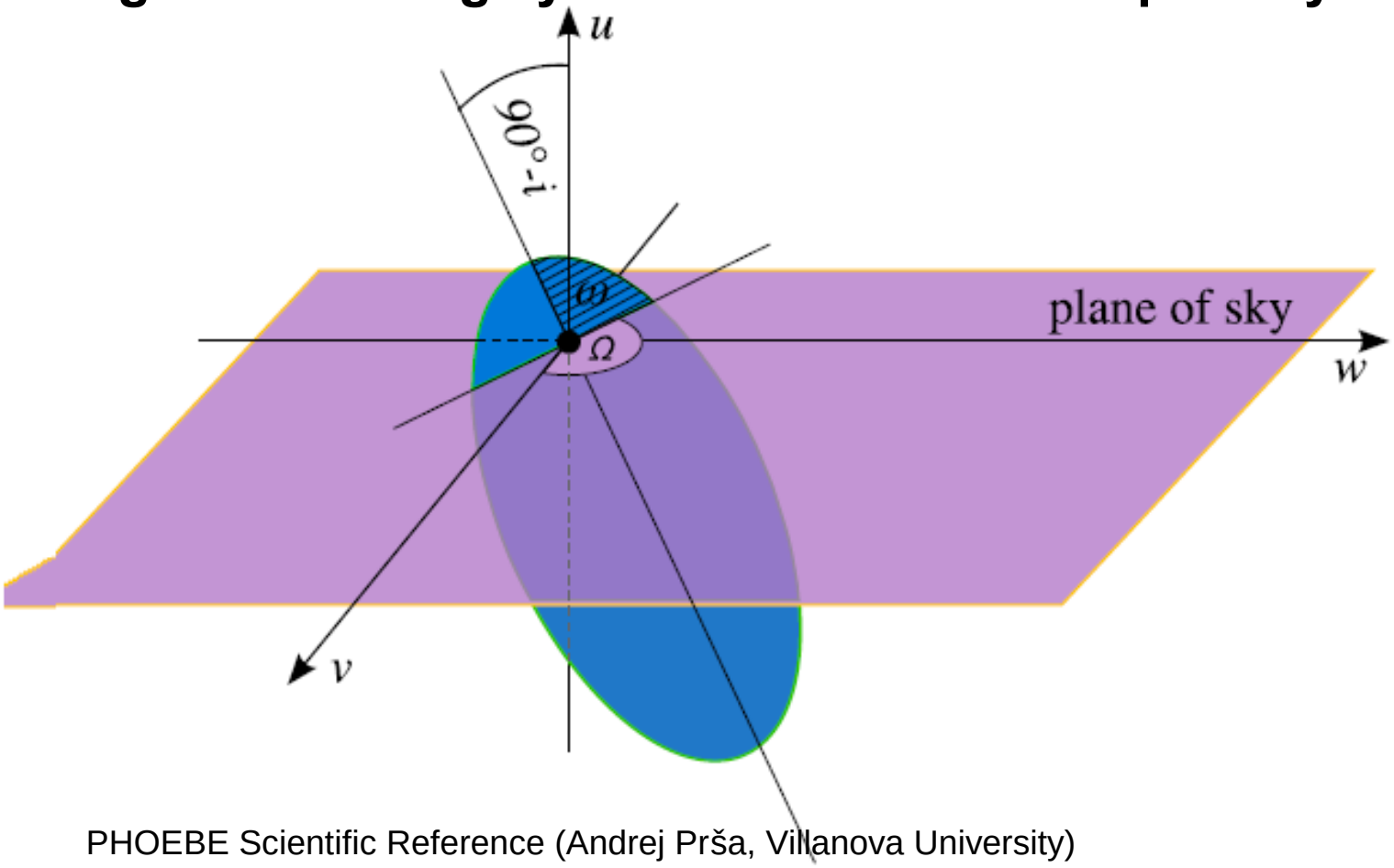
- Initial parameters:
  - orbital parameters
    - eccentricity
    - semi-major axis
    - inclination
    - argument of pericentre
    - longitude of ascending node
    - time of periastron passage
  - stellar parameters
    - radius, mass
    - effective temperature → Stephan-Boltzmann law → flux



PHOEBE Scientific Reference (Andrej Prša, Villanova University)

Orbital parameters

- **stellar positions are calculated by solving Kepler equation with Newton-Raphson method**
- **we using a co-rotating system in the center the primary star**



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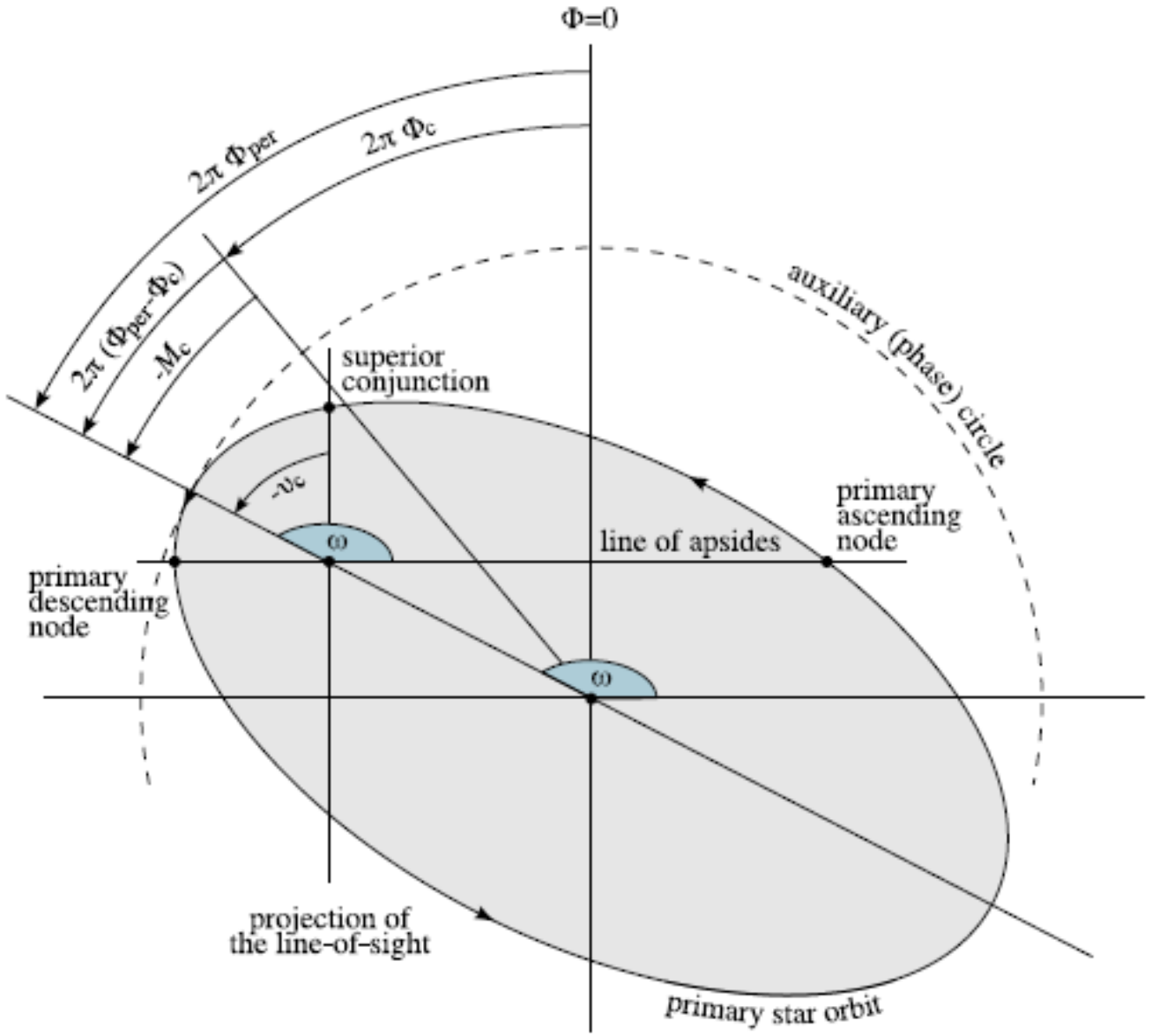
Orbital parameters



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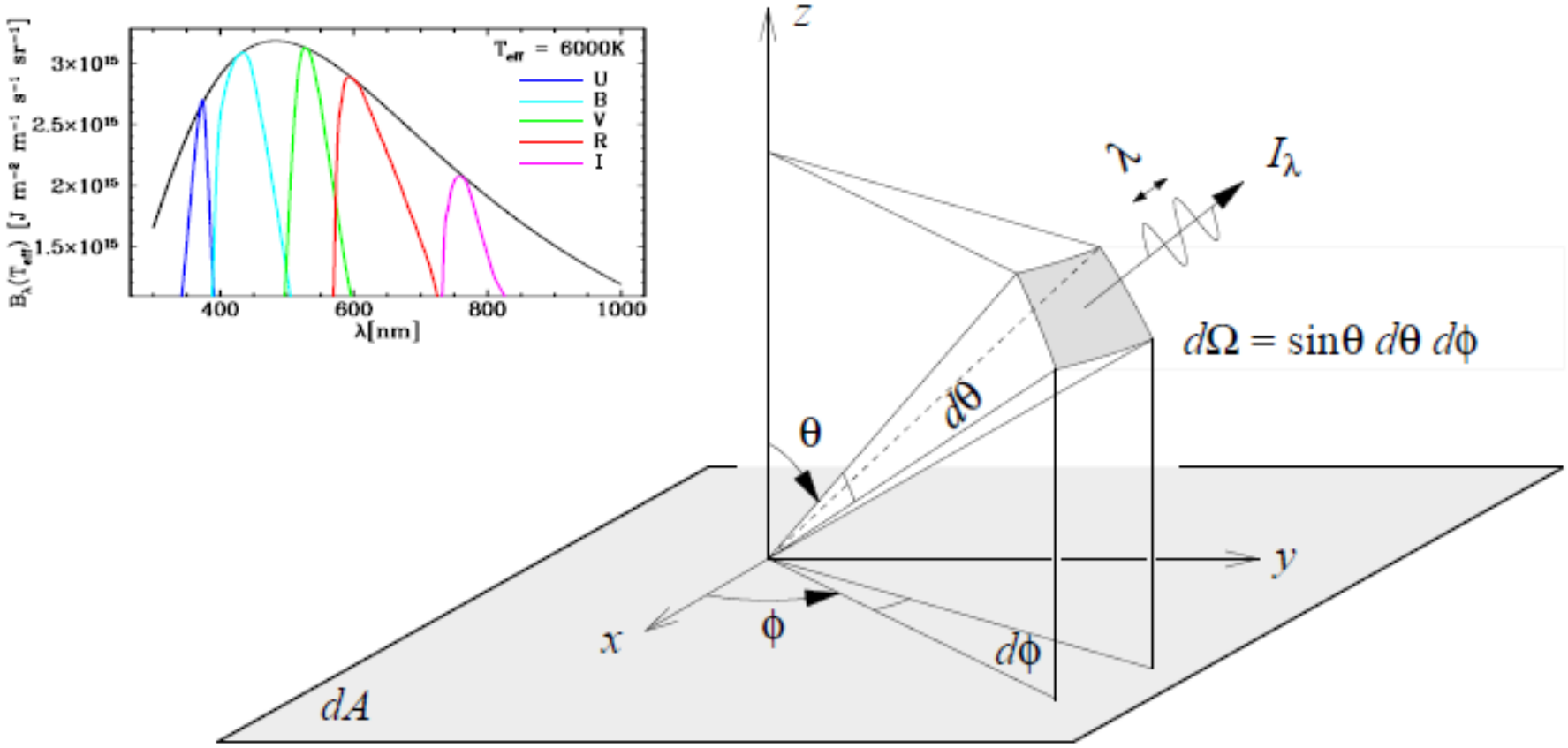
Radiative properties

- **we can calculate the emitted intensity for every surface element**
- **for the present only by means of the SB law.**



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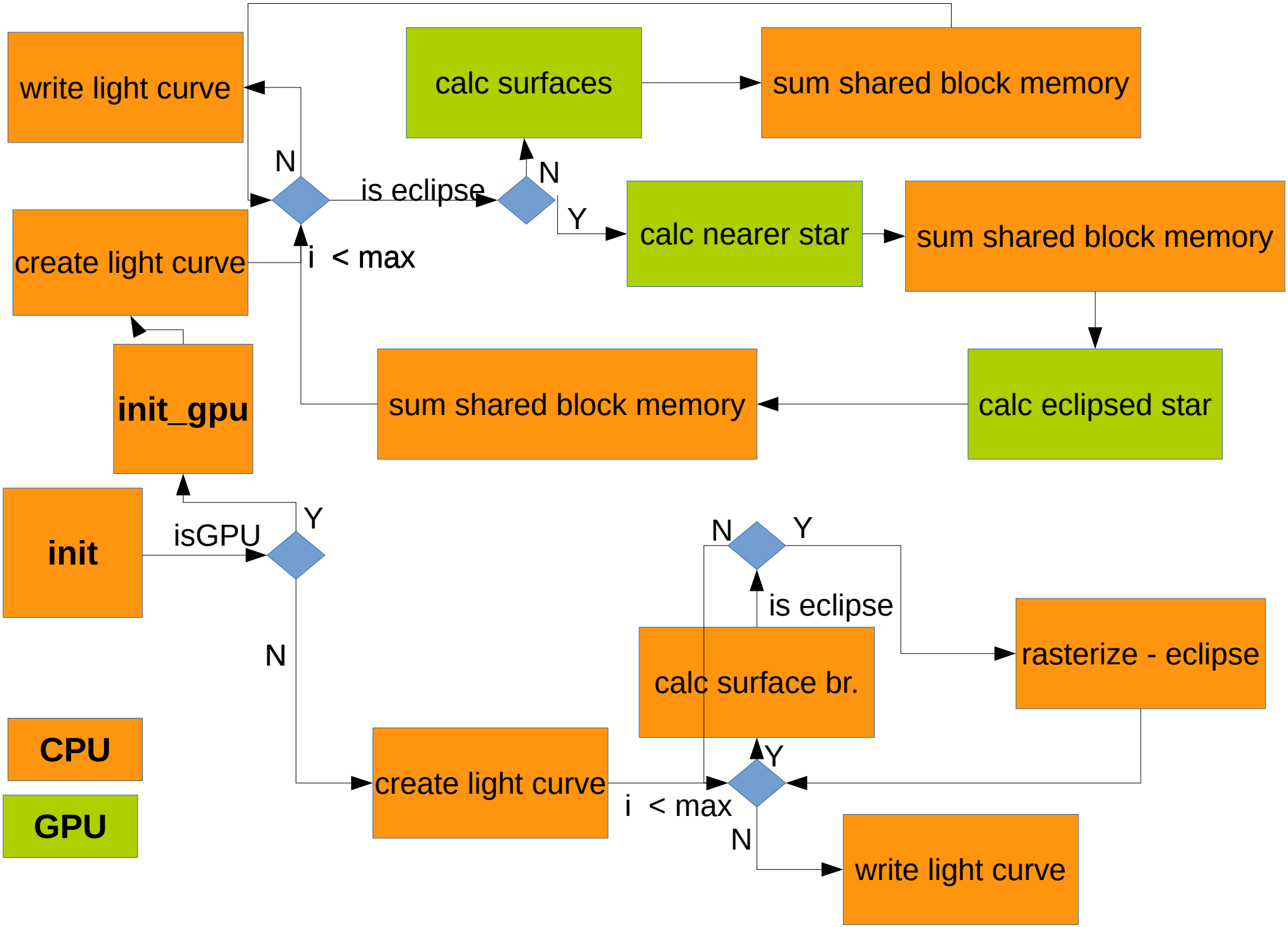

write light curve
calc surfaces
sum shared block memory
N
is eclipse
N
Y
create light curve
i < max
calc nearer star
sum shared block memory
init_gpu
sum shared block memory
calc eclipsed star
init
isGPU
Y
N
Y
is eclipse
rasterize - eclipse
N
calc surface br.
CPU
GPU
create light curve
Y
i < max
N
write light curve

init_gpu

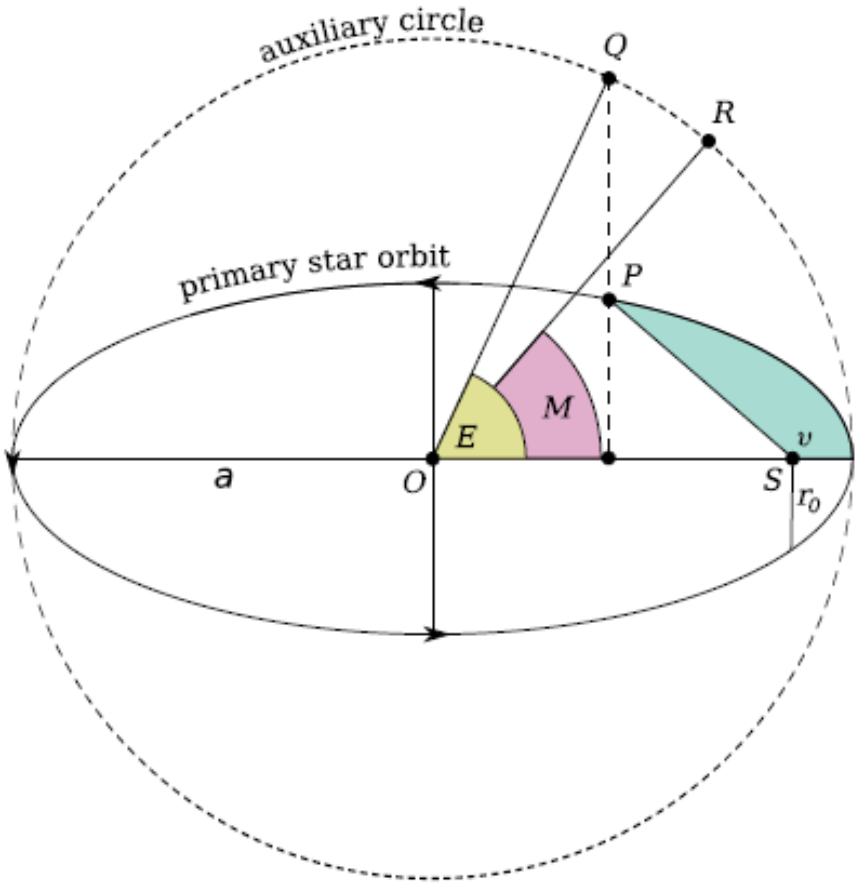
- **load parameters**
- **calculate surface grid**
- **solve Kepler equation with Newton-Raphson method**

$$M = E - e\sin(E)$$

- **calculate initial surface element positions in the plane of orbit**
- **and in the plane of sky.**

calc surface br.

- **calculate:**
  - **norm vector**
  - **surface area**
  - **cos(gamma)**
  - **temperature**



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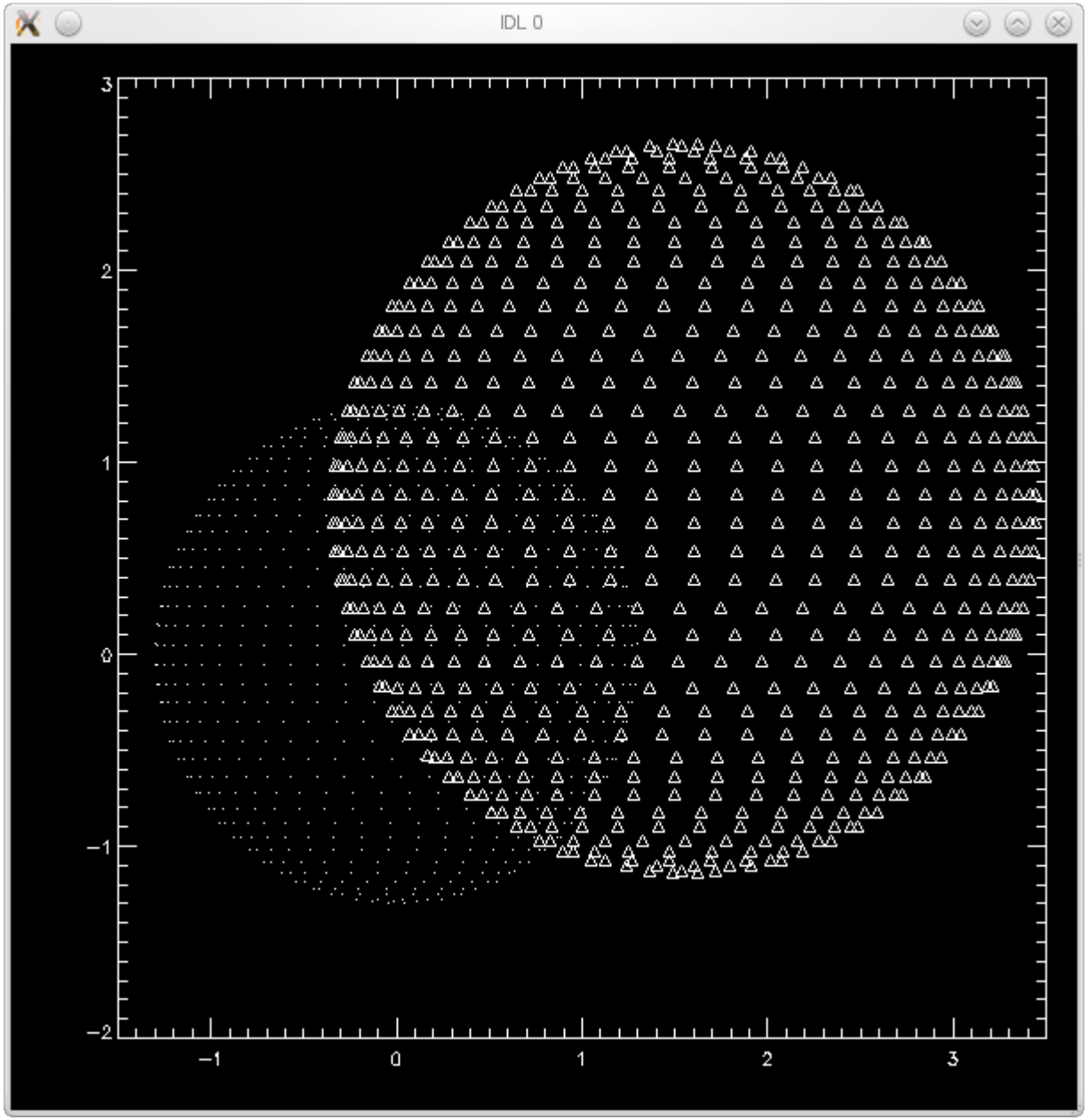
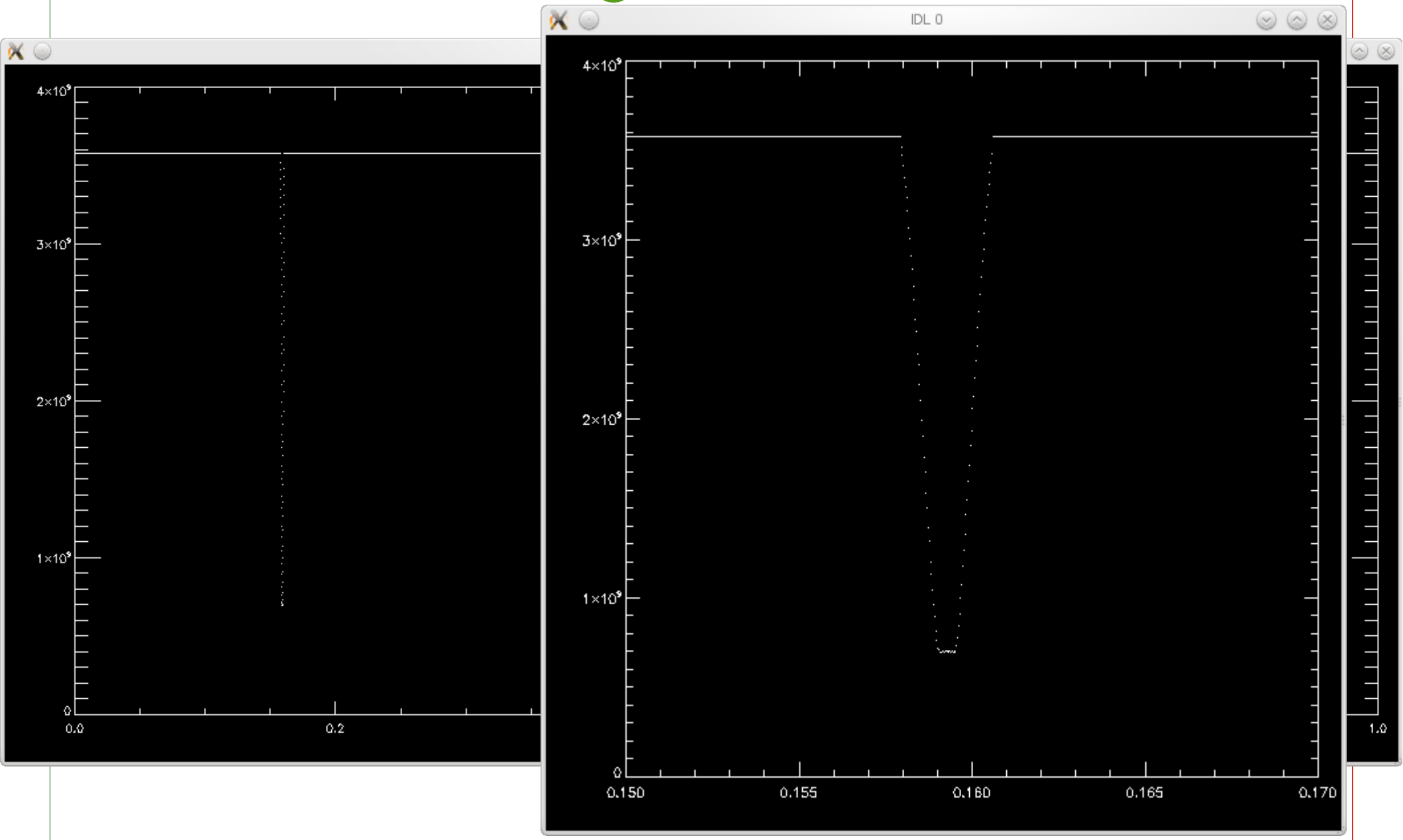
Surface grid



Lightcurve



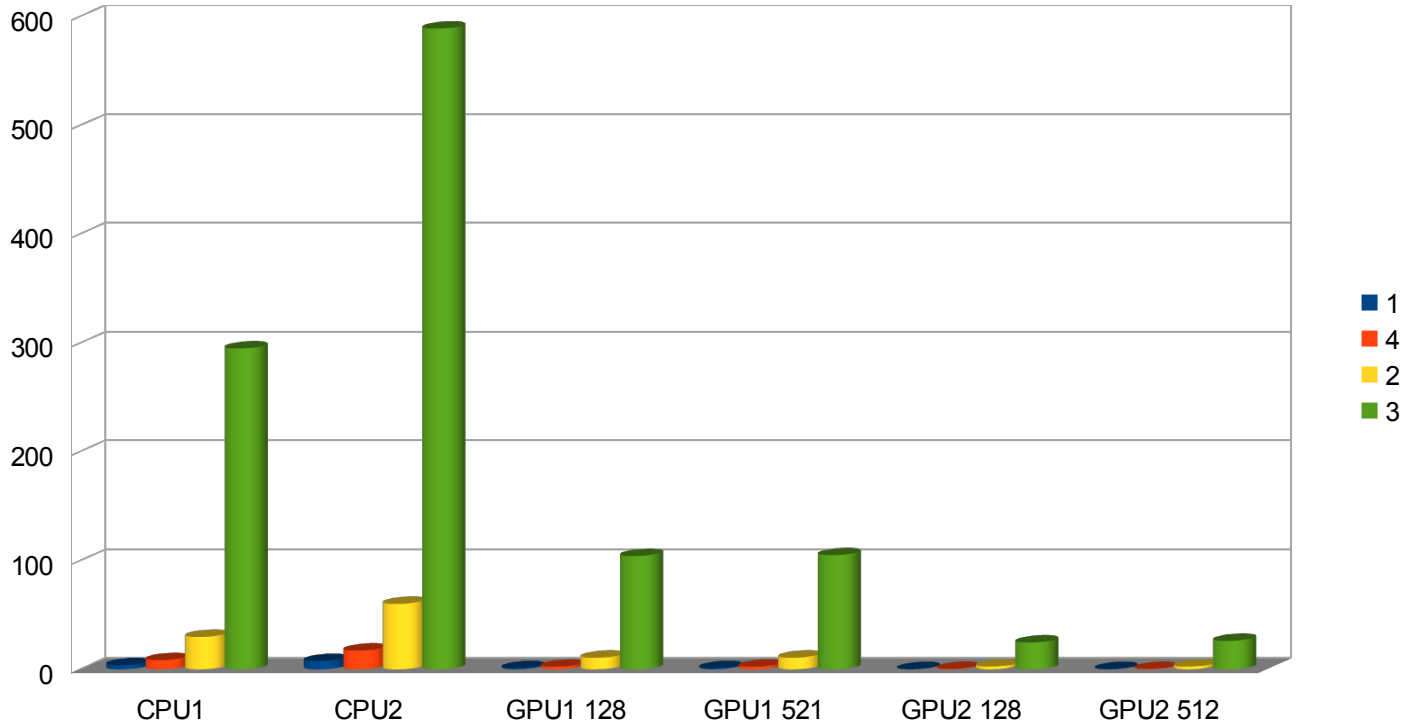
Computational prices

CPU 1 **Intel Core i7-4770 3.4 GHz** **4 cores, hyperthreading enabled**	**CPU 2** **Intel Core i7 920 2.67 GHz** **4 cores, hyperthreading enabled**
GPU 1 **NVIDIA GeForce GT 620** **compute capability: 2.1** **1024 threads/block**	**GPU 2** **NVIDIA GeForce GTX 980** **compute capability: 5.2** **1024 threads/block**

Case ID	Number of orbital positions	Number of theta grid points	number of surface elements
1	360	40	1348
2	3 600	40	1348
3	36 000	40	1348
4	360	60	3012

Computational prices

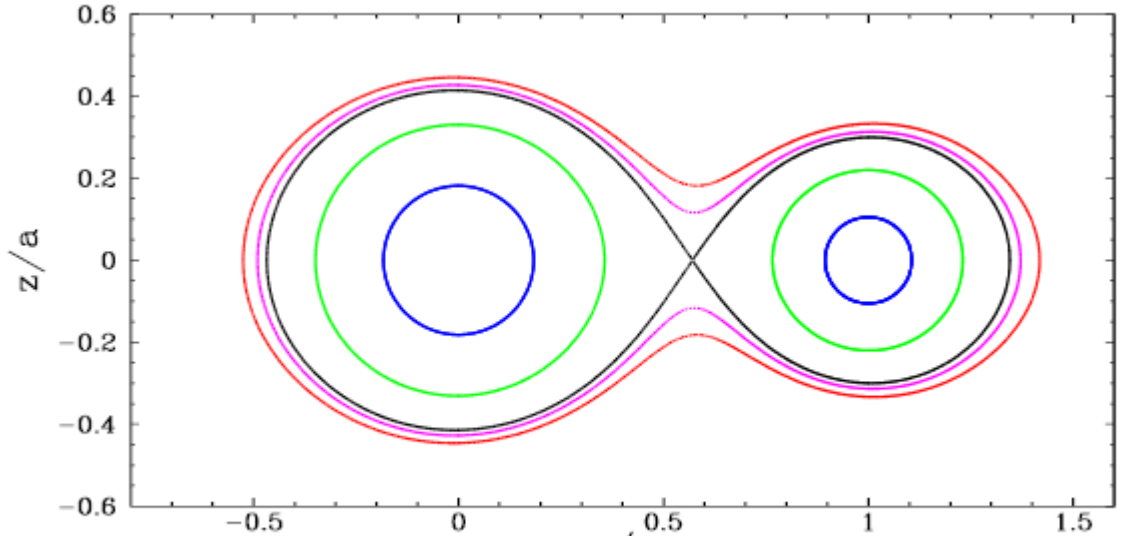
configuration	CPU1	CPU2	GPU1 128	GPU1 521	GPU2 128	GPU2 512
1	3,86	7,77	1,13	1,17	0,29	0,32
4	8,53	17,25	2,46	2,48	0,41	0,41
2	29,8	60,17	10,59	10,71	2,54	2,54
3	294,87	588,74	104,17	104,95	24,71	26,2



Features to involve

- tidal distortions of close binaries
- gravity darkening
- limb darkening
- reflection
- light-time variation
- the inverse problem
  - orbital and stellar parameters from the light (and radial velocity) curve
  - we had to create a great amount binary systems with different parameters (GPU!) for a lot of star
  - using Markov chain Monte Carlo
  - multiple stellar system and exoplanet modelling
  - GUI for setting initial parameters (partly is made)

Features to involve



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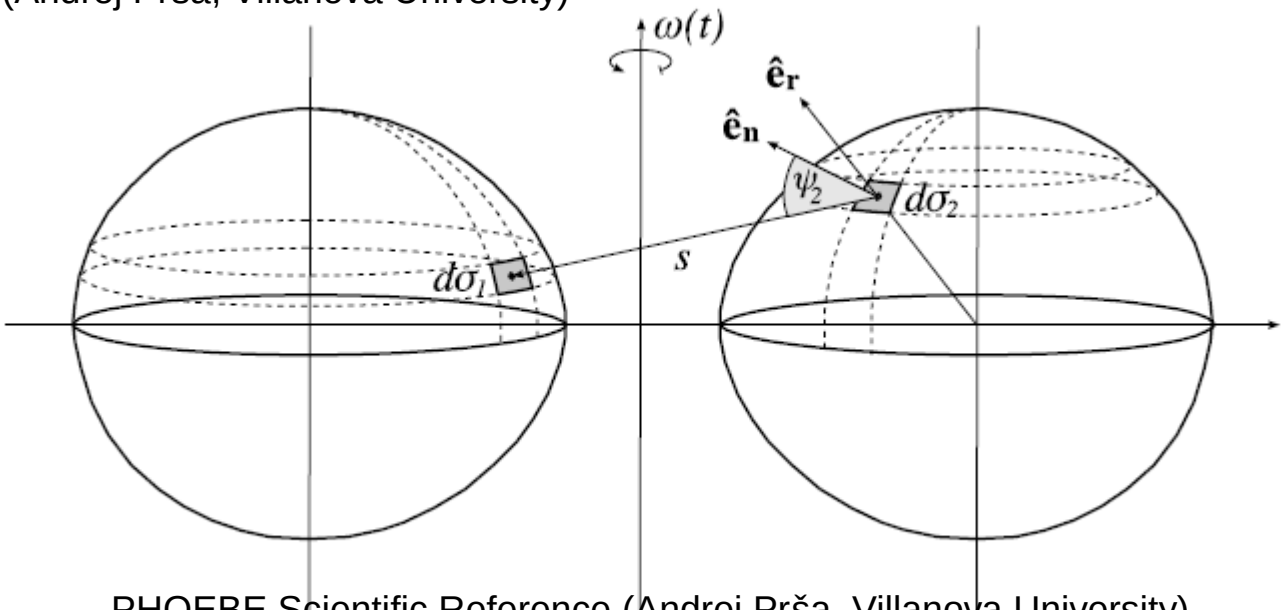

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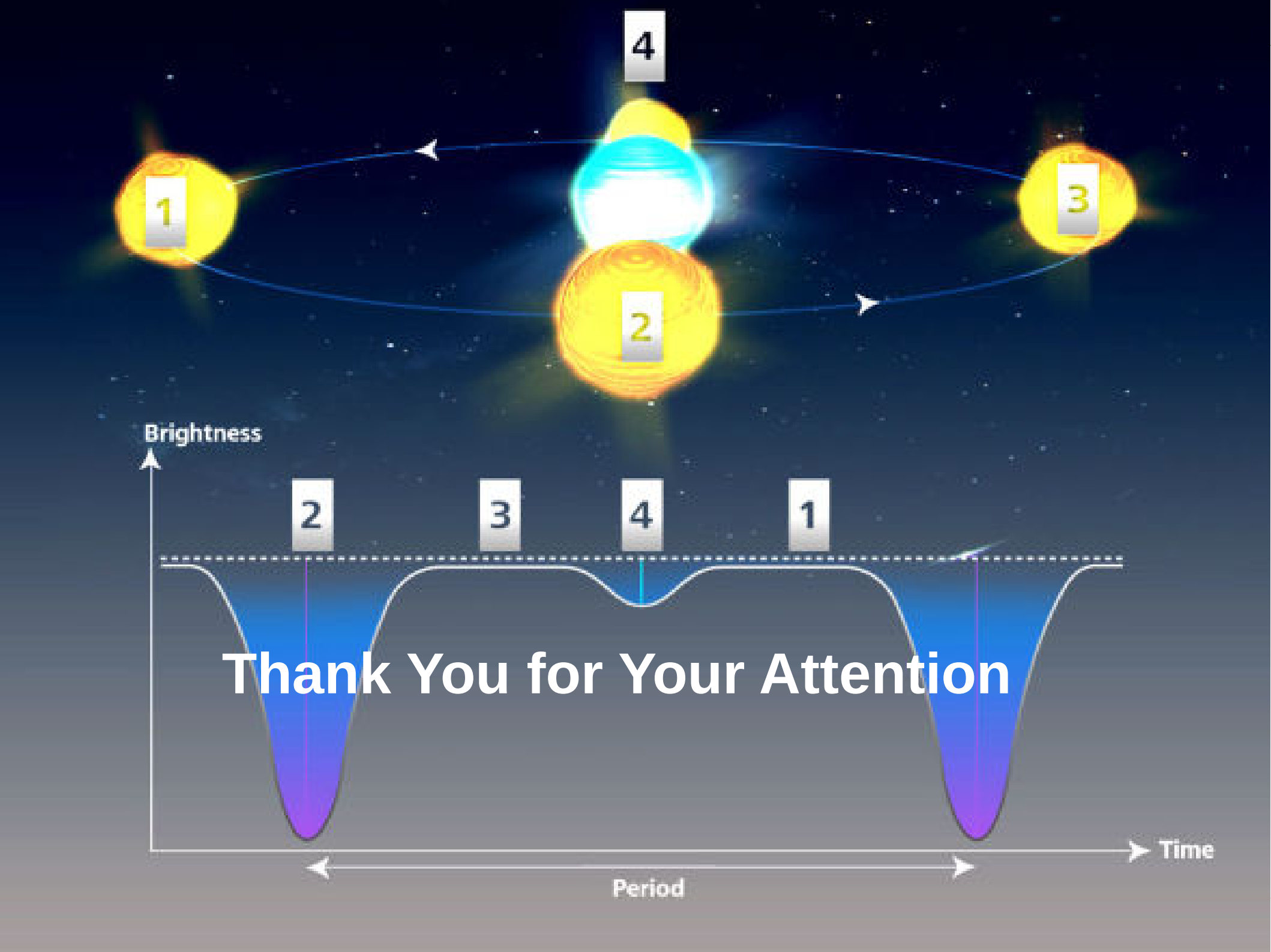
Acknowledgements

- I would like to thank my colleagues helping me during this project and Wigner Research Centre for Physics allowing us using GPU Labor's computers:
- Wigner Research Centre for Physics, GPU labor
- Tamás Borkovits
- Emese Forgács-Dajka
- Gergely Gábor Barnaföldi
- Máté Ferenc Nagy-Egri
- János Sztakovics
- Tamás Hajdú
- OTKA projekt #113117



Thank You for Your Attention