EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Polarisation as a tool to study the Solar System and beyond

Action MP1104

Spectropolarimetric study of Mira-type variable stars

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Introduction

Mira stars spectropolarimetric survey

About the physical origin of polarization

Conclusions & Prospects

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Variability

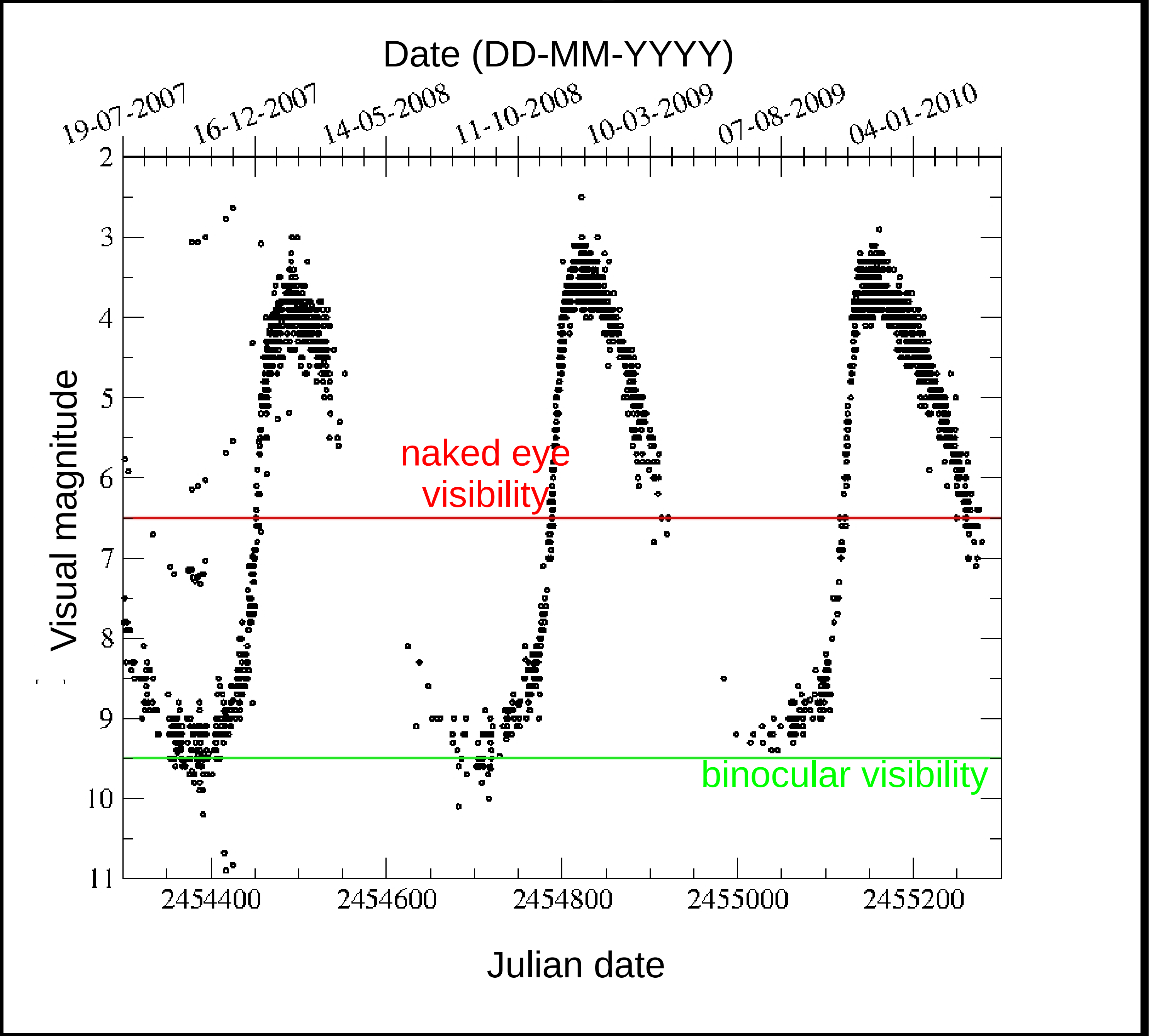
Long period
(~400 days)

Strong amplitude variation
(ΔV=8)

Rather regular variations

Pulsation :
- radial
- potentially linked to convection

(Xiong et al. 1998)

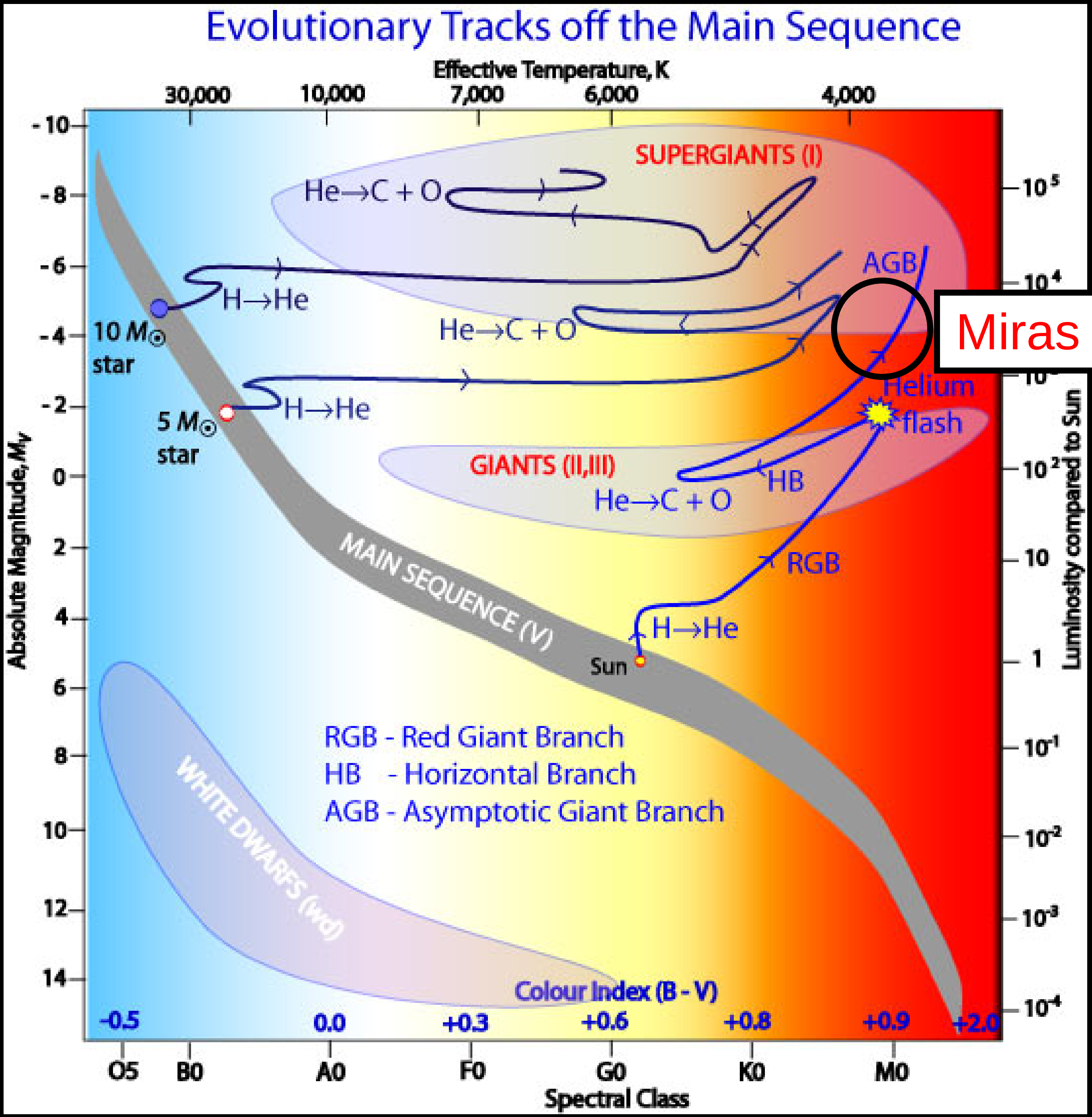


Evolution

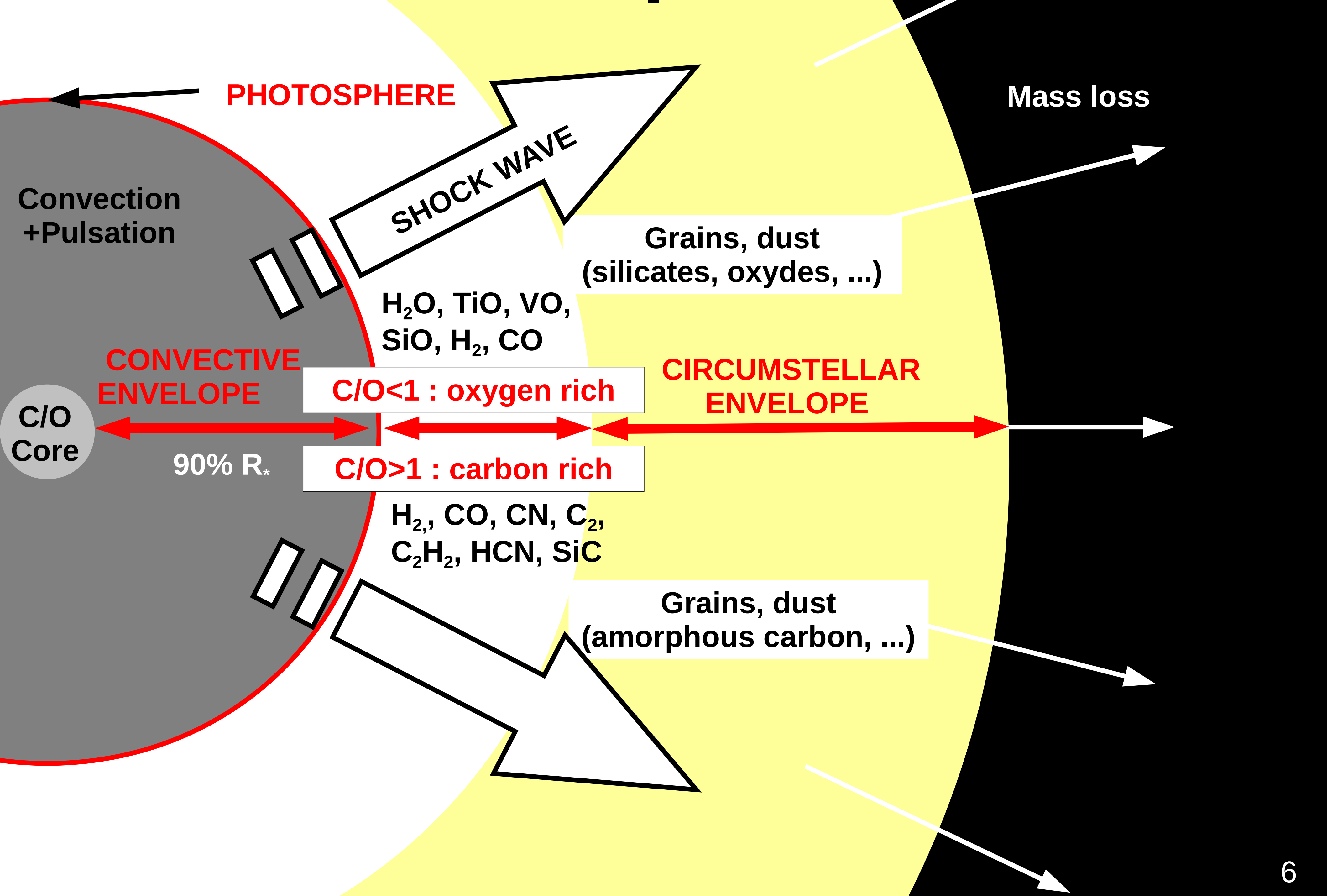
Mira stars :
- cool (T_{eff}<3000K)
- evolved (strong luminosity : from 1000 to 10,000 $L_☼$)

The AGB Phase:
- Inert core of carbon and oxygen + helium layer + hydrogen layer
- Initial mass : from 1 $M_☼$ to 8 $M_☼$

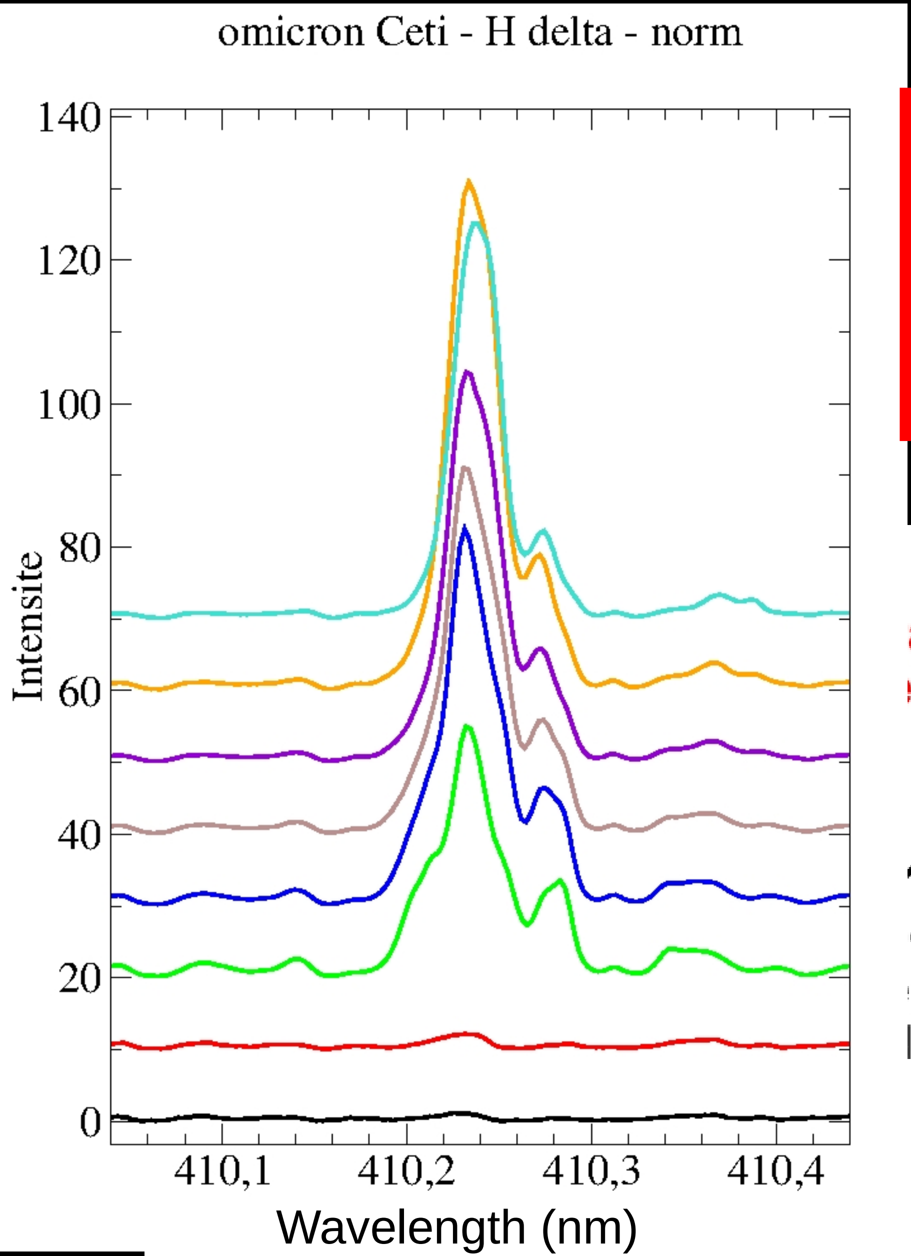
Evolution after AGB :
- C/O core → white dwarf
- Envelope + Atmosphere → planetary nebula (mass loss)



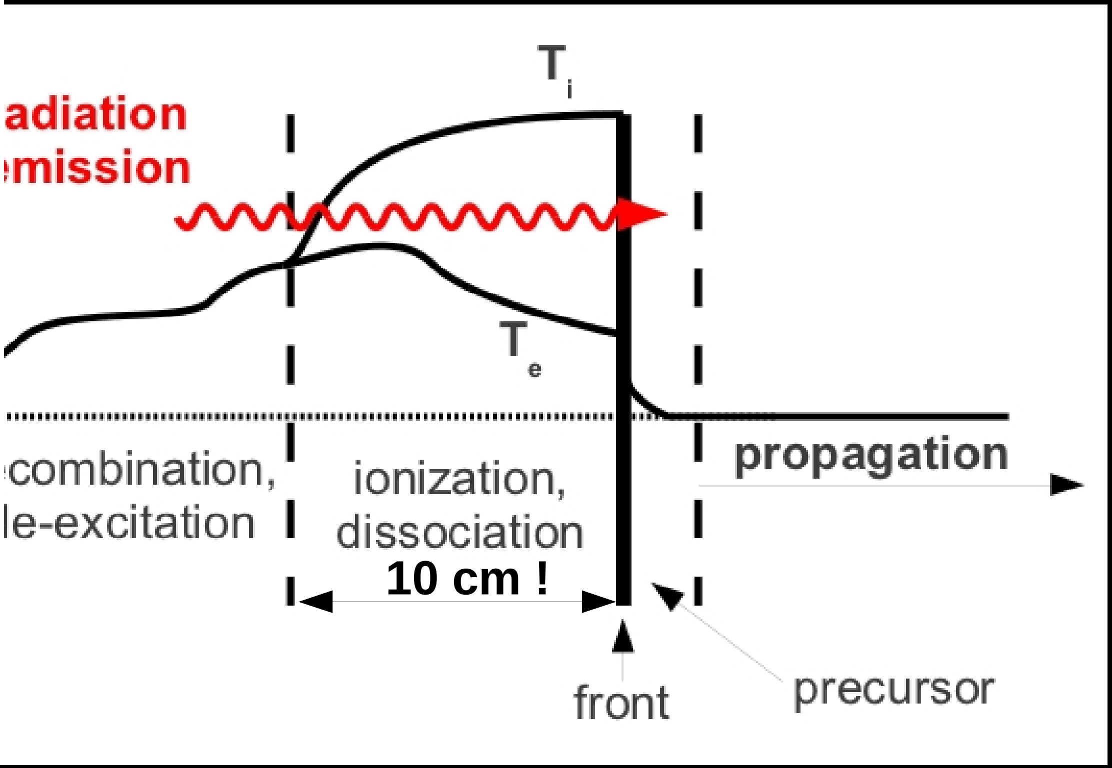
Atmosphere


PHOTOSPHERE
Mass loss
SHOCK WAVE
Convection
+Pulsation
Grains, dust
(silicates, oxydes, ...)
H_2O, TiO, VO,
SiO, H_2, CO
CONVECTIVE
ENVELOPE
C/O<1 : oxygen rich
CIRCUMSTELLAR
ENVELOPE
C/O
Core
90% R_*
C/O>1 : carbon rich
H_2, CO, CN, C_2,
C_2H_2, HCN, SiC
Grains, dust
(amorphous carbon, ...)

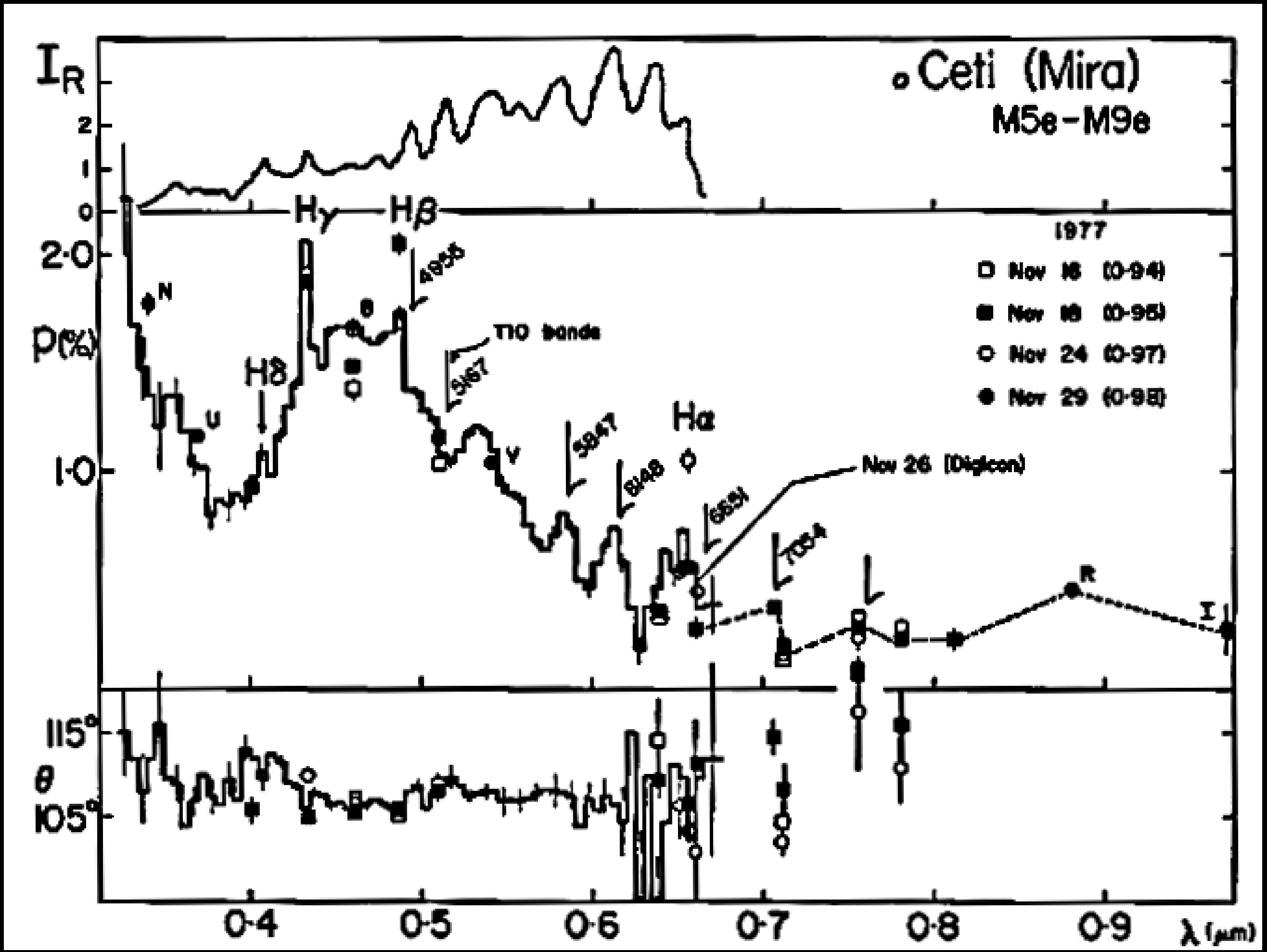
Shock wave

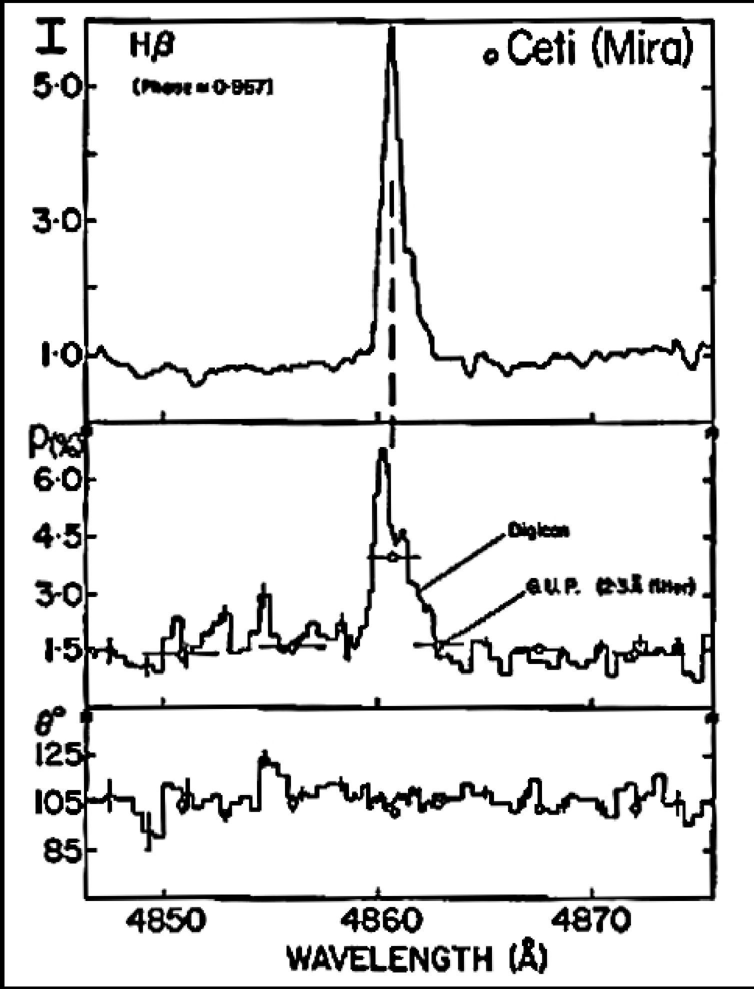


Strong emissions in the Balmer lines, which is typical of Mira stars
→ theoretically explained by the propagation of a shock wave



Polarimetry of Mira stars





Low resolution in visible

High resolution in Hβ

(McLean & Coyne 1978)

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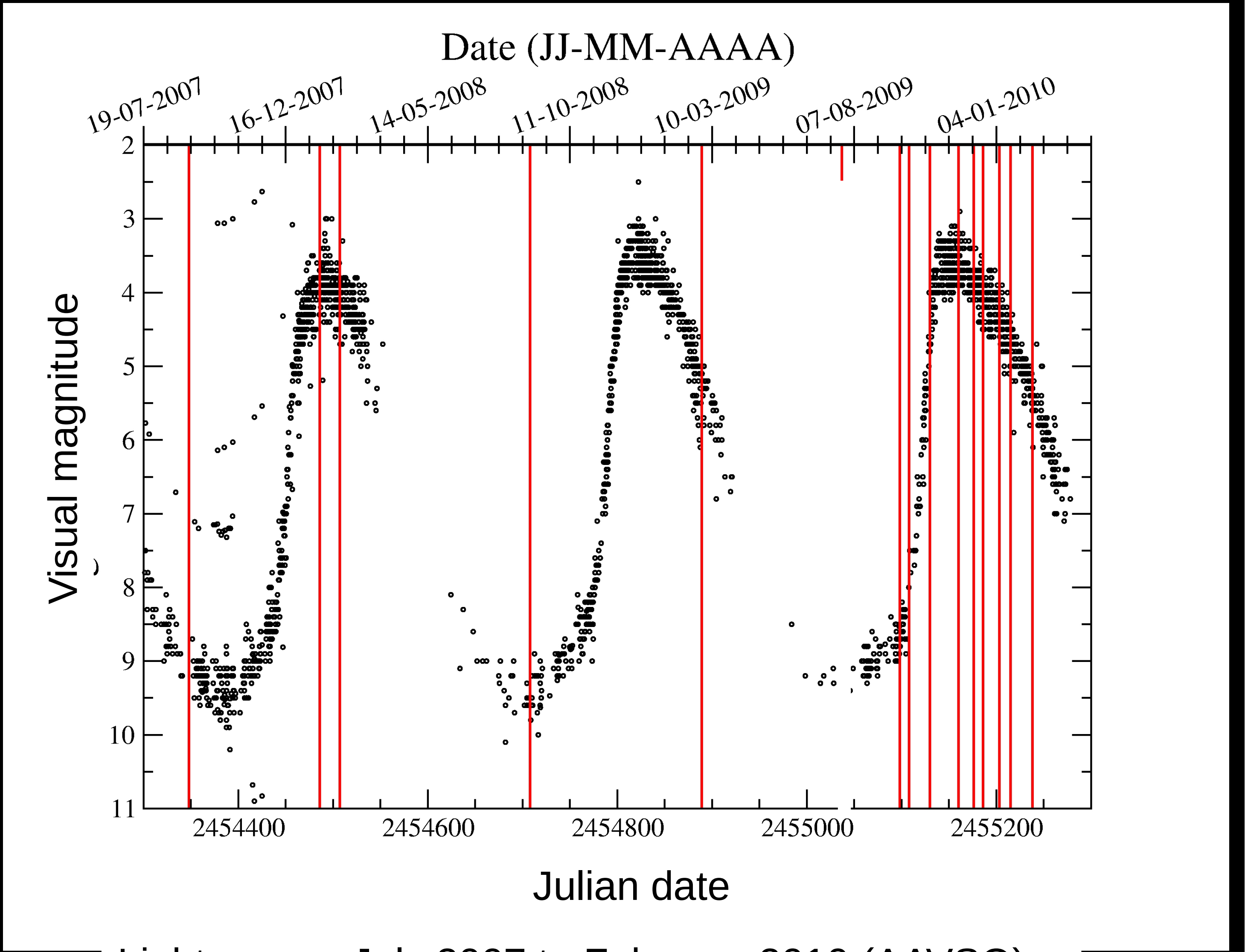
omicron Ceti

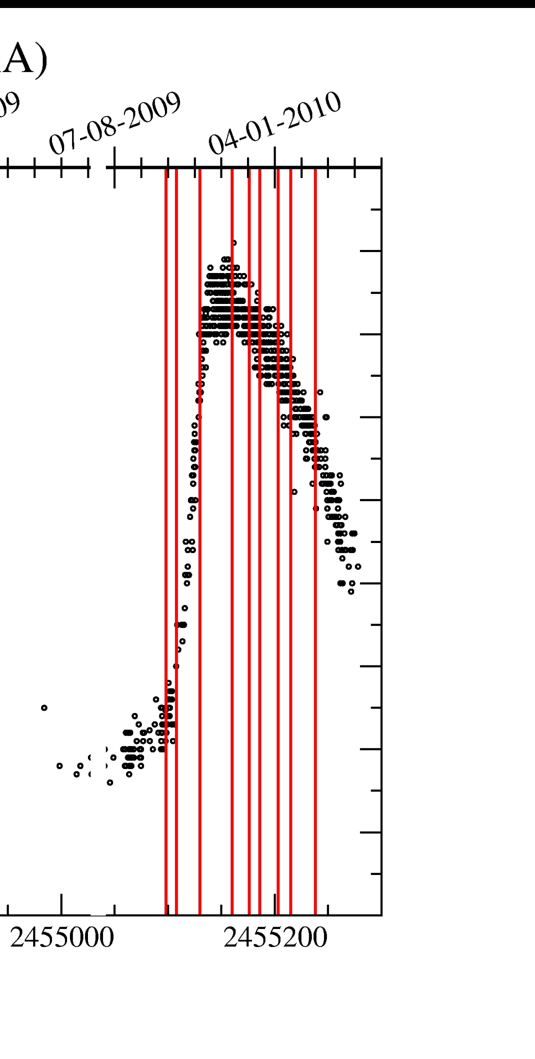
- First variable star ever discovered
- Mira stars' prototype
- Relatively near (131 pc)
- Presence of a compagnon (VZ Cet)

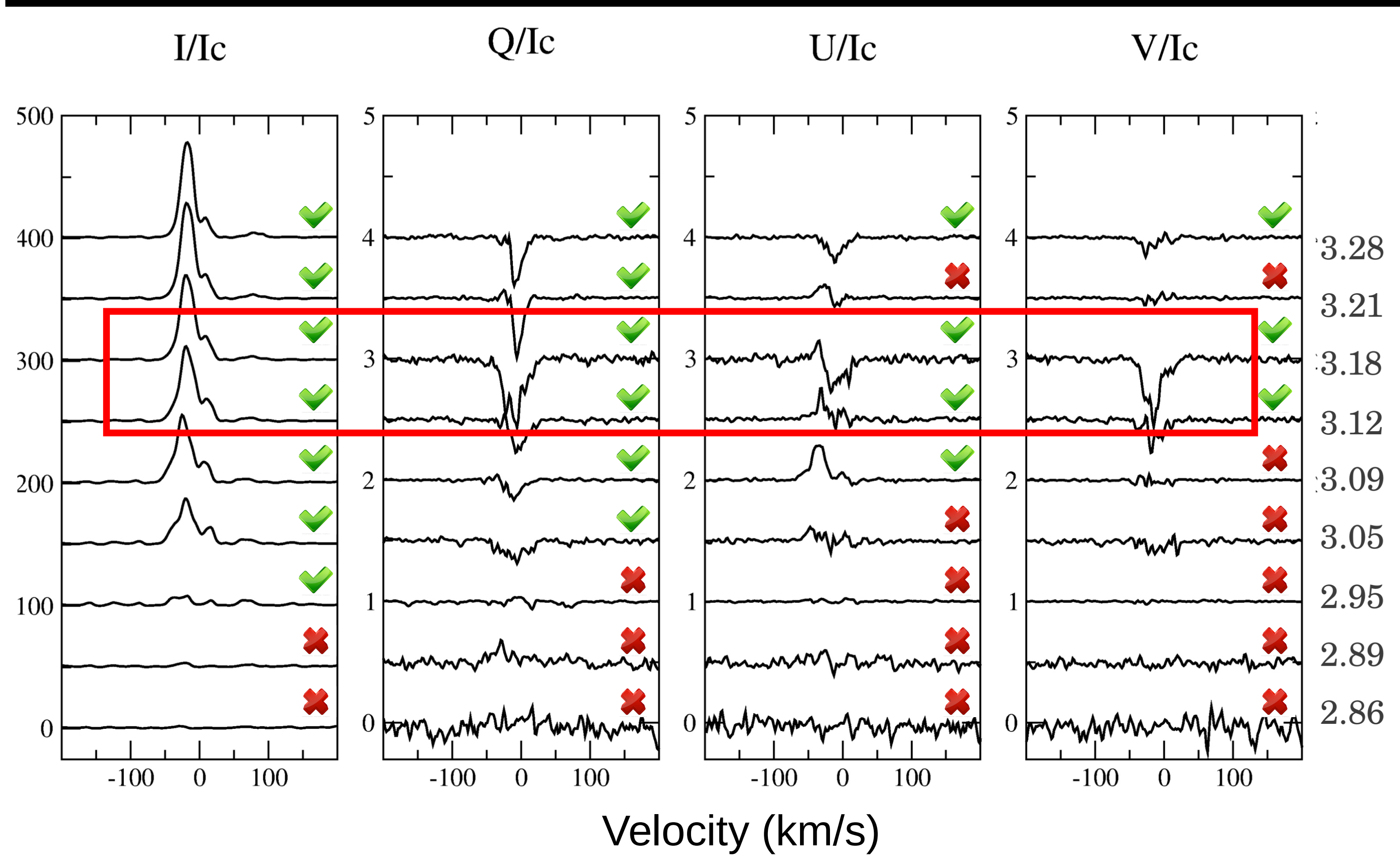


Light curve : July 2007 to February 2010 (AAVSO)

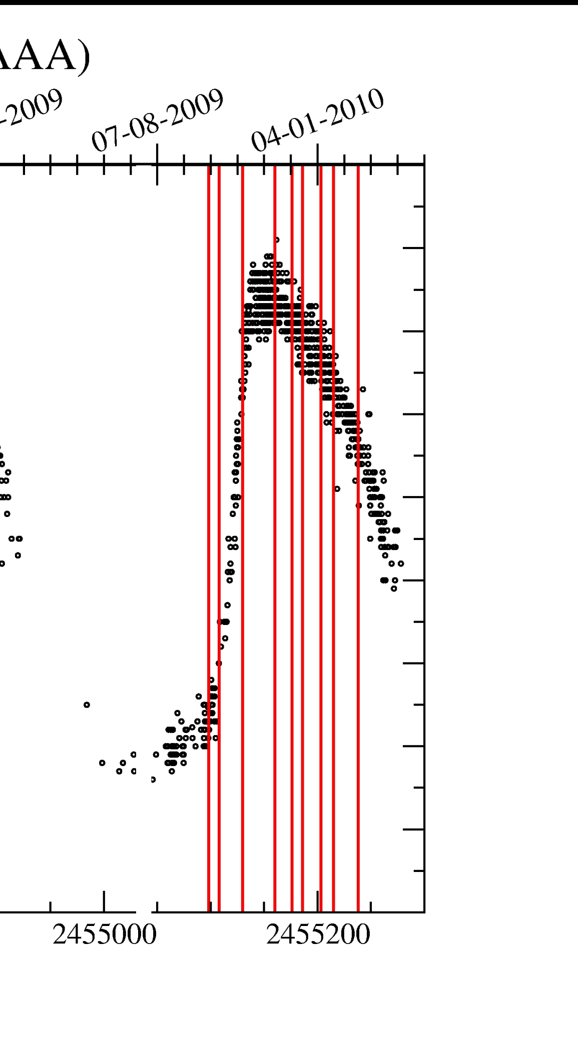
3rd cycle : Hδ

Detection : 3*σ ✔

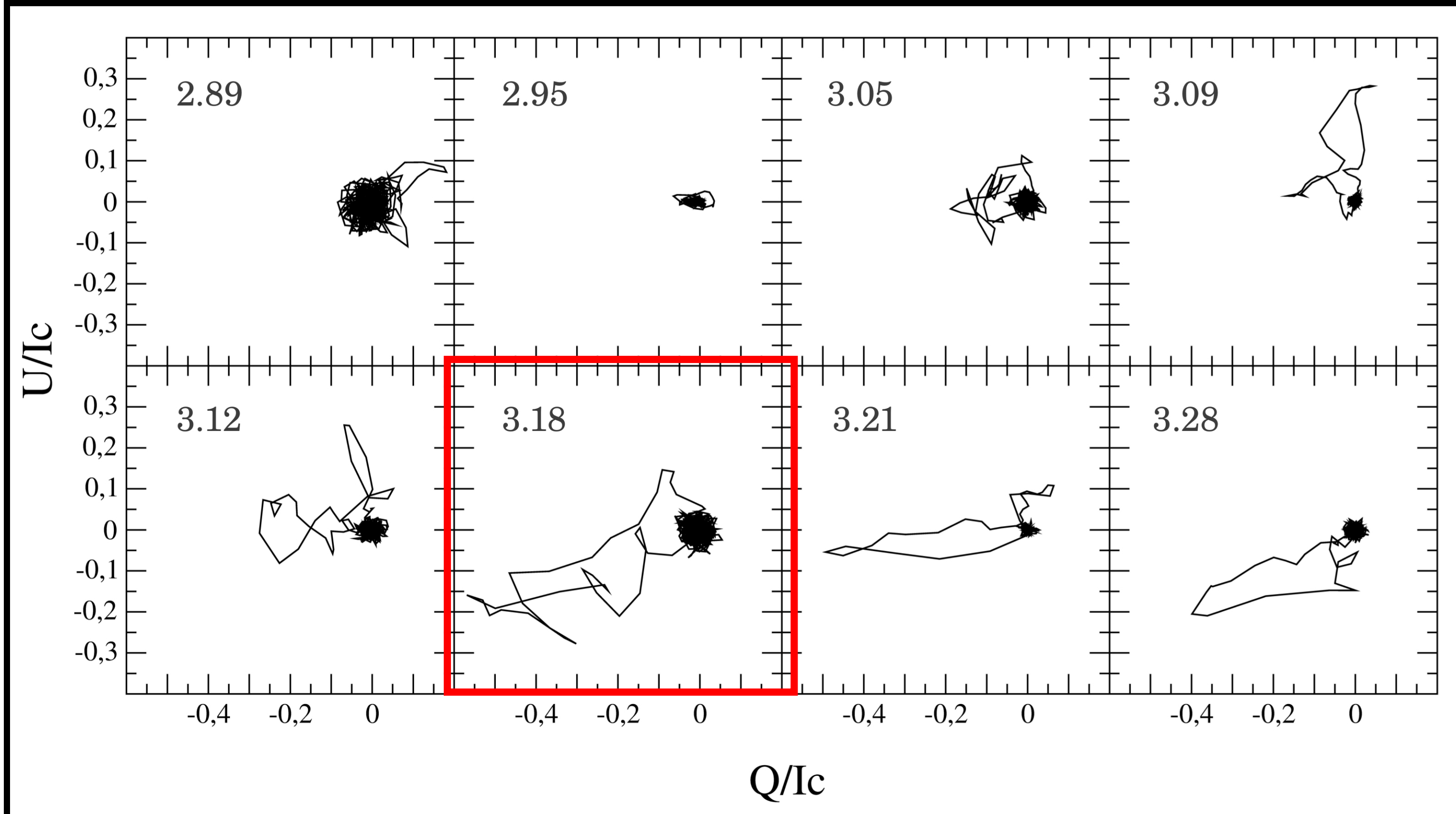




3rd cycle : Hδ



AAA)
-2009
07-08-2009
04-01-2010
2455000
2455200



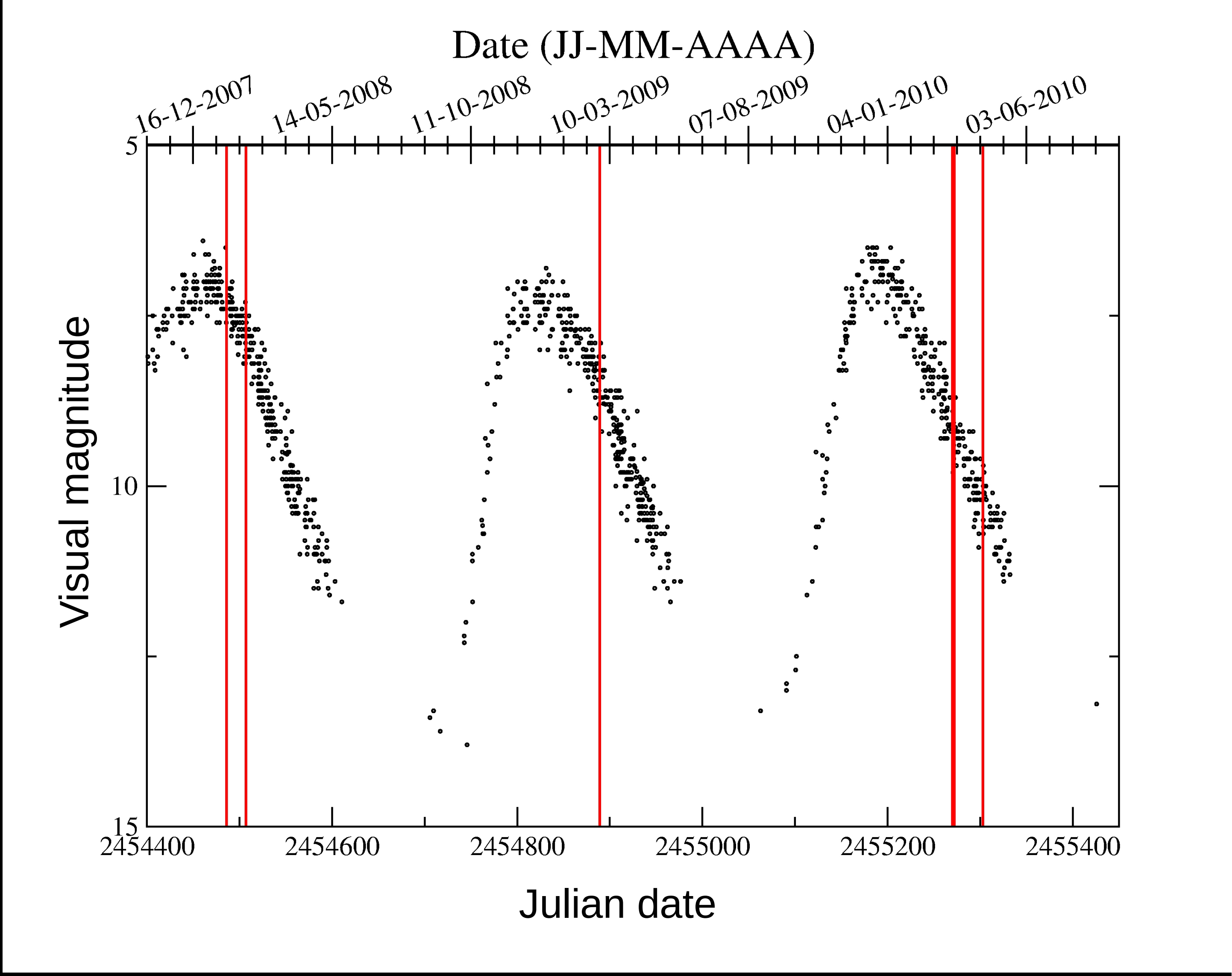
2.89
2.95
3.05
3.09
3.12
3.18
3.21
3.28
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
U/Ic
-0,4
-0,2
Q/Ic

R Geminorum

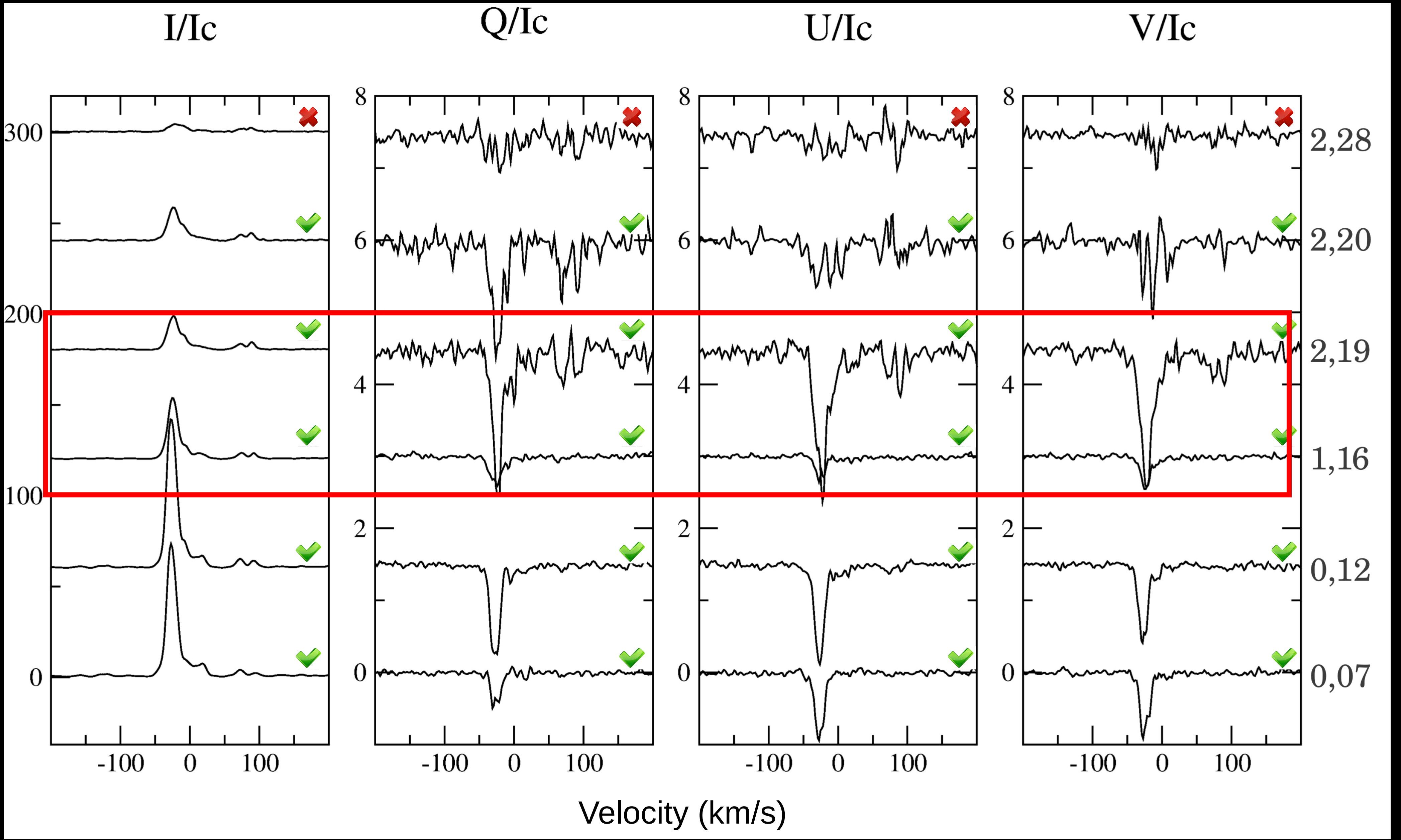
- Spectral type :S
→ different molecular composition of the atmosphere
→ different contamination of the emissions

- Period : 370 days

- Magnitude : between 6 and 14 m_V

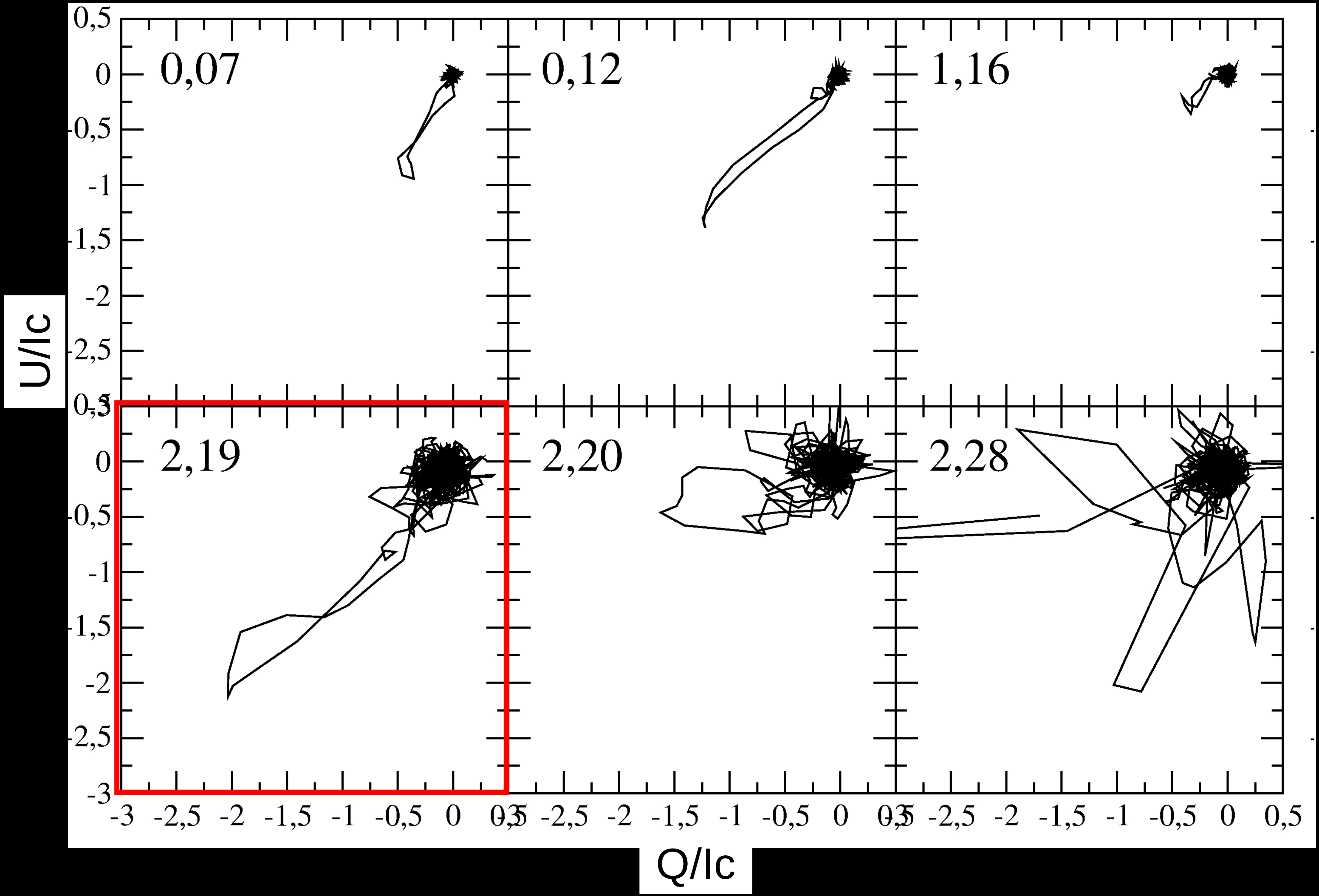


Hδ



I/Ic
Q/Ic
U/Ic
V/Ic
300
200
100
0
8
6
4
2
0
-100
0
100
2,28
2,20
2,19
1,16
0,12
0,07
Velocity (km/s)

Hδ



Summary

- Linear and circular polarimetric signature systematically associated to the presence of an emission in intensity

- Time evolution of this polarisation similar to the evolution of the emission in intensity

Polarizing mechanism potentially intrinsic to the shock wave
(results published in Fabas et al. 2011)

Interesting phase : φ=0,2 (a bit afer the max of luminosity)
Maximum of linear polarization
Apparition of circular polarization

Phase already noticed in works about SiO maser emission in the circumstellar envelopes of Miras ! (Pardo et al. 2004, Gray et al. 2009)
Interesting phase since it's the maximum of maser emission.

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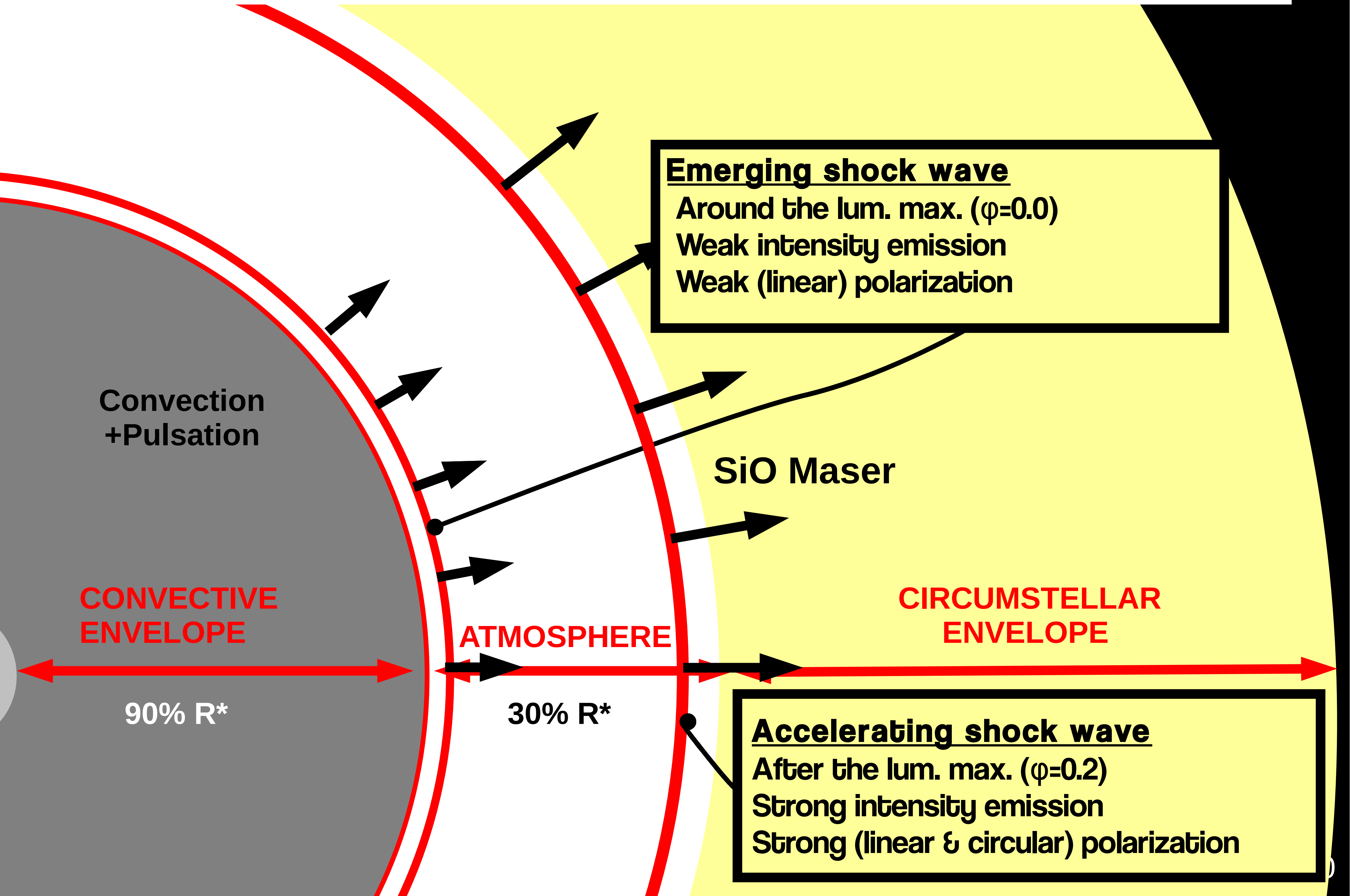
Link polarization-shock wave



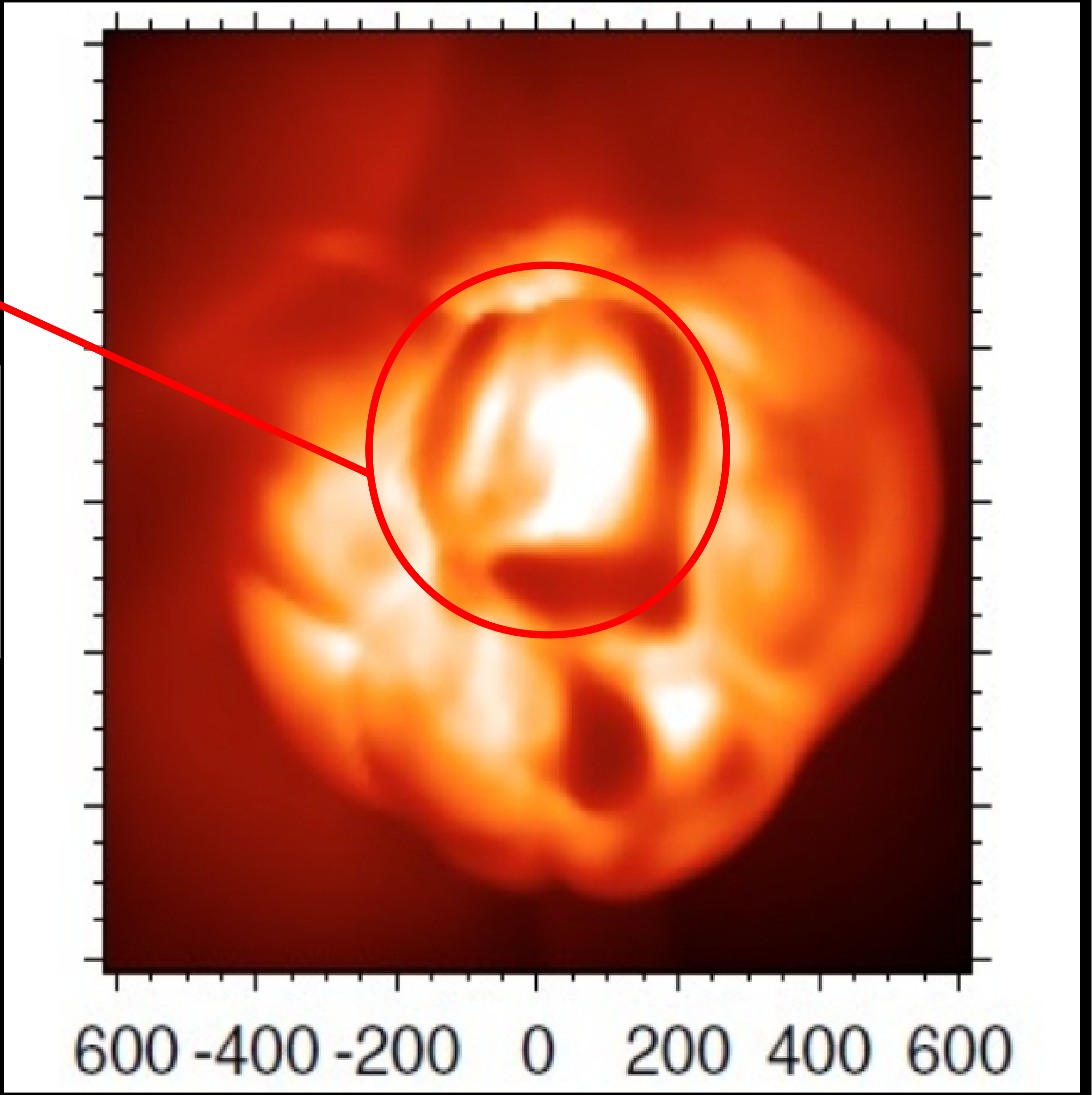
1. Global Asymmetry

Giant convective cells →
global **asphericity**

Interaction **convection/ pulsation** (Xiong et al 1998)	Interaction convection/ shock wave (Lele 1992)

Possible **asphericity** of the shock in a direct or indirect way

Could account for **global linear polarization** with e.g. **anisotropic scattering**



Convective surface of an AGB star
(3D simulation, bolometric intensity map, distance in solar radii, Freytag et Höfner 2008)

2. Local magnetic field

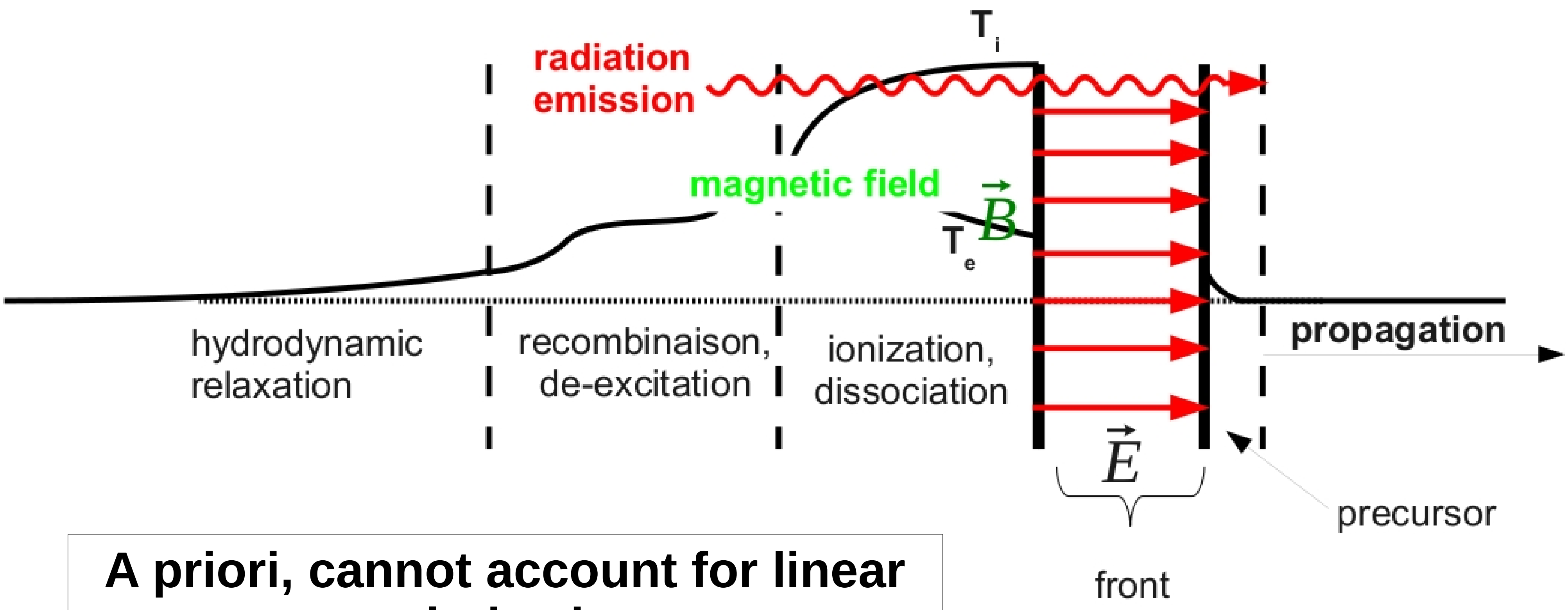
Propagation of a hypersonic shock

Electric field

Turbulence

Turbulent magnetic field

Possible source of circular polarization



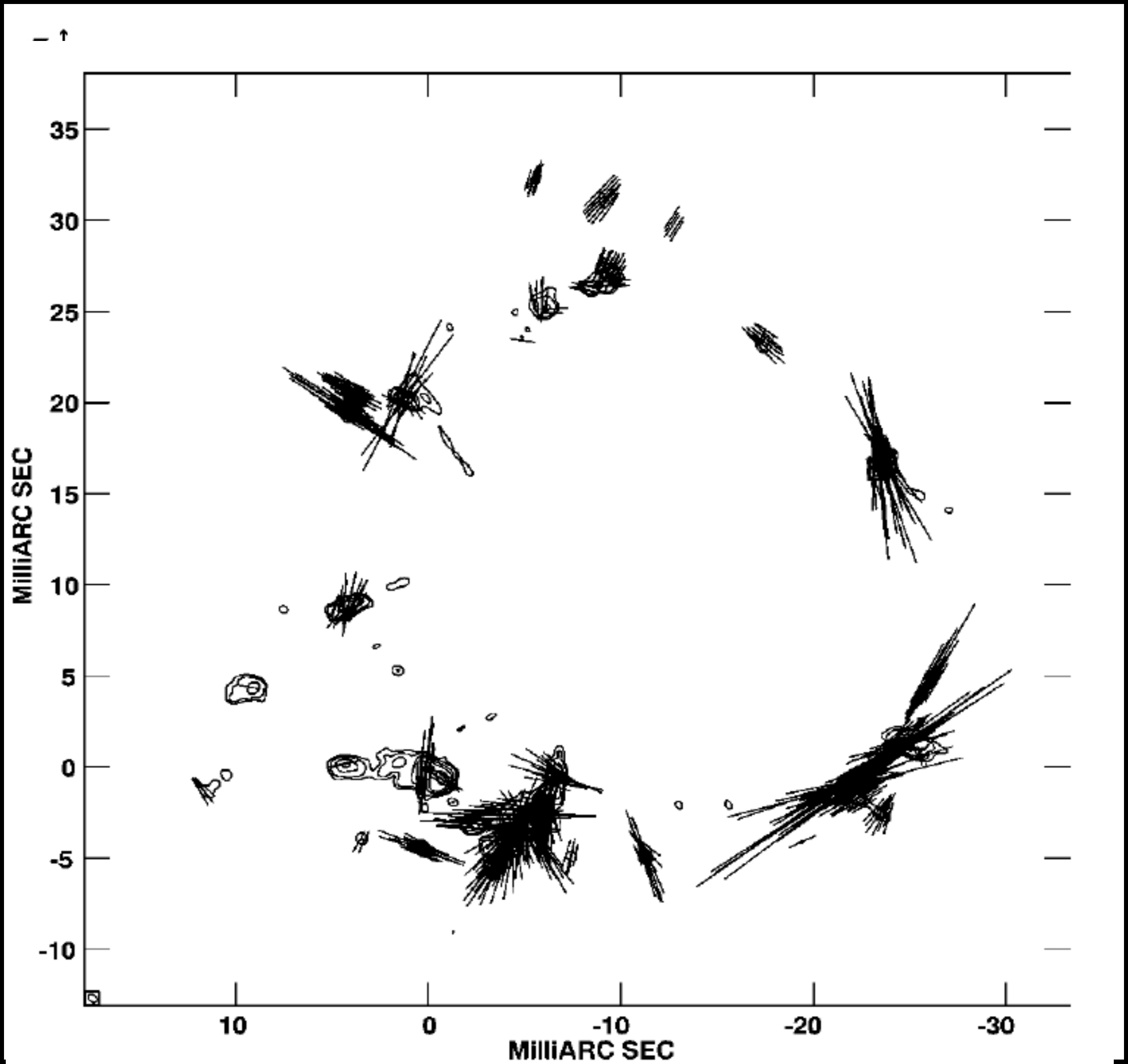
A priori, cannot account for linear polarization

Parker instability

Propagation of a shock
→ Amplification of magnetic field
→ Parker instability in the shock's wake
→ Creation of clumps in the SiO maser emission regions (Hartquist & Dyson 1997)

New link with maser emissions

maser emissions linearly polarized + time evolutionof the angle of polarization θ
→link with Balmer lines linear polarization ??



VLBI observation of SiO maser emissions for the Mira TX Cam (Kemball & Diamond 1997)

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Conclusions & Prospects

- ✔ Simulations of atmospheres which confirm the shock wave/Balmer emission link
  → to explore...
- ✔ Polarization systematically linked to the strong emissions in the Balmer lines and similar time evolution
  → link with maser ?
- ✔ Presentation of several likely polarizing mechanisms which could work together (global asymmetry, anisotropic scattering, shock-induced MF)
  ↓ interferometry
  ↓ link with solar physics...

Which fields of expertise can be involved within our COST action ?

Observations	● Further surveys of Mira stars involving both **optical** and **IR** Balmer lines (WHT ?) ● Polarization **continuum** surveys would also be needed (low resolution sufficient)
Data processing	● Need to design a **multi-line method** (similar to LSD) in order to assess the level of polarization in absoption lines and solving the problem posed by **overblending**.
Theoretical modelling	● Application of already existing tools (e.g. from solar physics) to **cool, extended and shocked atmospheres**. Preferential directions of research would be **anisotropic scattering**, **shock-generated magnetic field** and **gradient of velocity.**

Conclusions & Prospects

- ✔ CFHT observations of the variable stars RR Lyr and BW Vul → study of the phenomenon on other types of pulsating stars

- ✔ Search of a potentiel surface magnetic field for Miras by a multi-line method such as, e.g., LSD

- ✔ AMBER@VLTI interferometric observation of omicron Ceti in the near IR →
  Study of the asymetry of the shock wave, of the convective structure and the link between them

Introduction

Simulations of dynamical atmospheres

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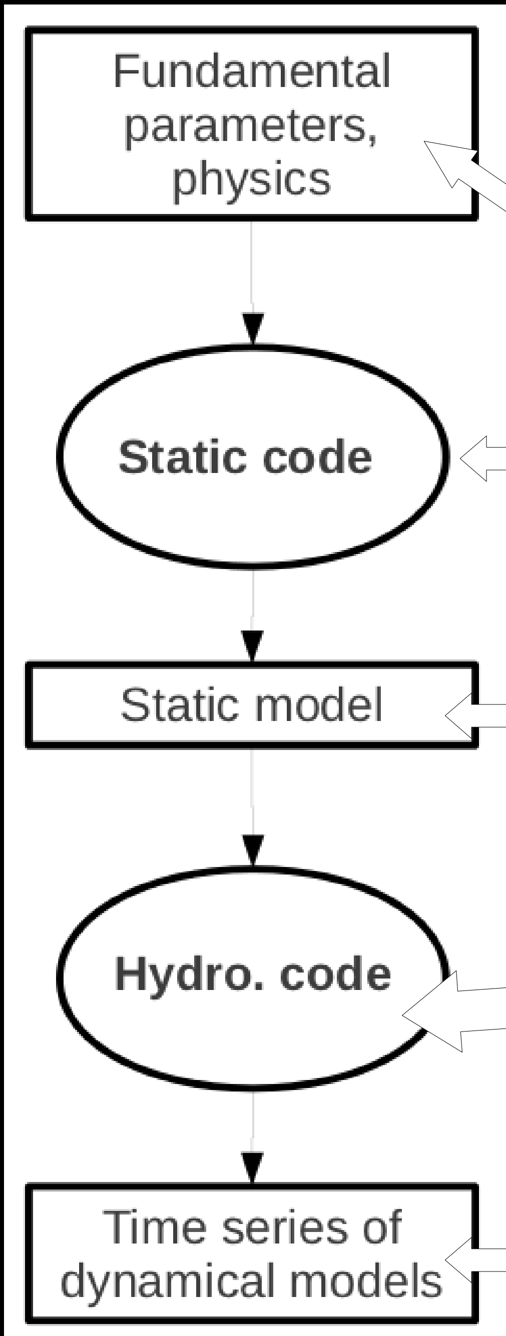
Code for dynamical extended atmospheres



L, T_{eff}, M...

$$\frac{\partial}{\partial t}=0$$

Discontinuity of velocity

Equations of hydrodynamic

T, vel...

Conservation of mass

$$m(r)=\int_0^r 4\pi r^2 \rho \, dr$$

Conservation of linear momentum

$$\frac{du}{dt}=-\frac{GM_r}{r^2}-4\pi r^2 \frac{dP}{dm}$$

Conservation of energy

$$\frac{dq}{dt}=\epsilon_N-\frac{dL}{dm}$$

Grid of models

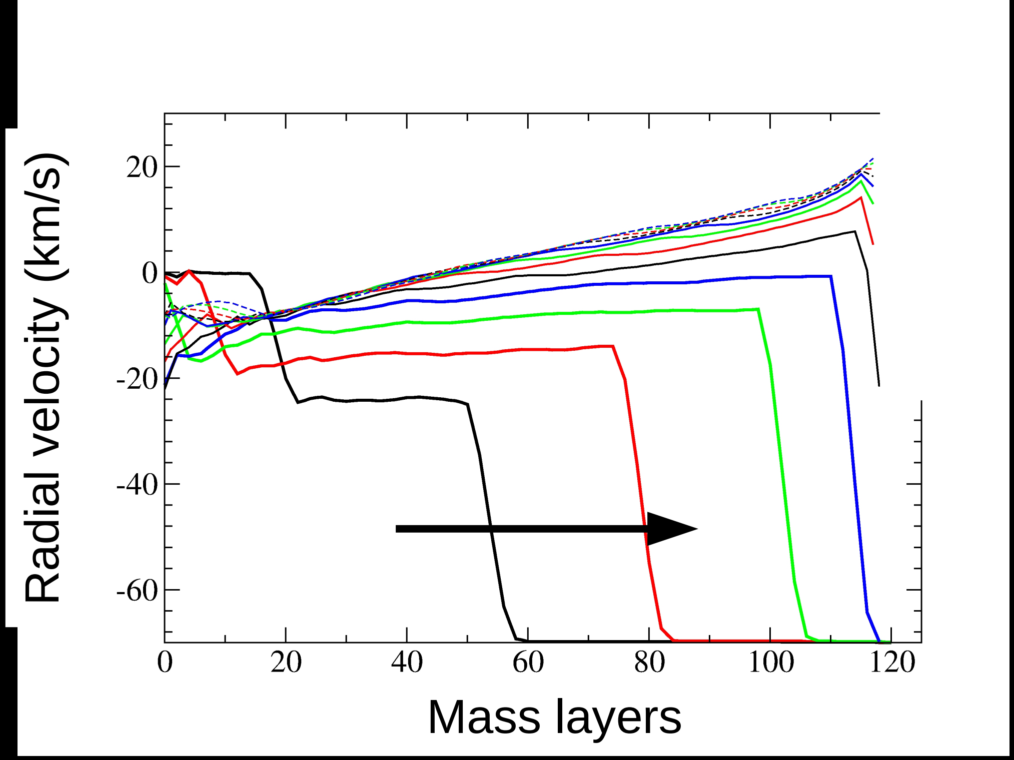
Fundamental parameters :

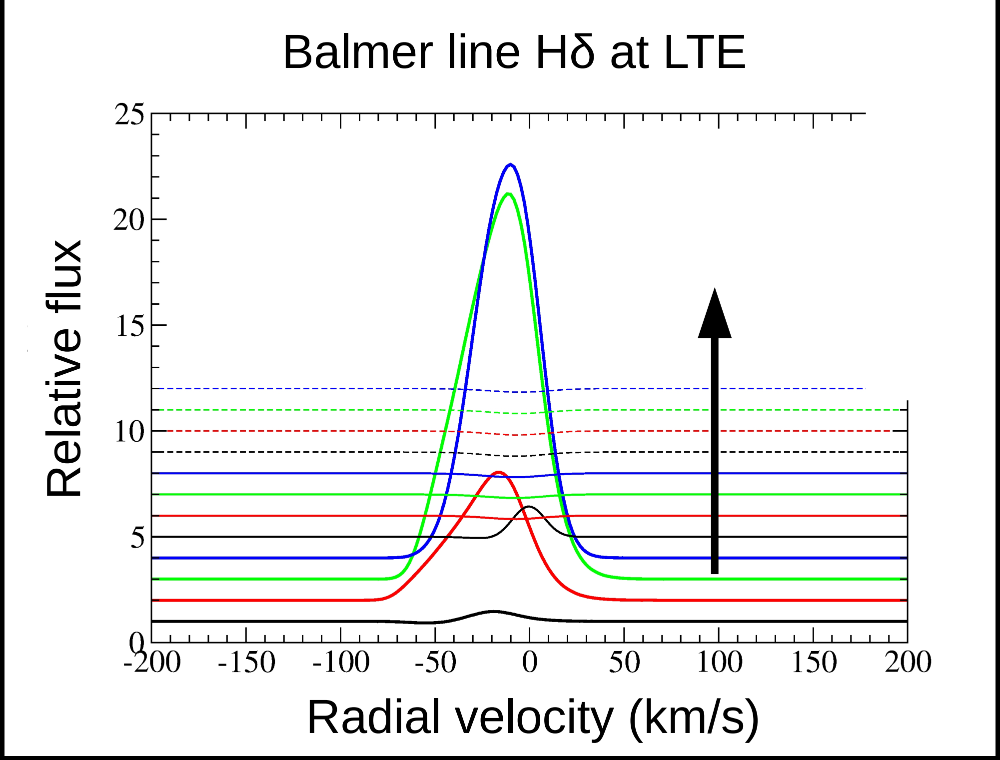
- Mass = 0.8 $M_\odot$
- Elementary composition : X=0.7 and Y=0.28
- Opacity table ig70h (Grevesse 1991, solar abundances)

Name of the static model	Luminosity ($L_\odot$)	Effective temperature (K)	Photospherical radius ($R_\odot$)
oc01	2000	2700	191
oc02	3000	2762	221
oc03	5000	2830	260
oc04	7000	2905	287
oc05	2000	3160	143
oc06	3000	3220	167
oc07	5000	3340	199
oc08	7000	3400	222

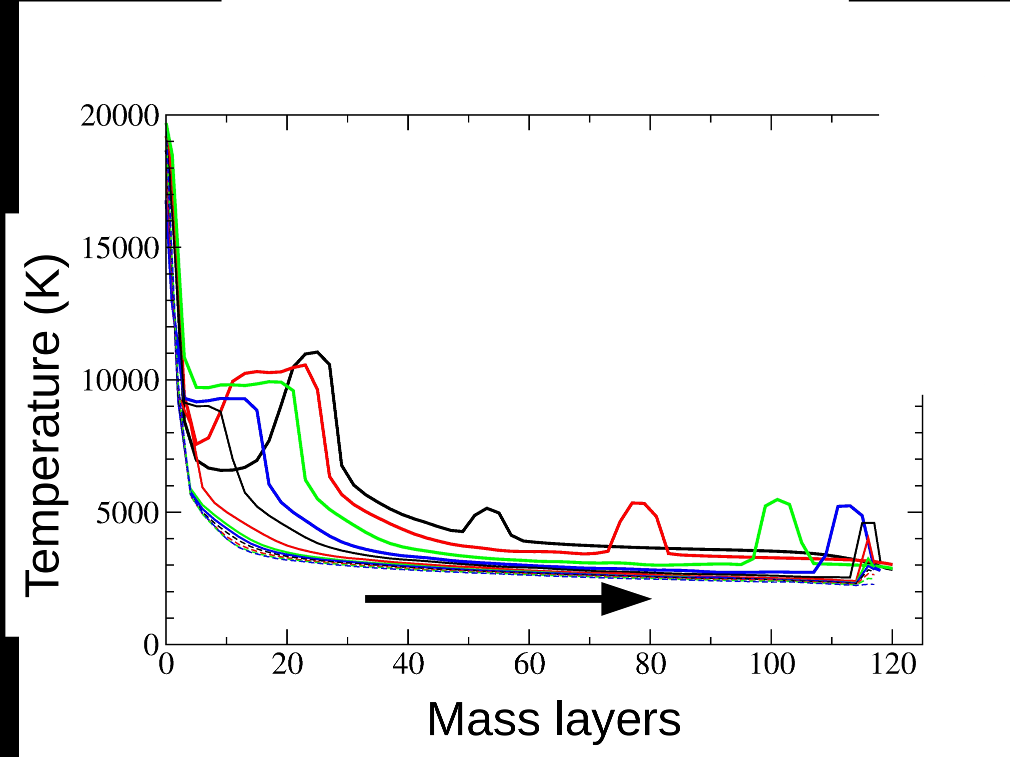
Typical values for Miras :
L from 1000 to 10000 $L_\odot$
T from 2700 to 3400K

Discontinuity of 70 km/s put under the photosphere





Time step : 1.15 days



- The discontinuity splits
- Outward propagation of one of the components

  → <u>shock wave</u>

Summary

- First results :
  - Presence of Balmer lines in emission linked to a shock wave propagation
  - Influence of the model's luminosity and effective temperature on the Balmer lines emissions

- Limitation of models : no convection

- Other parameters to handle:
  - Size and position of the initial discontinuity
  - Non-LTE degree
  - Other atomic lines in emission

→ To be continued