AMHRA (Analyse et Modélisation en HRA) MOIO/JMMC

Armando DOMICIANO DE SOUZA
(OCA-Lagrange)

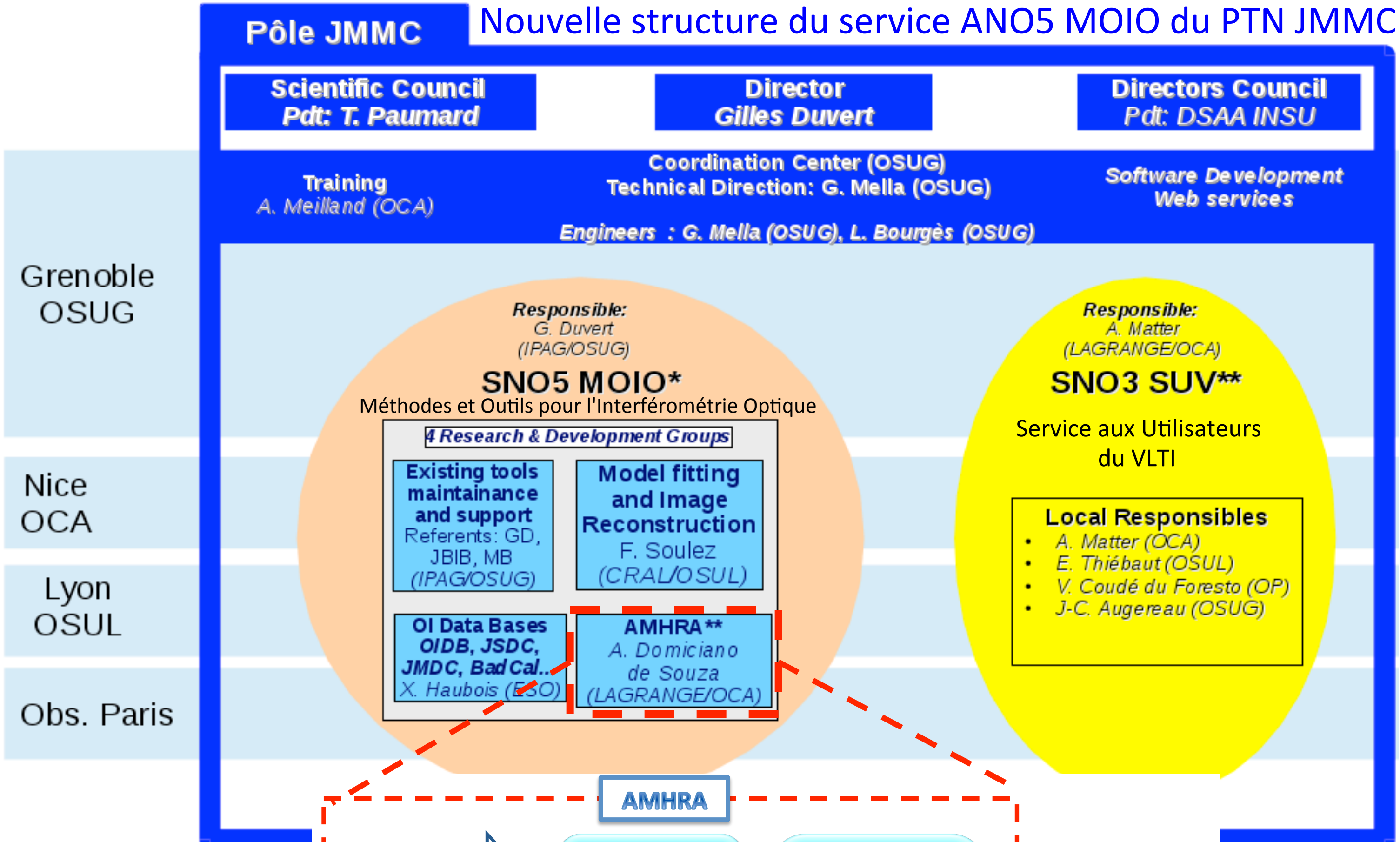
A. Meilland, C. Ordenovic, L. Abe,
A. Chiavassa, F. Guitton (OCA-Lagrange),
L. Bourgès, G. Mella (OSUG)

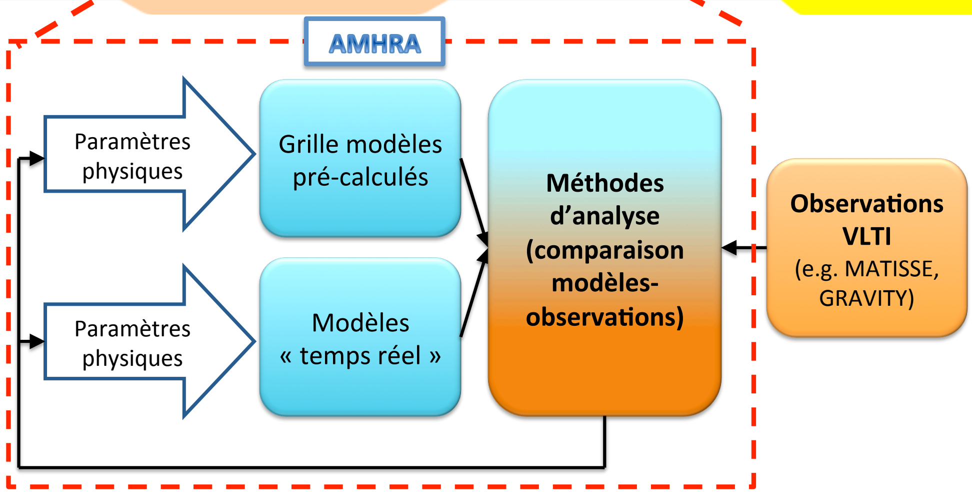
AG du JMMC – OBSPM, Paris, 15 mars 2018

- Présentation de AMHRA
- Modèles astrophysiques
- Prospective
- Démo AMHRA→ASPRO

- Présentation de AMHRA
- Modèles astrophysiques
- Prospective
- Démo AMHRA→ASPRO

AMHRA (ANO5 MOIO - PTN JMMC)



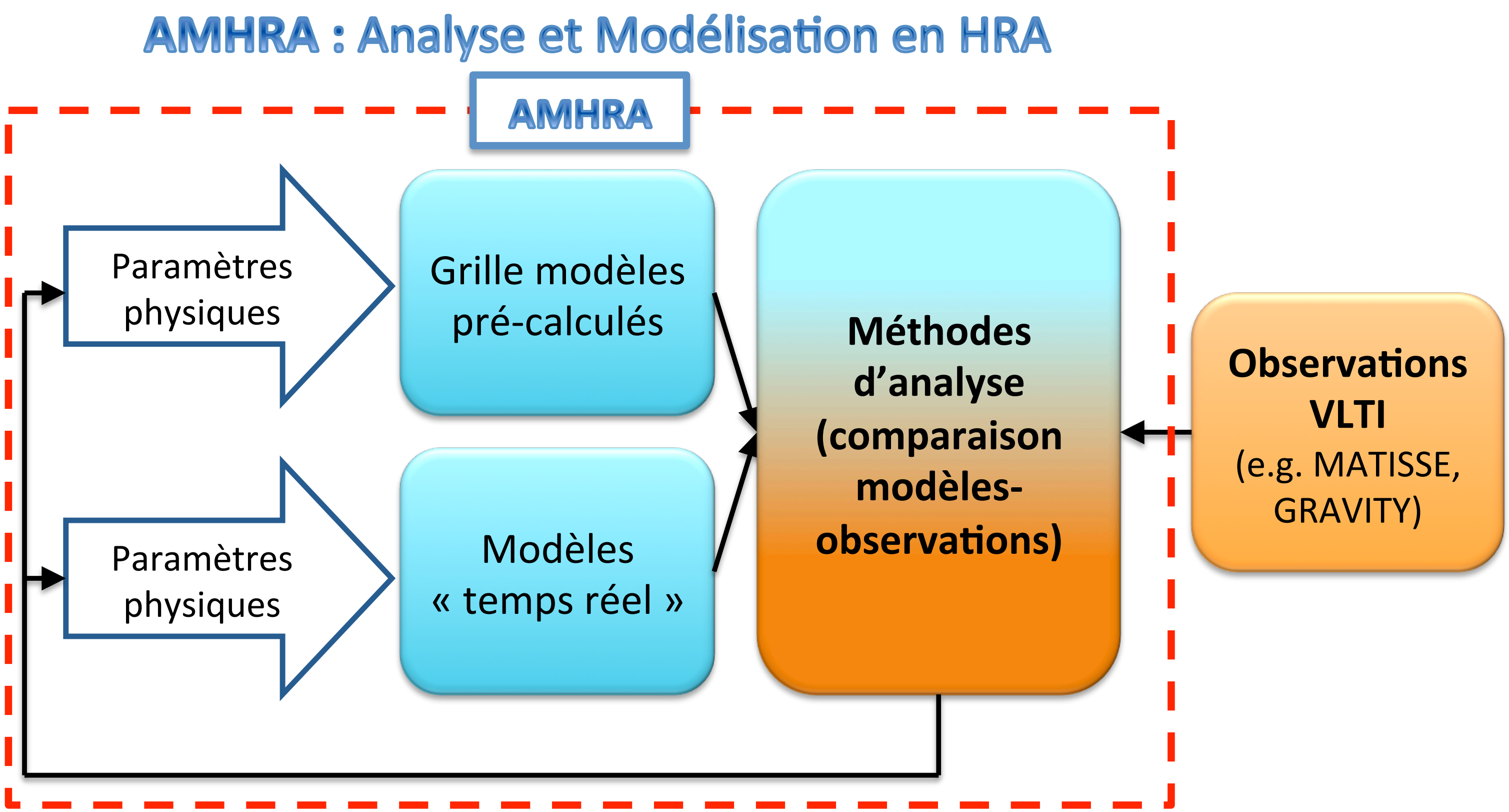


AMHRA : Analyse et Modélisation en HRA

Responsable du groupe:
A.Domiciano de Souza

Membres:
3-4 chercheurs
3-4 ITA

AMHRA (ANO5 MOIO - PTN JMMC)



Objectif d'AMHRA (texte page web MOIO/JMMC) :

… to develop and/or provide astrophysical models and data analysis tools dedicated to the scientific exploitation of high angular and high spectral facilities (in particular ESO-VLTI instruments) by the astronomical community, including non-specialists in interferometry.

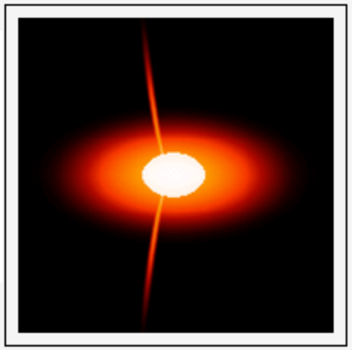
- Présentation de AMHRA
- **Modèles astrophysiques**
- Prospective
- Démo AMHRA→ASPRO

AMHRA: modèles astrophysiques

Real Time astrophysical models

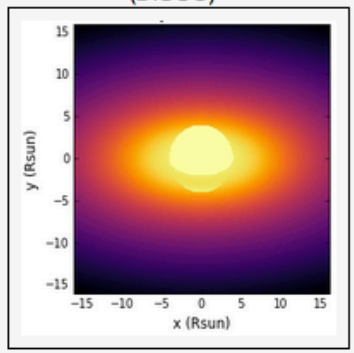
Kinetic Be Disk

A.Meilland



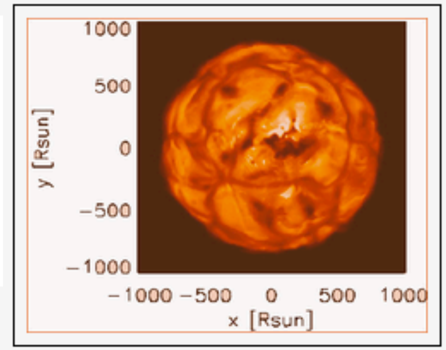
Disc and Stellar Continuum (DISCO)

A.Domiciano



Evolved stars(RSG,AGB) with CO5BOLD

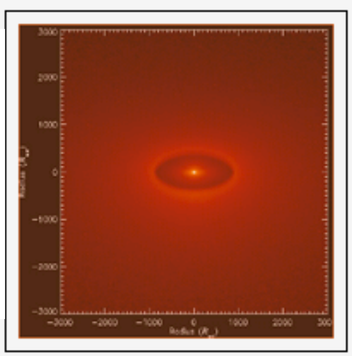
A.Chiavassa



Pre-calculated grids of astrophysical models

Supergiant B[e] with HDUST

A.Domiciano



Modèles disponibles dans la page web AMHRA

(prototype pour beta-tests)

http://azurvo3.oca.eu:8080/AMHRA/index.htm

AMHRA: modèles astrophysiques

Interface web utilisateur de AMHRA

http://azurvo3.oca.eu:8080/AMHRA

(simulation temps-réel ou grilles de modèles)

L'utilisateur défini les valeurs des paramètres physiques du modèle dans un formulaire web

Central Star Parameters

Star Radius :

0.0 Rsun

Star Temperature :

0.0 K

Star Mass :

0.0 MSun

Circumstellar gas-disc parameters

Disc outer radius :

0.0 RSun

Basis disc Temperature:

0.0 K

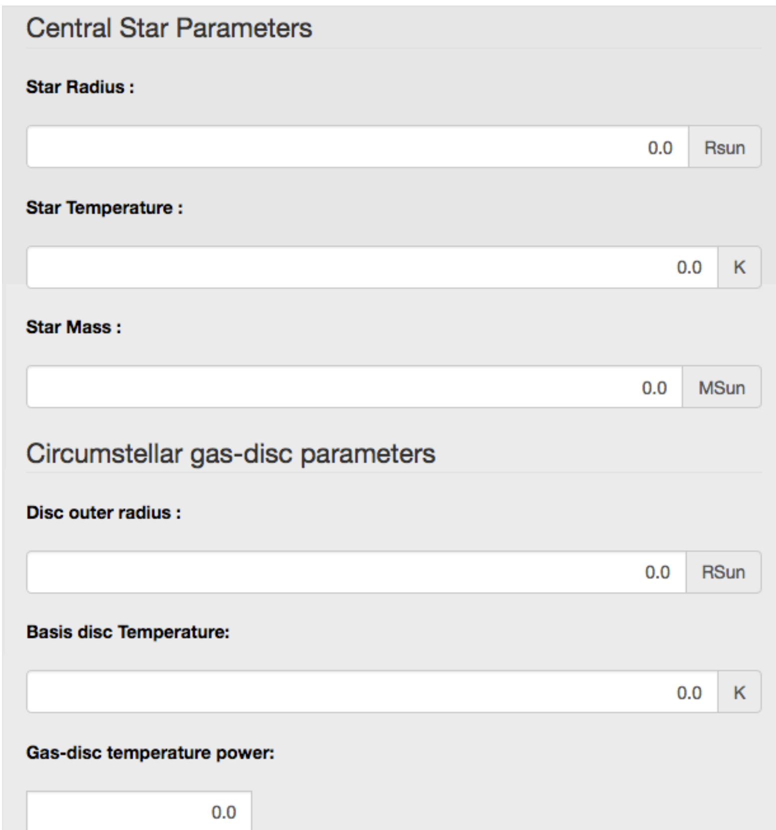
Gas-disc temperature power:

0.0

AMHRA: modèles astrophysiques

Interface web utilisateur de AMHRA
http://azurvo3.oca.eu:8080/AMHRA
(simulation temps-réel ou grilles de modèles)

L'utilisateur défini les valeurs des paramètres physiques du modèle dans un formulaire web



Central Star Parameters

Star Radius : 0.0 Rsun

Star Temperature : 0.0 K

Star Mass : 0.0 MSun

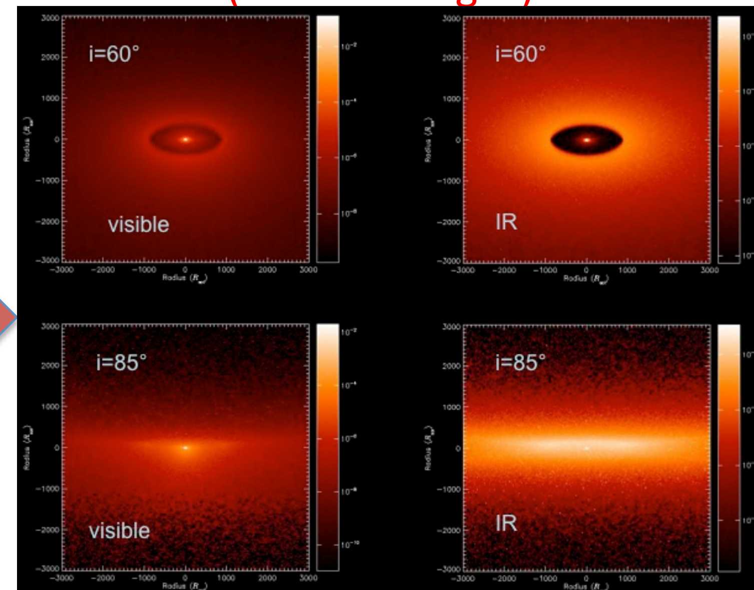
Circumstellar gas-disc parameters

Disc outer radius : 0.0 RSun

Basis disc Temperature: 0.0 K

Gas-disc temperature power: 0.0

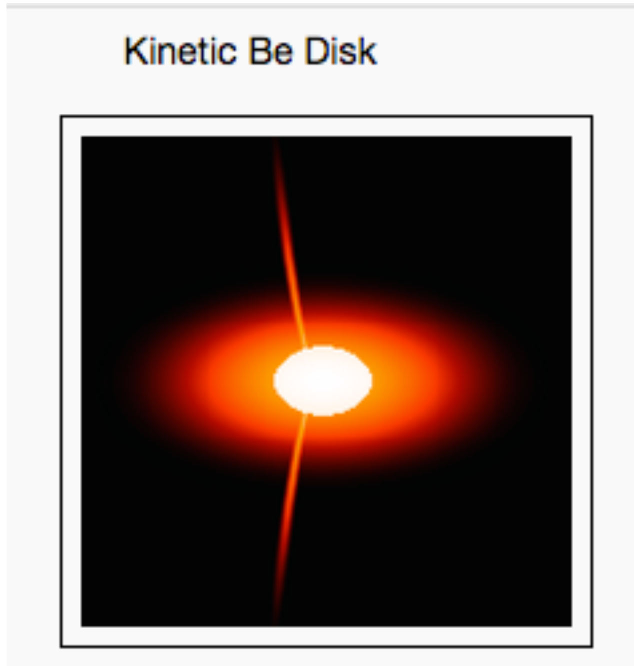
Cartes d'intensité polycromatiques (cube d'images)



Input pour d'autres outils JMMC

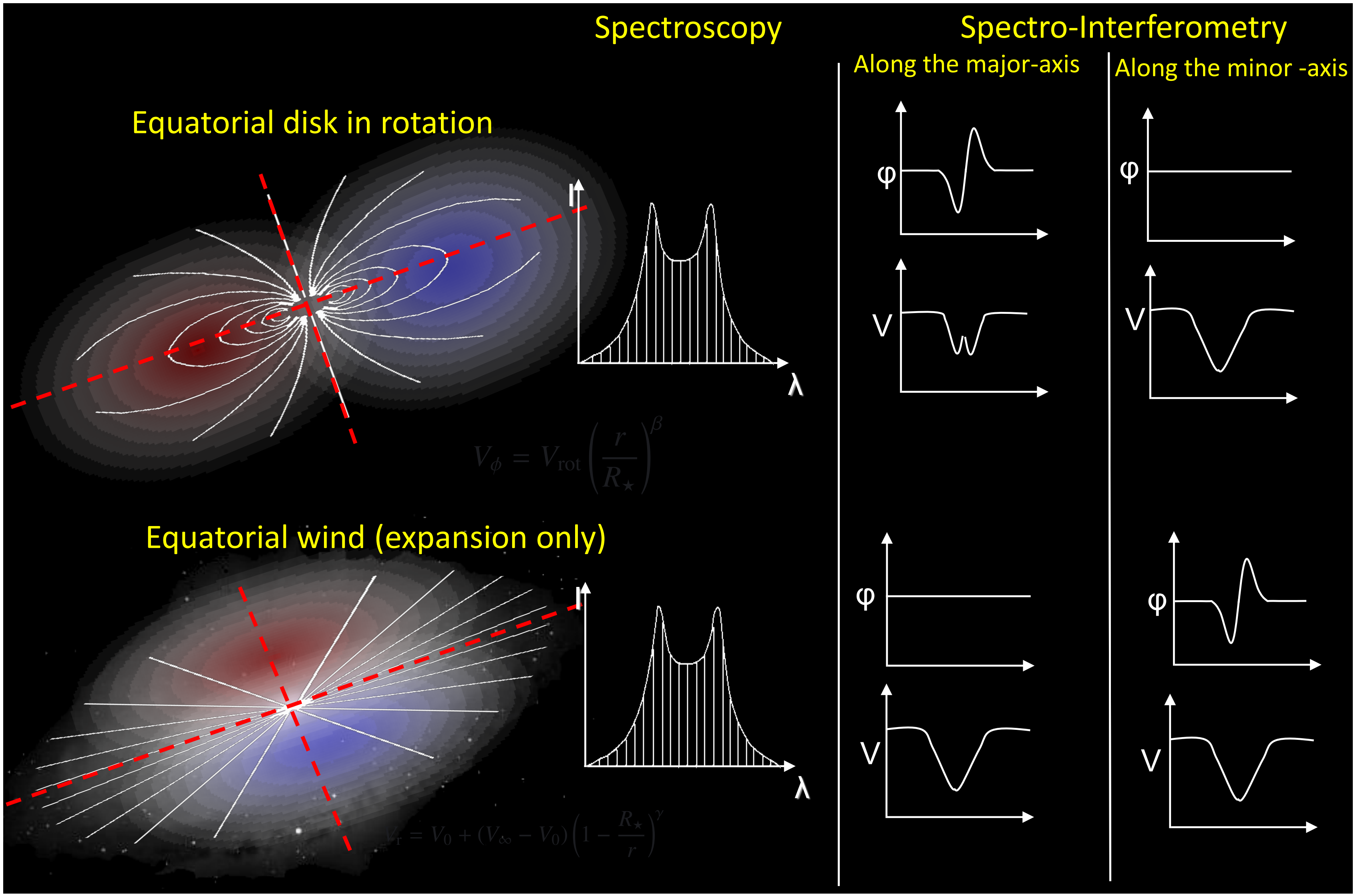
- ✓ **ASPRO** (préparation des observations)
- ✓ **LITPro** (ajustement de modèles)
- ✓ **WISARD, OIMAGING, MIRA**, etc (image de départ pour reconstruction d'images)
- ✓ **SUV** (support aux utilisateurs du VLTI)

Kinetic Be Disc
(A. Meilland)



Delaa et al. 2011, A&A, 529, A87

Kinetic Be Disc (A. Meilland)



Kinetic Be Disc (A. Meilland)

$$V_{\text{proj}}(x,y) = \left(V_\phi \sin\phi - V_{\text{r}} \cos\phi\right) \times \sin i$$

Vitesse projetée pour une inclinaison donnée

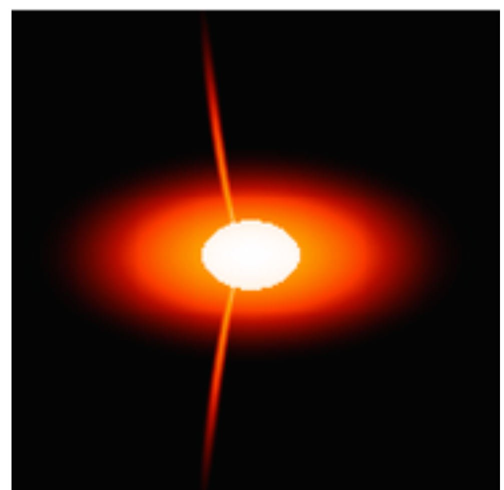
$$R(x,y,\lambda,\delta\lambda) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\left(\frac{V_{\text{proj}}(x,y) - V(\lambda)}{\sqrt{2}\sigma}\right)^2\right]$$

$$\sigma = \frac{\delta V}{2\sqrt{2\ \ln(2)}} = \frac{\delta\lambda\, c}{2\lambda\sqrt{2\ \ln(2)}}$$

Régions d'iso-vitesse avec décalage Doppler

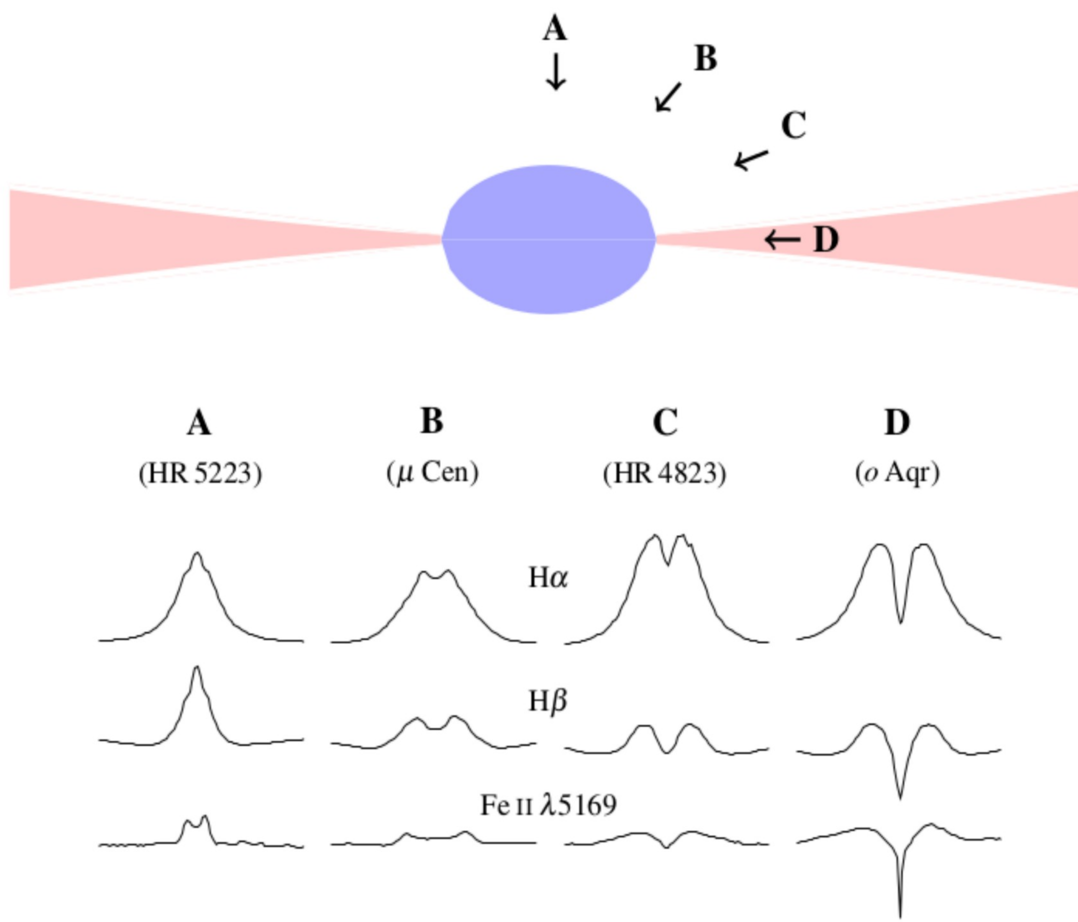
$$I_{\text{tot}}(x,y,\lambda,\delta\lambda) = I_\star(x,y) \times F_\star(\lambda) + I_{\text{env}}(x,y) \times F_{\text{env}} + I_{\text{line}}(x,y) \times R(x,y,\lambda,\delta\lambda) \times EW.$$

Cartes d'intensité (cube d'images) avec contribution de l'étoile centrale, du continuum du gaz et de la raie spectrale en émission



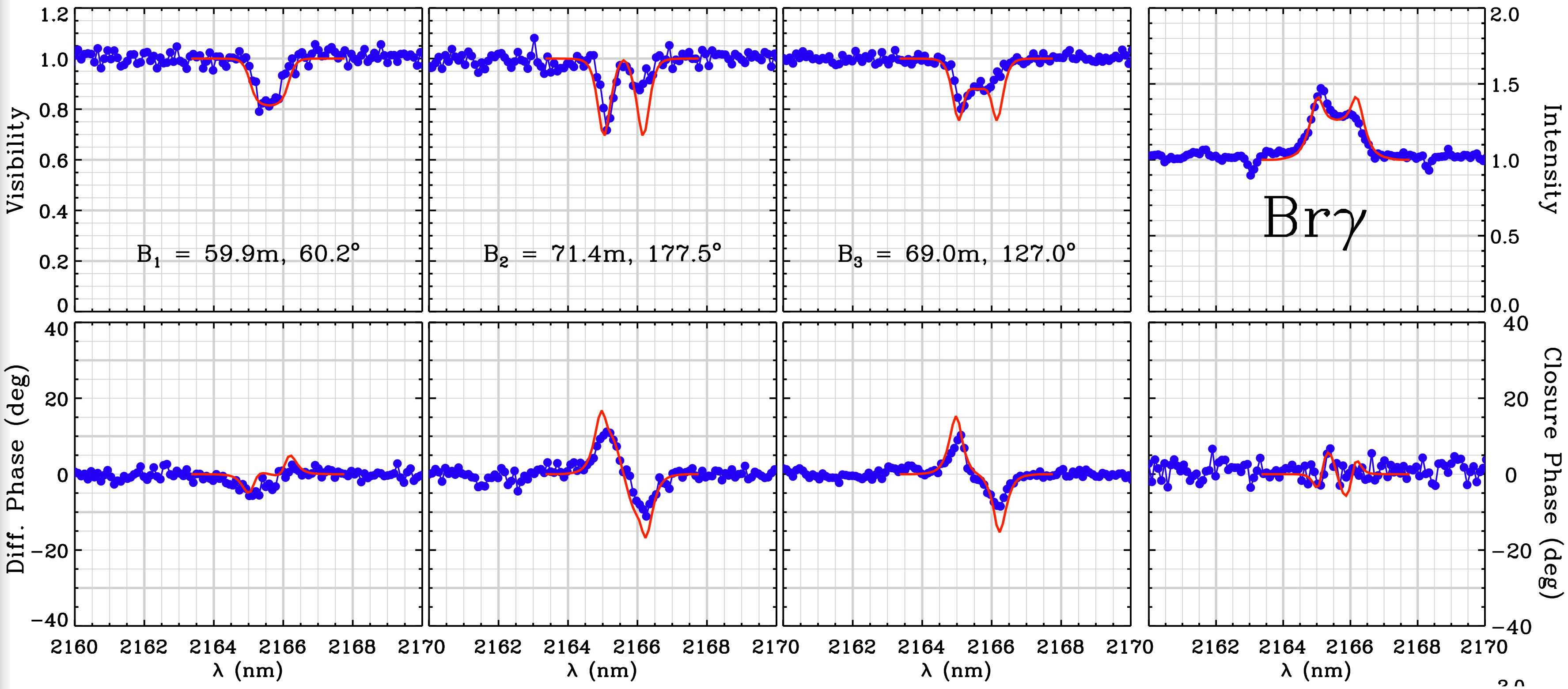
Kinetic Be Disc
(A. Meilland)

Vue schématique d'une étoile Be (étoile + disque)



Kinetic Be Disc (A. Meilland)

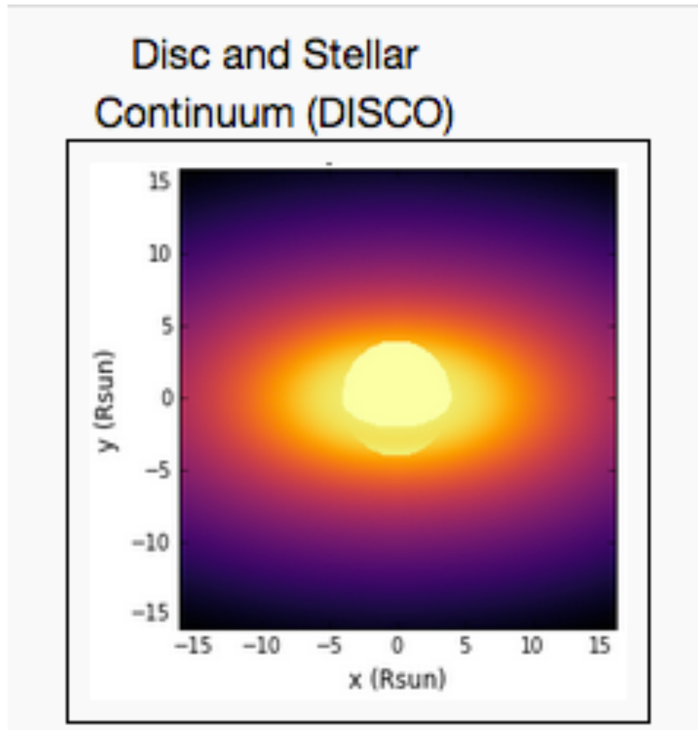
Modélisation d'observables spectro-interférométriques



Meilland et al. 2011

DISCO – DIsc and Stellar COntinuum

(A. Domiciano de Souza)



Vieira et al. 2015, MNRAS, 454, 2107

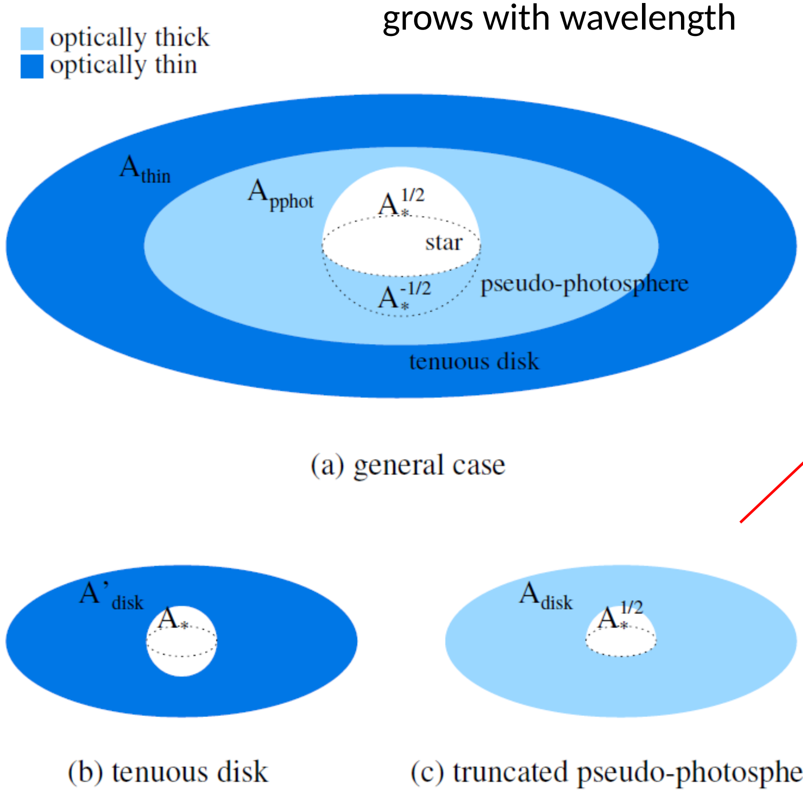
DISCO – DIsc and Stellar COntinuum

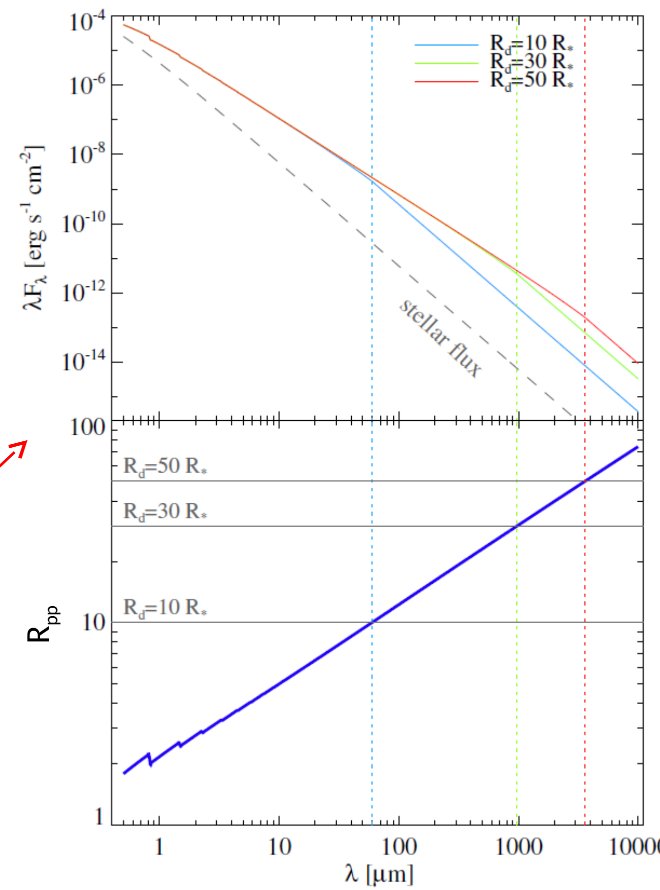
(A. Domiciano de Souza)

VDD continuum emission

Optically thick part (pseudo-photosphere) + optically thin part (tenuous disk)

grows with wavelength



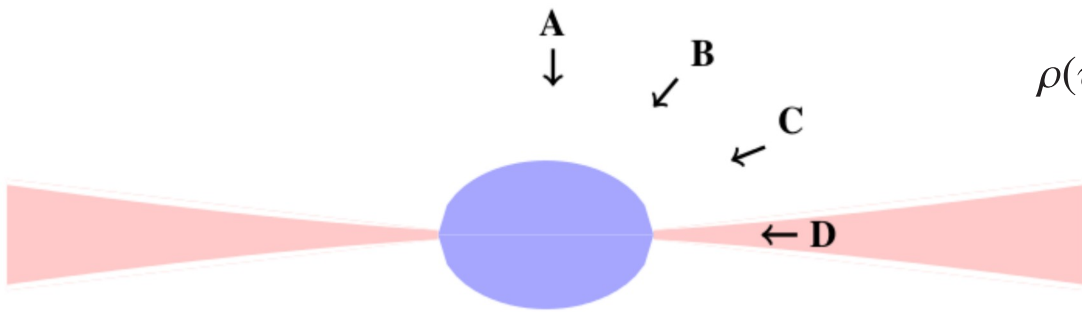


Vieira et al. 2015, MNRAS, 454, 2107

DISCO – DIsc and Stellar COntinuum

(A. Domiciano de Souza)

Viscous Decretion Disc (VDD) model for a geometrically thin disc



$$\rho(\varpi, z) = \rho_0 \left(\frac{\varpi}{R_\star}\right)^{-n} \exp\left(\frac{z^2}{2\,H^2}\right),$$

$$H(\varpi) = H_0 \left(\frac{\varpi}{R_\star}\right)^{\beta},$$

$$\tau_\lambda = \int_{-\infty}^{\infty} \kappa_\lambda dz = \tau_0 \frac{T_\star}{T_d(\varpi)} \left(\frac{\varpi}{R_\star}\right)^{-2n+\beta}.$$

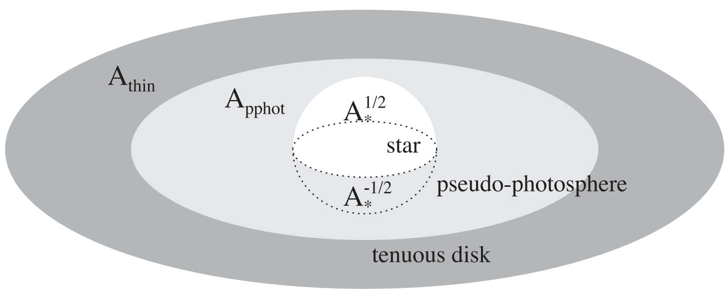
where we define

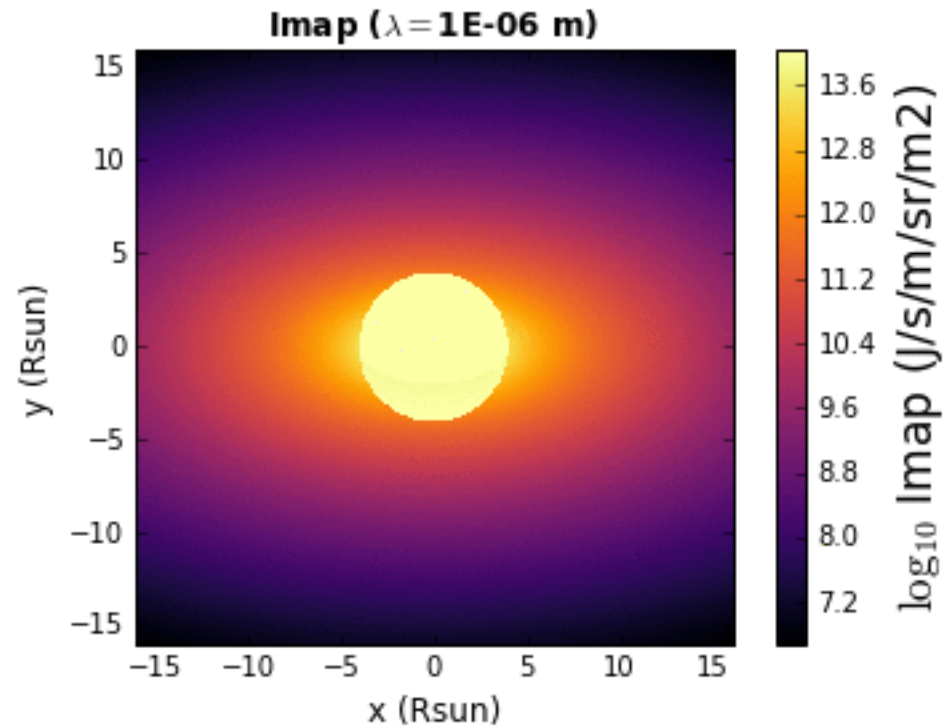
$$\tau_0 = \frac{0.018}{T_\star} \gamma\,\overline{z^2} \left(\frac{\rho_0}{\mu\, m_H}\right)^2 \left(\frac{\pi\, k}{\mu m_H} \frac{R_\star^3}{G M_\star}\right)^{1/2} (\lambda/c)^2 \left[g(\lambda, T_d) + b(\lambda, T_d)\right].$$

Vieira et al. 2015 and 2016

DISCO – DIsc and Stellar COntinuum
(A. Domiciano de Souza)

Cartes d'intensité polycromatiques
(cube d'images)

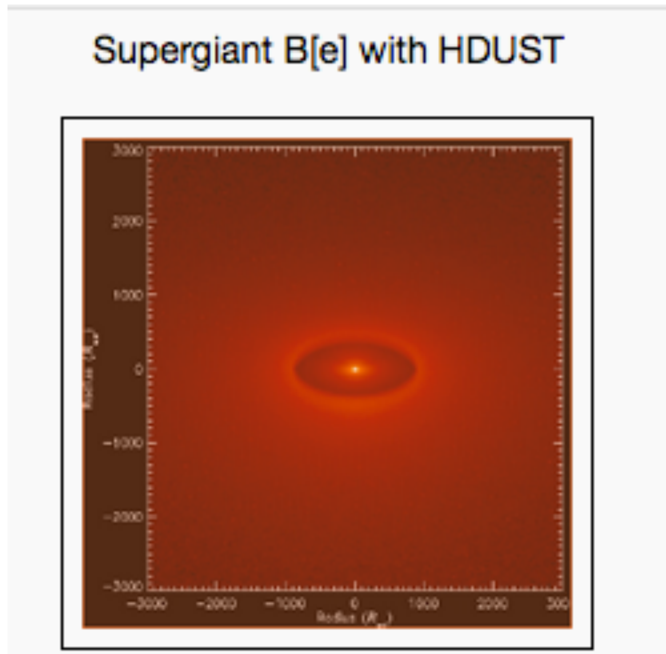




$$I_\lambda(\varpi') = \begin{cases} B_\lambda(T_{\rm eff}) & (A_\star^{1/2}) \\ B_\lambda(T_{\rm eff})\, e^{-\tau_i} + B_\lambda(T_{\rm d})\,[1 - e^{-\tau_i}] & (A_\star^{-1/2}) \\ B_\lambda(T_{\rm d})\,[1 - e^{-\tau_i}] & (A_{\rm disc}), \end{cases}$$

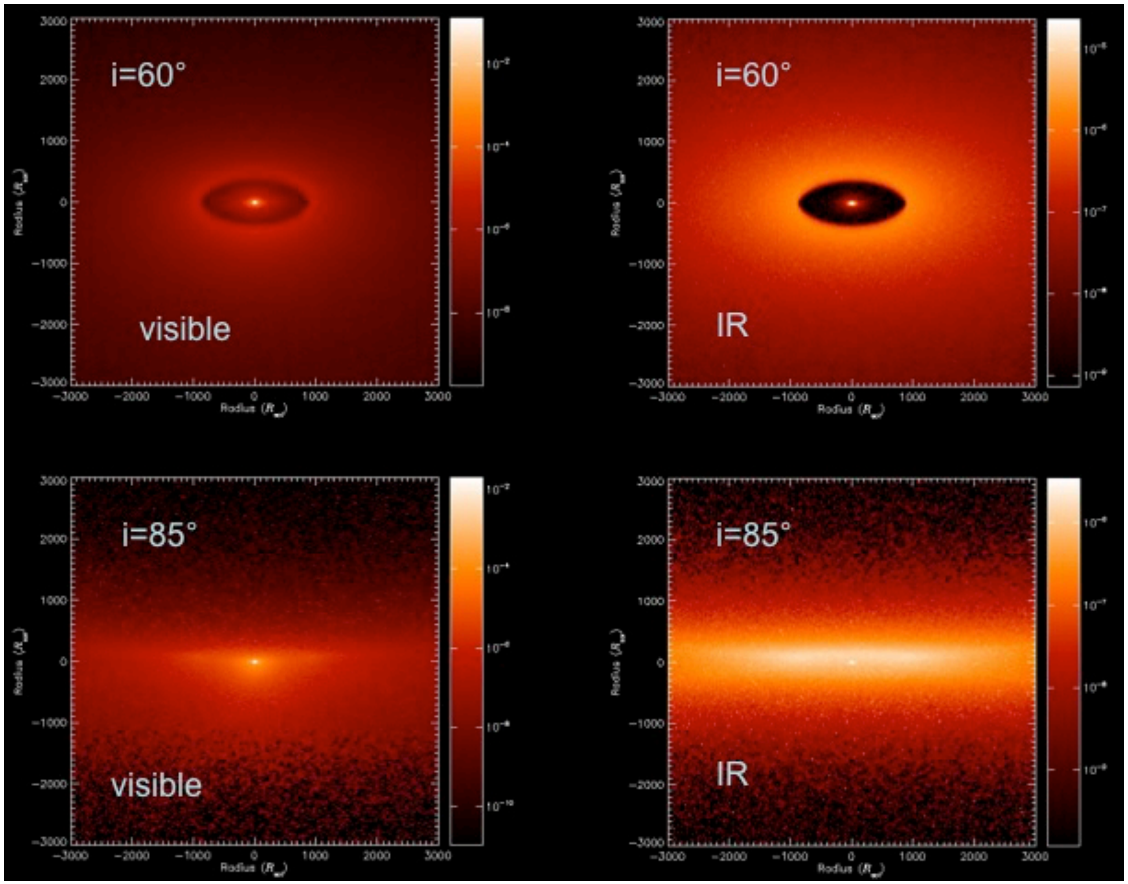
Vieira et al. 2015 and 2016

Grid of supergiant B[e] stars with HDUST
(A. Domiciano de Souza & A.C.Carciofi)



Domiciano de Souza & Carciofi 2012, ASPCS, 464, 149
Carciofi & Bjorkman 2006, ApJ, 2006, 639, 1081

Grid of supergiant B[e] stars with HDUST
(A. Domiciano de Souza & A.C.Carciofi)



Domiciano de Souza & Carciofi 2012, ASPCS, 464, 149

Grid of supergiant B[e] stars with HDUST
(A. Domiciano de Souza & A.C.Carciofi)

Hypothesis (model prescription):

Bimodal mass-loss with gas and dust
Enhanced equatorial mass loss/density
Axial-symmetry

Parametric model:

β law for radiatively driven winds:

$$v_r(r,\theta) = v_0 + [v_\infty(\theta) - v_0](1 - R/r)^{\beta(\theta)}$$

$$v_\infty(\theta) = v_\infty(0)[1 + A_2 \sin^m(\theta)]$$

$$\beta(\theta) = \beta(0)[1 + A_3 \sin^m(\theta)]$$

Bimodal mass-loss/density:

$$\frac{d\dot{M}(\theta)}{d\Omega} = \frac{d\dot{M}(0)}{d\Omega}[1 + A_1 \sin^m(\theta)]$$

$$\rho(r,\theta) = \frac{d\dot{M}(\theta)/d\Omega}{r^2 v(r,\theta)}$$

Stellar and wind parameters of HDUST grid of B[e] models

Parameter	Value
Stellar parameters	
R	$10\,R_\odot$
$T_{\rm eff}$	15 000, 20 000, 25 000 K
L ($\Rightarrow \log(L/L_\odot)$)	$12\,000\,L_\odot$ ($\Rightarrow$ 4.08)
Wind parameters	
$d\dot{M}(0°)/d\Omega$	$50,\ 100 \times 10^{-9}\ M_\odot\ {\rm yr}^{-1}\ {\rm sr}^{-1}$
v_0	$10\ {\rm km\ s}^{-1}$
$v_\infty(0°)$	$600\ {\rm km\ s}^{-1}$
β, A_1, A_2	2, 49, −0.7
m ($\Rightarrow \Delta\theta_{\rm dust}$)	182, 92, 20 ($\Rightarrow$ 5°, 7°, 15°)

Domiciano de Souza & Carciofi 2012, ASPCS, 464, 149

Grid of supergiant B[e] stars with HDUST

(A. Domiciano de Souza & A.C.Carciofi)

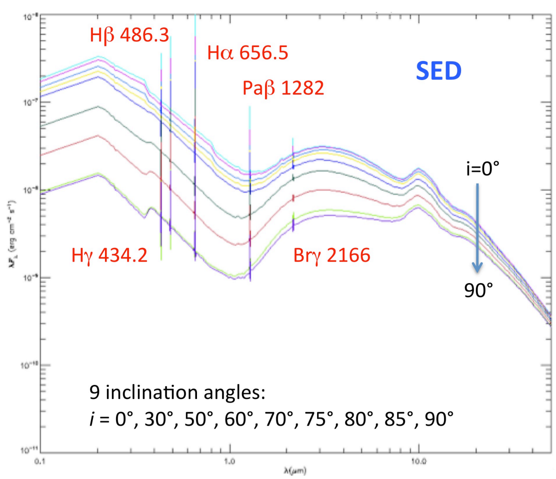
Each file of the grid contains:

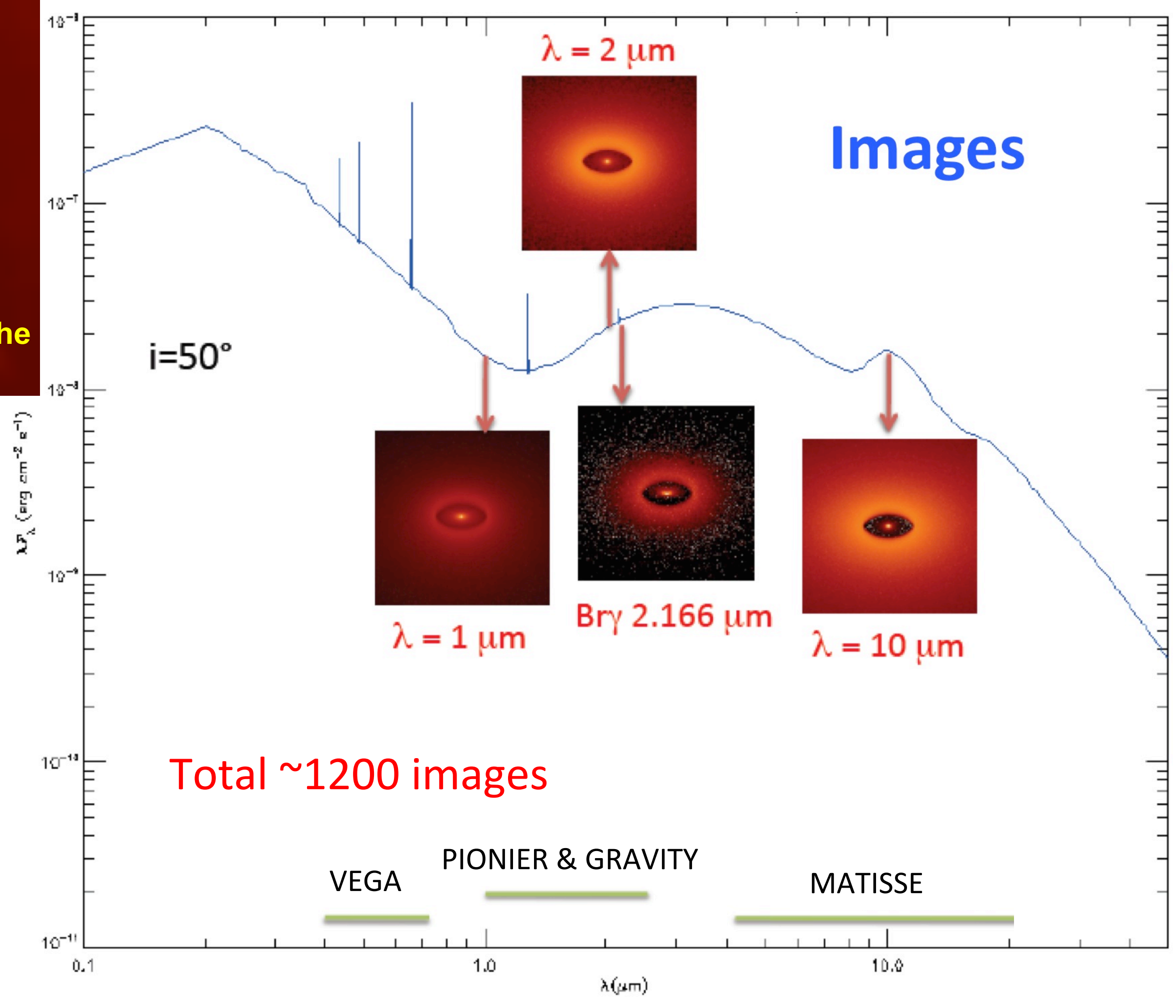
2 spatial scales: 6000 $R_\odot$, 30000 $R_\odot$

9 inclinations:
i = 0°, 30°, 50°, 60°, 70°, 75°, 80°, 85°, 90°

SED from visible to mid-IR with several hydrogen lines (Hα, Hβ, Hγ, Paβ, Brγ)

Images at 34 wavelength bins covering the visible, near- and mid-IR





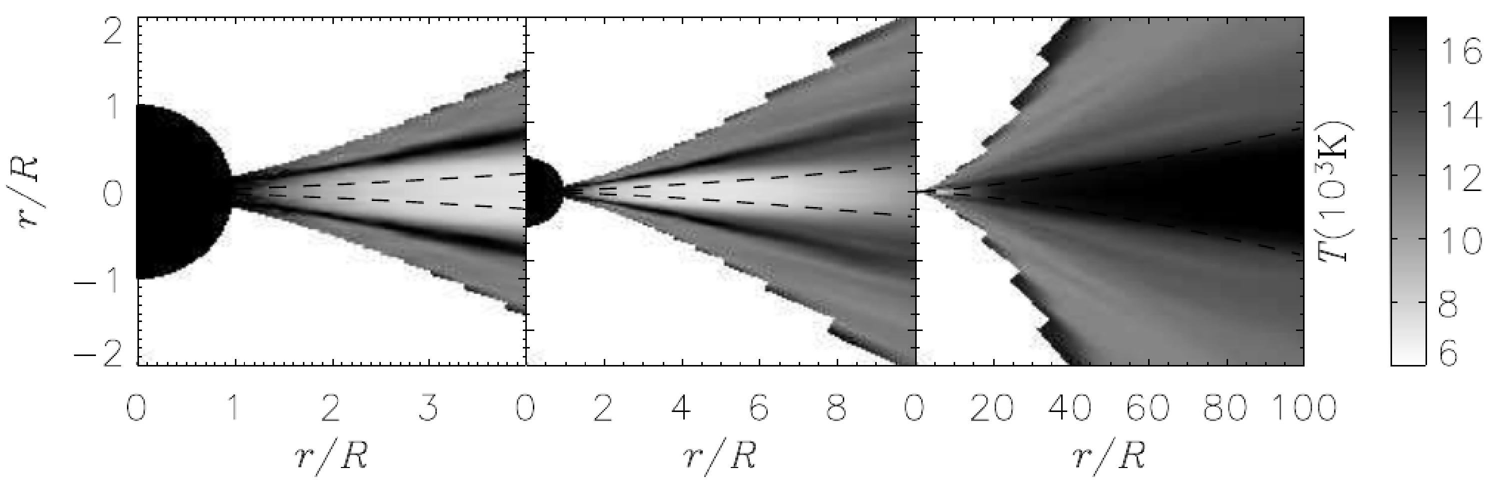
Domiciano de Souza & Carciofi 2012, ASPCS, 464, 149

HDUST code

(A.C.Carciofi & J. Bjorkman 2006, 2008)

3D NLTE Monte Carlo radiative transfer code

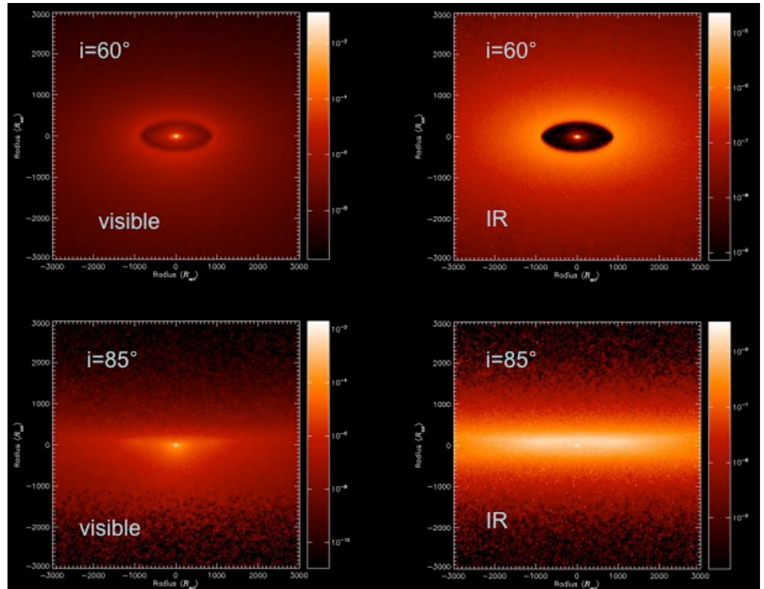
- Solves the transfer of the stellar radiation through the circumstellar environment with arbitrary structure
- Monte Carlo simulation
    - Probabilistic methods are used to simulate the random propagation of individual photon packets (PPs) through the medium
        - **Temperature, ionization (and density) structure** of the circumstellar environment is obtained
        - **Synthetic observables** - polarized spectra and intensity maps



- Présentation de AMHRA
- Modèles astrophysiques
- **Prospective**
- Démo AMHRA→ASPRO

AMHRA+ASPRO2: OIFits Modeler (?)

Cartes d'intensité polycromatiques (cube d'images)



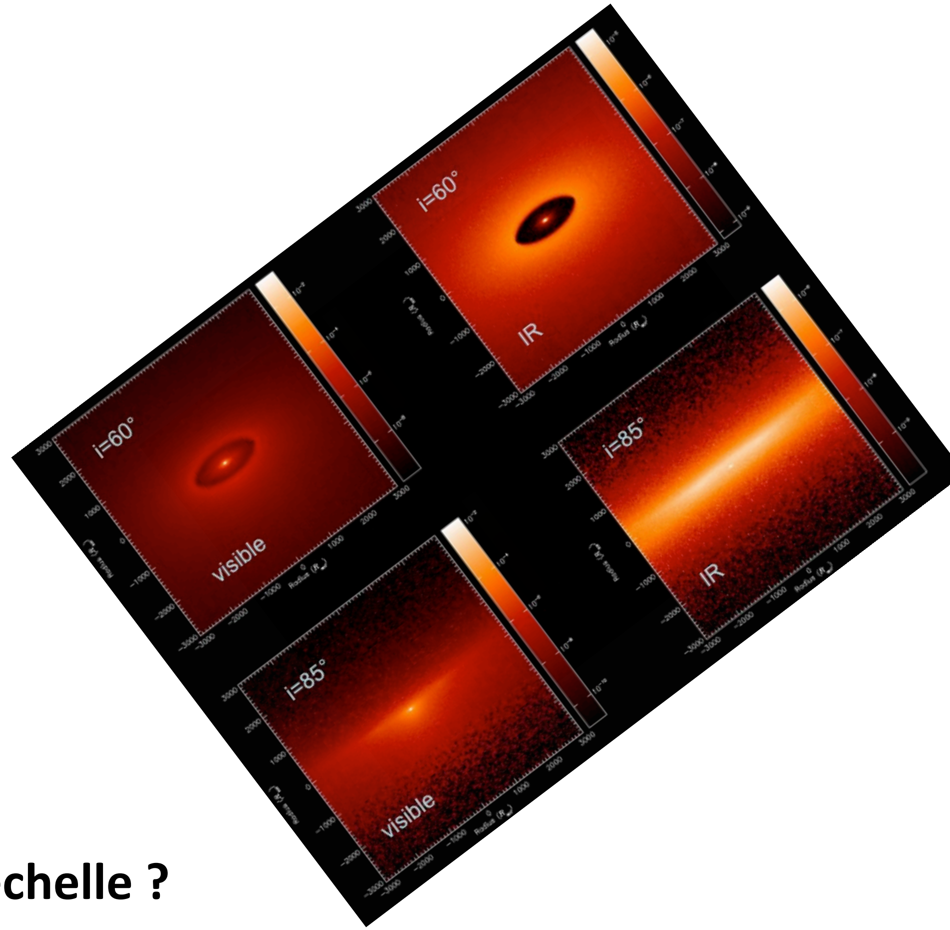
Travail en cours avec L. Bourgès, G. Mella

OIFits d'observations (e.g. MATISSE) → **OIFits Modeler** → **OIFits simulés** (+ chi^2, histogrammes)

Calcul d'observables interférométriques avec les algorithmes d'ASPRO2 + routines en développement pour calcul de chi^2, histogrammes, etc

AMHRA+ASPRO2: OIFits Modeler (?)

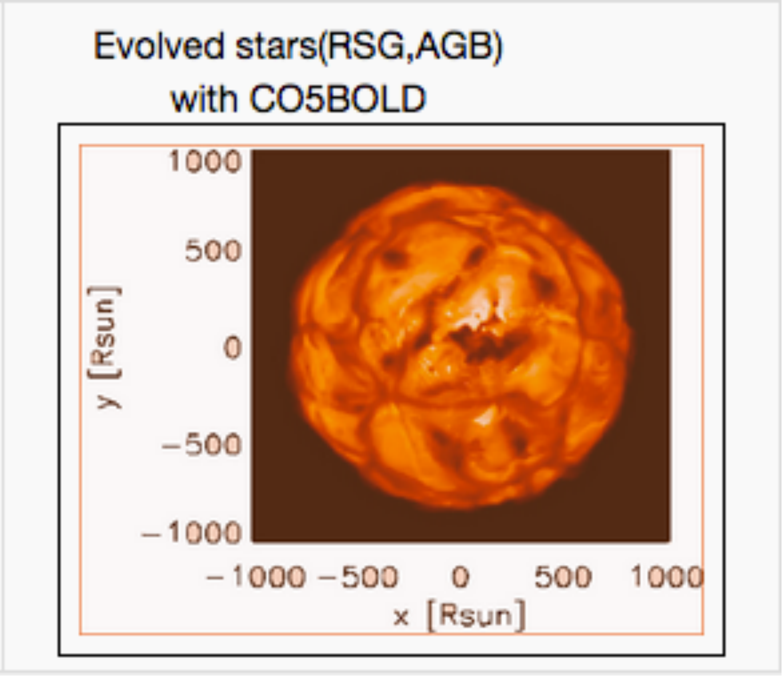
OIFits Modeler



Travail en cours avec
L. Bourgès, G. Mella

Rotation et facteur d'échelle ?

Evolved stars (RSG, AGB) with CO5BOLD
(A. Chiavassa)



Chiavassa et al. 2009, A&A, 506, 1351
Chiavassa et al. 2011, A&A, 535, A22
Freytag et al. 2012, JCoPh, 231, 919

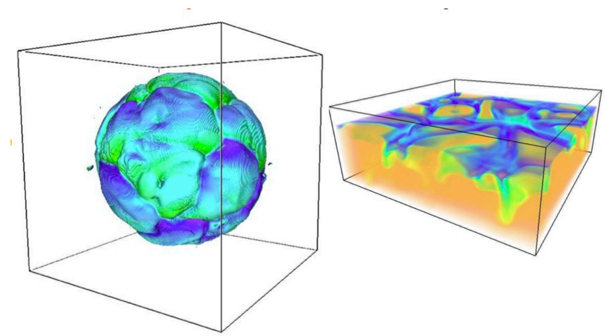
3D hydrodynamical simulations of stellar atmosphere

We use the stellar convection simulation computed with CO5BOLD code (Freytag et al. 2012)

- **Hydrodynamics 3D** (Grid: 200^3 - 300^3 - 400^3), time dependent
- Solution to the equations for the compressible hydrodynamics (conservation of mass, energy, and momentum) coupled with non-local transport of radiation with detailed opacities

Global simulations

Red supergiants and AGBs



3D simulations + Optim3D

- Detailed (billions of atomic and spectral lines) and fast (computational time slightly larger than 1D computation) post processing of 3D simulations with OPTIM3D (Chiavassa, Plez, Josselin, Freytag 2009, A&A, 506, 1351)

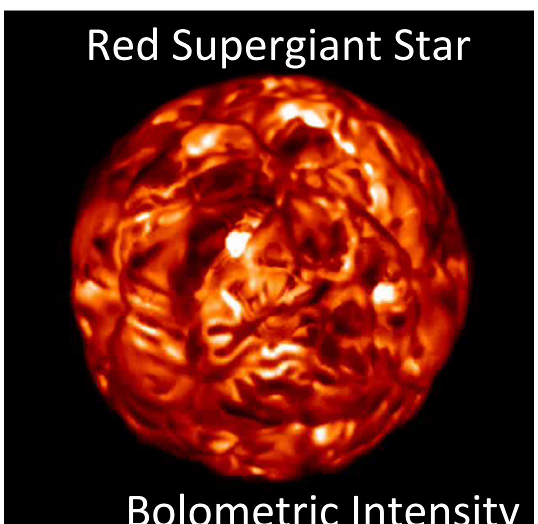
3D hydrodynamical simulations of stellar atmosphere

Typical values of a 3D simulation for:

Red Supergiant star:

Teff = 3500 K
Numerical resolution = 401^3
Log(g) = -0.33
Radius = 840 $R_{\odot}$
Luminosity = 90000 $L_{\odot}$
Mass enveloppe = 3 $M_{\odot}$
Total Mass = 12 $M_{\odot}$

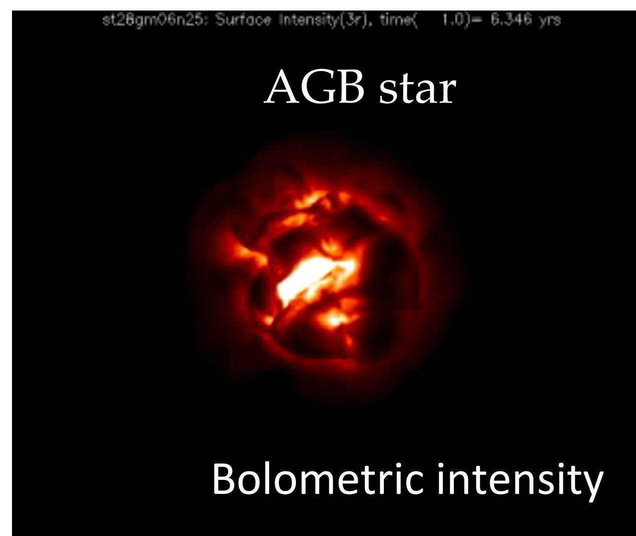
Chiavassa, Freytag, Masseron, Plez 2011, A&A, 535, A22



AGB star:

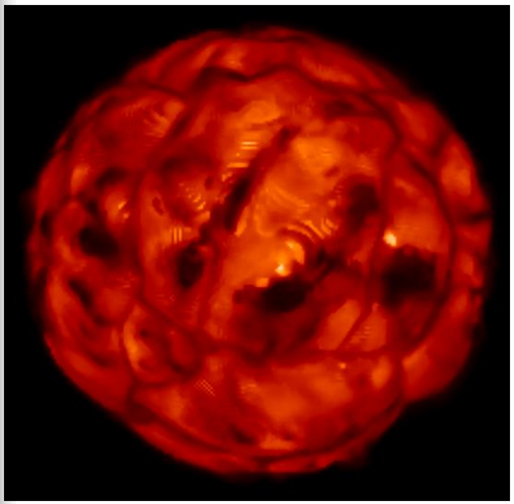
Teff = 2500 K
Numerical resolution = 401^3
Log(g) = -0.83
Radius = 429 $R_{\odot}$
Luminosity = 7000 $L_{\odot}$
Mass enveloppe = 0.186 $M_{\odot}$
Total Mass = 1 $M_{\odot}$

Freytag et al. 2017, A&A, 600, A137

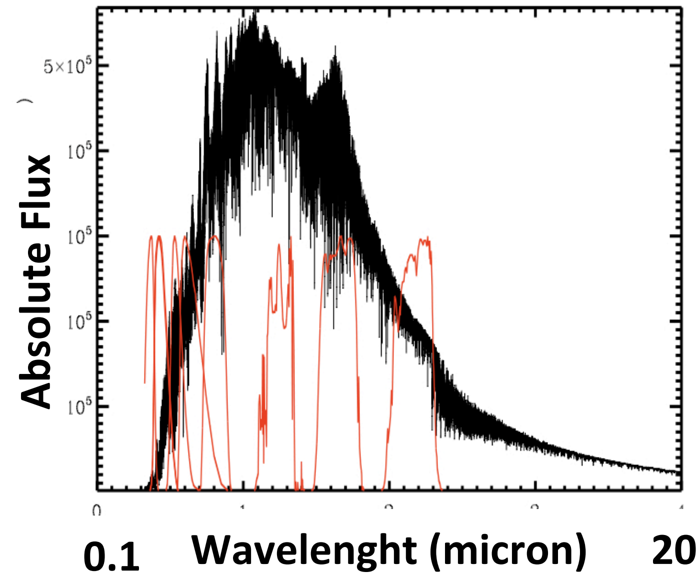


Detailed 3D radiative transfert code

Realistic 3D modelisation



OPTIM3D



Observations

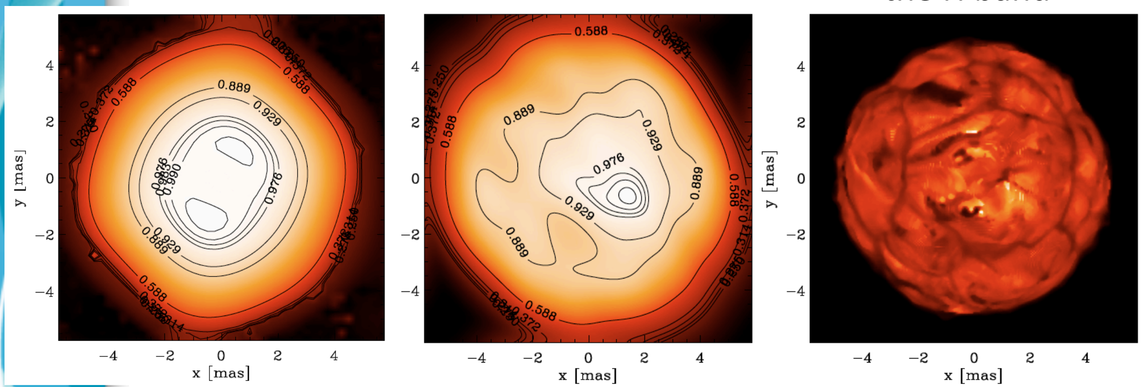
(Interferometry, spectrophotometry, astrometry, images)

Some Results

Resconstructed image with VLTI

Convolved image

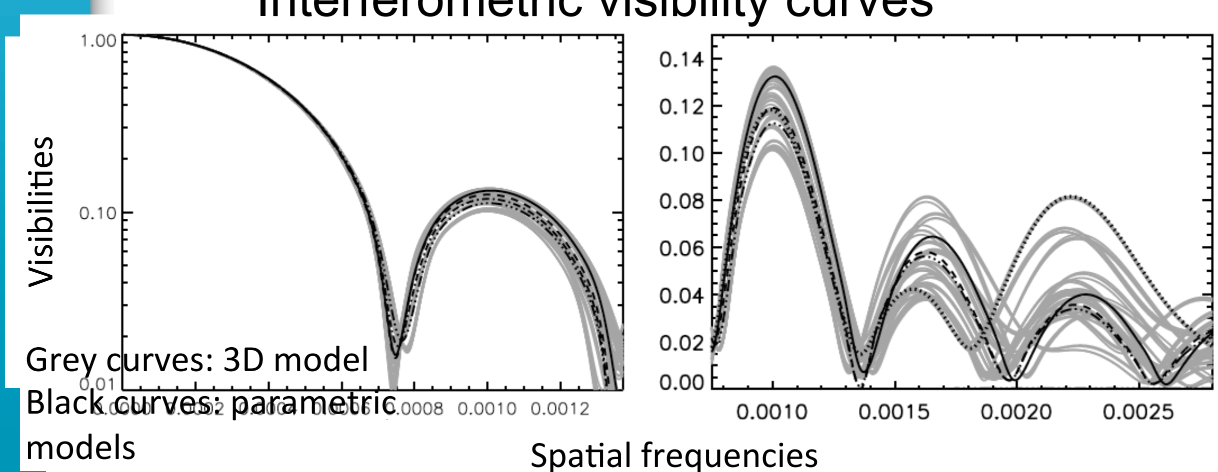
Simulated image in the H band



Chiavassa, Lacour, Millour et al. 2010, A&A, 511, A51

First image of a massive evolved star with VLTI Amber

Interferometric visibility curves



Chiavassa, Plez, Josselin, Freytag 2009, A&A, 506, 1351

Incertitude on radius determination. Clear deviations from spherical symmetry! Signature of convection

Cartes d’intensité

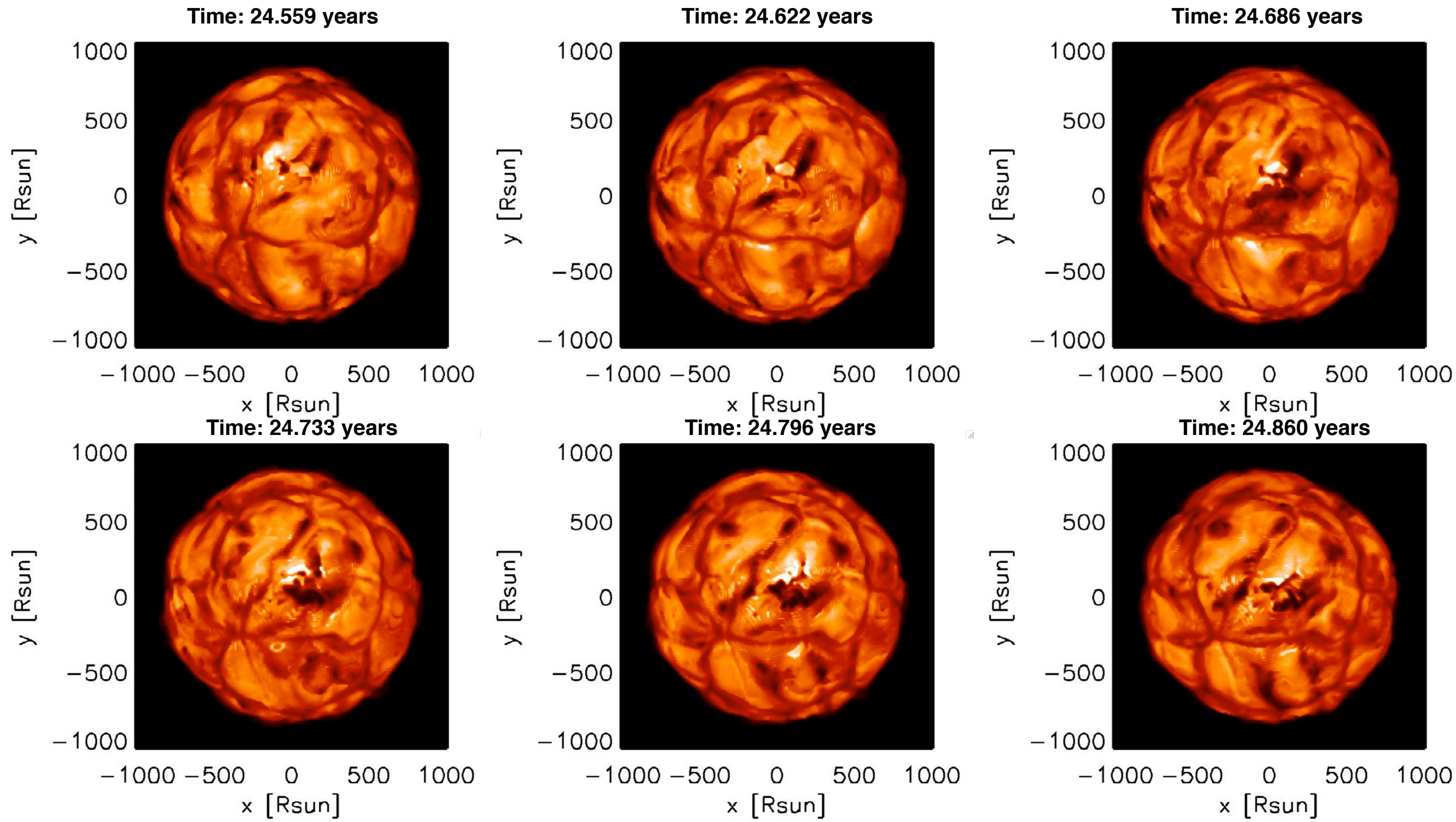


Fig. 4. *Top 6 panels*: maps of the intensity in the IONIC filter (linear scale with a range of [0;2.5 × 10^5] erg cm^{-2} s^{-1} $Å^{-1}$). The different panels correspond to snapshots separated by 230 days (~3.5 years covered). *Bottom 6 panels*: successive snapshots separated by 23 days (~140 days covered).

Chiavassa et al. 2009, A&A 506, 1351

- Présentation de AMHRA
- Modèles astrophysiques
- Prospective
- Démo AMHRA→ASPRO2