Disentangling and tomography: new tools in the analysis of binary systems

Laurent Mahy

GAPHE

Overview

- Disentangling
  - Gonzalez & Levato (2006)
  - Simon & Sturm (1994)
- Doppler Tomography
  - Filter-back projection
  - Algebraic methods
- Conclusions

Disentangling

Three different kinds of method exist:

1. Spectral separation

   (Doppler tomography, Subtraction procedure,...)

2. Spectral disentangling

   (SD in wavelenth domain, SD in Fourier domain, Iteration procedure differencing,...)

3. Spectroastrometric splitting

For more information, see Hensberge & Pavlovski (2007) and Pavlovski & Hensberge (2009)

Disentangling

Three different kinds of method exist:

1. ~~Spectral separation~~

   ~~(Doppler tomography, Subtraction procedure,...)~~

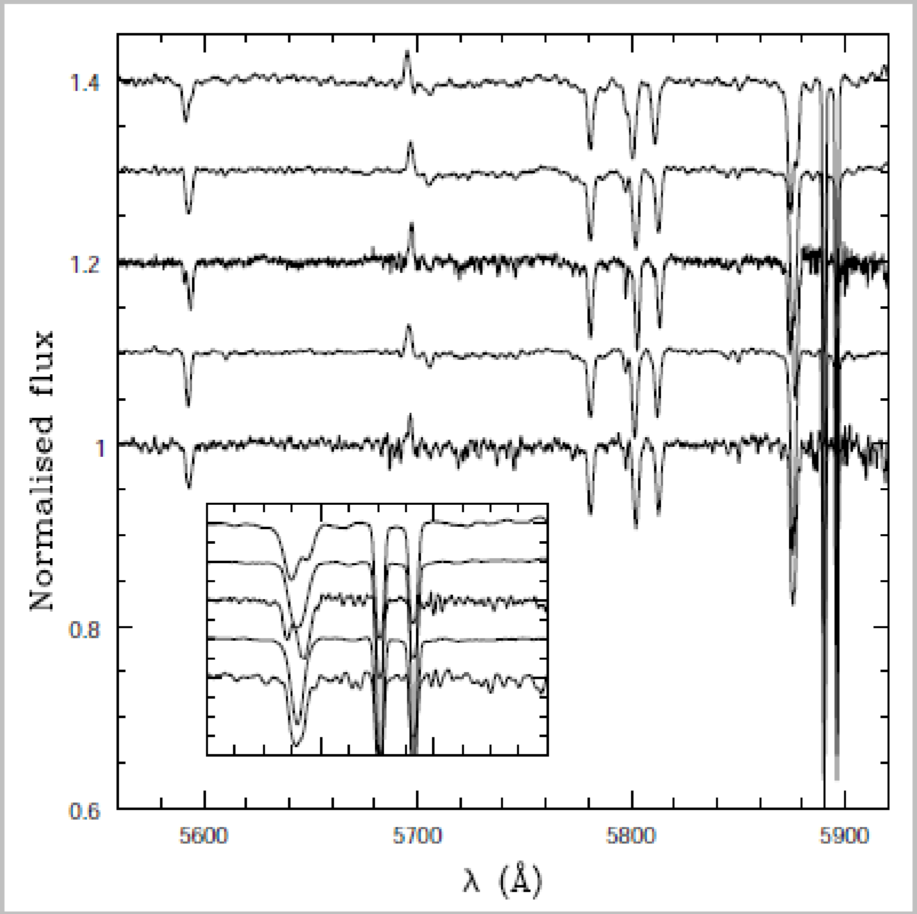
2. Spectral disentangling

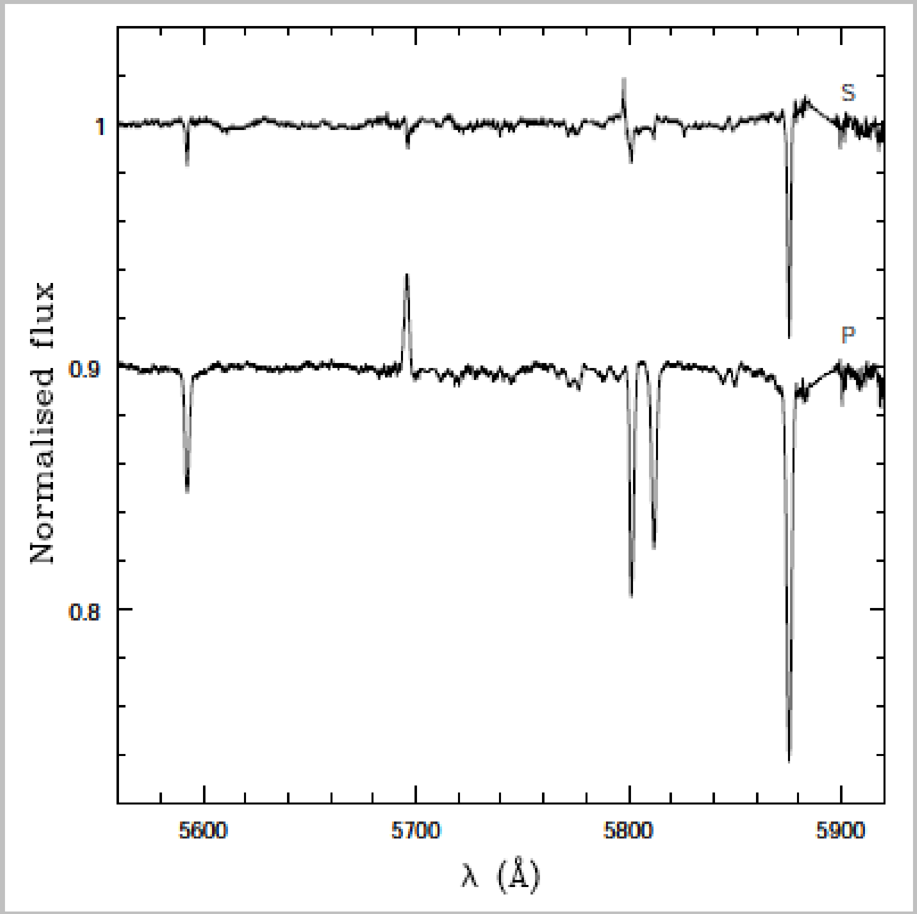
   (SD in wavelenth domain, SD in Fourier domain, Iteration procedure differencing,...)

3. ~~Spectroastrometric splitting~~

For more information, see Hensberge & Pavlovski (2007) and Pavlovski & Hensberge (2009)

How does it work?





Iterative procedure differencing

Gonzalez & Levato (2006)

We work in logarithmic scale

$$\begin{aligned} \ln\lambda &= \ln[\lambda_0(1+\frac{v}{c})] \\ &= \ln\lambda_0 + \ln(1+\frac{v}{c}) \\ &\simeq \ln\lambda_0 + \frac{v}{c} \\ \Rightarrow x &\simeq x_0 + \frac{v}{c} \end{aligned}$$

For a binary system:

$$S(x) = A(x - \frac{v_A(\phi)}{c}) + B(x - \frac{v_B(\phi)}{c})$$

$$\begin{aligned} A(x) &= \frac{1}{n}\sum_{i=1}^{n}\left[S_i\left(x+\frac{v_A(\phi_i)}{c}\right) - B\left(x - \frac{v_B(\phi_i)}{c} + \frac{v_A(\phi_i)}{c}\right)\right] \\ B(x) &= \frac{1}{n}\sum_{i=1}^{n}\left[S_i\left(x+\frac{v_B(\phi_i)}{c}\right) - A\left(x - \frac{v_A(\phi_i)}{c} + \frac{v_B(\phi_i)}{c}\right)\right] \end{aligned}$$

For a triple system or a double + interstellar medium system:

$$S(x) = A(x - \frac{v_A(\phi)}{c}) + B(x - \frac{v_B(\phi)}{c}) + C(x - \frac{v_C(\phi)}{c})$$

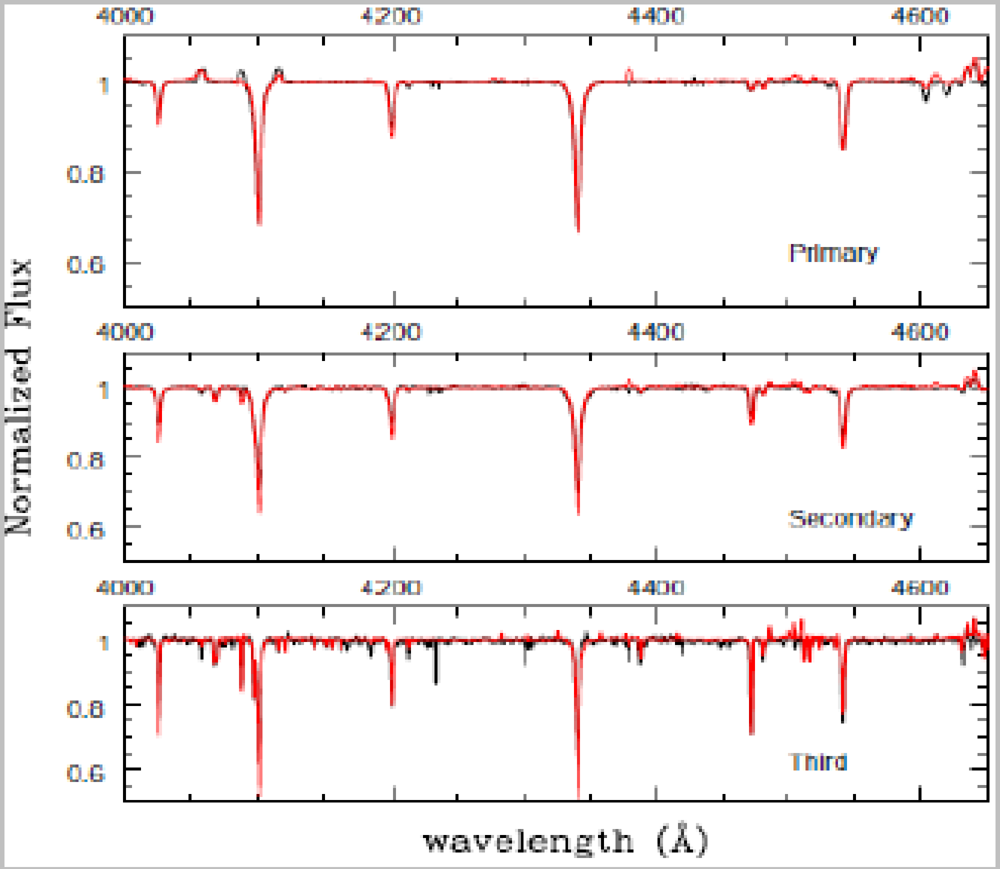
$$\begin{aligned} A(x) &= \frac{1}{n}\sum_{i=1}^{n}\left[S_i\left(x+\frac{v_A(\phi_i)}{c}\right) - B\left(x - \frac{v_B(\phi_i)}{c} + \frac{v_A(\phi_i)}{c}\right) - C\left(x - \frac{v_C(\phi_i)}{c} + \frac{v_A(\phi_i)}{c}\right)\right] \\ B(x) &= \frac{1}{n}\sum_{i=1}^{n}\left[S_i\left(x+\frac{v_B(\phi_i)}{c}\right) - C\left(x - \frac{v_C(\phi_i)}{c} + \frac{v_B(\phi_i)}{c}\right) - A\left(x - \frac{v_A(\phi_i)}{c} + \frac{v_B(\phi_i)}{c}\right)\right] \\ C(x) &= \frac{1}{n}\sum_{i=1}^{n}\left[S_i\left(x+\frac{v_C(\phi_i)}{c}\right) - A\left(x - \frac{v_A(\phi_i)}{c} + \frac{v_C(\phi_i)}{c}\right) - B\left(x - \frac{v_B(\phi_i)}{c} + \frac{v_C(\phi_i)}{c}\right)\right] \end{aligned}$$

Iterative procedure differencing

Gonzalez & Levato (2006)

At each iteration, the programme re-computes the Rvs of the different components by cross-correlation

Now, I am able to separate the contribution of every components in a triple system as made for HD 150136, the nearest system composed of an O3 star



Spectral disentangling in wavelength domain

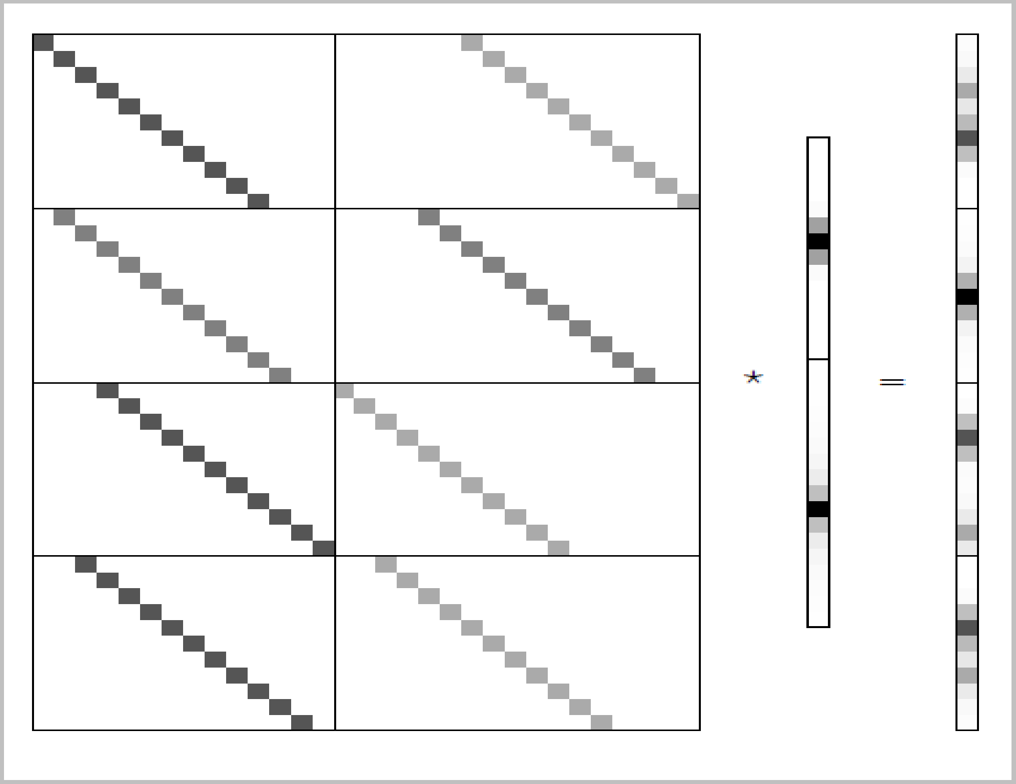
Simon & Sturm (1994)

We consider the following system:

$$A\,x = y$$ where A = Coefficient matrix

x = component spectra

y = observed spectra



Gonzalez & Levato vs. Simon & Sturm

Gonzalez & Levato (2006)

- Computation of radial velocities by cross-correlation
- Can fit the entire wavelength domain
- Faster
- Bad normalization
- Better resolution
- Need to be corrected by the brightness ratio

Simon & Sturm (1994)

- Computation of orbital parameters (K, a sin i, e,...)
- Focus on small parts of the spectrum
- Slow programme due to the matricial computation
- Good normalization
- Noisy results
- Brightness ratio can be directly implemented

Doppler Tomography

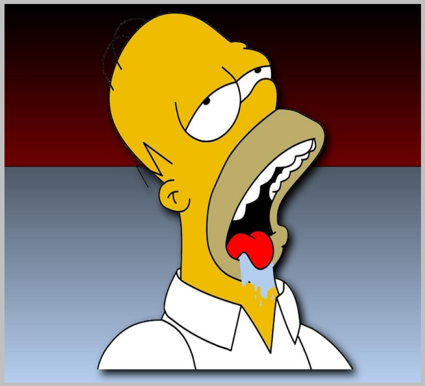
Method used to map the wind interaction zone based on the medical imagery

In medical imagery:

Doppler Tomography

Method used to map the wind interaction zone based on the medical imagery

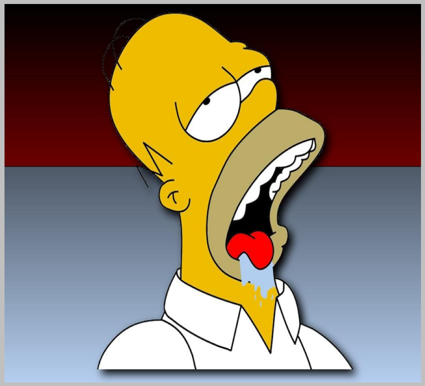
In medical imagery:



Doppler Tomography

Method used to map the wind interaction zone based on the medical imagery

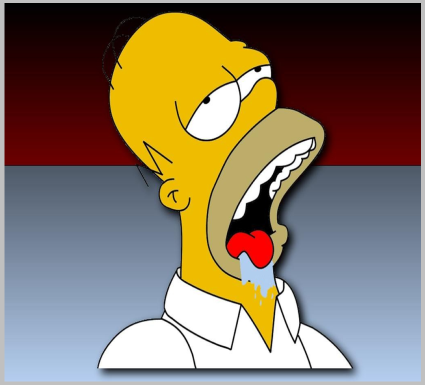
In medical imagery:

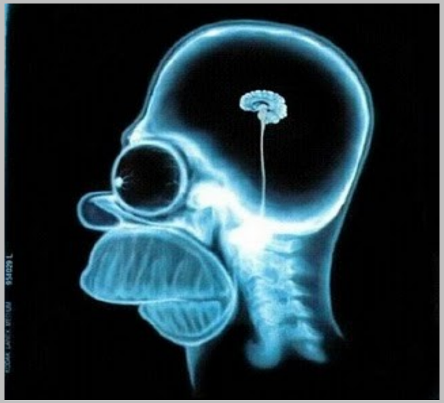


Doppler Tomography

Method used to map the wind interaction zone based on the medical imagery

In medical imagery:

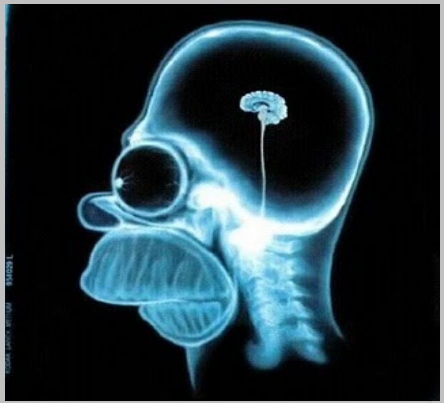


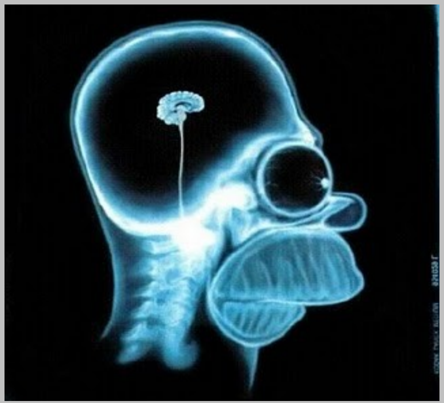


Doppler Tomography

Method used to map the wind interaction zone based on the medical imagery

In medical imagery:

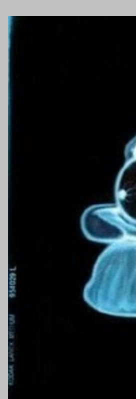


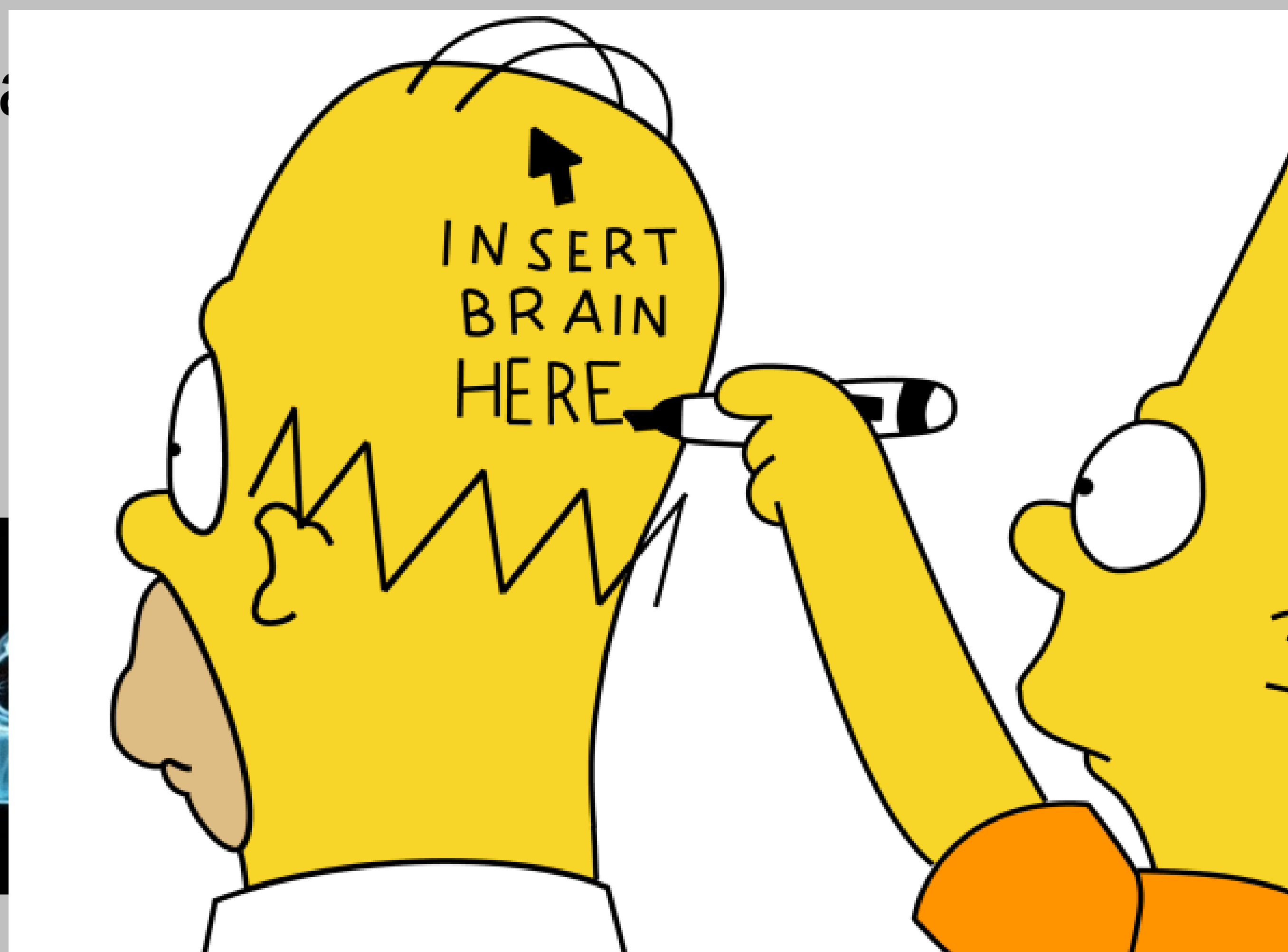


Doppler Tomography

Method used to map the wind interaction zone based on the medical imagery

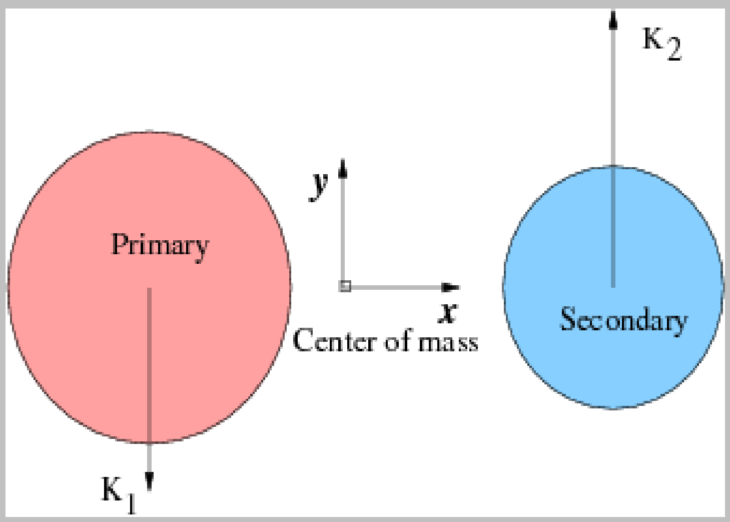
In medica

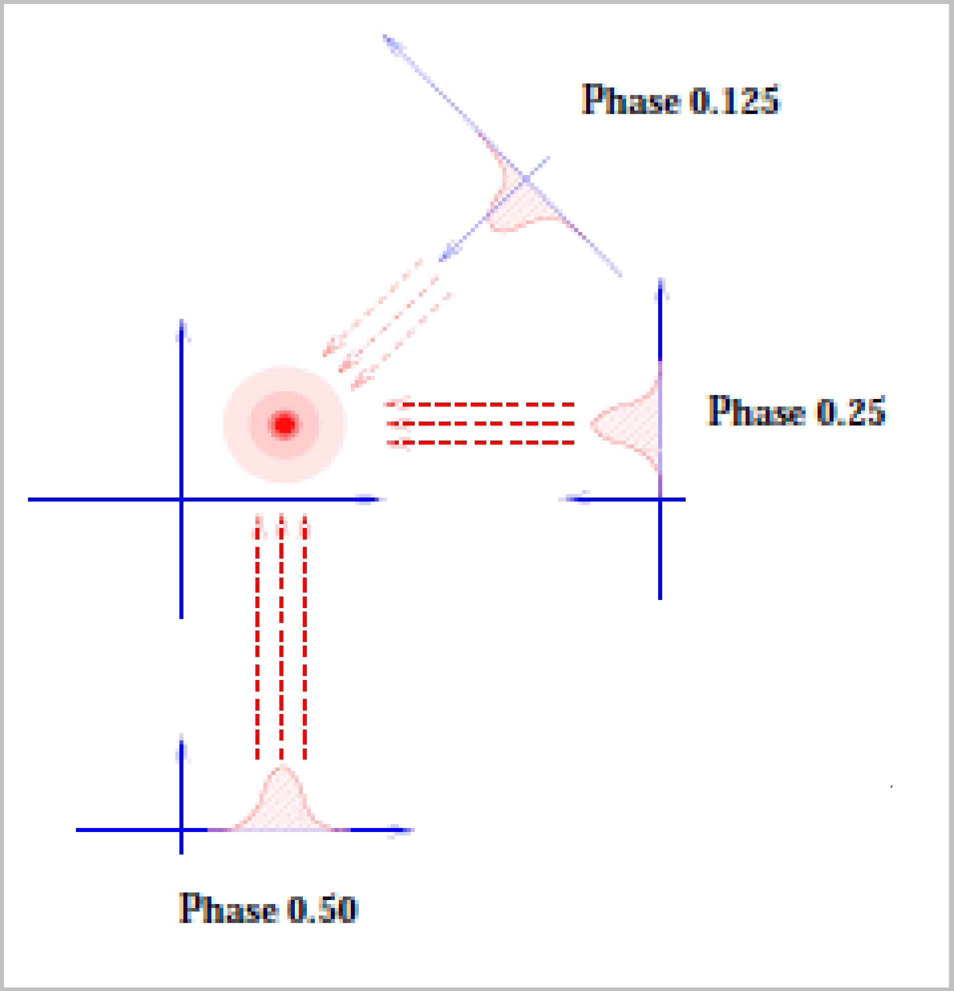




Doppler Tomography

In Astrophysics:





Emission due to stationary matter element in the referential of the binary system

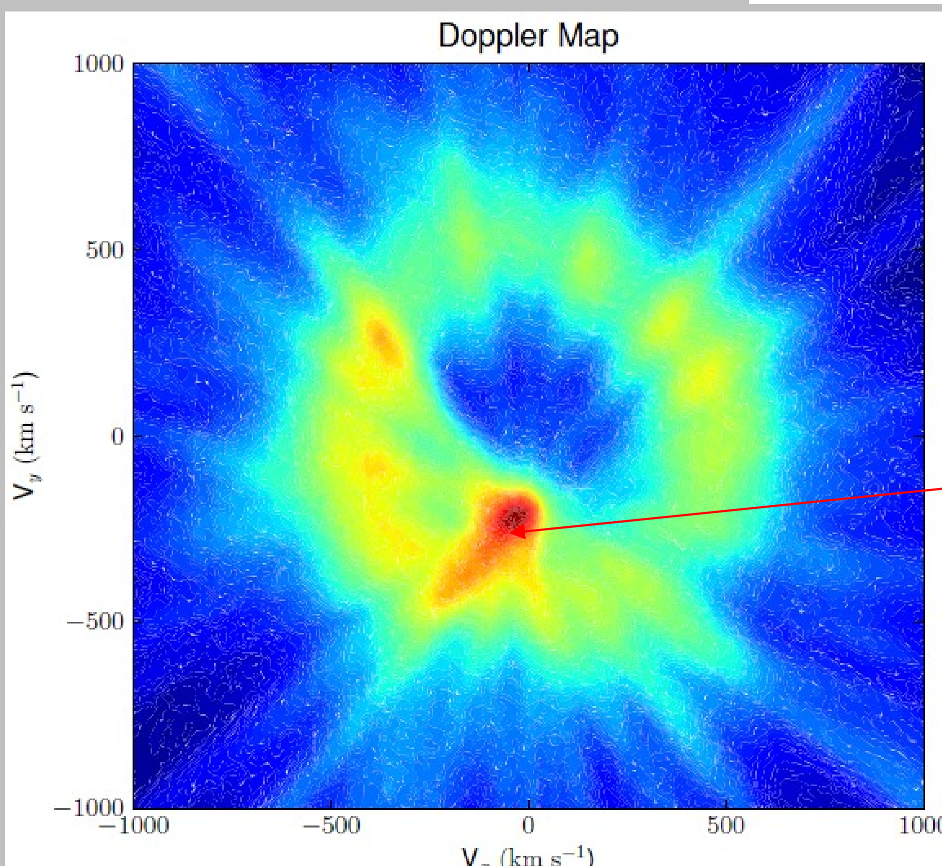
Doppler tomography

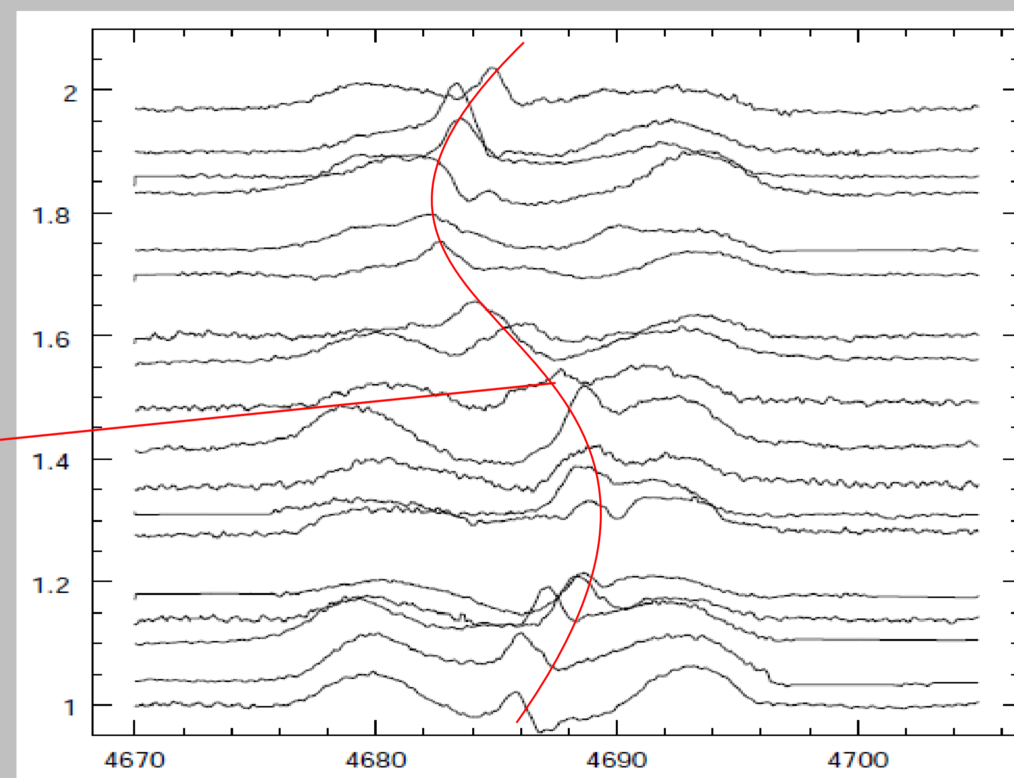
Filtered-back projection

Radon transform:

$$\begin{aligned} g(s,\theta) &= \mathcal{R}[f(x,y)] \\ &= \int_{-\infty}^{+\infty} f(s\cos\theta - t\sin\theta, s\sin\theta + t\cos\theta)\,dt \end{aligned}$$

$$v(\phi) = -v_x\ \cos\left(2\,\pi\,\phi\right) + v_y\ \sin\left(2\,\pi\,\phi\right) + v_z$$





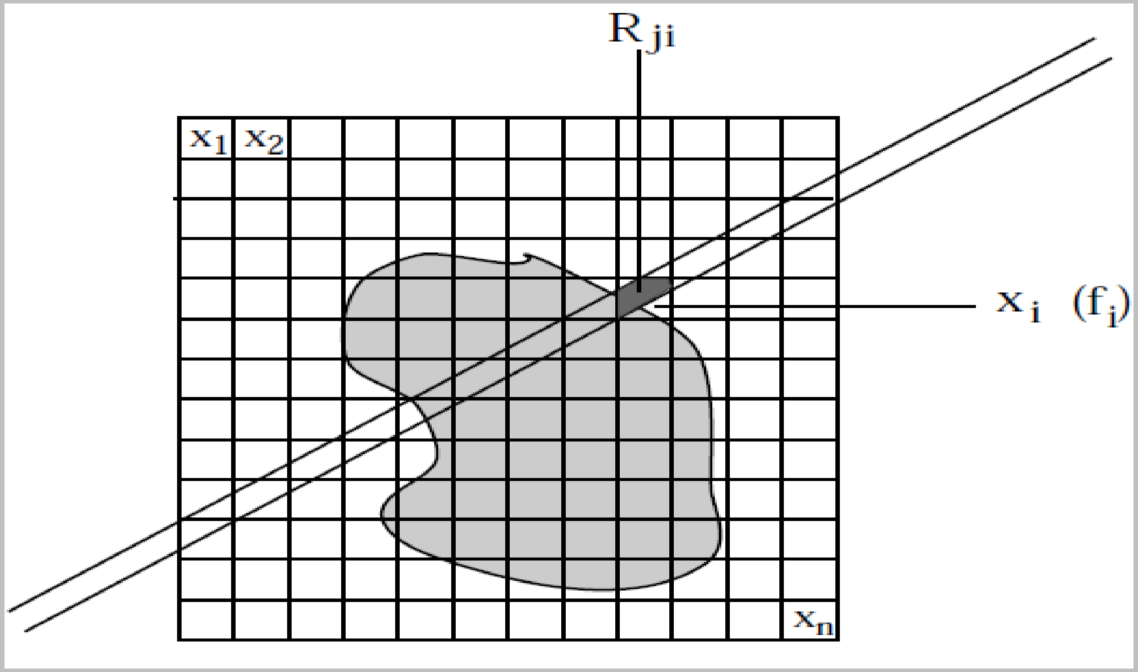
Doppler tomography

Algebraic methods:

$g = R\,f$ where g = observed spectra

f = emissivity map

R = Projection matrix

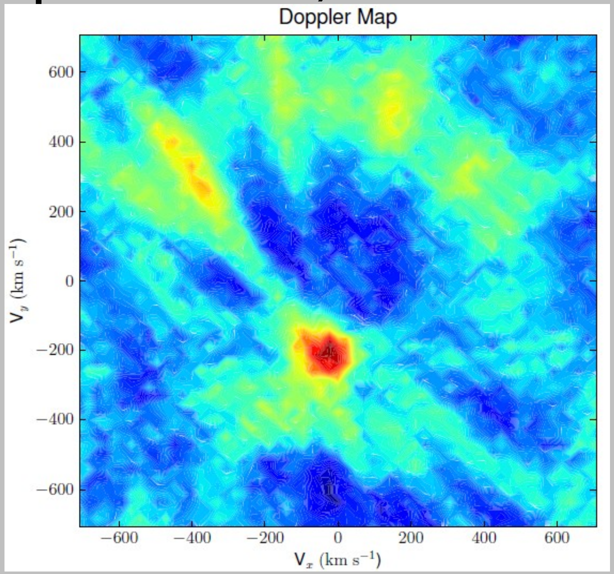


Doppler tomography

Algebraic methods using inversion techniques: ART, SIRT

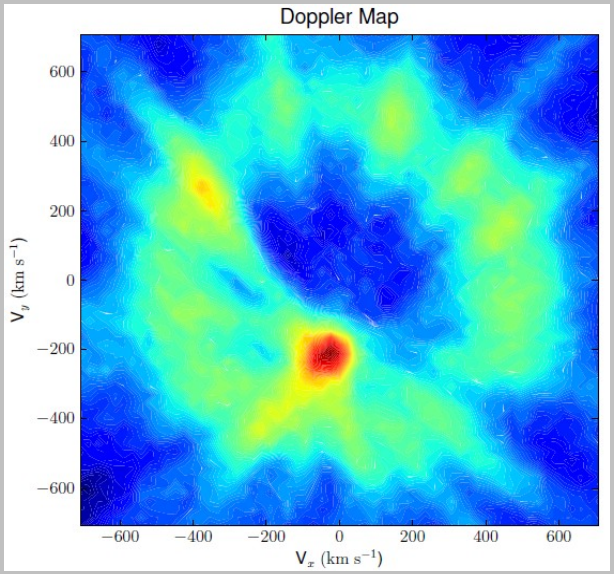
ART :

$$f^{(k)} = f^{(k-1)} + R_j \cdot \frac{\left(p_j - R_j^t . f^{(k-1)}\right)}{\| R_j \|^2}$$



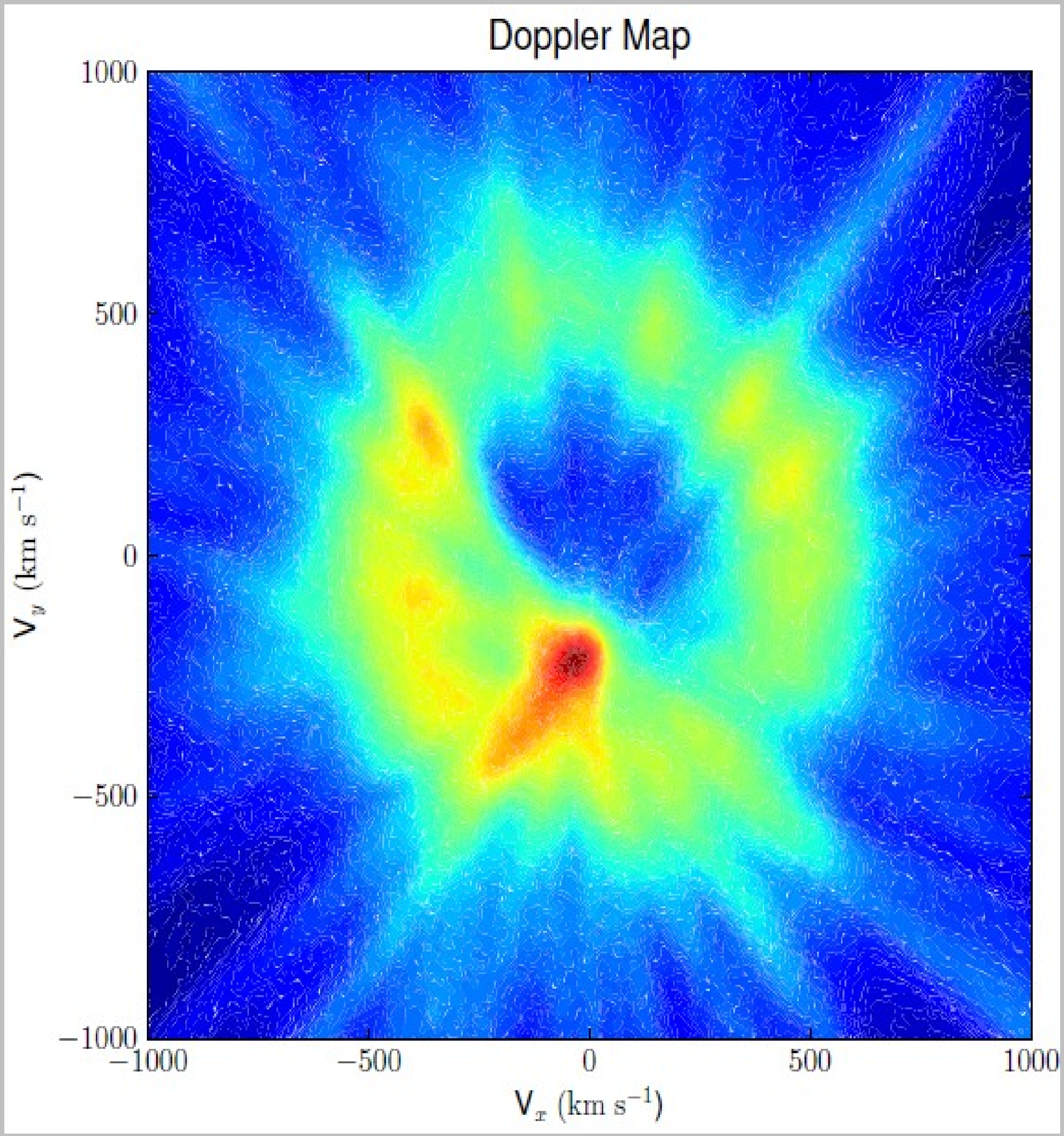
SIRT:

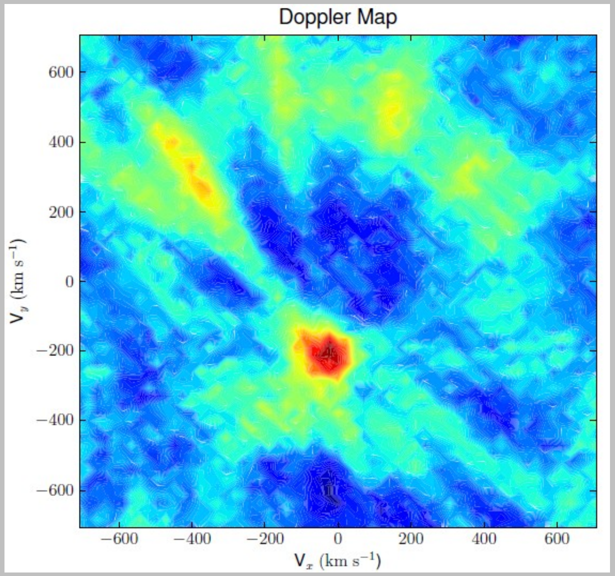
$$f^{(k)} = f^{(k-1)} + \lambda \cdot R^t \cdot \frac{\left(p - R . f^{(k-1)}\right)}{\| R_j \|^2}$$

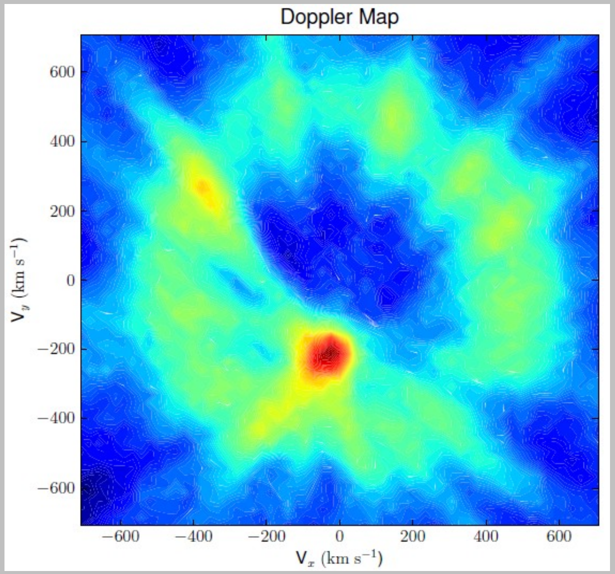


Doppler tomography

Algebraic methods: ART, SIRT







Conclusions

- These methods are extremely useful in astrophysics of massive stars
- These methods improve our knowledge
  - Disentangling allows us to determine the surface abundances of each component
  - Doppler Tomography allows us to better understand the wind properties in a binary system

→ It was the past, it's the present and it will be the future...
for the astrophysical understanding