

# SPECTRO-INTERFEROMETRY OF DISKS AND WINDS WITH THE VLTI

**Florentin Millour**



Observatoire  
de la CÔTE d'AZUR

# Disks and winds ?

- Are seen in all evolutionary status & all masses: YSOs, MS stars, evolved stars, or ... AGNs !

- Winds

- Radiation-driven
- Dust-driven
- Magnetic field

$\eta$  Car



Betelgeuse



Wolf-Rayet



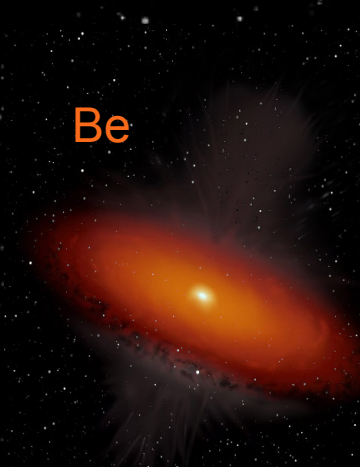
- Disks

- Accretion
- Decretion
- « Solid rotation »

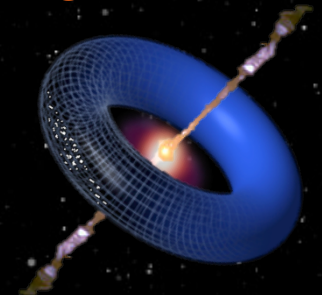
YSO



Be



AGN



# Spectro-interferometry ??

## Spectroscopy

*Analysis of light dispersion*

Information on :

- Chemistry
- Radial Velocity
- Temperatures
- Magnetic field

## Interferometry

*Analysis of light coherence*

Information on :

- Position (astrometry)
- Size
- Shape

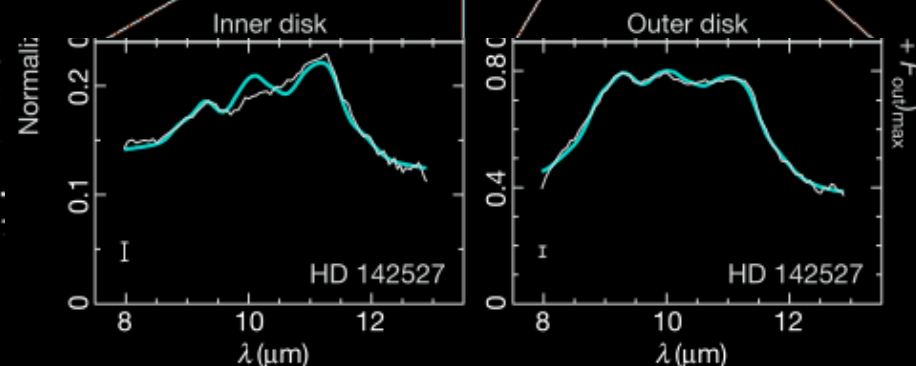
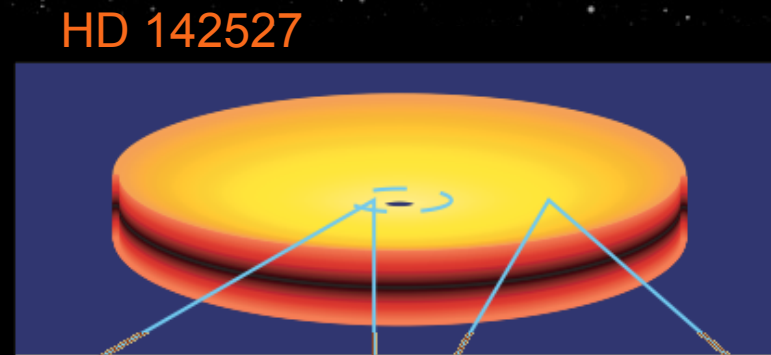
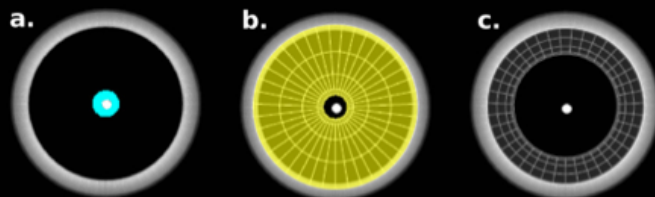
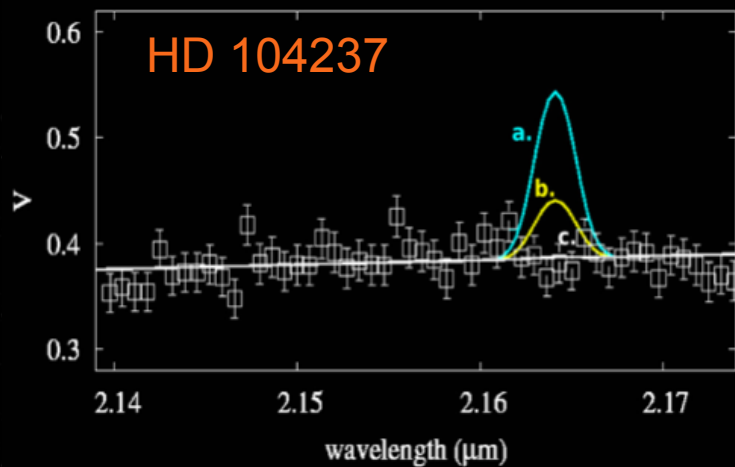
## Spectro-interferometry

*Best of both worlds !*

# Chemistry + Size = material-forming zones

- **Characteristic features in the spectrum**

- @2 $\mu\text{m}$ : Hydrogen / metallic lines + CO lines
- @10 $\mu\text{m}$ : Silicates dust features



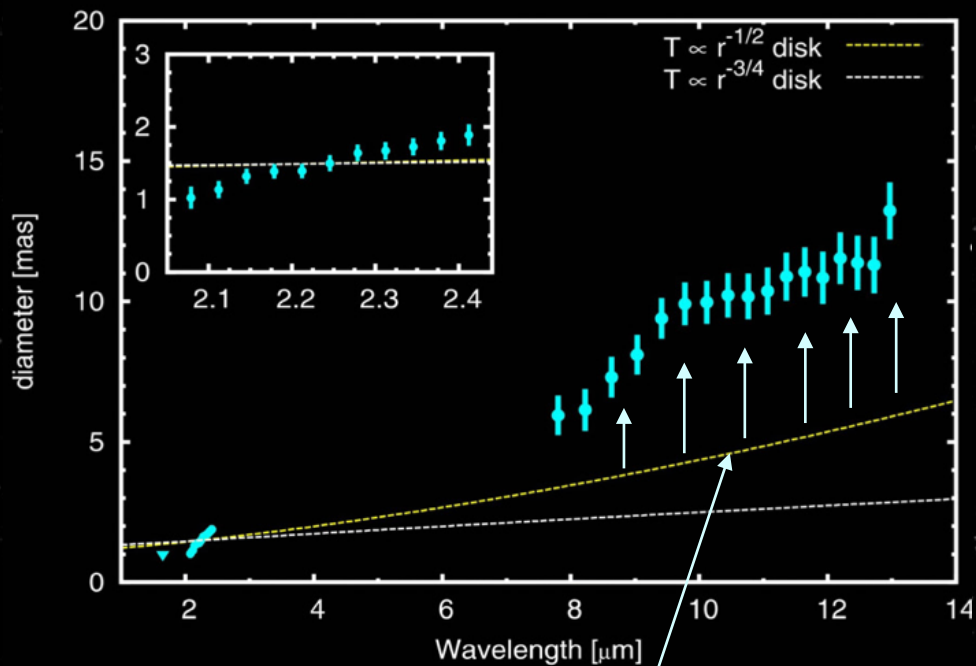
Tatulli et al. 2007

Van Boekel et al. 2004

# Size + Temperatures = nature of material

- Importance of multi- $\lambda$  information

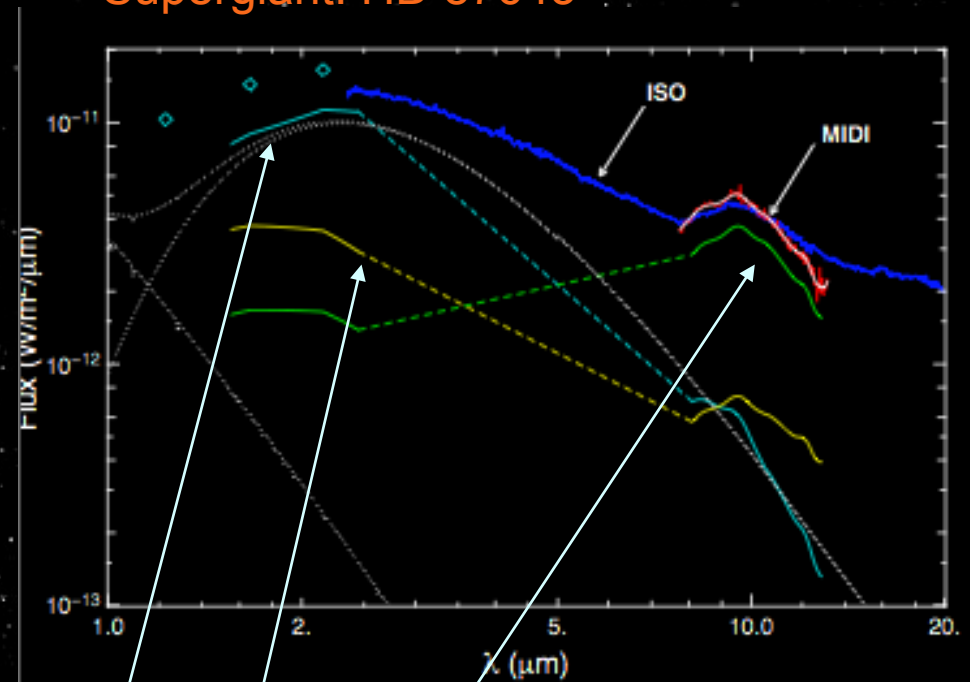
YSO: MWC 147



Kraus et al. 2008

An inner gas disk is needed to explain the observed size deficit

Supergiant: HD 87643



Millour et al. 2009

Main star disk dust-sublimation rim  
Companion star envelope  
Circumbinary disk

# Radial velocities + Position = kinematics

- **Disks**

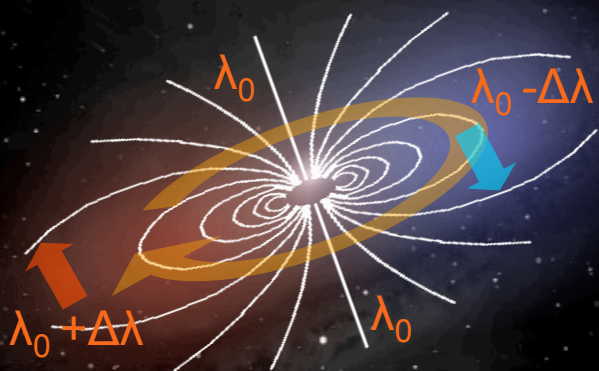
- **Rotation**
  - Keplerian
  - Solid
  - Angular momentum conservation
- **Accretion/Decretion**
- **Disk-wind (YSOs)**

- **Winds**

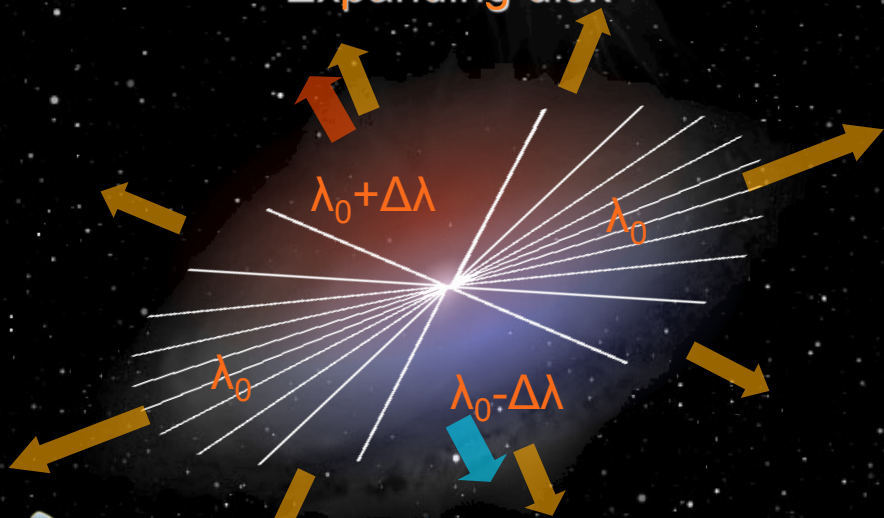
- **Prolate winds**
- **Fireballs / Bipolar outflows**
- **Inhomogeneous winds**

# Disk kinematics

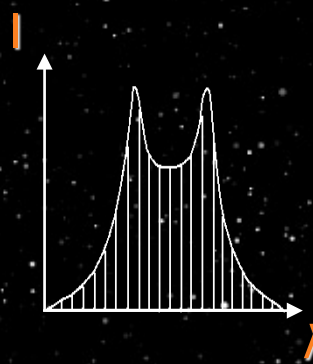
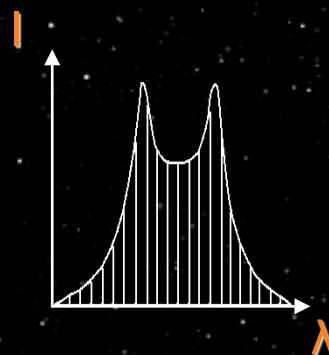
Rotating disk



Expanding disk

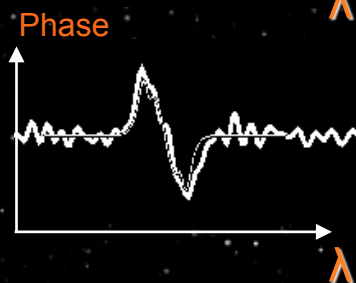
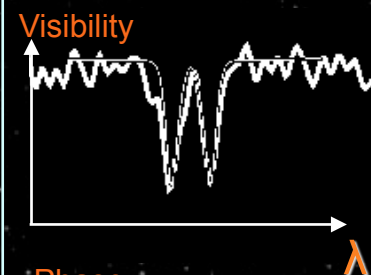


Spectroscopy

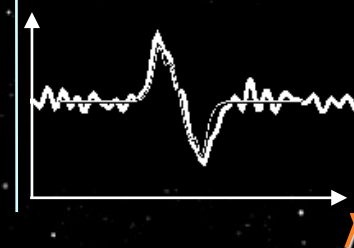
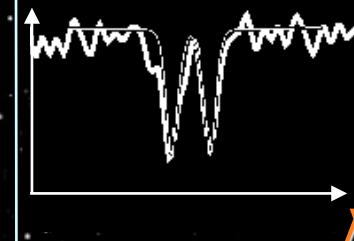
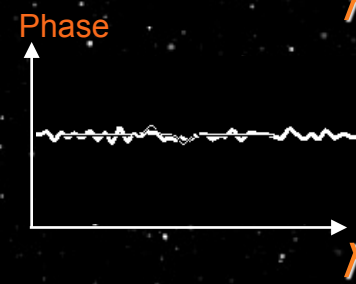
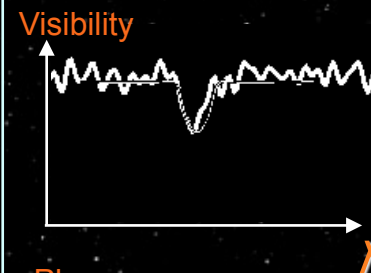
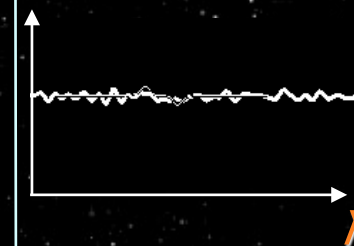
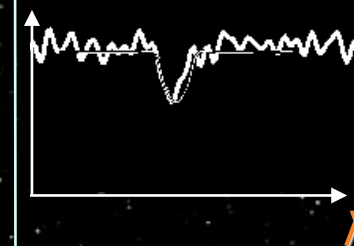


interferometry

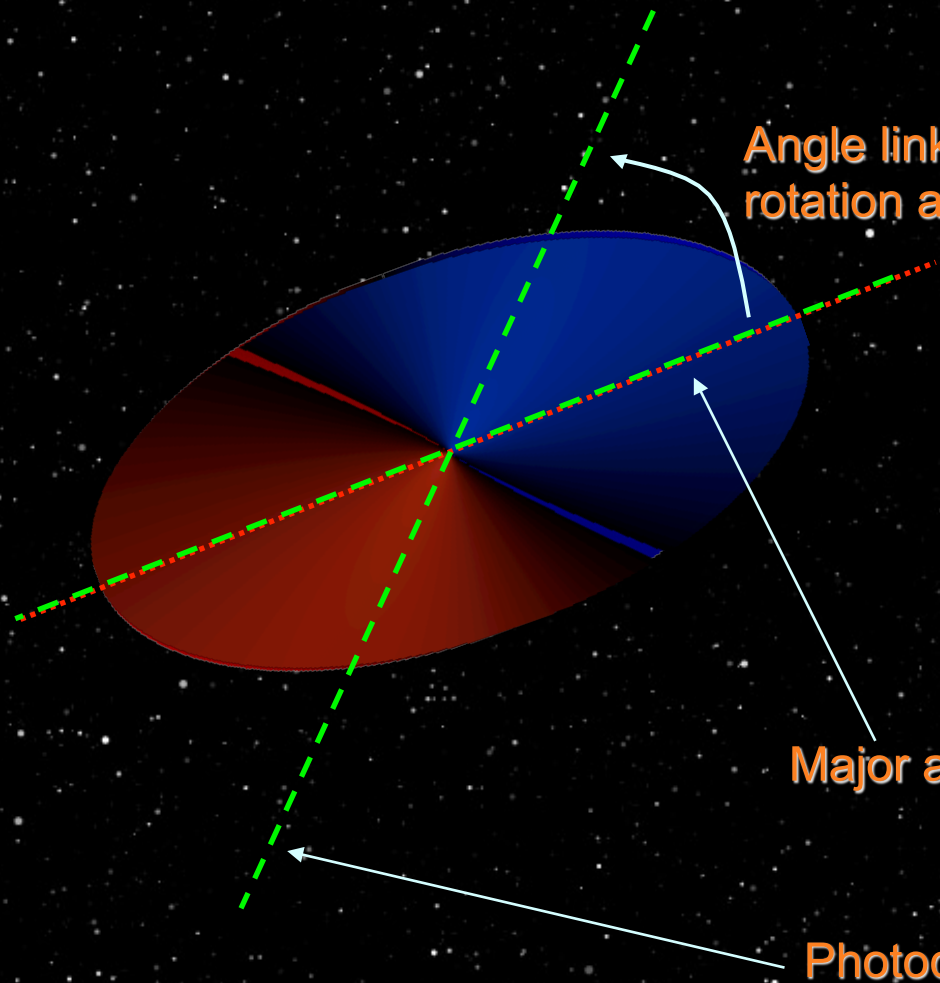
major-axis



minor-axis



# Disk kinematics



Angle linked to the relative weight of rotation and expansion

Adding expansion to a rotating disc:

Rotation of the photocenter-shift axis !

Major axis of the disc

Photocenter-shift axis

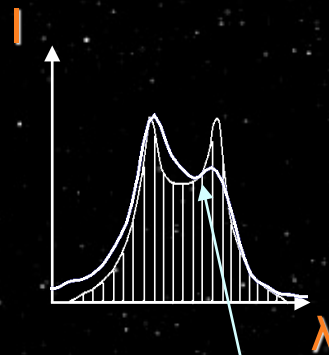


# Disk inhomogeneities

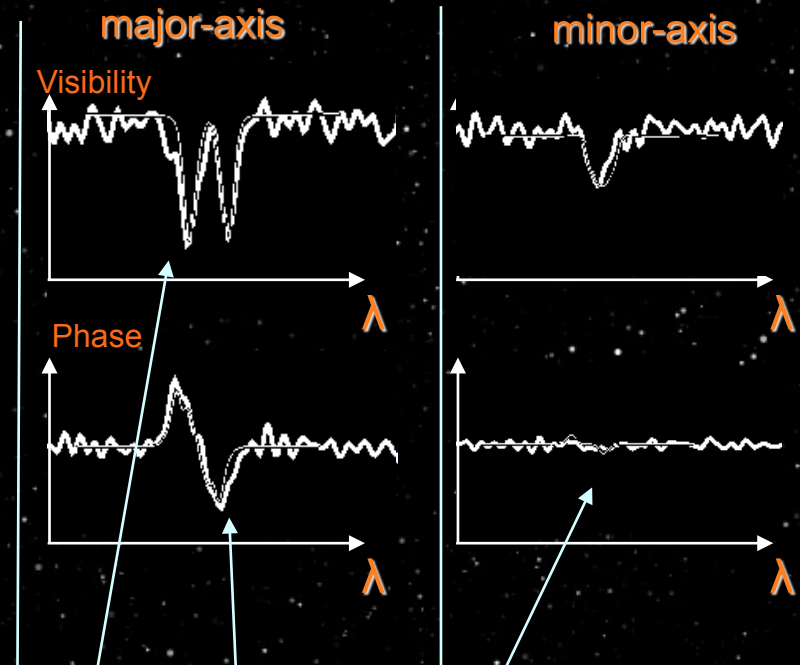
Rotating disk

Inhomogeneity  
(one-armed oscillation)

Spectroscopy



interferometry

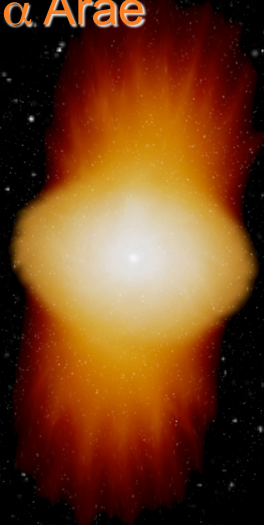


Asymmetries in the  
spectro-interferometric data

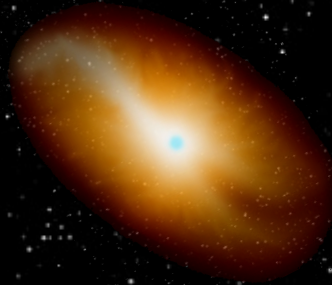
# Disk kinematics: applications

- Be stars

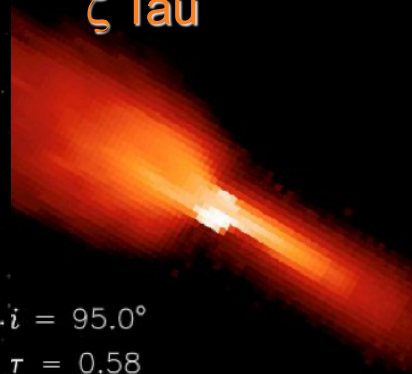
$\alpha$  Arae



$\kappa$  CMa



$\zeta$  Tau

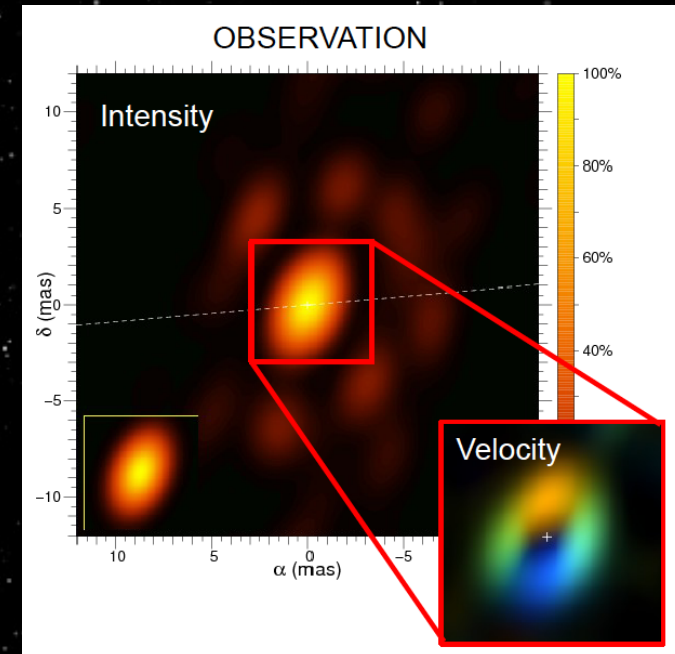


$i = 95.0^\circ$   
 $\tau = 0.58$   
 $v = -69.8 \text{ km/s}$

Meilland et al. 2007a, b, Carciofi et al. 2009  
+ 7 other Be stars  
All in Keplerian rotation

- Supergiant stars

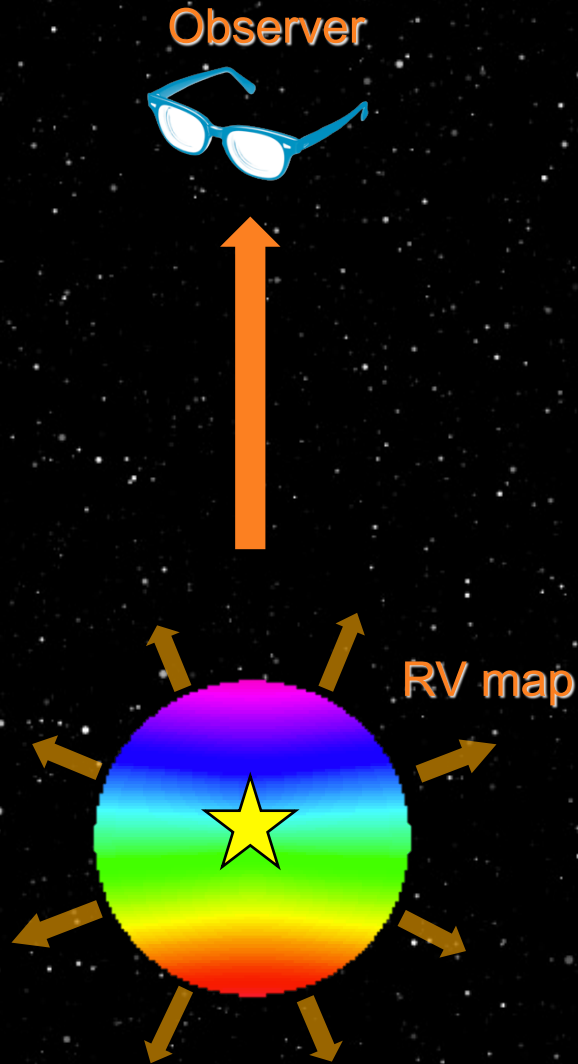
HD 62623: image!



Keplerian rotation  
Millour et al. 2011 A&A

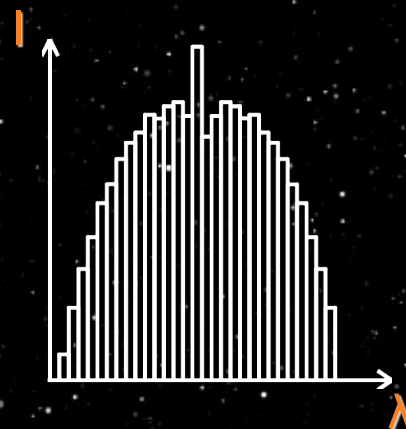
... Are all observed disks in Keplerian rotation?

# Wind kinematics



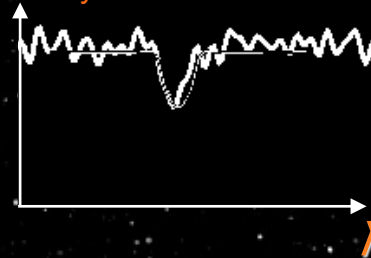
- A spherical wind do **NOT** produce phase signal
  - Need for
    - inhomogeneities
    - **Aspherical wind**

Spectroscopy

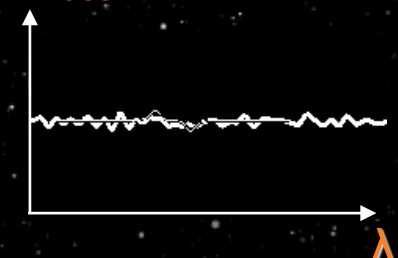


interferometry

Visibility



Phase

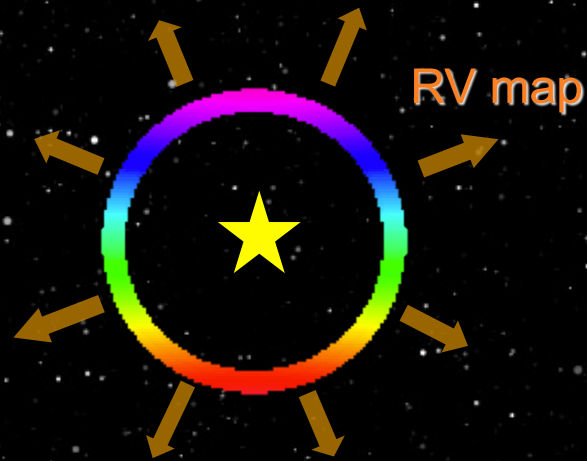


# Wind kinematics

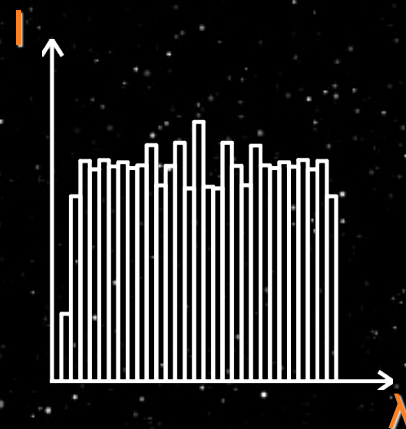
Observer



- A spherical wind do **NOT** produce phase signal
  - Need for
    - inhomogeneities
    - **Aspherical wind**

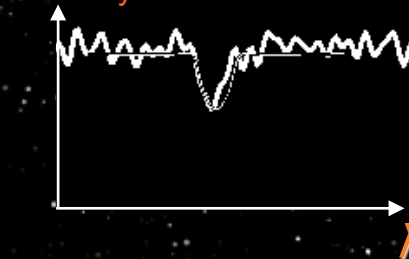


Spectroscopy

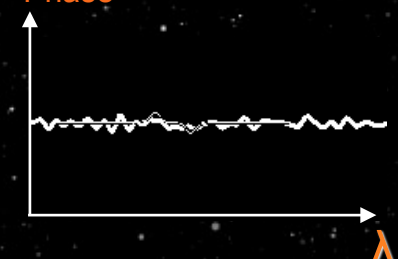


interferometry

Visibility



Phase

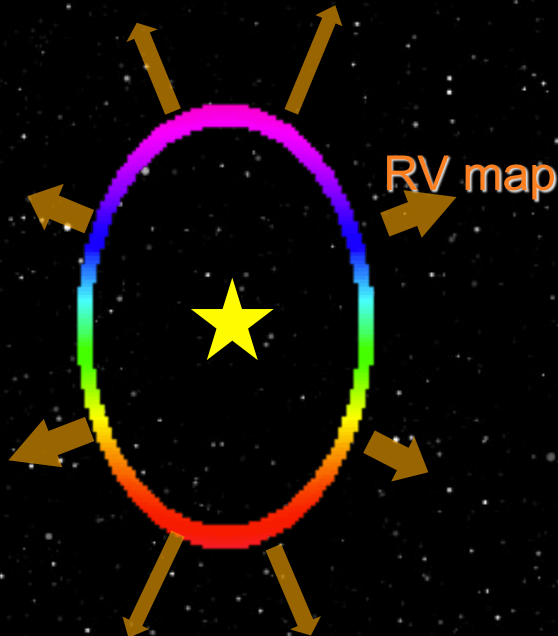


# Wind kinematics

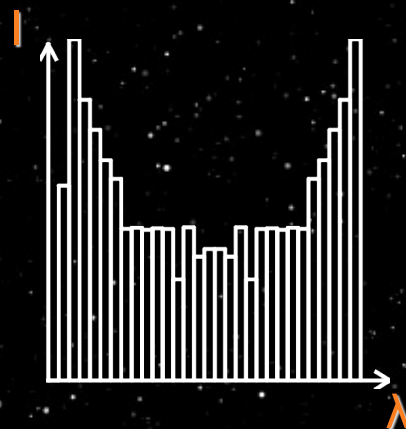
Observer



- A spherical wind do **NOT** produce phase signal
  - Need for
    - inhomogeneities
    - Aspherical wind

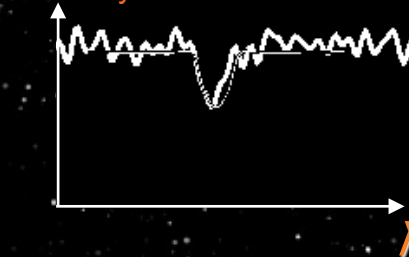


Spectroscopy

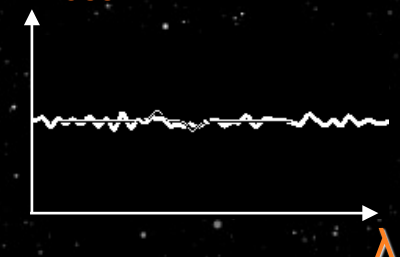


interferometry

Visibility



Phase



# Wind kinematics

Observer

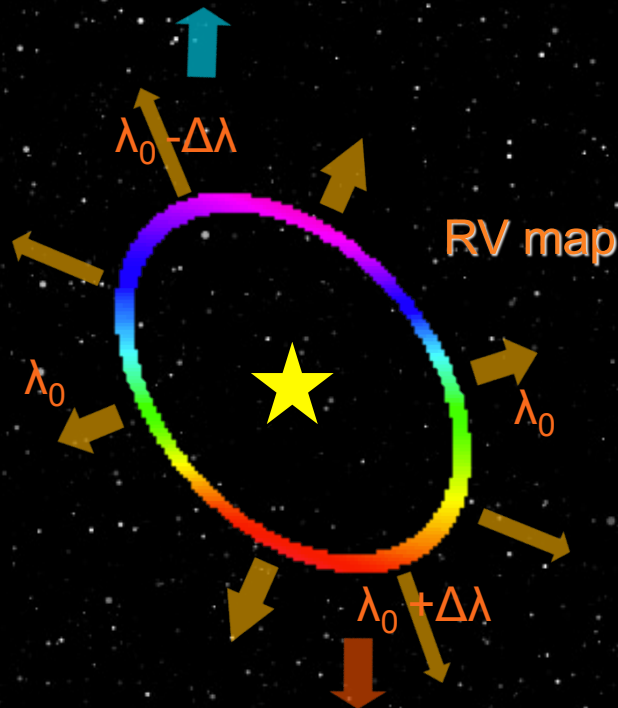


- A spherical wind do **NOT** produce phase signal

➤ Need for

➤ inhomogeneities

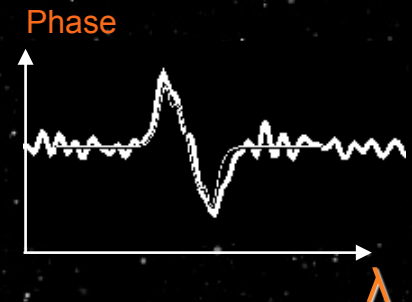
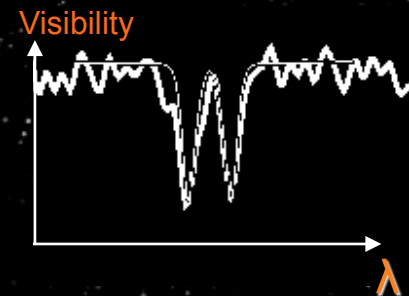
➤ Aspherical wind



Spectroscopy

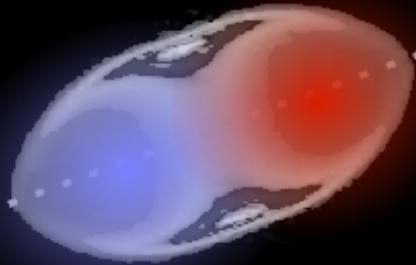


interferometry



# Wind / outflow kinematics: applications

- **Novae**



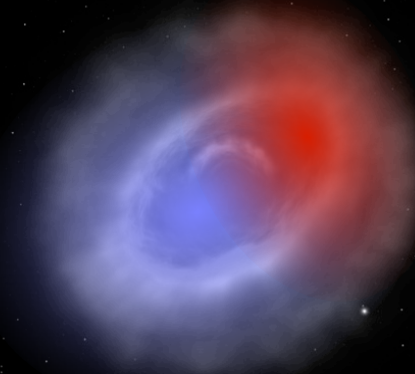
- **RS Oph**

- Chesneau et al. 2007

- **T Pyx**

- Chesneau et al. 2011

- **Supergiant**



- **$\eta$  Car**

- Weigelt et al. 2007
- Groh et al. 2010

- **IRC 10+420**

- Driebe et al. 2008

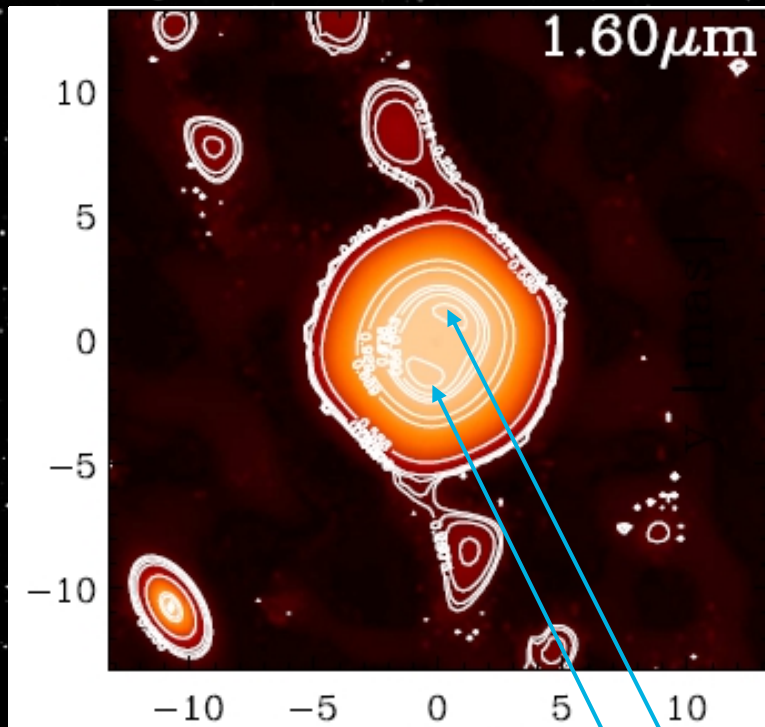
- **CPD-57+2874**

- Domiciano de Souza et al. 2007

... Are bipolar winds ubiquitous? Is there an observing bias?

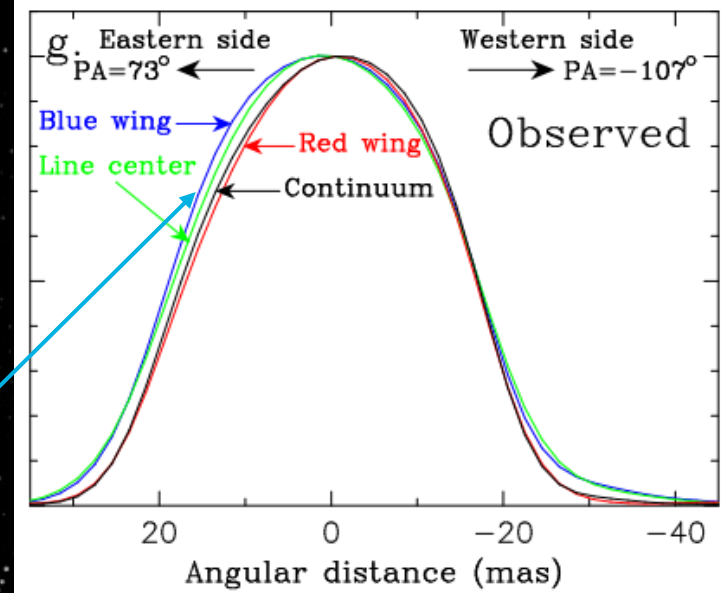
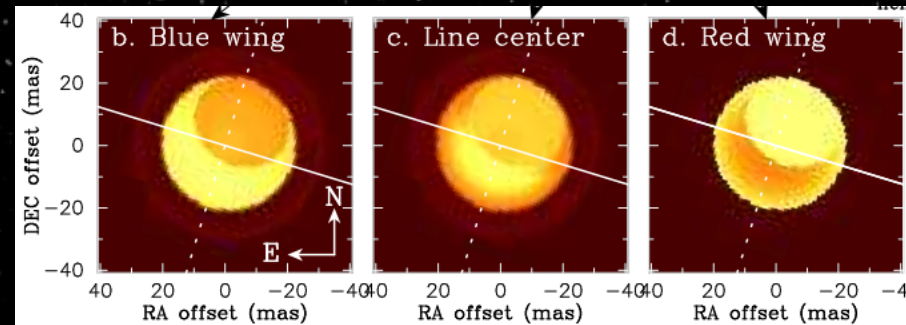
# Complex outflows: imaging

VX Sgr



Chiavassa et al. 2010

Betelgeuse



Ohnaka et al. 2011

These are real features!

... Spectro-imaging is possible now!



# Concluding remarks

- ✗ **Spectro-interferometry is ~~not yet~~ an easy thing to do:**
  - ? Need of simple (toy) models that can be used by anybody (for playing & understanding)
  - ✓ Spectro-Imaging: available now!
  
- ? **Disks: are they all Keplerian?**
  
- ✓ **Must-have for any backyard interferometer:**
  - ✓ spectroscopic capability in addition to interferometry
  - ✓ Multi-band interferometry (preferentially simultaneous)
  - ? Extension of VLTI to the visible?
  
- ✓ **MATISSE & GRAVITY**
  - ✓ Will provide images
  - ✓ will have spectro-interferometric capabilities

# Thank you

## 2011 observations with AMBER

K = 11.7 star → see M. Kishimoto talk

K = 10 quasar → see R. Petrov talk

