

# High Spatial and spectral Resolution in the NIR through Ground Instrumentation

The Latest Italy's Contribution to Understanding  
Accretion-Ejection Processes in Young Stars from  
VLTI Interferometry, AO Imaging, and GIANO Spectral  
Observations.

Exploiting Present and Future Facilities.

*F. Massi*

**INAF - Osservatorio Astrofisico di Arcetri**

MA2 - Bologna, 16/06/2016

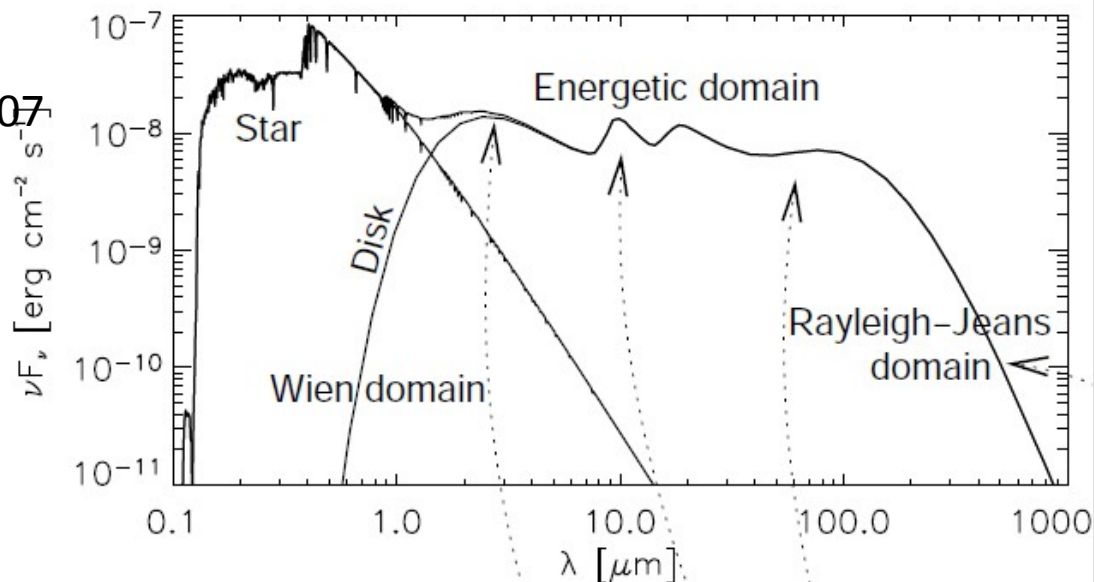
# Domande fondamentali per la fisica delle stelle giovani

- **Quadro valido per le stelle di bassa massa ( $< 2 M_{SUN}$ ) e massa intermedia ( $< 8-10 M_{SUN}$ ). Per le stelle di alta massa ( $> 8-10 M_{SUN}$ ) il quadro è più complesso e meno chiaro ancora (*talk Cesaroni Galli*).**
- **Comprendere i meccanismi di lancio (disk wind, X wind, stellar wind) e collimazione dei jet.**
- **Comprendere i meccanismi di accretion, cioè come il disco perde momento angolare favorendo la crescita in massa della stella e come questi siano legati ai jet.**
- **Tutti questi processi avvengono su scale di poche AU (1 AU = 7 mas a 150 pc), l'alta risoluzione è irrinunciabile per chiarire il quadro.**

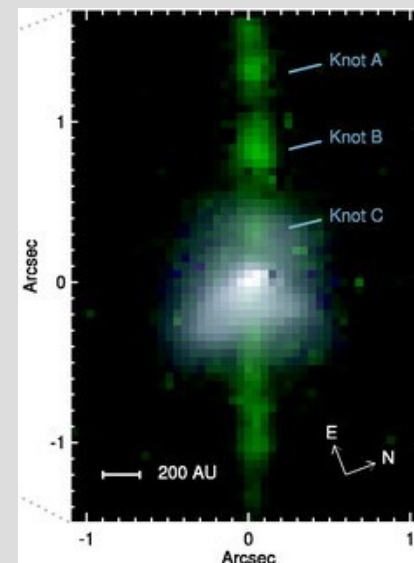
# Alta risoluzione (in NIR) per rispondere alle domande fondamentali nella fisica delle stelle giovani

## Il quadro qualitativo prima di risolvere il disco interno

Dullemond et al. 2007

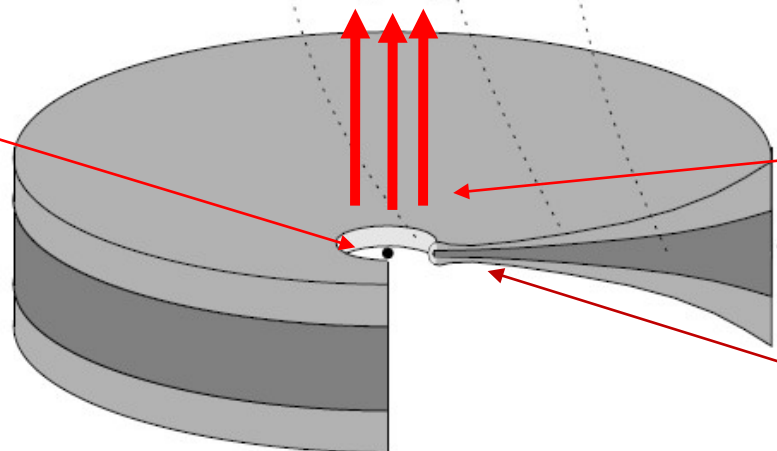


LkH $\alpha$  233  
Perrin & Graham 2007



Optically thick gas inside dust rim?

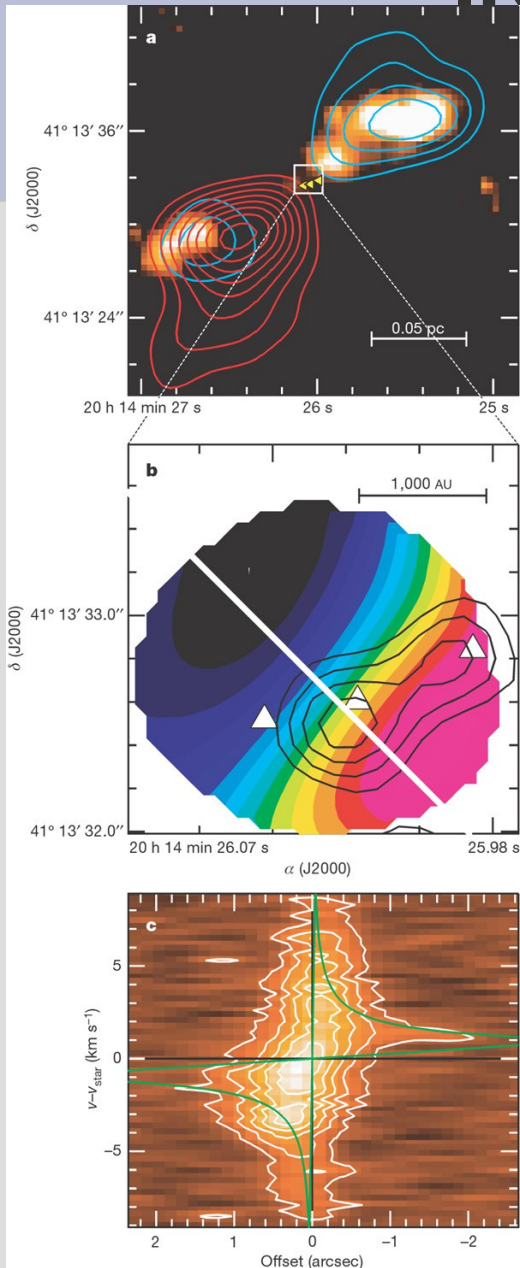
Accretion originates  
Br $\gamma$  emission in HAe/Be stars



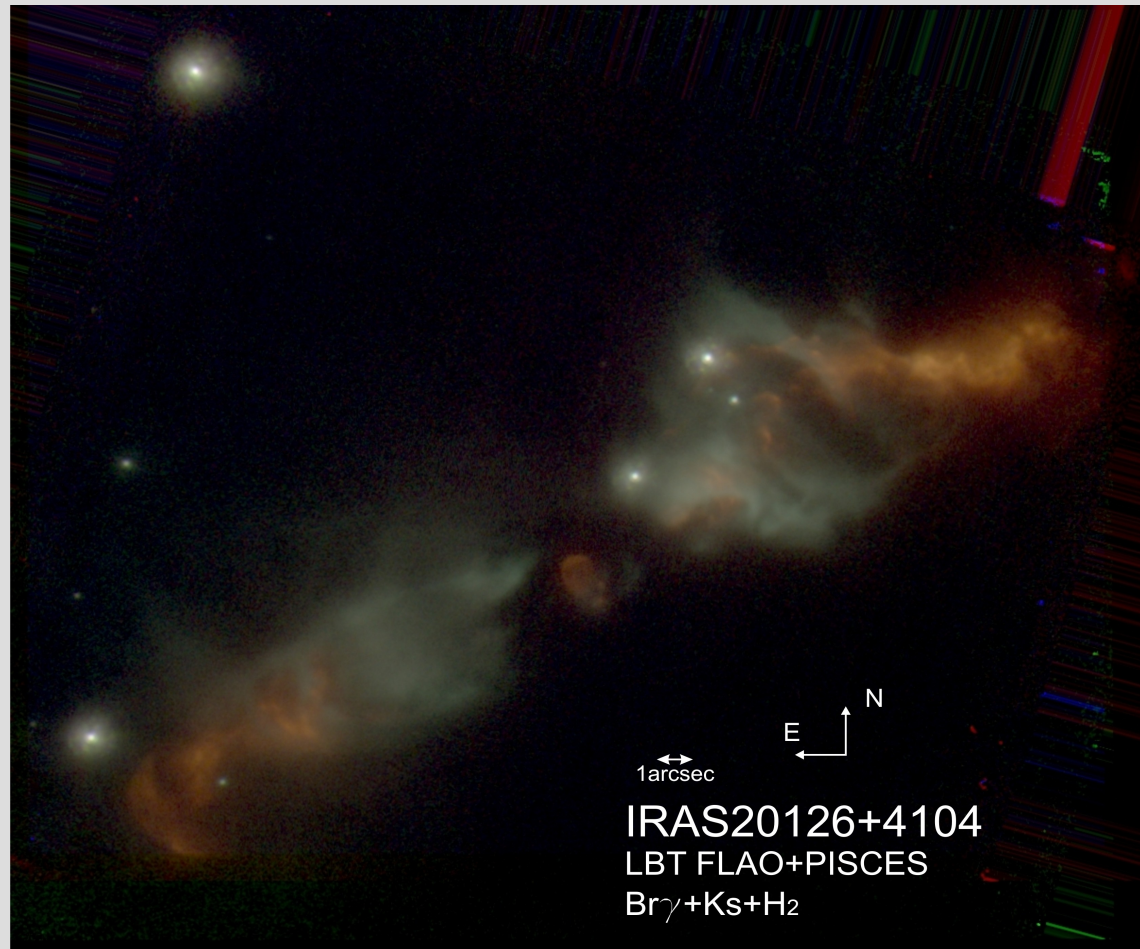
Collimated jet

Inner dust rim  
due to grain  
sublimation.  
Here arises most  
of NIR emission

# Ottica Adattiva: FLAO+Pisces@LBT IRAS 20126+4104 (SV 2013)



IRAS 20126+4104  
Distance 1.7 kpc  
Keplerian disk 1-4  $M_{\text{SUN}}$  around central (proto)star 7  $M_{\text{SUN}}$



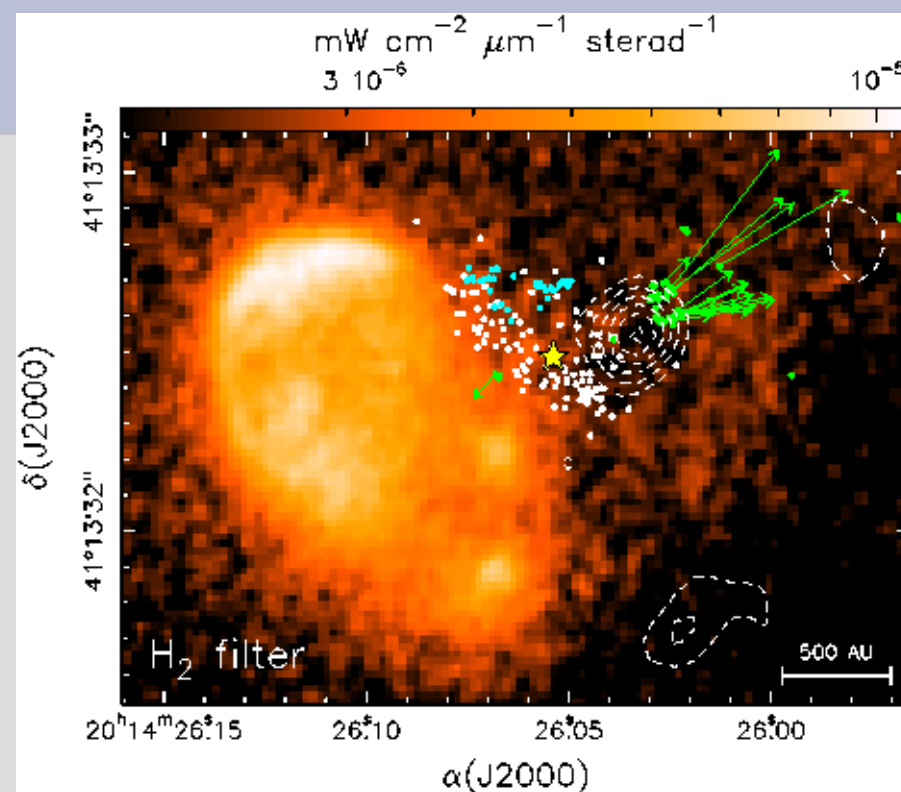
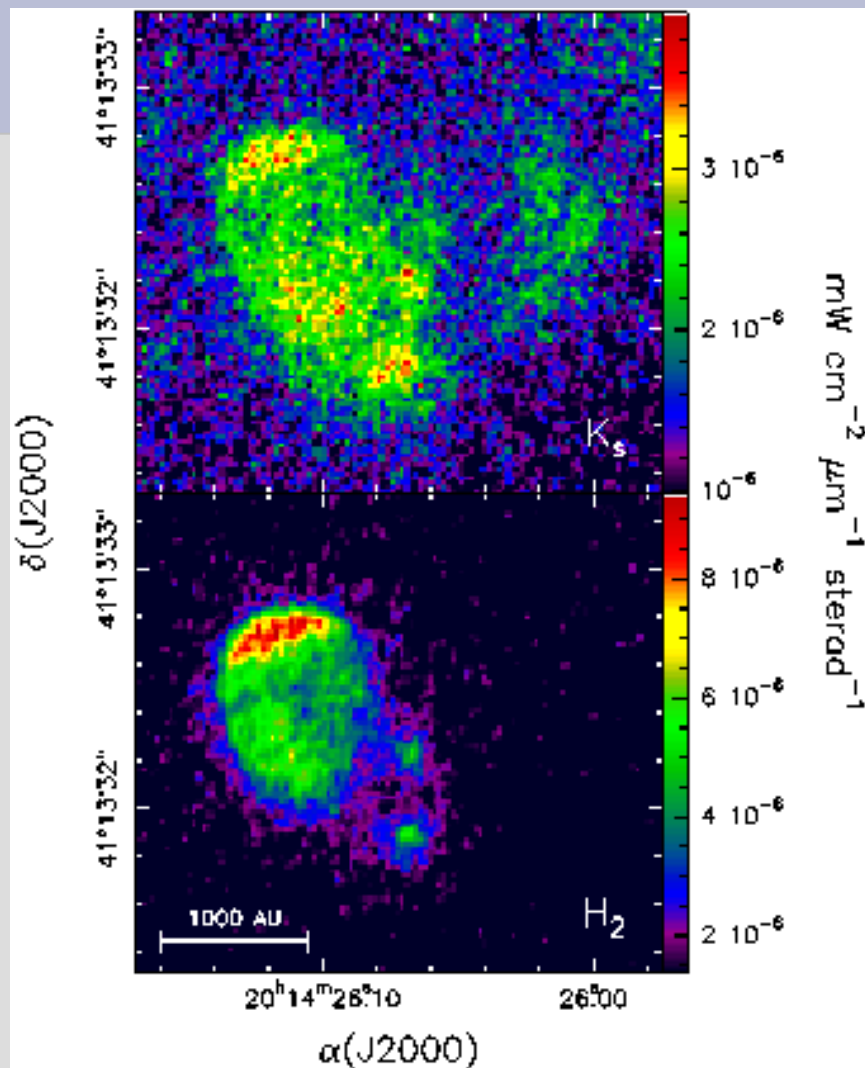
(Cesaroni et al. 2013, A&A 549, A146)

(Cesaroni et al. 2006, Nature 444, 703)

**90 mas (150 UA) resolution!**

# Ottica Adattiva: FLAO+Pisces@LBT

## IRAS 20126+4104 (SV 2013)



2.12  $\mu\text{m}$   $\text{H}_2$  emission and other high-res tracers:  
 3.6 cm cont. (dashed contours)  
 $\text{CH}_3\text{OH}$  maser spots (Cyan points)  
 $\text{H}_2\text{O}$  MASER spots (green)  
 $\text{CH}_3\text{CN}(12-11)$  and  $\text{C}^{34}\text{S}(5-4)$  peaks

**risoluzione 90 mas (150 UA)!**

(Cesaroni et al. 2013, A&A549, A146 444, 703)

# Adaptive Optics: FLAO+Pisces@LBT

## IRAS 05137+3919 (SV 2014)

LUCIFER@LBT, H,Ks,H2 risoluzione 1 arcsec

10 pc



IRAS 05137 +3919  
PISCES+AO @LBT  
H+Ks+H2

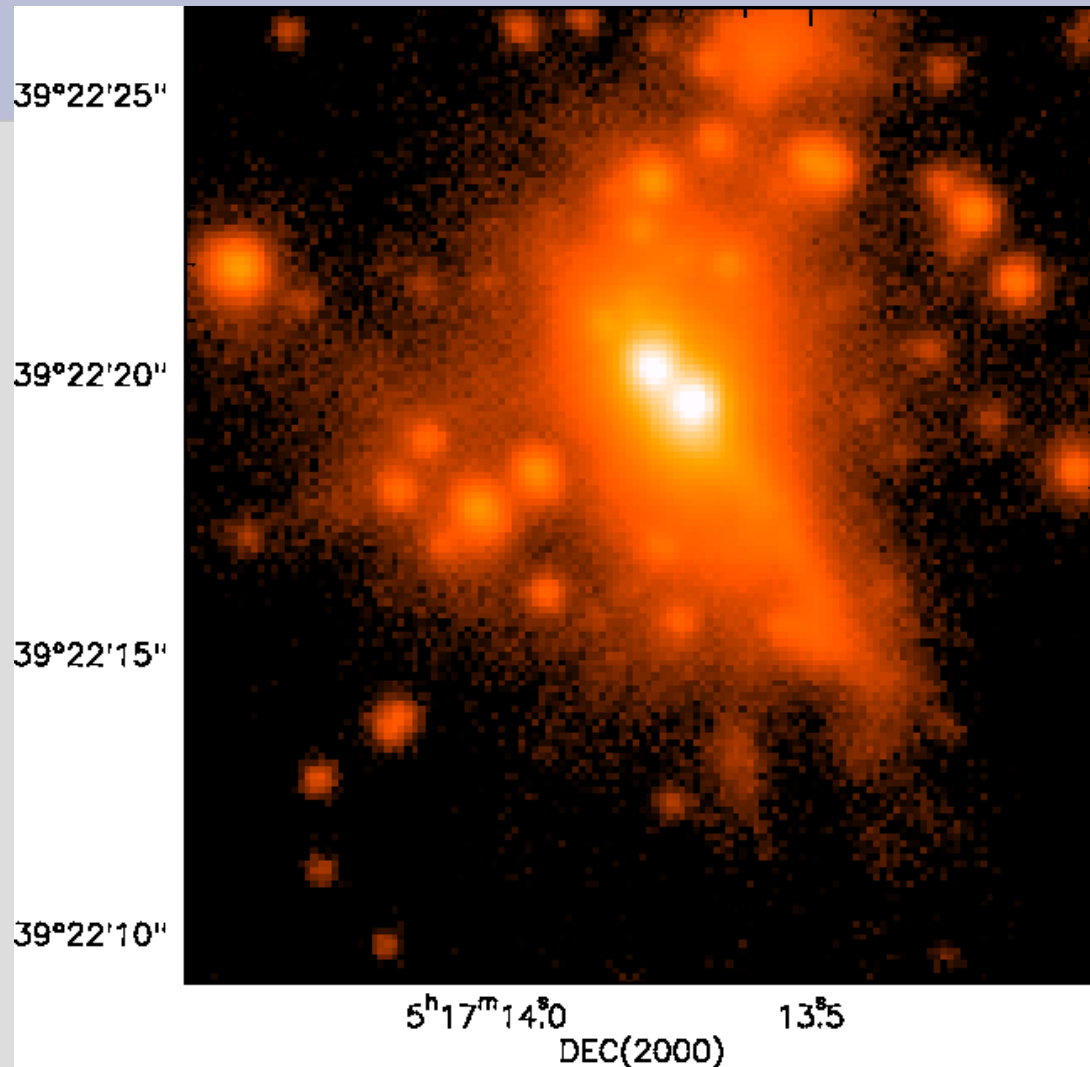
E

Distanza 11.6 kpc  $L_{bol} = 4 \times 10^4 L_{SUN}$  (O9 star)  
Cesaroni et al. 2015

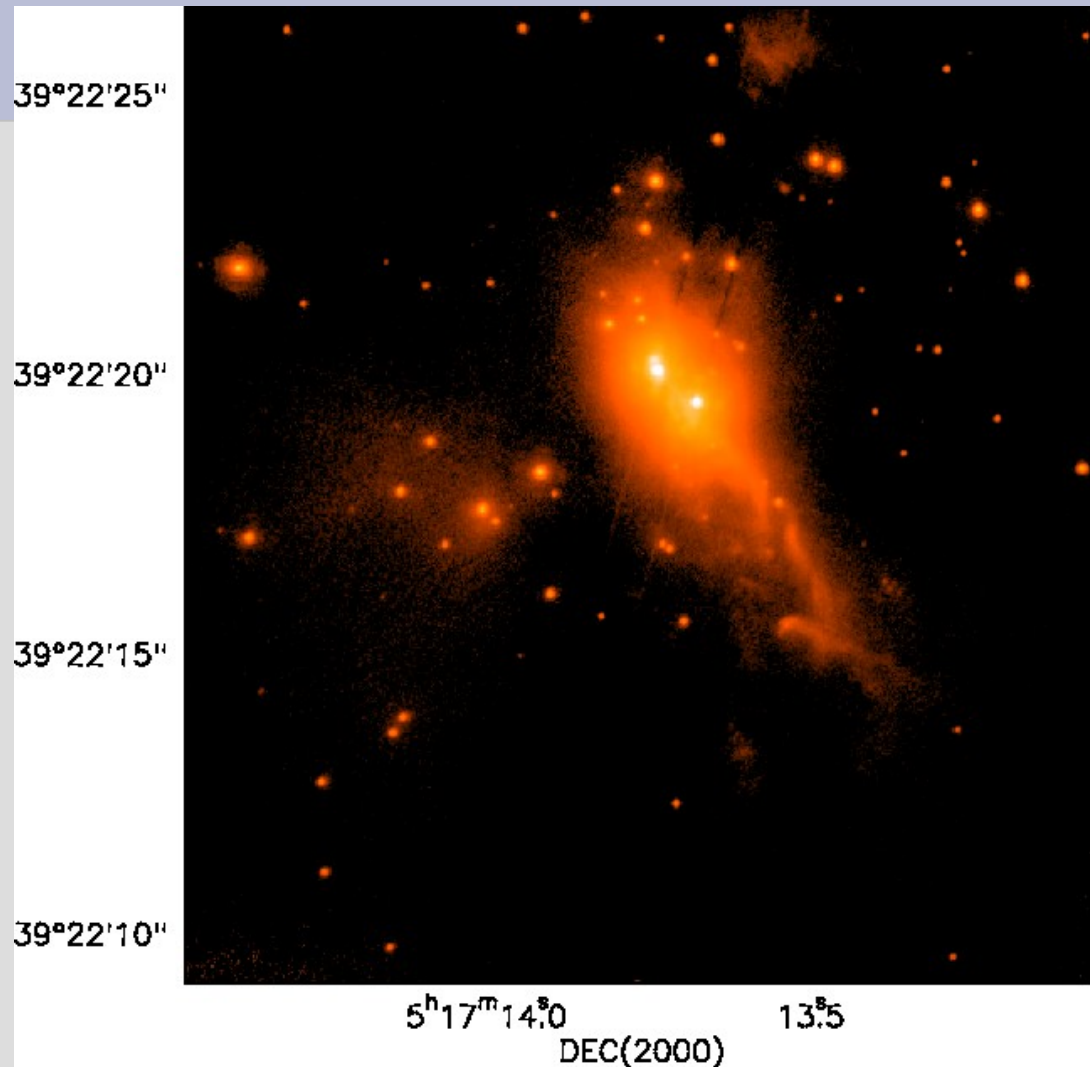
1,0"

FLAO+PISCES H,Ks,H2, risoluzione 0.08 arcsec (1000 UA)!

# Seeing limited vs. AO assisted IRAS 05137+3919



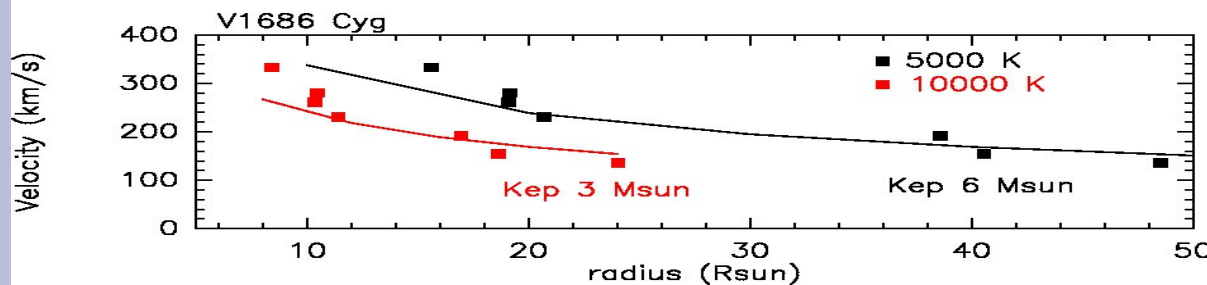
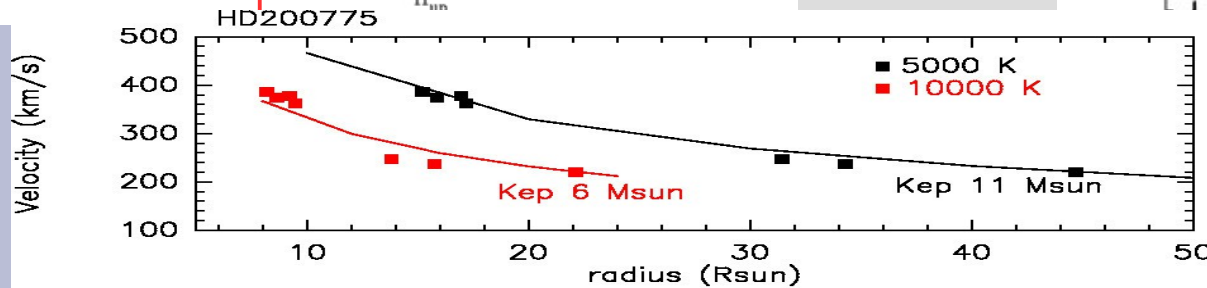
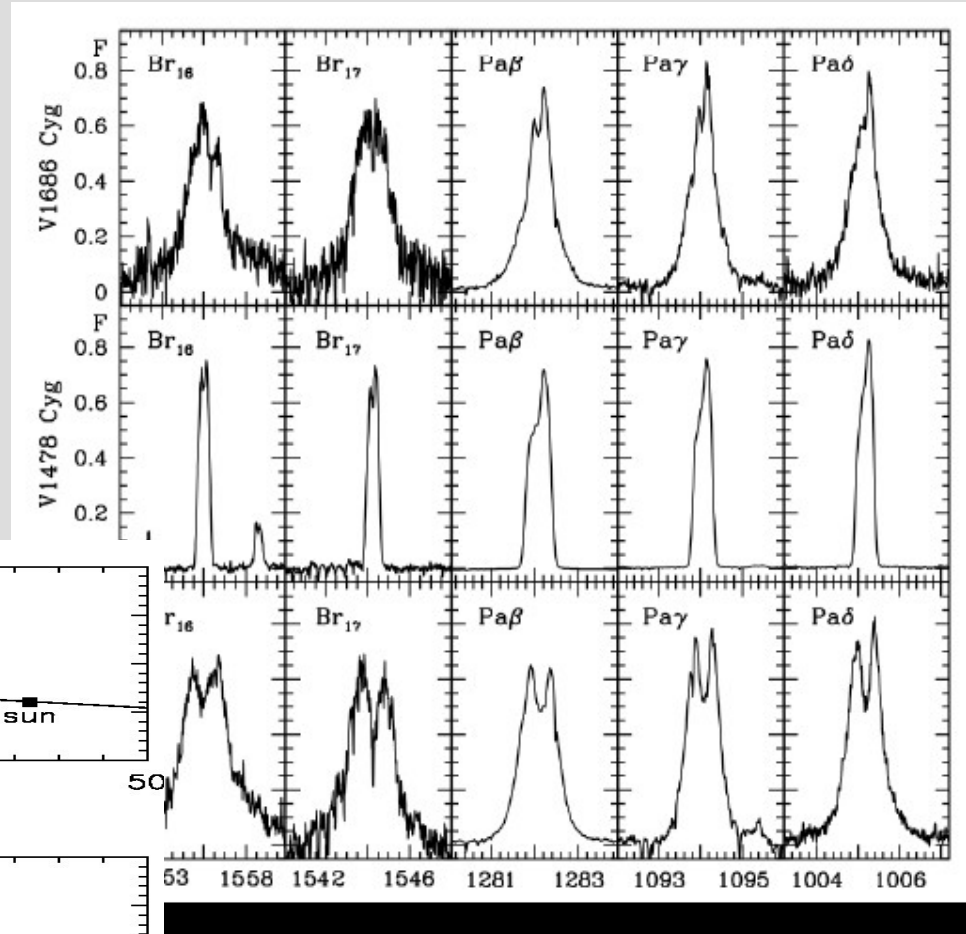
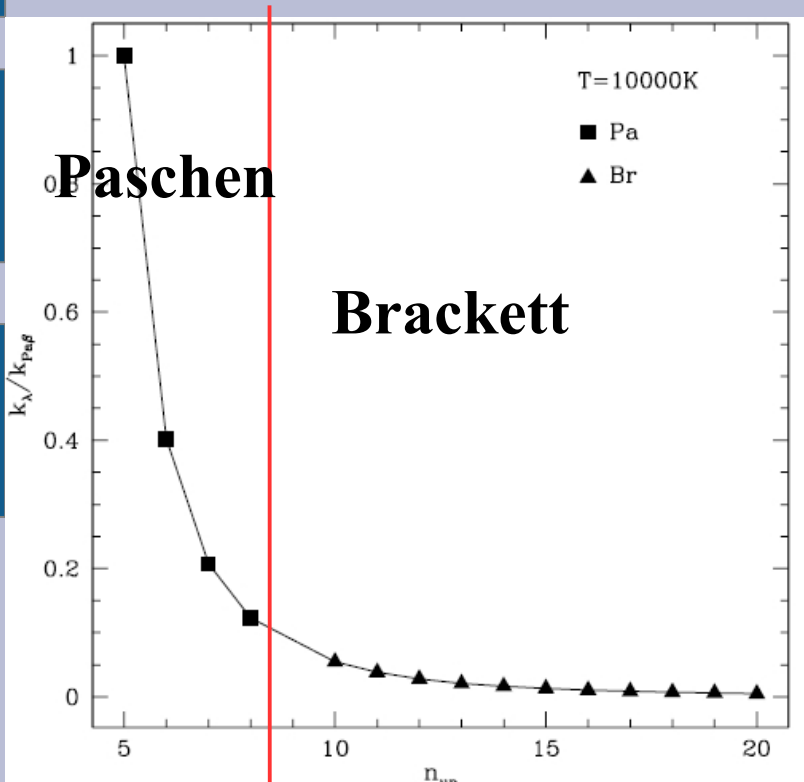
# Seeing limited vs. AO assisted IRAS 05137+3919





# ALTA risoluzione spettrale: **GIANO@TNG** (SV 2013)

*Line profile comparison: Brackett and Paschen lines*



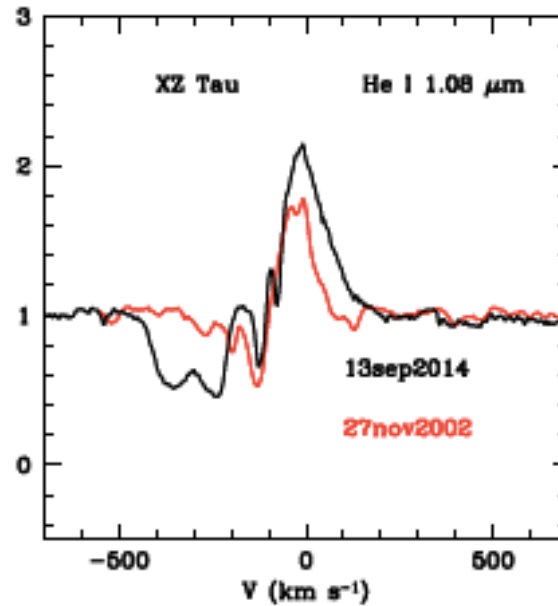
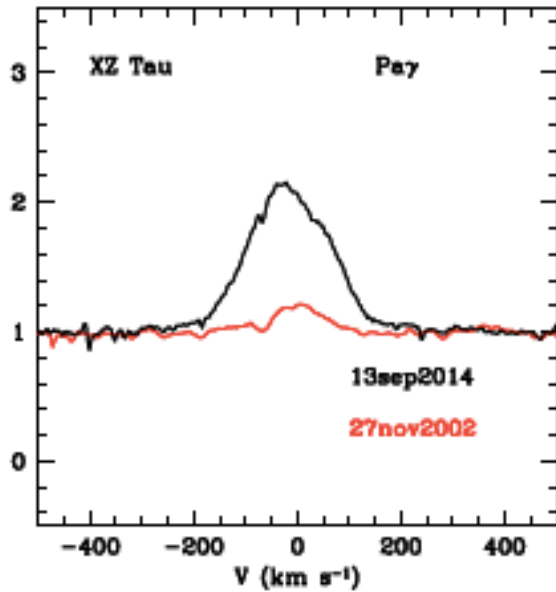
V1478 Cyg distance 429 pc  
 $L_{bol} = 3 \times 10^4 L_{SUN}$  (Be star)

**R = 50000, 6 km/s velocity resolution!**

# GIANO observations of T Tauri stars

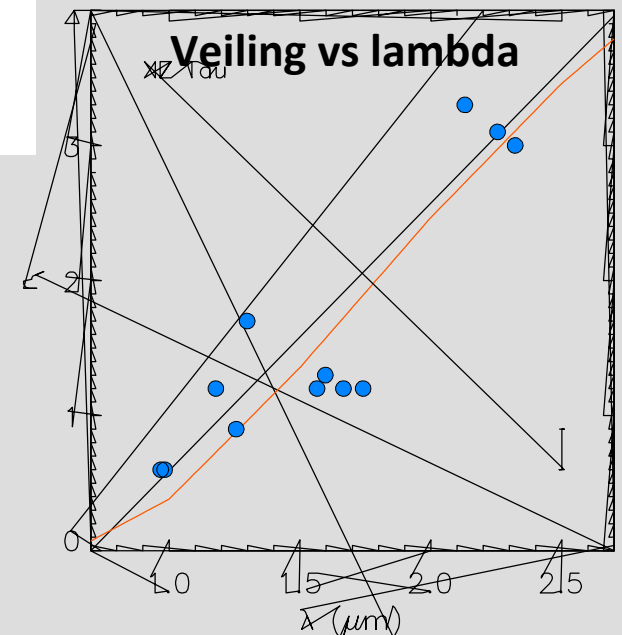
Pay XZ Tau

He I 1.08um

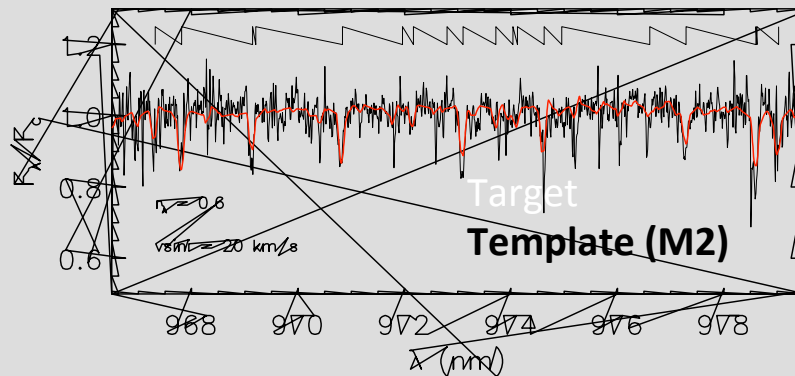


**Correlation between accretion and wind variability**

Y J H K



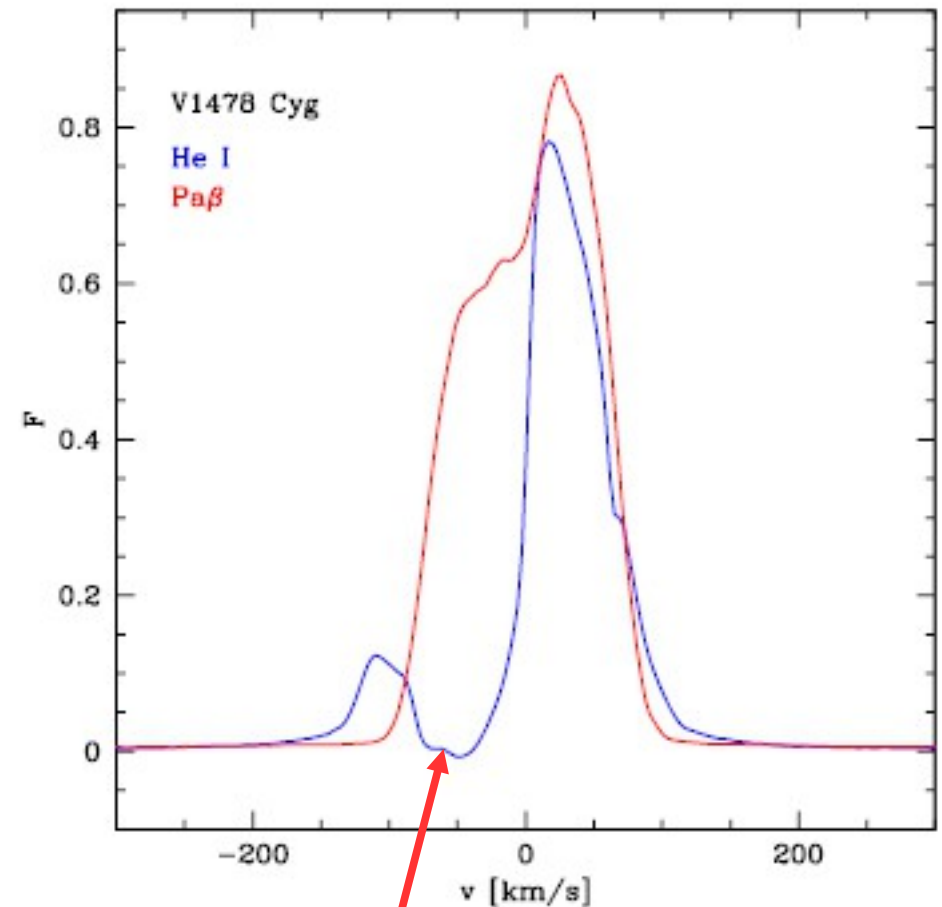
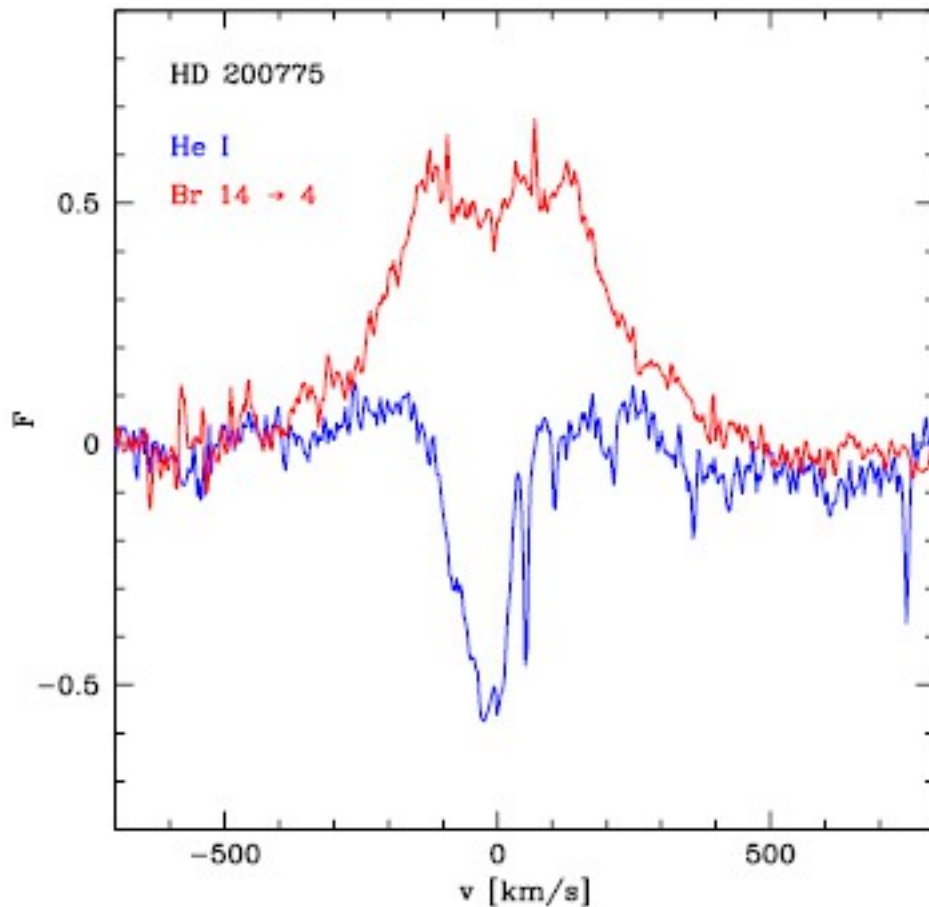
**Measurement of excess emission through IR veiling**



Antoniucci, Biazzo et al. in prep.

# ALTA risoluzione spettrale, importanza del tracciante: **GIANO@TNG** (SV 2013)

*He I 1.083  $\mu\text{m}$ : wind tracer (Edwards et al. 2006)*

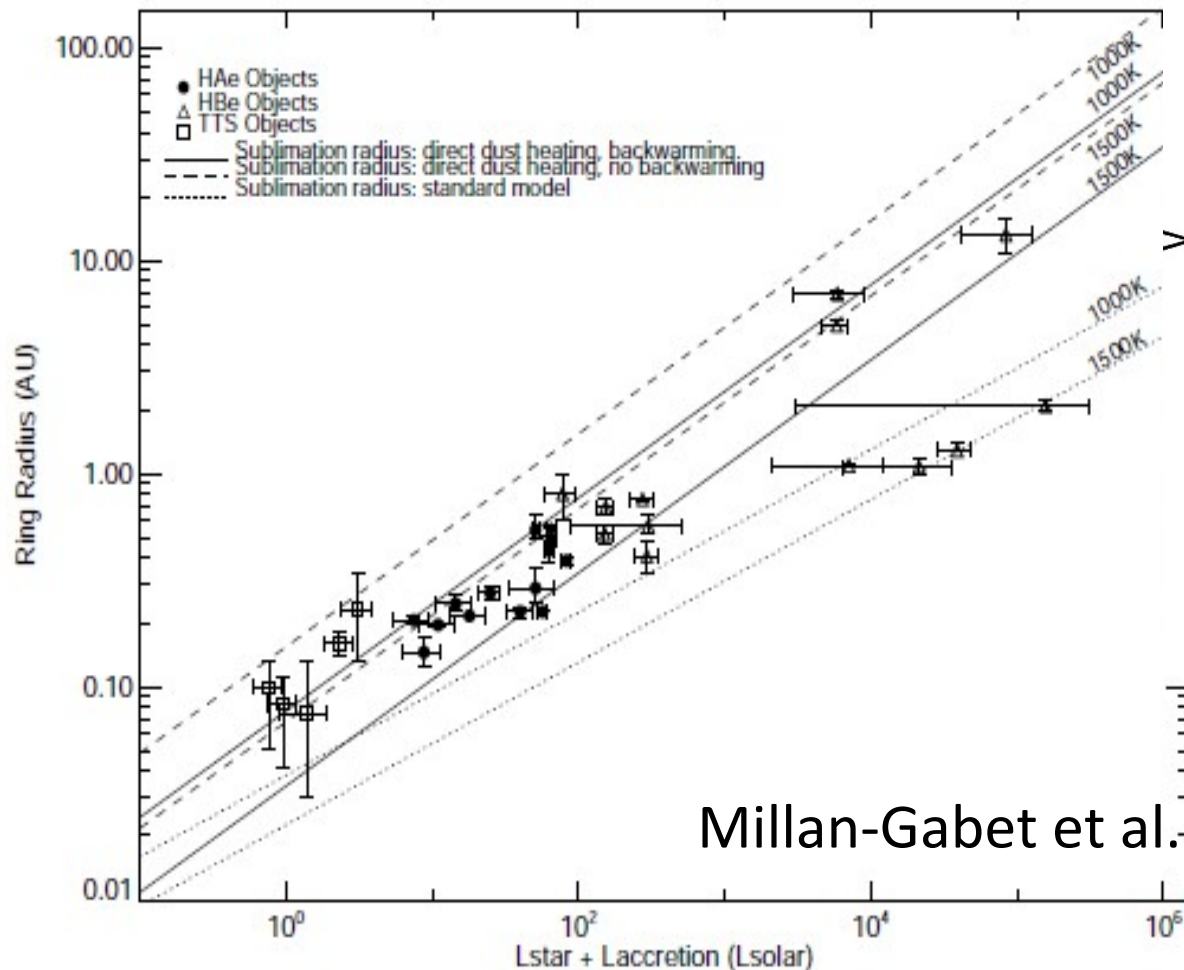


**In absorption, blueshifted**

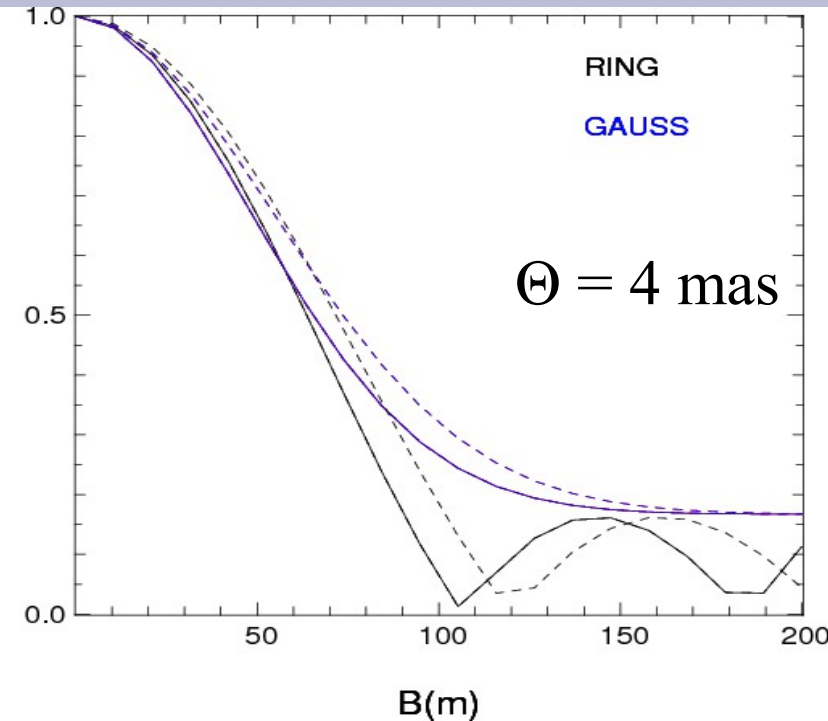
**Self-absorbed line blueshifted dip  
Consistent with disk wind 75 km/s**

**R = 50000, 6 km/s velocity resolution!**

# NIR interferometry: the ultimate spatial resolver



Millan-Gabet et al. 2007

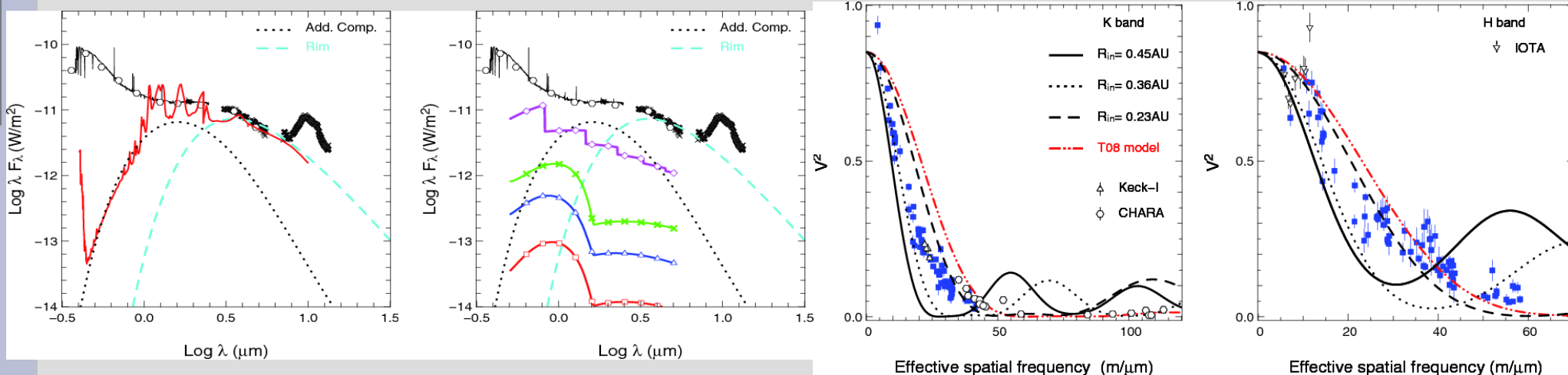


La maggior parte delle informazioni che abbiamo su una scala di pochi AU è legata a osservazioni interferometriche nel NIR

# Interferometria NIR: **AMBER@VLT**, GTO, >200 ore di tempo osservativo allocato ad Arcetri (2005-2010)

**HD163296 Herbig Ae star (A1) Mass = 2.3 Msun**

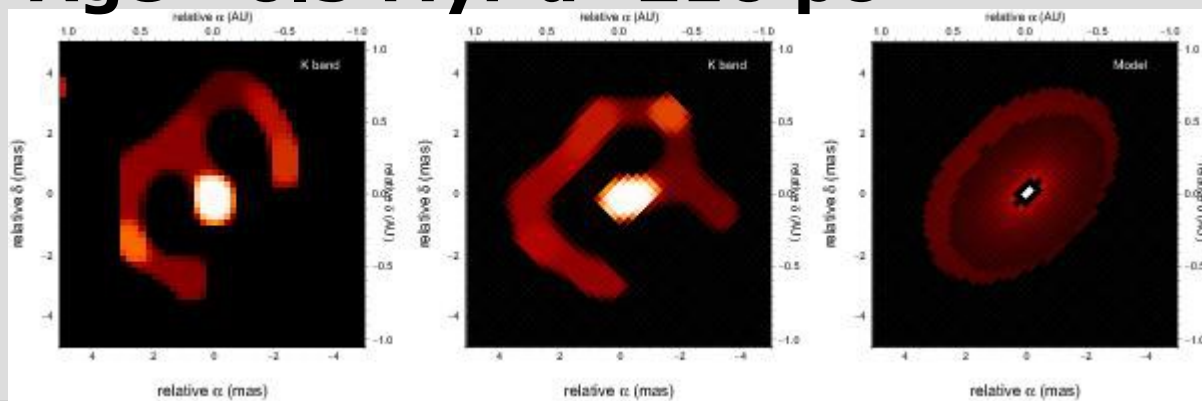
**Benisty et al. 2010, A&A 511, 74      Age = 4 Myr d=122 pc**



**HR5999 Herbig Ae (A7 III-IV) star**

**Mass = 3-4 Msun    Age = 0.5 Myr d=210 pc**

**Benisty et al.  
2011,  
A&A 531, 84**



# Interferometria NIR: AMBER@VLTI spettroastrometria (GTO 2005-2010)

**Z CMa Herbig Be star (B8) + FU Ori star**

**Mass = 12 Msun age = 1-4 Myr d = 1000 pc**

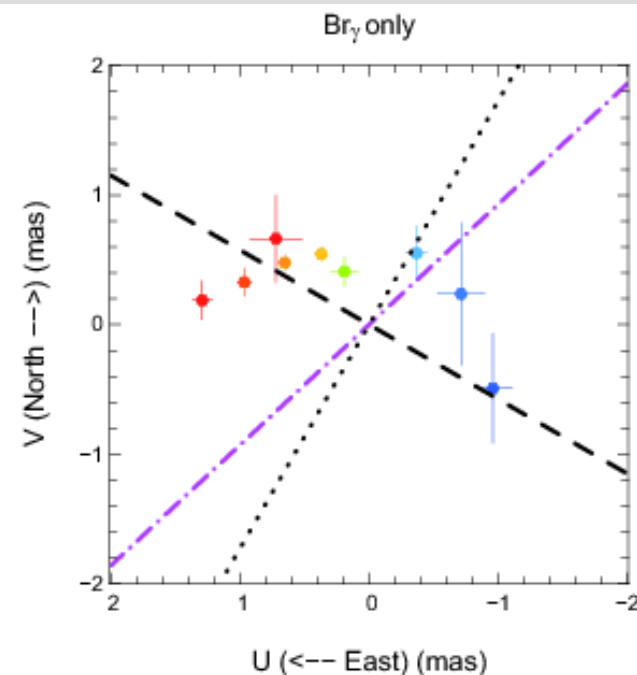
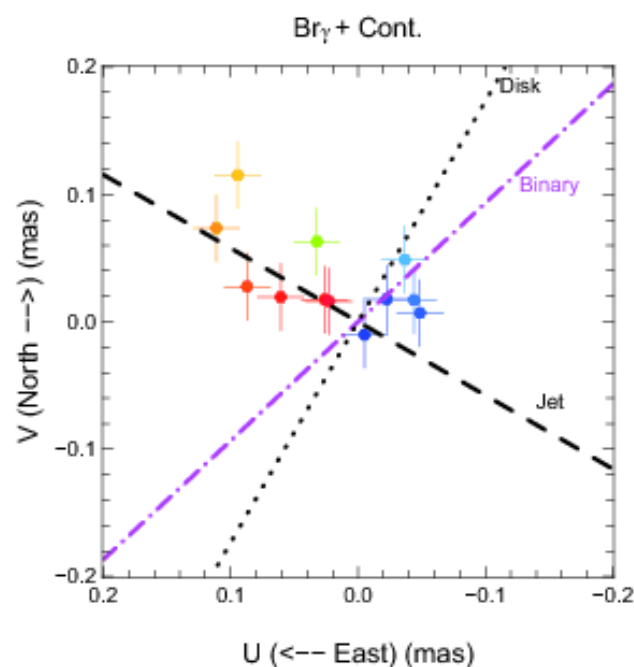
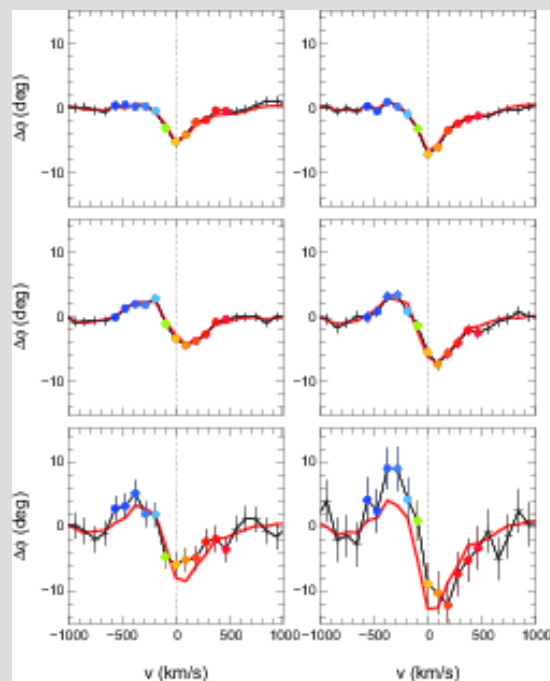
**Binary with 1 arcsec separation In January 2008, the HBe component underwent a luminosity increase by 2 mag**

**Size of Br $\gamma$  emission: 1.5 to 2.6 AU Size of continuum emission region: 3.6 AU**

**Outburst phase of strong mass loss possibly triggered by enhanced mass accretion**

**Benisty et al. 2010, A&A 517, L3**

**R=20  $\mu$ as (0.02 AU a 1 kpc!)**



# Facilities presenti e future



**E-ELT, ESO**

# Spettrometri ad alta risoluzione

## **TNG**

*GIANO, no AO, R=50000 da 0.95 a 2.45 micron in una expo*

*Sensibilità: JHK = 10, guide camera z=15*

*---> GIARPS (talk Benatti Sanna), JHK = 12, fine 2016*

## **ESO**

*CRIRES+, AO (MACAO), R=50000-100000, Y in una expo, J e H in 2 expo, K in 3 expo, L in 4 expo, Min 5 expo; spettropolarimetria, sensibilità JHK = 15, 2018*

## **E-ELT**

*HIRES (talk Origlia mercoledì), AO, R=100000, 0.4-2.5 micron, sensibilità K=18, 2026*



# Imager+AO per alta risoluzione spaziale

## **LBT**

*LUCI+FLAO, JHK, risol. 65 mas in K, sensibilità K=28 in 1 hr*

*LMIRCAM/LBTI, AO, J to M (5 micron), coro/ima, risol. 100 mas in L, sensibilità L=17-18, M= 13.8*

**SHARK+FLAO (talk d'Orazi), coronografo, JH, 2018**

## **ESO**

*NACO+CONICA, datato, risol. 56 mas, sensibilità K=23,4 in 1 hr*

*---> ERIS(+SCAO), JHK, coro/ima, 2020*

**SPHERE/IRDIS (talk Mesa), coro/ima**

## **E-ELT**

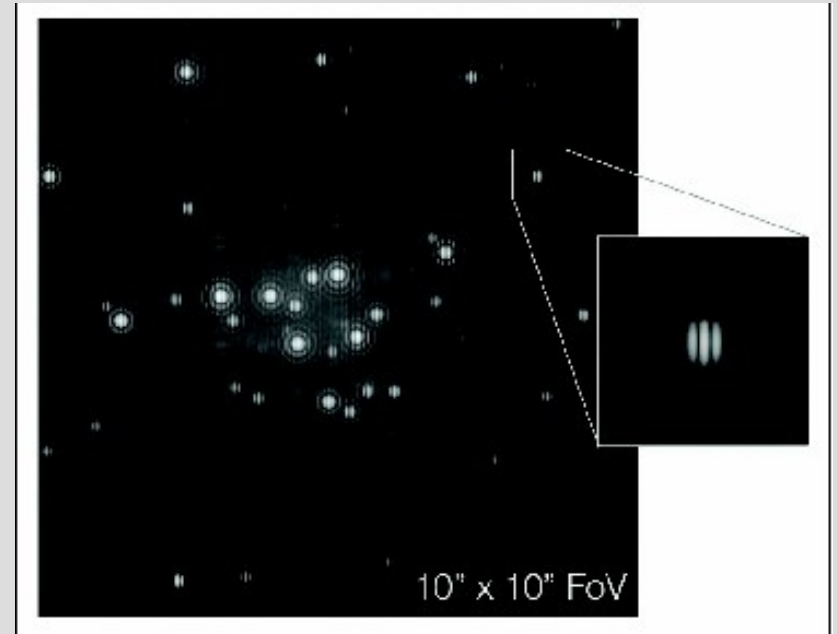
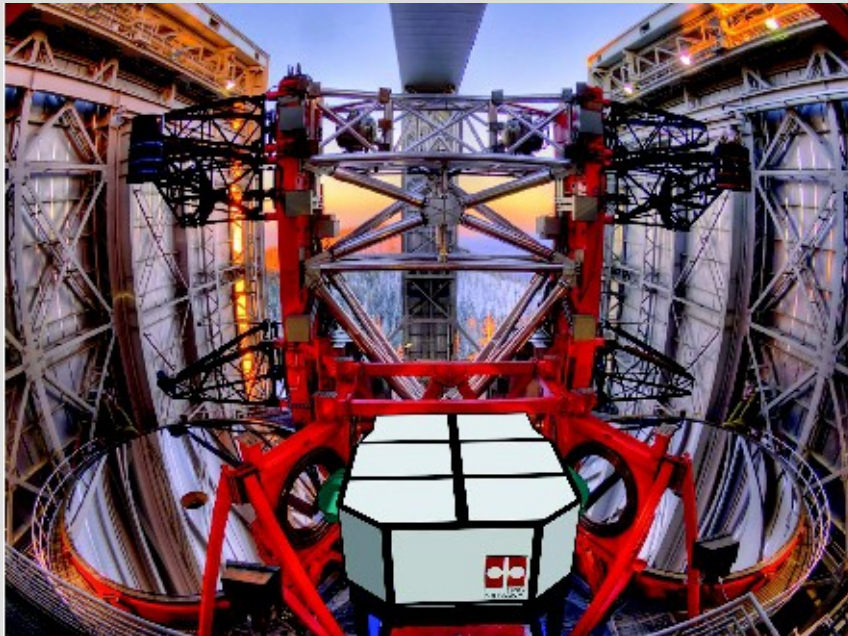
*MICADO+MAORY, 0.8 to 2,5 micron, risol. 6 mas (J), 10 mas (K) in 1 arcmin field, sensibilità K=30 in 1 hr, 2024*

# Interferometri

## ***LBT+LINC NIRVANA(+MCAO)***

***Interferometro di Fizeau, risoluzione equivalente a telescopio  
22.8 m (24 mas in K), area collettrice equivalente a  
telescopio 12 m, ottimo campionamento piano UV***

***Disponibile a breve ma fringe tracker non finanziato...***



# Interferometri: VLTi

***GRAVITY (max baseline 140 m, risol. 3 mas in K)***

*Science verification in corso, imminente anche il commissioning sugli UT*

*Fino a 6 basi correlabili (4 telescopi), K*

*Sensibilità in single mode: K=8-8.5 a R=4000, K=10-11 a R=50*

*Dual mode: necessaria stella brillante a 2 arcsec (6 arcsec con gli AT), sensibilità migliore!*

*In dual mode phase referencing: imaging!*

***MATISSE (max baseline 140 m, risol. 7 mas in M)***

***2017***

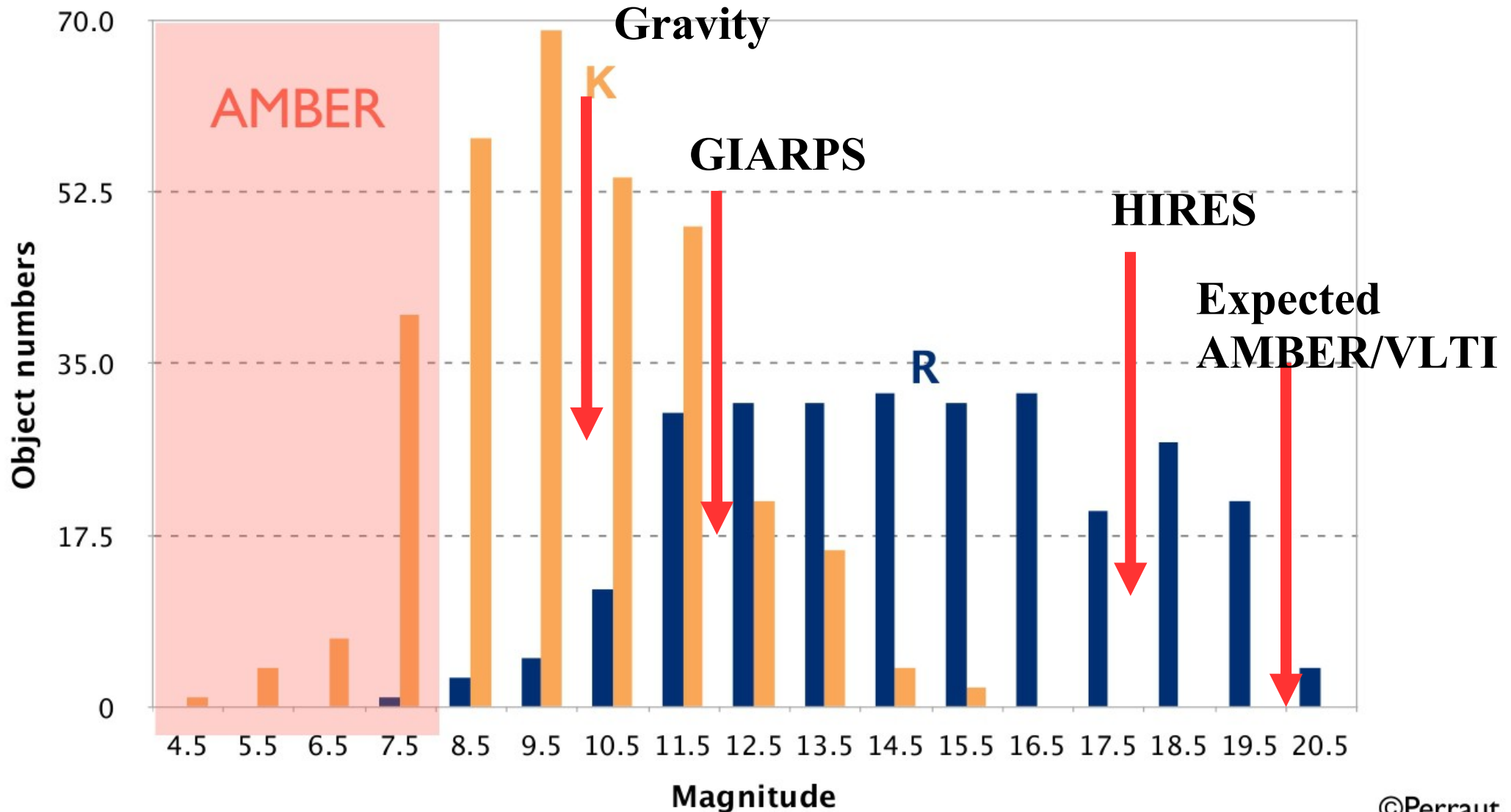
*Fino a 6 basi correlabili (4 telescopi), L, M, N*

*R=20-1000 in L, 20-550 in M, 20-250 in N*

*Image reconstruction*

# Sensibilità, confronto

Taurus-Aurigae



# Conclusioni

***Ampia disponibilità di strumenti per imaging OA-assisted e spettroscopia ad alta risoluzione, facilmente accessibili a programmi italiani in attesa di E-ELT.***

***Non sempre ottimizzati per osservazioni di oggetti stellari giovani (ad esempio no NIR WFS, GIANO/GIARPS non derotato).***

***Studi di inflow-outflow nelle parti interne del disco possibili con OA e spettrometri ad alta risoluzione, ma probabilmente solo l'interferometria NIR è in grado di fornire informazioni critiche. Astronomia italiana decisamente ai margini in questo campo.***