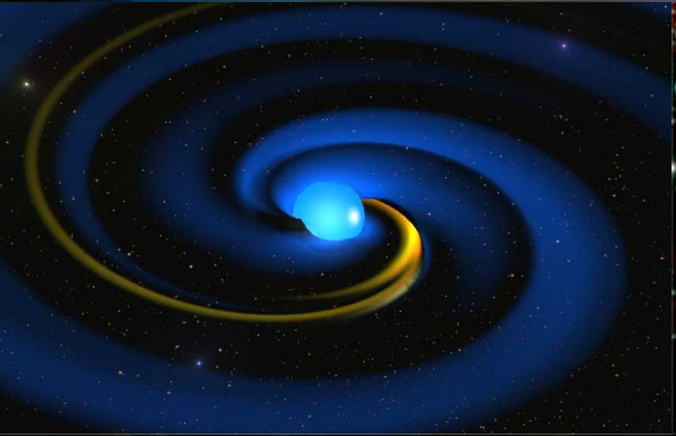
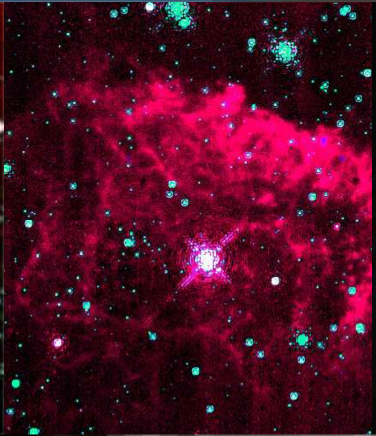
Long-term Spectroscopic Monitoring of LBVs and Hypergiants



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1. ROB Brussels, 2. MPI Bonn, 3. KU Leuven

Driving and structuring of the extended winds of LBVs and Hypergiants

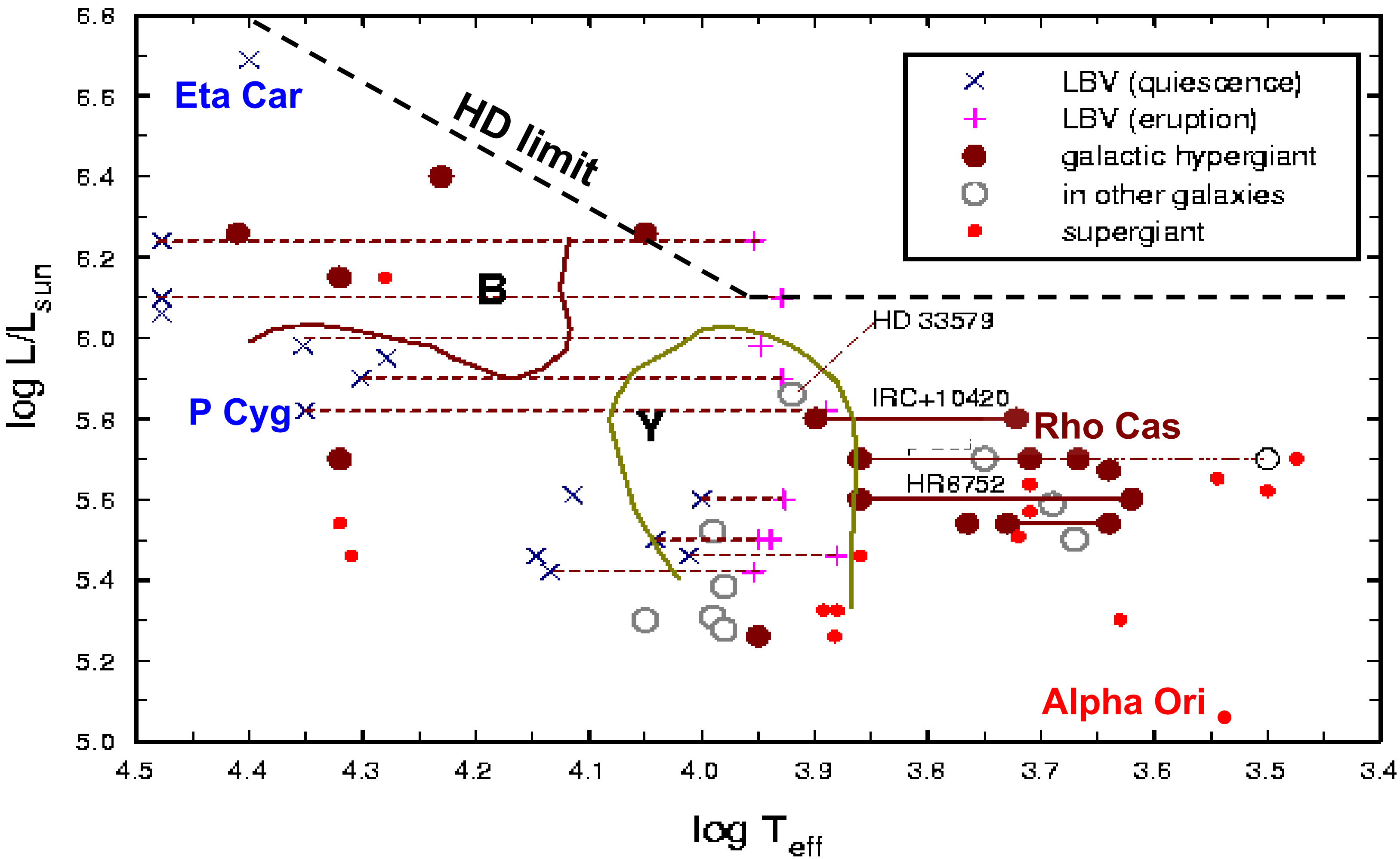
- **What physical mechanisms drive and structure the winds of hot and cool massive stars? What mechanisms shape their complex circumstellar environments?**

- **What causes and drives the recurrent outbusts of LBVs and Hypergiants? Are these outburts related to the fast evolution and late evolutionary stages of these super-massive stars?**

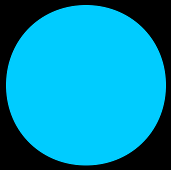
- **Long-term spectroscopic variability observed in LBVs and Cool Hypergiants is crucial for unraveling these mechanisms with detailed RT modeling of spectral lines.**

- **HERMES monitoring program addresses important science questions such as the role of mechanical wave action for structuring and driving massive-star winds.**

What is an LBV & Hypergiant? Where do they live in H-RD?



- **Most massive and luminous supergiants near upper luminosity limit (Ia+).**
- **Strong spectral variability with enhanced atmos. activity & wind dynamics.**
- **Recurrent eruption events with exceptionally large mass-loss rates.**
- **Cool Hypergiants are thought be on blueward evolutionary track.**



LUMINOUS BLUE VARIABLE

P Cygni B1 Ia+

T_{eff} = 19,300 K Log g = 0.0

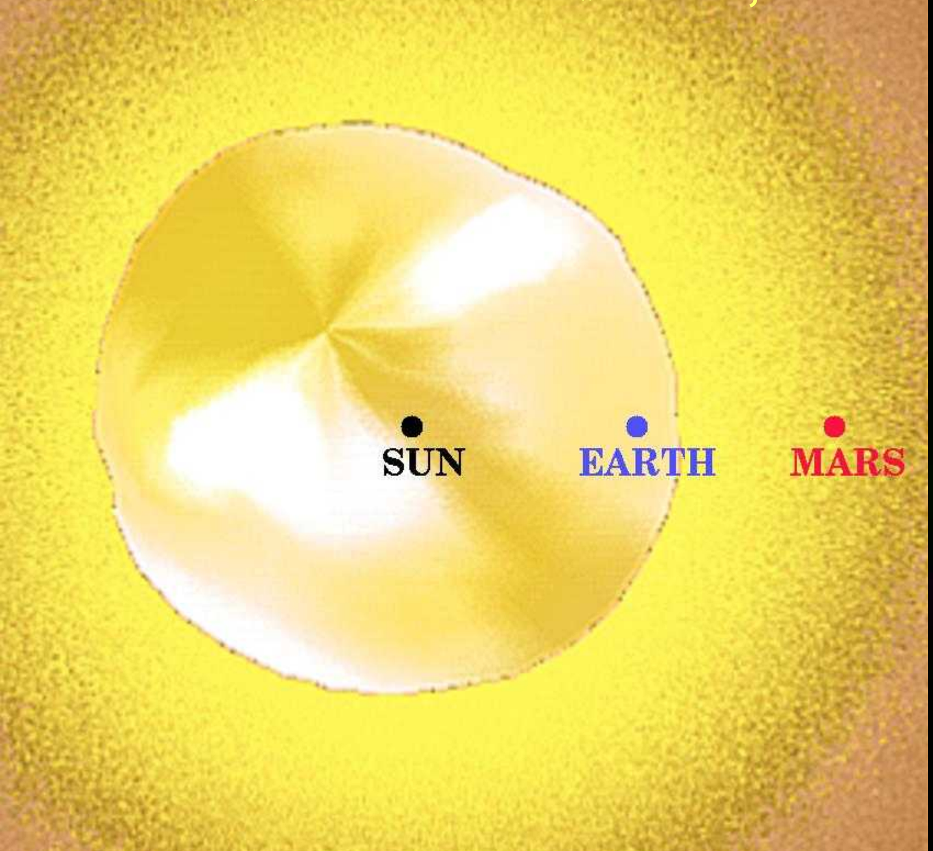
R_* = 76 $R_\odot$ L_* = 630,000 $L_\odot$

YELLOW HYPERGIANT

Rho Cas F - G Ia+

T_{eff} = 7200 K Log g = 0.5

R_* = 400 $R_\odot$ L_* = 100,000 $L_\odot$



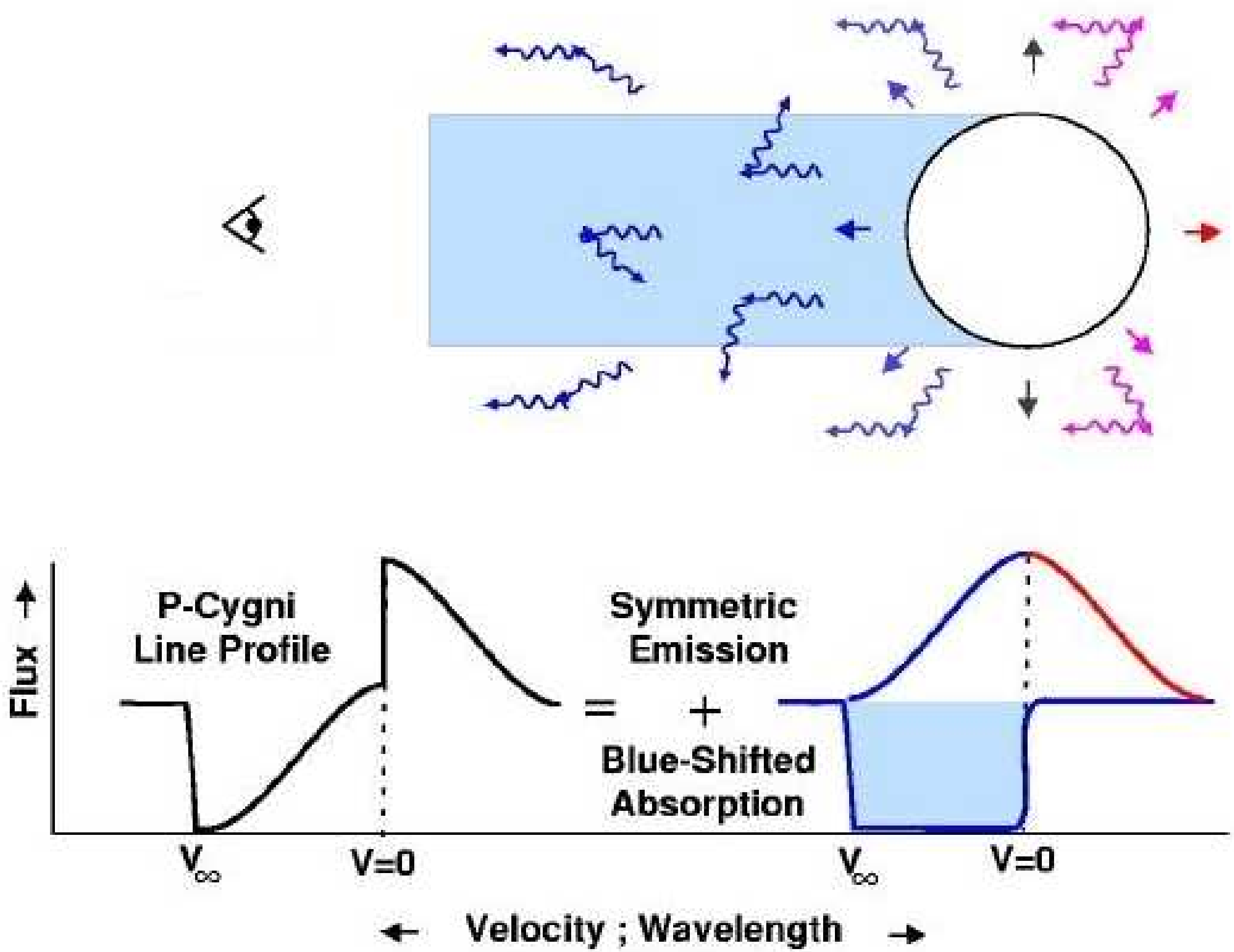
RED SUPERGIANT

Alpha Ori M2 Iab

T_{eff} = 3500 K Log g = - 0.5

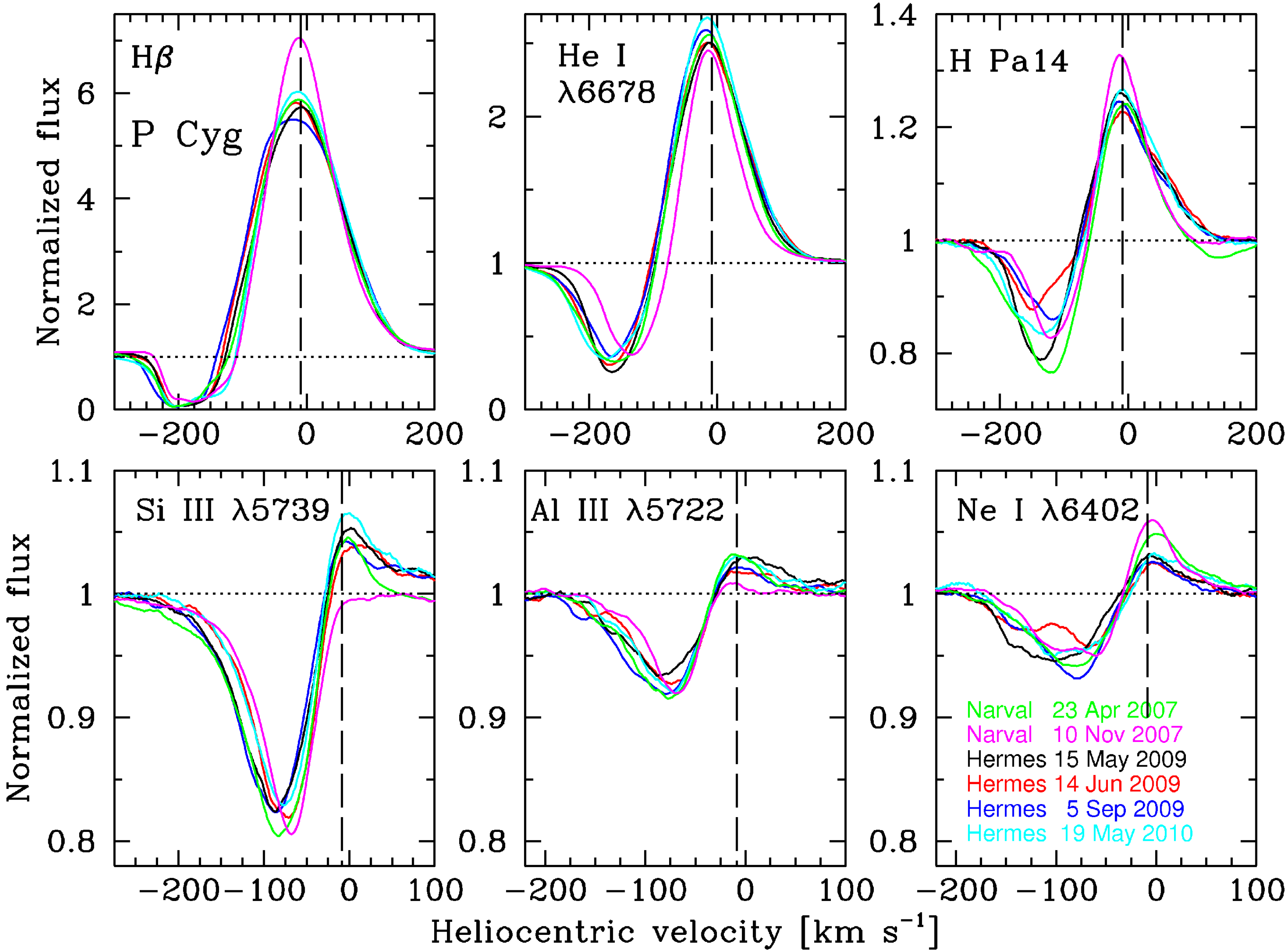
R_* = 700 $R_\odot$ L_* = 40,000 $L_\odot$

P Cygni Line Profile Formation



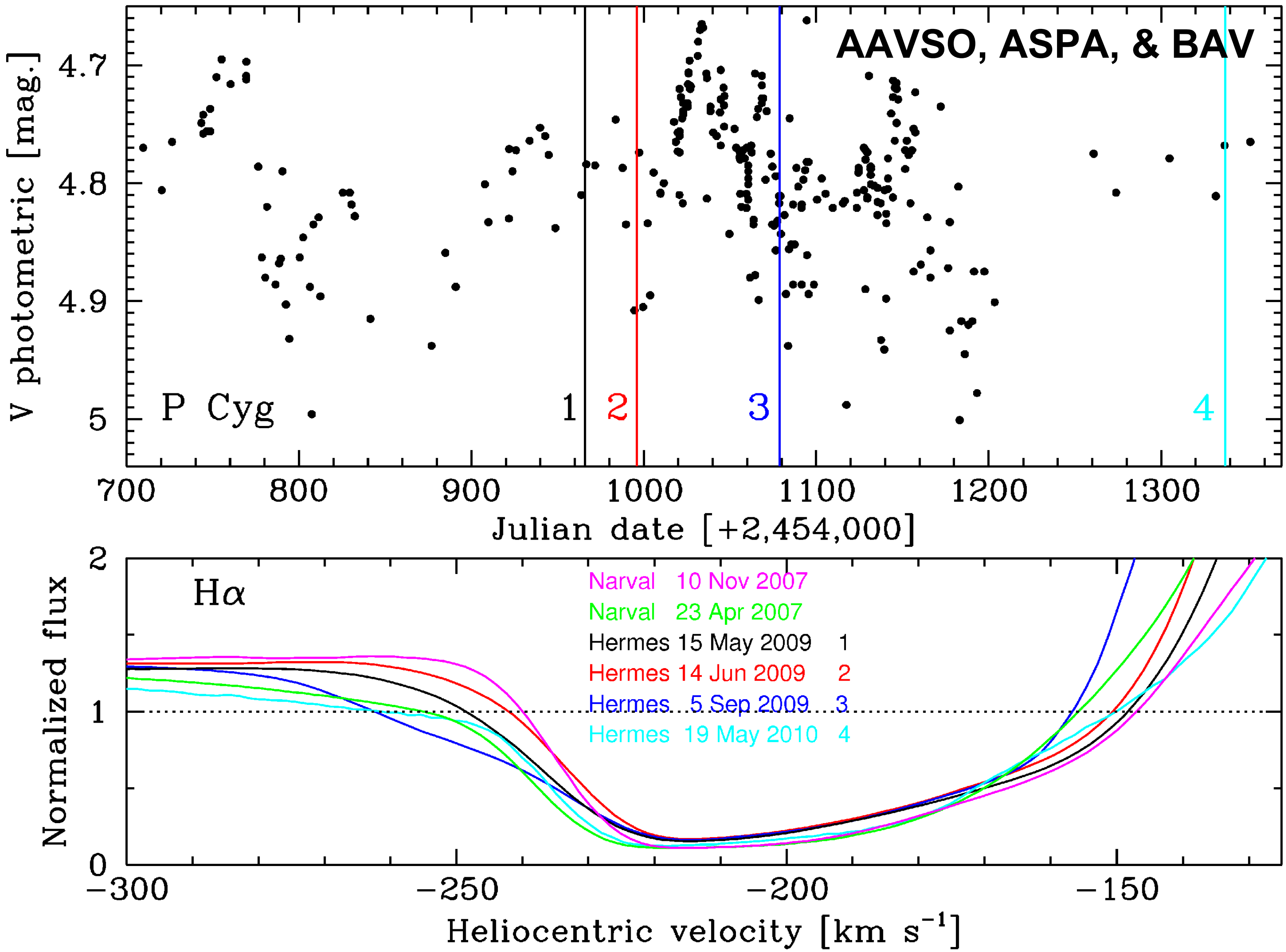
Absorption portion samples wind opacity in front of the stellar disc.

HERMES monitoring of line variability in P Cygni



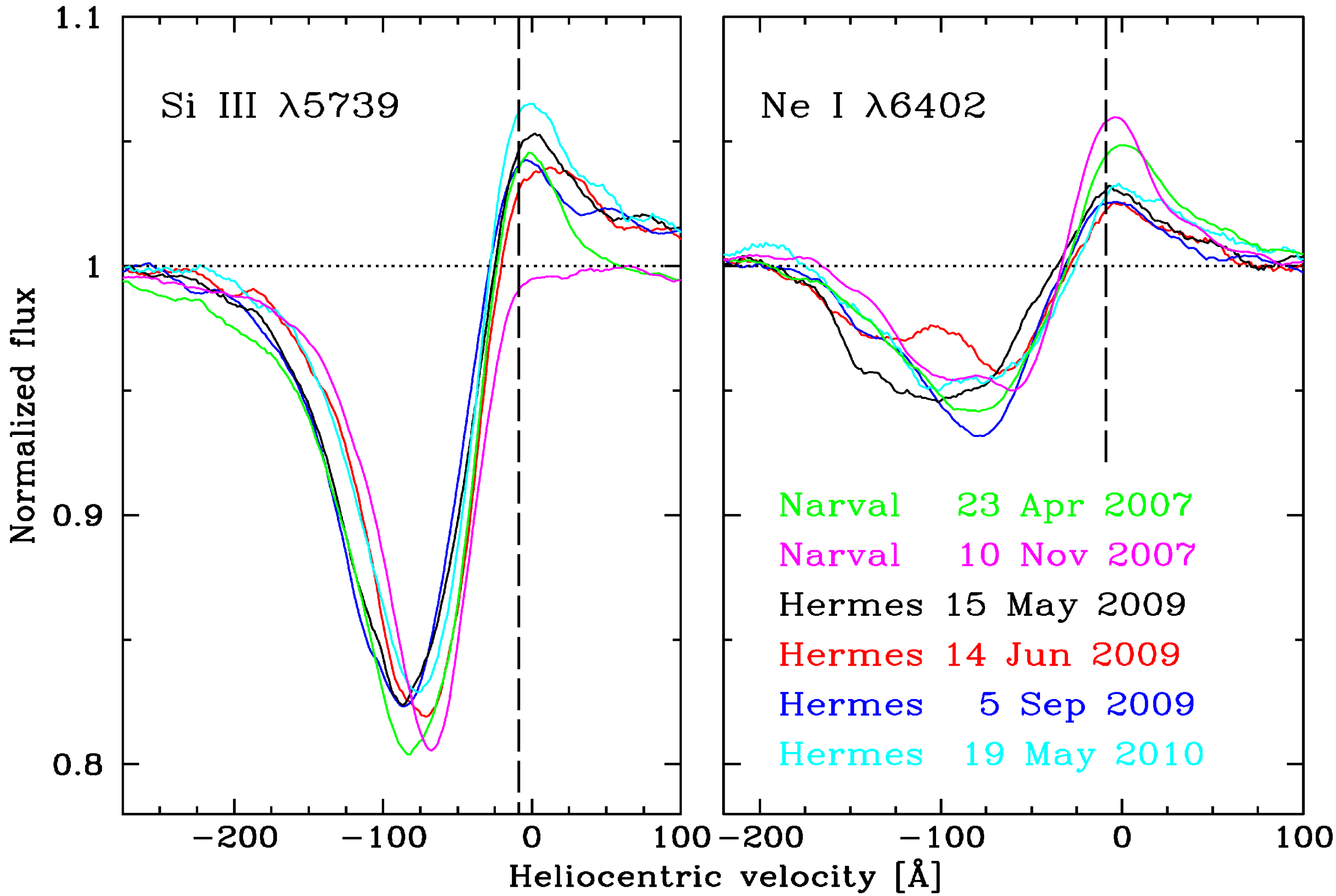
Variability of H and He line profiles due to changes in radiative wind acceleration?

HERMES monitoring of Hα variability in P Cygni



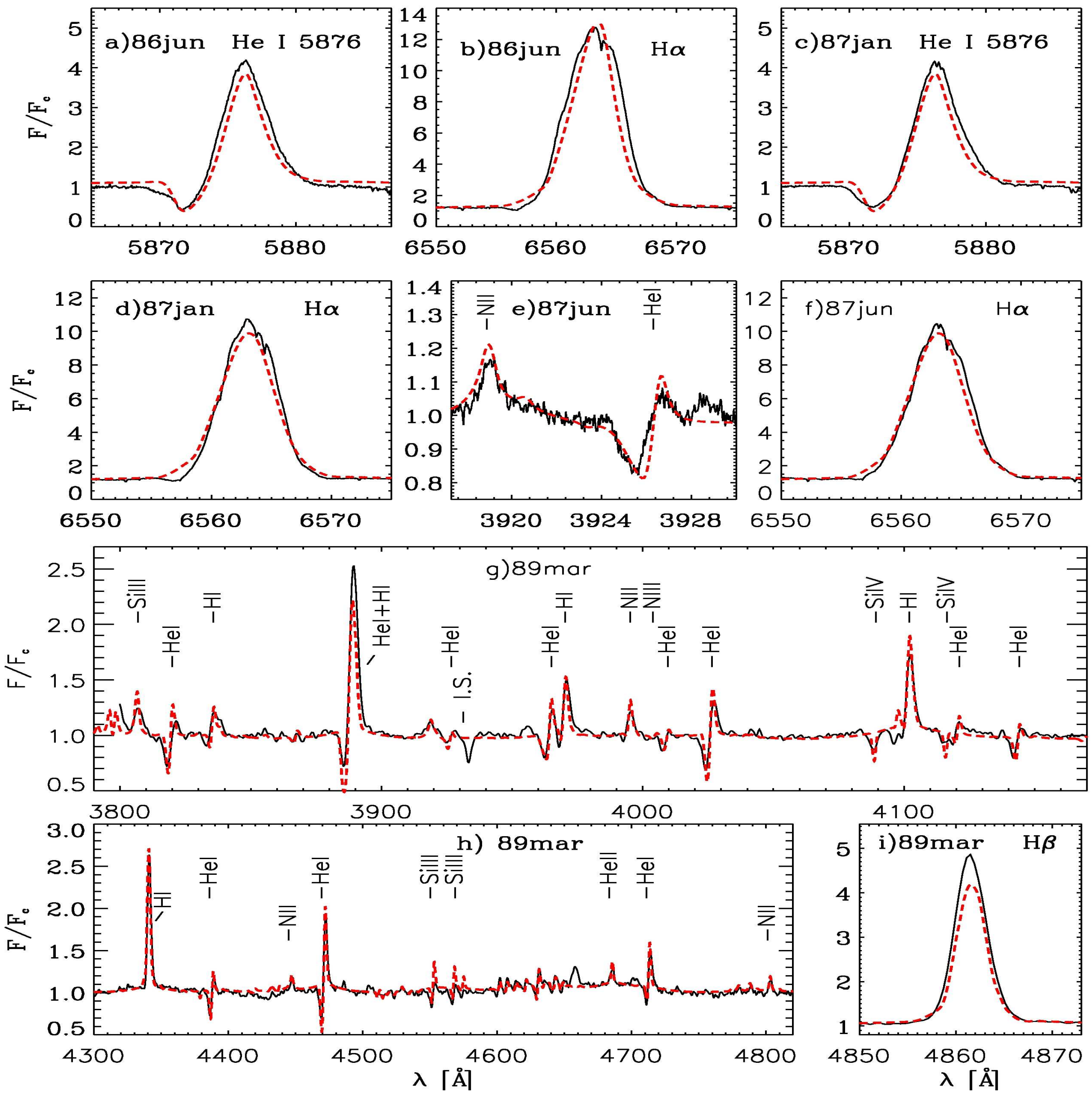
Physical link between *V* variability and wind acceleration region (β-law) ?

HERMES monitoring of line variability in P Cygni



Use large R of HERMES to investigate physical properties and variability of slow-wind regions close to the stellar surface from weak P Cyg profiles observed with large S/N ratios.

Synthesis of LBV spectra with CMFGEN RT code



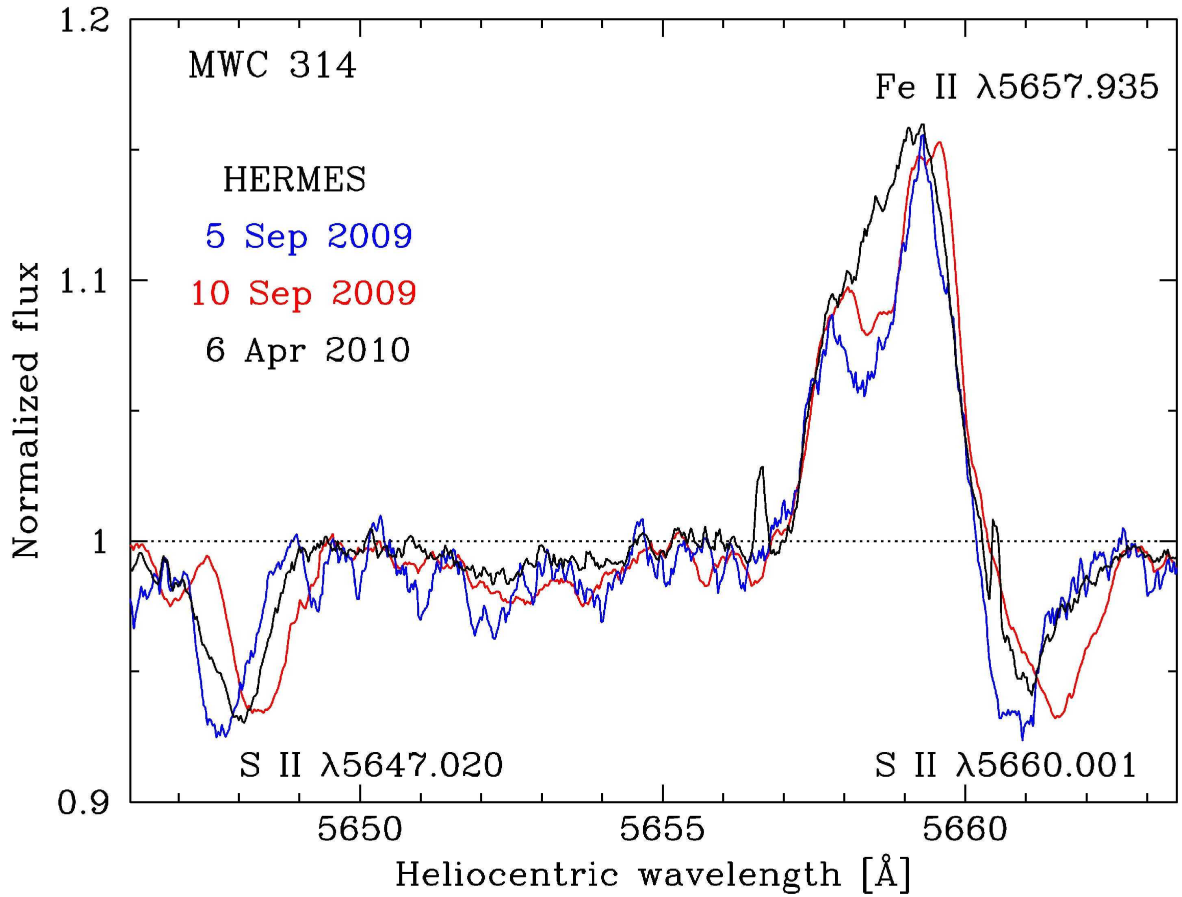
Synthetic RT fits provide stellar parameters

(Teff, R*, [X/H])

Detailed RT modeling of P Cyg line profiles provides accurate mass-loss rates & wind model parameters (Mdot, v∞, wind acceleration β-law)

HERMES monitoring investigates variable LBV wind conditions

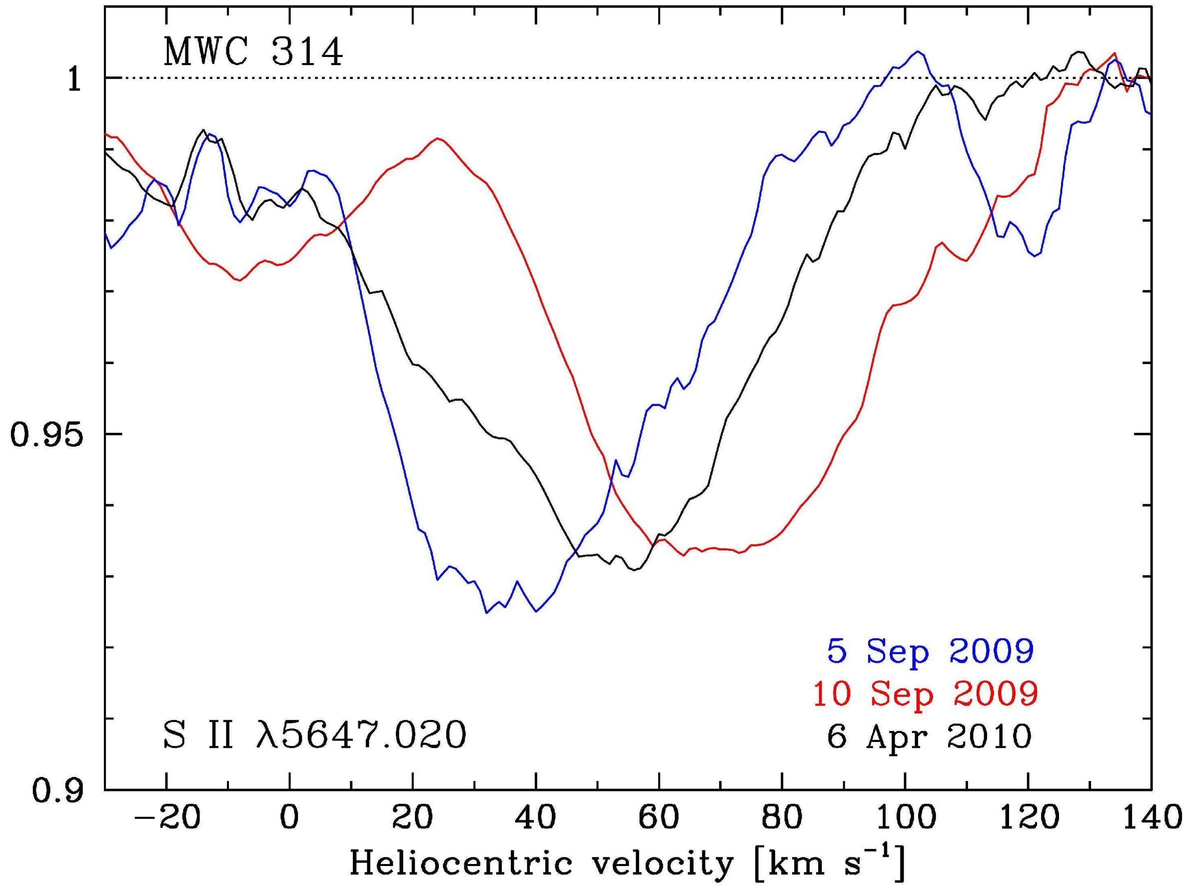
Hermes monitoring of LBV binary MWC 314



- Very few known LBV binaries - Eta Car and Pistol Star(?) - MWC 314 orbital period of ~1 month determined from sparse observations over almost 6 years (Muratorio et al. A&A, 2004).

HERMES monitoring: observe twice per month over one semester.

Proof of feasibility from S II λ5647 line

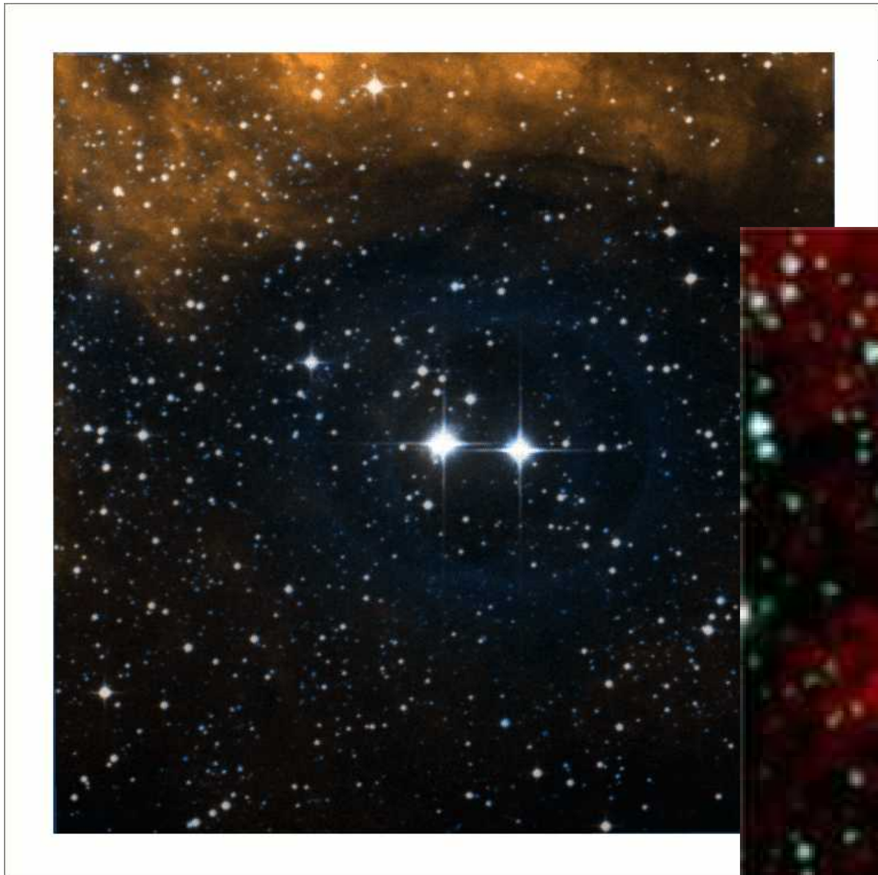


Strong indication of binarity of MWC 314 from large RV shifts of ~33 km s^{-1} observed with HERMES over only 5 days in Sep 2009.

⇒ A. Lobel, J. Groh, K. Torres, & N. Gorlova, *Long-term Monitoring of LBVs and LBV Candidates*, Proc. of IAU Symp. 272, 2010, in press.

Accurate determination of orbital parameters is possible with HERMES.

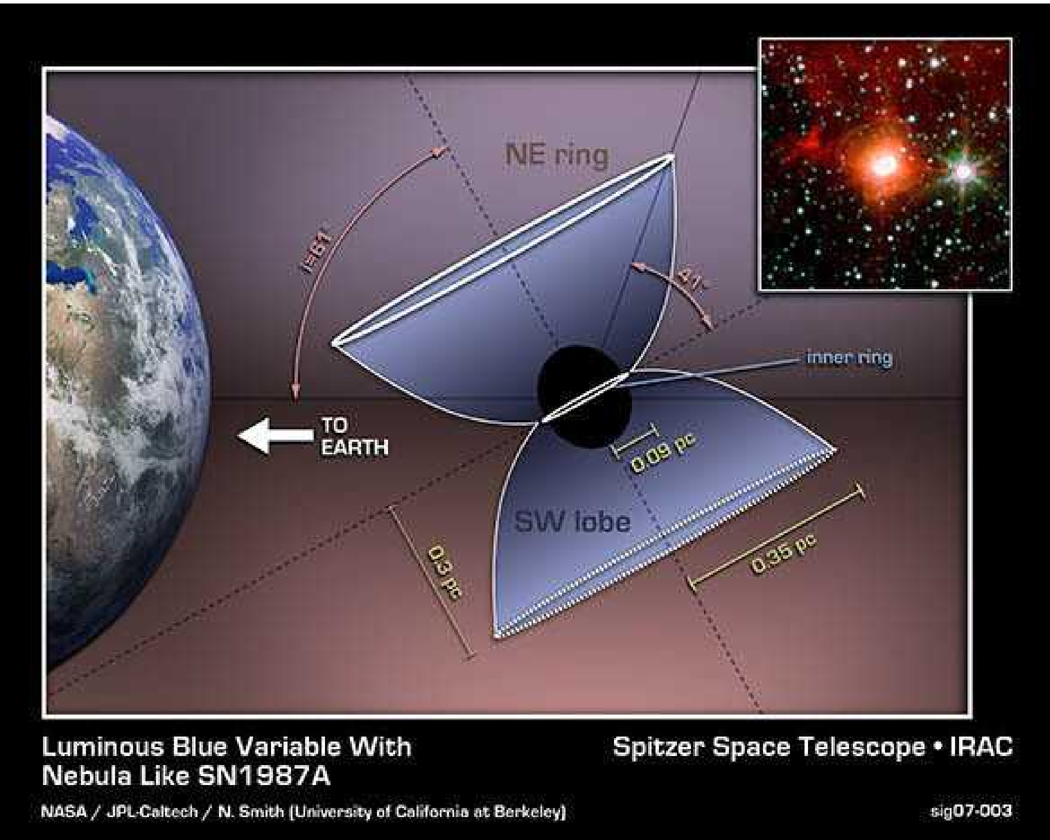
LBV Candidate HD 168625 and LBV HD 168607

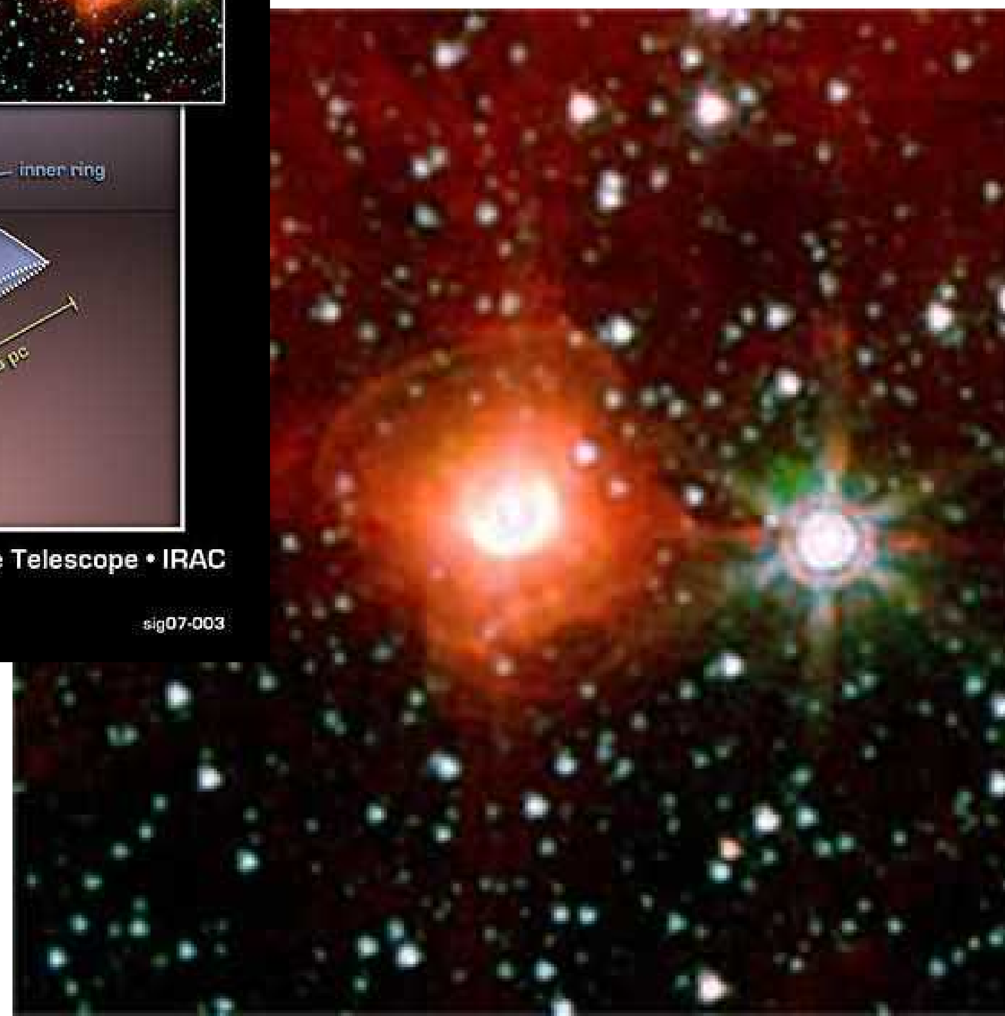


A remarkably close visual pair.

Spitzer observations of
triple-ring nebula like SN1987A
around HD168625.

Discovery of the large bipolar nebula of HD 168625





Spitzer observations of triple-ring nebula like SN1987A around HD168625. Dusty rings of ~370 K at 0.46 pc.

Long-term HERMES monitoring of LBV Candidate HD 168625

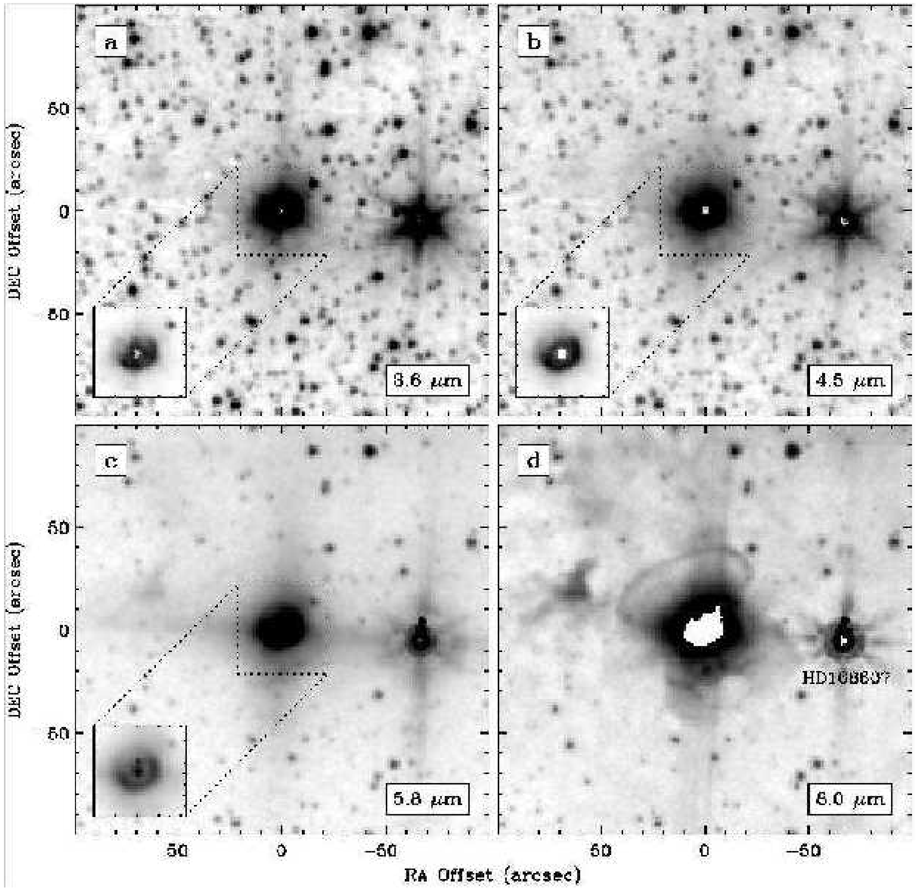
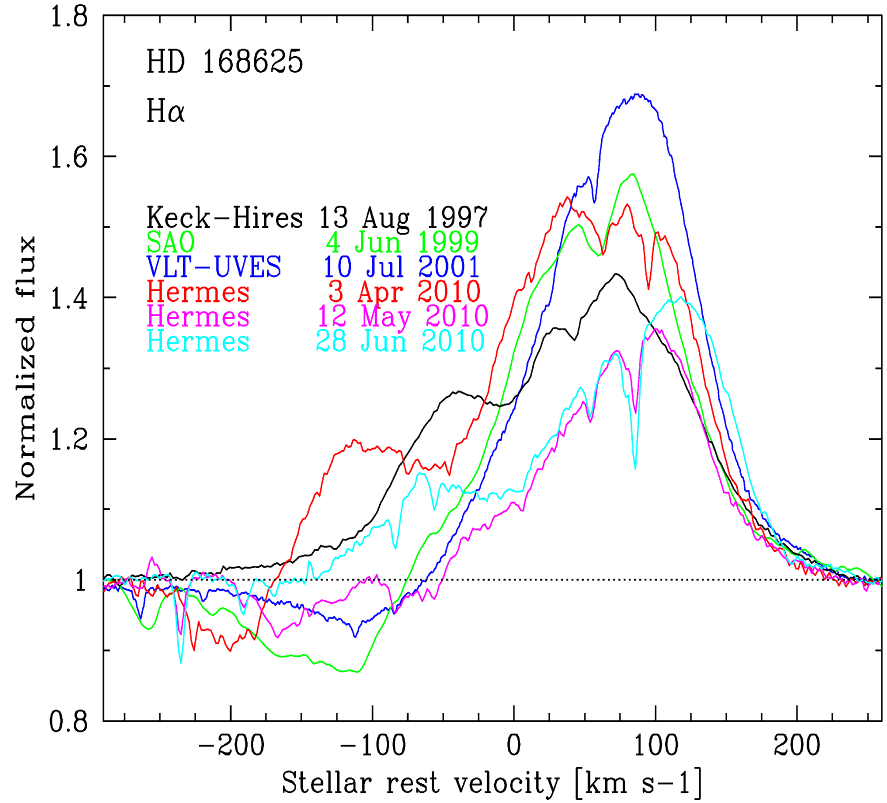


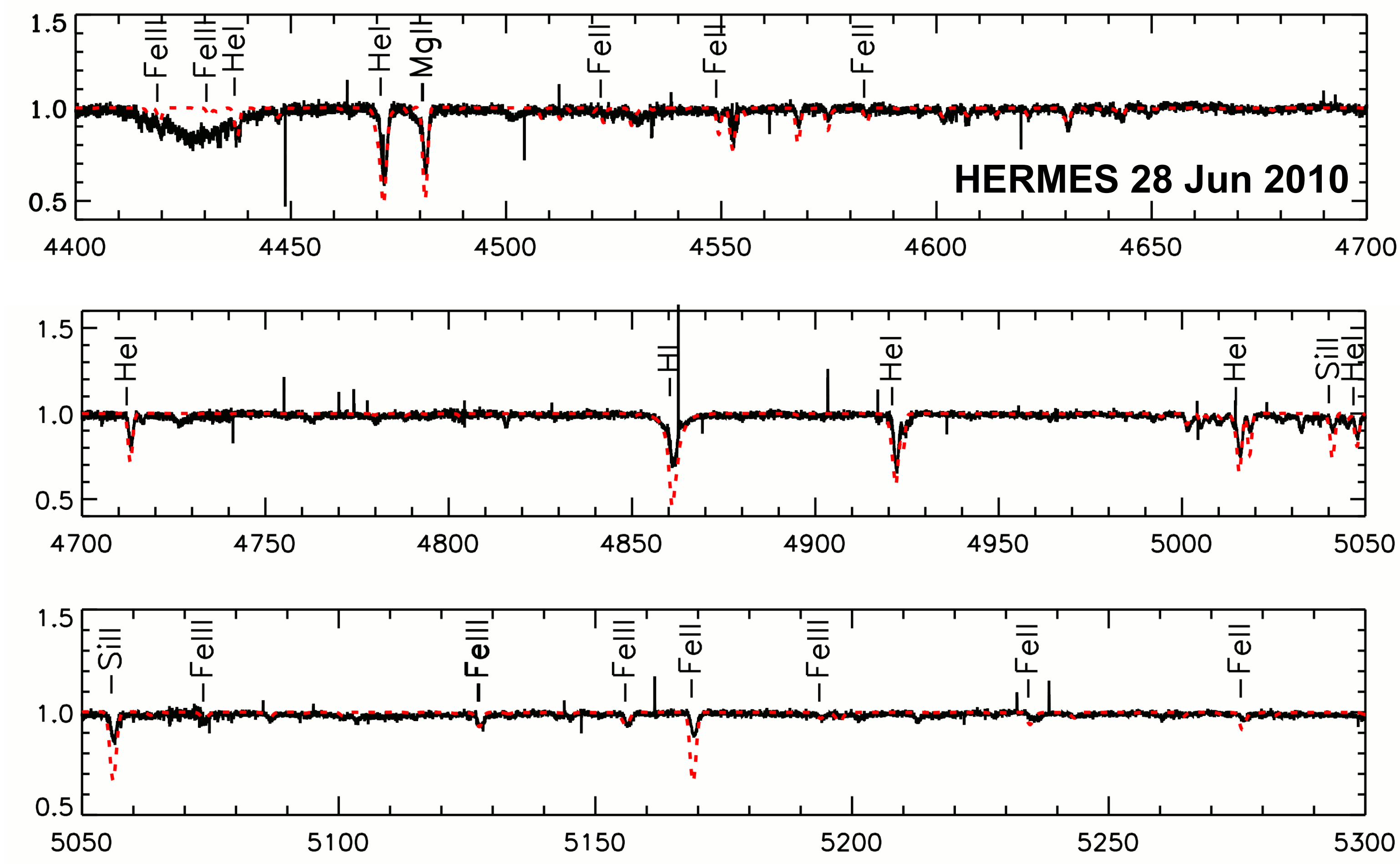
Fig. 1.— *Spitzer* images of the nebula around HD168625 in the four IRAC bands, taken as part of the GLIMPSE project. The faint outer bipolar nebula (especially the NE polar ring) is best seen at 8.0 μm. The blob located at offset $+60'',+20''$ may or may not be associated with the circumstellar ejecta. HD168607 is located $\sim65''$ west of center.



Strong Hα variability observed over ~3 months with HERMES.

Does the nebula of SN1987A result from multiple LBV eruptions rather than a swept-up RSG wind?

RT Modeling of HERMES spectra of HD 168625



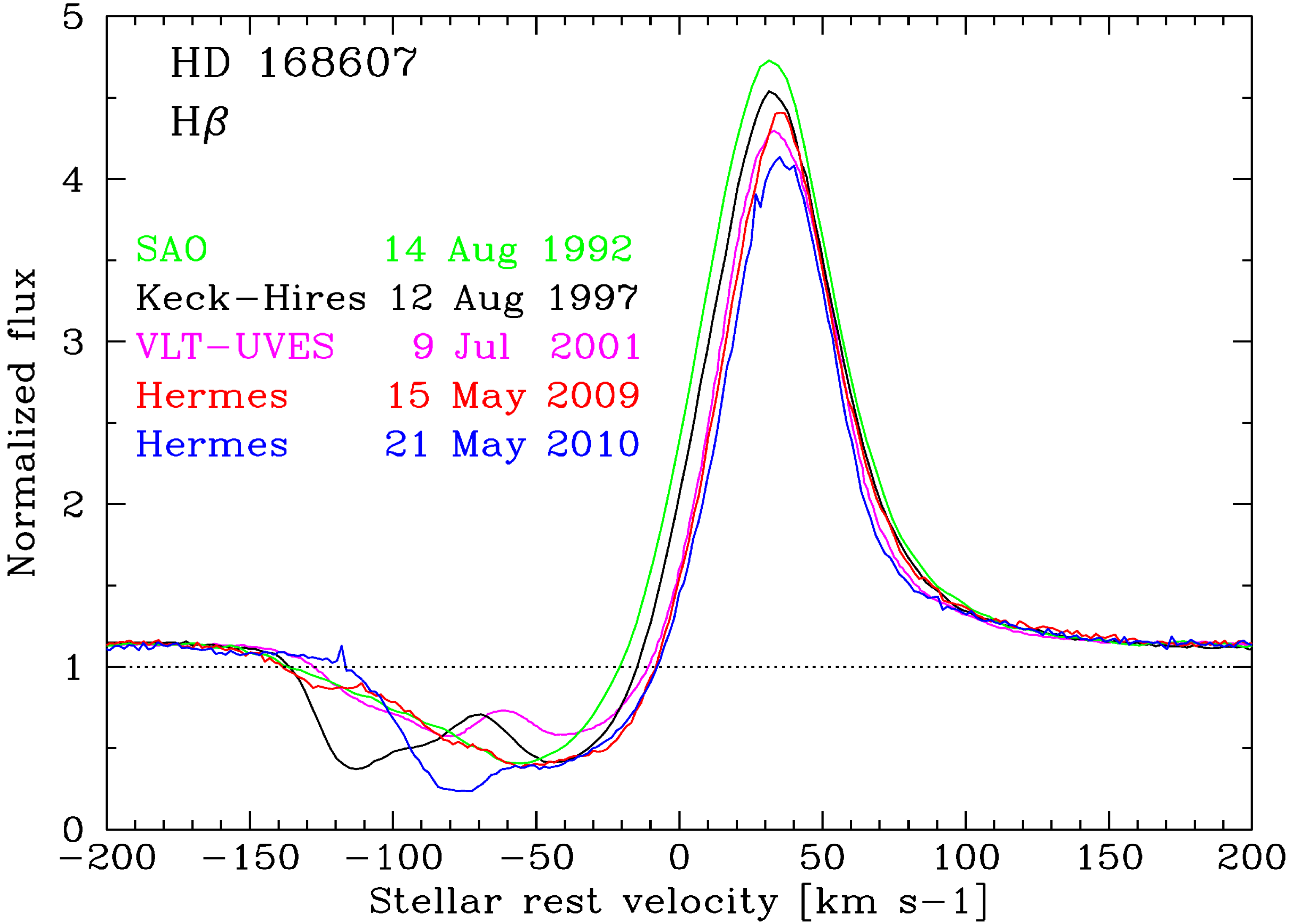
Best fit CMFGEN:

Atm. model: Teff=13,600 K $R_*=98.5\ R_\odot$ [He/H]=0.4 N is solar

Wind model: Mdot = 8 x $10^{-7}\ M_\odot$/yr (ϕ=0.25) V_∞=300 km s^{-1} β=2

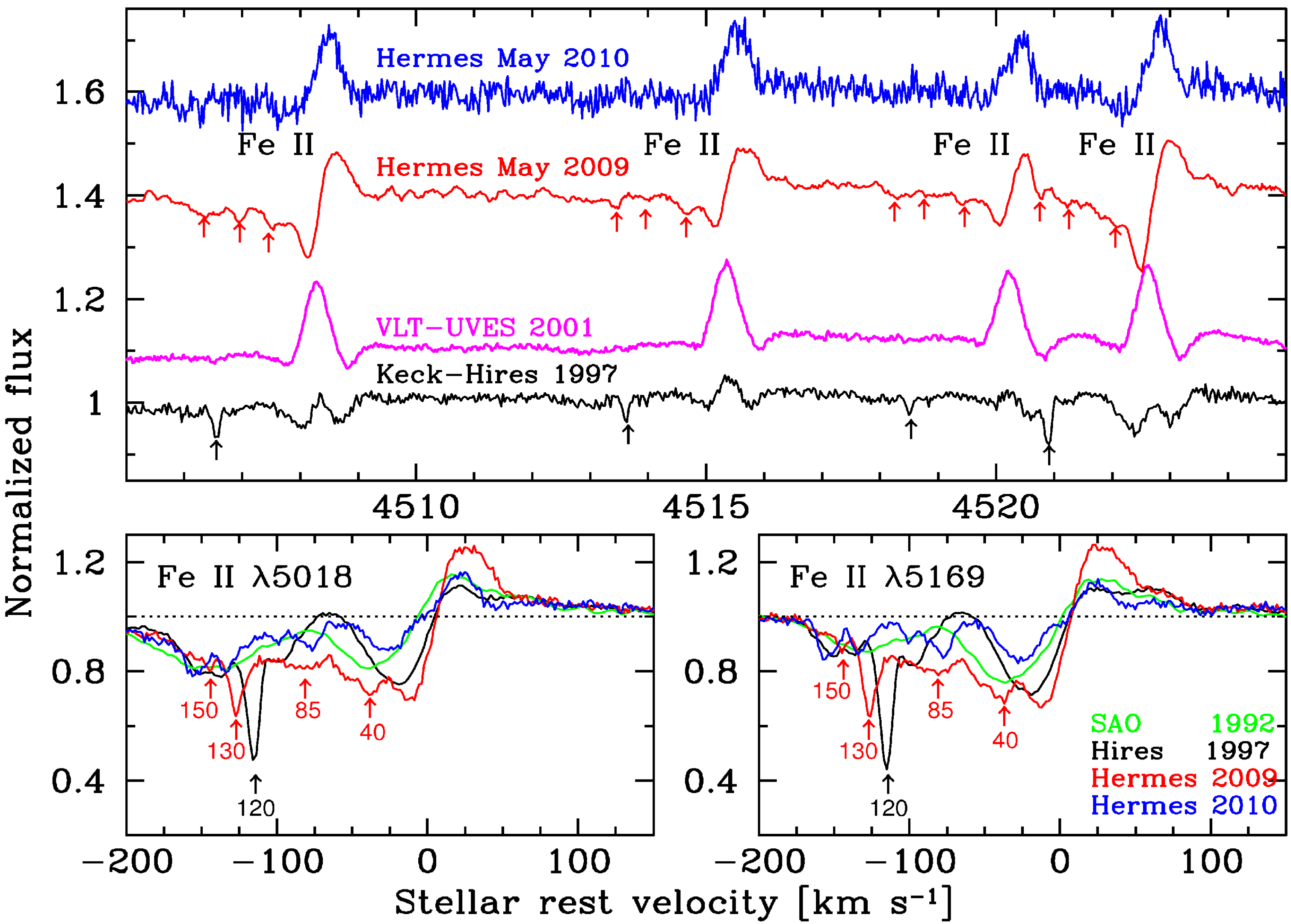
$\Rightarrow$ low-luminosty quiescent LBV of 20 to 25 $M_\odot$

Narrow Optical Absorption Components in LBV HD 168607



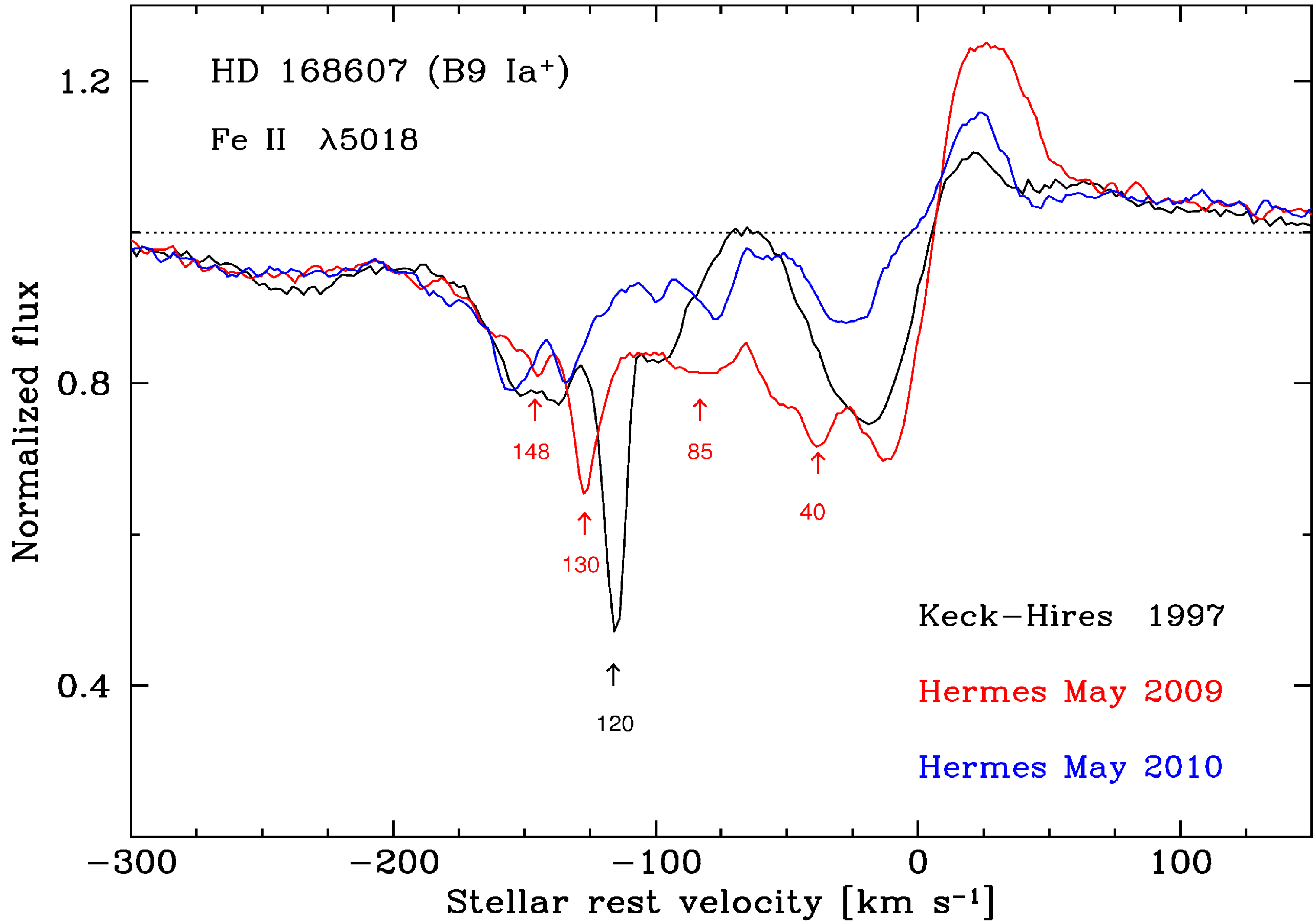
Strong variability of Hβ absorption observed with HERMES.

Narrow Optical Absorption Components in LBV HD 168607



Acceleration of NOACs on time-scale of moderate brightness variability?
NOACs acceleration can reveal smooth-wind velocity structure close to the surface.

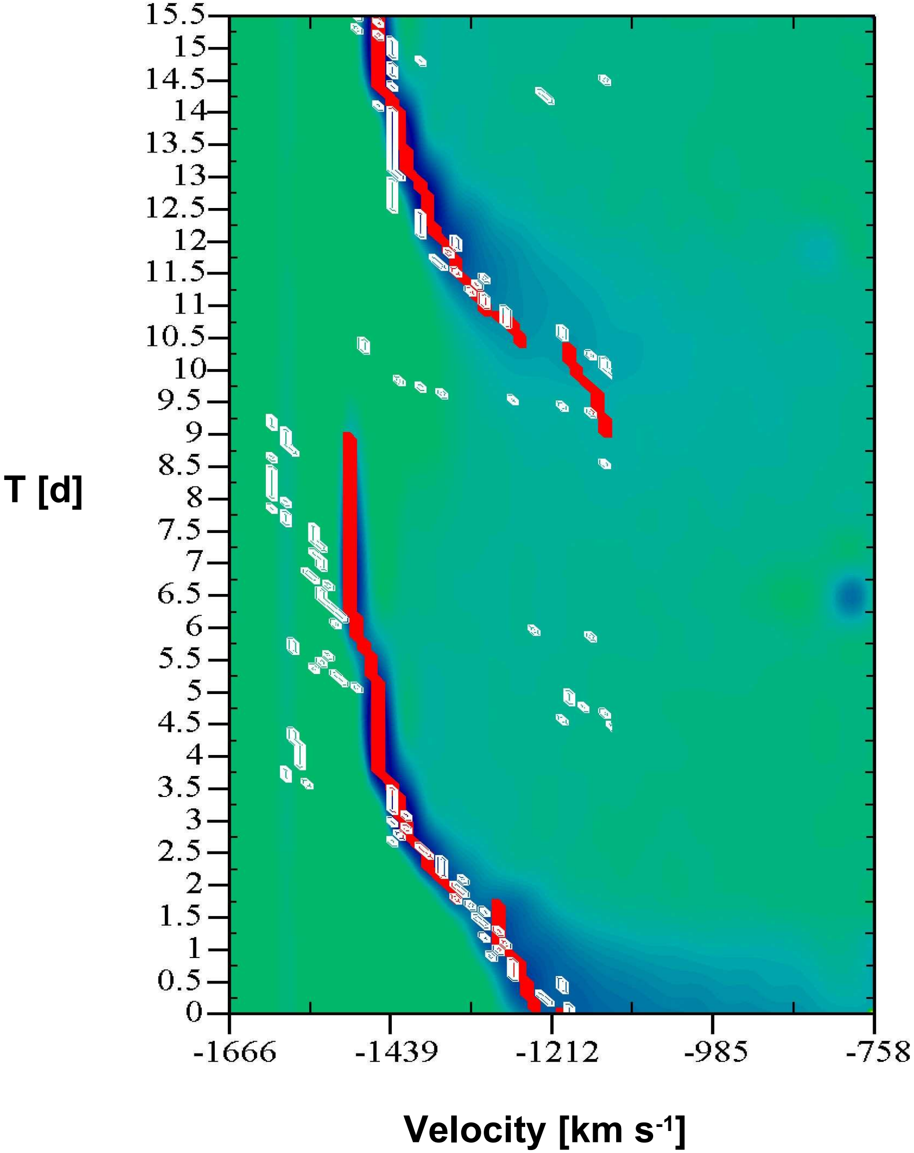
Narrow Optical Absorption Components in LBV HD 168607



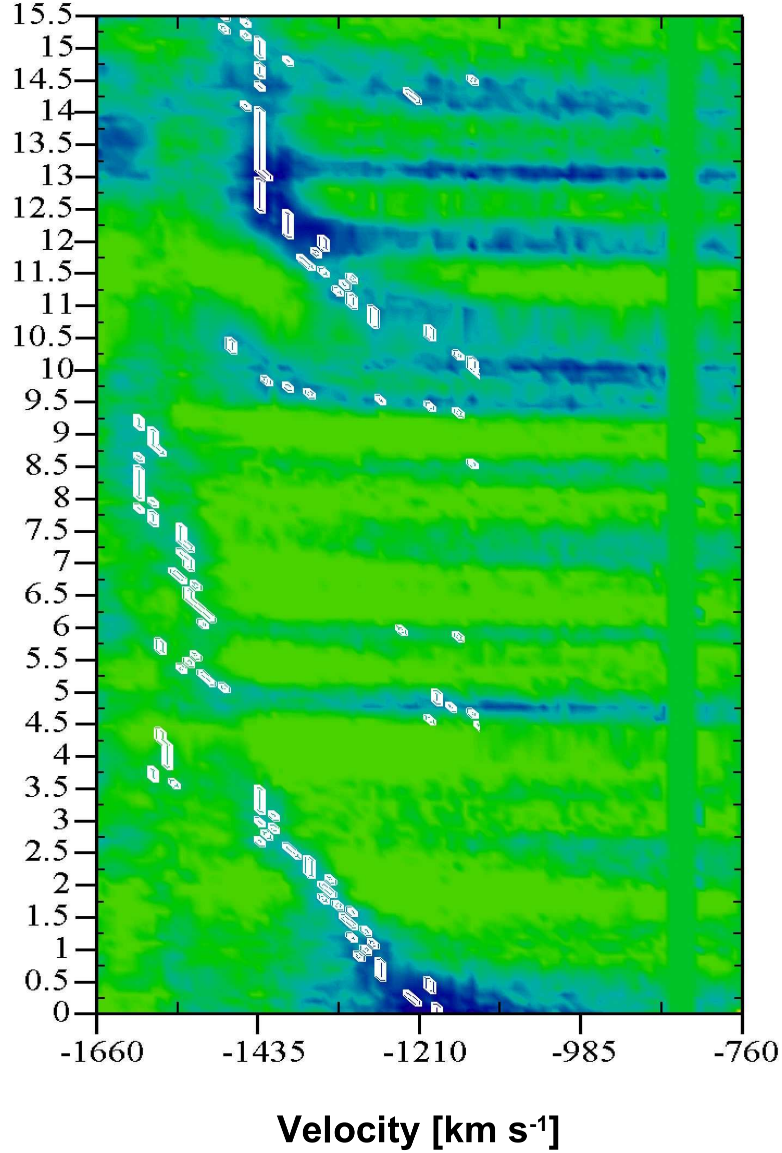
Ongoing and future work: More frequent monitoring and RT modeling of NOACs.

3-D Radiative Transfer Modeling of Discrete Absorption Components in Massive Hot Stars

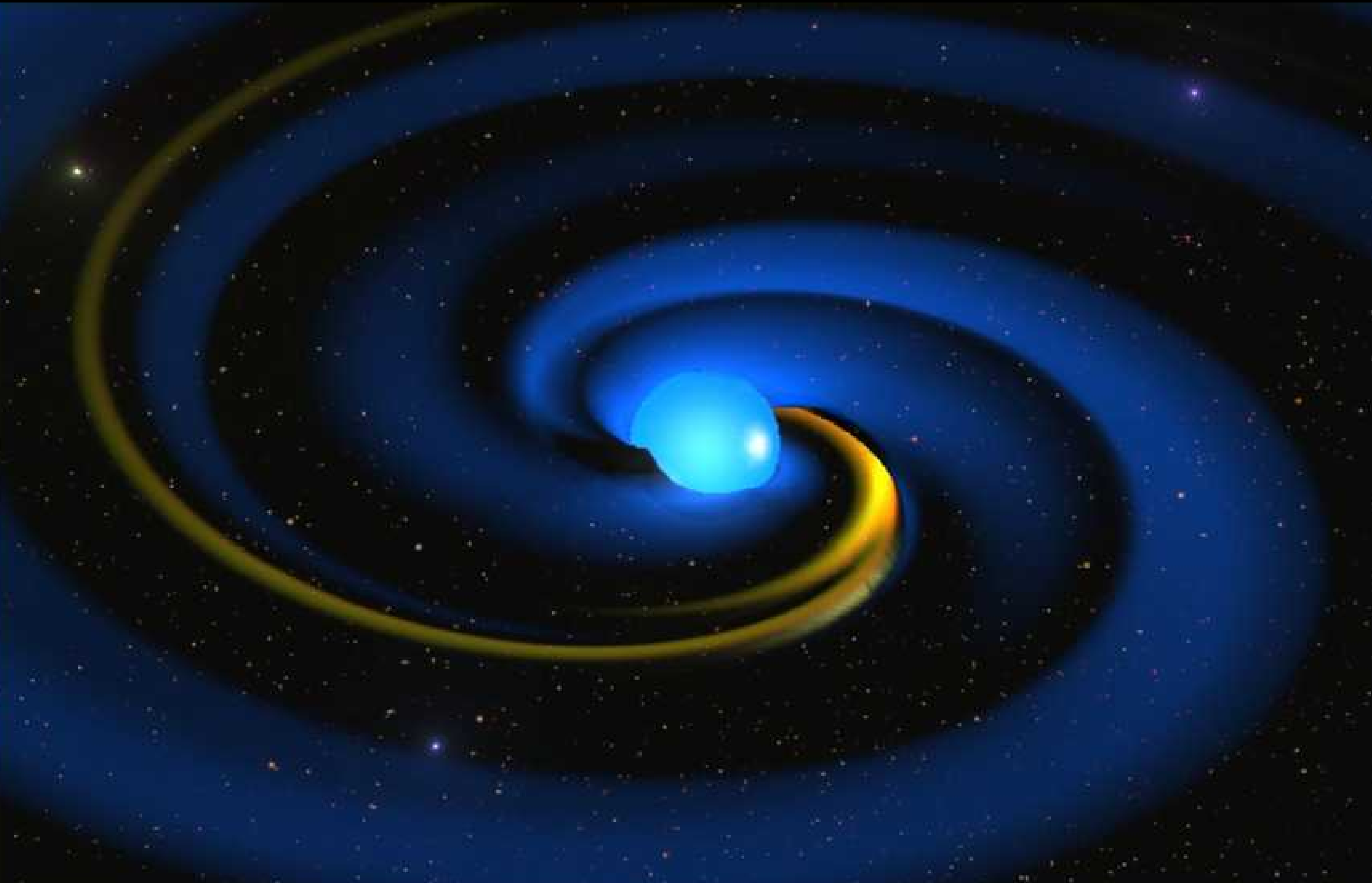
RT Model of DACs in Si IV λ1395



HD 64760 IUE 1995

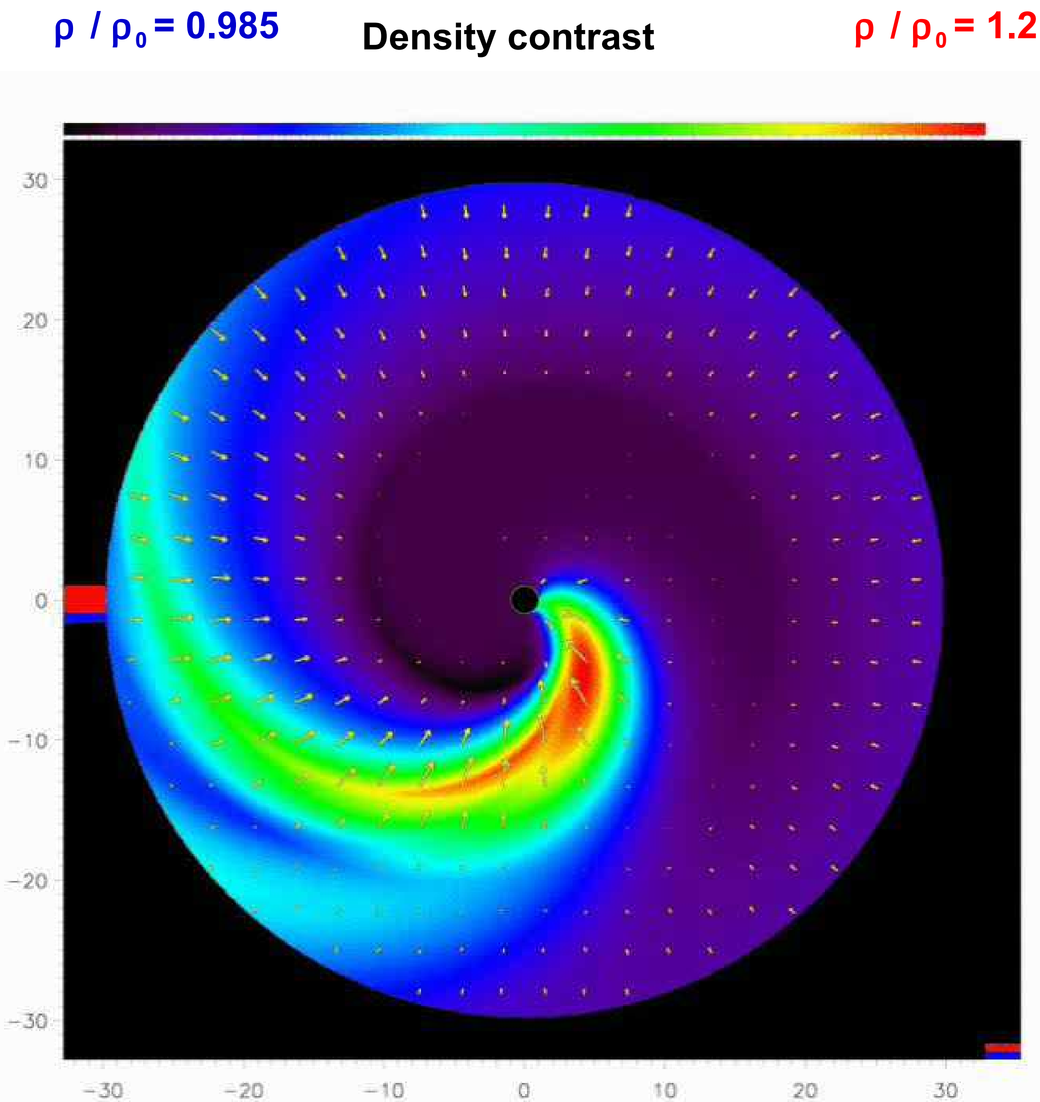


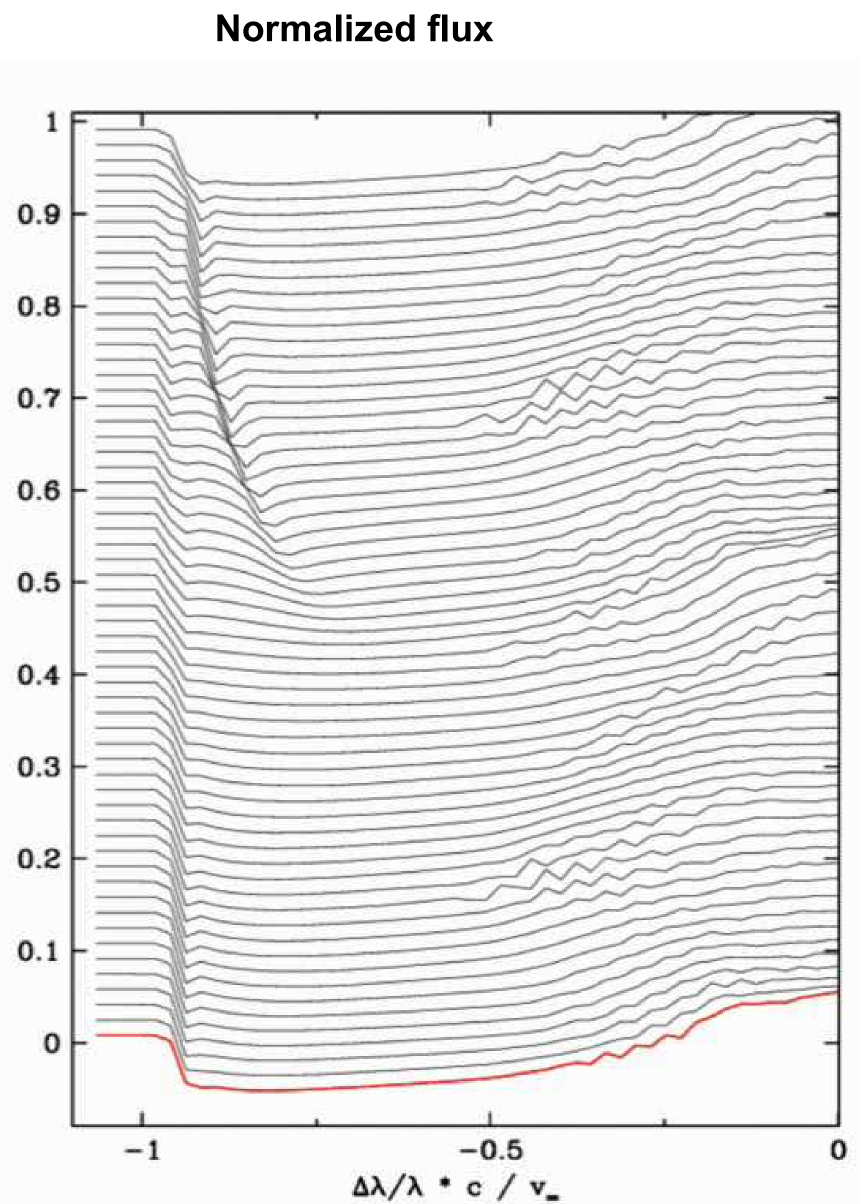
Co-rotating Interaction Regions are large-scale rotating density waves in the equatorial wind of massive hot stars



Hydrodynamic wind model with CIR due to one bright spot lagging behind surface rotation.

Si IV λ1394 computed with Wind3D



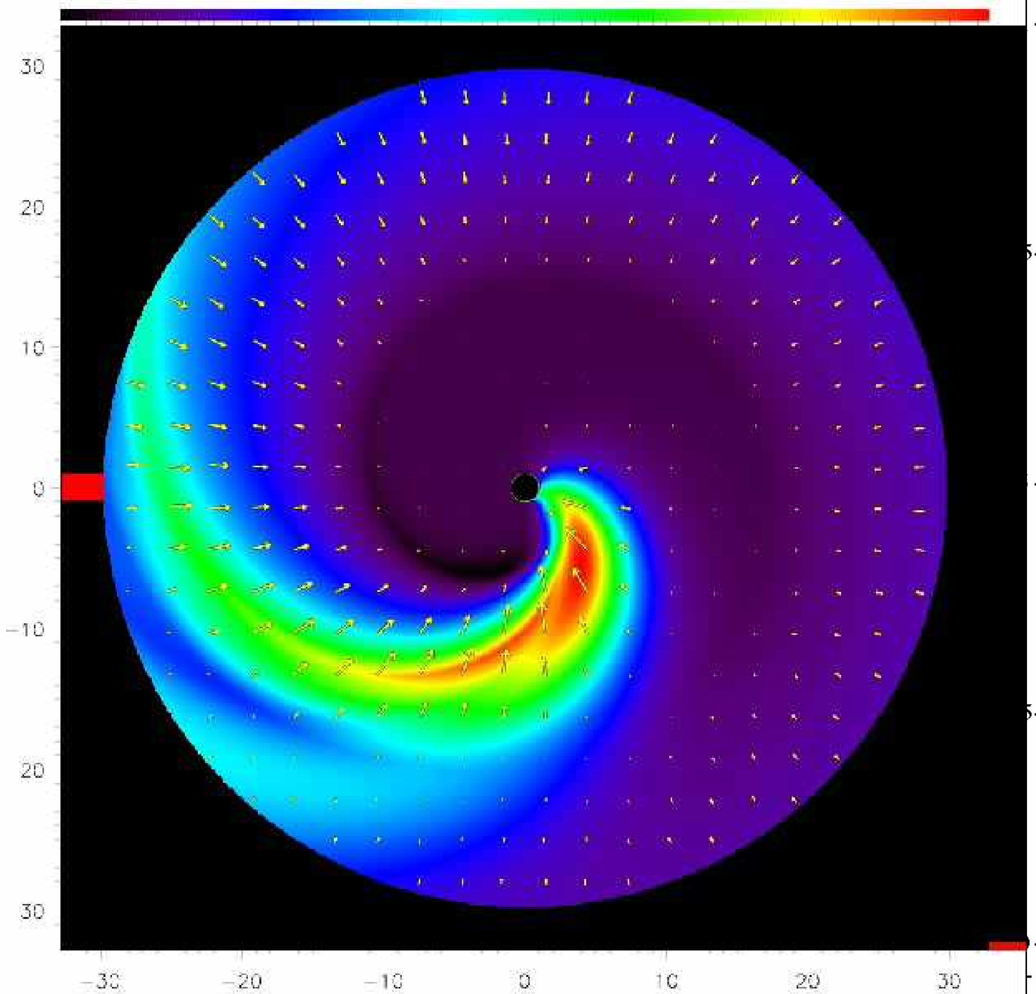


A_{sp}=0.1 Φ_{sp}=50° $V_{spot} < V_{rot}$

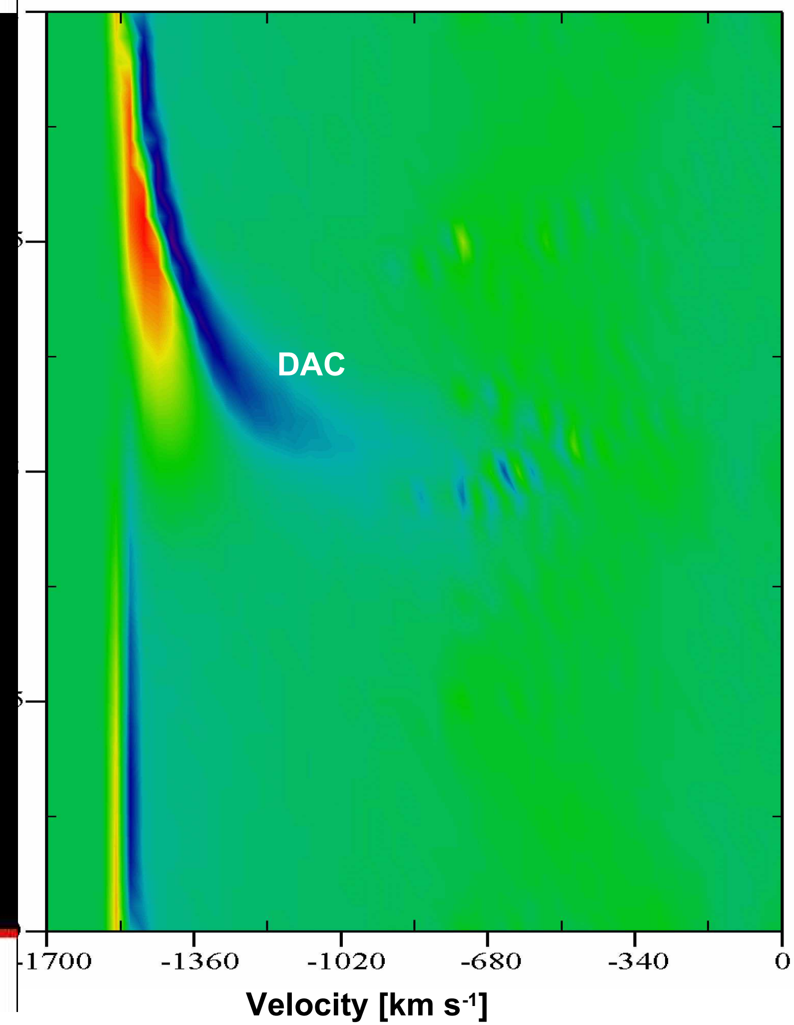
Hydrodynamic wind model with CIR due to one bright spot lagging behind surface rotation.

Si IV λ1394 computed with Wind3D

$\rho\ /\ \rho_0 = 0.985$ Density contrast $\rho\ /\ \rho_0 = 1.2$



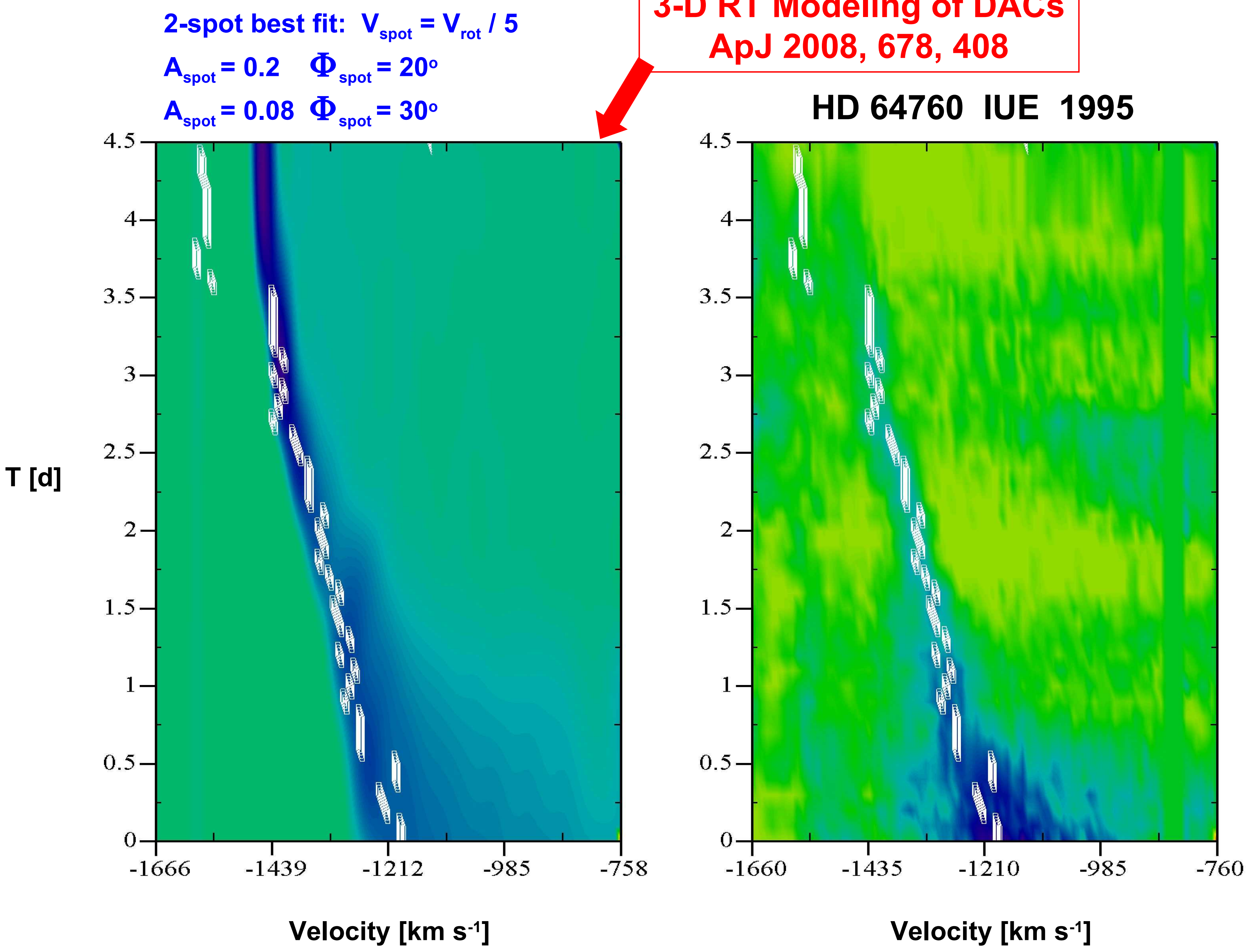
Flux difference



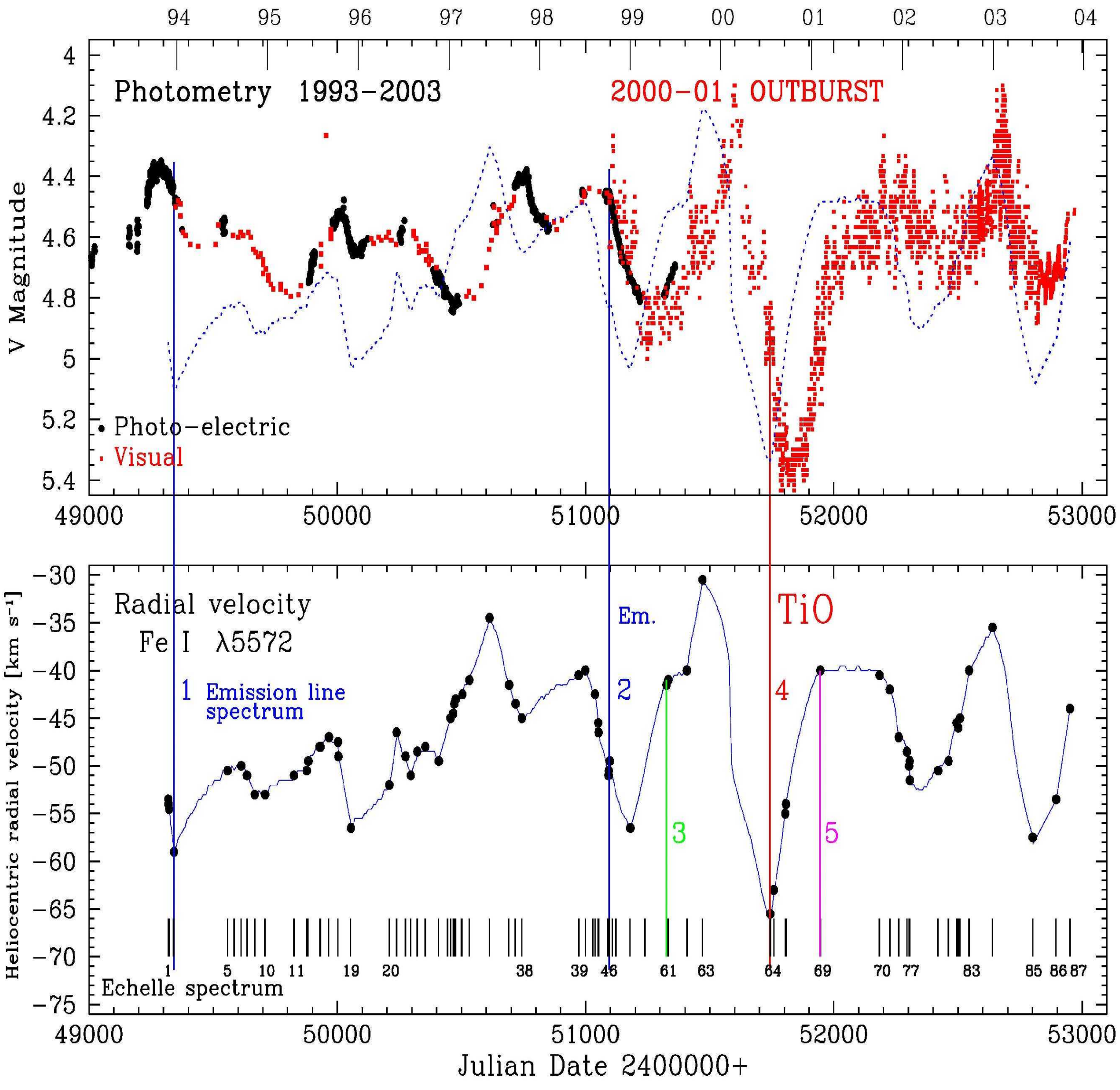
$A_{sp}=0.1\quad \Phi_{sp}=50^{o}\quad V_{spot} < V_{rot}$

CIR causes DAC because of increased wind density contrasts and velocity plateaus.

3-D RT Modeling of DACs
ApJ 2008, 678, 408

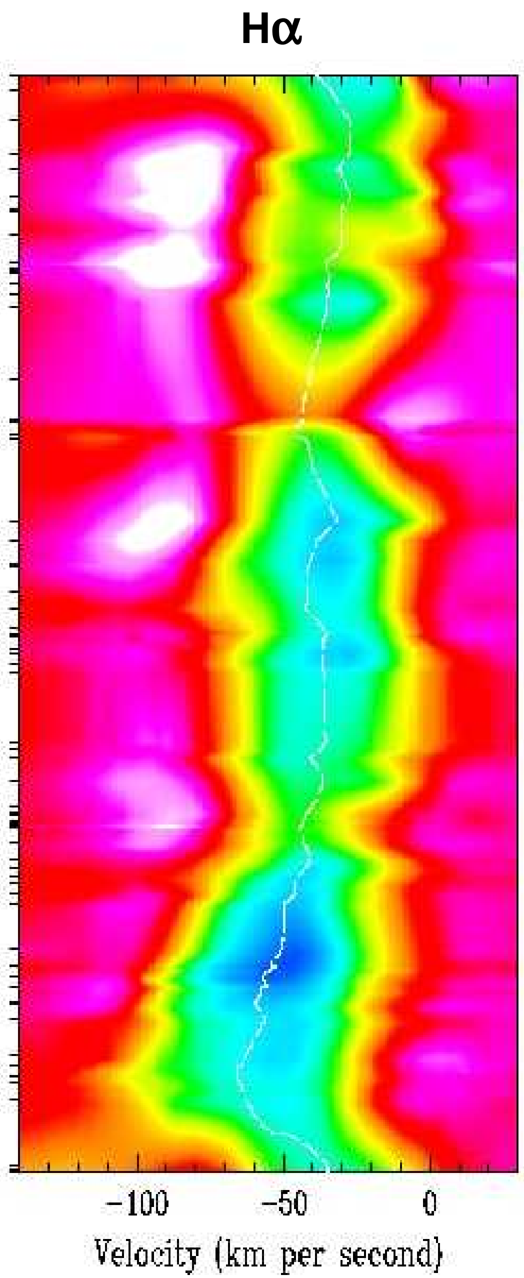


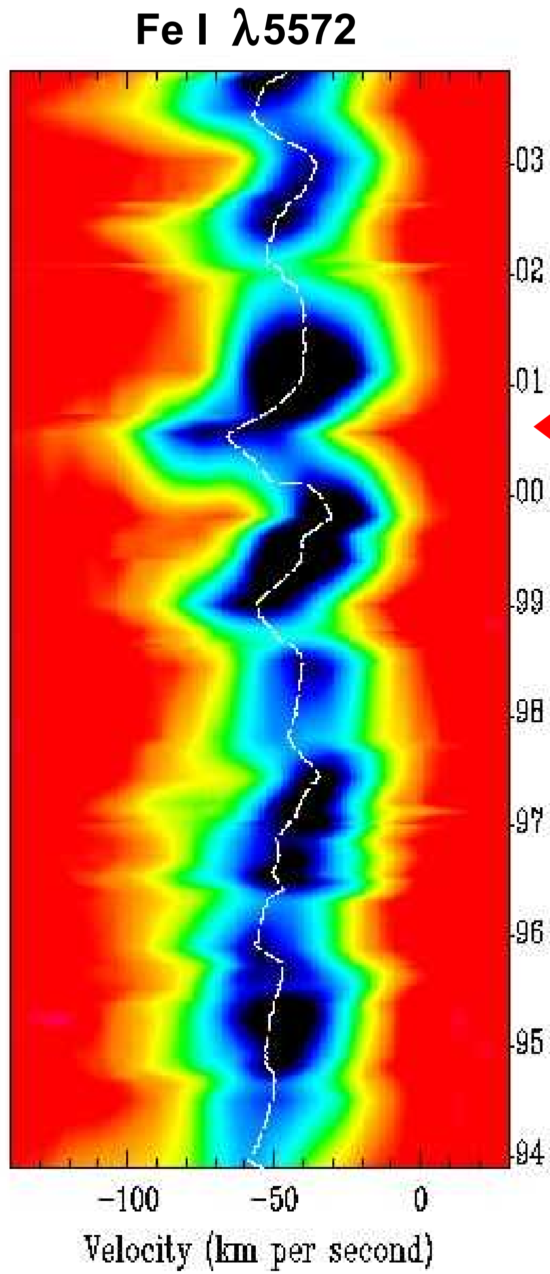
Millennium Outburst of Yellow Hypergiant Rho Cas (F-G Ia+)



- **Outburst related to very large amplitude of phot. Vrad curve with strong radial pulsation.**
- ***V* dims by 1.5 mag. in 200 d.**
- **T_{eff} decreases from ~7000 K to below 4000 K from RT modeling.**
- **Shell event with 35 ± 2 km/s observed in new TiO bands.**
- **Mdot increases from ~10^{-5} $M_{\odot}$/y to 5.4 10^{-2} $M_{\odot}$/y.**
- **Total gas-mass expelled by shell event ~5 % of $M_{\odot}$ from TiO bands and violet wings of phot. lines.**
- **Radiative line driving mechanism too weak and dust driving mechanism not efficient.**
- **Mechanical wind driving plays important role during outburst events.**

Long-term Spectroscopic Monitoring of Hypergiant Rho Cas



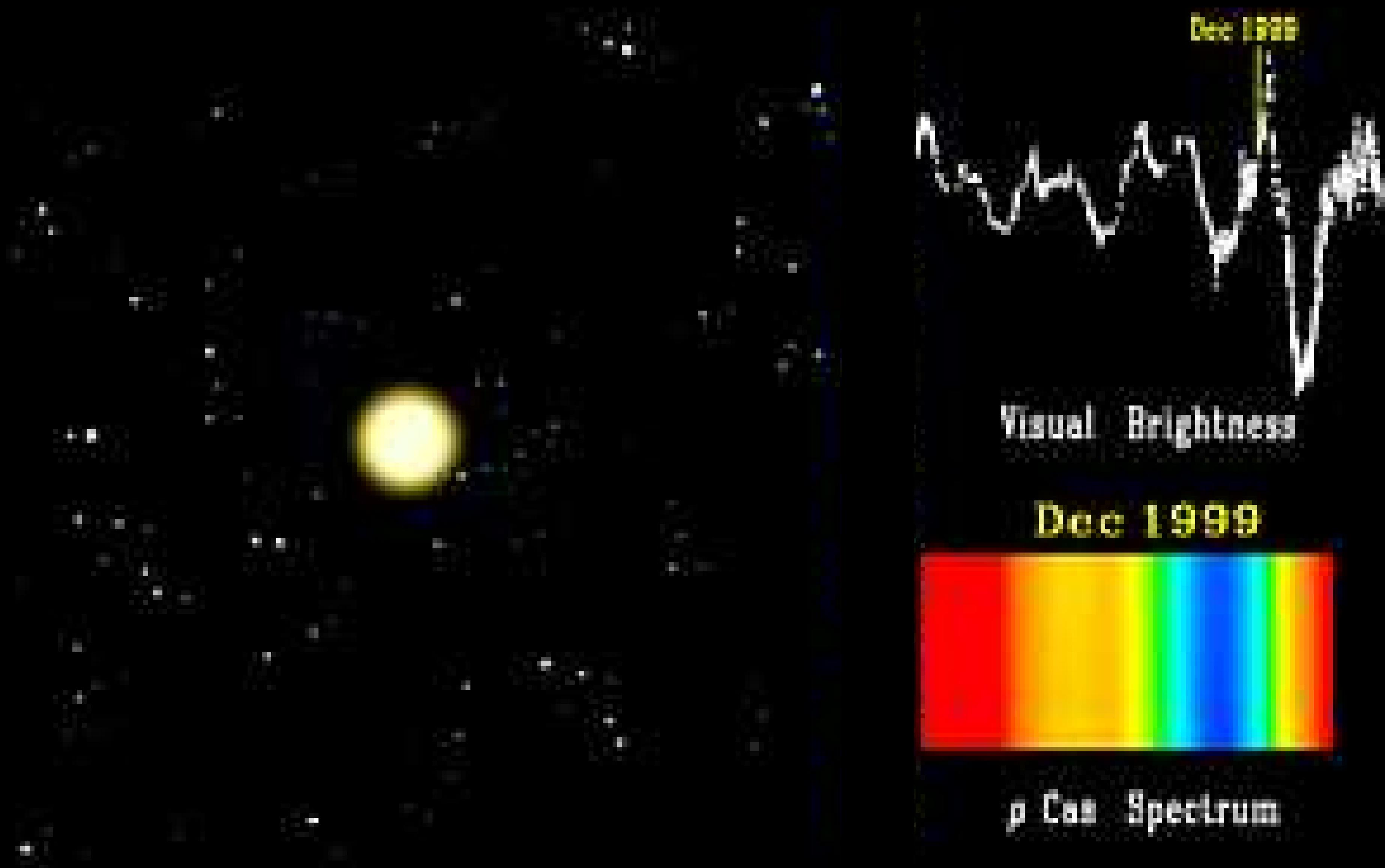


- Striking variability of photospheric lines with P_q = 300 to 500 d.
- Hα variability very different from photosperic metal lines.

Millennium Outburst
ApJ 2003, 583, 923

- Hα line formation region more extended and velocity stratified compared to photospheric lines.
- Yellow hypergiants have very broad abs. lines due to unusually strong broadening mechanism causing supersonic 'micro'- and 'macro'-turbulence velocity values.
- Far violet extended wings develop in photospheric lines during outburst events related to strong radial pulsations with <u>global</u> cooling of entire atmosphere.

2000-2001 Outburst of Yellow Hypergiant Rho Cas



movie at alobel.freeshell.org

Summary

- First results of long-term monitoring program of LBVs and Hypergiants with HERMES since mid 2009 are promising. Excellent data quality.

- Science goals will be accomplished when HERMES monitoring continues each semester. Overall impact on observing time schedules is small since program stars are relatively bright.

- More frequent monitoring of LBV binary MWC 314 requested to determine accurate orbital parameters. Observe 2 x per month during the same semester.