Temporal changes in R Aqr observed with SPHERE/ZIMPOL

H.M. Schmid, E. Lagadec, SPHERE consortium,
several ETH bachelor and master students

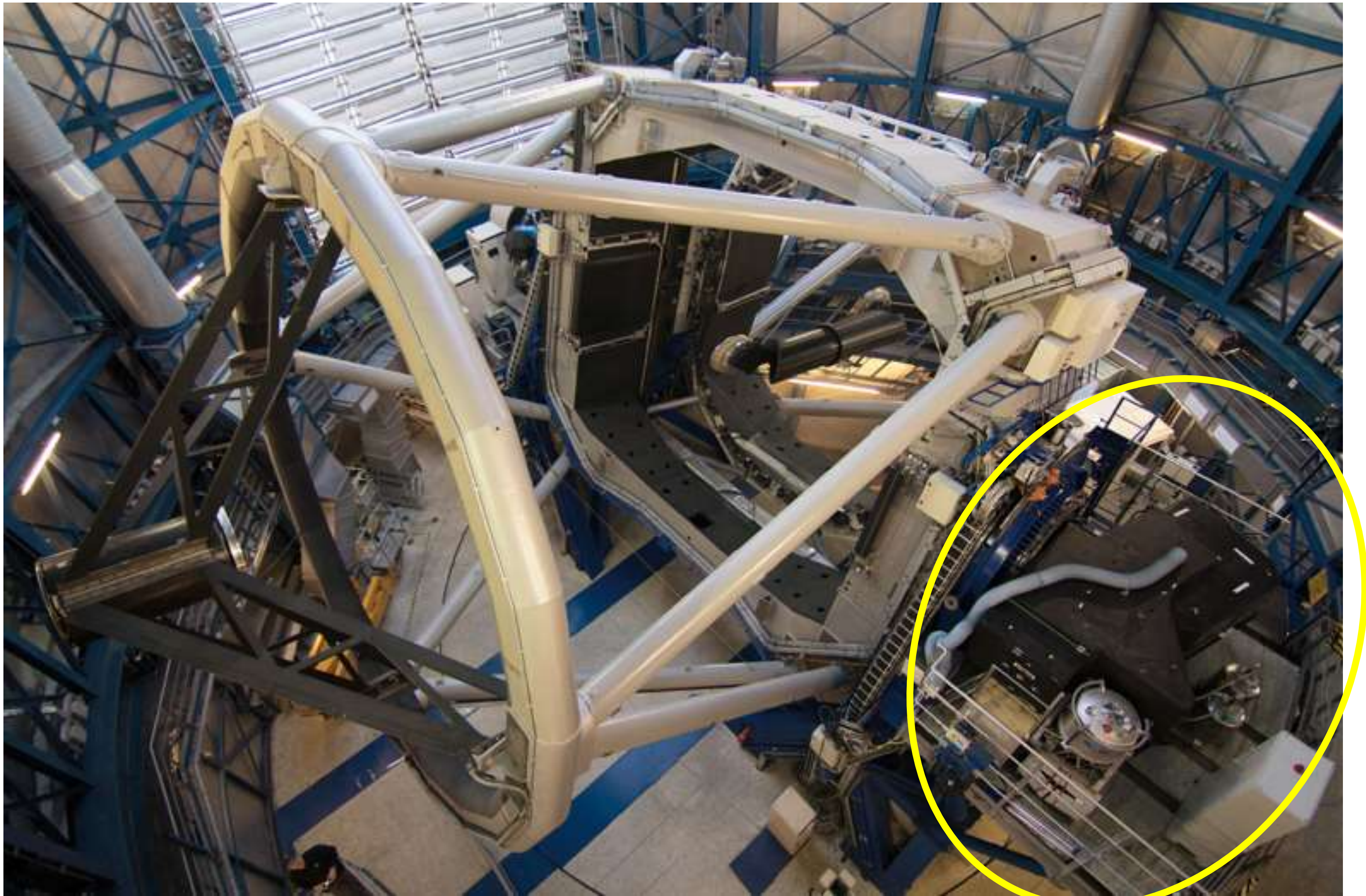
- R Aqr as SPHERE/ZIMPOL test target
- Hα cloud structures and motion
- dust cloud structures and motion
- first scientific results and outlook

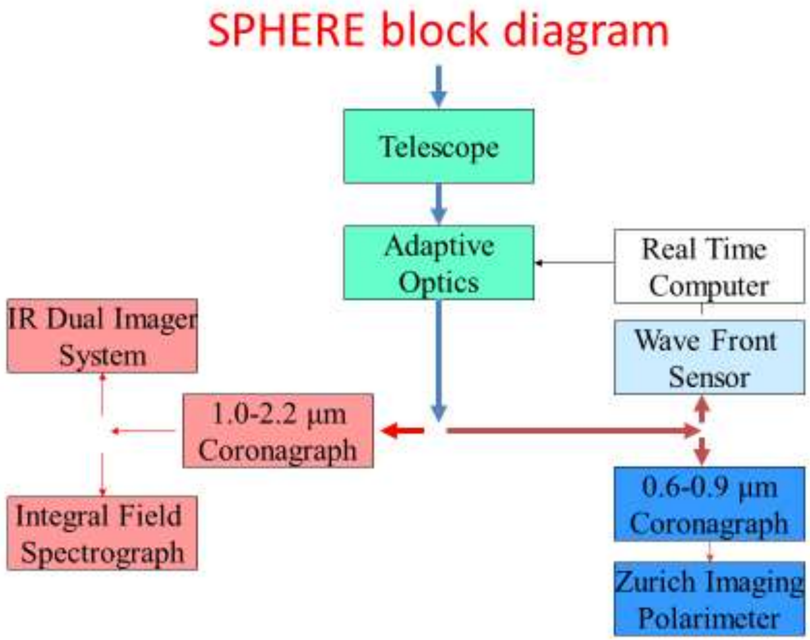
Papers: Schmid et al. 2017, A&A 602, A53, (R Aqr jet clouds with SPHERE/ZIMPOL)
Schmid et al. 2018, A&A 619, A9 (SPHERE/ZIMPOL instrument)
Gerlach, B., 2022, ETH Master Thesis, ETH Research Collection

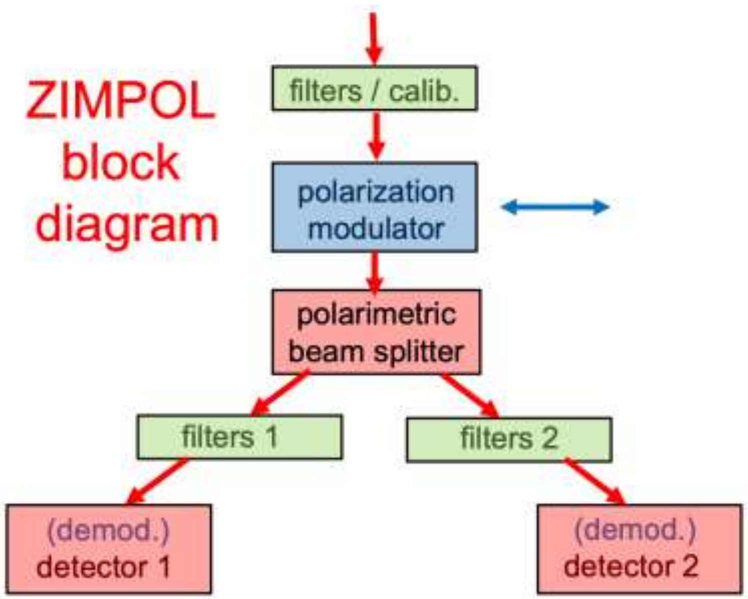
SPHERE "VLT Planet Finder"

Extreme adaptive optics system for high contrast imaging of extra-solar planetary systems

→ can also be used for bright R < 9^m (symbiotic) stars !







SPHERE system

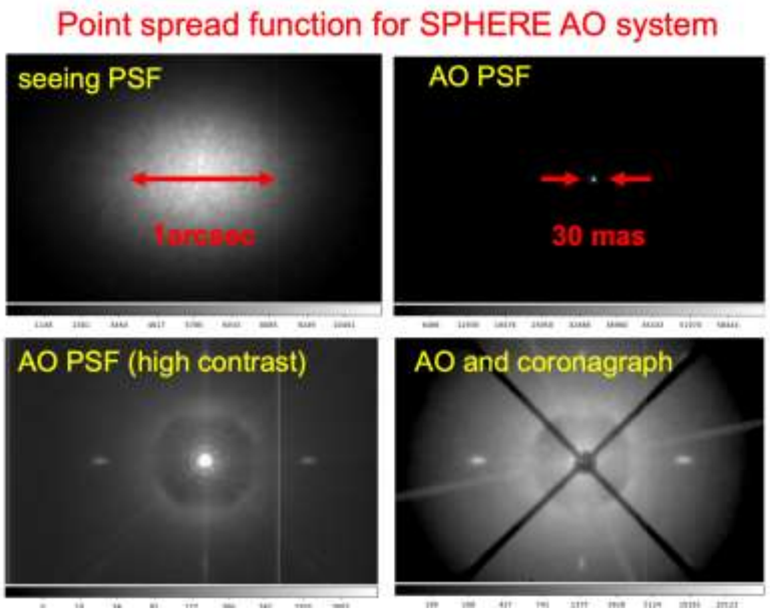
Extreme adaptive optics system

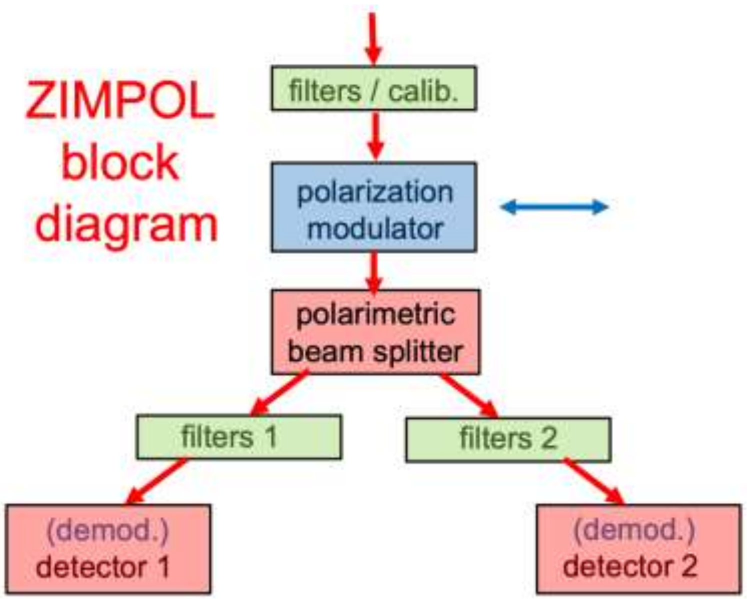
- small FoV around bright star $R<10^m$
- tuned for high contrast observation of the circumstellar region (stellar coronagraphs)
- field rotation to distinguish between sky signals and instrumental effects

ZIMPOL imager

Double beam camera tuned for high contrast differential imaging

- 520-900 nm
- resolution 20 - 25 mas ($\sim\lambda/D$)
- FoV 3.6“ x 3.6“ mas
- Spectral diff. imaging (Hα+cont.)
- Polarimetric diff. Imaging for circumstellar scattered light





SPHERE system

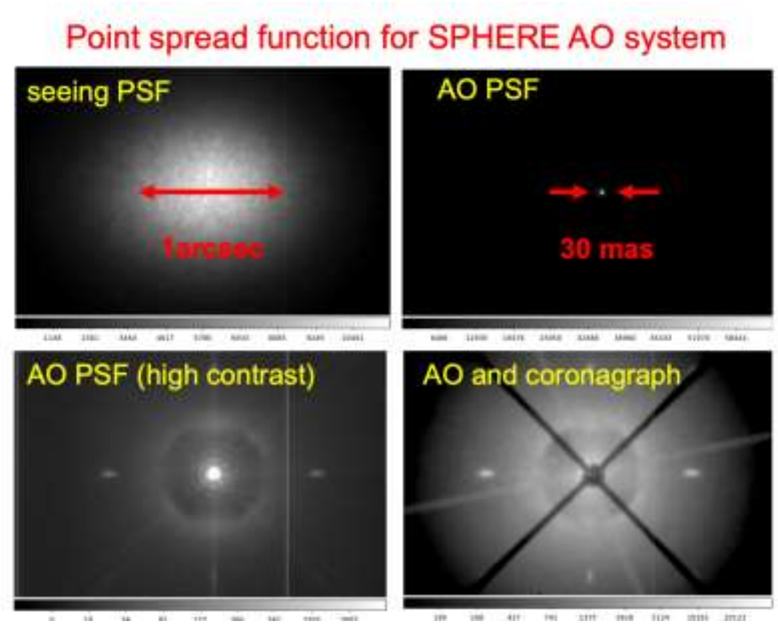
Extreme adptive optics system

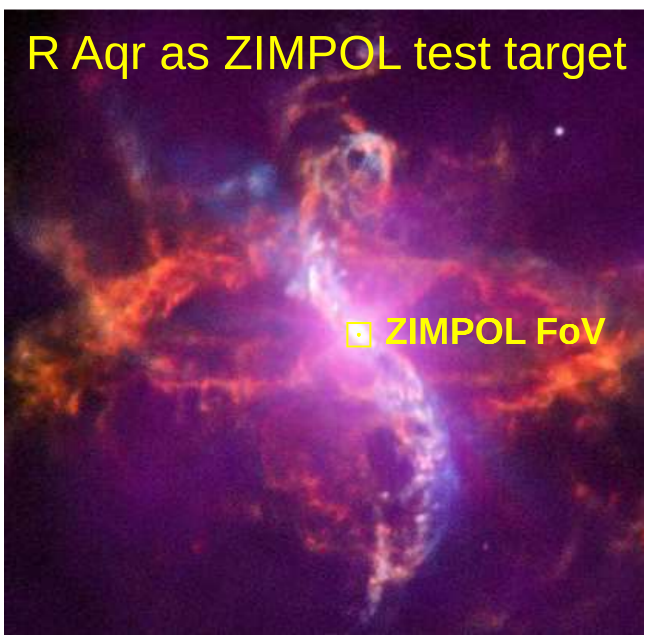
- small FoV around bright star R<10^{m}
- tuned for high contrast observation of the circumstellar region (stellar coronagraphs)
- field rotation to distinguish between sky signals and instrumental effects

ZIMPOL imager

Double beam camera tuned for high contrast differential imaging

- 520-900 nm
- resolution 20 - 25 mas ($\sim\lambda/D$)
- FoV 3.6“ x 3.6“ mas
- Spectral diff. imaging (Hα+cont.)
- Polarimetric diff. Imaging for circumstellar scattered light





Credit: Image courtesy of J.A. Toalá, L. Sabin, M.A. Guerrero, G. Ramos-Larios, Y.-H. Chu, T. Liimets and ESA

SPHERE system

Extreme adptive optics system

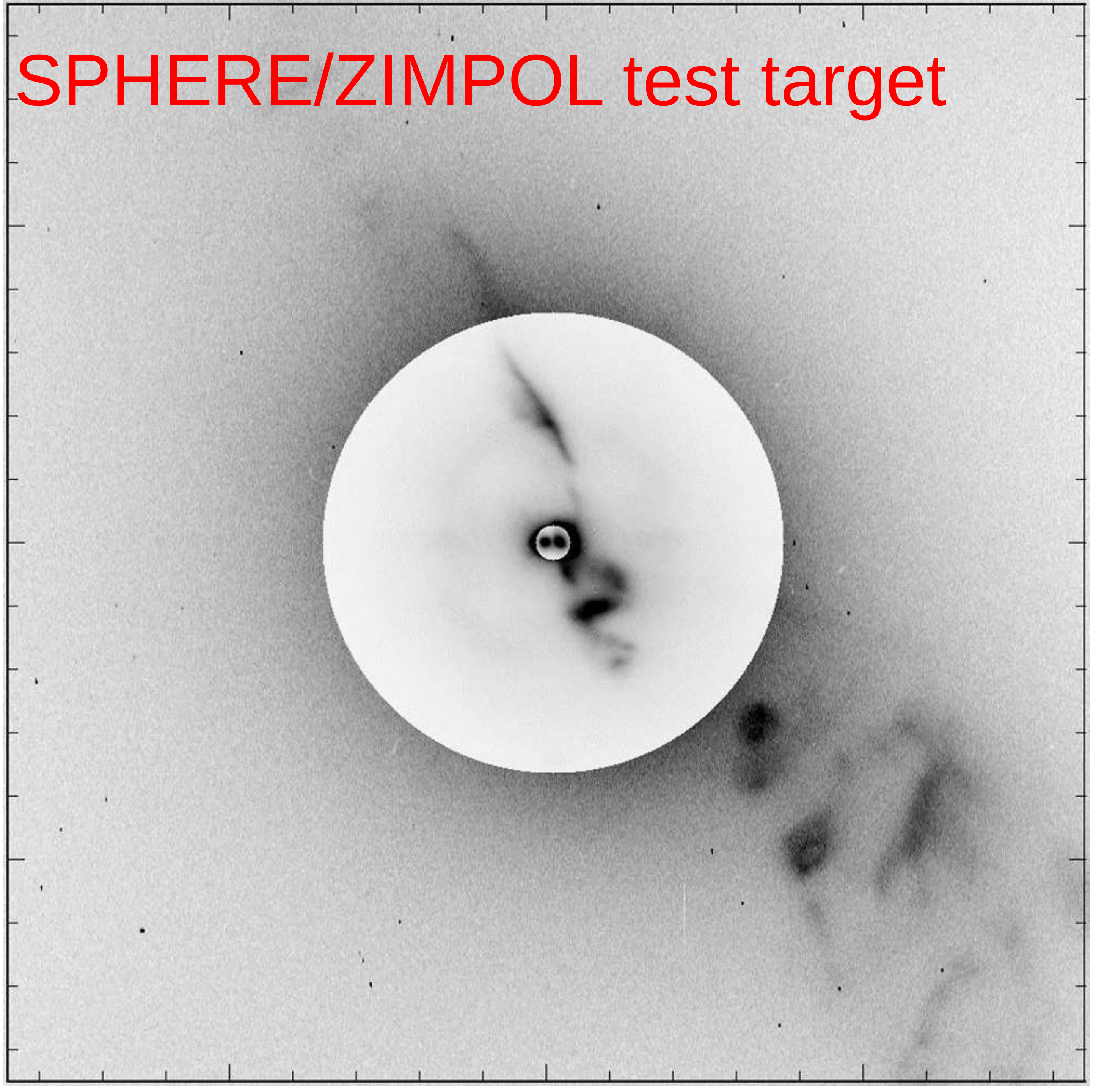
- small FoV around bright star $R<10^m$
- tuned for high contrast observation of the circumstellar region (stellar coronagraphs)
- field rotation to distinguish between sky signals and instrumental effects

ZIMPOL imager

Double beam camera tuned for high contrast differential imaging

- 520-900 nm
- resolution 20 - 25 mas $(\sim\lambda/D)$
- FoV 3.6“ x 3.6“ mas
- Spectral diff. imaging ($H\alpha$+cont.)
- Polarimetric diff. Imaging for circumstellar scattered light

R Aqr as SPHERE/ZIMPOL test target



R Aqr Hα map

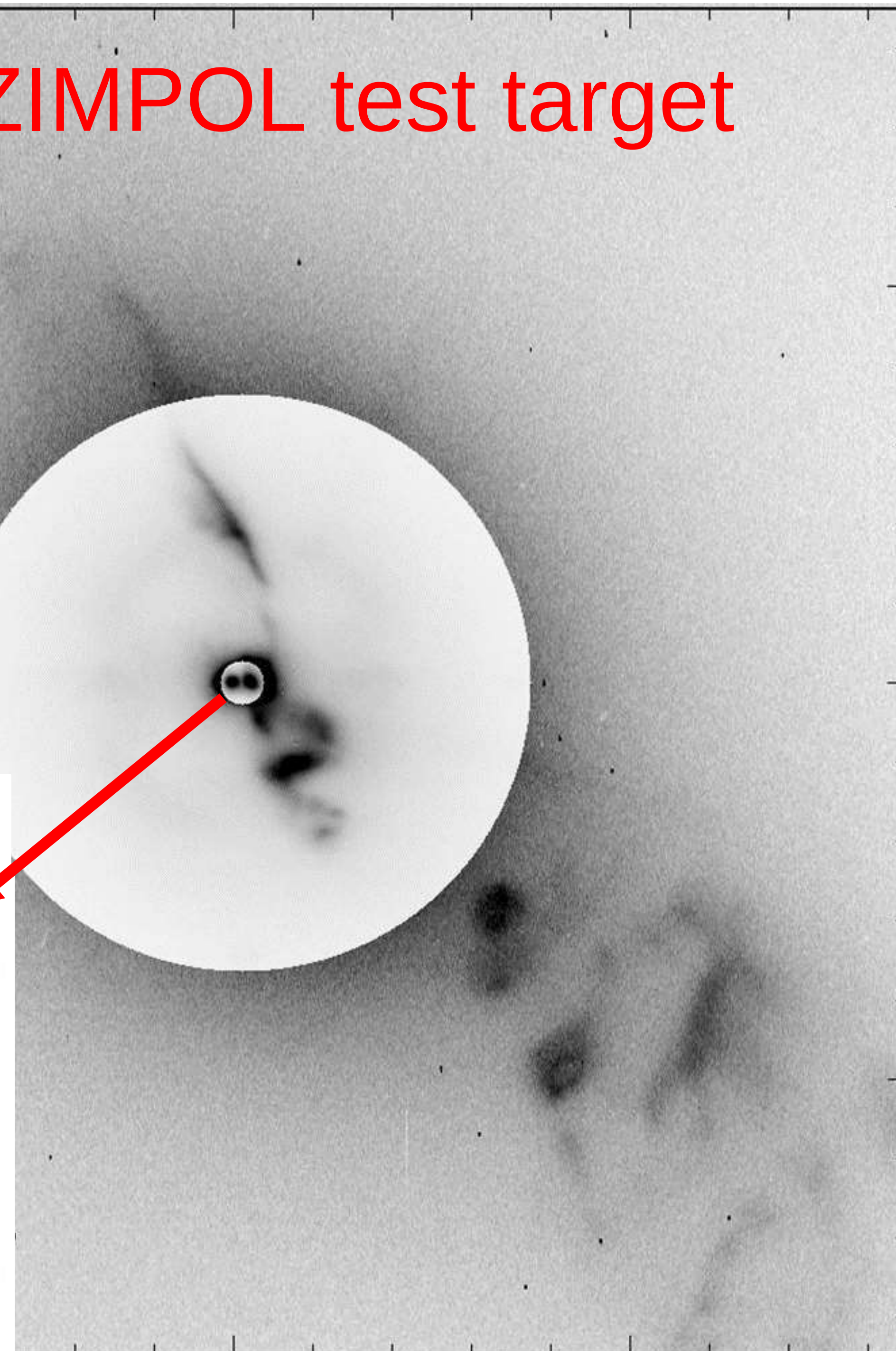
narrow (1nm) Hα
3.4” x 3.4”

3 grey scale regions

binary 10-10000 cts
“inner” jet 10-1000 cts
“outer” jet 10-100 cts

Schmid et al. (2017)

R Aqr as SPHERE/ZIMPOL test target



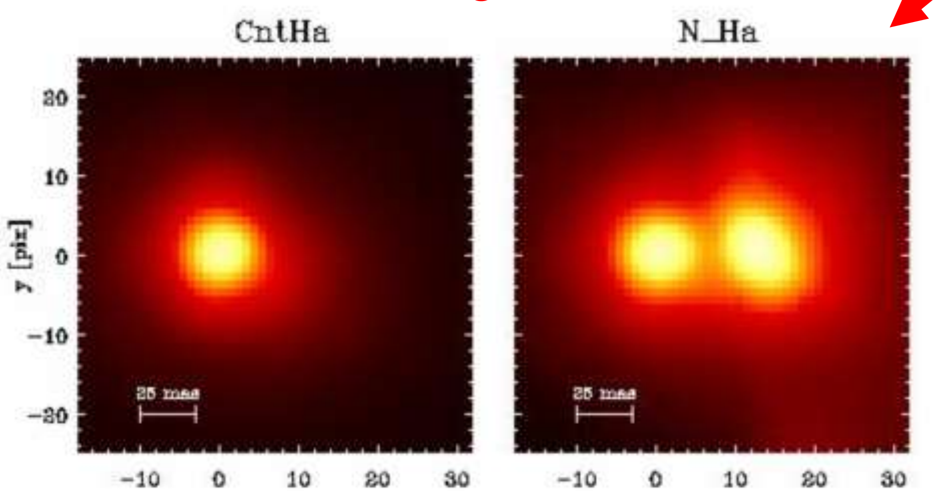
R Aqr Hα map

narrow (1nm) Hα
3.4” x 3.4”

3 grey scale regions

binary 10-10000 cts
“inner” jet 10-1000 cts
“outer” jet 10-100 cts

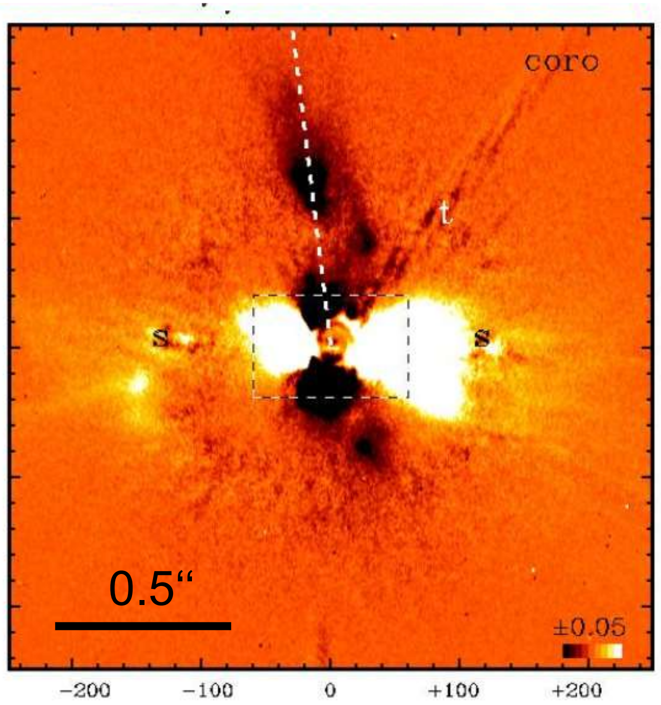
simultaneous images in two bands



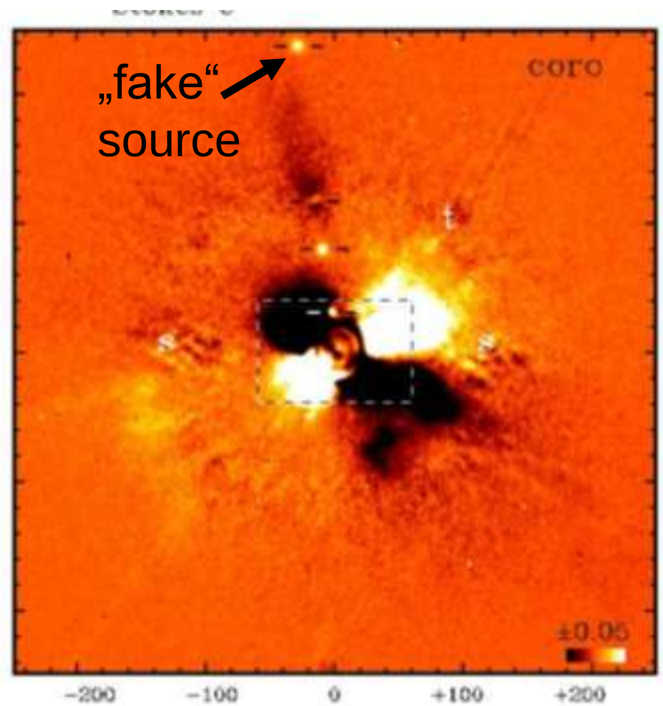
Differential polarimetric imaging of R Aqr

I-band
820 nm

Stokes $Q = I_0 - I_{90}$



Stokes $U = I_{45} - I_{135}$

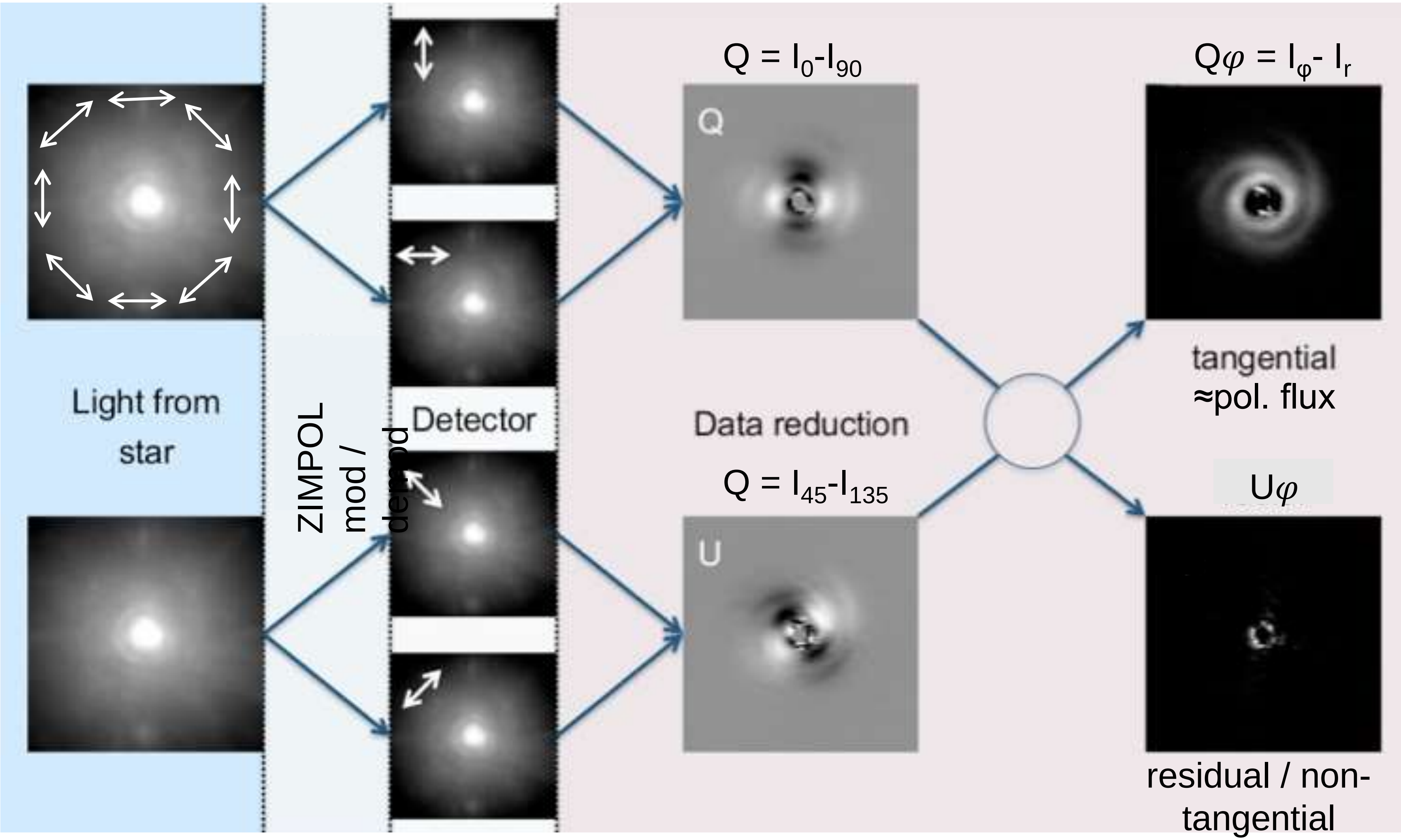


- direct light from the red giant (unpolarized)
- scattering by circumstellar dust produces polarized light

polarimetric imaging → dust distribution

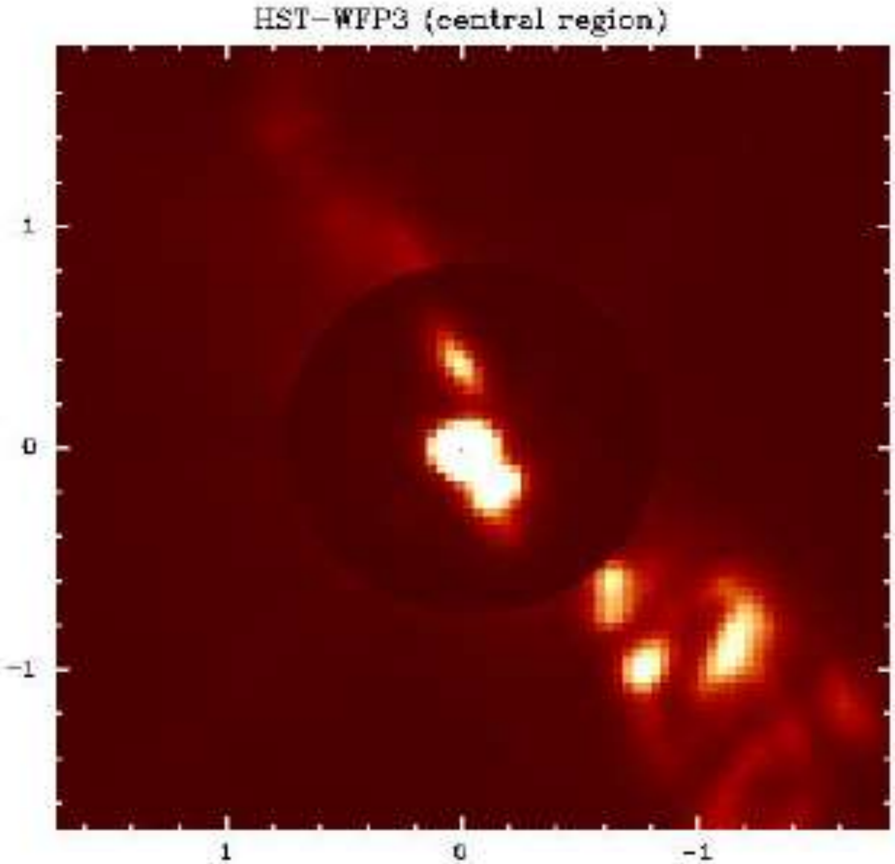
Differential polarimetric imaging of circumstellar dust

star = unpolarized , scattered light from dust =polarized



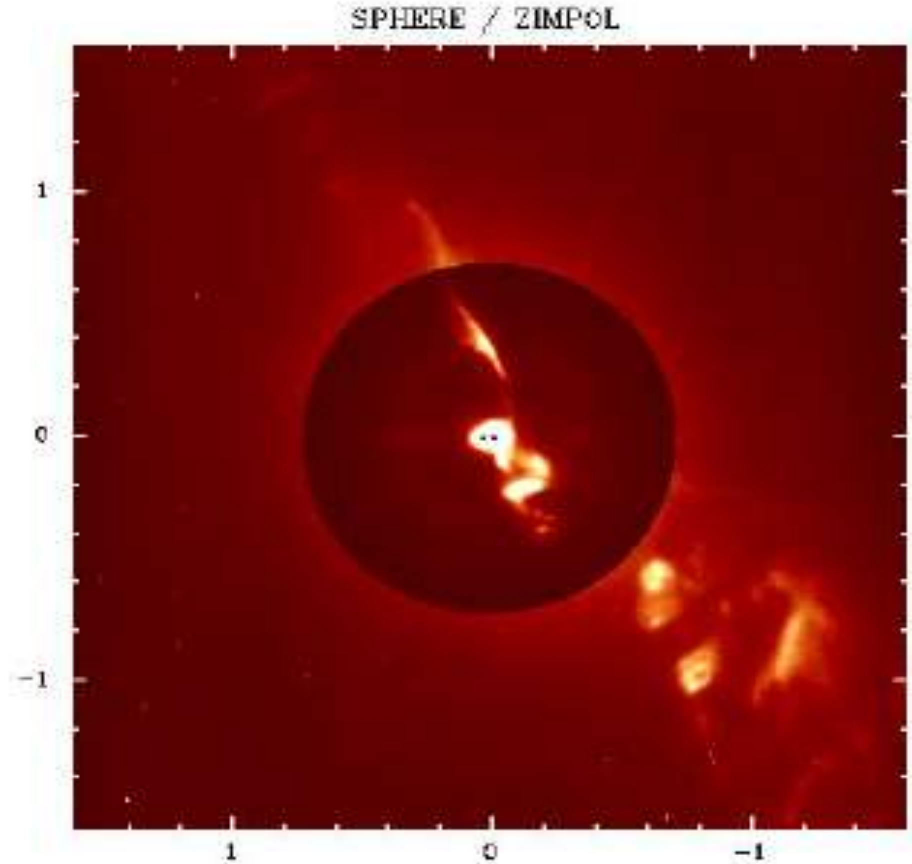
(Schmid, Thalmann, Avenhaus)

Hα cloud structures and motion



HST: Oct. 2014

Melnikov et al. (2018) A&A 612, A77



VLT: Oct. 2014

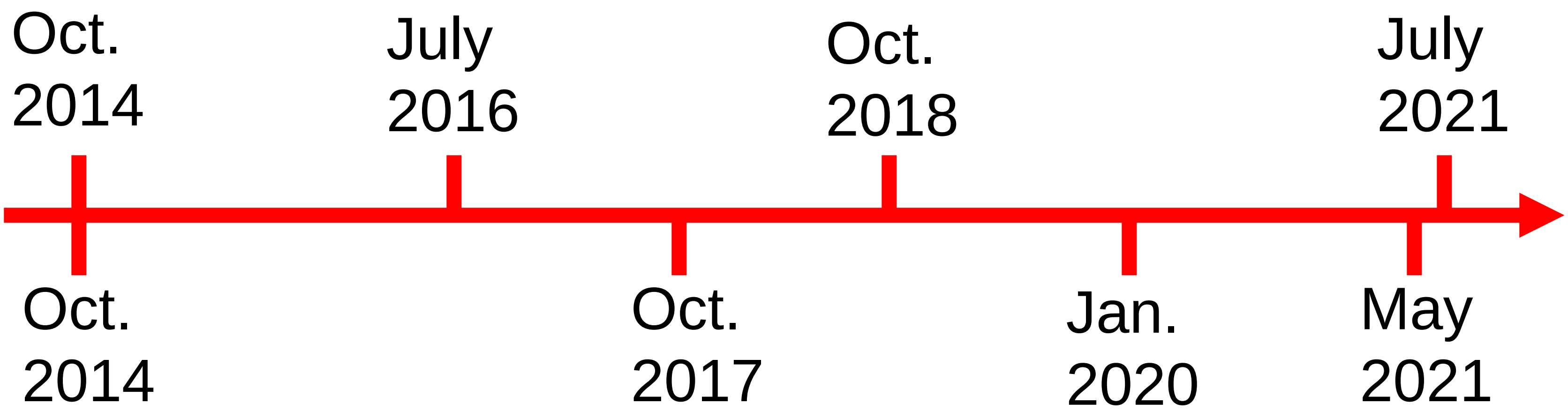
Schmid et al. (2017), A&A, 602, A53

Hα observations for R Aqr

SPHERE/ZIMPOL observations

Halpha imaging

imaging polarimetry in V-band and I-band

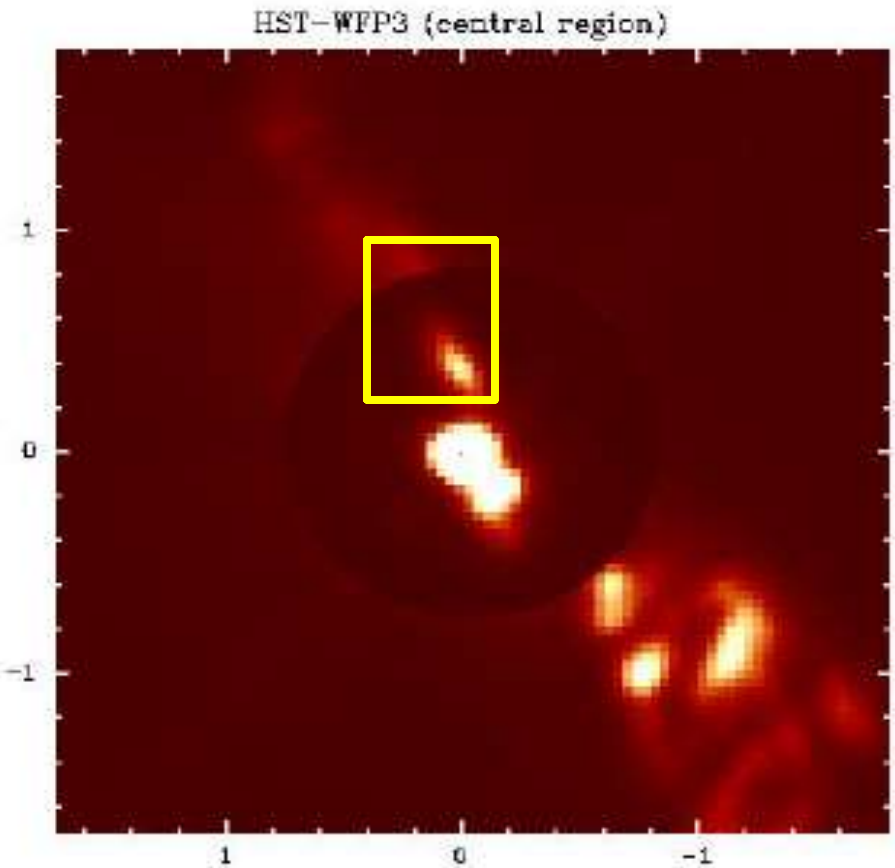


HST/UVIS observations

Halpha imaging

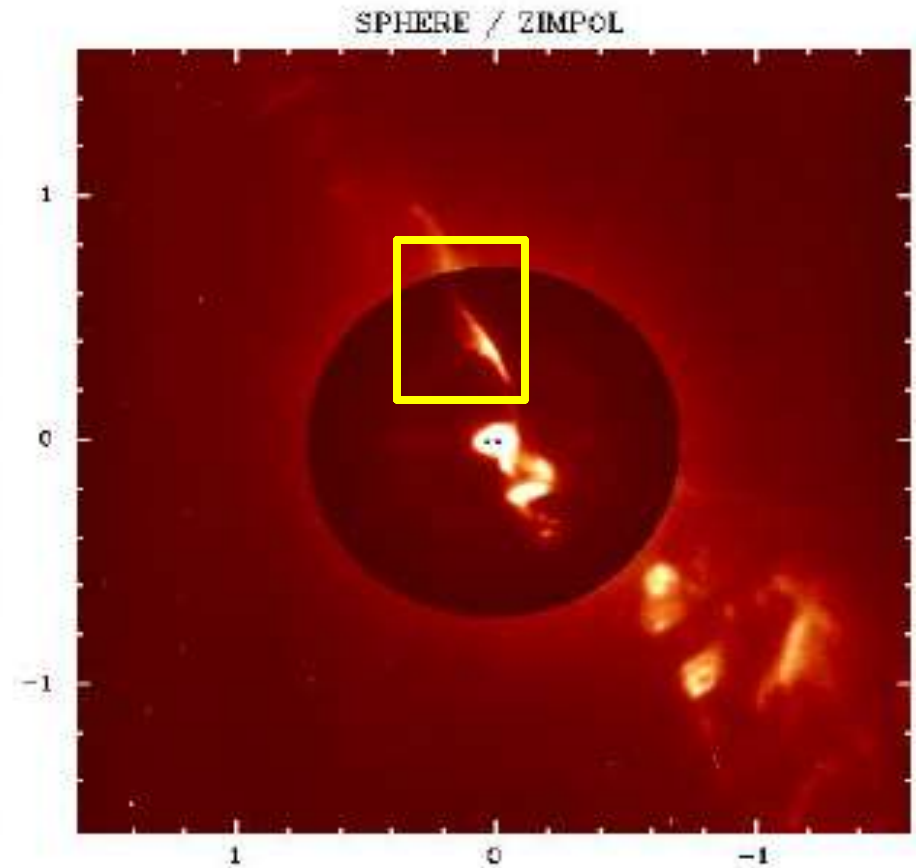
and several other emission line filters

HST and VLT Ha observation of the northern jet feature (d≈0.5“)



HST: Oct. 2014

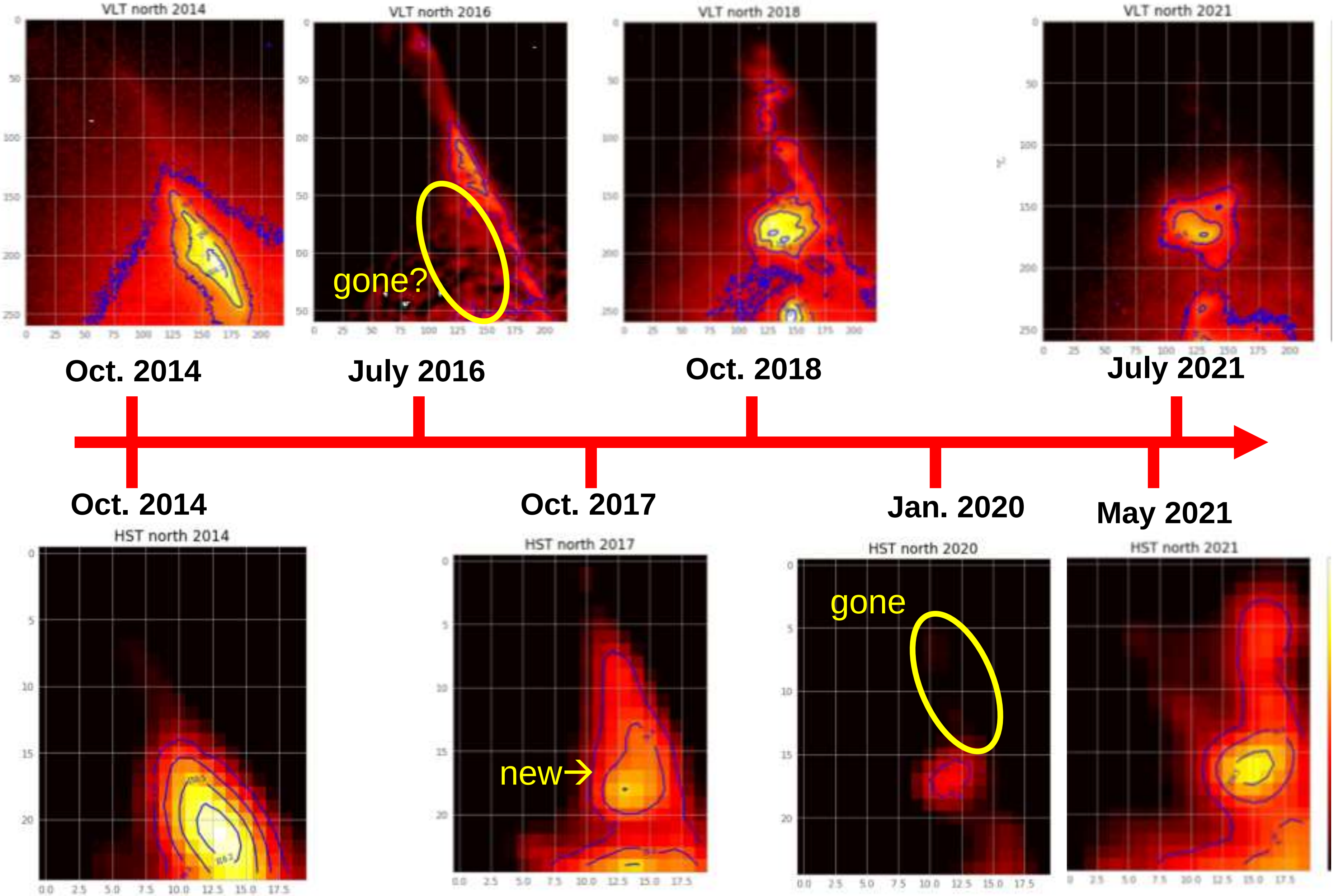
Melnikov et al. (2018) A&A 612, A77



VLT: Oct. 2014

Schmid et al. (2017), A&A, 602, A53

VLT Ha Observations



HST Ha Observations

ETH student project C. Staehl)

Hα cloud evolution in the SW (VLT)

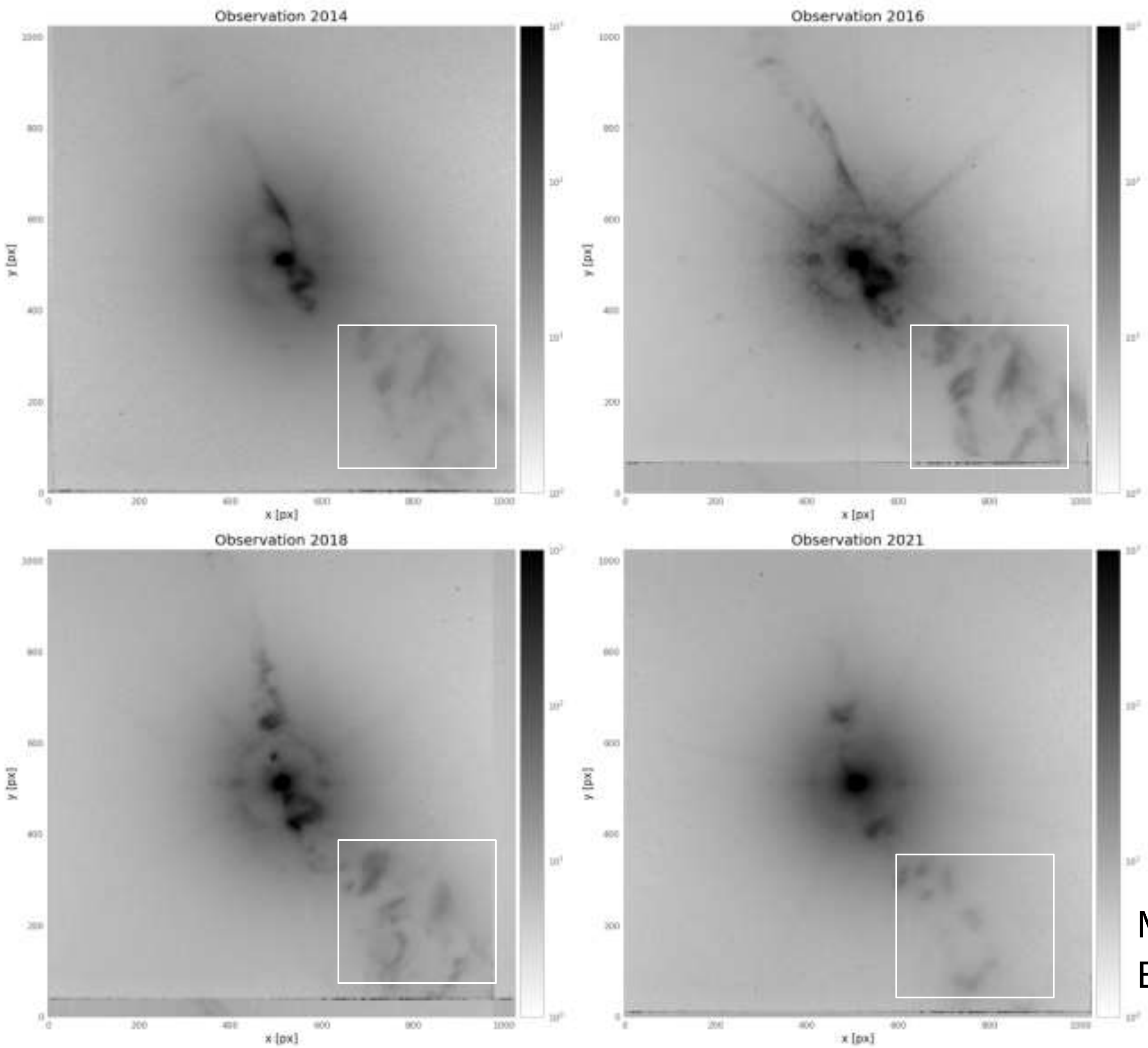
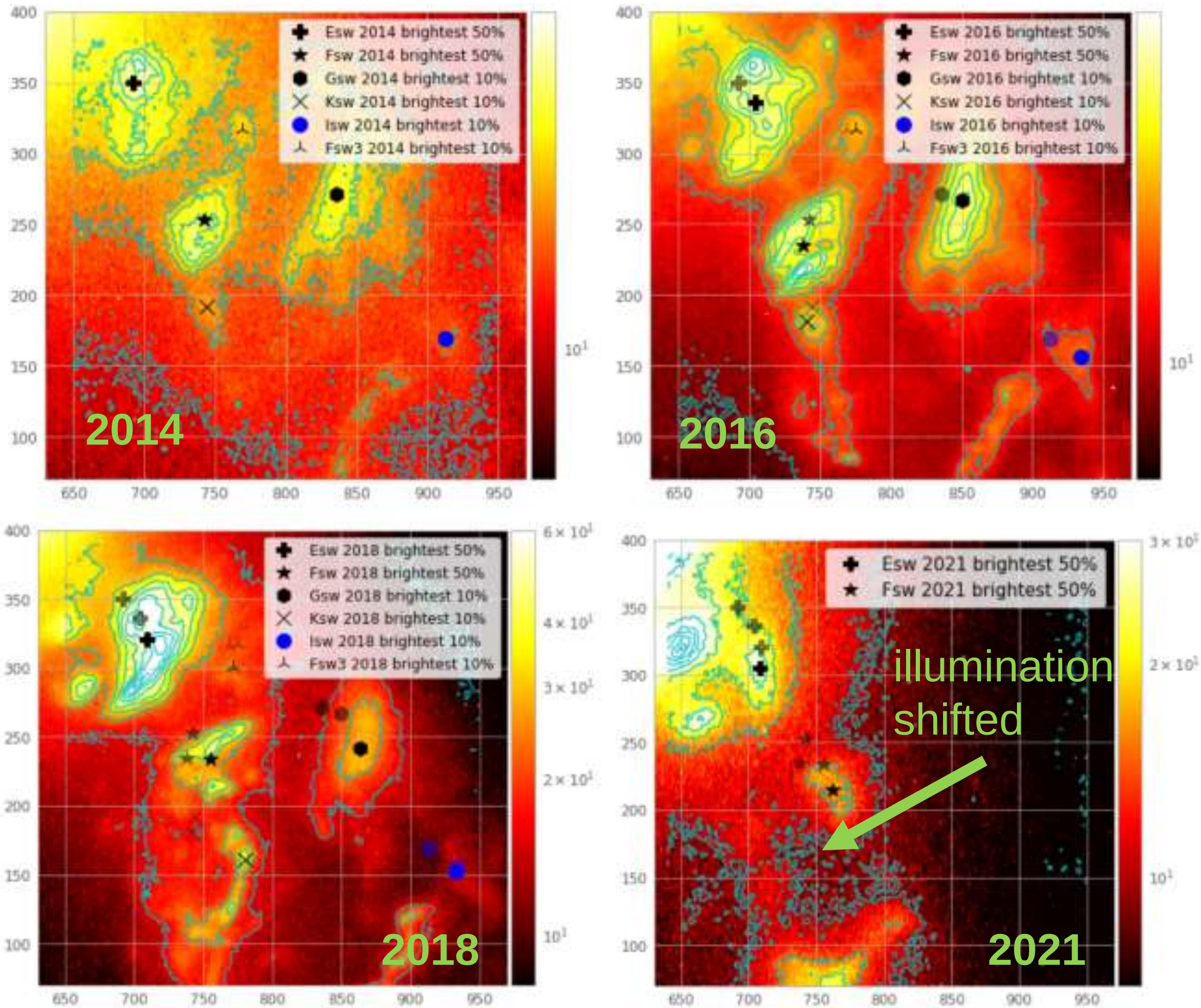


Figure 2.1: Narrow Hα observations from 2014/16/18/21. Different gas cloud features can be identified.

Masterthesis B. Gerlach
ETH Research Collection

Ha cloud evolution in the SW (VLT)



Cloud behaviour
- move radially
- change shape
- split up
- merge
- disappear
- new clouds appear

- typical time scale 2-4 years

Cloud distribution shifts from SW to S-SW
→ changing illumination

Master thesis B. Gerlach

Hα cloud motions in the SW

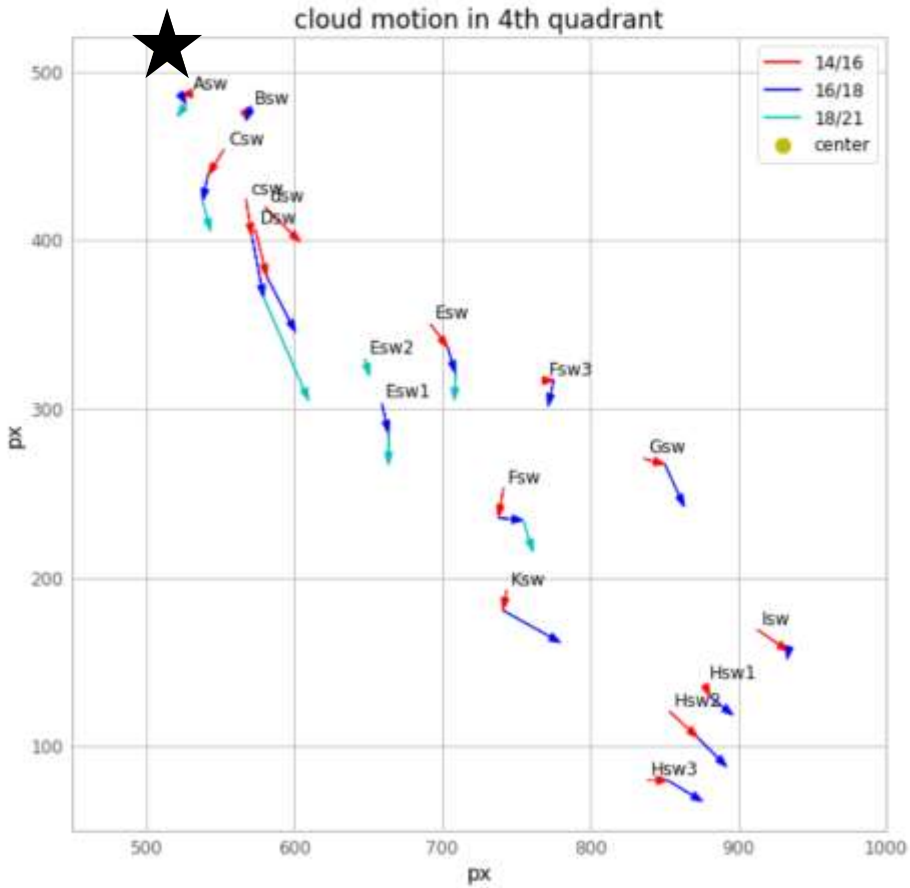


Figure 2.2: Illustration of the displacement of all evaluated clouds in the southwest. The center is marked yellow where the red giant is located. The different colors red, blue and cyan correspond to the temporally different shifts between two observations.

Master thesis B. Gerlach

Hα: mean projected velocity ≈ 27km/s

adopted distance = 218 pc, (Min et al.,2014,PASJ 66,38)

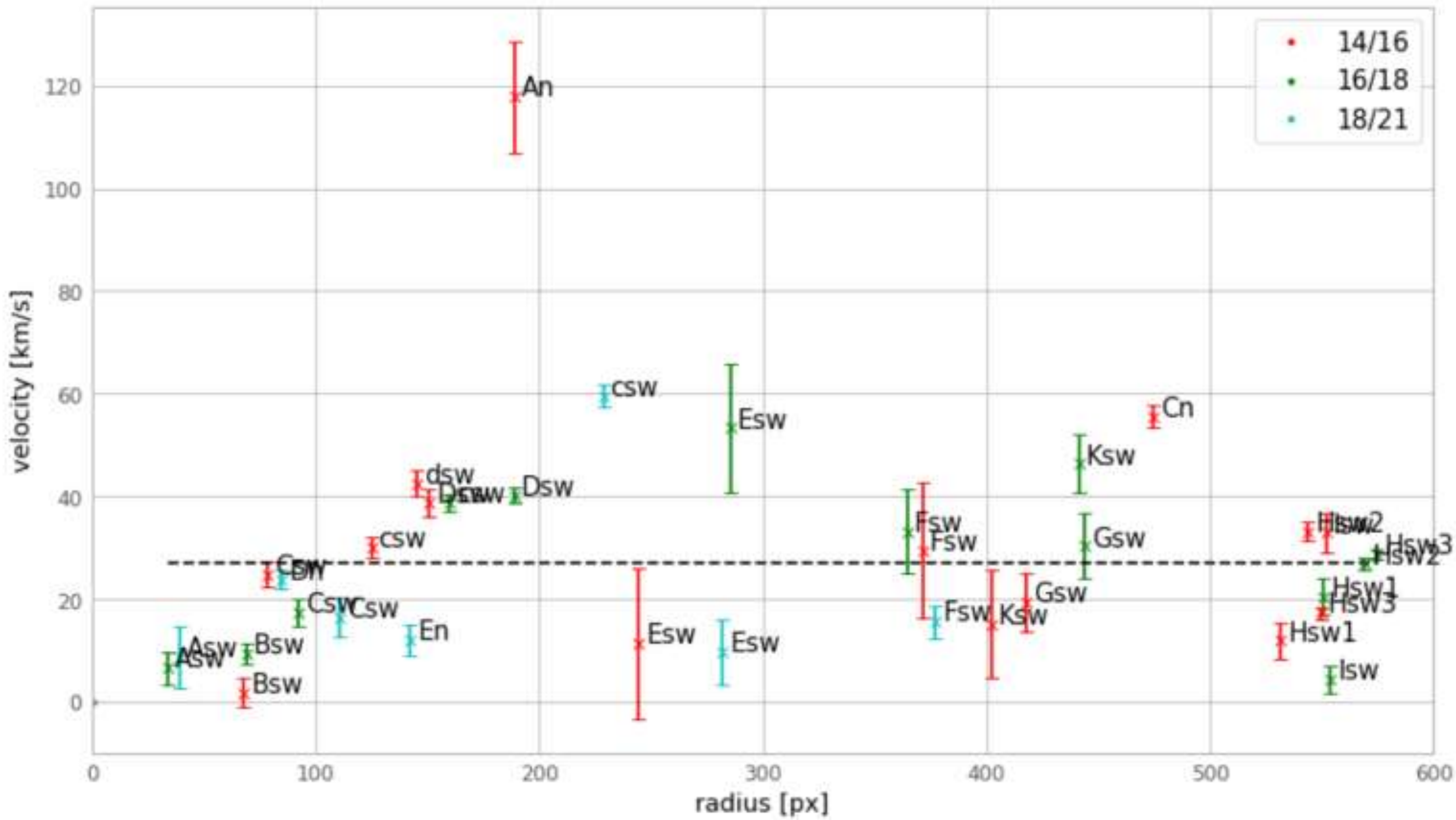


Figure 2.3: Cloud velocities in km/s plotted as a function of the radial distance from the star. According to [Bro17], the conversion 1 px $\approx 75 \cdot 10^6$ km was used. The horizontal line at about 27 km/s corresponds to the mean velocity.

Master thesis B. Gerlach

Highly variable Hα clouds

Central R Aqr clouds:

- compact, bright, and variable
  (also seen by sub-arcsec radio observations)

- high density $N_e \approx 10^6 cm^{-3}$

→ short time scales $\tau \propto 10^6 yr/N_e \approx$ few weeks to months
for cooling and recombination

→ therefore the clouds react on illumination changes
from the dusty central binary

Extended R Aqr nebula has $N_e \ll 10^4 cm^{-3}$

→ structures long lived and expand steadily over decades
(see e.g. Liimets et al. 2018)

Dust clouds and their motion

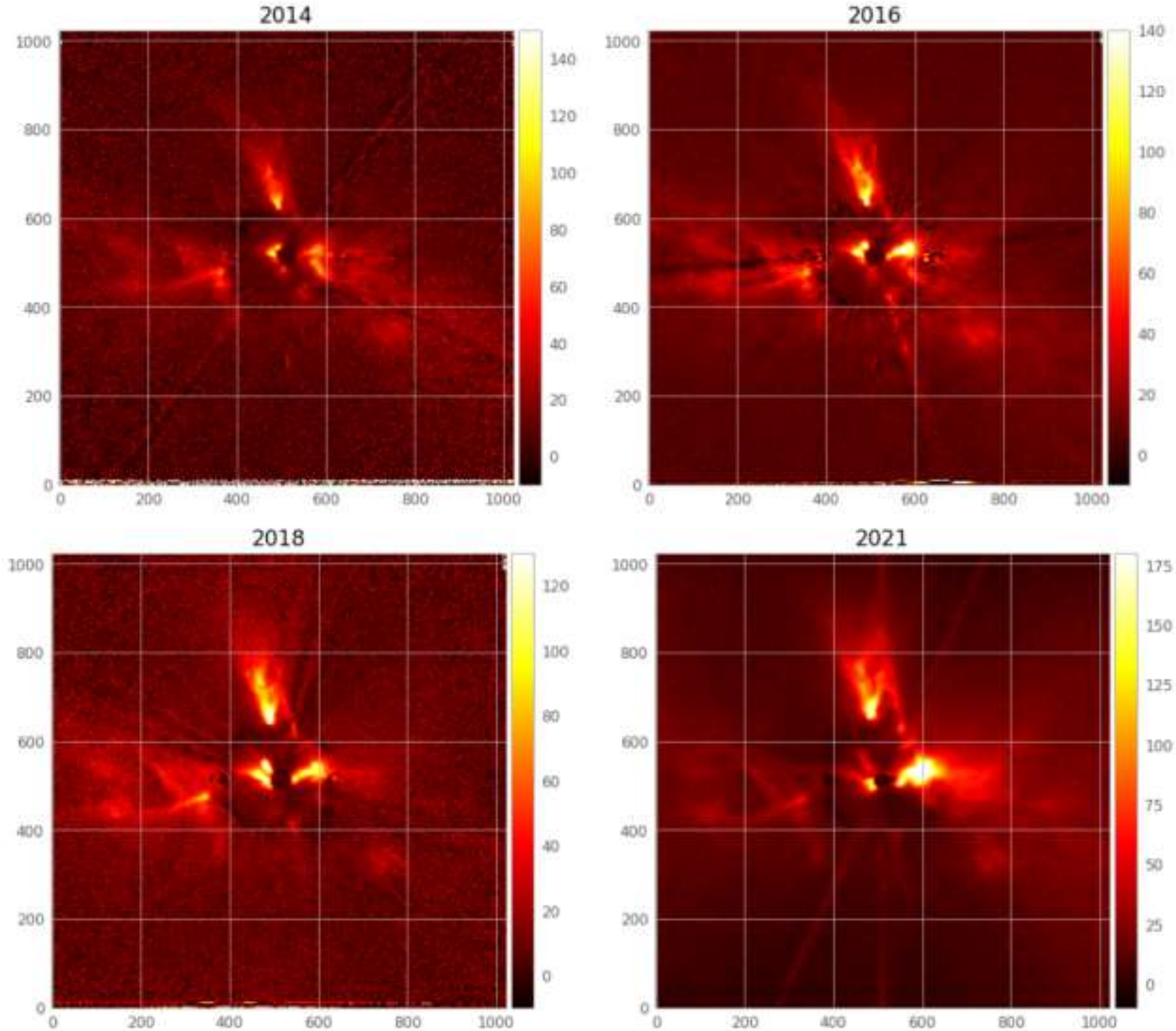
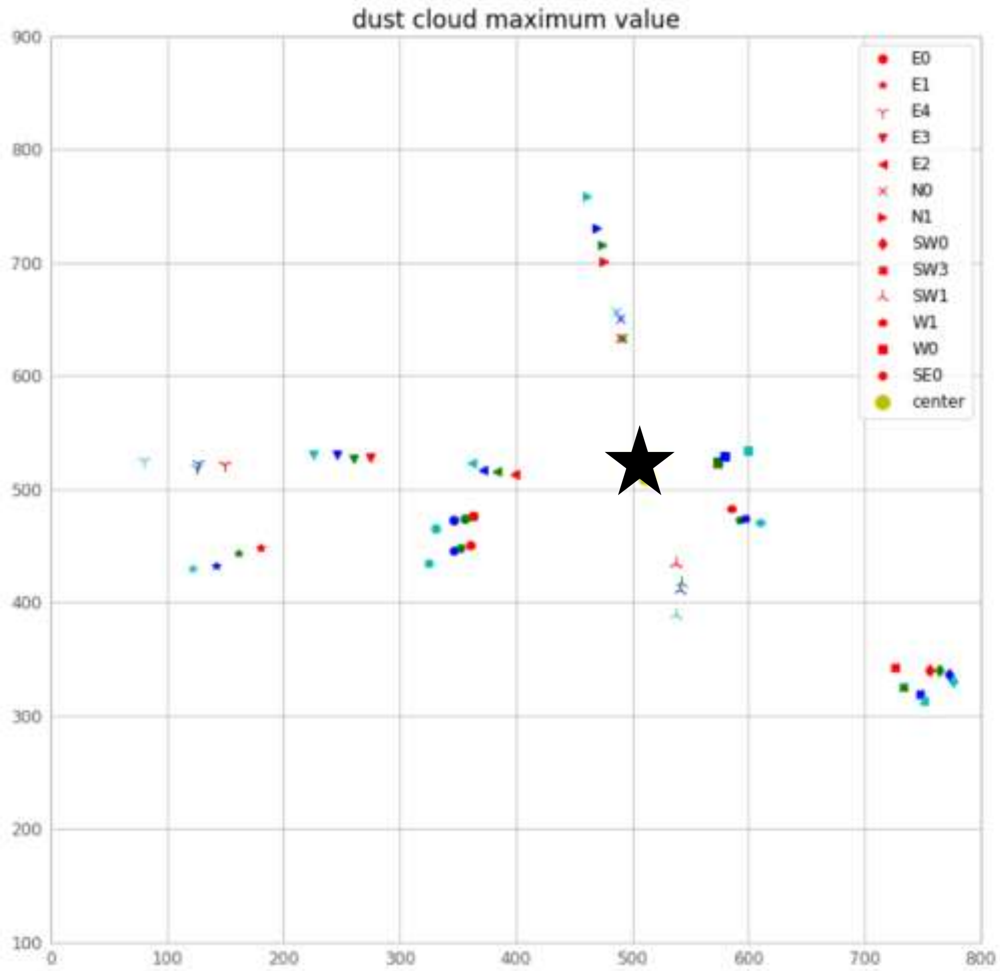


Figure 3.1: Images of dust cloud features: All but the last one are coronagraphic observations. The frames are listed in table 1.1, corresponding to the infrared filters I_PRIM in 2014 and N_I for the other 3 observations. A size 3 median filter was applied to the shown images. Moreover, they are scaled with $(r/100)^2$ for better visibility. The axes refer to the pixels.

Master thesis B. Gerlach

mean velocity of dust clouds: $16 \pm 5\ km/s$

for distance of 218 pc



Master thesis B. Gerlach

First scientific results

We derived based on SPHERE/ZIMPOL (and archival HST) data

for the binary:

- accurate position in Oct 2014: sep: 45.1$\pm 0.6\ mas$, θ: $(270.5 \pm 0.8)^o$
- hot Ha component not visible in 2016, 2018 and 2018

for the Halpha clouds

- strong variability (time scale ~ 1 to 5 years) because of high density
- systematic outflow within two jet cones
- mean transverse velocity of ~ 27 km/s (with large scatter)
- detailed geometry and dynamics of the inner jet (< 300 AU)

for the dust

- long lived (> 7 years), expanding dust structures
- radial dust outflow with mean transverse velocity of v ≈16+/-5 km/s
- detailed structure of the dust outflow
- future: constraints on particle properties

Outlook and opportunities

combine the ZIMPOL Hα cloud and dust scattering data with

- ALMA maps for CO gas and dust continuum

  talks by Javier and Miguel + e.g. Bujarrabal et al.(2018,2021), Ramstedt et al (2018)

- radio free-free emission maps (like Hα, but no extinction)

  e.g. Cotton et al (2021), Dougherty et al. (1995), Hollis et al.(1985)

- IR-interferometry and masers of the mira variable and outflow

  talk by Markus, + e.g. Ragland et al.(2008)

- the ionized jet gas, HST, ground based telescopes, X-ray

  talk by Tiina poster by Havva, + e.g. Santamaria et al. (2024), Huang et al. (2023), Toala et al. (2022), Liimets et al. (2018), Melnikov et al. (2018), Solf & Ulrich (1985)

- eclipse features from the disk with IR spectroscopy

  poster by Kenneth

R Aqr is a great system