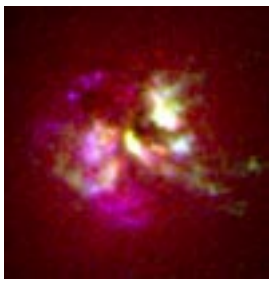
Reverse engineering Cygnus A



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(with thanks to Richard Hook)

We use Keck imaging- and spectro-polarimetry interpreted with the help of HST WFPC 2 filter imaging (from the public archive).

The purpose is to dissemble Cygnus A into its (optical) component parts and see how the pieces can be used to build high redshift radio galaxies.

Observations

Imaging polarimetry with LRIS on Keck II
in October 1996 (Ap J, 482, L37) B-band, 1hr.

Also LRIS spectropolarimetry, 1 arcsec slit in PA 101°,
3600 – 9000Å, 2.2hr.

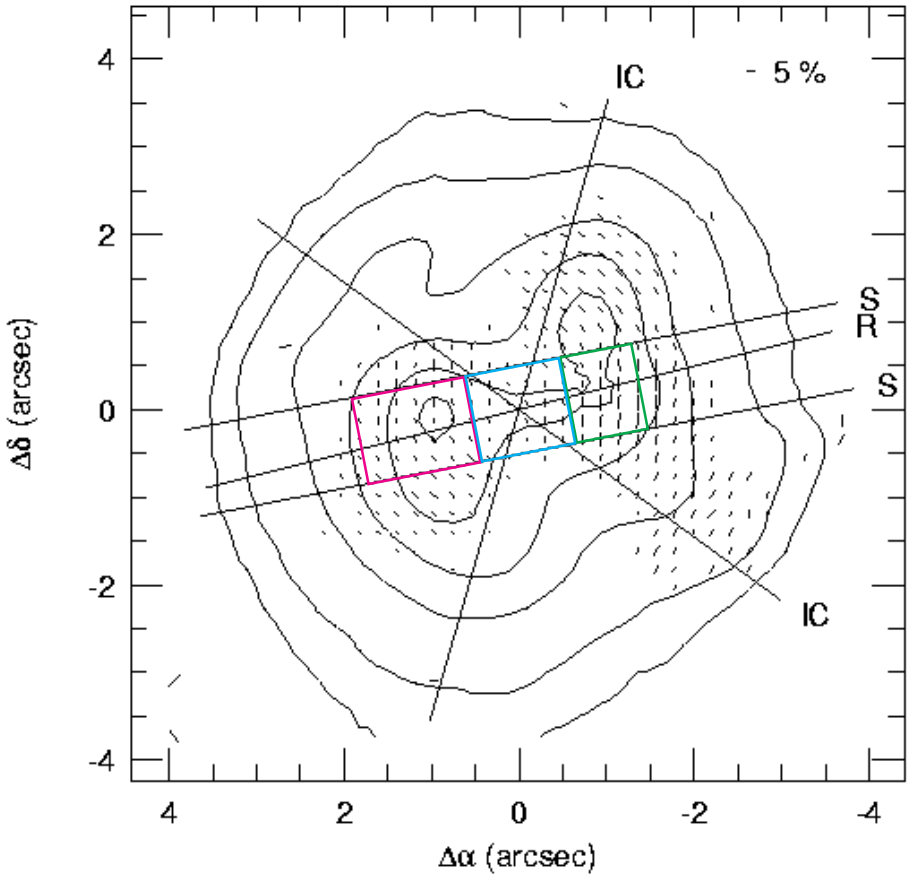
HST, WFPC 2 images in 450W, 550W, 622W, 814W
and narrow [OIII], Hα and [OI] (from a program by Neal Jackson — data now in the public archive).

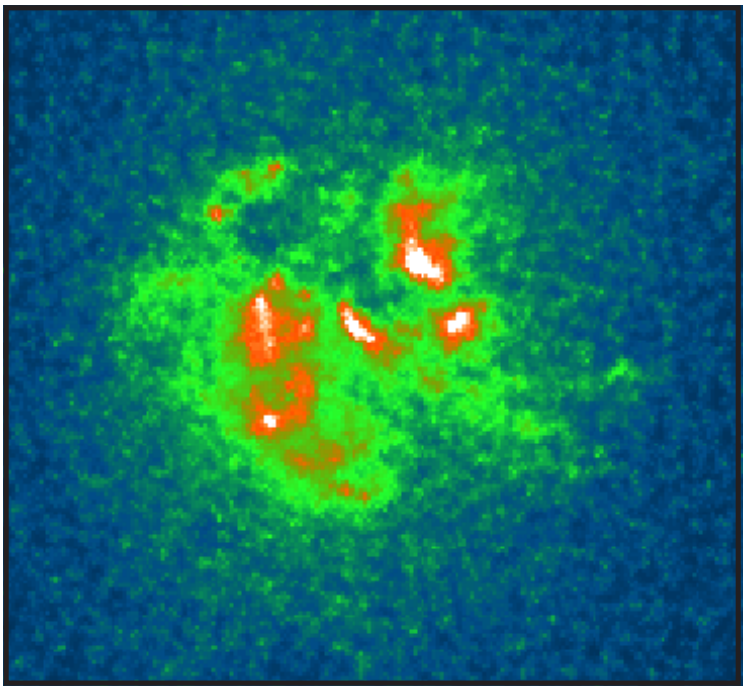
The HST 450W and Keck B-band images were combined using the Lucy-Hook iterative coaddition code to give a high s/n, high resolution B image. This extra signal adds significantly to the value of the HST imaging.

Imaging polarimetry

Peak polarization 10.8 ± 0.8% in the west.

Centro-symmetric pattern following the 55° half-angle bicone seen in the HST images.





Lucy-Hook coaddition of HST 450W and Keck B images (Tran & Hook, 1996)

Spectropolarimetry

Spectra corrected for Galactic reddening with E(B-V) = 0.5

Elliptical galaxy template (NGC 821) subtracted (70% of the observed flux at 5500Å in a 7.6 arcsec slit length).

Component separations (1.3 E, 0.8 W, 1.1 Nuc (x 1 arcsec)).

subtracted Galaxy fraction (5500Å) = 64% ± 3% (east)
62% ± 3% (west)

Broad lines

Hα seen in total flux

FWHM = 26,000 km s^{-1}, 5 x 10^{-15} erg cm^{-2} s^{-1} (Gal. Ext. corr.)

Seen in east and west, weaker in Nucleus.

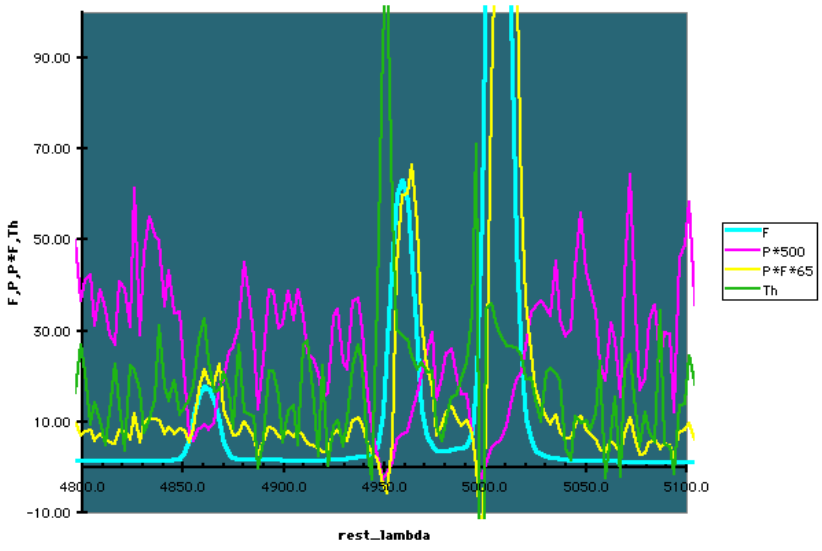
Hβ seen in polarized flux in west.

Narrow lines

P = 1.3% in PA 32° (total flux).

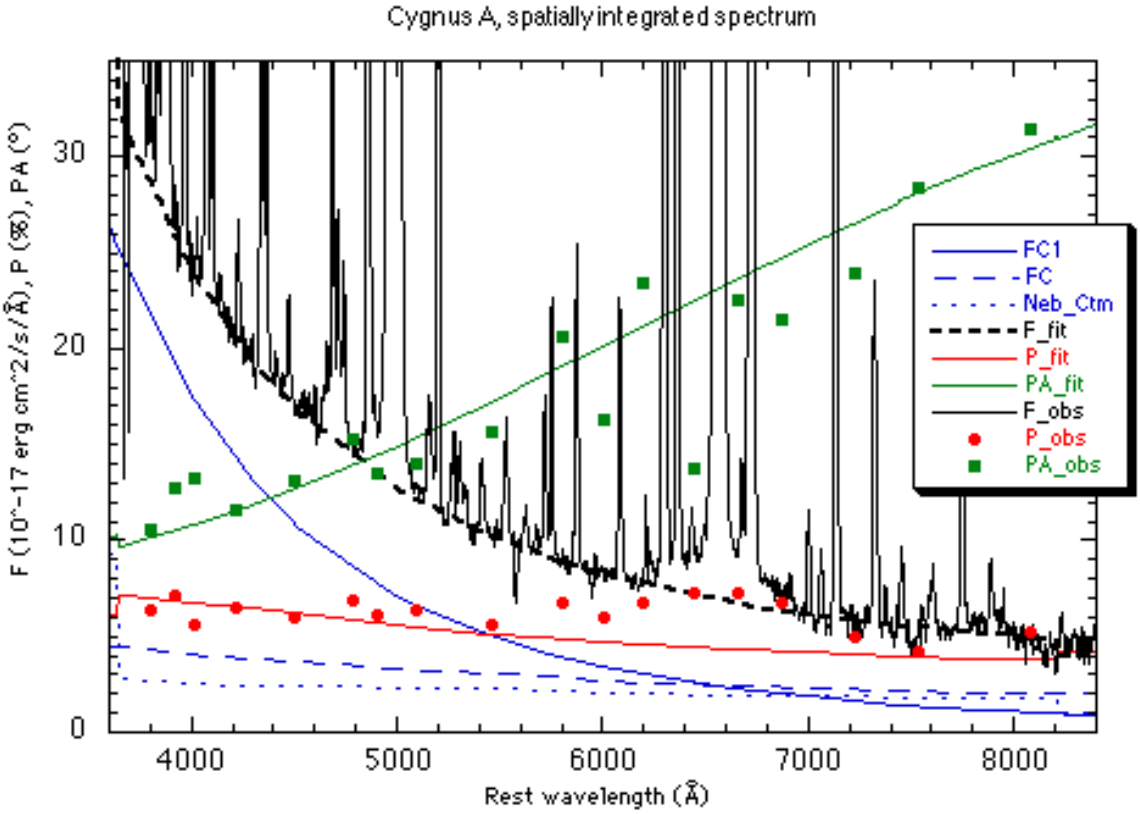
The narrow lines in polarized flux are redshifted by up to 230 km s^{-1} – greatest in the higher ionization lines.

Line spectra similar in east and west except for [Fe VII] and [Fe XI] which are stronger in the east. There is more line reddening in the east (where there is also a Balmer decrement anomaly — see later).



Continuum components

Analysis of the spatially integrated spectropolarimetry (slit length 7.6 arcsec, Ogle et al. 1997) suggests the presence of scattered AGN light (FC1), a second polarized continuum with a different E-vector PA (FC) and a nebular continuum.



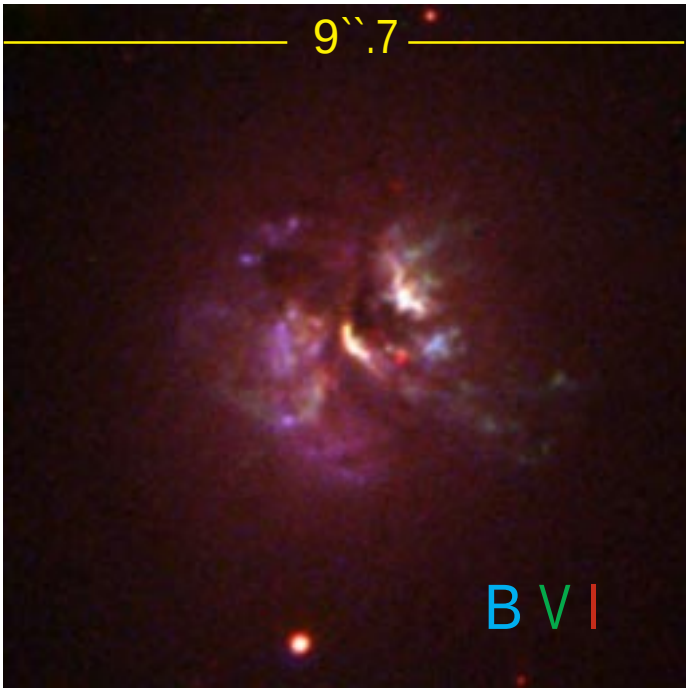
FC1 is relatively stronger in the west (forward scattering) while the continuum in the east is bluer and less polarized. This is consistent with the radio data which suggest that the western jet is closest to us.

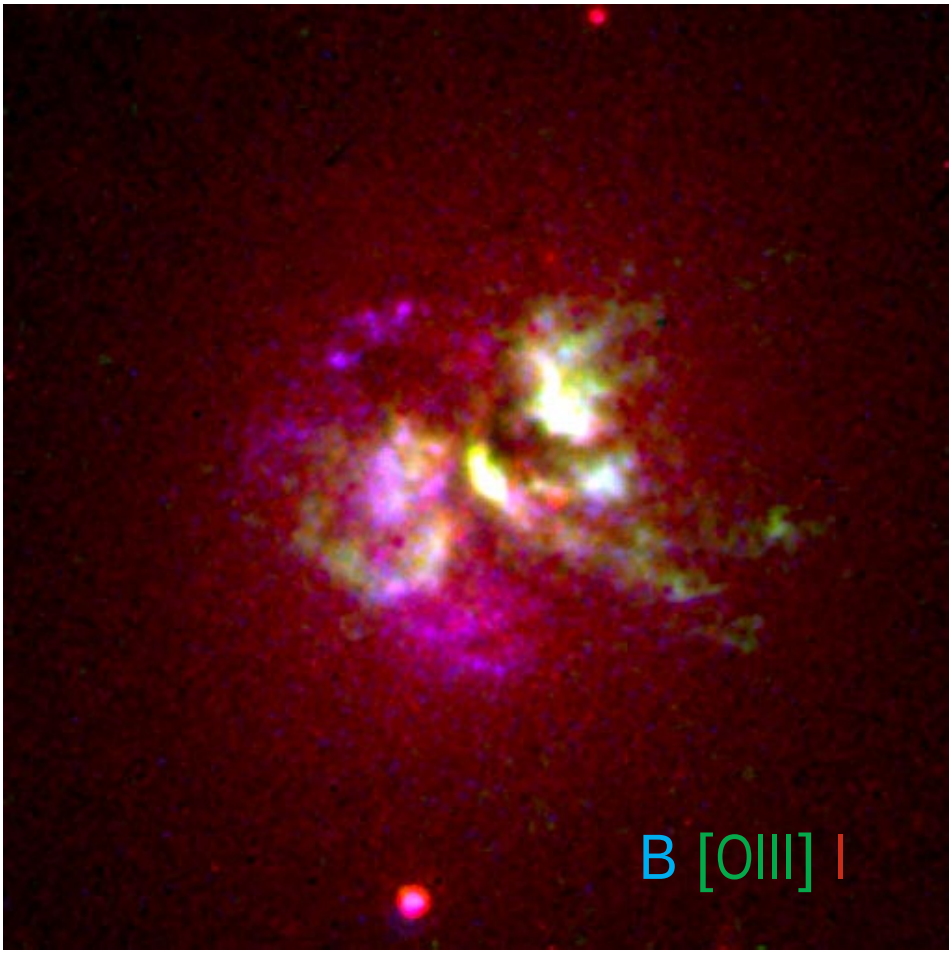
Fitting the eastern and western spectra

We have now attempted to build consistent fits to the eastern and western spectropolarimetry using the three continuum components used above. The key is provided by the HST images — which allow us to identify the spectral components with spatially distinct structures.

Which are the most informative HST images?

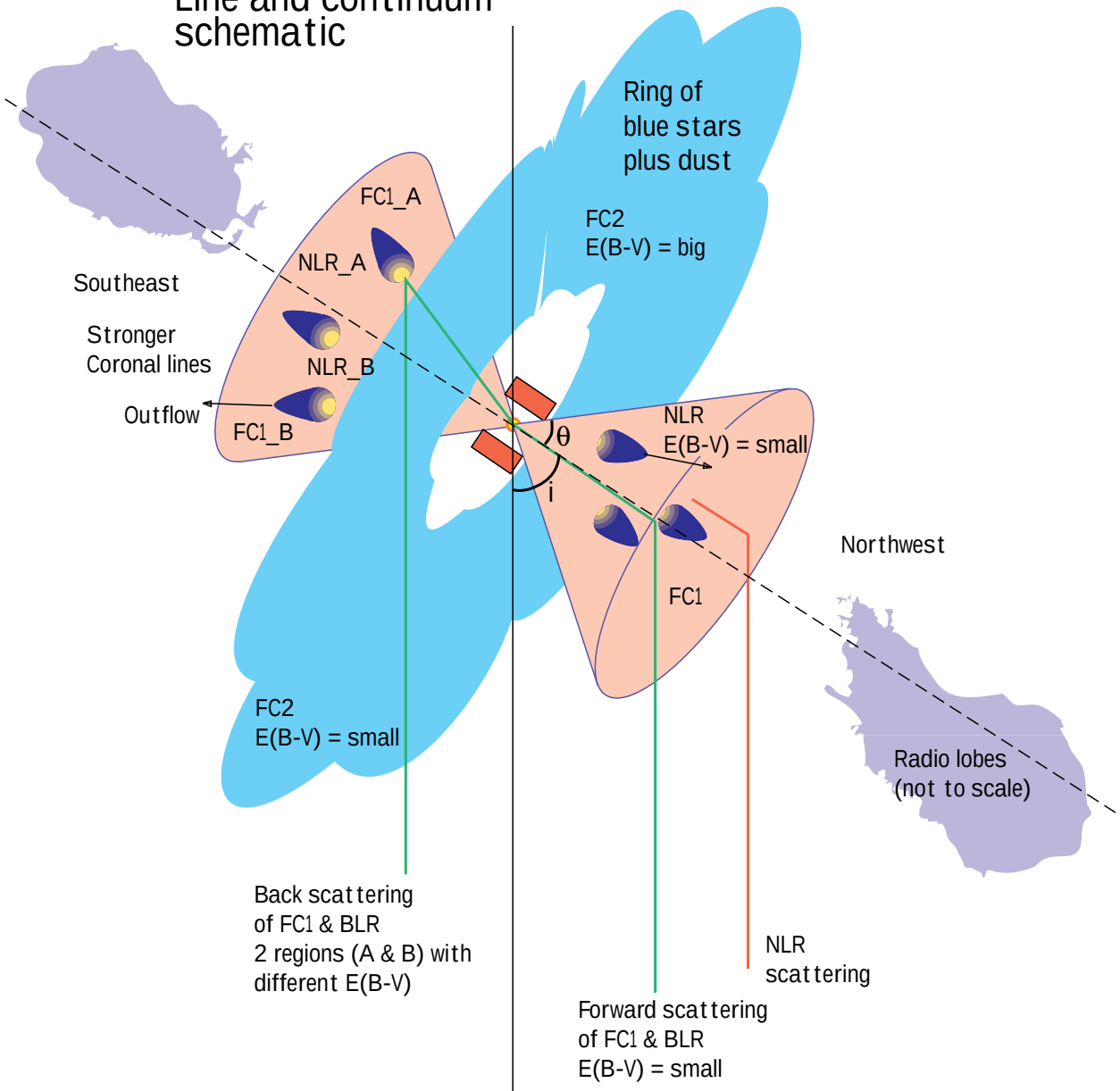
The broadband BVI or BRI images give a hint of what is going on — but the most interesting view is made by combining the B-band continuum (sensitive to young stars), the [OIII] line image (delineating the AGN-ionized gas) and the I-band continuum (which shows the elliptical component)





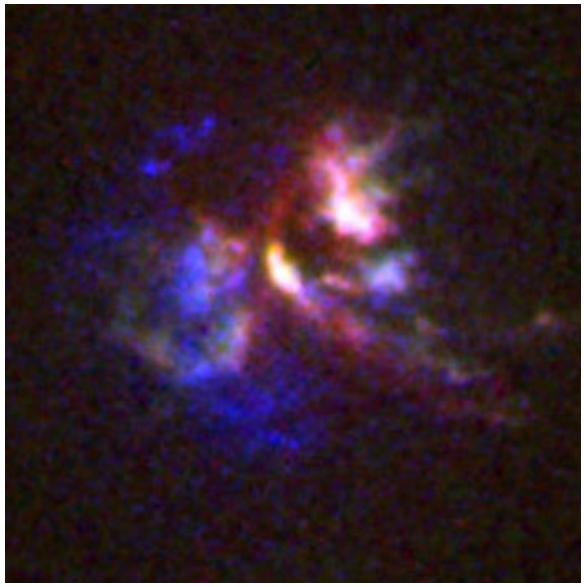
It is clear that the blue continuum in the east is not restricted to the ionization bicone. This suggests that it is blue starlight (as favoured by Stockton & Ridgway)

Cygnus A
Line and continuum schematic



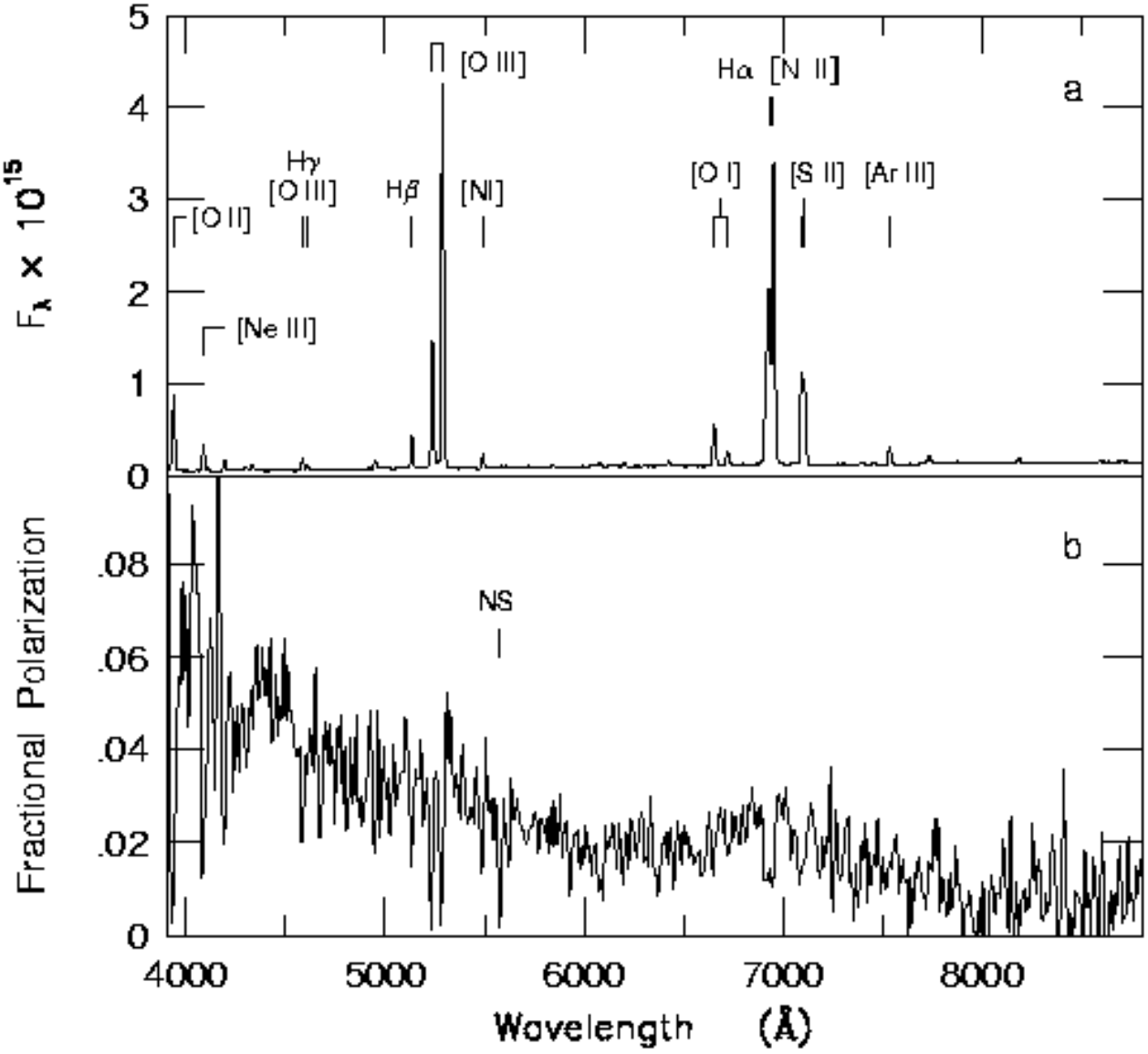
Cone half-angle $46° < \theta < 55°$
Inclination of cone axis $46° < i < 85°$
Inclination of stellar ring axis ~ 52°

Observer



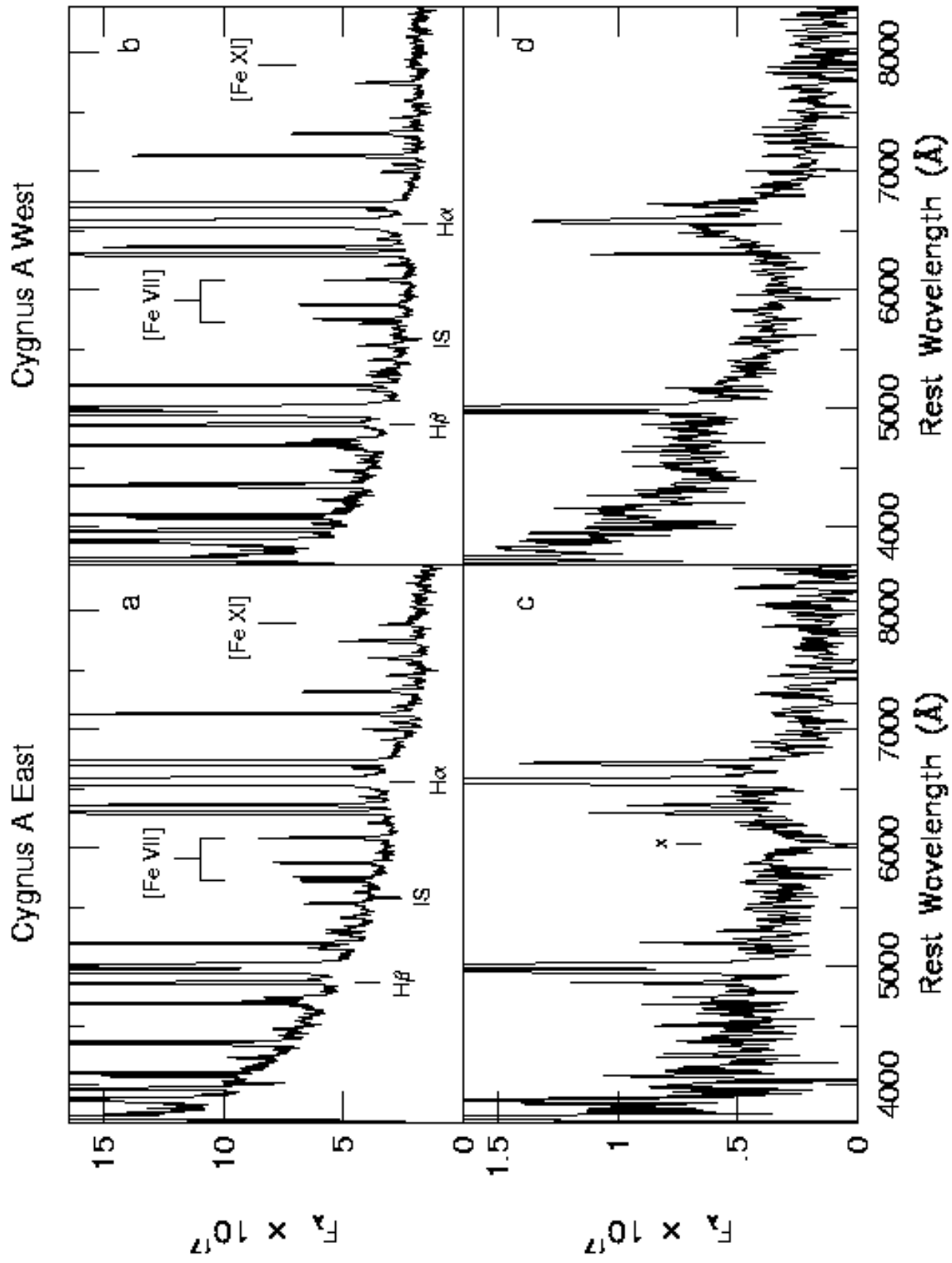
B, *[OIII]*, *Hα*

Spatially integrated spectrum (1 x 7``.6)

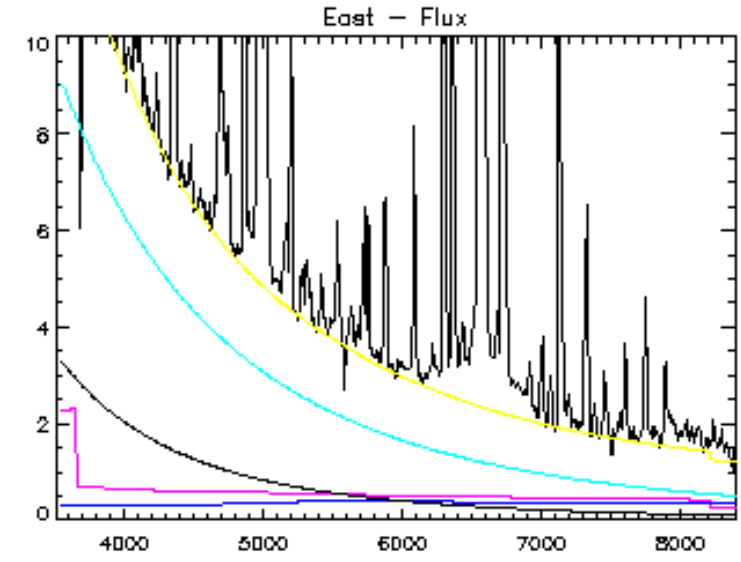


Total flux and fractional polarization spectra before subtraction of elliptical template.

Eastern and western spectra

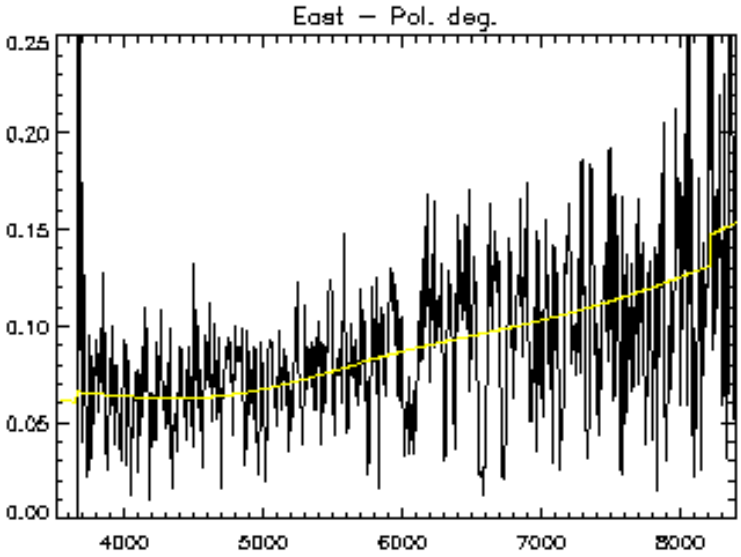


Continuum fitting — east

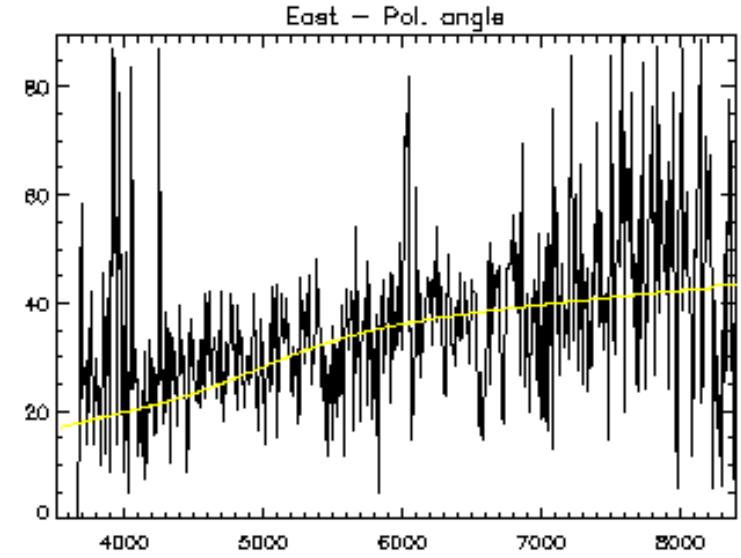


FC2 -> BB @ 25,000K

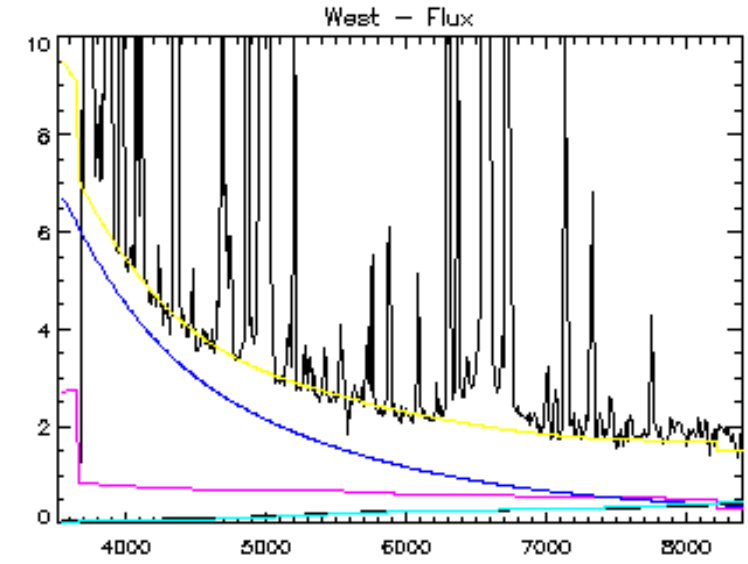
FC1 -> Power law, ν^{+2}



Comp.	P(%)	PA(°)	$F/F_{tot\_H\alpha}$	E_{B-V}
$FC1_A$	50	48	0.20	1.2
$FC1_B$	25	12	0.15	0
FC2	0	-	0.65	0

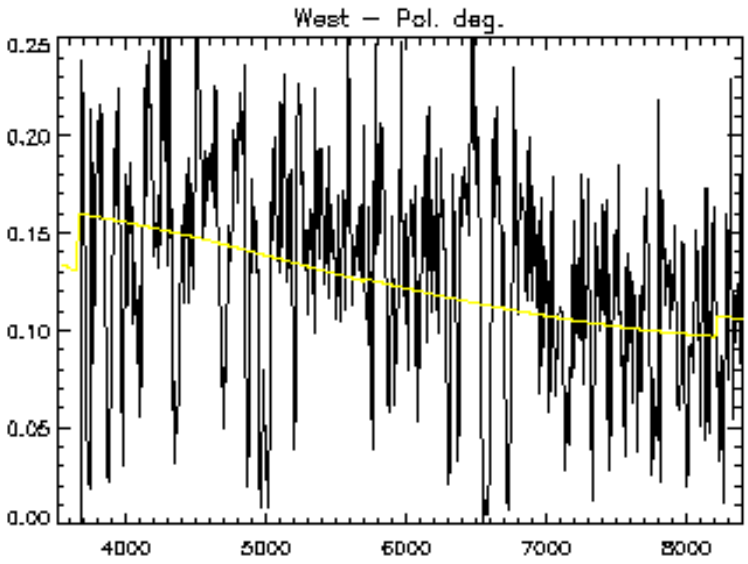


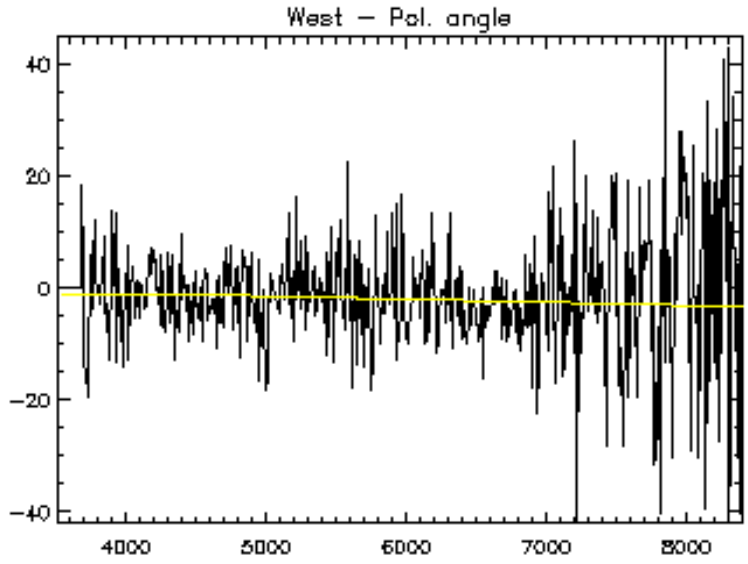
Continuum fitting — west



FC2 -> BB @ 25,000K

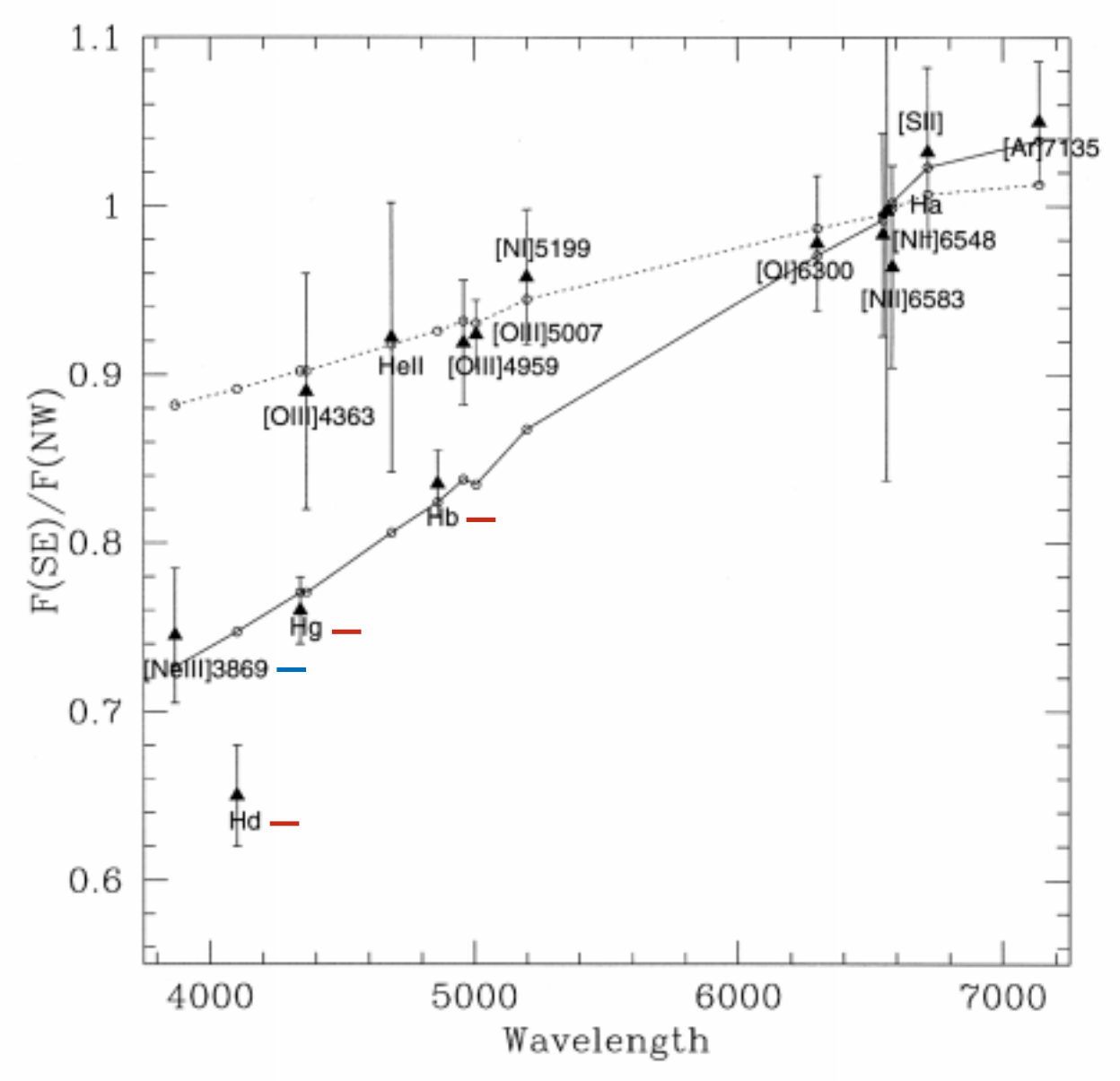
FC1 -> Power law, ν^{+2}





Comp.	P(%)	PA(°)	$F/F_{tot\_H\alpha}$	E_{B-V}
$FC1_A$	18	-1	0.60	0.18
$FC1_B$	20	-5	0.20	1.8
FC2	2	0	0.20	1.8

Emission line reddening



Most line ratios are very similar in the eastern and western regions.

A plot of the ratio of E/W intensities shows, however, the extra line reddening in the east. The Balmer lines and the blue [NeIII] lines do not follow the trend shown by the other lines ($\Delta E(B-V) = 0.07$). The Balmer anomaly can be due to the underlying Balmer absorption in the stars responsible for FC2 in the east.

Conclusions

The optically emitting components of Cygnus A comprise:

A dust-scattered AGN continuum from a quasar (BLRG) of modest luminosity and confined to an ionization bicone. This FC1 is highly polarized (locally up to P~50%) with the E-vector perpendicular to the line connecting it to the nucleus. Its spectral index $\alpha \sim +2$. Reddening differences suggest that the western cone is on the nearside.

Blue stellar continuum ('FC2') from a population of young stars (represented by $T_{eff.} = 25{,}000$K in our fits) with a low or zero polarization. This is unreddened in the east and significantly obscured in the west. This, together with the HST images, suggests the stars reside in a dusty equatorial ring with a diameter of around 5kpc and an axis coinciding with the radio and ionization cone axes. The starlight avoids the region of the radio jets — they are orthogonal.

Nebular continuum associated with the regions emitting the NLR

Polarized (dust scattered) broad permitted lines — Hα and Hβ in our data, Mg II in the HST spectroscopy of Antonucci, Hurt & Kinney (1994).

Narrow emission lines emitted mostly within the ionization cones (some low ionization lines associated with the extended dust). These are more reddened in the east and are weakly polarized in a manner suggestive of scattering in an outflowing wind.

We see all of these components in HzRG. How common is this geometrical configuration with an equatorial stellar ring? It seems to be common amongst the low z Seyferts. The balance between the FC1 and FC2 luminosity clearly varies from object to object and might be expected to evolve in a particular object.