1 Fluxes of the main lines

Table 1: Line Fluxes

	[NeIII]3869	Hδ	Hγ	[OIII]4363	HeIIλ4686
Nuc	66.2	12.78	23.80	10.10	11.39
SE	77.00	10.84	23.06	12.72	17.8
NW	105.8	16.98	31.29	14.34	19.6
	Hβ	[OIII]5007	[NI]5199		
Nuc	56.15	650.2	22.98		
SE	55.63	726.4	21.44		
NW	67.63	782.3	23.22		
	OI6300	Hα	NII6583	SII6716+6732	
Nuc	71.59	251.8	471.5	259.5	
SE	63.3	240.1	401.5	208.70	
NW	61.43	240.9	415.7	203.50	

2 The physical conditions of the gas and the ionizing mechanism

To study this aspect, we select line ratios involving emission lines close in λ so that the dust effects due to reddening are minor. Such emission line ratios are:

HeII/Hβ, [OI]λ6300/Hα, [OIII]λ5007/Hβ, [OI]λ6300/[OIII]λ5007, [NII]λ6583/α

Table 2: Line Ratios. They are coherent with standard non dusty photoionization models

	[SII]/Hα	HeII/Hβ	[OI]/Hα	[OIII]/Hβ	[OI]/[OIII]
SE	0.87	0.32	0.26	13.22	0.09
NW	0.84	0.29	0.26	11.56	0.08
μ=0	0.60	0.25	0.22	13.4	0.05
μ=0	0.56	0.25	0.27	11.7	0.07

Comparing the line ratios at both sides of the nucleus (Table 1), we see that they are very similar. This strongly suggest that the physical conditions of the gas, the ionization level and the excitation mechanism of the lines is the same at both sides of the nucleus.

Moreover, the line ratios lie well on the general trend defined by the EELR of other radio galaxies (see Figures 1 and 2) and are well described by photoionization models. The agreement between the the standard photoionization model predictions (see Table 1) and the difficulty of the shock models to reproduce the line ratios (see diagrams) unless a mixture of precursor and shocks is considered strongly supports AGN photoionization as the main ionization mechanism. The study of the line kinematics will provide important information about the possible existence of shocks in the EELR.

3 Discrepant line ratios with standard photoionization models

[NII]/Hα is too high compared to model predictions. Another explanation is required, like overabundance as proposed by Tadhunter et al.

3869/Hβ. The observed value is much higher than expected from non dusty models. External dust should decrease this line ratio, due to reddening effects. Therefore, external dust is not the solution, which, on the contrary, accentuates the problem. The intrinsic line ratio seems much higher than expected at both sides of the nucleus. As we will see, internal dust can help to solve this problem.

4 The dust.

4.1 Its existence

Clearly we need dust to explain the high Balmer decrement observed in all regions considered. The standard photoionization models which reproduce the other optical line ratios predict Hα/Hβ about 2.9 and the observed values are 4.32 and 3.52 in NW and SE respectively.

Another evidence supports the effects of the dust on the emission lines: While for the lines at longer wavelenghts, the relative intensity NW/SE is roughly 1, for lines at shorter λ the contribution of the SE to the NW decreases (Table 3) (Hβ is a bit of a problem). This strongly suggests that the SE is more reddened that the NW side. This is coincident with the larger Hα/Hβ decrement.

Table 3: Relative line intensities SE to NW. It decreases at shorter wavelenghts.

	3869	Hγ(λ4340)	HeII4686	Hβ	OIIIλ5007	Hα	6300
SE/NW	0.73	0.74	0.91	0.82	0.93	1.00	1.03

4.2 Its location

This has important implications for the scattering model and the nature of the scattering agent. The imaging polarimetry of Cyg A shows that there is emission of polarized light coincident, at least in projection, with the ionized cones. If this polarized light is scattered, the scattering agent must be inside the ionized cones. It could be electrons and/or dust.

If not enough dust is inside the ionized cones to explain the polarization this would support electrons as the scattering agent, or maybe that the polarization is due to dichroic absorption by intervening dust (?).

Therefore, the question we will try to answer from the optical lines is: *Where is this dust located? Is it mixed with the ionized gas or (/and) is it outside the ionized cones (intervening)?*

4.3 Internal dust (mixed with the ionized gas)

The depletion of the calcium element onto the dust grains suggested by the absence of the [Ca] doublet at $\sim$7300 Å shows that there is dust in the ionized cones. This does not tell us, however, how much dust exists. Very little amounts ($\leq$10% the dust to gas ratio in the solar neighbourhood) are able to deplete calcium as much as to make the doublet lines undetectable.

On the other hand, the Fe lines are strong. Fe is very sensitive to depletion (depletion factors as great as 1000 are seen in the interstellar medium). The strength of the lines suggests that, at least the regions emitting the Fe lines are rather dust-free.

4.3.1 The line ratios.

We will assume in this section the dust is only internal. We will compare the predicted line ratios with the observed ones to see if internal dust can explain the observations.

In section 1 we saw that non dusty photoionization models reproduce quite well the optical line ratios in Table 1. However this does not imply that internal dust does not exist, but that, if it exists does not have strong effects on these line ratios. Most of the line ratios used in that section were not very sensitive to reddening effects. Internal dust can, however, change the physical conditions of the gas and the ionizing continuum shape so that the line ratios can be modified. We look for dusty models which do not have strong effects on the line ratios in Table 1.

On the other hand, the models have to explain the high Balmer decrements observed and the different values at both sides of the nucleus. Asumming (from the similarity of the other line ratios) that the cones are identical (in physical conditions, ionization parameter, dust content), the factor which might explain the different Balmer decrement is perspective.

We have selected the best models in which perspective reproduces the two observed Balmer decrement, for two different amounts of dust. Table 4 shows the predictions of the models with μ =1 (dust to gas ratio is the same value as in the solar neighbourhood) and μ =0.3 (dust to gas ratio is 30% that amount).

Table 4: Line Ratios

	Hα/Hβ	[SII]/Hα	[NII]/Hα	HeII/Hβ	[OI]/Hα	[OIII]/Hβ	[OI]/[OIII]	3869/Hβ
SE	4.32	0.87	1.67	0.21	0.32	13.22	0.08	1.38
NW	3.57	0.84	1.73	0.29	0.29	11.56	0.08	1.56
μ=1 (b)	4.3	?	0.56	0.22	0.50	11.0	0.20	0.95
μ=1 (f)	3.03	0.91	0.53	0.29	0.38	12.5	0.09	1.56
μ=0.3 (b)	4.66	?	0.37	0.25	0.70	17.3	0.19	0.71
μ=0.3 (f)	3.31	?	0.27	0.47	0.40	18.4	0.07	1.04
μ=0	2.90	0.60	0.27	0.25	0.27	11.7	0.07	0.78
μ=0	2.89	0.54	0.19	0.24	0.22	13.4	0.05	0.81

The ? on Table 3 indicates that the files necessary to compute one of the SII lines are not available. I would need to run the models again

The models suggest that the amount of internal dust has to be quite high (μ=1) in order to obtain a good agreement with the observed line ratios. Models with low dust contents, as μ =0.3 (dust to gas ratio is 30% the value in the solar neighbourhood) are not allowed. This models require very high ionization parameters to produce the extreme dust effects required (dust is more efficient at high U values). However, problems appear because the other optical line ratios are strongly discrepant.

The perspective would explain the different Ha/Hb observed, but, what about other line ratios? The models predict that although some line ratios are not very sensitive to perspective, at least OI/OIII, 3869/Hb, OI/Ha are. This is not observed, the line ratios are very similar. We conclude that perspective effects are negligible. We conclude the same if we consider line ratios more sensitive to perspective and dust (see Table 5):

Table 5: Internal Dust, Line Ratios and Perspective

	$H\alpha/H\beta$	$3689/H\beta$	$5199/H\beta$	6300/Hb
SE	4.32	1.38	0.38	1.13
NW	3.57	1.56	0.34	0.91
μ=1 (b)	4.3	0.95	1.02	2.16
μ=1 (f)	3.03	1.56	0.6	1.14
μ=0	2.89	0.8	0.3	0.8

We would expect more extreme differences between SE and NW line ratios if the dust explaining the extreme Balmer decrement was internal.

4.3.2 The line intensities

Table 6: Relative intensities SE/NW of several lines.

	$H\alpha$ (B/F)	3869	$H\beta$	6300	HeII4686
SE/NW	1.00	0.73	0.82	1.03	0.91
μ=1 B/F	0.35	0.15	0.25	0.47	0.19

The fist row in Table 5 shows the intensity ratio for different lines between the SE and the NW blob. The second row shows the predicted ratios between back and front if the dust content was μ=1, the same models which better explain the Balmer decrements.

The intensity of the lines at both sides of the nucleus is very similar (Table 5). This confirms that perspective is not playing a mayor role. The models which could explain the extreme Balmer decrement observed predict to strong differences on the intensity of the lines at both sides which is not observed.

Obviously, we do expect that the perspective effects are not as extreme as 'front' and 'back' because CygA is a narrow line radio galaxy. Smaller perspective effects could explain the smaller differences, but this would then contradict the Balmer decrements.

Therefore, the internal dust can not explain the observations. External dust is required to explain the very different Balmer decrements at both sides of the nucleus.

We will consider now the μ=1 dusty models where perspective does not differentiate the two cones (as if they were in the plane of the sky). The results are presented in Tables 7 and 8, together with the observed line ratios and the non dusty models which reproduce a similar ionization level (OIII/Hβ).

Table 7: Dust, line ratios and non perspective effects.

	Hα/Hβ	[SII]/Hα	[NII]/Hα	HeII/Hβ	[OI]/Hα	[OIII]/Hβ	[OI]/[OIII]	3869/Hβ
SE	4.32	0.87	1.67	0.21	0.32	13.22	0.08	1.38
NW	3.57	0.84	1.73	0.29	0.29	11.56	0.08	1.56
μ=1 (f+b)	3.03	0.91	0.53	0.30	0.38	12.5	0.09	1.56
μ=0	2.90	0.60	0.27	0.25	0.27	11.7	0.07	0.78
μ=0	2.89	0.54	0.19	0.24	0.22	13.4	0.05	0.81

If we use other liner ratios more sensitive to dust we obtain the results shown in Table 5:

Table 8: Line Ratios Sensitive to Dust

	Hα/Hβ	3689/Hβ	5199/Hβ	6300/Hb
SE	4.32	1.38	0.38	1.13
NW	3.57	1.56	0.34	0.91
μ=1 (f+b)	3.03	1.44	0.7	1.34
μ=0	2.89	0.8	0.3	0.8

Internal dust in amounts as high as μ=1 (and no perspective effects) improve some of the line ratios, 3869/Hβ in particular, which is problematic and can not be explained with external dust. The overall agreement with the line ratios is better than with non dusty models, but it is not conclusive that internal dust is the solution.

4.4 External dust

(This is very preliminary study of the effects of the intervening (external) dust).

Can we explain the observed line ratios with pure external dust? (Not NeIII3869/Hβ at least)

The exercise I have done is: deredden the observed line ratios at both sides of the nucleus with the correction deduced from the Balmer decrements and the average extinction curve of our galaxy. Then, compare the resulting line ratios with non dusty models. If they are in good agreement this will strongly suggest that the dust affecting the optical lines is external and the inner dust/gas ratio in the ionized cones is smaller than outside (and than in our ISM)

The preliminary result is that the dereddened line ratios (also ratios like OI/Hb and NI5199/Hβ, which are sensitive to dust) are in remarkable good agreement with non dusty models. Indeed, except for NII/Hα and NeIII3869/Hβ (which could imply internal dust) I suspect that most line ratios can be explained in terms of pure reddening produced by external dust, with no internal dust required (or in amounts smaller than the one in our ISM so that the effects on the line ratios are negligible).

This agrees with Tadhunter results, who can explain the different Balmer ratios with the reddening produced by external dust.

5 Conclusions

- The physical conditions, the ionization level and the ionization mechanism of the gas are very similar at both sides of the nucleus.

- Shock models alone can not explain the observed line ratios. A contribution of photoionized precursor is required. Altough AGN photoionization models present some discrepancies (NII/Ha), they reproduce remarkably well the observed line ratios.

- As Tadhunter et al. observed, NII is much stronger than expected from photoionization (and shock) models. Internal dust increases the ratio, but not enough and another (or additional) explanation is required.

- [NeIII]3689/Hβ is too high compared with model predictions. Reddening effects produced by external dust do not solve the discrepancy.

- Ca depletion shows that there is dust mixed with the ionized gas.

- The strength of the Fe lines suggests that the ionized gas is less dusty than our ISM. This contrast with the result which indicates that ...

- internal dust in amounts as large as μ=1 are required to improve the agreement between photoionization models and the observed line ratios. It is required condition that perspective effects are not involved, to explain the similarity of the line intensities and line ratios at both sides of the nucleus.

- The optical lines do not show conclusive evidence that internal dust is present.

- External dust is required to explain the high Balmer decrements observed at both sides of the nucleus.

- The good agreement (I should study this a bit more in detail) between the dereddened line ratios and the non dusty models strongly suggests that the dust is mainly external to the ionized gas. If this is the case, the amount of dust/gas ratio in the ionized gas must be smaller than the one in our neighbourhood. The [NeIII]3689/Hβ problem will remain in this case.

6 The Iron lines

6.1 Results

Table 9 shows the line ratios of two FeVII lines with respect Hβ and the comparison with photoionization model predictions by Osterbrock (1987, his book) applied to CygA. Table 10 shows the ratio between the line intensities at both sides of the nucleus for different lines.

- The FeVII lines are twice stronger in the SE than in the NW (also other Fe lines are stronger in the in the SE, as you say in your

Table 9: Line ratios and comparison with photoionization models

	[FeVII]5720.71/Hβ	[FeVII]6086.97/Hβ
SE	0.10	0.15
NW	0.05	0.07
Models	0.03	0.04

Table 10: Relative line contribution NW/SE

HeII4686	Hβ	OIII5007	[FeVII]5720.71	[FeVII]6086.97	OI6300	H *alpha*	[NII]6583	[SII]
0.91	0.82	0.93	0.60	0.59	1.03	1.00	0.97	1.03

Letter).

- The contribution with respect other lines is also higher in the SE.

- Comparing the line ratios with the models by Osterbrock (1987) the observed lines are 1.4 (in SE) and 1.75 (in NW) times stronger than expected (more appropriate models should be built).

6.2 Discussion

The behaviour of the Fe lines contrast with the similarity of the other optical line intensities and ratios at both sides of the nucleus (very similar). This suggests that another ionization mechanism excites these lines. Shocks have been proposed to explain the FeII lines observed in many AGNs. However, I wonder if shocks can explain such high ionization states as Fe^{+4} to Fe^{+9}. Anyhow, high ionization Fe lines have been observed in some Seyferts. Literature could give us important clues about the excitation mechanism of these lines.

Another alternative explanation might be overabundance of Fe, in different degrees at both sides of the nucleus. This overabundance could be due to SN explosions in the past, which took place at different rates at both sides of the nucleus.

I think that we could learn more from the emission lines, I have a few ideas, also to connect the results with the results you get in your letter. If you collaborators agree on me getting involved, I can work on that.

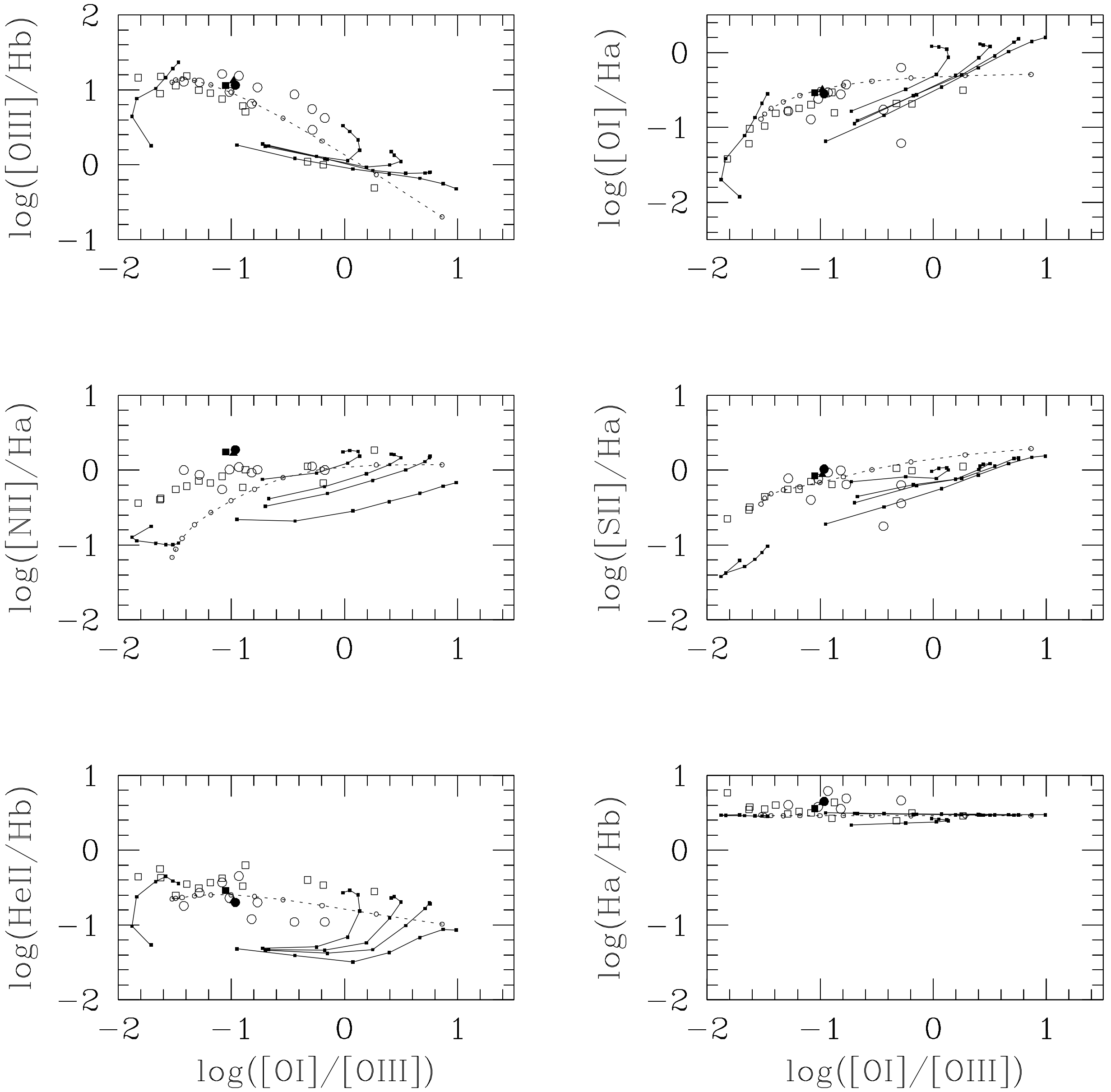

Figure 1: Comparison of CygA optical line ratios (hollow symbols) with -1.5 PL mode ls (solid line) and the optical line ratios of the EELR of Robinson et al. (1987) sample (solid symbols, the nuclear regions are represented by circles and the EELR by squares).
Hollow square –> NW; hollow triangle –> SE; hollow circle –> Nucleus

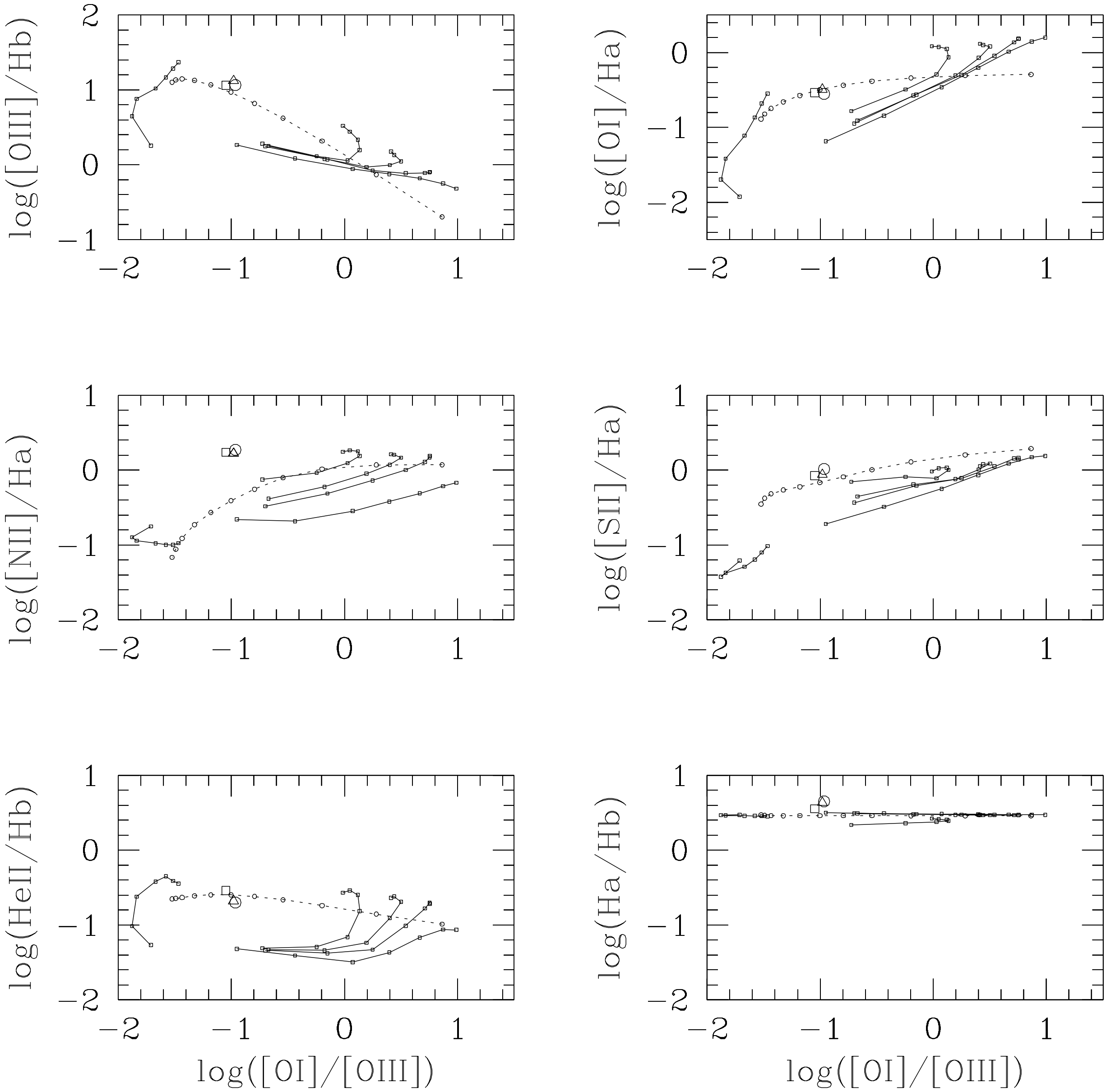

Figure 2: Comparison of CygA optical line ratios (hollow symbols) with -1.5 PL mo dels (solid line) and shock models (the set of dotted lines correspond to different velocities and magnetic parameters. The single dotted line to the left of the diagram corresponds to the precursor models).
Hollow square –> NW; hollow triangle –> SE; hollow circle –> Nucleus