Do the various types of LIS of PNe differ in terms of their physical parameters?

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R. Corradi (CoI INT+NOT data)
A. Mampaso (CoI INT+NOT data)
H. Schwarz (CoI DANISH data)

- Low-Ionization Structures – LIS
  - Morpho-kinematic classification

- LIS physical properties 'survey'
  - Long-slit optical spectroscopy
  - Sample
  - Preliminary results

- What have we learn with this 'survey'?

- Low-Ionization Structures – LIS
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- What have we learn with this 'survey'?

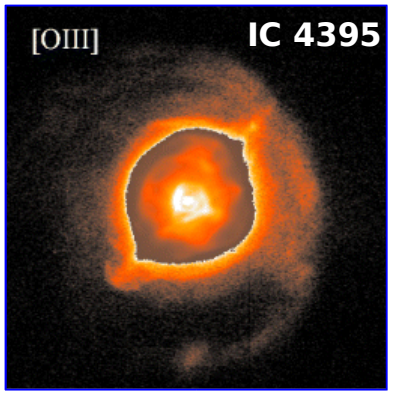
Low-Ionization Structures – LIS

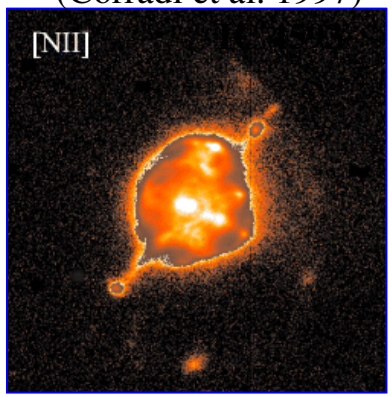
- prominent in the low-ionization lines, like [NII], [OII] and [SII]

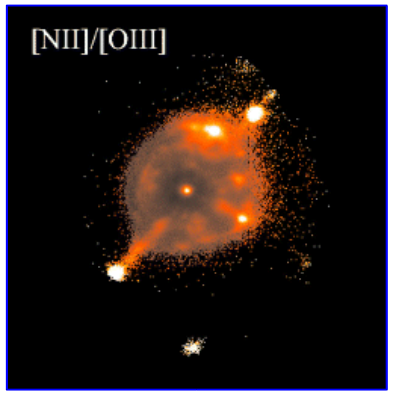
- fainter in Ha

- almost absent in [OIII]

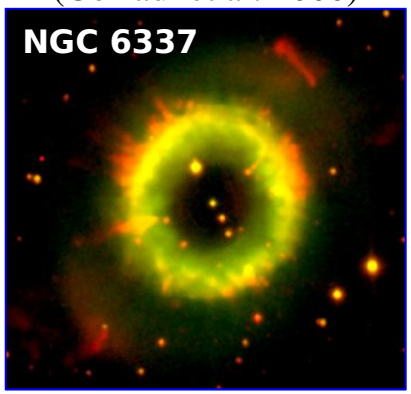
(Corradi et al. 1997)

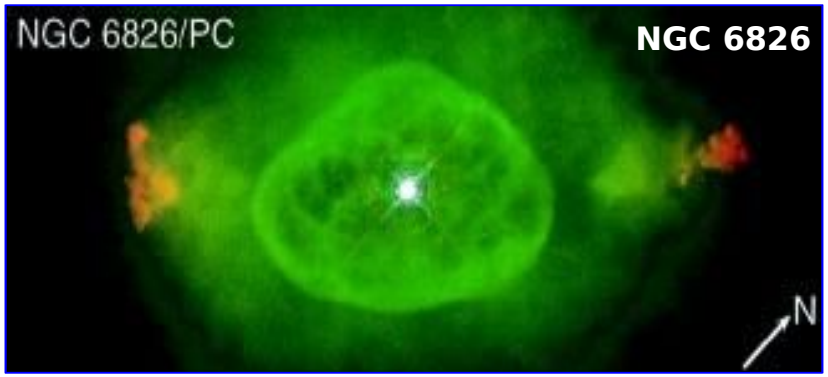




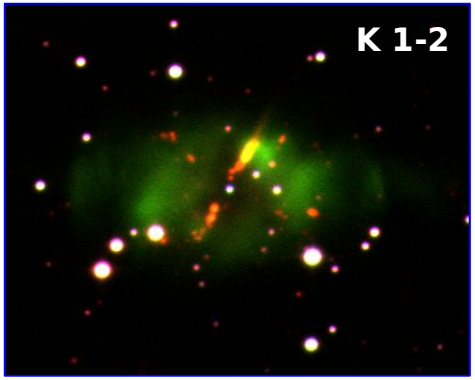


(Corradi et al. 2000)



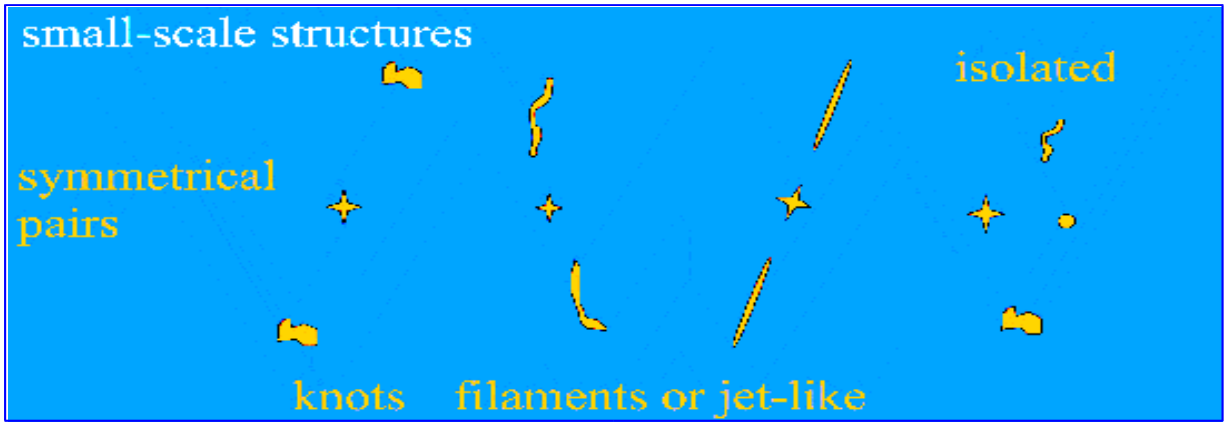


(Balick et al. 1998)



(Corradi et al. 1999)

Low-Ionization Structures – LIS
– Morpho-kinematic classification



Around ~10% of the Galactic PNe are known to possess LIS

- LIS are indistinctly spread among the all the PNe morphological classes
- 50% of these PNe have highly collimated, high-velocity jets, and/or high-velocity pairs of knots (**FLIERs, BRETs**)
- Most of them are mainly **photoionized**
- LIS (FLIERs) **are not** significantly **denser** than the main nebular components...

(from the analysis of few PNe, most from the literature)

(Gonçalves et al. 2001, Gonçalves 2003)

- Low-Ionization Structures – LIS
  - Morpho-kinematic classification

- A 'survey' of the LIS physical properties
  - Long-slit optical spectroscopy
  - Sample
  - Preliminary results

- What have we learn with this 'survey'?

Survey of the LIS physical properties – Long-slit optical spectroscopy

The present analysis is based on:

- Medium resolution spectra taken at the 2.5m INT, in 2001
- $\Delta\lambda$: 3650Å – 7000Å
- spectral reciprocal dispersion of 3.3 Å pixel^{-1}
- pixel scale of 0.71 arcsec

- We also consider DANISH data ... to build a sample with 20 PNe
- here only INT data are show (12 PNe)
- all types of LIS are included: **jets**, **jetlike** and **knots** (in pairs and isolated)

- Diagnostic emission line ratios

$N_e \propto$ I(6717)/I(6737) – [S II]

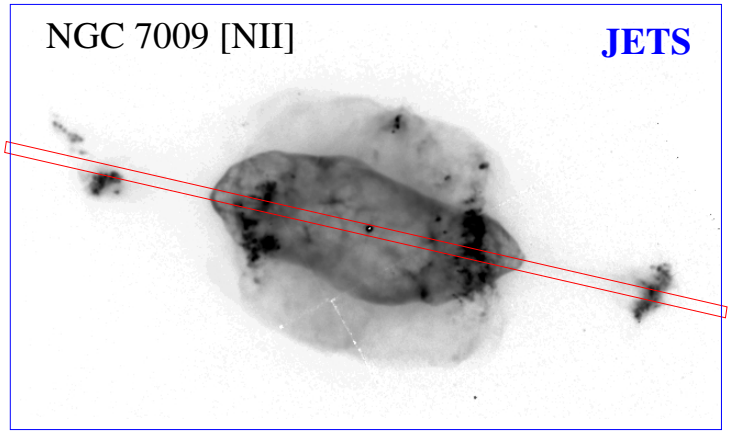
$N_e \propto$ I(5517)/I(5537) – [Cl III]

$T_e \propto$ I(4959+5007)/I(4363) – [O III]

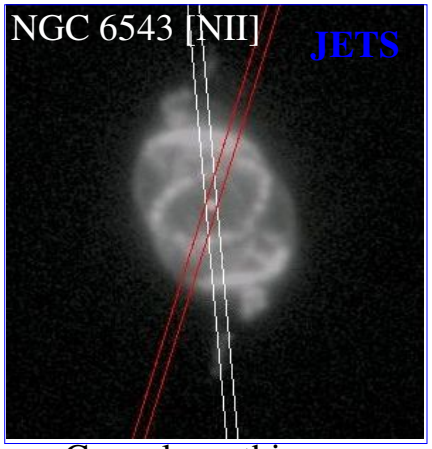
$T_e \propto$ I(6548+6583)/I(5755) – [N II]

$T_e \propto$ I(6717+6737)/I(4069+4076) – [S II]

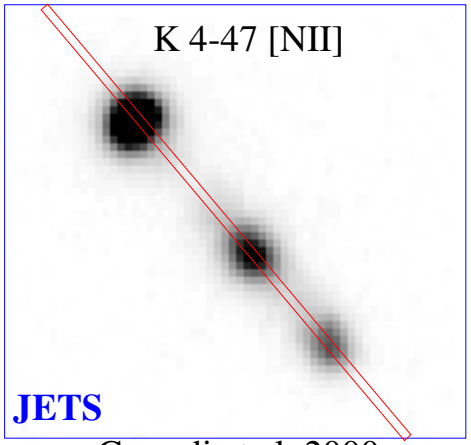
A 'survey' of the LIS physical properties – Sample



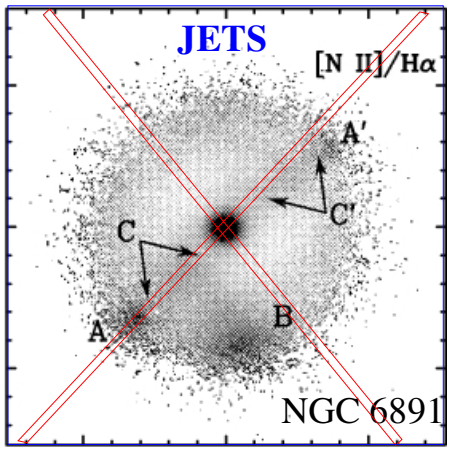
Gonçalves et al. 2003



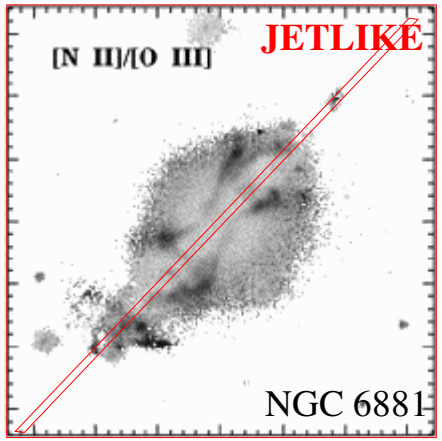
Gonçalves, this paper



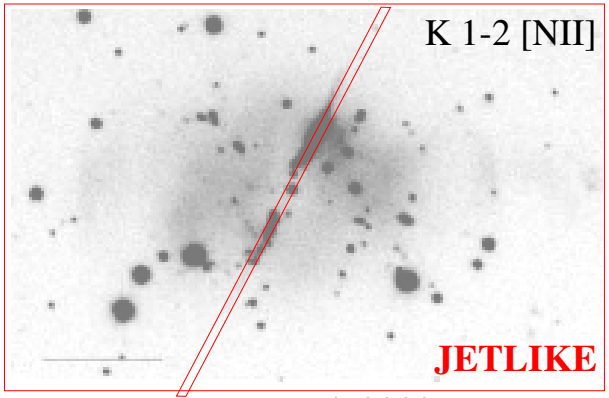
Corradi et al. 2000



Guerrero et al. 2002

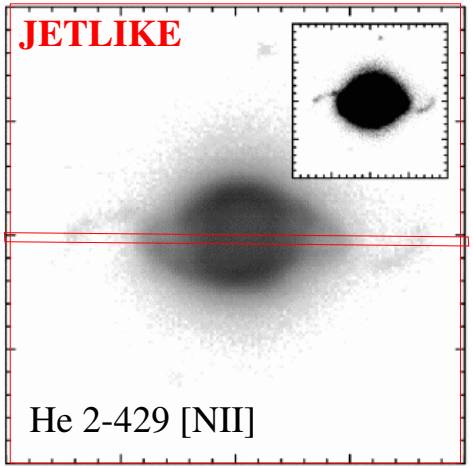


Guerrero & Manchado 1998

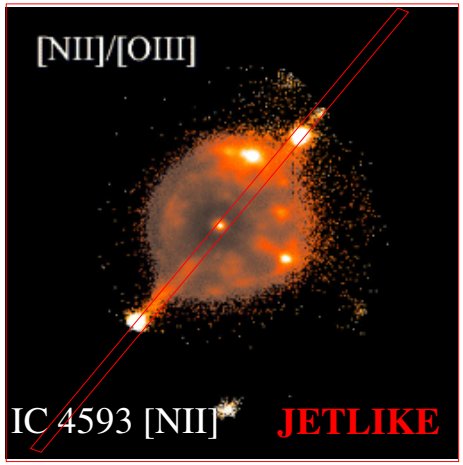


Exter et al. 2003

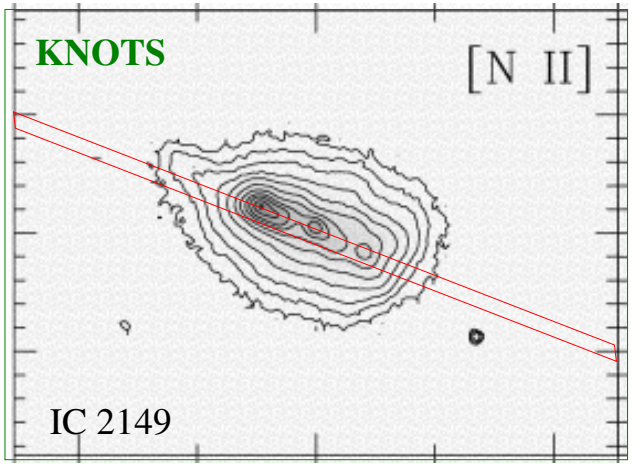
A 'survey' of the LIS physical properties – Sample



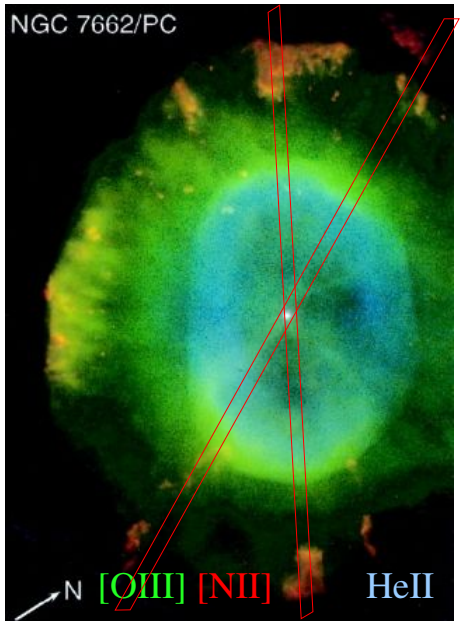
Guerrero et al. 1999



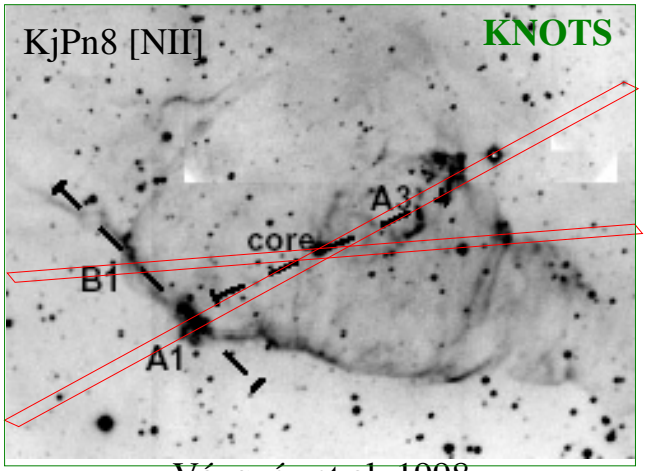
Corradi et al. 1997



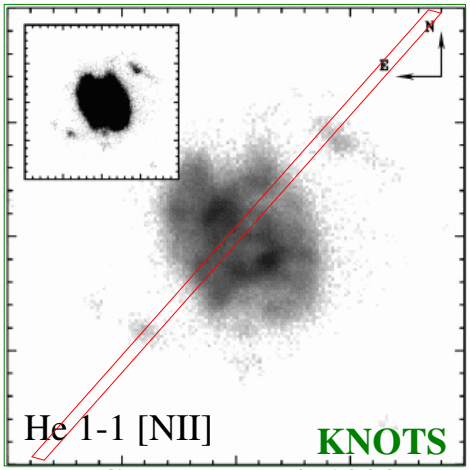
Vázquéz et al. 2002



Balick et al. 1998



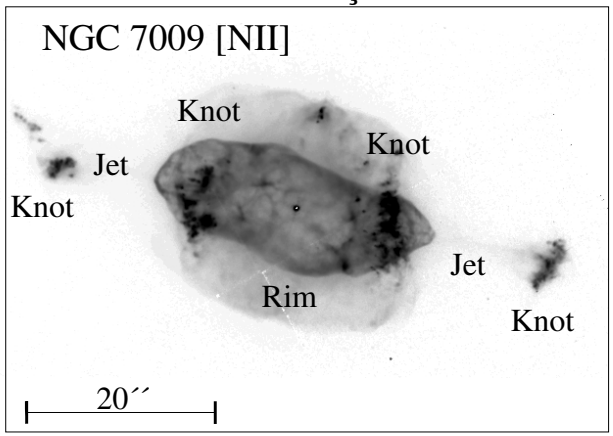
Vázquéz et al. 1998



Guerrero et al. 1999

A 'survey' of the LIS physical properties – Results: JETS

Gonçalves et al. 2003



Bright PNe with jets...

Table 1. NGC 7009: Physical parameters (P.A.=79°)

Parameter	Rim		Knots				Jets		NEB
	Eastern	Western	E outer	E inner	W inner	W outer	Eastern	Western	integrated emission
N_e[S II](cm^{-3})	5,500	5,900	2,000	4,500	5000	1,300	1,300	1,100	4,000
N_e[Cl III](cm^{-3})	5,200	5,900	-	4,700	6000	1,900	-	1,300	1,300
T_e[O III](K)	10,000	10,200	9,600	9,300	10,100	10,400	10,400	11,600	10,100
T_e[N II](K)	10,400	12,800	11,000	9,400	10,400	11,700	-	-	10,300
T_e[S II](K)	-	-	7,100	8,300	-	9,400	-	-	-

Gonçalves, in prep.

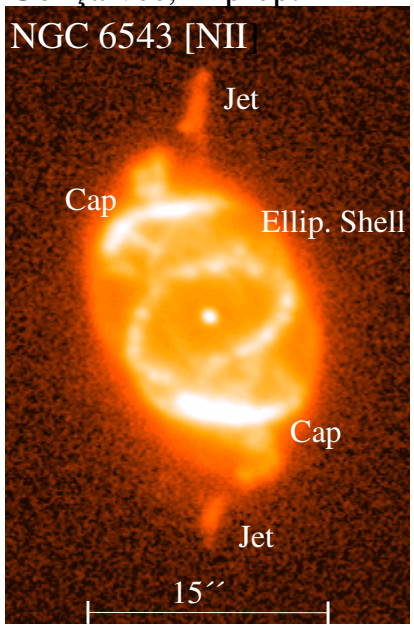
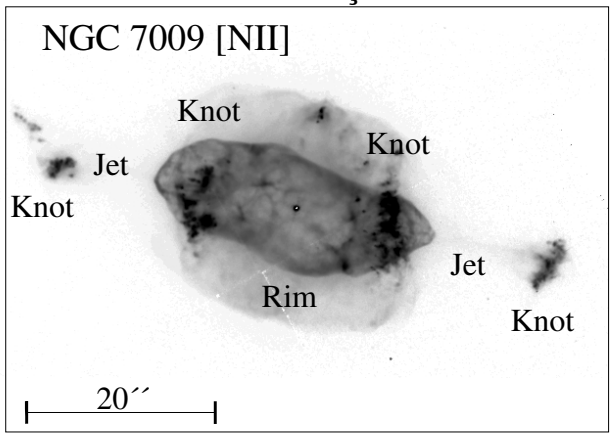


Table 1. NGC 6543: Physical parameters (P.A.=5°, 163°)

Parameter	Jets		Caps		Ellip. Shells		NEB
	Northern	Southern	Northern	Southern	Northern	Southern	integrated emission
N_e[S II](cm^{-3})	2,000	1,150	9,150	5,550	7,350	7,050	6,400
N_e[Cl III](cm^{-3})	6,900	2,550	9,350	4,750	5,500	6,100	6,400
T_e[O III](K)	9,850	9,250	7,950	7,600	8,100	7,750	8,000
T_e[N II](K)	7,600	7,000	8,450	9,000	9,250	9,350	8,500
T_e[S II](K)	9,250	7,150	10,700	7,550	-	-	8,400

A 'survey' of the LIS physical properties – Results: JETS

Gonçalves et al. 2003



$N_e[\text{jets}] \approx N_e[\text{knots}] < N_e[\text{other regions}]$

$T_e[\text{jets}] \approx T_e[\text{knots}] \approx T_e[\text{other regions}]$

Table 1. NGC 7009: Physical parameters (P.A.=79°)

Parameter	Rim		Knots				Jets		NEB
	Eastern	Western	E outer	E inner	W inner	W outer	Eastern	Western	integrated emission
N_e[S II](cm^{-3})	5,500	5,900	2,000	4,500	5000	1,300	1,300	1,100	4,000
N_e[Cl III](cm^{-3})	5,200	5,900	-	4,700	6000	1,900	-	1,300	1,300
T_e[O III](K)	10,000	10,200	9,600	9,300	10,100	10,400	10,400	11,600	10,100
T_e[N II](K)	10,400	12,800	11,000	9,400	10,400	11,700	-	-	10,300
T_e[S II](K)	-	-	7,100	8,300	-	9,400	-	-	-

Gonçalves, in prep.

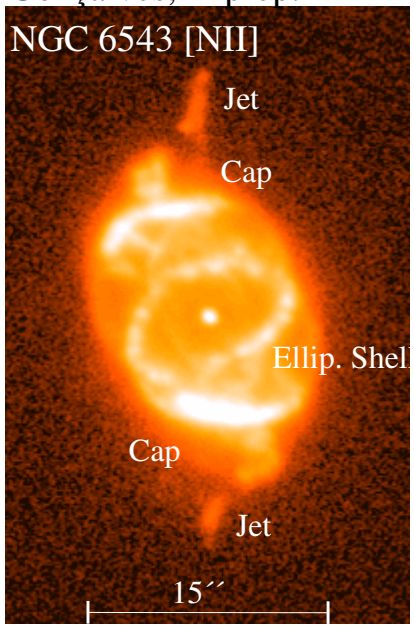


Table 1. NGC 6543: Physical parameters (P.A.=5°, 163°)

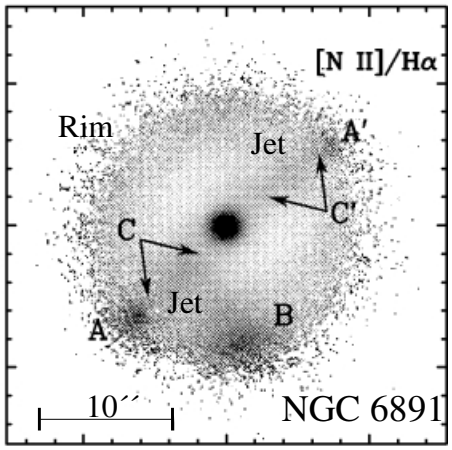
Parameter	Jets		Caps		Ellip. Shells		NEB
	Northern	Southern	Northern	Southern	Northern	Southern	integrated emission
N_e[S II](cm^{-3})	2,000	1,150	9,150	5,550	7,350	7,050	6,400
N_e[Cl III](cm^{-3})	6,900	2,550	9,350	4,750	5,500	6,100	6,400
T_e[O III](K)	9,850	9,250	7,950	7,600	8,100	7,750	8,000
T_e[N II](K)	7,600	7,000	8,450	9,000	9,250	9,350	8,500
T_e[S II](K)	9,250	7,150	10,700	7,550	-	-	8,400

$N_e[\text{jets}] < N_e[\text{shells}] < N_e[\text{caps}]$

$T_e[\text{jets}] \approx T_e[\text{caps}] \approx T_e[\text{shells}]$

A 'survey' of the LIS physical properties – Results: JETS

Table 1. NGC 6891: Physical parameters (P.A.=45°, 135°)



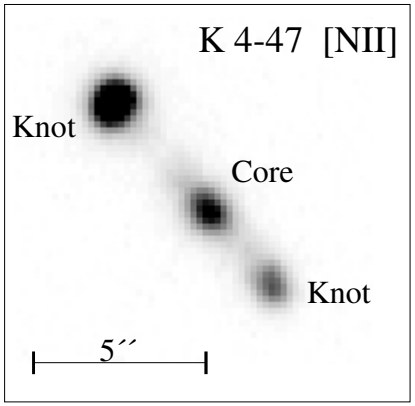
Guerrero et al. 2002

Parameter	Rim NE	Rim SW	Jets SE	Jets NW	NEB integrated emission
N_e[S II](cm^{-3})	1,950	1,000	1,400	1,100	1,250
N_e[Cl III](cm^{-3})	-	900	2,100	2,700	-
T_e[O III](K)	10,200	9,950	8,650	9,500	9,550
T_e[N II](K)	9,450	9,450	9,050	10,300	9,612
T_e[S II](K)	-	-	-	-	-

$N_e[\text{jets}] \leq N_e[\text{rim}]$ $\quad$ $T_e[\text{jets}] \approx T_e[\text{rim}]$

Table 1. K 4-47: Physical parameters (P.A.=41°)

Does this PN have jets? Or only a pair of knots?



Corradi et al. 2000
Gonçalves et al. 2004

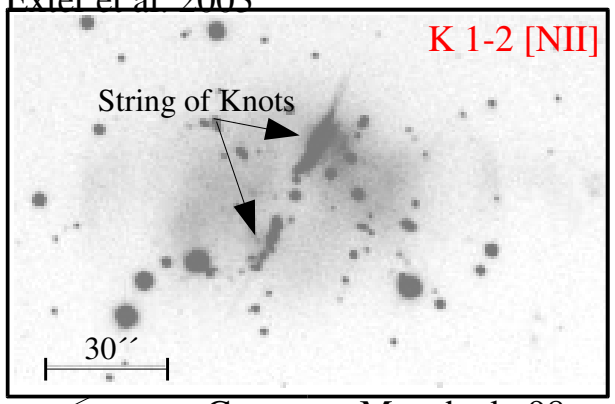
Parameter	Core	Knots NE	Knots SW	NEB integrated emission
N_e[S II](cm^{-3})	1,900	4,550	2,450	2,800
N_e[Cl III](cm^{-3})	-	-	-	-
T_e[O III](K)	19,300	> 21,000	16,100	19,300
T_e[N II](K)	> 21,000	18,900	16,950	20,600
T_e[S II](K)	-	-	-	-

$N_e[\text{knots}] > N_e[\text{core}]$

$T_e[\text{knots}] < T_e[\text{core}]$, very high everywhere!

A 'survey' of the LIS physical properties – Results: JETLIKE

Exter et al. 2003



Guerrero, Manchado 98

Table 1. K 1-2: Physical parameters (P.A.=-24°)

Parameter	NW String of Knots				SE String of Knots			NEB
	NWa	NWb	NWc	NWd	SEe	SEf	SEg	integrated emission
N_e[S II](cm^{-3})	1,000	600	1,000	-	-	450	1,450	500
N_e[Cl III](cm^{-3})	-	-	-	-	-	-	-	-
T_e[O III](K)	-	15,700	14,000	-	-	-	-	14,9000
T_e[N II](K)	-	-	-	-	-	-	-	11,000
T_e[S II](K)	-	-	-	-	-	-	-	-

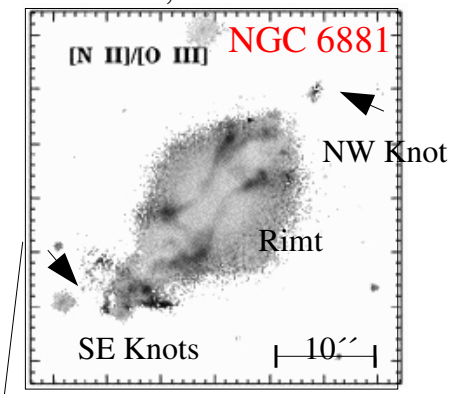
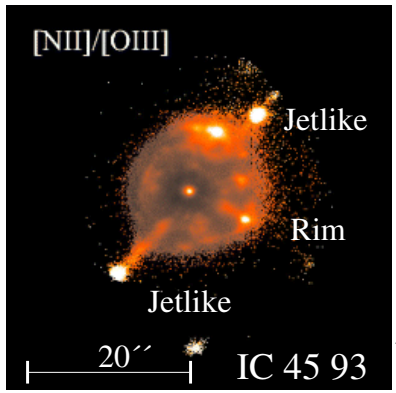
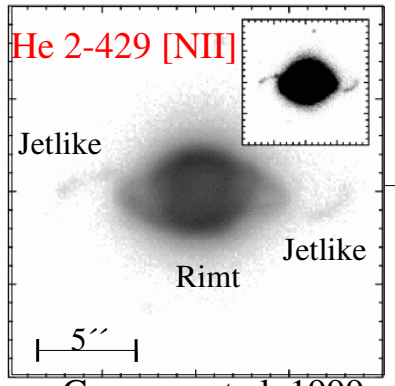


Table 1. IC 4593: Physical parameters (P.A.=139°)



Corradi et al. 1997

Parameter	Knots		Rim			NEB
	SE	NW	SE	Central	NW	integrated emission
N_e[S II](cm^{-3})	900	1,700	3,150	2,150	1,650	2,350
N_e[Cl III](cm^{-3})	-	-	3,050	1,500	-	1,800
T_e[O III](K)	12,600	10,350	9,700	7,850	7,400	8,200
T_e[N II](K)	20,450	-	11,500	9,350	-	9,950
T_e[S II](K)	-	-	-	-	-	-



Guerrero et al. 1999

NGC 6881: Physical parameters (P.A.=139°)

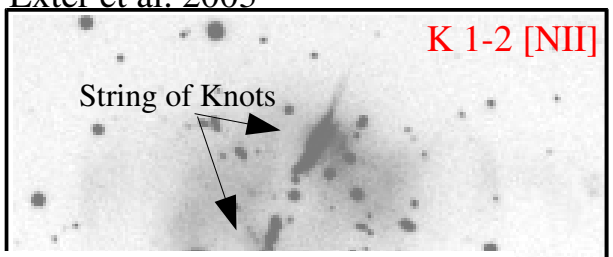
Parameter	Rim	Knots			NEB
		SE inner	SE outer	NW	integrated emission
N_e[S II](cm^{-3})	9,700	750	1,900	650	7,700
N_e[Cl III](cm^{-3})	-	-	-	-	-
T_e[O III](K)	12,750	-	-	-	13,450
T_e[N II](K)	14,350	-	-	> 21,000	15,050
T_e[S II](K)	-	-	-	-	-

Physical parameters (P.A.=89°)

Parameter	Rim	Jetlike		NEB
		Eastern	Western	integrated emission
N_e[S II](cm^{-3})	7,900	3,200	3,550	7,550
N_e[Cl III](cm^{-3})	14,100	-	-	16,350
T_e[O III](K)	8,700	-	-	8,700
T_e[N II](K)	-	-	-	4,300
T_e[S II](K)	-	-	-	-

A 'survey' of the LIS physical properties – Results: JETLIKE

Exter et al. 2003



K 1-2; IC 4593; NGC 6881 and He 2-429

N_e: all the jetlike structures are approx. a factor of 2 less dense than the other nebular regions!

T_e: hard to determine... when measured they show higher temperatures than the other components!

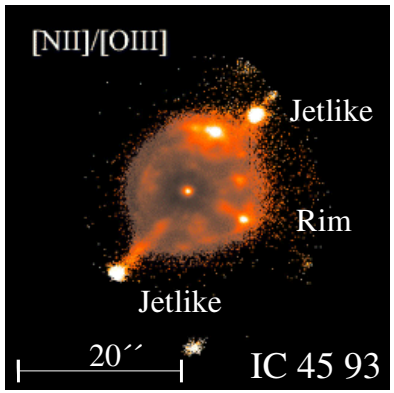
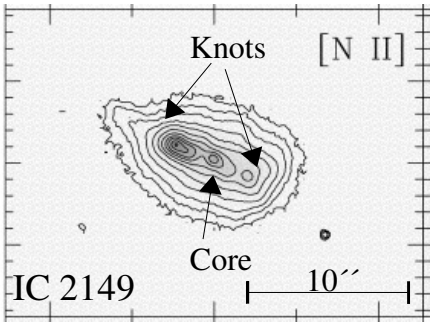


Table 1. IC 4593: Physical parameters (P.A.=139°)

Parameter	Knots SE	Knots NW	Rim SE	Rim Central	Rim NW	NEB integrated emission
N_e[S II](cm^{-3})	900	1,700	3,150	2,150	1,650	2,350
N_e[Cl III](cm^{-3})	-	-	3,050	1,500	-	1,800
T_e[O III](K)	12,600	10,350	9,700	7,850	7,400	8,200
T_e[N II](K)	20,450	-	11,500	9,350	-	9,950
T_e[S II](K)	-	-	-	-	-	-

A 'survey' of the LIS physical properties – Results: KNOTS

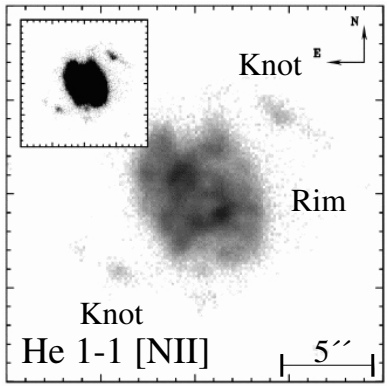
Table 1. IC 2149: Physical parameters (P.A.=70°)



Vázquéz et al. 2002

Parameter	Core	Knots Eastern	Knots Western	NEB integrated emission
N_e[S II](cm^{-3})	6,000	5,000	2,100	4,200
N_e[Cl III](cm^{-3})	-	8,000	2,550	1,800
T_e[O III](K)	11,350	10,300	9,800	11,200
T_e[N II](K)	10,400	10,900	12,450	10,200
T_e[S II](K)	-	-	7,600	9,550

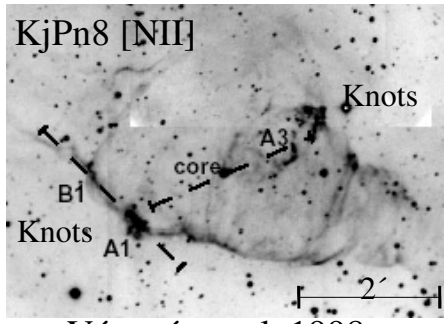
Table 1. He 1-1: Physical parameters (P.A.=315°)



Guerrero et al. 1999

Parameter	Rim	Knots Eastern	Knots Western	NEB integrated emission
N_e[S II](cm^{-3})	1,600	650	1,300	1,550
N_e[Cl III](cm^{-3})	-	-	-	-
T_e[O III](K)	12,050	>21,000	-	12,800
T_e[N II](K)	10,750	10,400	-	10,600
T_e[S II](K)	16,400	-	-	-

Table 1. KjPn8: Physical parameters (P.A.=98°, 120°)

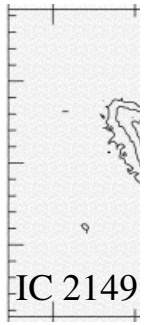


Vázquéz et al. 1998

Parameter	Knots, PA=98° SE	Knots, PA=98° NW	Knots, PA=120° SE	Knots, PA=120° NW
N_e[S II](cm^{-3})	600	600	500	500
N_e[Cl III](cm^{-3})	-	-	300	-
T_e[O III](K)	>21,000	20,600	>21,000	>21,000
T_e[N II](K)	-	8,700	10,050	8,300
T_e[S II](K)	-	-	14,200	11,500

A 'survey' of the LIS physical properties – Results: KNOTS

IC 2149; He 1-1; KjPn8

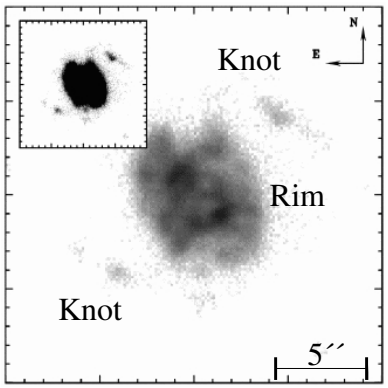


Trends are not very clear!

N_e: knots have lower (or equal) N_e than the other nebular regions

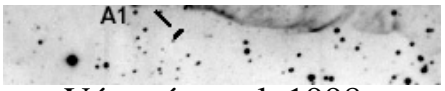
T_e: knots have equal or (higher) T_e than the other components

Table 1. He 1-1: Physical parameters (P.A.=315°)



Guerrero et al. 1999

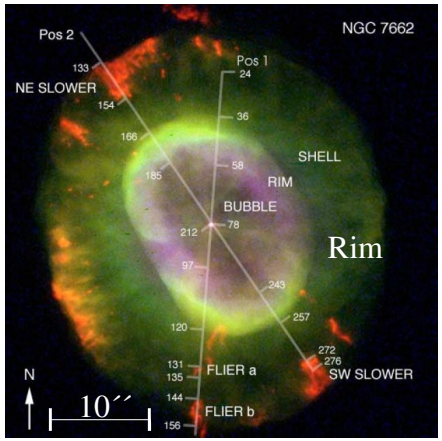
Parameter	Rim	Knots Eastern	Knots Western	NEB integrated emission
N_e[S II](cm^{-3})	1,600	650	1,300	1,550
N_e[Cl III](cm^{-3})	-	-	-	-
T_e[O III](K)	12,050	>21,000	-	12,800
T_e[N II](K)	10,750	10,400	-	10,600
T_e[S II](K)	16,400	-	-	-



Vázquéz et al. 1998

T_e[N II](K)	-	8,700	10,050	8,300
T_e[S II](K)	-	-	14,200	11,500

A 'survey' of the LIS physical properties – Results



Perinotto et al. 2004

Is NGC 7662 an especial case?

Table 1. NGC 7662: Physical parameters (P.A.=175° – FLIERs)

Parameter	Knots SE outer FLIERb	Knots SE inner FLIERa	Rim	Knots NW inner	Knots NW outer	integrated emission
N_e[S II](cm^{-3})	1,300	3,500	2,550	4,050	1,750	3,250
N_e[Cl III](cm^{-3})	800	3,200	-	3,600	850	2,150
T_e[O III](K)	12,400	13,200	14,850	14,550	13,650	13,700
T_e[N II](K)	12,000	8,450	-	13,650	14,650	-
T_e[S II](K)	-	-	-	-	-	-

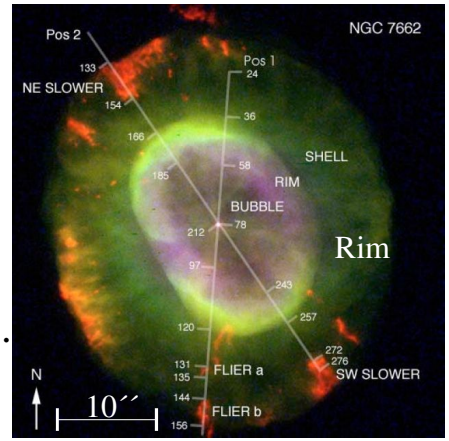
Table 2. NGC 7662: Physical parameters (P.A.=248° – SLOWERs)

Parameter	Knots NE outer SLOWER	Knots NE inner	Rim	Knots SW inner	Knots SW outer SLOWER	integrated emission
N_e[S II](cm^{-3})	2,350	3,600	2,850	5,000	2,600	2,900
N_e[Cl III](cm^{-3})	2,400	3,950	1,700	3,500	1,150	3,100
T_e[O III](K)	12,200	13,050	13,500	13,200	12,350	12,950
T_e[N II](K)	-	11,800	11,550	10,600	11,550	10,950
T_e[S II](K)	-	-	-	-	-	-

Symmetrical pairs of FLIERs do not differ form each other in N_e or T_e...

This is not the case for FLIERs at the same region of the nebula...

A 'survey' of the LIS physical properties – Results



Perinotto et al. 2004

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N_e[Cl III](cm^{-3})	800	3,200	-	3,600	850	2,150
T_e[O III](K)	12,400	13,200	14,850	14,550	13,650	13,700
T_e[N II](K)	12,000	8,450	-	13,650	14,650	-
T_e[S II](K)	-	-	-	-	-	-

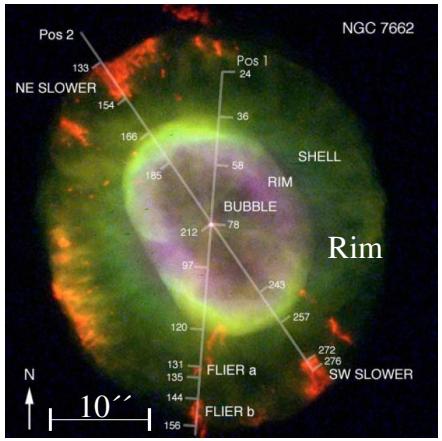
Table 2. NGC 7662: Physical parameters (P.A.=248° – SLOWERs)

Parameter	Knots NE outer SLOWER	Knots NE inner	Rim	Knots SW inner	Knots SW outer SLOWER	integrated emission
N_e[S II](cm^{-3})	2,350	3,600	2,850	5,000	2,600	2,900
N_e[Cl III](cm^{-3})	2,400	3,950	1,700	3,500	1,150	3,100
T_e[O III](K)	12,200	13,050	13,500	13,200	12,350	12,950
T_e[N II](K)	-	11,800	11,550	10,600	11,550	10,950
T_e[S II](K)	-	-	-	-	-	-

Symmetrical SLOWERs are similar in terms of N_e and T_e...

N_e[SLOWER] ≈ N_e[rim]

A 'survey' of the LIS physical properties – Results



Perinotto et al. 2004

Is NGC 7662 an especial case?

- Symmetrical knots differ significantly in terms of N_e... but not in T_e...

  Idem for FLIERs at the same portion of the nebula...
- Symmetrical SLOWERs are similar in terms of N_e and T_e...

  N_e[SLOWER] ≈ N_e[rim]

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T_e[O III](K)	12,400	13,200	14,850	14,550	13,650	13,700
T_e[N II](K)	12,000	8,450	-	13,650	14,650	-
T_e[S II](K)	-	-	-	-	-	-

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N_e[Cl III](cm^{-3})	2,400	3,950	1,700	3,500	1,150	3,100
T_e[O III](K)	12,200	13,050	13,500	13,200	12,350	12,950
T_e[N II](K)	-	11,800	11,550	10,600	11,550	10,950
T_e[S II](K)	-	-	-	-	-	-

High-velocity knots do (not) differ from low-velocity knots (either) in terms of T_e,N_e (or) and in terms of excitation (see Perinotto et al. 2004)

- Low-Ionization Structures – LIS
  - Morpho-kinematic classification

- LIS physical properties 'survey'
  - Long-slit optical spectroscopy
  - Sample
  - Preliminary results

- What have we learn with this 'survey'?

What do we have learn with this 'survey'?

Do the various types of LIS of PNe differ in terms of their physical parameters?

SO FAR:

- Jets have slightly lower Ne than knots ...
  Can this difference, approx. a factor of 2, be accounted for by the theoretical models?

- FLIERs and SLOWERs, as well as jets and jetlike LIS, are not significantly different from each other in terms of T_e, N_e and excitation.

- Jetlike LIS have slightly high T_e, but not as high as the T_e of the knots whose diagnostic diagrams show shock excitation (such as K 4-47).

- T_e and N_e trends for LIS should be compared with LIS's excitation trends in a consistent way... SEE Riera's talk

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AND FINALLY...

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