CRL 618: A Nascent Planetary Nebula

Daniel Tafoya[1,2], Laurent Loinard[1], Pablo Fonfría[3], Wouter Vlemmings[2], Ivan Martí-Vidal[2], Gerardo Pech[1]

[1]Centro de Radioastronomía y Astrofísica (UNAM)
[2]Onsala Space Observatory (Chalmers University)
[3]Instituto de Astronomía (UNAM)

The "pre-PN" CRL 618:

- Discovered during the Air Force Cambridge Research Laboratory rocket-borne infrared survey at 4, 11 and 20μ .

- Studied for the first time by Bill Westbrook in 1972 (this source is also known as the Westbrook nebula).

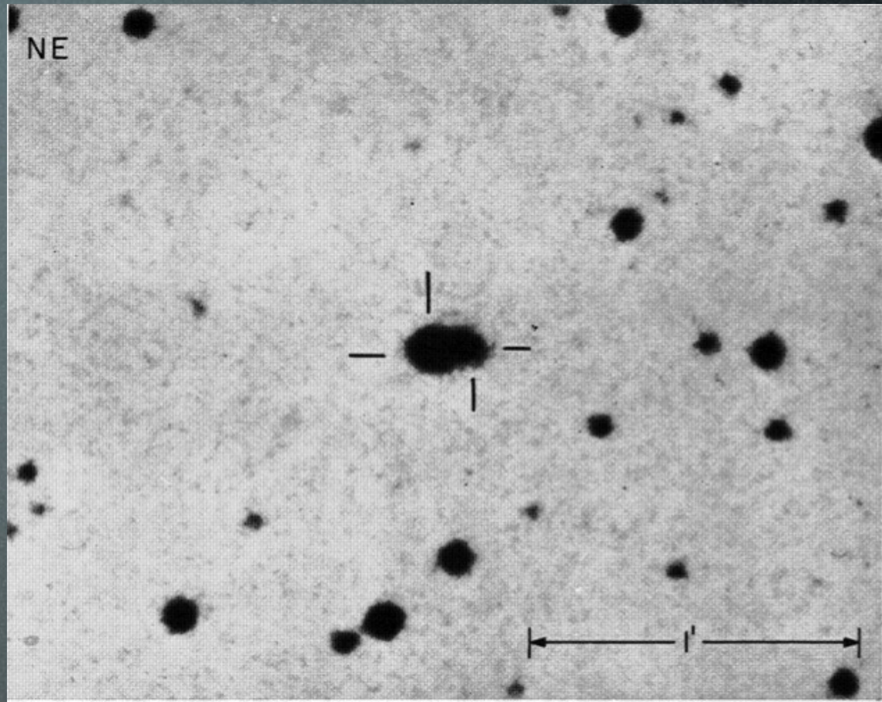


Fig. 1.—Detail from the red Sky Survey print showing the two nebulous objects associated with CRL 618. North is up; east is to the left.

OBSERVATIONS OF AN ISOLATED COMPACT INFRARED SOURCE IN PERSEUS

W. E. Westbrook,* E. E. Becklin,†‡ K. M. Merrill,§ G. Neugebauer,†‡ M. Schmidt,†
S. P. Willner,* and C. G. Wynn-Williams‡||

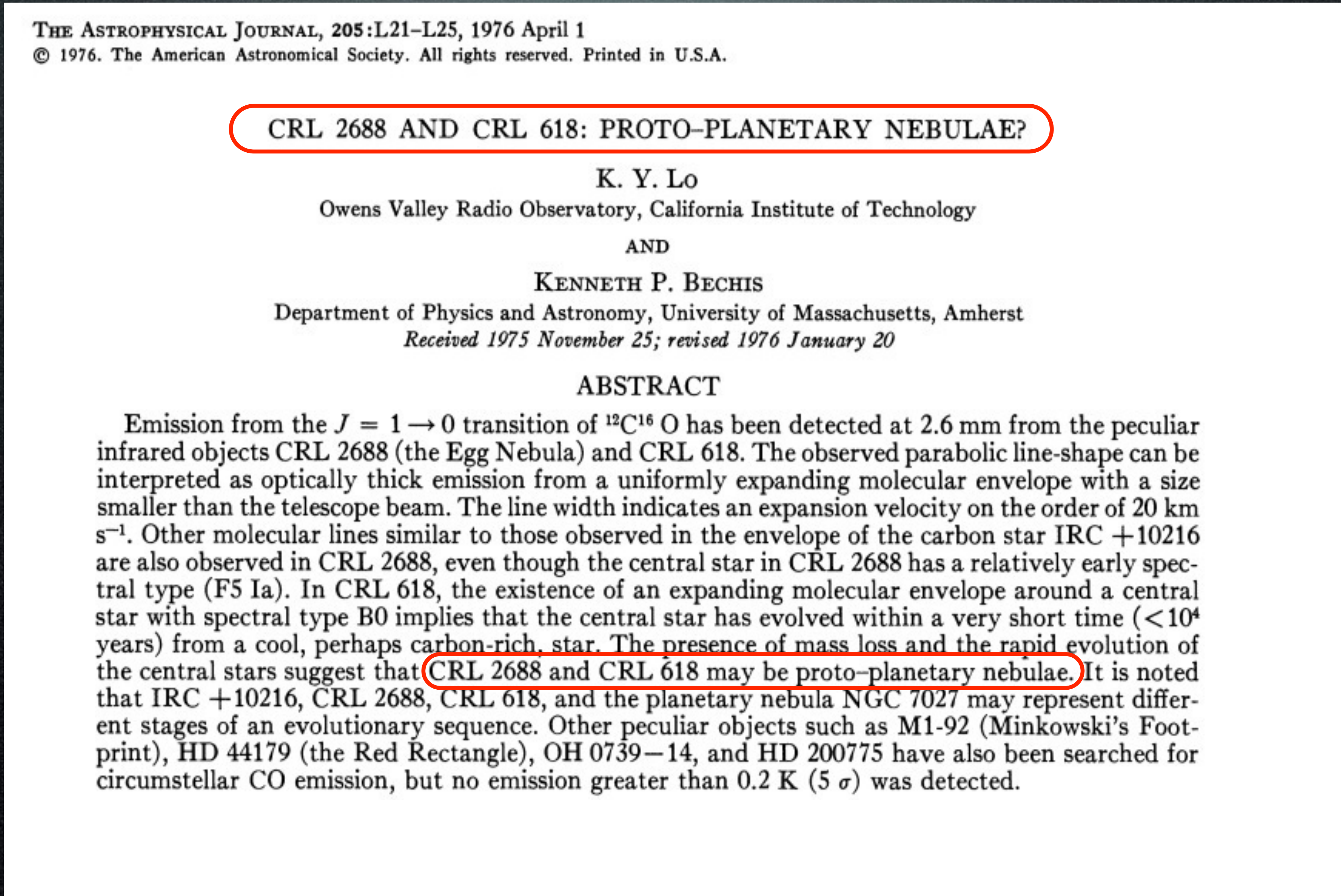
Received 1975 March 27; revised 1975 May 27

ABSTRACT

Infrared, optical, and radio observations are described of an unusual compact infrared source discovered during the AFCRL survey. It is suggested that the object may be a planetary nebula seen at an unprecedentedly early phase in its evolution.

Subject headings: infrared sources — planetary nebulae

The “pre-PN” CRL 618: CO emission



THE ASTROPHYSICAL JOURNAL, 205:L21–L25, 1976 April 1

CRL 2688 AND CRL 618: PROTO–PLANETARY NEBULAE?

K. Y. LO
Owens Valley Radio Observatory, California Institute of Technology

AND

KENNETH P. BECHIS
Department of Physics and Astronomy, University of Massachusetts, Amherst
Received 1975 November 25; revised 1976 January 20

ABSTRACT

Emission from the $J = 1 \rightarrow 0$ transition of $^{12}C^{16}O$ has been detected at 2.6 mm from the peculiar infrared objects CRL 2688 (the Egg Nebula) and CRL 618. The observed parabolic line-shape can be interpreted as optically thick emission from a uniformly expanding molecular envelope with a size smaller than the telescope beam. The line width indicates an expansion velocity on the order of 20 km s^{-1}. Other molecular lines similar to those observed in the envelope of the carbon star IRC +10216 are also observed in CRL 2688, even though the central star in CRL 2688 has a relatively early spectral type (F5 Ia). In CRL 618, the existence of an expanding molecular envelope around a central star with spectral type B0 implies that the central star has evolved within a very short time ($<10^4$ years) from a cool, perhaps carbon-rich, star. The presence of mass loss and the rapid evolution of the central stars suggest that CRL 2688 and CRL 618 may be proto–planetary nebulae. It is noted that IRC +10216, CRL 2688, CRL 618, and the planetary nebula NGC 7027 may represent different stages of an evolutionary sequence. Other peculiar objects such as M1-92 (Minkowski's Footprint), HD 44179 (the Red Rectangle), OH 0739−14, and HD 200775 have also been searched for circumstellar CO emission, but no emission greater than 0.2 K (5 σ) was detected.

The "pre-PN" CRL 618: Radio continuum rapidly increasing

Mon. Not. R. astr. Soc. (1977) **181,** *Short Communication,* 61P–62P

Radio emission from the infrared source CRL 618: an extremely young planetary nebula

C. G. Wynn-Williams *Mullard Radio Astronomy Observatory, Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE*

Received 1977 August 24

Summary. 15-GHz thermal radio emission has been found from the infrared source CRL 618. This observation strengthens the evidence that CRL 618 is an extremely young planetary nebula.

THE ASTROPHYSICAL JOURNAL, **247**:L67–L71 1981 July 15

DISCOVERY OF RADIO BRIGHTENING IN AFGL 618

SUN KWOK AND P. A. FELDMAN
Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa
Received 1981 February 2; accepted 1981 March 26

ABSTRACT

Recent radio continuum observations of AFGL 618 have shown that the free-free emission flux density has increased by approximately a factor of 2 over a 2–3 yr interval, whereas the spectrum has remained optically thick up to at least 12 GHz. This is interpreted as the result of expansion of a compact H II region within the molecular/dust envelope of AFGL 618. The central star of the nebula is likely to be a 1 $M_{\odot}$ star now rapidly evolving into the planetary nebula stage.

Subject headings: infrared: sources — nebulae: planetary — nebulae: reflection — radio sources: general

The "pre-PN" CRL 618: first maps

THE ASTROPHYSICAL JOURNAL, **276**:544–550, 1984 January 15

RADIO STRUCTURE OF THE PROTO-PLANETARY NEBULA GL 618

SUN KWOK
Herzberg Institute of Astrophysics, Ottawa; and Department of Physics, University of Calgary, Calgary
AND
R. C. BIGNELL
National Radio Astronomy Observatory, Socorro, New Mexico[1]
Received 1983 April 8; accepted 1983 June 20

ABSTRACT

Radio maps of the proto-planetary nebula GL 618 have been obtained with angular resolutions as high as 0"07. A bright radio core of size 0"4 × 0"1 is found to be surrounded by a halo of several arc seconds in size. The core shows an elongated structure having the same symmetry axis as the optical reflection nebulosities. It is suggested that the ionized region of GL 618 is ionization bounded in the equatorial directions, and the bipolar morphology is the result of an anisotropic density distribution in the circumstellar envelope of its red-giant progenitor. The small angular size and high emission measure ($>10^{10}$ cm^{-6} pc) of the core suggest that GL 618 is a planetary nebula of extremely young age ($\sim 10^2$ yr).

Subject headings: nebulae: individual — nebulae: planetary — radio sources: general

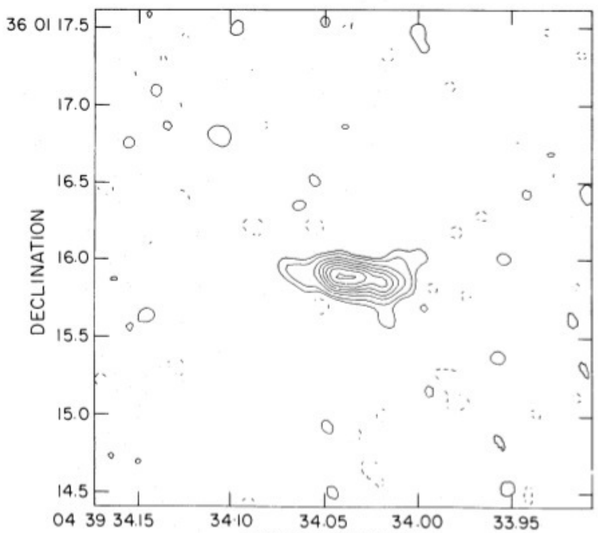


FIG. 2*a*

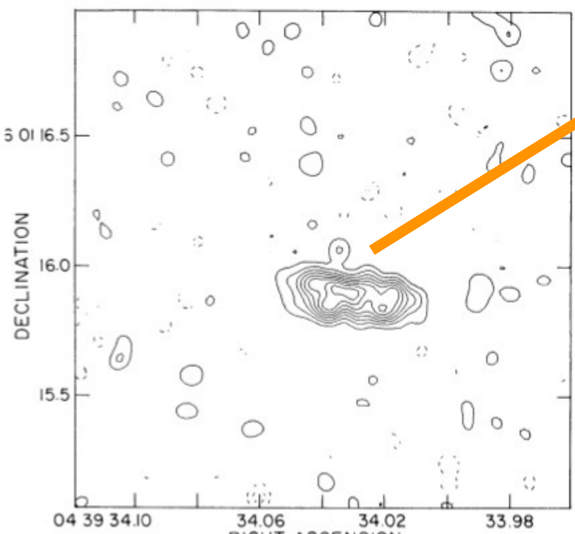


FIG. 2*b*

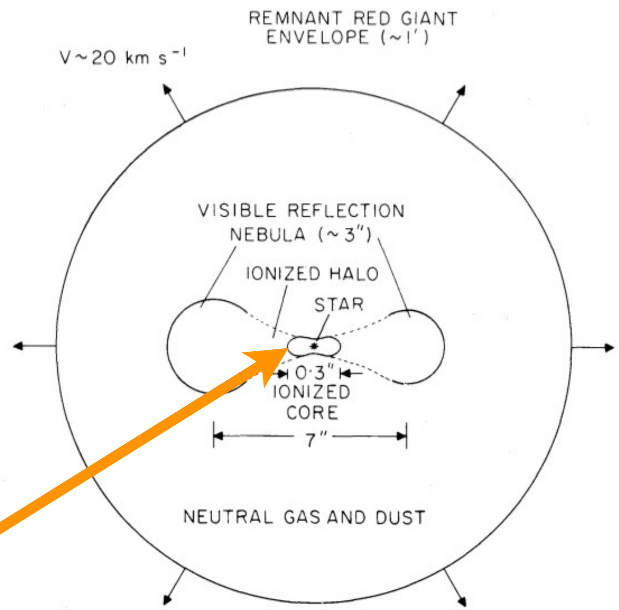


FIG. 6.—A schematic diagram of GL 618 (not to scale)

The "pre-PN" CRL 618:

Astron. Astrophys. 197, L15–L18 (1988)

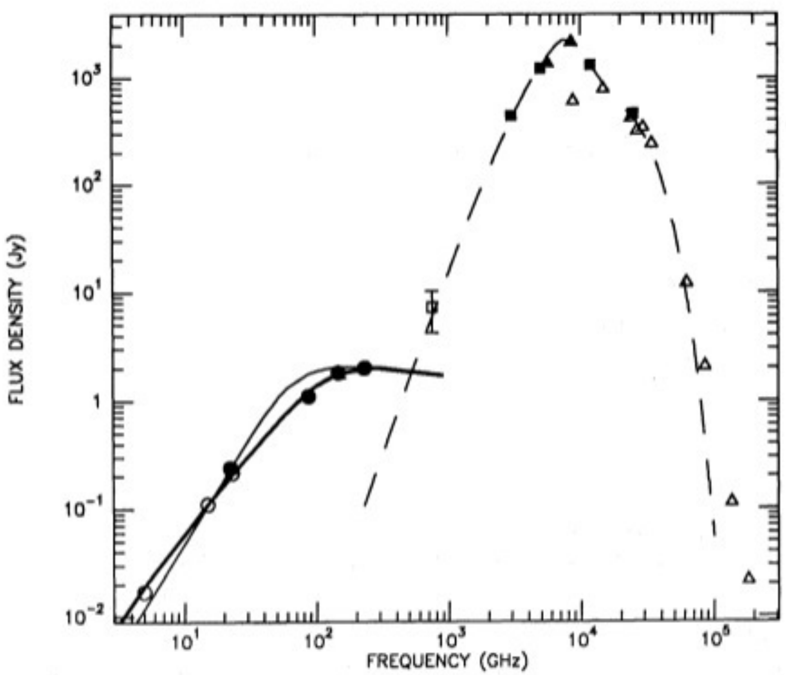
Letter to the Editor

ASTRONOMY AND ASTROPHYSICS

Radiocontinuum and recombination lines toward CRL 618. Evidence for an ionized stellar wind?

J. Martín-Pintado[1,2], V. Bujarrabal[1], R. Bachiller[1], J. Gómez-González[1], and P. Planesas[1]

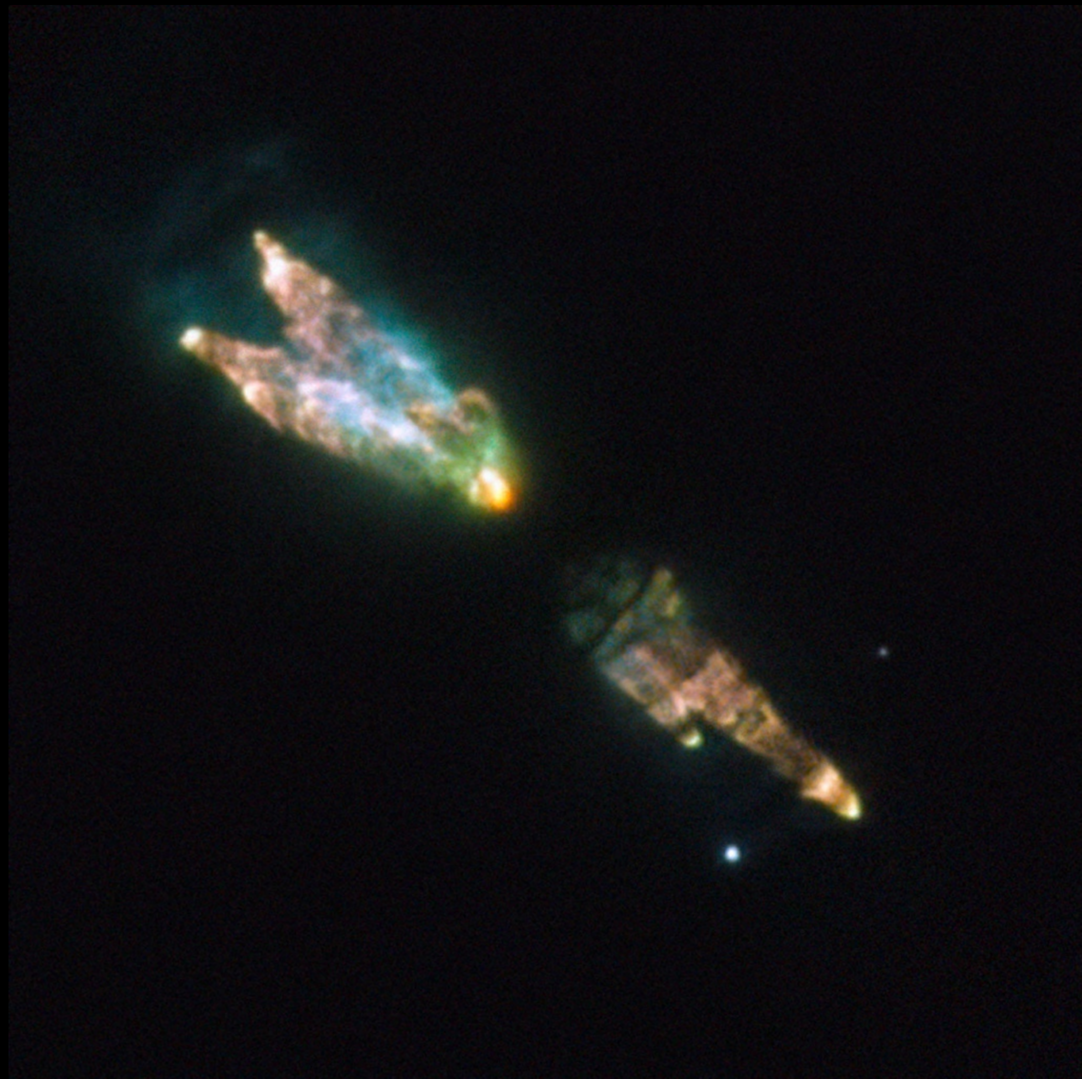
[1] Centro Astronómico de Yebes (OAN-IGN), Apartado 148, E-19080 Guadalajara, Spain
[2] I.R.A.M., Avda. Divina Pastora 7, Núcleo Central, E-18012 Granada, Spain



The star is still undergoing mass-loss in the form of an ionised wind. So, is it a planetary nebula, a pre-PN, or what?

The “pre-PN” CRL 618:

With the arrival of the HST, most of people forgot the central HII region of CRL 618.



The “pre-PN” CRL 618:   VLA archive data

- Interferometric data using the A configuration.
- Seven epochs at 22 GHz: 1982, 1983, 1990, 1992, 1995, 1998 and 2007.
- Six frequencies at epoch 1998: 1.43, 4.89, 8.44, 14.96, 22.49, 43,31 GHz.

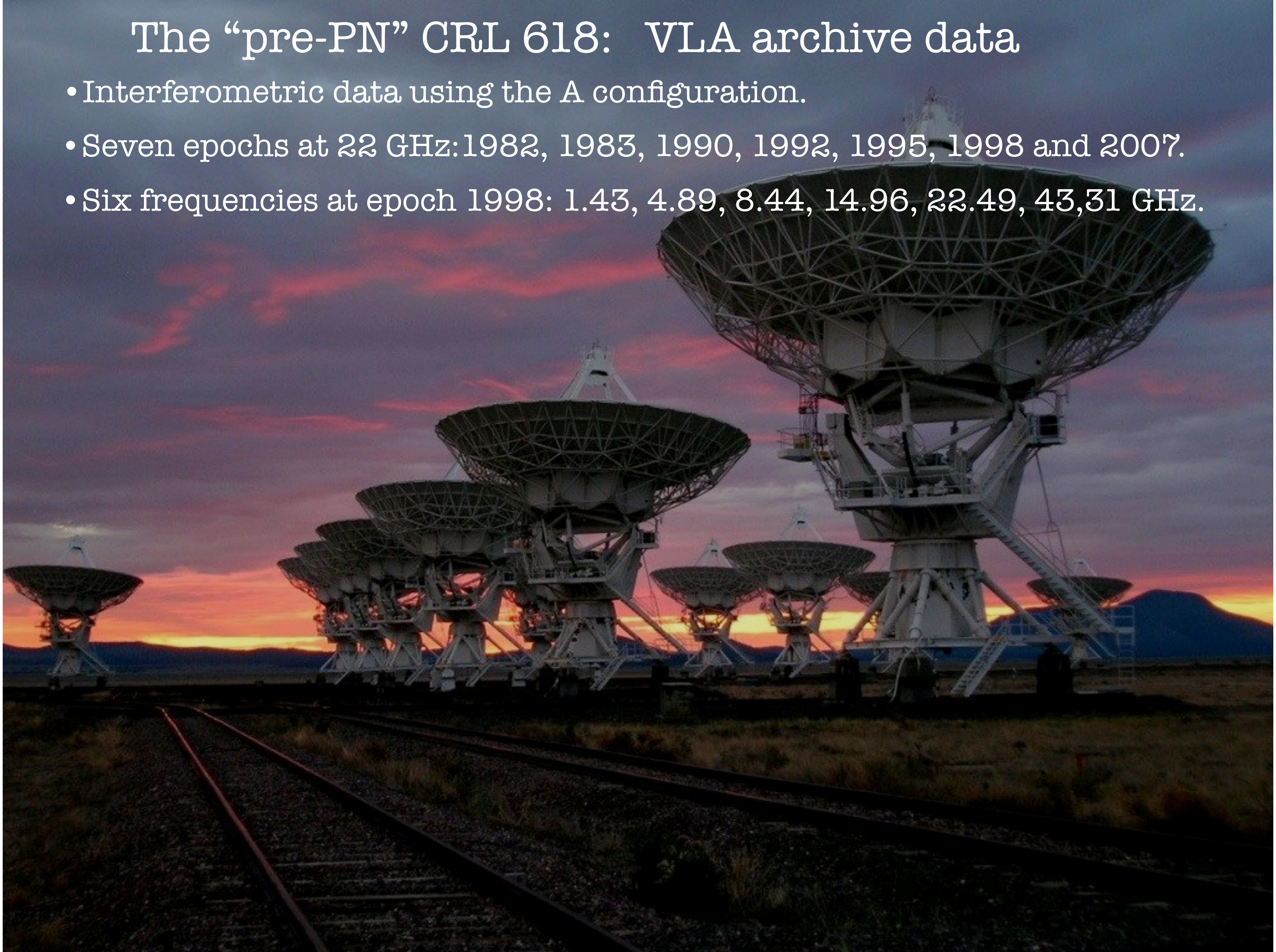


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Table 2. Calibration parameters of the observations at 22 GHz.

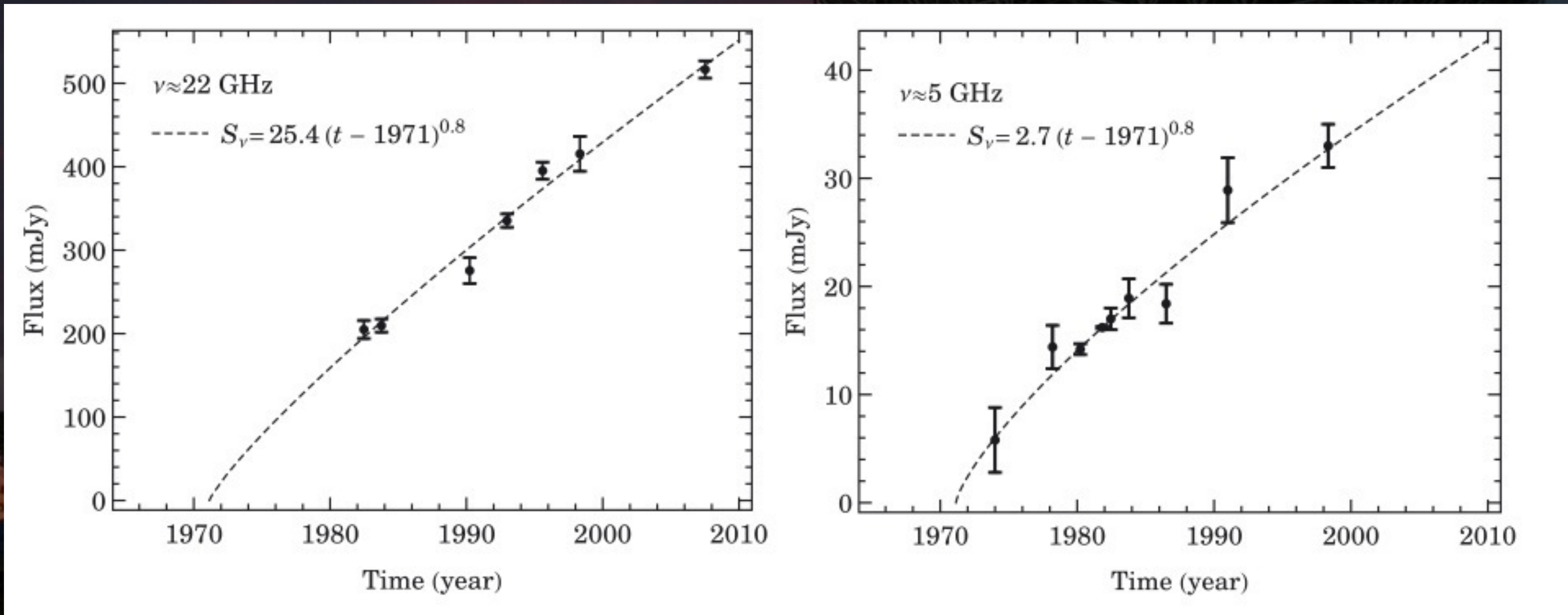
Date of observation	Flux calibrator	S_ν[1]	Phase calibrator	S_ν[2]	rms noise[3]	Beam[4]
(year)	(name)	(Jy)	(name)	(Jy)	(Jy beam^{-1})	($''$, °)
24 June 1982	3C 48	1.27	3C 119........	0.97	7.0×10^{-4}	0.11 × 0.09, −57
9 October 1983	3C 286	2.57	J0403+260....	0.68	1.2×10^{-3}	0.10 × 0.08, −71
29 March 1990	3C 84	37.7	3C 84	37.7	6.5×10^{-4}	0.13 × 0.09, −69
22 December 1992 ...	3C 48	1.2	3C 84.........	26.6	5.6×10^{-4}	0.09 × 0.08, −42
			J0359+509	3.1	5.6×10^{-4}	0.09 × 0.08, −42
3 August 1995	3C 286.......	2.55	3C 84.........	19.4	1.0×10^{-3}	0.11 × 0.10, −28
2 May 1998	J0443+3441 .	0.35	J0443+3441...	0.35	4.0×10^{-4}	0.14 × 0.10, −79
9 July 2007	3C 48	1.27	J04183+38015	5.2	1.3×10^{-4}	0.12 × 0.09, −81

Table 3. Calibration parameters of the observation on epoch 1998.33.

Frequency	Flux/phase calibrator	S_ν[1]	rms noise[3]	Beam[4]
(GHz)	(name)	(Jy)	(Jy beam^{-1})	($''$, °)
1.43	J0443+3441	0.70	5.3×10^{-5}	2.0 × 1.6, −66
4.89	J0443+3441	0.93	3.5×10^{-5}	0.63 × 0.52, −72
8.44	J0443+3441	0.74	4.7×10^{-5}	0.34 × 0.28, −71
14.96	J0443+3441	0.50	1.7×10^{-4}	0.20 × 0.16, −77
22.49	J0443+3441	0.35[2]	3.9×10^{-4}	0.14 × 0.10, −79
43.31	J0443+3441	0.20	3.1×10^{-4}	0.046 × 0.043, 30

The “pre-PN” CRL 618:

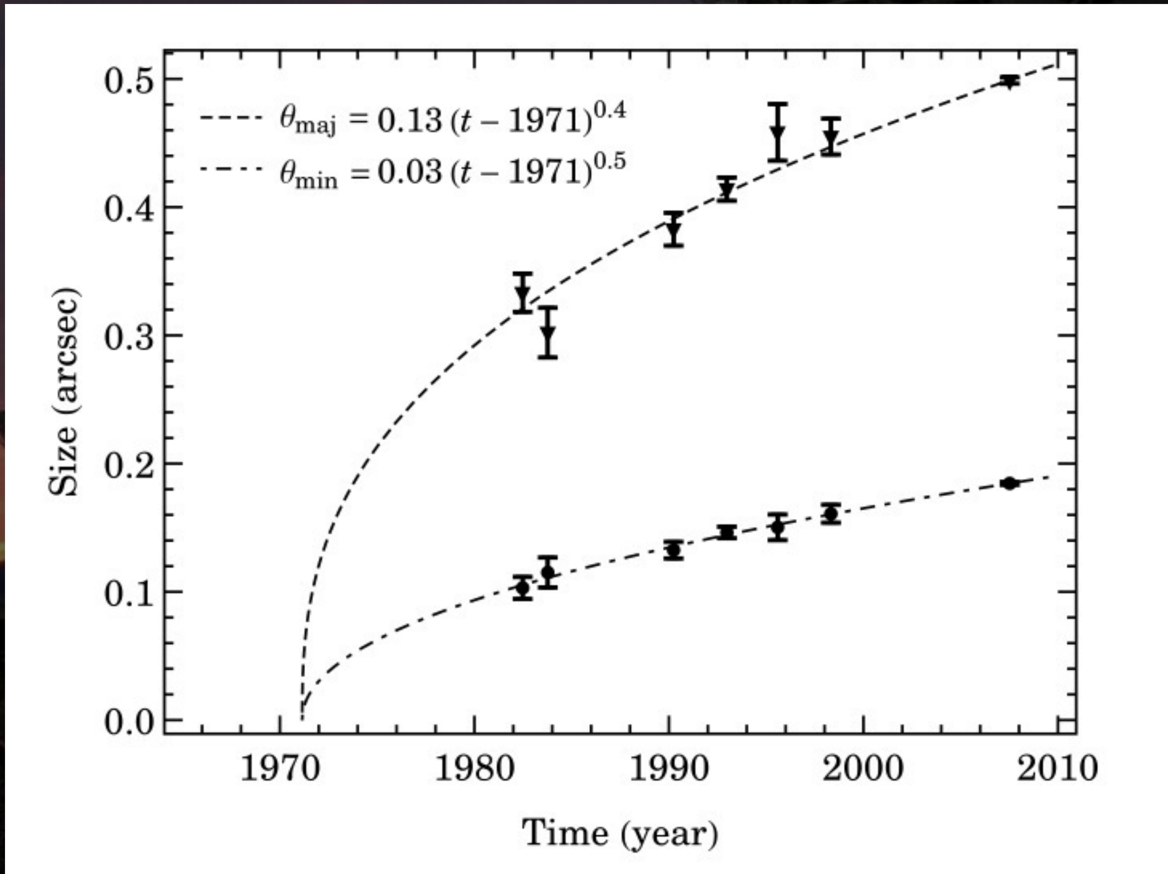
- Evolution of the flux at 22 GHz and 5 GHz
- The 5 GHz data were taken from literature, except for the epochs 1982 and 1998, which we obtained.



The fits were done simultaneously for the flux data and the size of the source (see next slide)

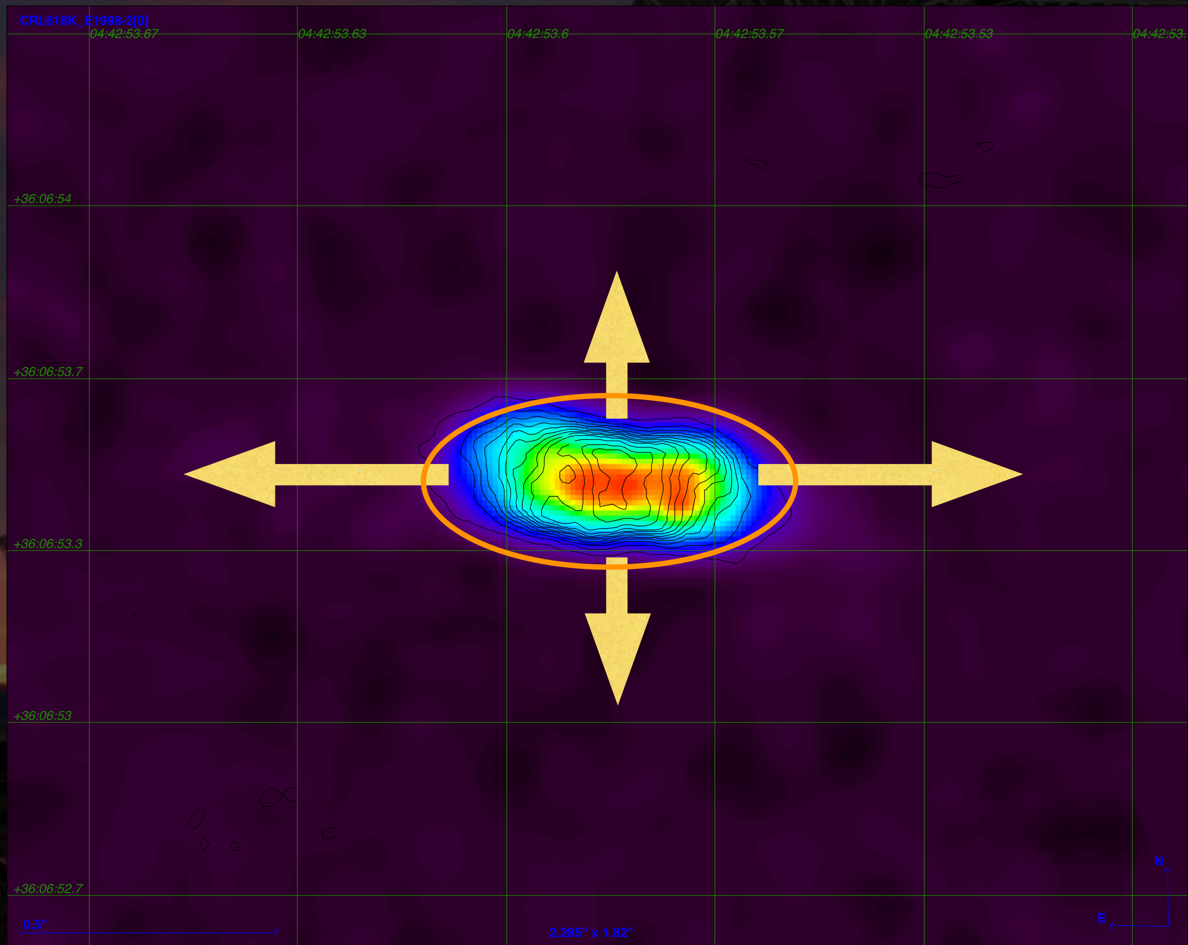
The “pre-PN” CRL 618:

- Evolution of the size at 22 GHz.
- The size was obtained by fitting 2-dimensional Gaussian functions to the brightness distribution.



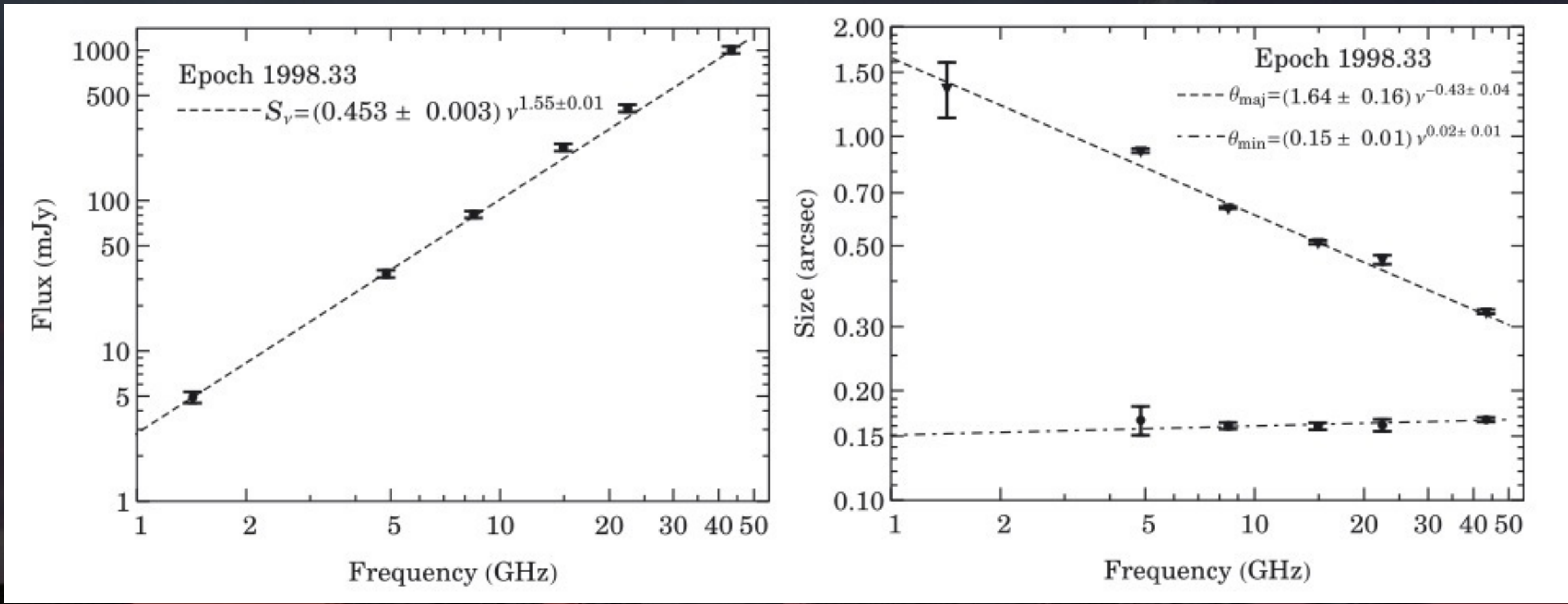
The “pre-PN” CRL 618:

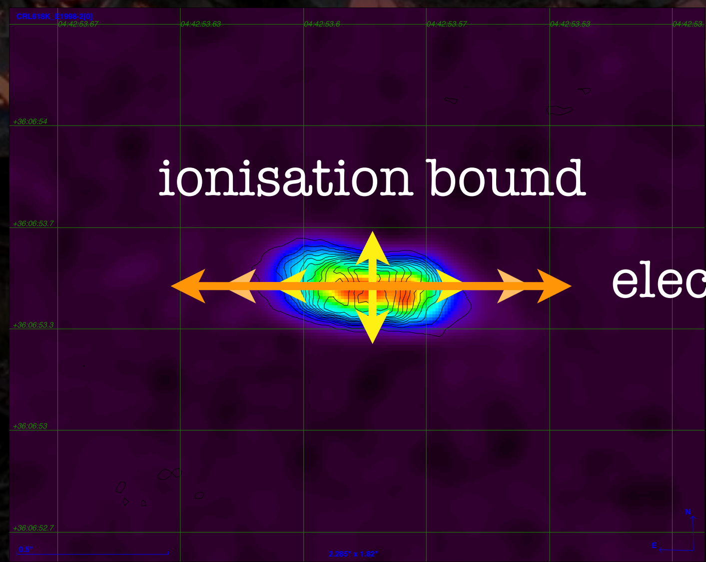
- The expansion is faster for the major axis than the minor axis.



The “pre-PN” CRL 618:

- SED and size vs. frequency of CRL 618 (epoch 1998)

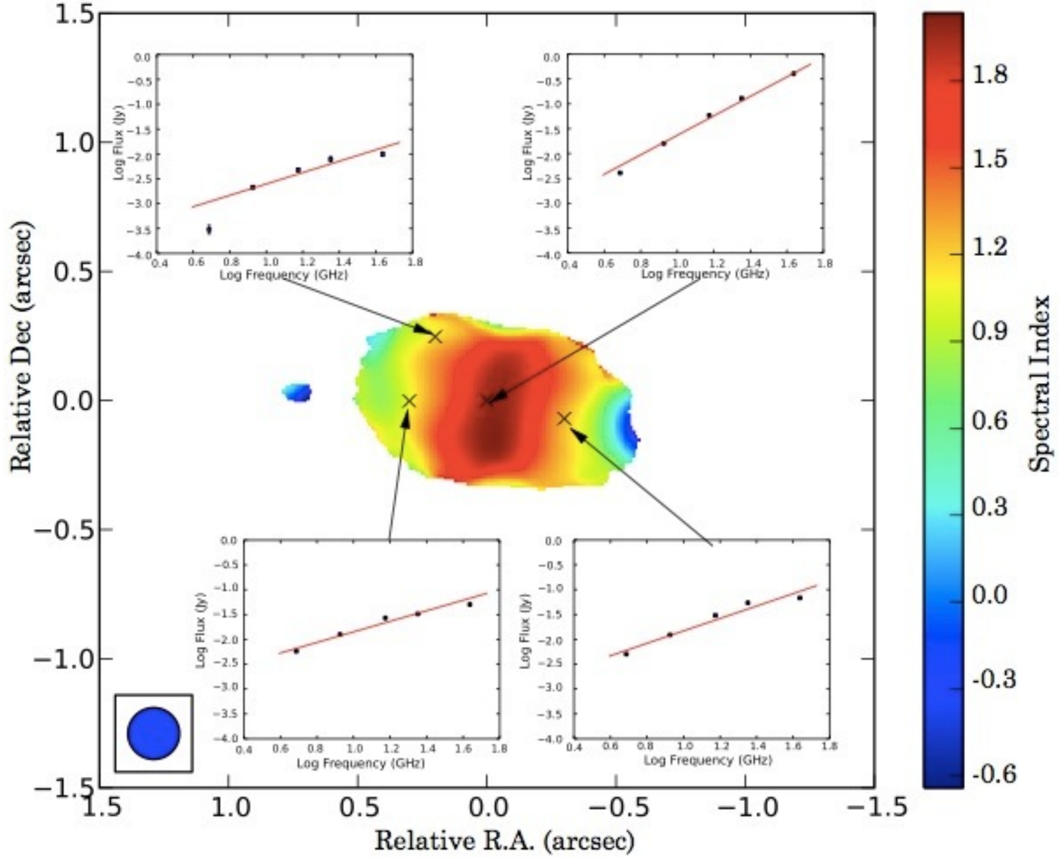




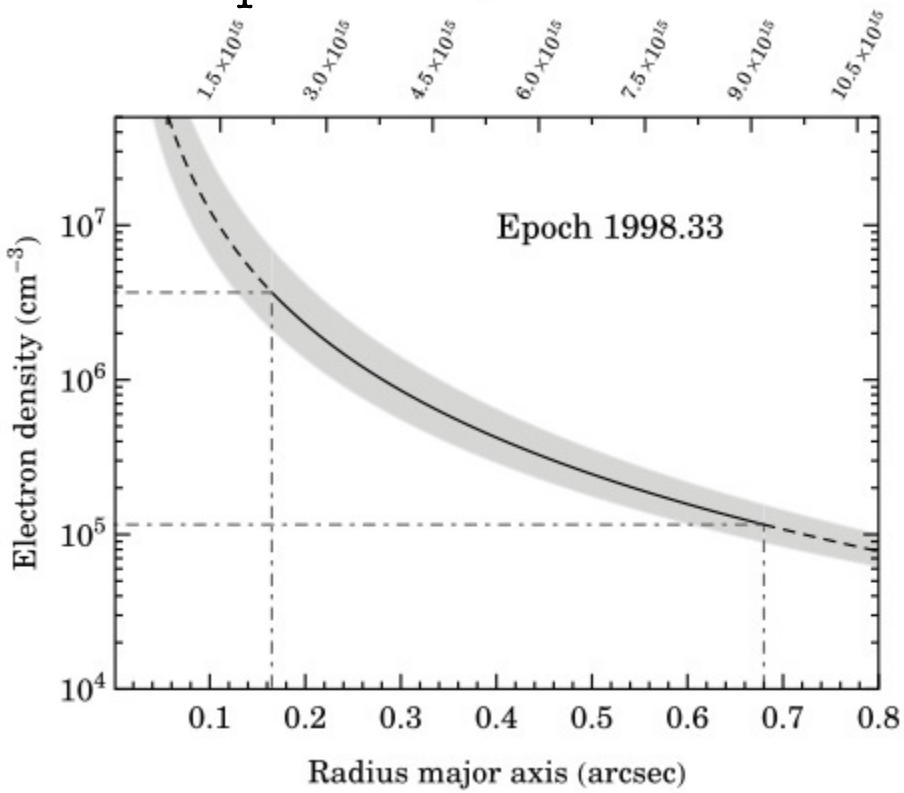
electron density gradient

The "pre-PN" CRL 618:

- Spectral index map and density profile along major axis of CRL 618.



D=900 pc

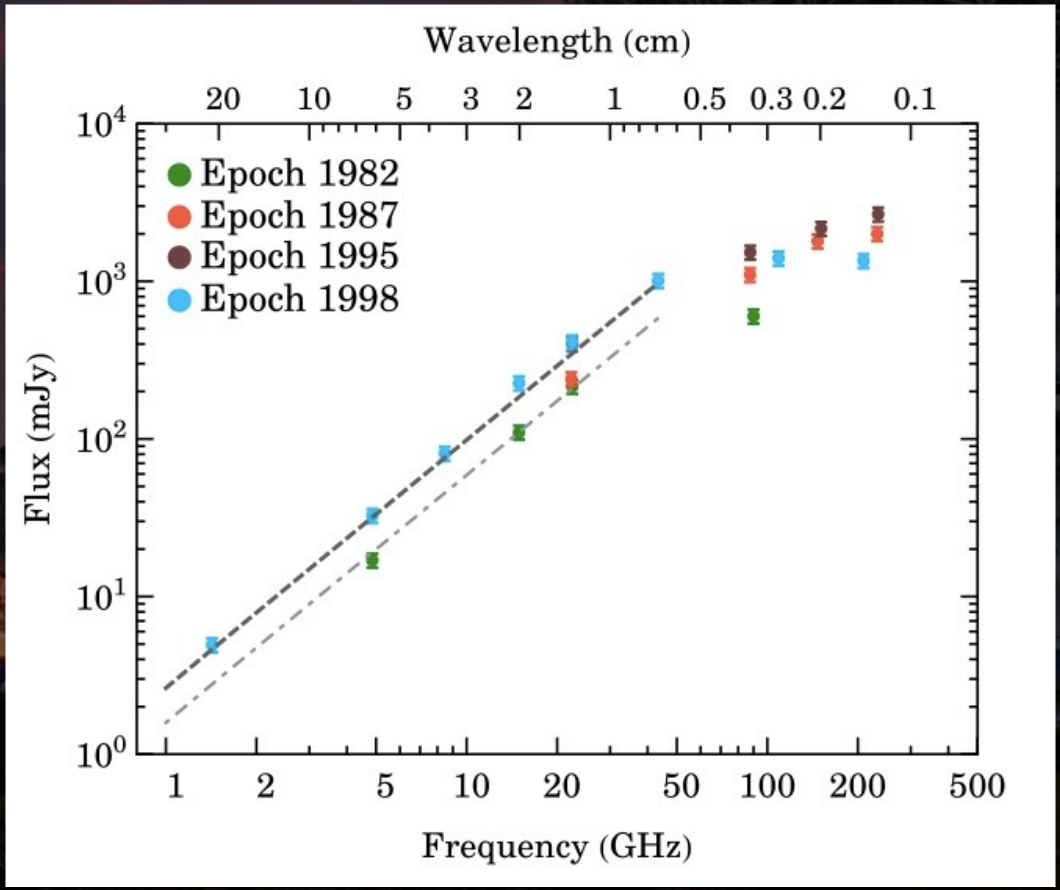


$$\tau_\nu = 8.235 \times 10^{-2} \left[\frac{EM}{\mathrm{cm^{-6}\,pc}}\right]\left[\frac{T_e}{\mathrm{K}}\right]^{-1.35}\left[\frac{\nu}{\mathrm{GHz}}\right]^{-2.1} \longrightarrow \left[\frac{n_{e,\tau=1}}{\mathrm{cm^{-3}}}\right] = (4.9 \pm 0.9) \times 10^4 \left[\frac{r^{-2.4\pm0.2}}{\mathrm{arcsec}}\right]$$

→ Increasing mass-loss rate

The “pre-PN” CRL 618:

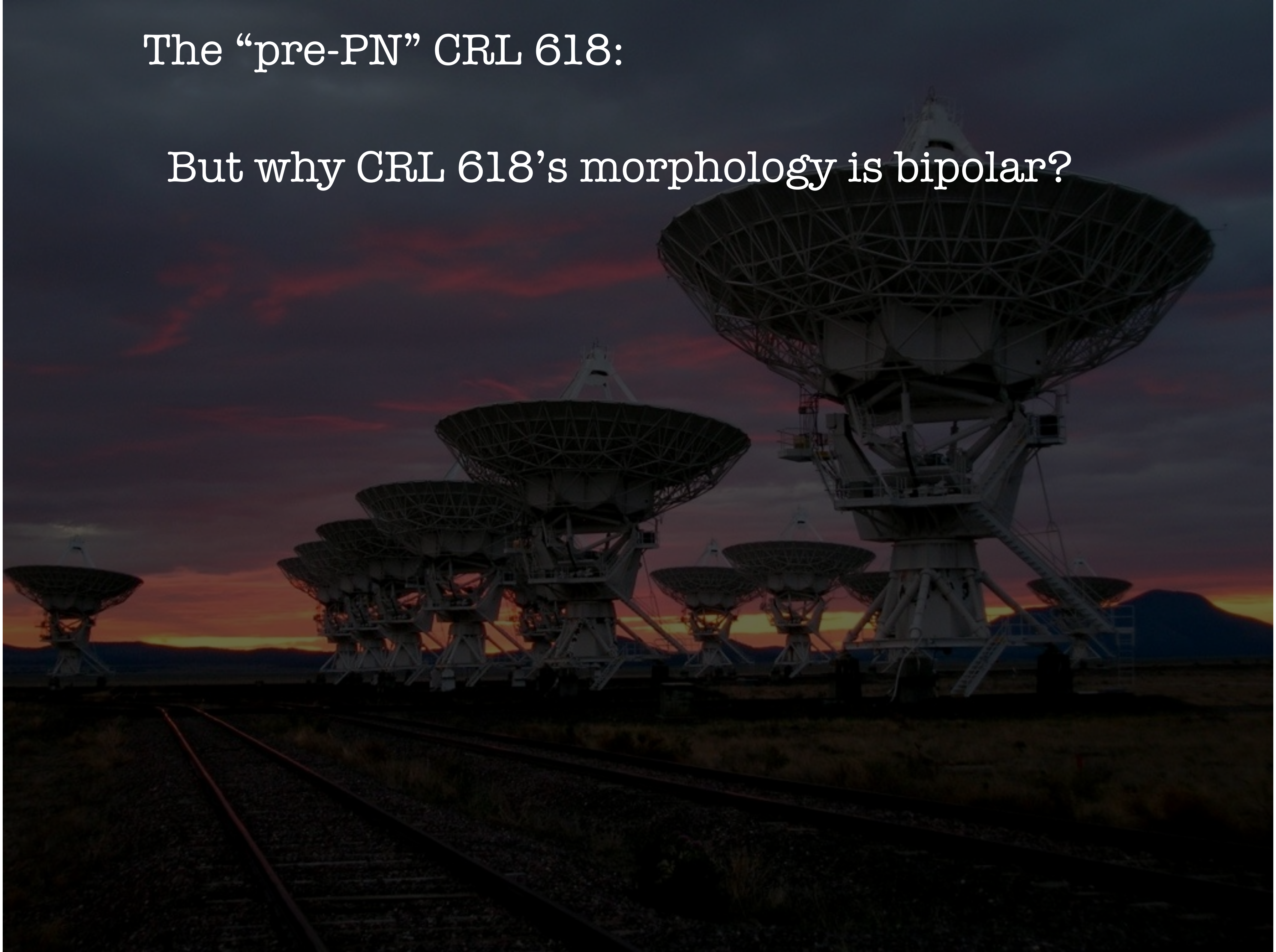
- Radiative transfer model of the radio continuum in CRL 618 using an increasing mass-loss rate and geometry from our results.
- Evolution of the SED:



➔increase of the mass-loss rate from ~4×10^{-6} to ~6×10^{-6} $M_\odot\ yr^{-1}$ in the ~130 years previous to 1998

The “pre-PN” CRL 618:

But why CRL 618’s morphology is bipolar?

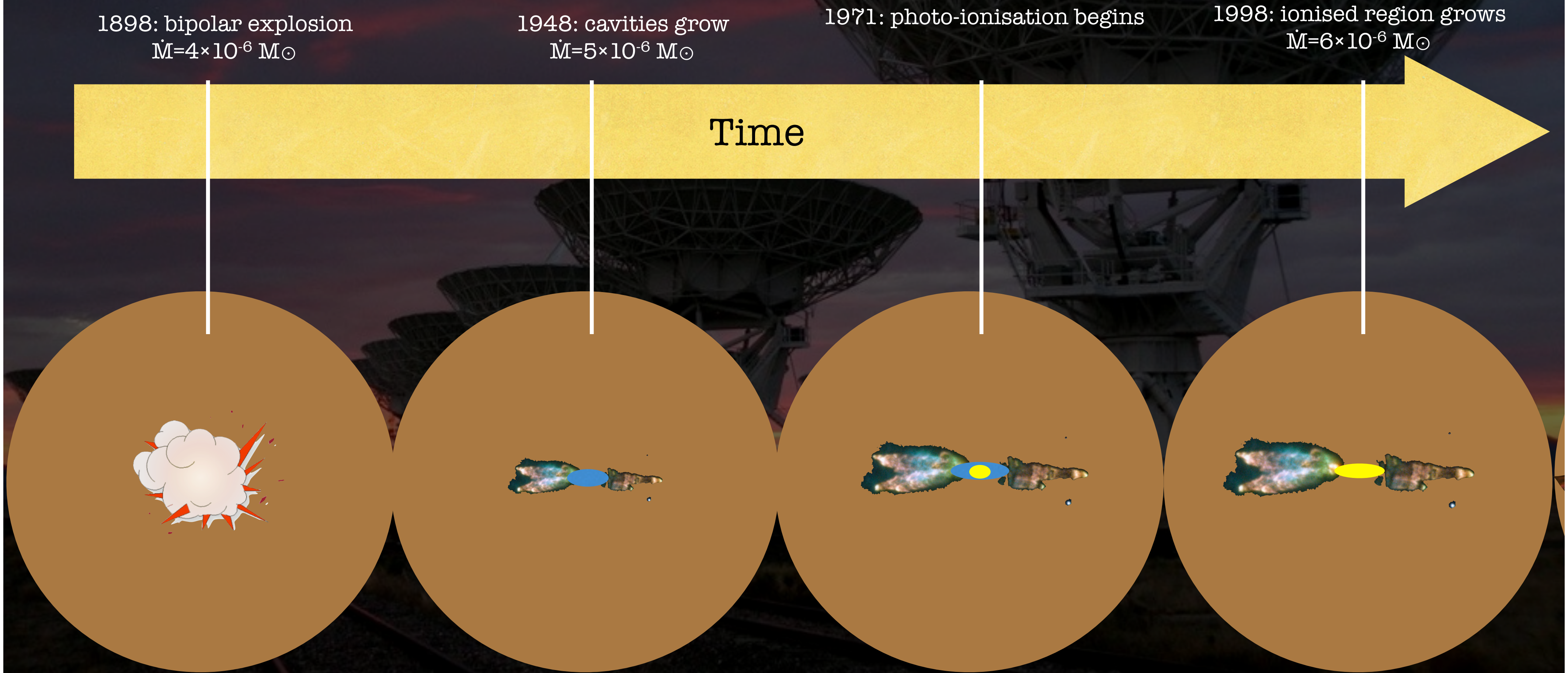


The “pre-PN” CRL 618:

- Balick et al. (2013) reported expansion motion from observations at optical wavelengths with the HST.
- All the fingers have the same kinematical age: explosion-like event.
- Time scale of the expansion ~100 years.

The “pre-PN” CRL 618:

- Timeline of the evolution of CRL 618:



The ionisation of the CSE began ➔ post-AGB phase lasted only ~100 yrs

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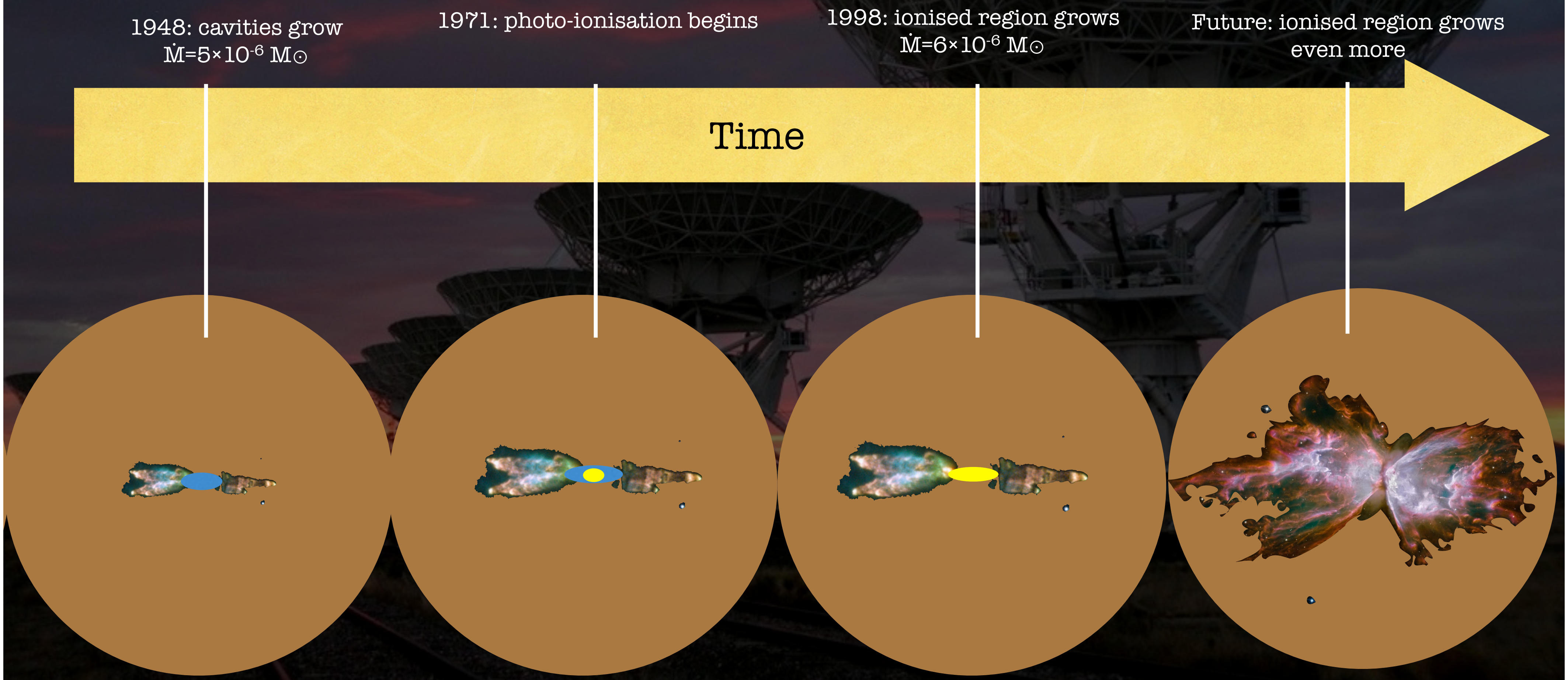
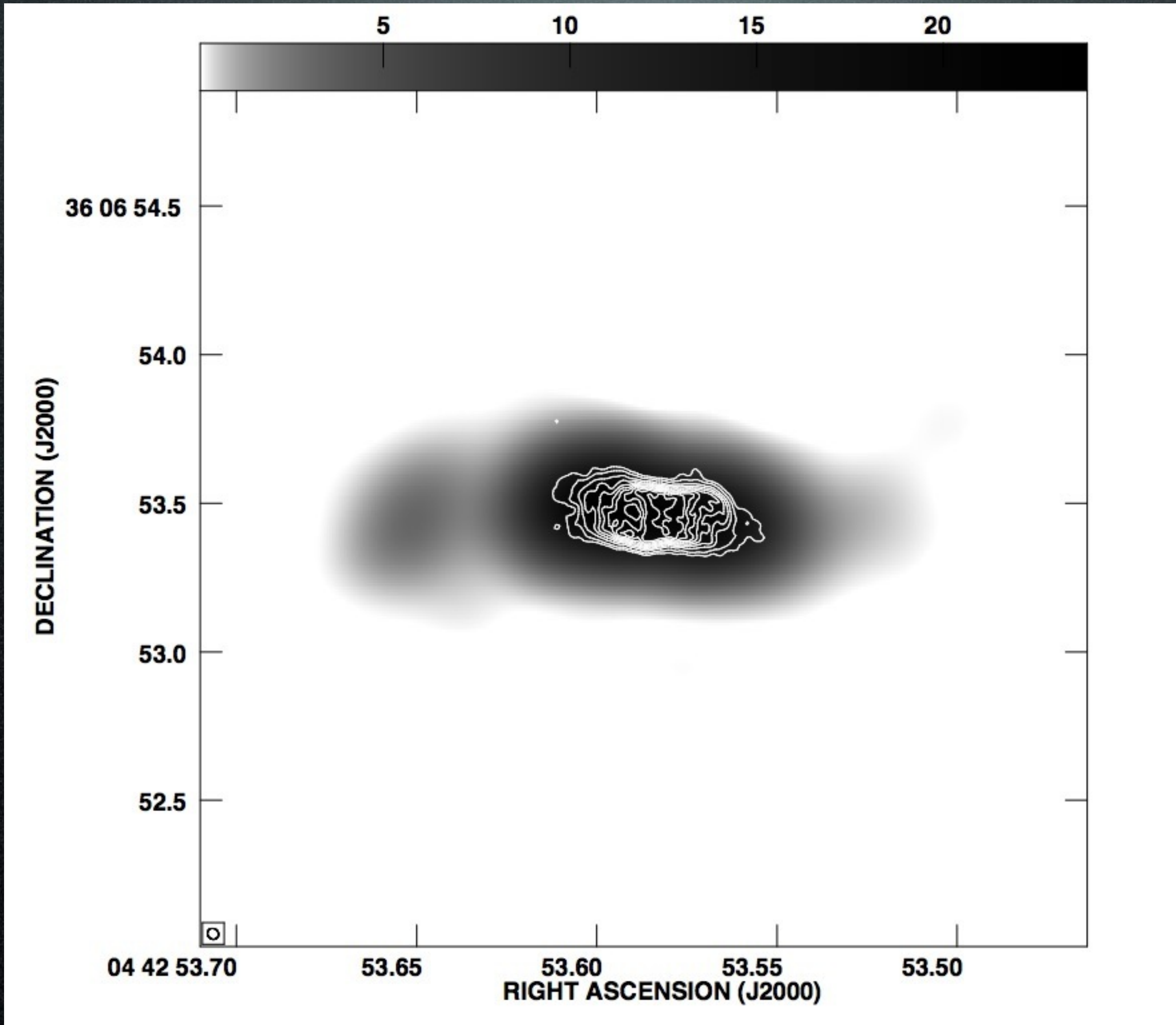


The ionisation of the CSE began ➔ post-AGB phase lasted only ~100 yrs

The "pre-PN" CRL 618: S-shape morphology?



7mm
&
3.6cm

Conclusions:

- The radio continuum and size of CRL 618 have been increasing in the last ~30 years

- The expansion is faster for the major axis than the minor axis.

- The nebula is ionisation bound in the minor axis and density bound in the major axis ➔ density gradient.

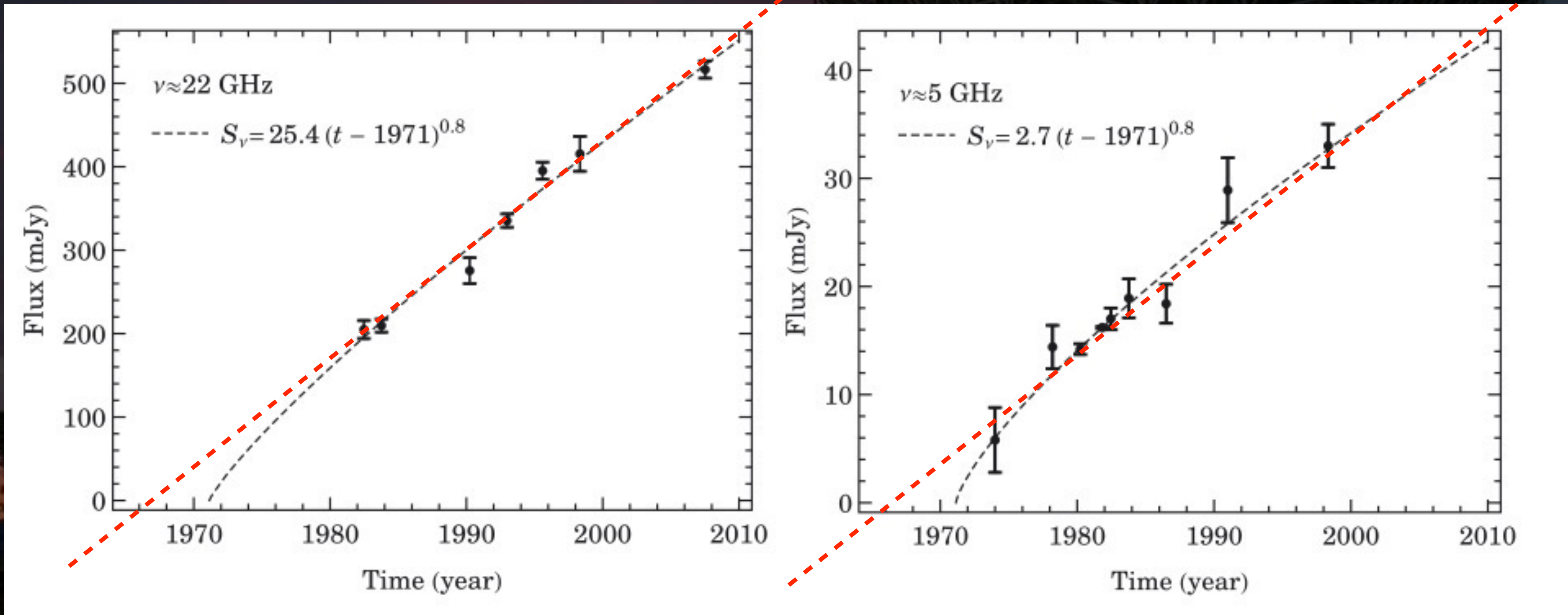
- The photo-ionisation of the material around CRL 618 began around 1971.

- This event marked the beginning of the planetary nebula phase for CRL 618, implying a very short time for its post-AGB phase ~100 years.

Thanks for your attention!

The “pre-PN” CRL 618:

- Evolution of the flux at 22 GHz and 5 GHz
- The 5 GHz data was taken from literature, except for the epochs 1982 and 1998



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