Witnessing the Expansion of Born-Again Planetary Nebulae

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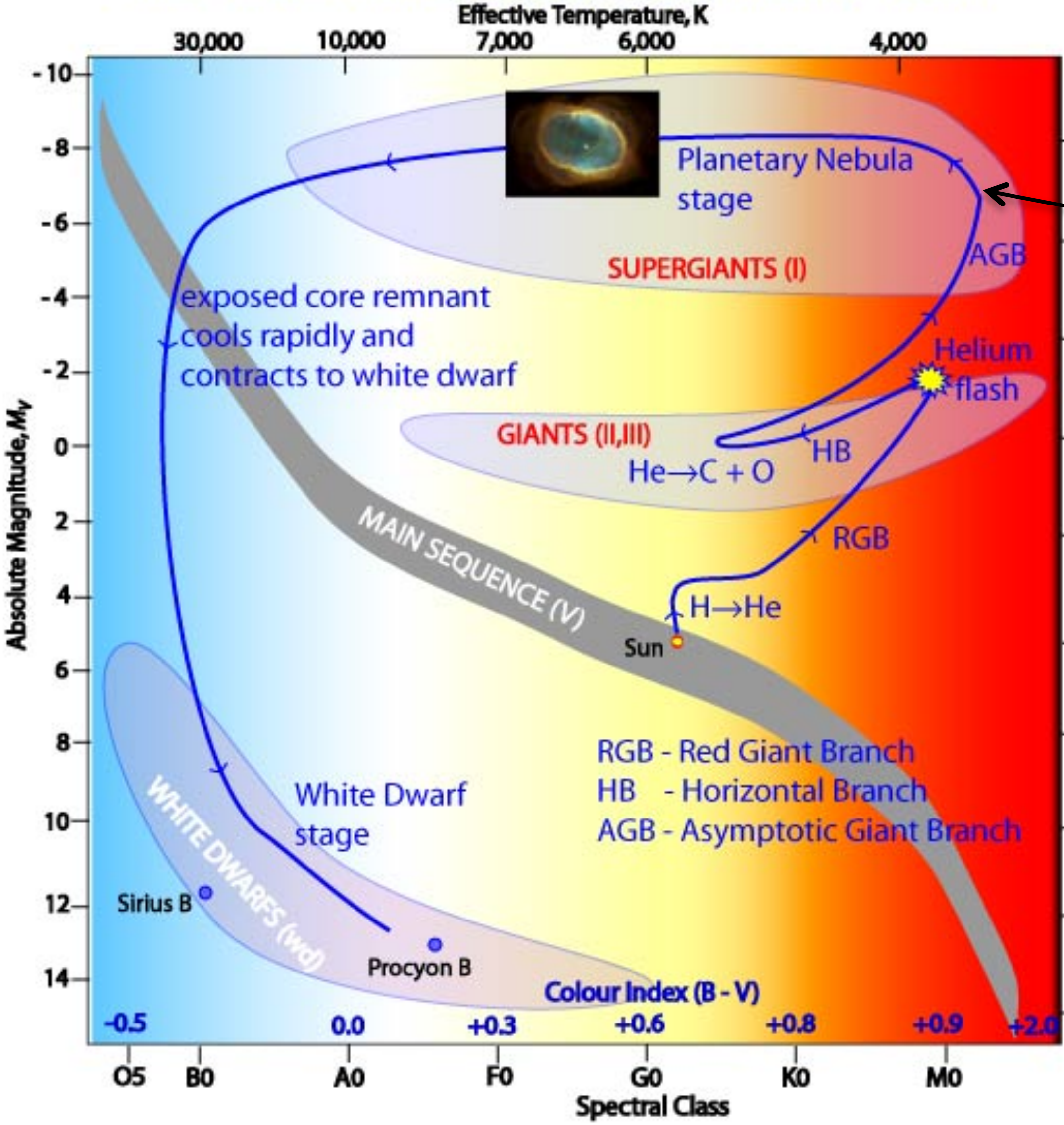
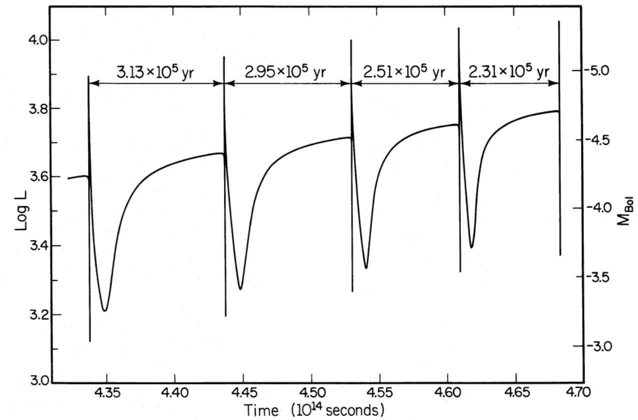
PN evolution: blowing little bubbles into the ISM

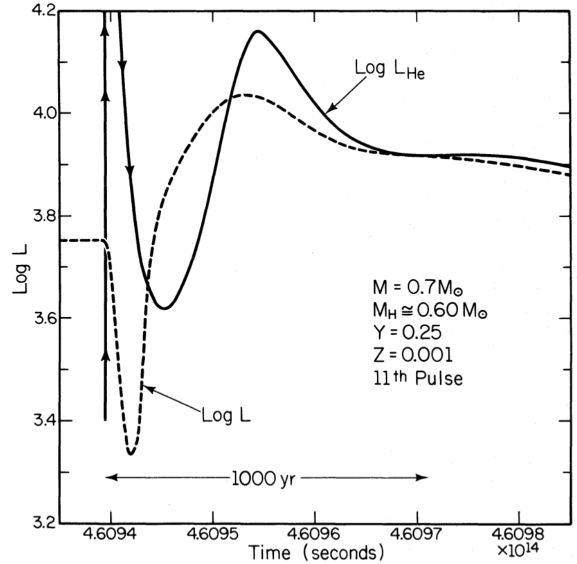
The Born-Again Phenomenon

Sun's Post-Main Sequence Evolutionary Track



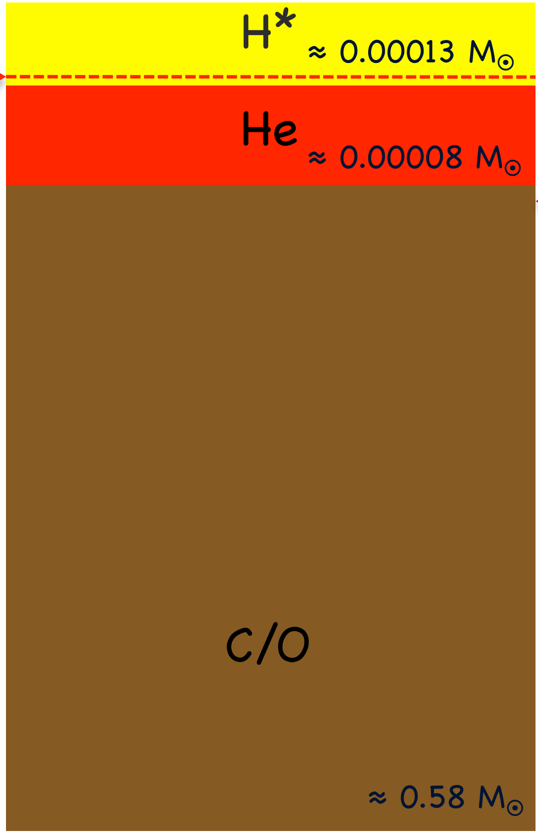
Late AGB: Thermal pulse (TP) phase

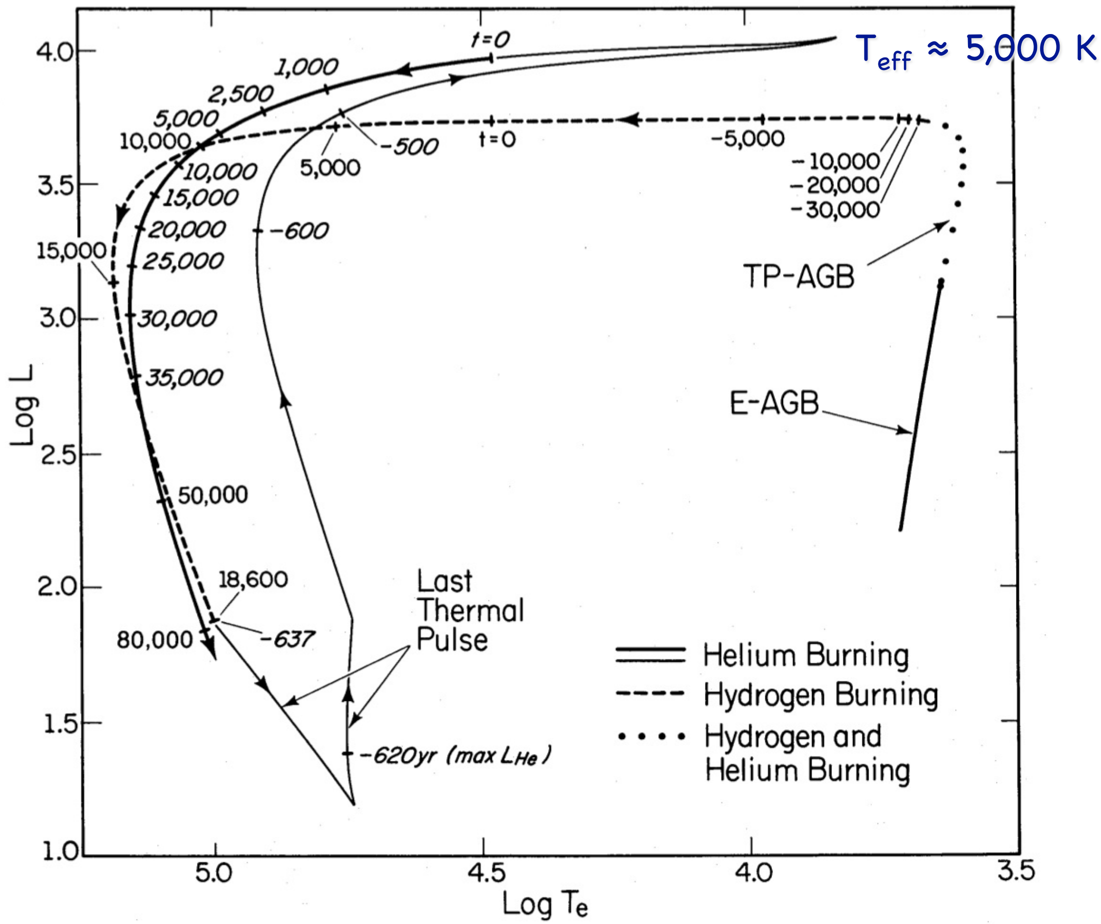




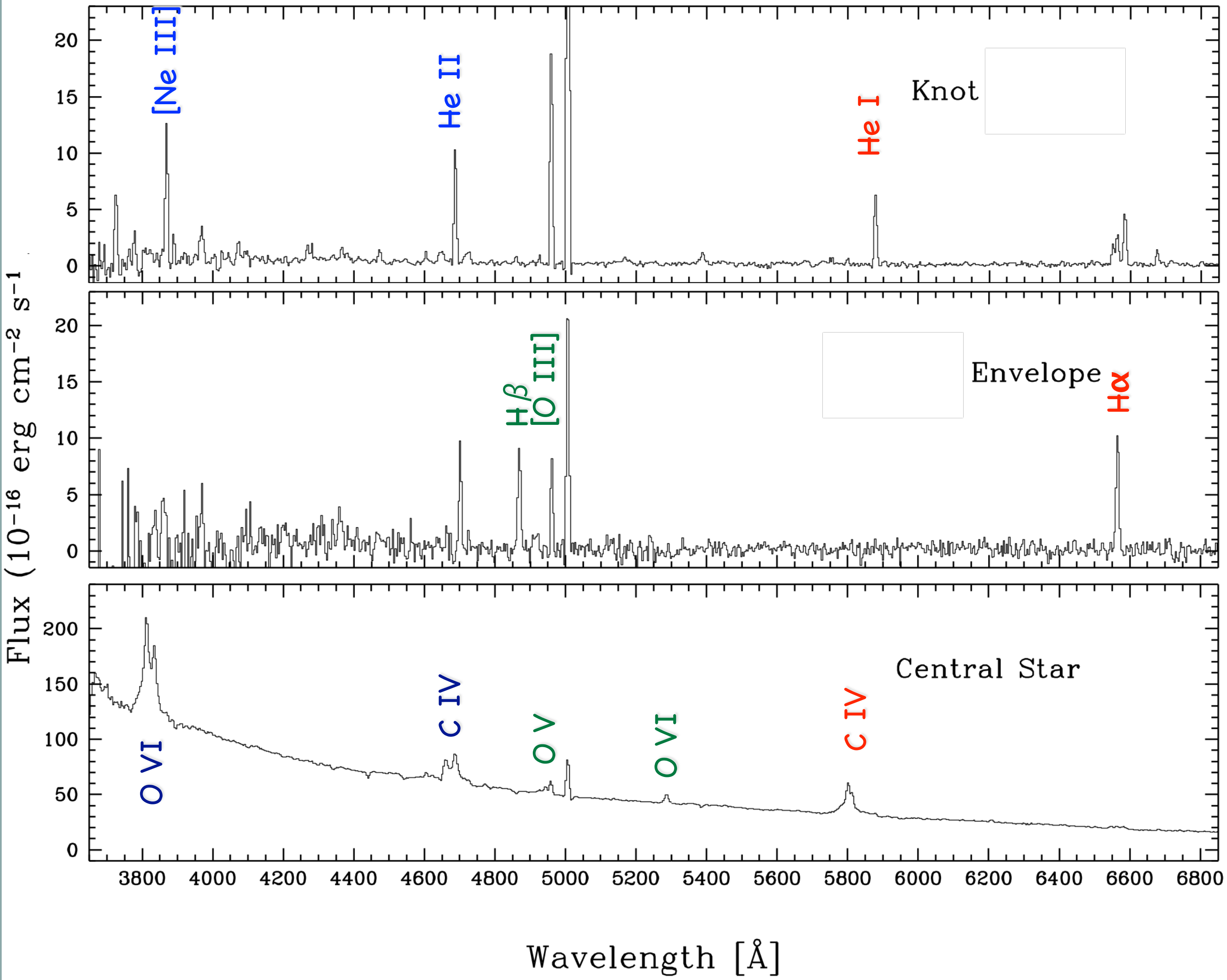
The Born-Again Phenomenon

A Very Late Thermal Pulse (VLTP) may occur in exceptional conditions, when the mass in the He shell after leaving the AGB phase is close to a critical mass.





Iben et al. (1983), Herwig et al. (1999), Althaus et al. (2005), Lawlor & MacDonald (2006), Miller Bertolami & Althaus (2006), Miller Bertolami et al. (2006)



Chemical composition by number of the H-poor knots:

H: He: C : N : O

1:11.2:0.5:0.3:1.3

Wesson et al. (2003)

Abell 30 spectra

Guerrero & Manchado (1996)

Notable absence of H I lines in the spectrum of the central knots.

Bright Ne, O, and He I and He II nebular lines.

Broad stellar C IV and O VI features.

Sakurai's Object: New Kid on the Block

NOVALIKE VARIABLE IN SAGITTARIUS

S. Nakano, Sumoto, Japan, reports the discovery by Yukio Sakurai, Otsuka-cho, Mito, Ibaragi-ken, of a possible "slow" nova, on Fuji G
17h52m33s
taken on
11.4. Pa
candidate
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inspection of a fully-reduced CCD spectrogram (range 375-985 nm; resolution 1.6 nm), taken by B. Leibundgut (ESO) with the ESO 3.6-m reflector (+ EFOSC1) on Feb. 23.4, reveals that the spectrum is consistent with a reddened early G-type star of high luminosity; no emission lines are visible. H-beta is in absorption at 485.7 nm, while H-alpha could be present in absorption, blended with another absorption feature (at 657.75 nm). Na I D lines are the strongest absorption feature of the spectrum (measured at 588.7 nm). The probable pre-outburst counterpart is visible as a star of mJ = 21, mR = 20.5 on the ESO/SRC sky survey films. While the outburst amplitude and lightcurve suggest a slow or symbiotic nova, the lack of obvious emission lines one year after brightening is very unusual."

1996 February 23 **(6322)** **Daniel W. E. Green**

THE ASTROPHYSICAL JOURNAL, 468:L111–L114, 1996 September 10

SAKURAI'S OBJECT—A POSSIBLE FINAL HELIUM FLASH IN A PLANETARY NEBULA NUCLEUS

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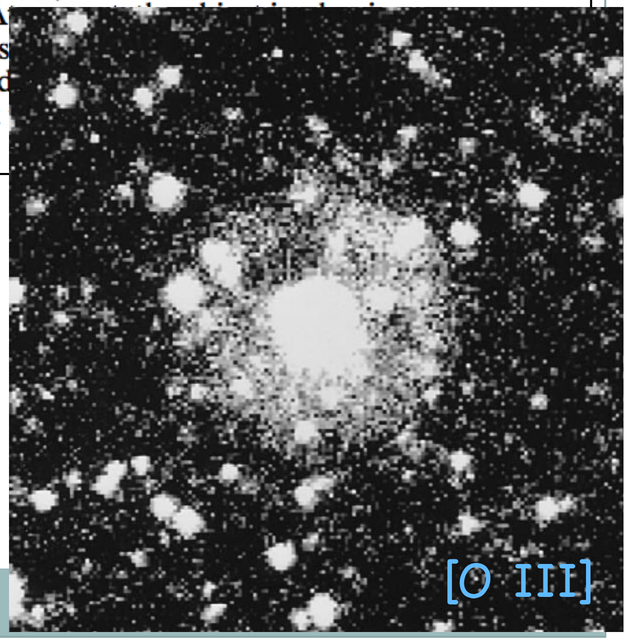
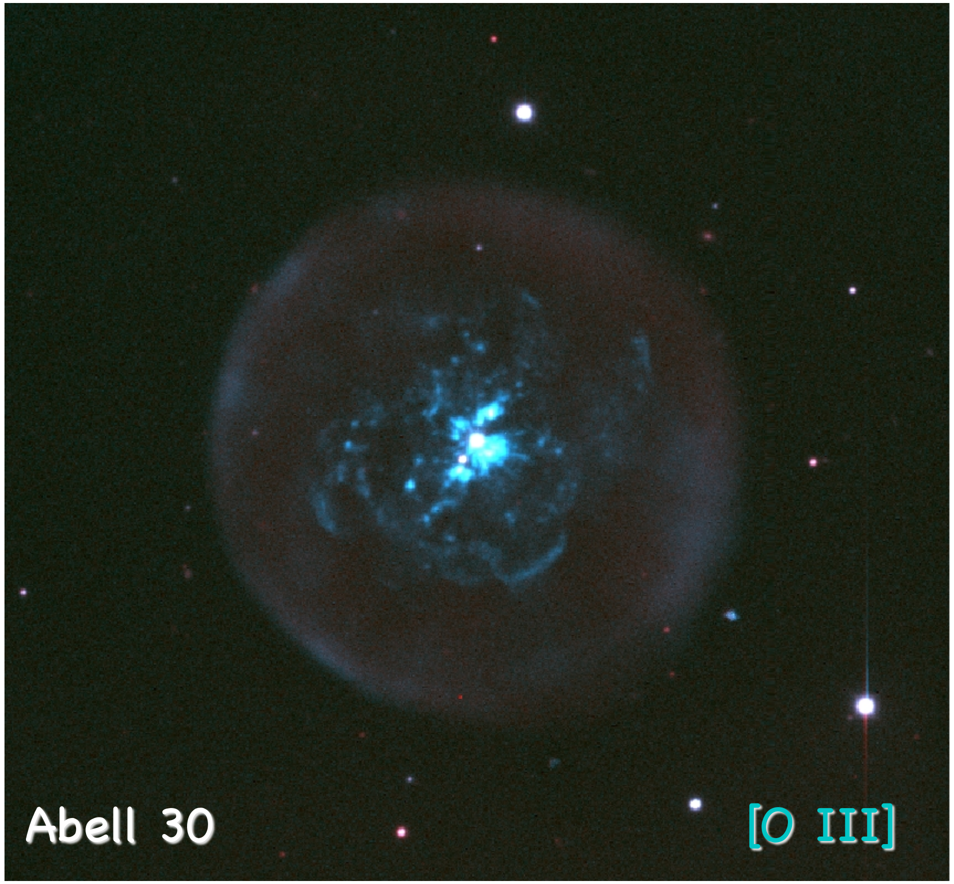
Received 1996 May 7; accepted 1996 June 21

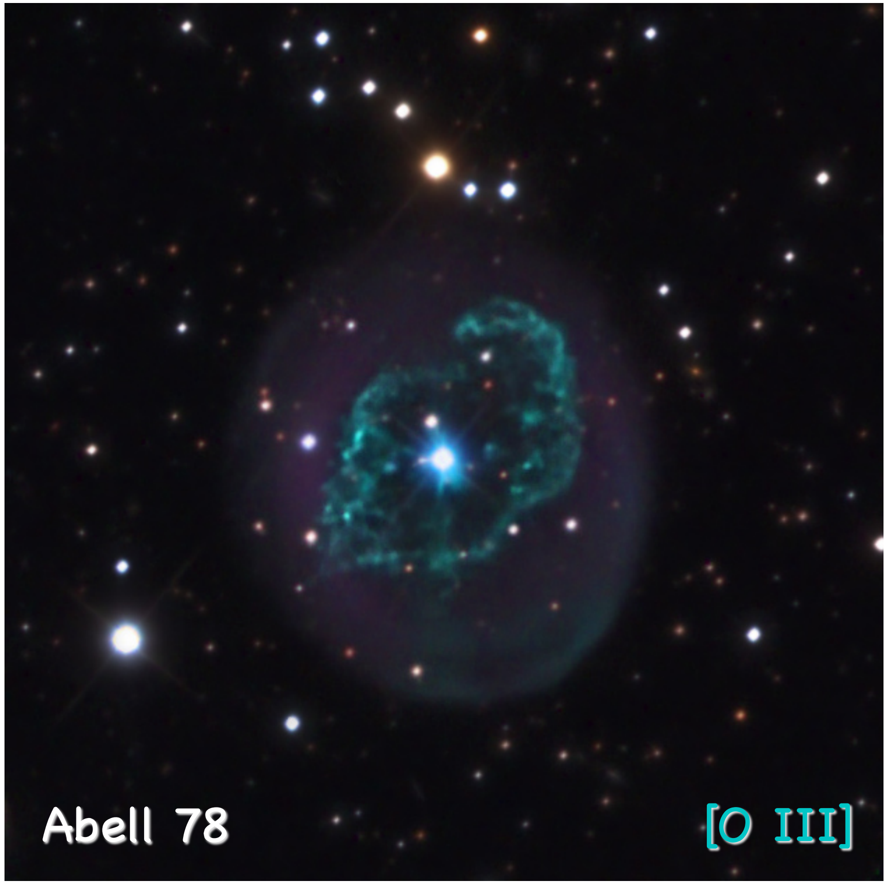
ABSTRACT

UBVRIJK photometry and optical spectroscopy of Sakurai's object and direct imaging of the surrounding nebulosity are presented. The progenitor star is identified as a faint blue object of $m_j = 21$. The circular planetary nebula has a diameter of 32″, its distance, derived from the Hβ flux, is 5.5 kpc. A
supergiant of approximate spectral type F2, having $M_V = -4.1$, and has
underabundance, with carbon and oxygen overabundance. Its photospheric rad
the surrounding planetary nebula, indicating that they are associated, and that
a thick wind. A marginal IR excess suggests the presence of some hot dust.



The Old, Grumpy Born-Again PNe

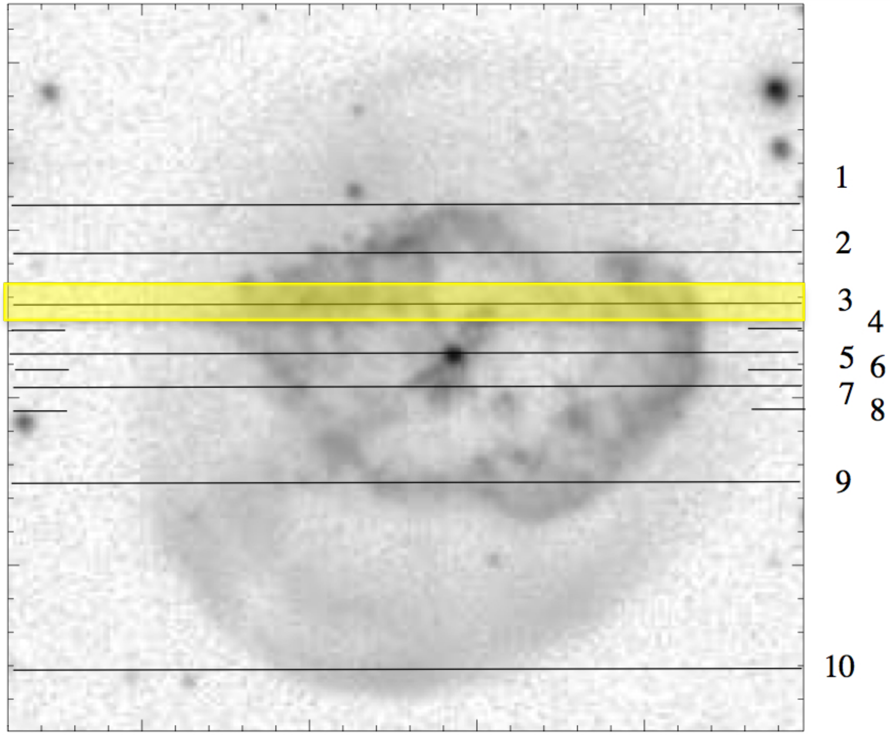


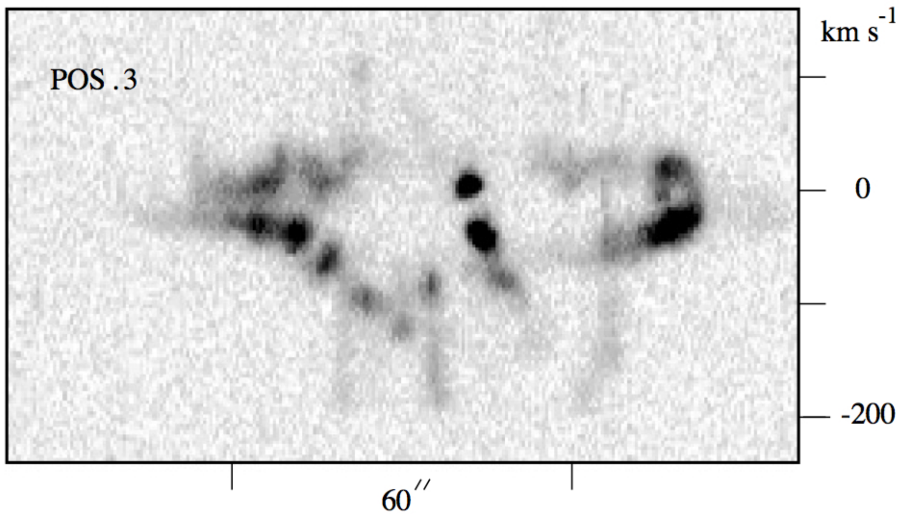


The CSPNe are surrounded by bright [O III] knots undetected in Hα images.

The knots are enveloped by "chaotic" [O III]-bright shells inside the smooth outer shells.

Kinematics of the Ejecta in Born-Again PNe





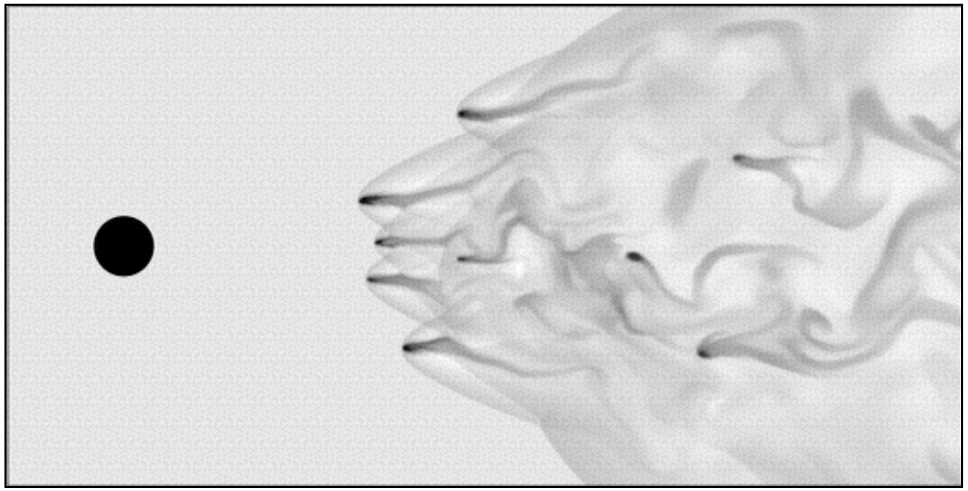
Expansion of Abell 78

Meaburn et al. (1998)

H-poor knots expand at similar speed than the outer shell, ≈40 km s^{-1}

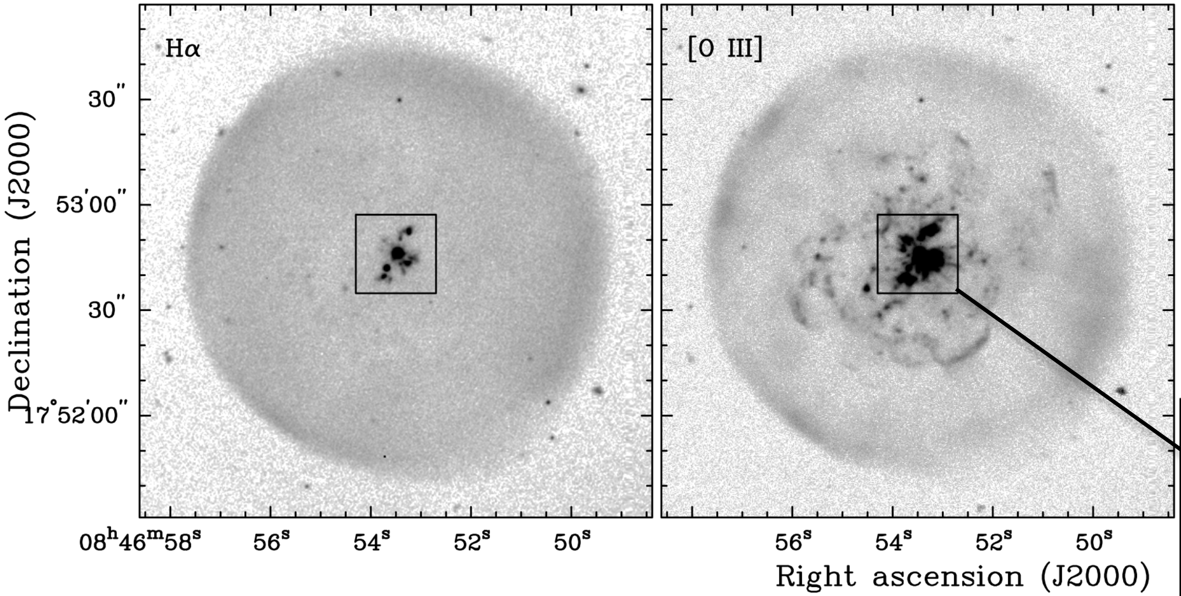
Tails expanding at speeds ≥200 km s^{-1}

Evidence of ablated knots and wind mass-loading

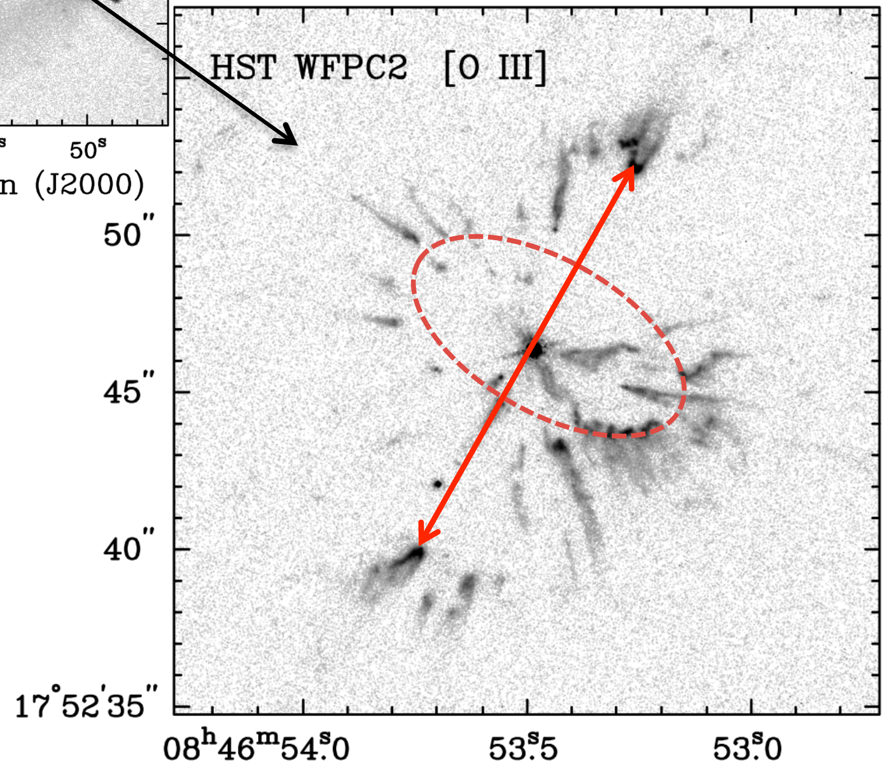


Steffen & López (2004)

Kinematics of the Ejecta in Born-Again PNe



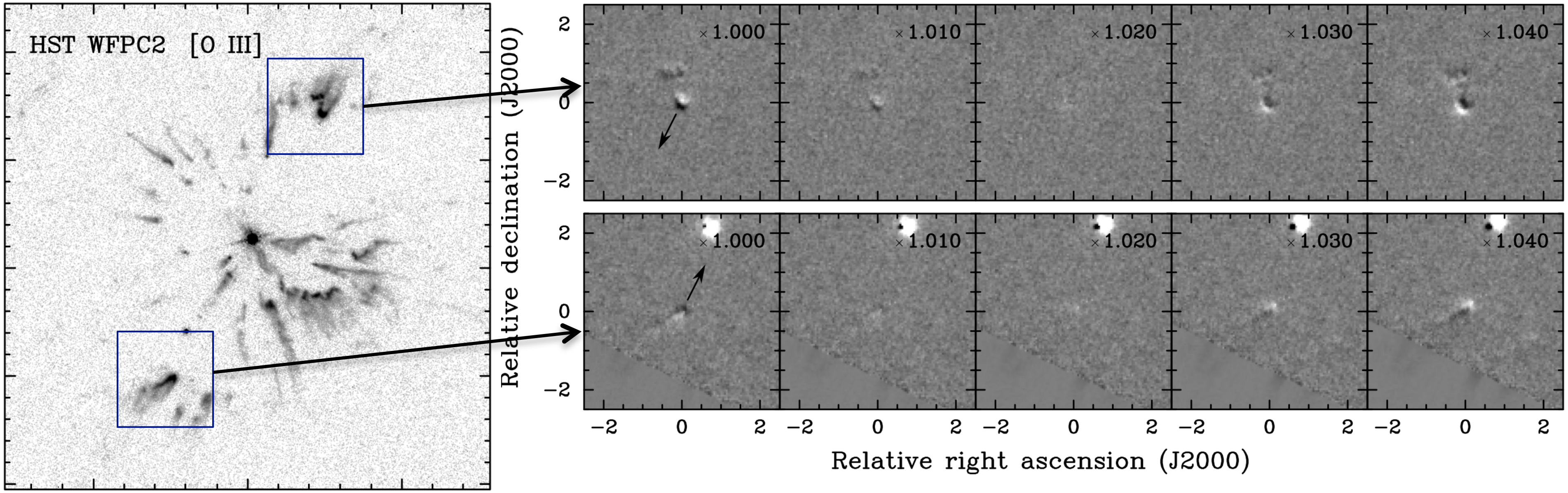
Meaburn & López (1996)
Chu & Ho (1996)



Slow-expanding disk and fast bipolar outflow.

Peculiar geometry of the ejecta: similar for other born-again PNe, including the younger Abell 58 and Sakurai's object (Clayton et al. 2012)

Expansion of the optical ejecta



Study of the expansion using *HST* multi-epoch observations:

WFPC2 [O III] 1994 March, WFC3 F555W 2009 December, 15.8 yr apart

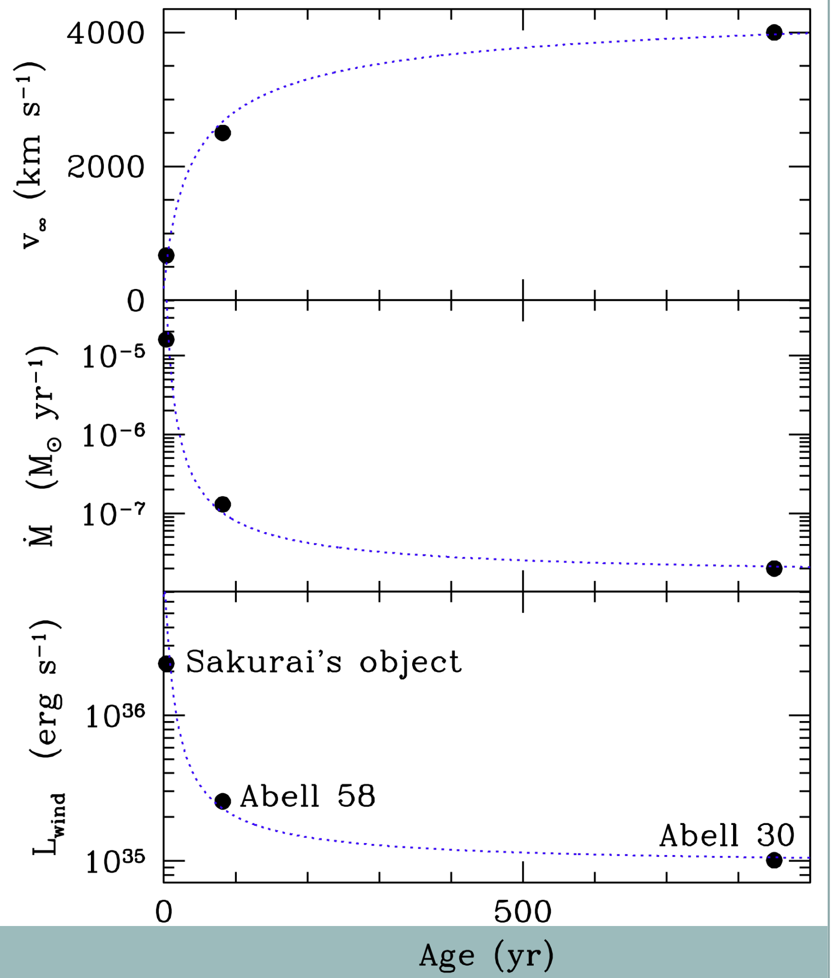
Proper motions of H-poor knots imply angular expansion rate: ≈2%

Age: 850 yr (circa AD 1160)

The Born-Again Phenomenon

Rare phenomenon: only a handful of born-again PNe are known

Abell 30	(circa AD 1160)
Abell 58	(aka Nova Aql 1919)
Abell 78	(age unknown)
Sakurai's object	(mid '90)



Extremely short evolution of the star and the stellar wind evolution after the born-again episode.

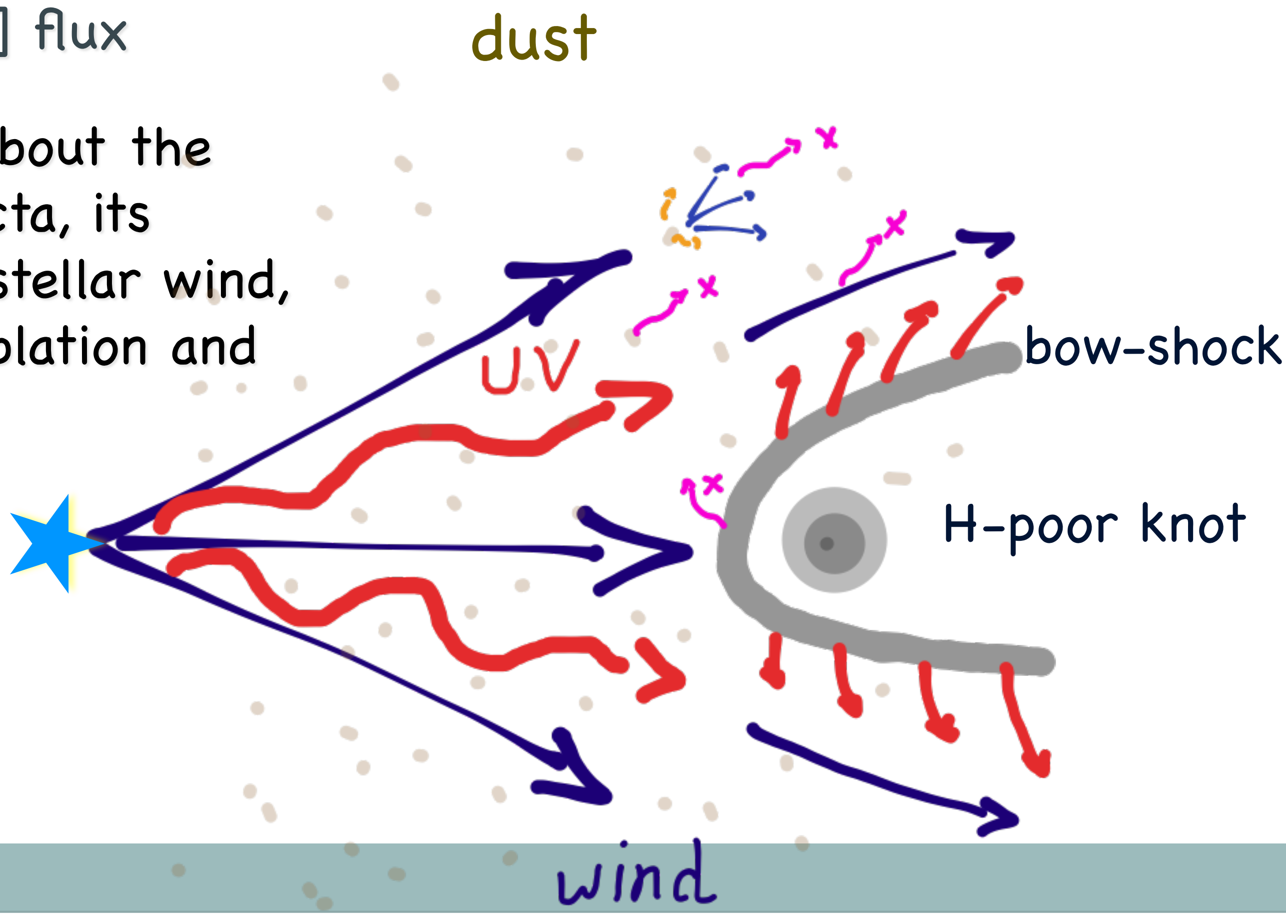
Opportunity to explore interactions between fast stellar winds and H-poor material close to the central star

Prospective work

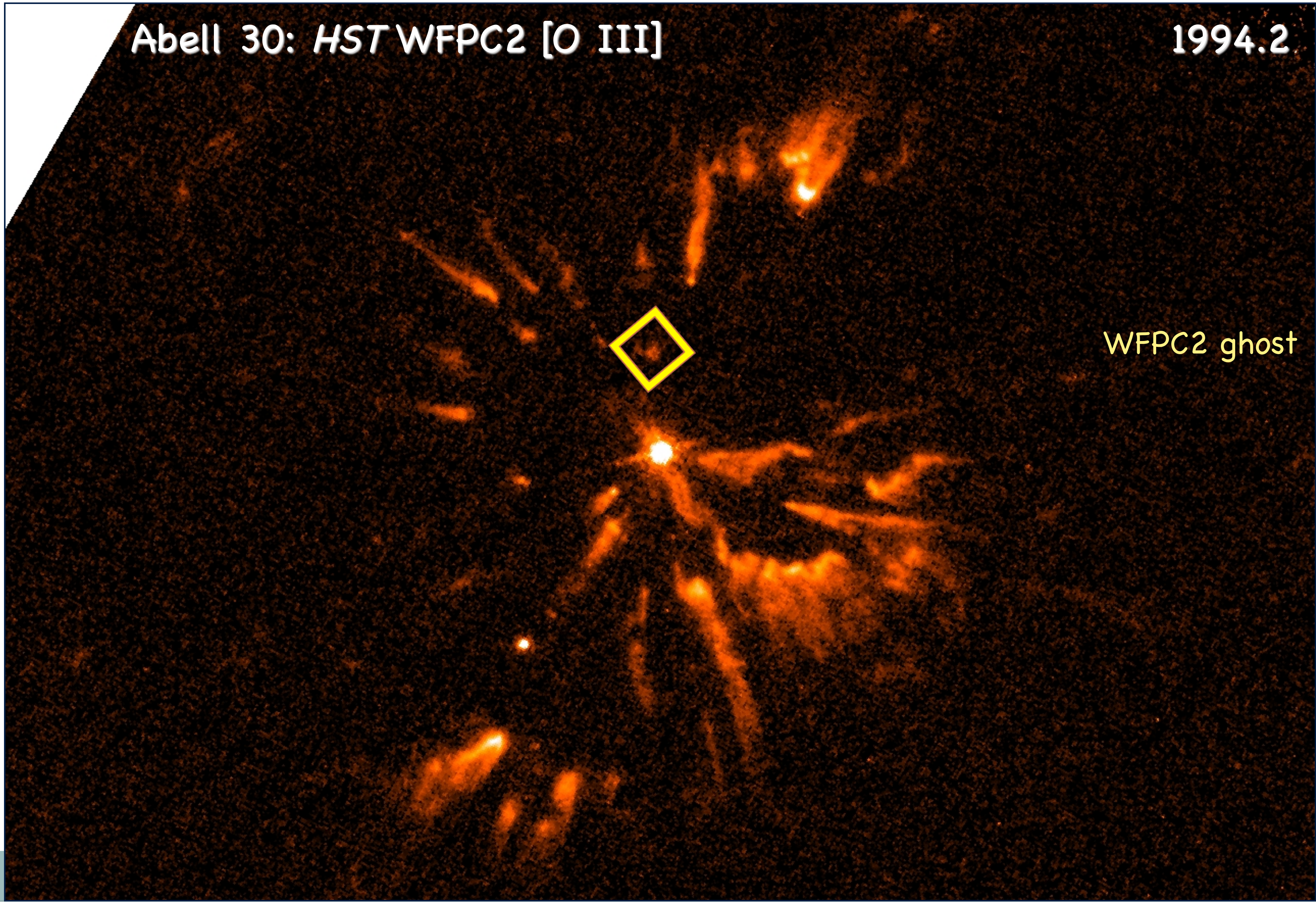
How do H-poor knots expand and interact with the stellar wind and the nebula?

- the proper motions in the H-poor cometary knots
- morphological changes of their heads and tails
- variations of [O III] flux

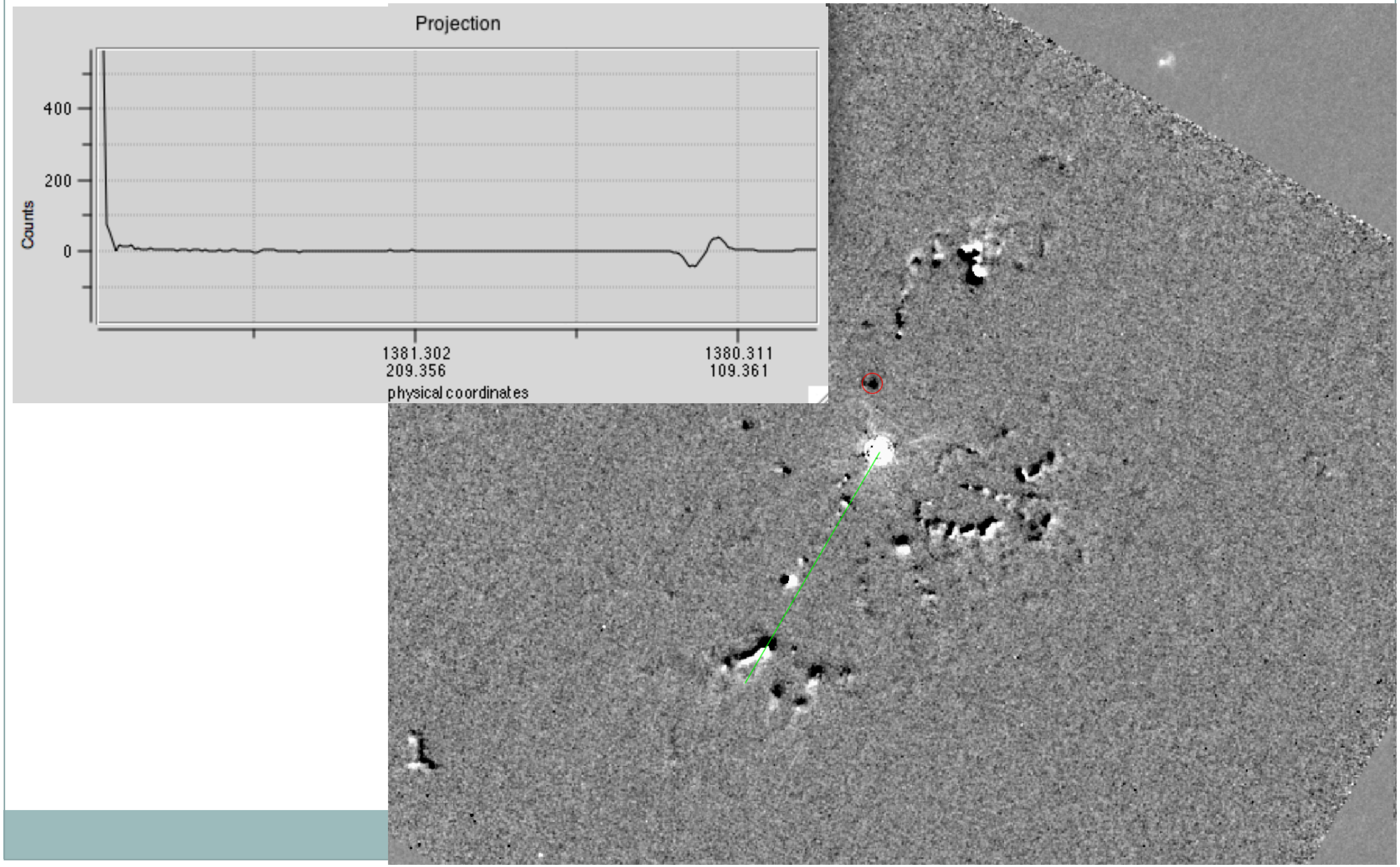
What can we learn about the expansion of the ejecta, its interaction with the stellar wind, processes of knots ablation and evaporation and wind mass-loading?



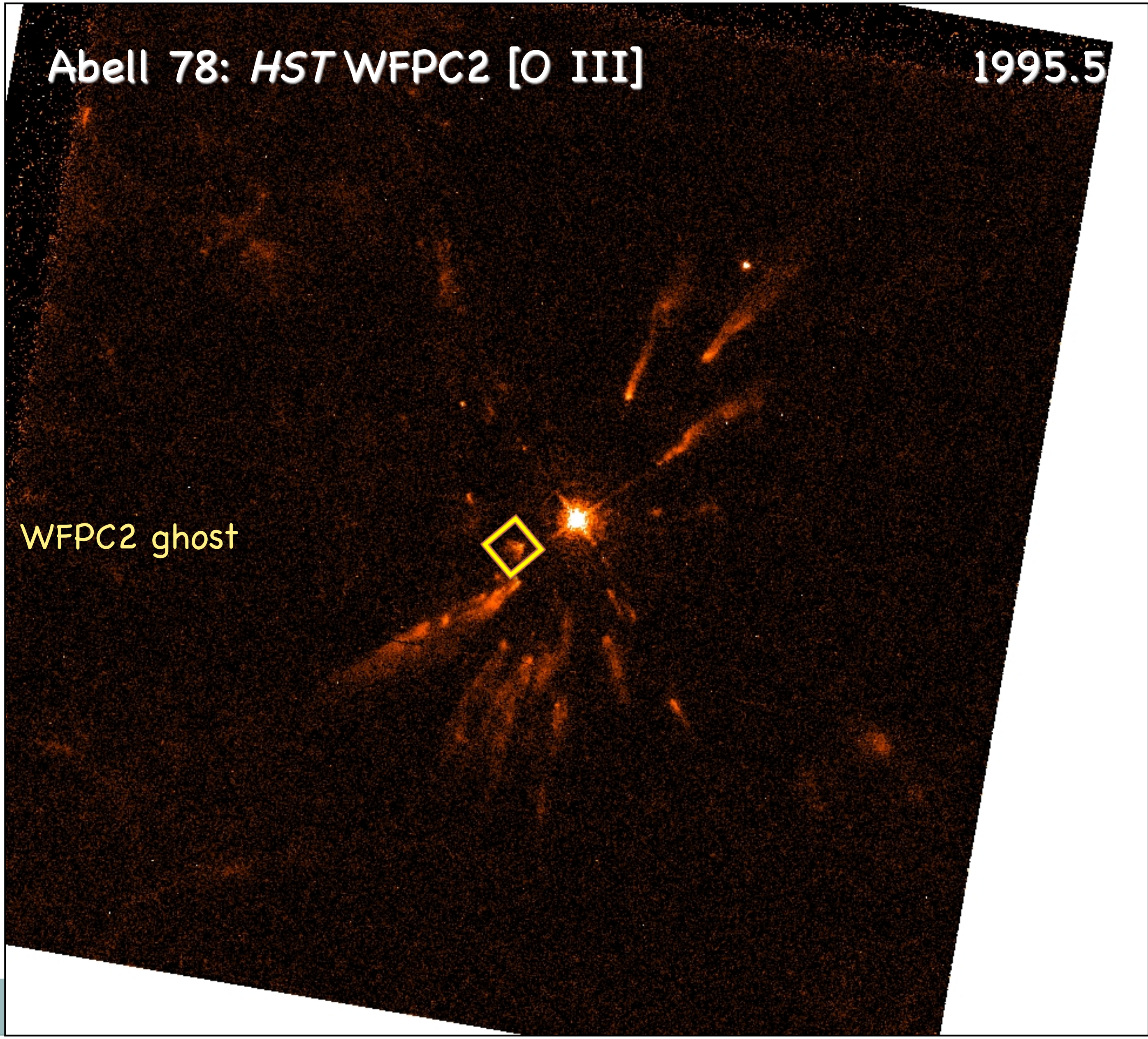
Expansion of the optical ejecta



Expansion of the optical ejecta



Expansion of the optical ejecta



Preliminary Results

Cycle 20 *HST* WFC3 [O III] images of Abell 30 and Abell 78

Determined the expansion rate of the innermost knots and age of the born-again episode:

Abell 30: ≈2%, ≈850 yrs,   Abell 78: ≈2.5%, ≈700 yrs

Evidence for non-homologous expansion: the farthest regions have the smallest relative proper motions

Evidence for changes in brightness and morphology of the knots: non-radial pseudo-motions and brightening/fading of different features

Evidence for knot ablation and wind-mass loading: tail length increase

Stay tuned for Fang et al., in preparation, for a detailed analysis and Toalá et al., in preparation, for hydro-dynamical simulations