Characterising the circumstellar environment of pre-SN Ia systems

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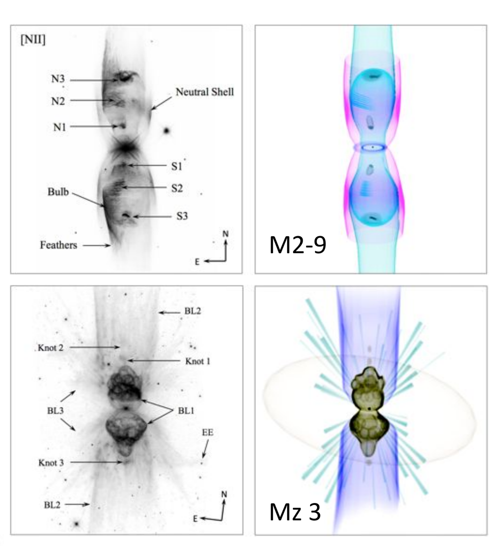
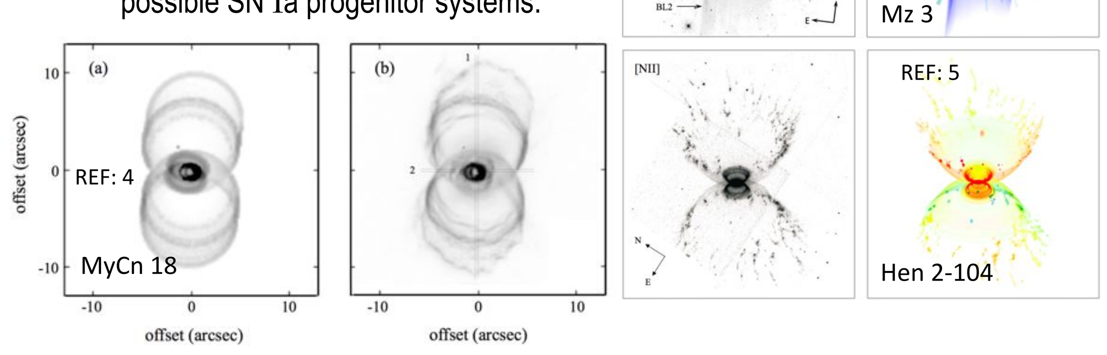
Classical & Recurrent novae as pre-SN Ia systems

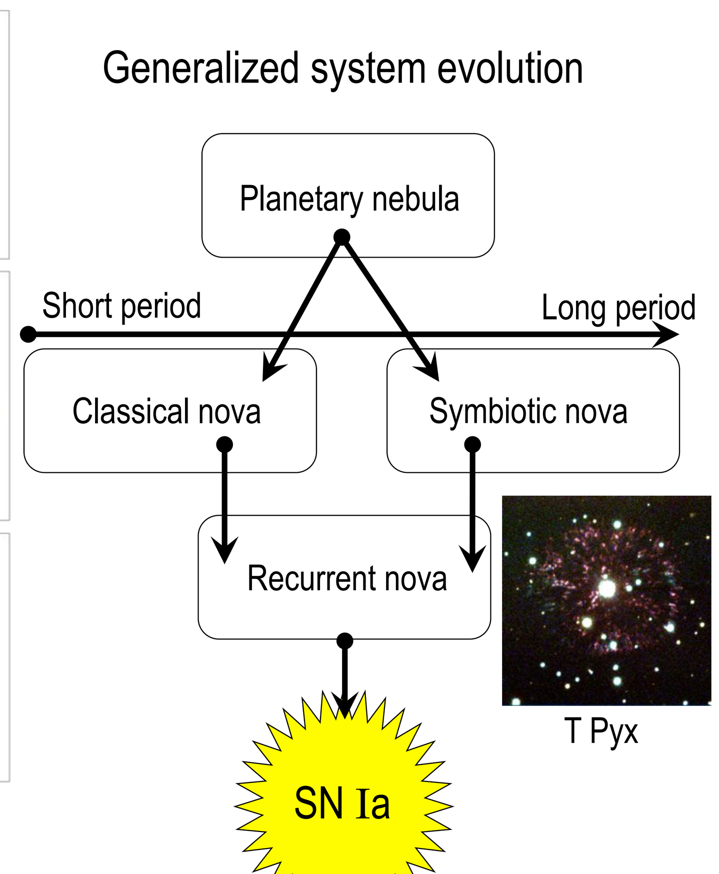
Classical novae are exciting objects that are well observed during outburst, but suffer from lack of attention during their quiescence. All classical novae are believed to reoccur, however only those that are seen to are called recurrent novae and do so on human timescales. The more frequent a nova's recurrence the closer it gets to the Chandrasekhar limit. To gain a fuller understanding of the character of evolving nova shells a campaign to study their morphology, structure and ionization was undertaken. As there are few (~40) known nova shells, a search through IR archives followed by an optical search with the Aristarchos 2.3 m telescope has led to the discovery of additional shells. In order to decipher the spatial and velocity constraints of these objects, long-slit high-resolution spectroscopy was undertaken at the San Pedro Martir 2.1 m telescope using the MES instrument. Aristarchos imaging paired with the MES spectroscopy allows for the construction of three-dimensional morpho-kinematic SHAPE[1] models of the shells.

The time evolution of the ionization structure of novae can also be followed using multi-epoch archival low and medium resolution spectra, which can be simulated using the Cloudy[2] code. The one-dimensional photoionization and three-dimensional morpho-kinematic models can then be combined via pyCloudy[3], a python wrapper for Cloudy. The result is a predicted spatial distribution for different emission lines and thus modeling the nova shell while quiescent allowing for a greater understanding of nova evolution and giving insight towards the environment into which type Ia supernovae expand.

- Symbiotic novae are wide binary systems with a Mira and WD – simultaneously pre-PN and post-PN.
- Classical novae are TNR events within tight binaries with a WD and MS star – again pre-PN & post-PN.
- Symbiotic, classical, recurrent novae and PNe all share morphological characteristics and are possible SN Ia progenitor systems.



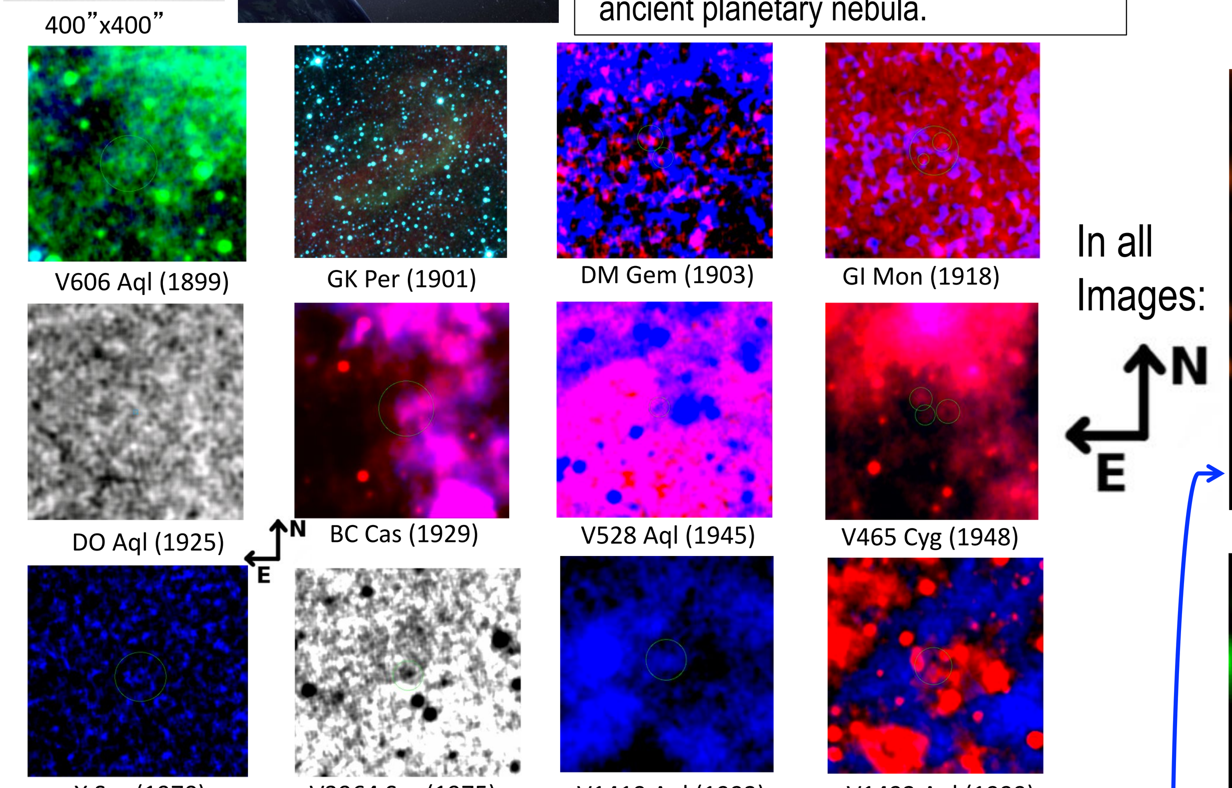




MyCn 18 = PN, M2-9 = PN, Mz 3 = PN, Hen 2-104 = SN, T Pyx = RN

WISE and Aristarchos search for nova shells

Pictured below is a sample of classical novae that were identified as having the potential of harbouring a shell with the exception being GK Per, which consists of a nova shell within an ancient planetary nebula.



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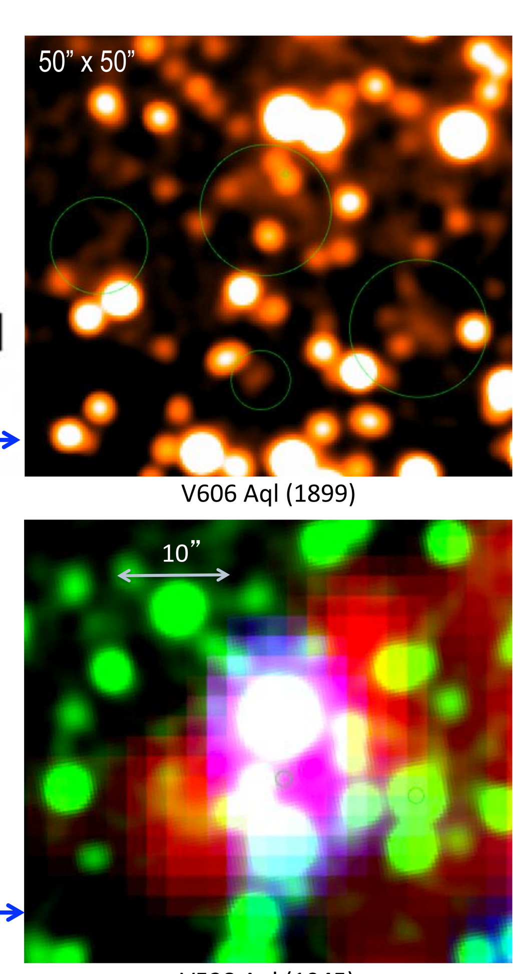
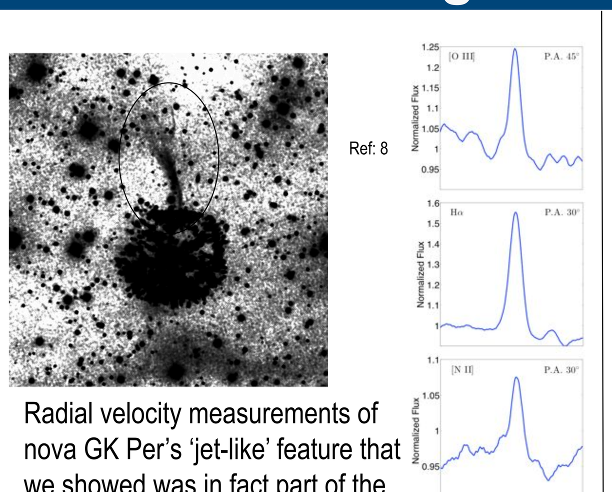


V606 Aql (1899)

V528 Aql (1945)

On the right are Aristarchos images of two classical nova shells that were discovered by following up hints of nebulosity in the WISE archive with the Greek 2.3m telescope. The upper right panel shows an inner dense core and a more diffuse extended lobe associated with V606 Aql. The lower panel has WISE bands 1 & 3 (blue and red) overlaid on the Aristarchos image of V528 Aql that we found was misidentified in the catalogues.

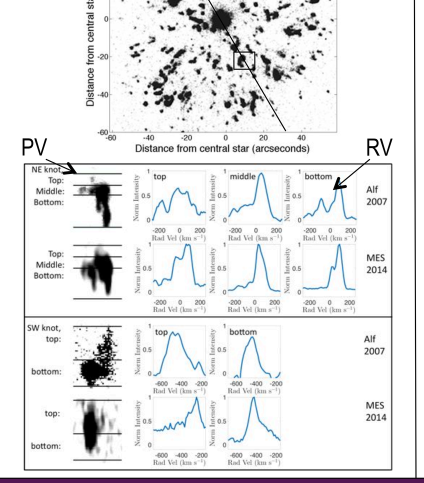
Long-slit Echelle Spectroscopy with MES



Radial velocity measurements of nova GK Per's 'jet-like' feature that we showed was in fact part of the ancient associated PN.

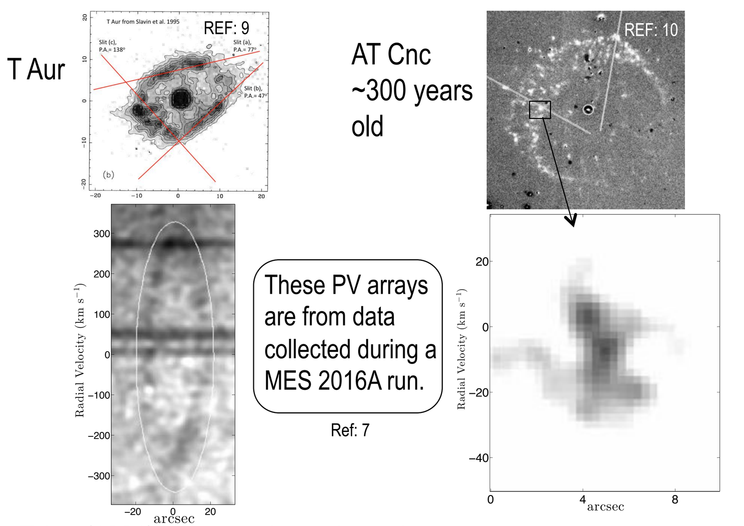
[O III] 5007Å	Hα 6562Å	[N II] 6583Å
14.3 km s^{-1}	16.1 km s^{-1}	16.6 km s^{-1}

GK Per (1901) Aristarchos image with corresponding ALFOSC ('07) and MES ('14) PV arrays and RV profiles.



T Aur

AT Cnc ~300 years old



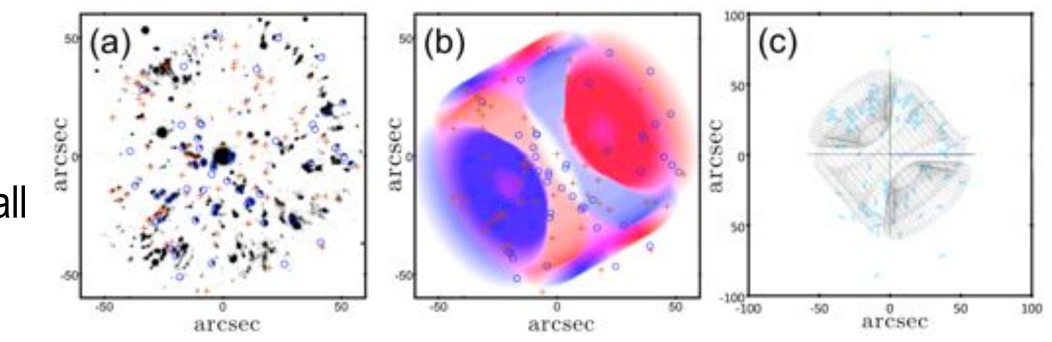
These PV arrays are from data collected during a MES 2016A run.

Ref: 7

T Aur (1891) has experienced considerable deceleration since erupting 125 years ago (~1/2 of its original velocity). There have been recent discoveries of ancient nova shells including that of AT Cnc, which is about 300 years old[10] (above right) .

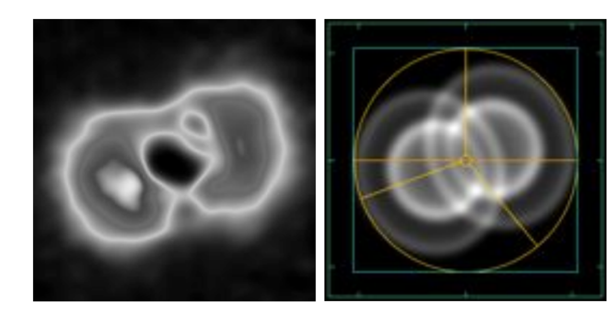
Morpho-kinematic modelling with SHAPE

GK Per (1901) has the longest period of any known classical nova system at 2 days. Its shell consists of at least a thousand knots[11] situated along an overall barrel structure with polar cones.

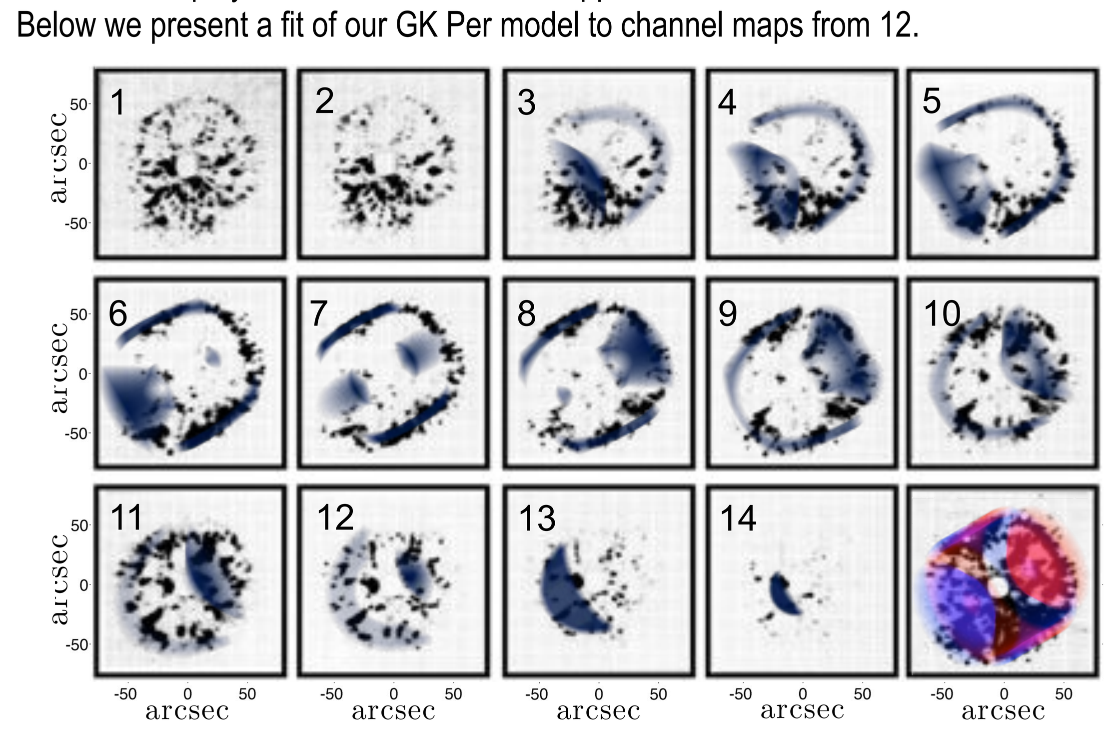


Above we display the observed red-blue doppler shift of the shell and the model fit. Below we present a fit of our GK Per model to channel maps from 12.

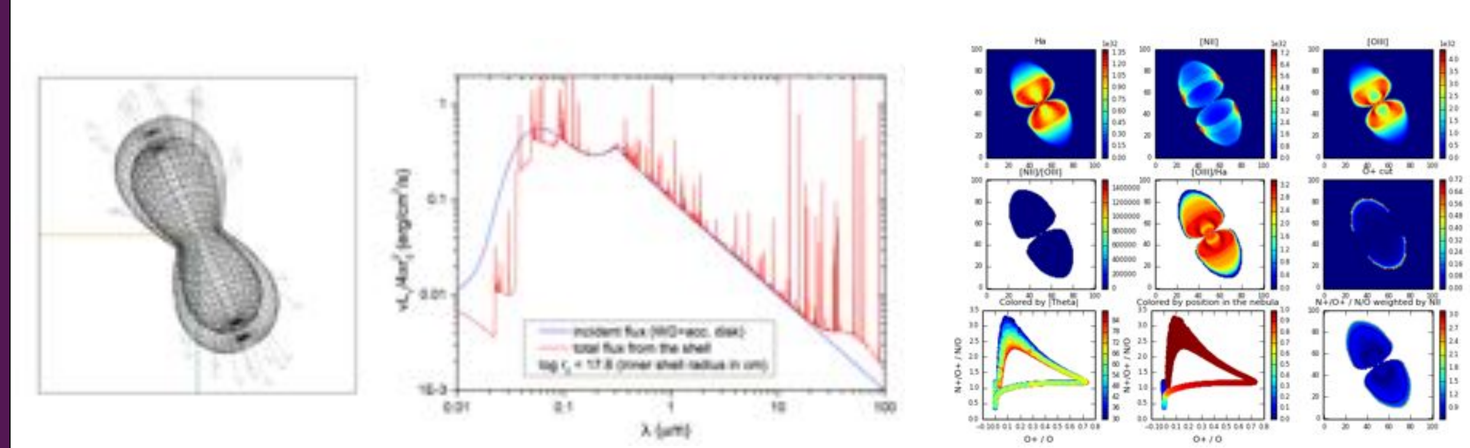
V1280 Sco (2007) is a young nova remnant whose bipolar morphology was detected two years after outburst, see 13. Another nova V339 Del was found to deviate from spherical symmetry days after maximum light[14].



NACO 2010 SHAPE model



Photoionization Modelling using pyCloudy



SHAPE model + Cloudy Model = pyCloudy model

Through combination of 3D morpho-kinematic models and 1D photoionization models we extract pseudo 3D emission models.

Recurrent novae growing towards M_{Ch}

For the pre-SN Ia systems described here their ejected matter accumulates to > 1 $M_\odot$ being swept up to a distance of roughly 1 parsec. However, before undergoing its SN Ia event the system is expected to undergo nova explosions every ~2 months such that the SN Ia ejecta should encounter the most recent nova ejecta around day 6 after ejection. Since the ejected shells of novae are non-spherical the material into which the SN Ia is expanding is not uniformly distributed. As well as the above examples the following table shows rough calculations of RN approaching M_{Ch} that estimate the remaining duration of the recurrent nova phases of the SN Ia progenitors from equations in 15.

Nova name	WD Mass ($M_\odot$)	Acc rate ($M_\odot$ yr^{-1})	Ejected Mass ($M_\odot$)	Inter-eruption T (yrs)	Growth Rate ($M_\odot$ yr^{-1})	Lifetime until SN Ia event	No. of known outbursts	Orbital T (days)	Distance (kpc)	Companion type
[15]RS Oph	1.35 h	1.2 x 10^{-7}	3-4 x 10^{-6}	8-12	5 x 10^{-8} – 1 x 10^{-7}	0.5 – 1 Myr	6	455.72	1.6	M0/2III
[15]T Crb	1.34 h	0.4 x 10^{-7}	3 x 10^{-6}	80	3.7 x 10^{-8}	1.6 Myr	2	227.67	1.3	M3III
[15]V3890 Sgr	≥ 1.35	1.1 x 10^{-7}	3 x 10^{-6}	28	1 x 10^{-7}	≤ 0.5 Myr	2	519.7	5.2	M5III
[15]V745 Sco	≥ 1.35	0.9 x 10^{-7}	5 x 10^{-6}	52	9.5 x 10^{-8}	≤ 0.53 Myr	2	510	4.6	M6III
[15]U Sco	1.37 ± 0.01	2.5 x 10^{-7}	3 x 10^{-6}	~10	2.7 x 10^{-7}	~ 0.1 Myr	7	1.23	6-14	K2IV
[16]V394 CrA	≥ 1.37	1.5 x 10^{-7}	6 x 10^{-6}	38	1.5 x 10^{-7}	≤ 0.2 Myr	2	0.758	5	K
[17&18]M31N 2008-12A	> 1.3	1.6 x 10^{-7}	3 x 10^{-8}	1 or 0.5	1.3 x 10^{-7} 2.6 x 10^{-7}	< 0.8 Myr	9		778	

Conclusion: type Ia supernovae occur within complex CSM

SN Ia occur in complex environments where previous stages of evolution, such as the planetary nebula and cataclysmic variable stages lead to knots, bipolarity, equatorial and polar over-densities surrounding the objects. Through the collective ejection episodes and swept up ISM several solar masses of debris is expected to accumulate in axisymmetric distributions around the SN Ia progenitor systems. This could introduce variations between type Ia SN systems dependent on the line-of-sight towards the object, or even produce the 'ears' seen in SN Ia remnants. These features can however be modelled in detail during the progenitor stages of evolution.

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