THE GK PERSEI NOVA SHELL AND ITS 'JET-LIKE' FEATURE

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Abstract. GK Persei (1901, the 'Firework Nebula') is an old but bright nova remnant that offers a chance to probe the physics and kinematics of nova shells. The kinematics in new and archival longslit optical echelle spectra were analysed using the SHAPE software. New imaging from the Aristarchos telescope continues to track the proper motion, extinction and structural evolution of the knots, which have been observed intermittently over several decades. We present for the first time, kinematical constraints on a large faint 'jet' feature, that was previously detected beyond the shell boundary. These observational constraints allow for the generation of models for individual knots, interactions within knot complexes, and the 'jet' feature. Put together, and taking into account dwarf-nova accelerated winds emanating from the central source, these data and models give a deeper insight into the GK Per nova remnant as a whole.

1 Introduction

GK Per (1901) is a nearby, historic and spectacular source with a proximity of 470pc Harrison et al., 2013. The system is one of only two classical novae observed within a planetary nebula to date, offering a chance to study the evolution of both classes of object.

A classical nova event is the result of thermonuclear runaway on the surface of a white dwarf accreting from, typically, a main sequence or a late G or K type star Warner, 1995. The accreted shell is ejected, at velocities that range from 5×10^2 to a few $\times 10^3$ km s^{-1} Bode et al., 2008. Dwarf novae, which are also exhibited by GK Per, are caused by an instability in the accretion disk surrounding the white dwarf star Osaki 1996. These events accelerate winds to the order of $1\text{-}6 \times 10^3$ km s^{-1}, see Kafka et al., 2004 and references therein. It is unknown if their ejection is spherically uniform or intrinsically bipolar Lloyd et al., 1997, Porter et al., 1998. The common envelope phase is thought to play a major role in the shaping of nova remnants and planetary nebulae alike. Slower nova

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events are believed to have stronger deviations from spherical symmetry e.g. V1280 Sco
Chesneau et al., 2012 when compared to their more energetic counterparts. The system
exhibits a pronounced stream of emission to the NE of the nova shell that is reminiscent
of a jet but whose origin has not been settled. New and archival observations are used to
explore the structure and kinematics of the GK Per nova shell.

2   Kinematics of the shell, knots and 'jet'

Using the Aristarchos telescope in Greece, new imaging was collected of GK Per in
September 2014. The observations consisted of three narrow band filters (Hα, [N ɪɪ]
and [O ɪɪɪ]), with 1800s exposures in each filter. Archival data of Liimets et al., 2012 was
used and of Lawrence et al., 1995, Shara et al., 2012. The imaging was reduced using
ɪʀᴀғ. To build a fuller view of the remnant and examine the 'jet-like' feature, Manchester
Echelle Spectrometer (MES) data were obtained at the San Pedro Mártir observatory in
Mexico. Position-Velocity (P-V) arrays were generated. The knot and shell P-V arrays
were simulated using the morpho-kinematic modelling code sʜᴀᴘᴇ Steffen et al., 2006[1].
A full discussion can be found in Harvey et al. (2016 in prep).

Shell kinematics: sʜᴀᴘᴇ modeling demonstrates that the shell most probably consists
of an oblate elongated ring-like equatorial structure (PA ~ 120° and inc ~ 54°) with polar
over-densities (Fig. 1). The 'boxy' nature of the nebula has long been observed e.g.
Seaquist et al., 1989. The position angle derived of the old nova shell fits that of the
'fossil' bipolar planetary nebula and the inclination to that of the binary. We find that
the 'polar caps' have a systematically lower expansion velocity than the rest of the shell.
In the IRSA archives the longer wavelength WISE Wright et al., 2010 bands show an
abundance of material along these polar regions, potentially having a significant effect on
their velocity structure evolution.

Knot Characteristics: In a clump-wind interaction their relative velocities must be
considered, as it is believed to be the main mechanism in the shaping of the clumps. Un-
der more uniform conditions, sub- sonic clumps have long tails and their supersonic coun-
terparts display short-stubby tails Pittard et al. 2005. There are a variety of tail shapes
present in GK Per suggesting diverse local flow conditions. The sinusoidal nature of the
tails of the knots along the outer edge of the shell are evident in the 1997 Hubble images
in Shara et al., 2012. These wavy tails could be attributed to shaping by the dwarf nova
winds, which can thus be found to have a velocity of ~ 4400 km s^{-1}. Bianchini et al., 1986
gave a velocity estimate of GK Per's dwarf nova winds of a few 1000 km s^{-1}.

Kinematics of the jet-like feature: Previously there have been several theories to
the origin of this feature, Bode et al., 2003, Anupama et al., 2005, Shara et al., 2012, first
mentioned in Anupama et al., 1993. Light-echo contours over IRAS imagery hinted that
it predated the nova shell Bode et al., 2003. As our new kinematic data suggests a low
velocity (<17 km s^{-1} with a Gaussian FHWM ranging from 30-40 km s^{-1}) we suggest
that the feature may be an illuminated part of the waist of the fossil planetary nebula.
This would also explain the curvature and spreading out of the feature. There is a slight

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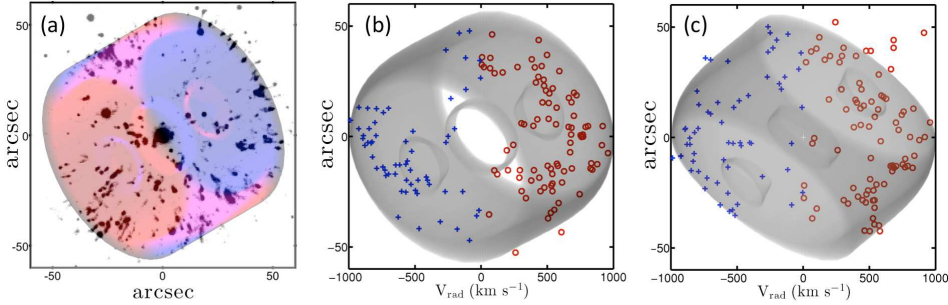[1]A full description of sʜᴀᴘᴇ can be found at $http://bufadora.astrosen.unam.mx/shape/$

Fig. 1: Panel (a) shows the red-blue Doppler distribution as derived from P-V arrays as well as channel maps overlaid on an image from the Mayall telescope, north is up and east is to the left. Panel (b) shows the observed radial velocities of 148 knots dependant on their 'y' position, i.e. from the north to south of the nebula, where the greyscale is the equivalent for the model created in SHAPE. Panel (c) is the same as the middle panel except the positional arguments are from the east to west.
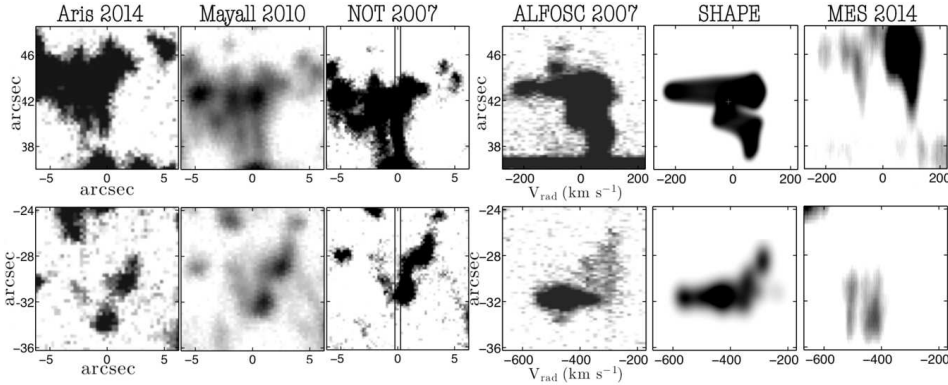

Fig. 2: Examples of knots progressing over time (2007-2014) and their corresponding P-V array and morpho-kinematic SHAPE model. Additional epoch P-V information is included, the knots here are along an axis of symmetry of the nova shell. The ALFOSC P-Vs correspond to the 2007 NOT image and the MES P-Vs correspond to the Aristarchos observations epoch.

augmentation in brightness of this line in the Hα and [O III] 5007 Å lines corresponding to the location of interaction with pre-existing material seen in radio and X-ray observations Anupama et al., 2005, Balman, 2005, Takei et al., 2015.

3　Discussion & Questions

One of the main findings from Liimets et al., 2012 was there is no significant deceleration of the knots in the SW quadrant of the nova shell, though it had been long believed

that the shell had been experiencing a stronger interaction with circumbinary material in this quadrant Duerbeck et al., 1987. The barrel with polar over-densities structure presented here, as well as the basic bullet crushing time calculation support their finding. Takei et al., 2015 indicates the system is moving through less dense material than during the time of the observations of Balman, 2005. The derived morphology is decidedly oblate, in contrast to the shapes of other nova shells e.g. Ribeiro et al., 2009, Munari et al., 2010. Lloyd et al., 1997 used a 2.5D code to investigate remnant shaping for a variety of speed classes and produced rings, blobs and caps as expected but also created oblate remnants. Later Porter et al., 1998 included the effects of a rotating accreted envelope, surprisingly the first panel in their Fig. 2 bares quite a resemblance to the morphology derived here.

SOKER: Have you looked at the jets in NGC 40 that are perpendicular to the shell?

HARVEY: Interesting but no. I will investigate.

HAMAGUCHI: Does your model fit the X-ray morphology?

HARVEY: It suggests that the flattened shell is an intrinsic feature and is supported by the non-perpendicular proper motion of the system from 1917-1993, derived by Bode.

DE MARCO: On the neon overabundance, could GK Per be a born again ABG star?

HARVEY: In photoionisation simulations, we conducted using Cloudy, a significant initial overabundance of neon was required. However, the stellar spectrum is not deficient in hydrogen nor enriched in helium, suggesting a nova origin is more likely.

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