Hα observations of Supernova remnants

Oliver Lux,
Ralph Neuhäuser, Markus Mugrauer, Baha Dinçel, Anna Pannicke

Astrophysikalisches Institut und Universitäts-Sternwarte Jena

Interstellar Medium in the Nearby Universe,
Bamberg, 26.-28.03.2018

Contents

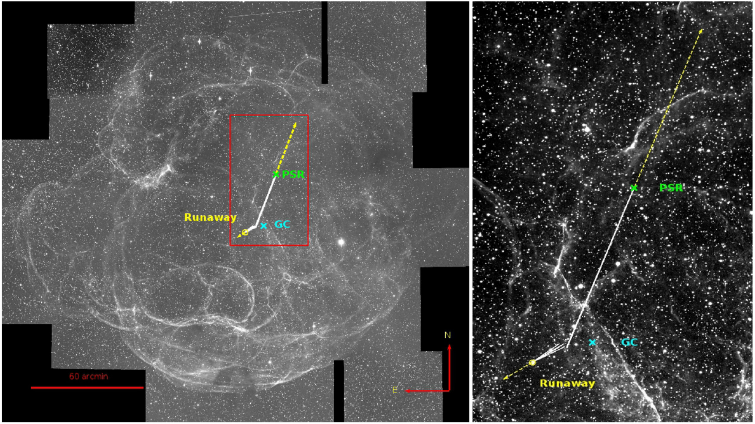
Runaway stars in supernova remnants (SNRs)

Motivation

- Currently 294 SNRs known in the Milky Way (Green 2014)
- Runaway stars:
  - produced either by dynamical interaction (Poveda et al. 1967)
  - or **ejection from a binary system after a supernova (SN) (Blaauw 1961)**
  - Velocities $v_{\mathrm{pec}} \gtrsim 25\,\mathrm{km/s}$ (Tetzlaff PhD, U Jena)
  - Example: HD 37424 in SNR S147 (Dinçel et al. 2015)
- We are looking for runaway stars of all spectral types in 30 Galactic SNRs with $d \lesssim 1.6\,\mathrm{kpc}$
- From a population synthesis (Boubert et al. 2017) it is expected that $\sim 1/3$ of all SNRs host a runaway star
  $\rightarrow$ We expect to find 9 further runaways

Goal

Finding the former companion, determine its properties
$\rightarrow$ Conclusions about SN physics and the evolution of the progenitor system



SNR S147 in Hα, Dinçel et al. 2015

- Runaway HD 37424
- PSR J0538+2817 (Kramer et al. 2003)
- $d = 1.33^{+0.10}_{-0.11}$ kpc, $t = 30 \pm 4$ kyr

- Centers as given in the Green (2014) catalog mainly based on radio observations
- Accuracy to the nearest few seconds of time and the nearest minute of arc, respectively, or coarser (Green 2009)
- Hα (6562.8 Å) emission mainly produced at the shock front
- Geometrical analysis of Hα images to derive SNR centres more precisely
- Constrain the area, in which we want to search for runaway candidates in *Gaia* DR2

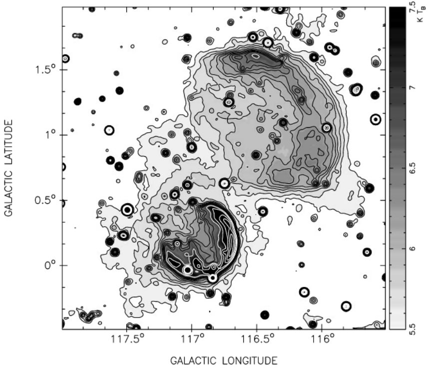


FIG. 3.—Contour map of CTB 1 (*lower left*) and G116.5+1.1 (*upper right*) at 21 cm radio continuum. Contours represent total intensity starting at 5.5 K T_B in steps of 0.12 K T_B up to 6.7 K T_B, in black. The higher emission regions are represented by white contours starting at 7 K T_B and 7.5 to 10.5 K T_B in steps of 1.0 K T_B.

Yar-Uyaniker et al. 2004

Xue & Schaefer (2015)

Motivation

- Analysed the centre of Tycho's Supernova:
  - From Tycho Brahes (and six other astronomers) astrometric measures in 1572 (black)
  - From intersections of perpendicular lines to baselines through the SNR in images at different wavelengths (blue)
  - Stars: Positions of proposed former companion candidates
- Centres consistent with each other
- Newly determined combined centre rules out some of the formerly suggested companion candidates and reveals new ones

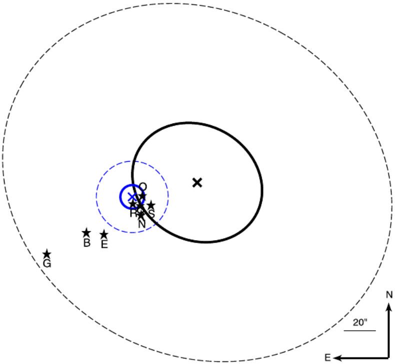


Figure 1 from Xue & Schaefer (2015): Two newly determined explosion sites of the Tycho SN (SNR G120.1+01.4)

Instrumentation

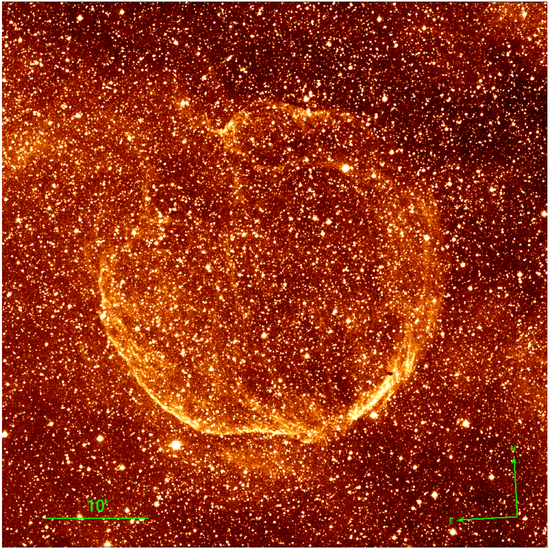
- Data taken at the Jena University Observatory, Großschwabhausen
- Schmidt Teleskop Kamera (STK): 90cm - Reflector telescope
- Detector: E2V CCD42-10
- Pixel 2048 x 2048
- FoV: 52.8' x 52.8'
- Filter: B, V, R, I, z, Hα
- Reference: Mugrauer & Berthold (2010)

http://www.astro.uni-jena.de/index.php/gsh-home.html

Name	RAJ2000	DEJ2000	Dist /kpc	D /arcmin	#Frames
G040.5−00.5[1]	19:07:10	+06:31	2.1 ± 1.1	22	1
G073.9+00.9[2]	20:14:15	+36:12	2.25 ± 1.75	27	1
G074.0−08.5 (Cygnus Loop)[3]	20:51:00	+30:40	0.55 ± 0.09	230×160	25
G089.0+04.7 (HB 21)[2]	20:45:00	+50:35	1.25 ± 0.45	90	9
G114.3+00.3[3]	23:37:00	+61:55	0.7	90×55	4
G116.5+01.1[3]	23:53:40	+63:15	1.6	80×60	4
G116.9+00.2 (CTB 1)[2]	23:59:10	+62:26	2.55 ± 0.95	34	1

[1] : No Hα emission visible
[2] : Analysed
[3] : Under construction

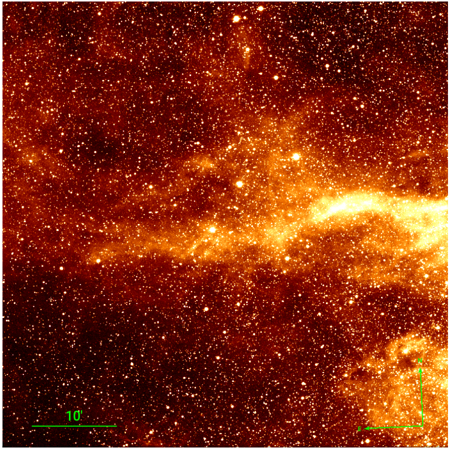
Data taken from the catalogs from Green (2014) and Ferrand & Safi-Harb (2012). All images were taken between June and August 2017 with the STK at cooling temperature -22°C, exposure time 3×600 s and airmass < 1.8.



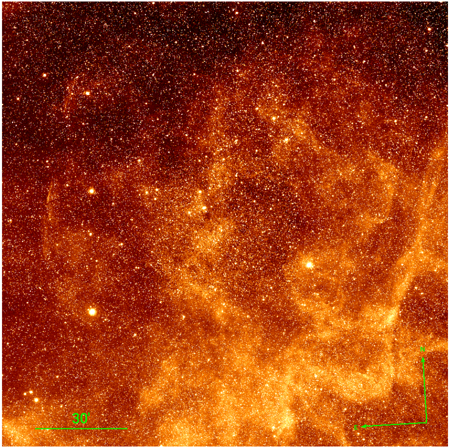
- Data reduction with *Eclipse*
- Further construction (appearance, framing) with *ds9* and *MaximDl*

Reduced Images: G073.9+00.9 and HB 21

Observations



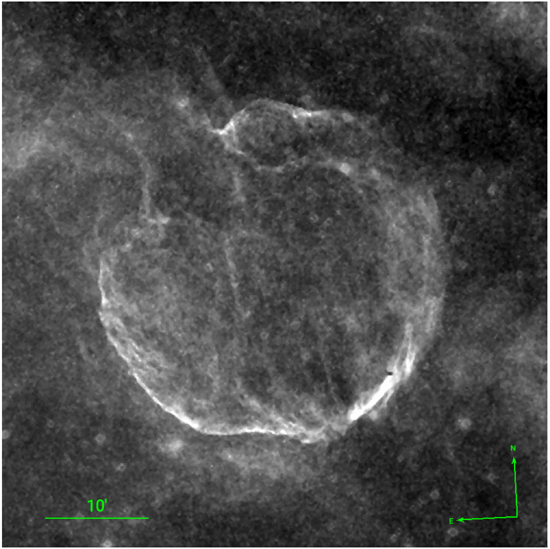
G073.9+00.9



G089.0+04.7 (HB 21)

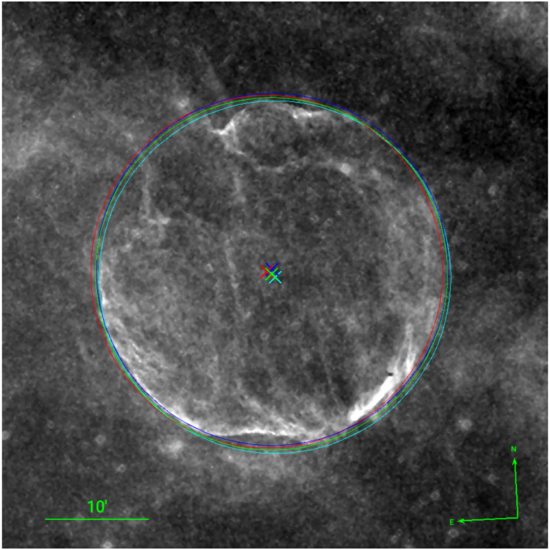
CTB 1 Circle Fits

Preliminary Analysis



CTB 1 Circle Fits

Preliminary Analysis



- Naive attempt:
  - Fitting different circles (here: $r = 17'$, consistent with Green) onto the edge of the SNR by eye
  - SNR centre as mean of different circle centres

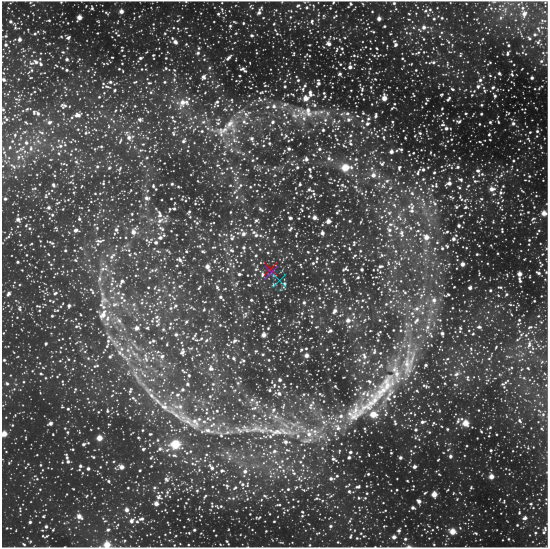
CTB 1 Light centre

Preliminary Analysis

- *Python* code to calculate the flux-weighted mean position of the pixel values
- Slightly varying bounding boxes, to take into account the uncertainty in recognising the edge of the SNRs
- Final result as mean of the individuals

CTB 1 Comparison

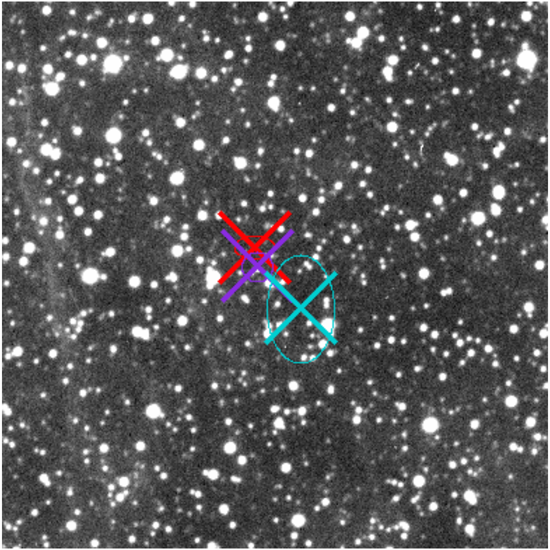
Preliminary Analysis



- Results for circle fit and light centre consistent with each other
- Both are close to the Green centre, which is shown for comparison
- RA $= 359.820 \pm 0.013$ deg, DEC $= 62.453 \pm 0.004$ deg
- RA $= 359.819 \pm 0.010$ deg, DEC $= 62.447 \pm 0.005$ deg
- RA $= 359.792 \pm 0.021$ deg, DEC $= 62.433 \pm 0.017$ deg

CTB 1 Comparison

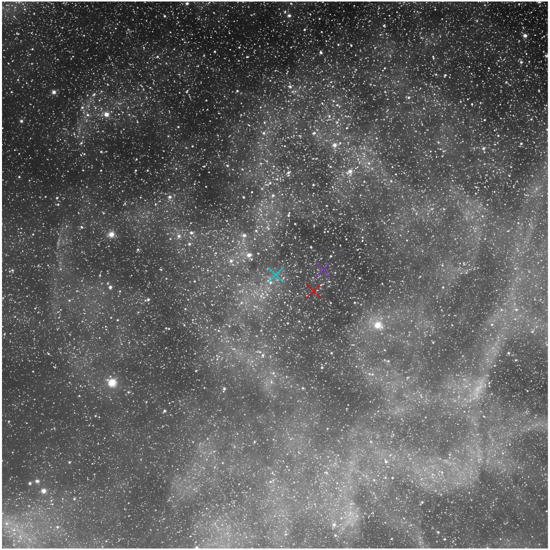
Preliminary Analysis



- Results for circle fit and light centre consistent with each other
- Both are close to the Green centre, which is shown for comparison
- RA $= 359.820 \pm 0.013\,$deg, DEC $= 62.453 \pm 0.004\,$deg
- RA $= 359.819 \pm 0.010\,$deg, DEC $= 62.447 \pm 0.005\,$deg
- RA $= 359.792 \pm 0.021\,$deg, DEC $= 62.433 \pm 0.017\,$deg

HB 21 Comparison

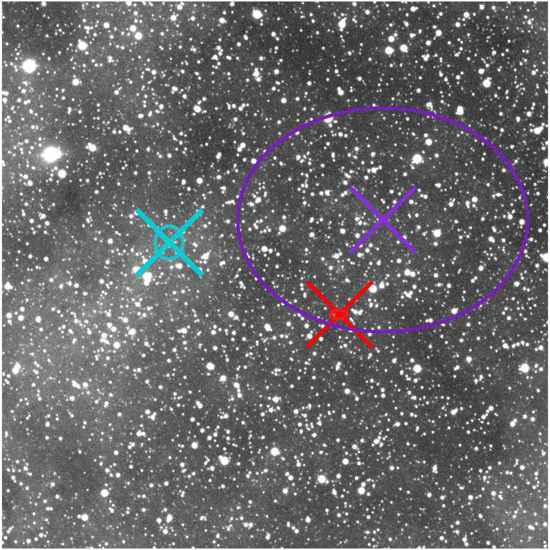
Preliminary Analysis



- RA $= 310.991 \pm 0.012$ deg, DEC $= 50.506 \pm 0.004$ deg
- RA $= 310.92 \pm 0.23$ deg, DEC $= 50.60 \pm 0.11$ deg
- RA $= 311.250 \pm 0.021$ deg, DEC $= 50.583 \pm 0.017$ deg

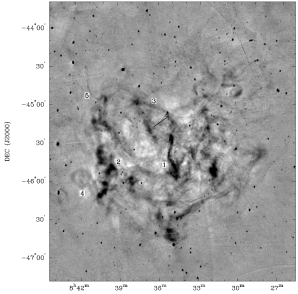
HB 21 Comparison

Preliminary Analysis

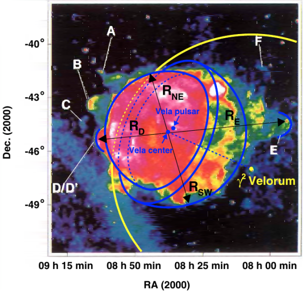


- RA $= 310.991 \pm 0.012$ deg, DEC $= 50.506 \pm 0.004$ deg
- RA $= 310.92 \pm 0.23$ deg, DEC $= 50.60 \pm 0.11$ deg
- RA $= 311.250 \pm 0.021$ deg, DEC $= 50.583 \pm 0.017$ deg

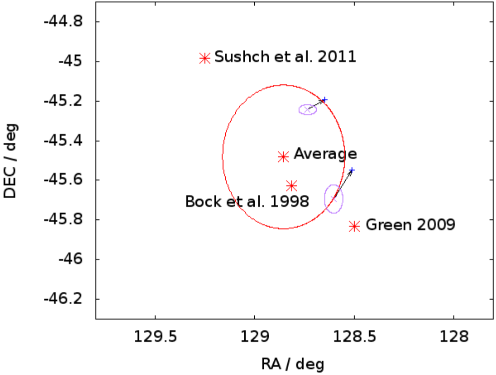
- Suggested methods work well for SNRs with a well-defined, roughly circular shape
- Results can be slightly more precise than Green (2009)
- Applying the method from Xue & Schaefer will give a further independent measure
- Problems: In some cases no Hα emission visible (G040.5$-$00.5) or indefinite shape (G073.9+00.9)
- Possible extension: Use SNR images from as many wavelength regimes as possible and average the results
- Example: Vela. Calculate average of
  - Green centre (Radio)
  - X-ray (ROSAT 0.1$-$2.4 KeV, Sushch et al. 2011)
  - Radio 843 MHz (Molonglo, Bock et al. 1998)



Bock et al. 1998

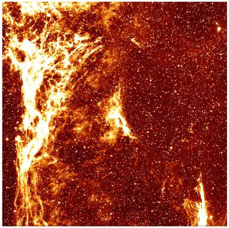


Sushch et al. 2011



Future Prospects

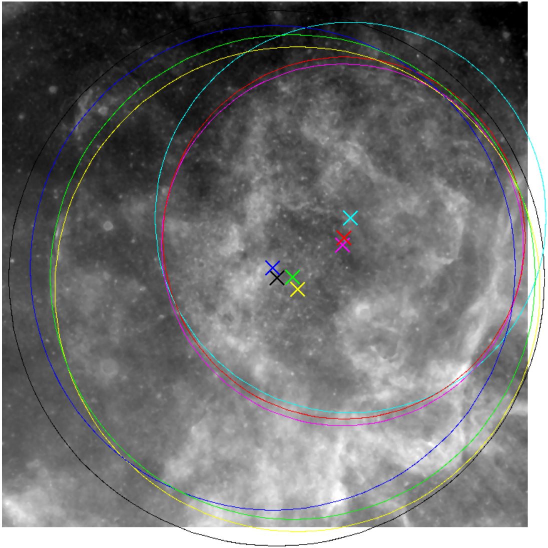
Discussion and Future Prospects



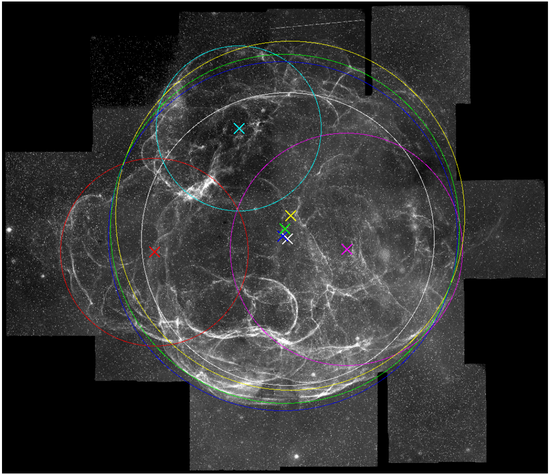
- Data reduction done for Cygnus Loop, G114.3+00.3 and G116.5+01.1. Averaging and framing in progress
- Hα observations of 11 further SNRs on the other half of the northern sky (not yet completed due to bad weather)
- First spectroscopic observations of runaway candidates done at the VLT
  $\rightarrow$ Need Hα observations also on the southern sky
- If a pulsar is known $\rightarrow$ trace back trajectory to check if it is consistent with the centre
- If runaway stars can be identified, this will yield the most precise estimate about time and location of the supernova


Thank you
for your attention!

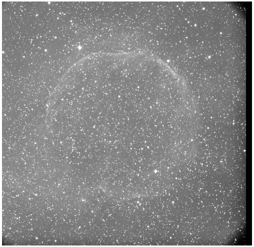
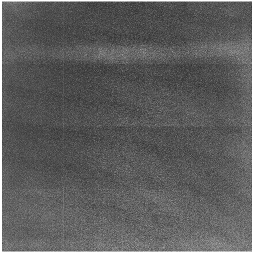
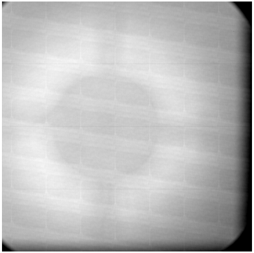
HB 21 Circle Fits



S147 Circle Fits



SNR CTB 1 Data Reduction

( − ) / 

=