Searching for runaway stars in supernova remnants

Oliver Lux,
Ralph Neuhäuser, Markus Mugrauer

Astrophysikalisches Institut und Universitäts-Sternwarte Jena

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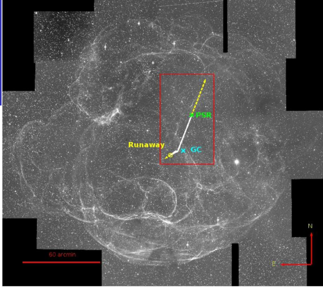
Contents

Motivation

Introduction

- **Search for runaway stars in near and historical core-collapse SNRs**
  → conclusions about the nature of the SNe and the evolution of their progenitor systems



SNR S147, Dinçel et al. 2015


Vela, apod.nasa.gov / Marco Lorenzi

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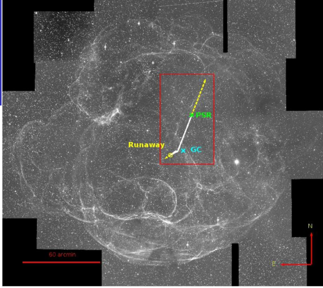
- **Search for runaway stars in near and historical core-collapse SNRs $\rightarrow$ conclusions about the nature of the SNe and the evolution of their progenitor systems**
- Up to now, most studies focussed on O- and B-type runaway stars $\rightarrow$ Now we also consider later spectral types



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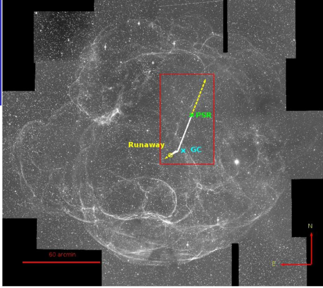
- Up to now, most studies focussed on O- and B-type runaway stars → Now we also consider later spectral types
- Using precise *Gaia* astrometry → More candidates, smaller errors
- This way we should find all nearby runaway stars and constrain their production rate
- If a neutron star is known, we could determine its kinematic age



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Runaway stars

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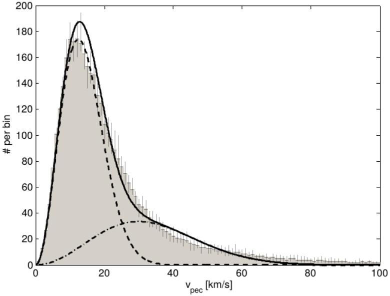
  - **Ejection from a binary system after a SN** (Blaauw 1961)
- Velocities $(25 \lesssim v_{\rm pec} \lesssim 1000)\,\rm km/s$ (Tetzlaff PhD, U Jena)
- Different directions compared to the bulk motion of stars



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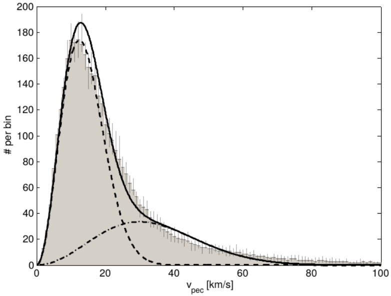

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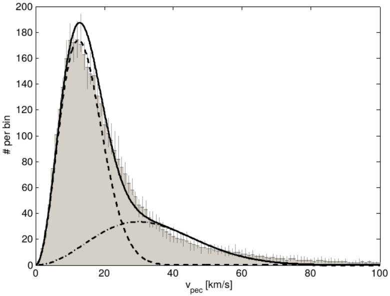
- *Hypervelocity stars*: Higher velocity, accelerated by dynamical interaction with *Sgr A**



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Previous work

- Hoogerwerf et al. (2000, 2001):
  $\rightarrow$ Traceback of 56 runaway star trajectories from *Hipparcos* data
  $\rightarrow$ Suggested common origin of ζ Oph and PSR B1929+10, falsified by later works
  Update: ζ Oph connected with PSR B1706$-$16 and the SN that ejected ^{60}Fe found in the earth crust (Neuhäuser, Gießler, Hambaryan 2019)
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  $\rightarrow$ 3 good candidates (inkl. HD 37424)

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  → Bayesian runaway probabilities of stars in 10 northern SNRs from *Gaia*-data
  → 3 good candidates (inkl. HD 37424)
- Renzo et al. (2019)
  → Population synthesis of massive binaries →$\sim$ 67 % of all binaries eject the secondary; $\sim 95^{+2}_{-14}$ % of all ejected MS-companions are *Walkaway* stars

Candidate selection SNRs

Sample selection

- We want to find runaways from core-collapse SNe, down to the latest possible spectral types

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- Plus 3 historical SNRs, age exactly known

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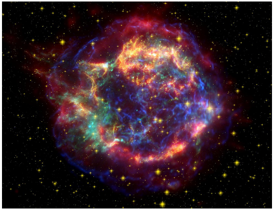
- SNR data taken from catalogs from Green (2009, 2014)
  $\rightarrow$ e.g. Geometrical center coordinates
  and U Manitoba (Ferrand & Safi-Harb 2012)

Candidate selection SNRs

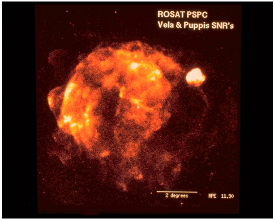
Sample selection

- Vela, Vela Jr., Lupus Loop, Cygnus Loop, HB9, Monoceros Loop
- Historical: Cas A, 3C58 (SN 1181), SN 393

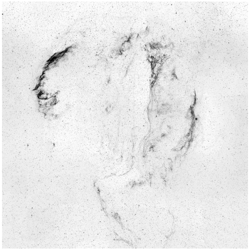


Cassiopeia A, Multi-wavelength (Spitzer, HST, Chandra) NASA / JPL-Caltech

3C58, Chandra X-ray NASA/CXC/SAO

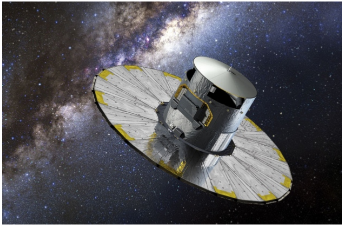


Vela region, X-ray MPE Garching



Cygnus Loop, GSH Hα, U Jena

- Stellar positions, proper motions and parallaxes from *Gaia*



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D. Ducros, 2013

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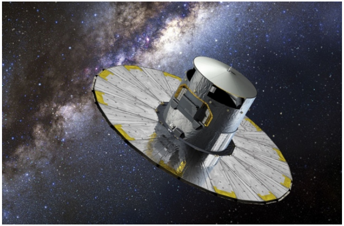
- Stellar positions, proper motions and parallaxes from *Gaia*
- Maximum runaway velocity 1280 (550) km/s for stars with 0.9 (10) $M_\odot$ (Tauris 2015), but much smaller on average



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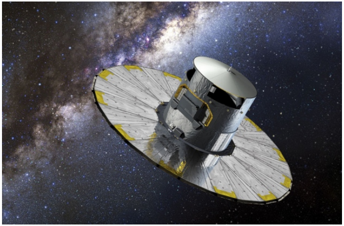

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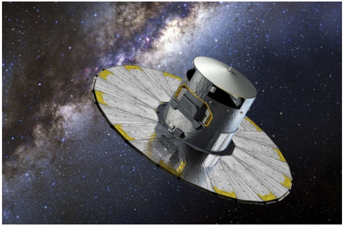

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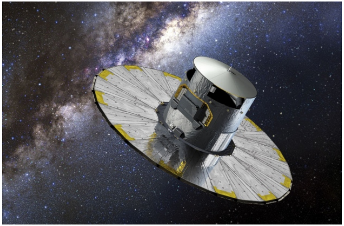
- Tracing back the trajectories of the stars $\rightarrow$ **Candidate, if position at the time of the SN is within the error range of the geometrical center, or of an associated neutron star**



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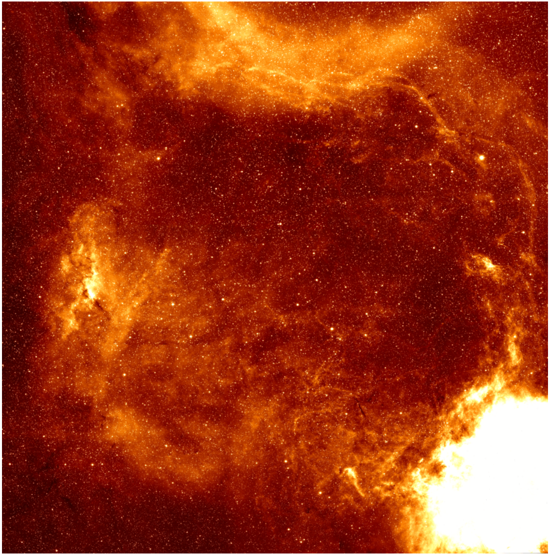
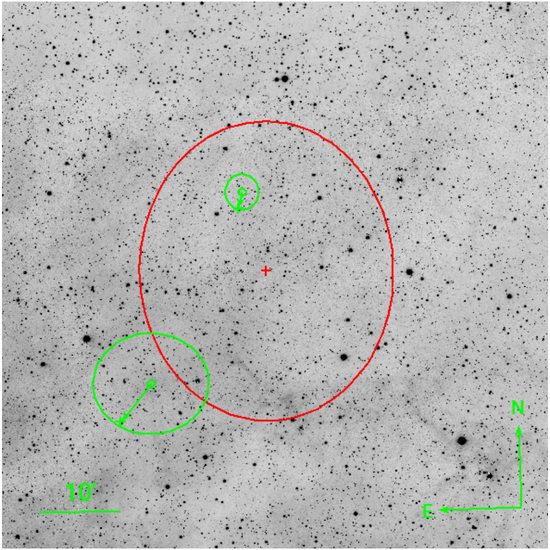

GSH Hα, Uni Jena

- Diameter 220 arcmin
- Distance 1100 ± 500 pc
- Age 90000 ± 60000 yr
- No associated PSR

Monoceros Loop

Sample selection



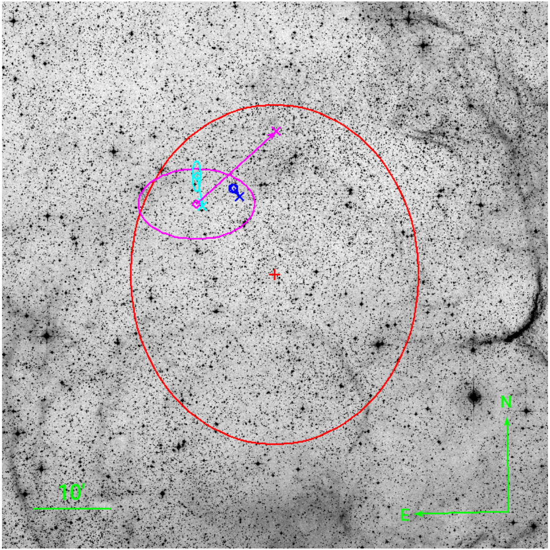
GSH Hα, Uni Jena

Vela (XYZ)

Sample selection

- Diameter
  255 arcmin
- Distance
  275 ± 25 pc
- Age
  18000 ± 9000 yr
- PSR characteristic age 11300 yr

Vela (XYZ)
Sample selection

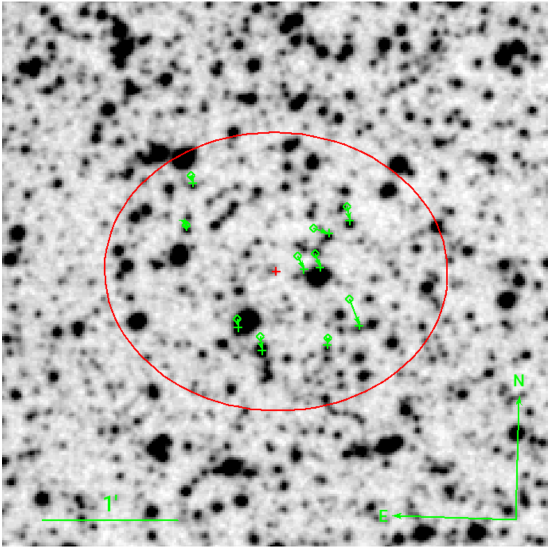


ESO-DSS Red

- Geometric center and error ellipse
- Vela PSR.
  x: current position,
  ⋄: Position at time of SN
  with error ellipse
- *Gaia* DR2 candidate
- Star A from Fraser & Boubert (2019) (*Gaia* DR2)

G347.3−00.5 from SN 393

Sample selection



ESO-DSS Red

- Diameter 65 × 55 arcmin
- Distance 1300 ± 400 pc
- Age 1626 yr
- 10 runaway candidates from *Gaia* DR2

Observations of runaway candidates

Observations

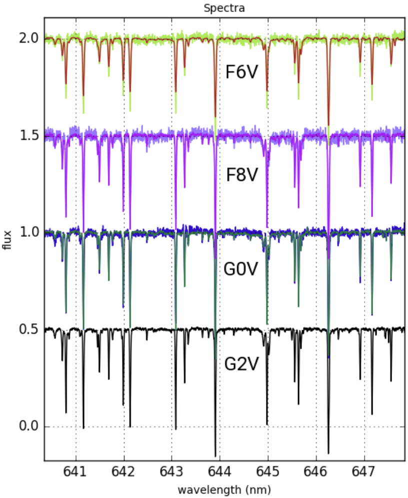
- High-resolution spectroscopy
- Up to now: Observations of runaway candidates in 7 SNRs with VLT/UVES (Chile, South) and Subaru/HDS (Hawaii, North)
- Selected from *Gaia* DR1 TGAS (distance limit 1.6 kpc); fainter stars from DR2 are yet to be observed

Wikimedia Commons / ESO (top); Denys (bottom)

Spectral properties of runaway stars

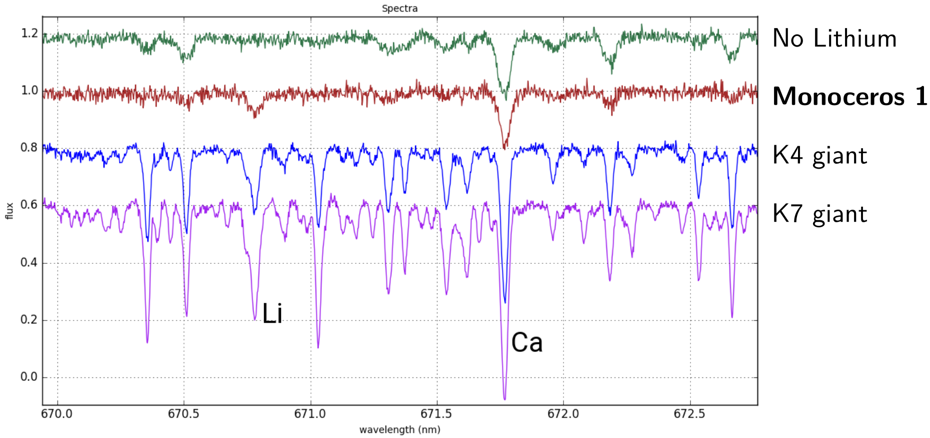
Observations

- (Re)determination of the spectral type
- For FGKM-stars: Lithium 6708 Å as indicator for a low age
- Exclude additional absorption lines, which would indicate that the star lies in the background
- Radial velocity: Consistent with motion away from the SNR center?
- Rotational velocity: Mass transfer?
- Later: SN debris in the stellar atmosphere (heavy- and α elements) $\rightarrow$ clear proof



Spectra

Analysis

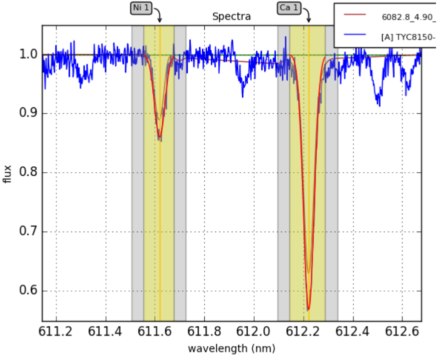


- VLT: Observations of 33 candidates in 5 SNRs → Lithium detected in 5 stars, among which 4 can be excluded as giants → **1 good candidate**

Spectra - Parameter fits with iSpec

Analysis

- Wavelength range 6035 - 7003 Å
- Fitting of model spectra to Fe, Ca, Si and Ni lines to determine the atmospheric parameters (temperature, surface gravity, metallicity, micro- and macroturbulence, rotational velocity)
- Radial velocity v_r measured with iSpec, Li equivalent width (EW) with IRAF splot



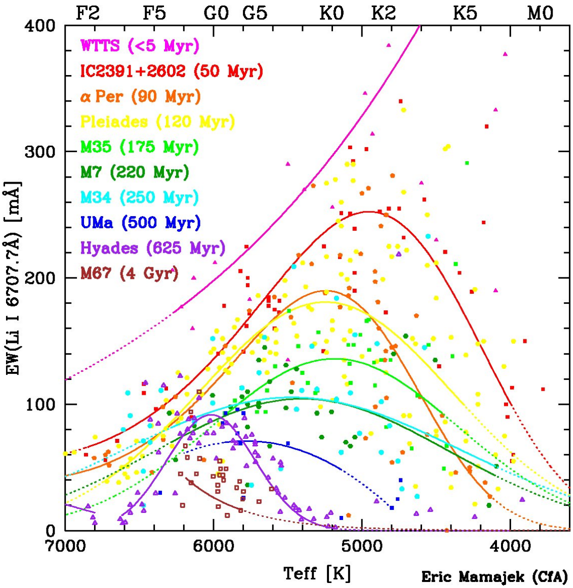
CaI 6122 Å

Star	T_{eff} / K	Li EW / Å	Li log(N)	v_r / km/s	v_{space} / km/s
Monoceros 1	7138 ± 397	0.031 ± 0.014	$2.67^{+0.15}_{-0.27}$	22.27 ± 0.41	25.69 ± 0.43

Spectral type F0 – F3 from T_{eff} according to Pecaut & Mamajek 2013
$\rightarrow$ very uncertain, comparison to reference stars yields F1 – F2

Comparison to cluster ages

Analysis



- Curves (fitted to dots): T_{eff} vs. Li EW for clusters of different ages

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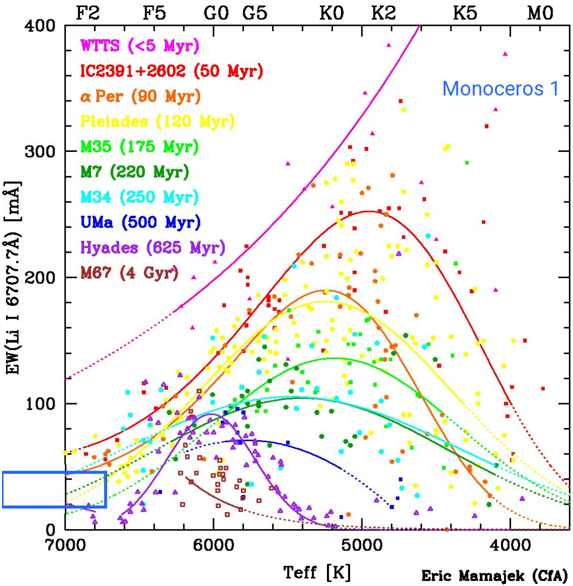

- Curves (fitted to dots): T_{eff} vs. Li EW for clusters of different ages
- Rectangle: T_{eff} and Li EW ranges for our Li candidate
- Comparison to cluster ages (Mamajek) yields 90 – 250 Myr → too old

Lithium abundances and applicability

Analysis

TABLE 2. Lithium abundances for the 6708 Å feature.

$\log W_\lambda(6708)$	Effective Temperature										
	4000	4250	4500	4750	5000	5250	5500	5750	6000	6250	6500
3.00	3.571	3.821	4.221	4.653	—	—	—	—	—	—	—
2.95	3.451	3.700	4.099	4.527	4.969	—	—	—	—	—	—
2.90	3.327	3.577	3.973	4.400	4.815	—	—	—	—	—	—
2.85	3.202	3.447	3.836	4.261	4.662	—	—	—	—	—	—
2.80	3.068	3.307	3.691	4.115	4.508	4.904	—	—	—	—	—
2.75	2.925	3.159	3.538	3.959	4.348	4.712	—	—	—	—	—
2.70	2.773	3.003	3.370	3.788	4.173	4.519	4.874	—	—	—	—
2.65	2.603	2.825	3.183	3.591	3.973	4.317	4.642	4.978	—	—	—
2.60	2.419	2.628	2.973	3.376	3.746	4.088	4.409	4.708	5.000	—	—
2.55	2.212	2.413	2.741	3.128	3.492	3.832	4.146	4.438	4.714	4.971	—
2.50	1.980	2.176	2.495	2.872	3.226	3.557	3.872	4.161	4.429	4.686	4.900
2.45	1.740	1.936	2.256	2.624	2.967	3.295	3.600	3.889	4.154	4.400	4.637
2.40	1.517	1.722	2.045	2.404	2.745	3.065	3.367	3.647	3.907	4.149	4.377
2.35	1.324	1.540	1.870	2.225	2.559	2.873	3.167	3.440	3.694	3.929	4.152
2.30	1.163	1.386	1.725	2.079	2.400	2.715	3.000	3.271	3.517	3.747	3.962
2.25	1.029	1.265	1.596	1.953	2.280	2.580	2.868	3.130	3.368	3.593	3.803
2.20	0.920	1.156	1.496	1.845	2.167	2.472	2.751	3.005	3.246	3.469	3.676
2.15	0.816	1.061	1.397	1.750	2.071	2.370	2.649	2.906	3.140	3.357	3.561
2.10	0.729	0.972	1.315	1.663	1.980	2.282	2.557	2.808	3.043	3.260	3.463
2.05	0.645	0.895	1.233	1.580	1.902	2.196	2.474	2.726	2.956	3.170	3.371
2.00	0.567	0.817	1.158	1.507	1.823	2.123	2.393	2.645	2.876	3.090	3.289
1.95	0.496	0.748	1.089	1.435	1.753	2.050	2.323	2.570	2.797	3.011	3.208
1.90	0.426	0.681	1.019	1.367	1.685	1.979	2.252	2.501	2.729	2.941	3.138
1.85	0.360	0.613	0.956	1.303	1.618	1.915	2.184	2.432	2.660	2.873	3.069
1.80	0.297	0.552	0.894	1.239	1.556	1.851	2.122	2.367	2.593	2.804	3.000
1.75	0.235	0.492	0.832	1.178	1.496	1.789	2.060	2.307	2.533	2.743	2.939
1.70	0.177	0.432	0.775	1.122	1.436	1.731	1.998	2.246	2.473	2.683	2.878
1.65	0.123	0.376	0.723	1.065	1.379	1.674	1.947	2.188	2.413	2.623	2.817
1.60	0.070	0.324	0.672	1.008	1.328	1.617	1.896	2.137	2.361	2.569	2.764
1.55	0.017	0.272	0.620	0.956	1.277	1.564	1.846	2.087	2.311	2.519	2.714
1.50	−0.036	0.220	0.566	0.904	1.226	1.513	1.794	2.036	2.260	2.470	2.665
1.45	−0.089	0.166	0.510	0.853	1.173	1.462	1.739	1.985	2.210	2.420	2.615
1.40	−0.143	0.111	0.455	0.801	1.118	1.411	1.683	1.930	2.156	2.367	2.561
1.35	−0.196	0.057	0.400	0.747	1.063	1.358	1.628	1.875	2.101	2.312	2.506
1.30	−0.249	0.002	0.347	0.694	1.009	1.305	1.573	1.820	2.046	2.257	2.451
1.25	−0.302	−0.052	0.293	0.640	0.956	1.251	1.519	1.766	1.992	2.202	2.396
1.20	−0.355	−0.107	0.240	0.586	0.903	1.198	1.466	1.713	1.939	2.149	2.342
1.15	−0.409	−0.162	0.186	0.534	0.850	1.146	1.412	1.660	1.886	2.096	2.289

Soderblom et al. (1993)

TABLE 2. Lithium abundances for the 6708 Å feature.

$\log W_\lambda(6708)$	Effective Temperature										
	4000	4250	4500	4750	5000	5250	5500	5750	6000	6250	6500
3.00	3.571	3.821	4.221	4.653	—	—	—	—	—	—	—
2.95	3.451	3.700	4.099	4.527	4.969	—	—	—	—	—	—
2.90	3.327	3.577	3.973	4.400	4.815	—	—	—	—	—	—
2.85	3.202	3.447	3.836	4.261	4.662	—	—	—	—	—	—
2.80	3.068	3.307	3.691	4.115	4.508	4.904	—	—	—	—	—
2.75	2.925	3.159	3.538	3.959	4.348	4.712	—	—	—	—	—
2.70	2.773	3.003	3.370	3.788	4.173	4.519	4.874	—	—	—	—
2.65	2.603	2.825	3.183	3.591	3.973	4.317	4.642	4.978	—	—	—
2.60	2.419	2.628	2.973	3.376	3.746	4.088	4.409	4.708	5.000	—	—
2.55	2.212	2.413	2.741	3.128	3.492	3.832	4.146	4.438	4.714	4.971	—
2.50	1.980	2.176	2.495	2.872	3.226	3.557	3.872	4.161	4.429	4.686	4.900
2.45	1.740	1.936	2.256	2.624	2.967	3.295	3.600	3.889	4.154	4.400	4.637
2.40	1.517	1.722	2.045	2.404	2.745	3.065	3.367	3.647	3.907	4.149	4.377
2.35	1.324	1.540	1.870	2.225	2.559	2.873	3.167	3.440	3.694	3.929	4.152
2.30	1.163	1.386	1.725	2.079	2.400	2.715	3.000	3.271	3.517	3.747	3.962
2.25	1.029	1.265	1.596	1.953	2.280	2.580	2.868	3.130	3.368	3.593	3.803
2.20	0.920	1.156	1.496	1.845	2.167	2.472	2.751	3.005	3.246	3.469	3.676
2.15	0.816	1.061	1.397	1.750	2.071	2.370	2.649	2.906	3.140	3.357	3.561
2.10	0.729	0.972	1.315	1.663	1.980	2.282	2.557	2.808	3.043	3.260	3.463
2.05	0.645	0.895	1.233	1.580	1.902	2.196	2.474	2.726	2.956	3.170	3.371
2.00	0.567	0.817	1.158	1.507	1.823	2.123	2.393	2.645	2.876	3.090	3.289
1.95	0.496	0.748	1.089	1.435	1.753	2.050	2.323	2.570	2.797	3.011	3.208
1.90	0.426	0.681	1.019	1.367	1.685	1.979	2.252	2.501	2.729	2.941	3.138
1.85	0.360	0.613	0.956	1.303	1.618	1.915	2.184	2.432	2.660	2.873	3.069
1.80	0.297	0.552	0.894	1.239	1.556	1.851	2.122	2.367	2.593	2.804	3.000
1.75	0.235	0.492	0.832	1.178	1.496	1.789	2.060	2.307	2.533	2.743	2.939
1.70	0.177	0.432	0.775	1.122	1.436	1.731	1.998	2.246	2.473	2.683	2.878
1.65	0.123	0.376	0.723	1.065	1.379	1.674	1.947	2.188	2.413	2.623	2.817
1.60	0.070	0.324	0.672	1.008	1.328	1.617	1.896	2.137	2.361	2.569	2.764
1.55	0.017	0.272	0.620	0.956	1.277	1.564	1.846	2.087	2.311	2.519	2.714
1.50	−0.036	0.220	0.566	0.904	1.226	1.513	1.794	2.036	2.260	2.470	2.665
1.45	−0.089	0.166	0.510	0.853	1.173	1.462	1.739	1.985	2.210	2.420	2.615
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log W_λ(6708)	Effective Temperature 4000	4250	4500	4750	5000	5250	5500	5750	6000	6250	6500
3.00	3.571	3.821	4.221	4.653	—	—	—	—	—	—	—
2.95	3.451	3.700	4.099	4.527	4.969	—	—	—	—	—	—
2.90	3.327	3.577	3.973	4.400	4.815	—	—	—	—	—	—
2.85	3.20									—	—
2.80	3.06									—	—
2.75	2.92									—	—
2.70	2.77									—	—
2.65	2.60									—	—
2.60	2.41								00	—	—
2.55	2.21								14	4.971	—
2.50	1.98								29	4.686	4.900
2.45	1.74								54	4.400	4.637
2.40	1.51								07	4.149	4.377
2.35	1.32								94	3.929	4.152
2.30	1.16								17	3.747	3.962
2.25	1.02								68	3.593	3.803
2.20	0.92								46	3.469	3.676
2.15	0.81								40	3.357	3.561
2.10	0.72								43	3.260	3.463
2.05	0.64								56	3.170	3.371
2.00	0.56								76	3.090	3.289
1.95	0.49								97	3.011	3.208
1.90	0.42								29	2.941	3.138
1.85	0.36								60	2.873	3.069
1.80	0.29								93	2.804	3.000
1.75	0.23								33	2.743	2.939
1.70	0.17								73	2.683	2.878
1.65	0.12								13	2.623	2.817
1.60	0.07								61	2.569	2.764
1.55	0.01								11	2.519	2.714
1.50	−0.03								260	2.470	2.665
1.45	−0.08								210	2.420	2.615
1.40	−0.143	0.111	0.455	0.801	1.118	1.411	1.683	1.930	2.156	2.367	2.561
1.35	−0.196	0.057	0.400	0.747	1.063	1.358	1.628	1.875	2.101	2.312	2.506
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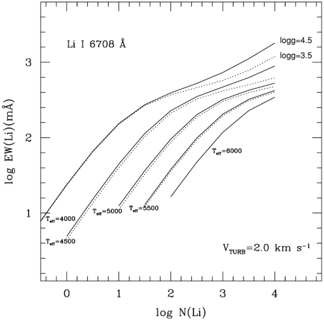

Figure 5. Li I λ6707.8 curves of growth for temperatures between 3500 K and 6000 K from Pavlenko & Magazzü (1996). The solid lines are for log $g = 4.5$; the dashed lines are for log $g = 3.5$.

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log W_λ(6708)	4000	4250	4500	4750	5000	5250	5500	5[illegible]			
	Effective Temperature										
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2.95	3.451	3.700	4.099	4.527	4.969	—	—				
2.90	3.327	3.577	3.973	4.400	4.815	—	—				
2.85	3.20[illegible]										
2.80	3.06[illegible]										
2.75	2.92[illegible]										
2.70	2.77[illegible]										
2.65	2.60[illegible]										
2.60	2.41[illegible]										
2.55	2.21[illegible]										
2.50	1.98[illegible]										
2.45	1.74[illegible]										
2.40	1.51[illegible]										
2.35	1.32[illegible]										
2.30	1.16[illegible]										
2.25	1.02[illegible]										
2.20	0.92[illegible]										
2.15	0.81[illegible]										
2.10	0.72[illegible]										
2.05	0.64[illegible]										
2.00	0.56[illegible]										
1.95	0.49[illegible]										
1.90	0.42[illegible]										
1.85	0.36[illegible]										
1.80	0.29[illegible]										
1.75	0.23[illegible]										
1.70	0.17[illegible]										
1.65	0.12[illegible]										
1.60	0.07[illegible]								[illegible]	[illegible]	[illegible]
1.55	0.01[illegible]								[illegible]311	2.519	2.714
1.50	−0.03								[illegible]260	2.470	2.665
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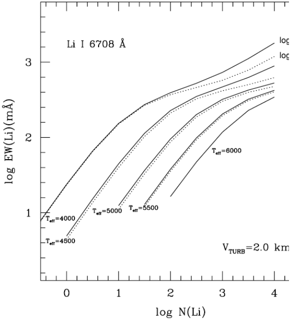

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F. D'Antona and I. Mazzitelli: Lithium depletion in stars

Table 6. See Table 1, but $M = 1.1 M_\odot$

log(age)	$\log(L/L_\odot)$	$\log T_e$	$\log T_c$	$\log \varrho_c$	M_{conv}	T_{conv}	Li/*init*
4.001	1.602	3.659	5.925	−1.997			1.000
5.016	0.959	3.647	6.215	−1.127			1.000
6.007	0.269	3.624	6.507	−0.249			1.000
6.267	0.097	3.621	6.580	−0.001	0.073	6.531	0.998
6.717	−0.170	3.622	6.691	0.521	0.407	6.523	0.974
7.018	−0.262	3.633	6.789	0.991	0.701	6.480	0.951
7.174	−0.181	3.657	6.868	1.304	0.863	6.408	0.949
8.111	0.007	3.761	7.136	1.874			0.949
9.014	0.056	3.769	7.149	1.949			0.949

Table 7. See Table 1, but $M = 1.2 M_\odot$

log(age)	$\log(L/L_\odot)$	$\log T_e$	$\log T_c$	$\log \varrho_c$	M_{conv}	T_{conv}	Li/*init*
4.020	1.661	3.664	5.943	−2.017			1.000
5.007	1.030	3.656	6.234	−1.147			1.000
6.005	0.328	3.630	6.527	−0.261	0.009	6.515	1.000
6.283	0.144	3.627	6.599	0.014	0.144	6.522	0.998
6.614	−0.049	3.627	6.679	0.404	0.397	6.514	0.990
7.030	−0.105	3.652	6.828	1.089	0.815	6.422	0.980
8.058	0.188	3.791	7.164	1.876			0.980
9.012	0.252	3.800	7.186	1.979			0.980

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2.50	1.98									
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1.85	0.36									
1.80	0.29									
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1.70	0.17									
1.65	0.12									
1.60	0.07									
1.55	0.01							311	2.519	2.714
1.50	−0.03							260	2.470	2.665
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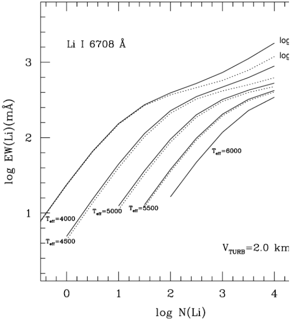

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6.007	0.269	3.624	6.507	−0.249			1.000
6.267	0.097	3.621	6.580	−0.001	0.073	6.531	0.998
6.717	−0.170	3.622	6.691	0.521	0.407	6.523	0.974
7.018	−0.262	3.633	6.789	0.991	0.701	6.480	0.951
7.174	−0.181	3.657	6.868	1.304	0.863	6.408	0.949
8.111	0.007	3.761	7.136	1.874			0.949
9.014	0.056	3.769	7.149	1.949			0.949

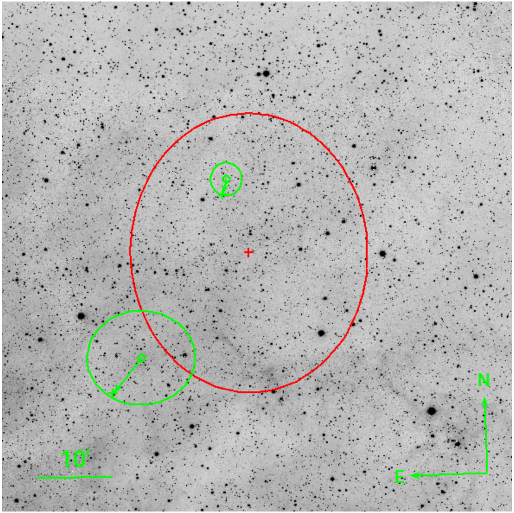
Table 7. See Table 1, but $M = 1.2\,M_\odot$ -> SpT F7 (Pecaut & Mamajek 2013)

log(age)	$\log(L/L_\odot)$	$\log T_e$	$\log T_c$	$\log \varrho_c$	M_{conv}	T_{conv}	Li/*init*
4.020	1.661	3.664	5.943	−2.017			1.000
5.007	1.030	3.656	6.234	−1.147			1.000
6.005	0.328	3.630	6.527	−0.261	0.009	6.515	1.000
6.283	0.144	3.627	6.599	0.014	0.144	6.522	0.998
6.614	−0.049	3.627	6.679	0.404	0.397	6.514	0.990
7.030	−0.105	3.652	6.828	1.089	0.815	6.422	0.980
8.058	0.188	3.791	7.164	1.876			0.980
9.012	0.252	3.800	7.186	1.979			0.980

- Not applicable to Monoceros 1 with SpT F1–2

Monoceros Loop

Analysis



GSH Hα, Uni Jena

- Runaway candidates consistent with movement away from the SNR center
- Monoceros 1:
  - Li EW $= 0.031^{+0.014}_{-0.012}$ Å
  - $T_{\text{eff}} = 7138 \pm 397$ K
  - SpT $\sim$ F1

    $\rightarrow$ No conclusive age estimate possible from Li
- HD261393 (Boubert et al. 2017) $\rightarrow$ consistent with beeing a runaway
- +11 further cands. observed in ESO P100

Summary

- Search for runaway stars in 9 SNRs; selection of runaway candidates from *Gaia* data and spectroscopic observations with VLT and Subaru

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- **Vela (XYZ)**: 1 DR2 candidate near PSR yet to be observed, Fraser cand. too faint for spectroscopy
- **Vela Jr.**: Many uncertain cands. (PSR proper motion unknown)
- **Monoceros Loop**: 13 cands., 1 early-F with Li, 1 from Boubert et al. (2017)
- **HB9**: No cands. in vicinity of PSR
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- **Lupus Loop**: 2 DR2 cands., yet to be observed
- **Cassiopeia A**: No cands.
- **3C58**: No cands. in vicinity of PSR
- **SN 393**: 6 DR2 cands. (G $<$ 17.0), yet to be observed

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- **Cassiopeia A**: No cands.
- **3C58**: No cands. in vicinity of PSR
- **SN 393**: 6 DR2 cands. ($G < 17.0$), yet to be observed
- $\Rightarrow$ **Total**: 27 cands.

Future work

- Proposals for remaining *Gaia* DR2 candidates submitted
- Currently: Lux et al. in prep.
- Kinematic analysis of the candidates $\rightarrow$ trace back 3D trajectory (incl. RV)
- If candidates can be verified, redermination of the SNR parameters (age, distance, expansion velocity) and the pre-SN binary properties
- For future searches: Careful re-determination of the explosion sites – biggest uncertainty!

Thank you
for the attention!

Atmospheric parameters

- Metallicity always assumed as $Fe/H = 0$ (solar)
- T_{eff} can be compared to *Gaia* DR2 $\rightarrow$ Consistent, but precision not higher

Star	T_{eff}/K	$\log(g)$	$v_t^{mic}/km/s$	$v_t^{mac}/km/s$	$v_{rot} \times \sin(i)/km$
Sun	5973 ± 81	4.66 ± 0.24	0.84 ± 0.26	2.2 ± 0.7	2.5 ± 0.6
lit.	5771	4.44	1.07	4.21	1.60
Monoceros 1	7138 ± 397	3.5 ± 1.4	2.9 ± 1.3	14.2 ± 7.8	8.9 ± 9.8
Gaia	7079 ± 232				
Vela 1	5960 ± 215	4.3 ± 1.0	1.0 ± 0.6	0	0
Gaia	5853 ± 100				
Vela 2	6117 ± 236	4.9	1.3 ± 0.3	2.4 ± 15.7	13.3 ± 3.3
Gaia	5614 ± 228				
Vela Jr 1	6476 ± 205	4.7 ± 0.7	1.2 ± 0.6	0	0
Gaia	6061 ± 192				
Vela Jr 2	6058 ± 171	4.3 ± 0.8	1.2 ± 0.5	1.4 ± 4.8	0
Gaia	5806 ± 77				