On the spatially and temporally resolved Supernova rate in the Solar vicinity

Where to search for unknown nearby neutron stars as gravitational wave sources - a population study of massive stars within 5 kpc

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Outline

- Einstein@home: all-sky survey cannot be reduced with best angular and timing resolution due to limited computing power

→ concentrate on small areas with a higher detection probability for gravitational waves (GWs) or neutron stars (NSs)?

- galactic super nova (SN) rate so far from indirect indications (counting SNe in other galaxies, etc., e.g. Tammann et al. (1994))
- **100...140 NSs** younger than 4 Myr should be **expected** within 1 kpc (Gould Belt, local mini-star burst): Popov et al., 2003-08, Palomba (2005); 120 ccSN progenitors (our work)
- **only 15 are known yet** (ATNF database) including Magnificent Seven (thermal radio quiet NS)

Idea: getting local super nova rate and small areas with possible over abundance of young precessing neutron stars from local population of SN progenitors assume: local SN rate in the near future ≈ local SN rate of the recent past (few Myrs)

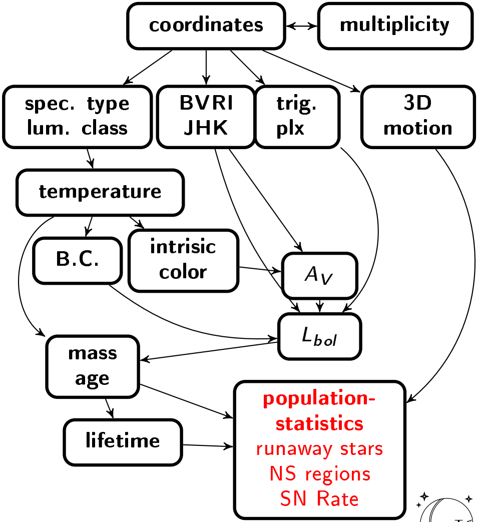
- **spatial distribution of SNe, young neutron stars, and GW sources (small areas on sky with temporal and spatial resolution)**
- study / find nearby neutron stars and massive binaries
- predictions of observability of neutron stars (log N – log S)
- prediction also of areas with more young nearby neutron stars, which can be either precessing ($\rightarrow$ GWs) or which may be non-symmetric (spin-down due to GW emission, e.g. Wette et al. 2008)
- compare local future SN rate with Galactic SN rate

previous study:

Hohle, Neuhäuser and Schutz 2010

- 2 323 O- & B stars + red super giants within 3 kpc, all observed with both HIPPARCOS ($V < 8$ mag) *and* 2MASS
- i.e. all known possible nearby SN progenitors observed best
- mass luminosity relation for lum. class I-IV
- BVRIJHK magnitudes

→ broad wavelength coverage yields extinction correction of brightness and good temperature estimate



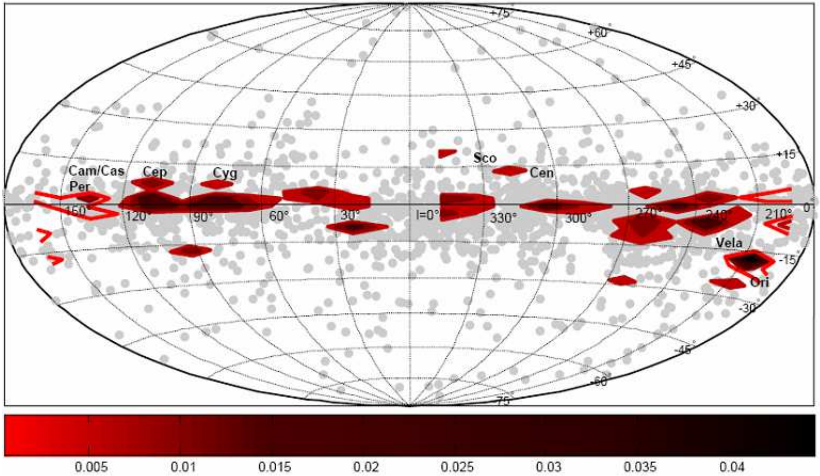


Figure : SN progenitors within 600 pc taken from Hohle et al. (2010), grey dots: all massive stars, red: areas with locally increased SN rate

our new study:

- expanding the sample from 3 kpc to all known massive stars in our Galaxy (not only HIPPARCOS and 2MASS stars): O- & B stars + red super giants *and* Wolf-Rayet stars
- Sample includes 23 407 stars (within 3 kpc 2 323)

→ 27 301 stars after correction for multiplicity (within 3 kpc 2 366), (multiple stars counted multiple), but very probable still incomplete

- usage of most recent data e.g. spectral classification (Skiff 2012, Sota et al. (2011)), photometry, multiplicity, evolutionary models, etc.

selection criteria: all SN progenitors

Sample

all known stars with following properties:

lum. class	I,II	III	IV,V,?
sp.type	all	O-B9	O-B4

- stars with those spec. types and lum. classes have masses $\gtrsim 8 M_\odot$
- 27 301 stars found

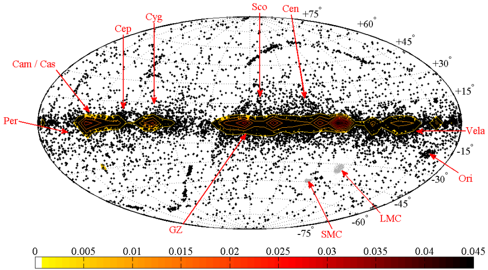


Figure : relative amount of our stars per 7 deg^2

Intrinsic values

search for supernova progenitors with $M > 8M_\odot$ and remaining life time $\tau \leq 10$ Myr

Luminosity and temperature

- evolution of stars / nucleosynthesis
- luminosity L_{bol} and effective temperature T_{eff}
- effective temperature from catalogues with spectral types and luminosity classes

$\rightarrow$ homogeneous / discrete classification

Intrinsic values

Bolometric Luminosity

- radiation in whole wavelength range

$$L_{bol}[L_{\odot}] = 10^{0.4\cdot(5\log_{10} d - 5 + 4.74 - m_{Vm} + A_V - B.C._V)}$$

- d distance [pc]
- apparent measured magnitude $m_{Vm} = m_V + A_V$ in V band
- reddening due to visual interstellar extinction A_V
- bolometric correction $B.C._V$

Intrinsic values

Physical Hertzsprung-Russell diagram (H-R D)

- luminosity and effective temperature
- plot into H-R D and derive mass and age with models:
  - Claret (2004) ($0.8\ M_\odot < M < 125\ M_\odot$)
  - Schaller et al. (1992) ($0.8\ M_\odot < M < 125\ M_\odot$)
  - Bertelli et al. (1994) ($0.8\ M_\odot < M < 34\ M_\odot$)
  - Meynet & Maeder (2003) (WR stars)

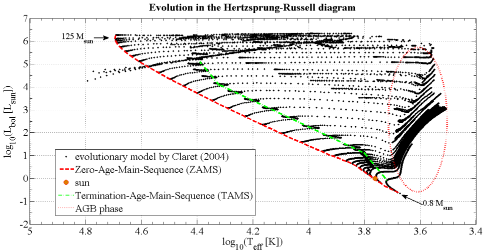
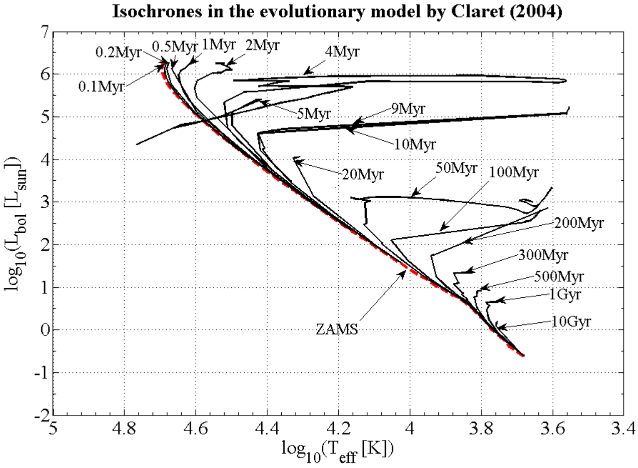


Figure : mass tracks in the theoretical H-R D by Claret (2004)

Age from evolutionary models



including:

- mass dependent evolution
- opacity
- convection
- core over-shooting
- solar metallicity

Multiplicity

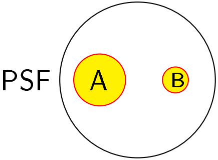


Figure : unresolved binaries yield misidentification of SN progenitors due to overestimated brightness, hence appear too massive

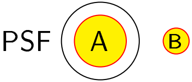


Figure : resolved binaries

resolving binaries

- Zinnecker & Yorke (2007): most massive stars are multiple (our sample ≈10%)
- detectable by spectroscopy
- then distribute photons to both stars
- measuring e.g. V magnitude of components
- follow up observations in progress to find remaining multiples

Multiplicity

massive eclipsing binaries

- dynamical masses
- radial velocity & Keplerian orbit
- dynamical masses more exact than model dependent masses
- five catalogues (Bondarenko & Perevozkina 2004; Brancewicz & Dworak 1980; Docobo & Andrade 2006; Perevozkina & Svechnikov 2004; Surkova & Svechnikov 2004)

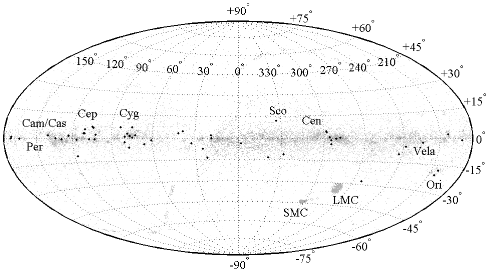


Figure : galactic distribution of 53 multiple stars with at least two components with $M > 8M_{\odot}$

still to be done: study of binary interaction total number of stars: 27 301

Parameter	number of stars
trigonometric distance within 5 kpc	4 739
spectral classification / temperature	25 913
luminosity class	16 862
photometry	21 274
multiplicity	3 894

- 4 739 stars can be analysed similar to Hohle et al. (2010) (all data are known: distance, BVJHK, spec. type, lum. class)
- within 5 kpc and remaining lifetime shorter than 10 Myr: **482** probable SN progenitors with $M \geq 8\ M_\odot$; 1 025 probable & possible SN progenitors with $M + 1\sigma \geq 8\ M_\odot$
- expected future improvement: better distance measurements with Gaia

Hertzsprung-Russell diagram

physical H-R D

- only 356 stars below ZAMS
- due to uncertain distances

→ calculation of mass and age

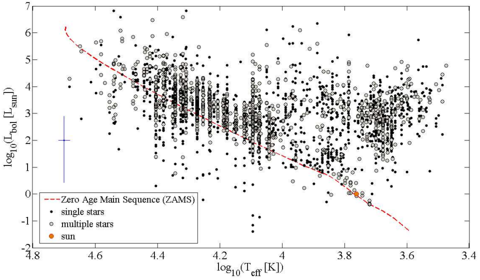


Figure : Hertzsprung-Russell diagram with derived L_{bol} and T_{eff}

consistency checks

mass function

- $\lg N \sim -\gamma \cdot \lg M/M_\odot$
- for M>10 $M_\odot$ in this work: γ=2.17±0.39
- for M>1 $M_\odot$ Kroupa et al. (1993): γ=2.7± 0.7

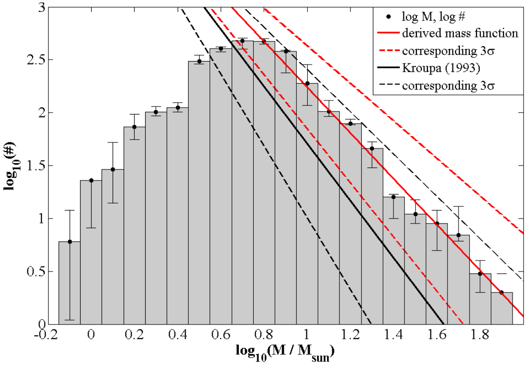


Figure : mass function of stars

consistency checks

Mass luminosity relation

- valid for main sequence stars
- $L \sim M^{\beta}$
- this work β=3.59±0.14
- Hohle et al. (2010): β=3.66±0.12
- Andersen (1991): β=3.84
- Hilditch (2001): β=3.6 for $M > 10 M_{\odot}$

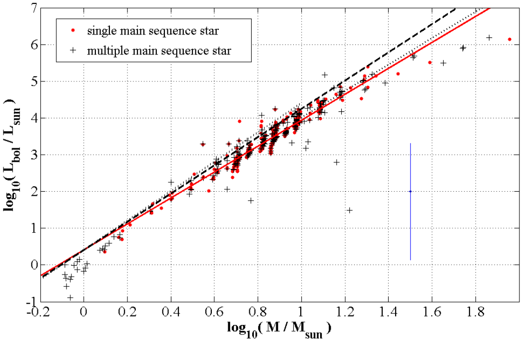


Figure : M-L relation for main sequence stars

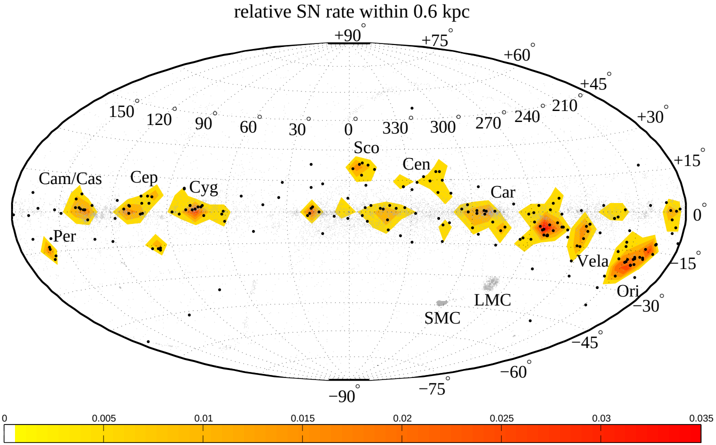


Figure : grey dots: all massive stars, black dots: SN progenitors within 600 pc (J. Schmidt, diploma thesis, 2011; Schmidt et al. 2012 in prep.); all SN events in 8 % area of the sky, 90 % events in 5 % area of the sky

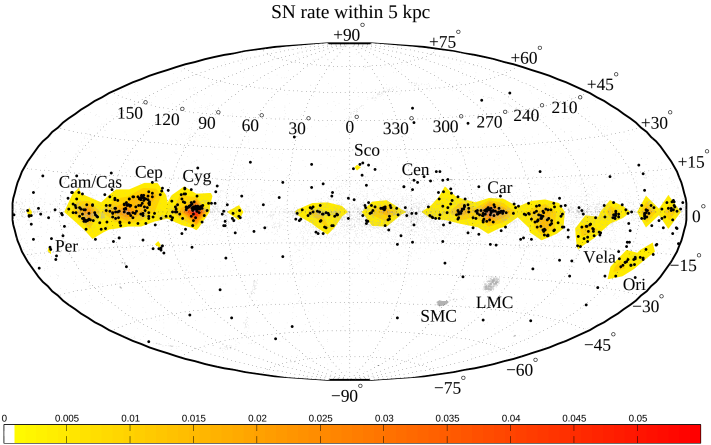


Figure : grey dots: all massive stars, black dots: SN progenitors within 5 kpc (J. Schmidt, diploma thesis, 2011; Schmidt et al. 2012 in prep.); all SN events in 39 % area of the sky, 90 % events in 9 % area of the sky

Summary & Perspective

- increasing the dataset from 3 kpc to all known massive stars in the Galaxy (not only HIPPARCOS and 2MASS stars)
- correction for multiple systems with 8m VLT adaptive optics observations: unresolved multiples appear too luminous and massive
- obtaining *missing* parameters (e.g. spectral classification, luminosity class, photometry and some multiples) at our Jena-telescopes
- select complete sub sample
- comparison with other techniques like birth places of runaway stars, the distribution of ^{26}Al or distribution of known pulsars
- binary interaction in massive binary evolution