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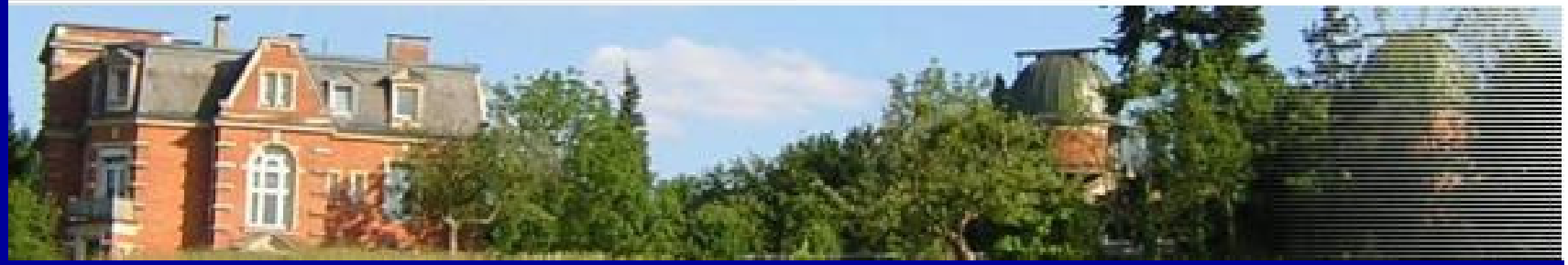
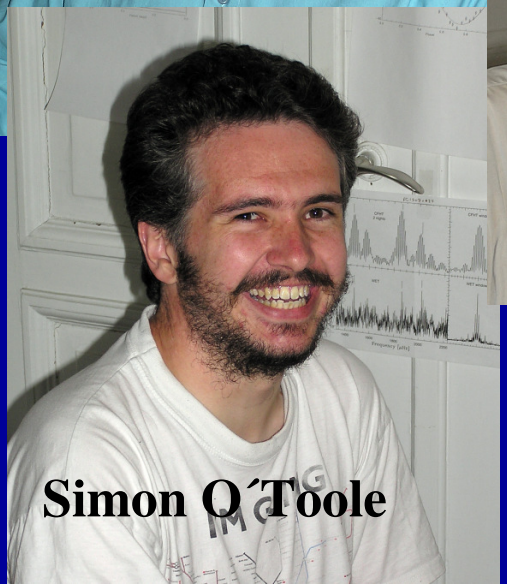


Hyper-velocity stars - ejected from the Galactic Centre?

Uli Heber

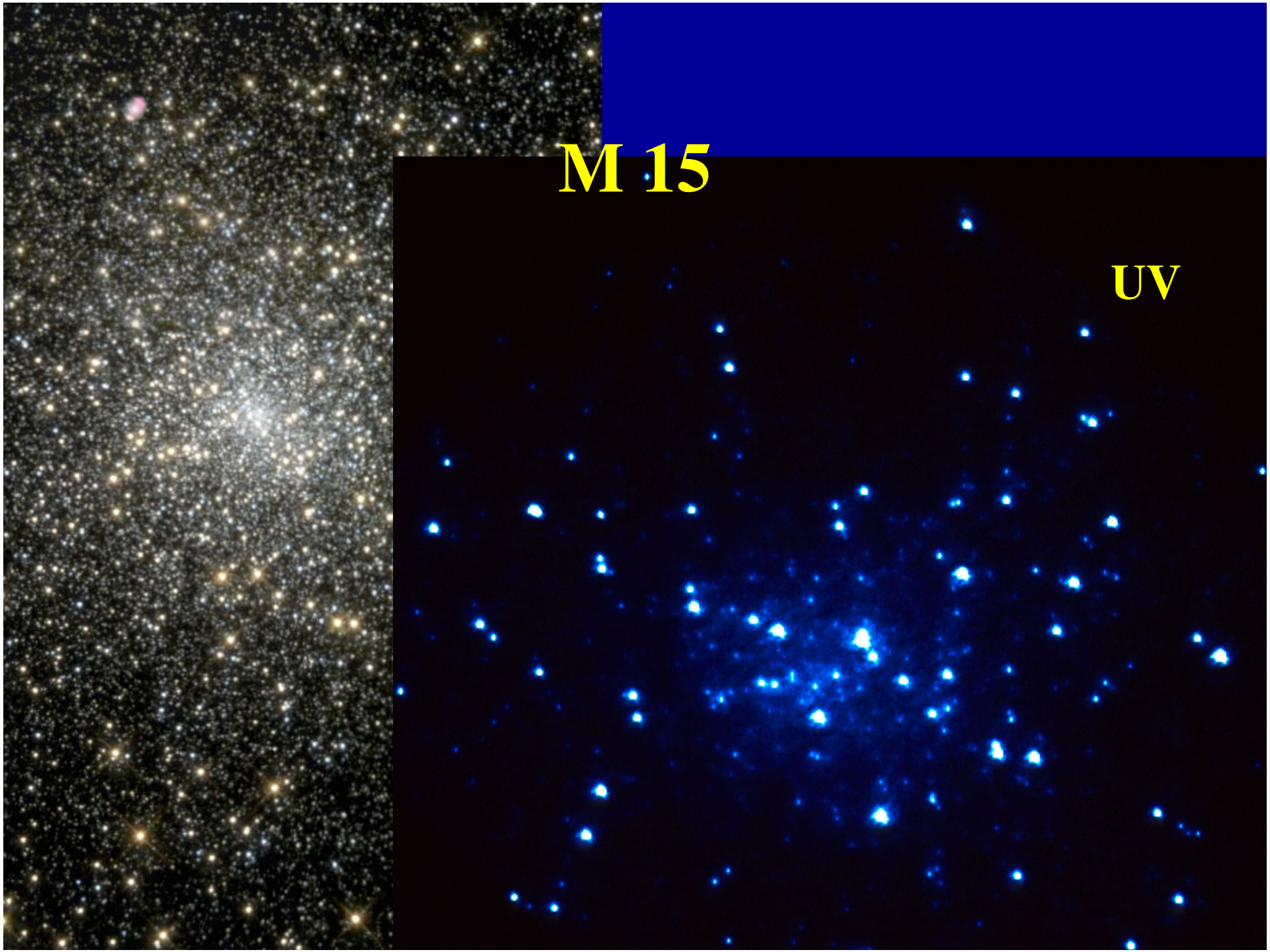
The Mikly Way Halo - Stars and Gas, Bonn 31.5.2007

The team



Outline

- faint blue stars at high galactic latitudes
- hot subdwarf stars
- apparently normal B stars in the Halo
- rotation and metal abundances
- hyper-velocity stars
  - a sdO star
  - a young main sequence star


M 15
UV

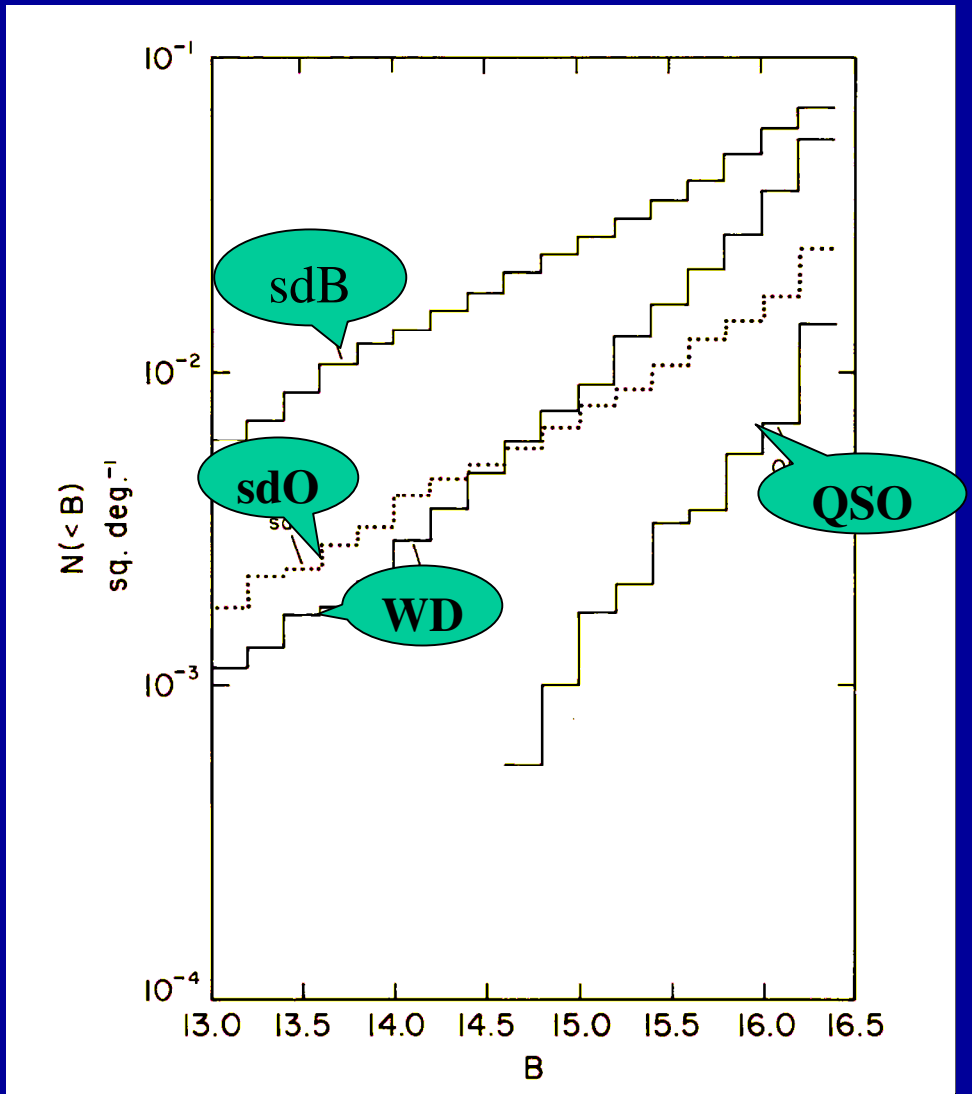
Faint Blue stars at high galactic latitudes

- UV-excess surveys aim at QSO
  - photometric: PG (Palomar Green)
    EC (Edinburgh Cape)
  - objective prism: HS (Hamburg Schmidt)
    HE (Hamburg ESO)
- Population of faint blue stars:
  white dwarfs, hot subdwarfs, BHB, pAGB ...

Mix of spectral types

- bright magnitudes:
  hot subluminous stars
  dominate:
  sdB; sdO
  Green et al. (1986, ApJS 61,305)

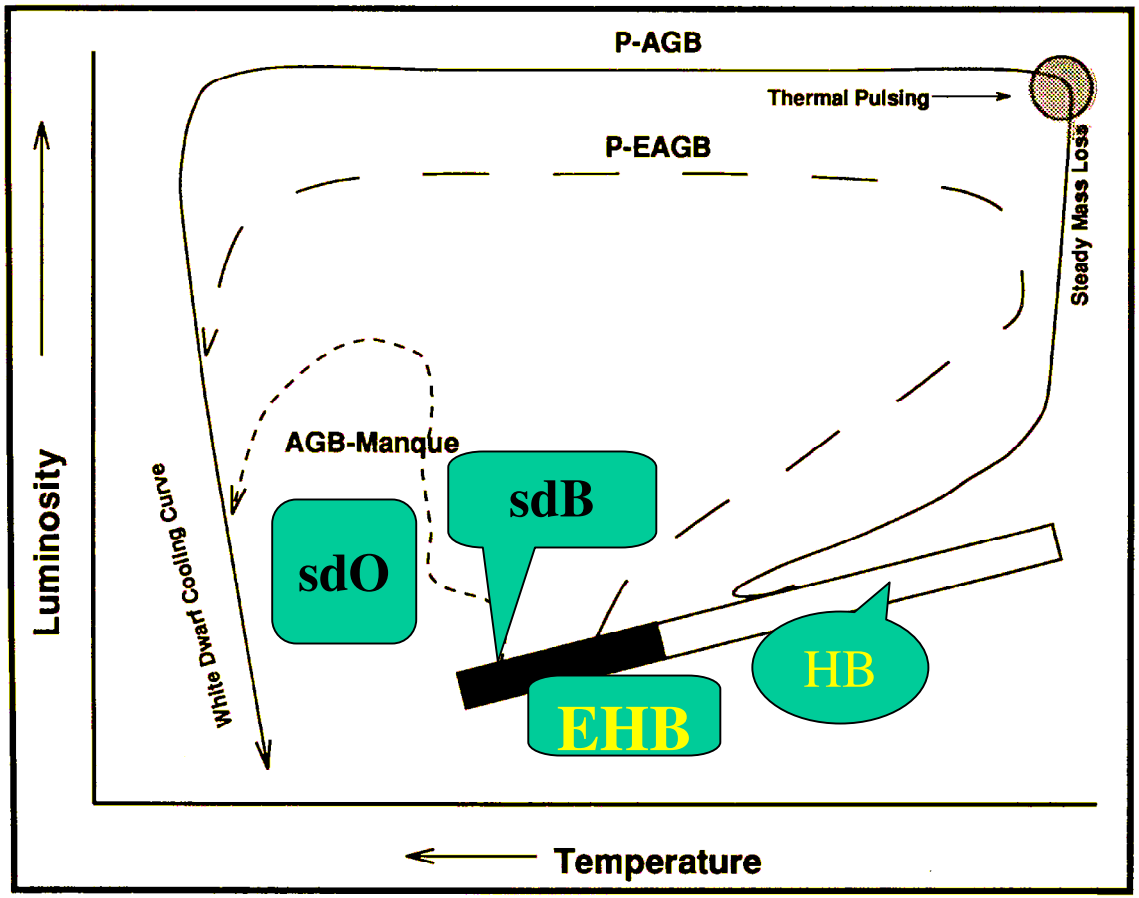
- white dwarfs and QSO
dominate at fainter mag



Hot subluminous stars

sdB : 20000-40000K
He-deficient
Extreme **H**orizontal
Branch stars

sdO: >40000K
He-rich



Dorman et al. (1993, ApJ 419, 596)

The origin of sdB & sdO stars

- EHB: H-envelope of very low mass ($<0.02M_o$)
- How to remove almost the entire envelope of a red giant at the same time helium ignites?
- sdBs: 40% in close binaries (P<10d),
  sdOs: <5% in close binaries (Napiwotzki et al. 2004, ApSS 291,321)
- Close binary evolution with mass exchange
- Merger of two He-core white dwarfs
- Delayed Helium core flash (see talk of S.Moehler)

Binary Population Synthesis (BPS)

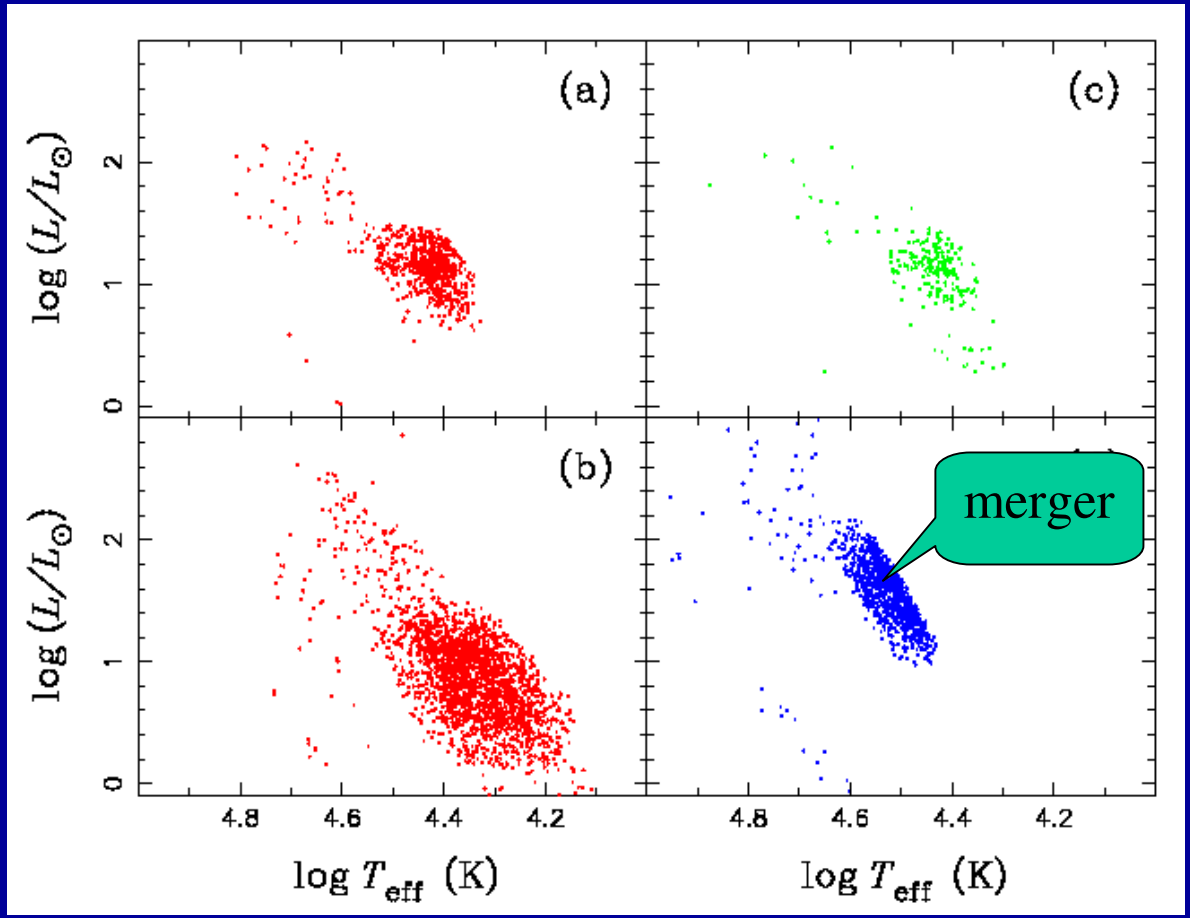
Han et al.
(2003, MNRAS 341, 669)

a: 1. CE ejection

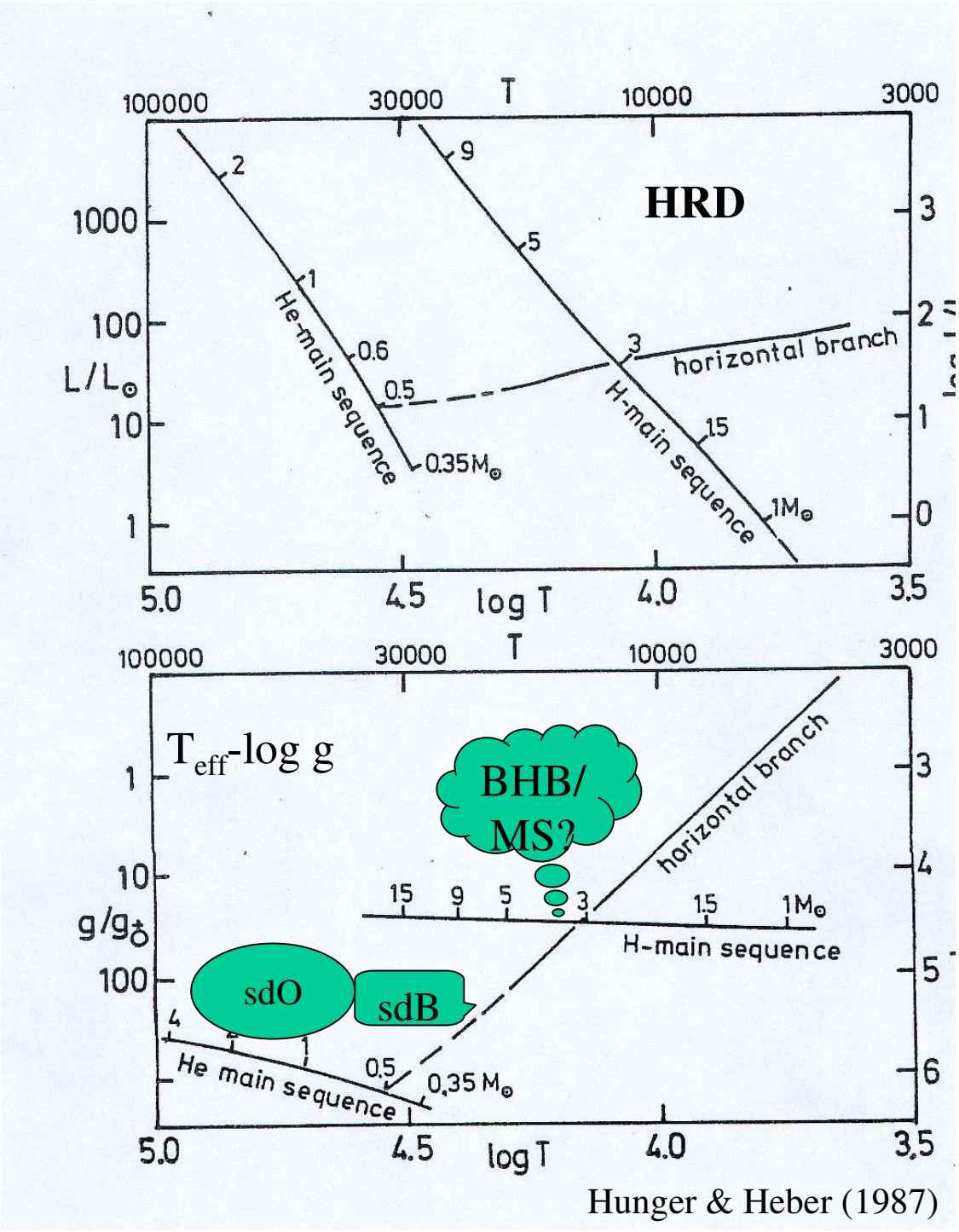
b: 1. stable RLOF

c: 2. CE ejection

d: merger of He white dwarfs



- Why is it difficult to distinguish a main sequence star from a blue horizontal branch (BHB) star?



Hunger & Heber (1987)

Apparently normal B stars at high Galactic latitudes

- Massive B stars and blue Horizontal Branch stars:
  similar T_{eff} and log g,
  different mass ⇒ **distances**!
- How to distinguish a massive B star from a BHB star?

BHB: - low helium
- weird metal abundance pattern
- slow rotators

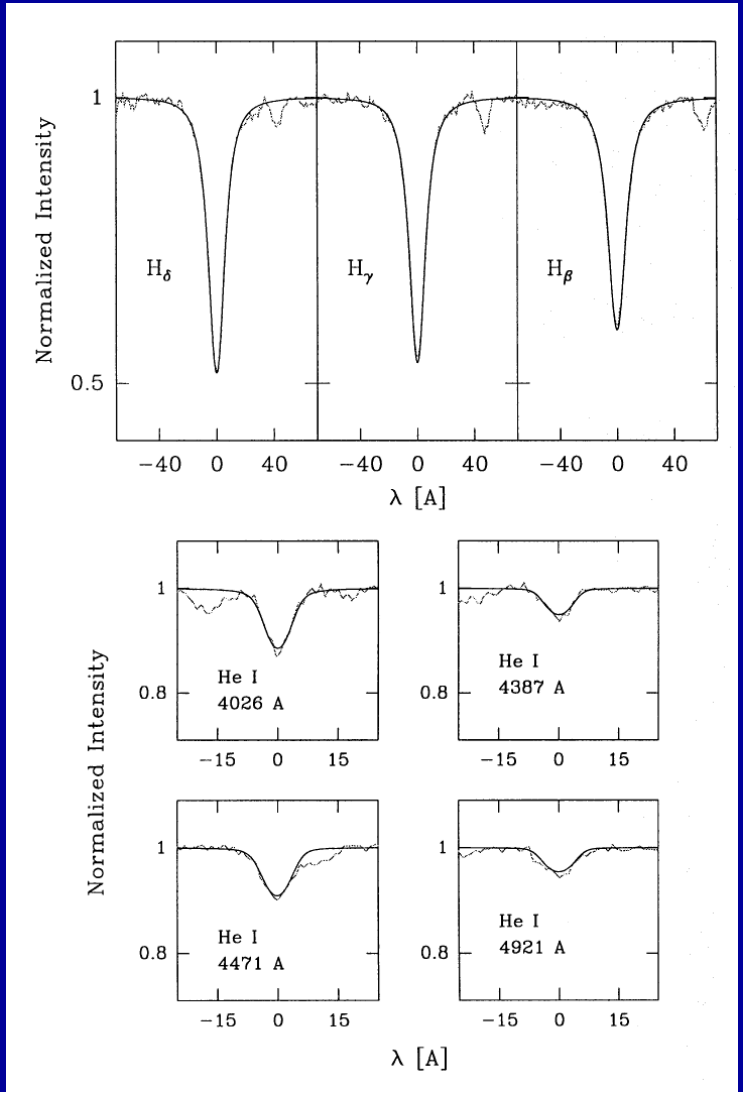
massive B stars:
- normal abundance pattern
- fast rotation

PG 0009+036

mass: 4.8 to 5.8 M_{sun}
distance: 5.9-6.4 kpc
hel. v_{rad}=144 km/s

v_{rot} sini = 320 km/s

Schmidt, Heber & de Boer
(1996, A&A 306,L33)



Run-away stars

- Normally massive stars are found in the Galactic plane

  ejection scenario:

  ⇒ born in the plane and ejected

  (Blaauw, 1961, BAN 15, 265)

  - binary supernova ejection
  - 3 body interaction in an open cluster

- Calculate path and time of flight:
  - radial velocities, distances & proper motion
  - orbit integrator: Odenkirchen & Brosche (1992, AN 313, 65)
  - Galactic potential: Allen & Santillan (1991, RMxAA 22, 255)

„Hyper-velocity“: speed limits in space

How fast can a „run-away“ star travel?

May a star leave the Galaxy?
Exceed the Galactic escape velocity:

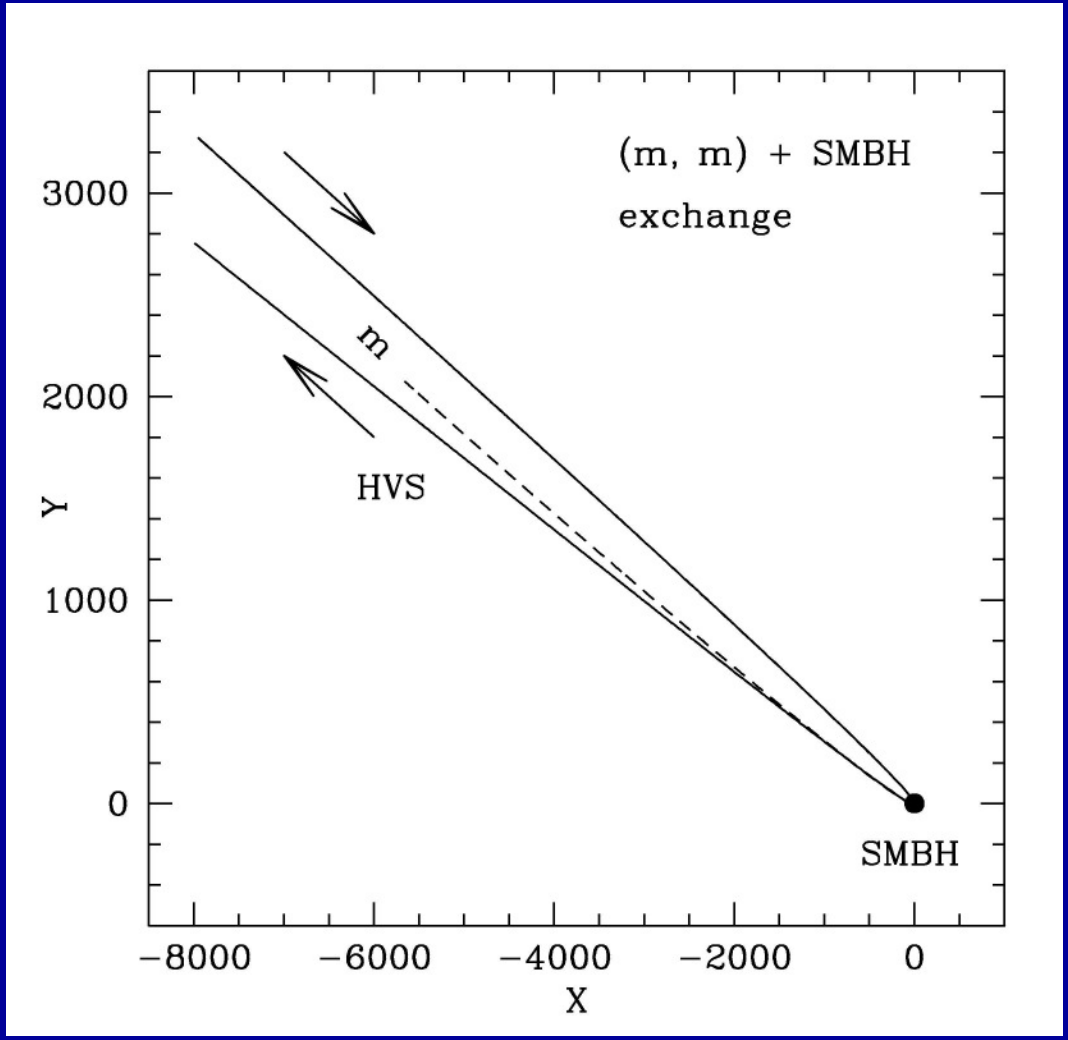
Solar-neighbourhood: Galactic Escape Speed:
544 km/s (498...608 km/s)
(Smith et al. 2006, astroph/0611671)

Tidal disruption of a binary

Hills (1988, Nature 331, 687):

- Disruption of a binary near the SMBH releases companion at up to 1000 km/s or more.
- Detection of a **single** HVS:

evidence for a SMBH



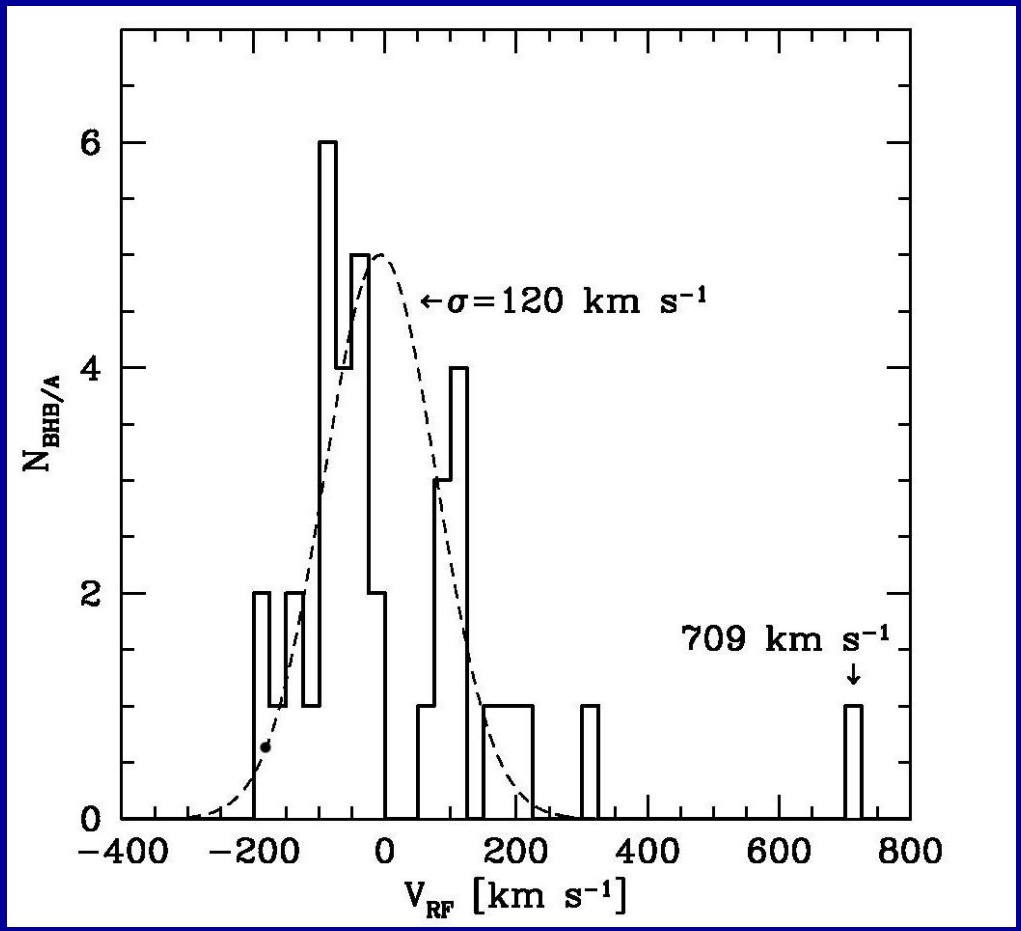
Gualandris et al. (2005, MNRAS 363,223)

The first hyper-velocity star

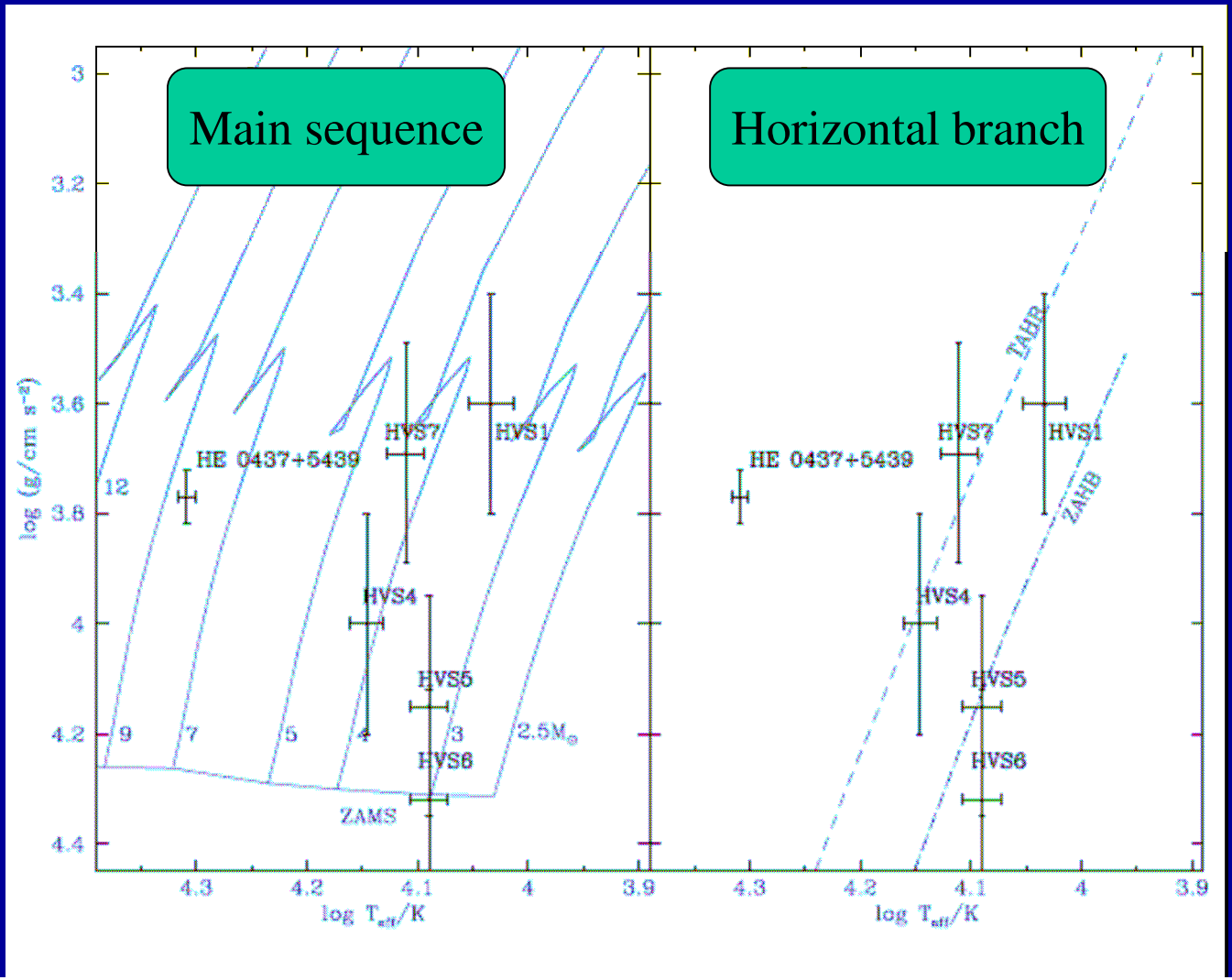
Sample auf HBA stars
from SDSS
(Brown et al. 2005, ApJ 622, L33)

Vrad = 853km/s (hel.)
> **709km/s** (gal.); pm=0
Late B-type ($B=19.8^m$)
d=40kpc (if HB)
d=110kpc (if MS)

Unbound to Galaxy



HVS of late B-type



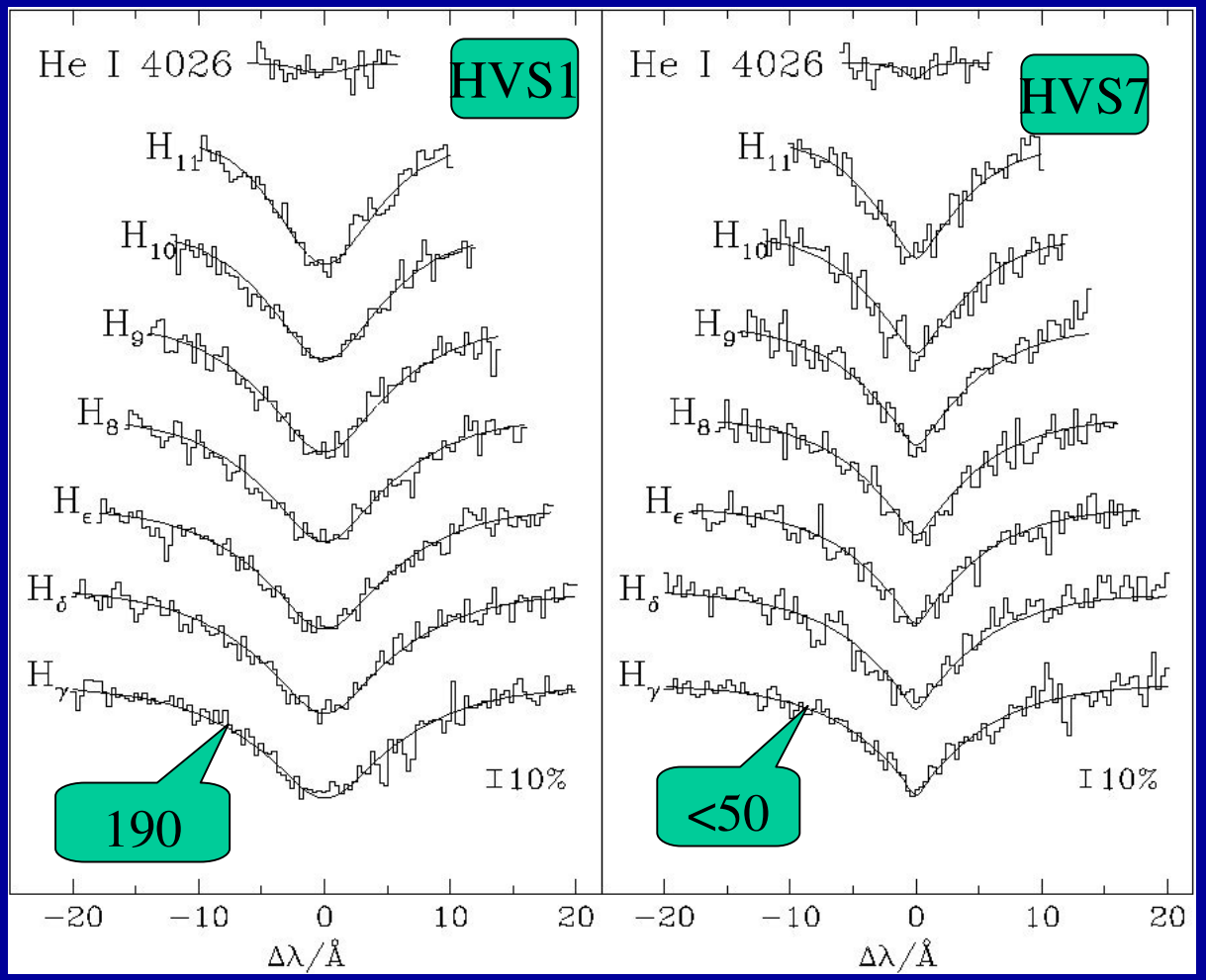
4 more HVS discovered by Harvard survey (Brown et al. 2006, ApJ 640, L35; Brown et al. 2006, astro-ph/0604111):

HVS 4-7

Rotation of HVS 1 & 7

Rotation of HVS 1:
v_{rot} sin i=190km/s
➡massive star

HVS 7:
v_{rot} sin i<50km/s
?? star
check:
metal abundances
ESO-VLT&UVES



Hunger & Heber (1987)

SAO-HVS: lifetime vs travel time

Late B-type stars of SAO survey:
assuming MS-distances:

Star	d/kpc	t_{flight} /Myrs	t_{evol} /Myrs
HVS 4	72	130	140
HVS 5	38	55	240
HVS 6	51	105	220
HVS 7	96	240	160

Errors: +-20%

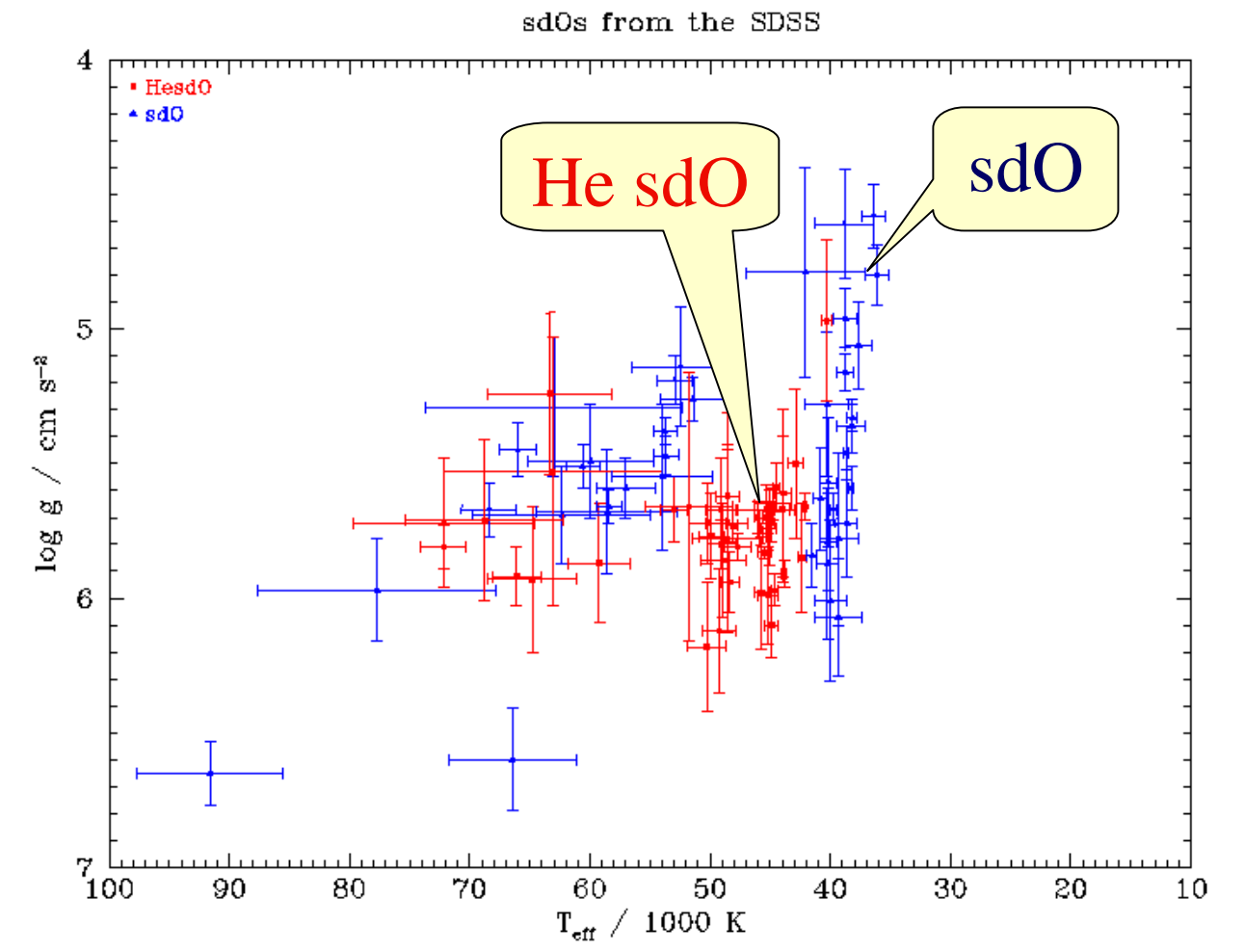
HVS 4-6: **o.k.** HVS 7: **o.k?**

SDSS-sdOs

Atmospheric models:

- NLTE:
- H+He, no metals
- TMAP code
  (Werner, Dreizler, 1999, JCaAM 109, 65)
- improved He atomic models
- temperature correction scheme (Dreizler, 2003, ASPC 288, 69)

See poster Hirsch et al



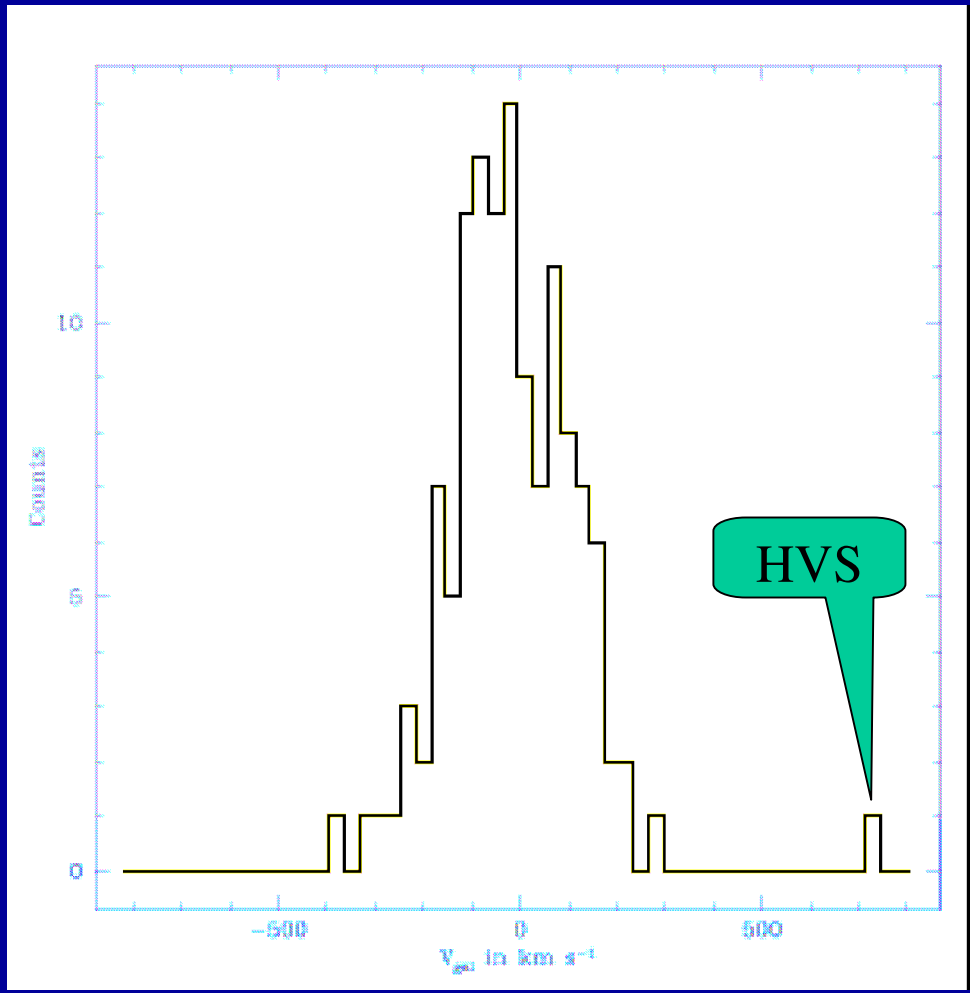
A HVS amongst sdO stars from SDSS

candidates selected from all releases according to colour: u-g<0.2 (0.4)

g-r<0.1

⇒11000 spectra:

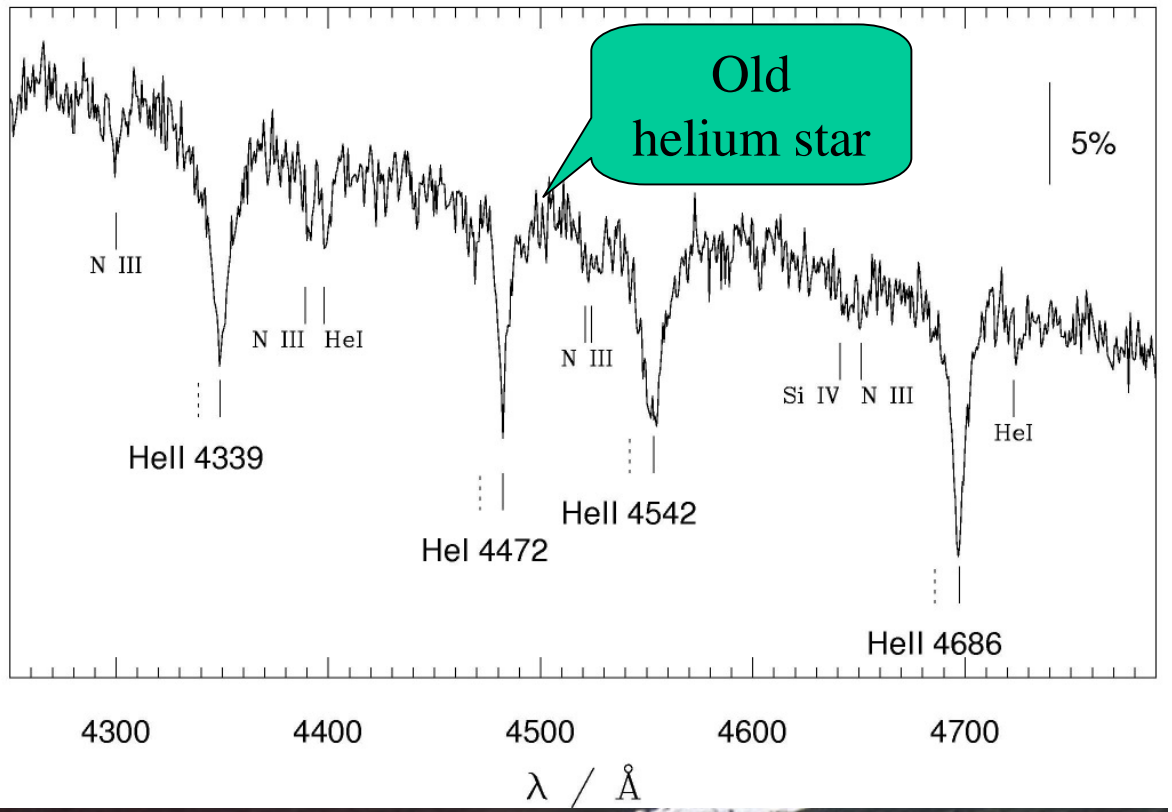
⇒ 40 sdO + 43 He sdO



The second hyper-velocity star

Spectrum from
Keck I +LRIS

Hel. RV=708km/s
Gal. RV=751km/s
(pm=0)



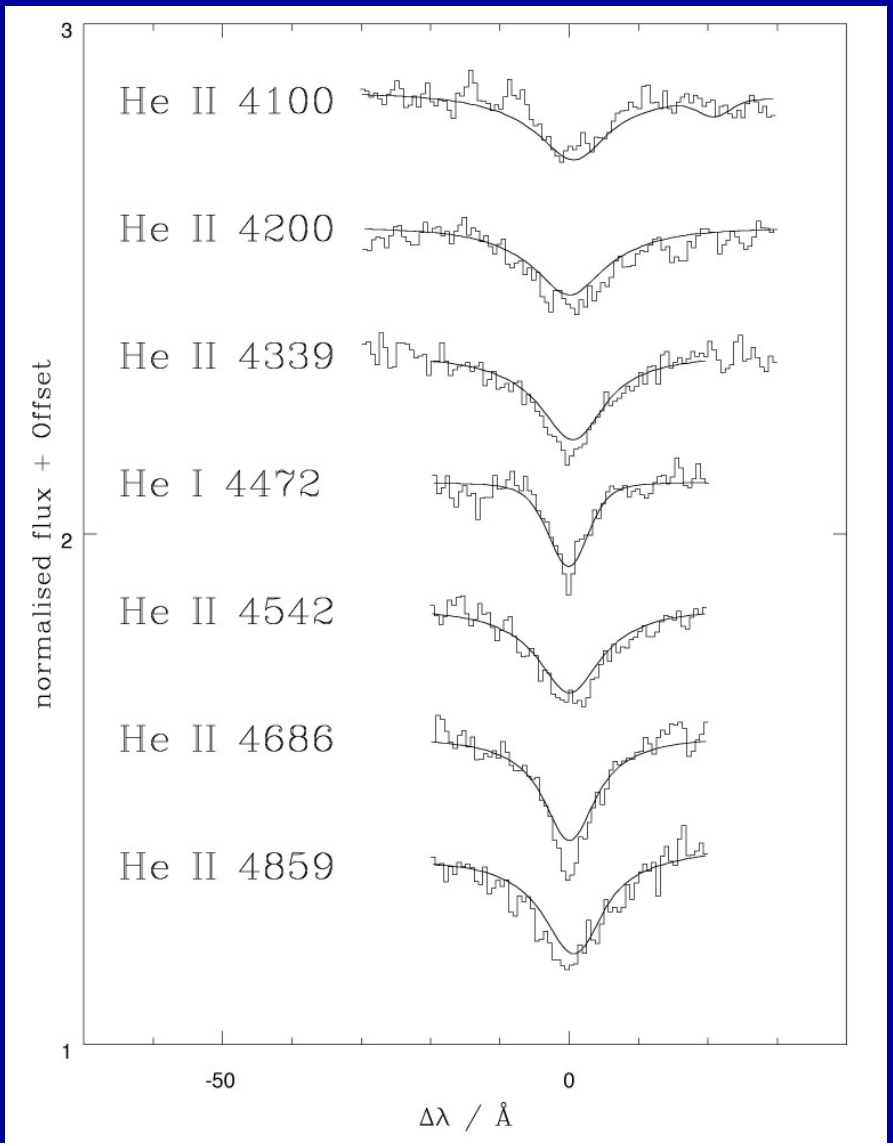
Helium star (sdO)

- Low mass:0.5M_{sun}
- **distance: 20kpc**

Hirsch, Heber, O´Toole & Bresolin (2005, A&A 441, L61)

US 708: Keck LRIS spectrum

- T_{eff} = 45500K,
- log g = 5.23,
- mass = 0.5 M_o
- B=19.0 mag
- ➡ Distance: 19 kpc



Kinematics of US 708

- vgal = 751km/s < v_{esc} = 430km/s ⟹ **unbound**
- Can be traced back to the **Galactic Center**:
  - proper motion required:

    pm_{RA} = -2.3 mas/yr

    pm_{DE} = -2.4 mas/yr
  - t_{flight} =32 Myrs < t_{evol}= 100 Myrs

✓ **MBH slingshot ejection from the Galactic Centre is plausible**:

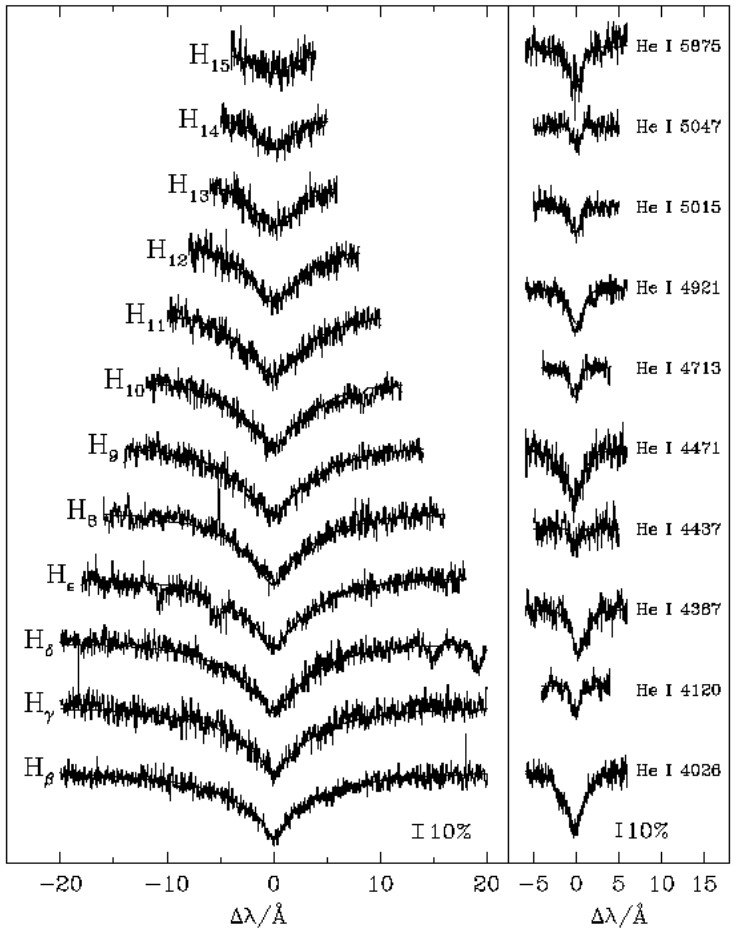
- US 708 was in binary, disrupted by tidal interaction with MBH

HE 0437-5439 = HVS 3

- **VLT-UVES:**
  v_{rad} = 723+-3 km/s
  v_{gal} > 563 km/s (pm=0)
- Teff = 20400 K
- Log g = 3.8
- normal Helium
- B=16.2 mag

Edelmann, Napiwotzki, Heber, Christlieb & Reimers (2005, ApJ 633, L181)

VLT UVES

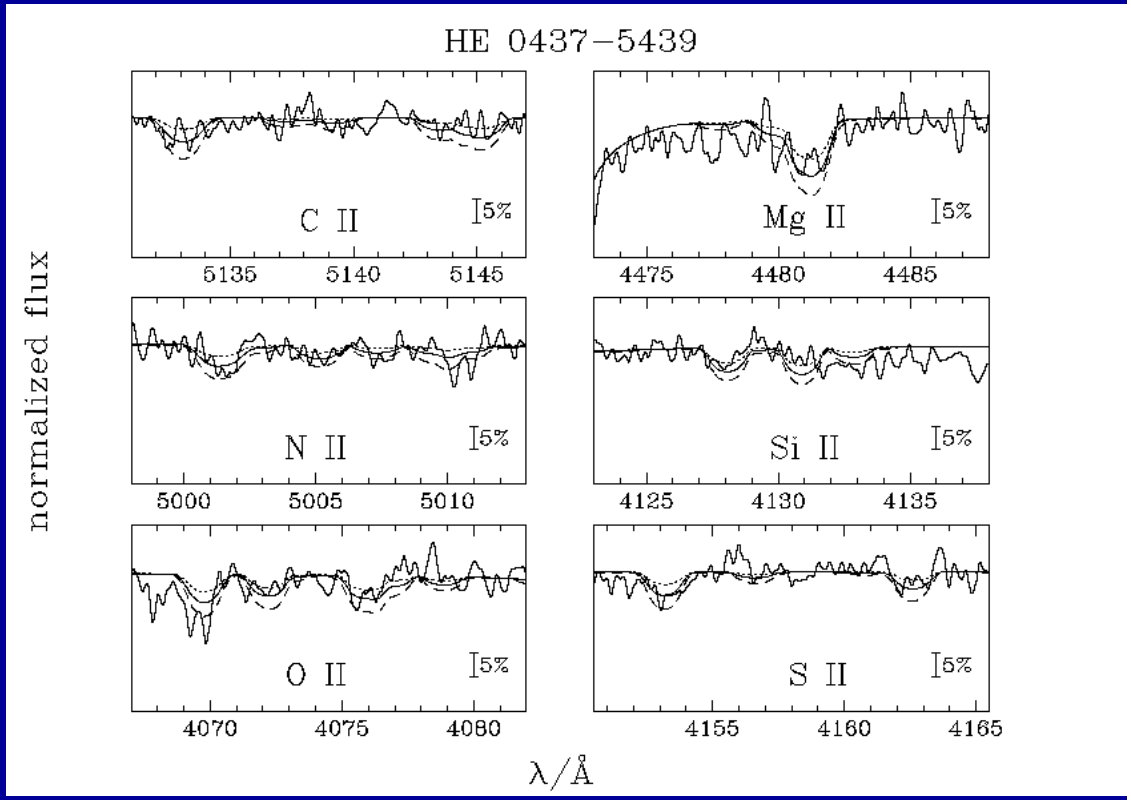


HE 0437-5439: metals & rotation

- V_{rot} sini =54 km/s
- metals: solar

(to within a factor of 3)

Main sequence star



… = 1/3 solar, --- = 3*solar, full drawn= solar

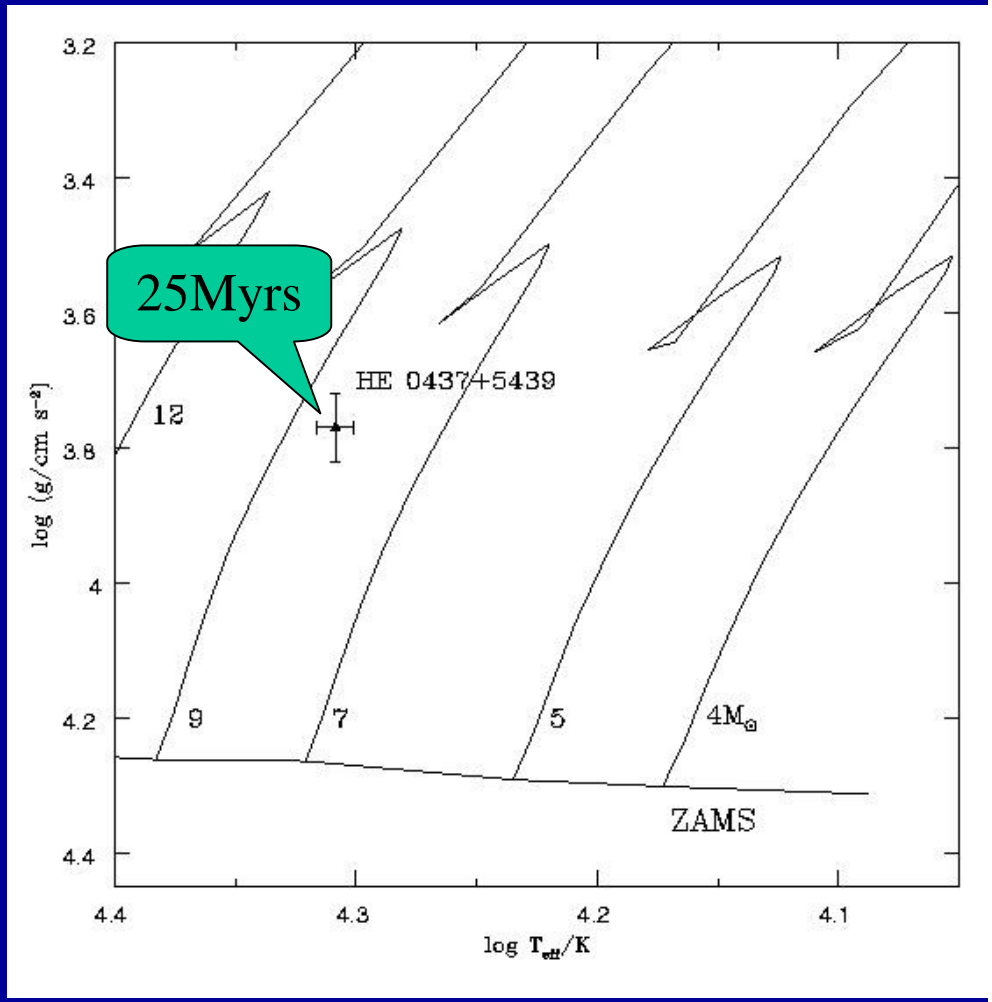
Mass, distance and age

- Comparison to evolutionary tracks for ms stars:
- Mass = 8 M_o
- Distance: **60 kpc**
- Age = 25 Myr
- v_{gal} > 563 km/s

  >

  v_{esc} = 317 km/s

➡ **unbound to Galaxy**



Kinematics

Time of flight to GC:

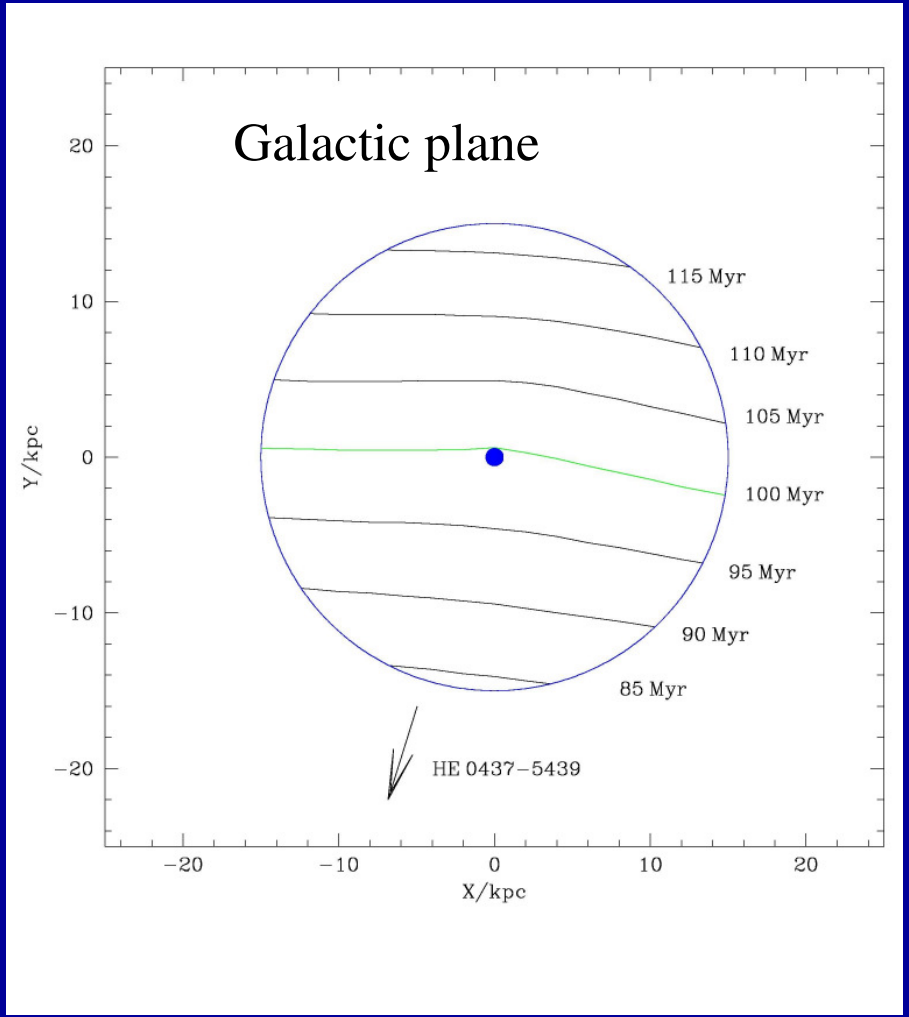
100 Myrs

= 4 times T_{evol}!!

<u>Alternatives</u>:

- Blue Straggler

- Other formation channel: not from Milky Way



Origin in the LMC ?

- Star is beyond LMC
- Closer to LMC (18kpc) than to Galaxy
- Can reach present position within $T_{evol:}$
  V_{eject}=600km/s
  (unbound to LMC)
  pm=2mas/yr
  (relative to LMC)

Do we need a SMBH as slingshot ?

Gualandris & Portegies Zwart, (astro-ph/0612673): **IMBH** (>1000M_o) may do also!!!

Candidate host clusters: NGC 2100, NGC 2004

Star Ejected from the Large Magellanic Cloud
(Artist's Impression)

ESO PR Photo 35/05 (November 9, 2005)

Summary

✓ SAO Survey: late B-type stars of 100 Myr

- populations of **unbound** and of **bound** HVS

- sdO **US 708**: the only bona-fide low mass, old HVS.

- origin from GC possible, requires pm measurements!

✓ a population of bound old low mass stars?

Search for high velocity sdB, sdO & hot WD stars

(poster Tillich et al.)

✓ **HE 0437-5439**: young (30Myr) massive B star:

origin from Milky Way unlikely, ejected from LMC ???

- **SMBH** slingshot may not be the only mechanism!

- **IMBH** in clusters**?** sdO star from a globular cluster??