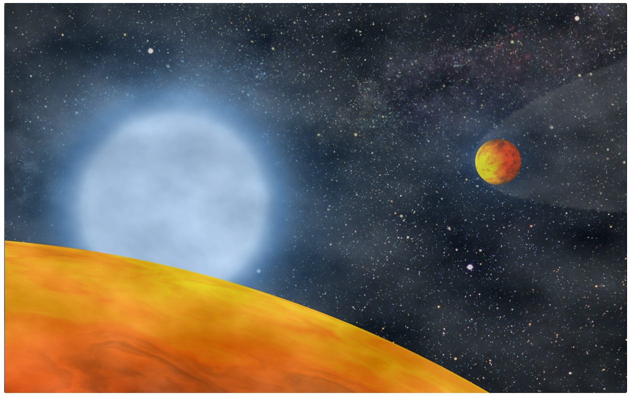
CHEOPS Science Workshop, Graz, 24-26 July 2017

Planet remnants around evolved stars with CHEOPS



Valérie Van Grootel
(STAR Institute, University of Liège)

S. Charpinet (IRAP Toulouse), R. Silvotti (INAF Torino)

CHEOPS Core Science Team
(L. Fossati, M. Lendl, K. Heng, D. Ehrenreich, I. Pagano, etc.)

What stars are we talking about ?

The ultimate stages of evolution for intermediate / low mass stars

The Extreme Horizontal Branch,
ie subdwarf (sdB) stars :

A path followed by 1-2% of stars
=Red giants that have lost most of their envelope

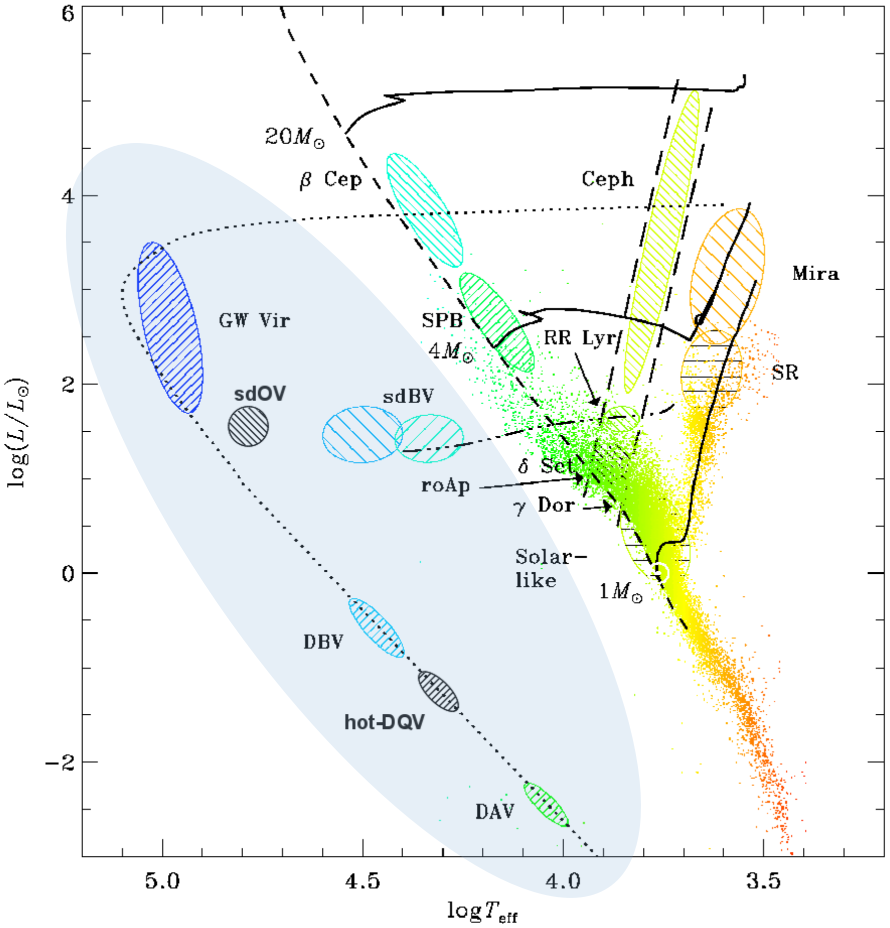
Compact objects in the core helium-burning phase,
T_{eff} ~30,000 K – R* ~0.15 R_{sun} – L*~20 L_{sun}

The white dwarf (WD) stars :

The end stage for ~ 98 % of all stars in the Universe

Cooling remnants of former stellar cores,
T_{eff} ~10,000 – 30,000 K – R*~ 1 R_{Earth}

HR (T_{eff}-L*) Diagram



Where are/What are the remains of planetary systems after the red giant phase ?

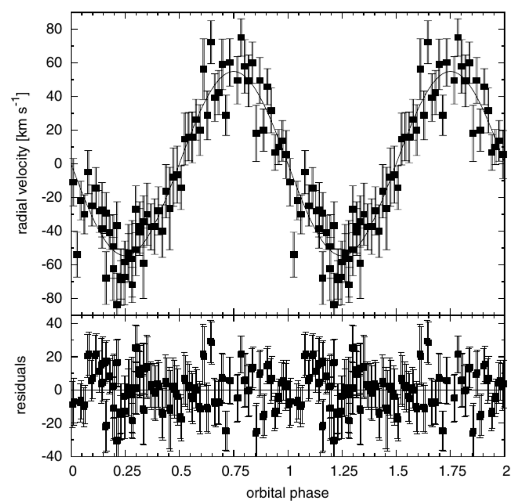
Searching for substellar objects orbiting evolved stars – Current Status

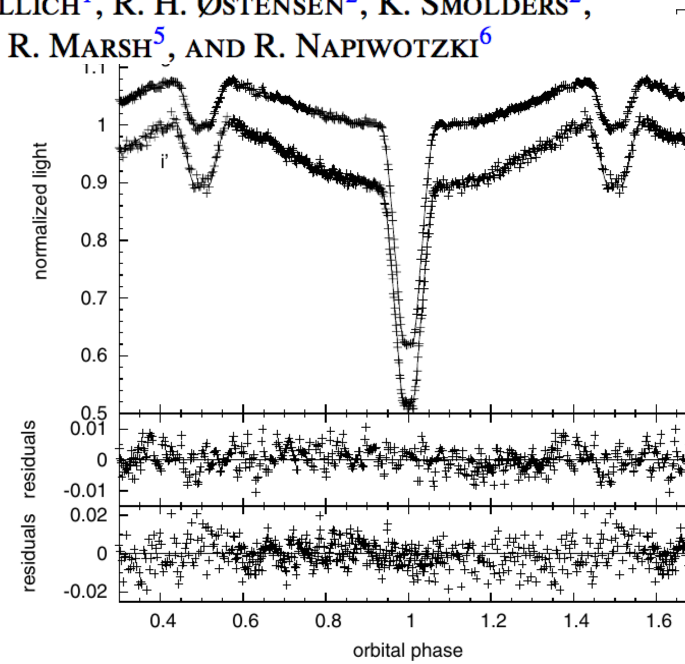
2011: 1st Brown Dwarf – sdB binary (eclipsing)

The Astrophysical Journal Letters, 731:L22 (5pp), 2011 April 20 doi:10.1088/2041-8205/731/2/L22

BINARIES DISCOVERED BY THE MUCHFUSS PROJECT: SDSS J08205+0008—AN ECLIPSING SUBDWARF B BINARY WITH A BROWN DWARF COMPANION

S. Geier[1], V. Schaffenroth[1], H. Drechsel[1], U. Heber[1], T. Kupfer[1], A. Tillich[1], R. H. Østensen[2], K. Smolders[2], P. Degroote[2], P. F. L. Maxted[3], B. N. Barlow[4], B. T. Gänsicke[5], T. R. Marsh[5], and R. Napiwotzki[6]





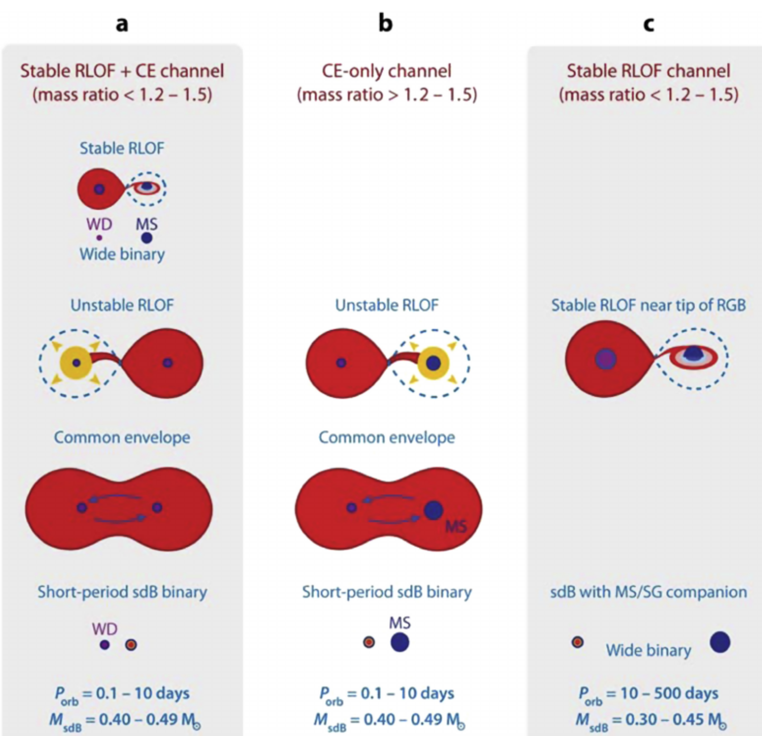
July 2017: 8% of sdB binaries have substellar companions

Stellar evolution in binary systems

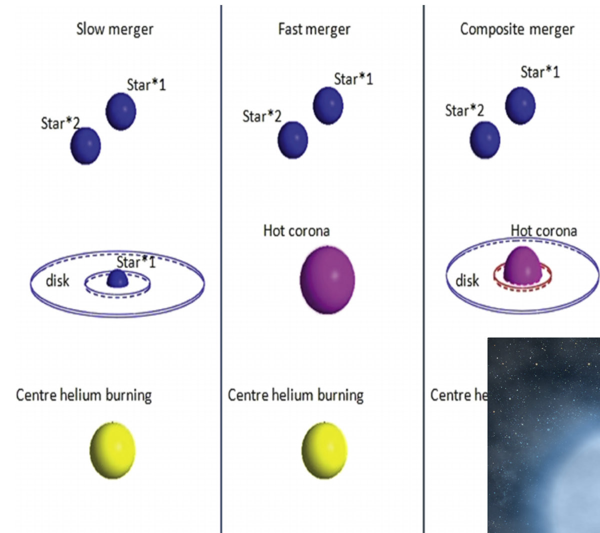
Occurrence and architecture of binary systems among EHB stars

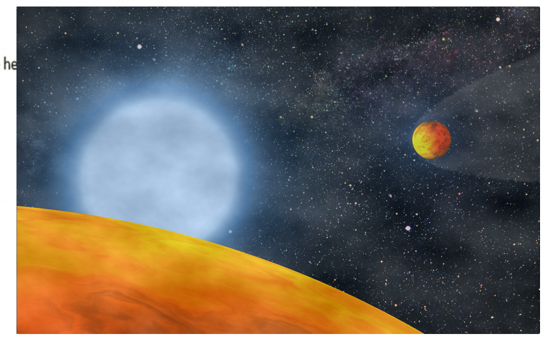
Binary evolution is key to account for the formation of Extreme Horizontal Branch stars

Stellar companion stripping the red-giant star nearly to its bare core



He-WD mergers … or





… substellar companion ?

→ Hot B subdwarfs in close / wide binaries
(~ 50%)

→ Single hot B subdwarfs
(~ 50%)

Searching for substellar objects orbiting evolved stars – Current Status

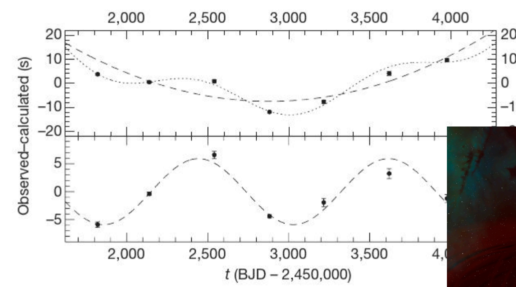
2007, 2011 (Kepler), 2014 (Kepler): Planets around sdB stars

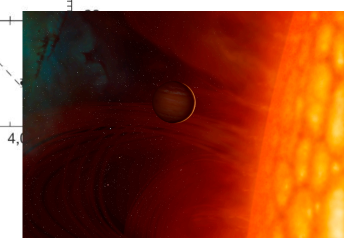
Vol 449 | 13 September 2007 | doi:10.1038/nature06143 nature

2007 LETTERS

A giant planet orbiting the 'extreme horizontal branch' star V 391 Pegasi

R. Silvotti[1], S. Schuh[2], R. Janulis[3], J.-E. Solheim[4], S. Bernabei[5], R. Østensen[6], T. D. Oswalt[7], I. Bruni[5], R. Gualandi[5], A. Bonanno[8], G. Vauclair[9], M. Reed[10], C.-W. Chen[11], E. Leibowitz[12], M. Paparo[13], A. Baran[14], S. Charpinet[9], N. Dolez[9], S. Kawaler[15], D. Kurtz[16], P. Moskalik[17], R. Riddle[18] & S. Zola[14,19]



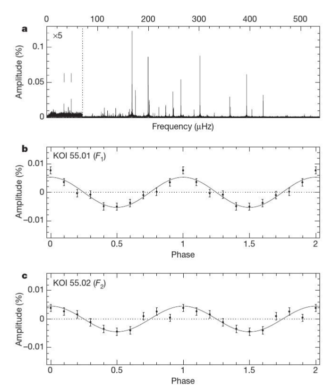


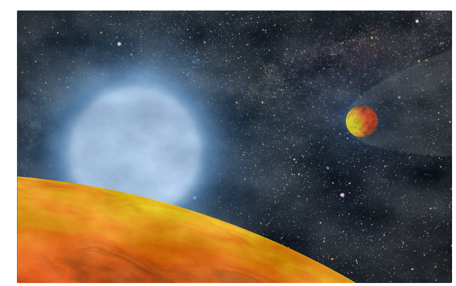
LETTER 2011

doi:10.1038/nature10631

A compact system of small planets around a former red-giant star (Kepler-70)

S. Charpinet[1,2], G. Fontaine[3], P. Brassard[3], E. M. Green[4], V. Van Grootel[5,6], S. K. Randall[7], R. Silvotti[8], A. S. Baran[9,10], R. H. Østensen[11], S. D. Kawaler[10] & J. H. Telting[12]





+ 2014: 3 planets around KIC10001893 (Silvotti et al. incl. Van Grootel, A&A, 570, 130)

Searching for substellar objects orbiting evolved stars – Current Status

2007, 2011 (Kepler), 2014 (Kepler): Planets around sdB stars

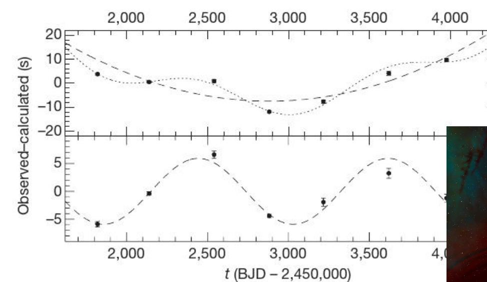
Vol 449|13 September 2007|doi:10.1038/nature06143 nature

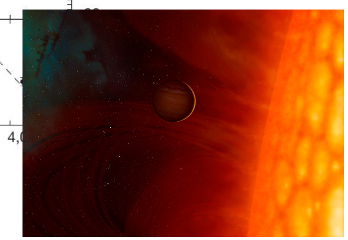
2007 LETTERS

A giant planet orbiting the 'extreme horizontal branch' star V 391 Pegasi

R. Silvo ... Gualandi[5],
A. Bona ... [9], N. Dolez[9],
S. Kawa

Msin i=3.2 MJup, 1.7 AU





LETTER 2011

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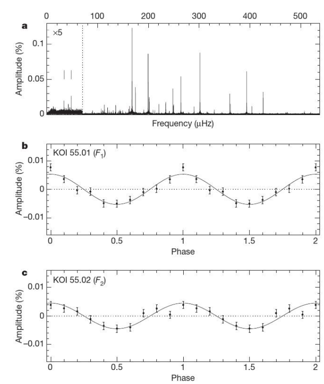
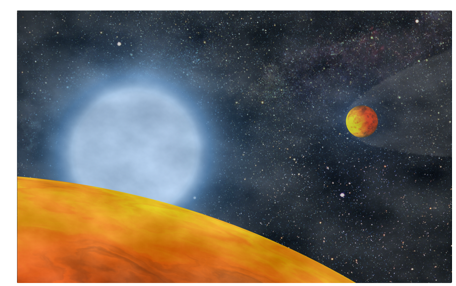
A compact system of small planets around a former red-giant star (Kepler-70)

S. Charpinet[1,2], G. Font
R. H. Østensen[11], S. D.

R=0.76 Rearth, 0.006 AU (5.7h)
R=0.87 Rearth, 0.008 AU (8.2h) (3:2)





+ Silvotti et al. 2014: KIC10001893 b, c & d: **P_{orb}=5.3, 7.8,19.5h (3:2 & 5:2)**

No transiting planet so far

(Kepler, short-cadence data: 17 sdB stars over 2-4 years; K2: 22 observed so far)

Searching for substellar objects orbiting evolved stars – Current Status

WD+BD systems are common (about 20 systems are known)

2015 (K2): disrupting planet transiting a white dwarf

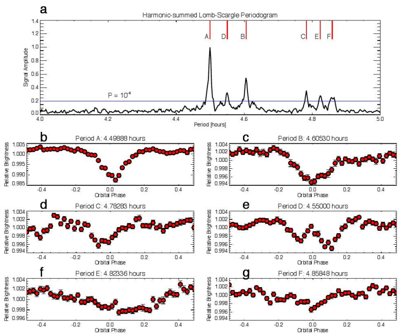
LETTER

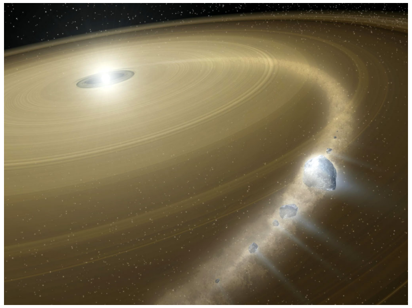
2015

doi:10.1038/nature15527

A disintegrating minor planet transiting a white dwarf

Andrew Vanderburg[1], John Asher Johnson[1], Saul Rappaport[2], Allyson Bieryla[1], Jonathan Irwin[1], John Arban Lewis[1], David Kipping[1,3], Warren R. Brown[1], Patrick Dufour[4], David R. Ciardi[5], Ruth Angus[1,6], Laura Schaefer[1], David W. Latham[1], David Charbonneau[1], Charles Beichman[5], Jason Eastman[1], Nate McCrady[7], Robert A. Wittenmyer[8] & Jason T. Wright[9]



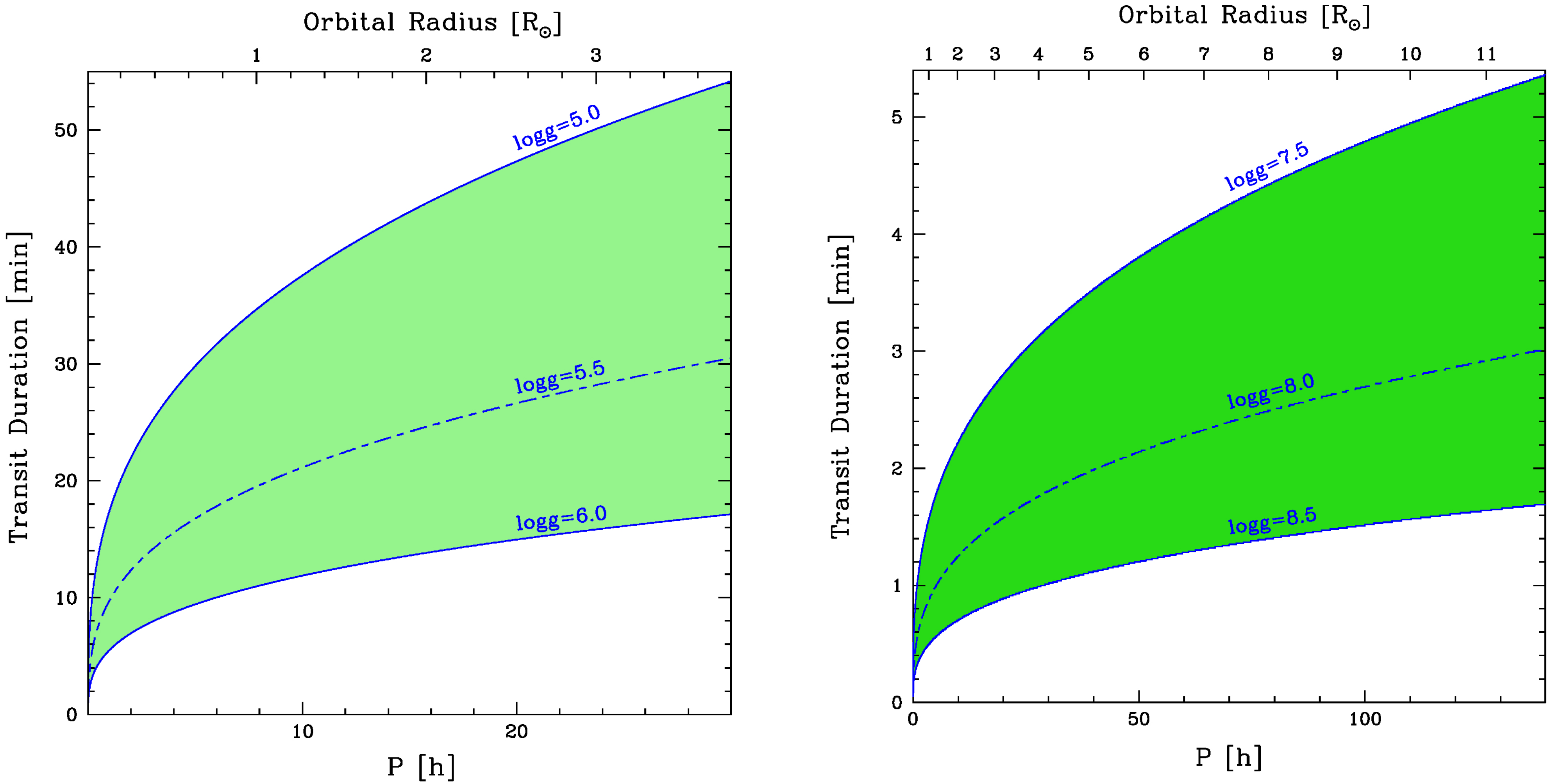


Planetary debris around white dwarf stars : ultimate fate of planetary systems

30% of WDs have metals in their atmospheres (normal: pure, gravitationnally settled H/He atmospheres); best explanation: accreted asteroids

(Kepler, short-cadence data: 2 WDs, K2: 35 WDs observed so far)

Transit duration

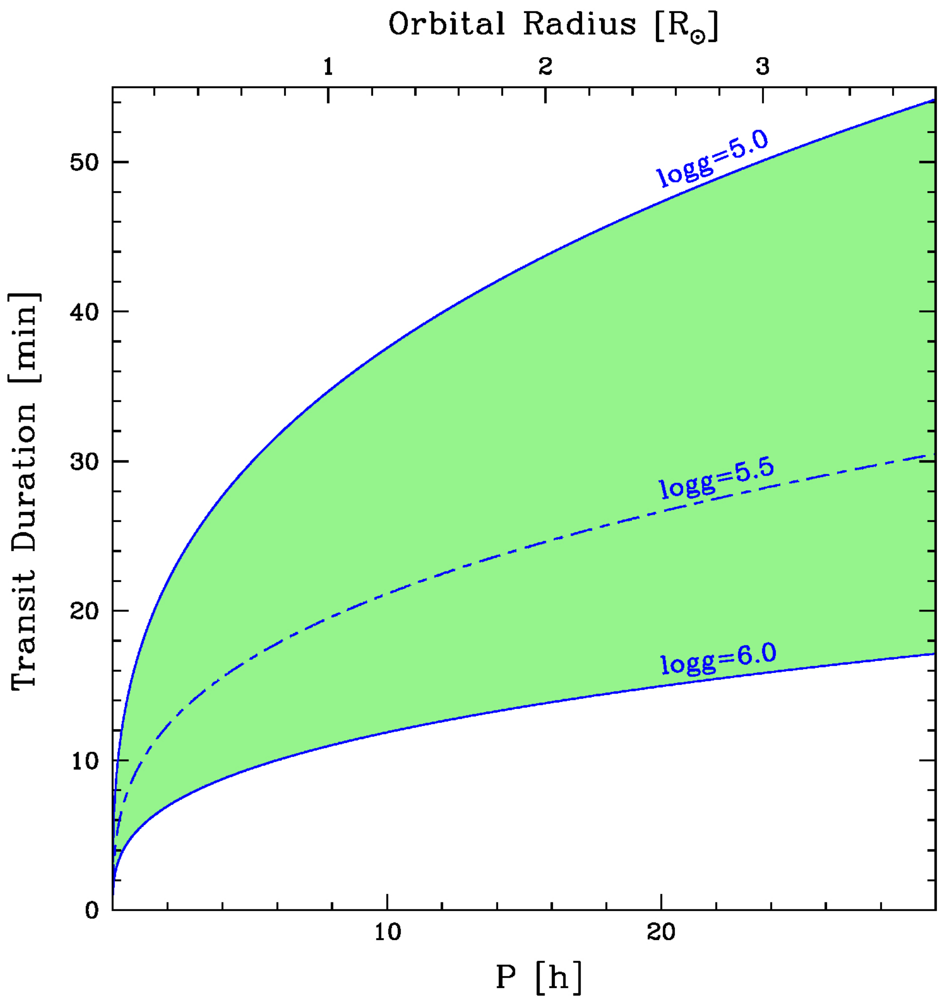


Hot B Subdwarfs

White Dwarfs

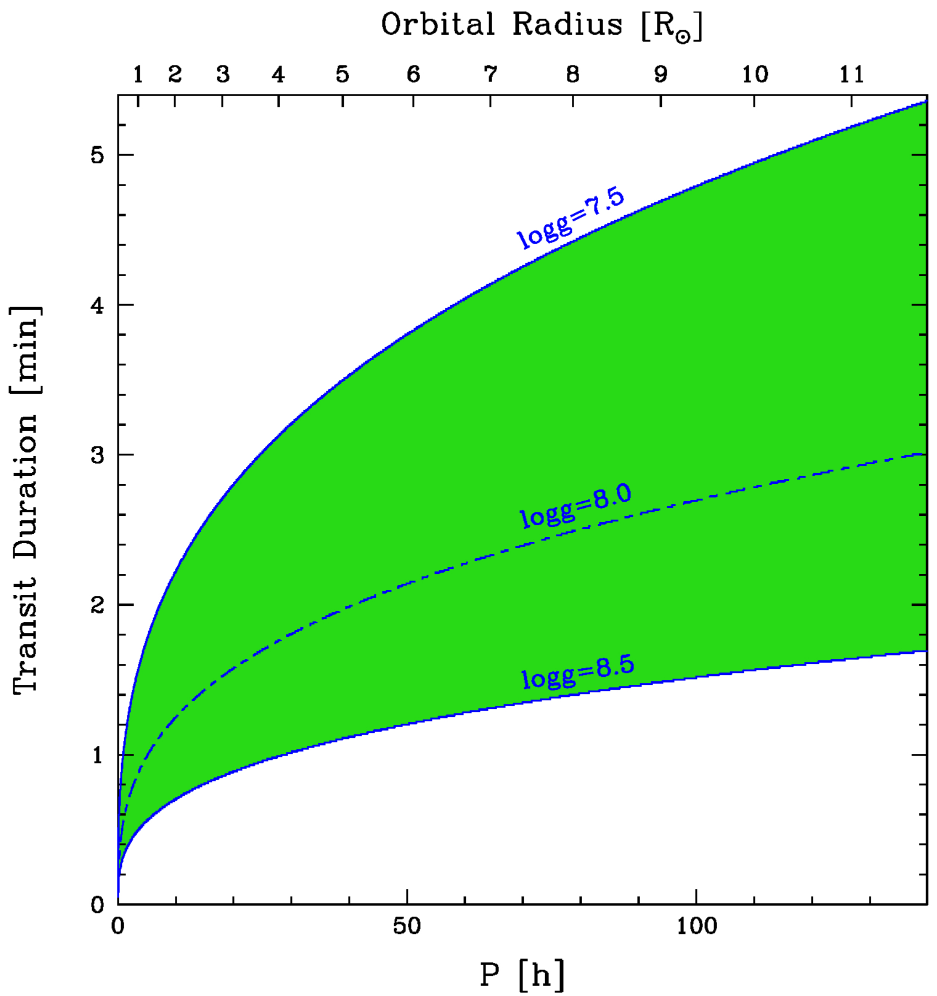
Transit duration

sdB+BD: P_{orb}= 1.5h-> a few days
Kepler-70b & c: P_{orb}=5.7 & 8.2 h
KIC10001893 b, c & d: P_{orb}=5.3, 7.8,19.5h



Hot B Subdwarfs

WD1145+017: P_{orb}=4.5-4.9h



White Dwarfs

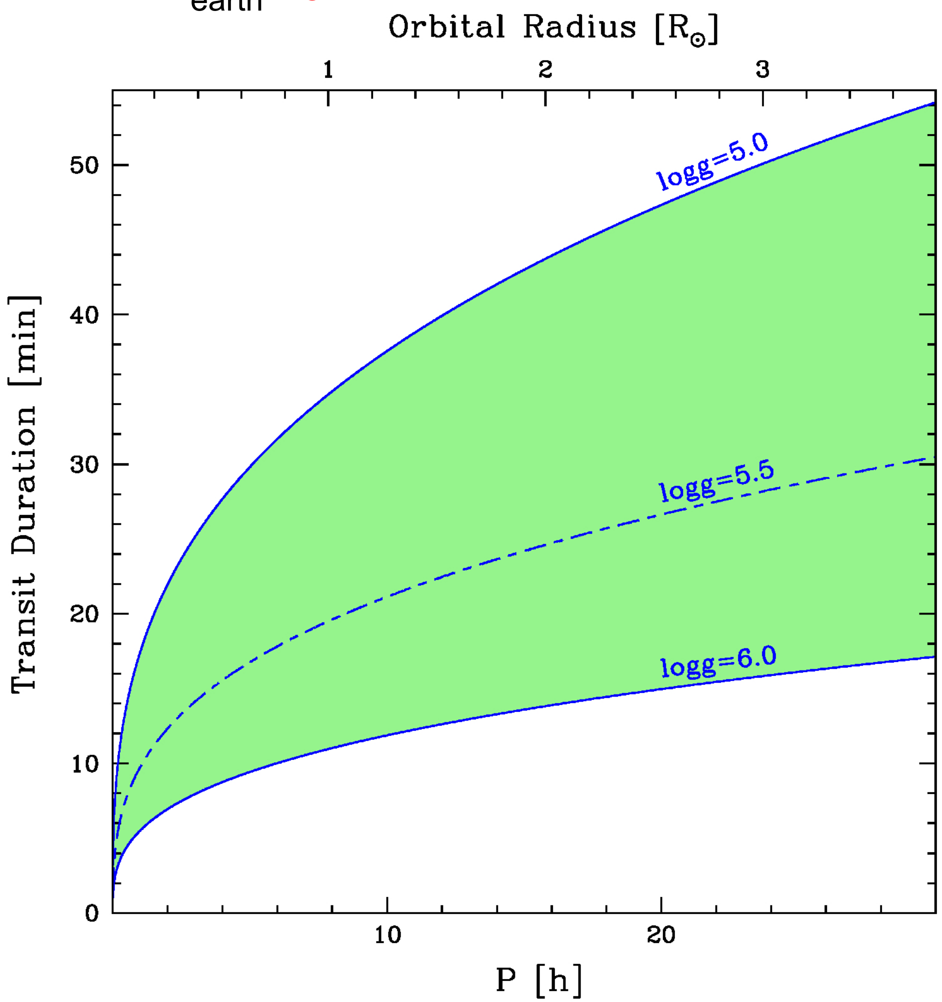
Transit probabilities (R_{sdb}~0.15 R_{sun}, R_{WD}~1.3 R_{earth})

For ~1 R_{Jup}: 0.27 0.13 0.09

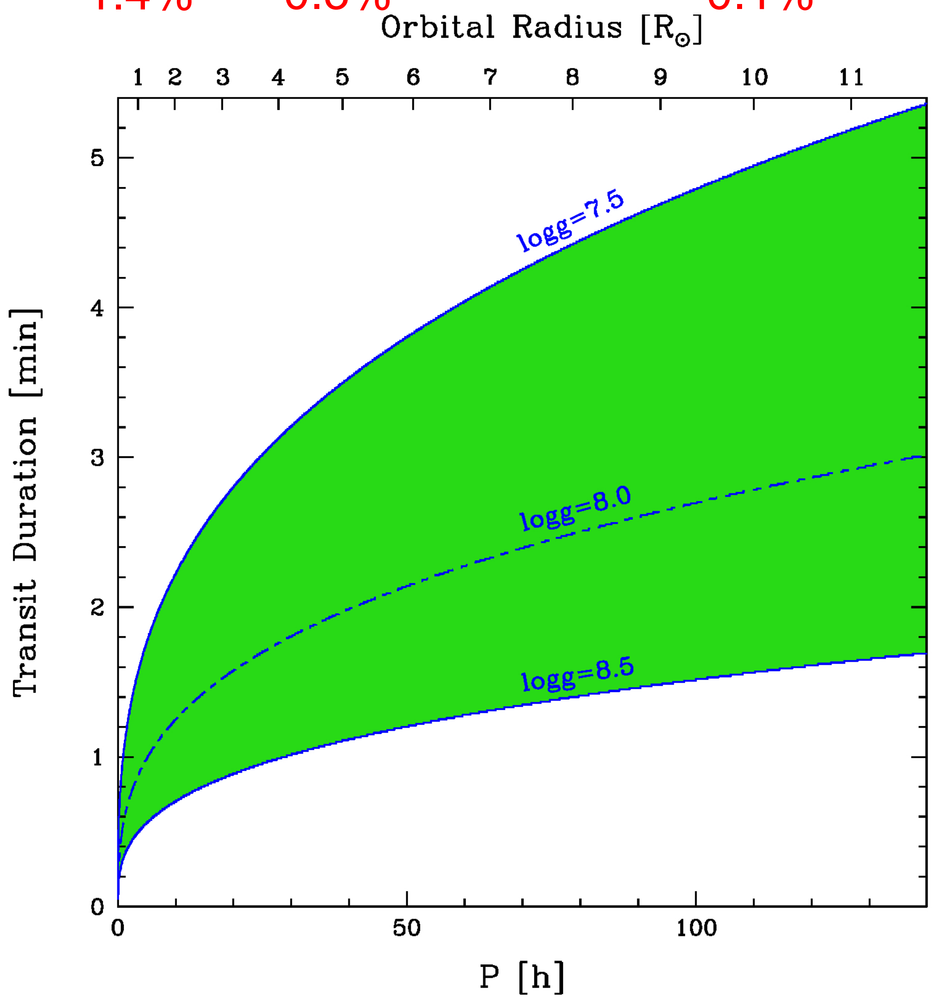
For ~1 R_{earth}: 0.17 0.09 0.06

For ~0.1 R_{earth}:

1.4% 0.3% 0.1%



Hot B Subdwarfs

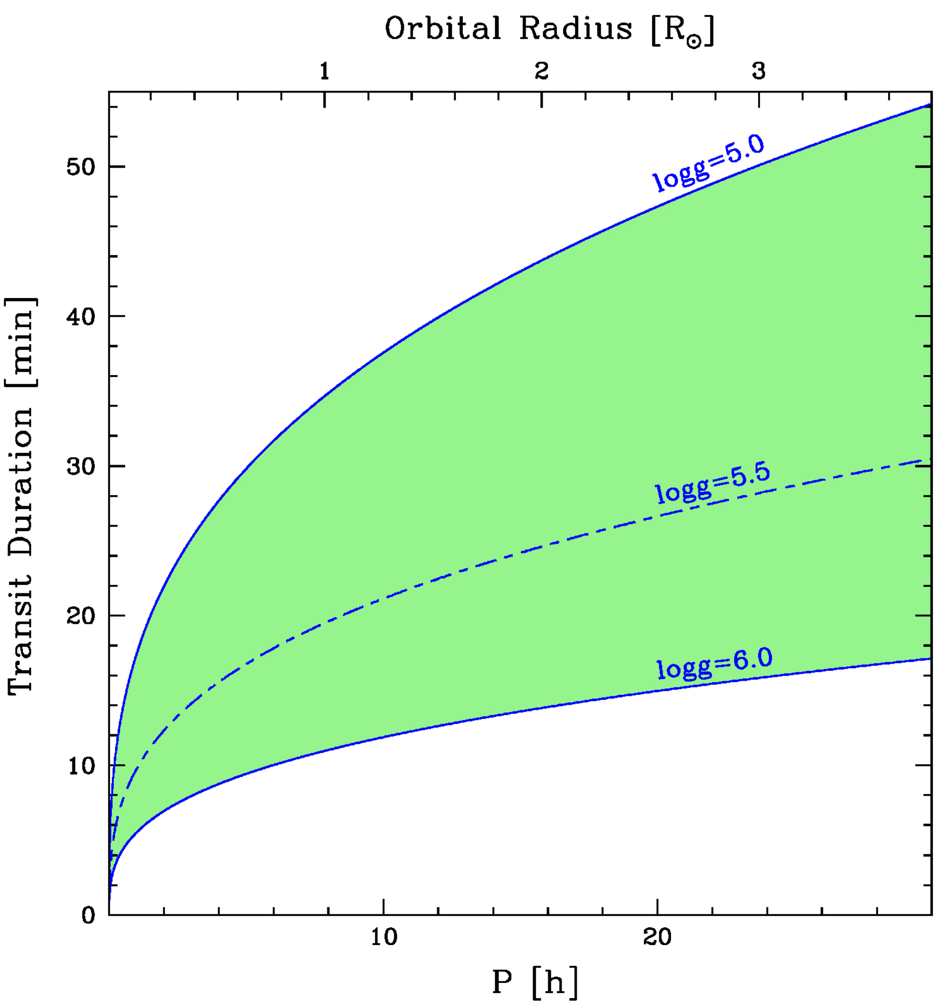


White Dwarfs

Assuming e=0, allowing grazing eclipses

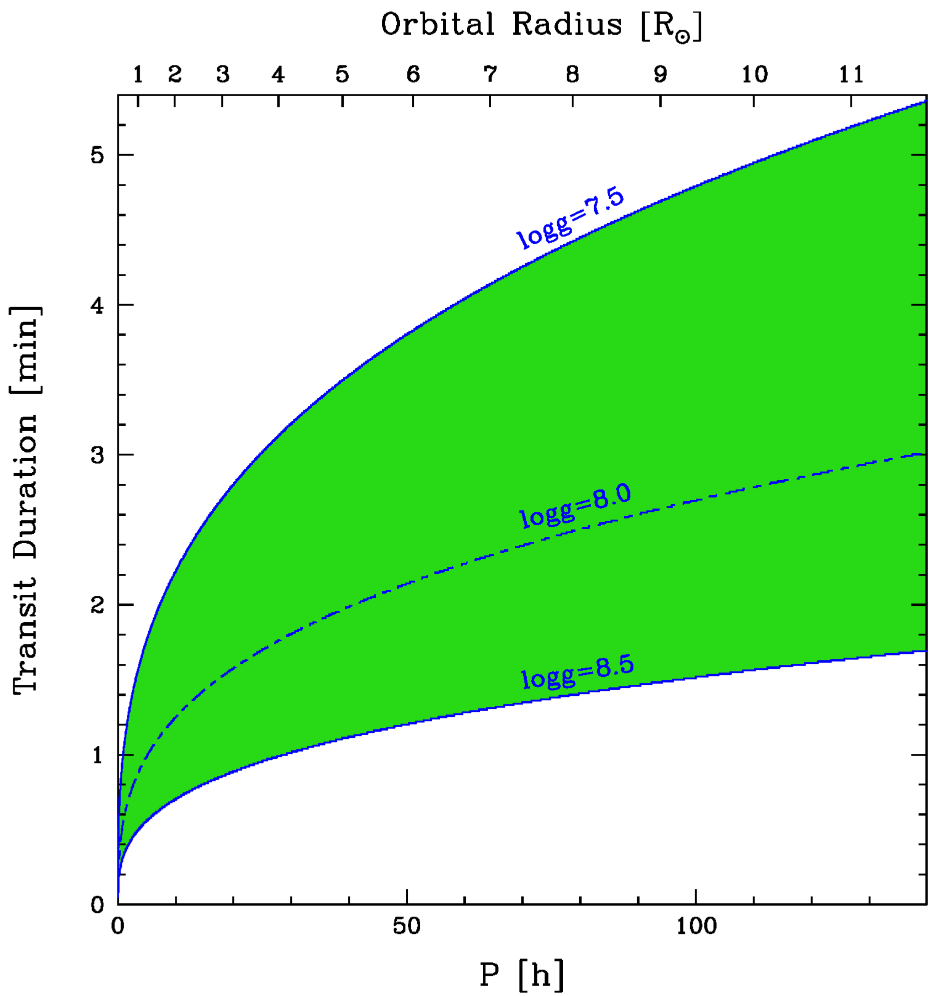
Transit depth (R_{sdb}~0.15 R_{sun}, R_{WD}~1.3 R_{earth})

For ~1 R_{earth}: ~3000 ppm (0.3%)



Hot B Subdwarfs

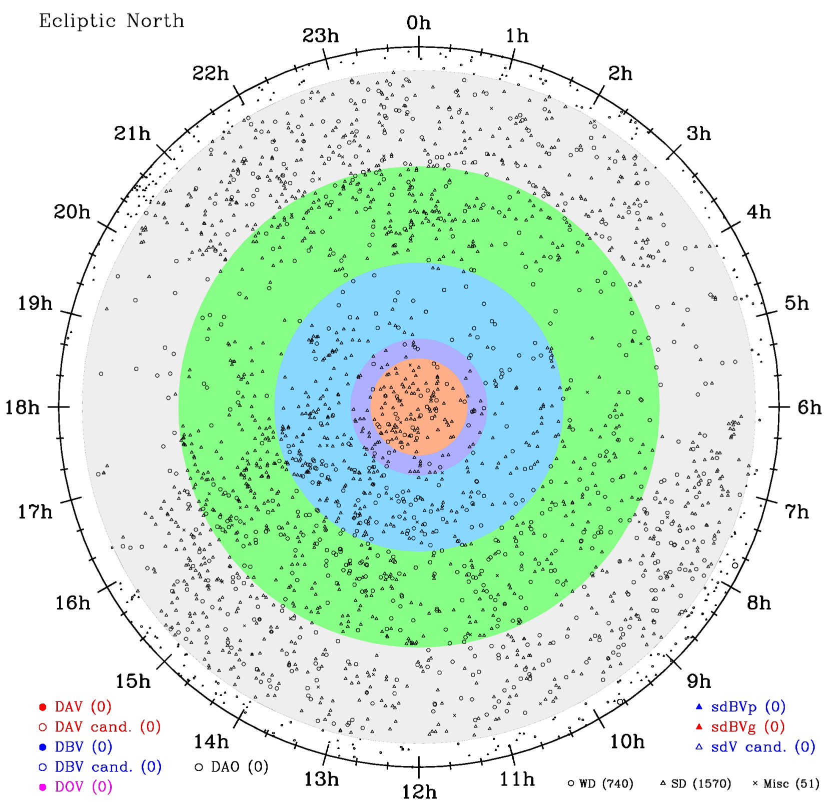
For ~0.1 R_{earth}: ~5000 ppm (0.5%)

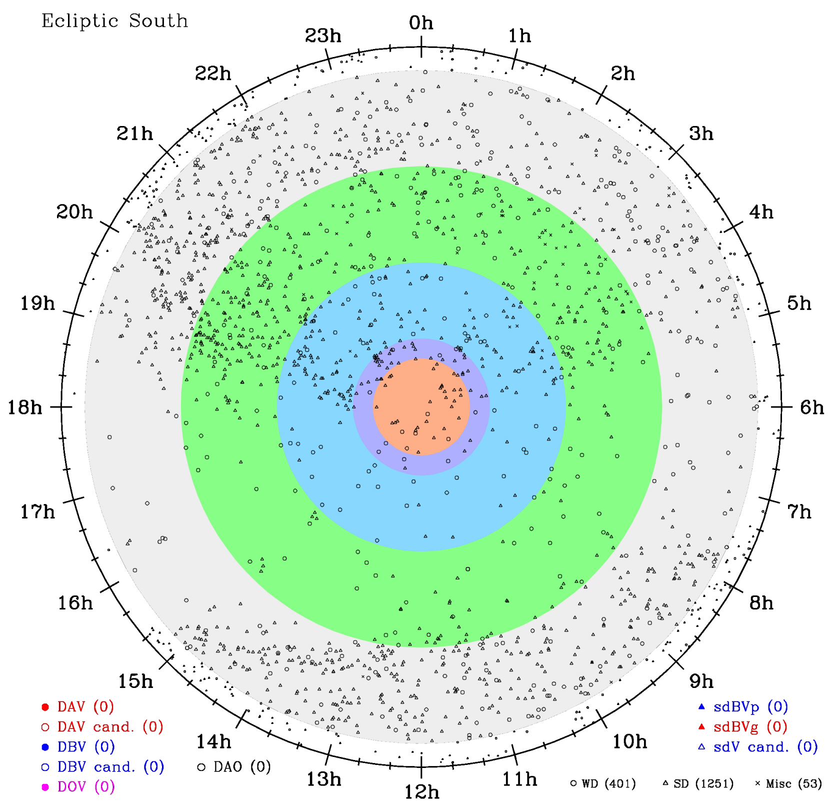


White Dwarfs

TESS Transit search around evolved stars

First nearly complete all-sky survey for the late stages of evolution





High precision continuous light curves for up to ~ 3000 hot subdwarfs and ~ 1000 white dwarfs with V<16

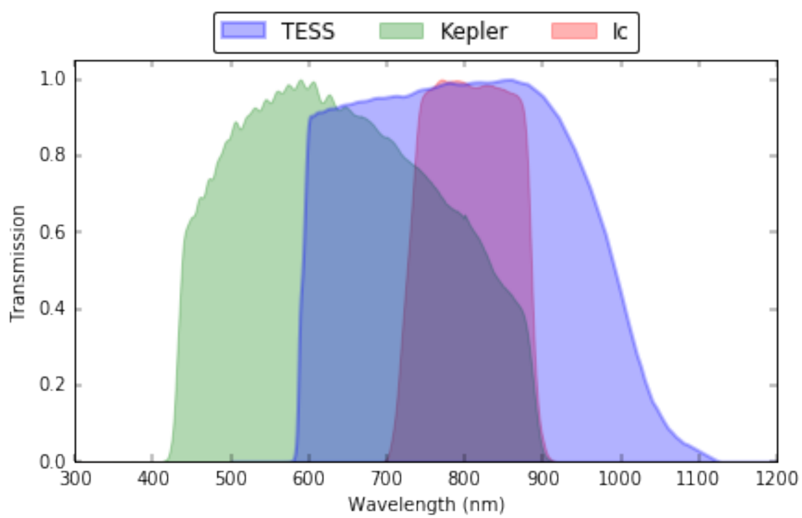
2 min sampling

This sample is proposed to the TESS core program through 2 special lists

What can we do with CHEOPS ?

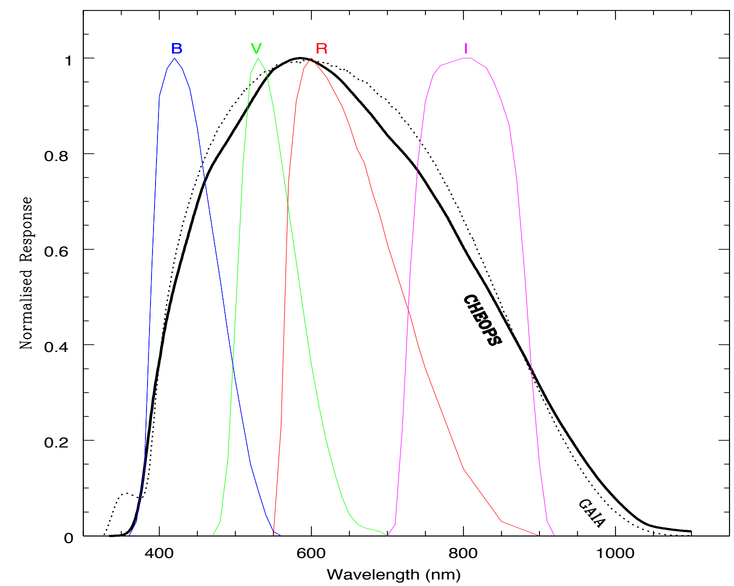
sdB star: T_{eff}~30,000 K -> **λmax ~ 100 nm**
White dwarf: T_{eff}~10,000-30,000 K (and higher) -> **λmax ~ 300 – 100 nm**

TESS



11 cm effective aperture
600-1100 nm
Sampling: 2 min

CHEOPS



30 cm effective aperture
300-1100 nm
Sampling: 1 min (and shorter)

Much higher sensitivity for CHEOPS !

What can we do with CHEOPS ?

Strategy 1: filler programme

- From lists of existing sdB and WDs (about 4000 sdBs and 1200 WDs with V<16), select those that have a good visibility with CHEOPS

- Given transits probabilities & duration (~15 min for P_{orb}~15h for sdB stars; vs ~2min for P_{orb}~50h for white dwarfs), search for transits around **sdB stars** preferred ?

- **Strategy 1a**: choose brightest ones – overlap with TESS ?
- **Strategy 1b:** choose not-too-bright, to reach other planet remnants than TESS

- Byproduct: asteroseismology (pulsations of few minutes to a few hours, amplitudes ~1% to 0.1%)

This is an excellent filler programme

- A full transit can be observed within 1 orbit
- Hundreds of possible targets
- Interesting science with a limited number of orbits

Number of targets:

	sdB	WD
V<12	152	20
12<V<14	859	197
14<V<15	1017	461
15<V<16	2252	

Visibility with CHEOPS (% time along one orbit)

	sdB >80%	sdB > 50%	WD>80%	WD>50%
V<12	35	136	3	17
12<V<14	289	780	51	171
14<V<15	TBD			
15<V<16				

Predicted transit Signal-to-Noise Ratio

	1 Rearth - sdB	0.1 Rearth - WD
V=10	40	17
V=12	17.8	6.4
V=14	5.4	1.7
V=15	2.5	0.8

What can we do with CHEOPS ?

Strategy 2: TESS follow-up (time-constrained observations)

- Wait for TESS interesting targets…
- To be discussed within CHEOPS/TESS collaboration (I. Ribas)
- CHEOPS higher sensitivity and better cadence will allow to **refine objects properties** + CHEOPS could **detect further objects** in a same system
- Non-detection *is* science ! Statistics are needed !

Summary & Discussion

Main question: what are the planet remnants after the red giant phase ?

-> Search for transiting planets/planetesimals around sdB stars and white dwarfs

Current status :

- Brown dwarfs (Jupiter-sized objects) around sdB stars and white dwarfs are common
- Suspected planets around sdB stars through light travel time and phase curves
- No transits so far for sdB stars
- Minor planet transiting a white dwarf

Transit properties : - 0.3% transit depth for 1 Rearth around an sdB star (a few % probability)
- 0.5% transit depth for 0.1 Rearth around a WD (<~1% probability)

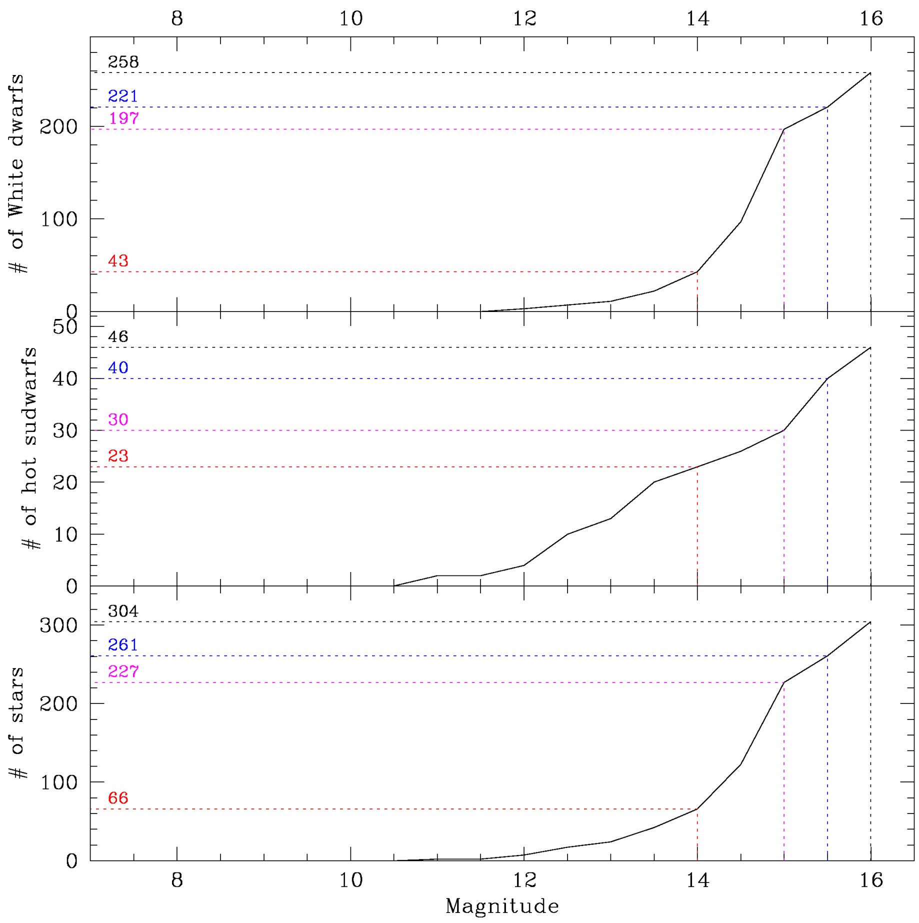
TESS: nearly complete all-sky survey down to V=16 (~1000 WDs and ~3000 sdB stars)

What **CHEOPS** can do:

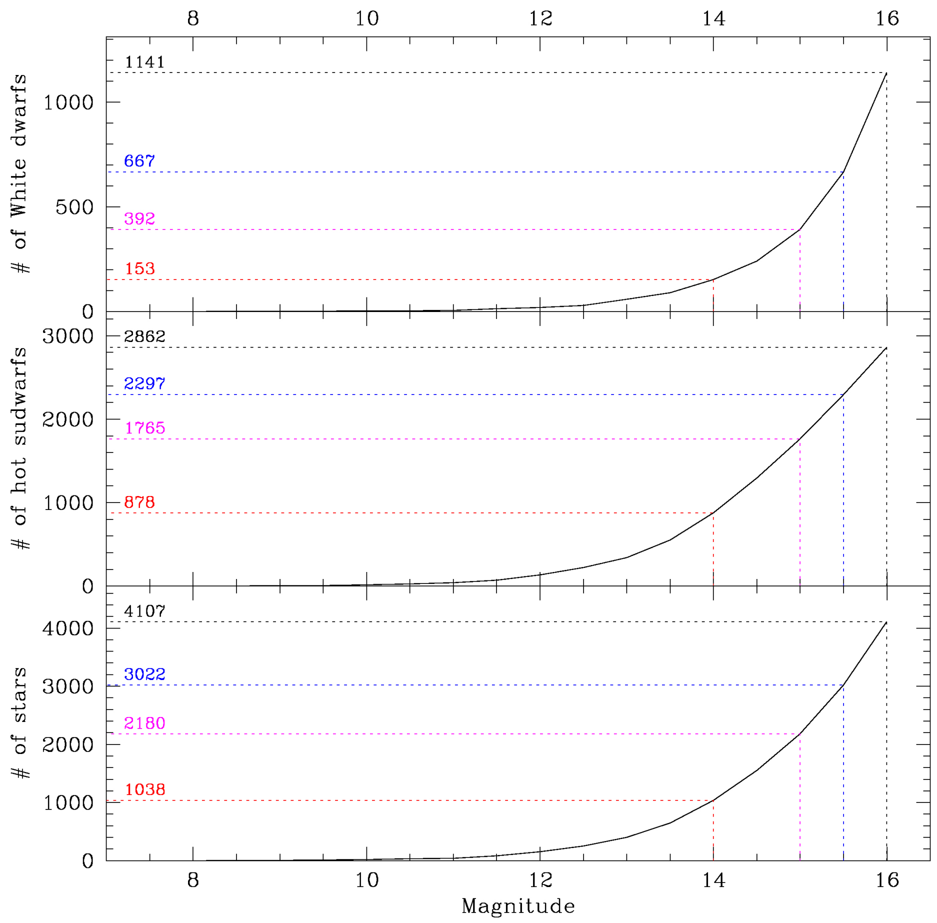
- Better sensitivity than TESS in the blue, higher cadence possible -> follow-up for the most interesting objects TESS will find (refined properties, additional objects)

- Search for planets transiting sdBs (and WDs ?) can be an excellent filler programme

Number of stars as a function of mag limit



20s cadence



2min cadence

About TESS *(Transiting Exoplanet Survey Satellite)*

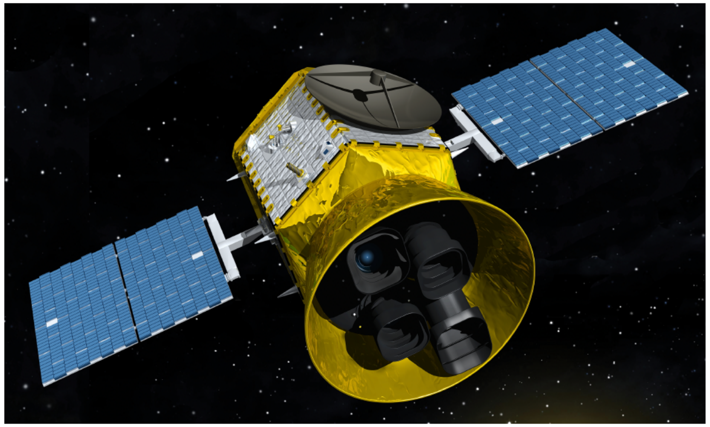
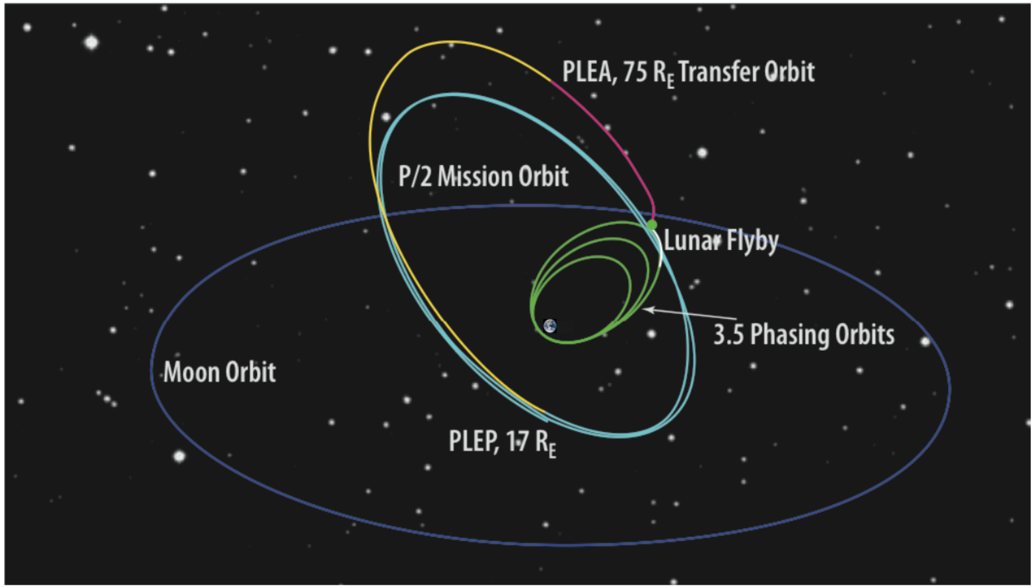



Figure 4. *Left.*—Diagram illustrating the orientations of the four *TESS* cameras, lens hoods, and mounting platform. *Right.*—Artist's conception of the *TESS* spacecraft and payload.



About TESS *(Transiting Exoplanet Survey Satellite)*

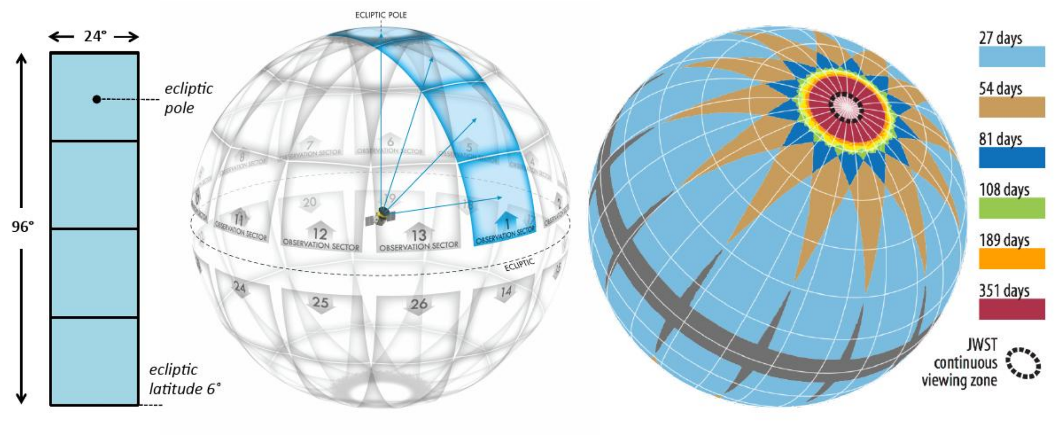


Figure 7. *Left.*—The instantaneous combined field of view of the four *TESS* cameras. *Middle.*—Division of the celestial sphere into 26 observation sectors (13 per hemisphere). *Right.*—Duration of observations on the celestial sphere, taking into account the overlap between sectors. The dashed black circle enclosing the ecliptic pole shows the region which *JWST* will be able to observe at any time.

The 20s-cadence list (Attach:wg8-20s-20170403) contains 328 stars among which 292 are observable with TESS (known bright p-mode sdB pulsators, DAV and DBV white dwarfs, DAV, DBV, DAOV and sdV candidates). The potentially observable stars include 45 p-mode sdBVs, 47 DAVs, 3 DBVs and 197 pulsator candidates that could occupy a maximum of ~ 620 20s-slots (considering the longest possible run for each object; For instance a star in Zone 1 monitored for 1 year will take 13 slots).

The 2mn-cadence list (Attach:wg8-2mn-20170403) contains 4631 stars among which 4119 are observable with TESS (known bright g-mode sdB pulsators, GW Vir stars, and all known white dwarfs and hot subdwarfs down to mag 16). This list includes 11 GW Vir stars, 41 g-mode sdBVs, 1153 white dwarfs and 2861 hot subdwarfs. Assuming that we'll request the longest possible light curves for the pulsators and only 27d observations for the other stars (whatever the zone they fall in), we would need a maximum of ~ 4176 2mn-slots.