Spectral Surveys

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Outline

– Introduction to spectroscopy

– The need of large spectroscopic surveys

– Past spectroscopic surveys

– Ongoing spectroscopic surveys

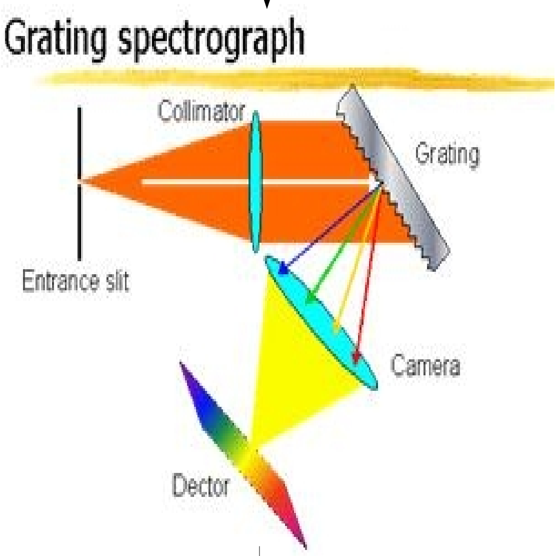
– White dwarf research based on past and ongoing surveys

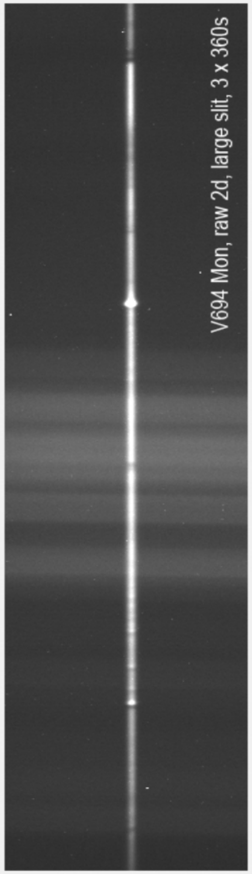
– Future spectroscopic surveys

– White dwarf research based on future surveys

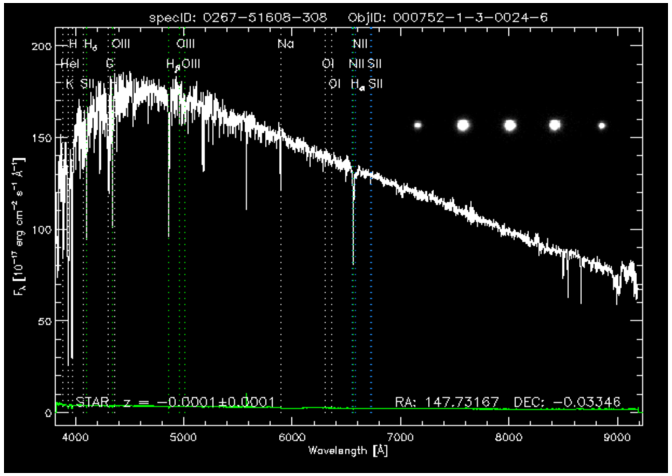
– Conclusions

1. Introduction to spectroscopy





Flux

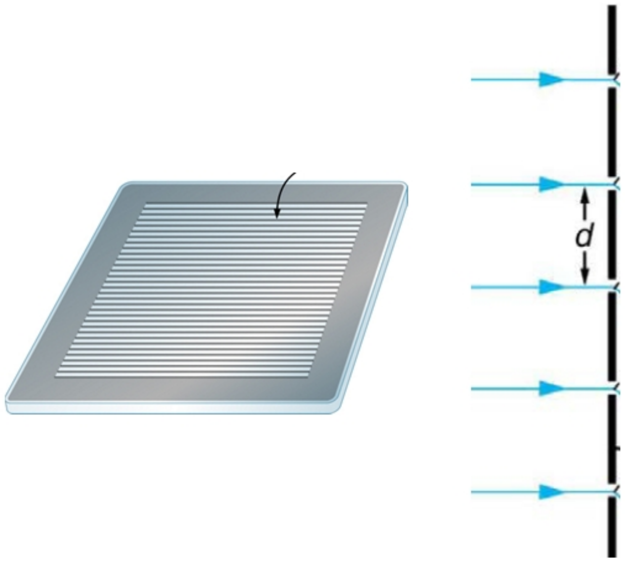


Wavelength

1. Introduction to spectroscopy

Diffraction Grating

A large number of slits closely separated

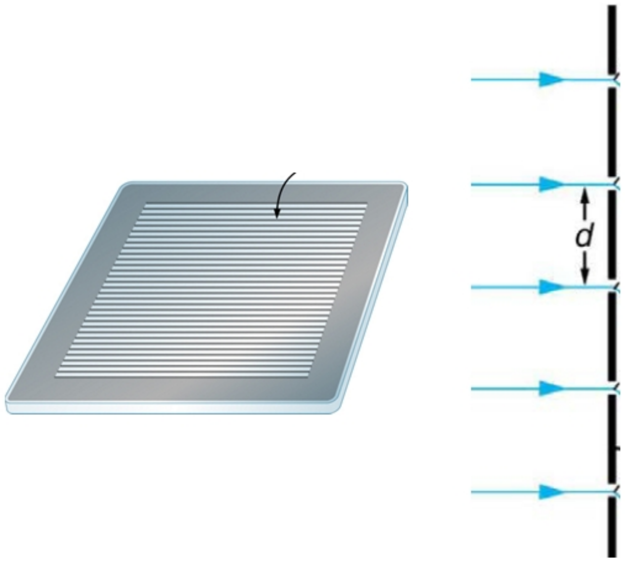


Transmission or reflection

1. Introduction to spectroscopy

Diffraction Grating

A large number of slits closely separated

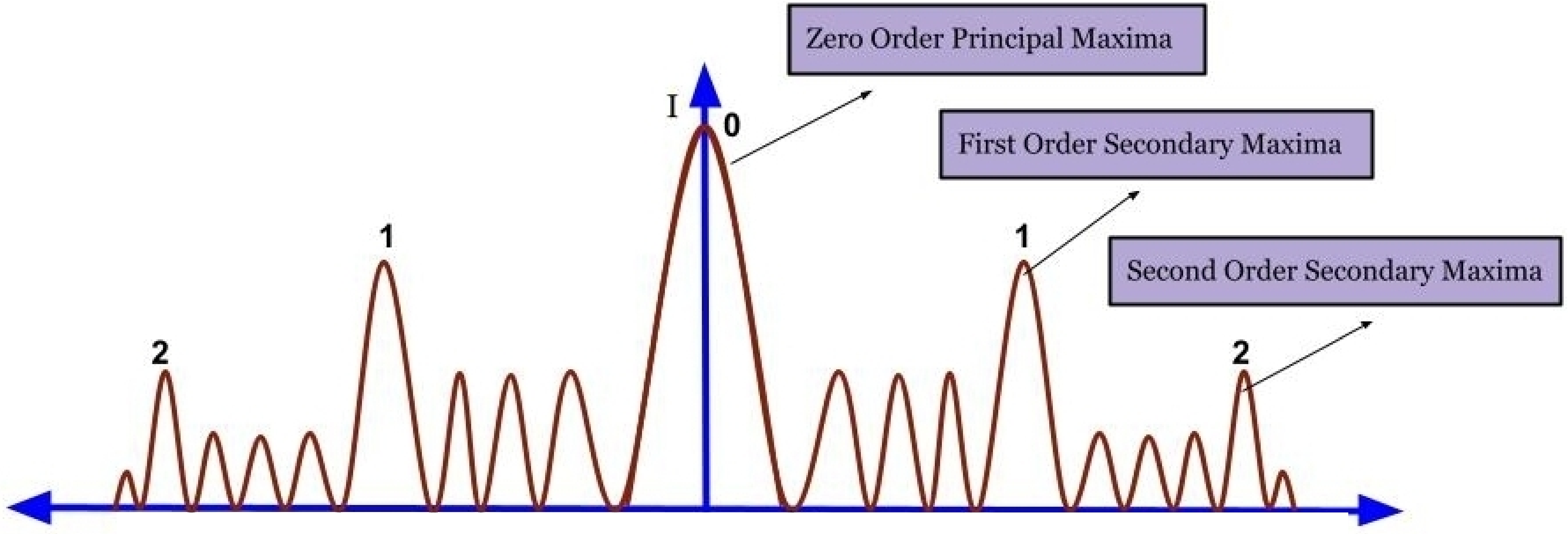


$$I = Io\left[\frac{\sin\left(\frac{kpa}{2}\right)}{\frac{kpa}{2}}\right]^2\left[\frac{\sin\left(\frac{Nkpd}{2}\right)}{N\sin\left(\frac{kpd}{2}\right)}\right]^2$$

a = slit size
d = separation between slits
N = number of slits
k = 2π/λ
$p = \sin(\theta_i) - \sin(\theta_m)$ (trans.)
$p = \sin(\theta_i) + \sin(\theta_m)$ (refl.)

Transmission or reflection

1. Introduction to spectroscopy

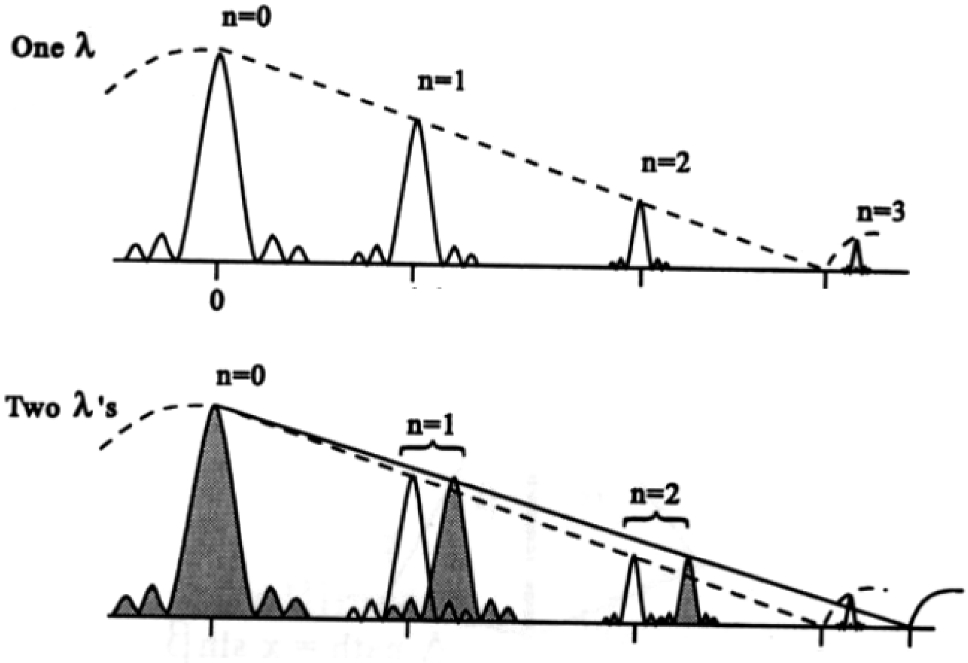


It can be demonstrated that the maxima occur when p = $n\lambda/d$

$n\lambda = d[\sin(\theta_i) - \sin(\theta_m)]$ (trans.) $n\lambda = d[\sin(\theta_i) + \sin(\theta_m)]$ (refl.) → grating equation

Note that the zeroth order is not dispersed!

1. Introduction to spectroscopy



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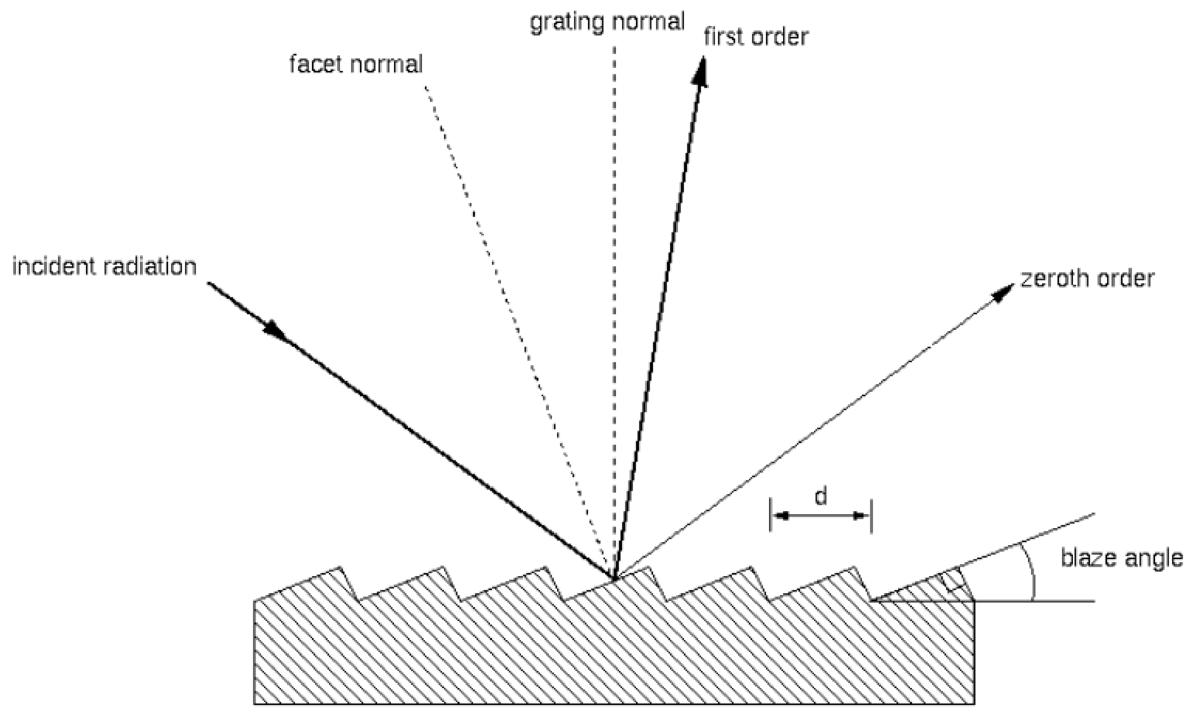
Note that the zeroth order is not dispersed!

1. Introduction to spectroscopy

Avoiding this issue is possible introducing differences between the optical path that light follows after crossing the slits. The way to do this is to incline the grating



Reflecting grating

1. Introduction to spectroscopy

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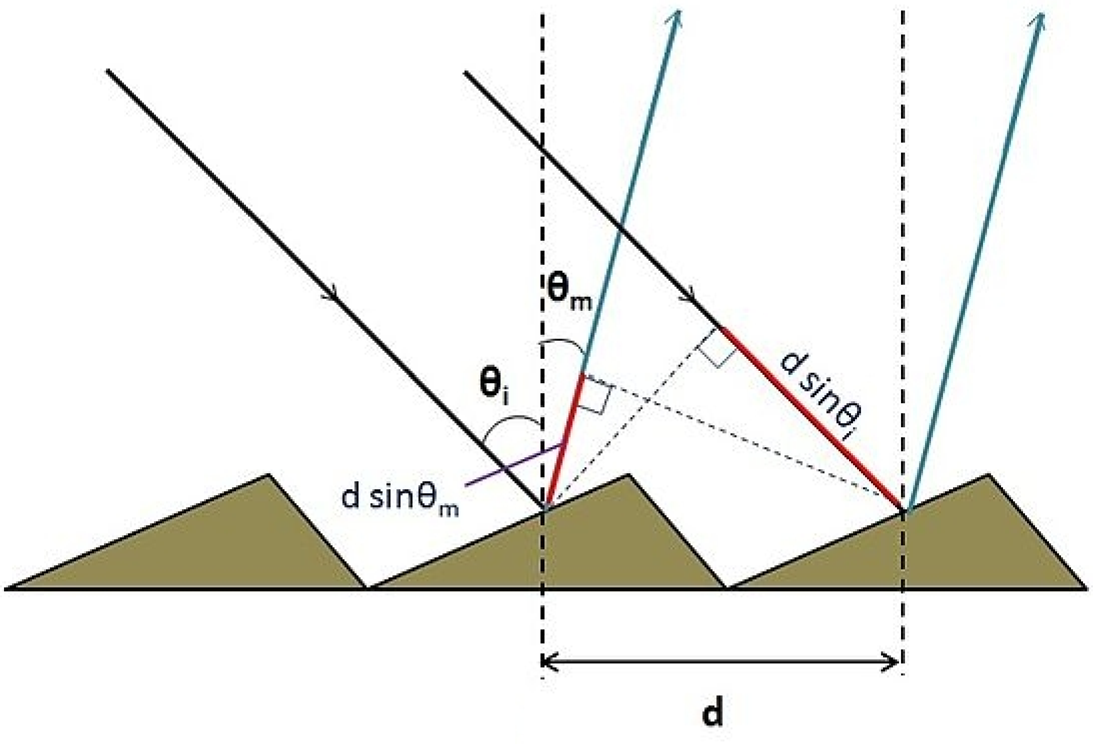


Reflecting grating

In this case the difraction pattern is as follows:

$$I = Io\left[\frac{\sin\left(\frac{kpa}{2}\right)}{\frac{kpa}{2}}\right]^2\left[\frac{\sin\left(\frac{Nk\,\delta}{2}\right)}{N\sin\left(\frac{k\,\delta}{2}\right)}\right]^2$$

where $\delta = d[\sin(\theta_i+\varphi) + \sin(\theta_m+\varphi)]$ and φ is the blaze angle

The grating equation transforms into $d[\sin(\theta_i+\varphi) + \sin(\theta_m+\varphi)] = n\lambda$

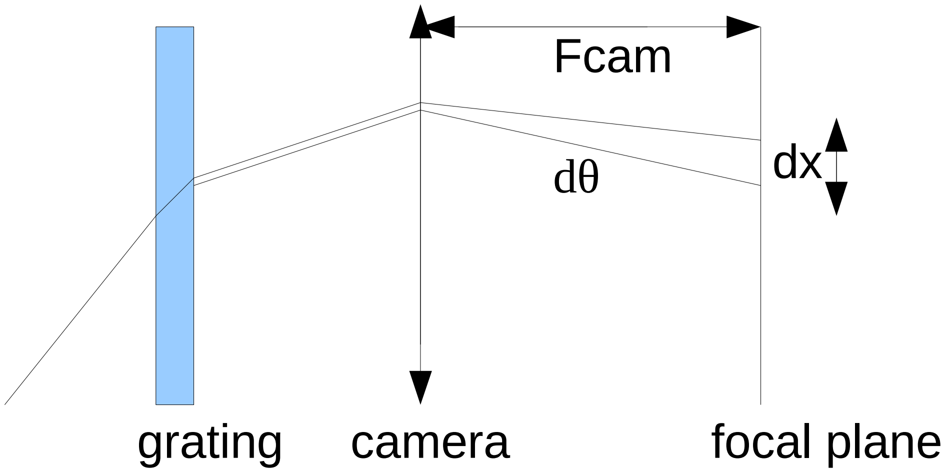
For $n = 0 \rightarrow \sin(\theta_i+\varphi) = -\sin(\theta_m+\varphi) \rightarrow$ assuming small angles (which is the case) $\rightarrow$ $\theta_i+\varphi = -(\theta_m+\varphi) \rightarrow \theta_m = -2\varphi - \theta_i$

Angular dispersion: the rate of change of the angle of the dispersed light with wavelength

$n\lambda = d[\sin(\theta_i) + \sin(\theta_m)]$
$n d\lambda = d\cos(\theta_m)(d\theta_m)$
$d\theta_m/d\lambda = n/d\cos(\theta_m)$

Linear dispersion: the rate of change of the linear distance, *x*, along the spectrum with wavelength

$dx/d\lambda = (dx/d\theta_m)(d\theta_m/d\lambda) = (dx/d\theta_m)\,(n/d\cos(\theta_m)) = Fcam\,(n/d\cos(\theta_m)) = nFcam\,/\,d\cos(\theta_m)$



$d\theta\, Fcam = dx \rightarrow dx/d\theta = Fcam$

1. Introduction to spectroscopy

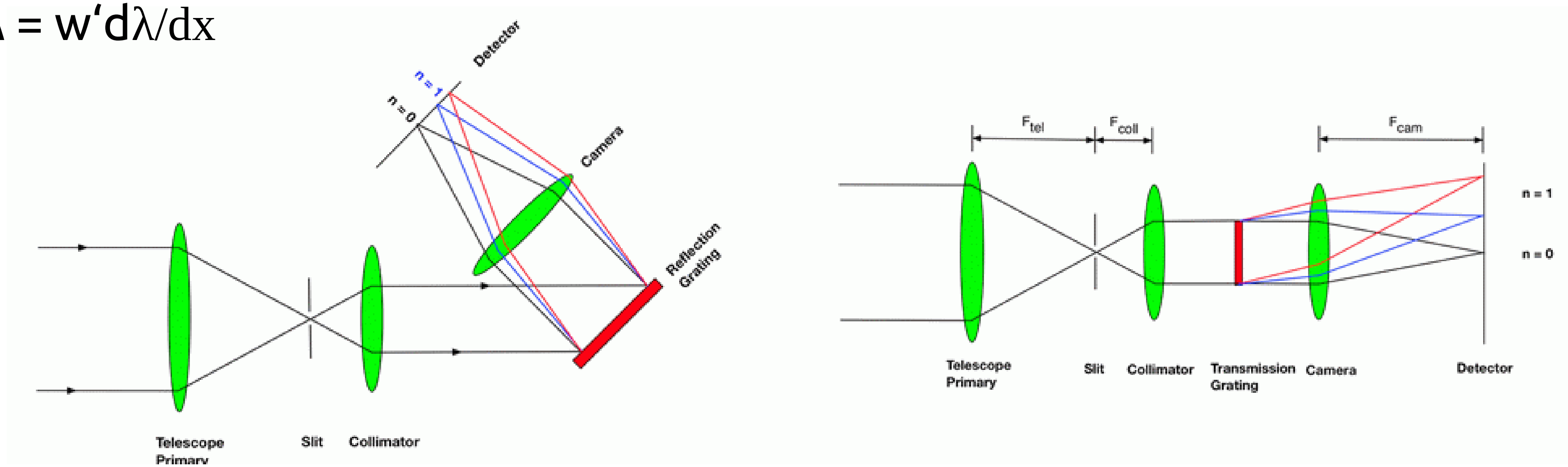
Reciprocal linear dispersion: the inverse of the linear dispersion. This is the value normally provided by the instrument web pages and referred to as *dispersion*

$d\lambda/dx = d\cos(\theta_m)/nF_{cam} \approx d/nF_{cam}$

Wavelength Range: Disp. (A/mm) x detector-size (mm; in the dispersion direction)

Resolution: the ability to distinguish two wavelengths separated by a small amount $\Delta\lambda$. It can be considered as the FWHM of a spectral line. It depends on the reciprocal dispersion and the size of the entrance slit:

$\Delta\lambda = w' d\lambda/dx$



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$\Delta\lambda = w' d\lambda/dx$

Resolving Power: $R = \lambda/\Delta\lambda$

Low resolution: R <~ 4000; Δλ >~ 1.6 A at Hα

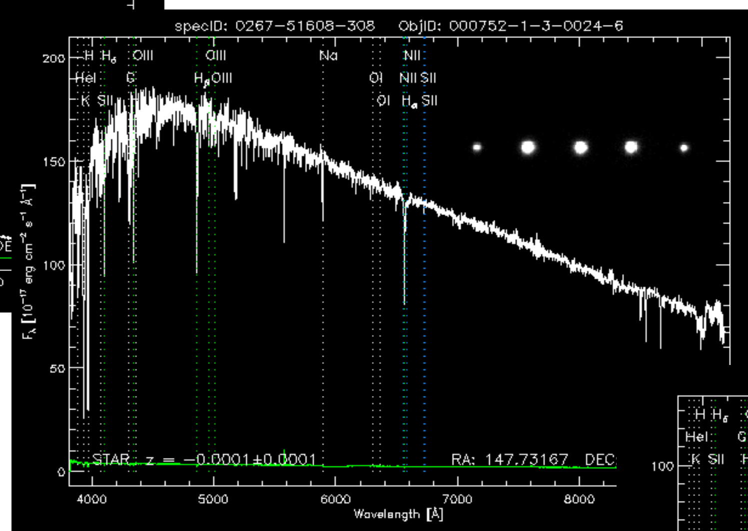
Medium resolution: 4000 <~ R <~ 15000; 1.6 A >~ Δλ >~ 0.4 A at Hα

High resolution: R >~ 15000; Δλ <~ 0.4 A at Hα

1. Introduction to spectroscopy

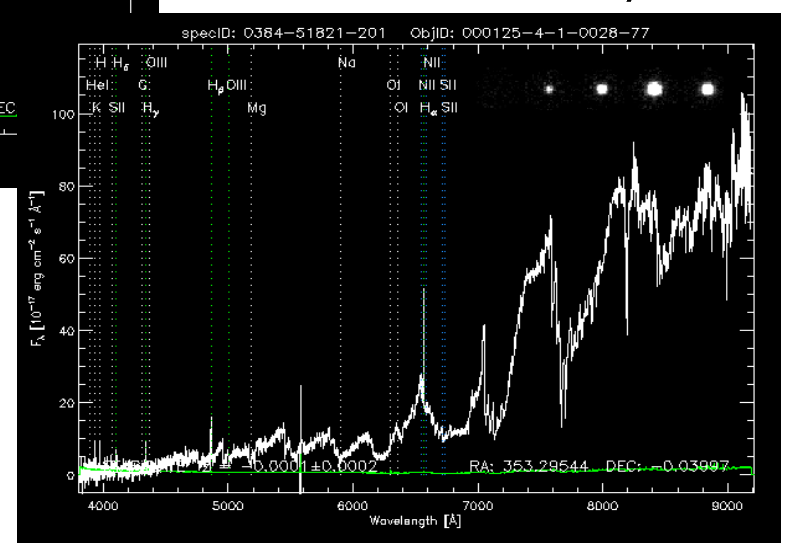
The spectral continuum informs
about the temperature
of the stars (celestial bodies)

40,000 K



6,000 K (~Sun)

3,000 K



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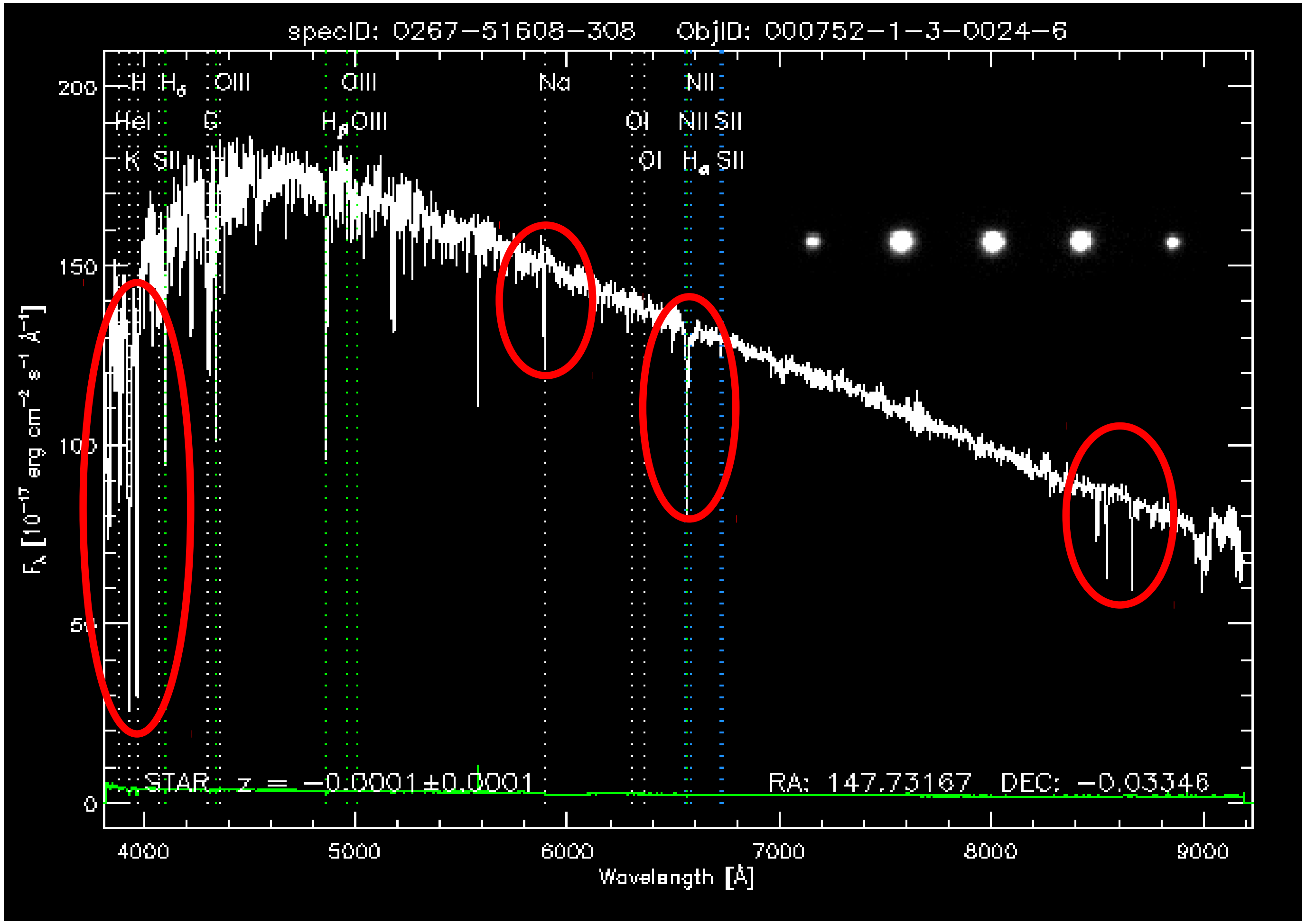
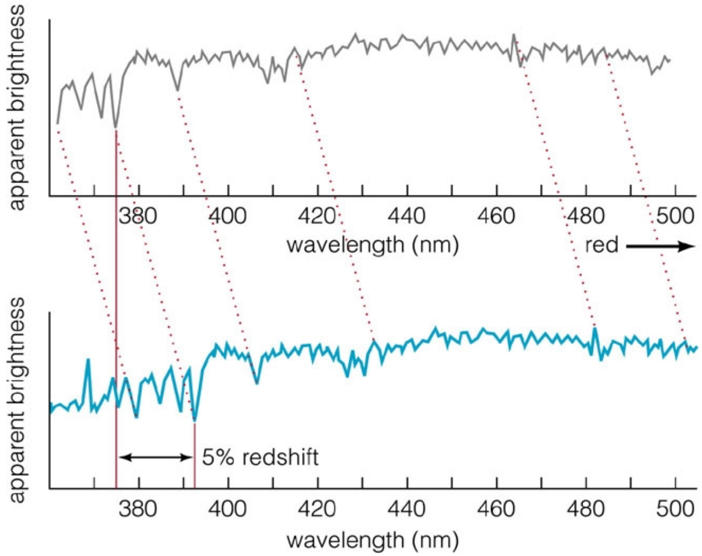
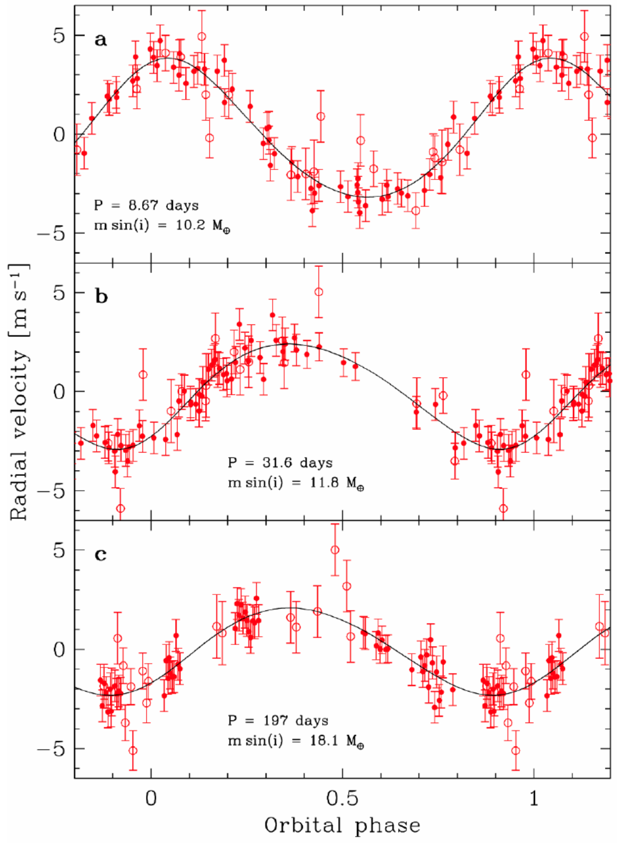


The spectral lines inform about the chemical composition of the atmosphere

1. Introduction to spectroscopy





The spectral lines inform about the chemical composition of the atmosphere

About the radial velocity of the body

2. The need of large spectroscopic surveys

Spectra can be obtained by ground-based and space telescopes

Normally high over subscription factor (2.5-6) → strategy OK for *small* projects

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It becomes unfeasible for large scale projects → need of large spectroscopic surveys

Data publicly available through data releases

Being involved generally implies priorities

Who decides what to observe?

3. Past spectroscopic surveys

The Hamburg-Quasar survey

– Dedicated to finding QSOs in the northern sky (~14.000 deg²)

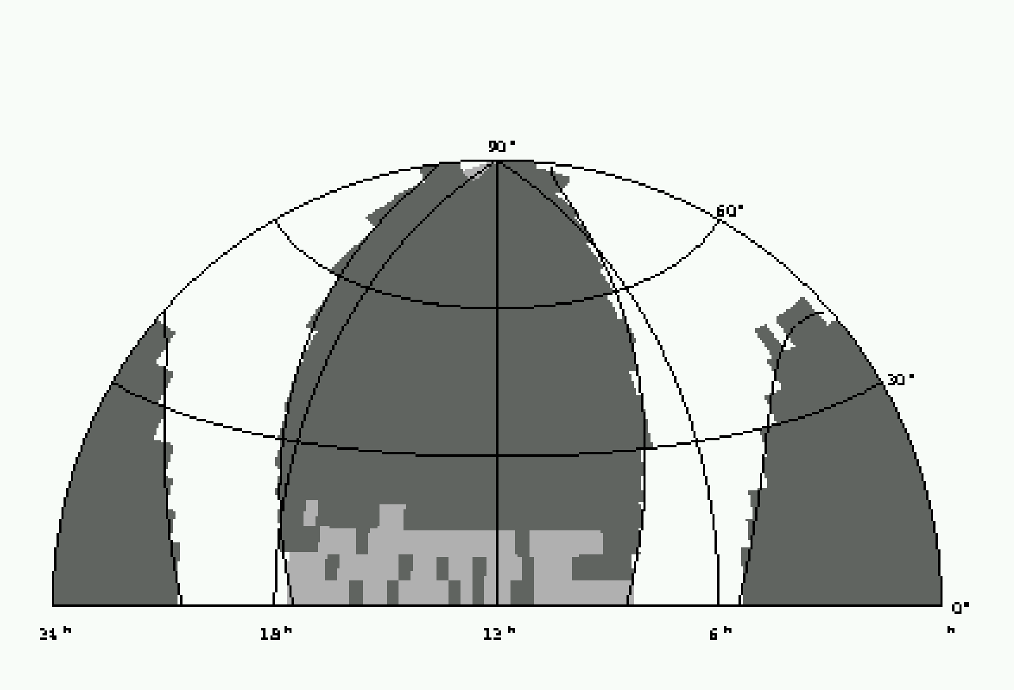
– 2.2m telescope at Calar Alto from 1980 to 1997

– ~150.000 spectra obtained with 1930 plates (5.5º x 5.5º)

– Wavelength range 3400-5400 A

– R ~ 100; Δλ ~ 45 A at Hγ

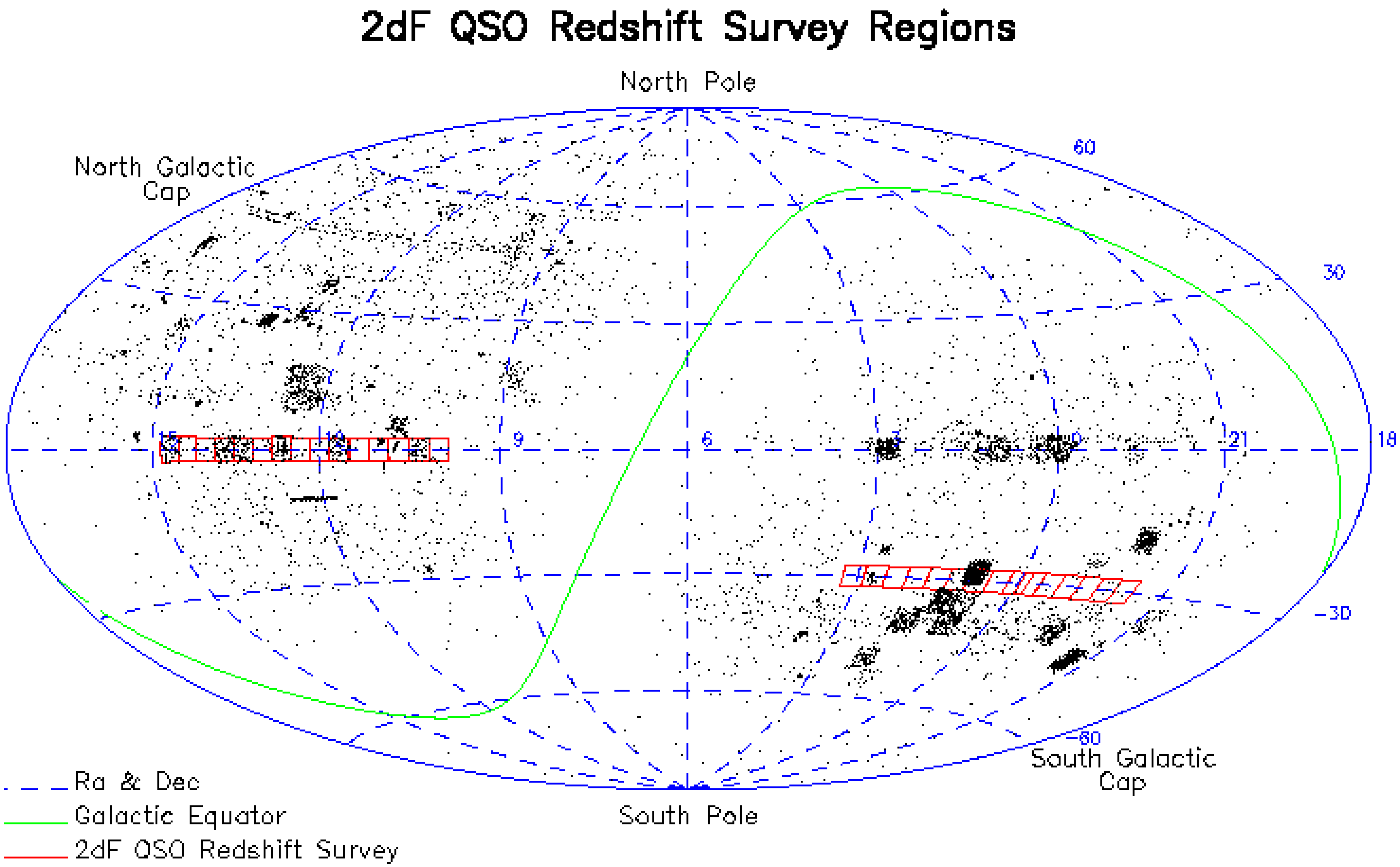
– 13 mag <~ B <~ 17.5 mag



3. Past spectroscopic surveys

The 2df QSO redshift survey (2QZ)

– Dedicated to measurging redshifts of 25.000 QSOs in two 75º x 5º strips



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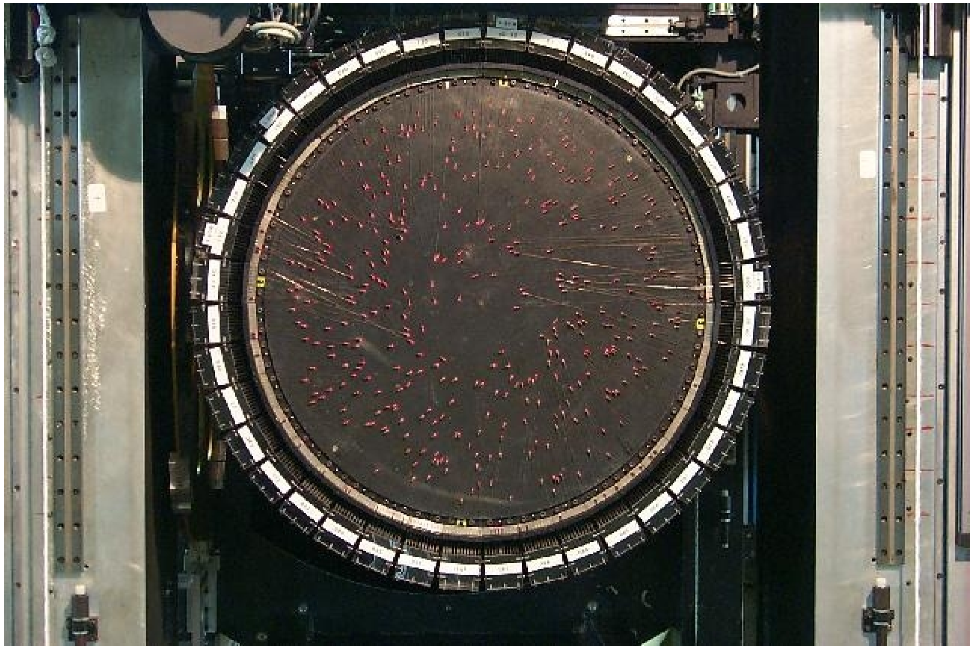
– It operated the 3.9m AAT at Siding Spring Observatory from 1997 to 2002

– It used the 2 degree field multi-object spectrograph (400 spectra per obs.)



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– It used the 2 degree field multi-object spectrograph (400 spectra per obs.)

– Wavelength range 3700-7900 A

– R ~ 700; $\Delta\lambda \sim 9$ A at Hα

– 18.25 mag <~ b_J <~ 20.85 mag

3. Past spectroscopic surveys

The RAVE survey

– Dedicated to derive RVs, Teff, log(g), abundances of stars

– It operated the 1.2m UK Schmidt telescope at the Siding Spring Observatory from 2003 to 2013

– It used the 6dF multi-object spectrograph (150 spectra per obs.) → ~570.000 spectra in total

– Wavelength range 8410-8795 A

– R = 7500; $\Delta\lambda$ = 0.9 A at Hα

– 9 mag < I < 12 mag

3. Past spectroscopic surveys

The SDSS survey (SDSS-I,II; Legacy, Supernova Survey + SEGUE-1)

– The main driver was the selection of QSOs and galaxies for spectroscopy to build a uniform, well-calibrated map of the Universe

– It operated the 2.5m telescope at Apache Point Observatory from 2000 to 2008

– It used fibre-fed plates (640 spectra per obs.) → nearly 1 million spectra

– Wavelength range 3800-9200 A

– R ~ 1800; Δλ ~ 3.6 A at Hα

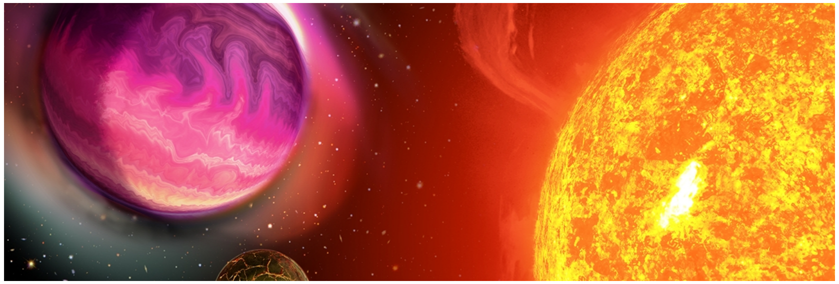
– 15 mag <~ i <~ 19.1 mag

3. Past spectroscopic surveys

The SDSS survey (SDSS-III; BOSS, MARVELS, APOGEE, SEGUE-II)

– The main driver was mapping the clustering of galaxies and intergalactic gas in the distant universe (BOSS), the dynamics and chemical evolution of the Milky Way (SEGUE-2 and APOGEE), and the population of extra-solar giant planets (MARVELS)

– It operated the 2.5m telescope at Apache Point Observatory from 2008 to 2014



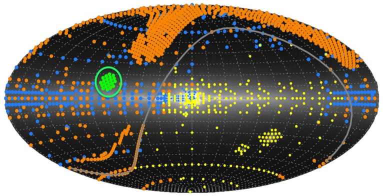
– It used fibre-fed plates (1000 spectra per obs.) +1.6 million additional spectra

– Wavelength range 3600-10400 A

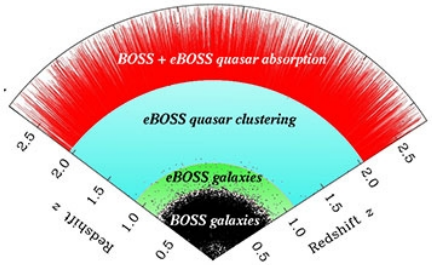
– R ~ 2200; Δλ ~ 3 A at Hα – 15 mag <~ g <~ 22 mag

The SDSS survey (SDSS-IV: 2014-2020)

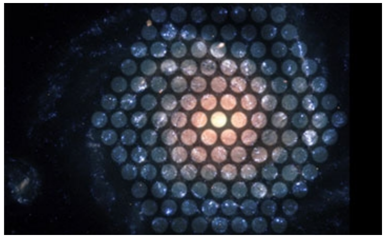
– APOGEE-2: stellar spectroscopic survey of the Milky Way using the 2.5m Apache Point + 2.5 du Pont telescopes



– eBOSS: a cosmological survey of quasars and galaxies



– MaNGA: explored the detailed structure of 10.000 nearby galaxies



4. Ongoing spectroscopic surveys

The SDSS survey (SDSS-V: October 2020 – 2025): mapper programs

– Milky Way Mapper: multi-object spectroscopic survey to obtain near-infrared and/or optical spectra of more than 4 million stars throughout the Milky Way and Local Group

– Local Volume Mapper: optical, integral-field spectroscopic survey that targets the Milky Way, Small and Large Magellanic Clouds, and other Local Volume galaxies

– Black Hole Mapper: multi-object spectroscopic survey that emphasizes optical spectra for more than 300,000 quasars to jointly understand the masses, accretion physics, and growth and evolution over cosmic time of supermassive black holes

4. Ongoing spectroscopic surveys

The LAMOST survey

– The scientific goal focuses on the extragalactic observation and structure and evolution of the Galaxy

– It operates the 4m LAMOST telescope at Xinglong Observatory from 2012

– It used fibre-fed plates (4000 spectra per obs.) → nearly ~190 million spectra

– Wavelength range 3700-9000 A

– Medium-resolution spectra (R = 7000) available from phase II (2018; ~170 million spectra)

– R ~ 1800; Δλ ~ 3.6 A at Hα

– 13 mag <~ r <~ 19 mag

4. Ongoing spectroscopic surveys

The GALAH survey

– Dedicated to trace the full evolutionary history of the Milky Way

– It operates the 3.9m AAT at Siding Spring Observatory from 2014

– It uses the HERMES spectrograph (400 spectra per obs.) → ~850.000 spectra

– Wavelength range 4700-7900 A

– R ~ 28.000-50.000; Δλ ~ 0.25-0.13 A at Hα

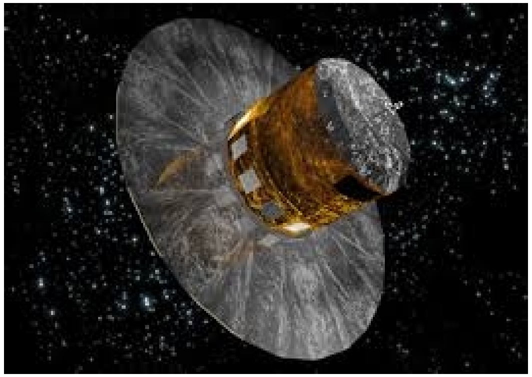
– 9 mag <~ V <~ 14 mag

4. Ongoing spectroscopic surveys

The Gaia survey

– Satellite designed by the ESA. Launched in 19-12-2013; reached L2 in 8-1-2014. Initiated operations in 25-7-2014

– Objetive: to provide a 3D map of the Galaxy via measuring parallaxes and proper motions



– DR3 (June 2022) yields such values for ~1.8 billion sources

– DR3 also provides spectra for ~220 million objects

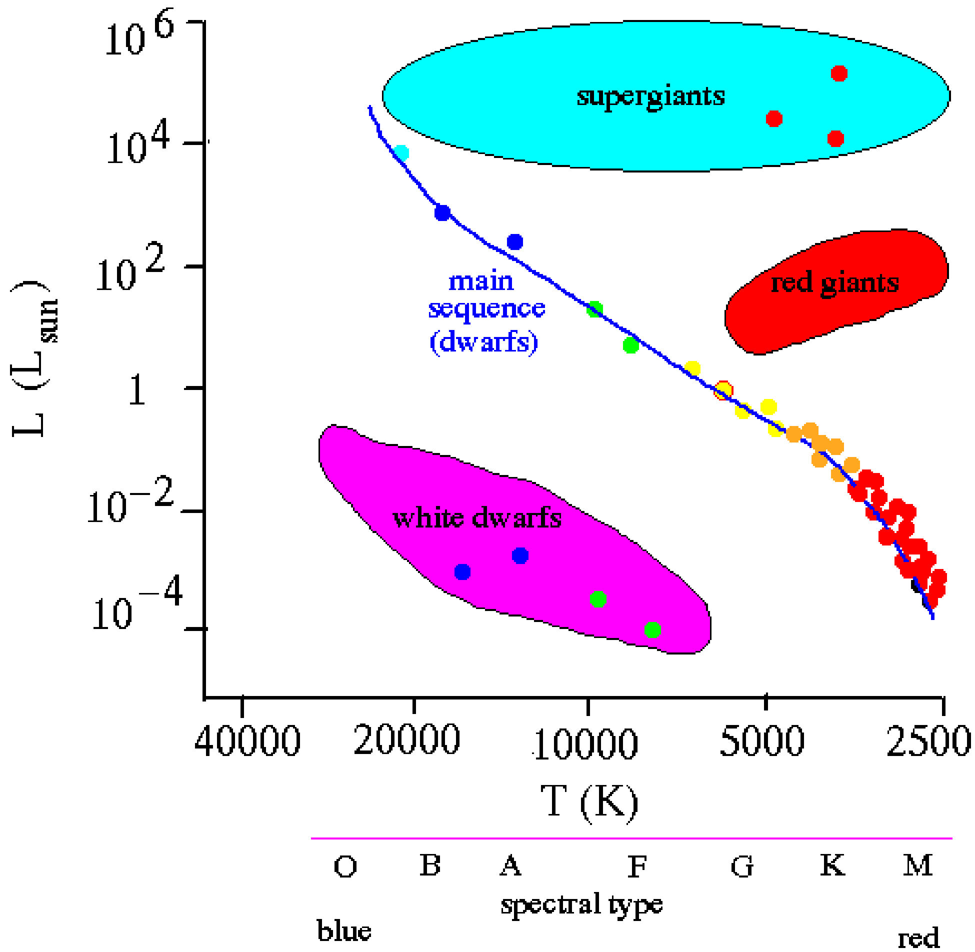
– Wavelength range 3300-10.000 A

– <R> ~ 66; <Δλ> ~ 100 A at Hα

– V <~ 17.6 mag (although fainter mag possible)

5. White dwarf reseach: past and ongoing surveys

What are white dwarfs?



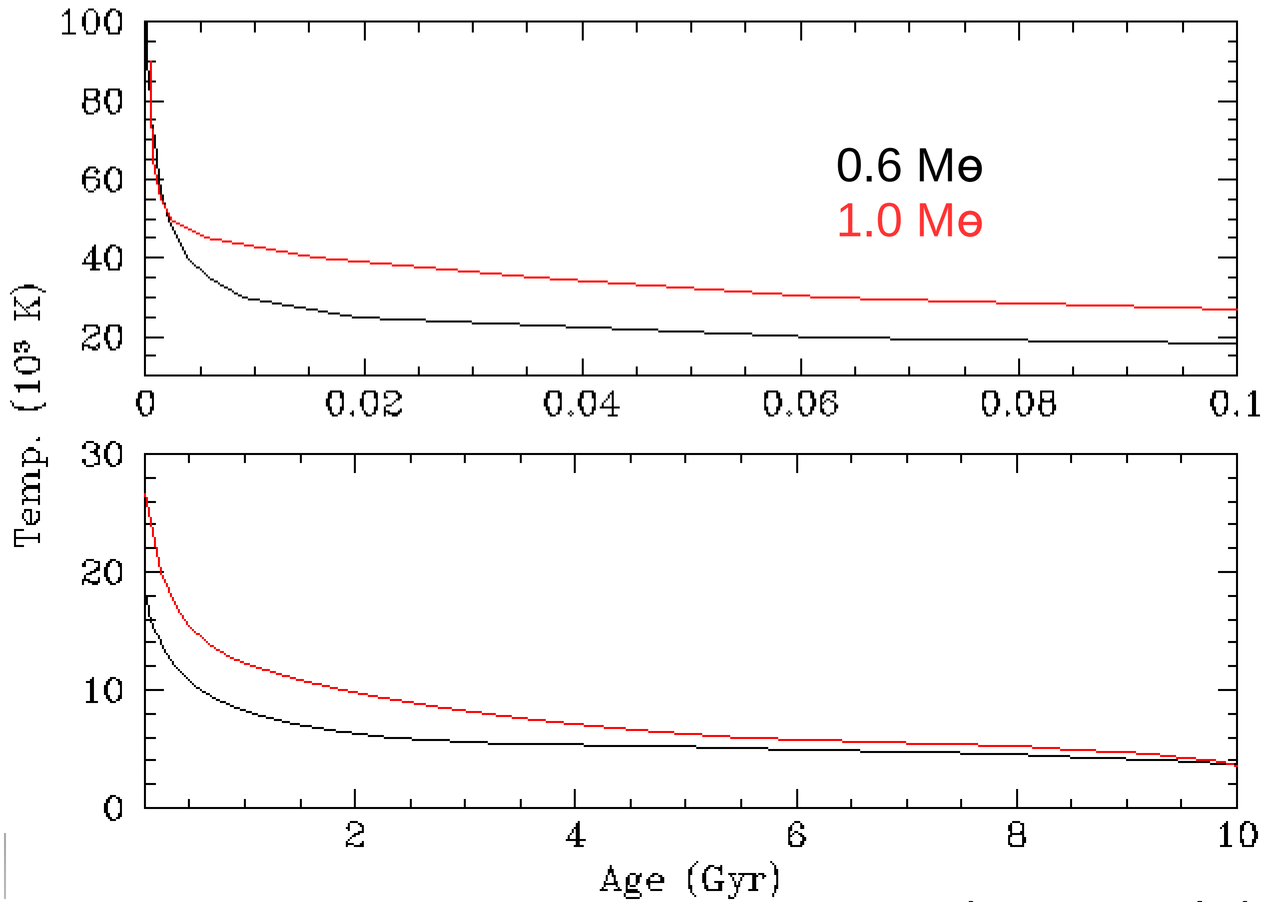
Giant star nucleus → WD

Small → low luminosity
But hot → Sp ~ A

Evolution → cooling

5. White dwarf reseach: past and ongoing surveys

How do single white dwarfs evolve? Thin H layer through which heat is radiated away → cooling



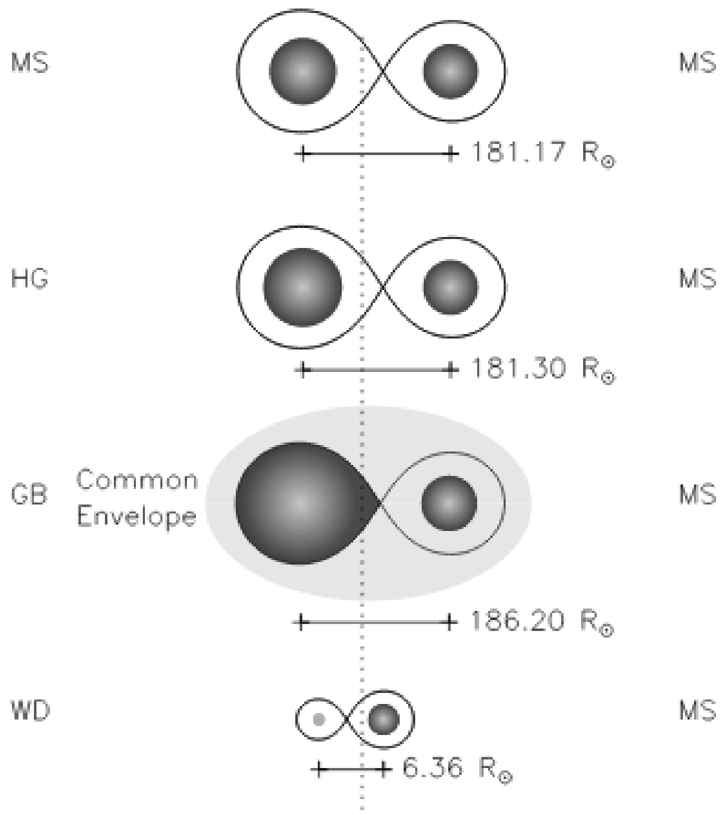
Camisassa et al. (2019)

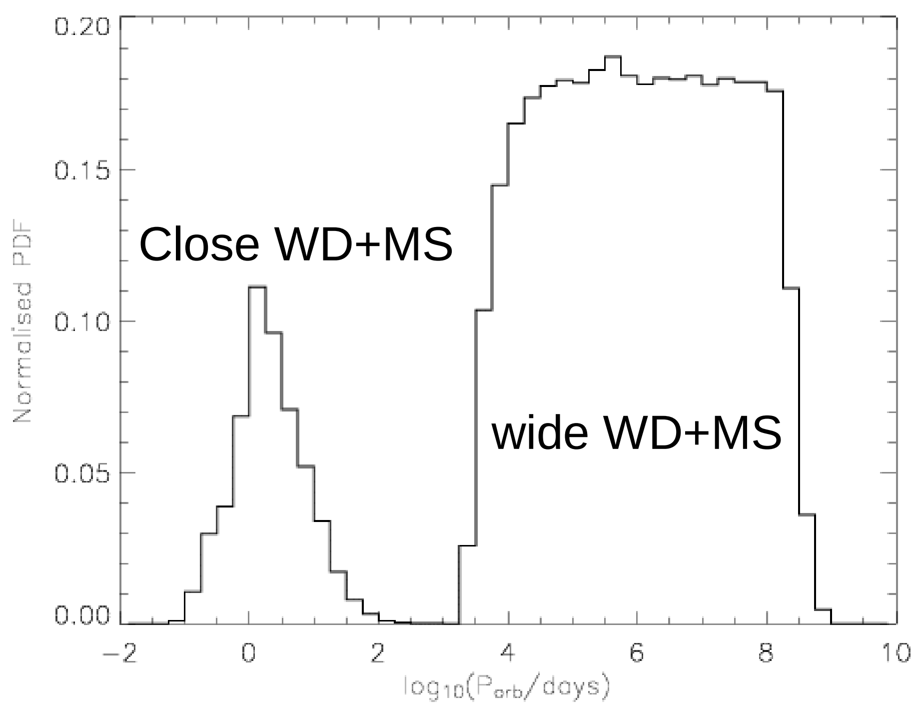
By knowing T and M we can calculate the age

How do we get T and M? From the specra

5. White dwarf reseach: past and ongoing surveys

How do binary white dwarfs evolve? If the WD progenitor and the companion are sufficiently closed the binary may undergo mass transfer episodes





Willems+Kolb (2004)

5. White dwarf reseach: past and ongoing surveys

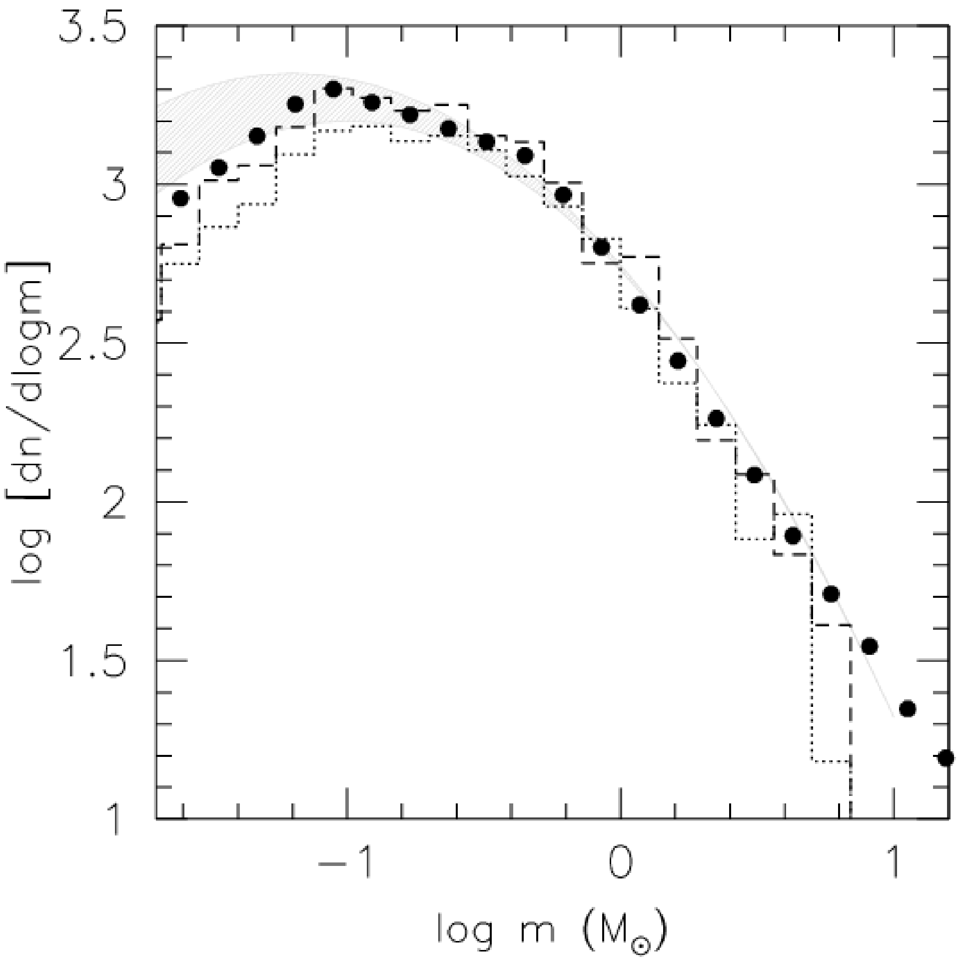
How many WDs do we know?

- Proper motions → ~100 WDs in 1950
- McCook & Sion catalogue→ ~600 WDs in 1977

  (spectroscopic observations)
- First surveys (e.g. KISO, Hamburg, Edinburgh, etc.) → ~2.200 WDs in 1999
- SDSS → ~50.000 WDs (DR14) + ~3.500 WDMS binaries
- LAMOST → ~1.000 WDs (DR2) + ~1.000 WDMS binaries
- Local sample (unbiased) → 599 WDs at 40 pc (~70% complete)
- Gaia → ~350.000, ~100.000 with spectra, ~13,000 within 100pc

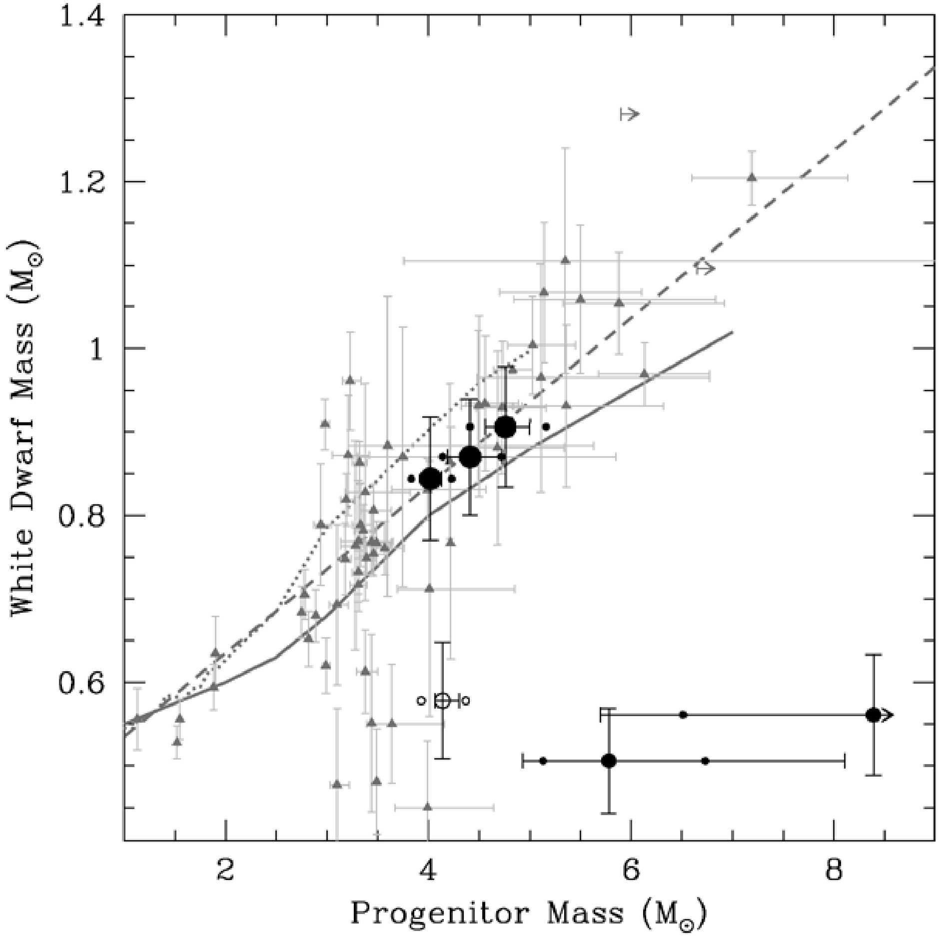
5. White dwarf reseach: past and ongoing surveys

How do we expect the WD mass distribution?



Initial mass function

Moraux, Kroupa & Bouvier (2004)



Initial-final mass relation

Catalan et al. (2008)

5. White dwarf reseach: past and ongoing surveys

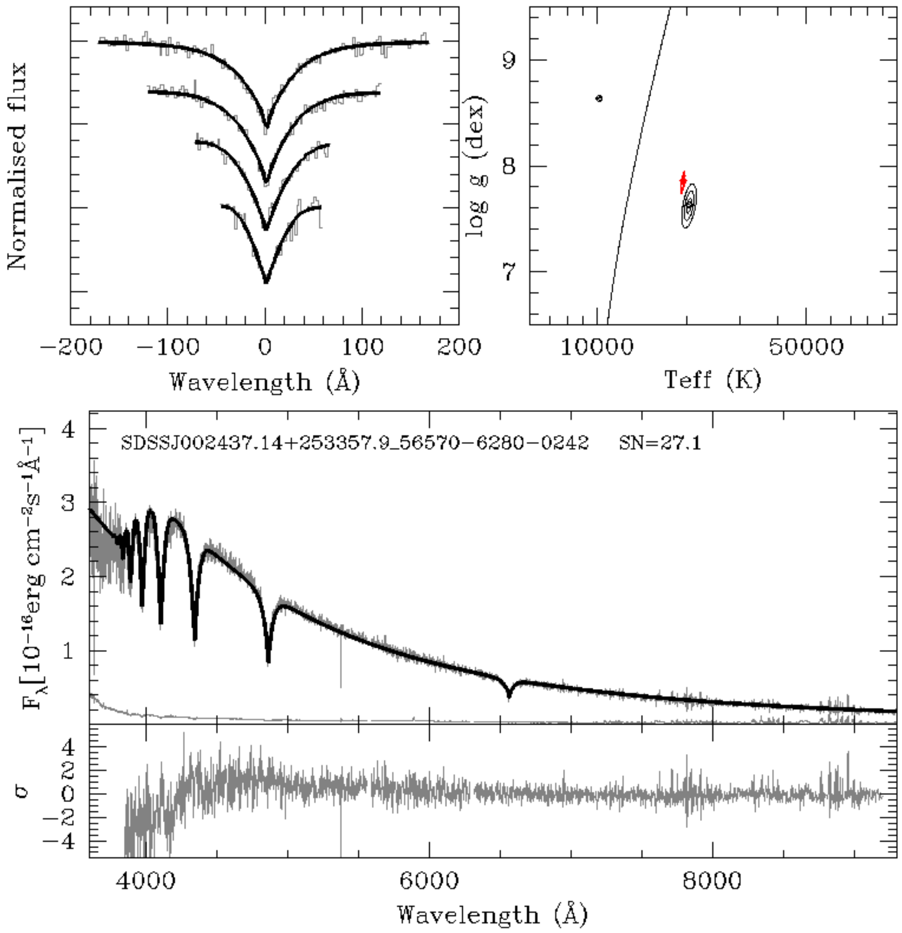
How do we expect the WD mass distribution?

Table 13.2 Typical Properties of Main-Sequence Stars

Spectral Class	Surface Temperature (kelvins)	Mass (M_{sun})	Luminosity (L_{sun})	Radius (R_{sun})	Approximate Lifetime (years)
O5	45,000	60.0	800,000	12	8×10^5
B5	15,400	6.0	830	4.0	7×10^7
A5	8,100	2.0	40	1.7	5×10^8
F5	6,500	1.3	17	1.3	8×10^8
G5	5,800	0.92	0.79	0.92	12×10^9
K5	4,600	0.67	0.15	0.72	45×10^9
M5	3,200	0.21	0.011	0.27	20×10^{11}

5. White dwarf reseach: past and ongoing surveys

How is the observed WD mass distribution? Analysing the SDSS sample



Spectral fitting of SDSS Wds provides Teff and log(g), hence mass, radius, luminosity and age can also be obtained for thousands of WDs

Rebassa-Mansergas et al. (2016)

5. White dwarf reseach: past and ongoing surveys

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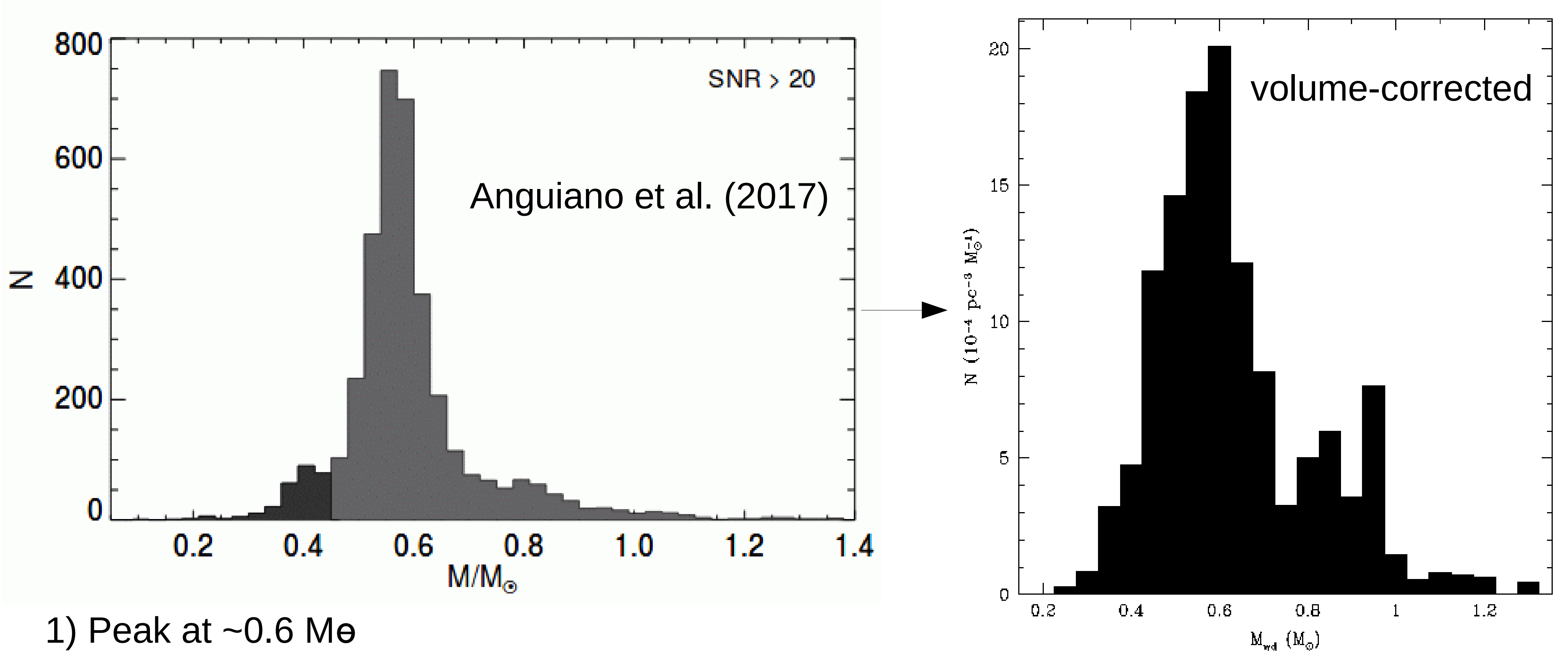


Rebassa-Mansergas et al. (2015)

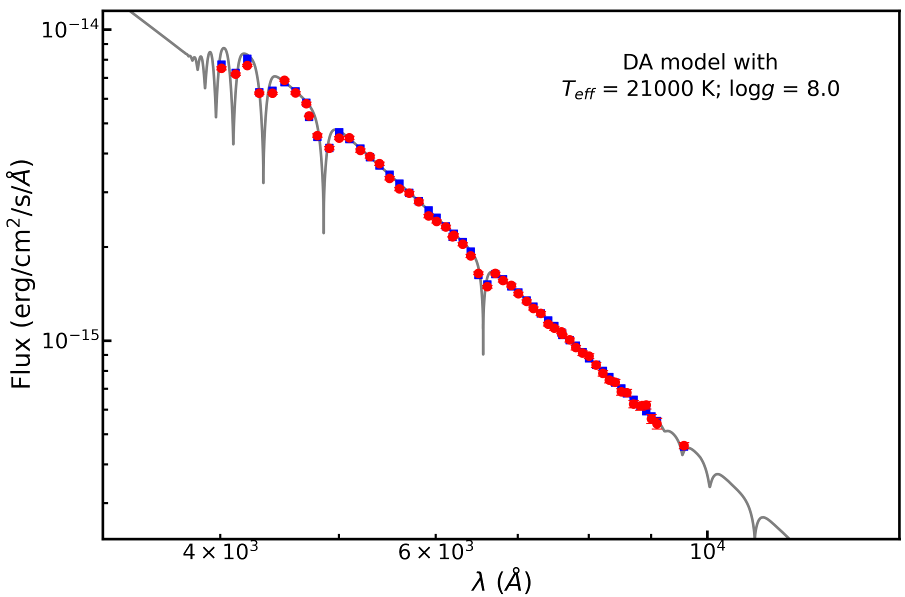
1) Peak at ~0.6 Mʘ

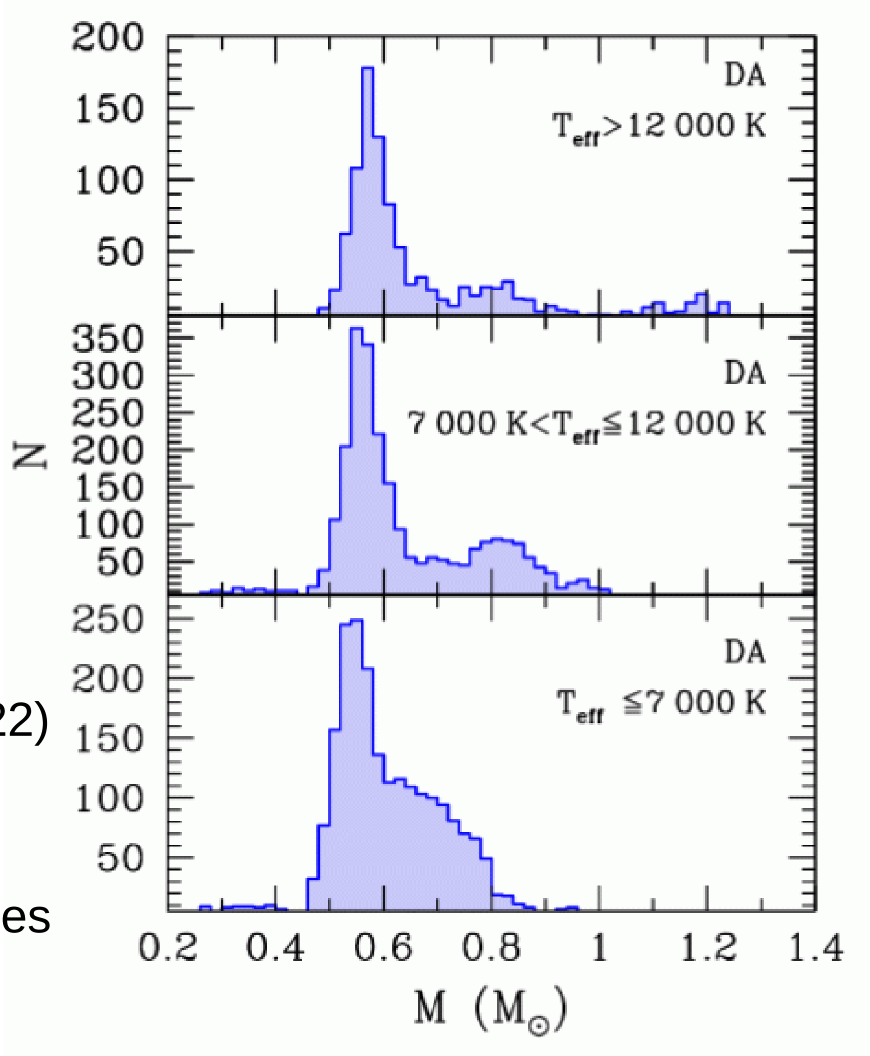
2) Low-mass peak, WDs presumably formed in binaries

3) High-mass peak. Real? Origin?

5. White dwarf reseach: past and ongoing surveys

How is the observed WD mass distribution? Analysing the Gaia 100 pc volume-limited sample





Jiménez-Esteban et al. (2022)

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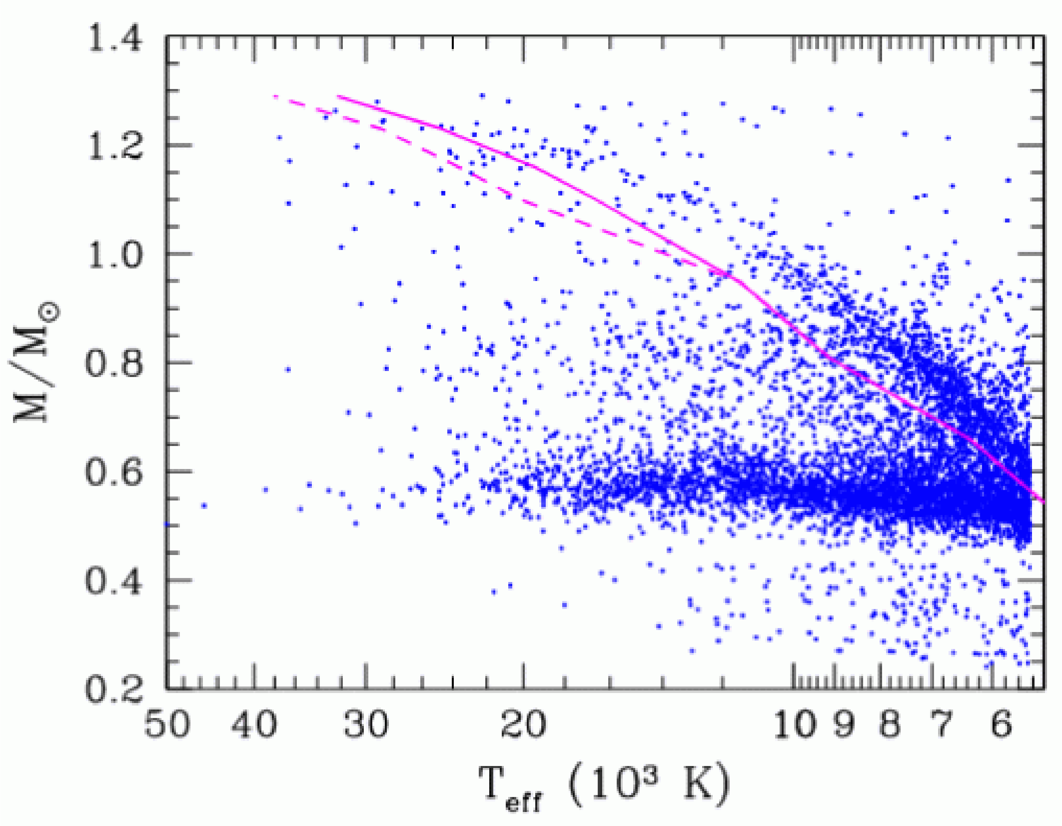


1) Peak at ~0.6 Mʘ

2) Low-mass peak, WDs presumably formed in binaries

3) High-mass peak. Origin? → Crystallization? Mergers? Flatten IFMR?

6. Future spectroscopic surveys

The WEAVE survey

– Dedicated to study the assembly of the Milky Way, the evolution of galaxies, the star formation history, the IFMR, etc.

– It will operate the 4.2m WHT at Roque de los Muchachos Observatory from November 2022

– It will use the WEAVE spectrograph (up to 1000 spectra per obs.)

– Wavelength range 3700-10.000 A

– R ~ 5.000 or 20.000; Δλ ~ 1.3-0.3 A at Hα

– G <~ 20.5 mag

6. Future spectroscopic surveys

The DESI survey

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

– The aim is to measure the effect of dark energy on the expansion of the Universe

– It will operate the 4.2m Mayall at Kitt Peak Observatory

– It will use the DESI spectrograph (10 spectrographs with 500 fibres)

– Wavelength range 3600-9800 A

– R ~ 2.000 (blue)-5.000 (red); $\Delta\lambda$ ~ 3.2-1.3 A at Hα

– m_z <~ 20.5 mag

6. Future spectroscopic surveys

The 4MOST survey

– Currently in its Manufacturing, Assembly, Integration and Test Phase

– 2436 fibres (2/3 LR; 1/3 HR)

– Spectra for >25 million objects in ~5 years

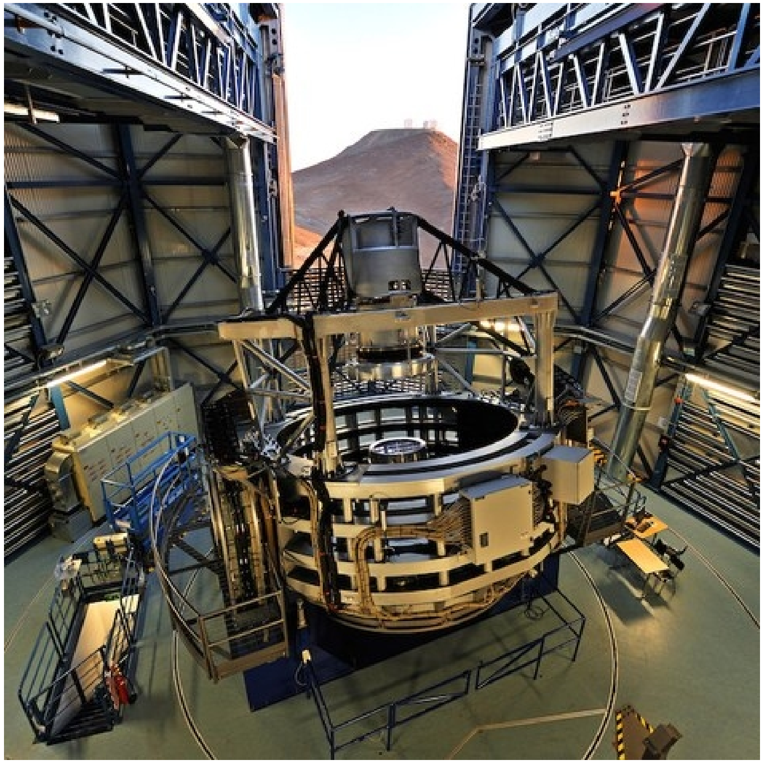
– Operations start in early 2024

– Around 1000 people involved

– 18 different surveys (8 community)

– 77,000 fibres hours awarded

S11 The White Dwarf Binary Survey



6. Future spectroscopic surveys

4MOST: 4-m Multi-Object Spectroscopic Survey

All surveys share the focal plane

Survey	PI
S1 - Milky Way Halo Low Resolution Survey	Else Starkenburg
	C. Clare Worley
S2 - Milky Way Halo High Resolution Survey	Norbert Christlieb
S3 - Milky Way Bulge and Disk Low Resolution Survey (4MIDABLE-LR)	Ivan Minchev
	Cristina Chiappini
S4 - Milky Way Bulge and Disk High Resolution Survey (4MIDABLE-HR)	Thomas Bensby
	Maria Bergemann
S5 - Galaxy Clusters Survey	Johan Comparat
S6 - AGN Survey	Andrea Merloni
S7 - Galaxy Evolution Survey (WAVES)	Joe Liske
	Simon Driver
S8 - Cosmology Redshift Survey (CRS)	Jean-Paul Kneib
	Johan Richard
S9 - Magellanic Clouds Survey (1001MC)	Maria-Rosa Cioni
S10 - Time-Domain Extragalactic Survey (TiDES)	Isobel Hook

4MOST: 4-m Multi-Object Spectroscopic Survey

All surveys share the focal plane

S11 - White Dwarf Binary Survey (WDB)	Alberto Rebassa-Mansergas
	Odette Toloza
S12 - 4MOST Survey of Young Stars (4SYS)	Giuseppe Germano Sacco
S13 - Stellar Clusters in 4MOST	Sara Lucatello
	Angela Bragaglia
	Antonella Vallenari
S14 - 4MOST Survey of Dwarf Galaxies and their Stellar Streams (4DWARFS)	Ása Skúladóttir
S15 - Chilean Cluster Galaxy Evolution Survey (CHANCES)	Christopher Haines
S16 - 4MOST Chilean AGN/Galaxy Evolution Survey (ChANGES)	Franz Bauer
	Paulina Lira
S17 - Understanding the Baryon Cycle with High-Resolution QSO Spectroscopy (4HI-Q)	Celine Peroux
S18 - 4MOST Hemisphere Survey of the Nearby Universe (4HS)	Edward Taylor
	Michelle Cluver

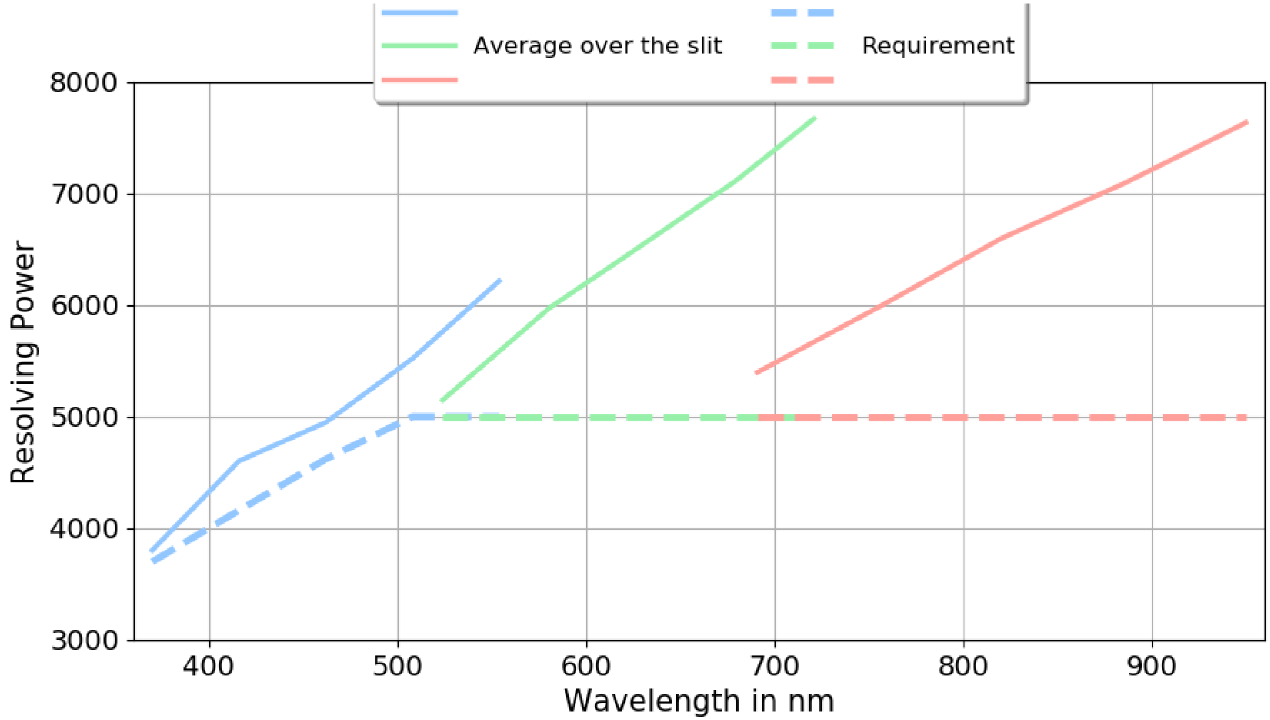
6. Future spectroscopic surveys

The (x2) low-resolution spectrograph (2x812 fibres)

– Wavelength range: 3700-9500 A

– R = 4000-7000

– Limiting magnitude AB ~ 20 mag



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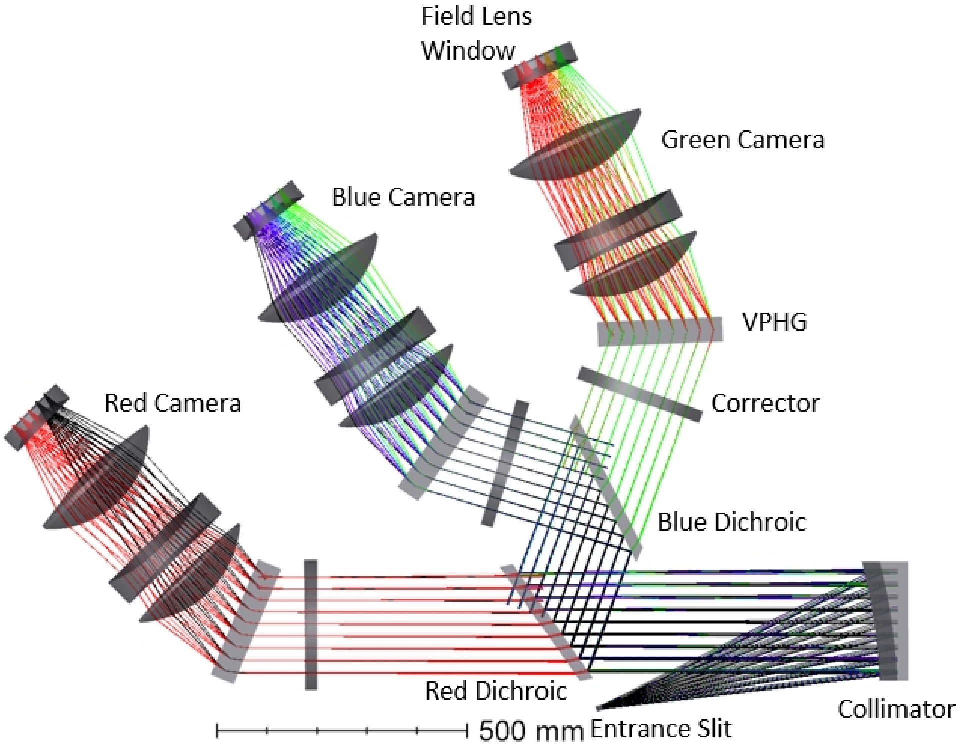


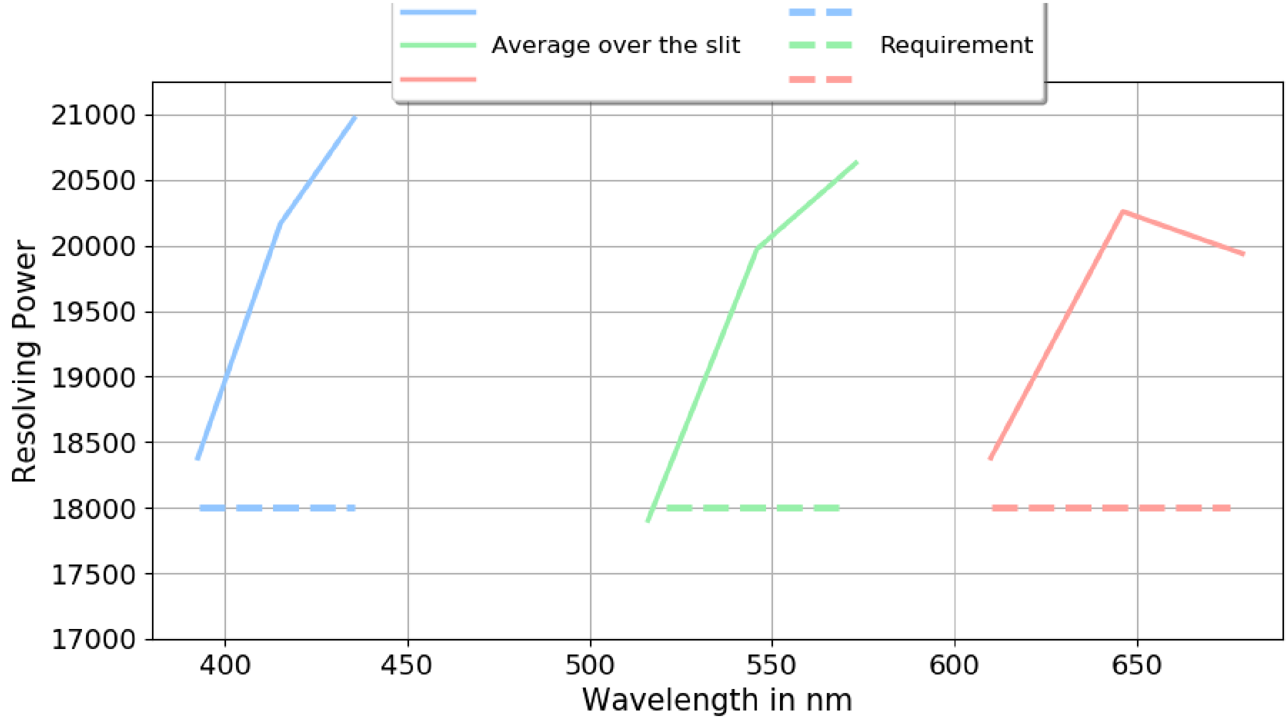
6. Future spectroscopic surveys

The high-resolution spectrograph (812 fibres)

– Wavelength range: 3926-4355, 5160-5730, 6100-6790 A

– R = 18000-21000

– Limiting magnitude AB ~ 16 mag



6. Future spectroscopic surveys

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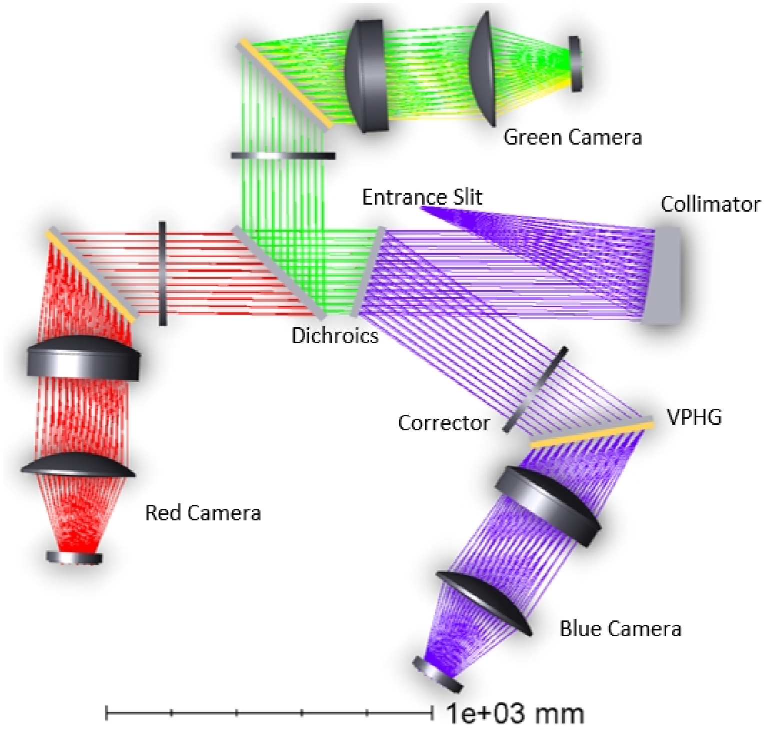
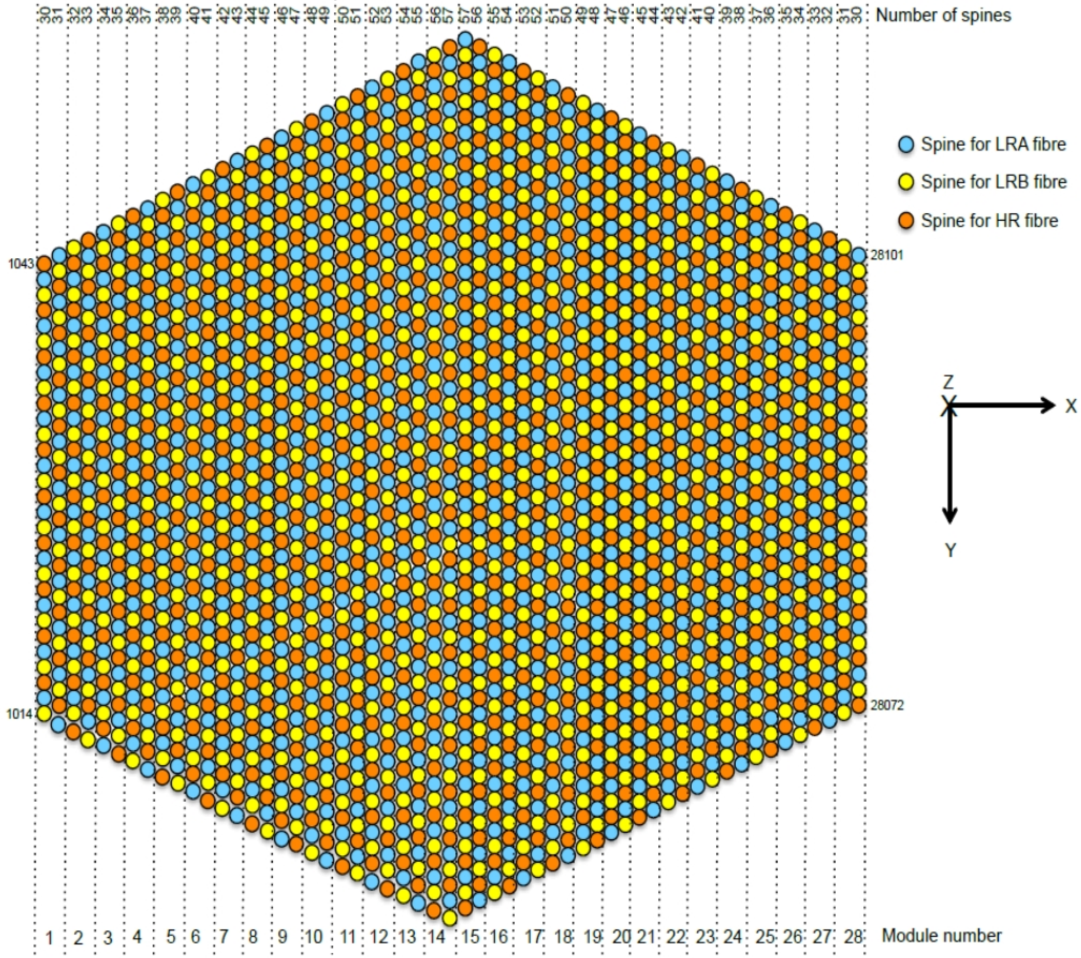
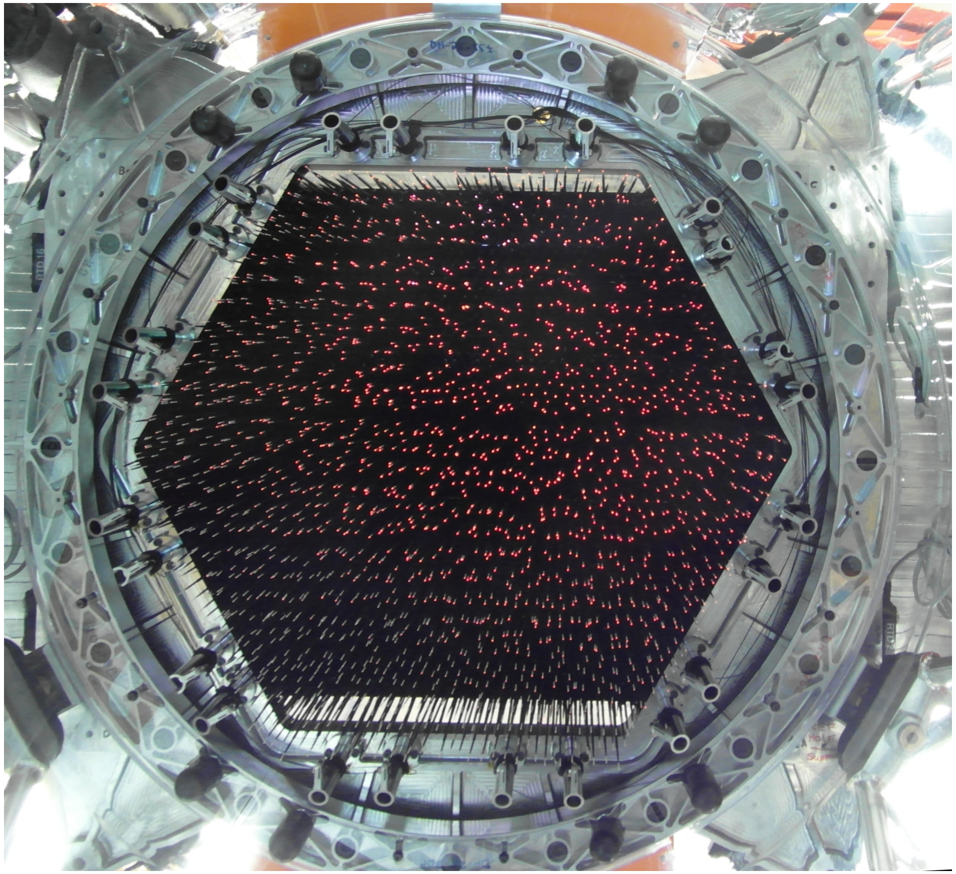


6. Future spectroscopic surveys

Arrangement of the fibres





6. Future spectroscopic surveys

Infrastructure working groups

IWG1 - Targeting Support

IWG2 - Survey Strategy and Simulations

IWG3 - Pipeline Calibration and Science Verification

IWG4 - Selection Functions

IWG5 - Science Simulations

IWG6 - Data Curation and Data Release

IWG7 - Galactic Analysis Pipeline

IWG8 - Extragalactic Analysis Pipeline

IWG9 - Object Classification

6. Future spectroscopic surveys

Work packages

WP
WP 6.1 - System Integration, Installation, and Maintenance
WP 6.2 - Telescope Interface
WP 6.3 - Fibre Positioner
WP 6.4 - Low resolution Spectrograph
WP 6.5 - High resolution Spectrograph
WP 6.6 - Detector Systems
WP 6.7 - Facility Control Software
WP 6.9 - Calibration System
WP 6.10 - Facility Control Hardware
WP 7.4 - Data Management
WP 7.5 - Operations System

6. Future spectroscopic surveys

Other working groups

– Bright targets

– Supplementary targets

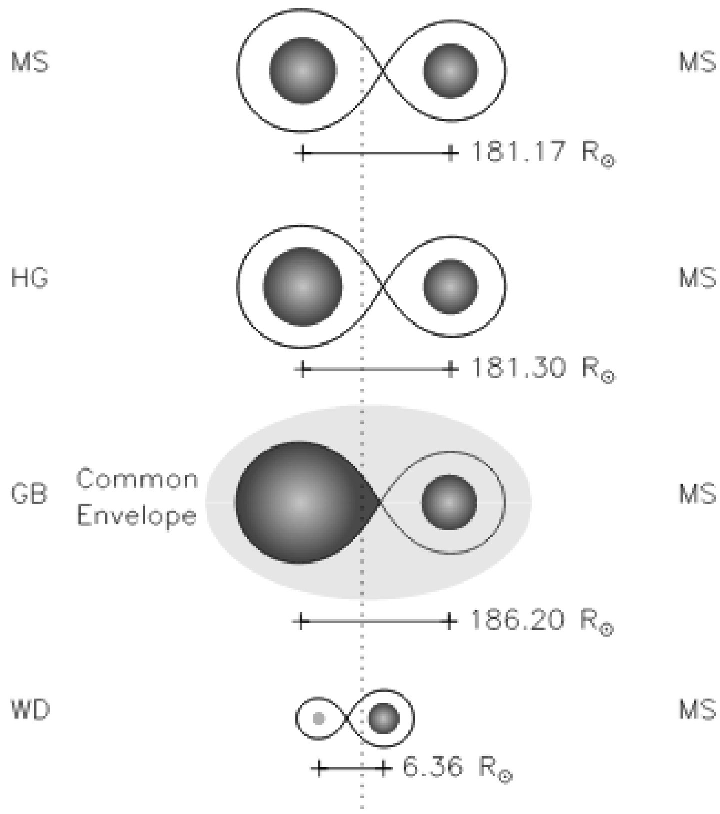
– Multiplicity (cadence)

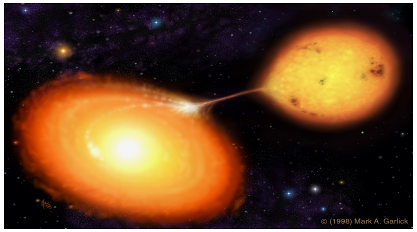
– Management Plan

– Project Culture

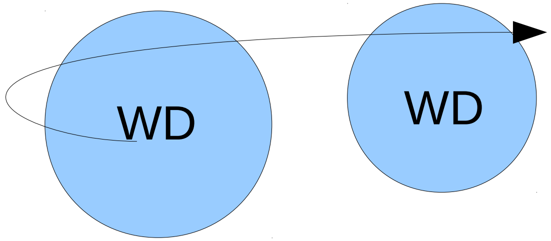
7. White Dwarf research: future surveys

S11: the close binary sample





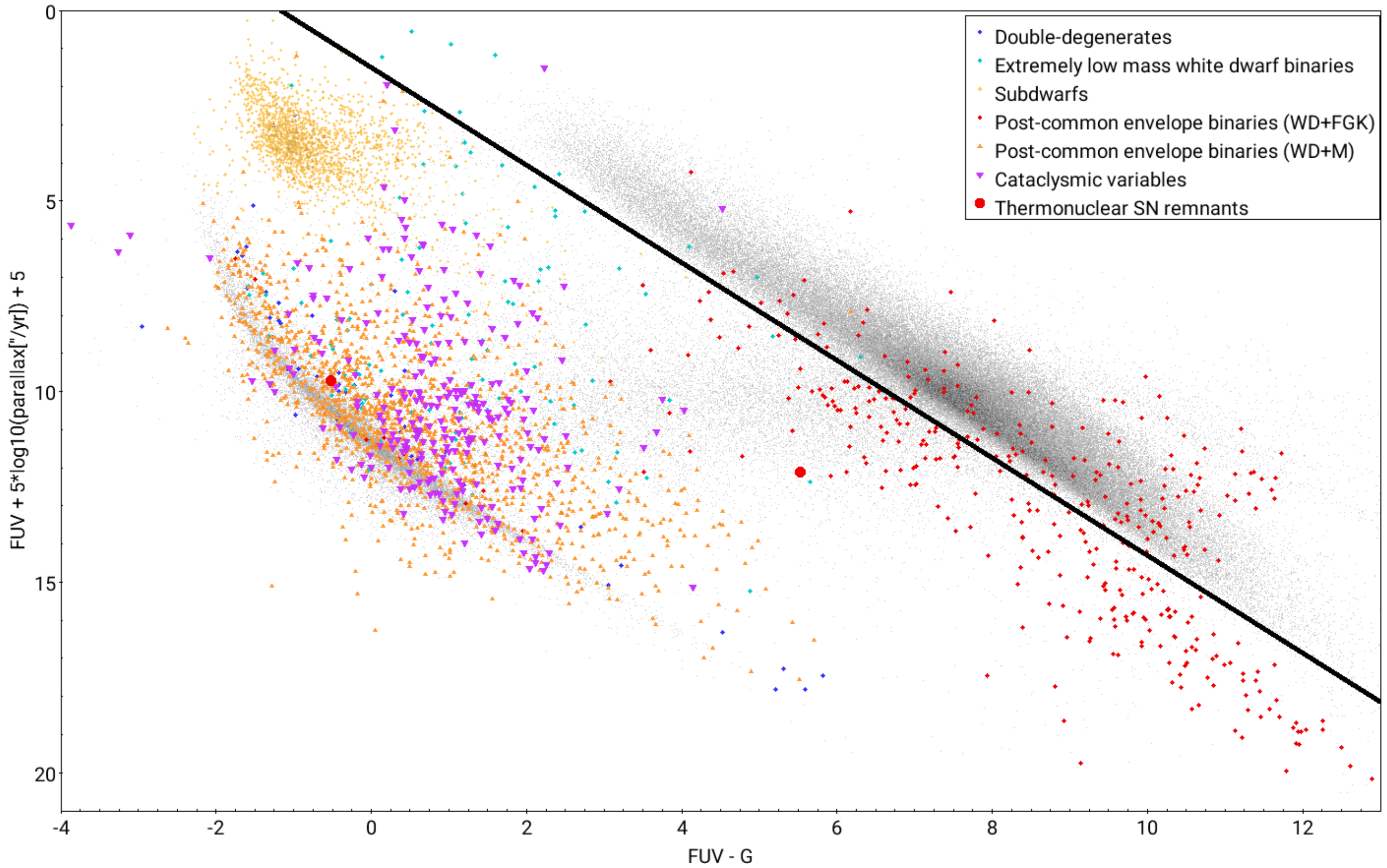
Angular momentum loss
CVs, SSSs



Second CE phase, DDs

7. White Dwarf research: future surveys

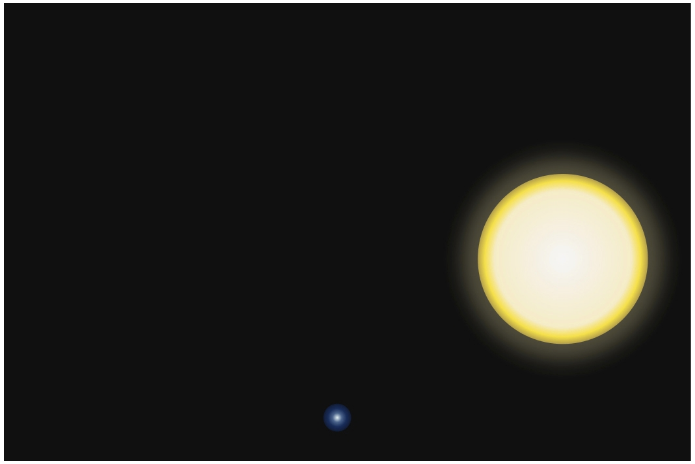
S11: the close binary sample



~100.000 selected targets

7. White Dwarf research: future surveys

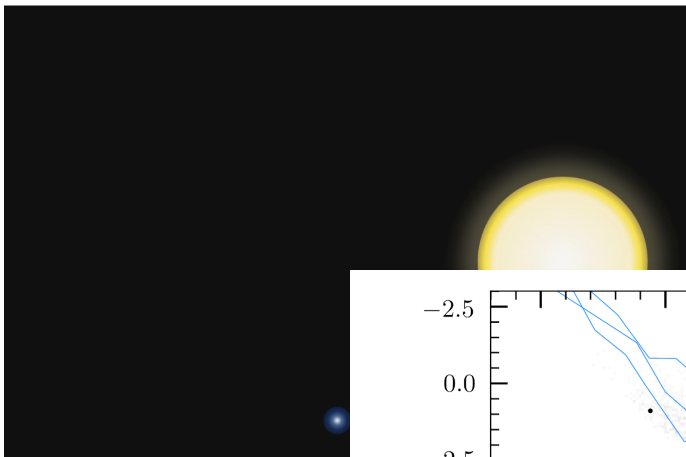
S11: the wide binary survey



The stars evolve without mass transfer episodes but the ages are the same

7. White Dwarf research: future surveys

S11: the wide binary survey



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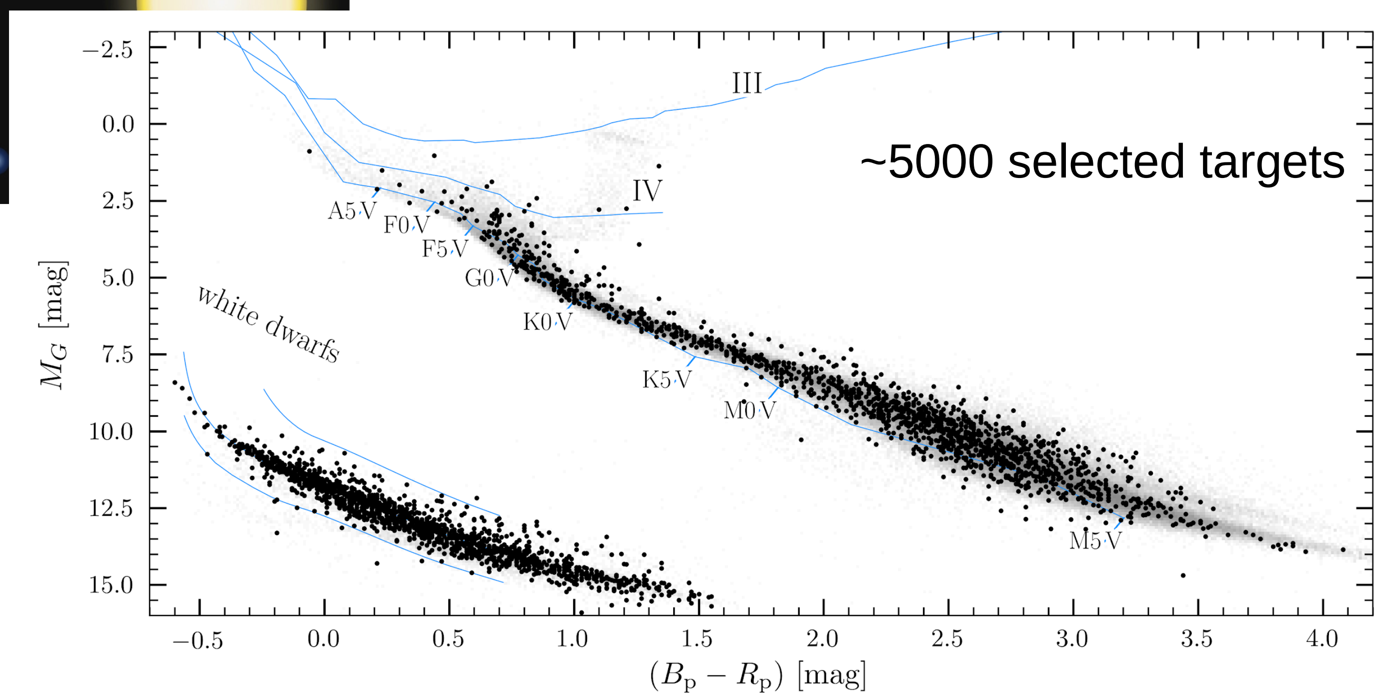

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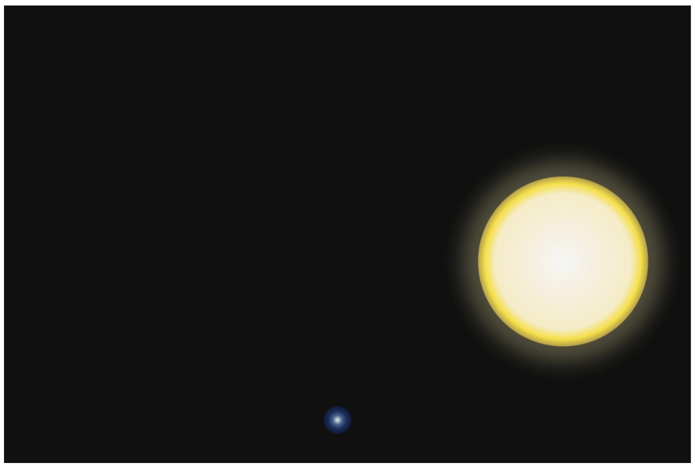
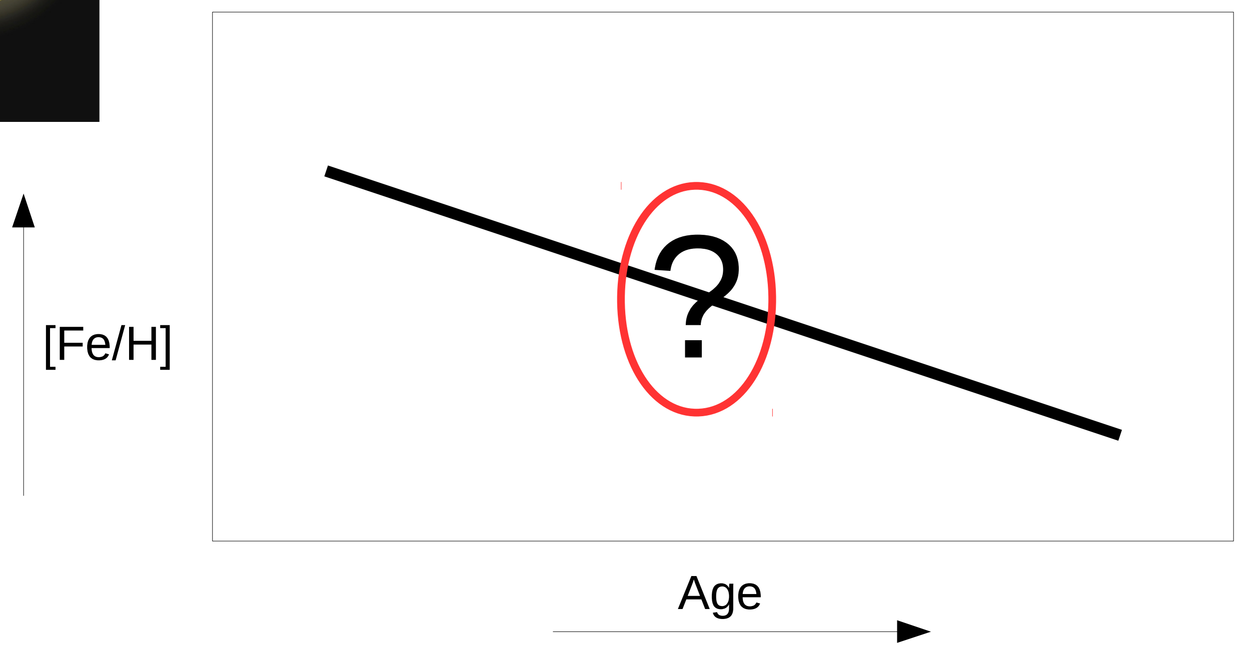


The stars evolve without mass transfer episodes but the ages are the same

Constraints on the age-metallicity relation



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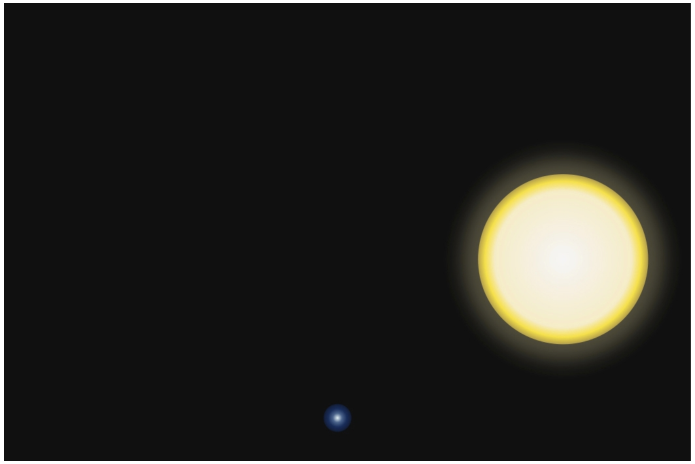
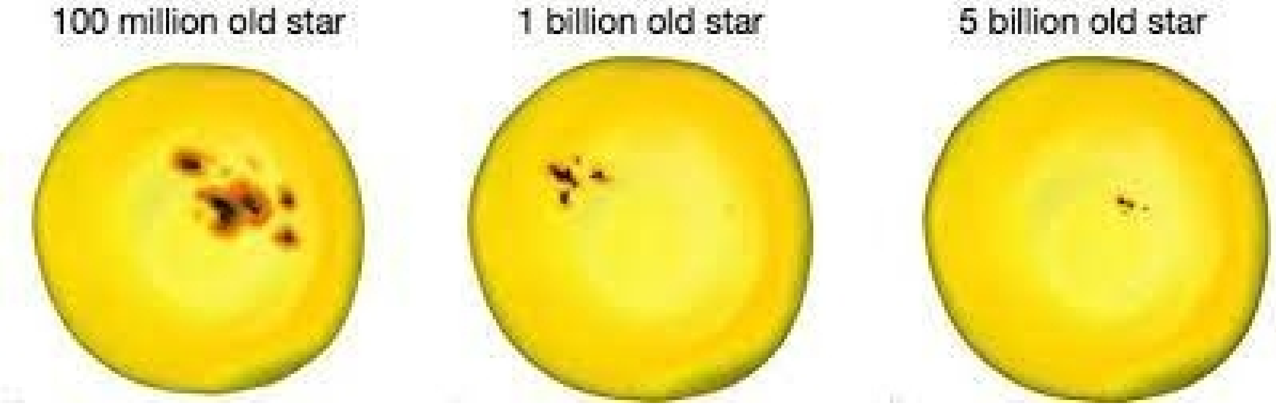


The stars evolve without mass transfer episodes but the ages are the same

Constraints on the age-activity relation



7. Conclusions

– Spectroscopy is fundamental in all areas of astrophysics

– Since the 1980s spectroscopic surveys started operating due to the much-needed collective effort for improving our understanding of a wide variety of open problems

– Future spectroscopic surveys that make use of 4m apperture telescopes with allow to acquire millions of additional high-quality spectra

– The data provided by current and future spectroscopic surveys, as well as by new large-aperture facilities (30-40m telescopes) and the data being collected by satellites such as Gaia imply that we are living a golden age in astronomy