Accurate M/R of Hyades White Dwarfs (through Gravitational Redshift)

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Why accurate WD M/R?

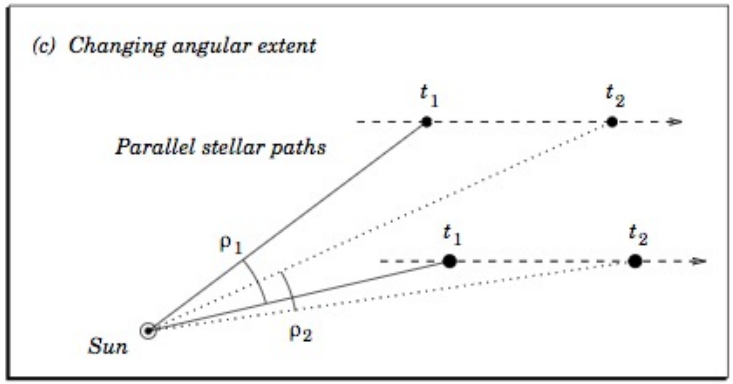
- WDs are the most common stellar renmant (Gentile Fusillo, yesterday)
- Knowledge of WDs physical parameters
  - Stellar evolution
  - Age of disk and halo
  - Initial to Final Mass Ratio (IFMR) is a key ingredient for chemical evolution (integrated mass losses of low and intermediate mass stars) (see P. Marigo yesterday)
- ..As physicists we must measure as accurately as possible …

Ingredients

- The velocity shift in the spectrum of a star can be expressed as : DV = RV + GR + V_{res}
  - RV = radial velocity
  - GR=gravitational Redshift
  - V_{res}= convective motions and other effects, negligible in WDs, DV measured in the NLTE core of Balmer lines
  - DV measurements may be extremely precise (for exoplanet search below 1ms^{-1}) but we need them to be accurate
- GR can be measured if other terms are known.
- GR ~ 0.636*M/R -0.003 (Km/s)

Astrometric Radial velocities

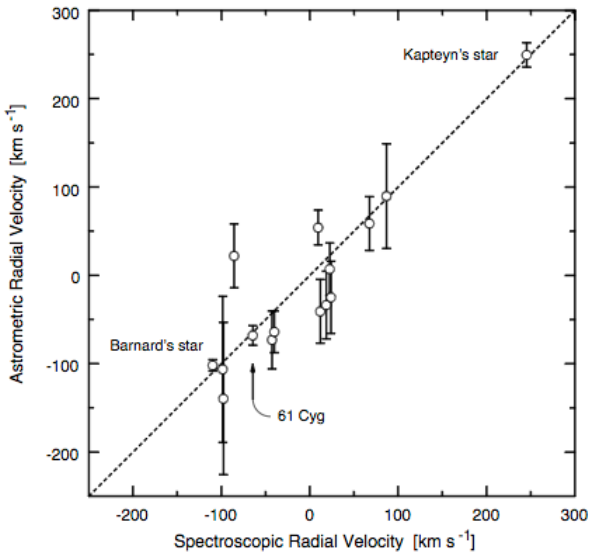
- Can be measured in a few cases (Dravins et al. 1999) with 3 methods:
  - Change of parallax
  - Perspective acceleration (16 stars)
  - **Changing angular extent (Moving-Cluster method)**
    - Hypothesis: all stars move through space with common velocity vector
    - RV is the projection of velocity vector on the line of sight



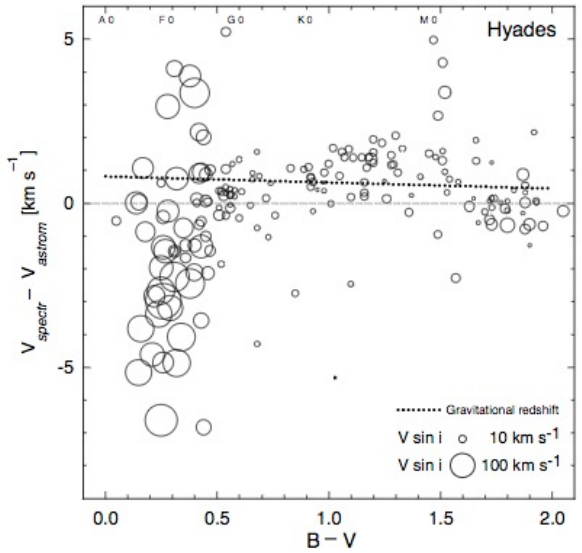
From Dravins et al. 1999

Astrometric and Spectroscopic RV

- To which extent do spectroscopic and astrometric radial velocities agree ??
  - What is the accuracy of RV measurement ?



(Dravins et al. 1999)



Madsen et al. 2003

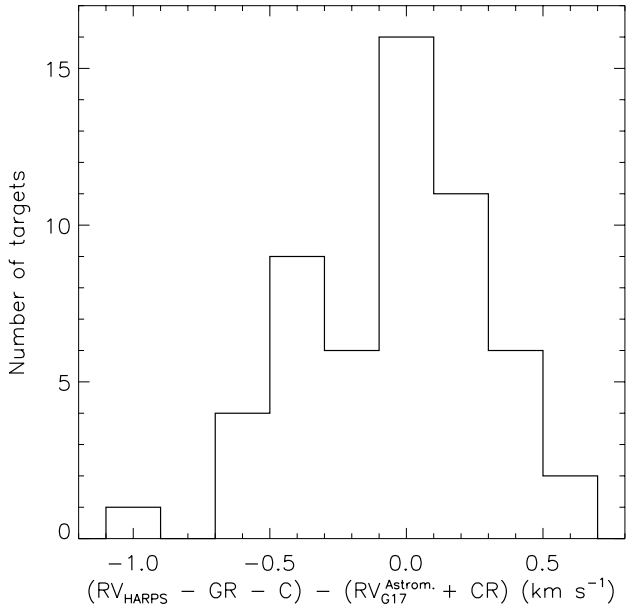
Qualitative agreement
Possible dependence on V*sini*

The Hyades (Leao et al. 2019)

- Hyades best cluster to be studied
  - Nearby, extended
    - Most accurate astrometric RV
  - Small systematic bias (<70 m/sec) by neglecting expansion or asymmetries
- HARPS observations of 131 stars, precise spectroscopic RV (<2 ms^{-1})
  - All computed using the same (G2) mask
  - 1 observation/star on average: Spectroscopic RV precision ultimately determined by jitter induced by activity (~30-40 ms^{-1}) (Paulson et al. 2004)
    - Activity Jitter should produce extra noise, no bias

RV Results (Leao et al. 2019)

- RV_{spec} - RV_{astro} Corrected for (GR, Convective shift, cluster rotation) : -16 ms^{-1} (median) – 33 ms^{-1} (mean)



σ = 347 ms^{-1}
Dominated by cluster internal dispersion

Internal cluster dispersion estimated in ~320 ms^{-1} from proper motions (Perryman et al. 1998, Lindegren et al. 2000, Reino et al. 2018)

Gravitational Redshift

- Given that RV_{astro} is the same as RV, for the Hyades WDs we can use:

  GR = DV - RV_{astro}

RV_{astro} is computed using stars coordinates and GAIA parallaxes and Hyades cluster parameters (Reino et al. 2018, GAIA Collaboration 2018)

V_{res} is negligible for WDs (no convective shifts)

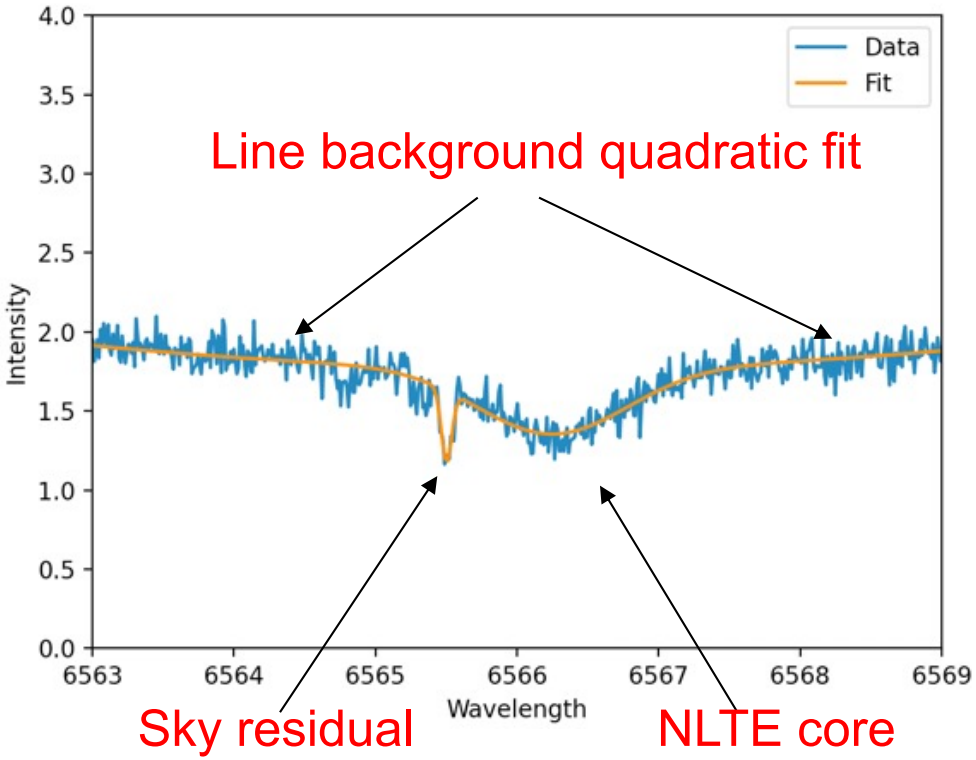
- **GR** provides a clean measurement of M/R

M/R Hyades WDs (Pasquini et al 2019)

- Pasquini et al. 2019 applied the method to existing VLT-UVES and Keck-HIRES results, finding a systematic difference: *M/R from GR was systematically smaller than from models*.
- Further conclusions were hampered by the quality of Observations (~2 Km/s) because
  - Both UVES and HIRES are slit instruments
  - Observations were taken for other purposes
  - Both instruments suffer of wavelength distortions (e.g. Withmore & Murphy 2015)
  - Moderate Resolving power (R~20000)

ESPRESSO measuremnts

- ESPRESSO at VLT is the last generation HR sectrograph, with superior precision and accuracy (Pepe et al. 2022)
- 8 bona fide HYADES WD were observed, with sufficient S/N to get a DV error measurement comparabe to cluster dispersion (~320 m/s)
- Hα fitting NLTE core (quadratic `+double gaussian lines for sky residuals and NLTE line core)
  - New Gravitational Redshifts are larger than previous ones



Gravitational Redhsift in Hyades WDs

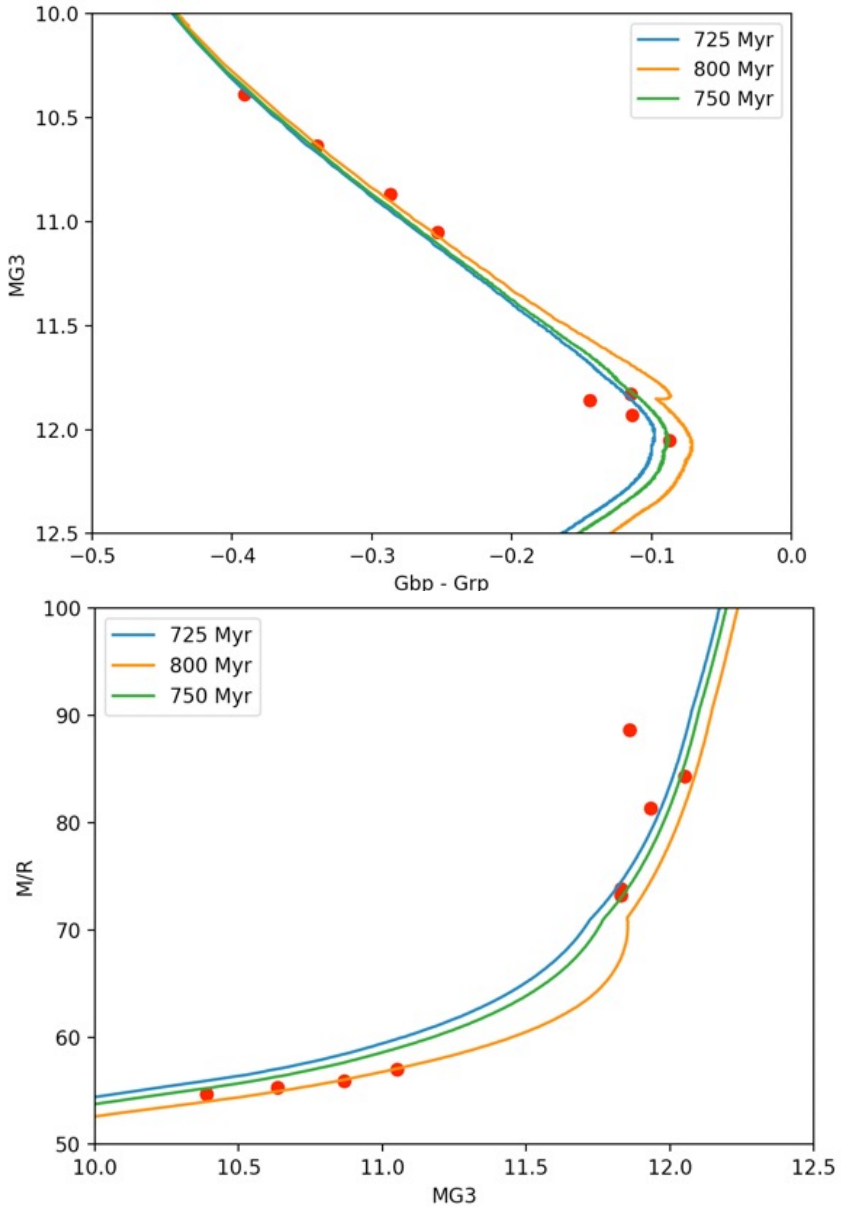
- Measurements accuracy in line with expectations
- Stellar parameters retrieved fitting Gaia magnitudes and colours with Bergeron et al. models (Salaris et al. 2009 IFMR)

name	$T_{\rm eff}$	$\sigma T_{\rm eff}$	Log(g)	σLog(g)	R	Mass	$M_{\rm bol}$	MG	Age	M/R	σ	M/R_{GR}
HZ4	14241	170	8.27	0.01	0.01078	0.781	10.701	11.829	877	72.45	1.5	73.68
EGGR29	15085	280	8.36	0.020	0.01011	0.836	10.584	11.860	744	82.69	2.6	88.45
LAWD18	18851	309	8.10	0.019	0.01226	0.681	9.202	11.050	1023	55.55	1.6	56.87
LAWD19	23450	406	8.09	0.021	0.01238	0.688	8.241	10.635	911	55.57	1.8	55.15
HZ7	20430	400	8.08	0.021	0.01245	0.672	8.811	10.867	1044	53.98	1.7	55.77
HZ14	26753	550	8.11	0.027	0.01231	0.703	7.678	10.387	800	57.11	2.3	54.52
HG7-85	14280	174	8.34	0.014	0.01023	0.825	10.799	11.932	816	80.65	1.7	81.23
GD52	13627	184	8.37	0.013	0.01000	0.842	11.049	12.051	868	84.20	1.7	84.2

- The two methods are completely independent
- M/R globally Agree to better than 1% (except EGGR29)

A consistent Picture

- Large spread in age. But IFMR and age are degenerate
- Salaris&Bedin(2018) assume Gaia Hyades age from TO (790Myr) and derive an ad-hoc IFMR for Hyades
- By using S&B IFMR: all stars in age range between **725 and 800** Myr, **also in the M/R plane.** (cfr. Brandner) and same mass as S&B
- EGGR29 exception, possibly a merger



Spectroscopic analysis (Cummings et al. 2018)

- T_{eff} and Log(g) derived by fitting Balmer lines
- Spectroscopic T_{eff} are systematically higher than photometric, R up to 15% smaller (and M larger)
- Known disagreement (e.g Beregron et al. 2018)…
  - Experimental and theoretical studies not conclusive

Star	Our	Gianninas	Claver	Koester	Limoges
HZ14	26753	27540	27390		26820
Lawd19	23450	25130	24420	24000	24200
HZ7	20430	21890	21340	21374	20810
Lawd18	18851	20010	19570	19616	19140
HZ4	14241	14670	14770	14440	
EGGR29	15085	15810	15180	16049	
HG7-85	14280	14620		14623	
GD52	13627	14820			

Comparison of our photomteric Teffs with spectroscopic ones from literature

New: M/R Comparison

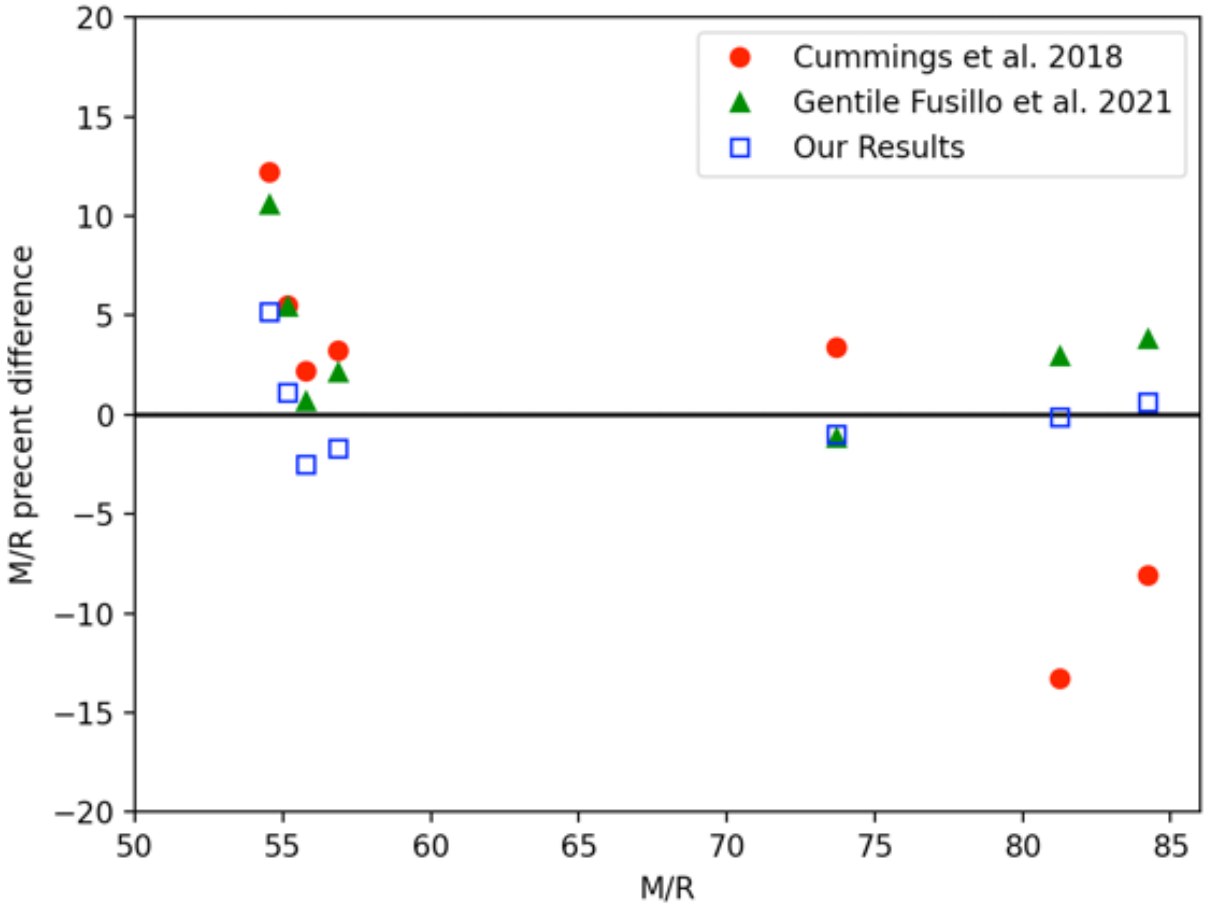
- Spectroscopic M/R do not agree well with M/R from GR observations

Percent difference between M/R measured with GR with the same quantity derived from models:

Our photometric estimates, open squares

Spectroscopic (Cummings et al. 2018), red circles

Photometry (different zero point) (Gentile Fusillo 2021) , green triangles



Other clusters?

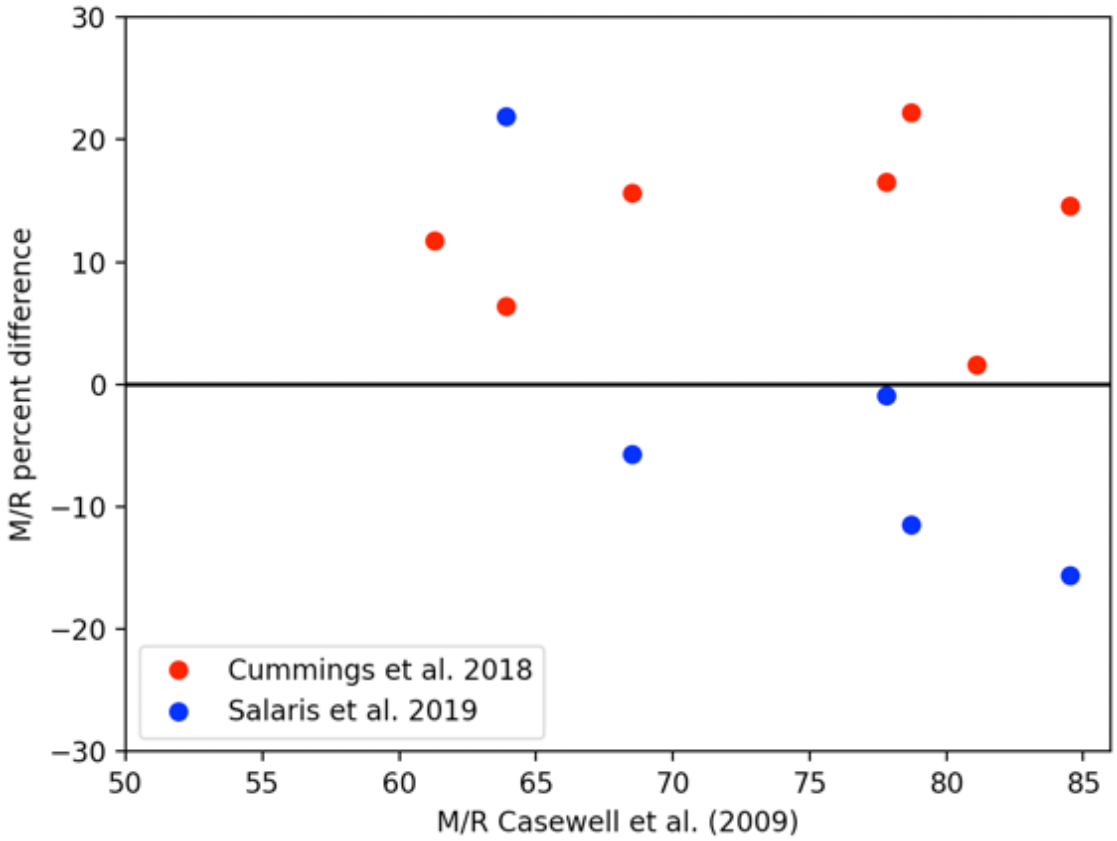
- Praesepe published data show a rather poor agreement … (UVES, Casewell et al. 2009)

Same as previous figure for the Paesepe Cluster;

M/R derived from Casewell et al. GR measurements

Spectroscopic estimates from Cummings et al. 2018 (Red circles)

Photometric estimates from Salaris & Bedin 2019 (Blue circles)



Conclusions

- We measured Velocities and GR for the Hyades WDs to about 1% accuracy
- M/R derived from theoretical (photometric) models and those measured with GR agree to better than 1%.
- A consistent picture is reached using ad-hoc isochrones (with modified IFRM): Hyades WDs ages are constrained between 725 and 800 Myr and masses agree to better than 1% with S&B(2018)
- One star (EGGR29) stands out and is possibly the product of a merger
- Confirm disagreement between photometric and spectroscopic analysis
  - *Add a new powerful comparison: Spectroscopic M/R do not match well observations for the Hyades WDs*
- Only other cluster (Praesepe) with GR published data show serious discrepancies with models' M/R values