The GAPS programme with HARPS-N @ TNG

Properties of the M dwarf sample

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Telescopio Nazionale Galileo/Fundación Galileo Galilei seminar

Outline

1. Introduction
2. Basic stellar parameters
3. Rotation-activity relationships
4. Summary

The GAPS M dwarf programme I

GAPS: Global Architecture of Planetary Systems

- Architectural properties of planetary systems as a function of the hosts characteristics
- HARPS-N @ TNG
- Around 50 INAF and associated scientist in Italy + 15 foreign institutes

- Low-mass companions in known planetary systems
- Neptune-size planets around low-metallicity stars
- Giant planets in crowded environments
- Astereoseismology, star/planet interactions
- Planetary orbits by RML effect
- Low-mass planets around M dwarfs

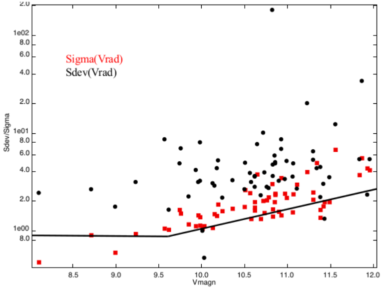
http://www.oact.inaf.it/exoit/EXO-IT/Projects/Entries/2011/12/27_GAPS.html

The GAPS M dwarf programme II

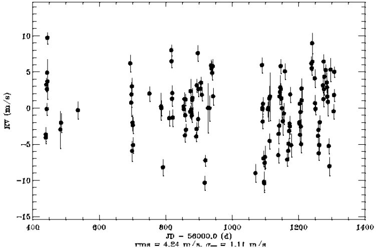
71 observed late-K/early-M

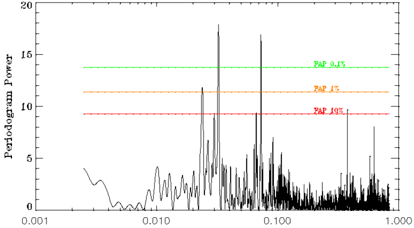
- 3400-3900 K / K7.5V to M3V
- PMSU and Lépine catalogues
- Stars from the APACHE survey
- Observations in collaboration with some Spanish institutes

- $>$ 1200 useful observations
- RV precision of the order of 1 m/s at V $\sim$ 10
- 15 min observing time

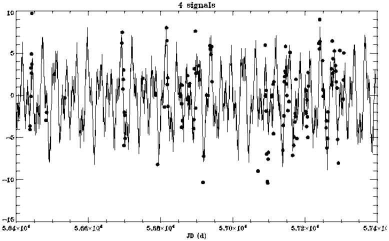


Several planet candidates emerging





Two Super-Earth planets around an M1 GAPS target (+ activity, + activity/dif. rotation)



More to come!

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2 **Basic stellar parameters**

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Basic stellar parameters of M dwarfs

Motivations

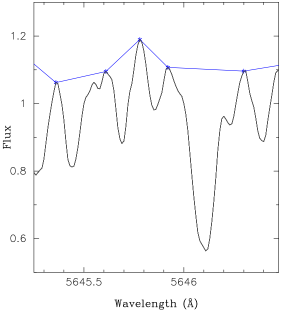
- Physical parameters of M dwarfs not well understood: We need them to characterise planetary systems
- M dwarfs are faint: Only few M dwarfs bright enough for direct measurement of their radii
- Discrepancies observations/predictions: M dwarfs larger and cooler

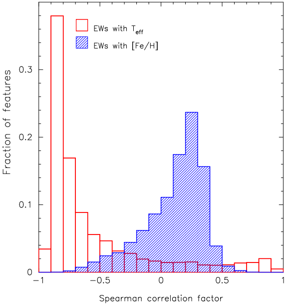
Methods

- Empirical calibrations (e.g. V-K) : biased towards nearby and bright stars
- Optical Indices (e.g. TiO): calibrations valid for data from a particular observatory/instrument; O, Ca, Ti are α elements
- nIR Indices (e.g. H2O-K2): need of new observations, calibrators, problems associated with the nIR
- Spectral synthesis: significant computational resources, extensive databases of oscillator strengths and opacities

Same spectra that are being use for RV measurements

- Pseudo-EWs of spectral features

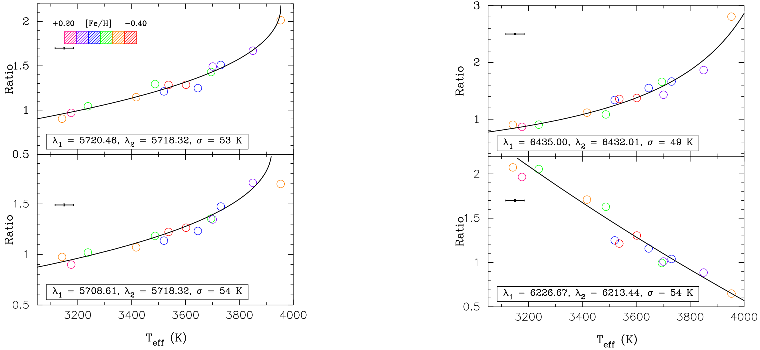




- 4229 identified features

- T_{eff} : 43% high anticorrelation, $\sim$ 3% + correlation
- [Fe/H] : peak at +0.25 dex

- 112 temperature-sensitive ratios of features
- 14 calibrators with angular sizes by long-baseline interferometry
- Uncertainties of about 70 K



Our methodology II

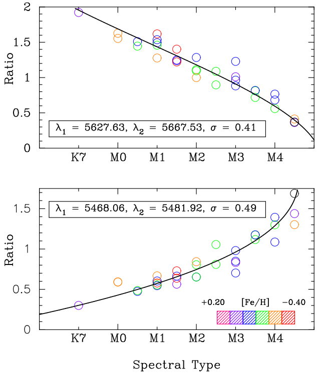
Spectral types and metallicities

Spectral Type

- 33 stars from Kirkpatrick et al. (1991) and Henry et al. (1994)
- 82 ratios of features with a standard deviation lower than 0.5 subtypes

Metallicity

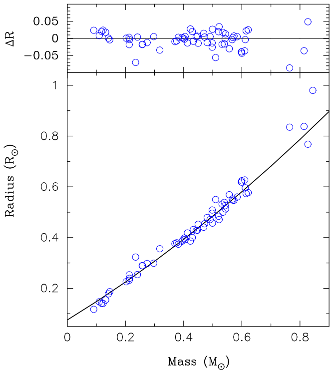
- Empirical relationships: $[Fe/H] = (A \times EW) + (B \times r) + C$
- 696 calibrations with $\sigma \sim$ 0.07-0.10 dex
- Calibrations with photometric metallicities



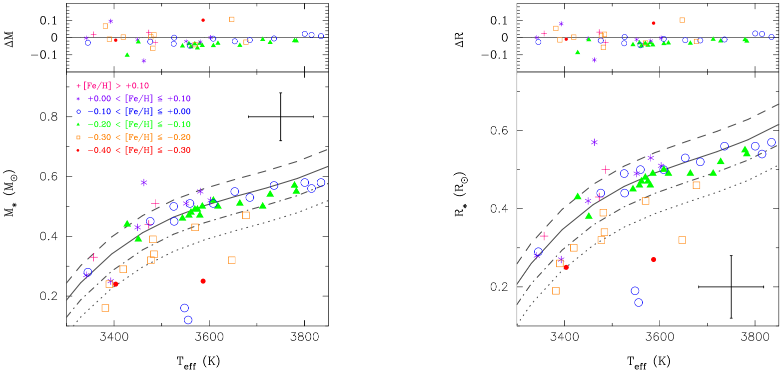
Our methodology III
Evolutionary parameters I

Empirical calibrations between T_{eff}, [Fe/H] and stellar mass, radius, and surface gravity

- Derivation of a mass-radius relationship (stars with interferometric data + eclipsing binaries) $R = 0.0753 + 0.7009 \times M + 0.2356 \times M^2$
- Masses from near-IR photometry
- $\log g$ from masses and radius



Parameters found to show a dependence on the metallicity ($p \sim 0.02$)



Functional form:

$$M_{\star}(M_{\odot}) = -171.616 + 0.139 \times T_{\rm eff} - 3.776 \times 10^{-5} T_{\rm eff}^{2} + 3.419 \times 10^{-9} T_{\rm eff}^{3} + 0.382 \times [Fe/H]$$

Our methodology V
Maldonado et al. 2015, A&A, 577

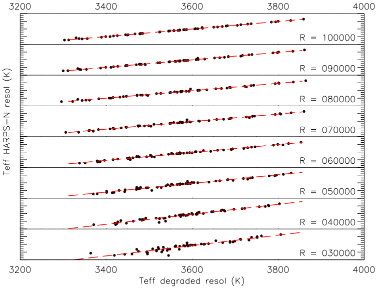
Code available for the community:

http://www.astropa.inaf.it/~jmaldonado/Msdlines.html

- F90 + CFITSIO
- Input ascii/fits; HARPS-N/HARPS spectra
- $T_{\rm eff}$, [Fe/H], $\log g$, SpType, $M_\star$, $R_\star$, $L_\star$

On progress

- Possibility of using spectra other than HARPS-N
- Linear relationships *P*(HARPS-N resolution) - *P*(Other resolutions)



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Understanding the chromospheres of M dwarfs is crucial

Detection of low-mass planets around low-mass stars: currently challenging by stellar activity (spots, oscillations, granulation)

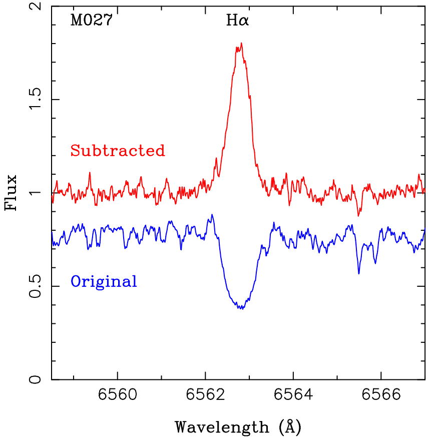
One example: GJ581d

- Mayor et al. (2005): planet in HZ!
- Robertson et al. (2014): activity signal in Hα, no planet!
- Anglada-Escudé & Tuomi (2015): HZ planet + stellar activity
- Robertson et al. (2015): a planet at $P_{rot}/2$ is suspicious

High-levels of activity (strong flares and high UV emission in quiescence): potential hazard for habitability

Strength of the emission excess:

$$F_\lambda^{excess} = EW_\lambda^{excess} \times F_\lambda^{continuum}$$



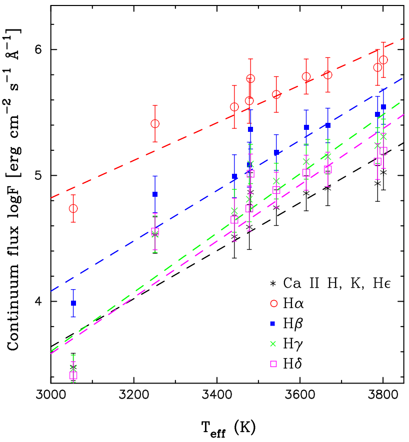
Equivalent widths

- **Spectral subtraction technique:** Subtraction of the underlying photospheric contribution from the stellar spectrum
- **Reference stars:** Lowest activity in the S index-temperature plane

Band	Centre (Å)	Width (Å)
Red wing	3901.07	20
K core	3933.67	3.28
H core	3968.47	3.28
Blue wing	4001.07	20

Activity analysis II

Derivation of our own continuum flux calibrations



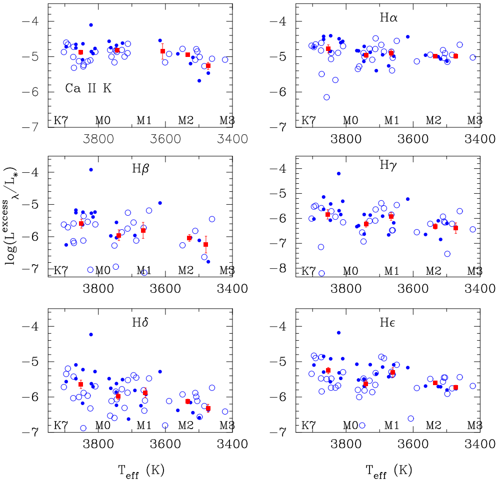
Continuum flux

- Measured over flux-calibrated spectra of M dwarfs (Cincunegui & Mauas (2004))
- Transformation: measured-continuum fluxes using ϕ (angular diameter)
- No blanketing correction
- Linear relationships with the effective temperature

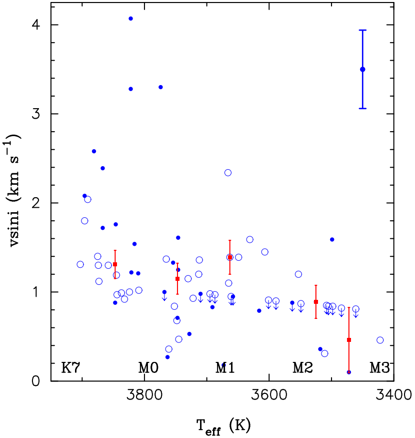
- Relationships for Hβ, Hγ, Hδ, Hϵ
- Good agreement with Hall et al. 1996 relationships

Activity versus effective temperature

Strength of the emission excess: roughly constant in all activity indicators



Rotation vs. effective temperature



Rotation: CCF Technique

$$\sigma^2_{obs} = \sigma^2_{rot} + \sigma^2_0$$

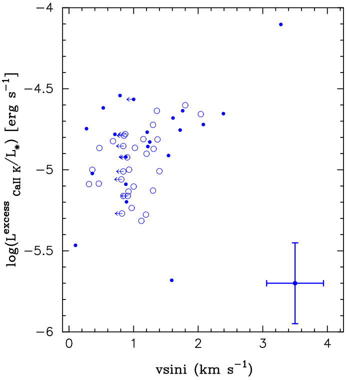
$$v \sin i = A \times (\sigma^2_{obs} - \sigma^2_0)^{1/2}$$

- **A constant:** artificially broadening the spectra of slow rotating stars
- **σ_0-T$_{eff}$: PHOENIX-BT-Settl** atmosphere models

Temperature

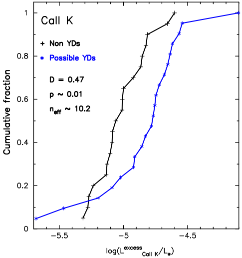
- Low sensitivity to vsini at cooler stars
- Very low rotation levels
- Lower rotation levels towards cooler stars

Rotation vs. activity and age



Age

- (U, V, W) velocities and membership to SKGs
- Possible age differences in Ca

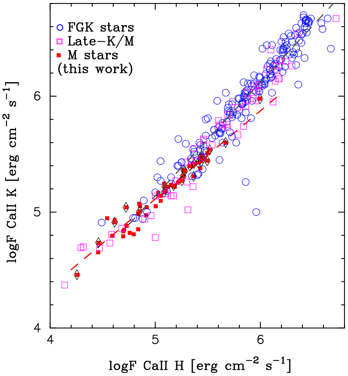


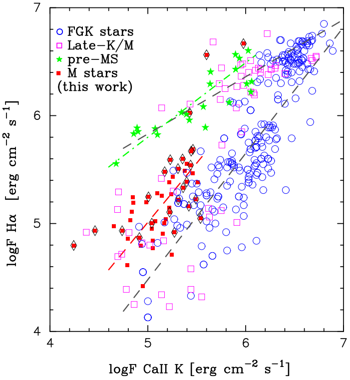
Activity

- ⇑ vsini with ⇑ activity
- Possible biases

Calcium and Balmer lines

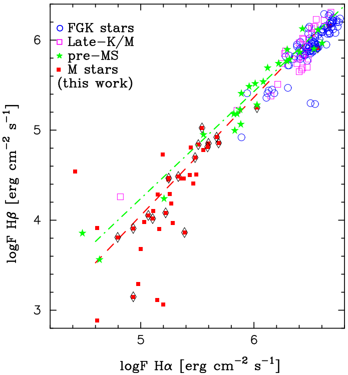
Empirical relationships: $\log F_1 = a_0 + a_1 \log F_2$

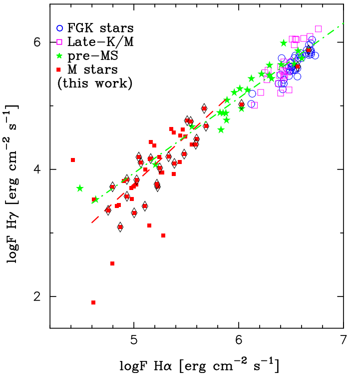




- Similar behaviour than FGK stars
- Less emission in the Ca II, K line when comparing with FGK stars

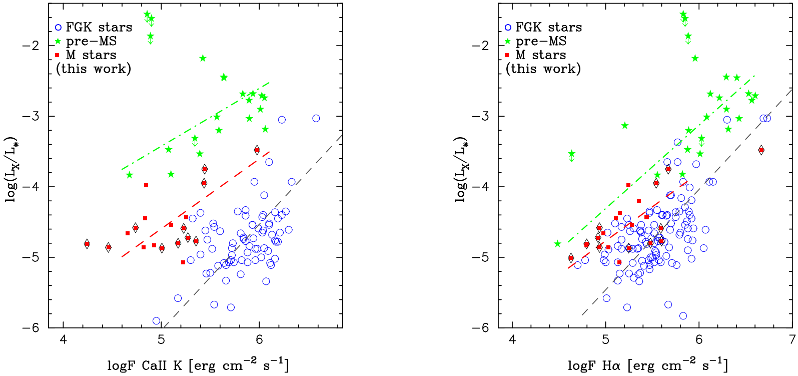
Balmer-Balmer





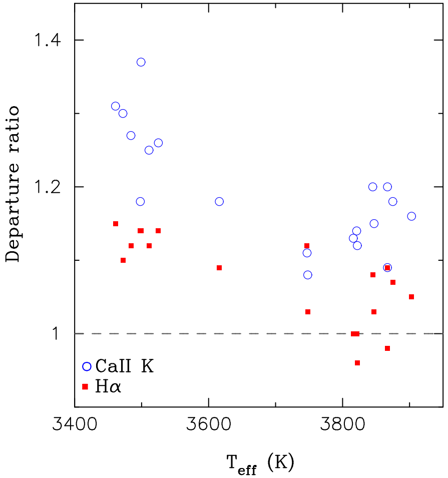
- Similar for Hδ, Hϵ
- Similar behaviour than FGK stars

"Deficit" of chromospheric emission?



For a given L_X, M dwarfs show ⇓ K/Hα emission that they should have if they followed the FGK flux-flux relation

Deviation from FGK stars



Departing coefficients

- Increase towards cooler stars
- Lower for Hα (higher line-formation temperature)

Implications

- **Cooler dwarfs:** chromospheric emission moves from Ca, Hα to other emission lines
- **Transition:** rotation/turbulent dynamo?
- Agreement with previous work (e.g. Rutten 1989)

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Conclusions

1. **GAPS-M dwarf programme**
   - Ongoing programme
   - Several "candidate" planets emerging (more to come)
2. **Stellar parameters**
   - From the same HARPS-N spectra
   - $\sim$ 70 K, 0.5 subtypes, 0.07-0.10 dex
   - Empirical relationships for $M_\star$, $R_\star$, $\log g$
   - Public code
3. **Rotation-activity-stellar parameters relationships**
   - Strength of the emission constant for M0-M3 stars
   - Lower rotation levels in cooler stars
   - Correlation rotation-activity strength
   - "Deficit" of chromospheric emission with respect to FGK stars