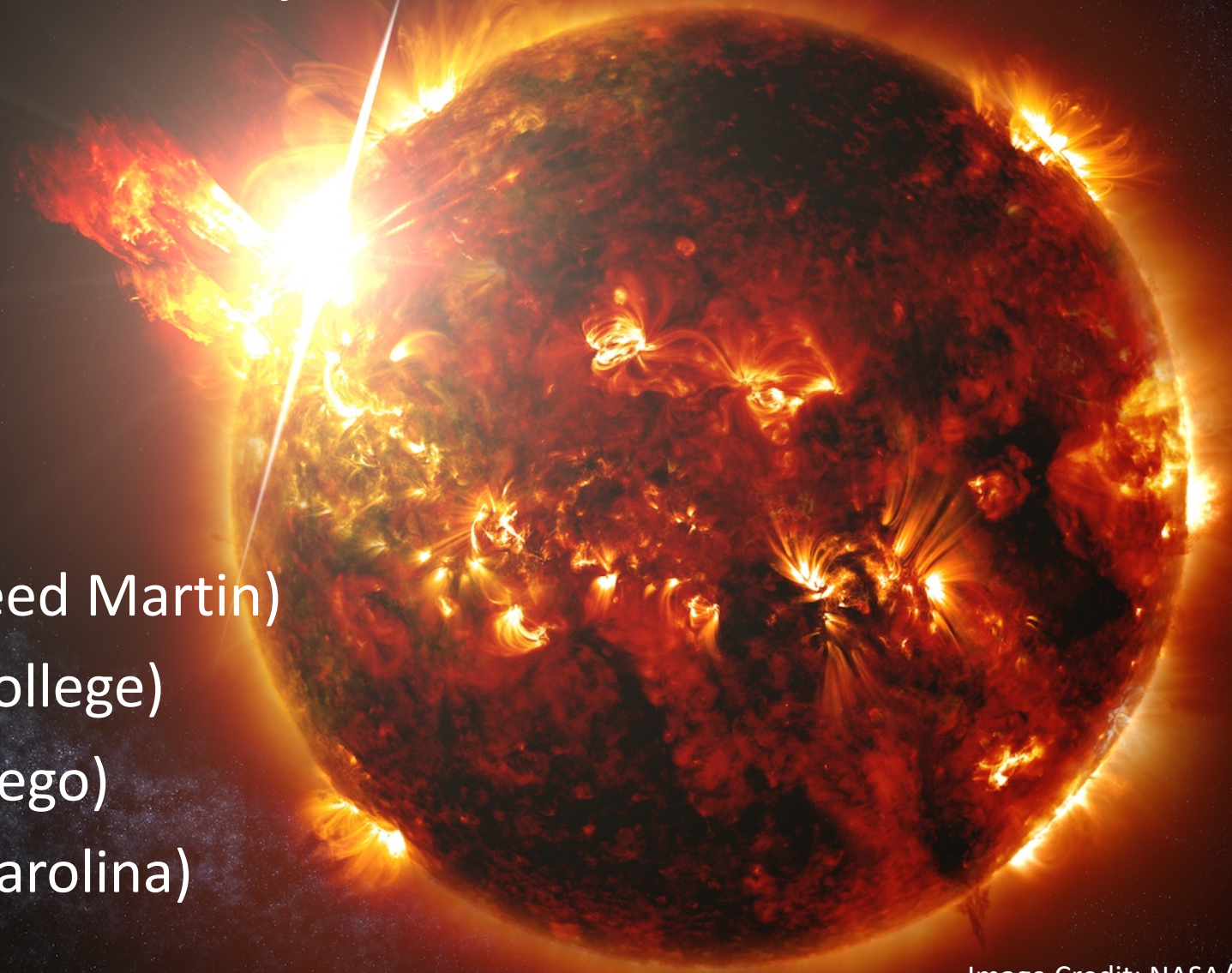
Intensification and Saturation of M-dwarf Absorption Lines with Rossby Number

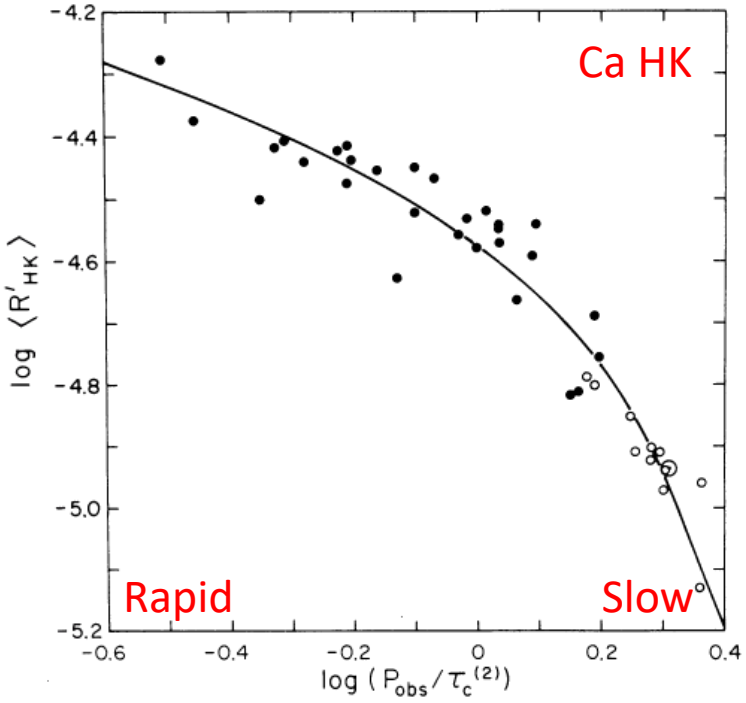
arXiv:1912.01004



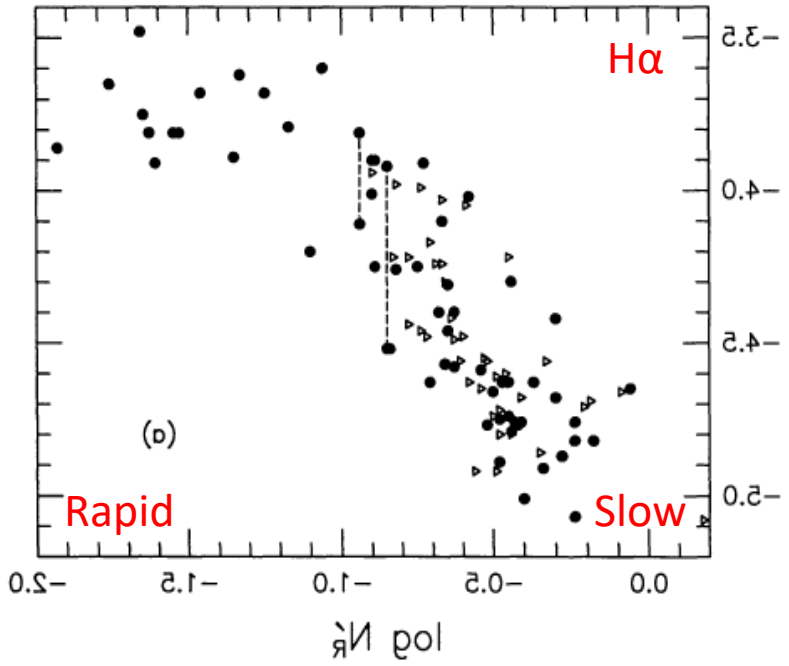
Phil Muirhead (Boston Univ.)
Mark Veyette (BU PhD -> Lockheed Martin)
Elizabeth Newton (Dartmouth College)
Christopher Theissen (UC San Diego)
Andrew Mann (Univ. of North Carolina)

Image Credit: NASA/IPAC

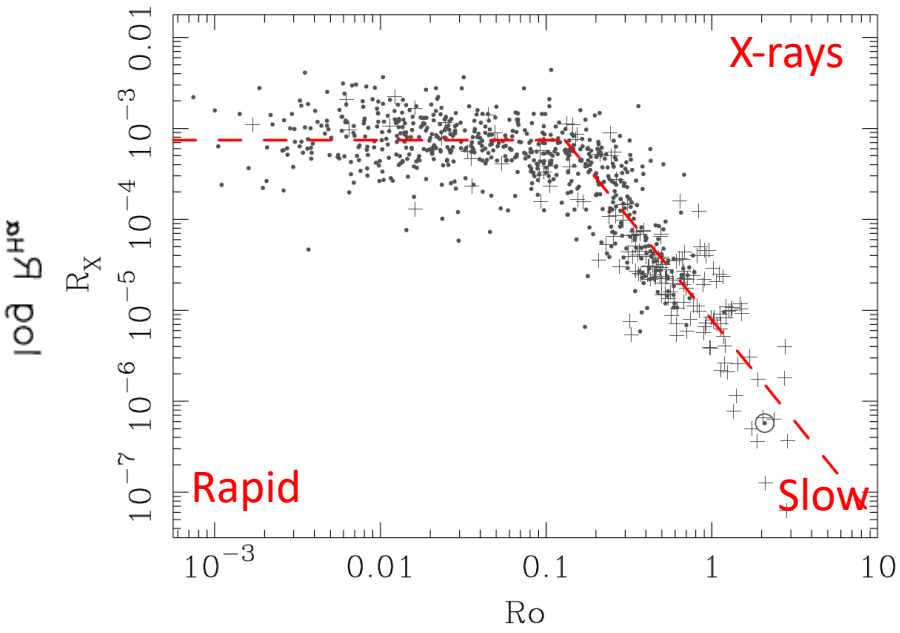
Saturation of activity indicators with Rossby no. (rotation period / convective turnover time)



Noyes et al. (1984)
Neighborhood FGK stars
Vsini a proxy for rotation



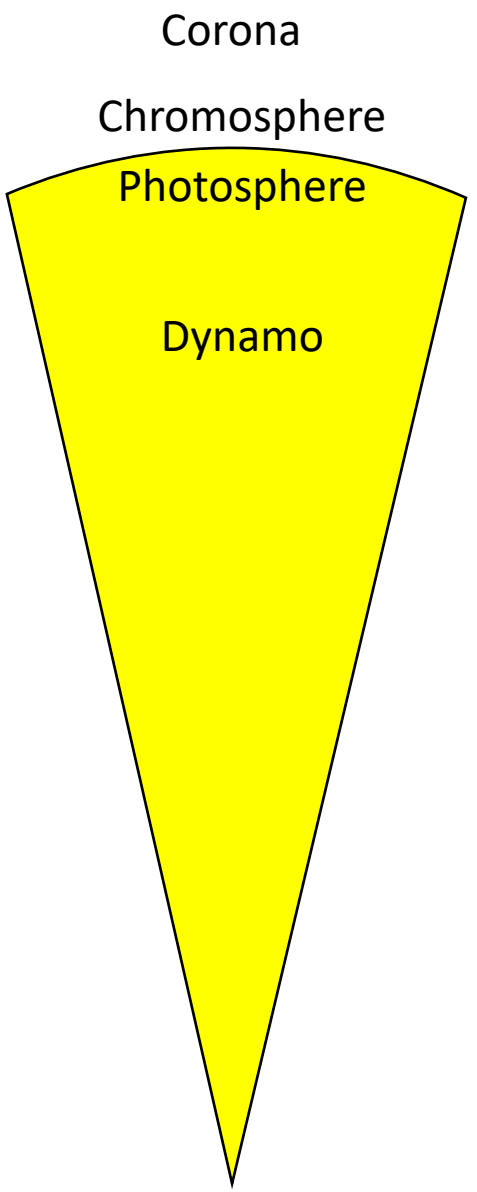
Soderblom et al. (1993)
Pleiades FGK stars
Vsini a proxy for rotation



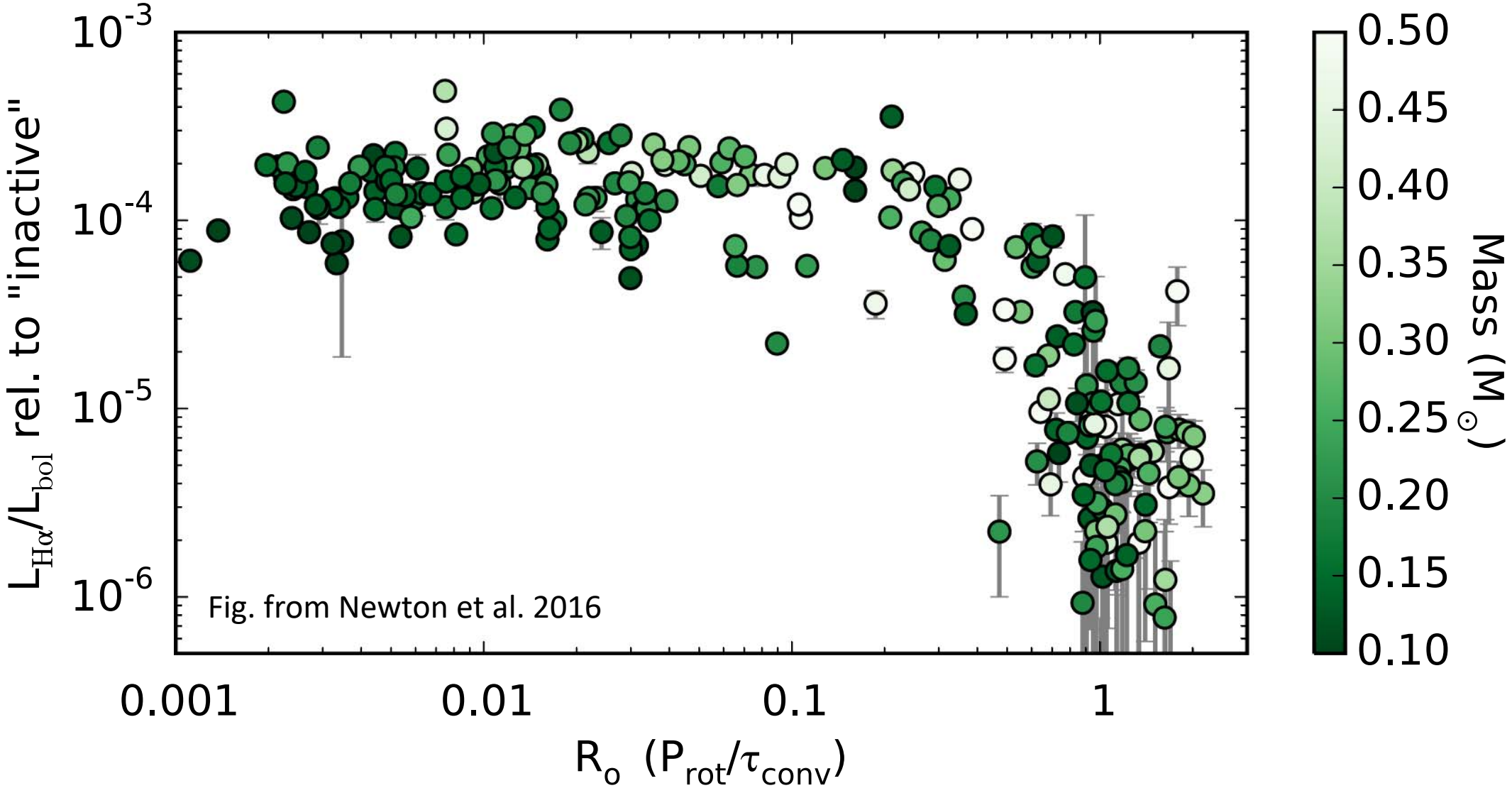
Wright et al. (2011)
Anything with X-rays and
photometric rotation periods

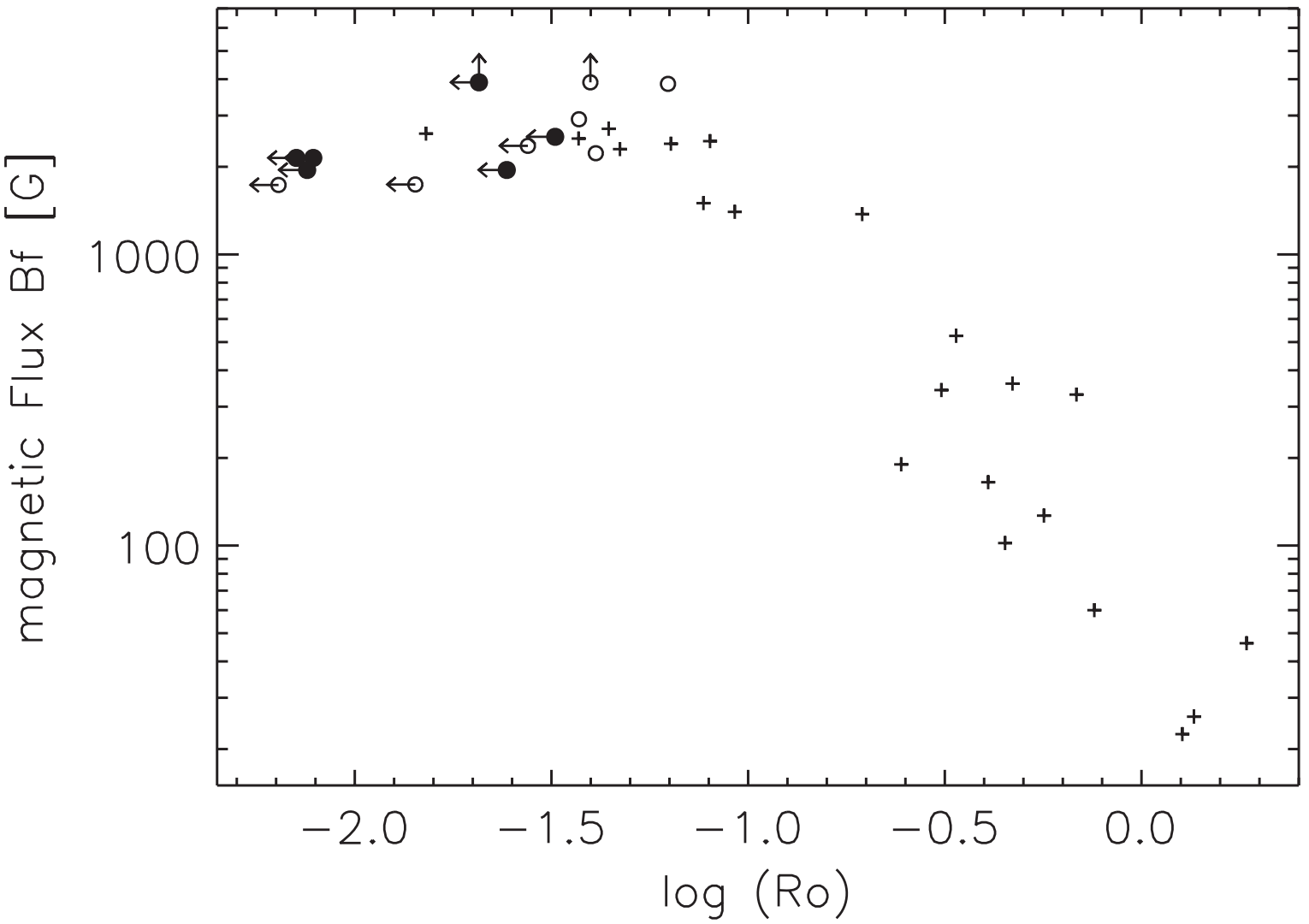
Proposed Mechanisms for the Saturation

- **Coronal stripping (Jardine & Unruh 1999)**
  - At fast rotation, B-field centrifugal stripping reduces density and cancels increase in temperature, leading to appearance of saturation.
- **Maximum spot filling factor (Vilhu 1984)**
  - An intrinsic limit to where you can put B-fields on the stellar photosphere.
- **Saturation of the dynamo itself (Gilman 1983; Vilhu & Walter 1987)**



M dwarf Opportunity: Numerous with long spin-down timescales



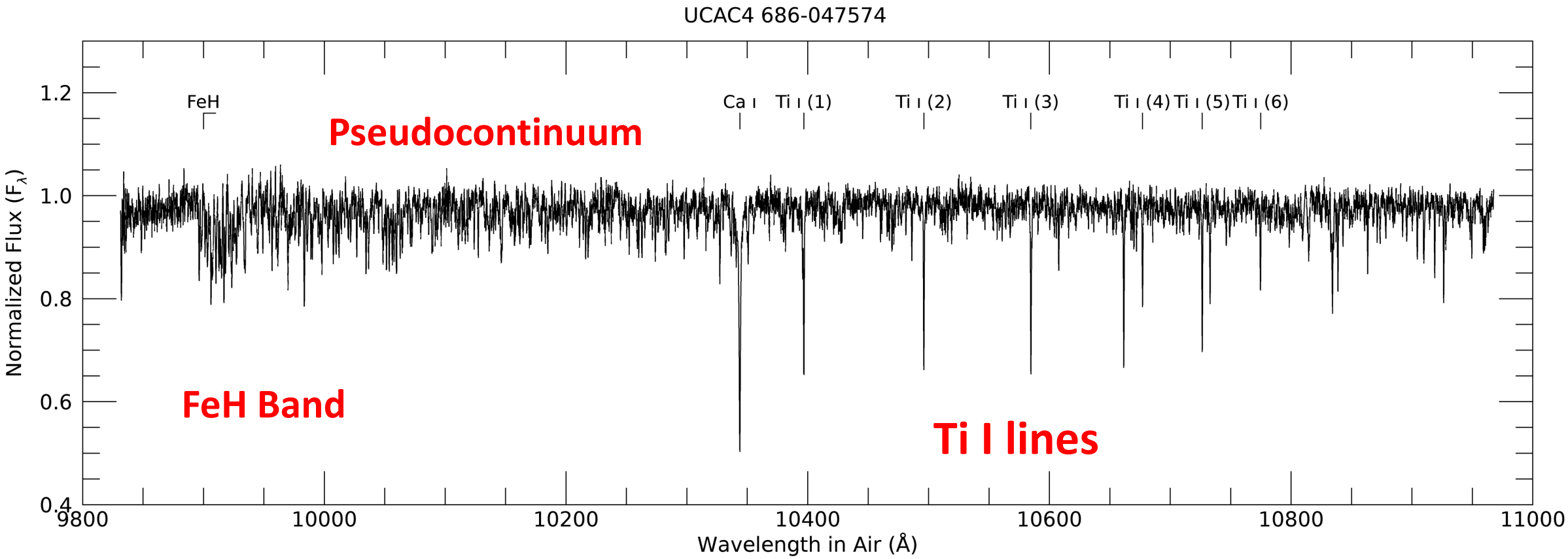


Reiners, Basri & Browning (2009)

Derived B from Zeeman effect on FeH lines (Ro from vsini).

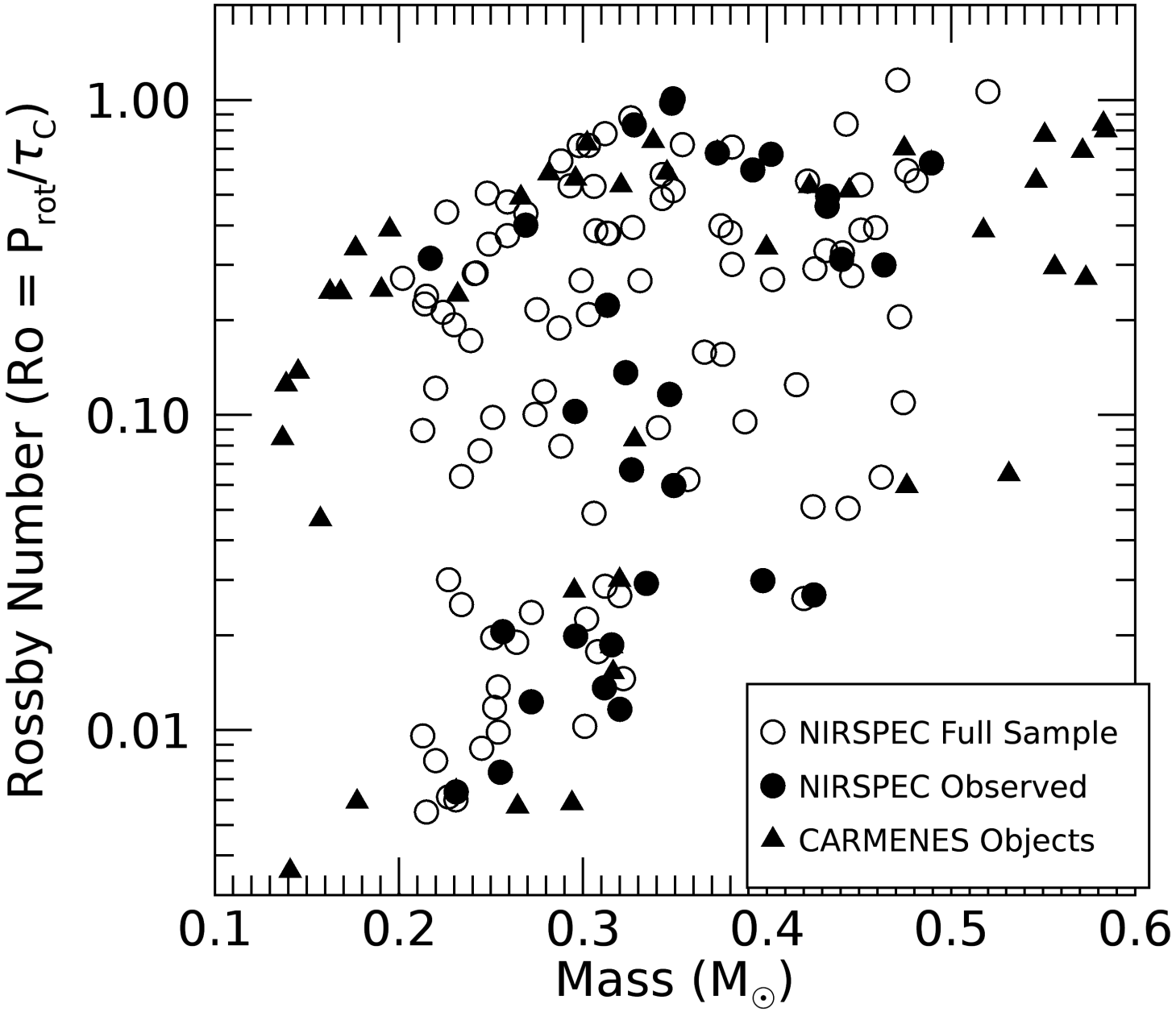
First evidence for saturation mechanism at or beneath the **photosphere** of M dwarfs.

M Dwarfs in Y-band with Keck-NIRSPEC



Y band: No telluric absorption lines

Originally Set out to measure chemical-kinematic ages (e.g. Veyette & Muirhead 2018)

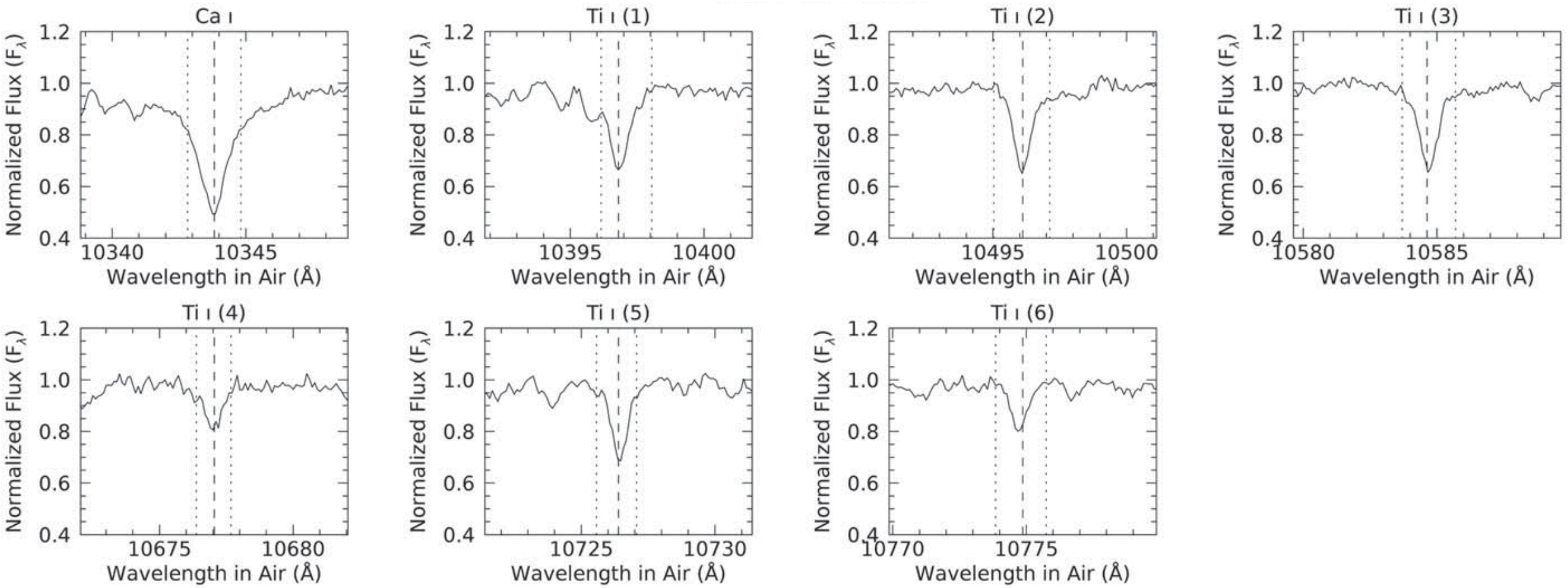


Acquired **30 Y-band spectra** of nearby M dwarfs with NIRSPEC (periods from Newton+2017).

Augmented with **44 public spectra from CARMENES** GTO program (Reiners+2018, Díez-Alonso+2019).

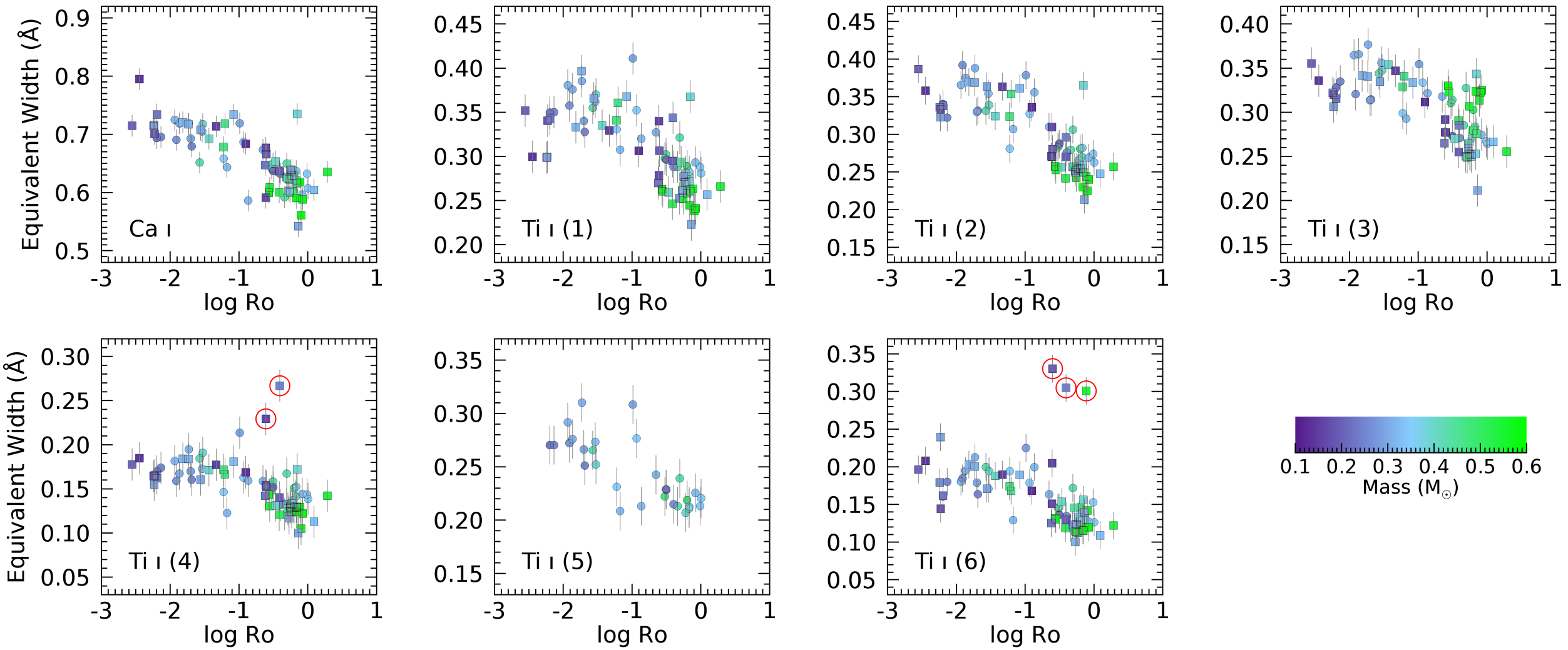
Variety of stellar masses and Ro.

M Dwarfs in Y-band with Keck-NIRSPEC



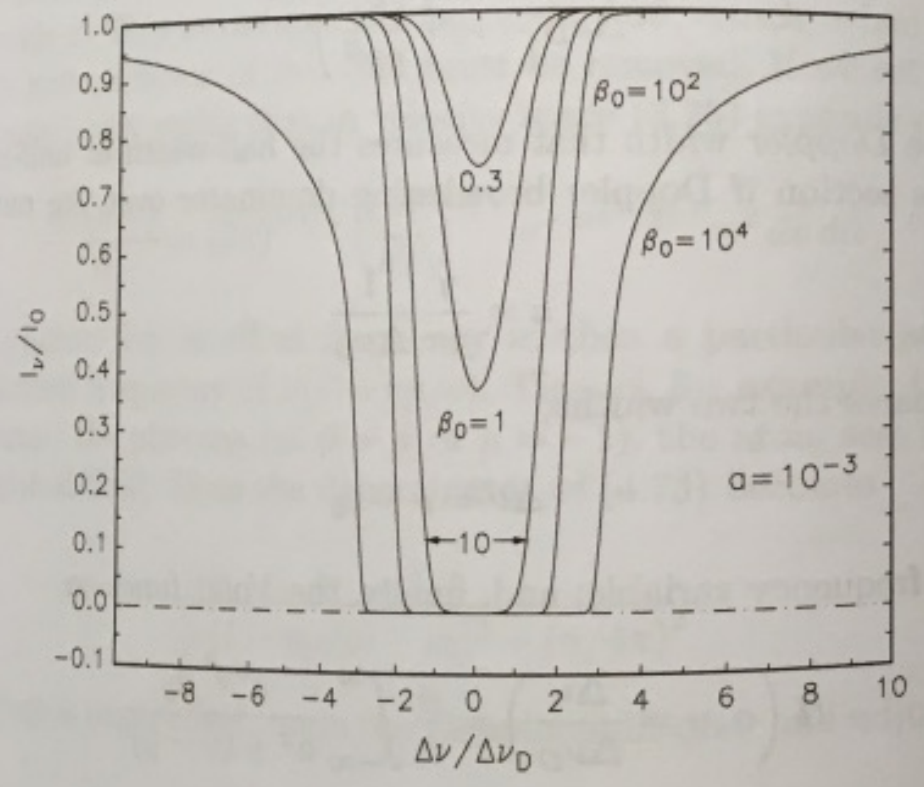
Procedures for measuring EWs described in Veyette et al. (2017) and his thesis.
All targets have c/vsini < 25000 (resolution of NIRSPEC). Convolved CARMENES data to NIRSPEC resolution for consistency.

Line Equivalent Width vs. Rossby



Muirhead et al. (2020)

Magnetic/Zeeman **Enhancement**



4.10. The evolution of a spectral absorption line with increasing number ity of absorbers is shown for sample values of β_0 (see text). The ratio $a =$ $\Delta\nu_D$ is fixed at 10^{-3}.

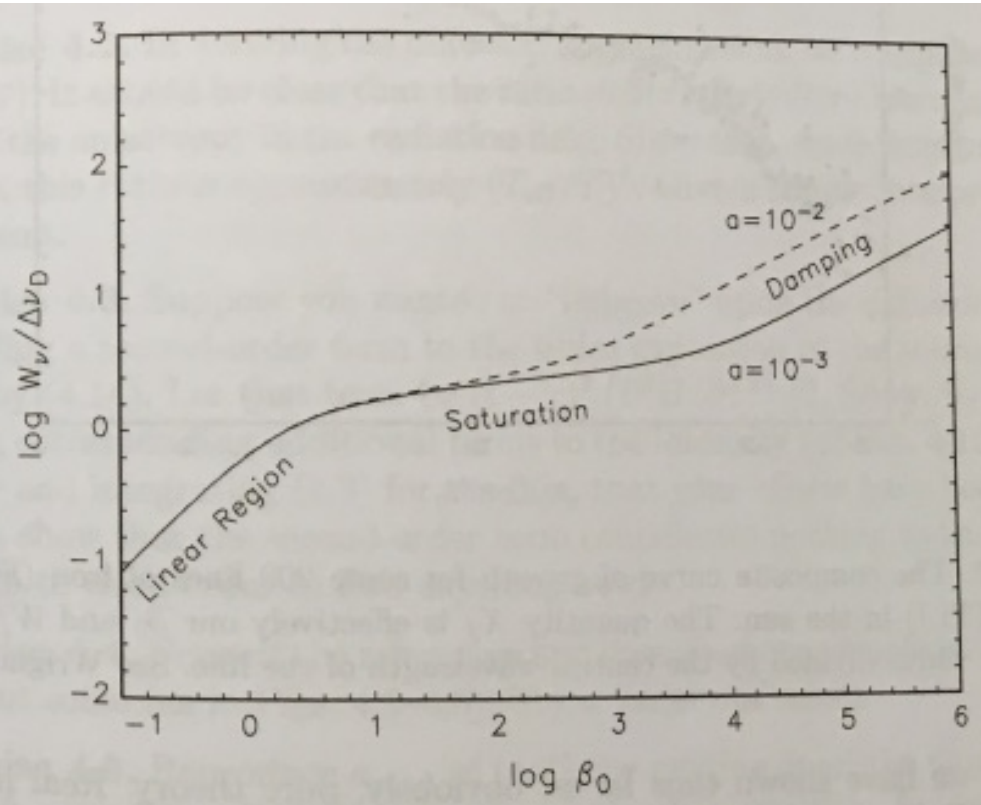
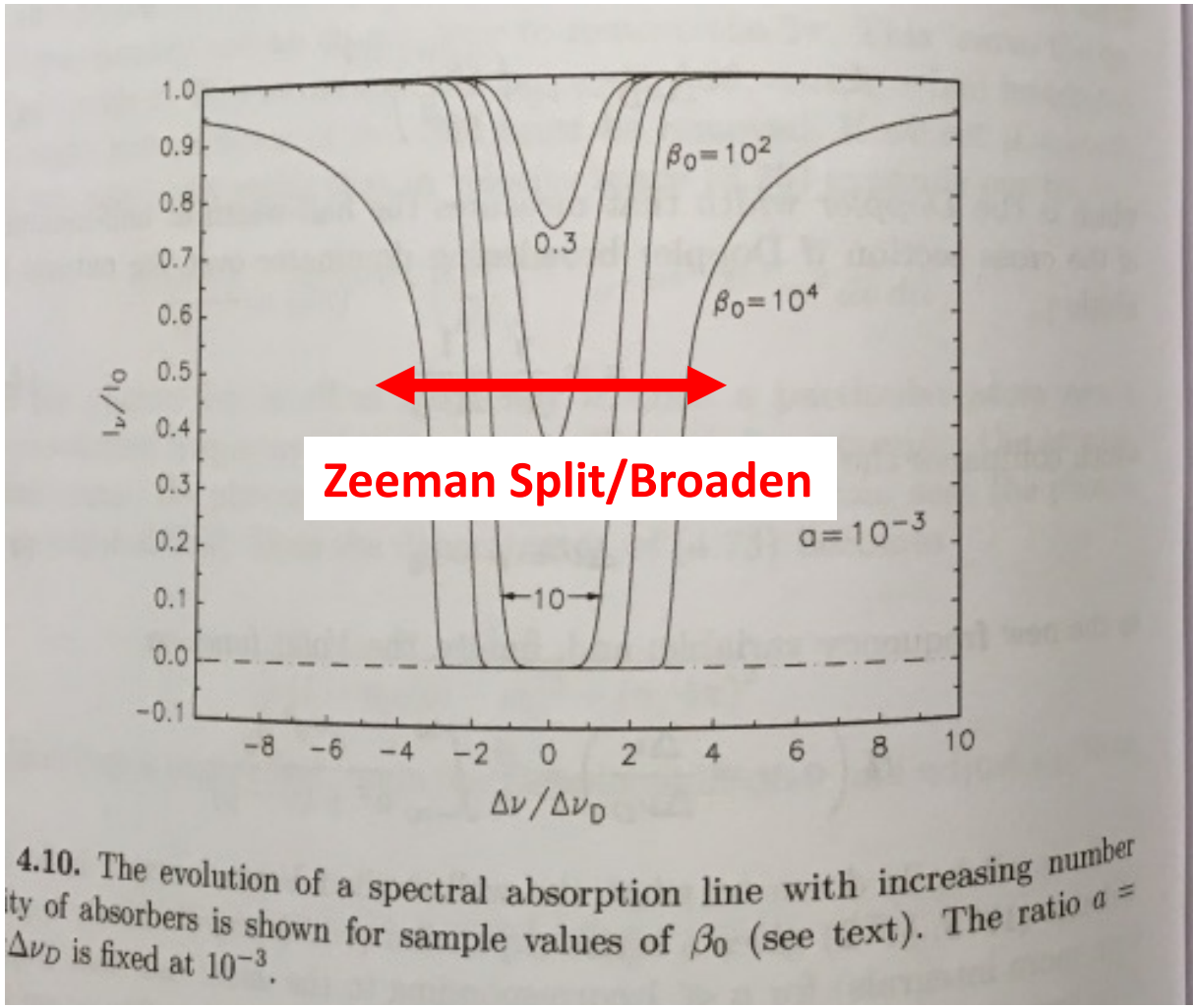


Fig. 4.11. The solid curve is the curve of growth corresponding to the line profi of Fig. 4.10 with $a = 10^{-3}$ ($a \propto 1/\Delta\nu_D$). For $a = 10^{-2}$ (dashed line) the dampi portion of the curve begins sooner because $\Delta\nu_D$ has been reduced.

Hansen, Kawaler & Trimble

Magnetic/Zeeman Enhancement



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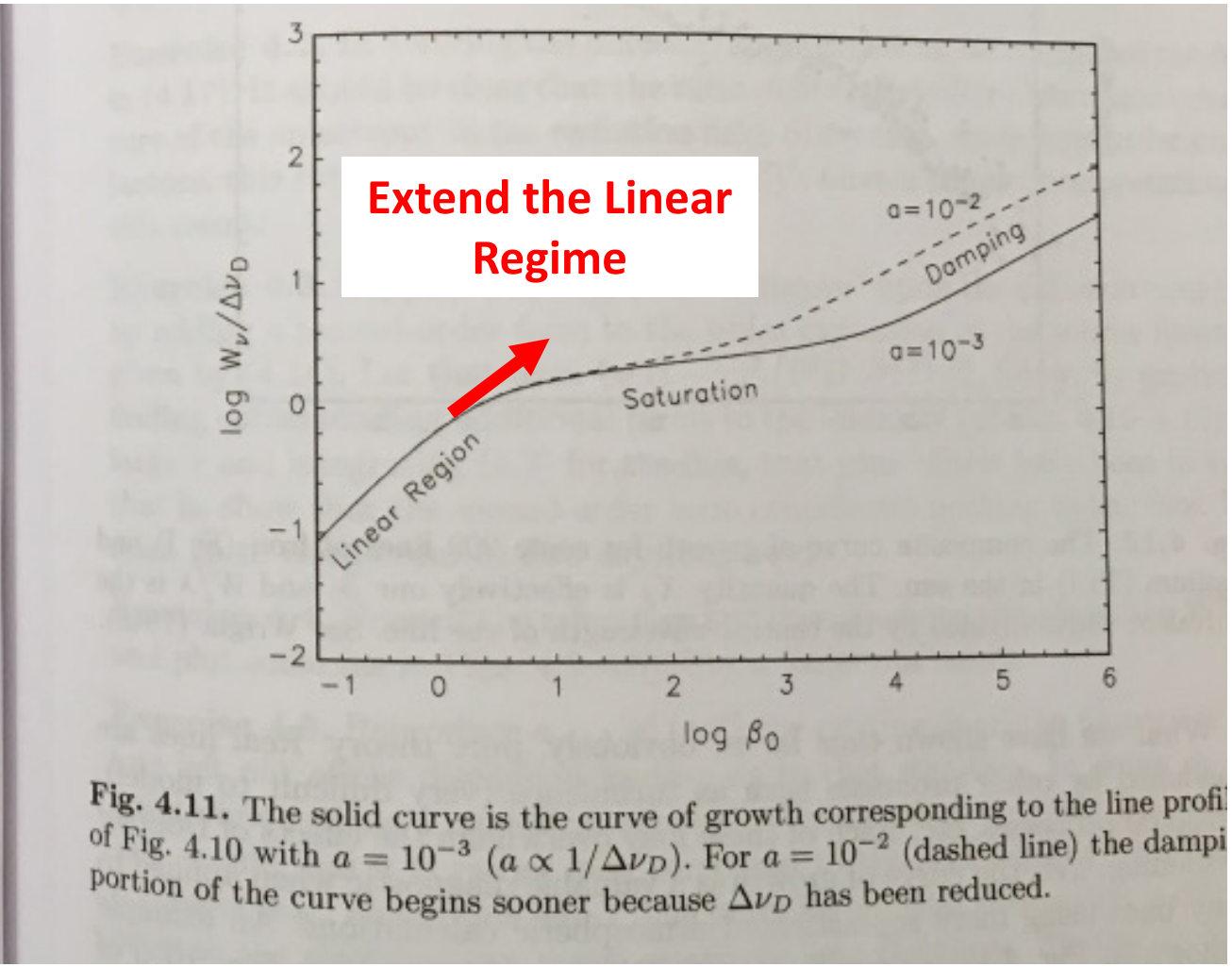

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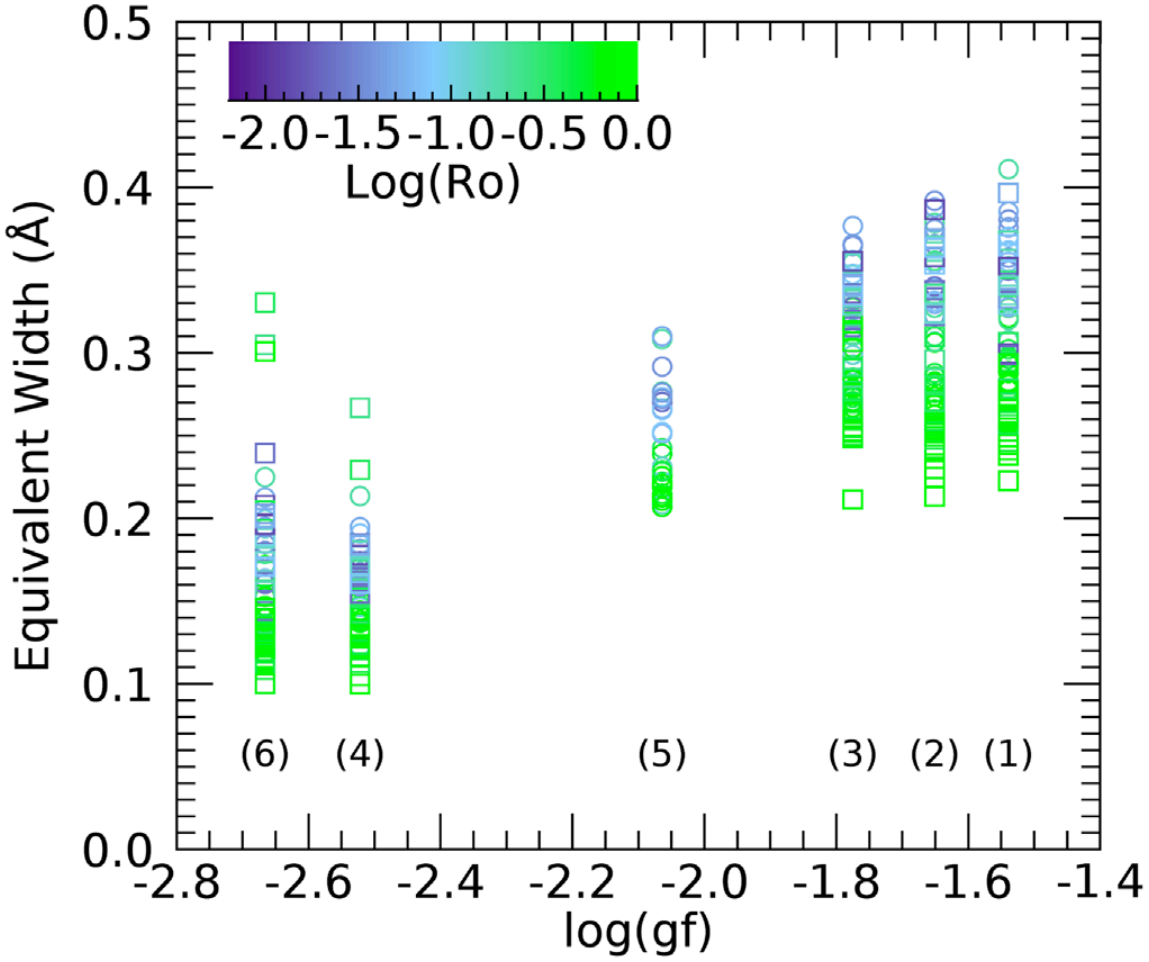
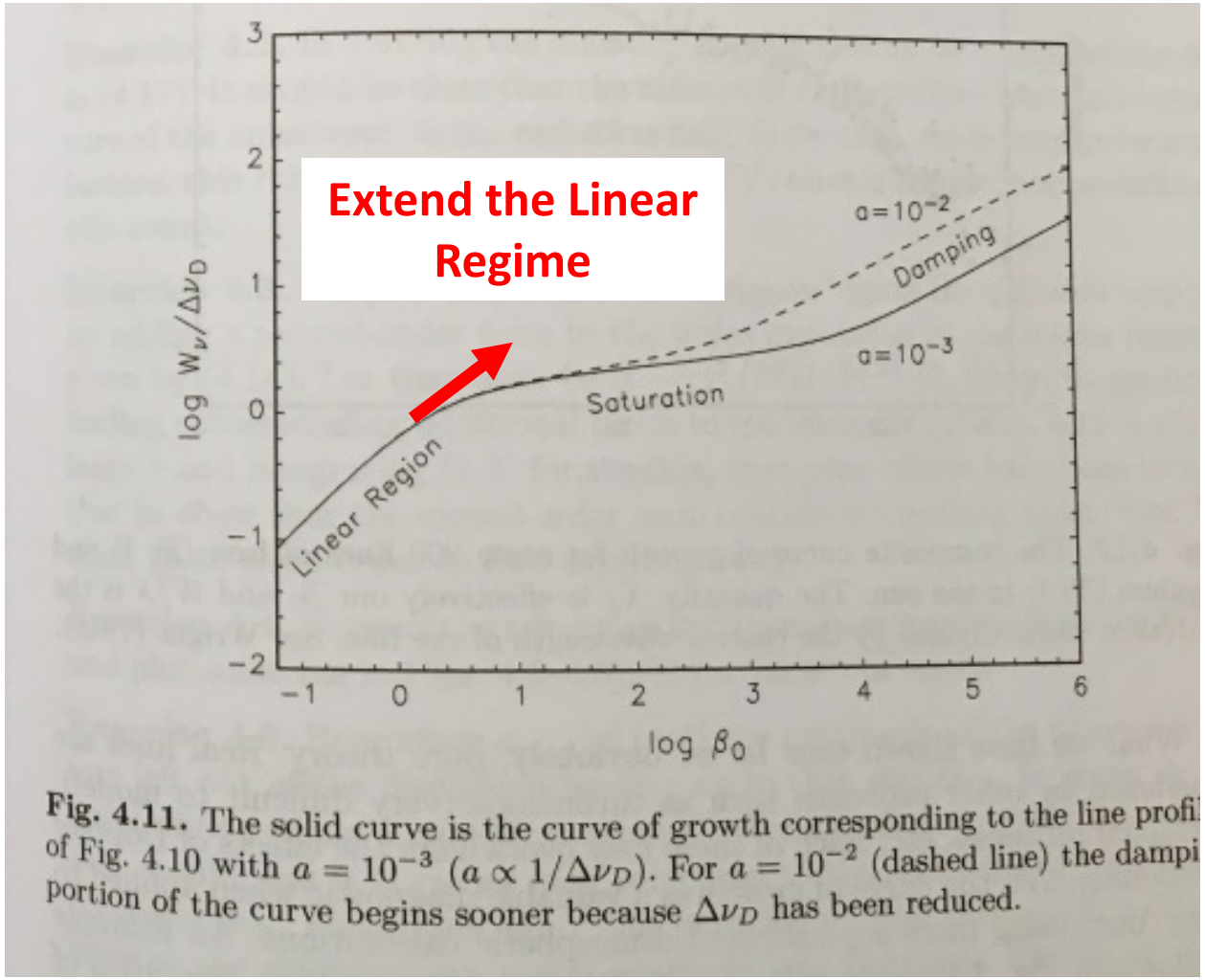
Hansen, Kawaler & Trimble

See extensive work by Basri+, Berdyugina+, Shulyak+

Magnetic/Zeeman Enhancement



(oscillator strength)



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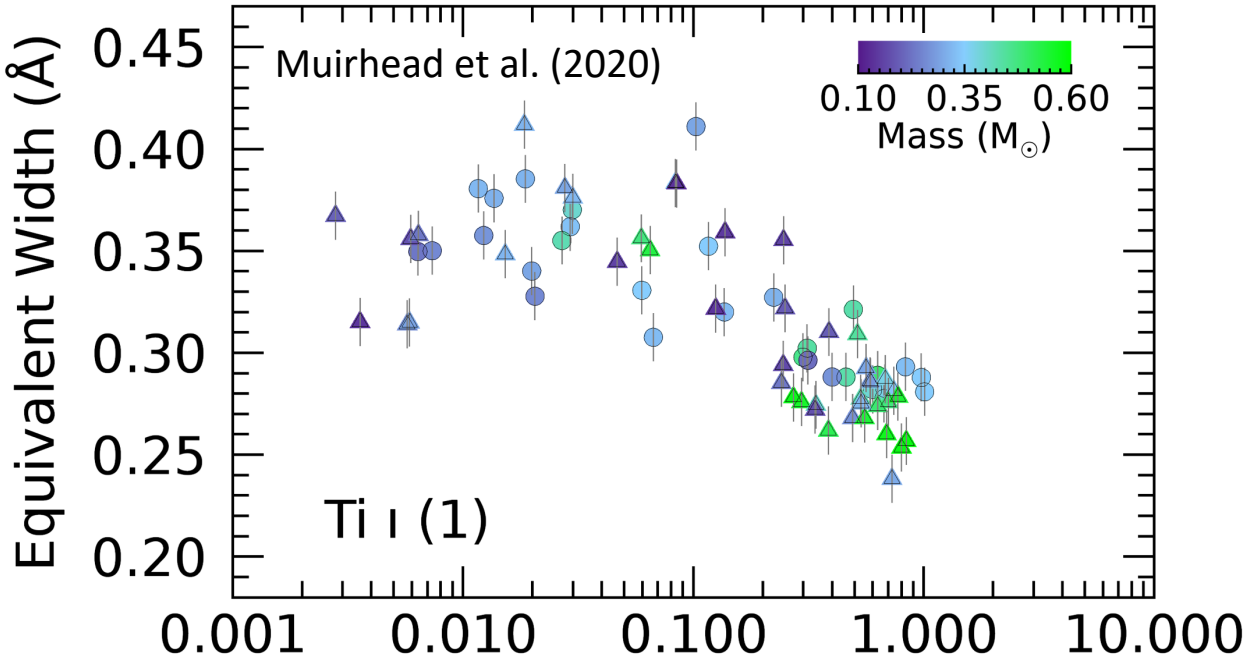
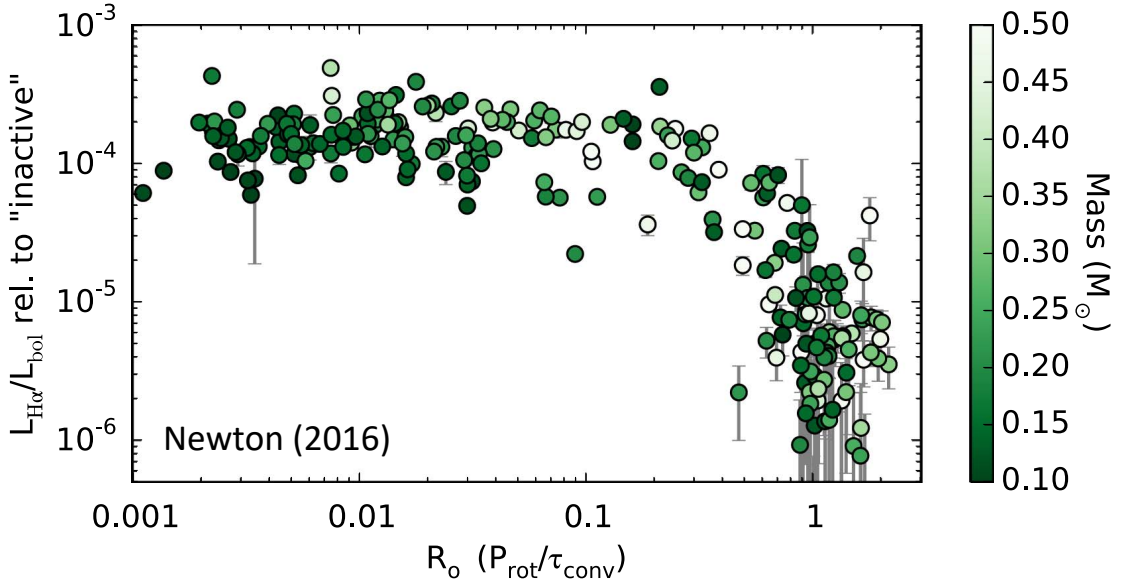


Young

Old



Lines are saturating in *absorption*.

Line strength is not mass dependent, only Rossby dependent.

Purely empirical, no modelling of B fields.

Saturation mechanism is at or below the photosphere

- Consistent with Reiners et al. (2009) but uses *photometric* rotation periods and avoids modelling.

Proposed Mechanisms for the Saturation

- **Coronal stripping (Jardine & Unruh 1999)**
  - At fast rotation, B-field centrifugal stripping reduces density and cancels increase in temperature, leading to saturation.

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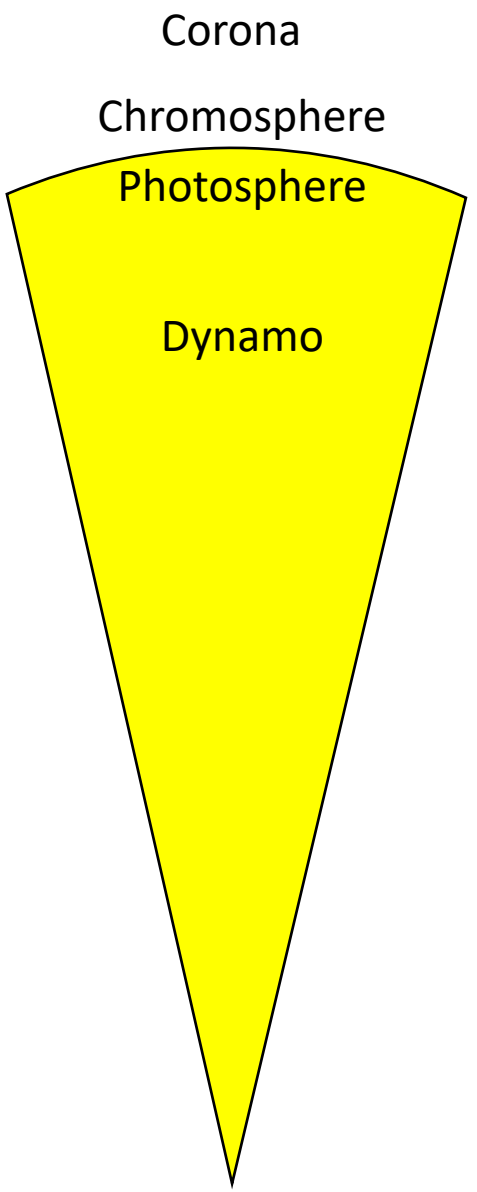

Next Steps: Atmospheric Modelling

- Two new efforts recently funded by NSF:
  - Apply “spectral retrieval” used on L and T dwarfs to M dwarfs (with J. Fortney and M. Line).
  - Add magnetic fields to atmospheric models used in APOGEE data (with K. Cunha and V. Smith).
- Both will tell us more about the saturation effects in the photosphere, but not where the mechanism is localized.
  - How can we test whether the *dynamo* saturates (quenching)?

Some things I learned from ExoStar

- E. Newton was very helpful in understanding the state of the field.
- S. Berdyugina was very helpful with modelling (we skipped modelling in this result, but hoping to spin back up soon).
- J. Fuller was curious how the increased opacity would affect evolutionary models (could it explain radius discrepancies?).
  - I don't know, but now I'm curious about Zeeman enhancement and H_2O, a dominant opacity source for Ms.

Thank you to the ExoStar Organizers

- See our AJ paper at: arXiv:1912.01004