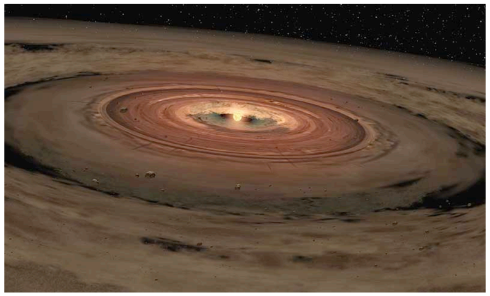
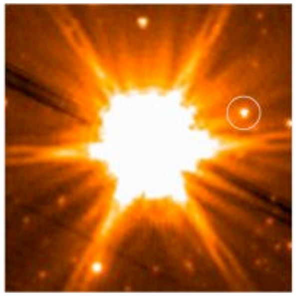
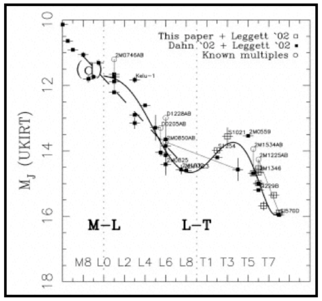
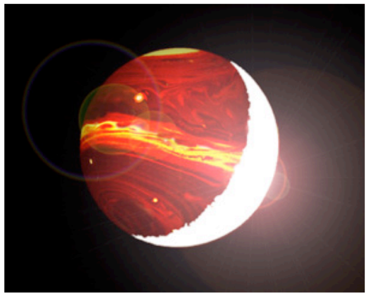
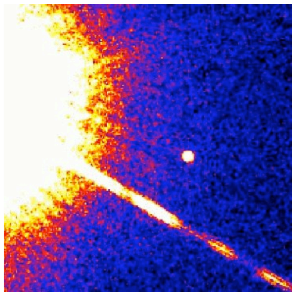
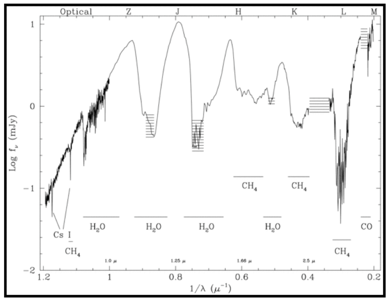
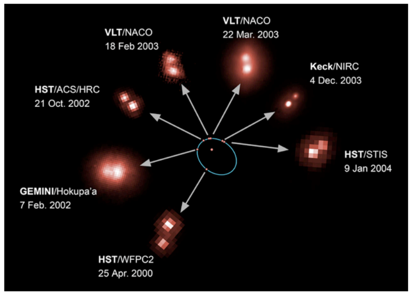




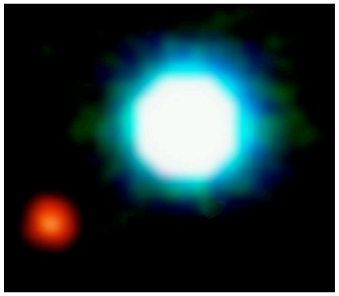


Lecture 13:

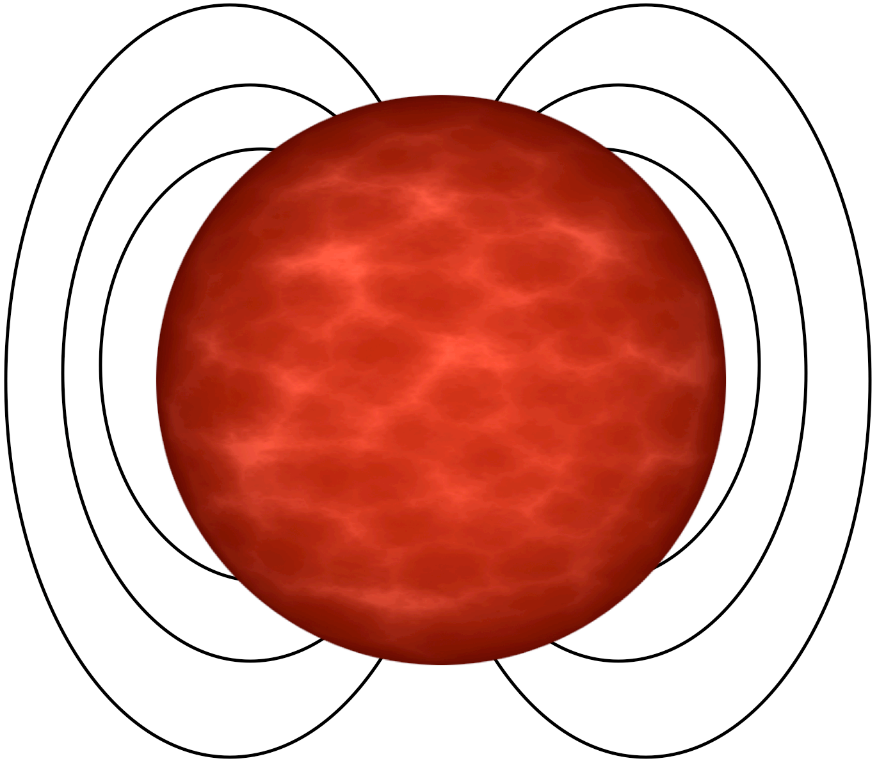
Magnetic Activity and Rotation





Why are Magnetic Fields Important for Brown Dwarfs & Planets?



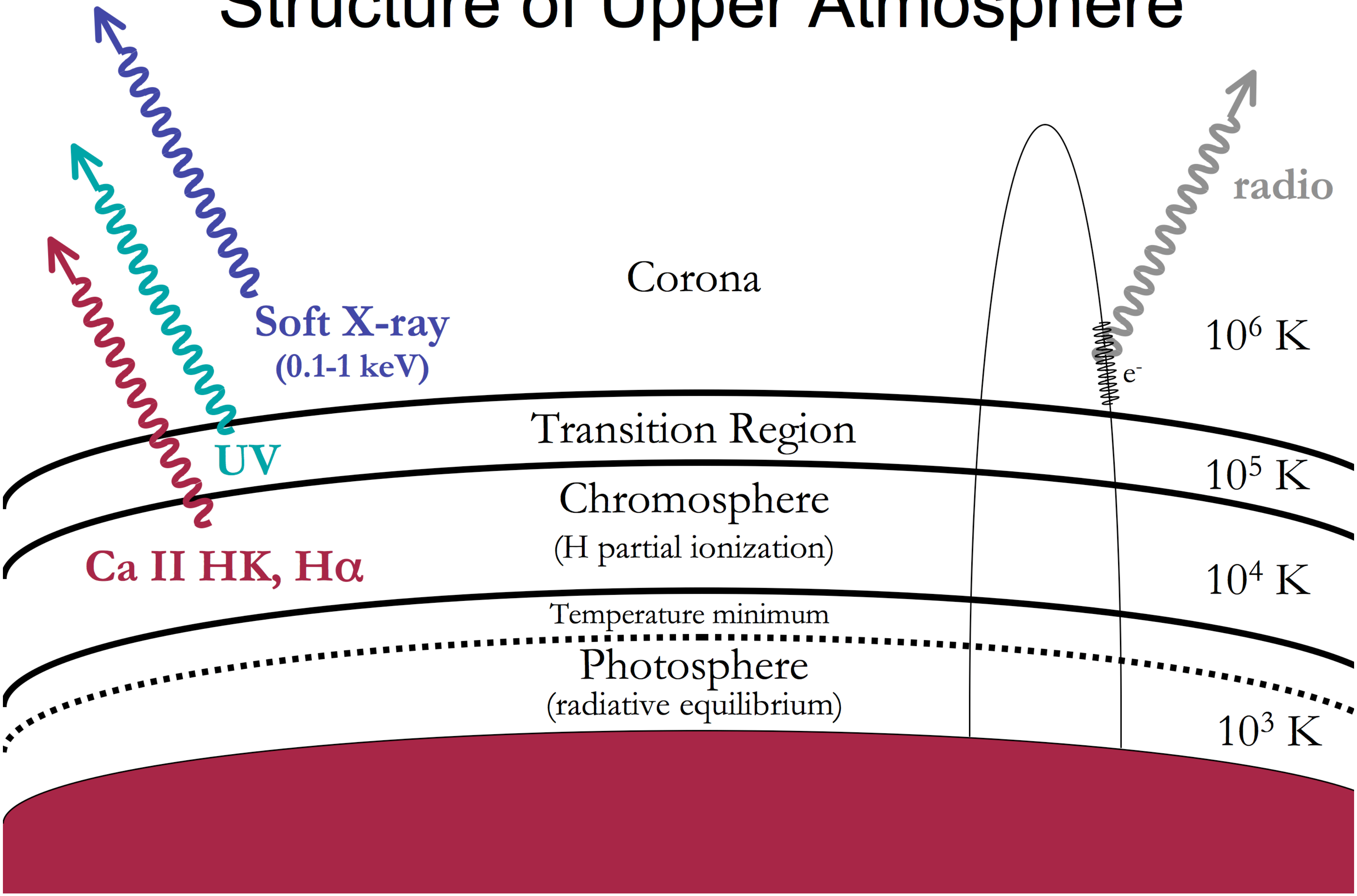
Magnetic fields generated in interior ⇒ **direct probe of interior physics**

Link to angular momentum loss mechanisms and interactions with external bodies

Detectability at non-thermal wavelengths (X-ray, radio)

Habitability (star & planet!)

Structure of Upper Atmosphere



Soft X-ray
(0.1-1 keV)

UV

Ca II HK, Hα

radio

Corona

e^-

Transition Region

Chromosphere
(H partial ionization)

Temperature minimum

Photosphere
(radiative equilibrium)

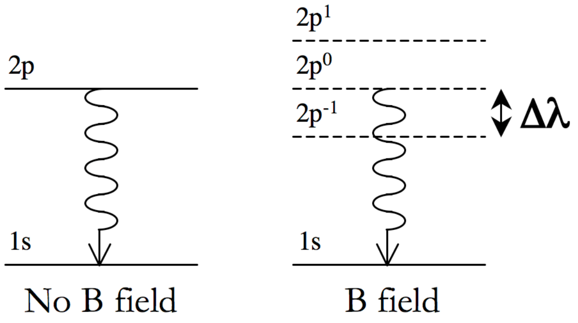
10^6 K

10^5 K

10^4 K

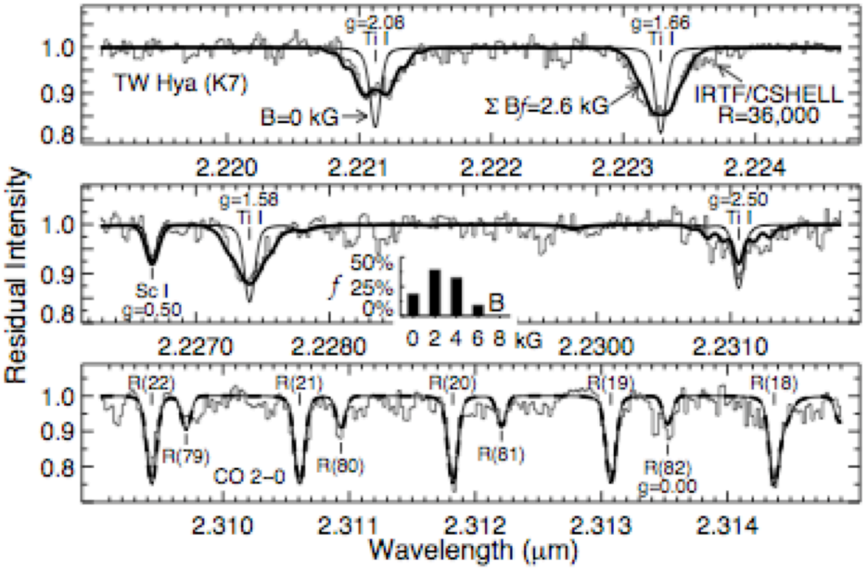
10^3 K

Magnetic Field Measurements



Magnetic fields can be measured directly for low mass stars via Zeeman line splitting

$$\Delta\lambda = \frac{e}{4\pi m_e c^2}\lambda^2 \underbrace{g_{eff}}_{\textbf{Lande g factor}} \mid B \mid$$



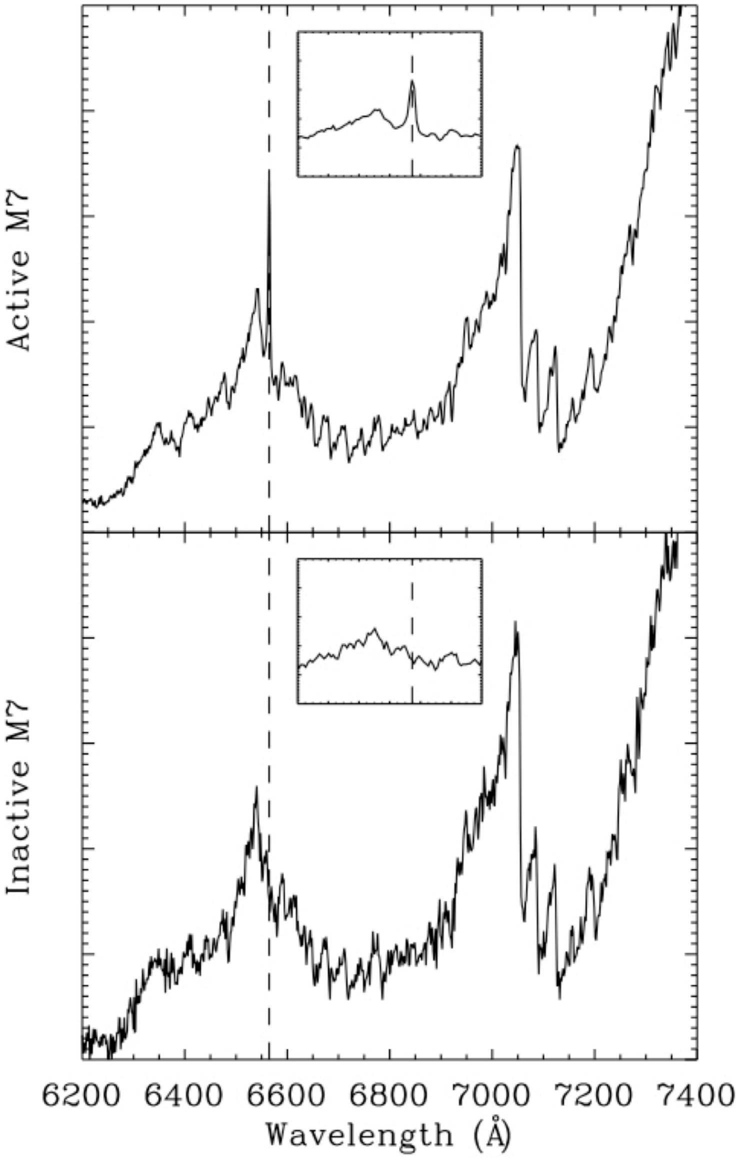
Valenti & Johns-Krull (2001)

Measurements for mid-type M dwarfs yield **B ≈ 2-4 kG for *f* ≈ 50-80%** at photosphere (B = 1.5 kG and *f* = 1% for Sun)

Emission Diagnostics

- **Ca II H&K** (3930/3970 Å) - standard for solar-type stars (e.g., Mt. Wilson Project), difficult to measure in very cool stars/brown dwarfs
- **Hα** (6563 Å) - common measure for MLT dwarfs
- **UV & X-ray** - sensitive to hot transition region/coronal emission
- **Radio** - sensitive to synchrotron/maser emission from electrons in B fields
- **Photometric bursts** - generally seen during flares

Chromospheric Emission: Hα

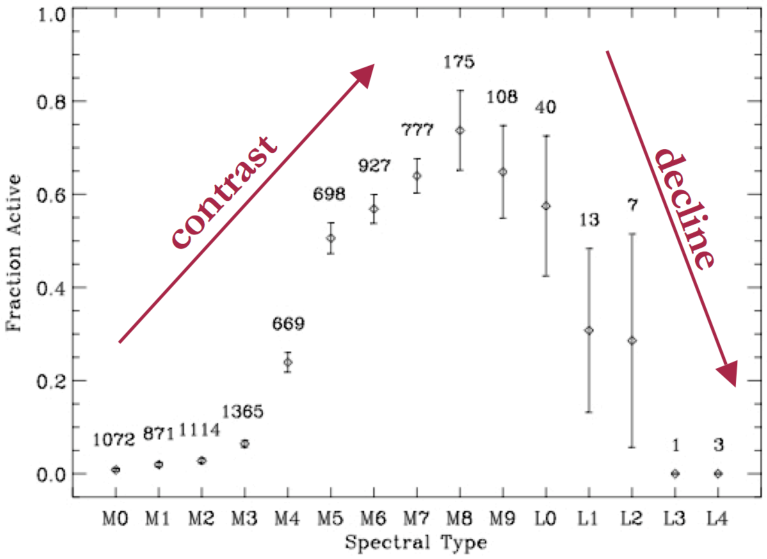


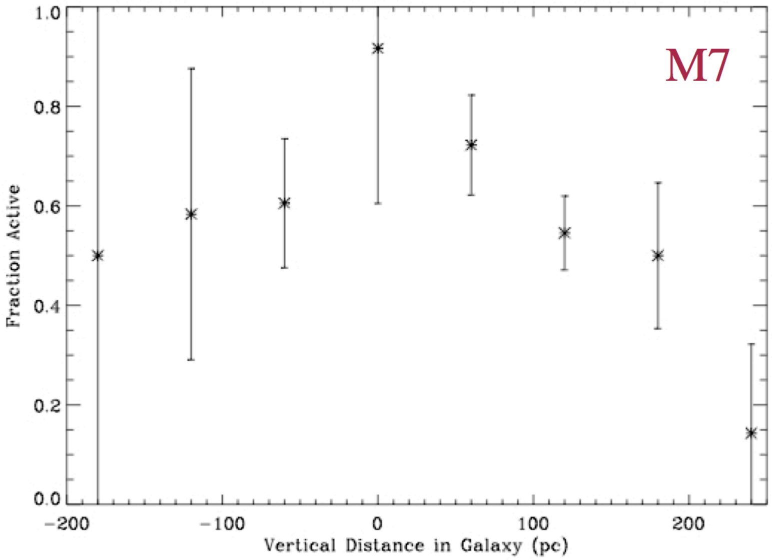
West et al. (2004)

Induced by collisions between B-field bound electrons/ions and neutral H atoms (Alfven waves along field lines or acoustic heating *may* provide power source)

Most common activity metric for late-type dwarfs

Frequency of Hα Emission



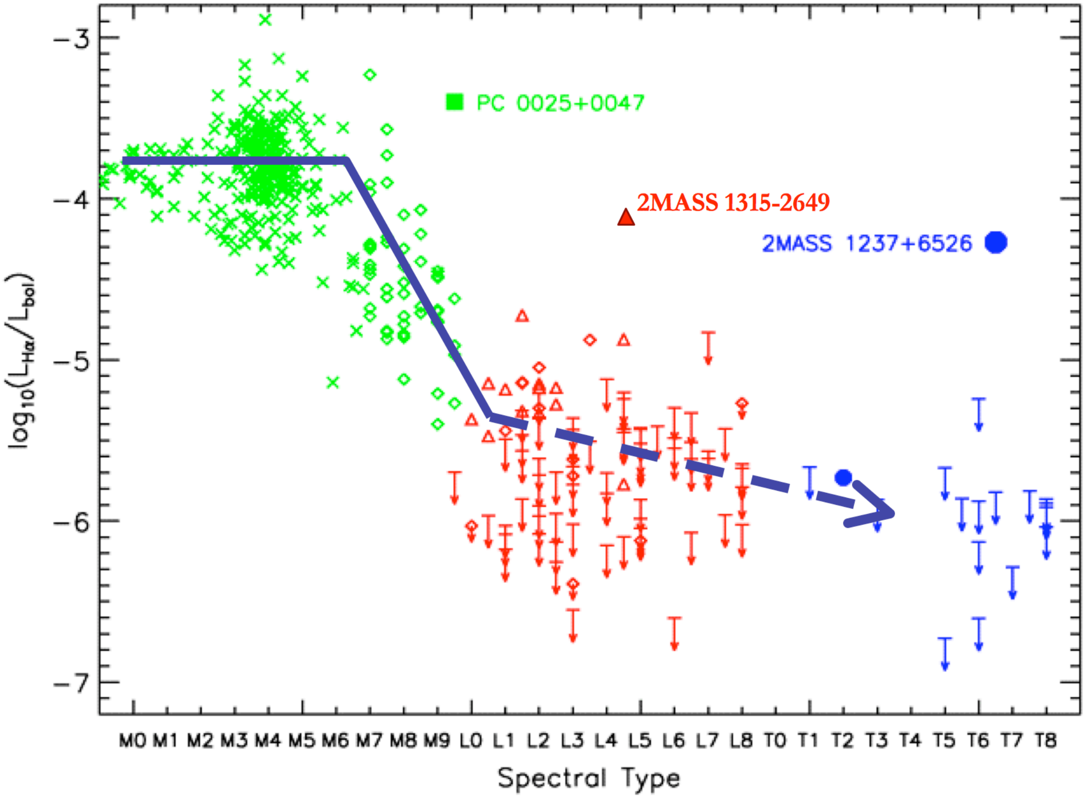


The fraction of emission line objects rises to ≈ **80-100% for spectral types M7-M8**, then declines rapidly in the L dwarf regime.

Some dependence on height above Galactic disk ⇒ age effect?

West et al. (2004); see also Gizis et al. (2000)

Strength of Hα Emission

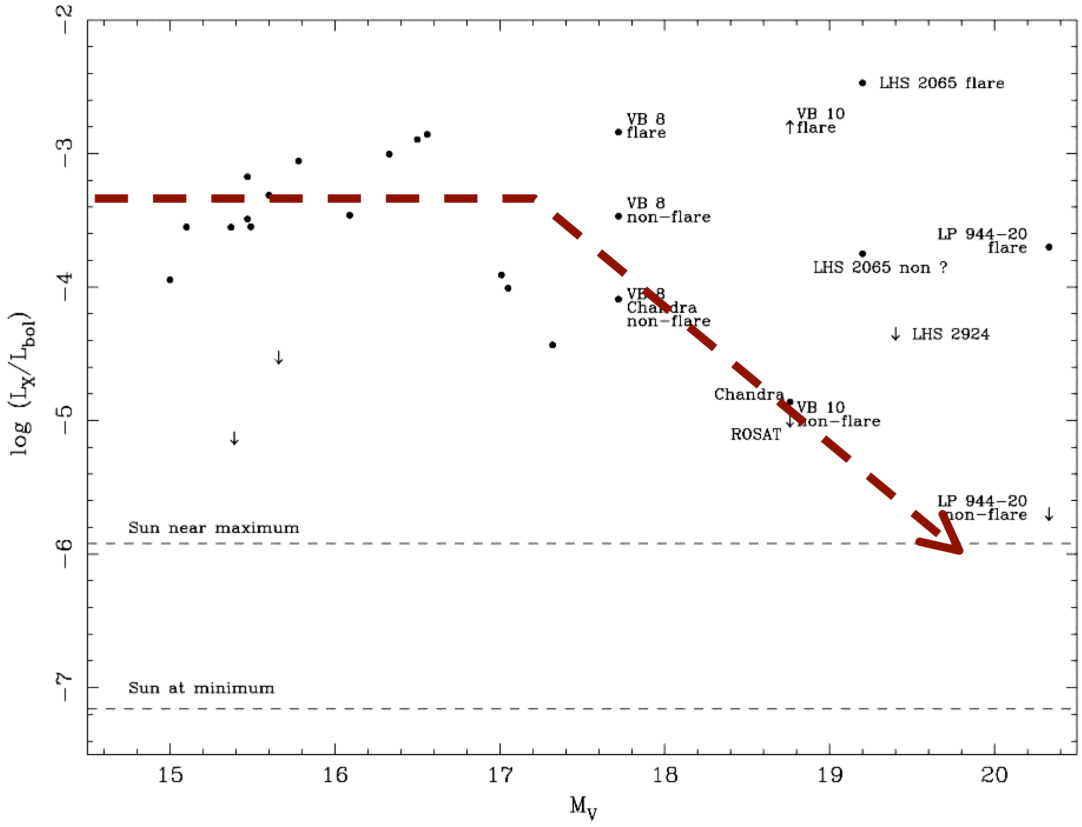


Burgasser et al. (2002)

Strength of Hα emission peaks at M5-M7 ($L_{H\alpha} \approx 10^{-4}$ - 10^{-3} L_{bol}), drops off rapidly past this (mostly upper limits)

A few interesting exceptions…

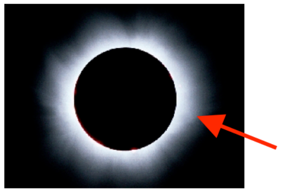
Coronal Emission: X-ray



Fleming et al. (2003); see also Rutledge et al. (2000)

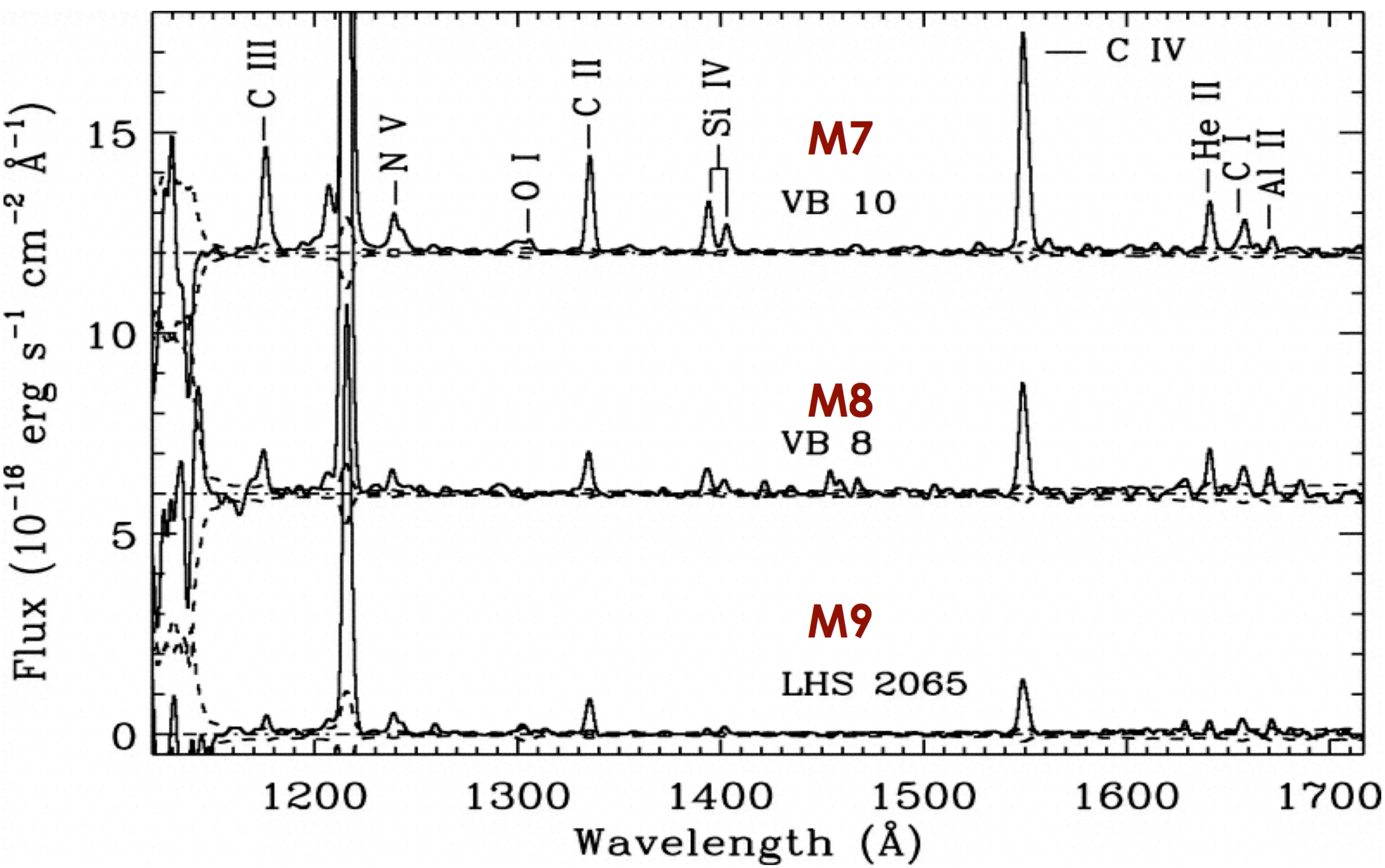
Active M stars emit up to ~0.1% of L_{bol} in X-rays, **more energetic (relatively) than the Sun**

Drop off in quiescent X-ray emission beyond M5-M7 coincident with quiescent Hα



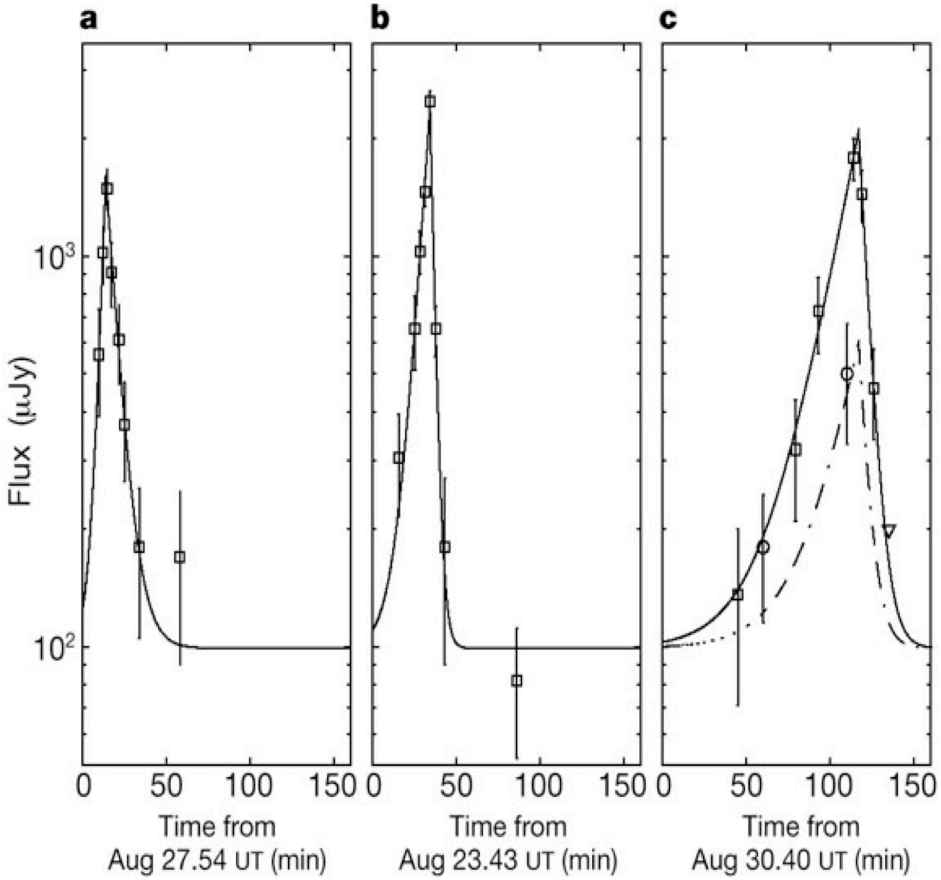
Solar corona

Transition Region Emission: UV



Hawley & Johns-Krull (2003)

Radio Emission

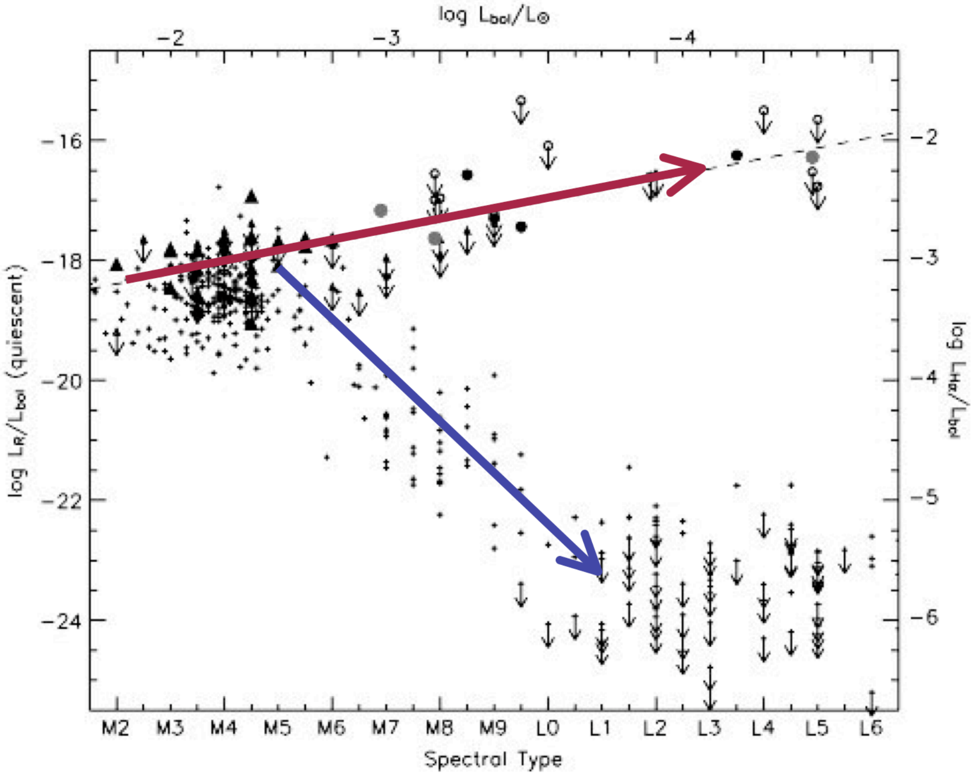


Berger et al. (2001)

Quiescent radio emission arises from electron gyrosynchrotron emission

Quiescent and flaring emission detected in late-M and L-type dwarfs - not expected!

Radio Emission Trends

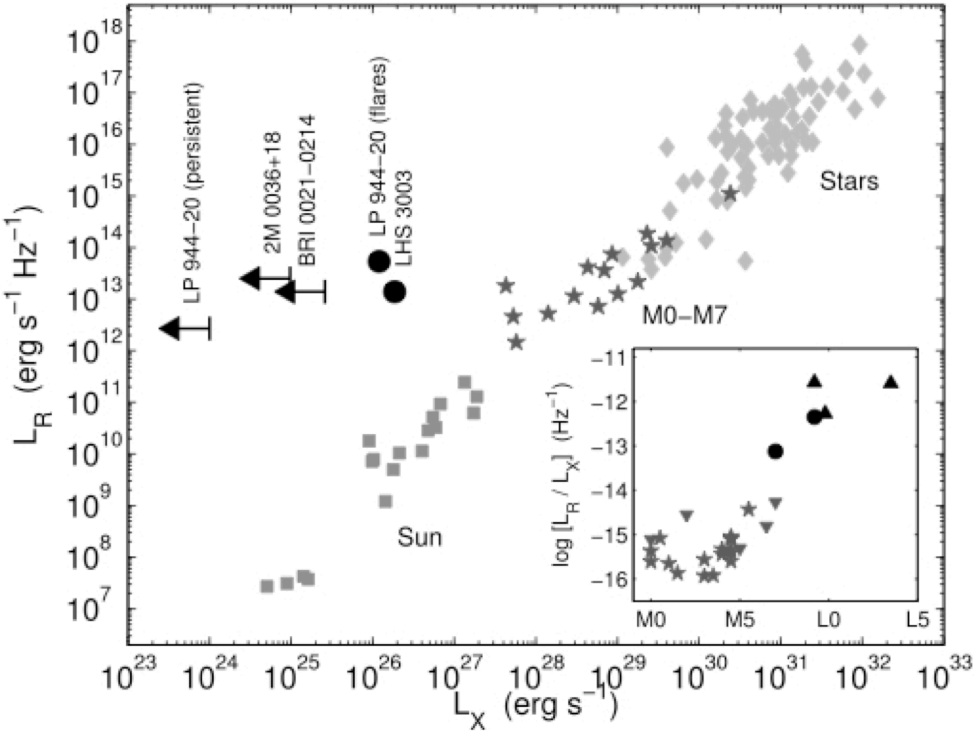


Burgasser & Putman (2006);
see also Osten et al. (2005); Berger (2006)

Unlike Hα and X-ray emission, relative radio emission appears to **increase with later spectral types**

Requires steady supply of plasma to corona ($\tau_{decay} \approx$ minutes)

Violations of Guedel-Benz Relation

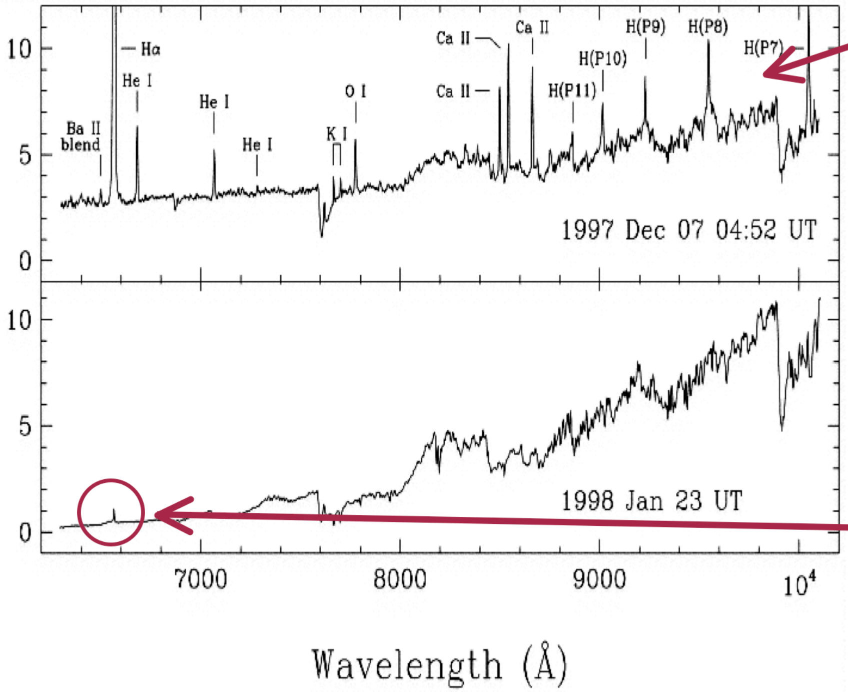


Berger et al. (2006)

Correlation between X-ray and radio emission over many orders of magnitude of emission, stellar types/environments, etc

Very low mass stars & brown dwarfs violate this relation considerably.

Quiescent vs Flaring Emission

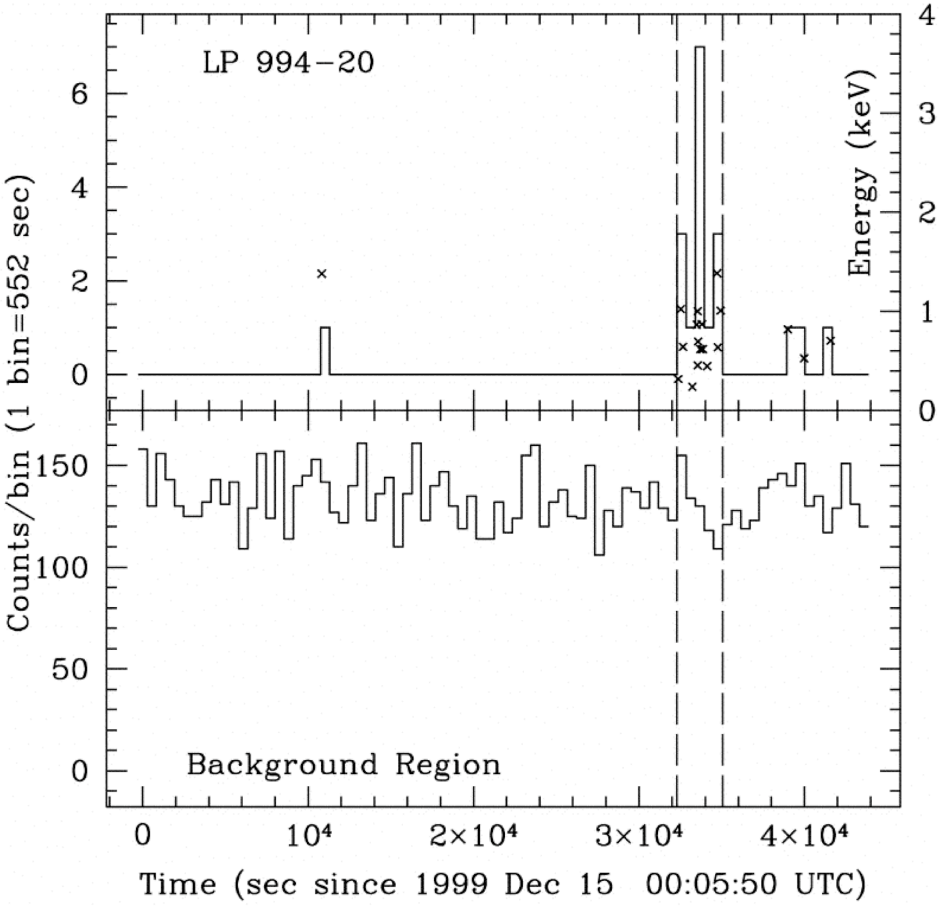


Liebert et al. (1999)

Flaring: strong, impulsive emission that decays rapidly (minutes to hours), both line and continuum flux may be detected ($L \approx 10^{-3}$ - $10^{2}\ L_{bol}$)

Quiescent: steady emission that persists over long periods, typically line flux only in optical ($L \approx 10^{-6}$ - $10^{-3}\ L_{bol}$)

X-ray flares

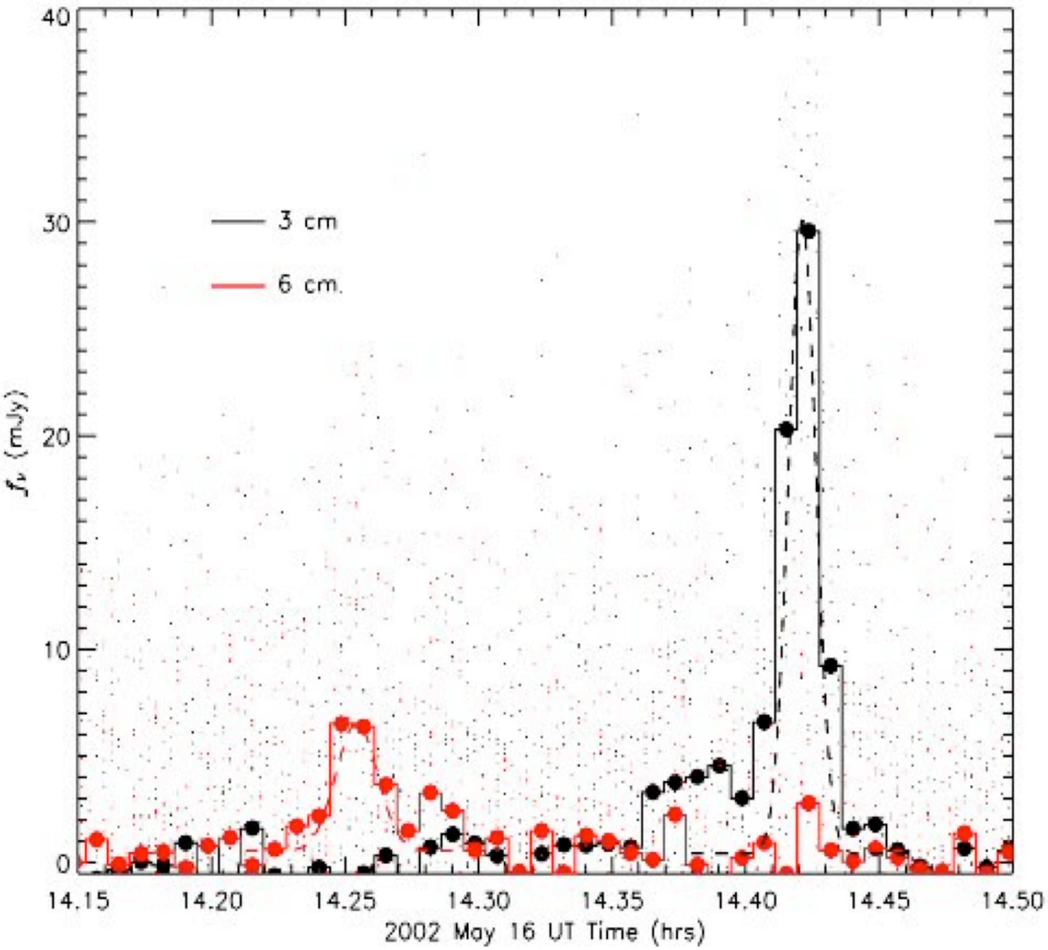


Rutledge et al. (2001)

M9 LP 944-20 (500 Myr brown dwarf at 5pc with Li I absorption) exhibited a 1-2 hr burst with $L_X/L_{bol} \approx 10^{-4}$

Note: no quiescent emission!

Radio Flares

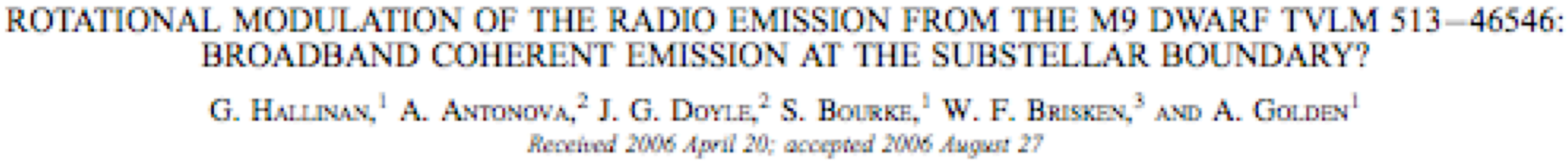


Burgasser & Putman (2005)

M8 DENIS 1048-3956 caught in two flaring events at different frequencies spaced by ≈ 10 min (≈ 1 min bursts)

100% polarized, $T_b \approx 10^{13}$ K ⇒ coherent (maser) emission

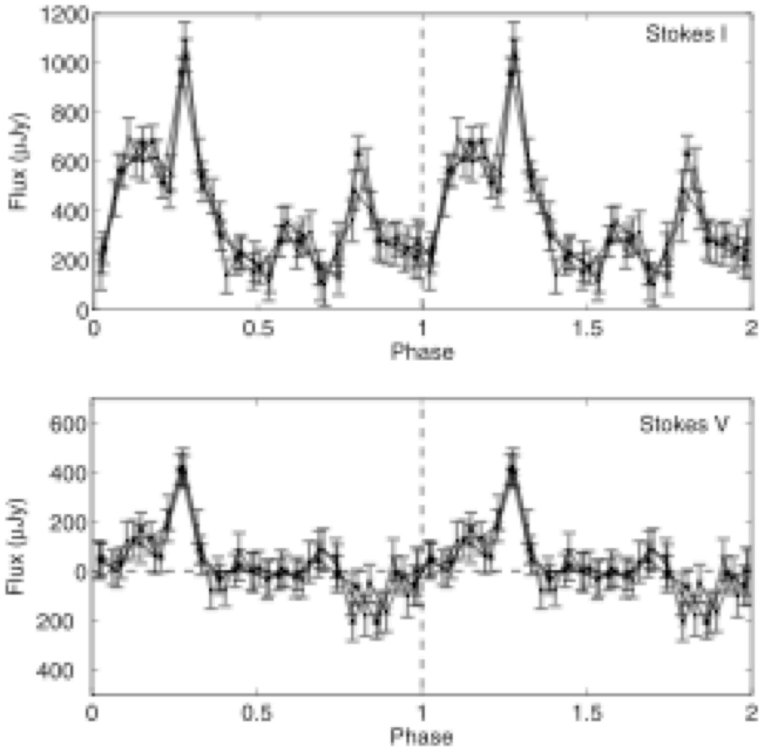
Pulsar-like emission?



ROTATIONAL MODULATION OF THE RADIO EMISSION FROM THE M9 DWARF TVLM 513−46546:
BROADBAND COHERENT EMISSION AT THE SUBSTELLAR BOUNDARY?

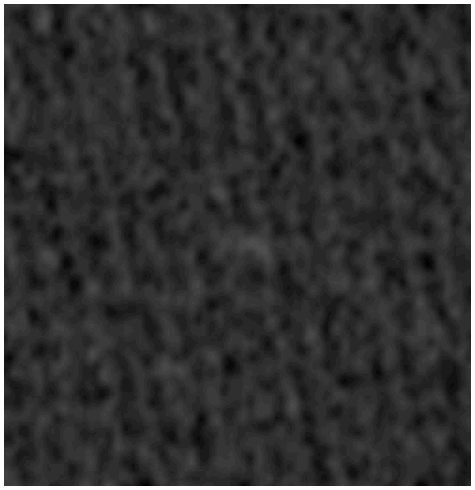
G. Hallinan,[1] A. Antonova,[2] J. G. Doyle,[2] S. Bourke,[1] W. F. Brisken,[3] and A. Golden[1]

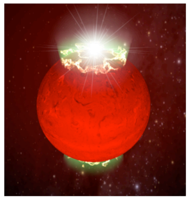
Received 2006 April 20; accepted 2006 August 27



Hallinan et al. (2007)

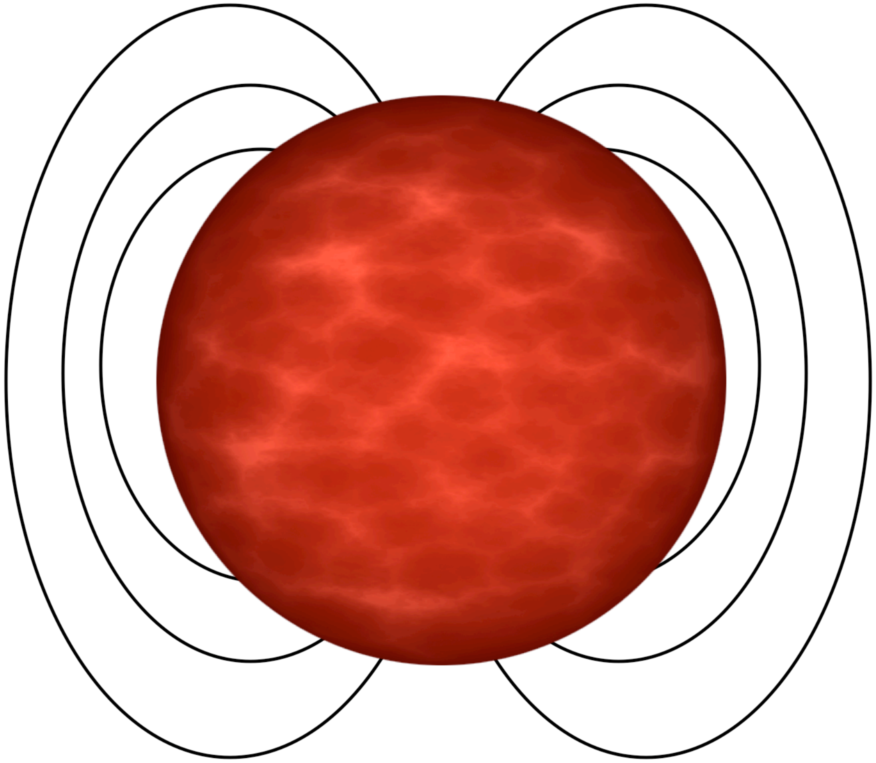
Periodic emission, indicative of rotation of beamed emission source





Brown dwarf as pulsar?

What do observations tell us about magnetic fields around brown dwarfs?

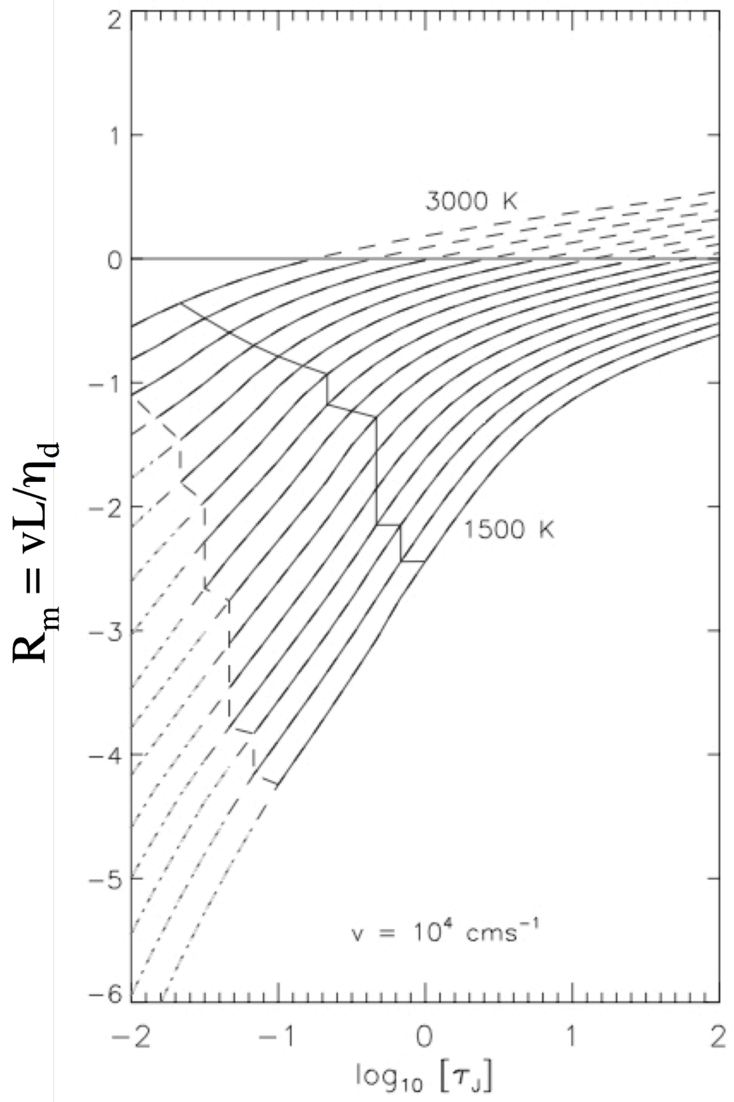


(1) Magnetic fields exist

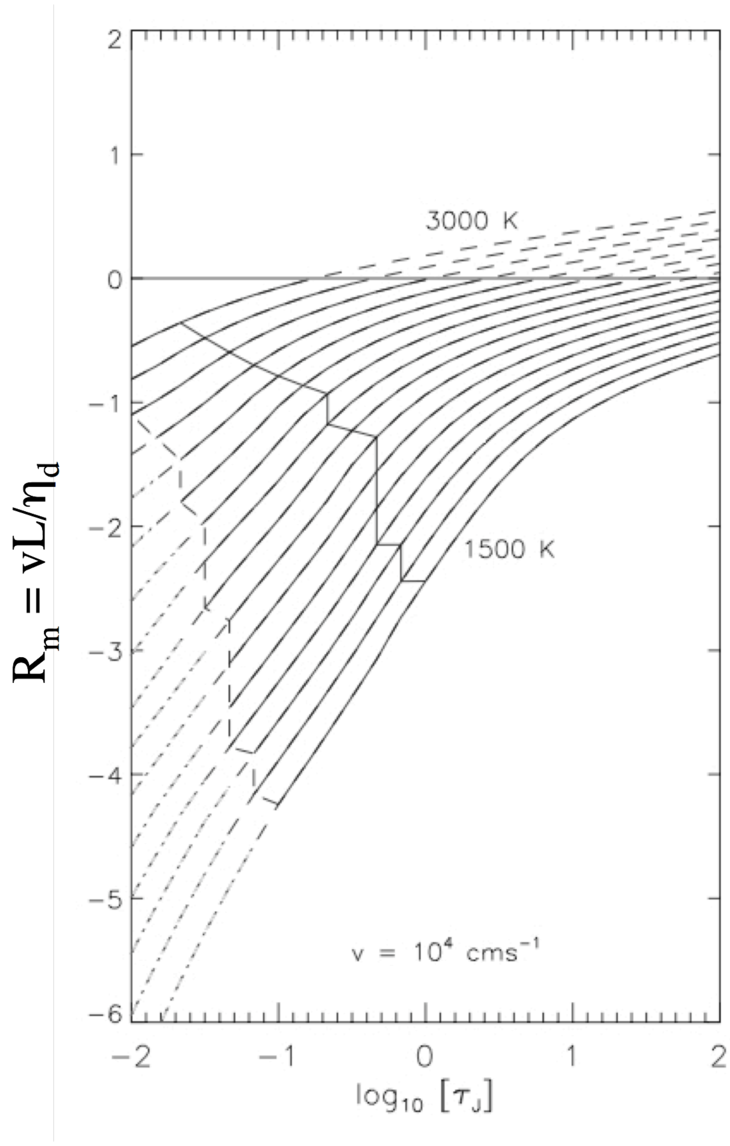
(2) Magnetic fields are (possibly) as strong around brown dwarfs as around low mass stars

(3) Chromospheres/coronae may not be as prominent around the coolest dwarfs

Activity and Cool Atmospheres



Mohanty et al. (2002)



Mohanty et al. (2002)

Activity and Cool Atmospheres

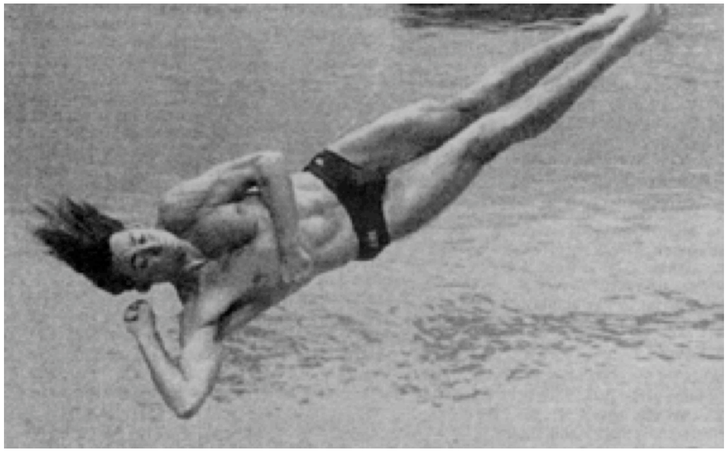
At lower temperatures, photospheres have **low ionization fractions and high resistivities**

⇒ B field decoupled from photosphere, difficult to generate magnetic stress

⇒ Propagation of magnetic stresses from interior damped by electrical resistance

⇒ Decline in "activity"

Rotation

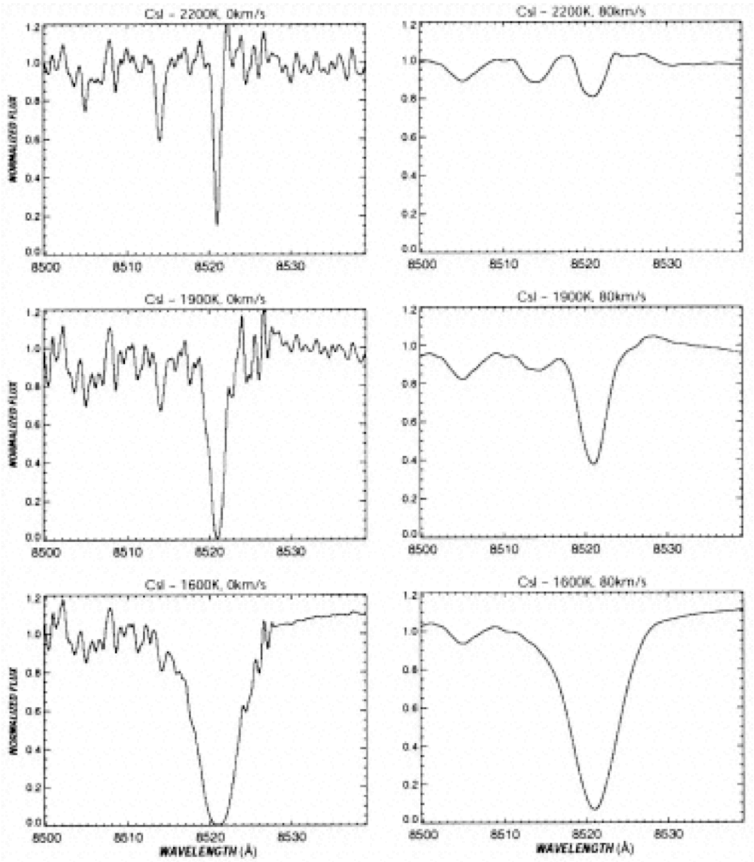


Rotation

Rotation in brown dwarfs & planets is directly relevant to:

- origin
- angular momentum evolution, including tidal dissipation
- early interactions with disks
- magnetic properties

Rotation: vsin(i)



Basri et al. (2000)

Rotation of star results in **Doppler shifts** across stellar surface - broadening of <u>all</u> spectroscopic features

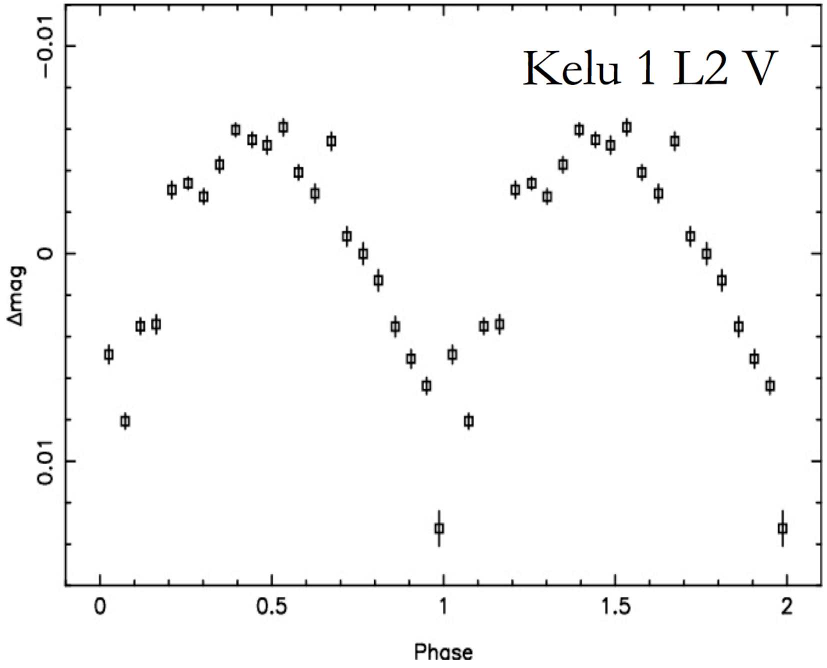
Pros:

- Single observation measurement
- Does not require surface variations

Cons:

- Significant investment in telescope time (5 km/s ⇒ R=60,000)
- sin(i) ambiguity

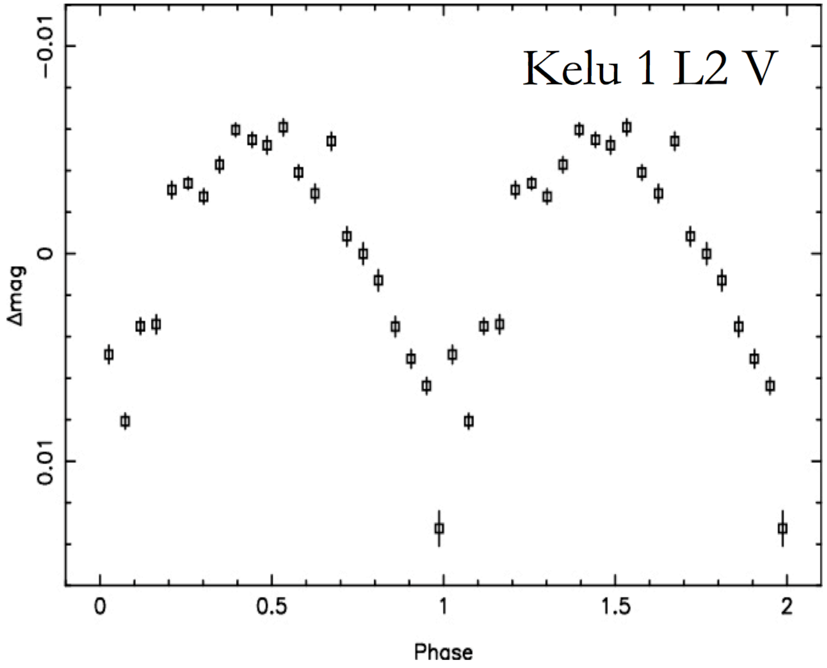
Rotation: Photometric Variability



Clarke, Tinney, & Covey (2002)

$$P = 5\sin i\left(\frac{R}{0.1\ R_\odot}\right)\left(\frac{v\sin i}{\mathrm{km/s}}\right)^{-1}\ \mathrm{days}$$

Rotation: Photometric Variability

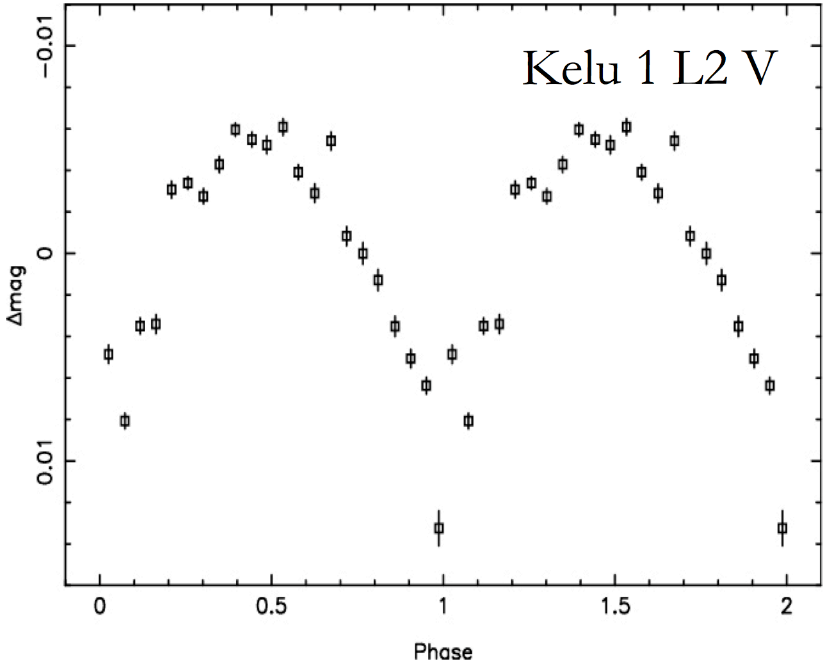


Clarke, Tinney, & Covey (2002)

Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

$$P = 5 \sin i \left(\frac{R}{0.1\ R_\odot}\right)\left(\frac{v \sin i}{\mathrm{km/s}}\right)^{-1} \ \mathrm{days}$$

Rotation: Photometric Variability



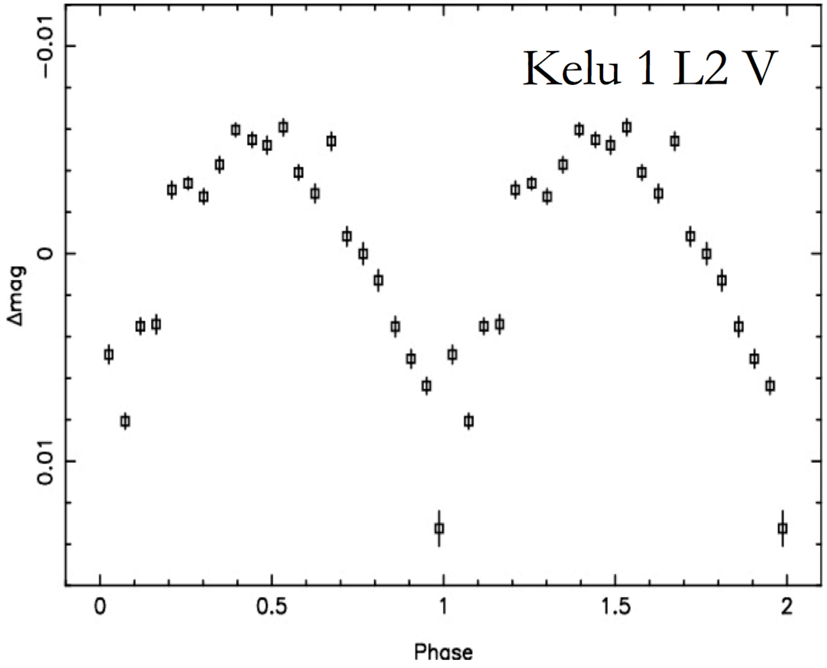
Clarke, Tinney, & Covey (2002)

Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

Pros:

$$P = 5 \sin i \left(\frac{R}{0.1\ R_\odot} \right) \left(\frac{v \sin i}{\mathrm{km/s}} \right)^{-1} \ \mathrm{days}$$

Rotation: Photometric Variability



Clarke, Tinney, & Covey (2002)

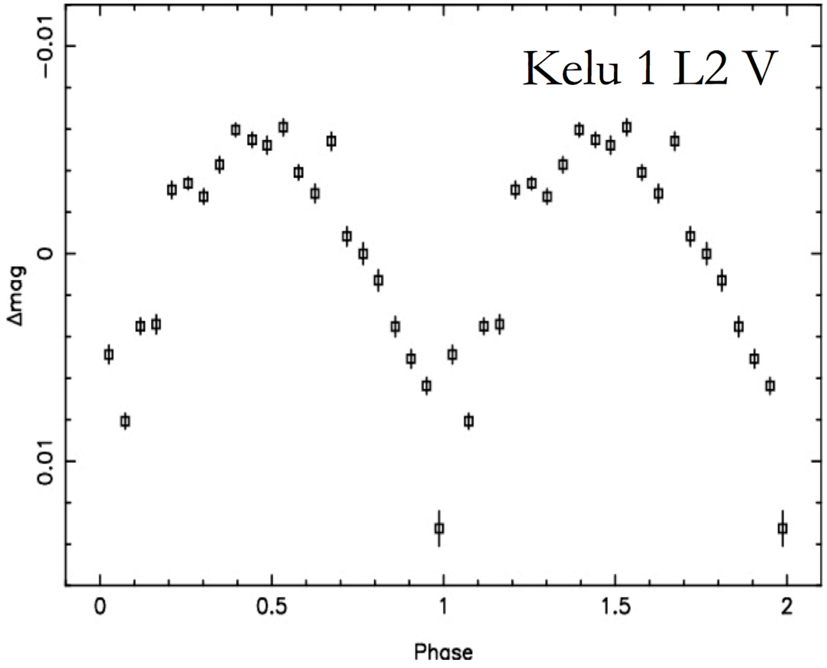
Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

Pros:

- Can be measured with small telescopes

$$P = 5 \sin i \left(\frac{R}{0.1\ R_\odot}\right)\left(\frac{v \sin i}{\mathrm{km/s}}\right)^{-1} \text{ days}$$

Rotation: Photometric Variability



Clarke, Tinney, & Covey (2002)

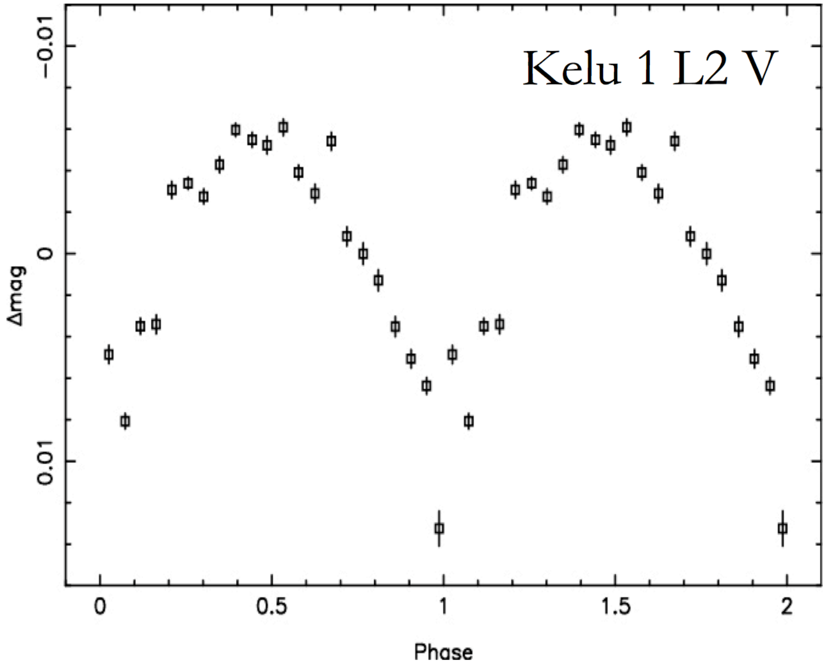
Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

Pros:

- Can be measured with small telescopes
- Differential photometry is easy

$$P = 5 \sin i \left(\frac{R}{0.1\ R_\odot}\right) \left(\frac{v \sin i}{\mathrm{km/s}}\right)^{-1} \text{ days}$$

Rotation: Photometric Variability



Clarke, Tinney, & Covey (2002)

Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

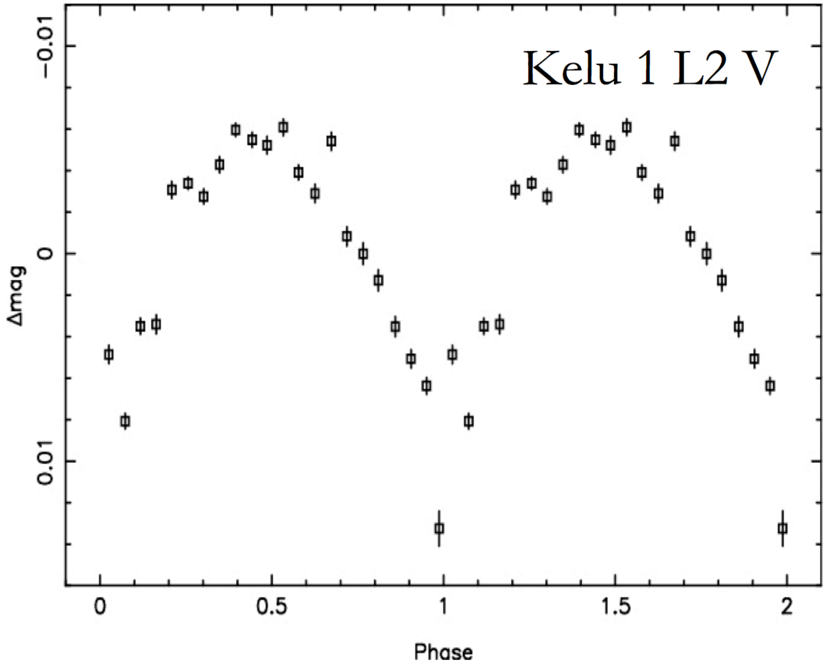
Pros:

- Can be measured with small telescopes
- Differential photometry is easy

Cons:

$$\boxed{P = 5 \sin i \left(\frac{R}{0.1\ R_\odot}\right) \left(\frac{v \sin i}{\mathrm{km/s}}\right)^{-1} \ \mathrm{days}}$$

Rotation: Photometric Variability



Clarke, Tinney, & Covey (2002)

Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

Pros:

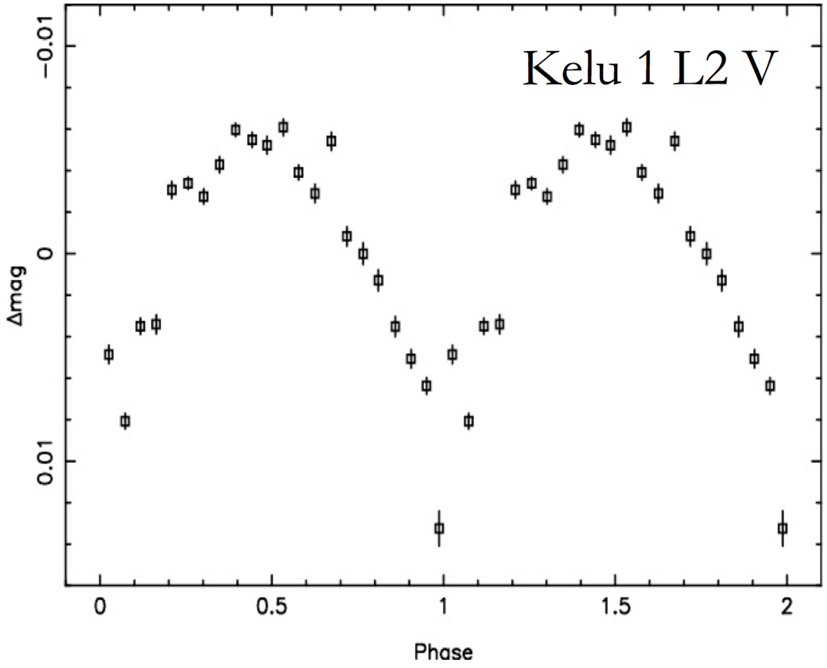
- Can be measured with small telescopes
- Differential photometry is easy

Cons:

- Long monitoring periods required

$$\boxed{P = 5 \sin i \left(\frac{R}{0.1\ R_\odot}\right)\left(\frac{v \sin i}{\mathrm{km/s}}\right)^{-1} \text{ days}}$$

Rotation: Photometric Variability



Clarke, Tinney, & Covey (2002)

Rotation of stable surface features (spots, clouds) in/out of line of sight produces periodic light curve

Pros:

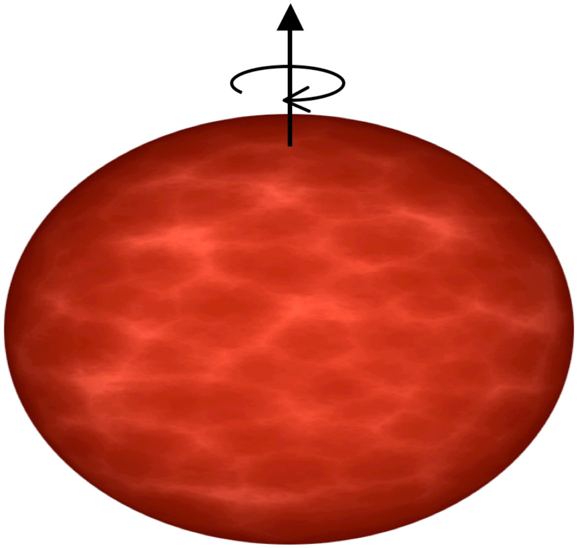
- Can be measured with small telescopes
- Differential photometry is easy

Cons:

- Long monitoring periods required
- Surface features must exist and be relatively stable (few rotation periods)

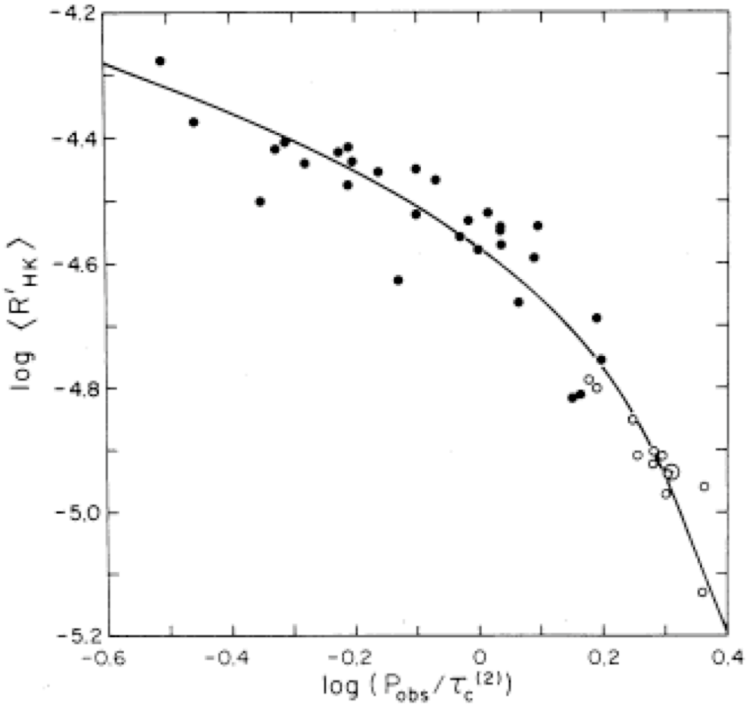
$$\boxed{P = 5 \sin i \left(\frac{R}{0.1\ R_\odot}\right)\left(\frac{v \sin i}{\mathrm{km/s}}\right)^{-1} \text{ days}}$$

Rotation Properties of LMSs/BDs



- Ultracool dwarfs are very **rapid rotators:**
  - vsin(i) up to 60 km/s
  - P as low as 2 hr
  - $j = J/M \approx 10^{14} \ldots 10^{15}$ cgs ($j_\odot \approx 5 \times 10^{15}$ cgs)
  - Fastest rotators may be significantly flattened

Rotation and Activity

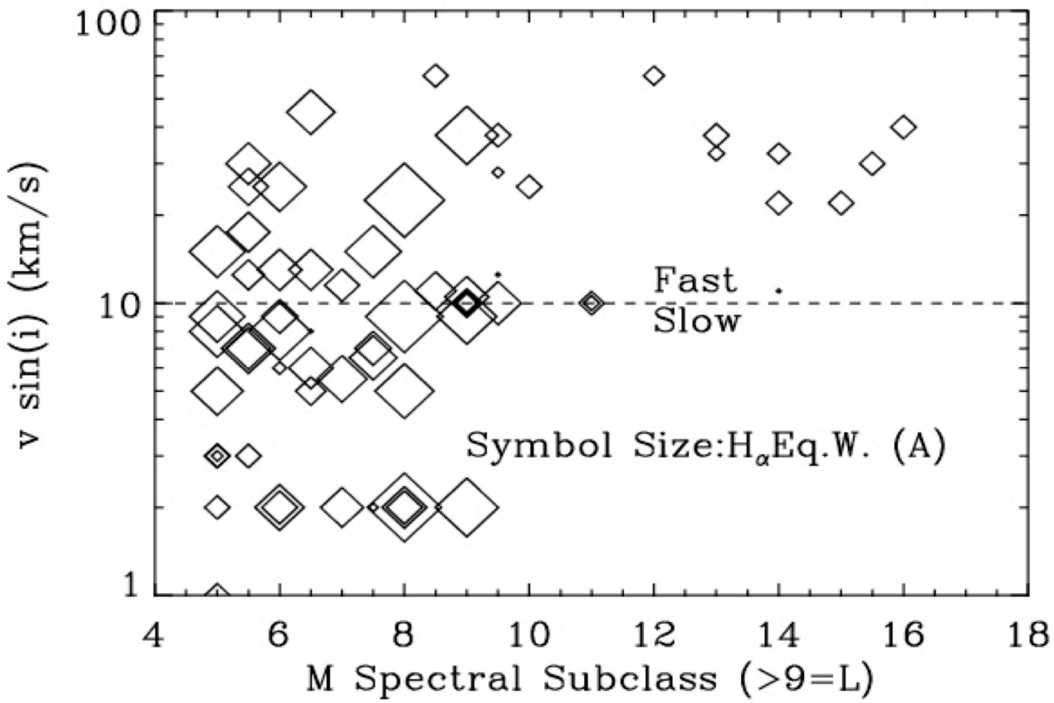


Noyes et al. (1984)

In stars, there is a correlation between rotation (specifically the Rossby number, the ratio of rotation and convection timescales) and chromospheric emission

Largely believed to be indicate **more effective dynamo generation with faster rotation**

Rotation and Activity

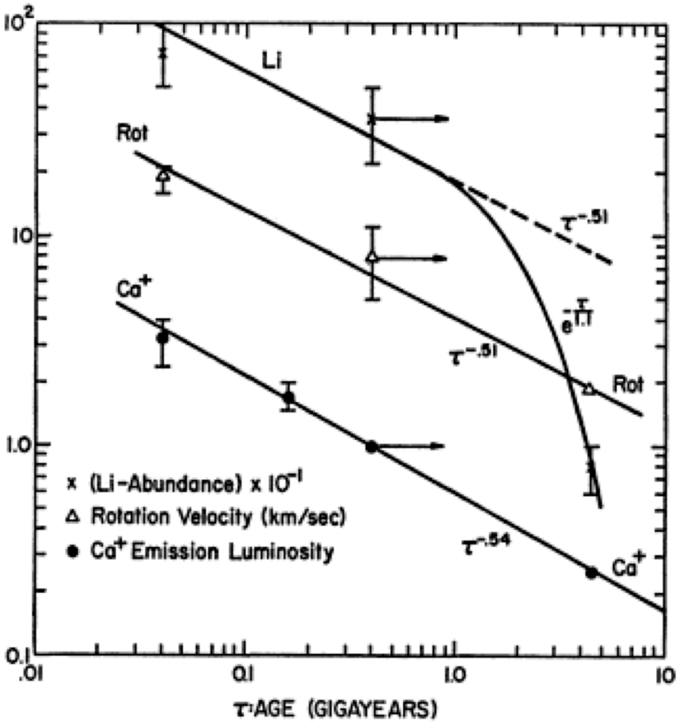


L dwarfs are all **rapid rotators without significant Hα emission**

No clear correlation between rotation and radio emission either

Basri (2000)

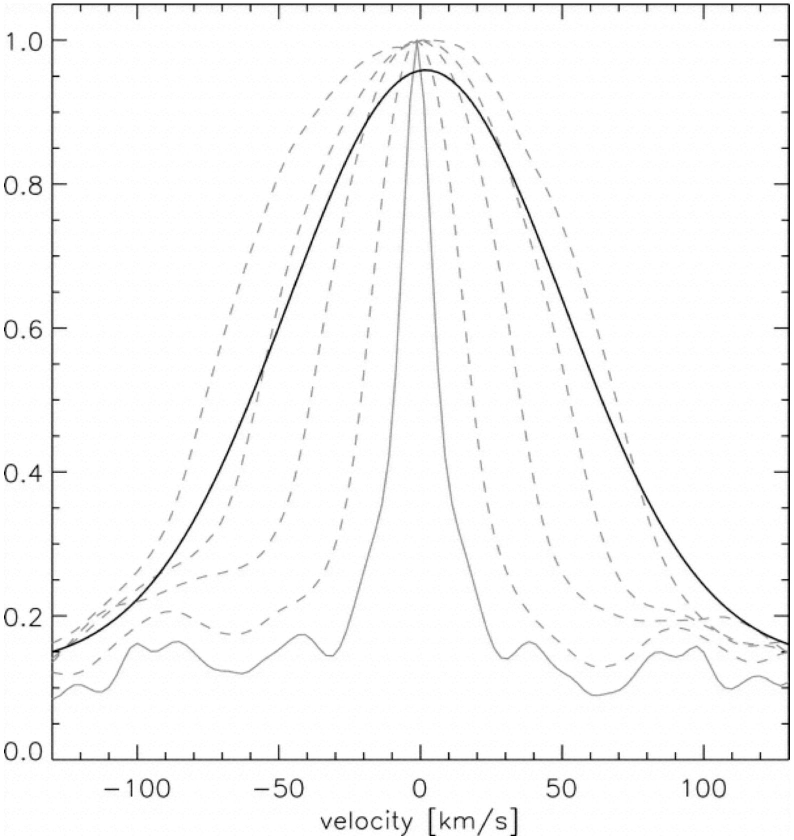
Rotation and Age



Skumanich (1972)
[2 pages, 556 citations!]

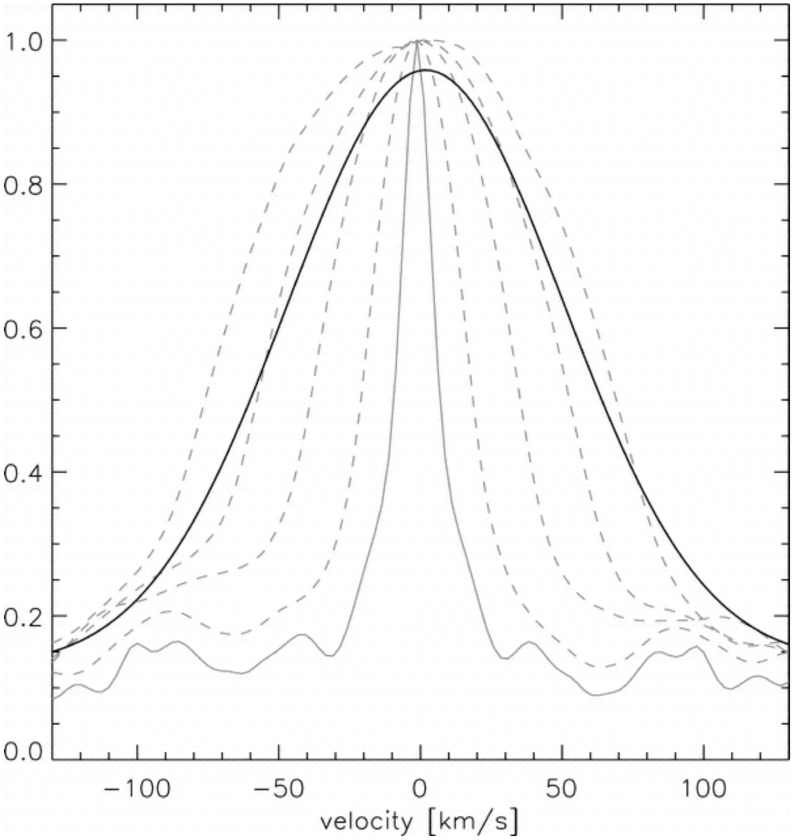
Stars appear to spin down over time - angular momentum loss largely from magnetized winds (e.g., coronal mass ejections)

Rotation of a Halo Brown Dwarf



Reiners & Basri (2006)

Rotation of a Halo Brown Dwarf

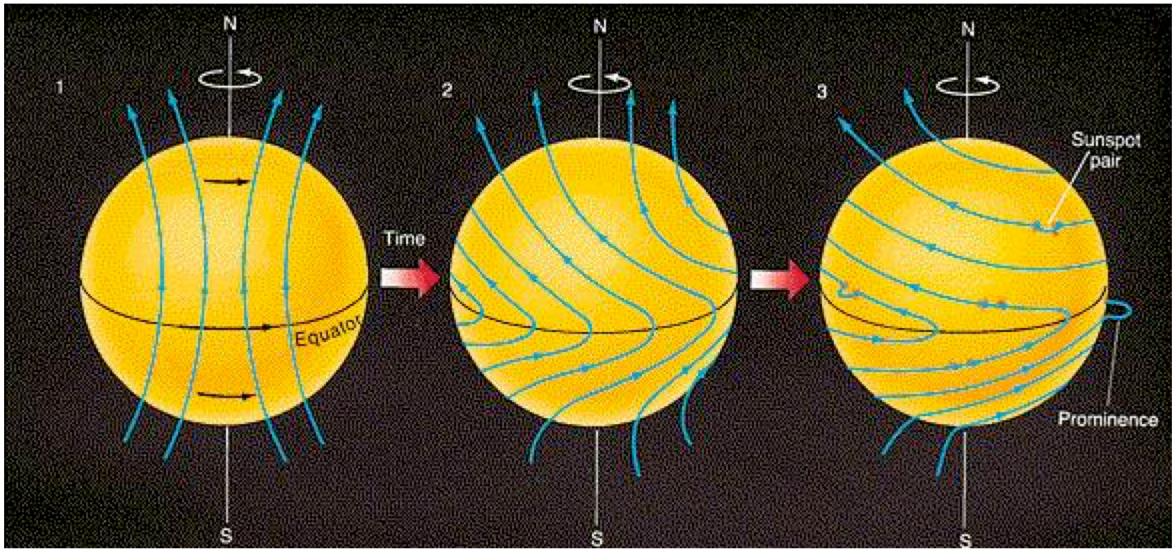


Reiners & Basri (2006)

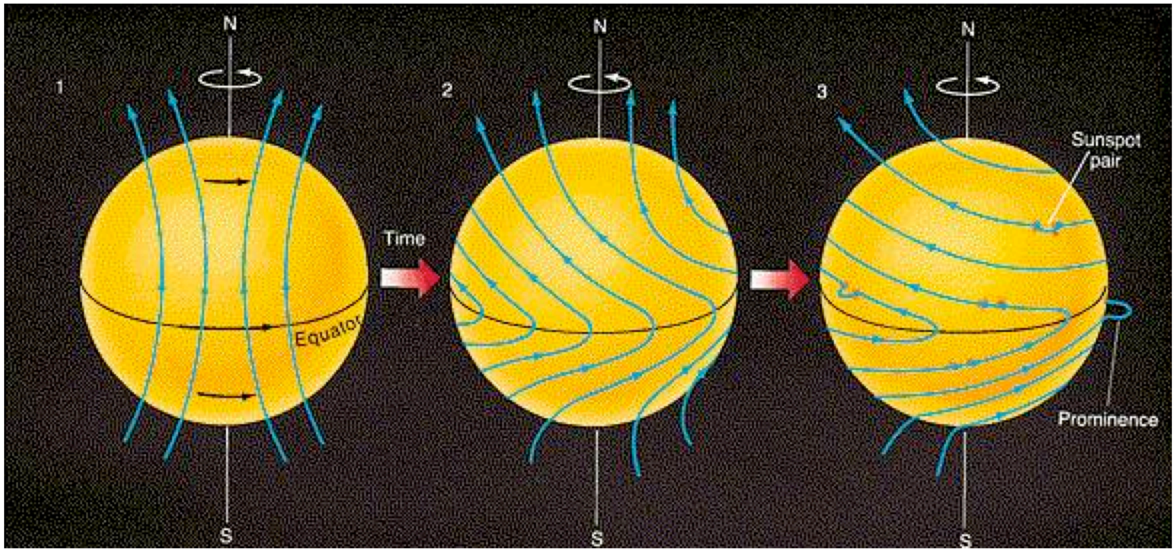
10 Gyr Halo L subdwarf **2MASS 0532+8246** has vsin(i) = 65±15 km/s

Is there no (significant) braking mechanism at play in (some) very low mass objects? Do L dwarfs never slow down?

How are these fields generated?



How are these fields generated?

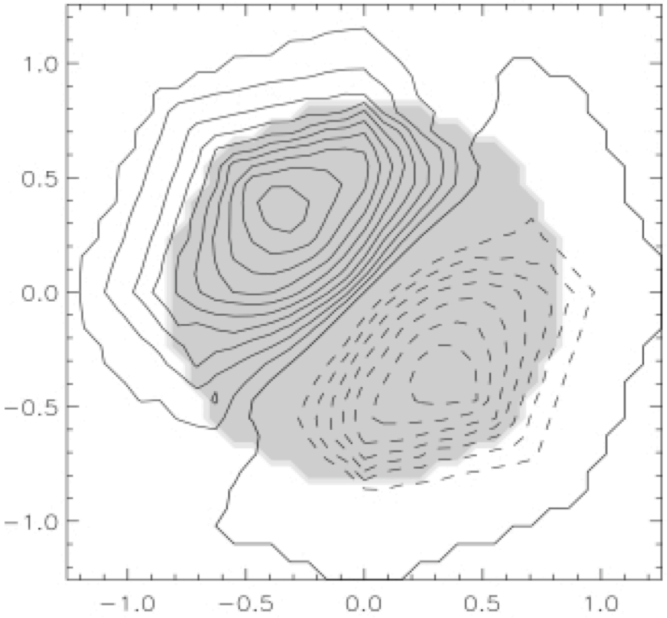


"Standard" model of field generation in stars is **αΩ dynamo** (Parker 1955) – requires convective/radiative boundary to anchor field (also Ω only shell dynamo - Babcock 1961)

Problem: Stars/BDs later than type M3 are fully convective ⇒ alternate dynamo mechanism required

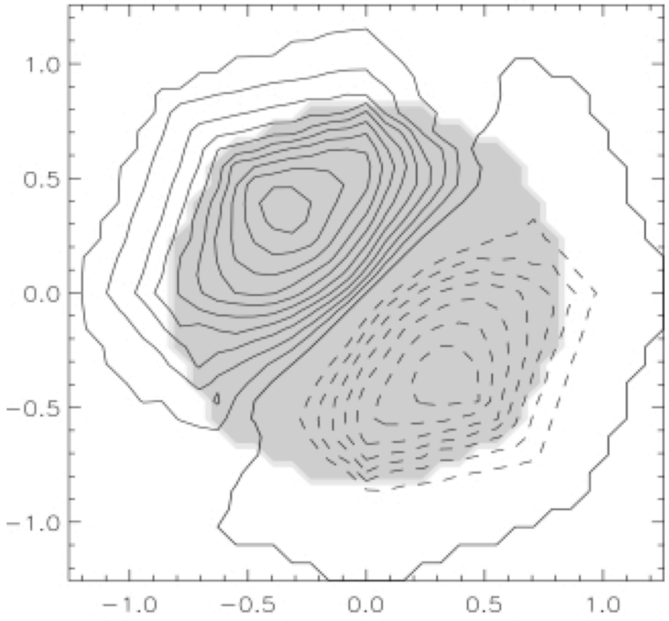
Activity relations, B field strengths over M2-M6 show no "kinks"

An Alternative α^2 Dynamo



Chabrier & Kuker (2005);
also Radler et al. (1990)

An Alternative α^2 Dynamo



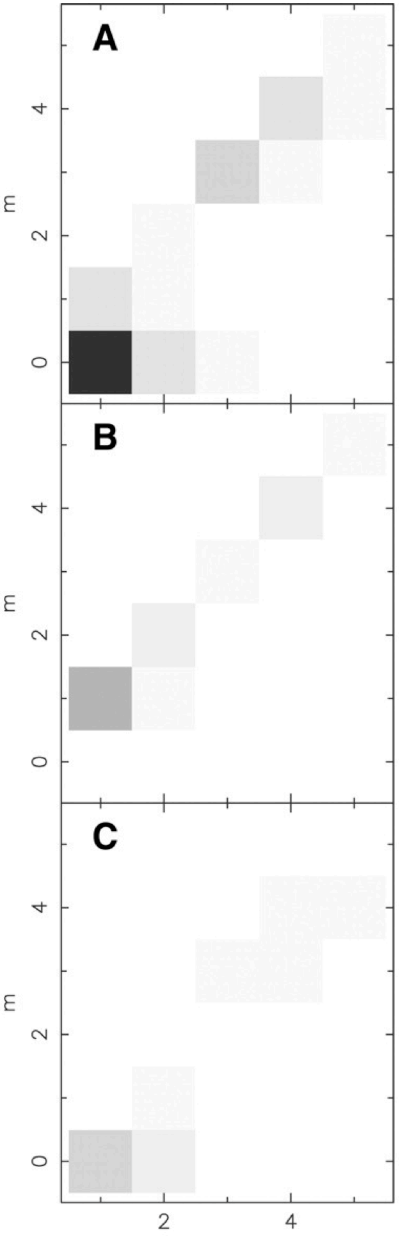
Chabrier & Kuker (2005); also Radler et al. (1990)

Dynamo action generated by Coriolis effects on convective flows.

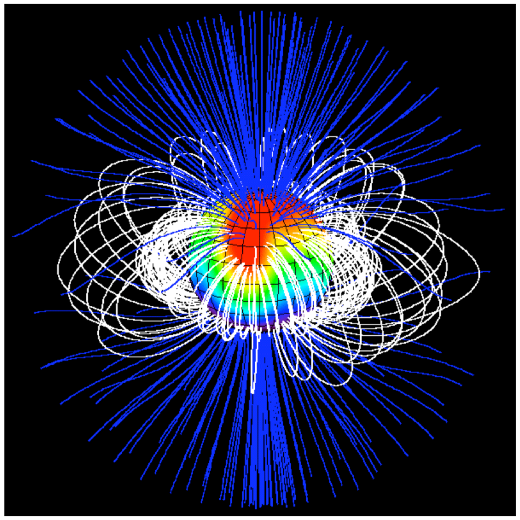
Produces large-scale, *non*-axisymmetric field (i.e., not a dipole)

Consequences:

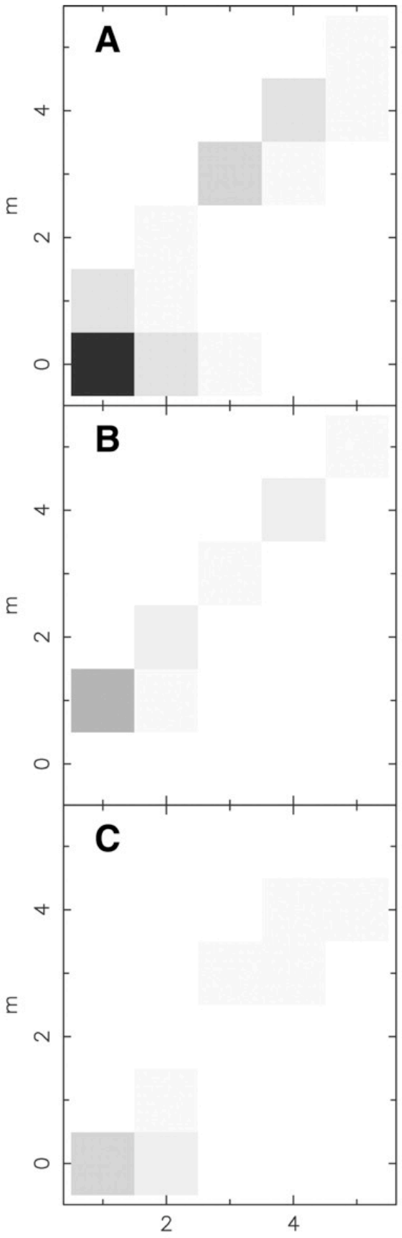
- Rotation dependent
- Weakened coupling to magnetic winds
- Works for fully convective stars



Do these models fit the observations?



**V374 Peg:
Donati et al. (2006);
Jardine & Donati**

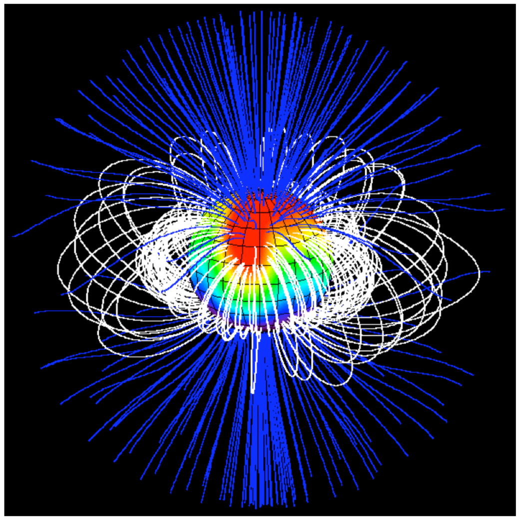


Do these models fit the observations?

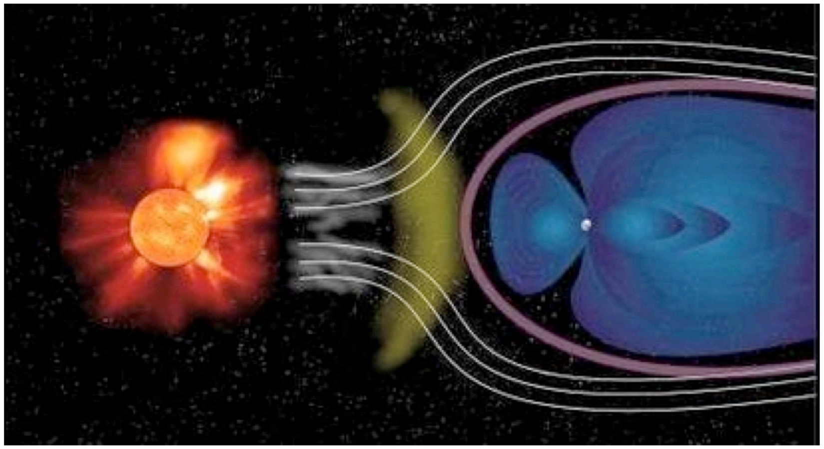
High resolution spectropolarimetry of fully convective star V374 Peg (M4) indicates a **global, axisymmetric** field.

Jupiter has a **global, axisymmetric** field.

V374 Peg:
Donati et al. (2006);
Jardine & Donati

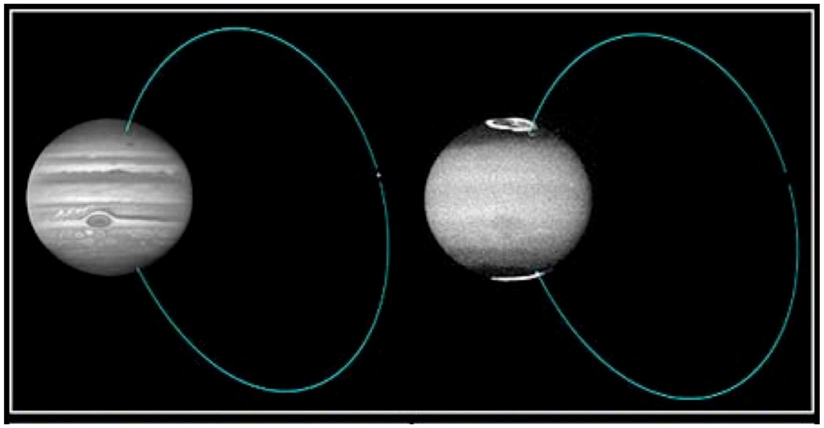


Magnetic Emission from Planets



Interaction with Solar wind

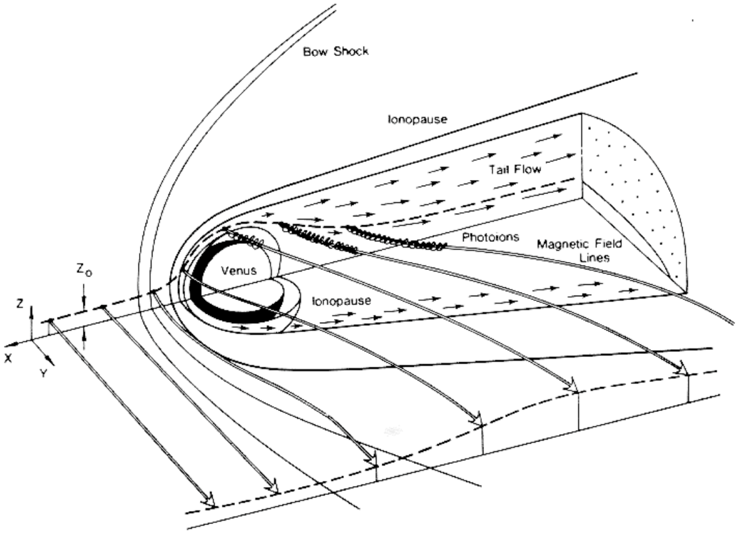
largely applies to planets with intrinsically strong magnetic fields (E,J,S,U,N)



Jupiter/Io-like interaction

magnetic disturbance induced by conductor (moon) passing through planet's magnetic field

Planetary interactions with Stellar winds

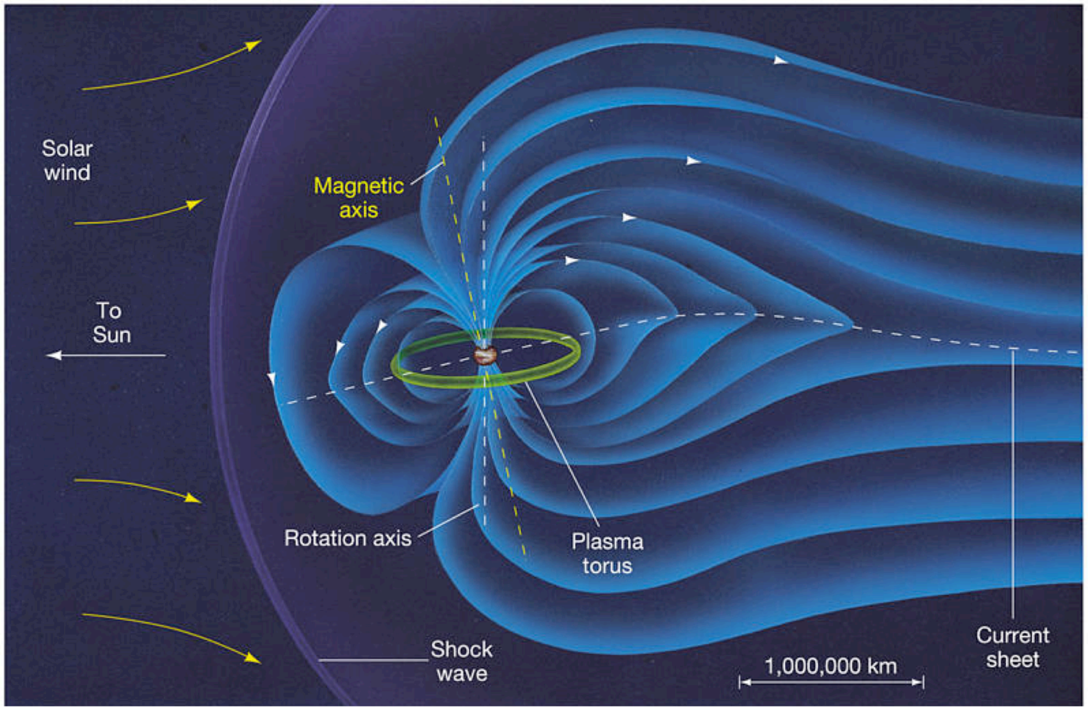


Magnetic shock around Venus
Russell & Vaisberg (1983)

Planets with magnetic fields largely deflect solar wind, charged particles are capture to form aurorae

Planets w/o magnetic fields highly conductive, will acquire a weak induced field, may have atmosphere stripped (e.g. Mercury, Mars)

Magnetosphere Structure



Jupiter:

Largest structure in solar system (50-100 $R_{jupiter}$)

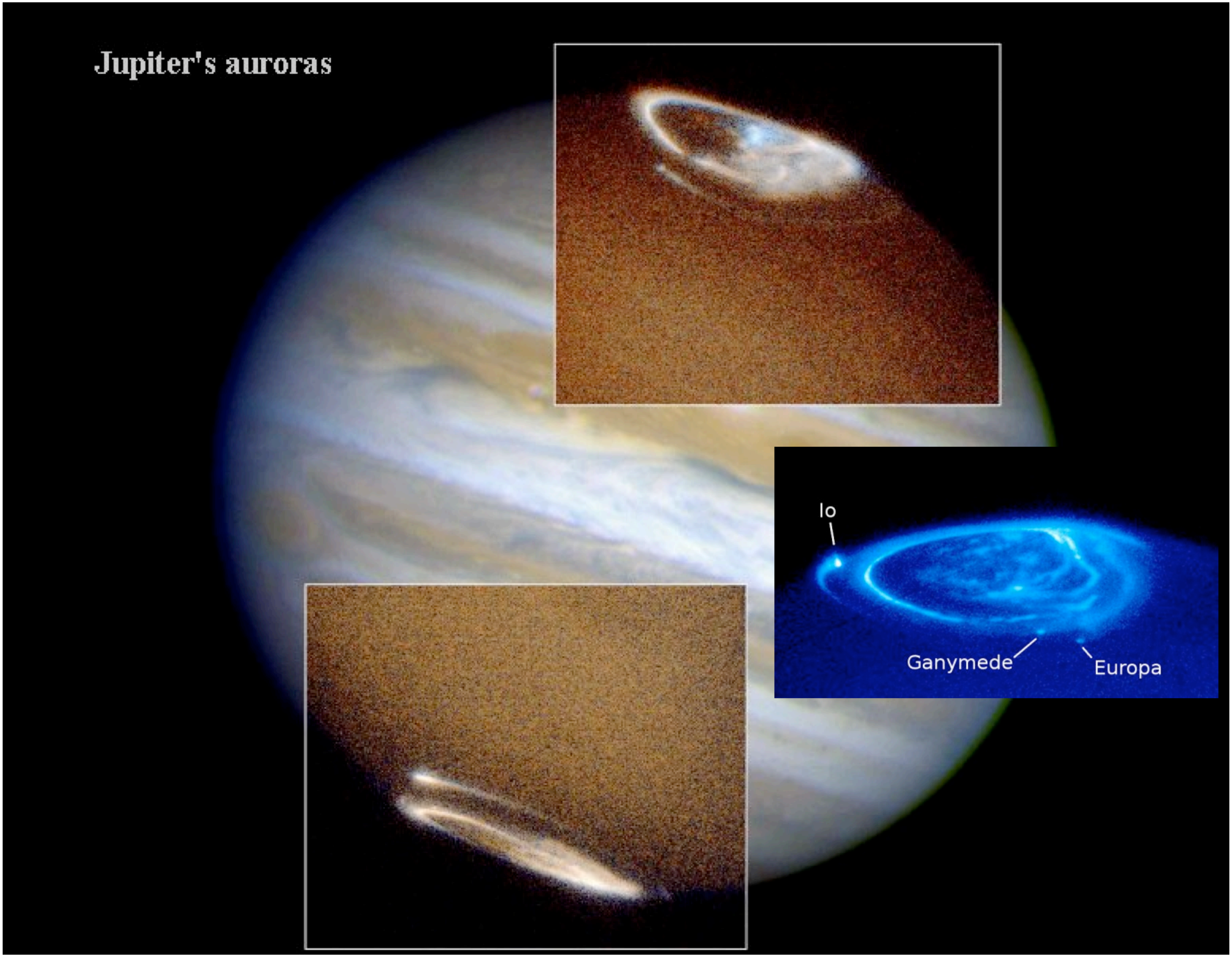
Surface field: ~5-15 G

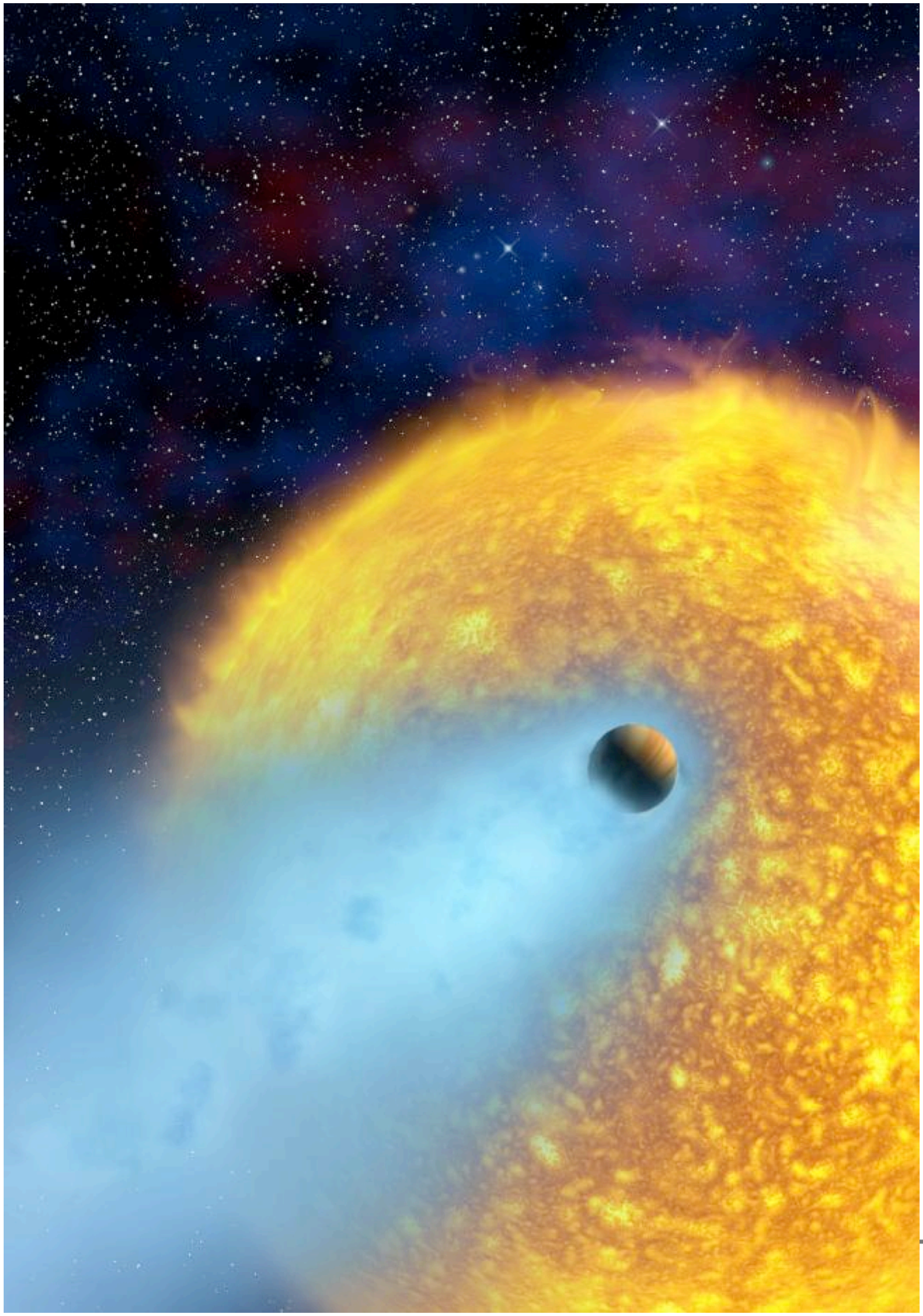
Relative inclination: 9.6°

Co-discoverer - Bernie Burke (1959)!

B fields of Saturn, Uranus and Neptune are ~ 10x weaker

Jupiter's auroras





Exoplanet B field measurements?

HD 209458b:

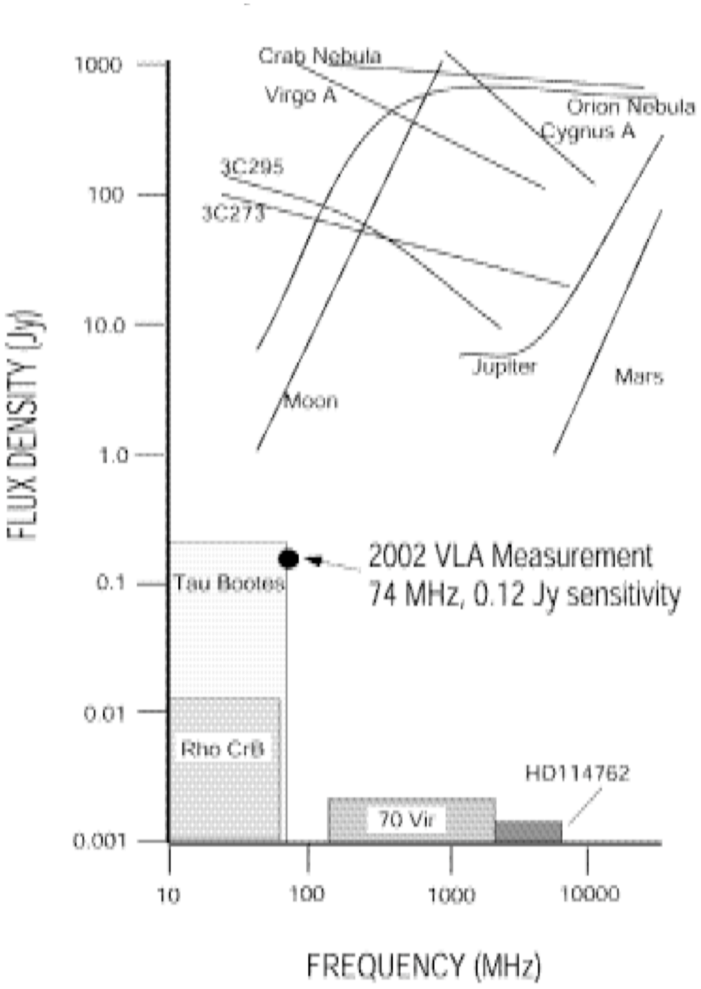
Hot plasma is ejected from planet (Vidal-Madjar et al. 2003, 2004)

G0 V primary: possibly as magnetically active as the Sun

Higher incident solar wind power is 10^4 times strong than Jupiter

Could this be detected?

No luck yet



Farrell et al. (2003)

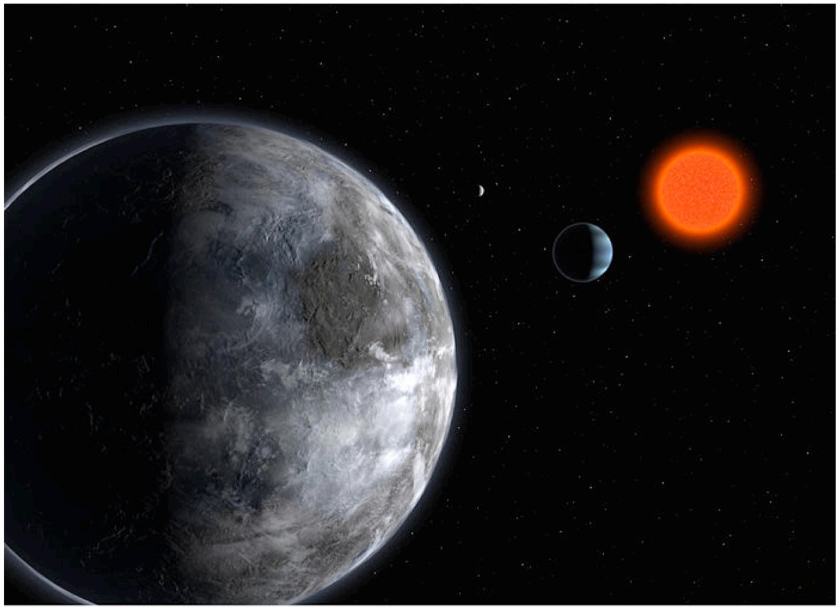
Magnetic fields of tidally locked planets may be weak (~1 G; Sánchez-Lavega 2004)

May be possible with SKA

Best candidates: τ Bootes, Gliese 86, υ Andromeda, HD 1237 and HD 179949 (Stevens 2005)

Other magnetic interactions may be present (e.g. Puesse et al. 2006)

Habitability



Artist's impression of the Gliese 581 system (ESO)
Primary is an M3 dwarf at 6.3 pc

Fact: M dwarfs are the most common stars in the Galaxy

Fact: The habitable zones of M dwarfs are < 0.1 AU

Fact: M dwarfs are the most frequently and persistently magnetically active stars

How does magnetic activity impact the genesis and evolution of life in the Galaxy?