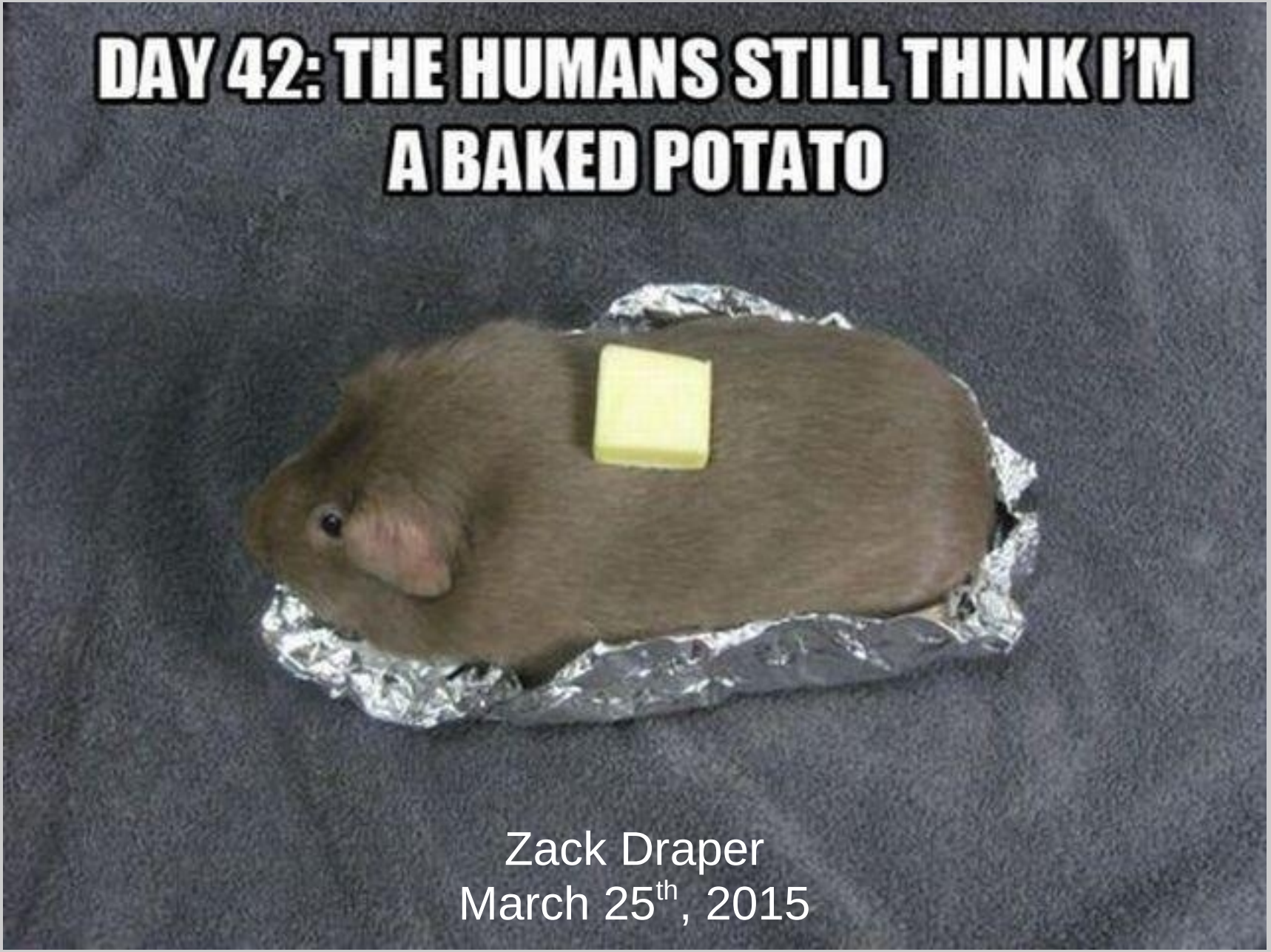
# Chemically Peculiar Stars




Zack Draper
March 25th, 2015

# Outline

- What are the CP stars?
- Why do CP stars exist?
- Mechanisms
  - Atomic Diffusion (*/adt.pdf)
    - Re-derivation of Chapter 7.
  - Magnetic Fields
  - Accretion
- Class-by-class
- Find slides at */cp_slides.pdf

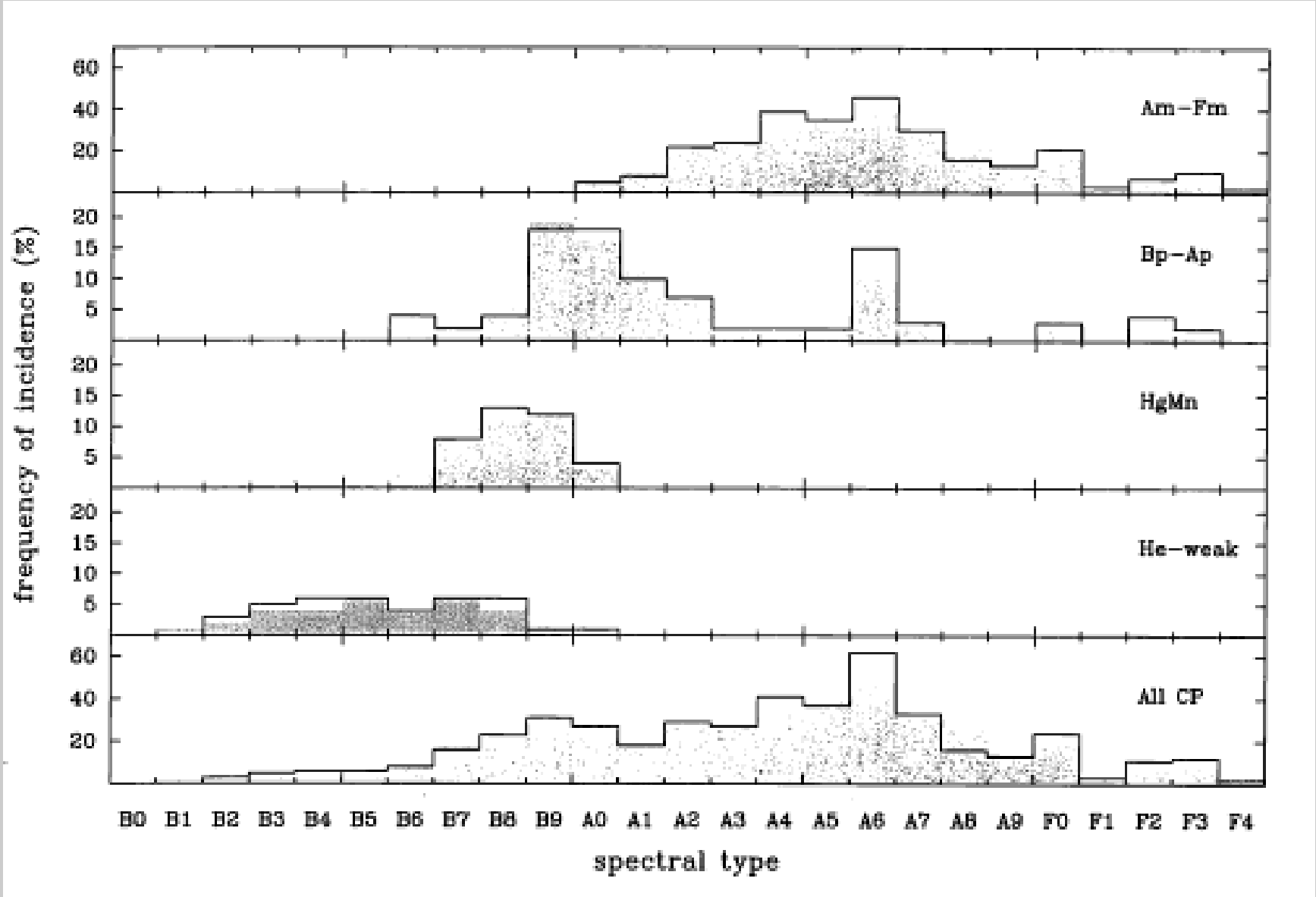
* http://www.astro.uvic.ca/~zhd/teaching

# CP Stars

| Class | Criteria | Spectral Type |
|---|---|---|
| Am-Fm | Weak CaII & ScII, enhanced metals | A0-F4 |
| Ap-Bp | Enhanced Sr, Cr, Eu, Si | B6-F4 |
| HgMn | Enhanced HgII & MnII | B6-A0 |
| λ Boo | Weak Mg, Fe, Ca, etc. | A0-F3 |
| He-weak | Weak HeI | B2-B8 |
| He-rich | Enhanced HeI | B2 |

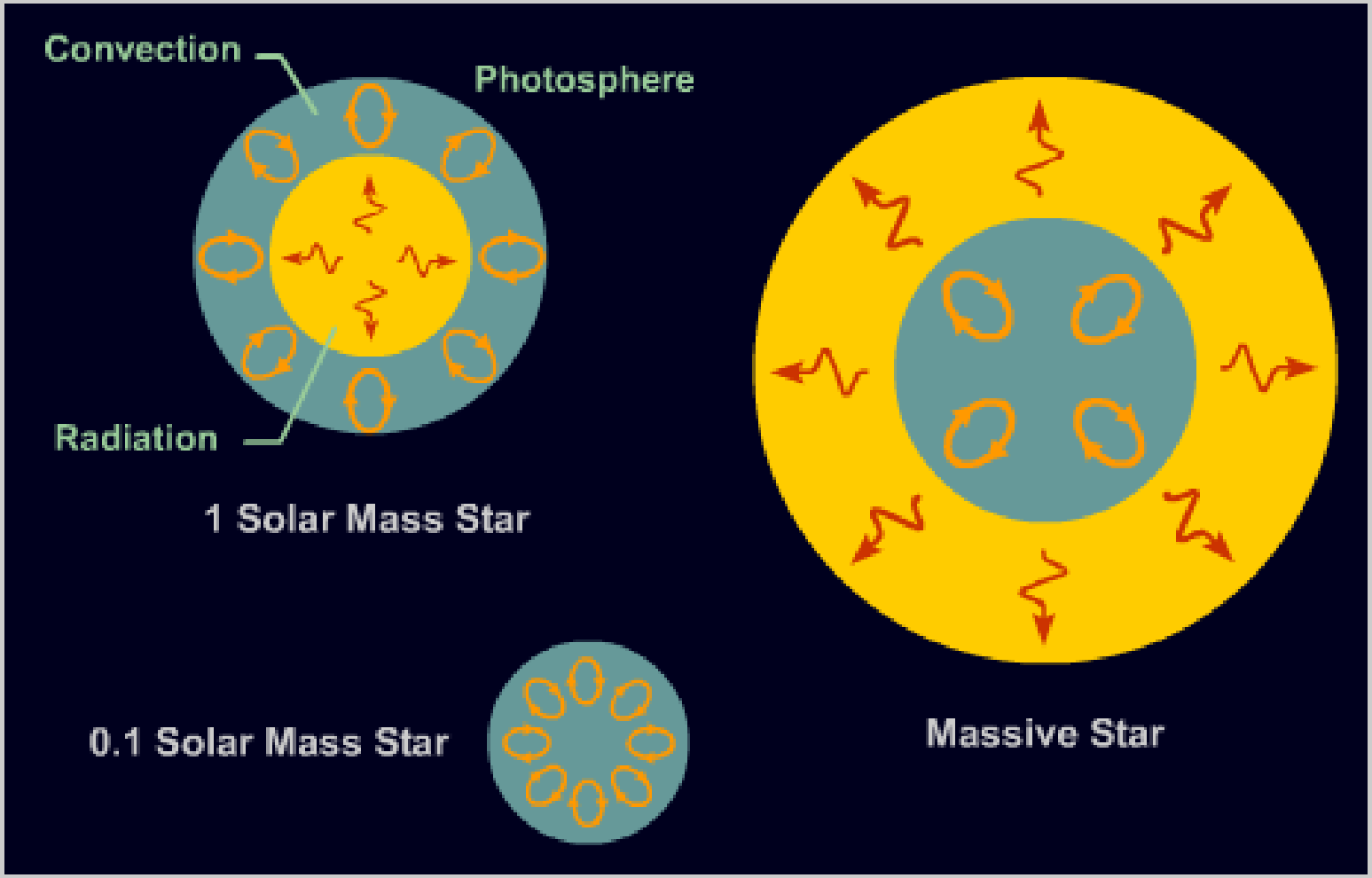
**Smith, K.C 1996**

# CP Stars




Smith, K.C 1996

# Convection




Radiative envelope dominates the surface with a lower bound of 1.15 $M_\odot$ (**Meynet 2008**)

# 2nd Order Effects

- Atomic...
  - charge
  - mass
  - opacity
- Radiation pressure
- Magnetic fields
- Accretion
- Stellar rotation

→ Atomic Diffusion

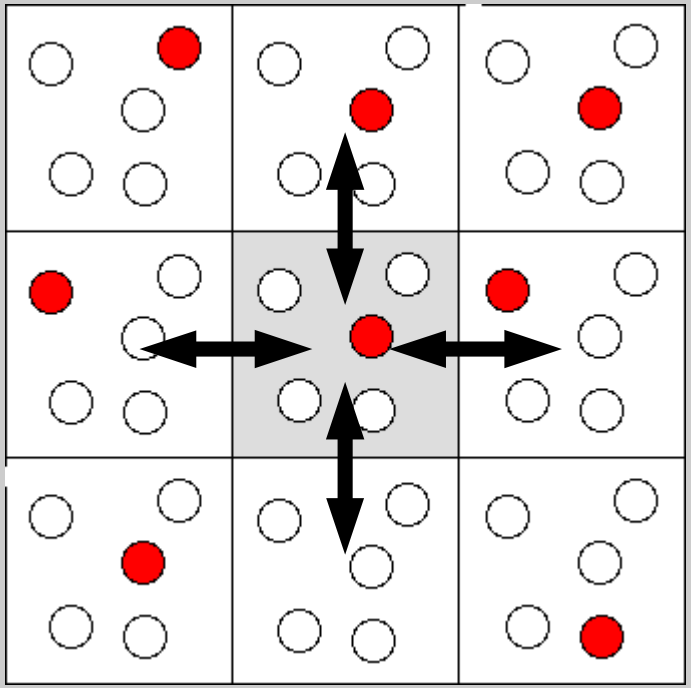
→ Mass-loss, stellar wind

→ Levitation and suppression with direction.

→ Exostellar environment

→ Meridional circulation

# Atomic Diffusion Theory



1) Imagine a box with particles in a sea of other particles inside a star ( z = metal and x = hydrogen)

$$F = n V$$

Number density of particles times a “diffusion” velocity gives particle flux in/out of box

2) Impose hydrostatic equilibrium; gas pressure = a constant for a small box.

$$P = 0; F_z = -F_x$$

3) Use mean free path to derive diffusion with respect to mean velocities of particles. Spherical symmetry allows one to take the radial component of interest.

# Atomic Diffusion Theory

Flux of species z:

$$F_z = n_z V_z = (n_z^+ - n_z^-)V_z = -\frac{1}{3} V_z \ell_z \frac{dn_z}{dr}$$

Mean velocity:

$$\bar{V} = \frac{n_z V_z + n_x V_x}{n_z + n_x}$$

Diffusion of species z:

$$F_z - \bar{F} = n_z V_z - n_z \bar{V} = n_z V_{z,diff}$$

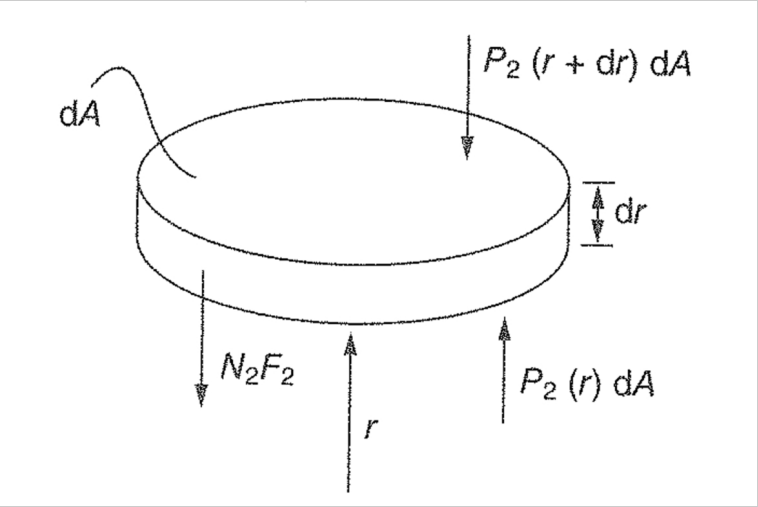
Diffusion velocity of species z:

$$V_{z,diff} = -\frac{D_{zx}}{n_z} \frac{dn_z}{dr}$$

Diffusion coefficient:

$$D_{zx} = \frac{1}{3(n_z + n_x)} (n_x V_z \ell_z + n_z V_x \ell_x)$$

# Atomic Diffusion Theory




Assume equilibrium; sum of all forces = zero

pressure gradient * area = - N particles * force per particle

[P(r+dr)-P(r)] dA = N F

$$\frac{1}{n}\frac{dn}{dr} = -\frac{F}{kT}$$

$$V_{z,diff} = -D_{zx}\left(\frac{1}{n}\frac{dn}{dr} + \frac{F_z}{kT}\right)$$

$$F_z = ?$$

# Atomic Diffusion Theory

| Physics | Relative force |
| --- | --- |
| Gravity: | $F_z = m_z g - m_p g$ |
| Radiation: | $F_z = m_z(g - g^z_{rad}) - m_p g = A m_p (g - g^z_{rad}) - m_p g$ <br> $F_z = ((A-1)g - A g^z_{rad}) m_p$ |
| Electric field: | $-m_p g + eE = -m_e g - eE$ <br> $F_z = -(Z-1)\frac{m_p g}{2e}$ |

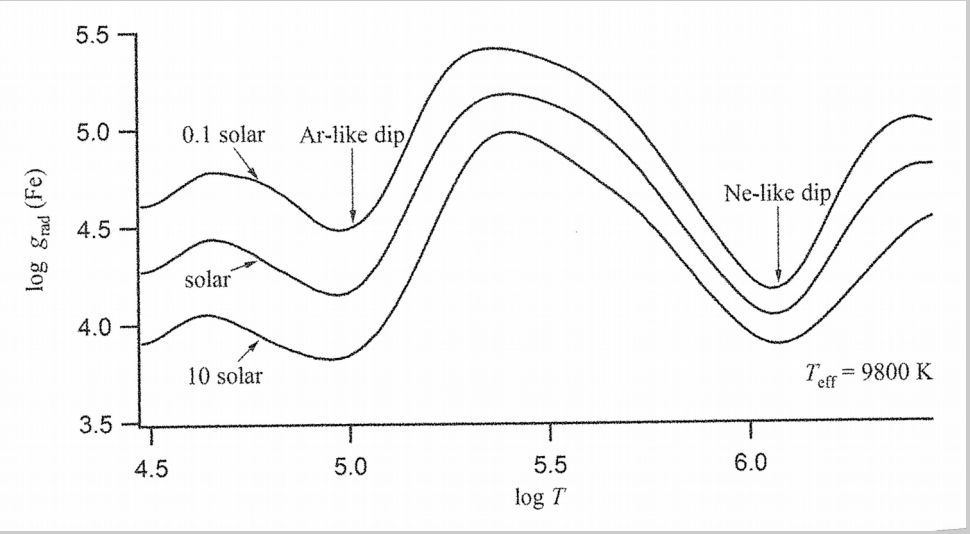
# Atomic Diffusion Theory

$$V_{z,diff} = -D_{zx}\left(\frac{1}{n}\frac{dn}{dr} + \frac{m_p}{kT}\left((g - g^z_{rad})A - (Z-1)\frac{g}{2e}\right)\right)$$

Diffusion of species (x) interacting with a bulk hydrogen gas (x) in a spherically symmetric hydrodynamic equilibrium inside a star.

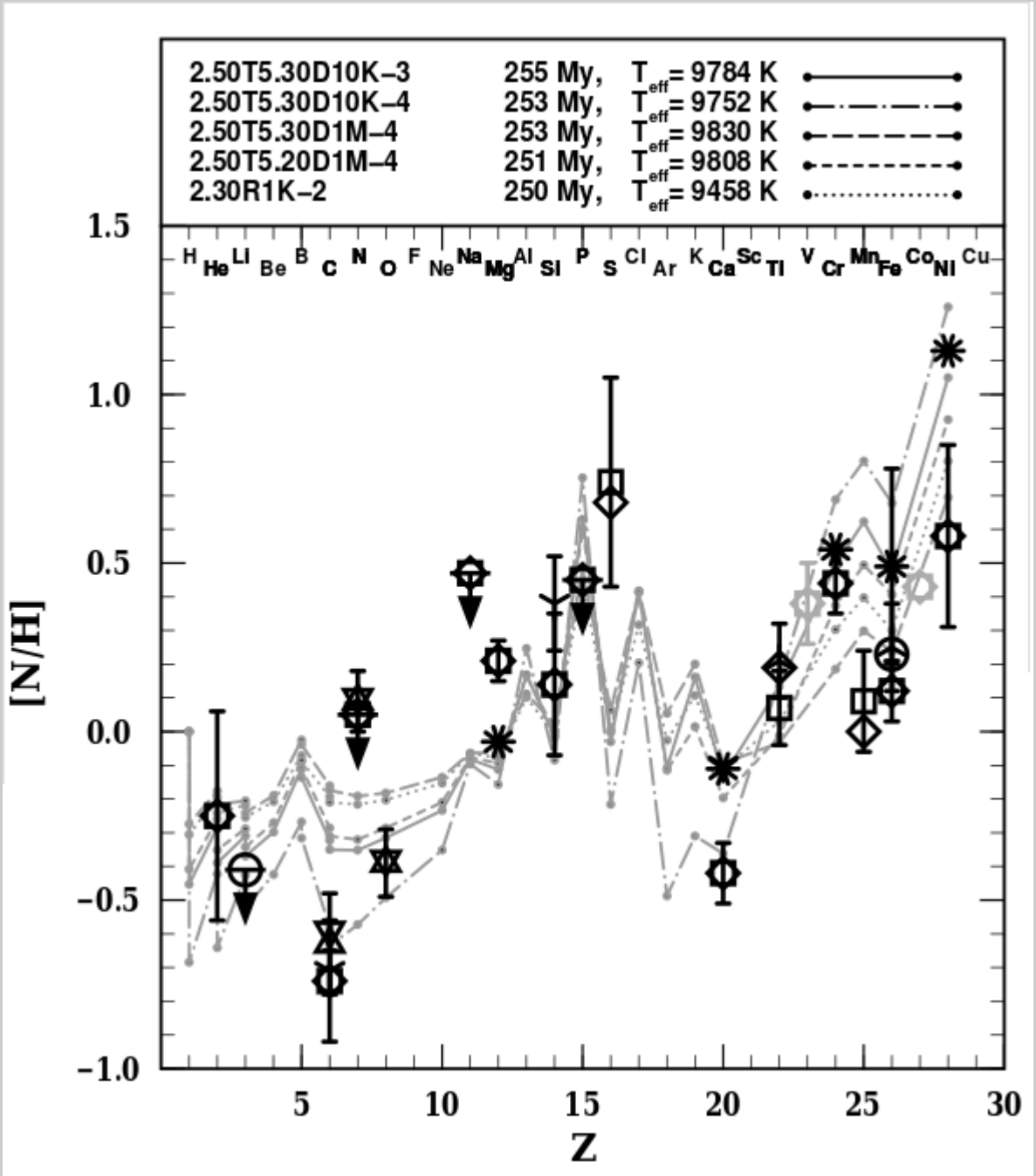
Free parameters:

- A = atomic number
- Z = charge number
- $g_{rad}$ = radiative acceleration
- g = gravitational acceleration
- n = number density of species



# Am-Fm Stars

**Sirius**




**Ca is under abundant, but iron peak metals are over abundant?**

Ca II is “argon-like” so radiative acceleration term drops.

Fe-peak still have radiation pressure propelling to surface.

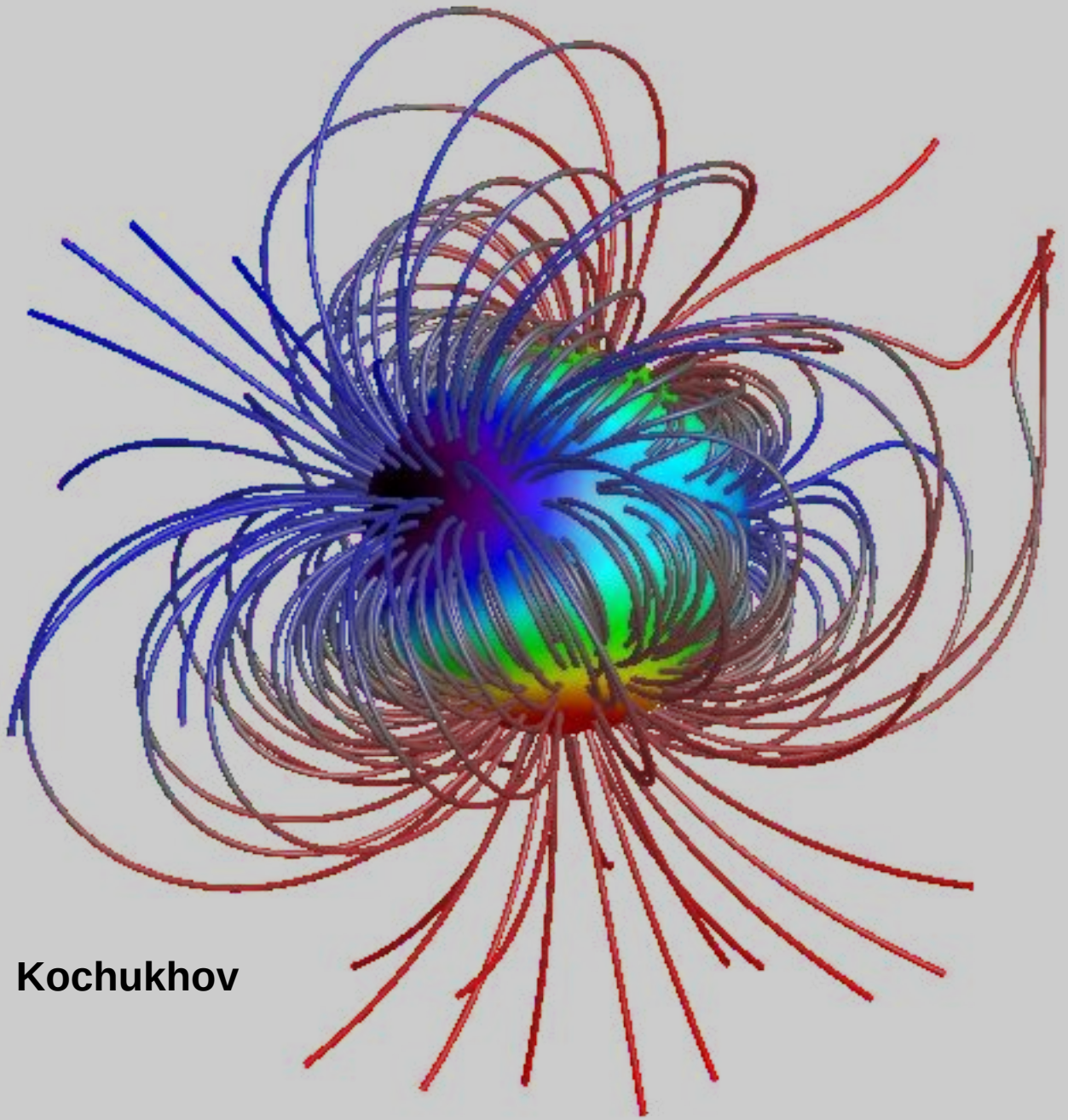
Fe-peak convection zones and mass-loss compete to bring surface abundances down.

No δ Scutti pulsations with no He convection.

Rotational velocity cutoff (< 90 km/s); high binary fraction

**Richer, Michaud, Turcotte 2000**

# Ap-Bp



**Kochukhov**

But wait there's more: magnetic fields!

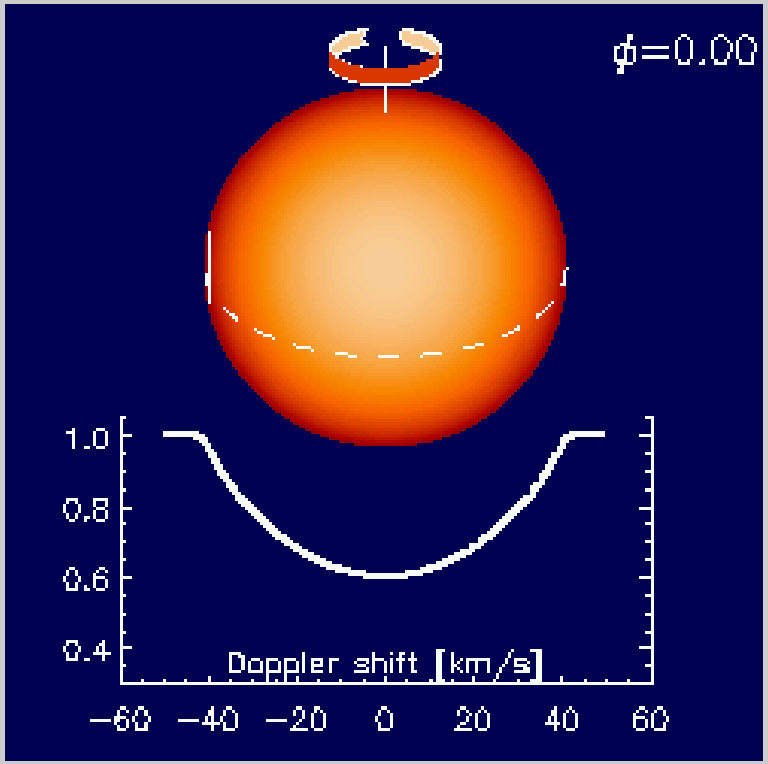
Field enforces rigidity and allows for atomic diffusion to occur

Dipole magnetic fields likely from a “fossil” origin; rotation might break up field in Be stars

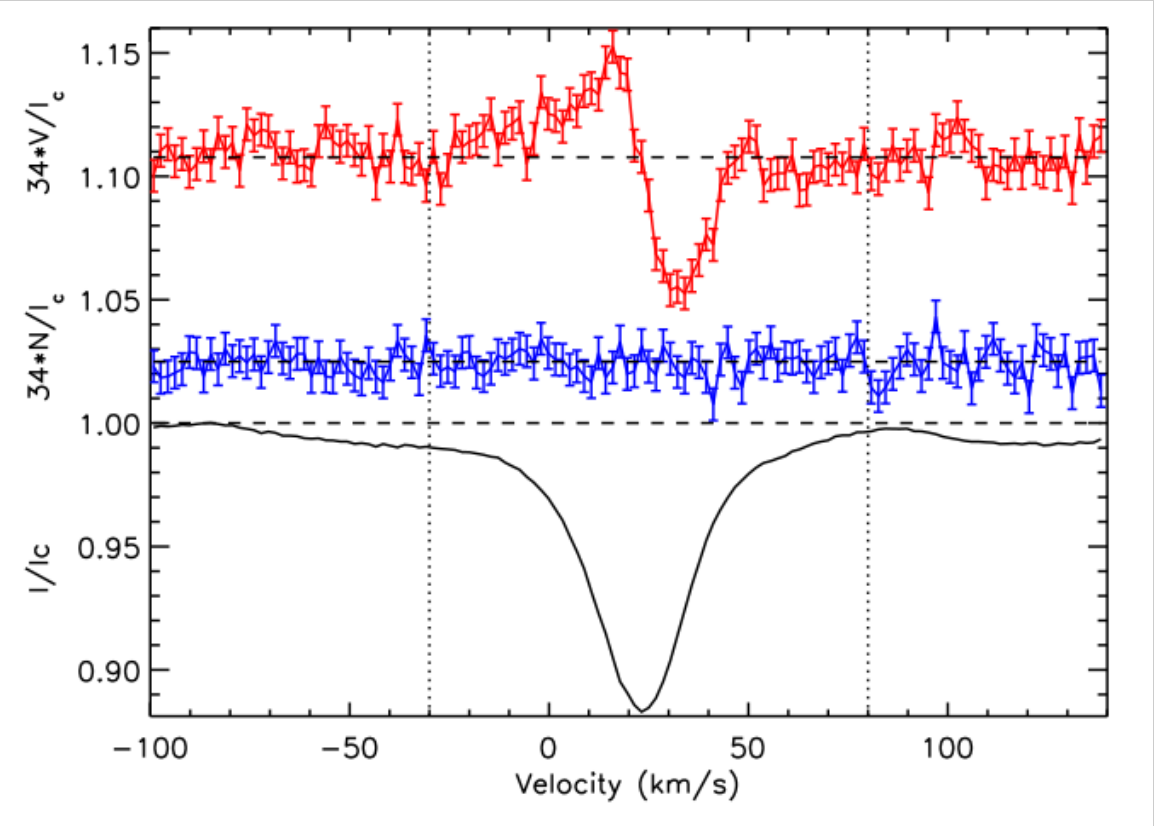
**Michaud 1970, Niener 2014**

# Magnetic Field Observations

**Dopper Imaging (Tomogrophy)**




**Kochukhov**



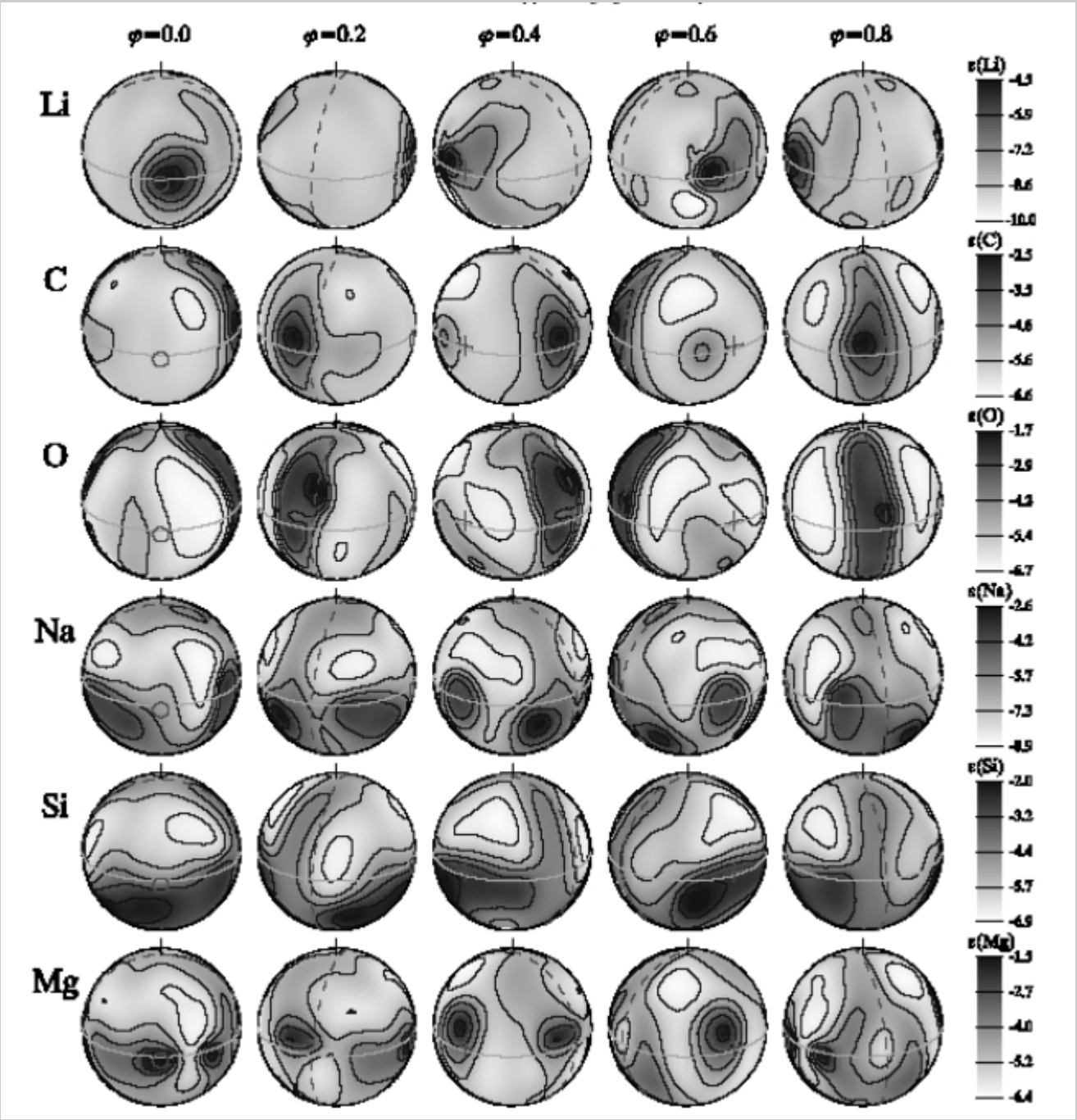

**Spectropolarimetry with ESPaDOnS @ CFHT**

**Reaches 37 G**

**Wade 2010**

# Surface Variations

**Ap star**
**HR 3831**




**Kochukhov**
**2004**

# HgMn Stars

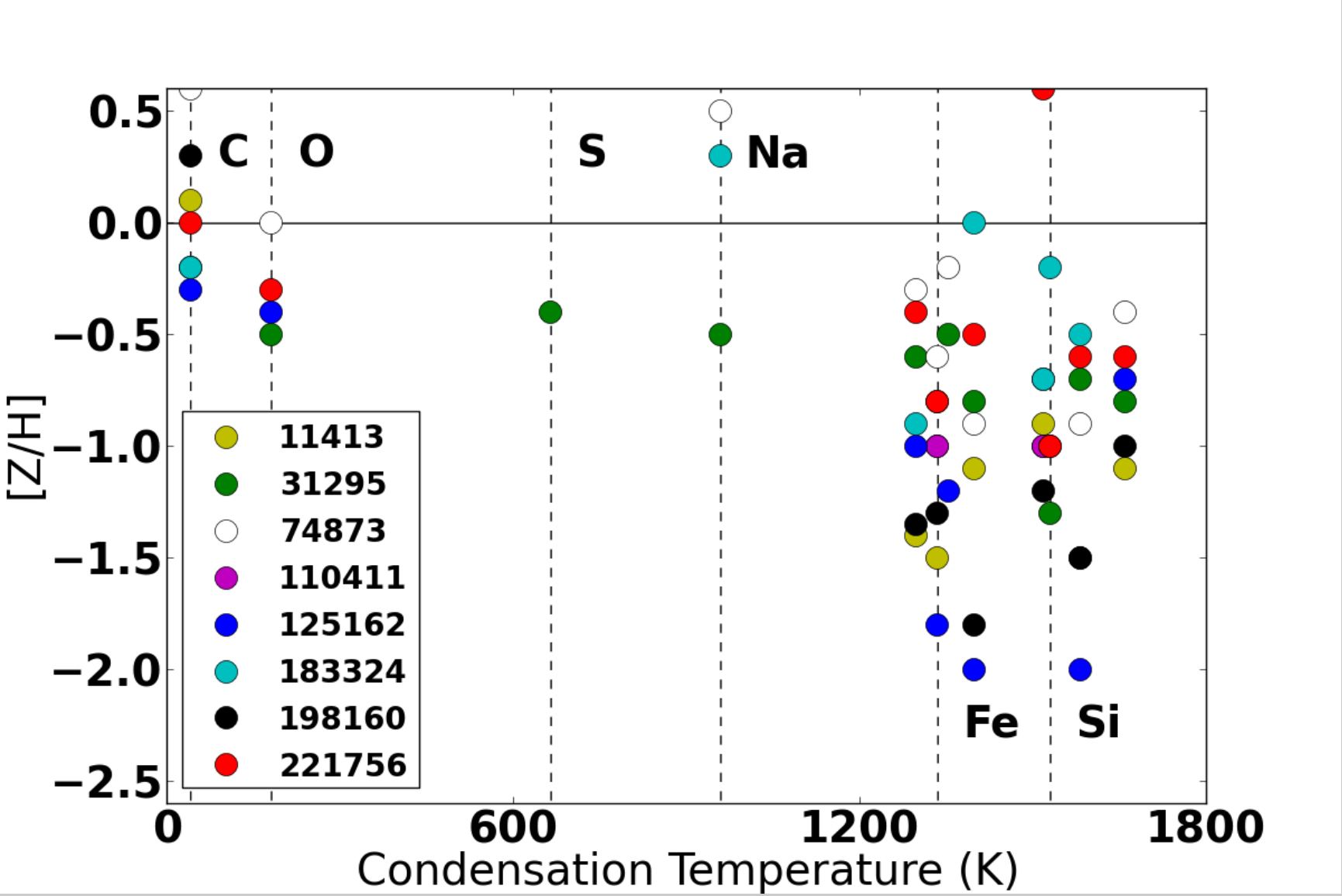
- B type; 10,000-14,000 K
- Hg overabundant by 6 dex! Particularly $^{204}$Hg (heaviest and rare)
- Mn overabundant by 3 dex!
- Slow rotators (vsin(i) < 29 km/s)
- 2/3 are spectroscopic binaries
- Underabundant He, Al, Zn, Ni, and Co
- “Splotchy” abundances, but **weak** magnetic fields...
- Variations from atomic diffusion model are uncertain

**Hubrig 2012, Castelli 2004, Smith 1996**

# λ Boo stars

- A0-F3; 9500-6500 K
- C, N, O and S are solar abundant where as metals are underabundant.
- Moderate rotators (~ 120 km/s)
  - Meridional circulation induced
  - Diffusion theory fails unless stellar wind extremely high
- No magnetic field detections (λ Boo, ρ Vir)
- External Accretion? (ISM or Debris Disk)

# λ Boo stars

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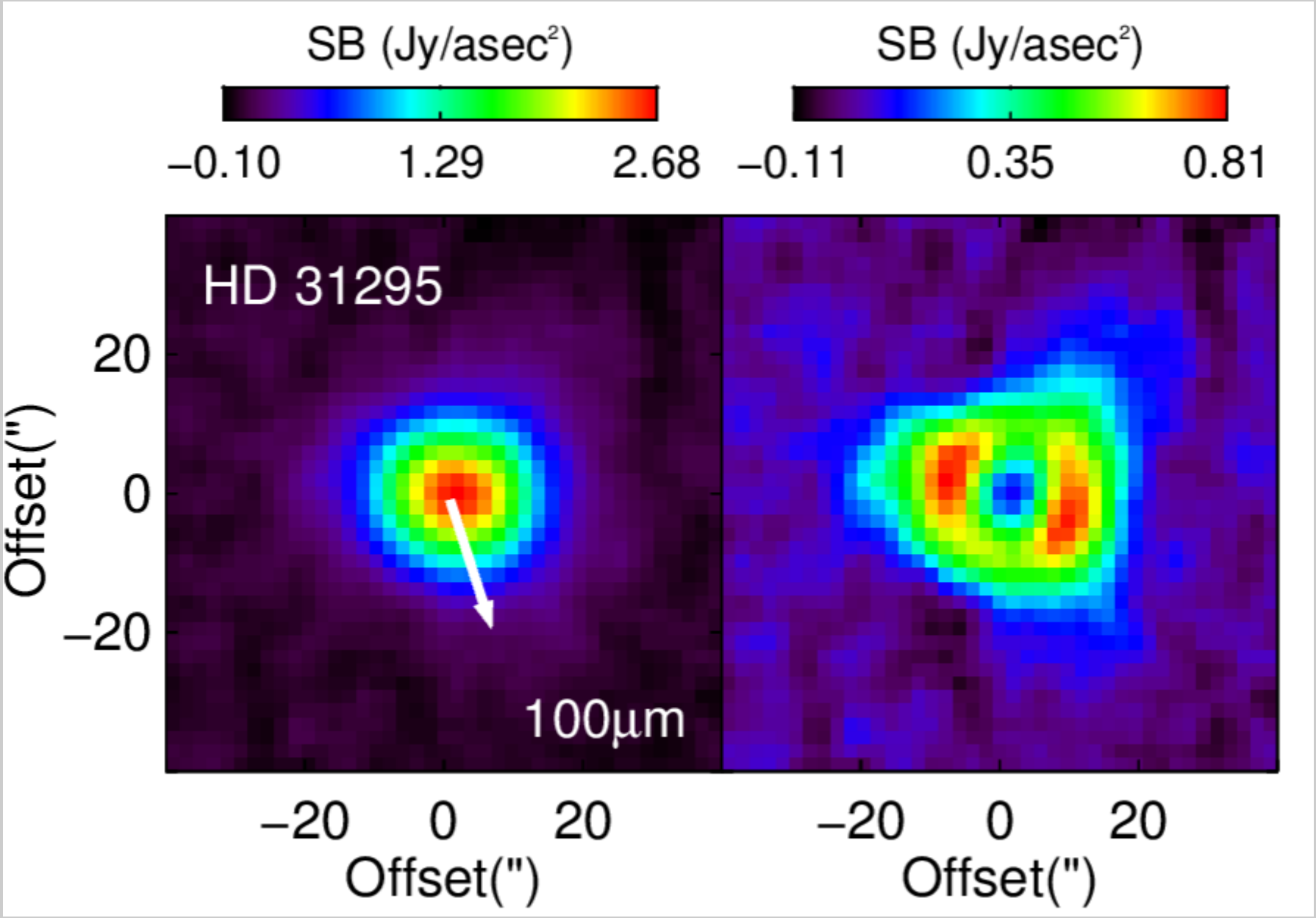
# λ Boo stars

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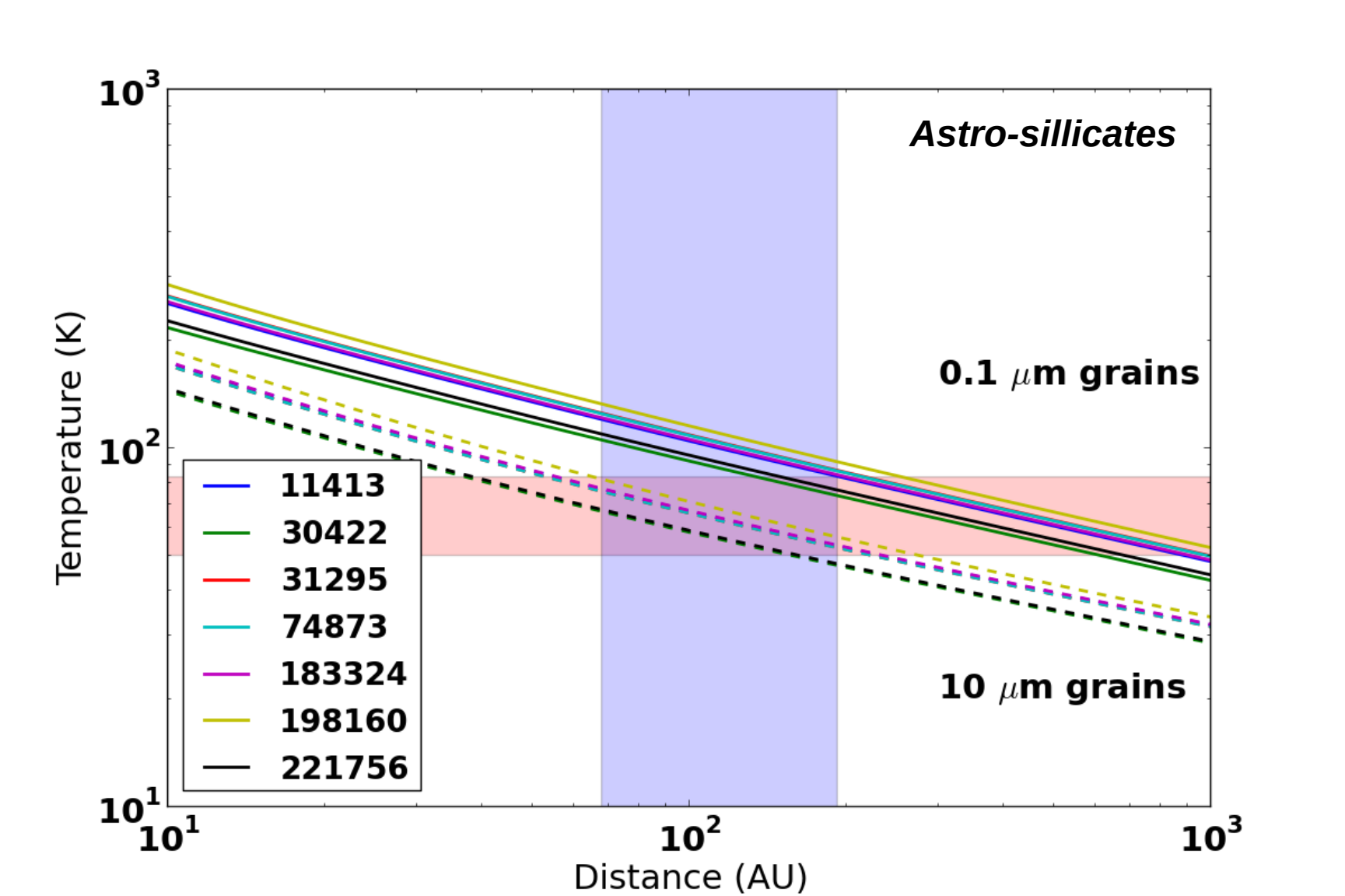
# λ Boo stars

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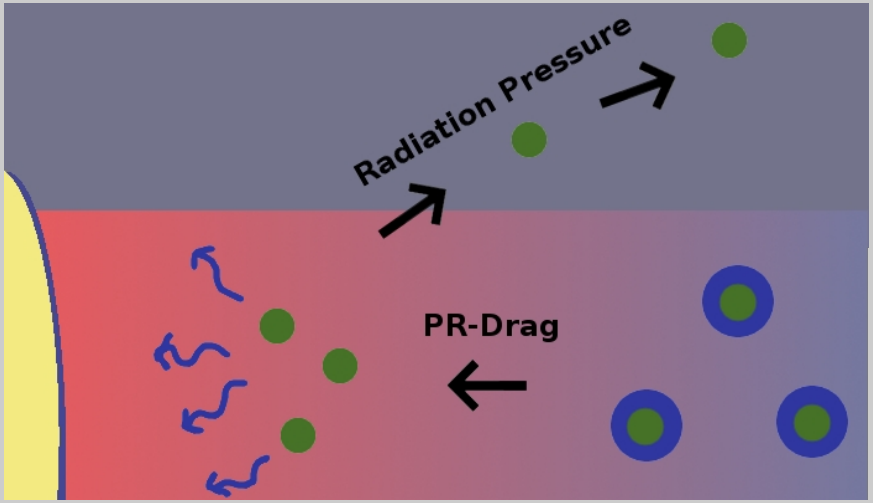
# Accretion Mechanisms

- Poynting–Robertson Drag
  - $10^{-12}$ $M_{\oplus}$/yr
  - Take about 33 Gyrs...




- Planetary Migration
  - $10^{-9}$ $M_{\oplus}$/yr
  - Within main sequence lifetime!

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**Questions?**