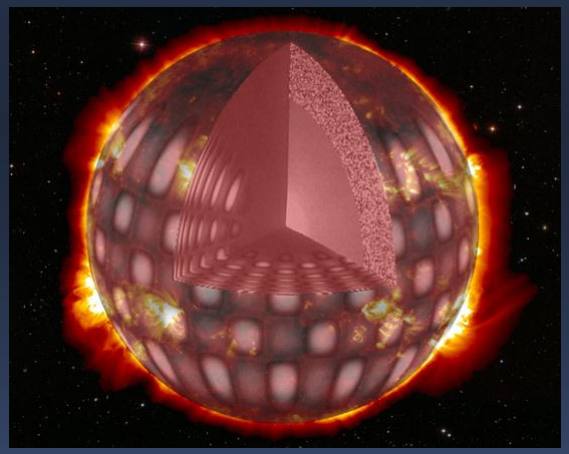
KU LEUVEN

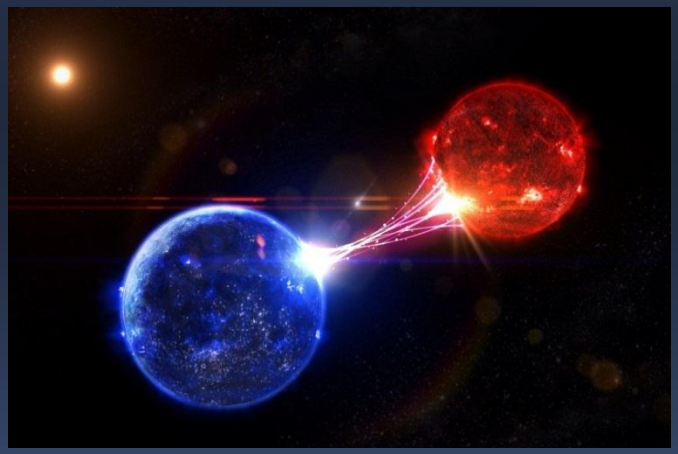
Dynamic Asteroseismology:
towards improving the theories of stellar structure and (tidal) evolution

~~Andrew Tkachenko~~ Andrew

Easier for you
Still fine with me!!!

Institute of Astronomy, KU Leuven



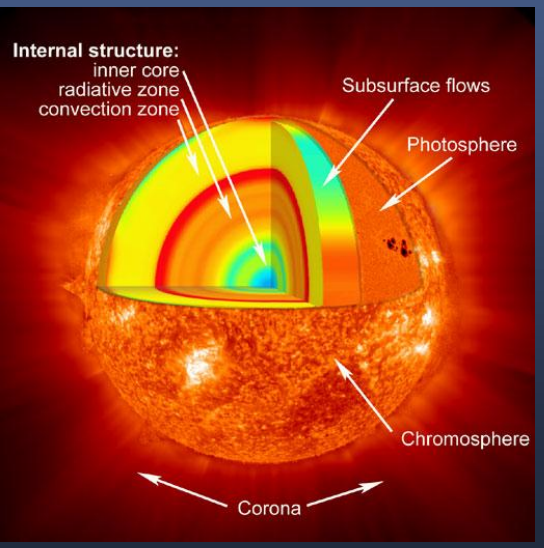


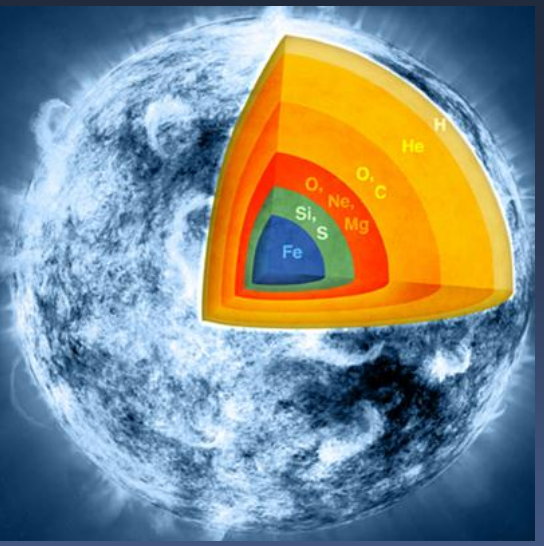
$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3} \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}$$

$$P^2 = \frac{4\pi^2}{G(m_1+m_2)} a^3$$

Dynamic Asteroseismology





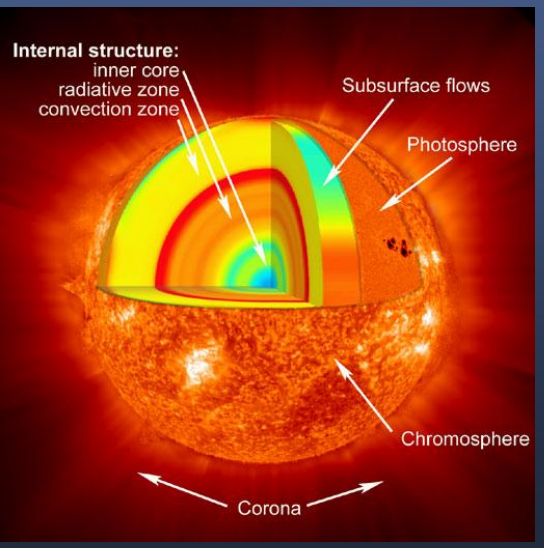
~1 solar mass

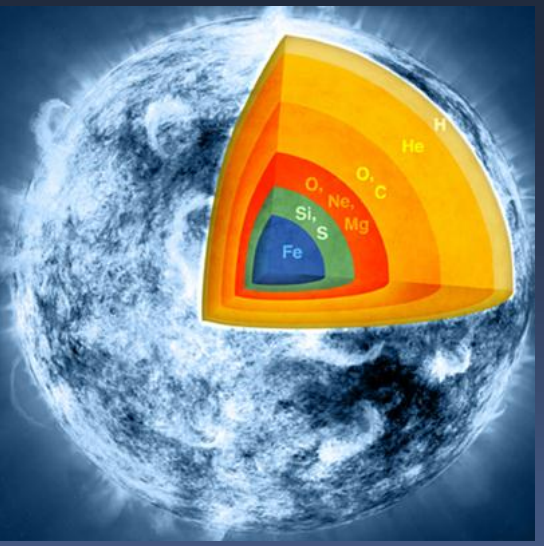
~20 solar masses

Builds upon synergies between binary stars and asteroseismology

Pulsation HR-diagram

Dynamic Asteroseismology





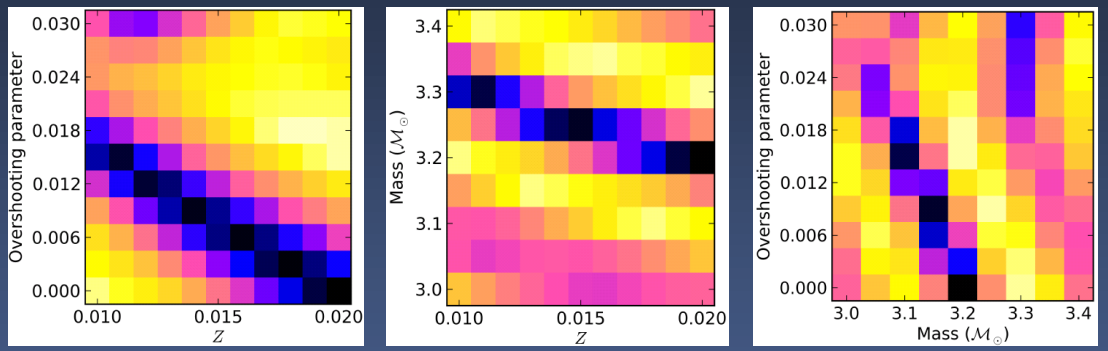
~1 solar mass

Asteroseismology: model dependence

~20 solar masses

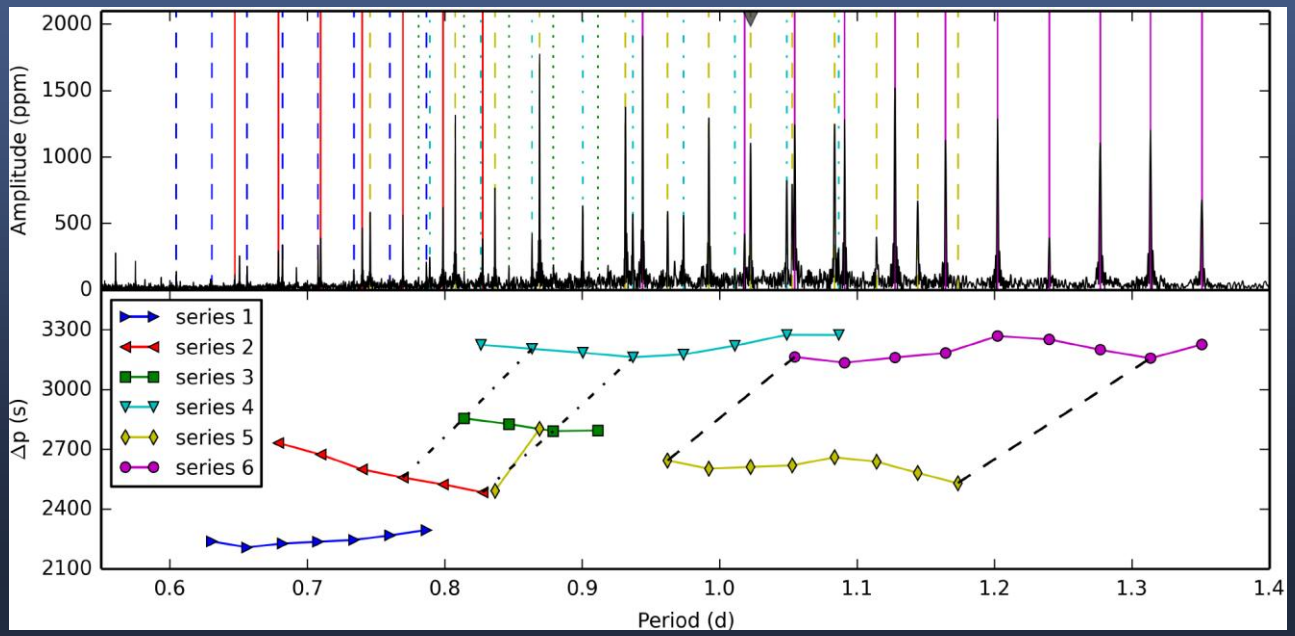
Builds upon synergies between binary stars and asteroseismology

Gentle feeding!!!



KIC 10526294 – SPB star; Papics et al. 2014; see also Moravveji et al. 2015

Dynamic Asteroseismology

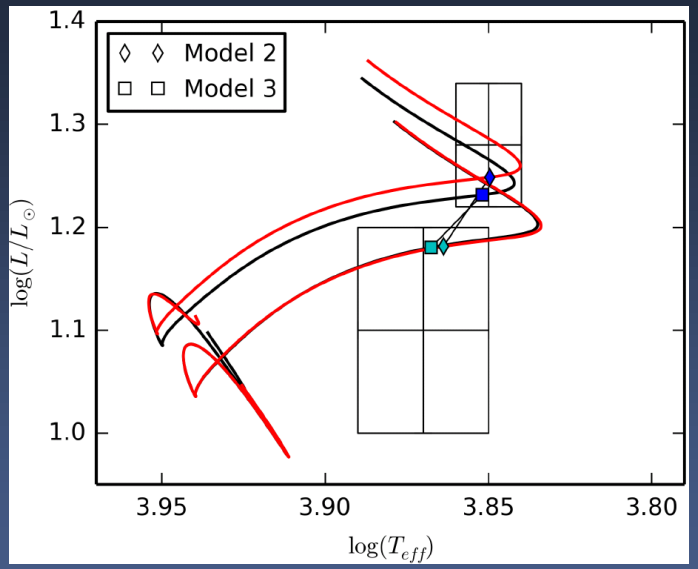


KIC 10080943:

two F-type g-mode pulsators in an eccentric, ~1Myr old binary

Keen et al. 2015; Schmid et al. 2015; Schmid & Aerts 2016

V. Schmid's talk (Thursday)



Seismology

Period spacing patterns

+

rotational splitting

Binarity

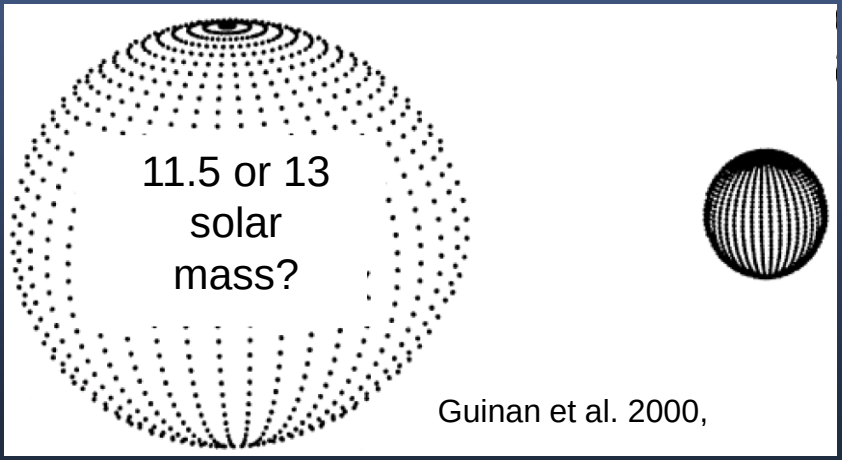
Same age and composition

+

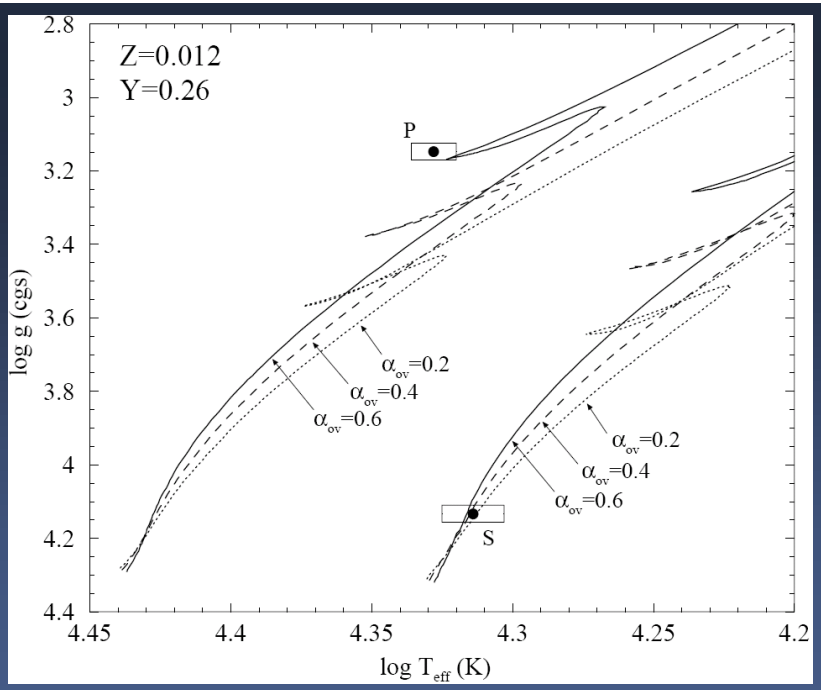
Masses and radii (???)

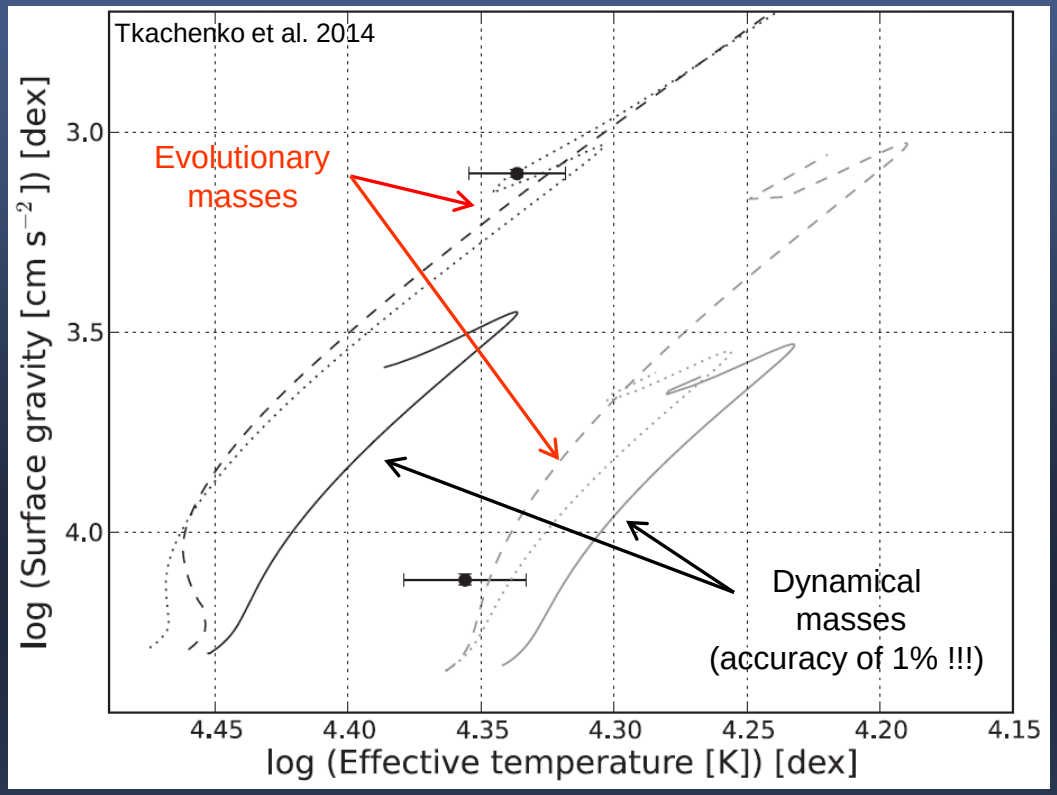
Stellar structure and evolution

V380 Cyg



Guinan et al. 2000,



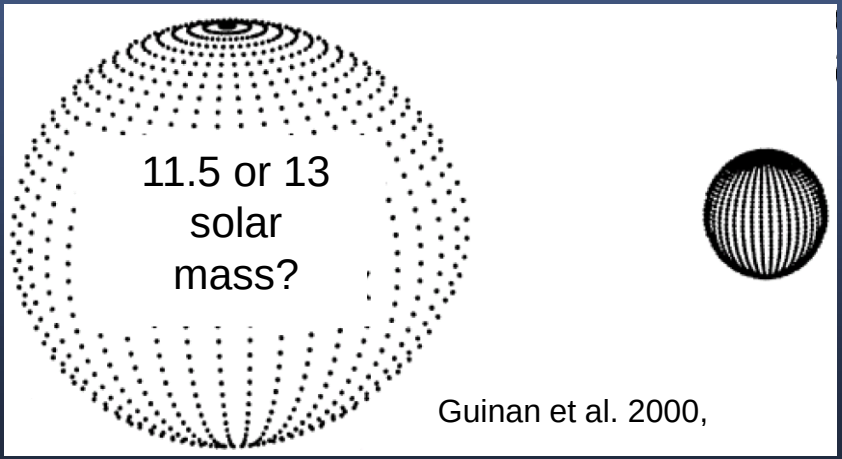


Mass discrepancy:

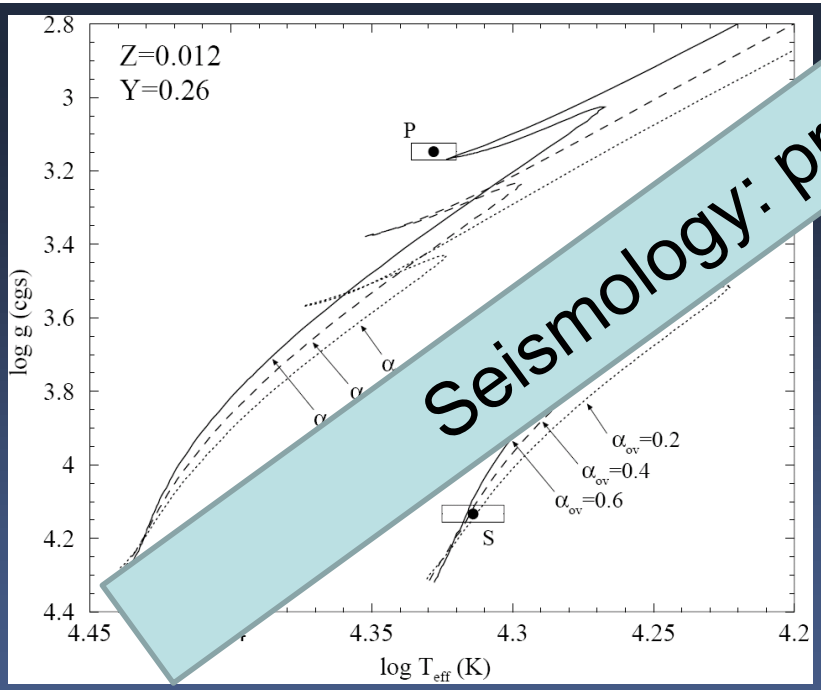
- ≥10% in high(intermediate)-mass binaries
- IS a function of evolutionary stage
- Overshoot, metallicity help?

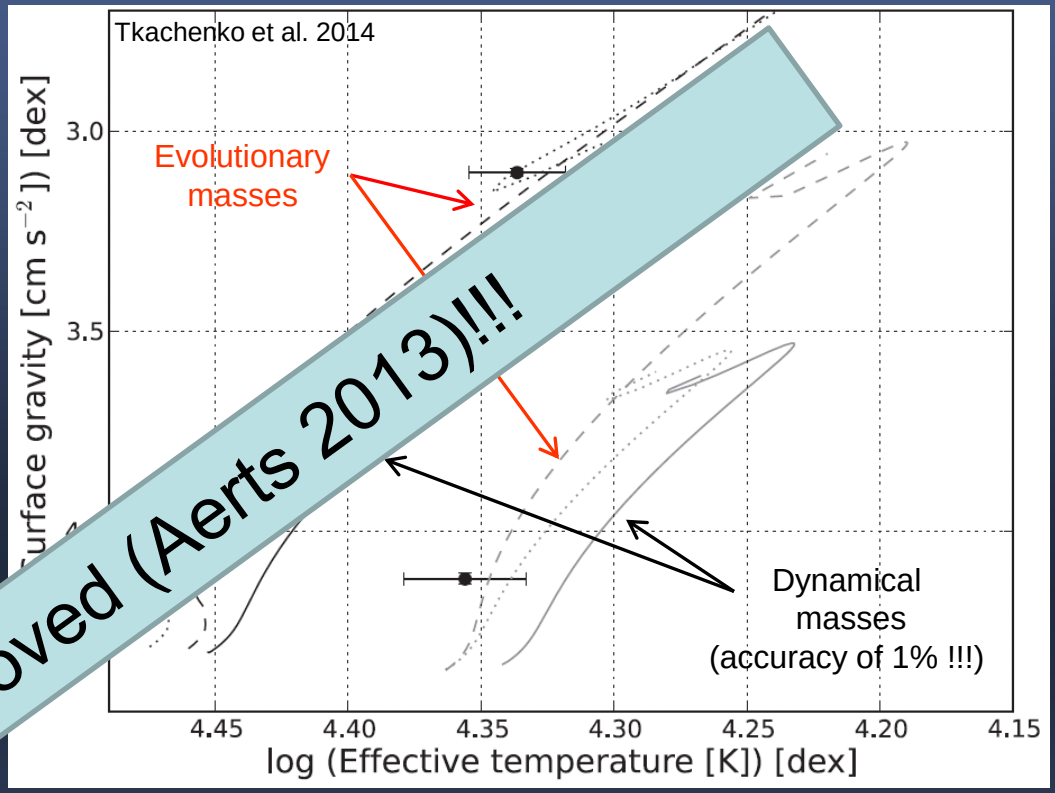
Stellar structure and evolution

V380 Cyg



Guinan et al. 2000,





Seismology: proved (Aerts 2013)!!!

Mass discrepancy:

- ≥10% in high(intermediate)-mass binaries
- IS a function of evolutionary stage
- Overshoot, metallicity help?

Stellar structure and evolution

THE MASS-RADIUS RELATION OF YOUNG STARS, I: USCOCTIO 5, AN M4.5 ECLIPSING BINARY IN UPPER SCORPIUS OBSERVED BY K2

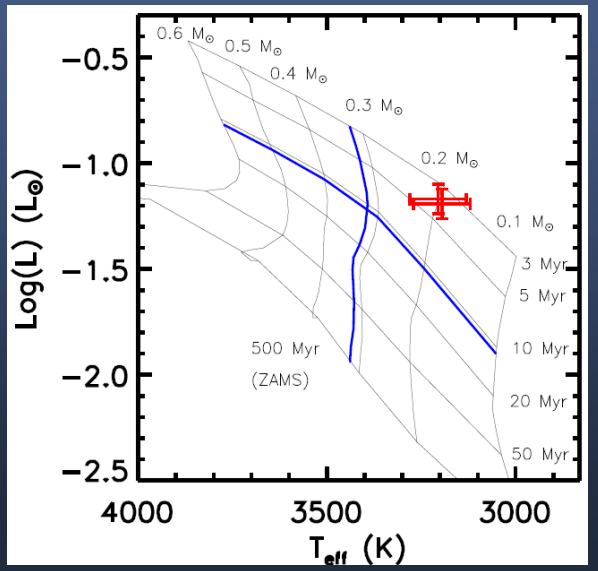
Adam L. Kraus[1], Ann Marie Cody[2], Kevin R. Covey[3], Aaron C. Rizzuto[1], Andrew W. Mann[1,4], Michael J. Ireland[5]

New Pleiades Eclipsing Binaries and a Hyades Transiting System Identified by K2

Trevor J. David[1,2], Kyle E. Conroy[3], Lynne A. Hillenbrand[1], Keivan G. Stassun[3,4], John Stauffer[5], Luisa M. Rebull[5], Ann Marie Cody[6], Howard Isaacson[7], Andrew W. Howard[8], Suzanne Aigrain[9]

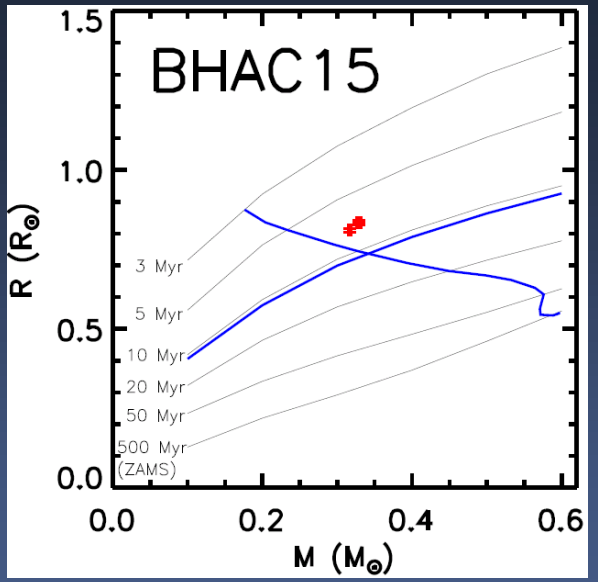
K2 DISCOVERY OF YOUNG ECLIPSING BINARIES IN UPPER SCORPIUS: DIRECT MASS AND RADIUS DETERMINATIONS FOR THE LOWEST MASS STARS AND INITIAL CHARACTERIZATION OF AN ECLIPSING BROWN DWARF BINARY

Trevor J. David [1,2], Lynne A. Hillenbrand [1], Ann Marie Cody [3], John M. Carpenter [1], Andrew W. Howard [4]

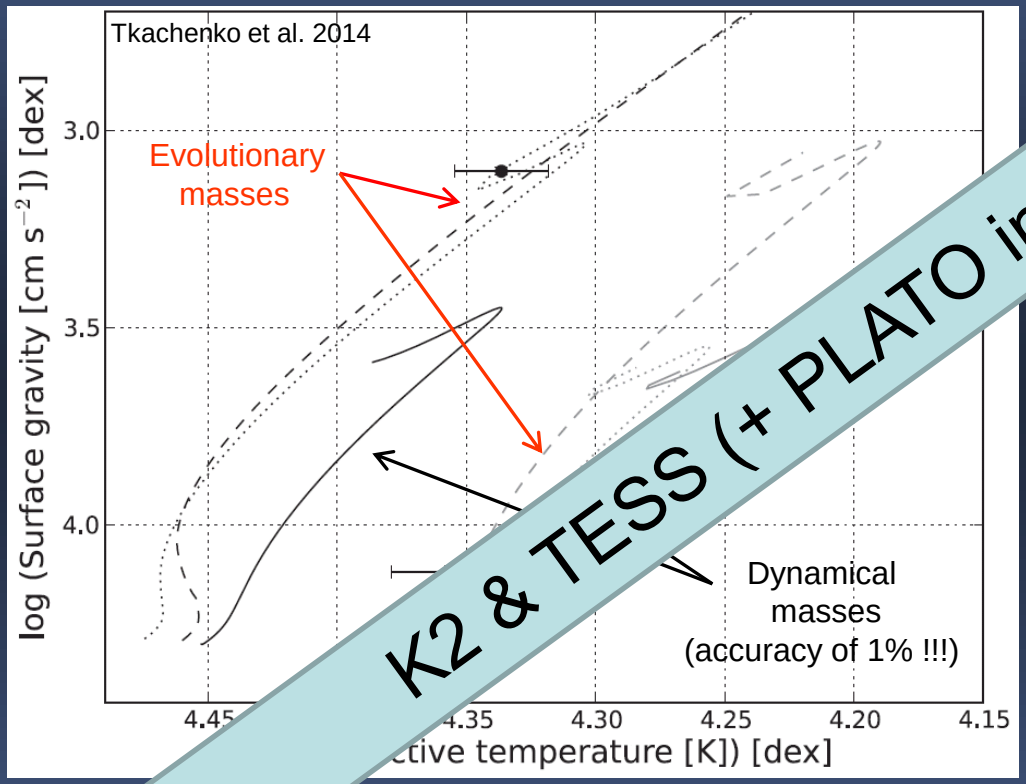


Models

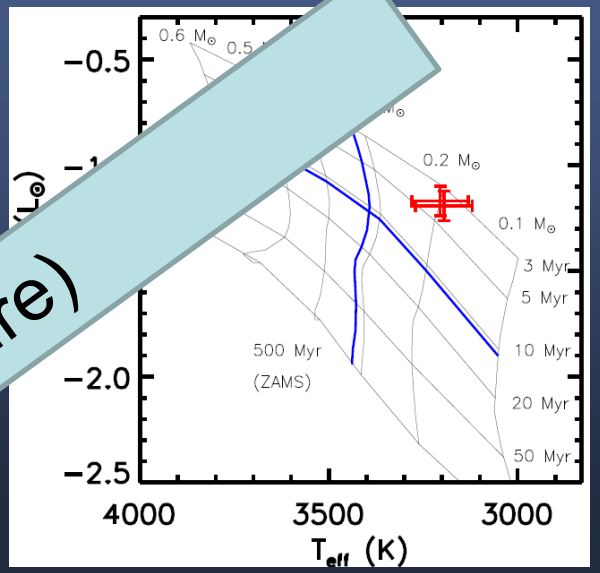
- Over (under) predict temperatures (masses) by 10 % (50)%
- Models are inter (and intra) inconsistent
- Model discrepancies are mass-dependent
- Magnetic fields help to resolve (some of) the discrepancies?

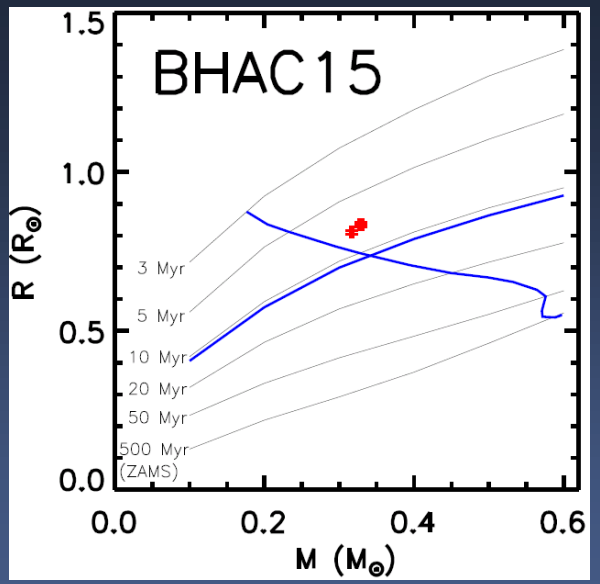


Stellar structure and evolution

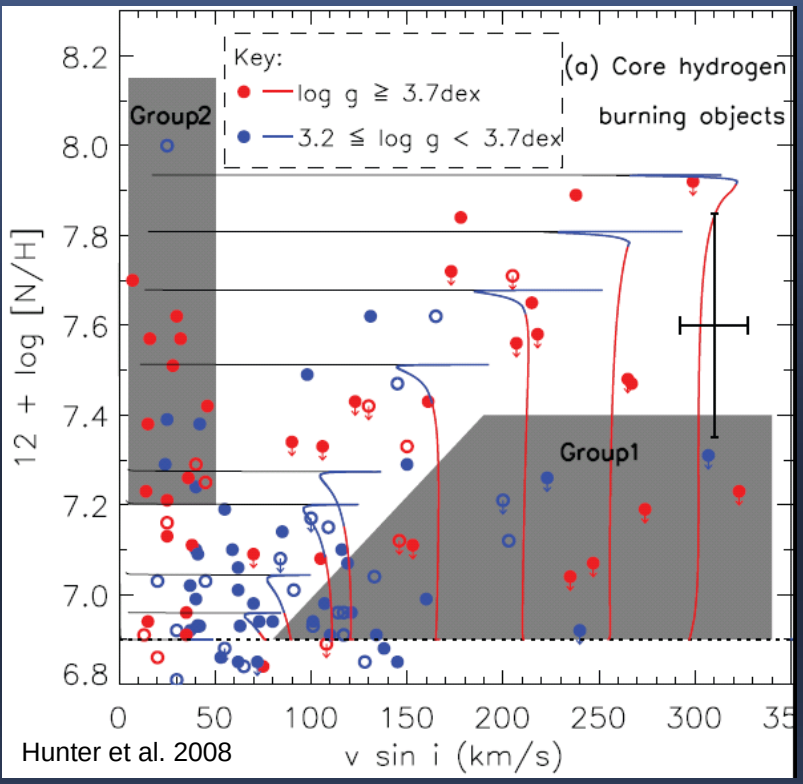


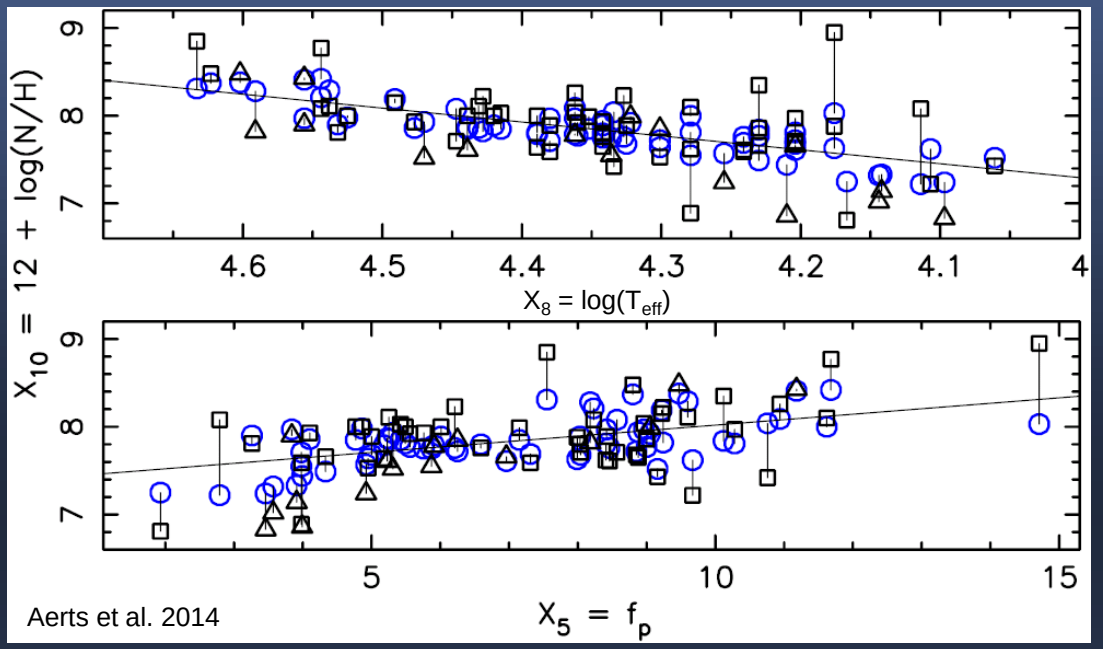
K2 & TESS (+ PLATO in future)





Rotationally-induced mixing





Hunter et al. 2008

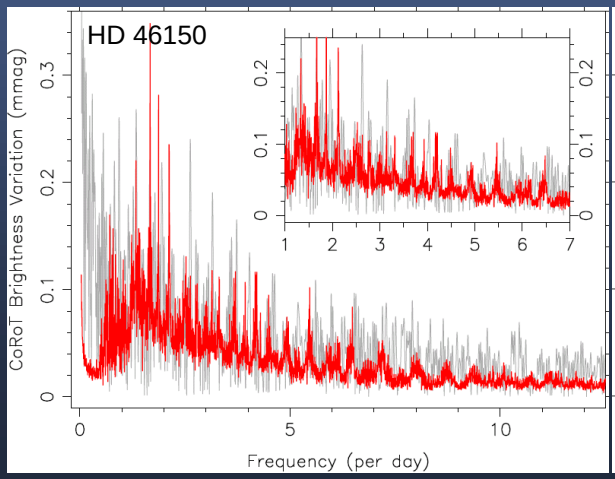
- [N/H] vs. vsini observational trend
- Rotation brings nitrogen to the surface
- Two "groups" contradicting theory

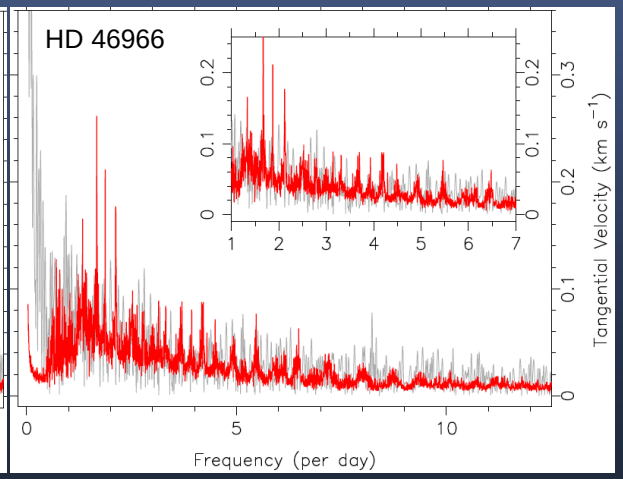
Aerts et al. 2014

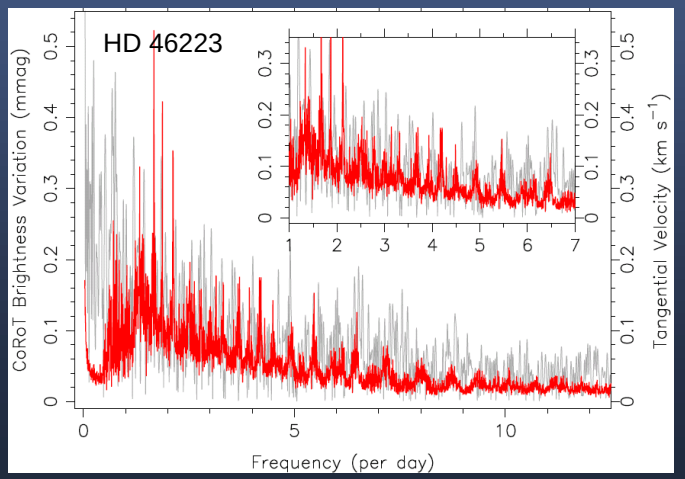
- [N/H] vs. f_{ROT} → no trend
- Rotation does not seem to play a role
- [N/H] vs. T_{EFF} & [N/H] vs. f_P trends

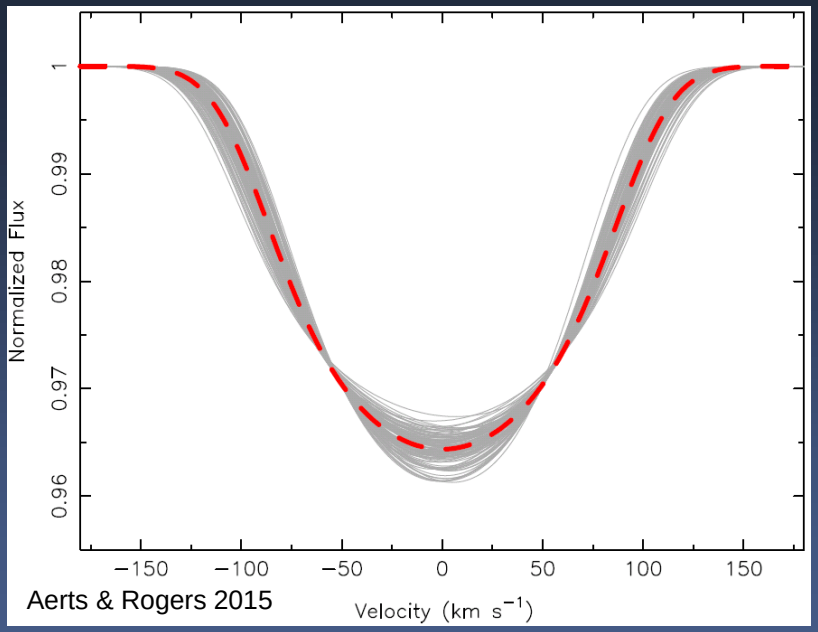
Internal Gravity Waves (IGWs)

T. Roger's talk (Tuesday)







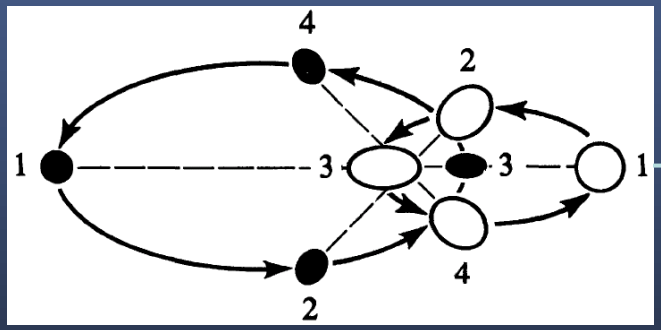


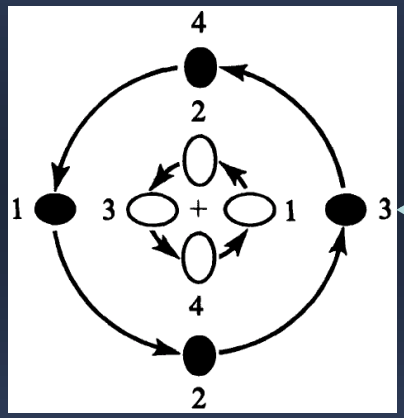
Aerts & Rogers 2015

IGWs

- Efficient way to transport angular momentum (F-type stars too???)
- Mixing chemical species
- Contradicting or supporting the theory of rotational mixing?
- What is their role in binary evolution (if any)?

Tidal evolution in binaries





Stars with outer convective zones

- Turbulent friction on the equilibrium tide
- Operating in convection zones

Stars with outer radiative zones

- Radiative damping of dynamical tide
- Operating in radiation zones

Kepler

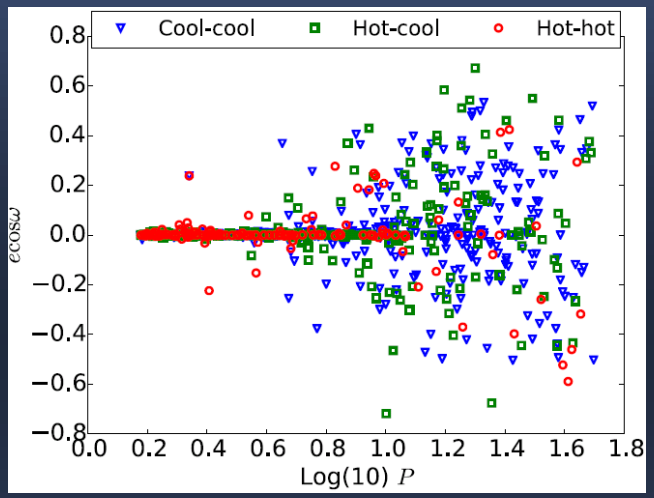
Spin-orbit synchronization issue

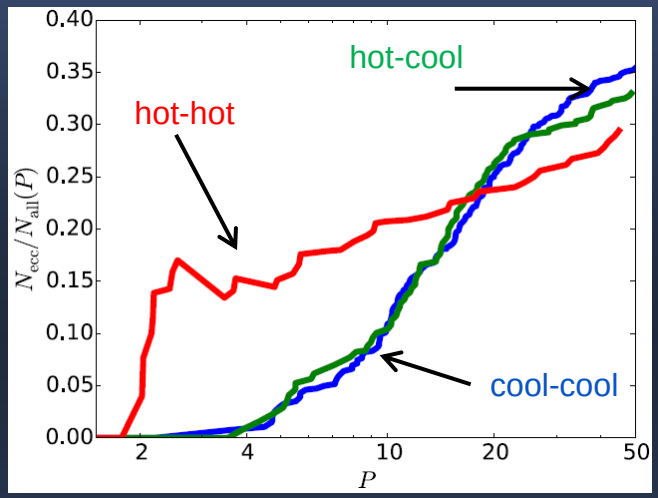
- Observations: non-synchronized spins where synchronization is expected
- Theory: tidal torque applied to the outermost part; angular momentum transport within a star
- IGWs: a way to transport angular momentum? Can explain non-synchronous binaries?

Tidal evolution in binaries: circularization

ORBITAL CIRCULARIZATION OF HOT AND COOL *KEPLER* ECLIPSING BINARIES

VINCENT VAN EYLEN[1,2], JOSHUA N. WINN[2,3], AND SIMON ALBRECHT[1]





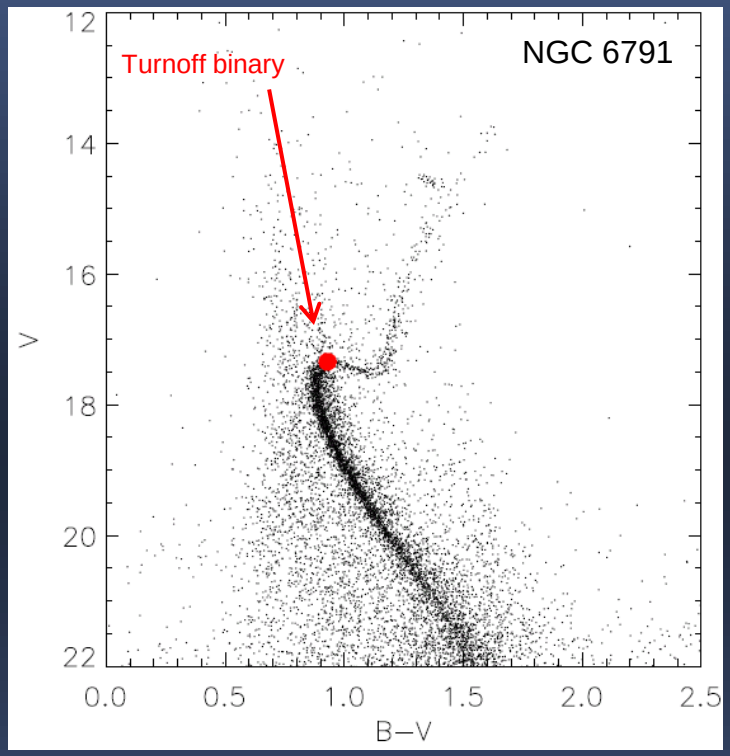
Limitations

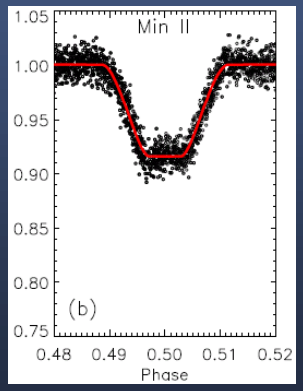
- Ecosω; no ages, masses, evolutionary states; all stars are on the MS; Teff < 10 000K; boundary at 6250 K

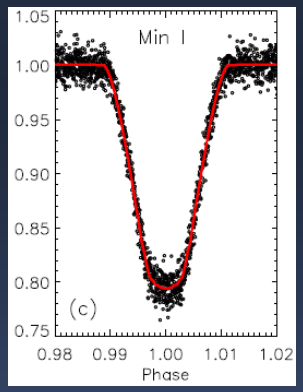
Conclusions

- Theory performs OK, at least for stars with cooler components
- Tidal dissipation (age) dominates in binaries with (without) cool component

Tidal evolution in binaries: circularization



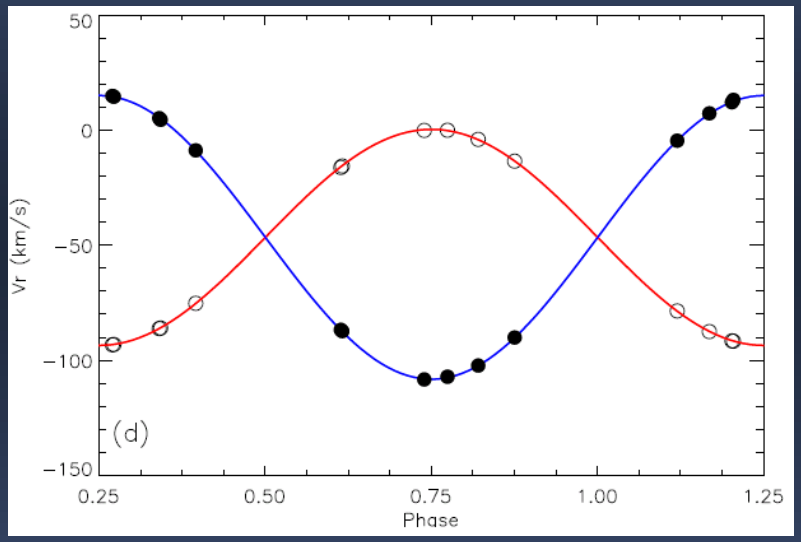




Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 453, 2937–2942 (2015) doi:10.1093/mnras/stv1773

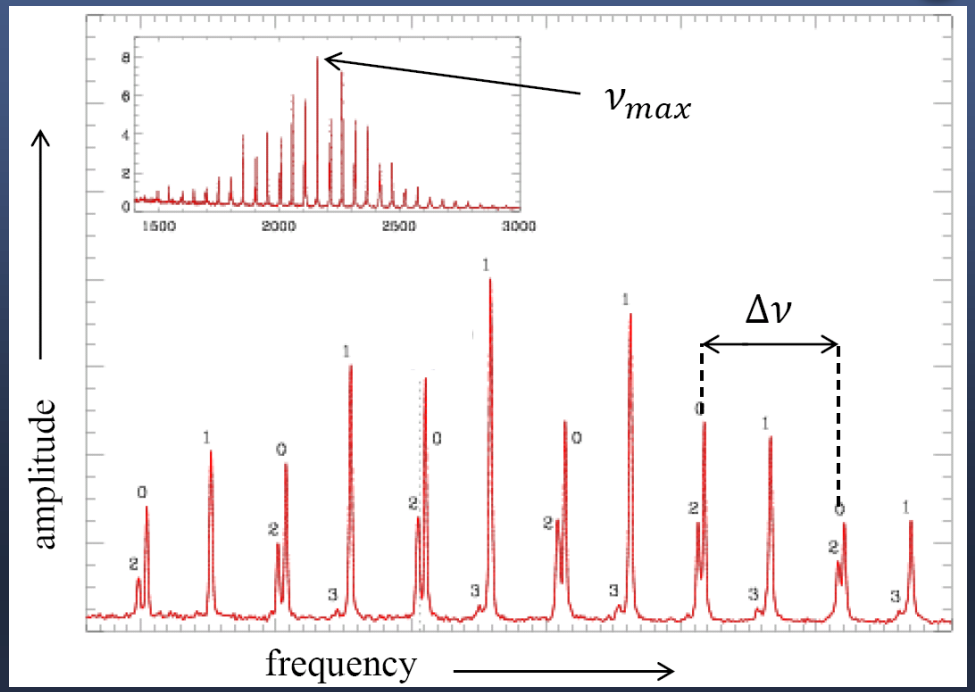
A turn-off detached binary star V568 Lyr in the *Kepler* field of the oldest open cluster (NGC 6791) in the Galaxy

K. Yakut,[1,2⋆] P. P. Eggleton,[1,2,3⋆] B. Kalomeni,[1,4⋆] C. A. Tout[2] and J. J. Eldridge[2,4]



Model tidal friction increased by factor of 100!!!

Scaling relations



Kjeldsen & Bedding 1995, A&A, 293, 87

$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^{3} \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

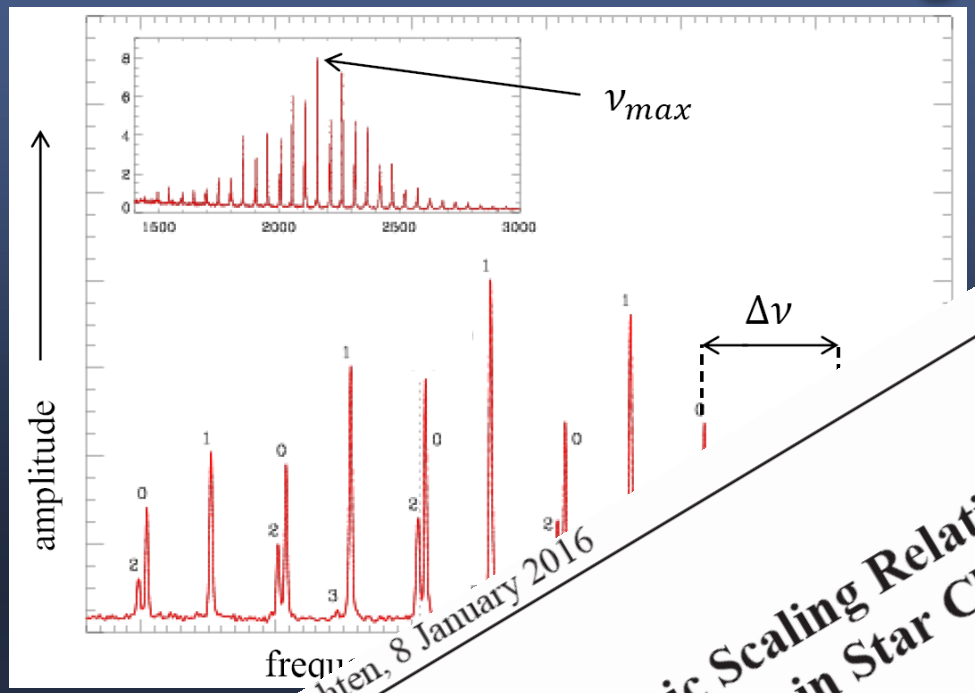
$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}$$

Incorrect writing according to Tim Bedding

Challenge

Just guess the number of objects analysed using the relations and the number of the published papers…

Scaling relations



Kjeldsen & Bedding 1995, A&A, 29

$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\rm m}}{}\right.$$

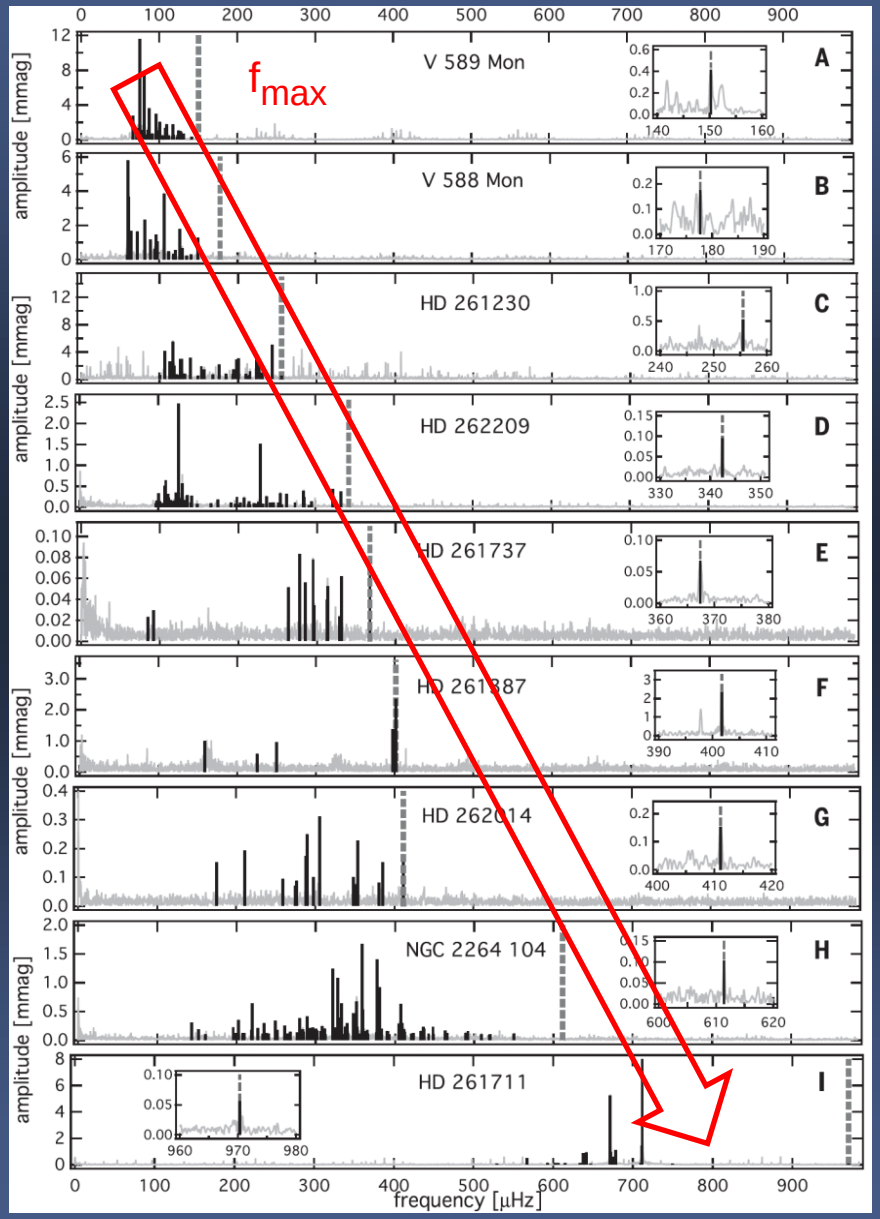
Astronomische Nachrichten, 8 January 2016

Testing Asteroseismic Scaling Relations using Eclipsing Binaries in Star Clusters and the Field

K. Brogaard[1,⋆], J. Jessen-Hansen[1], R. Handberg[1], T. Arentoft[1], S. Frandsen[1], F. Grundahl[1], H. Bruntt[1], E. L. Sandquist[2], A. Miglio[3], P. G. Beck[4], A. O. Thygesen[5], K. L. Kjærgaard[1], and N. A. Haugaard[1]

J. McKeever's talk (Thursday)

for heat-driven pulsators?



Zwintz et al. 2014, Science, 345, 550

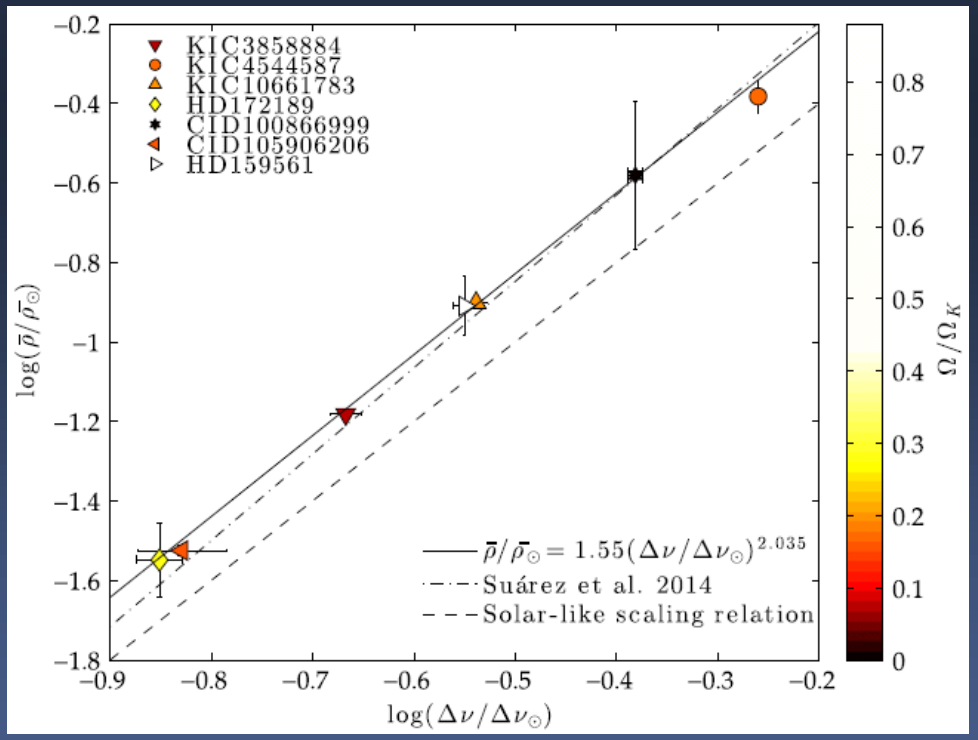
Talk by K. Zwintz (Thursday)

The Astrophysical Journal Letters, 811:L29 (6pp), 2015 October 1 doi:10.1088/2041-8205/811/2/L29

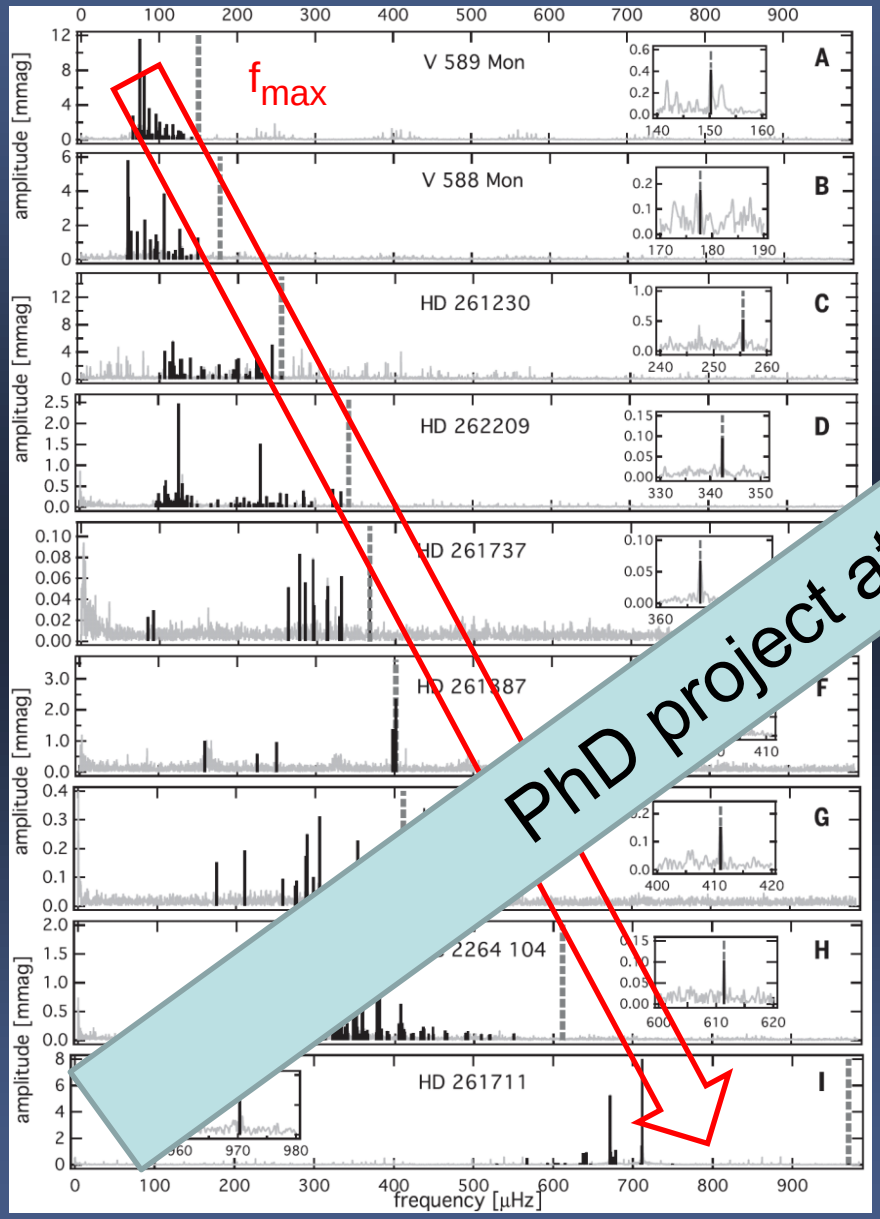
OBSERVATIONAL $\Delta\nu$–$\bar{\rho}$ RELATION FOR δ Sct STARS USING ECLIPSING BINARIES AND SPACE PHOTOMETRY

A. García Hernández[1], S. Martín-Ruiz[2], Mário J. P. F. G. Monteiro[1,3], J. C. Suárez[2,4], D. R. Reese[5,6], J. Pascual-Granado[2], and R. Garrido[2]

Talk by A. Garcia Hernandez's (Thursday)



for heat-driven pulsators?



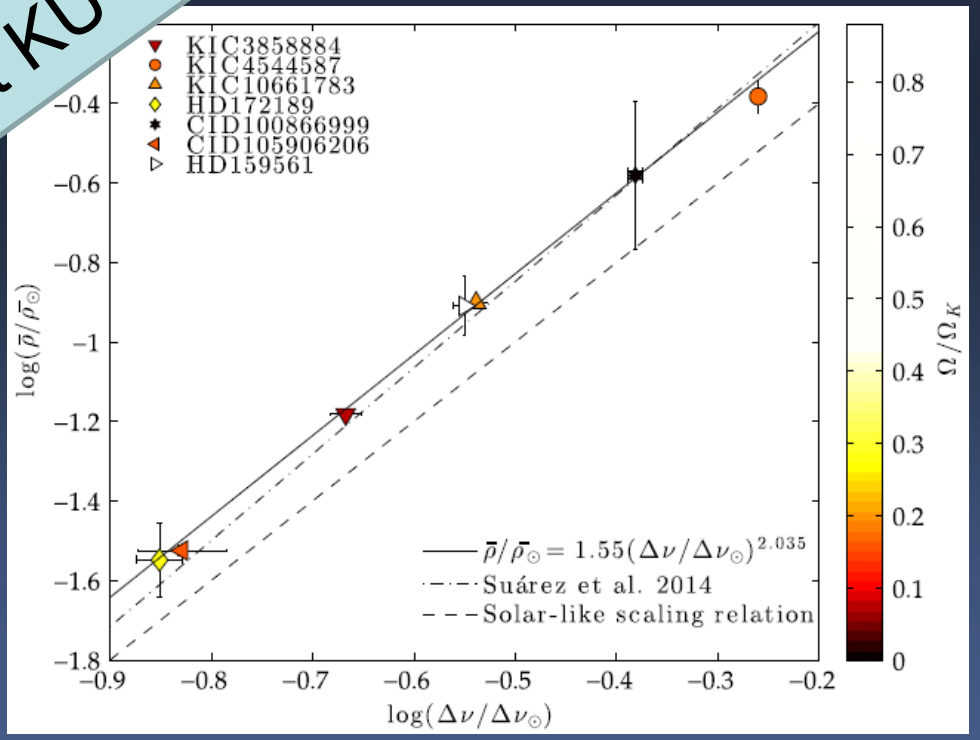
Talk by K. Zwi… …day)

The Astrophysical Journal Letters, 811:L29 (6pp), 201…
doi:10.1088/2041-8205/811/2/L29

OBSE… …LATION FOR δ Sct STARS USING …ES AND SPACE PHOTOMETRY

A. G… …TÍN-RUIZ[2], MÁRIO J. P. F. G. MONTEIRO[1,3], J. C. SUÁREZ[2,4], …[5,6], J. PASCUAL-GRANADO[2], AND R. GARRIDO[2]

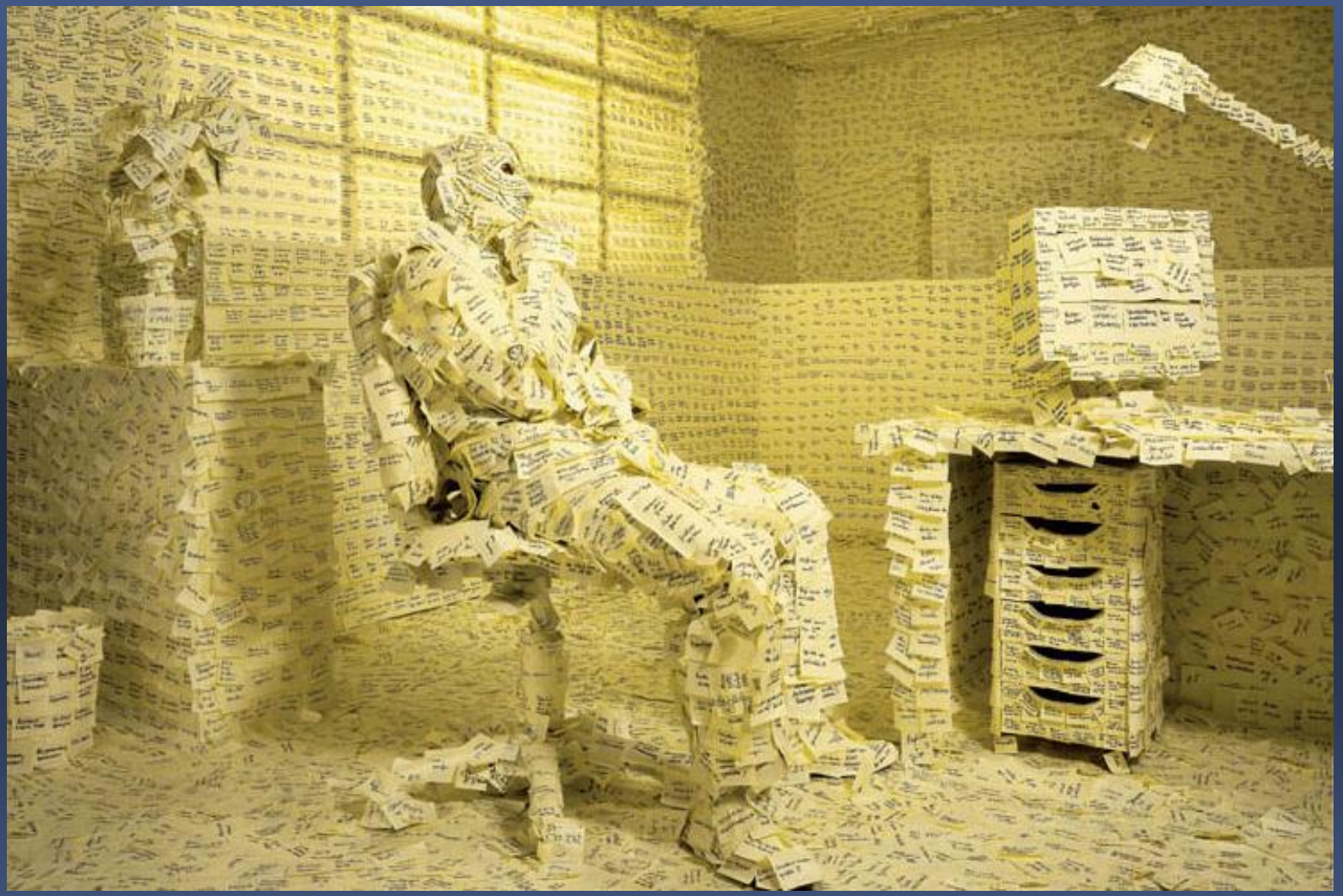
… Garcia Hernandez's (Thursday)



PhD project at KU Leuven

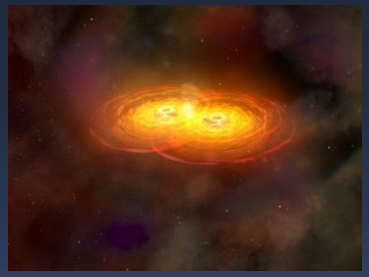
Zwintz et al. 2014, Science, 345, 550

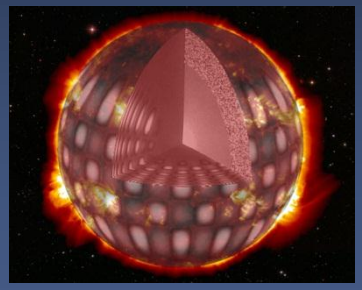
To conclude



Let’s clean this office a bit !

Opinion of public





"We live in hope of deliverance from the darkness that surrounds us" – Sir Paul McCartney