

Reviving the Kuhfuß model

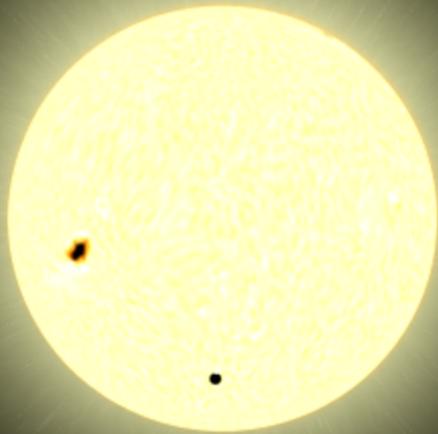
A strategy for algorithmic, self-consistent convection
across the PLATO-mission

Dr. Günther Wuchterl
Kuffner-Sternwarte.at

STESCI workshop II
Milazzo, Sicily
2018-05-24, 12:00-12:15

Convection from two perspectives

The Sun and Venus – June 2004



CoRoT-7 with CoRoT-7b authentic and to scale – Feb 2009

ANTRVM PLATONICVM



The cave of convection

Maxima pars hominum cecis immersa tenebris
Voluitur assidue, et s' fulio letatur inani:
Alaspice ut obiectis obtutais in hereat umbris,
Vt VERI simulacra omnes mirentur amenty,



Et s' solidi vanâ ludantur imagine rerum.
Quam pauci meliore luto, qui in lumine puro
Secreti à s' solida turba, ludibria cernunt
Rerum umbras rectay, expendunt omnia lauce:



Hi posita erroris nebula dignoscere possunt
Vera bona, atque alios ceca sub nocte latentes
Extrahere in claram lucem conantur, at illis
Nullus amor lucis, tanta est rationis egestas.



C.C. Harlemensis Inv.
Sanredam Sculpsit.
Henr. Hondius excudit.
1604.

The need to specify a framework
for algorithmic convection:

Algorithmic Box for Convection

For the summer of 2020 – PGSRQDR!

Mach about Plato

It would be easy to demonstrate from other areas of physics that humans generally tend to To ascribe material existence to their self-created abstract concepts, to ascribe to them a reality outside the consciousness. Plato just used this tendency rather freely in his theory of ideas. Even scientists like Newton where, in spite of the principles, not cautious enough.

15. Es liesse sich leicht durch analoge Beispiele aus andern Gebieten der Physik darthun, dass die Menschen überhaupt die Neigung haben, ihre selbstgeschaffenen abstrakten Begriffe zu hypostasiren, ihnen Realität ausserhalb des Bewusstseins zuzuschreiben. Platon hat von dieser Neigung in seiner Ideenlehre nur einen etwas freien Gebrauch gemacht. Selbst Forscher wie Newton waren, ihren Grundsätzen zum Trotz, nicht immer vorsichtig genug. Es verlohnt sich also wohl der Mühe, zu untersuchen, vorauf dieser Vorgang in diesem besonderen Falle beruhen mag. Wir gehen bei unsern Beobachtungen von der

Example: modified Kuhfuß convection

- Kuhfuß 1987, W+F 1998, Flaskamp 2003, Wuchterl+Tscharnuter 2003
- deduced* from fd; robust: gas+rad, $L < 0$, $g < 0$, Mach > 100
- time-dependence with finite rise and damping times
- start from zero-gradients
- combination with stellar/planetary radiation-fluid dynamics
- Minimise complexity and flow-interaction physics checks for protoplanet / protostar work:
 - Regularised equations, transport limit by convective flux limiter
 - Standard solar convection OK;
 - MLT-limit;
 - Standard set of parameters for “overshooting” and α_{ML} , eddy-thermal losses
- Protostellar Collapse – Wuchterl + Klessen, Wuchterl + Tscharnuter,
- RR Lyrae ok (pre-space)
- Stellar Evolution Flaskamp, Strakka : mass dependent overshooting but limits of the three equations version.
- Wuchterl 1995, Wuchterl and Feuchtinger 1998
- Difficult with classical stellar evolution algorithms

The deduction of the Kuhfuß equations is not necessarily endorsed by all theorists and mathematicians

Mass-dependent properties of K-convection

- M_{\odot} Helio-Seismo

- M_* Overshoot

114 KAPITEL 6. SIMULATIONEN NICHTLOKALER KONVEKTION

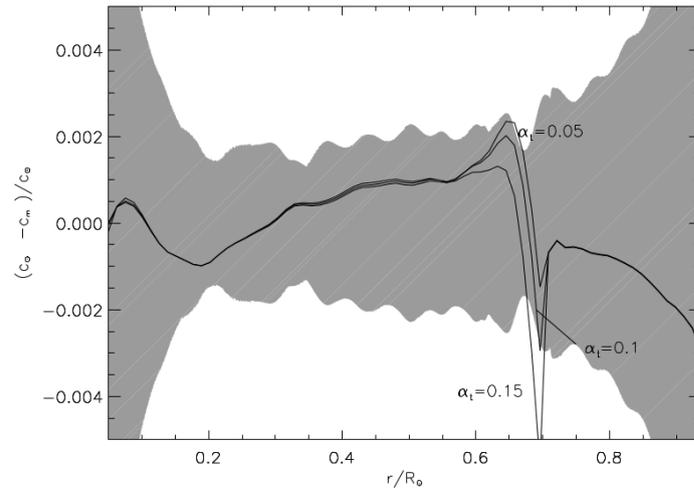


Abbildung 6.26: Sonnenmodelle mit der Kuhfußtheorie im nichtlokalen Fall. Verwendet wurden unterschiedliche Parameter für α_t , somit ergaben sich unterschiedliche Ausdehnungen der Überschießzone. Damit die sich ergebenden Schallgeschwindigkeiten innerhalb des Fehlerbereichs mit der Helioseismologie übereinstimmt, sollten für α_t Werte zwischen 0.05 und 0.1 gewählt werden.

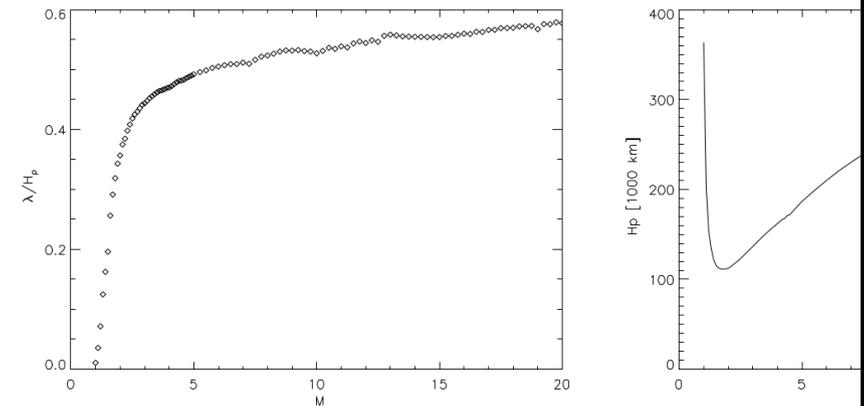


Abbildung 6.8: (links) Überschießlänge in Einheiten der H_p im Eingleichungsmodell. Auffallend ist der starke Anstieg in $6M_{\odot}$. In der rechten Abbildung ist die Druckskalenhöhe H_p im nichtlokalen Fall abgebildet. Hier fällt auf, wie die H_p bei $2M_{\odot}$ stark ansteigen.

Modified Kuhfuß convection in dynamic action

- Mach 20 supercrit. accretion shock ->
- RR-Lyrae driver

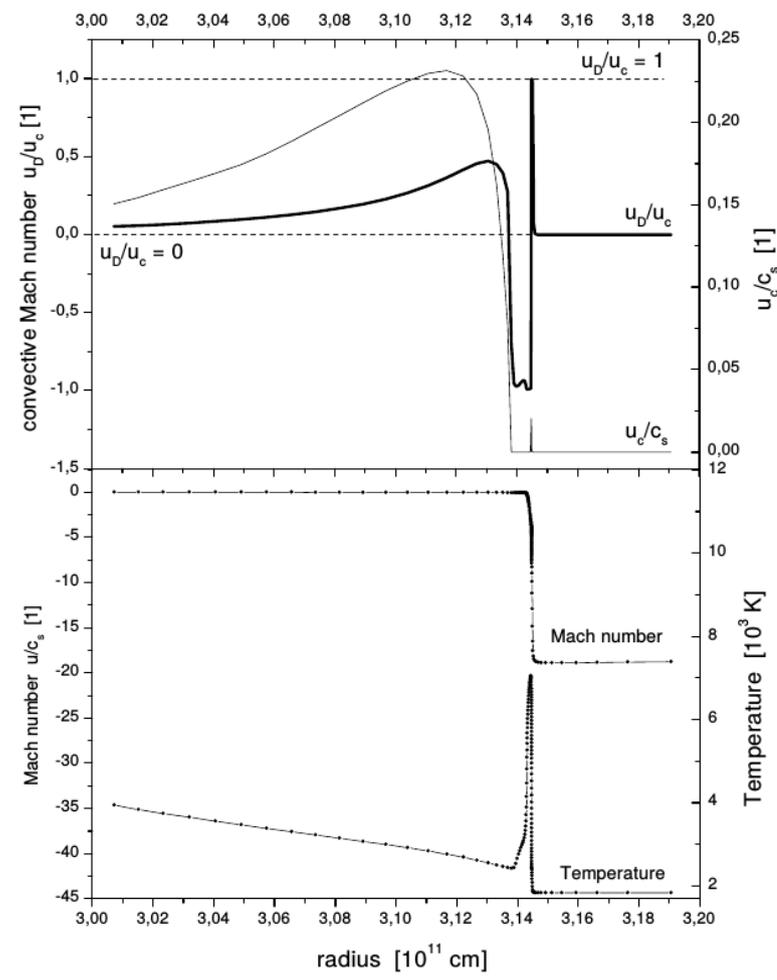


Fig. 2. Flow structure in the vicinity of a protostellar accretion shock with convective enthalpy flux-limiter. Each point in the lower panel corresponds to one cell in the numerical computation. See text for details.

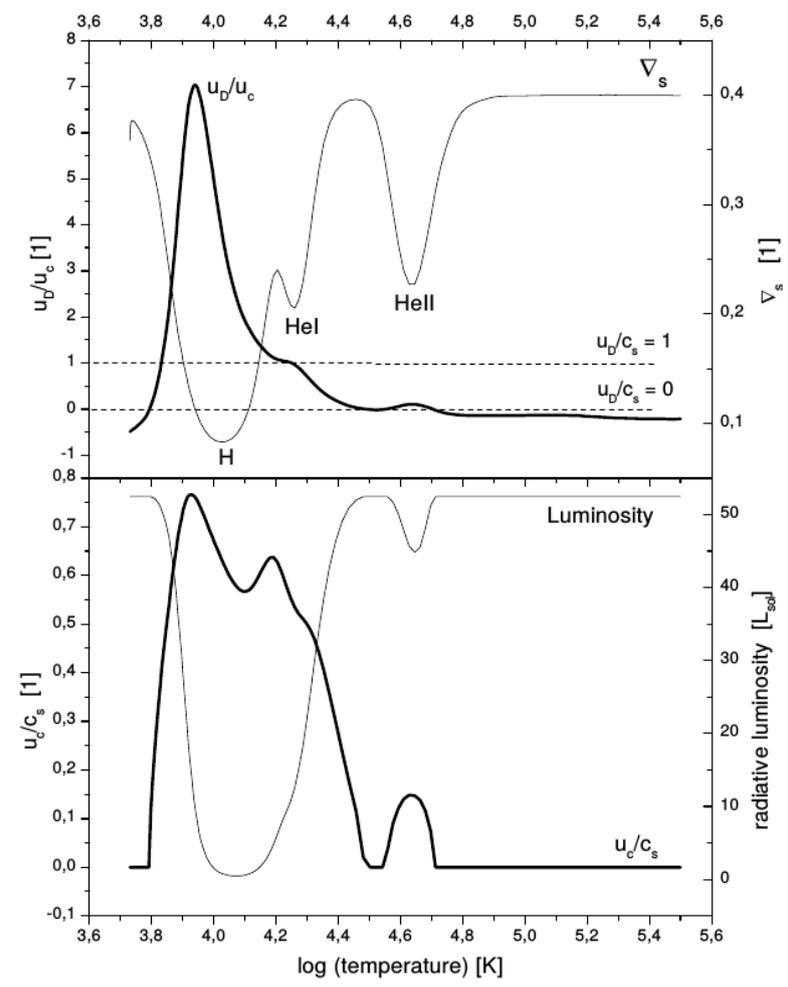


Fig. 3. Convective structure for an RR Lyrae envelope with stellar parameters of $M = 0.65M_{\odot}$, $\log(L/L_{\odot}) = 1.72$, $T_{\text{eff}} = 6400$ K and $XYZ=(0.760, 0.239, 0.001)$. We use OPAL opacities and the equation of state from Wuchterl (1990). The outer boundary is located on the left-hand side while the right-hand side corresponds to some point in the interior of the envelope. See text for details.

----->
 Kuhfuß 1987,
 Wuchterl and
 Feuchtinger 1998,

Mission footprint of convection challenges

the glorious 7

- 1) energy transfer in stellar evolution, the core of the mission's age concept;
- 2) overshooting and mixing, that feed back to ages;
- 3) surface boundary conditions for the seismic analysis;
- 4) excitation and damping as feedback to mode-detectability;
- 5) photospheric convection for stellar spectral analysis: T_{eff}
- 6) limb darkening in transit fitting;
- 7) feedback to FU, e.g. line-bisectors in RV-campaigns;

Convection “instances” of the mission

- distributes physics-packages to work packages;
- minimum algorithm necessary to server the mission tasks (limb darkening, atmos, evol, modes for theory class and parameter);
- connect convection development to the mission by providing equation-forms and parameter estimates from detailed convection studies (3D, non FD, multiple equations, lab experiments);
- allows constraints from the mission on the convection algorithm;
- provides (component for) accuracy management by enabling theoretical distributions (theory uncertainties – range of confidence);

New observables for convection-theory

- b_i , c_i , ν_{max}
- Synoptic description of power density spectra
- Power density spectra connect osci- to granulation
- *The connection between stellar granulation and oscillation as seen by the Kepler mission*, Kallinger et al. 2014, A&A...570A..41K
- correlates to $\log g$

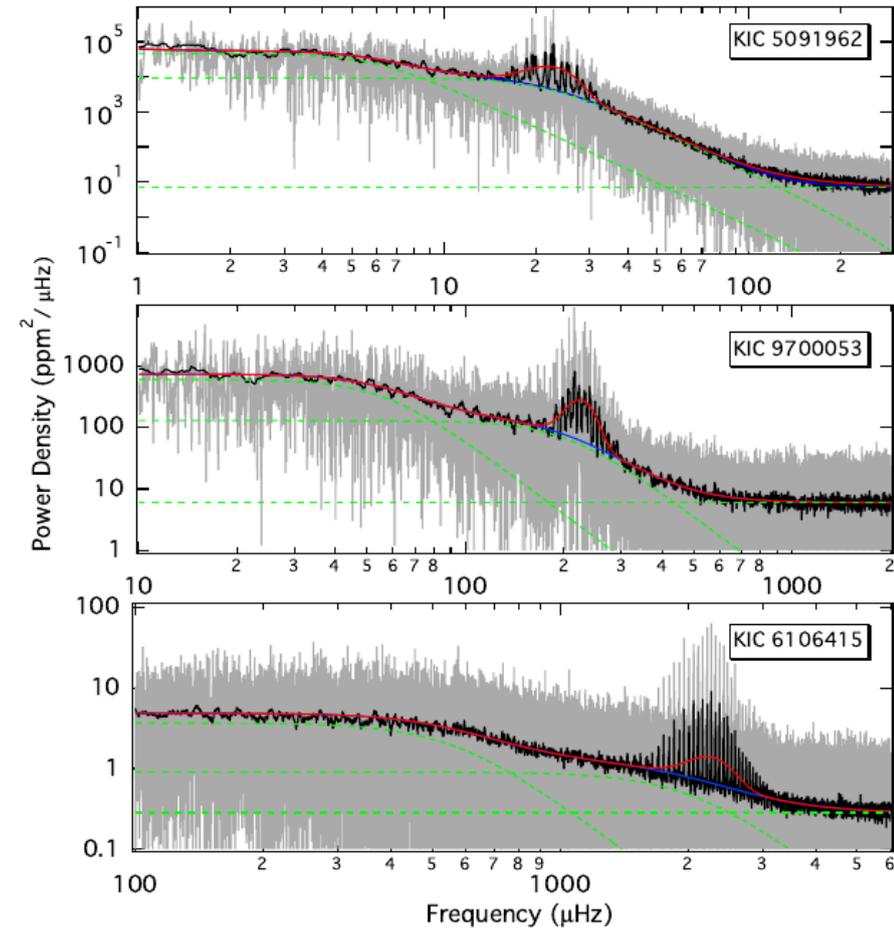


Fig. 7. Power density spectra of three typical stars with $\nu_{\text{max}} \simeq 22$, 220, and 2200 μHz , respectively, showing that all timescales and amplitudes (granulation as well as pulsation) scale simultaneously. Grey and black lines indicate the raw and heavily smoothed spectrum, respectively. The global fit is shown with (red) and without (blue) the Gaussian component. Green lines indicate the individual background and white noise components of the fit.

PLATO convection algorithm requirements

Any class of convection theory should provide quantitative info, suitable for the mission instance on the following observables (with Kallinger)

- 1) The two time-scales of granulation (Kallinger et. 2014);
- 2) the parameter governing the limit cycle / the balance between excitation and damping, the ν_{max} (scaling with the acoustic cut);
- 3) the parameter governing the determination of the frequency with the maximum net-energy ("largest amplitude mode");
- 4) limb darkening for transit fits for all PIC-spectral types;
- 5) the three classical constraints - radius of the Sun, age of the Sun, bottom of convection zone;
- 6) mode lifetime;
- 7) Balmer-line wings $\alpha_{\text{ML}}^{\text{phot}}$;
- 8) acoustic excitation - mode power excess (with respect to the granulation signal)

The PLATO consense convection theory

$$C_{\pi} = 0$$

The PLATO convection class

- Simple but not too simple [implement at PDC from 2021 to launch
- At least three extra new nonlinear PDEs (3 for modified versions of the Kuhfuss 3 equation model);
- Convective transport anisotropy factor (eddington factor);
- Provide feedback on what you think is absolutely needed for the convection algorithm with implementation rules;
- What **form** do we need – variables, parameters, equation types: strictly algorithmic!
- No solution for convection – a workaround for PLATO goals!

The PLATO convection form/class/box

$$\begin{aligned} C_{\eta} & [\text{MLT}(1\text{D}); \\ & \text{MLT}(3\text{D}); \\ & \text{CCT}; \text{MKT}; \text{XKT?}] \\ & = 0 \end{aligned}$$

The PLATO convection form/class

- Helio
- Evolution
- C_{η} [MLT(1D);
MLT(3D);
CCT;MKT;XKT?]
= 0
- Pre flight transit
 - CHEOPS
 - ground
- Convection studies
 - 3D LES
 - Num. Theory
 - lab
- Calibration at stars
- Teff

The shape of the convection system

Shape + Calibrations \Rightarrow CBB \Rightarrow distribution to
mission tasks

Please put the ABC into the Requirements

- An algorithm that also contains the modified Kuhfuß model;
- A requirement to the PDC to built the ABC;
- A requirement for the ABC to learn from the mission, particularly the planet-transit curves;
- A requirement for the ABC to be open for two extra equations for convection;
- A requirement for the ABC to “instance” the “current convection” from the ABC for all covvection usage in other algorithms (exoplanet transit fitting) according to the data processing cadence.

ABC = Algorithmic Box for Convection

LVX VENIT IN MVNDVN ET DILEXERVNT HOMINES MAGIS TENEBRAS QVAM LVCEM. IO. 3. 19

ANTRVM PLATONICVM



View of the cave 1605

Maxima pars hominum cecis immersa tenebris
Voluitur assidue, et s' fulio letatur inani:
Aspice ut obiectis obtutis in hereat umbris,
Vt VERI simulacra omnes mirentur amenty,



Et s' solidi vanâ ludantur imagine rerum.
Quam pauci meliore luto, qui in lumine puro
Secreti à s' solidâ turba, ludibria cernunt
Rerum umbras rectay, expendunt omnia lauce:



Hi posita erroris nebula' dignoscere possunt
Vera bona, atque alios ceca sub nocte latentes
Extrahere in claram lucem conantur, at illis
Nullus amor lucis, tanta est rationis egesitas.



C.C. Harlemensis Inv.
Sanredam Sculpsit.
Henr. Hondius excudit.
1604.

H.L. SPIEGEL FIGVRARI ET SCVLPV CVRAVIT. AC DOCTISS. ORNATISS. OZD.PET.PAAW IN LVGDVN. ACAD. PROFESSORI MEDICO DD.

Remember Socrates' remark:

"As for the man who tried to free them and lead them upward, if they could somehow lay their hands on him and kill him, they would do so."



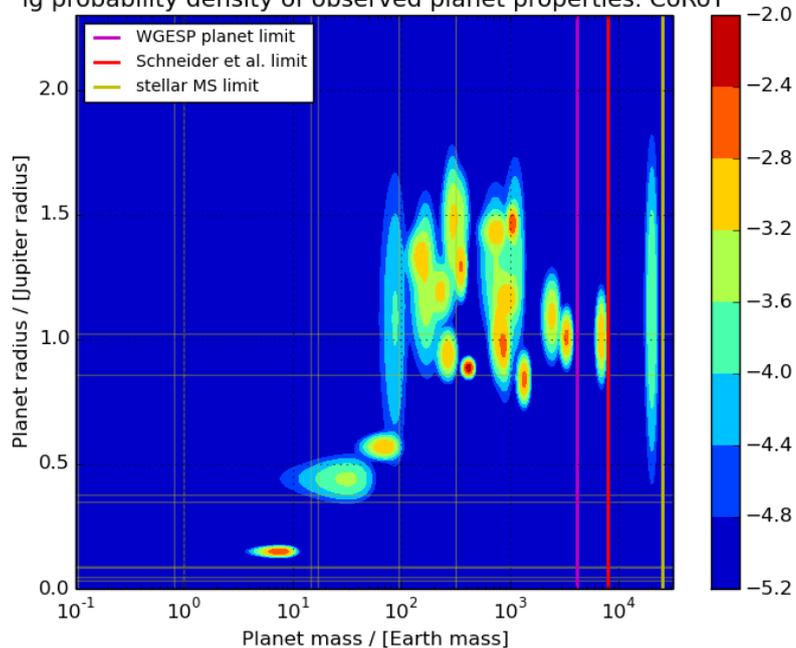
Time Critical Photometry with Small Telescopes (143 200)

- Axiom Beta by Apertus
-

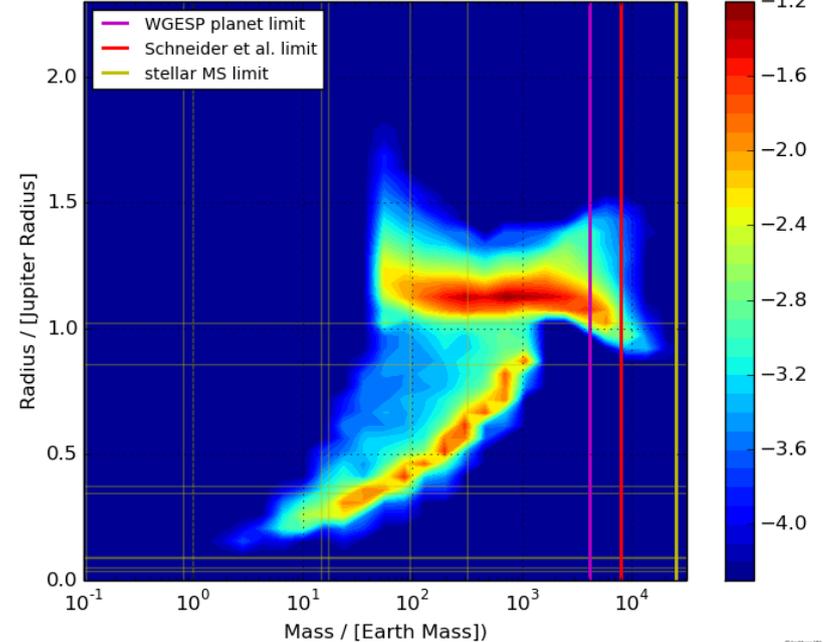
Why another convection algorithm?

- CoRoT R-IgM planet-density
- CoRoT-Mark 1R theory planet-density

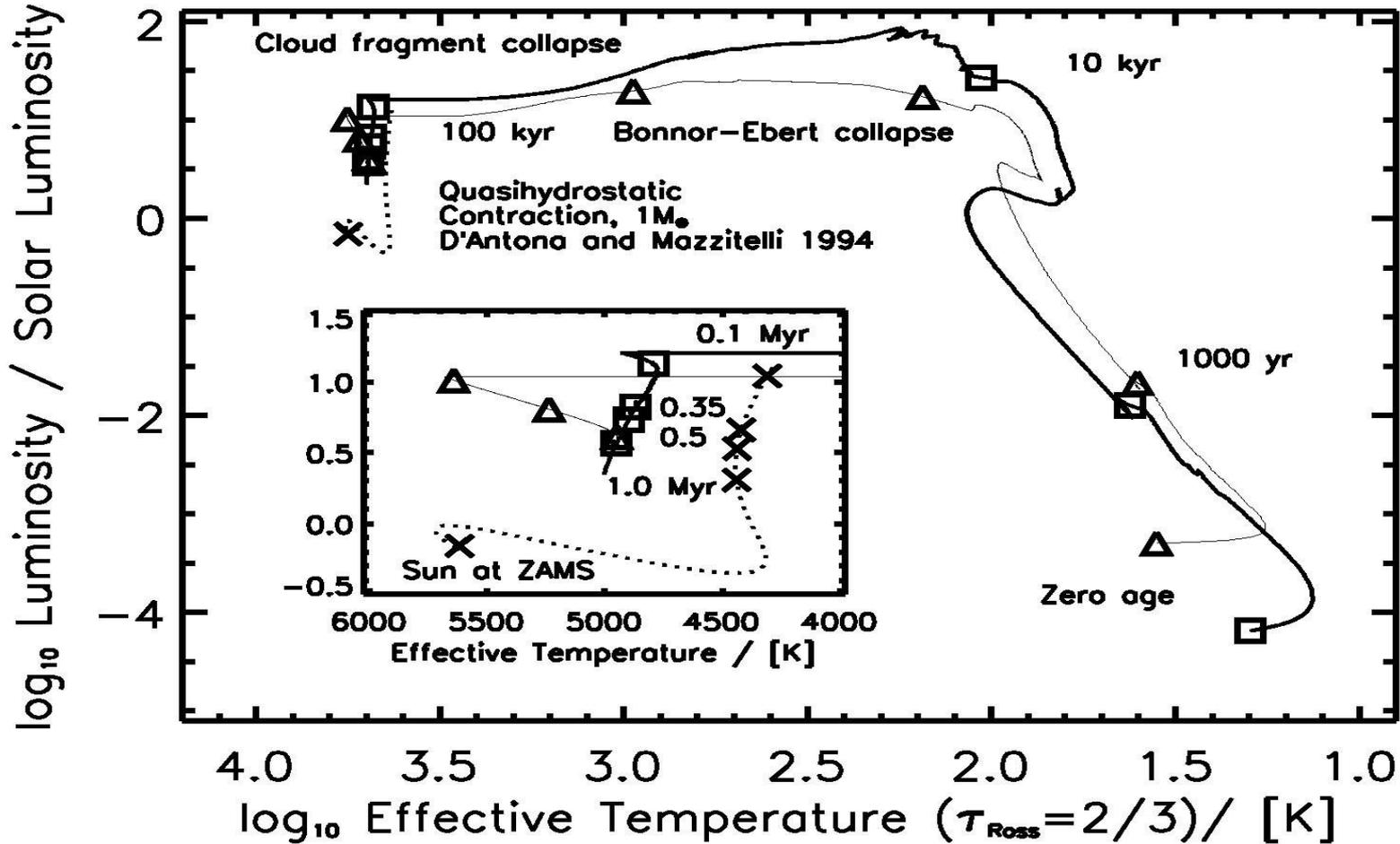
Ig probability density of observed planet properties. CoRoT

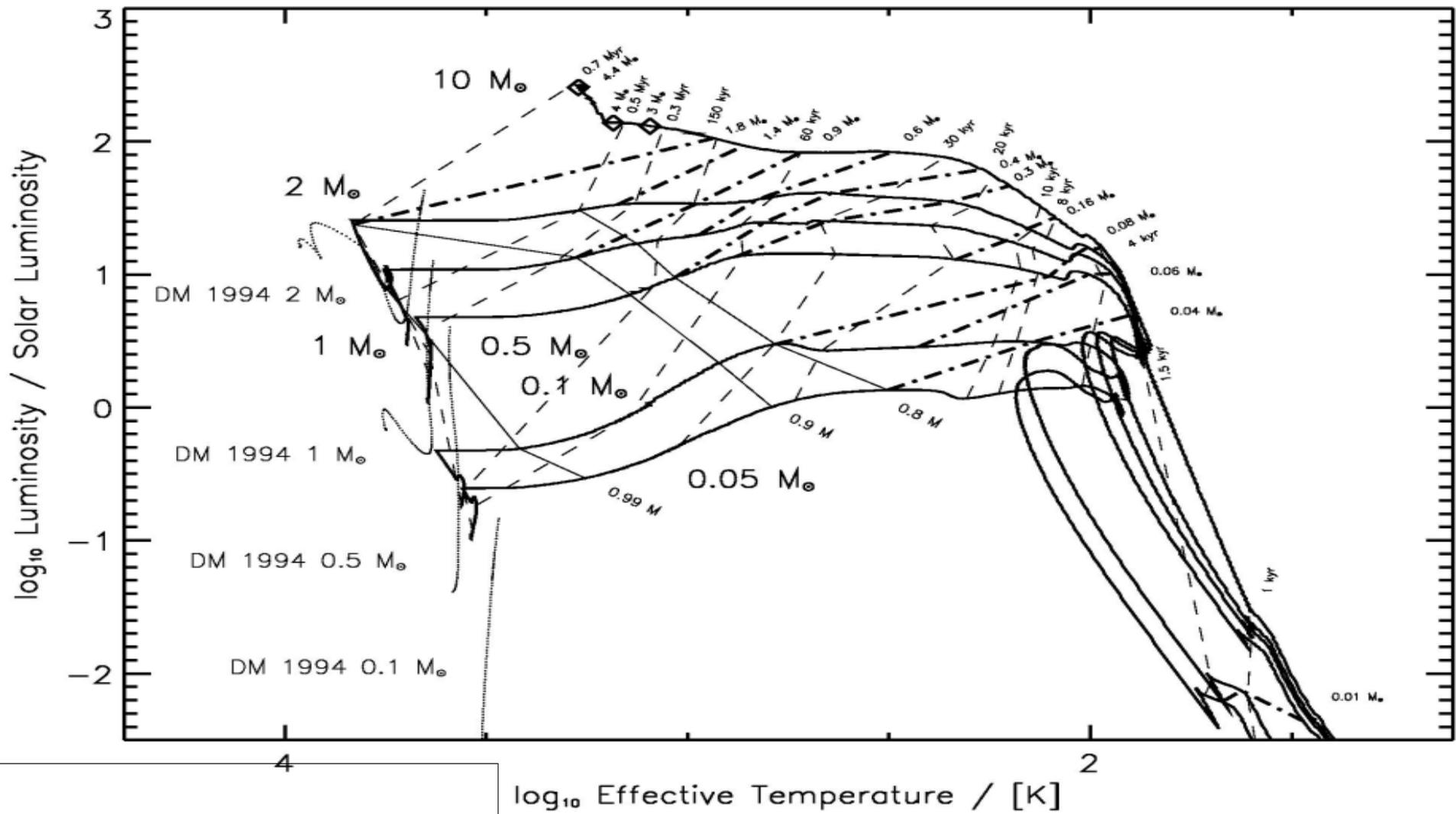


Ig CoRoT-Mark1R theoretical probability density, Bias: CoRoT

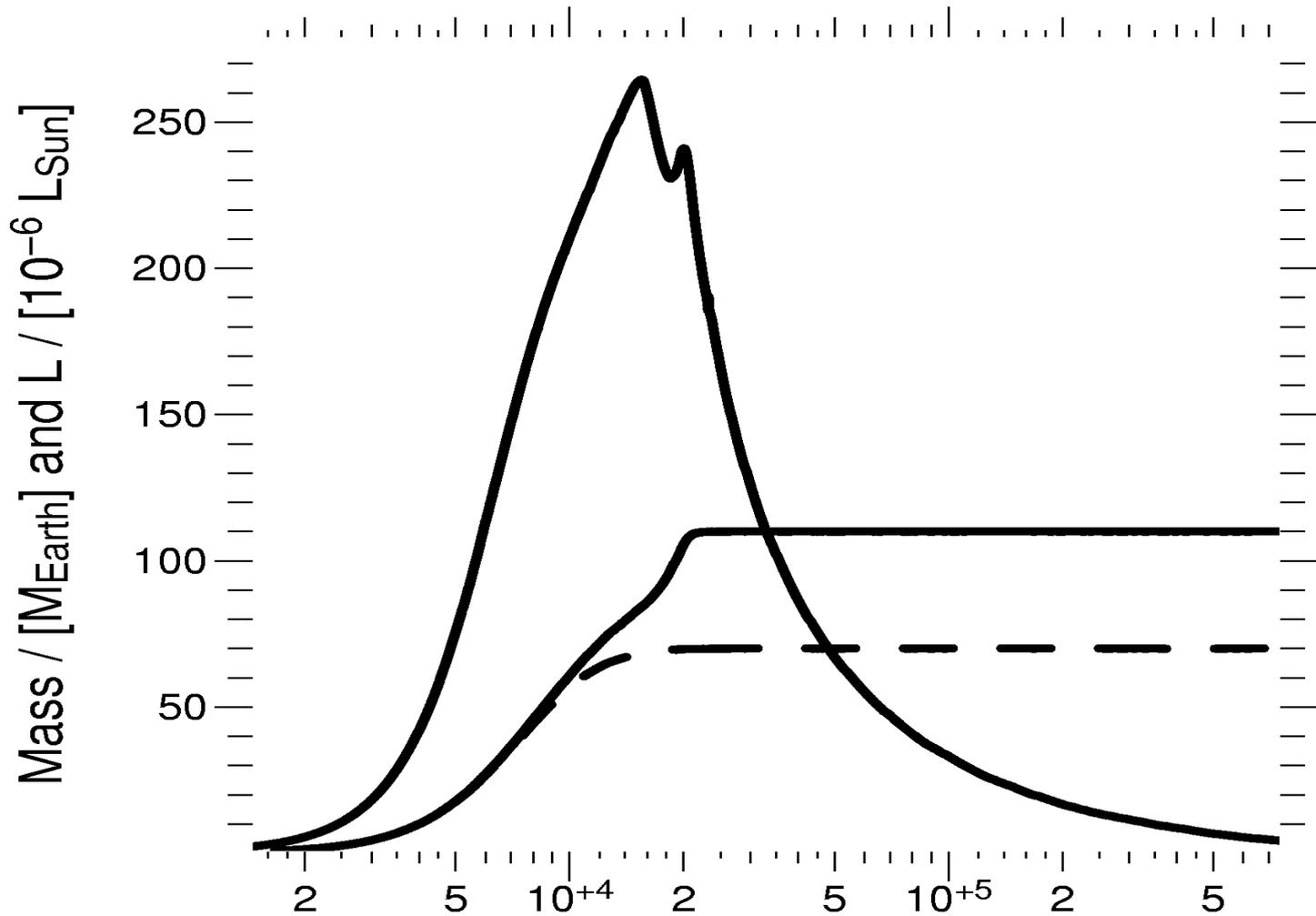


Towards the Hayashi Line: Bonnor-Ebert vs. Cloud Fragmentation

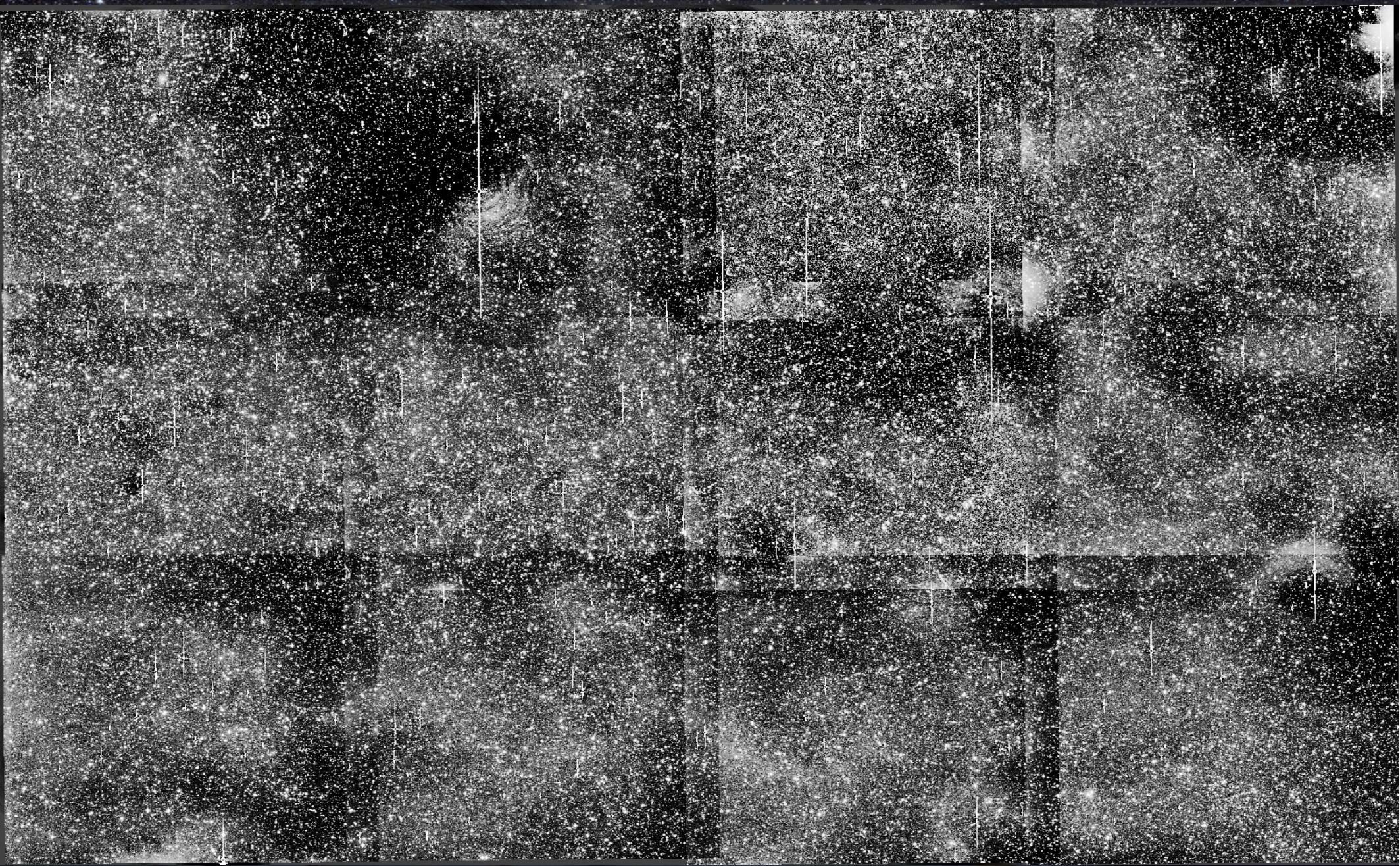


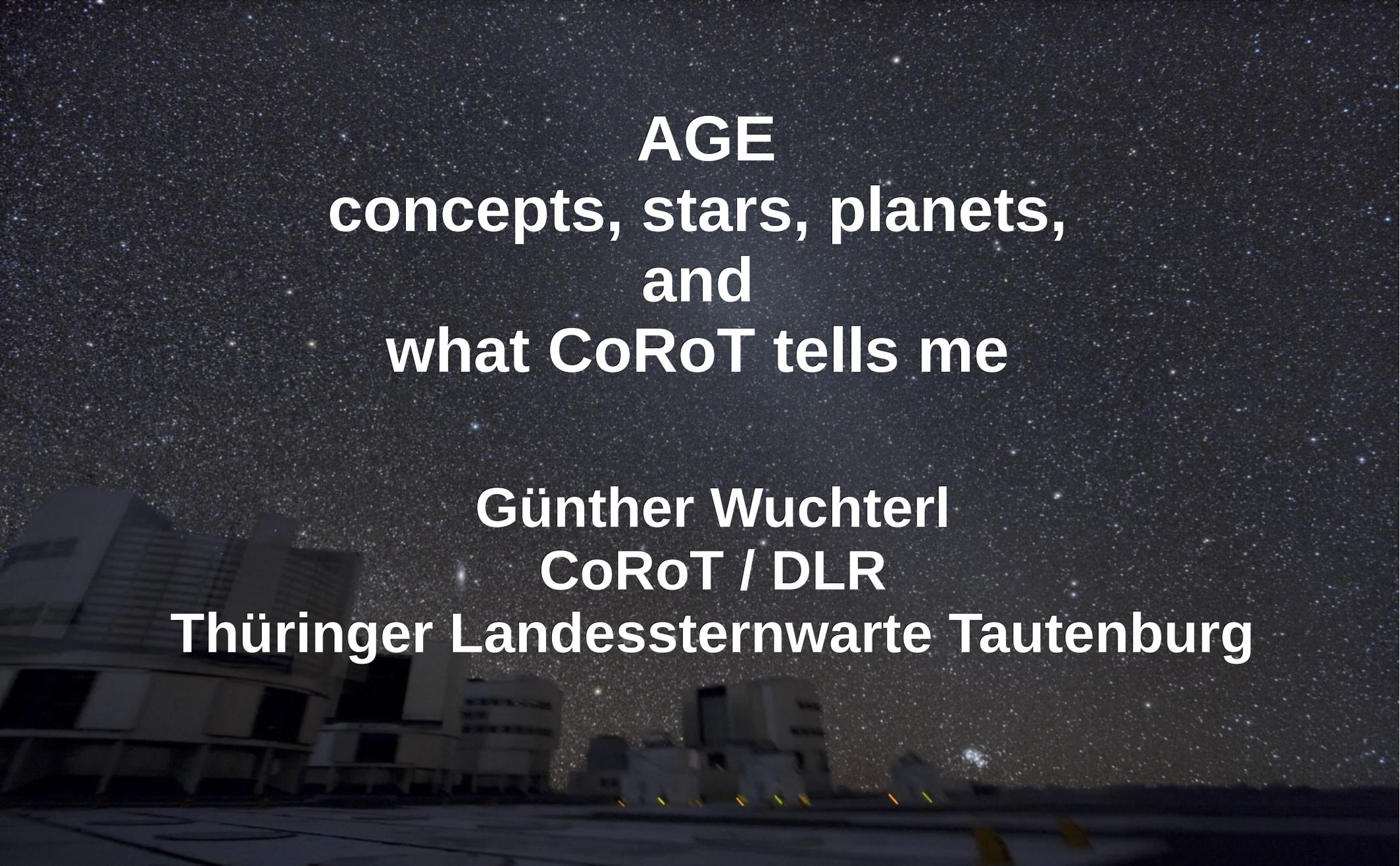


HD149026b: Mass and Luminosity CRFD+PiB(10)



Age/[a] Wuchterl and Tscharnuter 2003





AGE
concepts, stars, planets,
and
what CoRoT tells me

Günther Wuchterl
CoRoT / DLR
Thüringer Landessternwarte Tautenburg

PLATO

... guiding astrophysics out of
the cave.

Accuracy: M,R: 1% Age: 10%

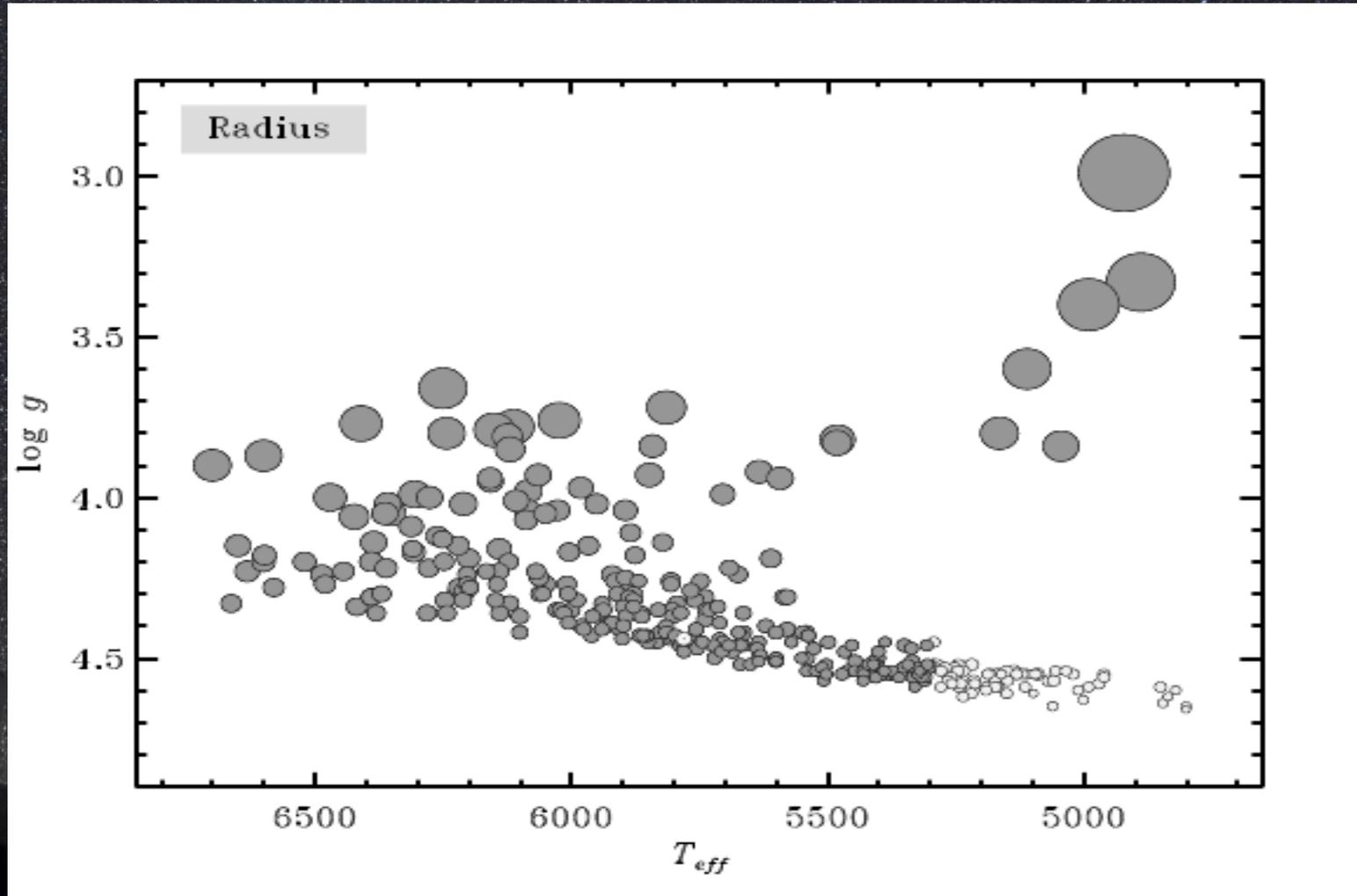
View of the cave Feb 2011

- The light: 115 planet host
- The shadows: 122 transiting planets
- The sound: p-modes $l=0,1,2$ for 5+ hosts
- The wall
 - Measurement of stellar parameters
 - Quantitative origin an early evolution of stars and planets
 - Convection

Accuracy
now

Spectro-
scopic
Stellar Radii

F,G,K
<25 pc



Accuracy – spectro vs. interferometry

Table 2. Stellar radii from Balmer line effective temperatures versus interferometry. The homogeneously derived spectroscopic data have 1σ uncertainties at the 2 per cent level; the precision stellar radii from interferometry reach even down to 0.5 per cent. The stars in this table are arranged from dwarfs, turnoff stars, and subgiants, to the bottom of the red giant branch. The differences in the stellar radii, while generally small, are tentatively related to this sequence. Note that both sets of data refer here to the revised van Leeuwen (2007) Hipparcos parallaxes.

Object	HR	HD	T_{eff} (K)	$\log g$ (cgs)	$R_{Balmer\ lines}$ (R_{\odot})	$R_{Interferometry}$ (R_{\odot})	Ref.	Diff. (per cent)
ϵ Eri	1084	22049	5054	4.54	0.763 ± 0.015 ($\pm 1.99\%$)	0.735 ± 0.005 ($\pm 0.68\%$)	1	+3.81
σ Dra	7462	185144	5265	4.57	0.786 ± 0.015 ($\pm 1.94\%$)	0.776 ± 0.007 ($\pm 0.96\%$)	2	+1.29
τ Cet	509	10700	5373	4.54	0.816 ± 0.016 ($\pm 1.91\%$)	0.791 ± 0.004 ($\pm 0.51\%$)	1	+3.16
μ Cas A	321	6582	5387	4.45	0.779 ± 0.017 ($\pm 2.13\%$)	0.790 ± 0.009 ($\pm 1.12\%$)	2	-1.39
Procyon	2943	61421	6470	4.00	2.118 ± 0.038 ($\pm 1.78\%$)	2.058 ± 0.022 ($\pm 1.07\%$)	3	+2.92
						2.059 ± 0.022 ($\pm 1.07\%$)	4	+2.87
η Boo Aa	5235	121370	6023	3.76	2.761 ± 0.061 ($\pm 2.20\%$)	2.781 ± 0.050 ($\pm 1.81\%$)	3	-0.72
						2.696 ± 0.054 ($\pm 2.00\%$)	5	+2.41
						2.683 ± 0.042 ($\pm 1.57\%$)	6	+2.91
β Vir	4540	102870	6085	4.04	1.687 ± 0.031 ($\pm 1.84\%$)	1.704 ± 0.022 ($\pm 1.26\%$)	7	-1.00
μ Her Aa	6623	161797	5592	3.94	1.706 ± 0.030 ($\pm 1.73\%$)	1.746 ± 0.035 ($\pm 2.00\%$)	3	-2.29
δ Eri	1136	23249	5044	3.84	2.339 ± 0.047 ($\pm 2.00\%$)	2.328 ± 0.028 ($\pm 1.20\%$)	5	+0.47
η Cep	7957	198149	4990	3.40	3.986 ± 0.080 ($\pm 2.01\%$)	4.066 ± 0.062 ($\pm 1.52\%$)	8	-1.97
η Ser	6869	168723	4921	2.99	5.822 ± 0.120 ($\pm 2.05\%$)	5.871 ± 0.028 ($\pm 0.48\%$)	9	-0.83

Notes: (1) Di Folco et al. (2007); (2) Boyajian et al. (2008); (3) Mozurkewich et al. (2003); (4) Kervella et al. (2004); (5) Thévenin et al. (2005); (6) van Belle, Ciardi & Boden (2007); (7) North et al. (2009); (8) Nordgren et al. (1999); (9) Mérand et al. (2010)

Present Accuracy Limit for Radii of Bright Stars

2%

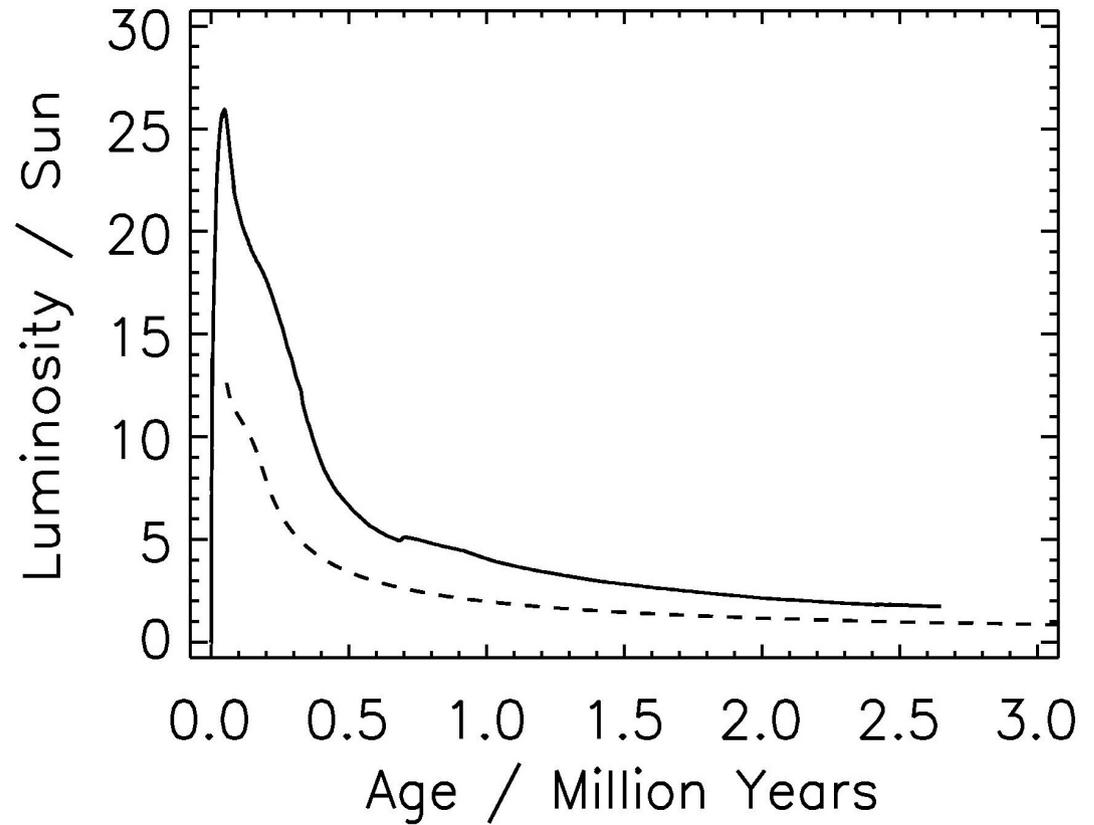
Chronology I: Age

- No sit, watch and count in stellar evolution
- Age is not a direct empirical quantity
- A parameter in a theory
- Needs
 - epoch (zero – point)
 - clock
- Clock: well constraint, controlled and understood physical process
- : **Clock=mature theory in the PLATO context**

Chronology II: On Clocks and Clouds

- Cloud collapse to PMS
- Age zero: formation of the photosphere

- Contraction- clock
- Radiative YSO
- PMS: 10% at UMa age
- Memory?



Chronology III: The Convection Trilemma

- The clock – stellar interior: $\Lambda/H_p = 1.5 - 2.0$
- The temperature – atmosphere: $\Lambda/H_p = 0.5$
 - Seismo density needs T_{eff} or $T(r)$ for sound-speed to get the mean stellar density
- The planet radius – ingress with limb-darkening
 $\Lambda/H_p = ?$

Present heuristics: freeze convection to 1958
MLT, Christensen Dalsgaard et al. 2009

Mach about Plato

15. Es liesse sich leicht durch analoge Beispiele aus andern Gebieten der Physik darthun, dass die Menschen überhaupt die Neigung haben, ihre selbstgeschaffenen abstrakten Begriffe zu hypostasiren, ihnen Realität ausserhalb des Bewusstseins zuzuschreiben. Platon hat von dieser Neigung in seiner Ideenlehre nur einen etwas freien Gebrauch gemacht. Selbst Forscher wie Newton waren, ihren Grundsätzen zum Trotz, nicht immer vorsichtig genug. Es verlohnt sich also wohl der Mühe, zu untersuchen, vorauf dieser Vorgang in diesem besonderen Falle beruhen mag. Wir gehen bei unsern Beobachtungen von der

It would be easy to demonstrate from other areas of physics that humans generally tend to To ascribe material existence to their self-created abstract concepts, to ascribe to them a reality outside the consciousness. Plato just used this tendency rather freely in his theory of ideas. Even scientists like Newton where, in spite of the principles, not cautious enough.

Mach, Wärmelehre, p.551, Leipzig 1900

What CoRoT tells me - I

Theory:

- systems to be expected (Lissauer 1995, pre Peg, Funk et al. 2009)
- 2/3 Neptunes, 1/3 Jupiters (Wuchterl et al. 2006, pre CoRoT; Broeg 200);

Observations:

- RV for planet mass: 2 measurements at extremes → CoRoT-7: 110 meas. to disentangle system
- Kepler: no RV-mass for half the multis (... “America waives the rules”) - rem. Neptune

What CoRoT tells me - II

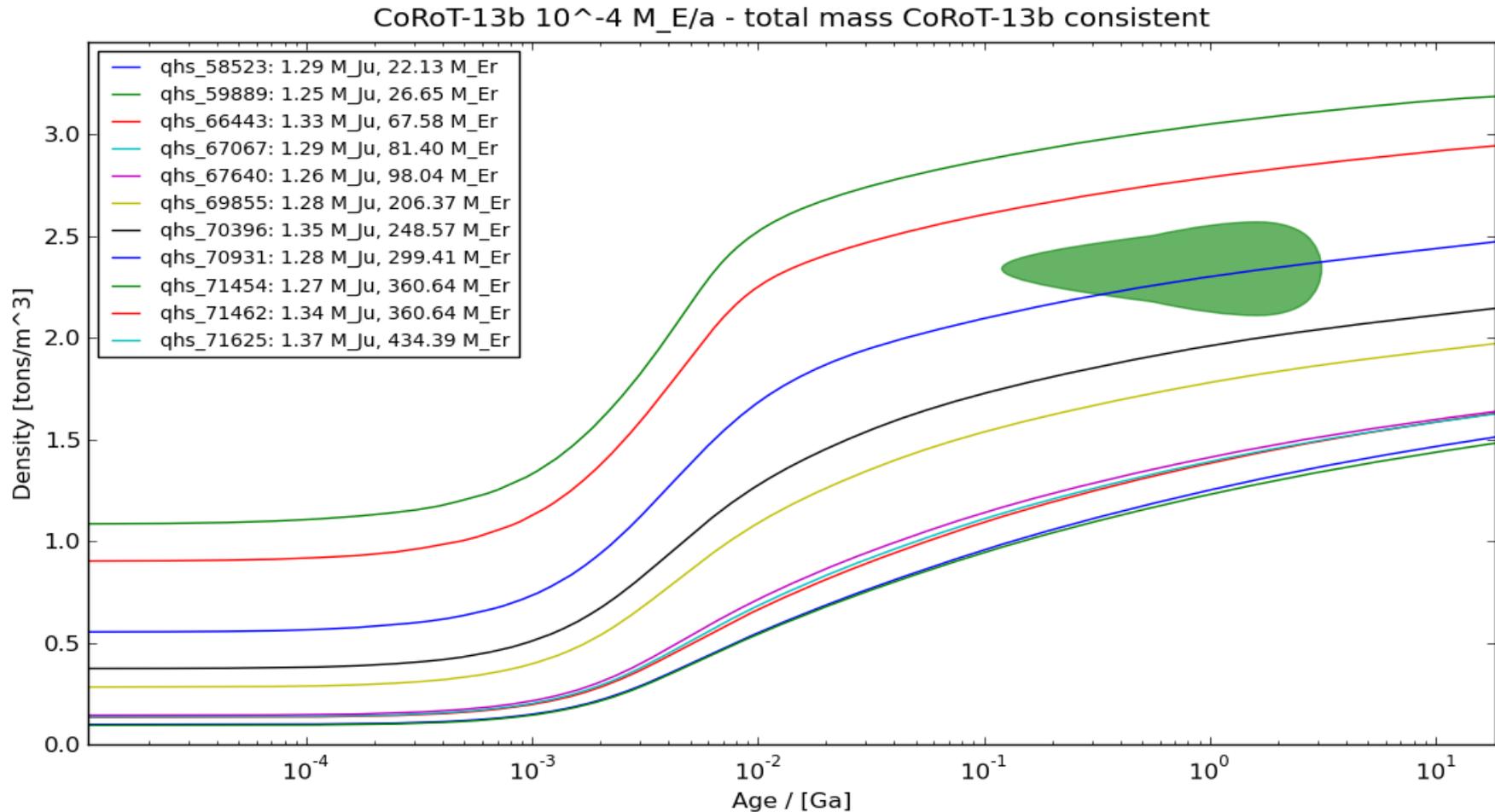
- : make correctable theory tools accessible to data analysis design and procedures as well as observation-planning.

e.g. consistent limb darkening, stellar atmospheres, planet radii and ages for your favourite flavour of convection.

A night sky filled with stars, with a cityscape visible in the foreground. The text "One planet analysis one physics" is overlaid on the sky.

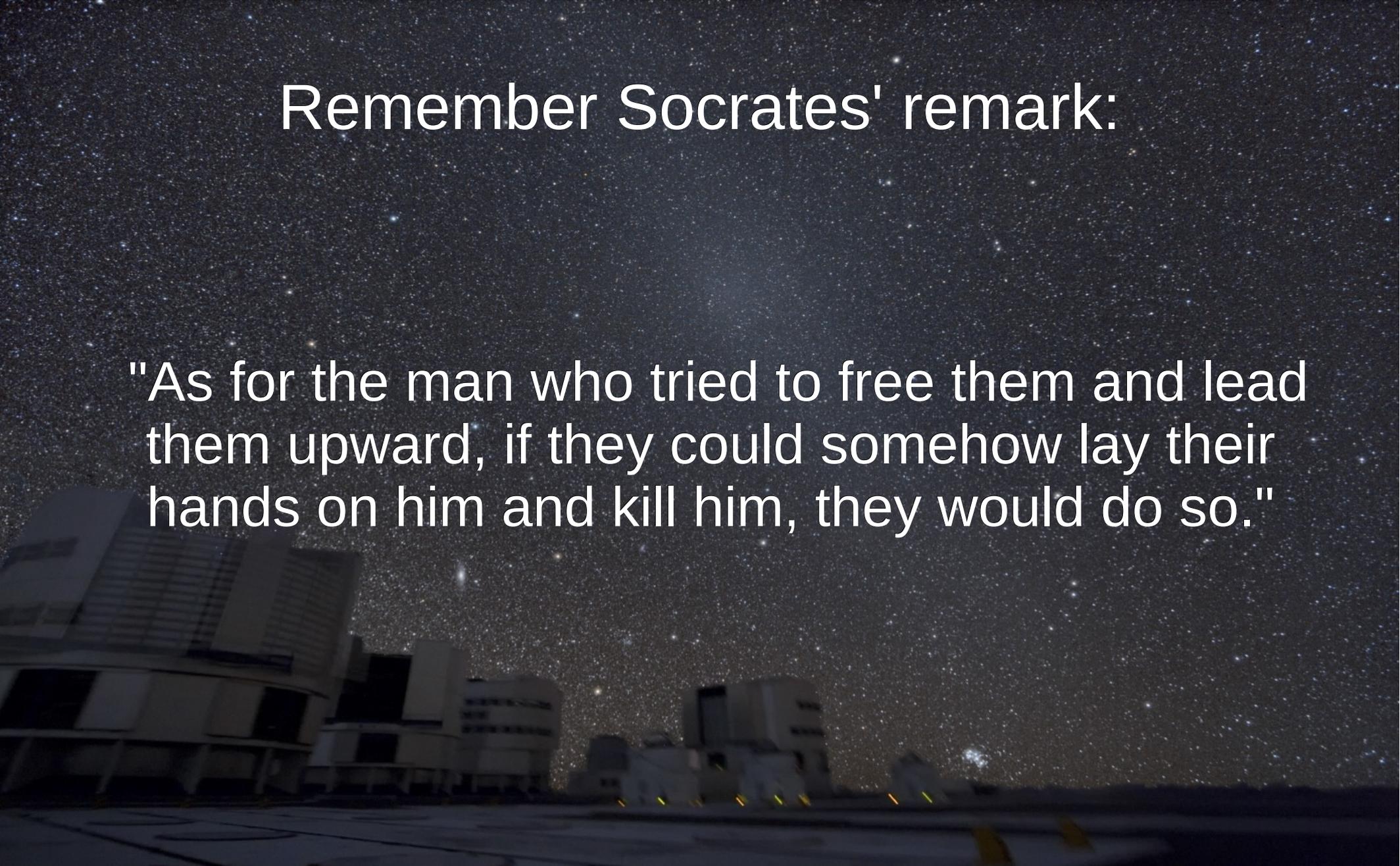
One planet analysis one physics

CoRoT-13b: density and theory



MACH - the PLATO clockmaker

- Theoretical mission support with age accuracy management
- Consistent theory for
 - stellar and planet formation and evolution
 - seismological and planet-transit analysis
- Motto: try another convection this morning
- determine limb darkening for transit-planet-radii with same convection theory used for seismo stellar structure and stellar atmos for T_{eff}



Remember Socrates' remark:

"As for the man who tried to free them and lead them upward, if they could somehow lay their hands on him and kill him, they would do so."

Conclusion

- Inter community theoretical mission support needed to unify tools in seismo and exoplanets and to control the better than 10% age accuracy.
- Break the de-facto freezing of convection to 1958 MLT in all theory domains.
- Bridge the gap between data analysis and theoretical progress.
- Build a toolbox for PLATO-astrophysics.

A night sky filled with a dense field of stars, ranging from small, faint points to larger, brighter ones. The stars are scattered across the dark expanse, creating a rich, multi-colored star field. At the bottom of the image, the dark silhouette of a cityscape is visible, with several buildings of varying heights and shapes. The foreground shows a dark, flat surface, possibly a road or a field, with some faint yellow markings. The overall scene is a composite of a starry night sky and a cityscape, likely representing a virtual or simulated environment.

Plato.astronomy2009.at