Expect the unexpected:
non-equilibrium processes in Brown Dwarf (model) atmospheres

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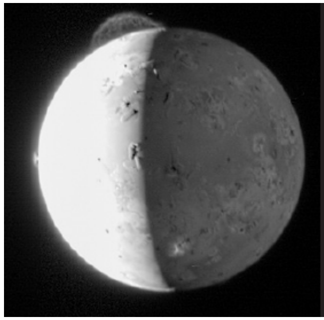
IDEAS

University of St Andrews



charge processes in planetary environments
LEAP
life electricity atmosphere planet

Two things to remember:

- **Applying model atmospheres to observed data:**
  Using multiple model families allows to
  assess systematically systematic model uncertainties
  (hence, derive confidence intervals for derived parameters)

- **If model reproduces data only partially:**
  Expect the unexpected, like for example,
  ionisation signatures in a seemingly unionised atmosphere

Model atmosphere grids available for use:

ATLAS (Kurusz 1970, Castelli & Kurucz 2004)
oxygen-rich, various metallicities with α-elements enhanced, $T_{eff} \geq 3400$K
(enhanced α-elements: O, Ne, Mg, Si, S, Ar, Ca, and Ti), no dust

MARCS (Gustafsson et al. 1975, 2008; Laverney et al. 2012)
carbon-rich & oxygen-rich; both various metallicities, T_{eff}=2200 … 8000K, no dust

PHOENIX (Hauschildt, Baron & Allard 1997):
oxygen-rich, various metallicities, no dust
NextGen-PHOENIX: improves opacities,
DUSTY/COND equilibrium dust for low T_{eff} (Allard et al. 2001)
Gaia-PHOENIX (Brott & Hauschildt 2005):
NextGen update, plus α-elements enhanced
BT-Settl-PHOENIX (Allard et al.)
improved NextGen regarding dust treatment (time-scales)
Drift-ACES-PHOENIX (Dehn 2007, Witte et al. 2009, 2011):
improved NextGen regarding dust *formation* and gas-phase chemistry (ACES)

Model atmosphere grids available for use:

ATLAS (Kurusz 1970, Castelli & Kurucz 2004)
MARCS (Gustafsson et al. 1975, 2008; Laverney et al. 2012)
PHOENIX (Hauschildt, Baron & Allard 1997)

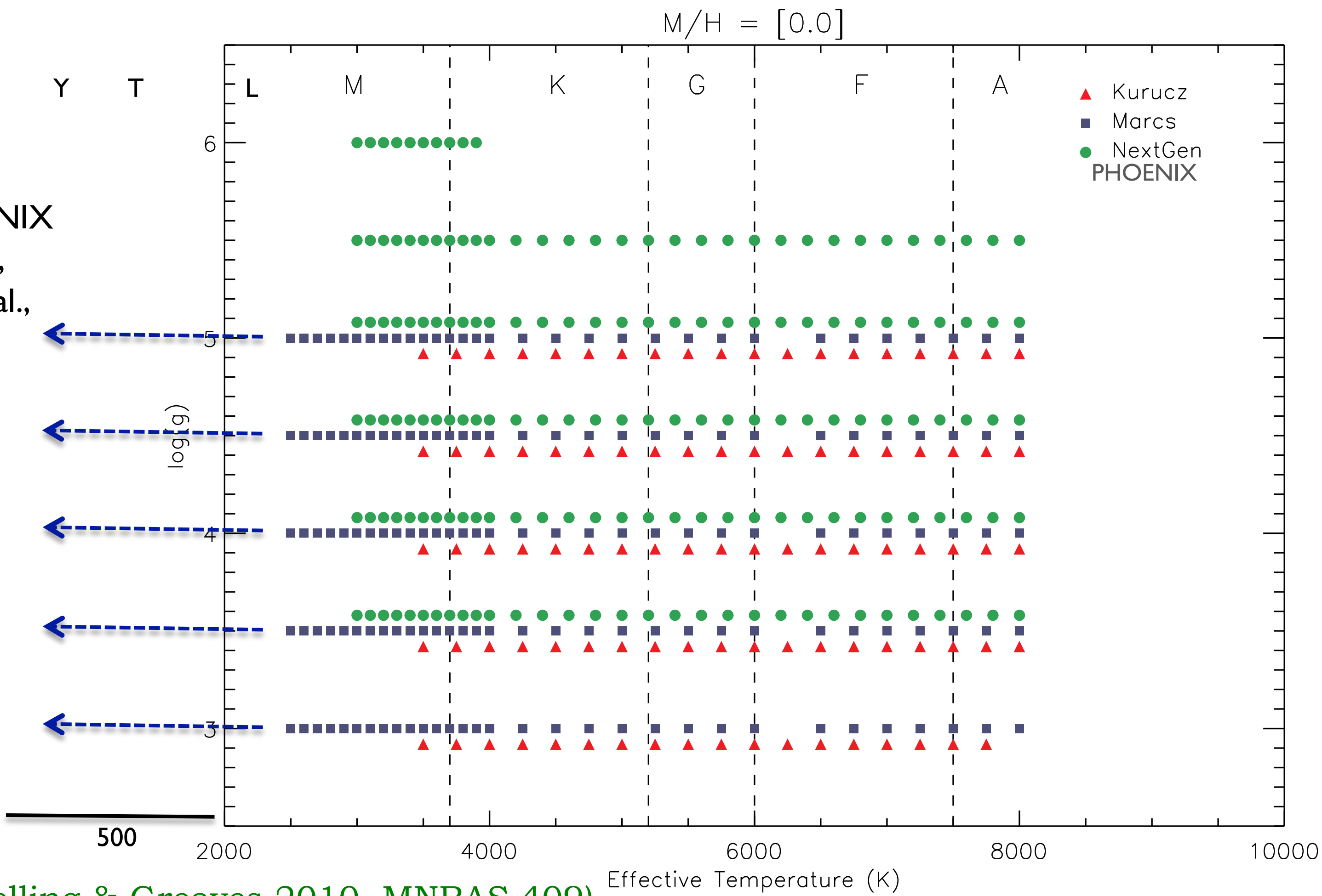
Tsuji (Tsuji 1973, 2002, 2005)
carbon-rich & oxygen-rich, dust opacity, T_{eff}<2200 … 4000K

Marley, Ackerman, Fortney, Stevensen, Saumon et al.
(Ackerman & Marley 2001, Saumon & Marley 2008, Stevensen et al. 2009)
oxygen-rich, dust included, T_{eff}< 3000K

Burrows, Hubany, Lunine, Liebert et al. (Burrows et al. 2001)
oxygen-rich, dust opacity, T_{eff}< 3000K

Model atmosphere grids available for use:

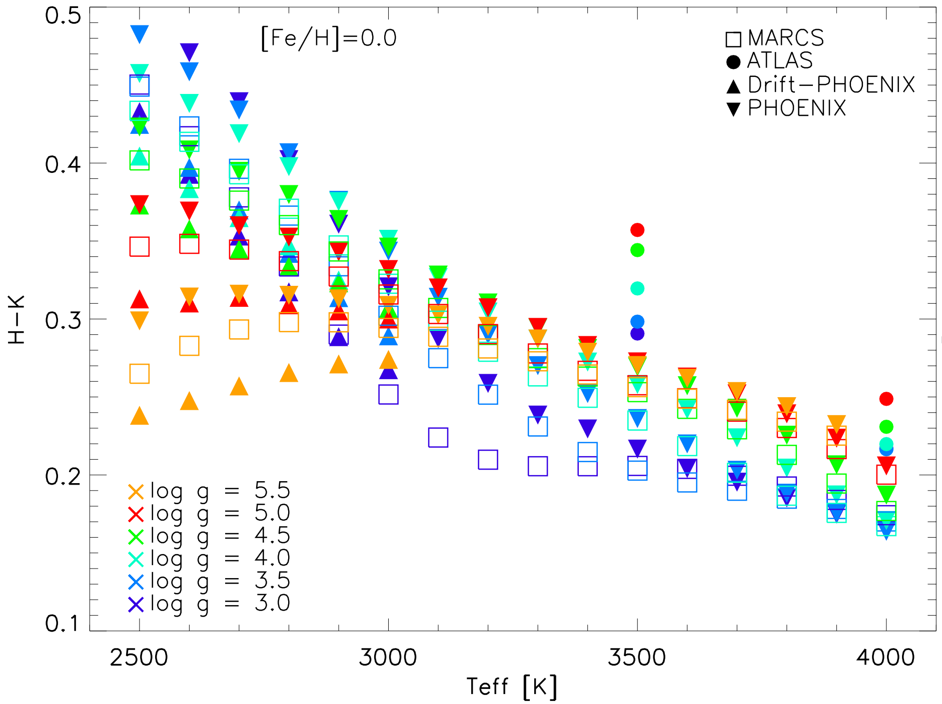
planets / brown dwarfs planetary host stars

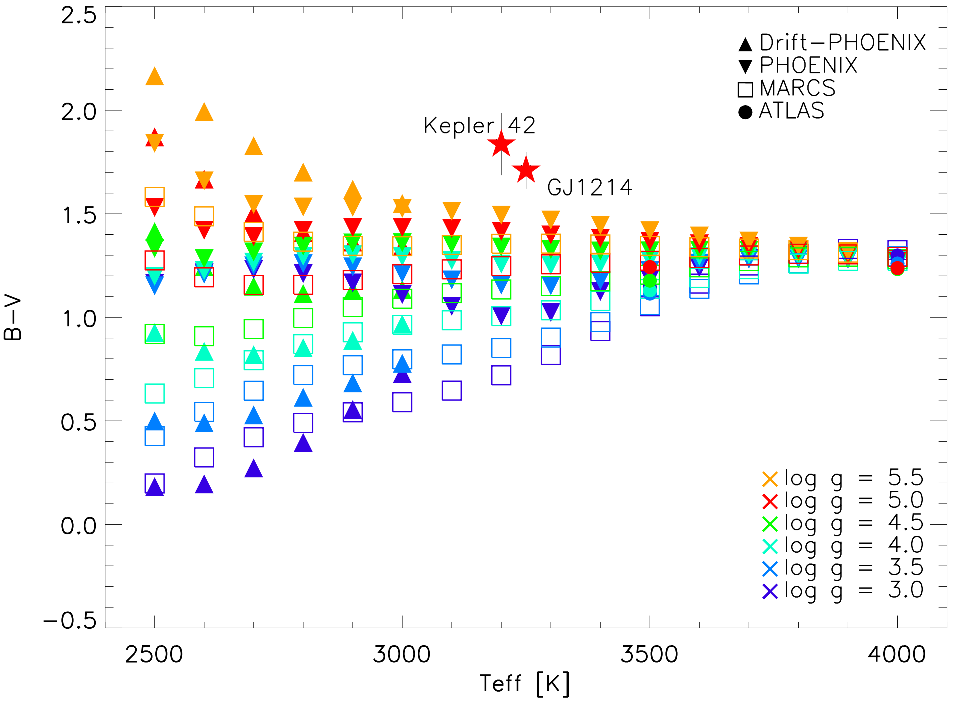


BT-Settle,
Drift-PHOENIX
Marley et al.,
Burrows et al.,
Tsuji et al.

(Sinclair, Helling & Greaves 2010, MNRAS 409)

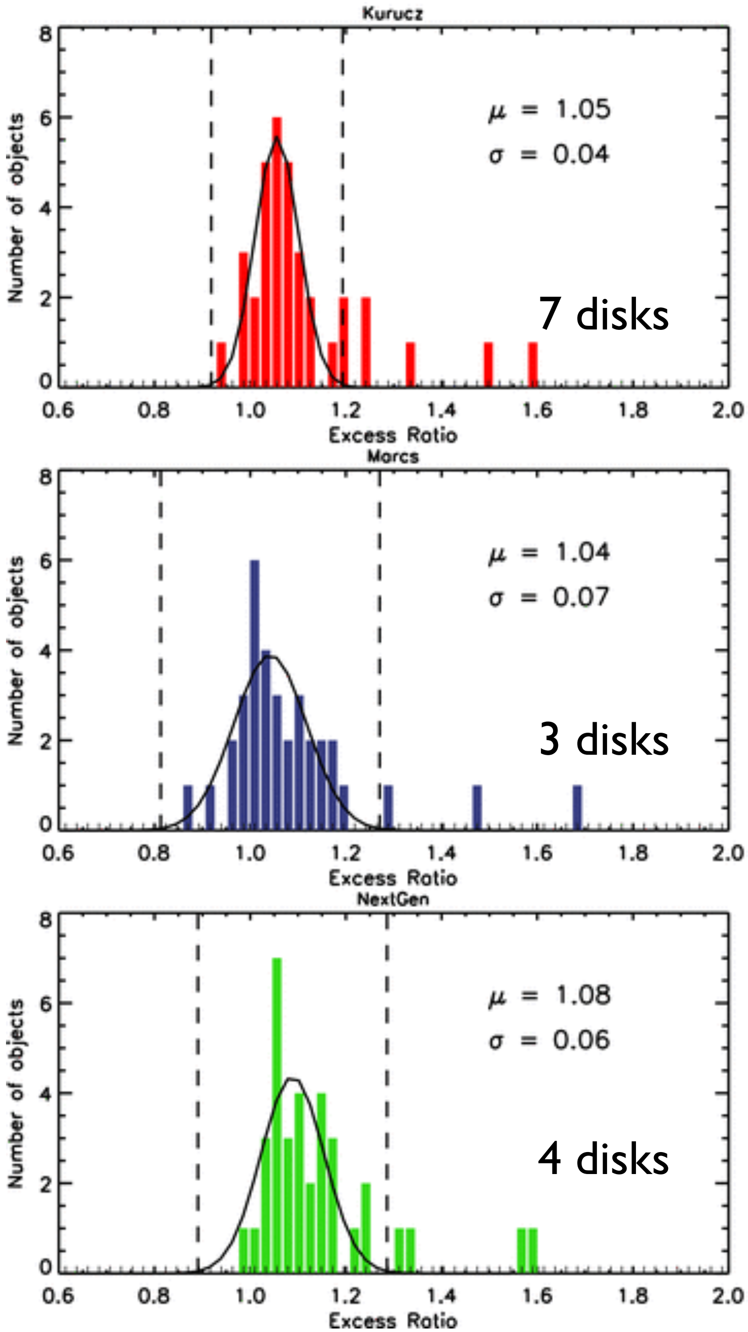
Comparison of warm model atmosphere (no clouds)





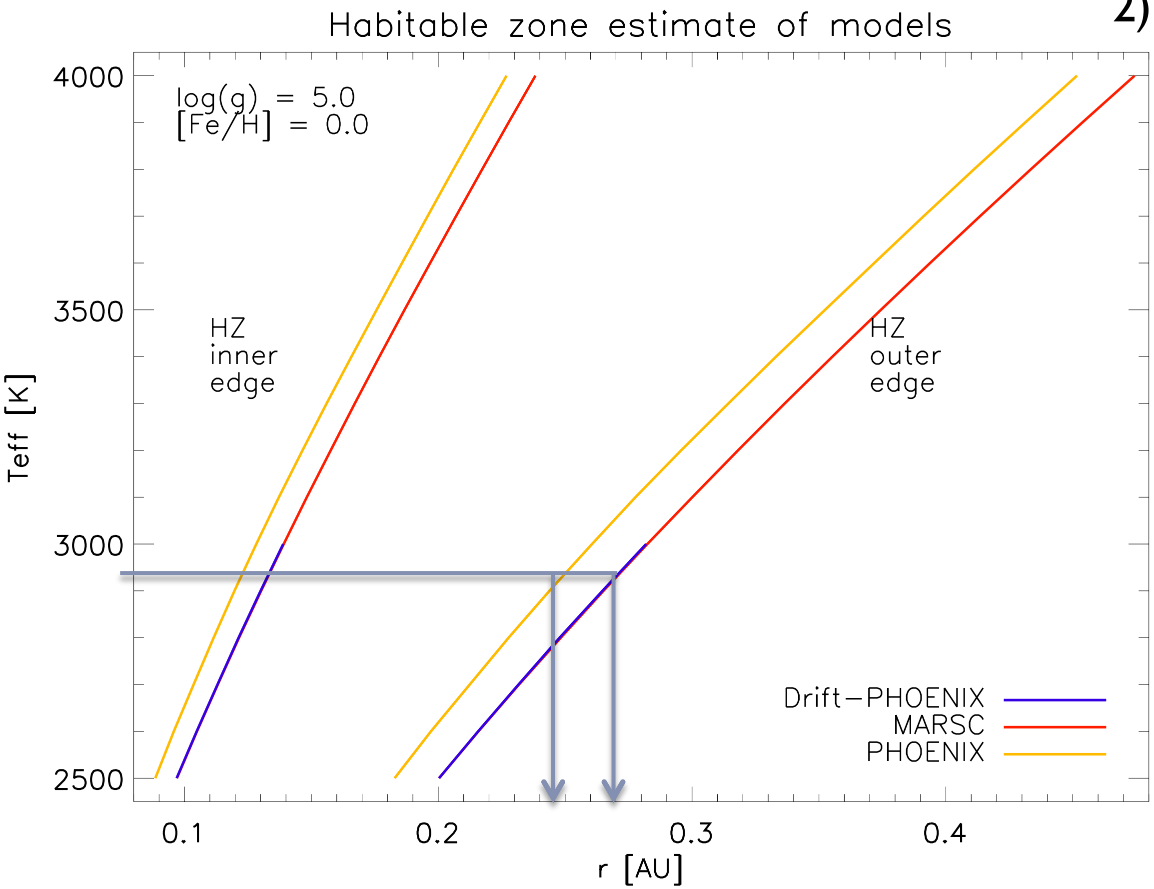
(Bozhinova, Helling & Scholz 2014, MNRAS, subm)

The impact of model uncertainties



1) Model uncertainties do influence number of disks observed (via far-IR excess with Spitzer)
(Sinclair, Helling & Greaves 2010, MNRAS 409)

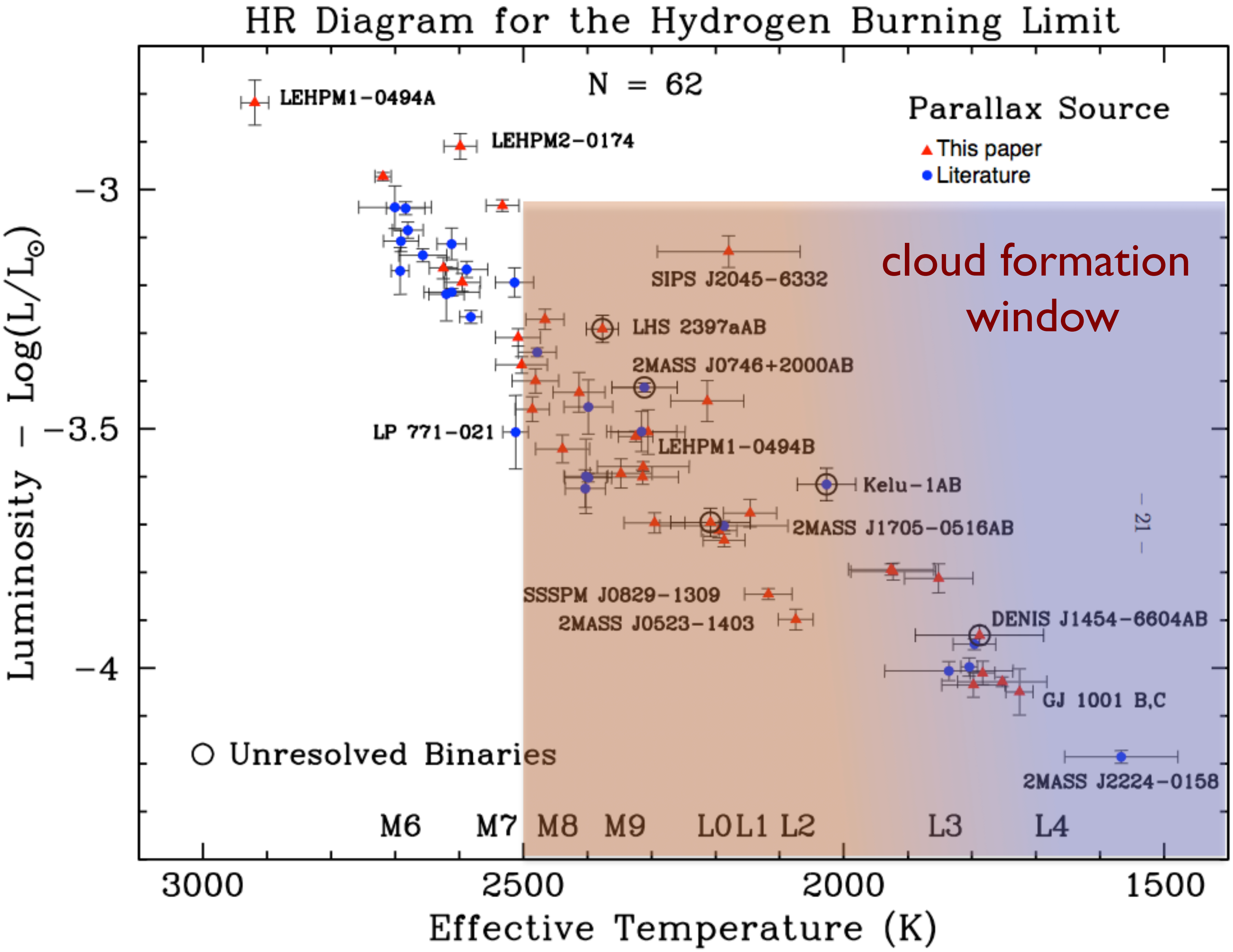
The impact of model uncertainties



2) Model uncertainties do influence derived planetary parameter

→ location of habitable zone

(Bozhinova, Helling & Scholz 2014, MNRAS, subm)

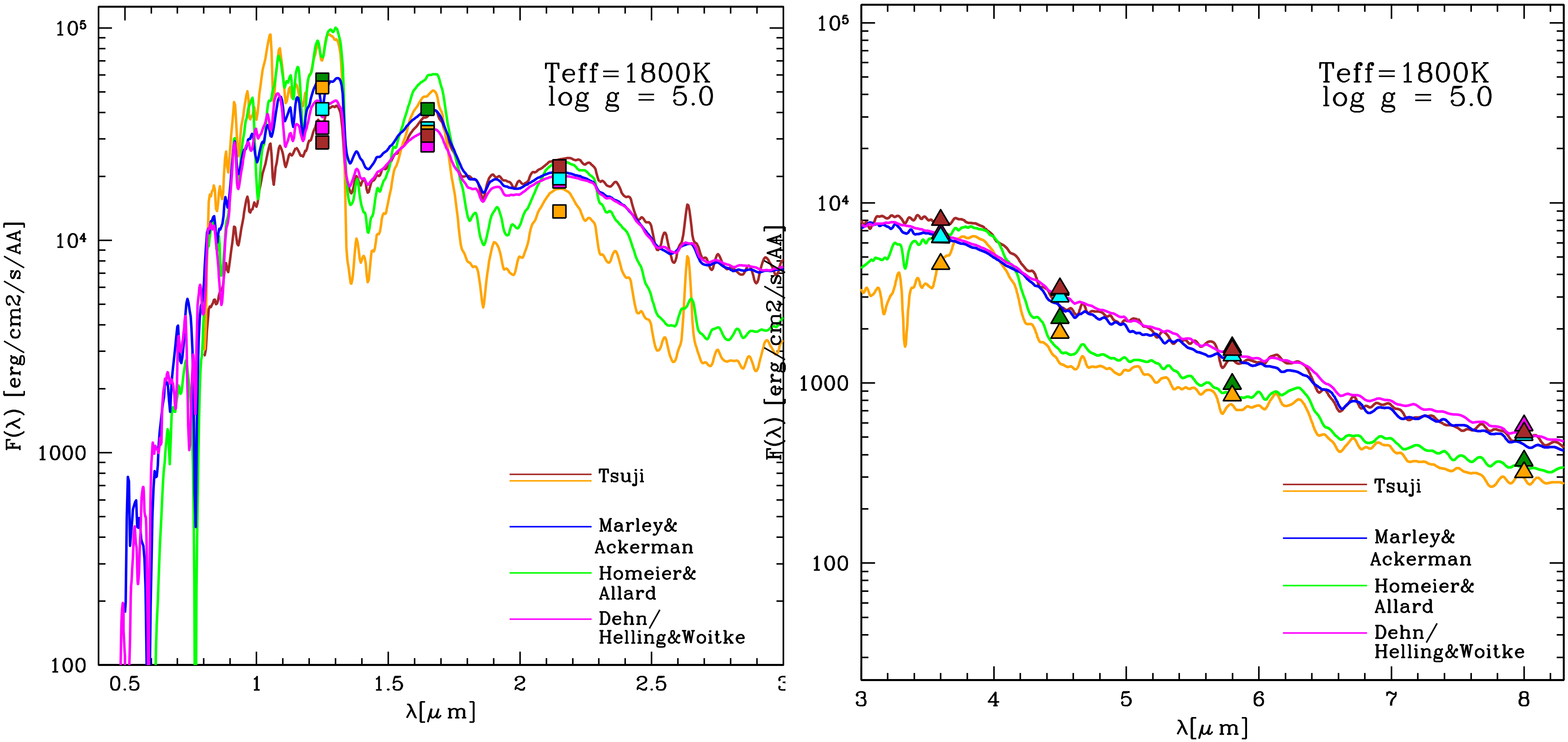


HR Diagram for the Hydrogen Burning Limit

(Dieterich et al. 2013)

Brown Dwarf model atmosphere comparison

(Helling, Ackerman, Allard, Dehn, Hauschildt, Homeier, Lodders, Marley, Rietmeijer,Tsuji & Woitke 2008, MNRAS 391)



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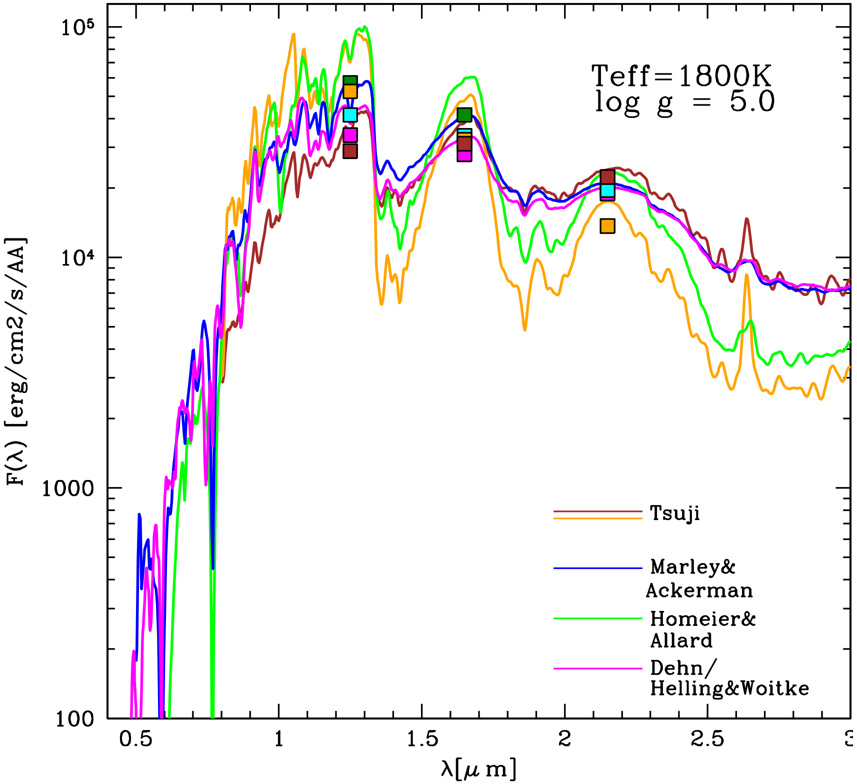
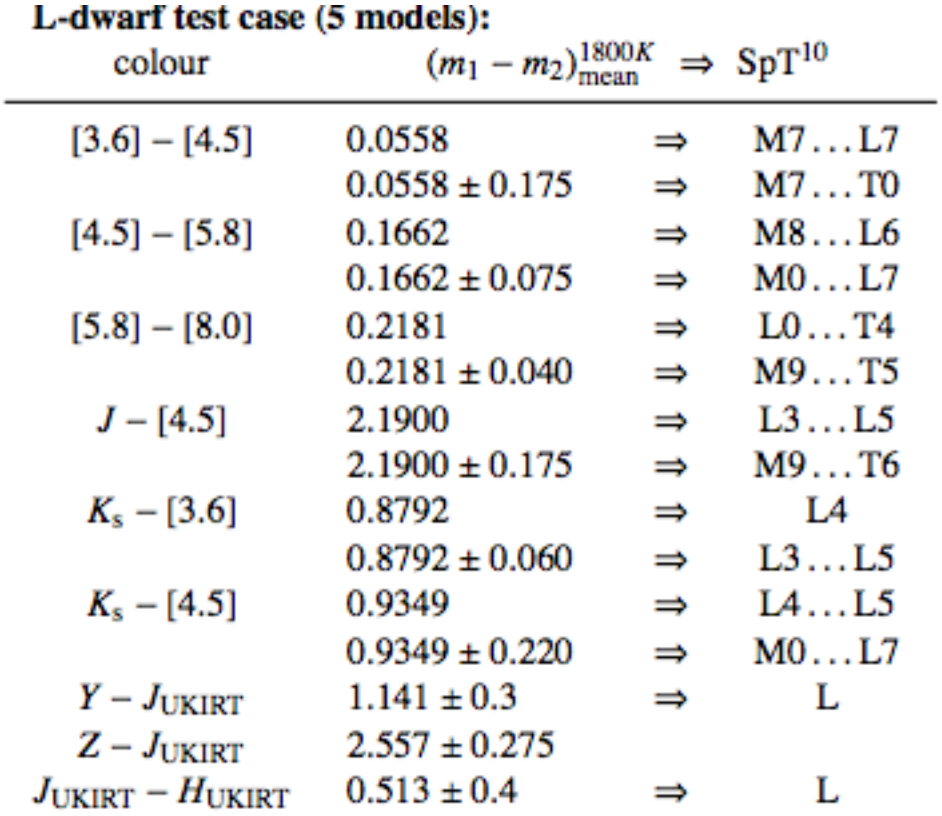
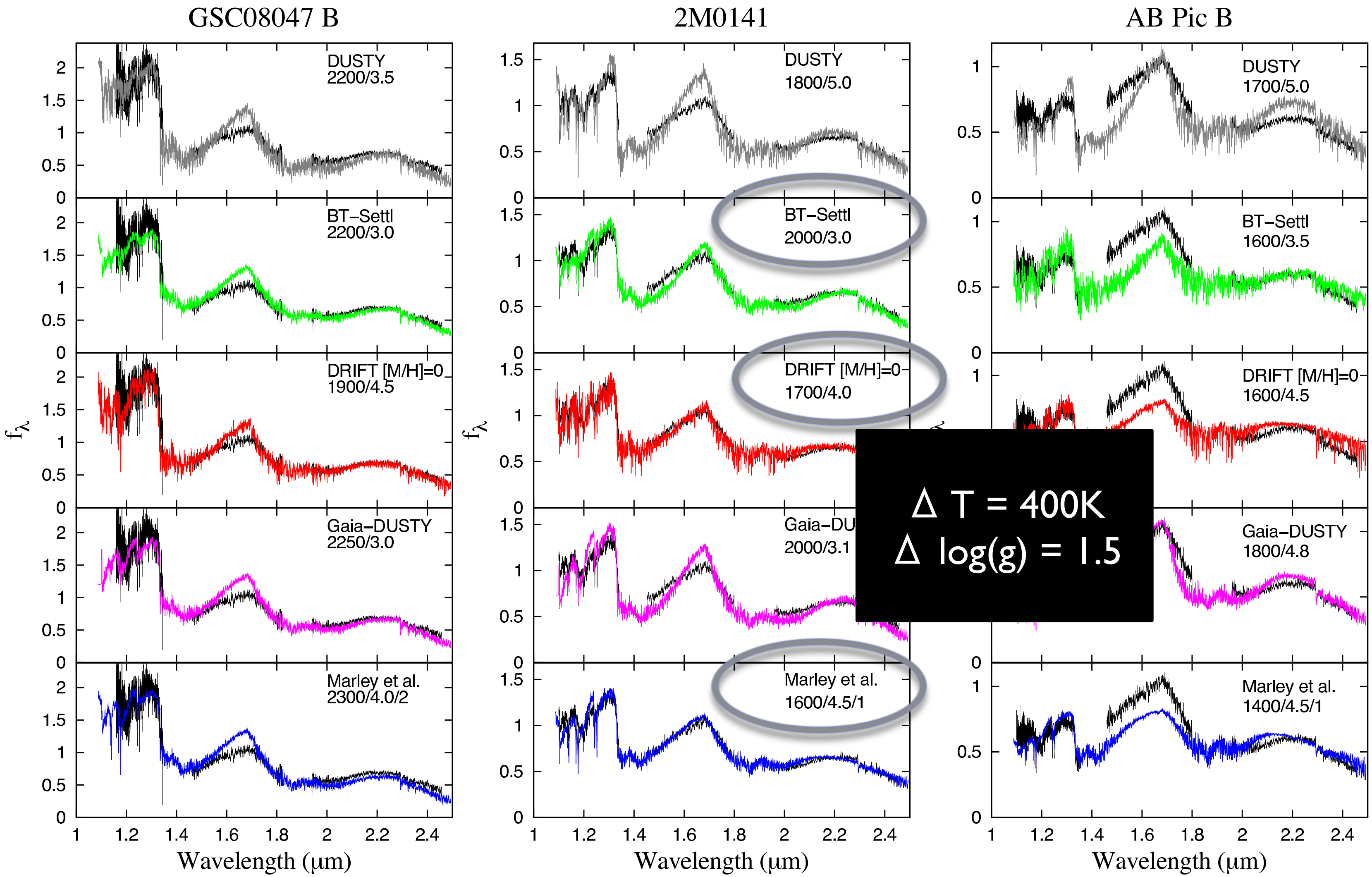


L-dwarf test case (5 models):



colour	$(m_1 - m_2)^{1800K}_{\rm mean}$	⇒	$\rm SpT^{10}$
$[3.6]-[4.5]$	0.0558	⇒	M7...L7
	0.0558 ± 0.175	⇒	M7...T0
$[4.5]-[5.8]$	0.1662	⇒	M8...L6
	0.1662 ± 0.075	⇒	M0...L7
$[5.8]-[8.0]$	0.2181	⇒	L0...T4
	0.2181 ± 0.040	⇒	M9...T5
$J-[4.5]$	2.1900	⇒	L3...L5
	2.1900 ± 0.175	⇒	M9...T6
$K_s-[3.6]$	0.8792	⇒	L4
	0.8792 ± 0.060	⇒	L3...L5
$K_s-[4.5]$	0.9349	⇒	L4...L5
	0.9349 ± 0.220	⇒	M0...L7
$Y-J_{\rm UKIRT}$	1.141 ± 0.3	⇒	L
$Z-J_{\rm UKIRT}$	2.557 ± 0.275		
$J_{\rm UKIRT}-H_{\rm UKIRT}$	0.513 ± 0.4	⇒	L

Model diversity

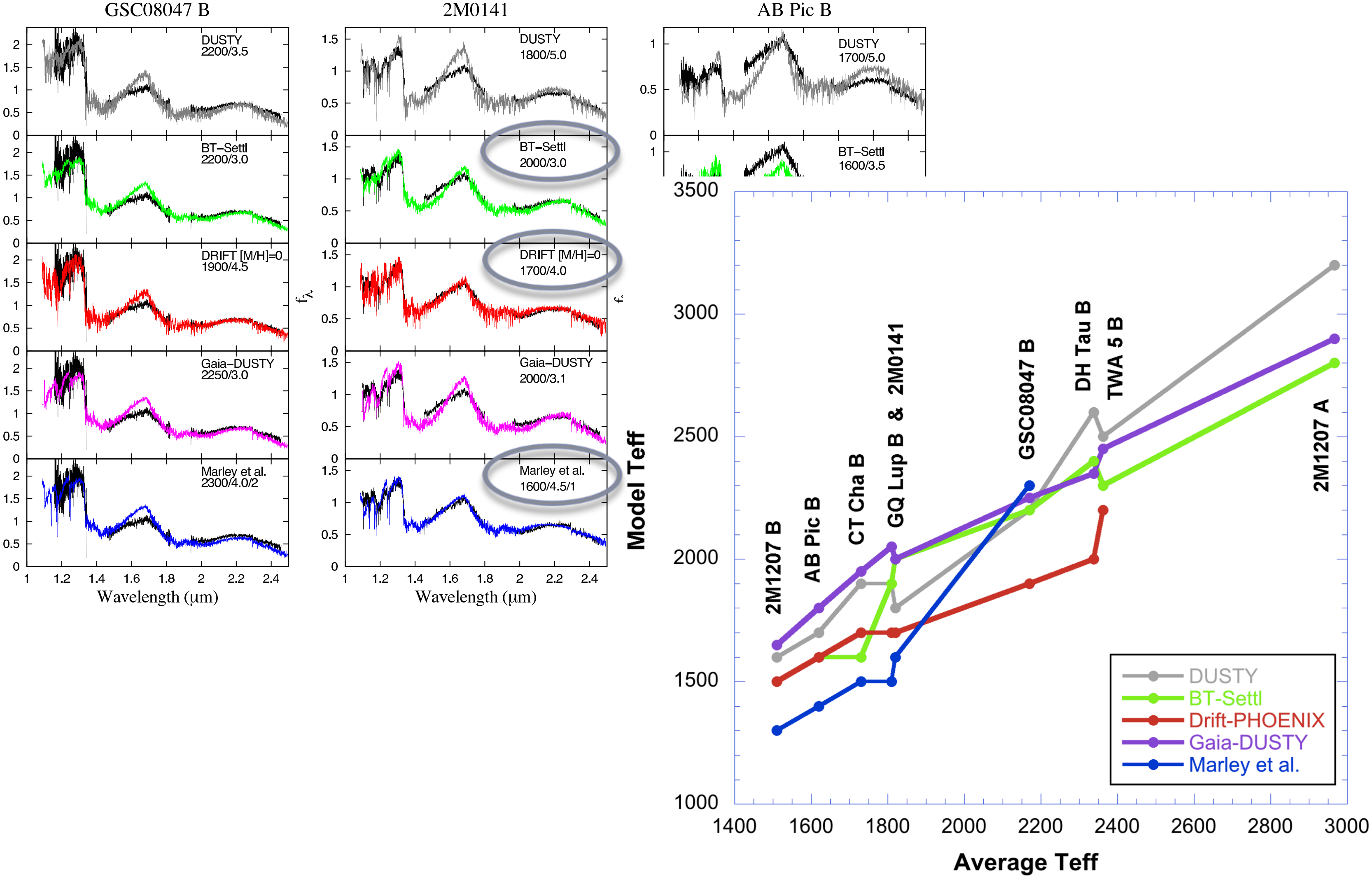


Δ T = 400K
Δ log(g) = 1.5

(Patience et al. 2012)

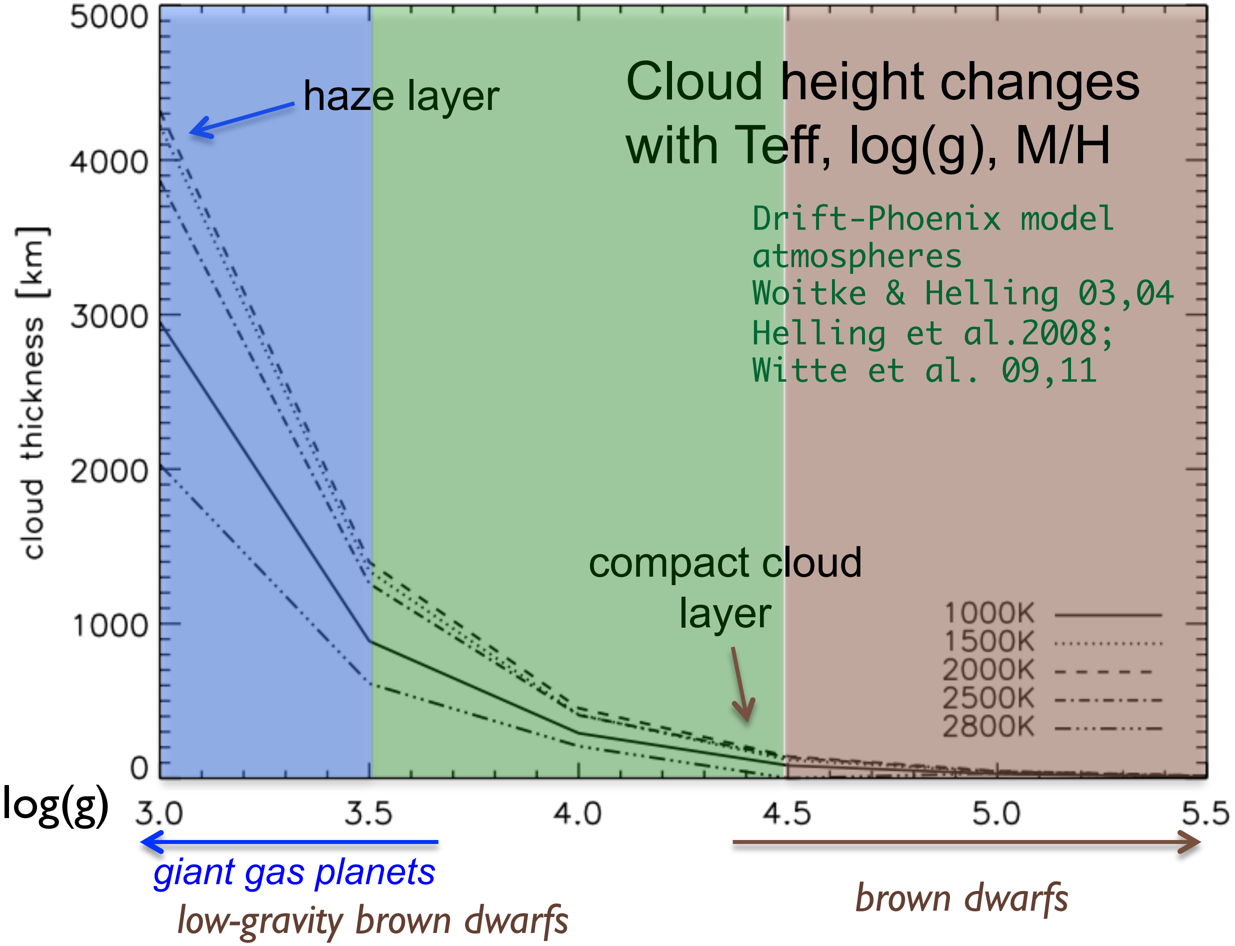
Model diversity = tool for error estimates

(Patience et al. 2012)



Brown dwarfs have atmospheres that form clouds

`Nucleation, growth, evaporation, drift, element conservation, conv mix`



Cloud height changes with Teff, log(g), M/H

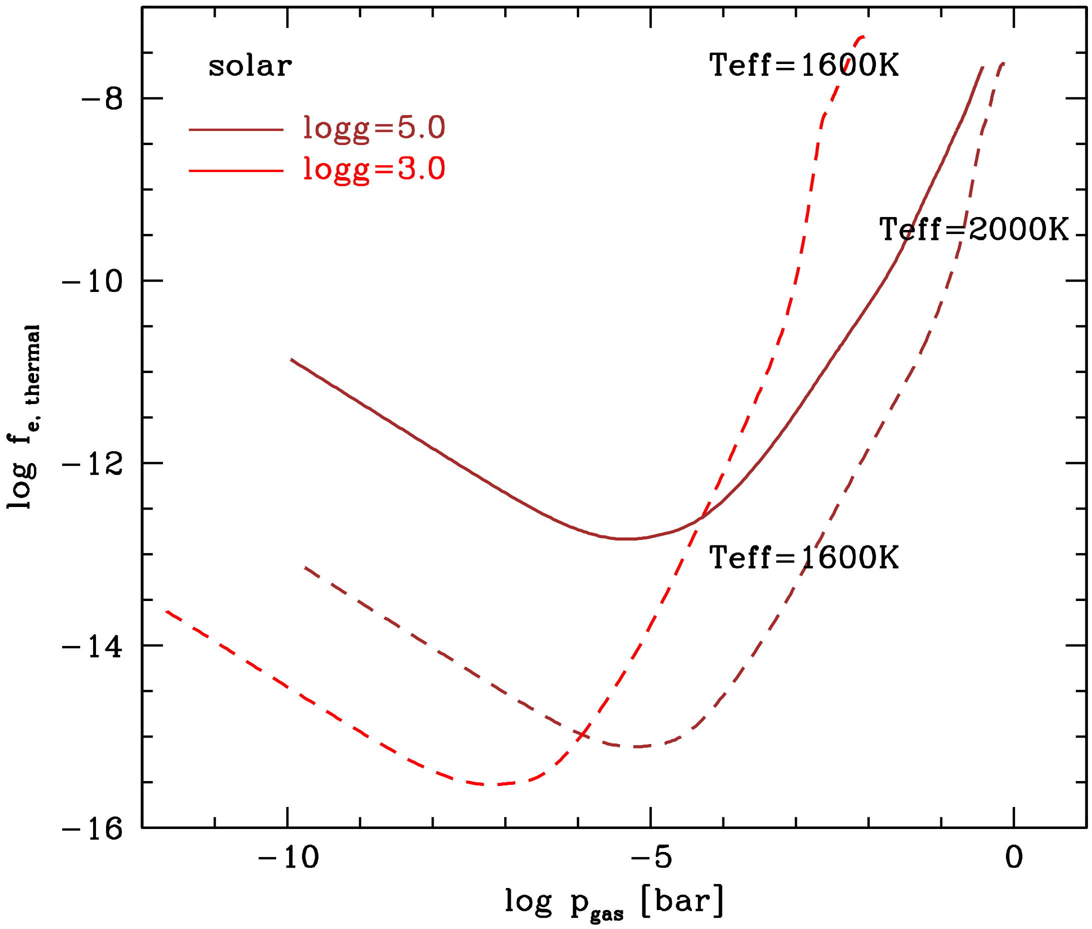
`Drift-Phoenix model atmospheres`
`Woitke & Helling 03,04`
`Helling et al.2008;`
`Witte et al. 09,11`

Cloud top:
nucleation,
small silicate grains
(incl. FeO/Al2O3)

Cloud middle:
grain growth & settling,
mixed silicates
(SiO, Mg2SiO4, FeO, …)

Cloud base:
evaporation,
big iron grains
(incl. Al_2O_3)

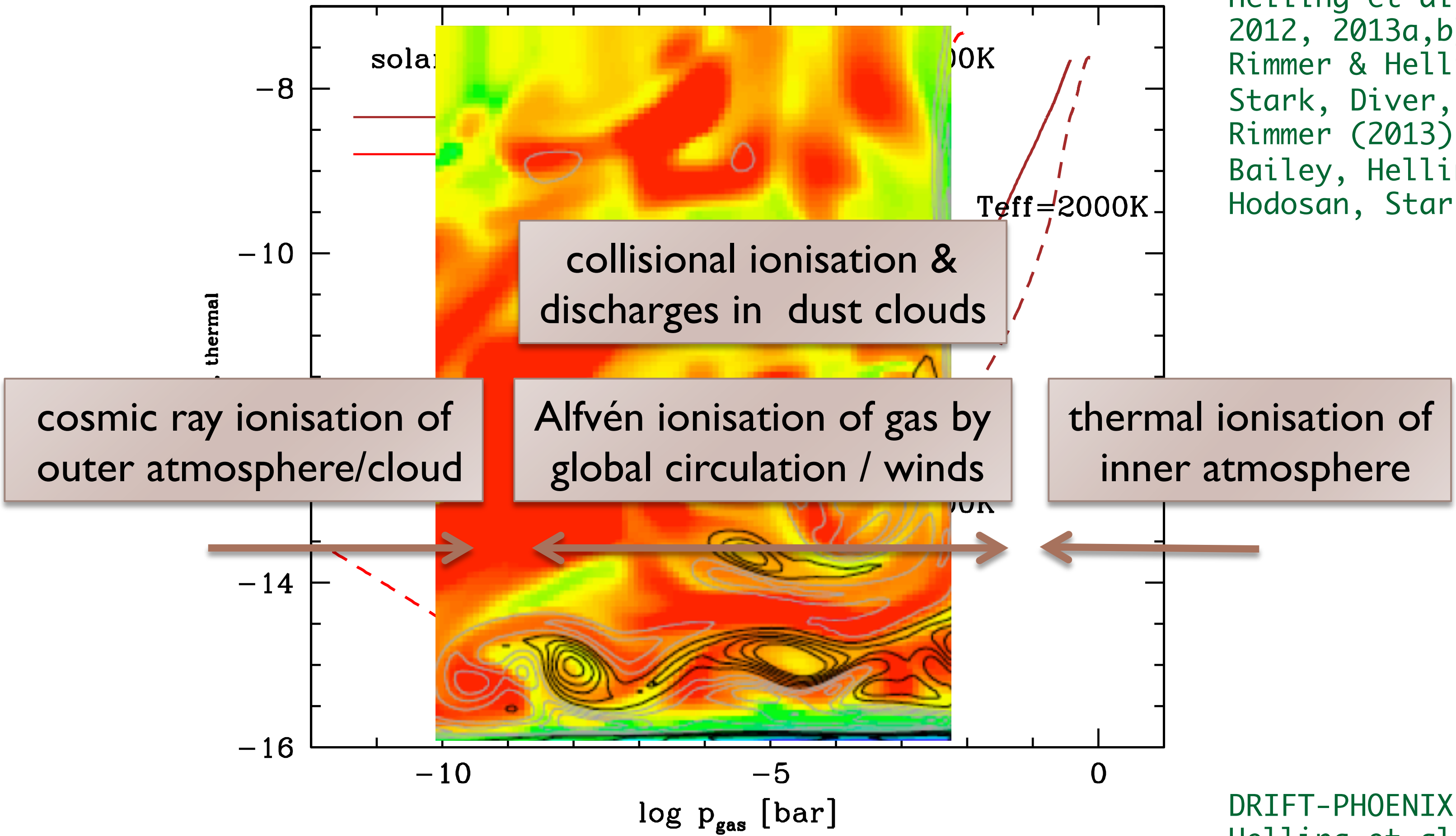
Ionisation processes in ultra-cool atmospheres



thermal ionisation

DRIFT-PHOENIX: Dehn 2007; . . . ; Witte et al. 2009, 2011

Ionisation processes in ultra-cool atmospheres



collisional ionisation & discharges in dust clouds

cosmic ray ionisation of outer atmosphere/cloud

Alfvén ionisation of gas by global circulation / winds

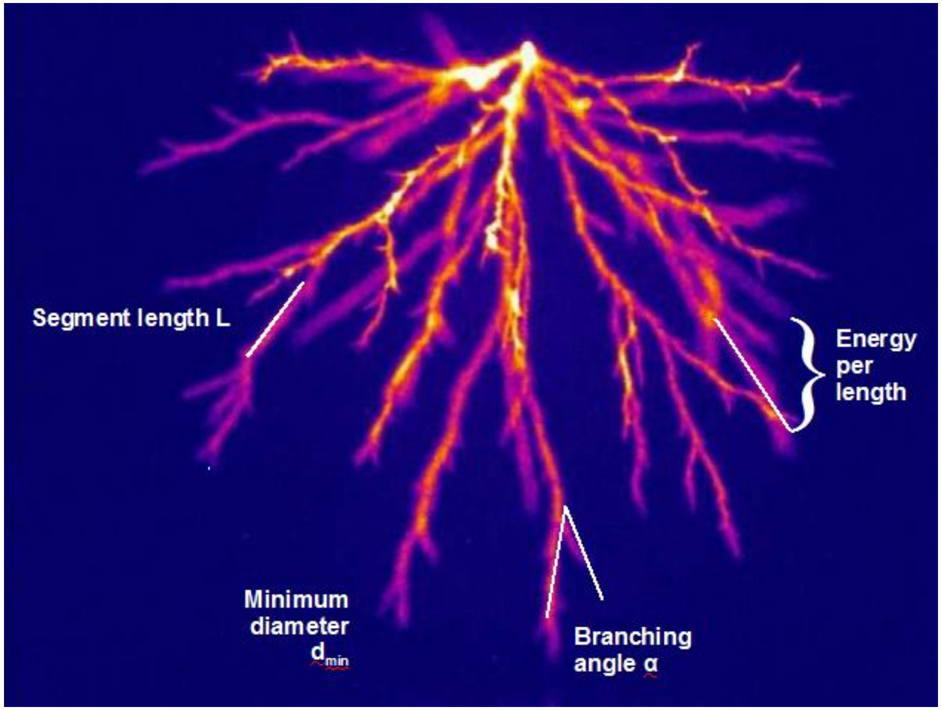
thermal ionisation of inner atmosphere

Helling et al. (2011, 2012, 2013a,b), Rimmer & Helling (2013), Stark, Diver, Helling, Rimmer (2013) Bailey, Helling, Bilger, Hodosan, Stark (2014)

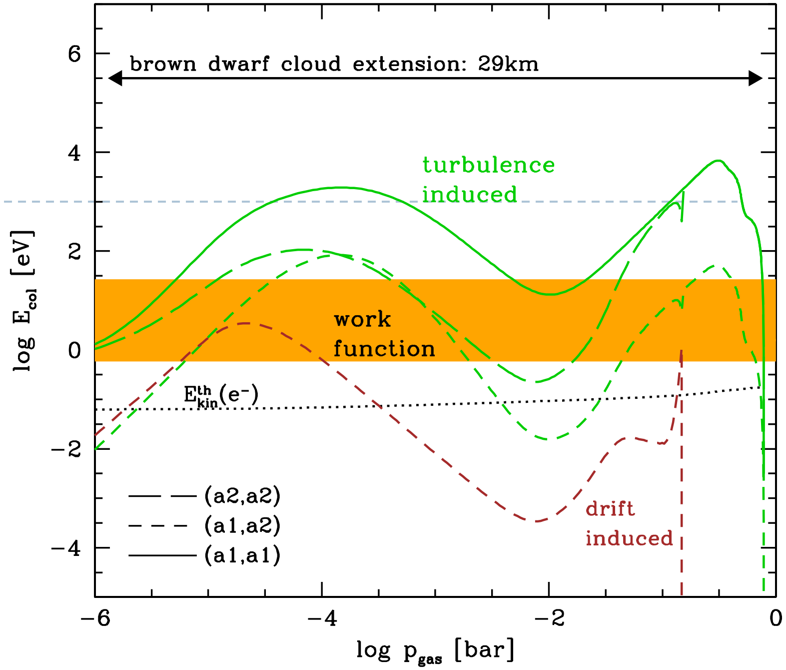
DRIFT-PHOENIX: Dehn 2007; Helling et al. 2008; Witte et al. 2009, 2011

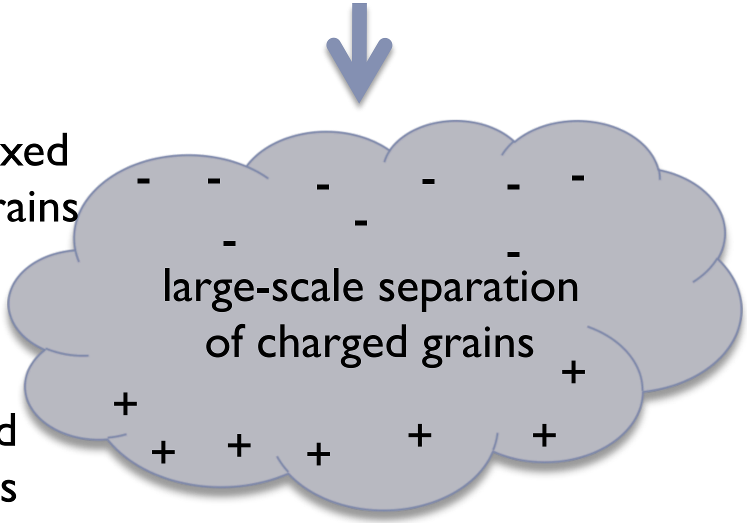
Cloud ionisation discharge

lightning is started by
a small-scale streamer (discharge!)



(Briels et al.2008)





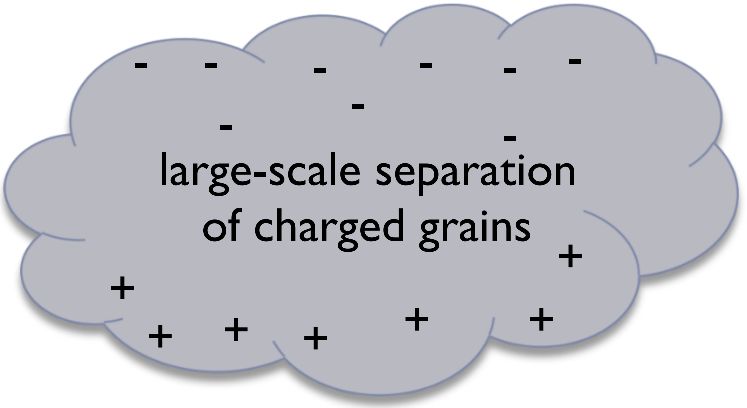
large-scale separation
of charged grains

small, mixed
silicate grains

big, mixed
iron grains

(Helling, Jardine, Diver, Stark 2013)
(Helling & Woitke 2006)

Cloud ionisation discharge

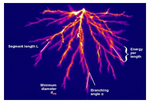


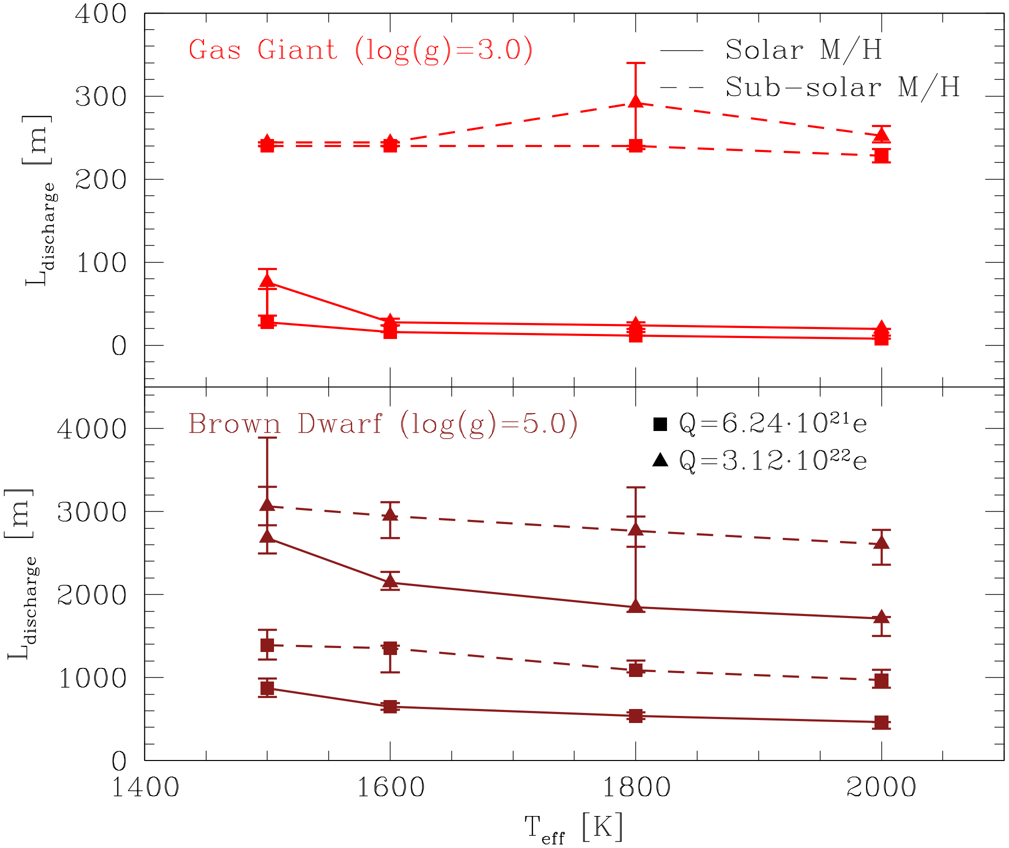
large-scale separation of charged grains

(Helling, Jardine, Diver, Stark 2013)

(Helling, Jardine, Mokler 2011)

charged cloud particles→ **streamer→ lightning**

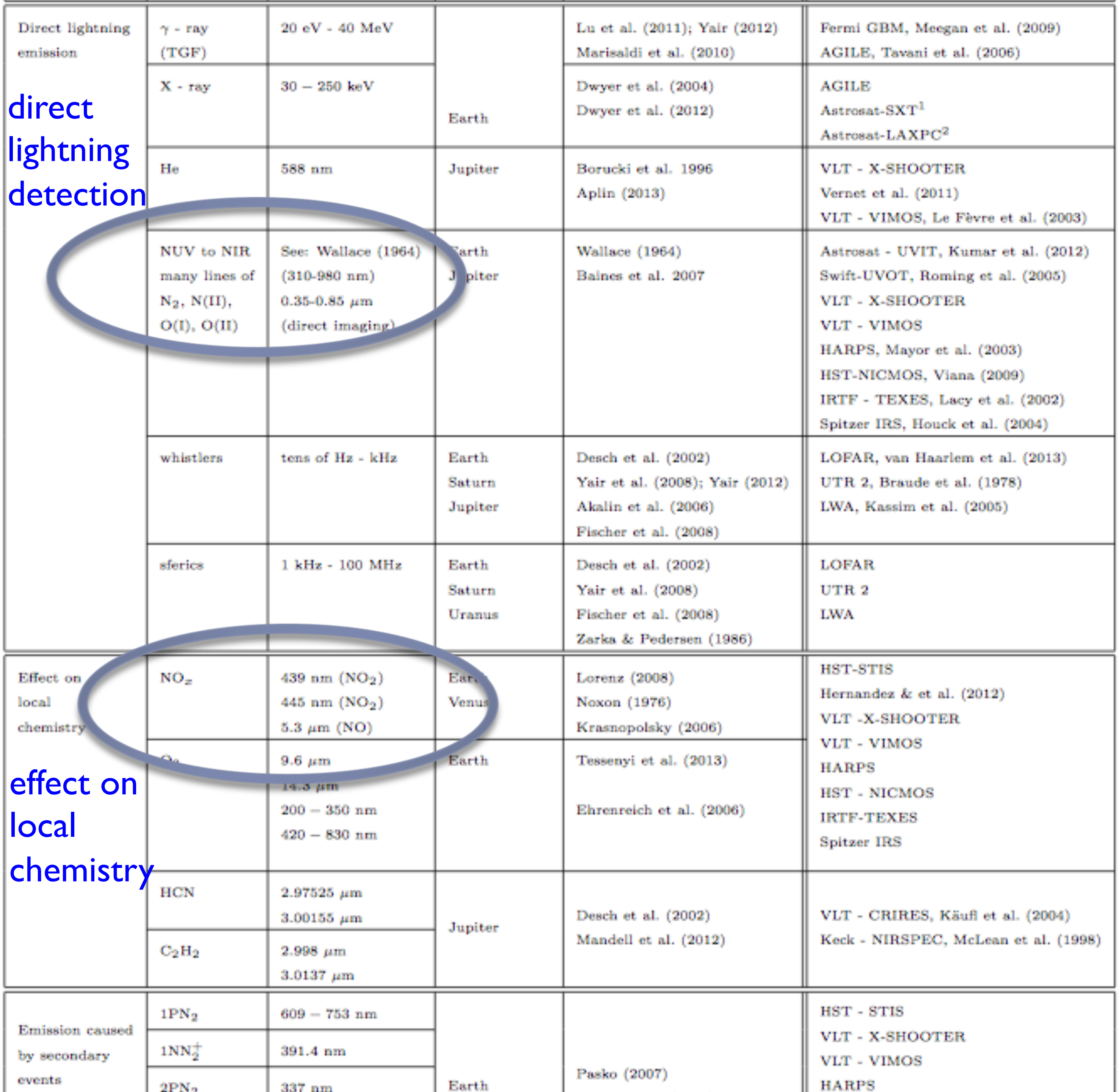




(Bailey, Helling, Stark 2014, ApJ, in press)

Large-scale properties of discharge events:

larger volume of atmosphere affected in Brown Dwarfs than in planets



Direct lightning emission	γ - ray (TGF)	20 eV - 40 MeV	Earth	Lu et al. (2011); Yair (2012) Marisaldi et al. (2010)	Fermi GBM, Meegan et al. (2009) AGILE, Tavani et al. (2006)
	X - ray	30 – 250 keV		Dwyer et al. (2004) Dwyer et al. (2012)	AGILE Astrosat-SXT^1 Astrosat-LAXPC^2
	He	588 nm	Jupiter	Borucki et al. 1996 Aplin (2013)	VLT - X-SHOOTER Vernet et al. (2011) VLT - VIMOS, Le Fèvre et al. (2003)
	NUV to NIR many lines of N_2, N(II), O(I), O(II)	See: Wallace (1964) (310-980 nm) 0.35-0.85 μm (direct imaging)	Earth Jupiter	Wallace (1964) Baines et al. 2007	Astrosat - UVIT, Kumar et al. (2012) Swift-UVOT, Roming et al. (2005) VLT - X-SHOOTER VLT - VIMOS HARPS, Mayor et al. (2003) HST-NICMOS, Viana (2009) IRTF - TEXES, Lacy et al. (2002) Spitzer IRS, Houck et al. (2004)
	whistlers	tens of Hz - kHz	Earth Saturn Jupiter	Desch et al. (2002) Yair et al. (2008); Yair (2012) Akalin et al. (2006) Fischer et al. (2008)	LOFAR, van Haarlem et al. (2013) UTR 2, Braude et al. (1978) LWA, Kassim et al. (2005)
	sferics	1 kHz - 100 MHz	Earth Saturn Uranus	Desch et al. (2002) Yair et al. (2008) Fischer et al. (2008) Zarka & Pedersen (1986)	LOFAR UTR 2 LWA
Effect on local chemistry	NO_x	439 nm (NO_2) 445 nm (NO_2) 5.3 μm (NO)	Earth Venus	Lorenz (2008) Noxon (1976) Krasnopolsky (2006)	HST-STIS Hernandez & et al. (2012) VLT -X-SHOOTER VLT - VIMOS HARPS HST - NICMOS IRTF-TEXES Spitzer IRS
	O_3	9.6 μm 14.3 μm 200 – 350 nm 420 – 830 nm	Earth	Tessenyi et al. (2013) Ehrenreich et al. (2006)	
	HCN	2.97525 μm 3.00155 μm	Jupiter	Desch et al. (2002) Mandell et al. (2012)	VLT - CRIRES, Käufl et al. (2004) Keck - NIRSPEC, McLean et al. (1998)
	C_2H_2	2.998 μm 3.0137 μm			
Emission caused by secondary events	1PN_2	609 – 753 nm	Earth	Pasko (2007)	HST - STIS VLT - X-SHOOTER VLT - VIMOS HARPS
	1NN_2^+	391.4 nm			
	2PN_2	337 nm			

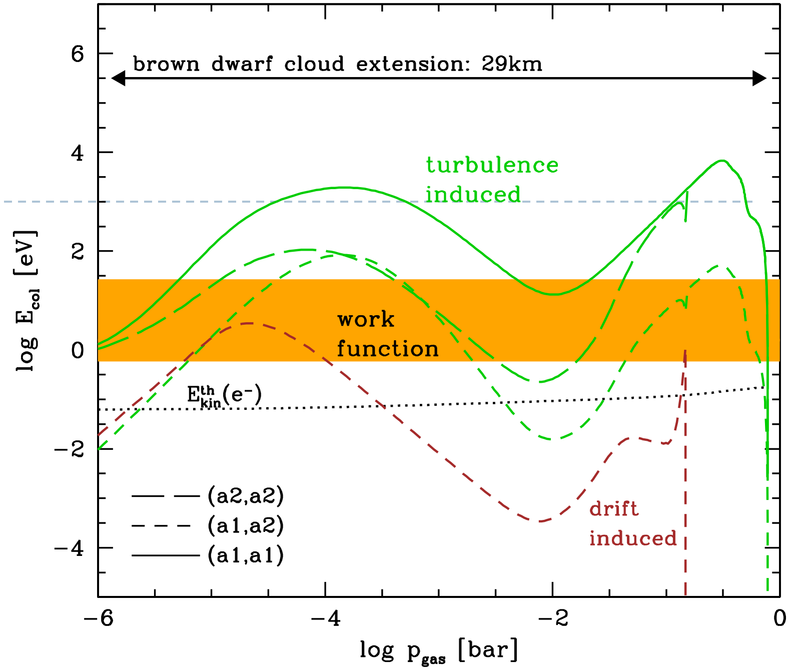
direct lightning detection

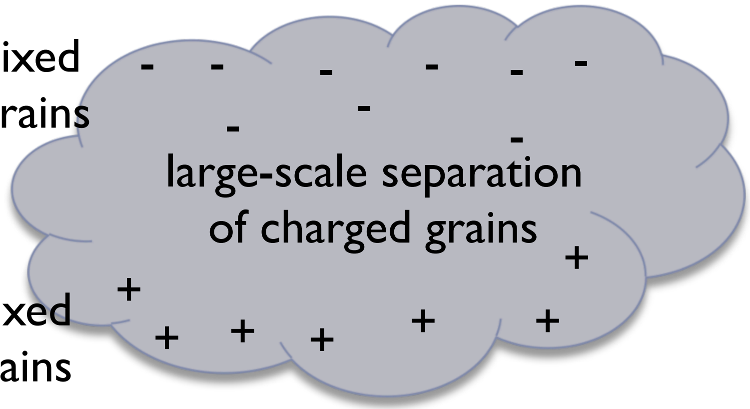
effect on local chemistry

Atmospheric ionisation

- Cloud particle collisions
  (Helling, Jardine, Mokler 2011, ApJ)
  → leading to gas-discharges
- Cosmic Ray ionisation
  → ionises gas and cloud particles
  (Rimmer & Helling 2013, ApJ)
- Alvén ionisation
  → ionises gas
  (Stark, Helling, Diver, Rimmer 2013, ApJ)

Signatures that have yet to be modelled





small, mixed silicate grains

large-scale separation of charged grains

big, mixed iron grains

(Helling, Jardine, Diver, Stark 2013)

Electrification in dusty atmospheres inside and outside the solar system

8th – 11th September 2014

Pitlochry, Scottish Highland

http://leap1.sciencesconf.org/

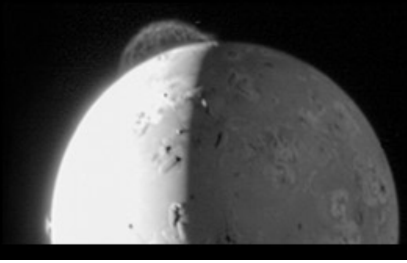
Lab & Observation: Collisional charge separation processes in dusty media

Modelling charge separation / discharge in dusty, turbulent atmospheric gases

Solar system charging and electrostatic processes in volcanoes

Radiation and CR impact on cloud ionisation

Astrophysical context in exoplanetary research



Charge processes in planetary atmospheres

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life electricity atmosphere planets