On the origin of the WD1145 disk and pollution

Stochastic accretion of planetesimals?

Mark Wyatt

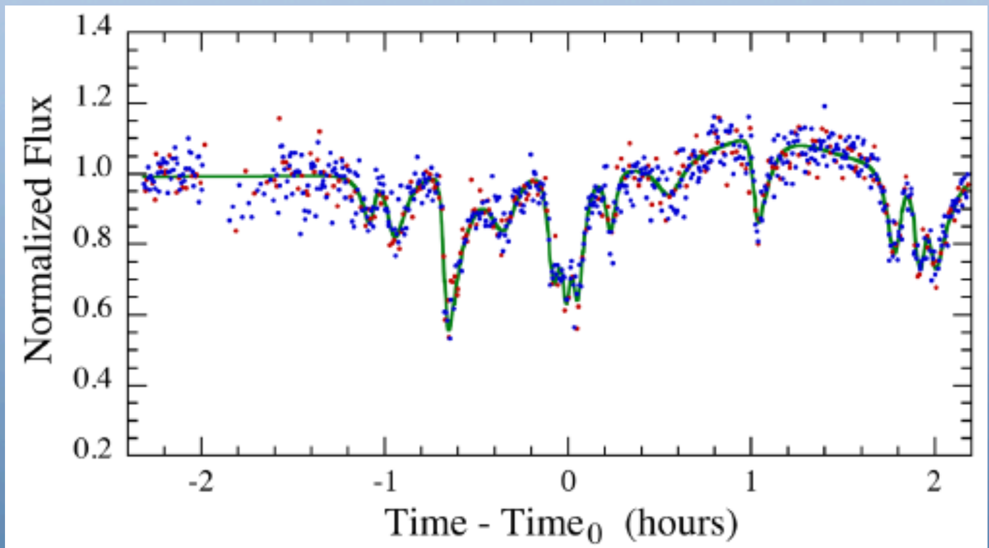
Institute of Astronomy, University of Cambridge

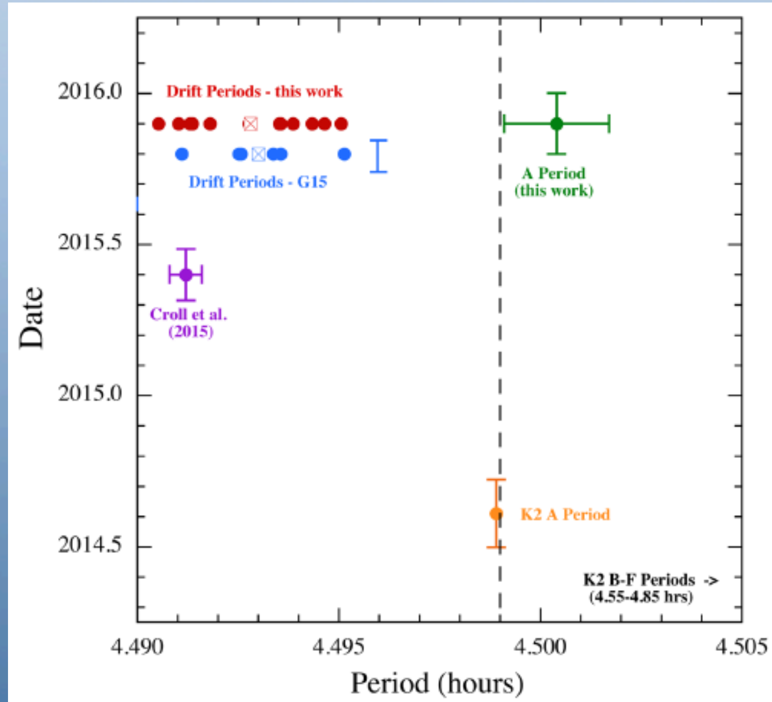
+ Rik van Lieshout, Jay Farihi, Jim Pringle, Amy Bonsor

Recap on WD1145: transits

WD1145 is a DB White Dwarf, cooling age 180 Myr, found by K2 to have variable dips in brightness up to 40% with period ~4.5hr (1.2R_{sun}) (Vanderburg et al. 2015)

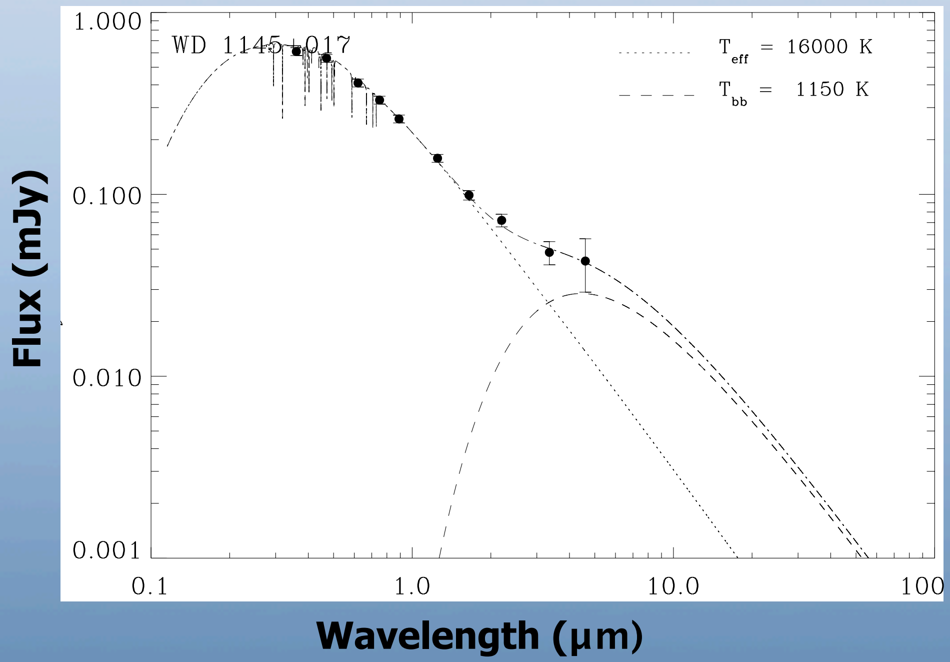
Subsequent studies showed shorter dips, with range of periods, average extinction 11% (Gaensicke et al. 2016; Rappaport et al. 2016; Gary et al. 2017)



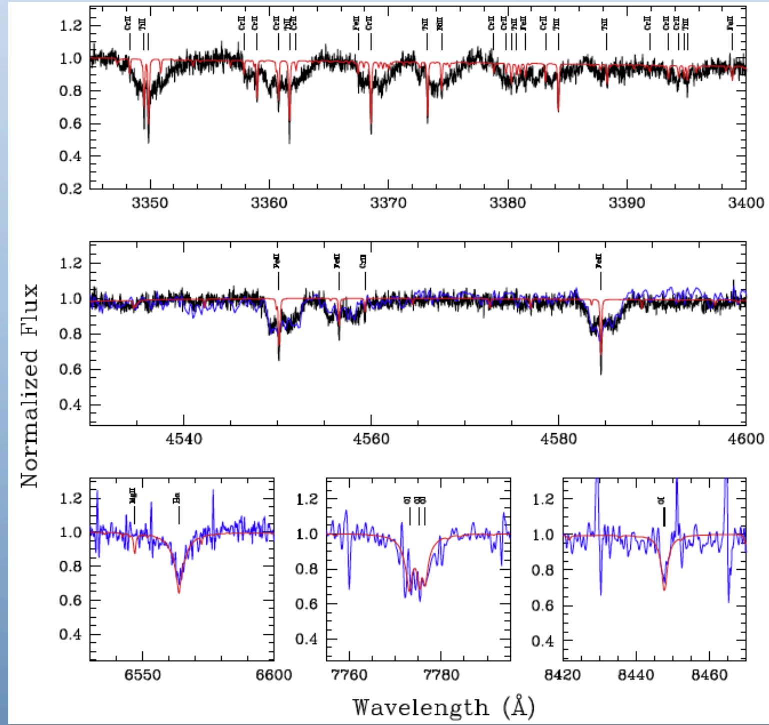


Recap on WD1145: disk and pollution

Like ~3% of WDs, WD1145 has near-IR emission from hot dust near ~1R_{sun} tidal destruction radius (Vanderburg et al. 2015).



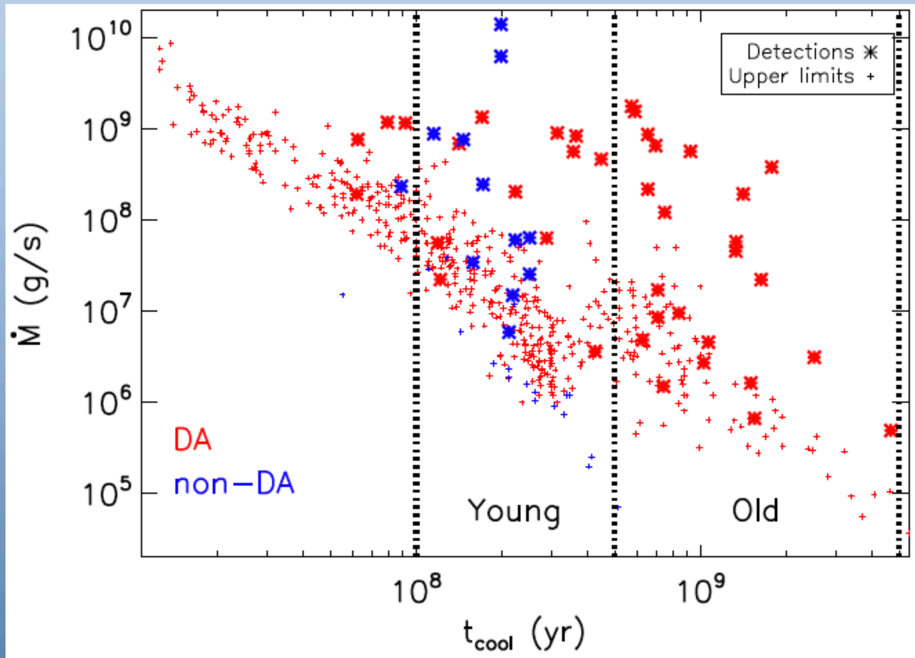
Like ~30% of WDs, WD1145 has a metal polluted atmosphere from accretion of rocky material at rate 10^{11} g/s



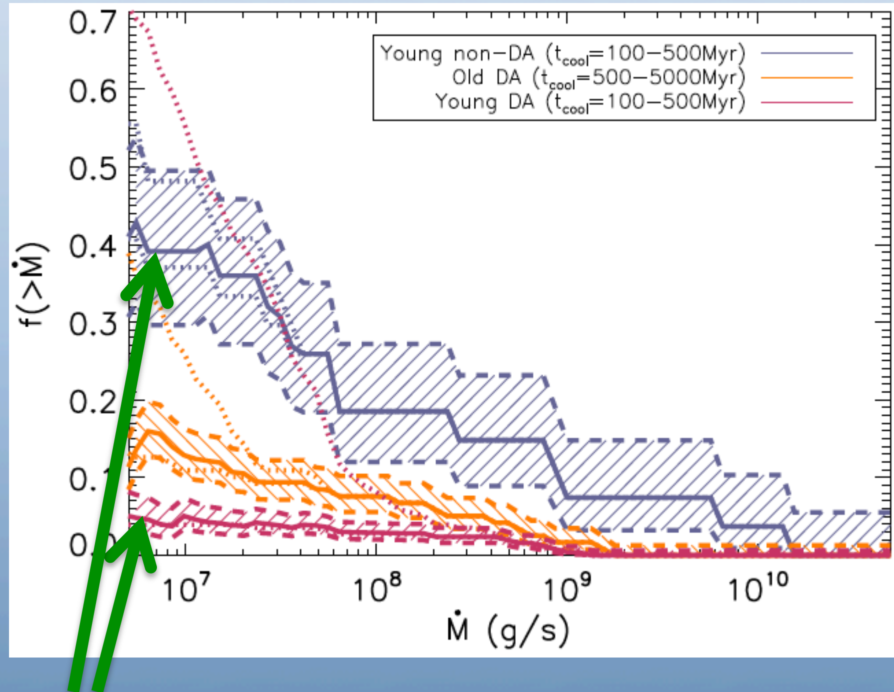
Like a smaller subset of WDs it also has absorption from circumstellar gas at same location as the dust accreting at 10^{12} g/s (Xu et al. 2016)

Mass accretion rate distributions

Detection bias: Lower levels detectable for older (cooler) stars, doesn't mean decrease with age



So need unbiased sample, including upper limits to get distribution of accretion rates (Wyatt et al. 2014)

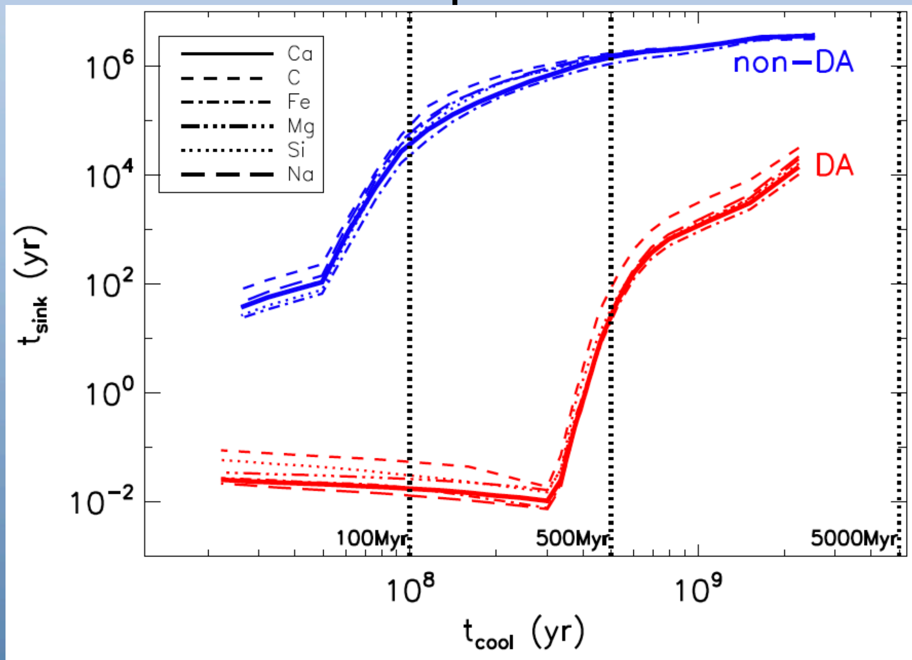


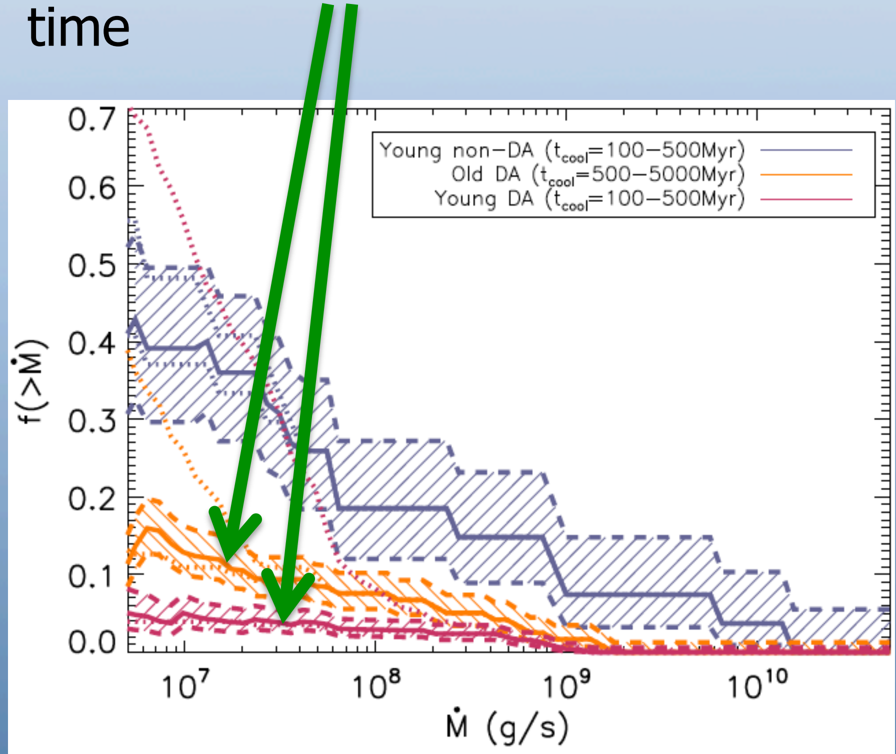
Clear evidence for dependence on atmospheric type (Farihi et al. 2012)

Accretion rates depend on sinking time

Main difference between atmospheric types is sinking time, yet assumption is no intrinsic difference in DA and non-DA other than stellar atmosphere

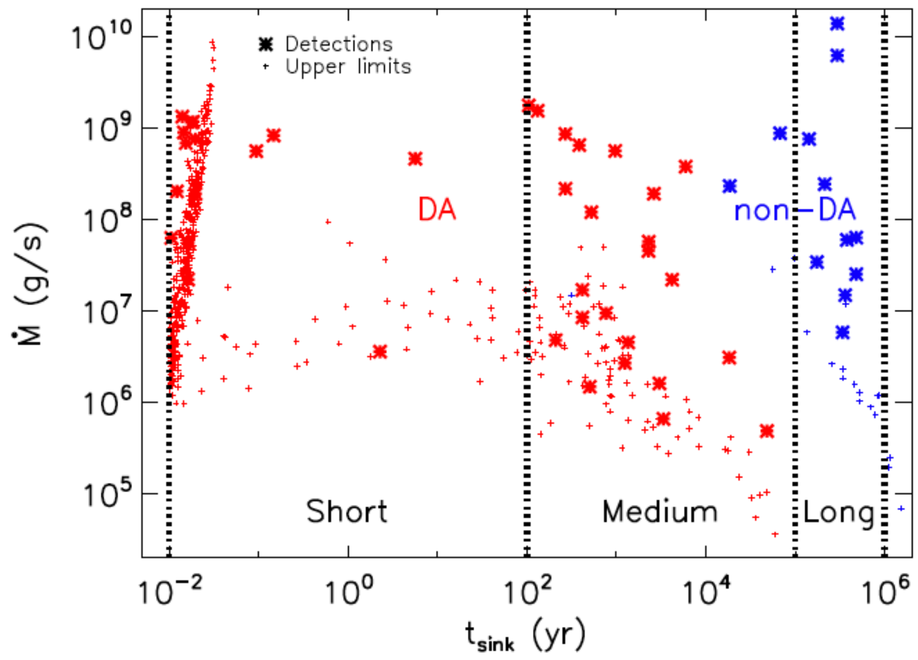
No strong evidence for dependence on age, since higher rates for older DAs could be due to longer sinking time



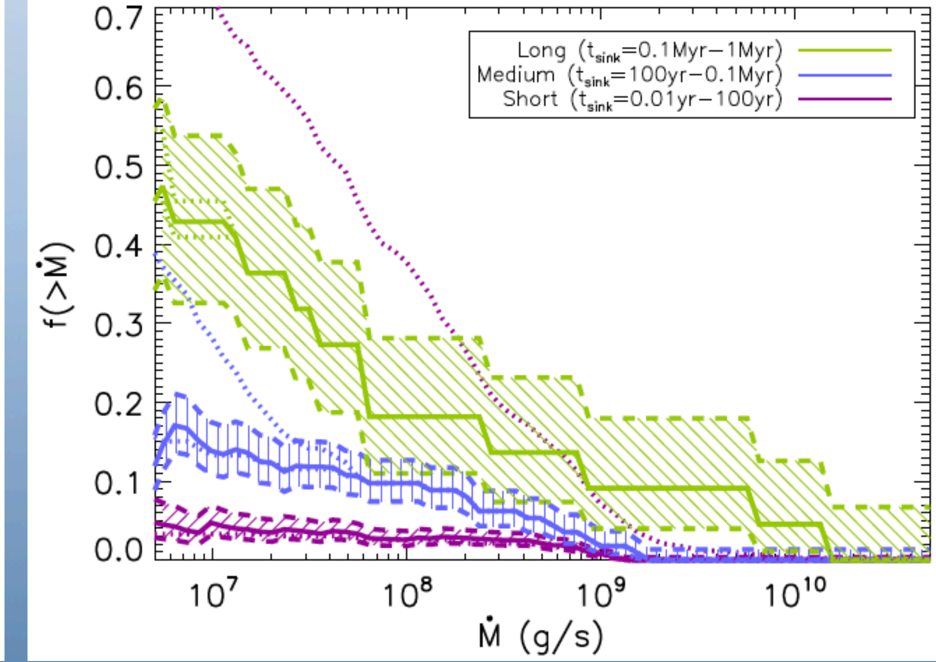


Quantify dependence on sinking time

So, plot accretion rates as a function of sinking time for unbiased sample to get distributions



Systematic change: accretion rates are larger when measured over longer sinking times



Modelling the origin of accreted material

Details:

- Main sequence star is born with planets + planetesimal belts
- That belt is depleted by collisional erosion on the main sequence
- Post-main sequence processes cause material to be scattered in
- Material is tidally disrupted and forms an accretion disk
- Material ends up on the star

Modelling the origin of accreted material

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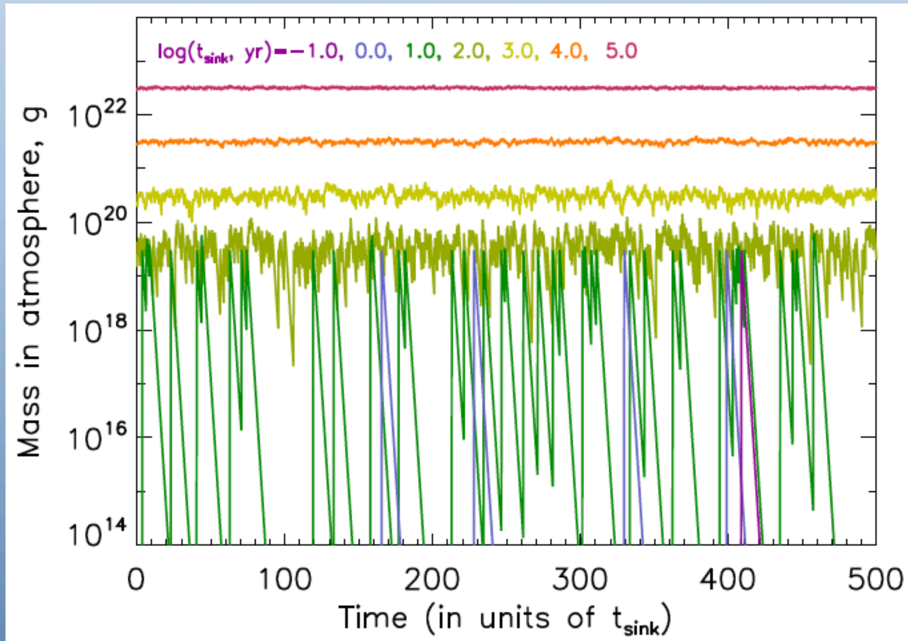
Simplified version:

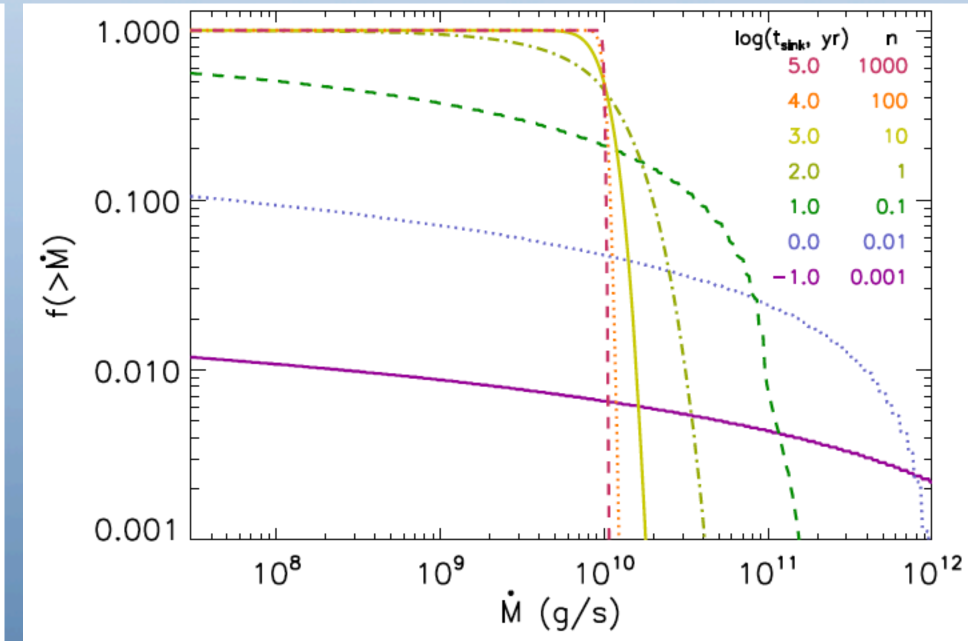
- Planetesimals are thrown onto the star at some mean rate $\mathbf{(dM/dt)_{in}}$
- Mass arrives in quanta $\mathbf{m_p}$ and so $(dM/dt)_{obs}$ is not $(dM/dt)_{in}$
- Mass in atmosphere decays exponentially on timescale $\mathbf{t_{sink}}$

Accretion of mono-mass planetesimals

The amount of mass in the stellar atmosphere depends on the sinking time

Good news: this means the distribution of accretion rates that would be measured inevitably depends on sinking time

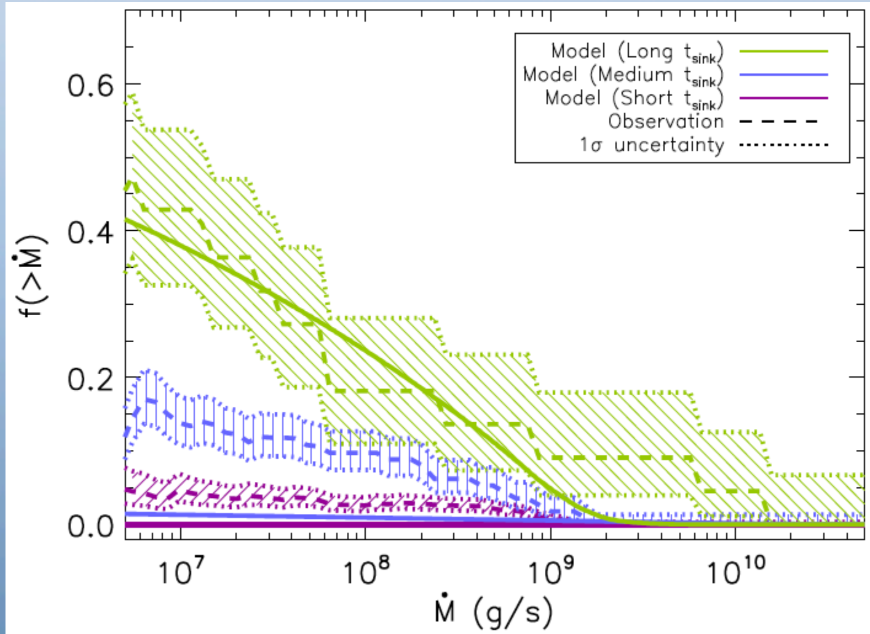




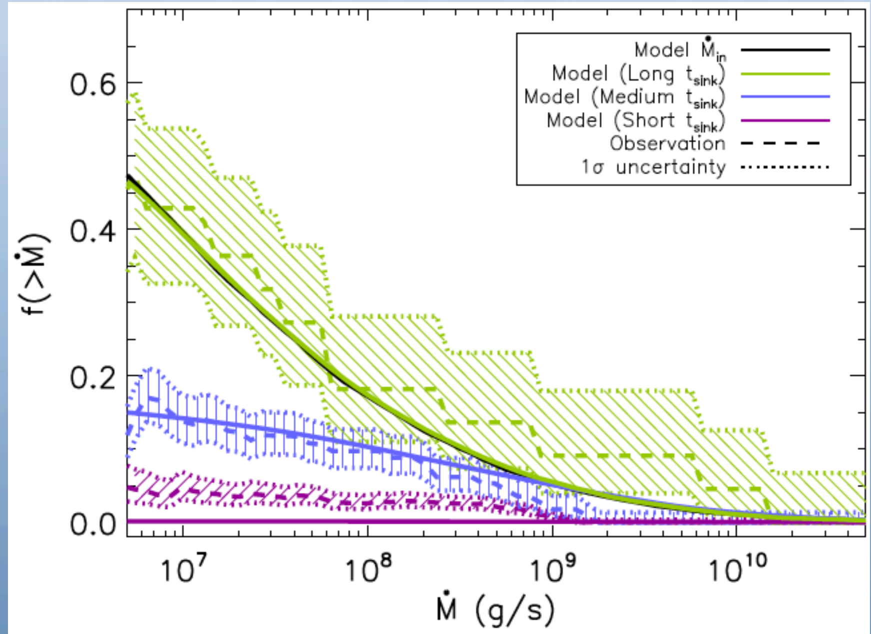
Accretion of 3.2×10^{19}g planetesimals at 10^{10}g/s

Poor fit with mono-mass distribution

Bad news: Accreting from a mono-mass size distribution doesn’t work, as predicts stronger dependence on sinking time than observed



Accretion of 2.2×10^{22}g planetesimals at 1.7×10^{8}g/s



Accretion of 1×10^{20}g planetesimals with a distribution of accretion rates

Modelling the origin of accreted material

For each star:

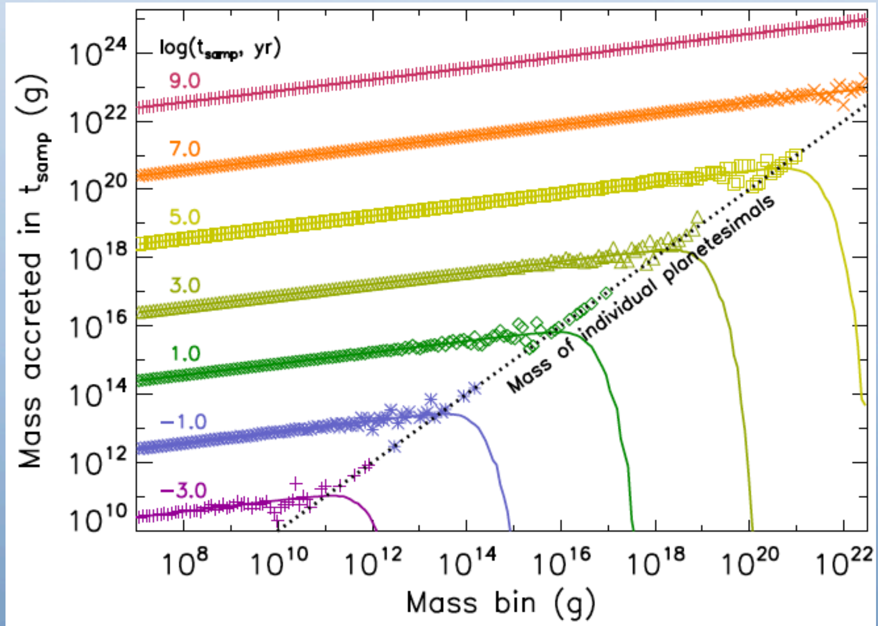
- Planetesimals are thrown onto the star at some mean rate $\mathbf{(dM/dt)_{in}}$
- Mass arrives in quanta, but planetesimals have a range of masses $\mathbf{n(m_p) \propto m_p^{-q}}$ up to a maximum $\mathbf{m_{max}}$
- Mass in atmosphere decays exponentially on timescale $\mathbf{t_{sink}}$ but also passes through a disk for timescale $\mathbf{t_{disk}}$

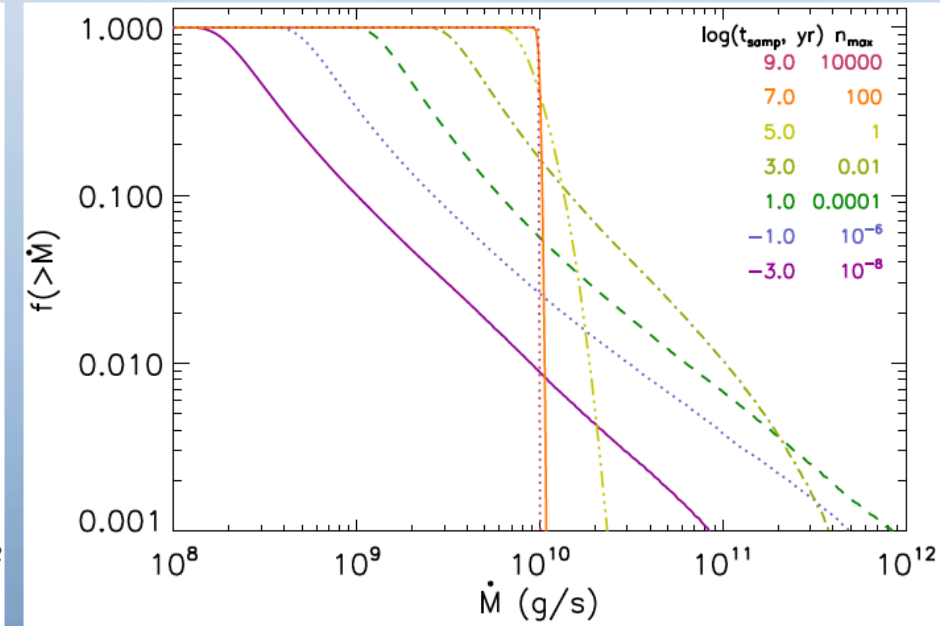
For the population:

- The mean rates are drawn from a distribution where $\log(dM/dt)_{in}$ has a mean $\boldsymbol{\mu}$ and deviation $\boldsymbol{\sigma}$
- The distribution of $\mathbf{t_{sink}}$ is that of the unbiased sample

Accretion from a mass distribution

E.g., accretion from n(m) oc $m^{-11/6}$ up to 3.2×10^{22}g at 10^{10}g/s





For a given sinking time there is always a planetesimal mass below which accretion is continuous, and that mass dominates the median accretion rate

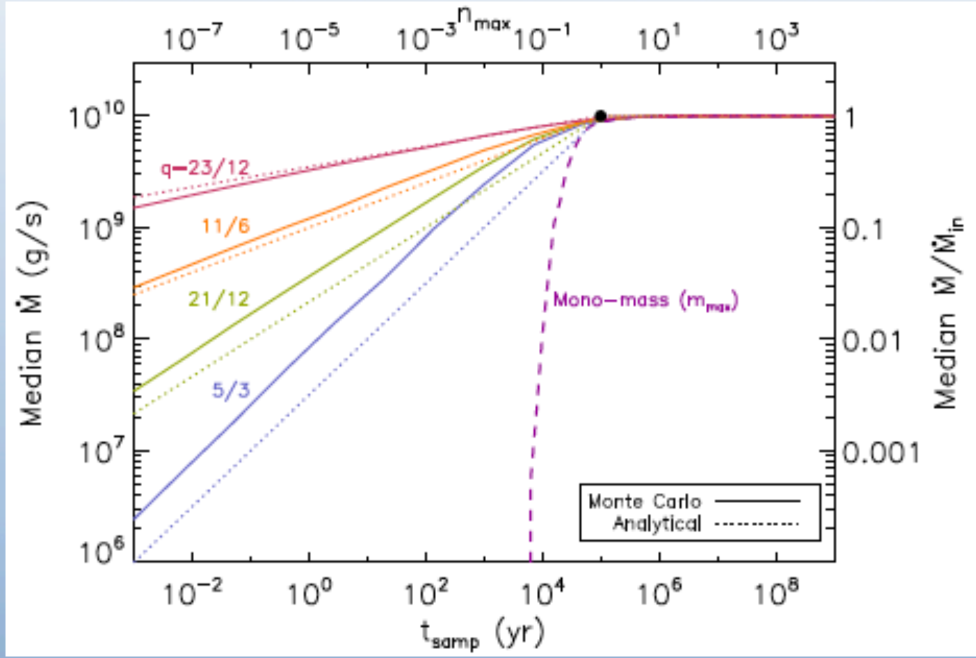
This results in a less strong dependence on sinking time

Accretion from a mass distribution

Number of largest bodies needed to reproduce dM/dt
$n_{max}=(dM/dt)_{in}t_{samp}/m_{max}$

Accretion is continuous for planetesimals below
$m_{tr}=m_{max}n_{max}^{1/(q-1)}$

Sampling times not stochastic above
$t_{samp,crit}=m_{max}/(dM/dt)_{in}$



Median accretion rate expected to be observed
$(dM/dt)_{obs}=(m_{max}/t_{samp})n_{max}^{1/(q-1)}$

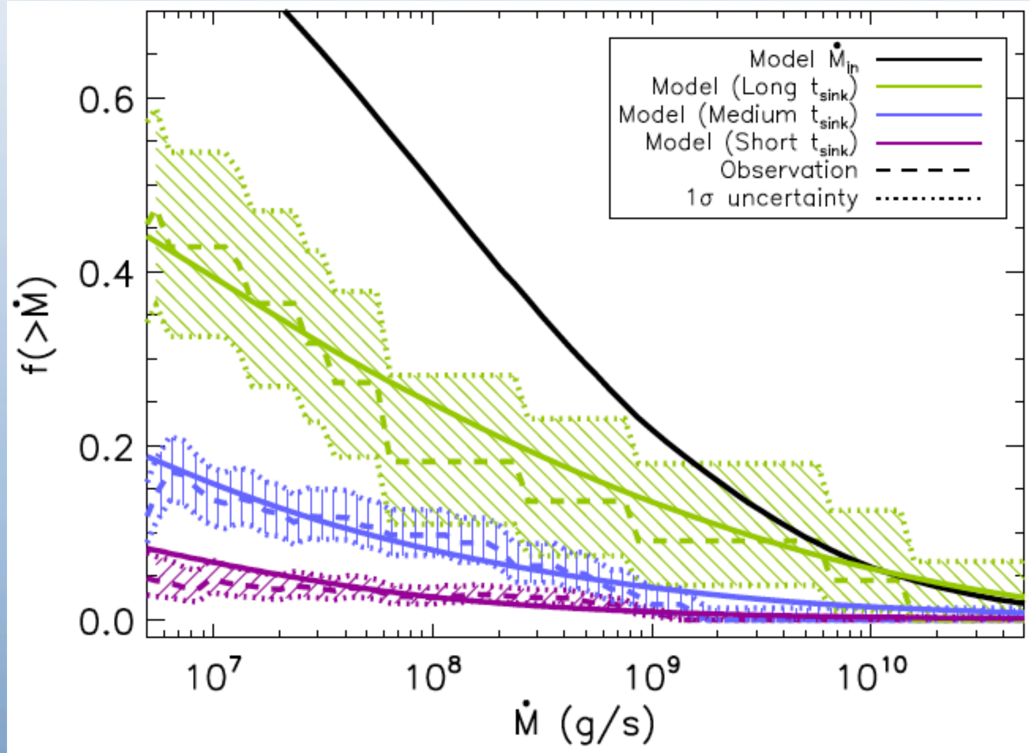
Estimating input accretion rate:
$(dM/dt)_{in}/(dM/dt)_{obs}=[(dM/dt)_{obs}t_{samp}/m_{max}]^{q-2}$

Observed accretion rate distributions well fit

Accreted material has
$n(m_p) \sim m_p^{-1.57}$
up to m_{max}=3.2x10^{24}g

Rates drawn from a log-normal distribution centred on 10^{8}g/s

Assumes disc lifetime 20yrs

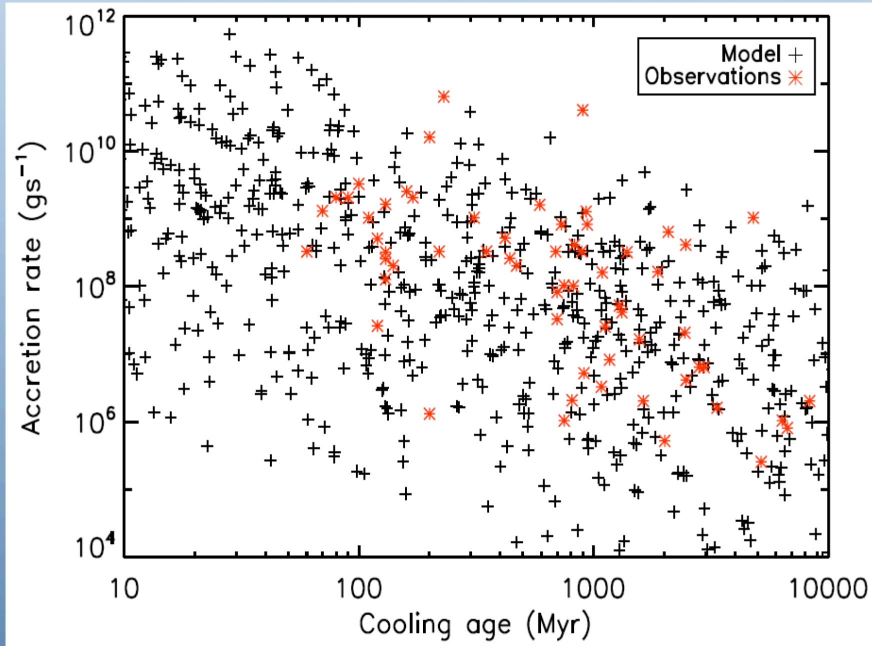


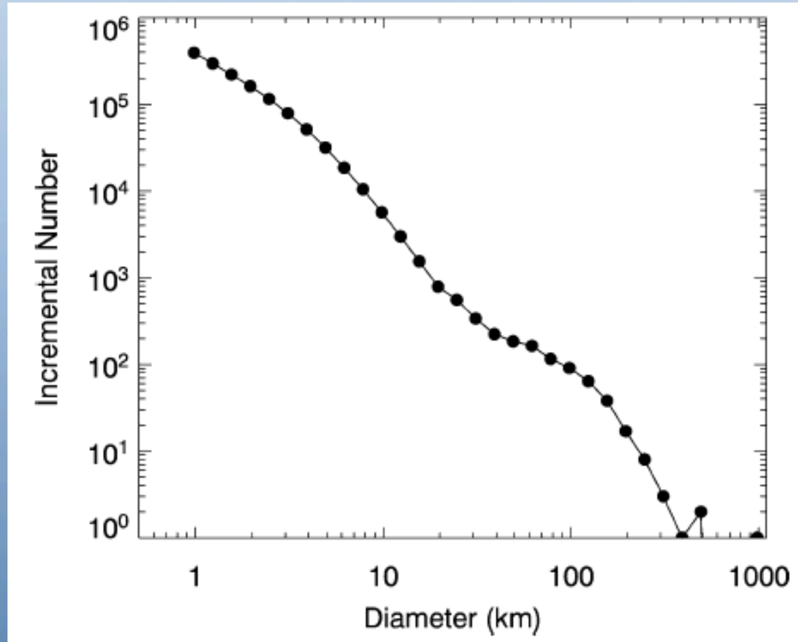
Implies pollution typically dominated by accretion of ~35km planetesimals

Accretion rates and size distribution ok

Rates consistent with population of A star debris disks left by WD phase, eroded by increased resonance overlap from stellar mass loss (Bonsor, Mustill & Wyatt 2011)

Size distribution consistent with that of collisionally evolved population (q=5/3, Wyatt et al. 2011) like Asteroid Belt (Bottke et al. 2005)





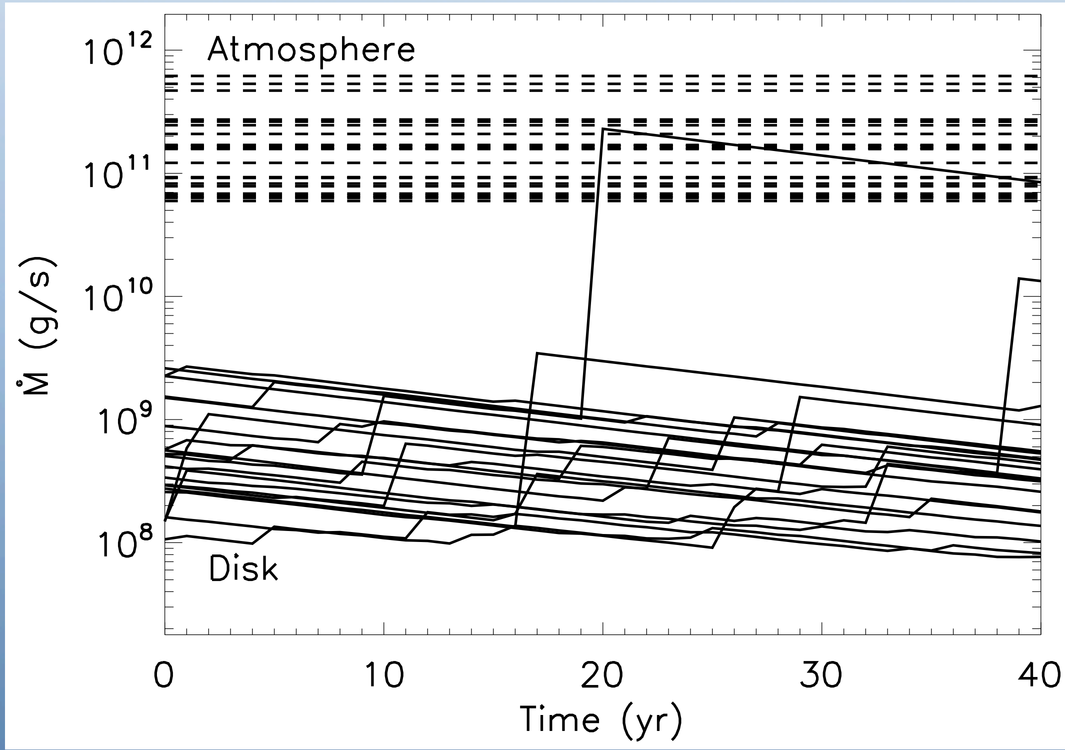
Disk lifetime of 20years may not be representative – needs better model

What does this mean for WD1145?

Pollution likely occurred from continuous accretion of $<7x10^{23}$g bodies
Inferred underlying dM/dt=$1.9x10^{11}$g/s is in top 0.6% of WD population

Current disk fed continuously by $<6x10^{16}$g objects, median accretion rate 10^8g/s, variable on 20yr timescale

Observed gas accretion 10^{12}g/s possible if $6x10^{20}$g body recently incorporated into disk (but rare event, 0.5%)

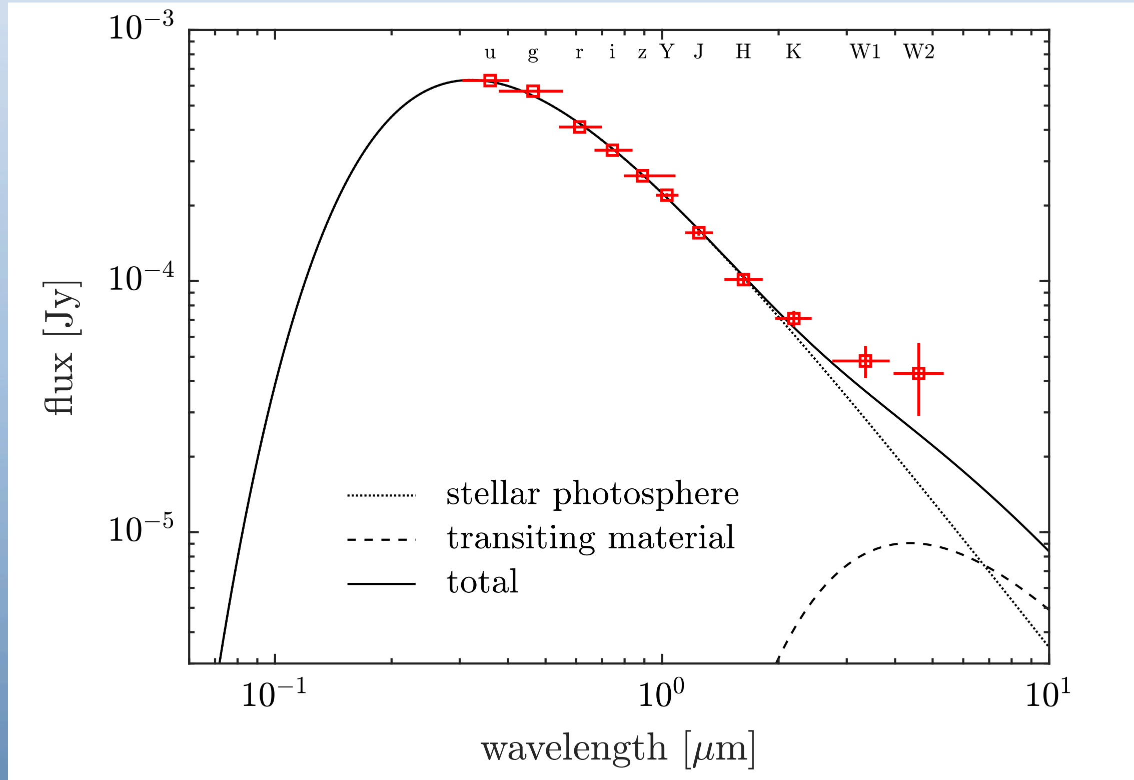


Can test this from the disk and transits?

For WD1145 the material seen to transit in front of the star provides much of the thermal emission

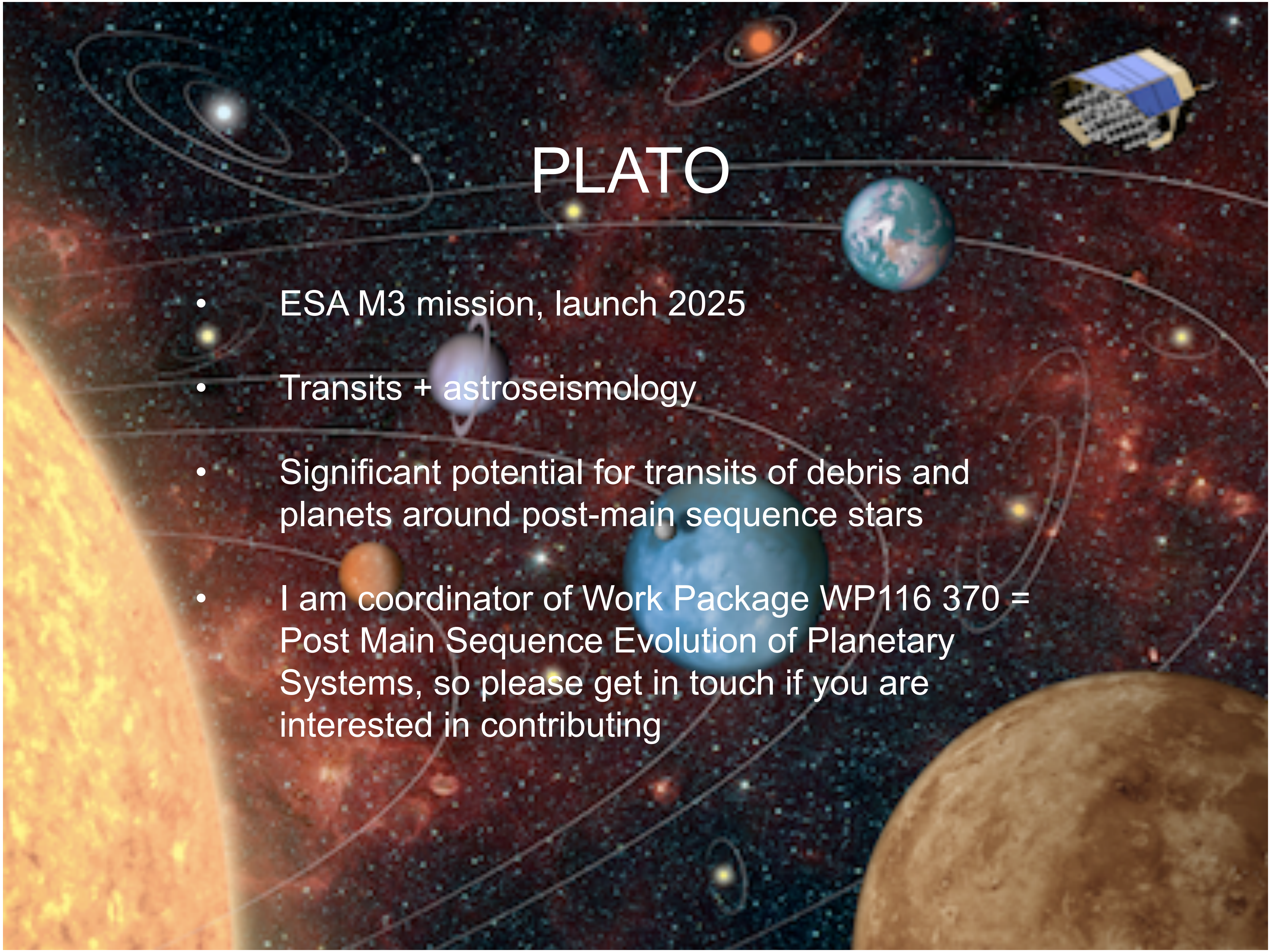
But, typical interpretation of the thermal emission is an optically thick disk, so is WD1145 atypical?

Or is this structure expected when large object incorporated into disk?



Conclusions

- Upper limits are important, and need to consider distribution of accretion rates
- Distributions depend on sinking time
- Accretion from mono-mass planetesimal distribution doesn't work because exponential decay means that short sinking times should rarely detect anything
- Accretion from mass distribution does because accretion is quasi-steady, dominated by accretion of ~35km planetesimals
- WD1145 disk should be accreting at 10^8g/s, so high gas accretion could imply recent (rare) accretion event, or revision to model (or to the observation!), or formed a different way


PLATO
ESA M3 mission, launch 2025
Transits + astroseismology
Significant potential for transits of debris and planets around post-main sequence stars
I am coordinator of Work Package WP116 370 = Post Main Sequence Evolution of Planetary Systems, so please get in touch if you are interested in contributing