A Review of White Dwarf Discs

Laura Rogers

Credit: NASA

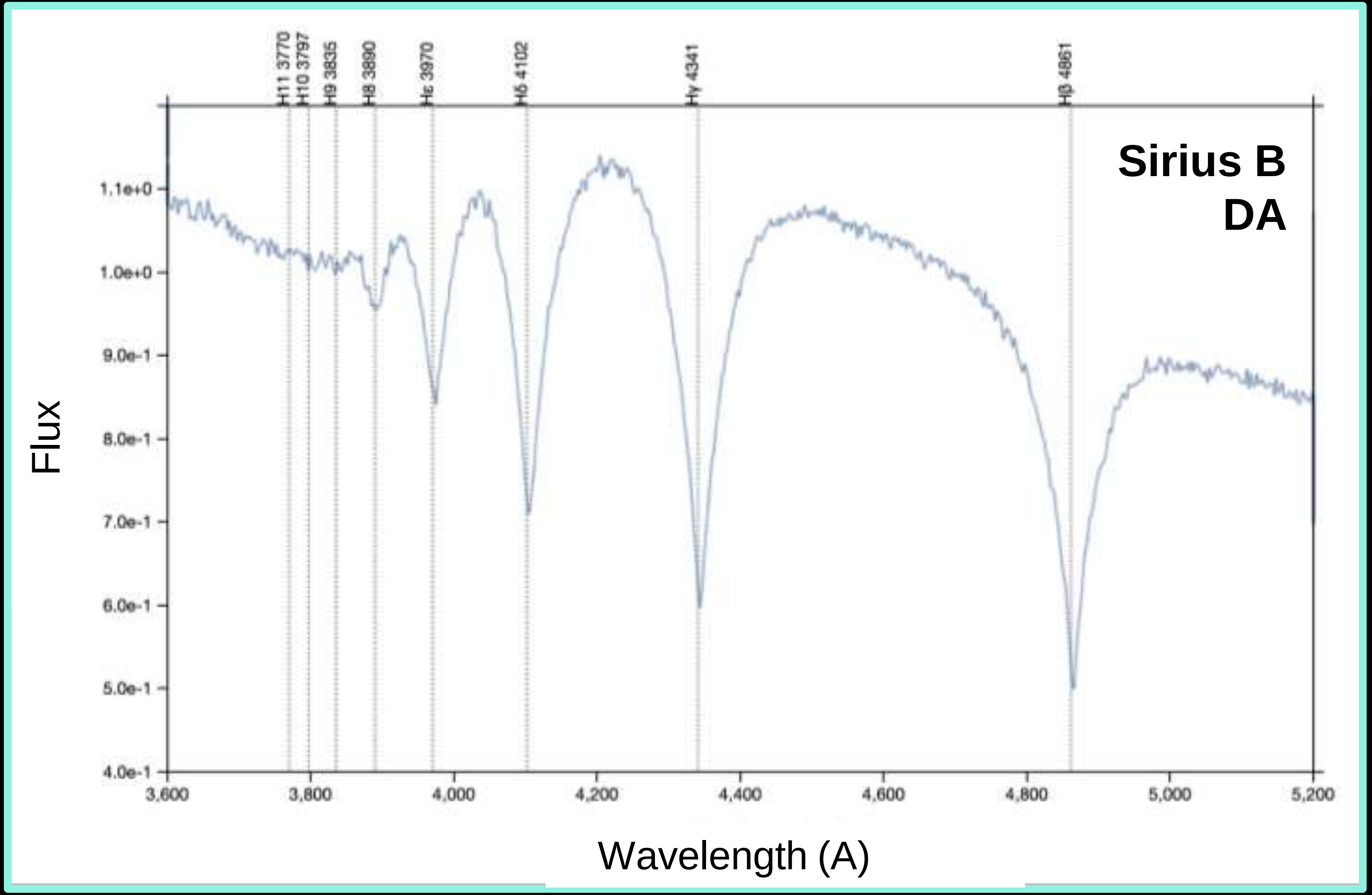
White dwarfs

Stellar remnants – core of low mass stars

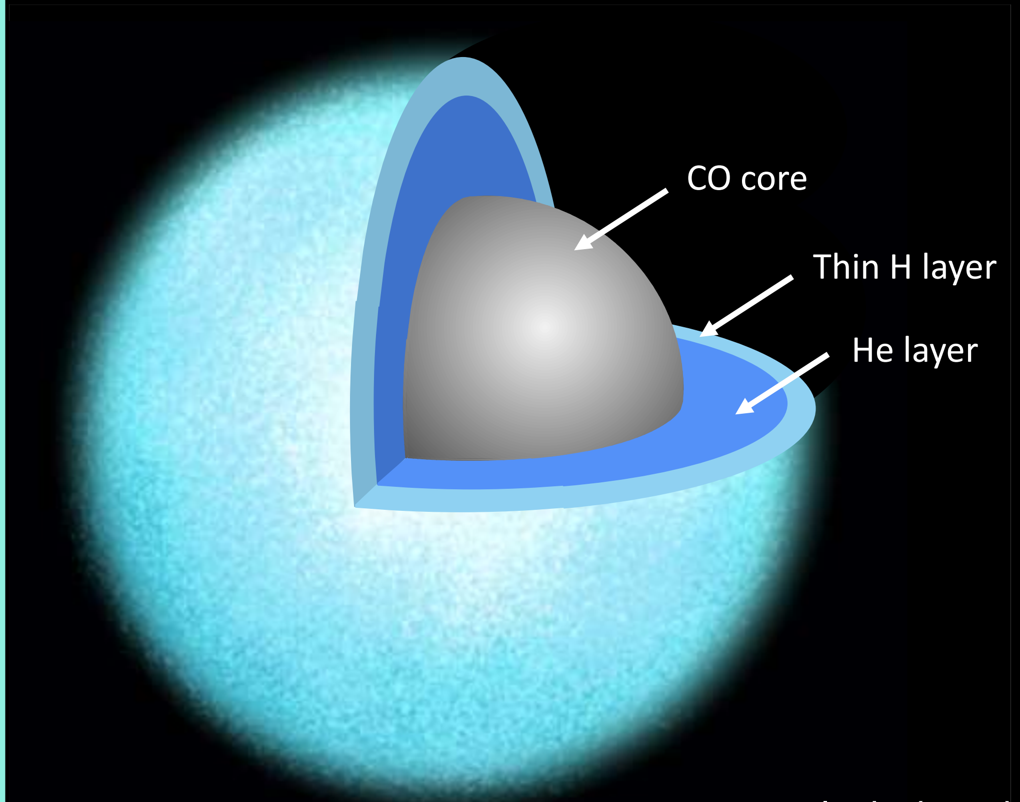
Very dense - Mass of ~ 0.6 $M_\odot$ packed into the radius of the Earth

High surface gravities

White dwarfs should have clean atmospheres due to their high surface gravity

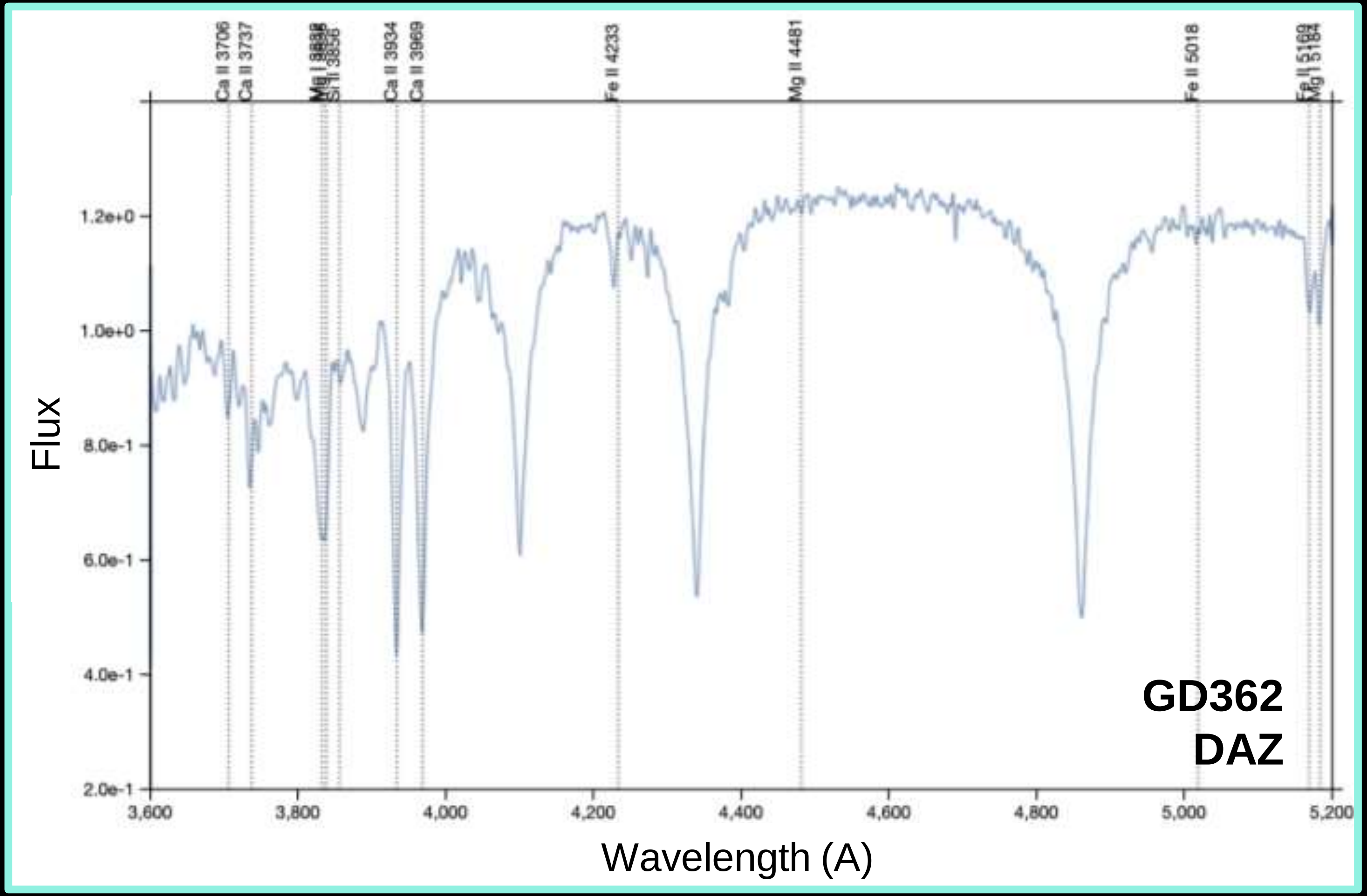


From MWDD

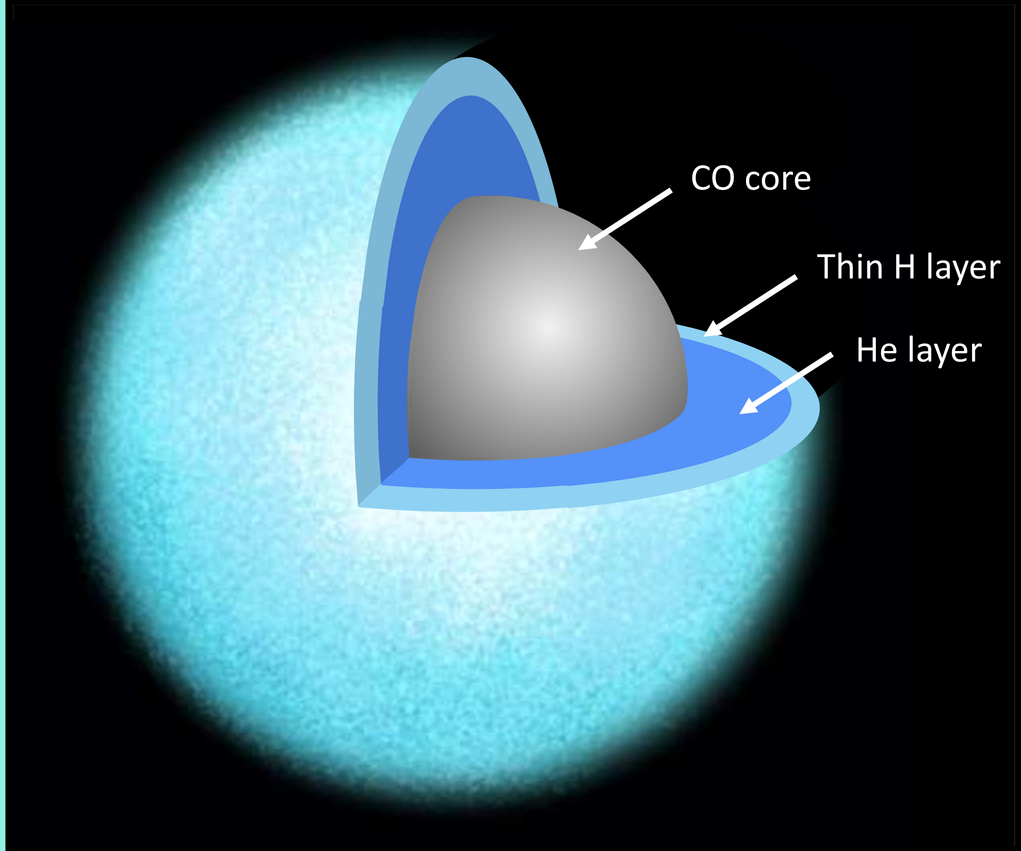


Xu, Rogers, Blouin (2024)

~30% of white dwarfs accrete planetary material

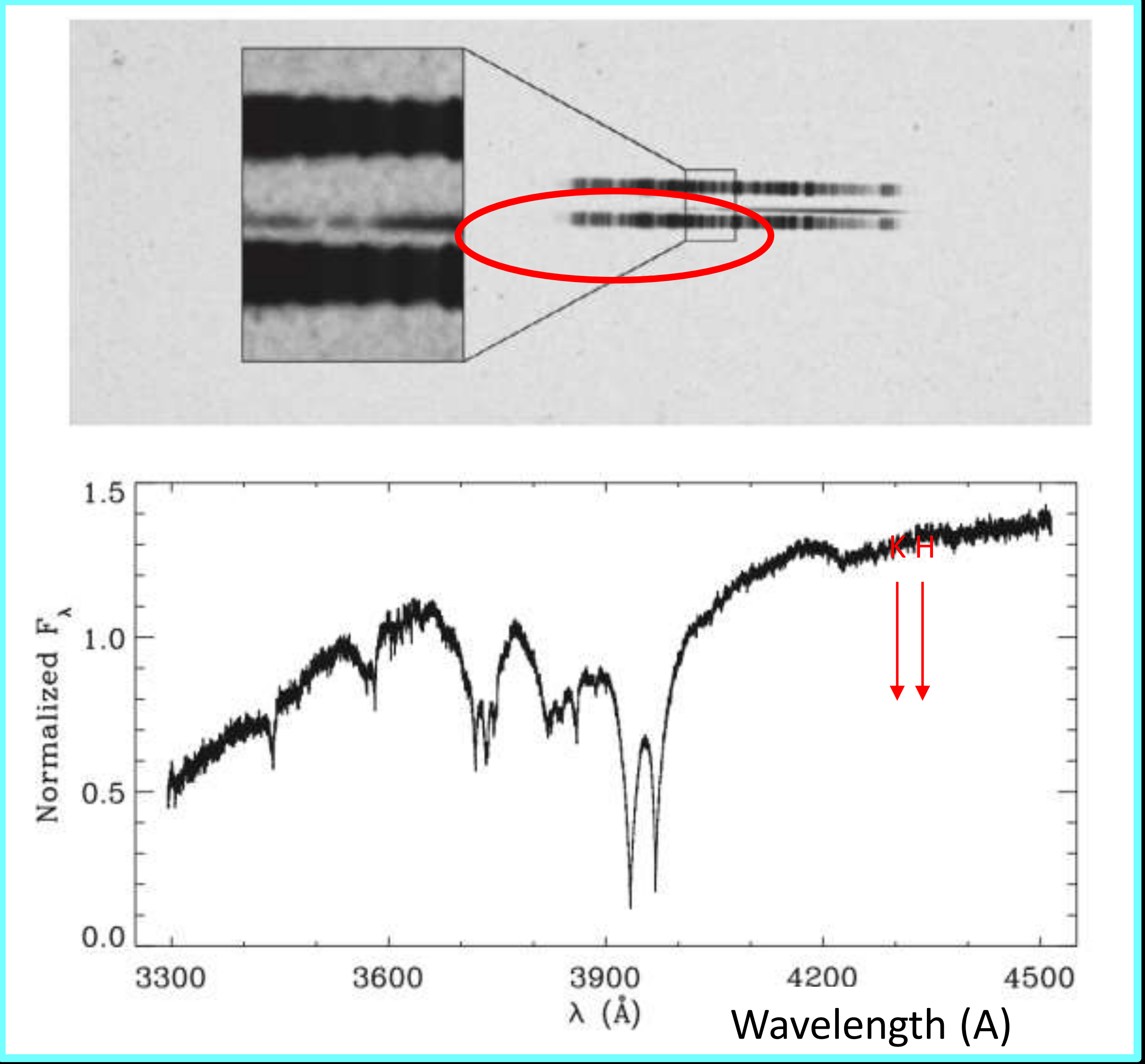


From MWDD



See: Xu, Rogers, Blouin (2024) for more details

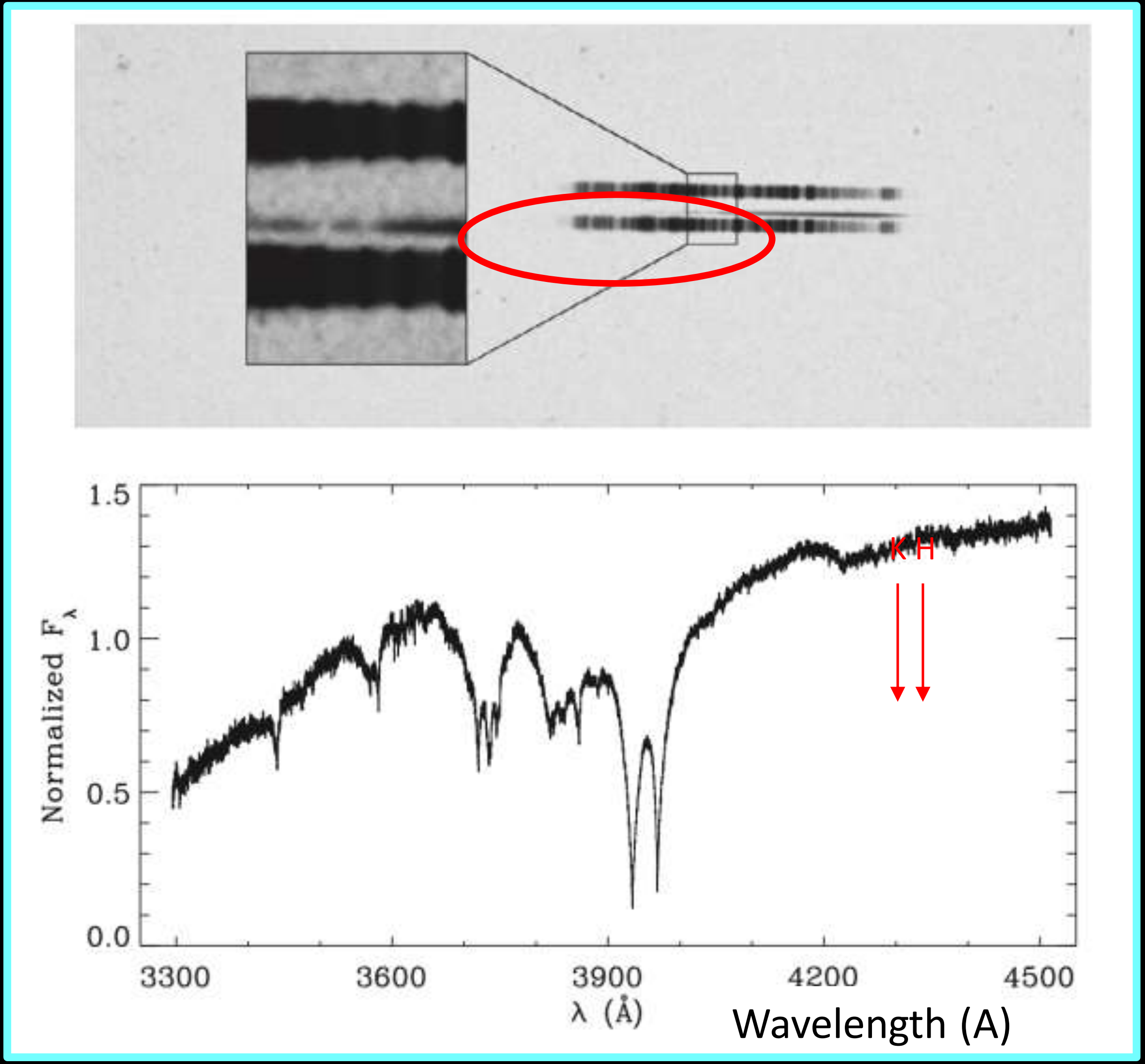
First Detection of exoplanetary material was in 1917!



Farihi (2016)

van Maanen (1917) reported a star with spectral type ‘about F0’

First Detection of exoplanetary material was in 1917!



Farihi (2016)

van Maanen (1917) reported a star with spectral type ‘about F0’

Wasn’t until the 1980s that white dwarfs with metals in their photosphere related to planetary material from outer belts, e.g. Alcock et al. (1985)

ON THE NUMBER OF COMETS AROUND OTHER SINGLE STARS

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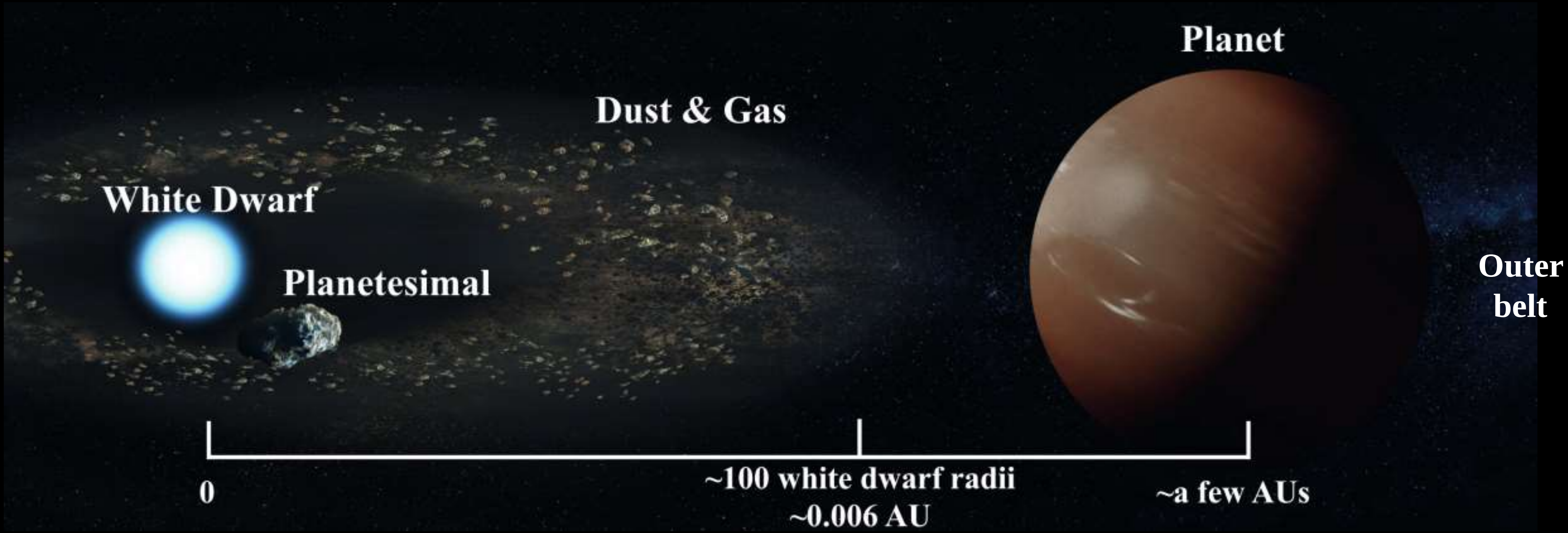
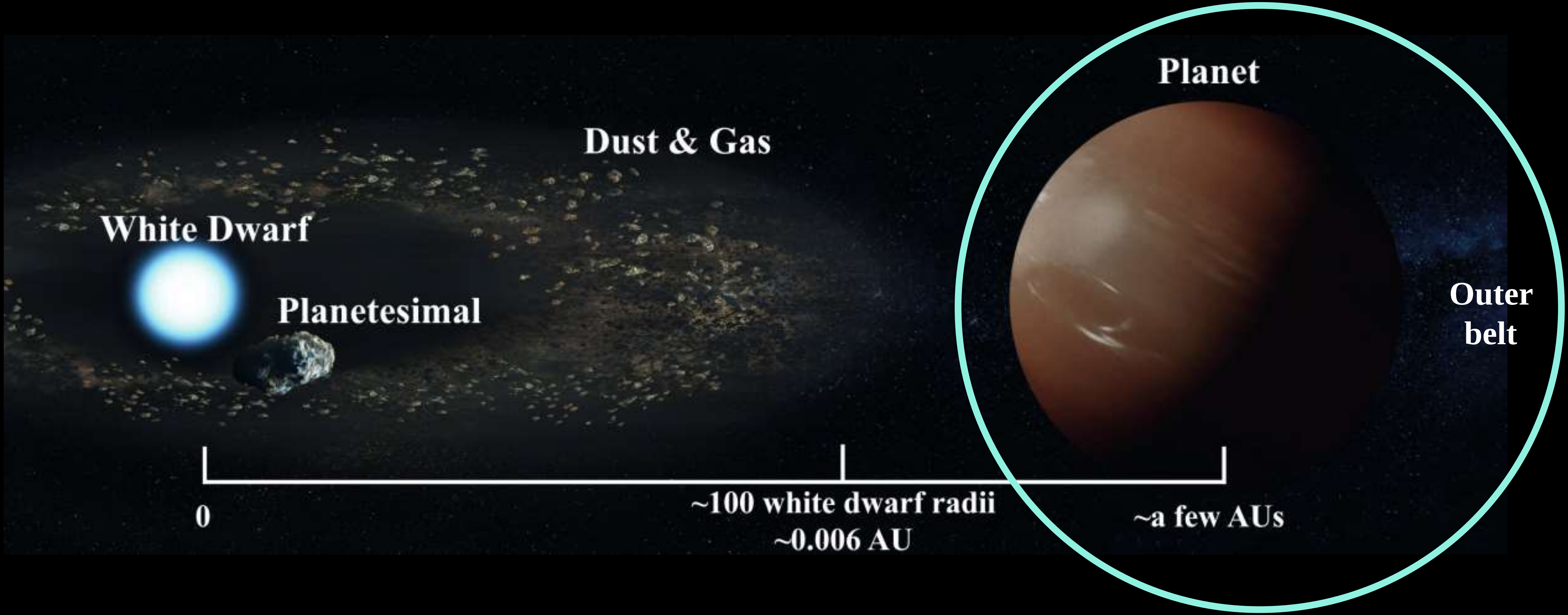
Department of Physics, Center for Space Research, and Center for Theoretical Physics, Massachusetts Institute of Technology

Received 1985 May 6: accepted 1985 September 3

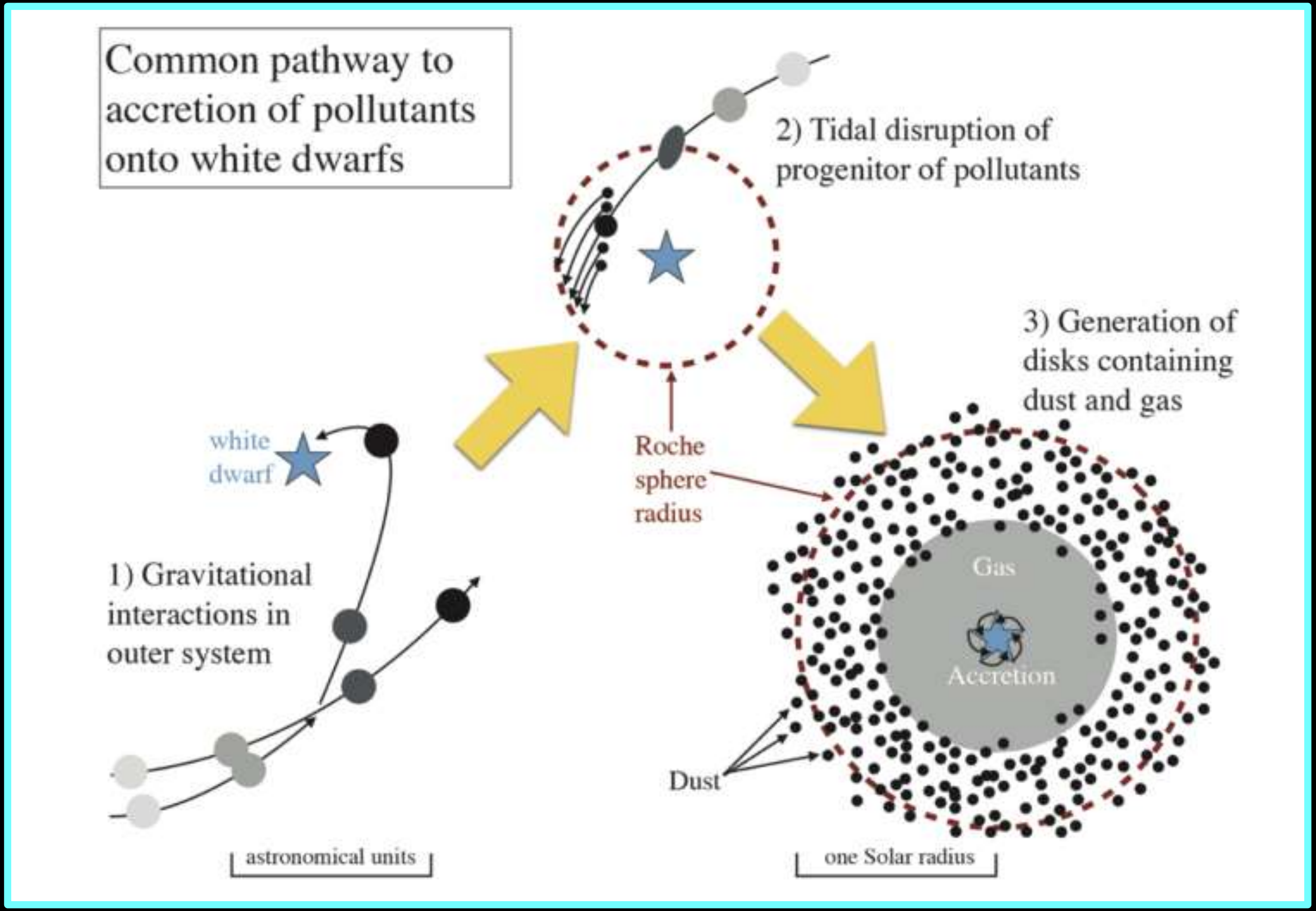


Xu and Bonsor (2021)



Xu and Bonsor (2021)

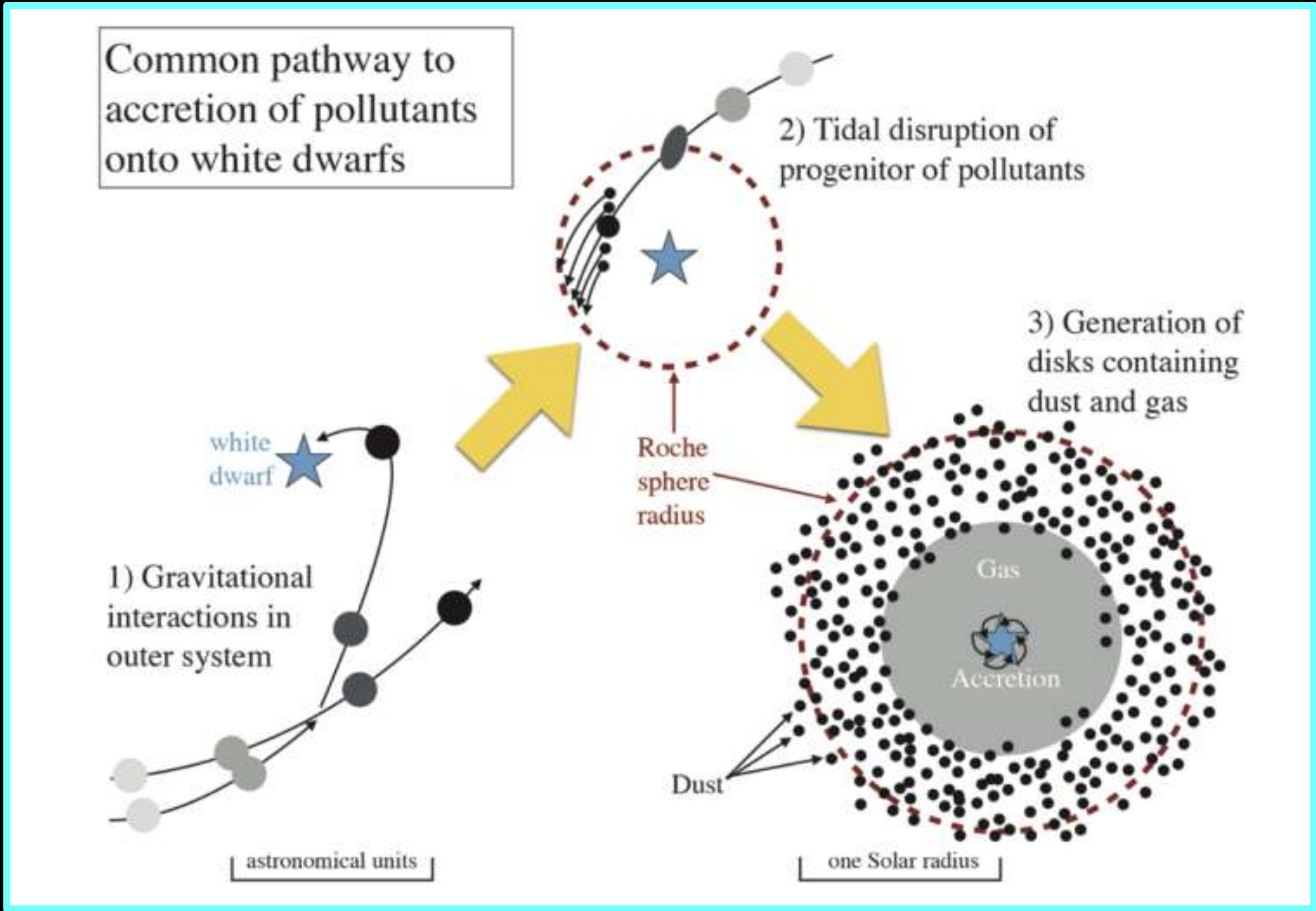
Models to explain white dwarf pollution and discs



Veras et al. (2024)

Models to explain white dwarf pollution and discs

Outer planets?



Veras et al. (2024)

Models to explain white dwarf pollution and discs

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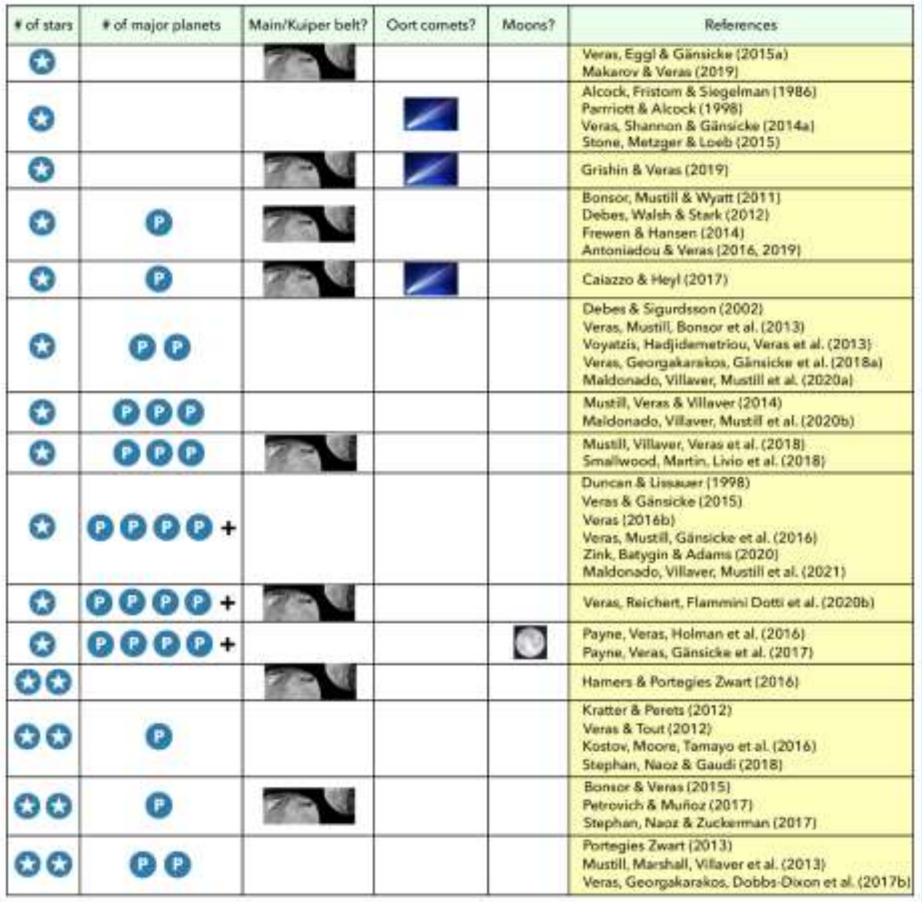
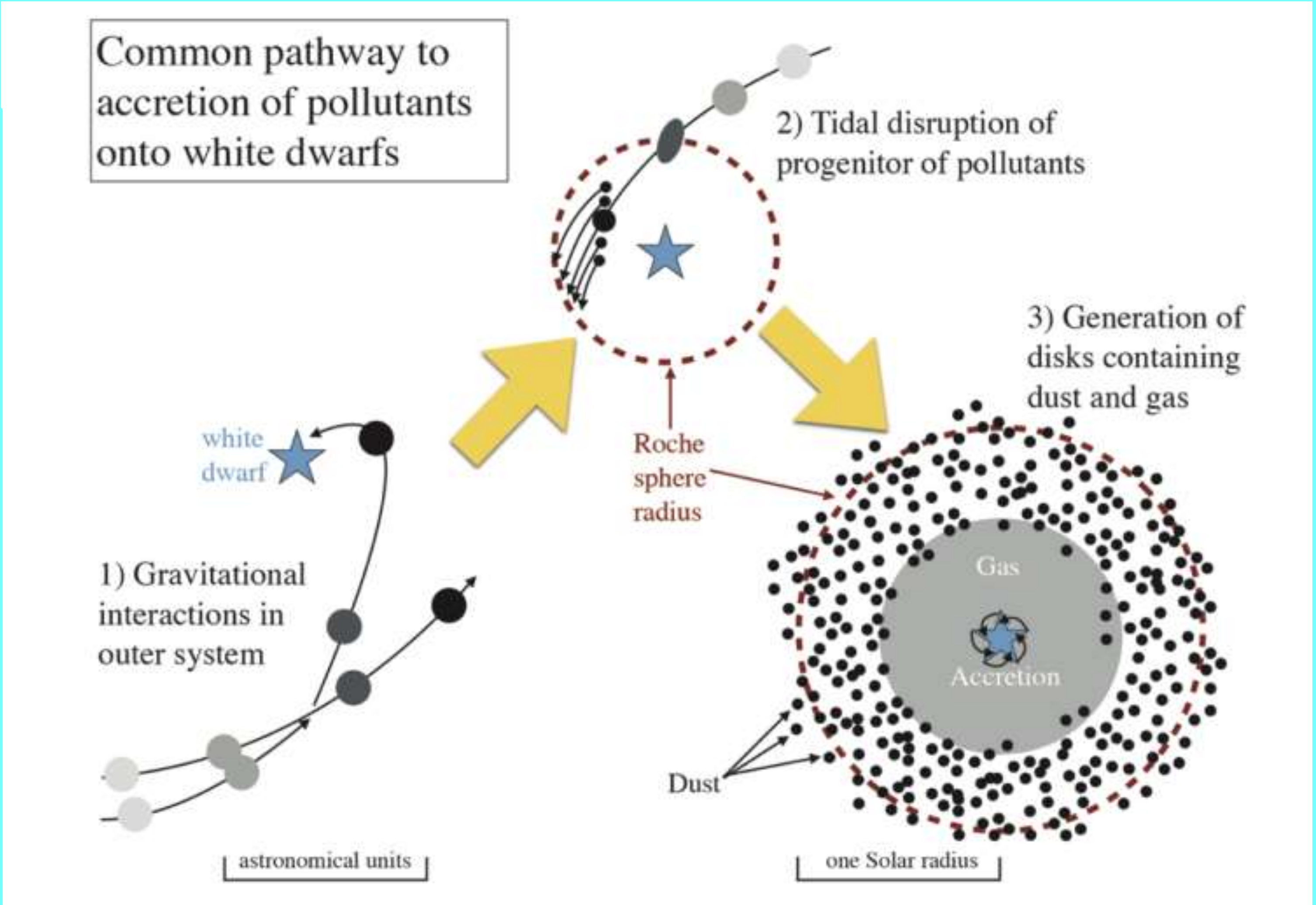


# of stars	# of major planets	Main/Kuiper belt?	Oort comets?	Moons?	References
					Veras, Eggl & Gänsicke (2015a) Makarov & Veras (2019)
					Alcock, Fristom & Siegelman (1986) Parriott & Alcock (1998) Veras, Shannon & Gänsicke (2014a) Stone, Metzger & Loeb (2015)
					Grishin & Veras (2019)
	P				Bonsor, Mustill & Wyatt (2011) Debes, Walsh & Stark (2012) Frewen & Hansen (2014) Antoniadou & Veras (2016, 2019)
	P				Caiazzo & Heyl (2017)
	P P				Debes & Sigurdsson (2002) Veras, Mustill, Bonsor et al. (2013) Voyatzis, Hadjidemetriou, Veras et al. (2013) Veras, Georgakarakos, Gänsicke et al. (2018a) Maldonado, Villaver, Mustill et al. (2020a)
	P P P				Mustill, Veras & Villaver (2014) Maldonado, Villaver, Mustill et al. (2020b)
	P P P				Mustill, Villaver, Veras et al. (2018) Smallwood, Martin, Livio et al. (2018)
	P P P P +				Duncan & Lissauer (1998) Veras & Gänsicke (2015) Veras (2016b) Veras, Mustill, Gänsicke et al. (2016) Zink, Batygin & Adams (2020) Maldonado, Villaver, Mustill et al. (2021)
	P P P P +				Veras, Reichert, Flammini Dotti et al. (2020b)
	P P P P +				Payne, Veras, Holman et al. (2016) Payne, Veras, Gänsicke et al. (2017)
					Hamers & Portegies Zwart (2016)
	P				Kratter & Perets (2012) Veras & Tout (2012) Kostov, Moore, Tamayo et al. (2016) Stephan, Naoz & Gaudi (2018)
	P				Bonsor & Veras (2015) Petrovich & Muñoz (2017) Stephan, Naoz & Zuckerman (2017)
	P P				Portegies Zwart (2013) Mustill, Marshall, Villaver et al. (2013) Veras, Georgakarakos, Dobbs-Dixon et al. (2017b)



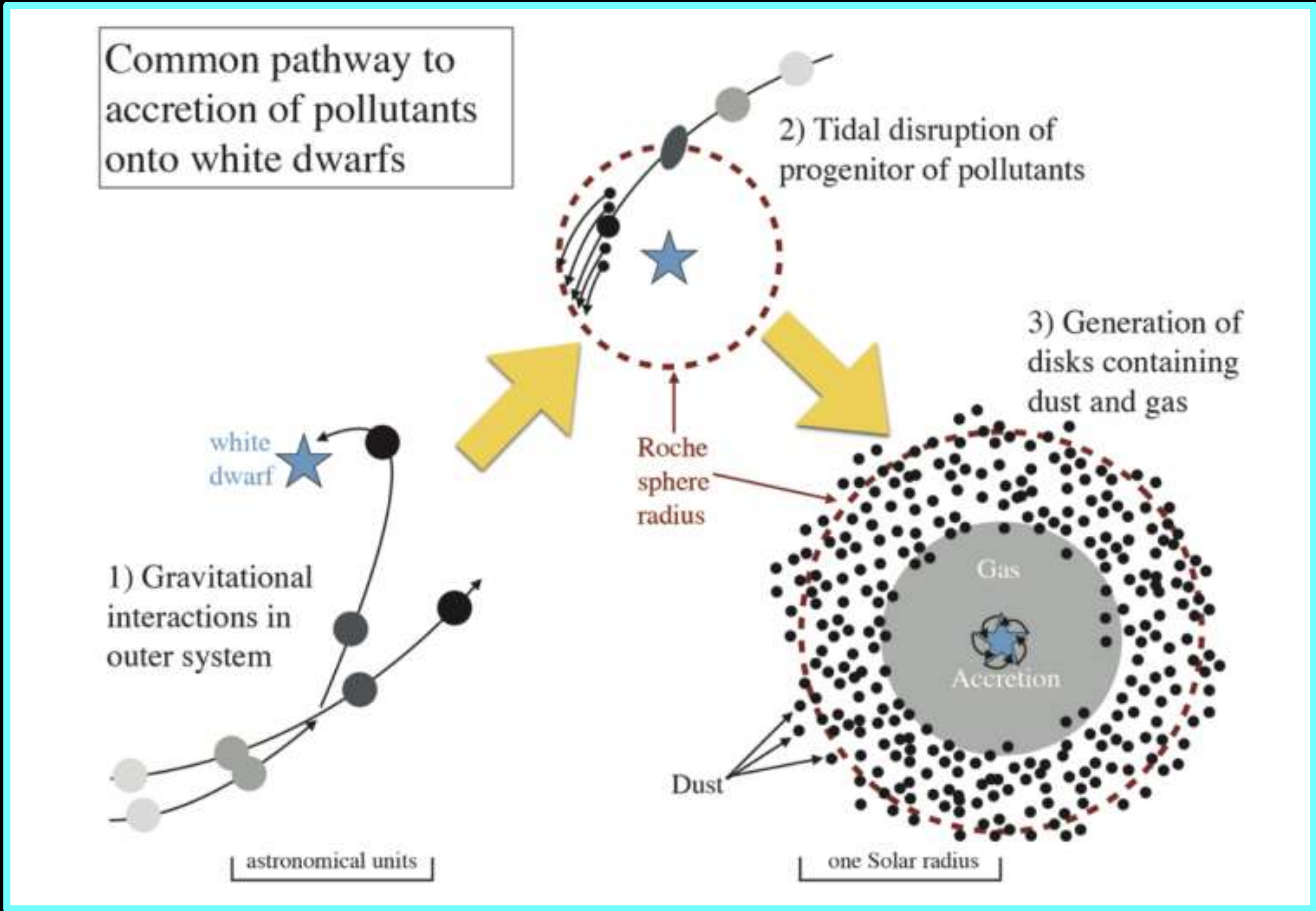
Veras (2021)

Veras et al. (2024)

Models to explain white dwarf pollution and discs

Outer planets?

Galaxy tides/stellar flybys?
E.g. Parriott & Alcock (1998), *Veras & Wyn Evans (2013)*



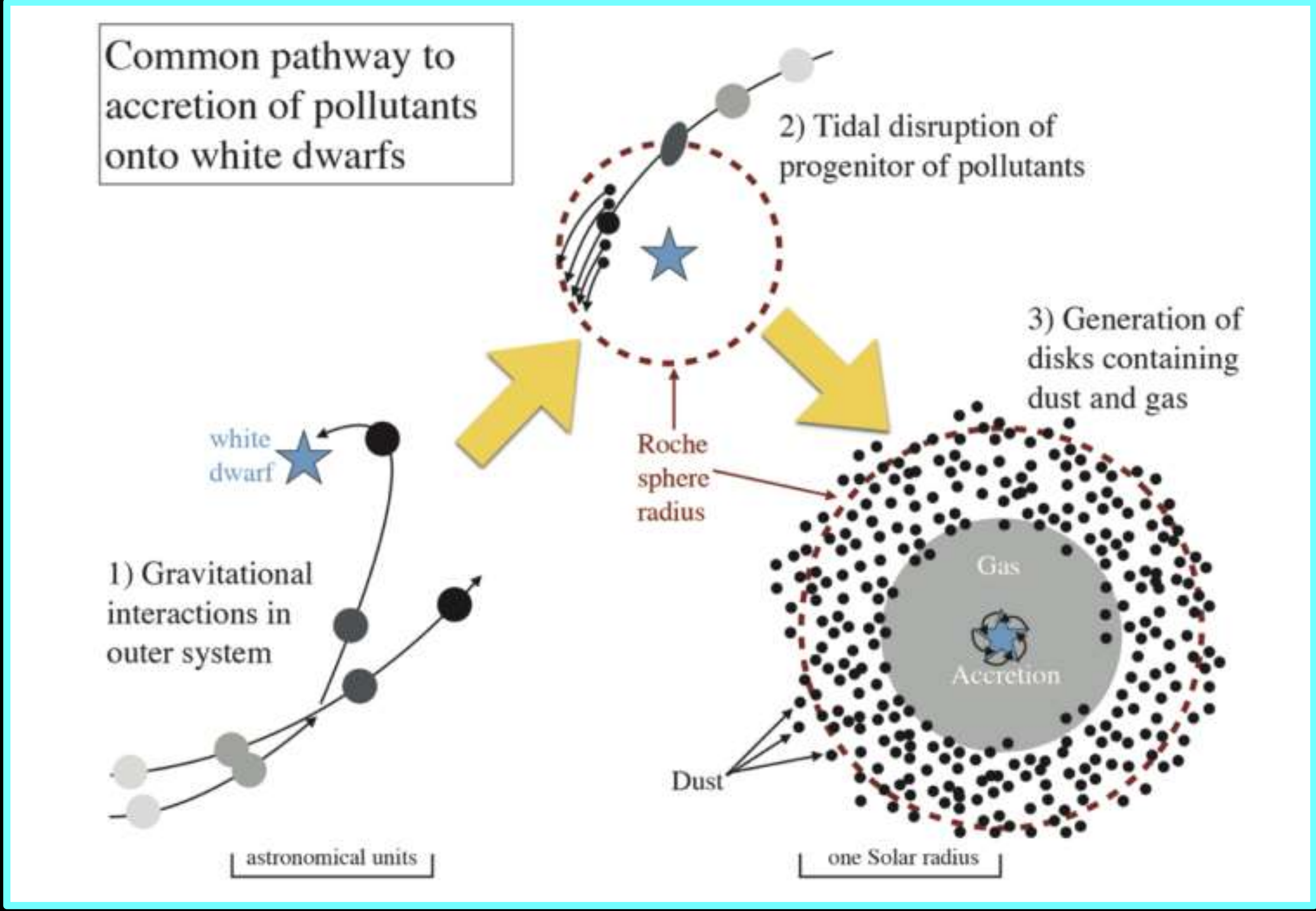
Veras et al. (2024)

Models to explain white dwarf pollution and discs

Outer planets?

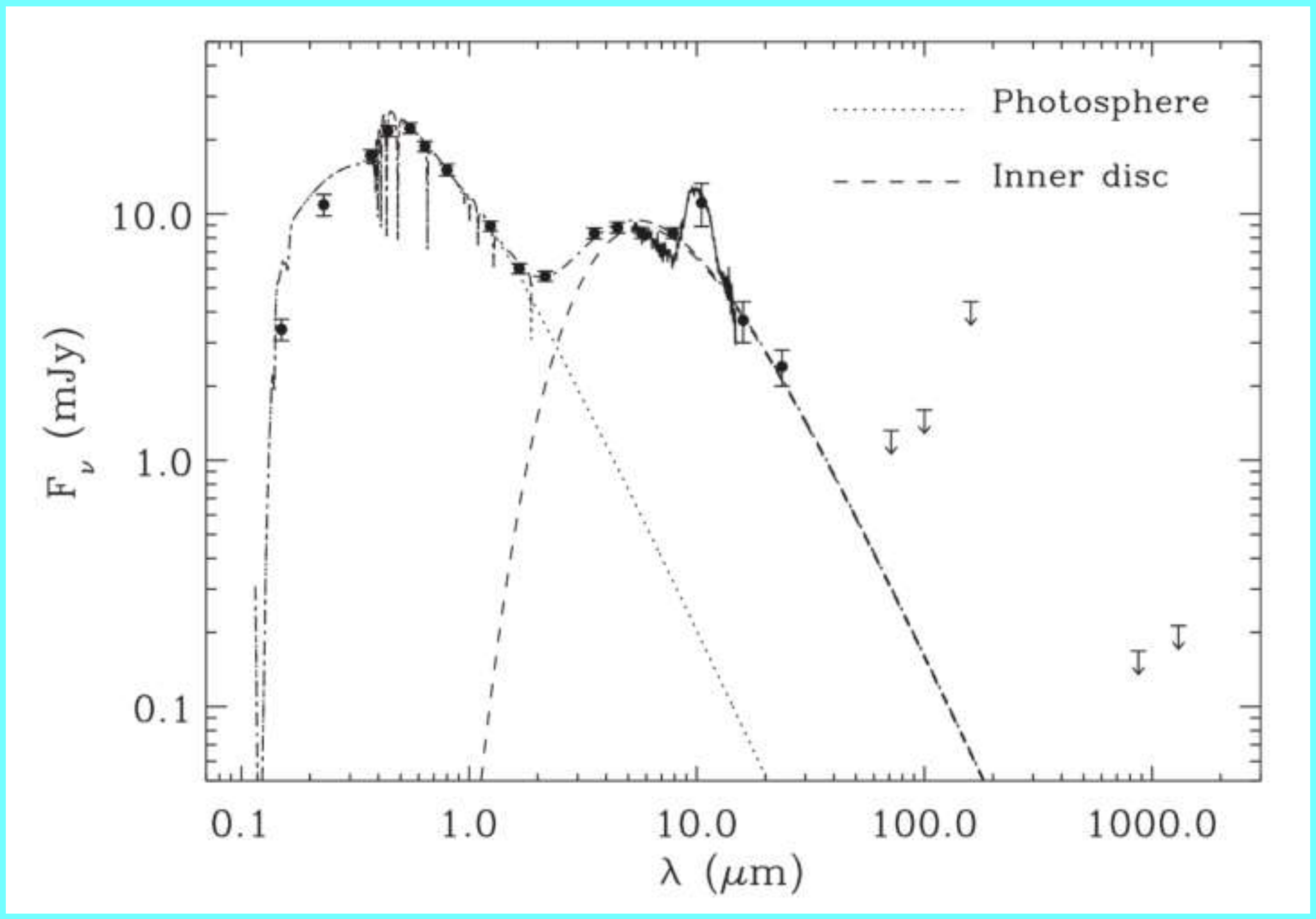
Galaxy tides/stellar flybys?
E.g. Parriott & Alcock (1998), *Veras & Wyn Evans (2013)*

These require the survival of outer belts

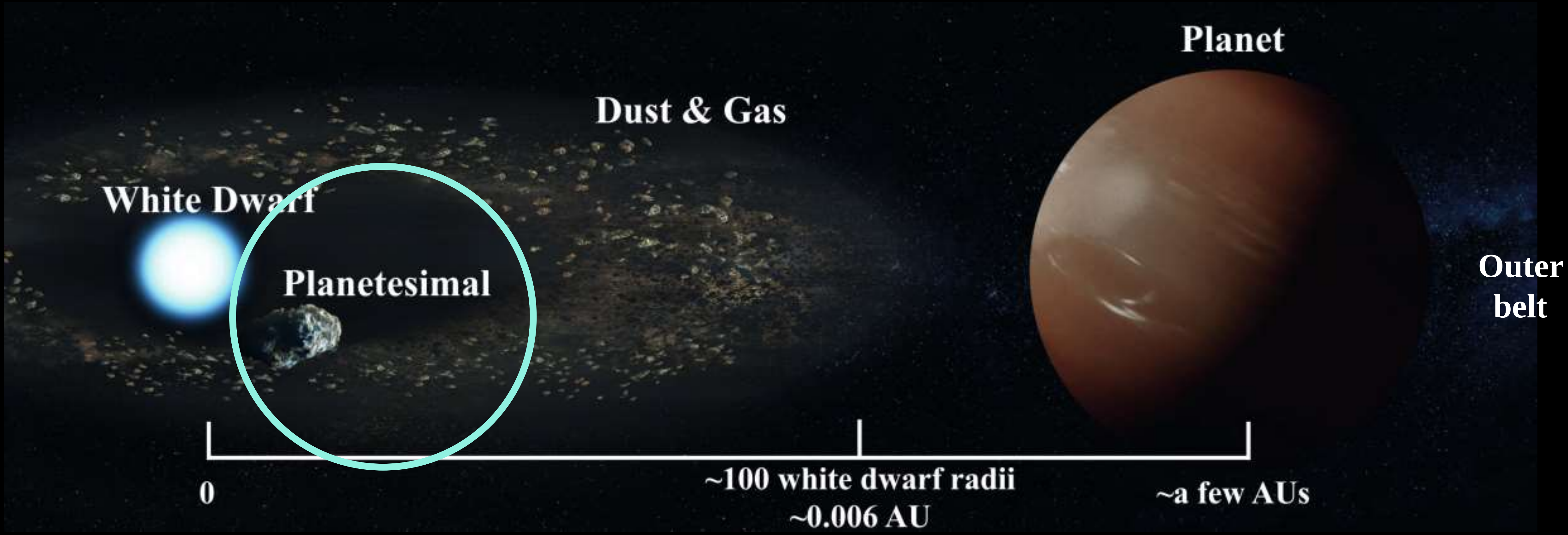


Veras et al. (2024)

No detections of cool infrared excesses

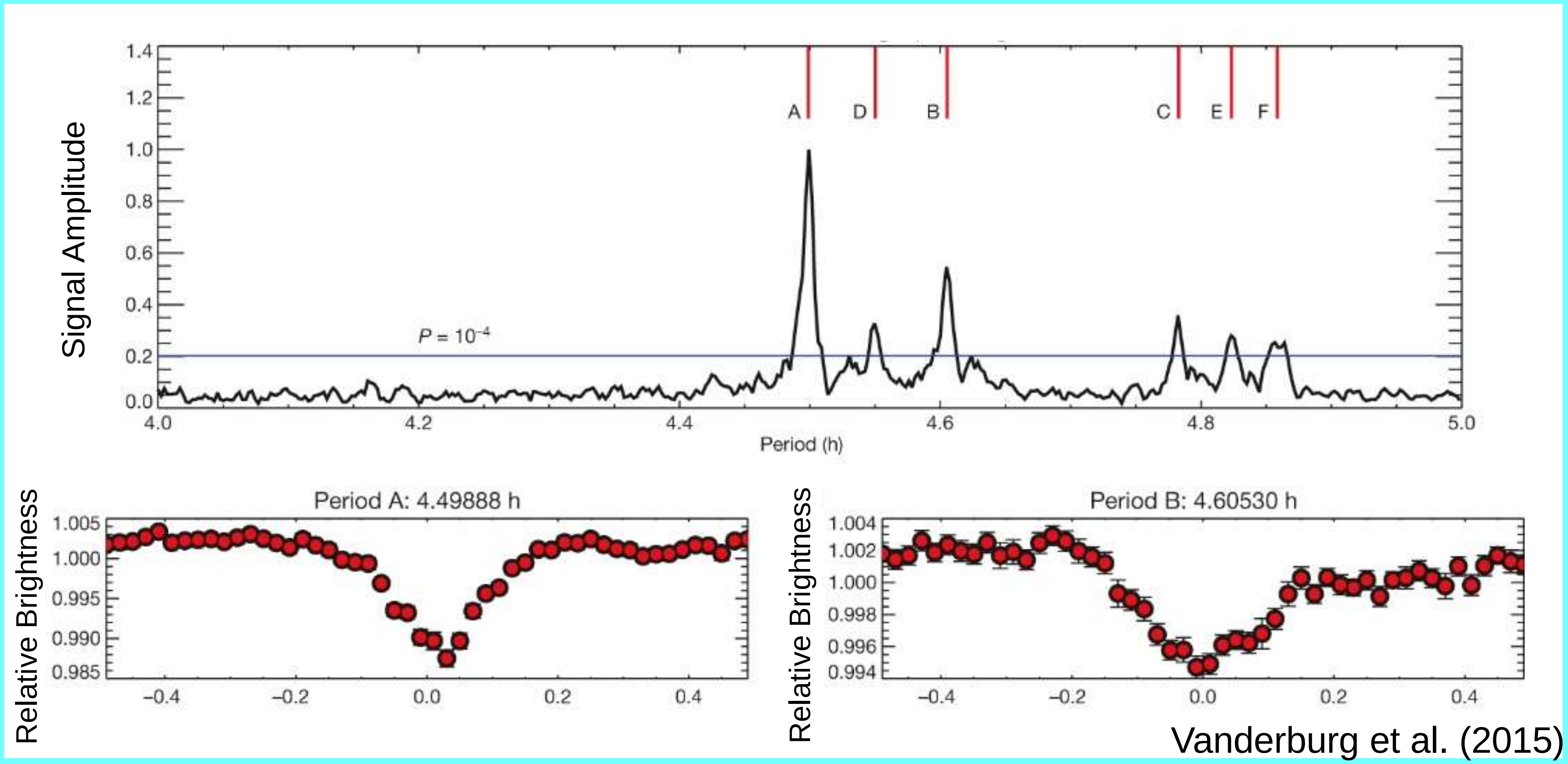


Farihi et al. (2014)



Xu and Bonsor (2021)

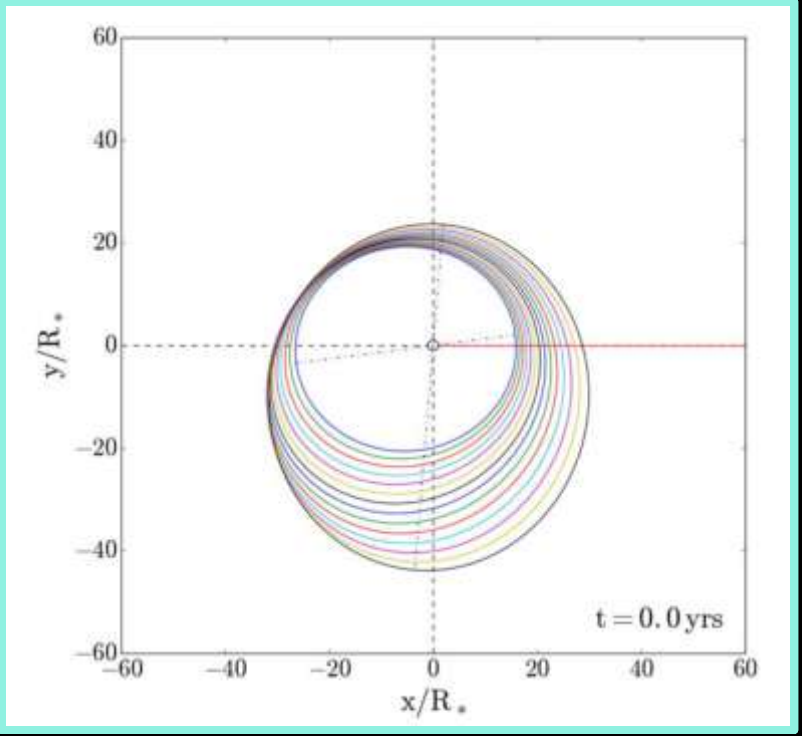
Transiting Debris around WD1145+017



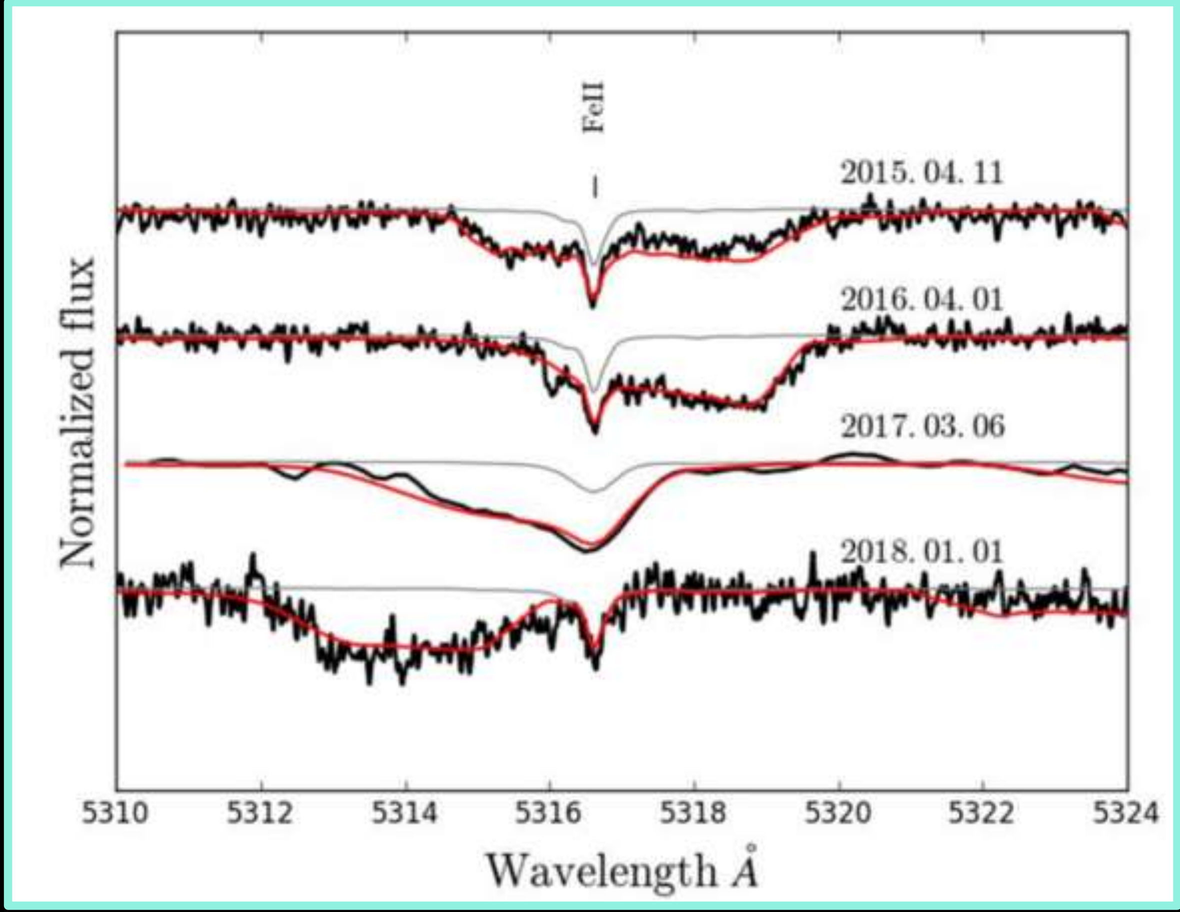
6 noticeable periodicities (4.5 and 5 hrs) in the K2 data
Asymmetric profiles with cometary like tail -> actively disintegrating asteroid

Transiting debris and variable gas absorption

Eccentric gas disc precessing with period of 4.6 years



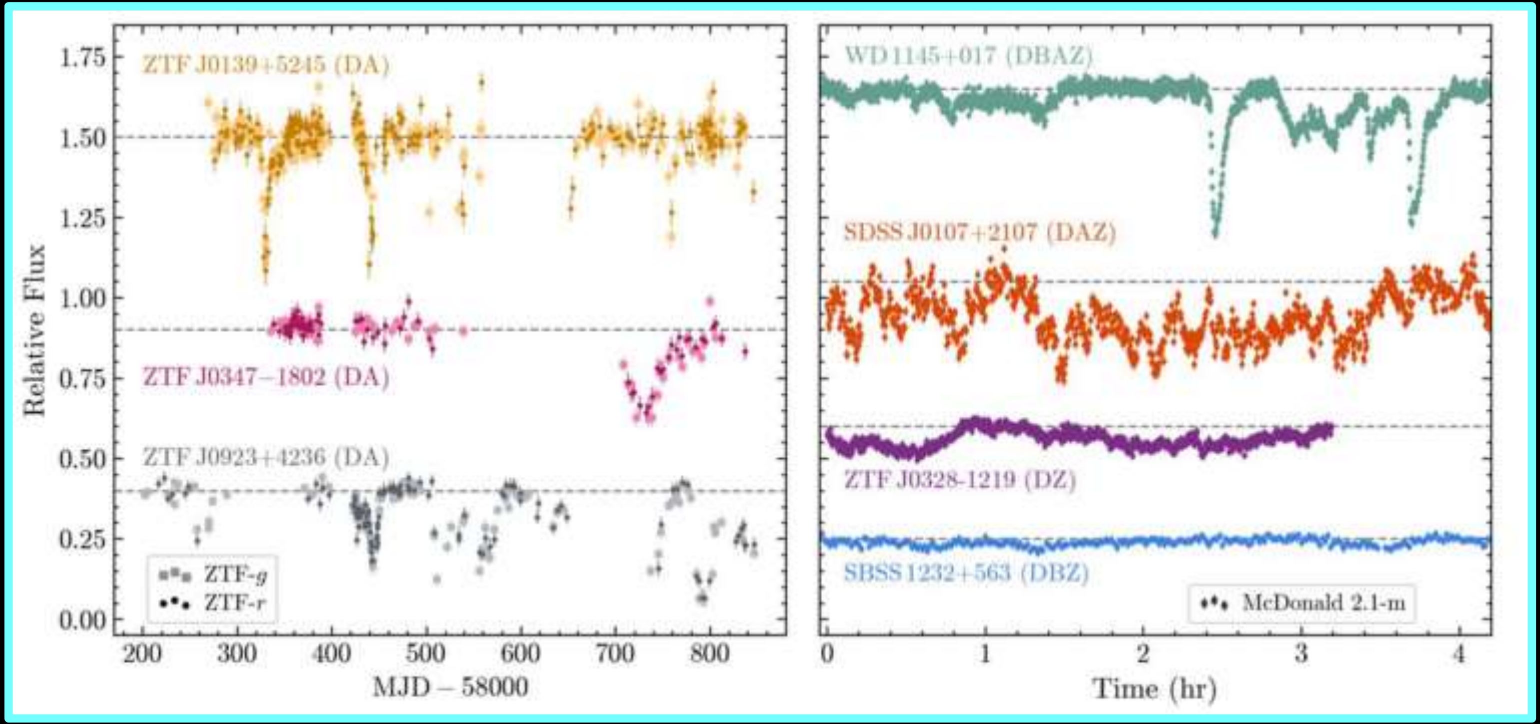
Example of Fe II 5316A line with photospheric absorption and variable circumstellar gas absorption:



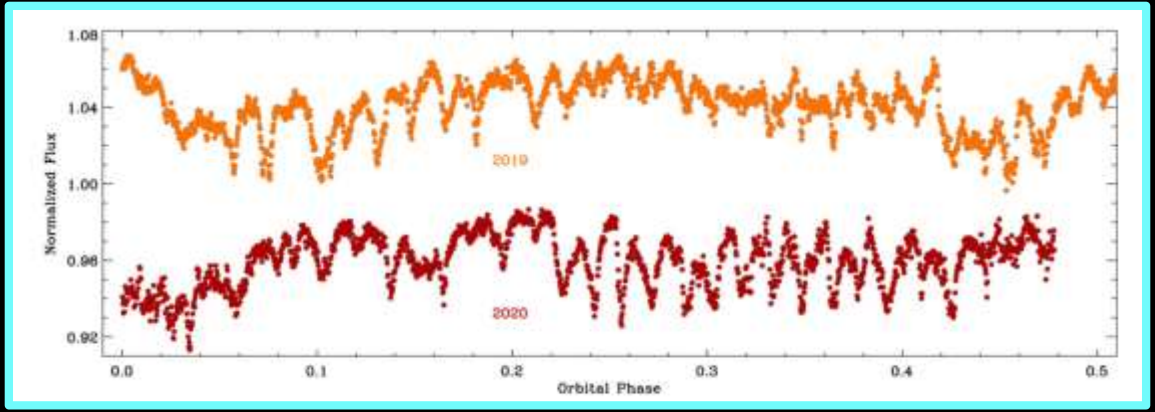
Fortin-Archambault et al. (2020)

New models: Le Bourdais et al. (in review)

More transiting systems

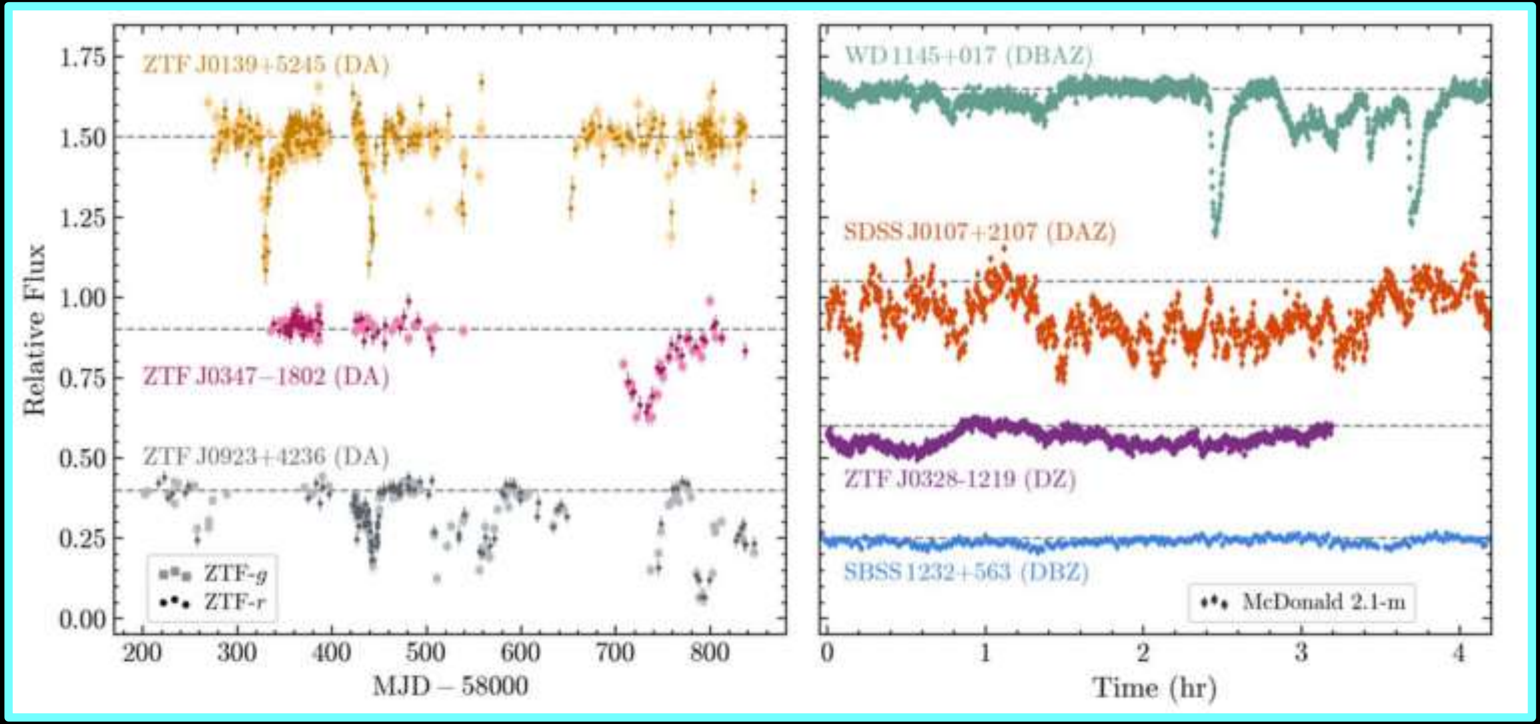


Guidry et al. (2021)



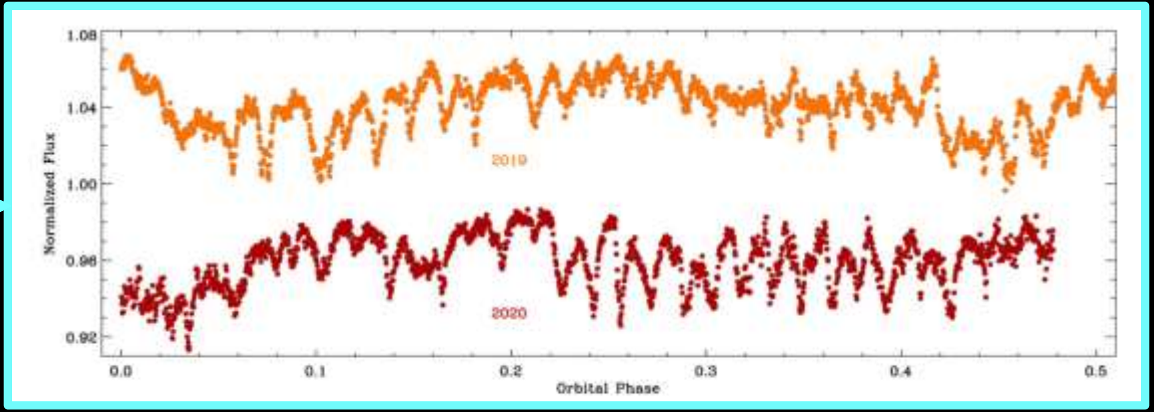
Farihi et al. (2022)

More transiting systems



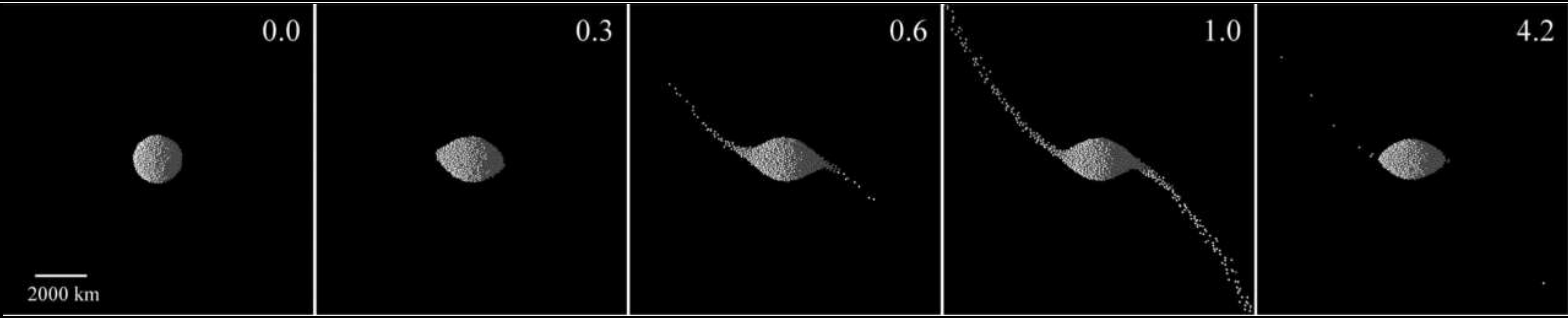
Guidry et al. (2021)

See talk by Akshay Robert (Tuesday 16:26) on new observations of this transiting WD



Farihi et al. (2022)

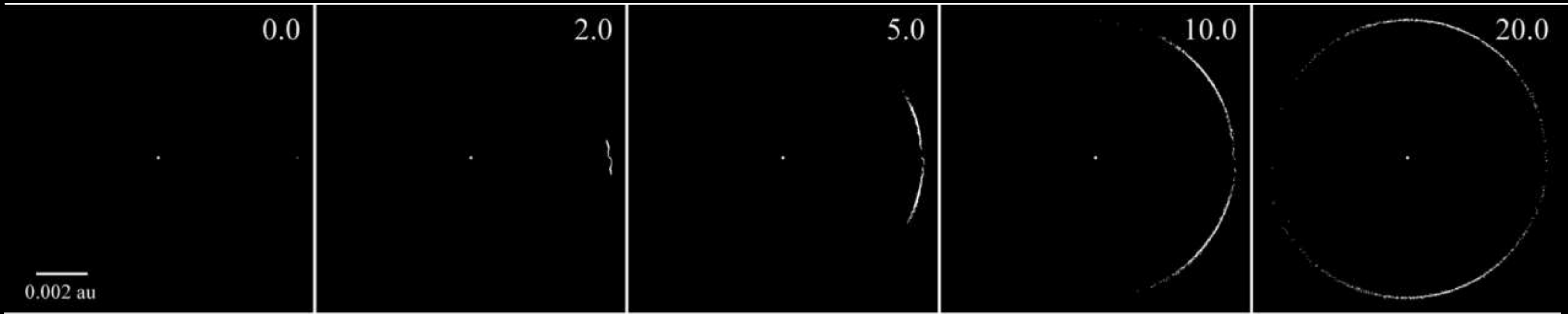
Tidal disruption to explain WD1145+017



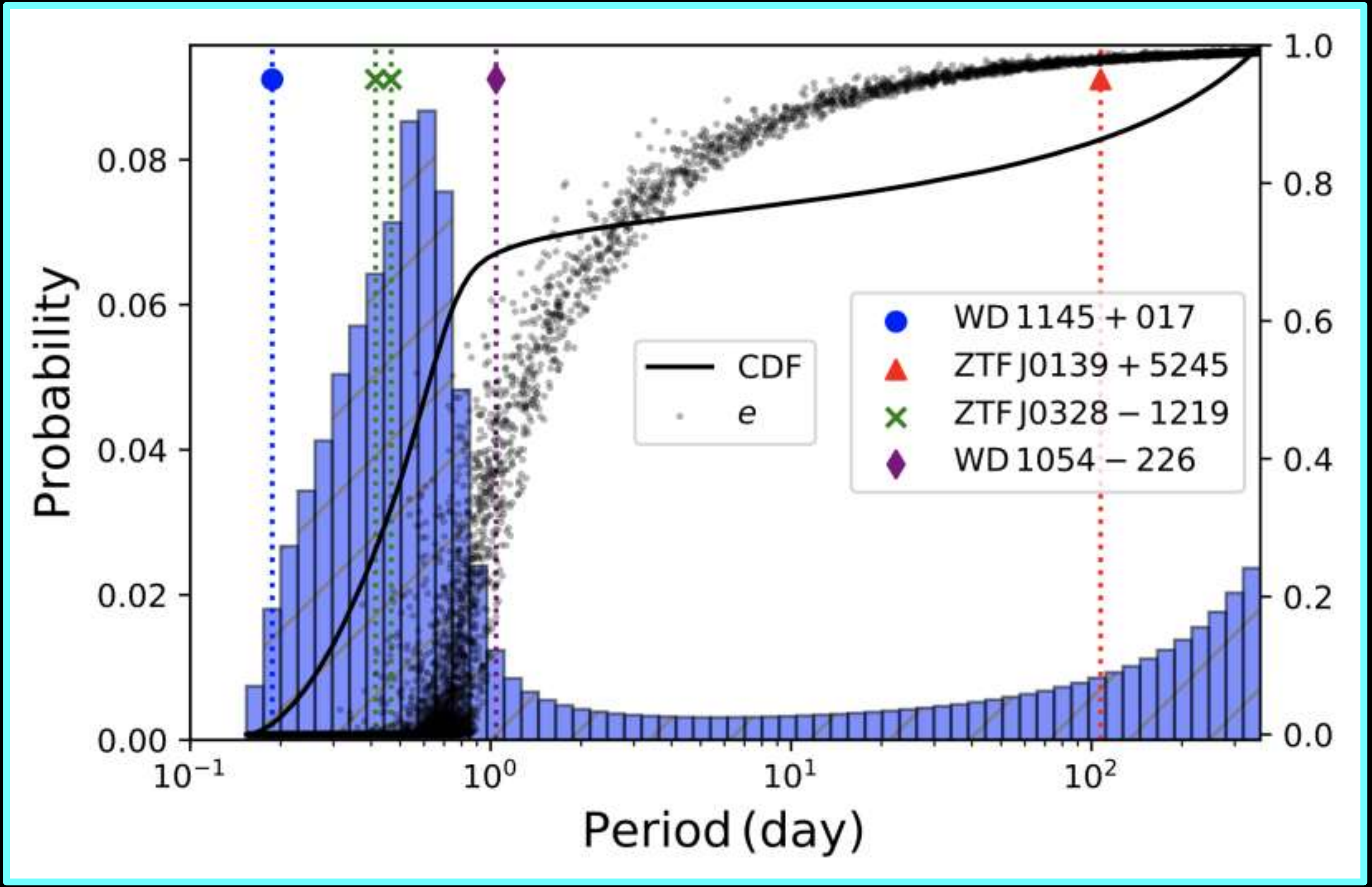
Top: Tidal disruption of differentiated rubble pile

Bottom: Spreading of particles around the WD

Veras et al. (2017)

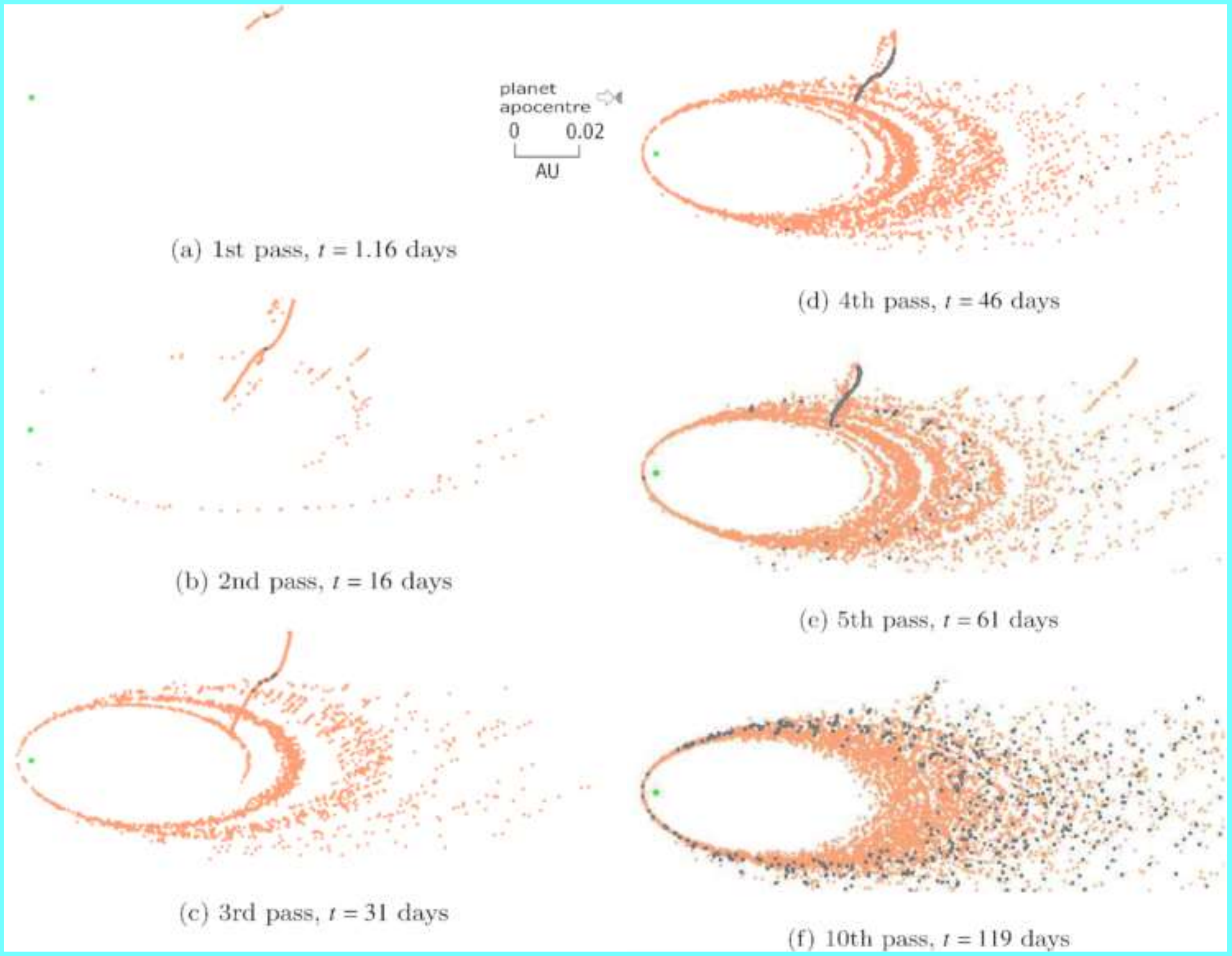


Tidal evolution to explain transiting systems



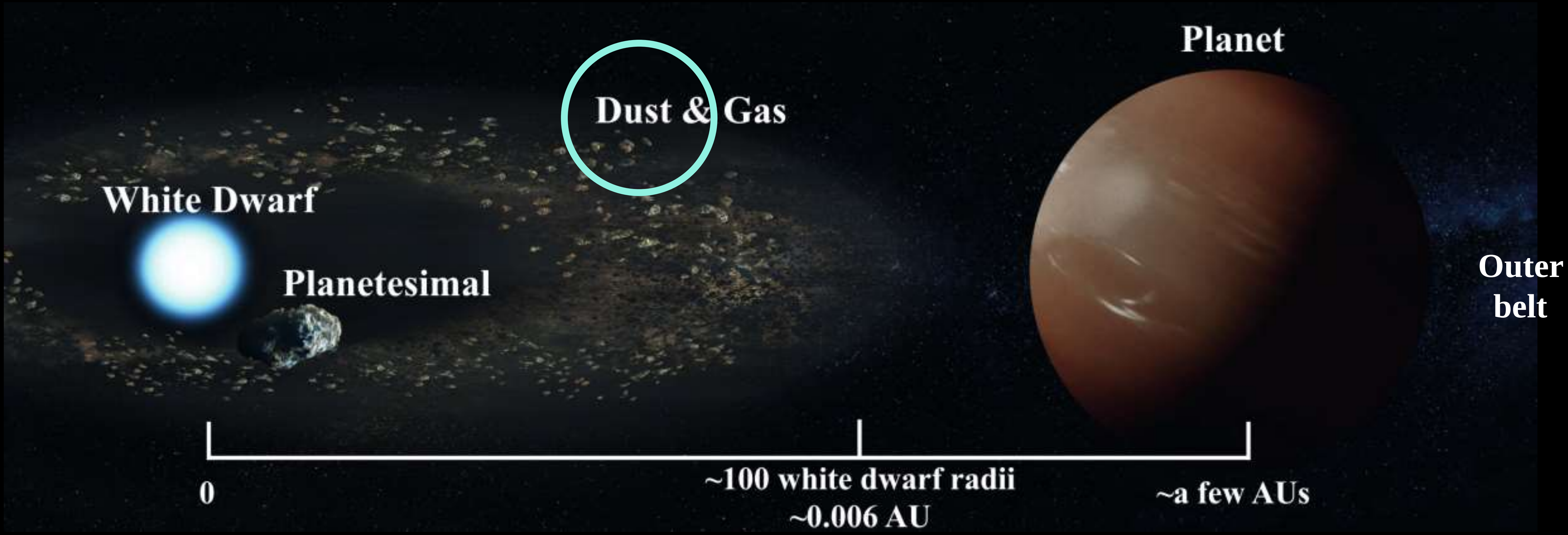
Li … Rogers et al. (submitted)

From the outer system inwards – disc formation



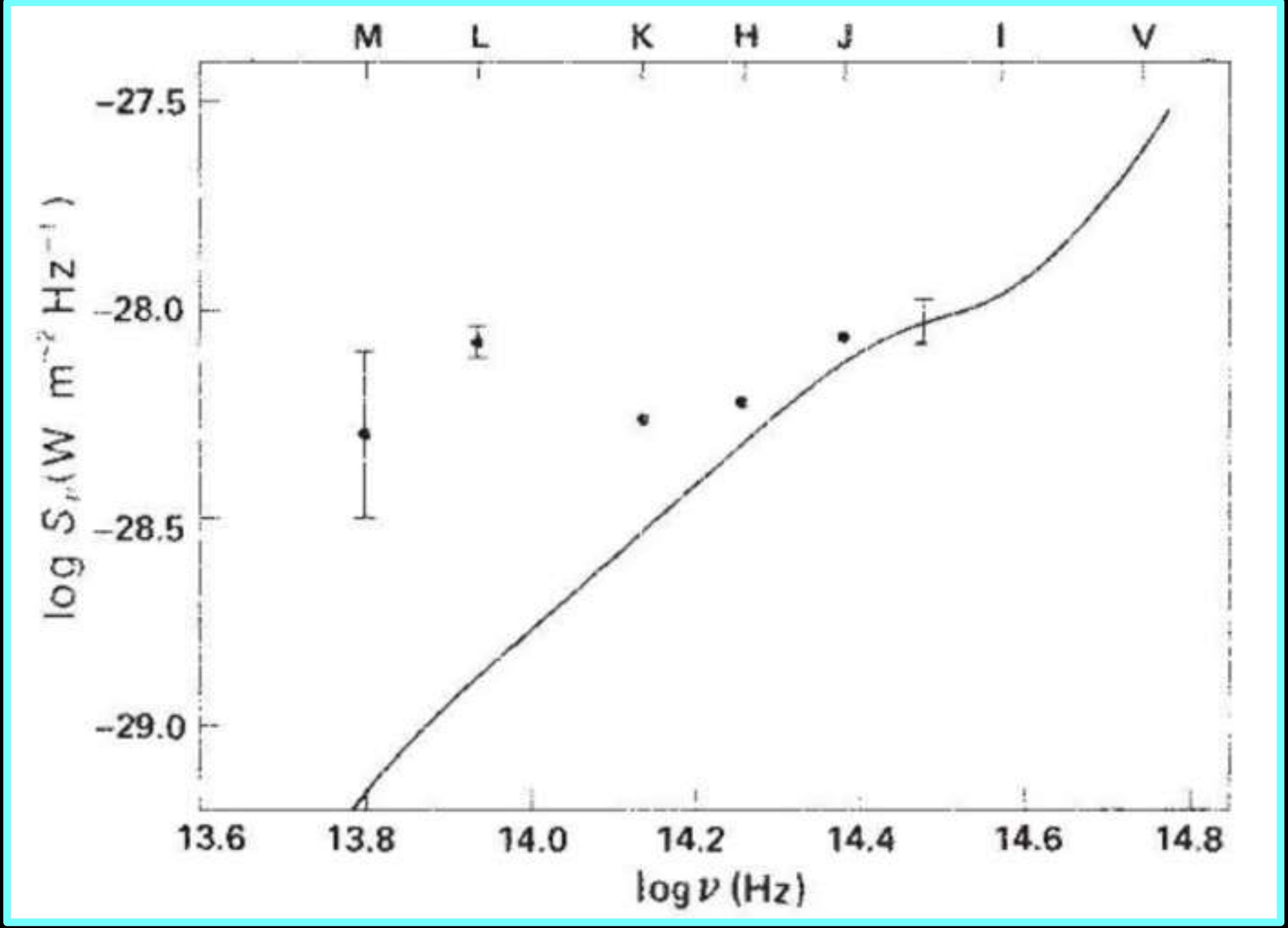
Simulations of disc formation through partial tidal disruptions of an Earth-sized planet

Malamud & Perets (2020)



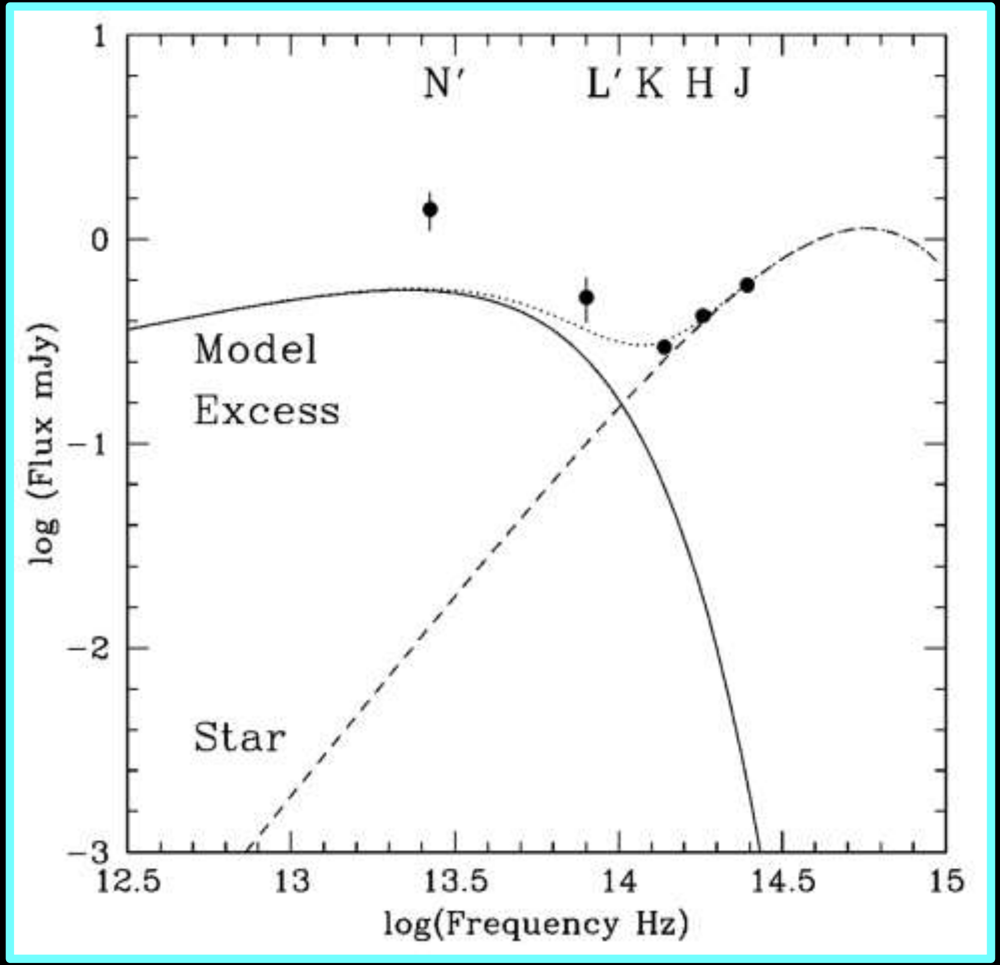
Xu and Bonsor (2021)

First Detection of an infrared excess from a disc

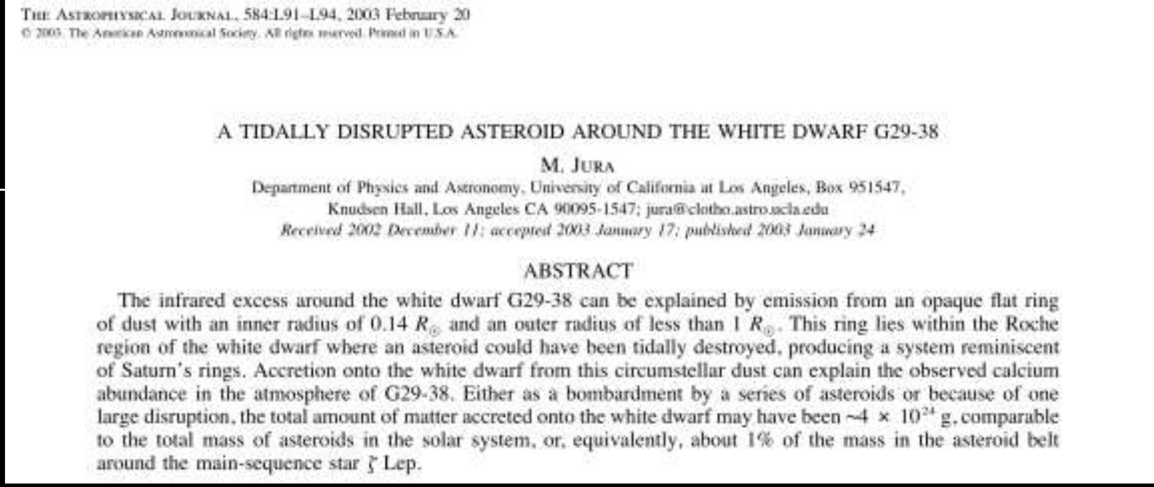


Zuckerman and Becklin (1987)
Graham et al. (1990)

Model fits to the data



Becklin et al. (2005)


The Astrophysical Journal, 584:L91–L94, 2003 February 20

A TIDALLY DISRUPTED ASTEROID AROUND THE WHITE DWARF G29-38

M. Jura
Department of Physics and Astronomy, University of California at Los Angeles, Box 951547, Knudsen Hall, Los Angeles CA 90095-1547; jura@clotho.astro.ucla.edu
Received 2002 December 11; accepted 2003 January 17; published 2003 January 24

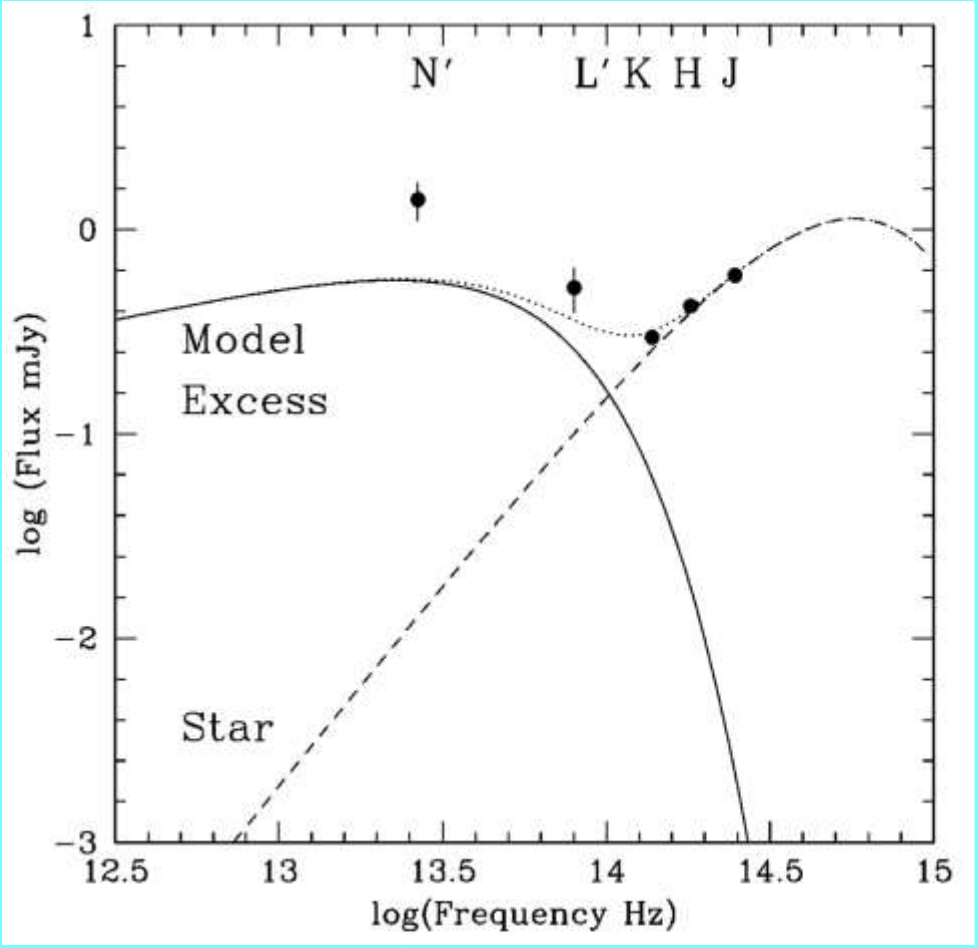
ABSTRACT

The infrared excess around the white dwarf G29-38 can be explained by emission from an opaque flat ring of dust with an inner radius of 0.14 $R_{\odot}$ and an outer radius of less than 1 $R_{\odot}$. This ring lies within the Roche region of the white dwarf where an asteroid could have been tidally destroyed, producing a system reminiscent of Saturn's rings. Accretion onto the white dwarf from this circumstellar dust can explain the observed calcium abundance in the atmosphere of G29-38. Either as a bombardment by a series of asteroids or because of one large disruption, the total amount of matter accreted onto the white dwarf may have been ~4 × 10^{24} g, comparable to the total mass of asteroids in the solar system, or, equivalently, about 1% of the mass in the asteroid belt around the main-sequence star ζ Lep.

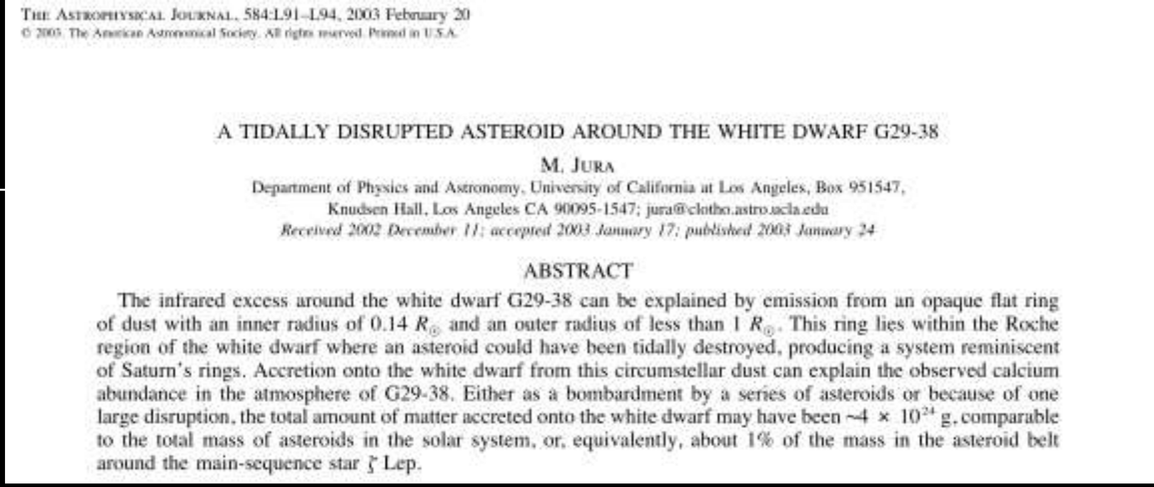
Jura et al. (2003)

Optically thick, razor thin dust disc often fitted to data

Model fits to the data



Becklin et al. (2005)



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Jura et al. (2003)

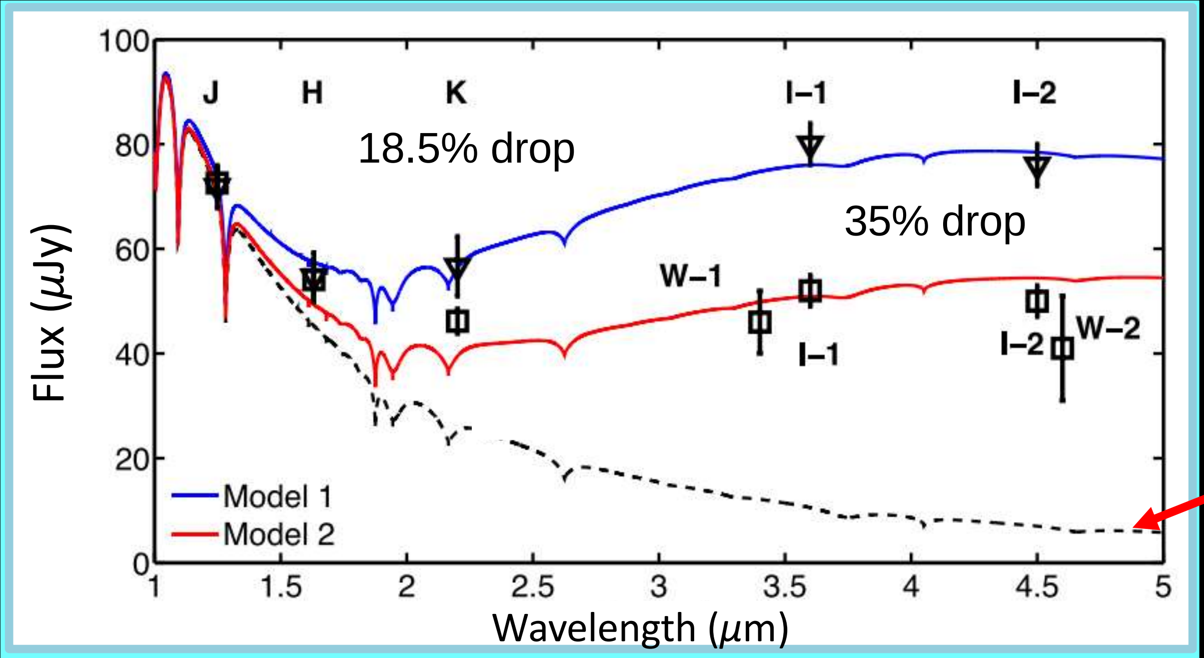
Optically thick, razor thin dust disc often fitted to data

But, this only works up to a limit…

See talk by Yixuan Chen (Wednesday 10:06) on fitting flared disc models to IR excesses

Dust Variability

Near-infrared Mid-infrared



WD J0959−0200: Xu and Jura (2014)

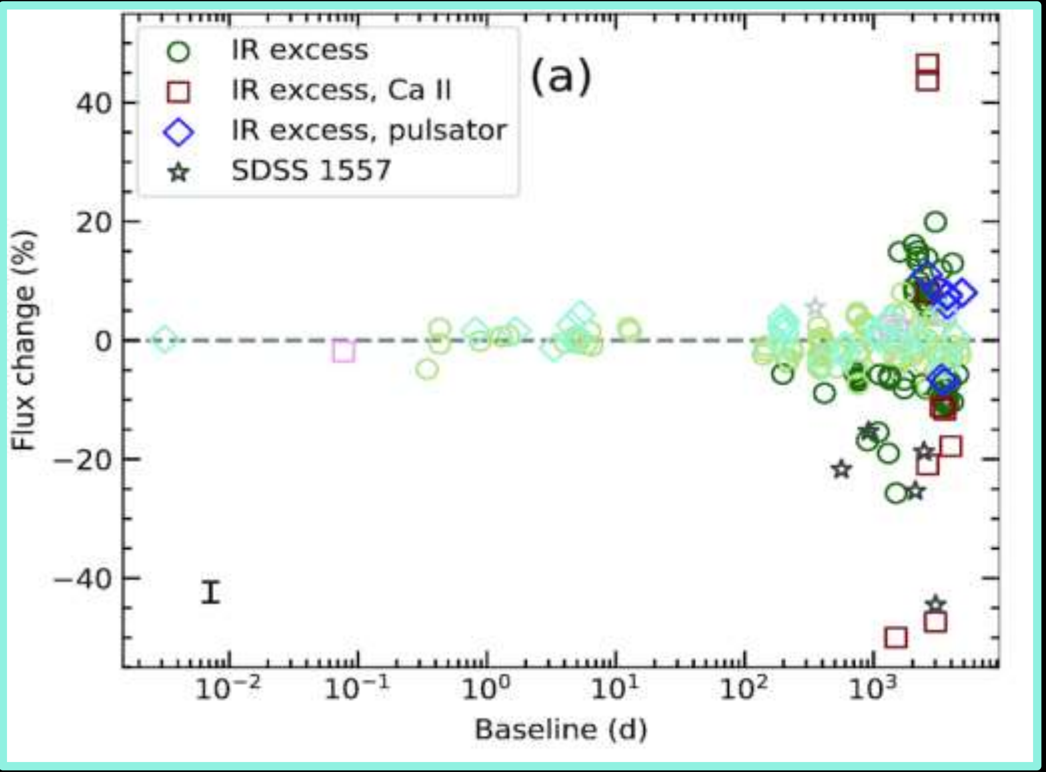
Drop in disc flux between ▼ and ■

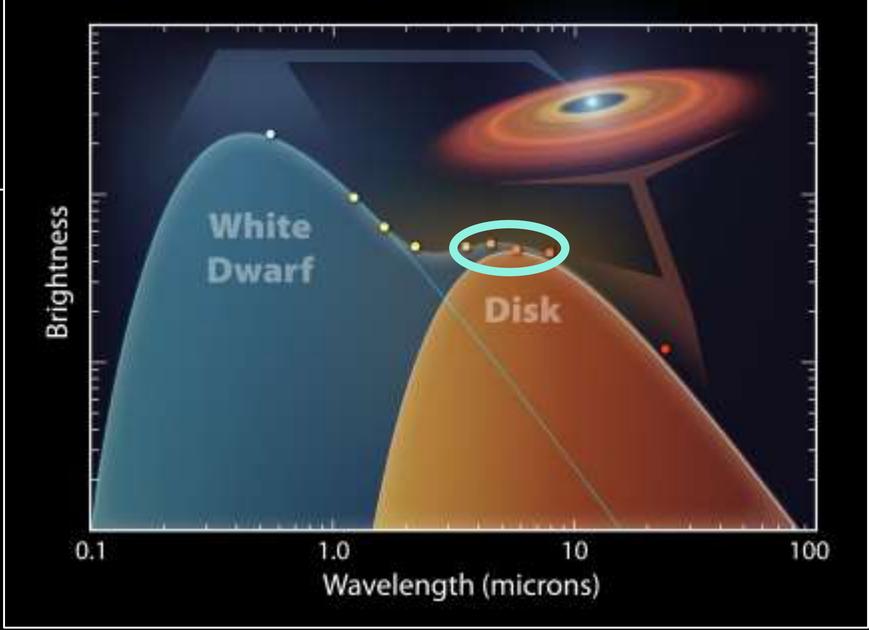
White dwarf flux

Variability in individual systems: GD 56 (Farihi et al., 2018), SDSS J1228+1040 (Xu et al., 2018), WD 0145+234 (Wang et al. 2019)

Variability surveys: Near-infrared (Rogers et al. 2020), Mid-infrared (Swan et al. 2019, 2020)

Variability Survey: Mid Infrared

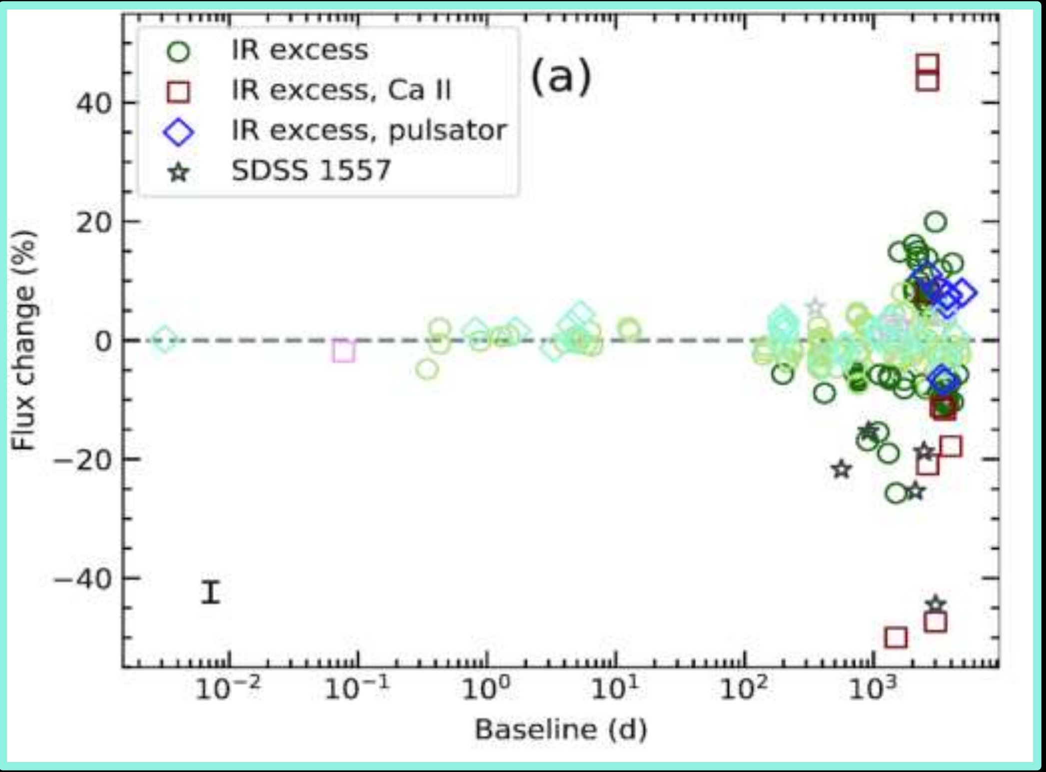


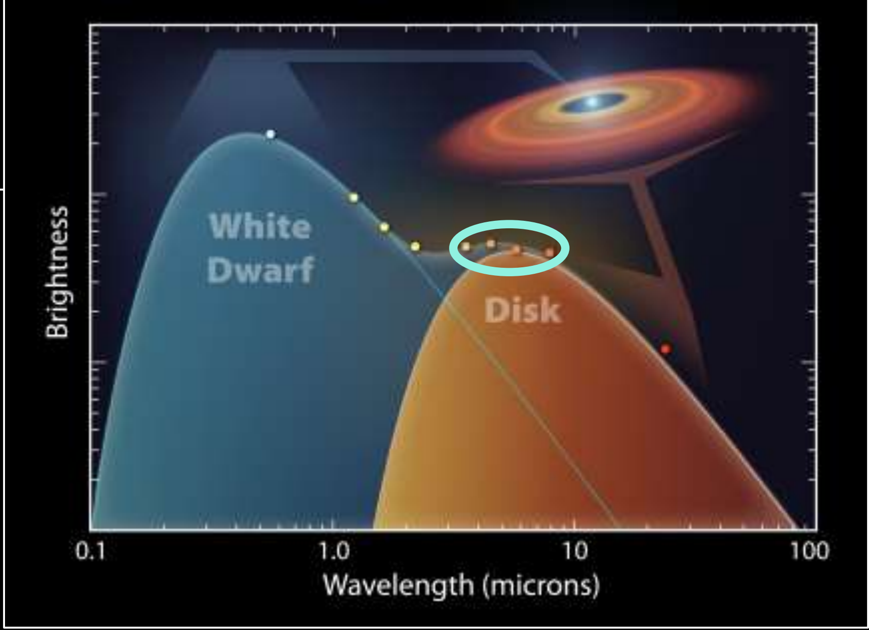


<u>Swan et al. (2020):</u>

- Spitzer survey looking for **mid infrared variability** of 37 stars with 2+ epochs.
- The largest flux changes happened on longer time-scales, reaching several 10’s of percent over baselines of a few years.

Variability Survey: Mid Infrared





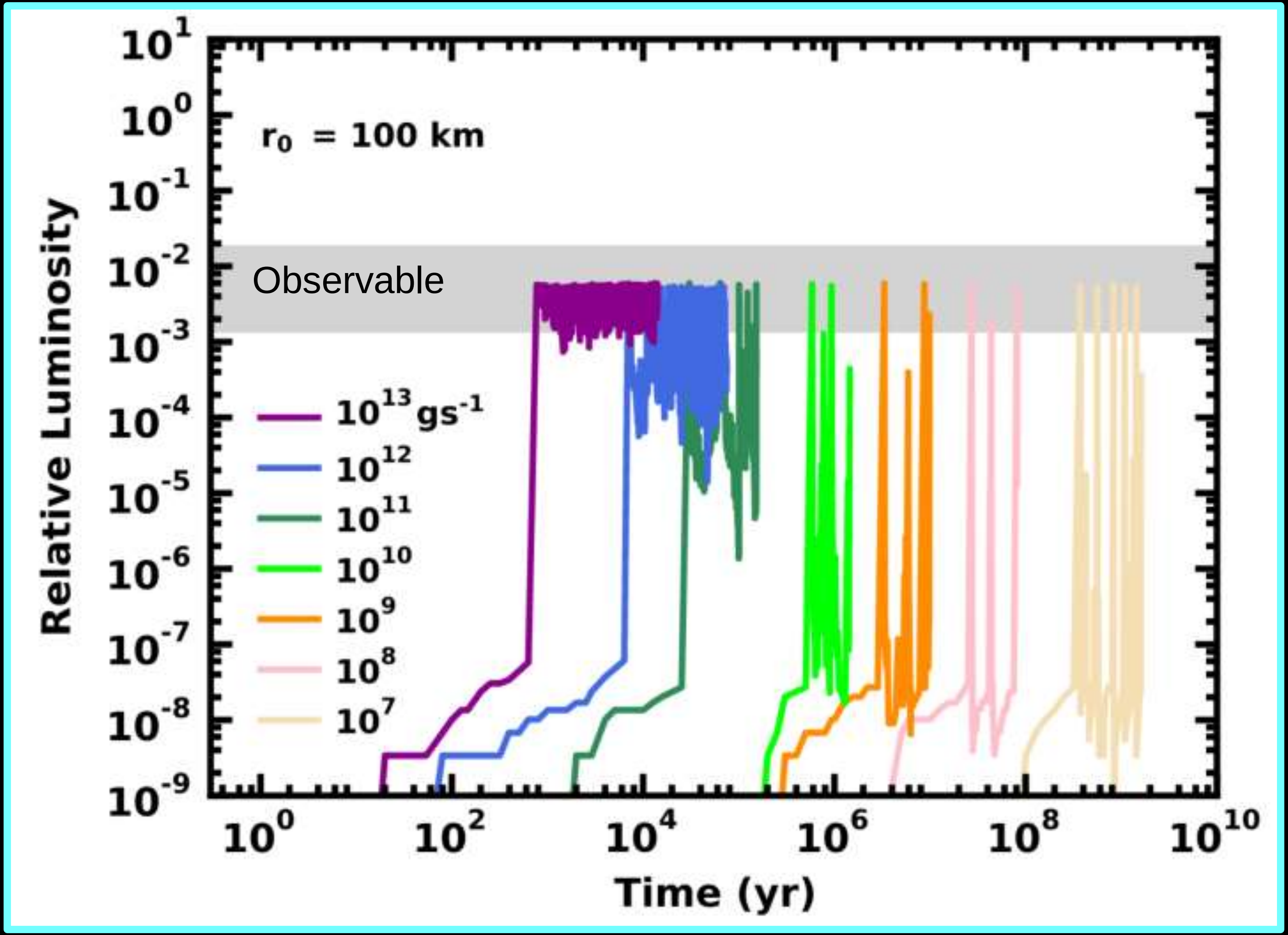
Swan et al. (2020):

- Spitzer survey looking for **mid infrared variability** of 37 stars with 2+ epochs.
- The largest flux changes happened on longer time-scales, reaching several 10's of percent over baselines of a few years.

See talk by Hiba tu Noor (Wednesday 14:20) on a new Spitzer Survey

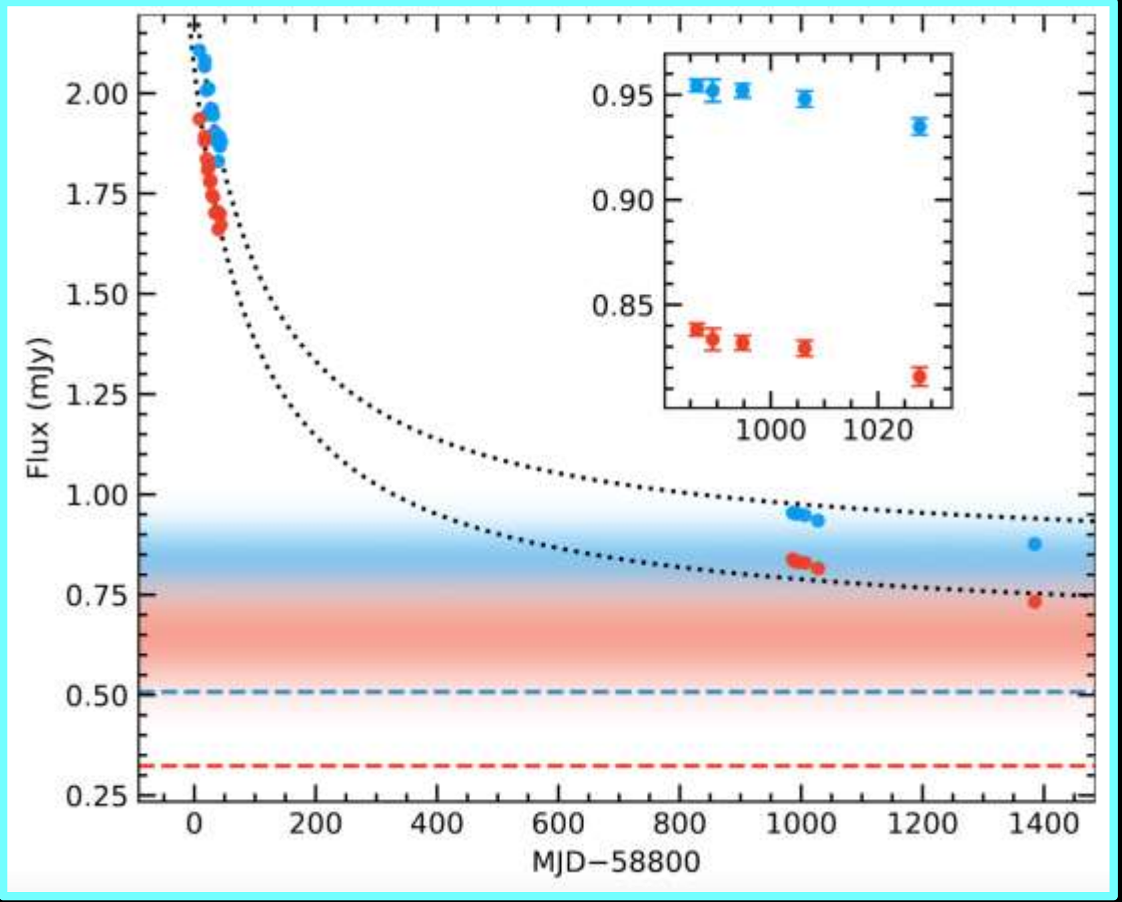
Simulations of collisional cascades

Kenyon and Bromley (2017a,b)

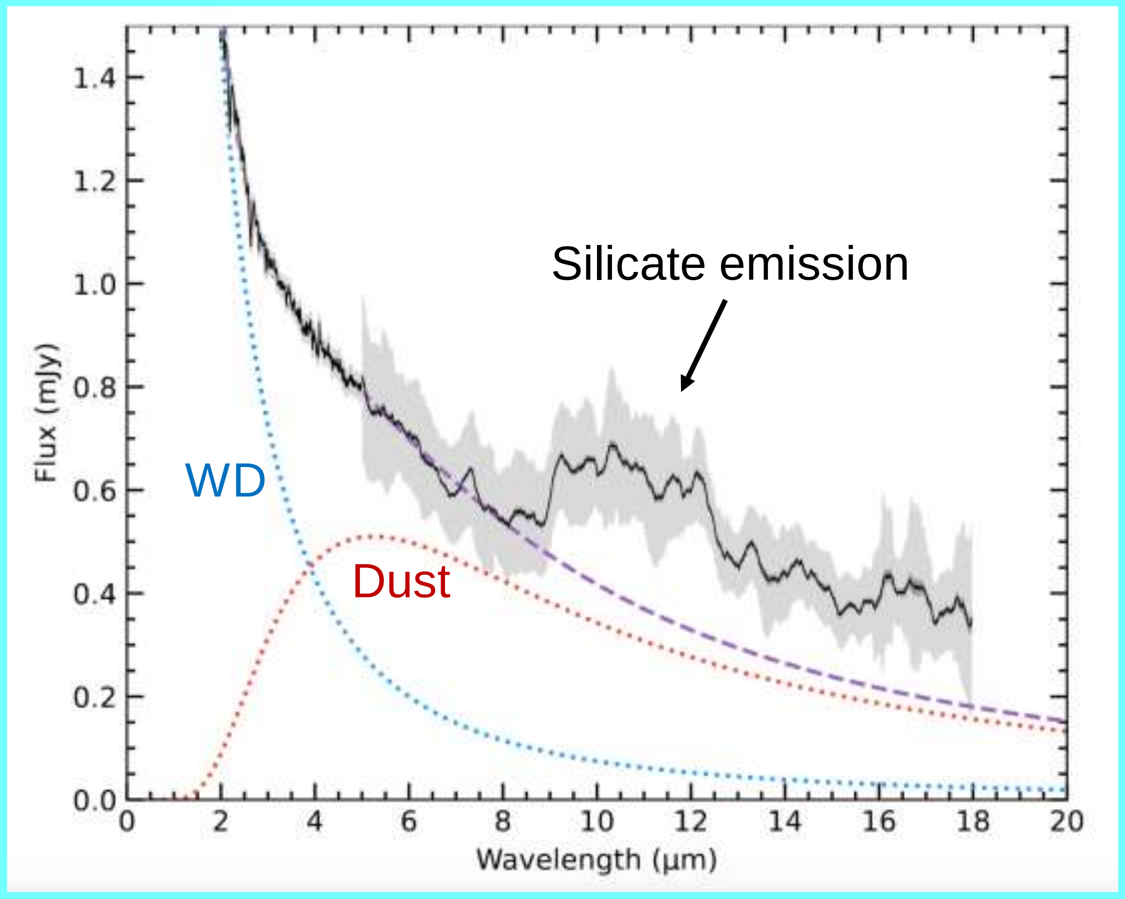


Collisional cascades can sometimes generate enough small particles to match the observed luminosity.

First JWST infrared spectra of a WD disc



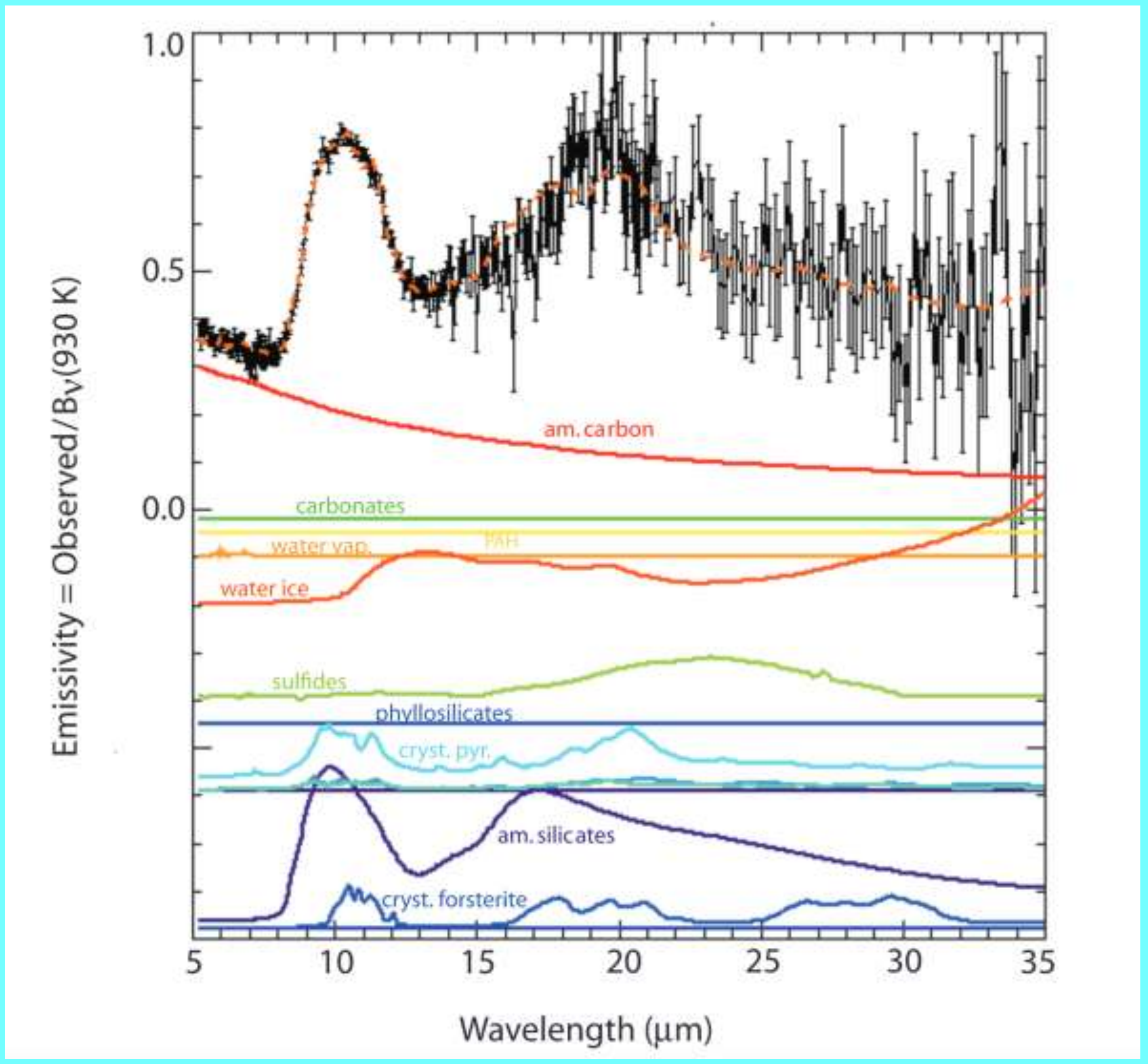
Infrared emission consistent with collisional cascade models



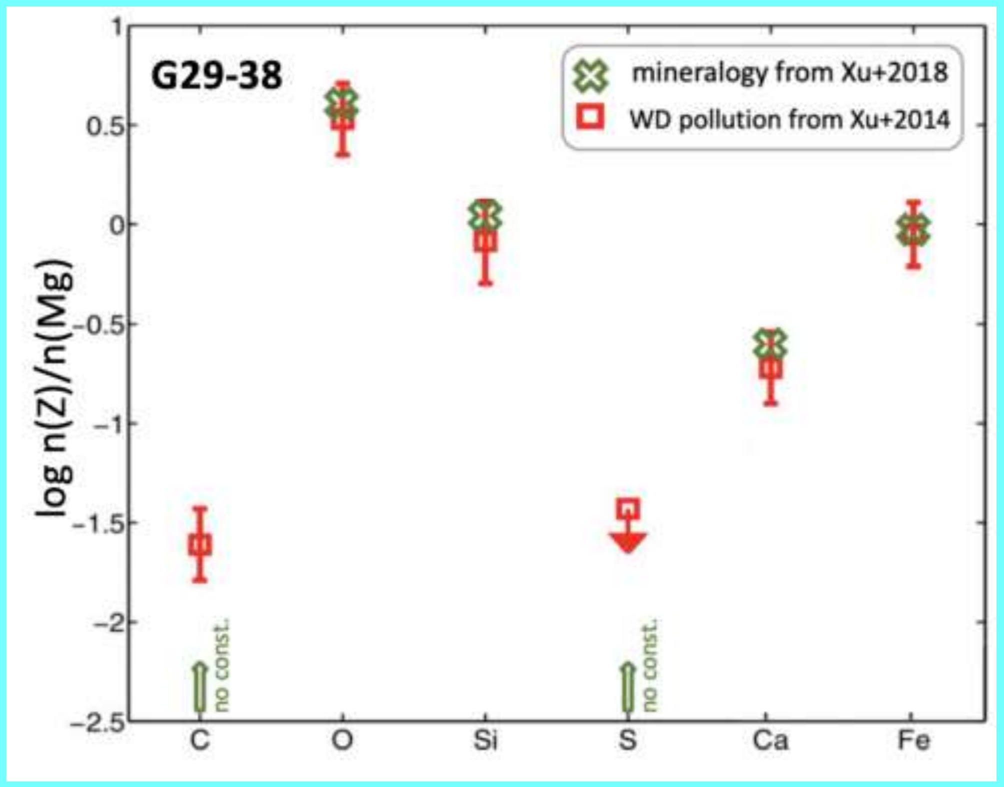
Silicate emission feature at 10 micron

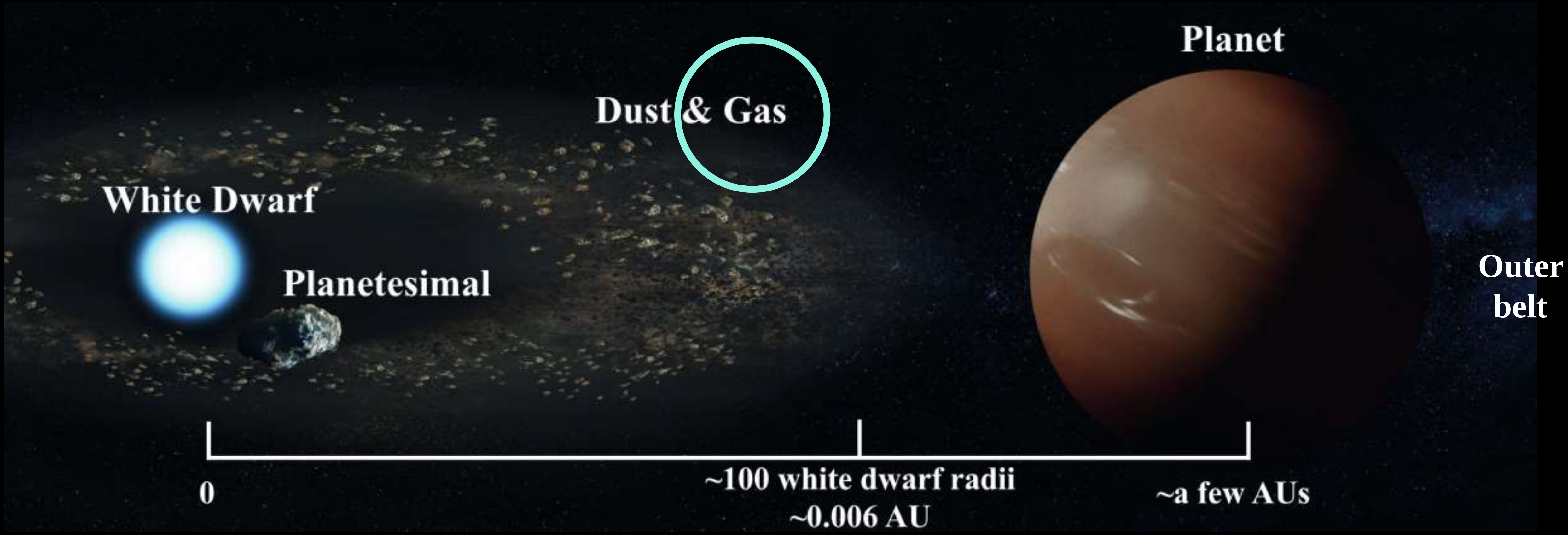
Swan et al. (2023)

Dust Composition



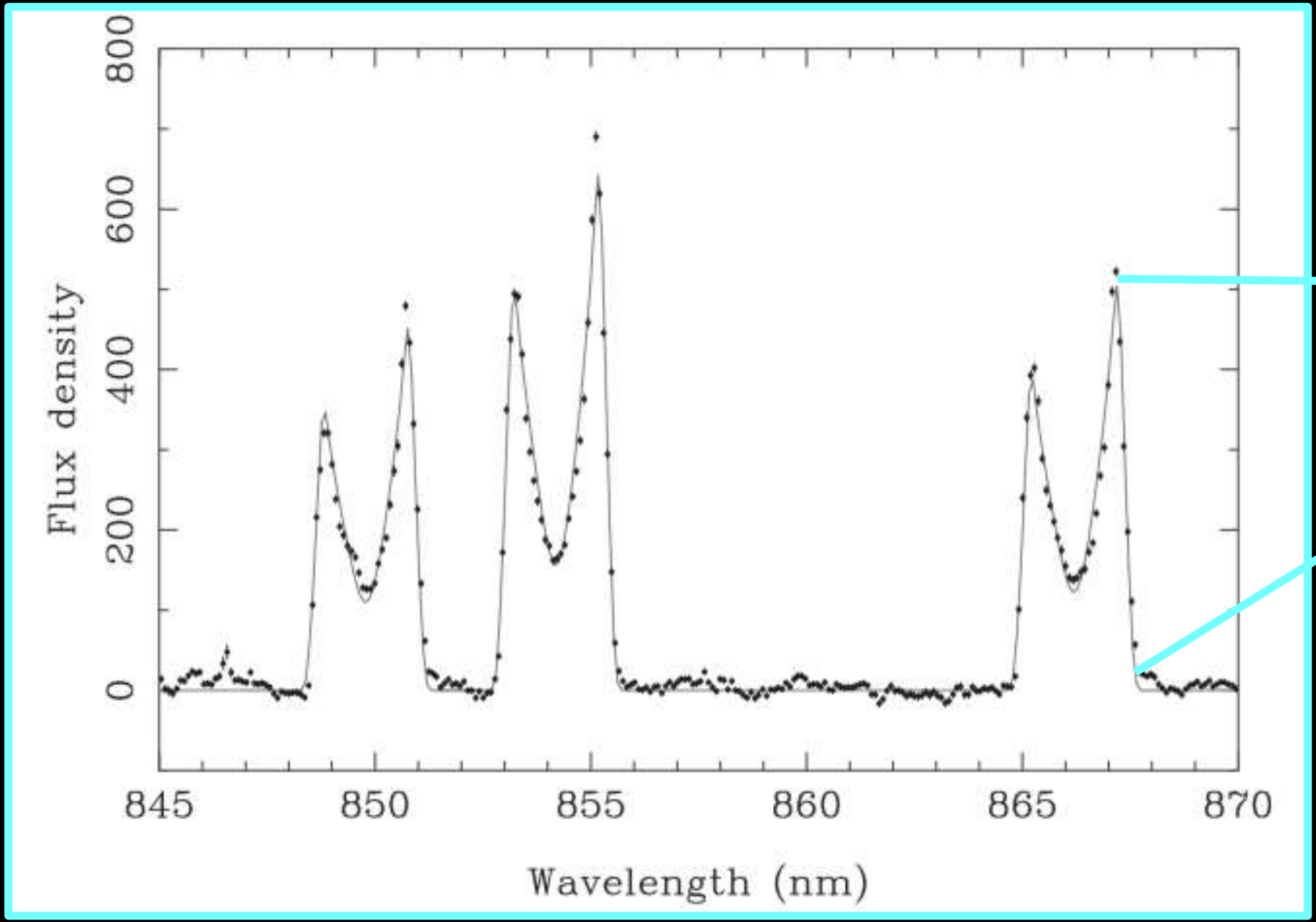
Reach et al. (2008)



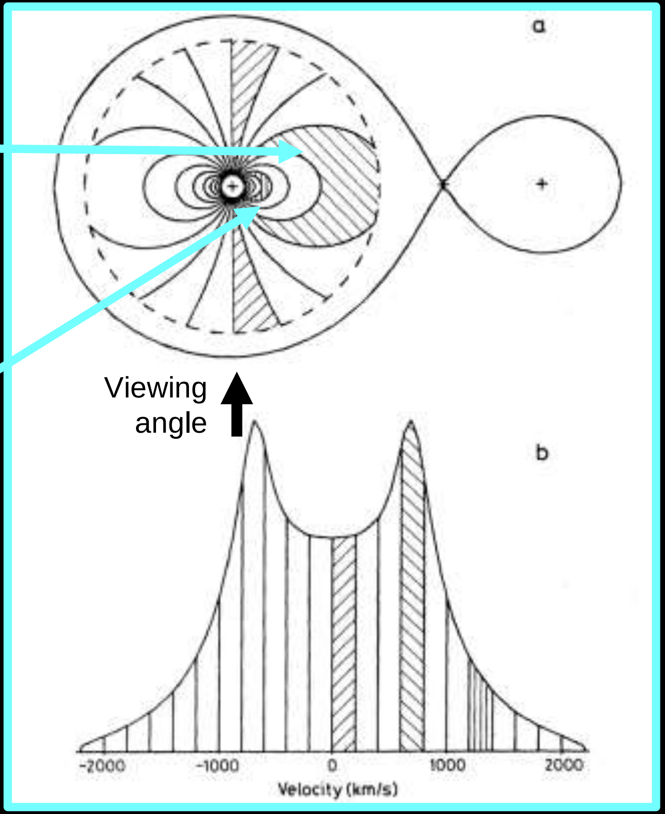


Xu and Bonsor (2021)

First Detection of Gas in emission



Gänsicke et al. (2006)

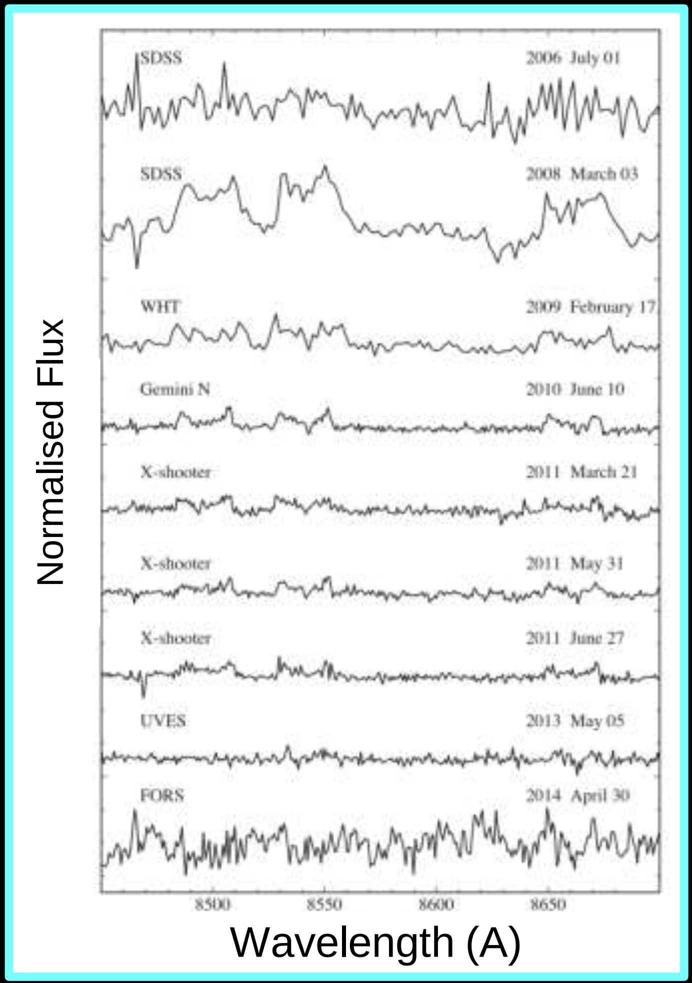


Horne & Marsh (1986)

Variability in Gas discs: Morphology and Strength

Equivalent Width Changes:

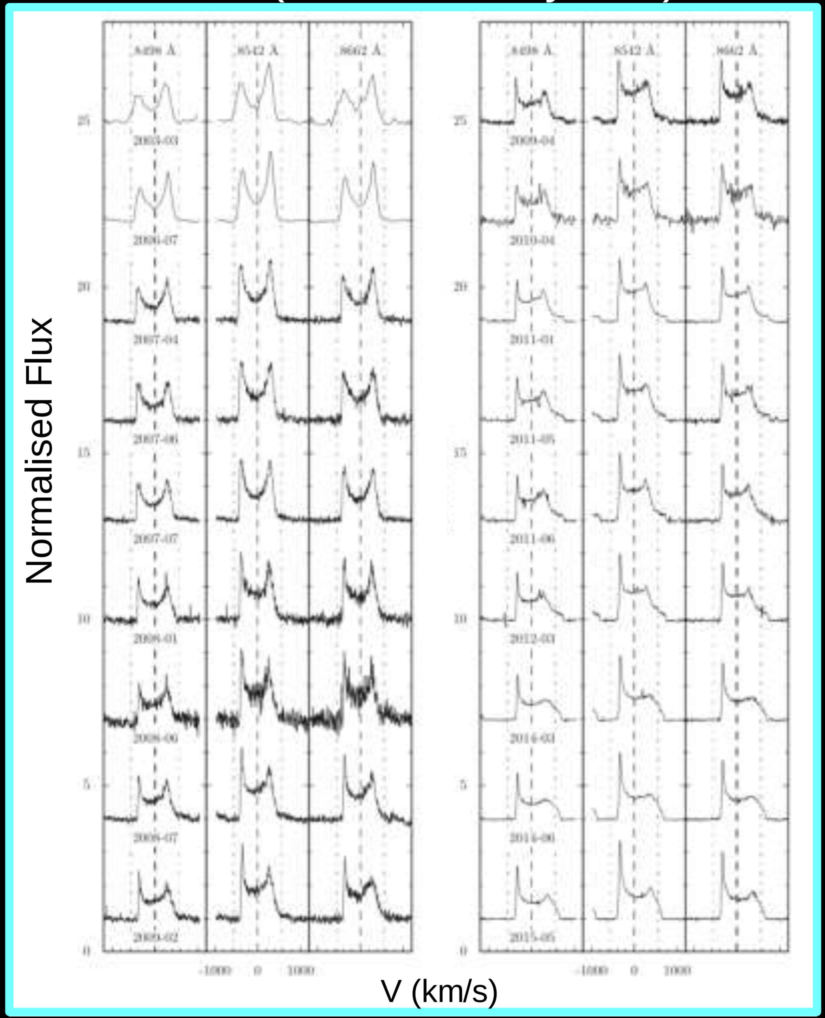
Brightening event – new collision?



SDSS J1617+1620: Wilson et al. (2014)

Morphological Changes:

Precession? (Period = 27 years)

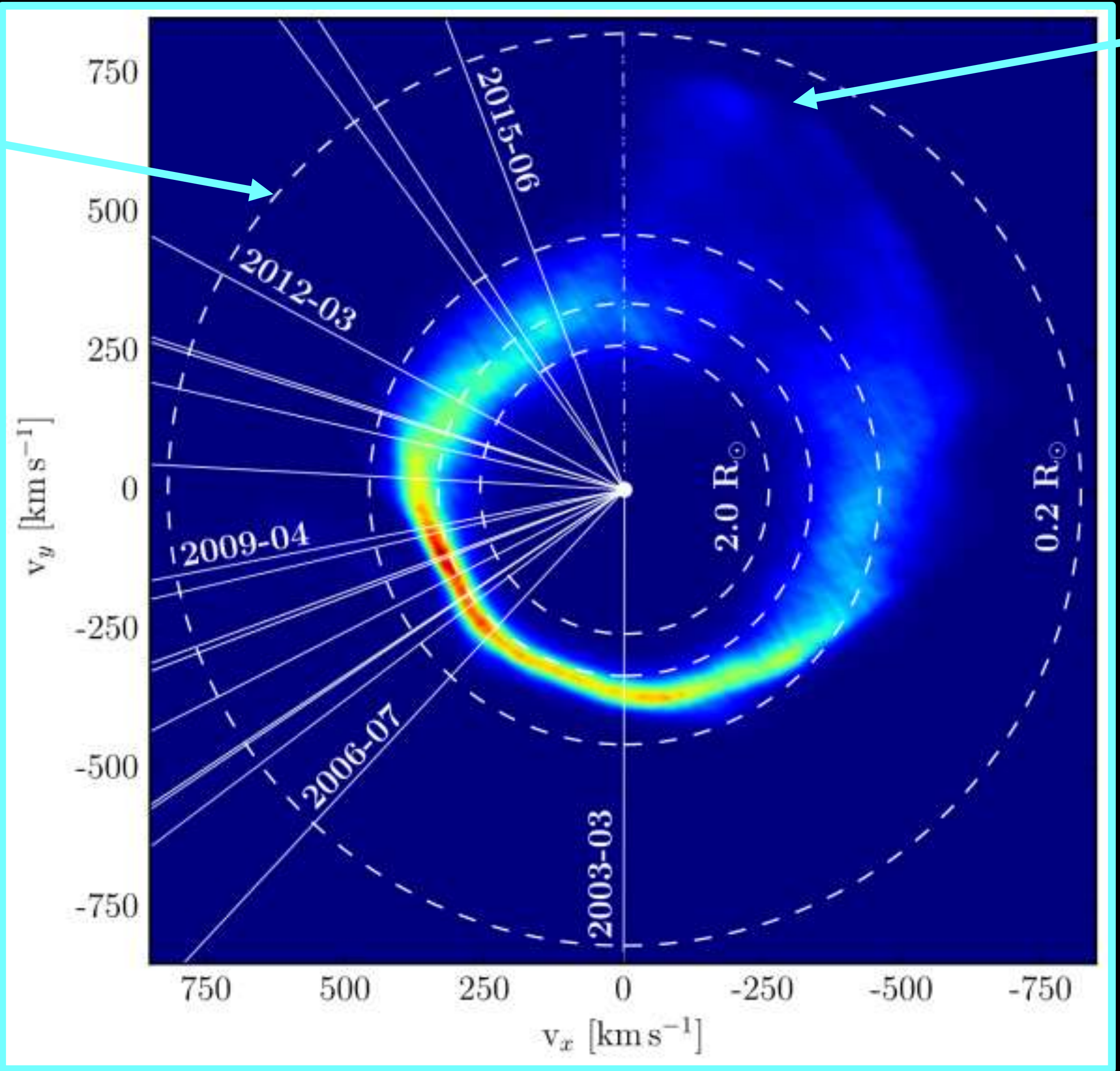


SDSS J1228+1040 : Manser et al. (2016)

Laura Rogers

Doppler tomography of gas discs

Circular orbits in velocity space, data clearly not circular



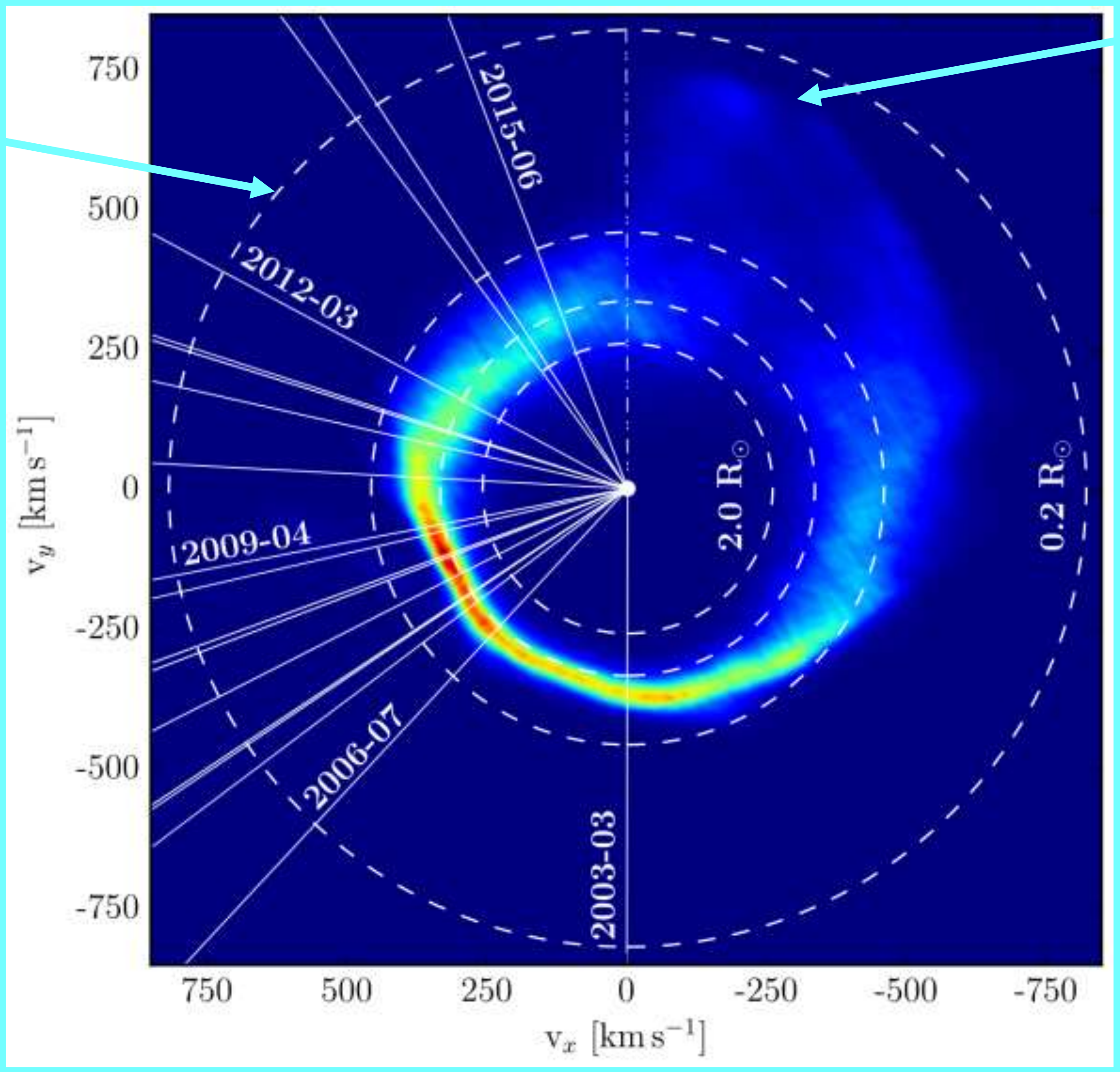
Manser et al. (2016, 2021)

Highest velocities tell you about the inner edge

Young eccentric disc that precesses due to general relativity

Doppler tomography of gas discs

Circular orbits in velocity space, data clearly not circular

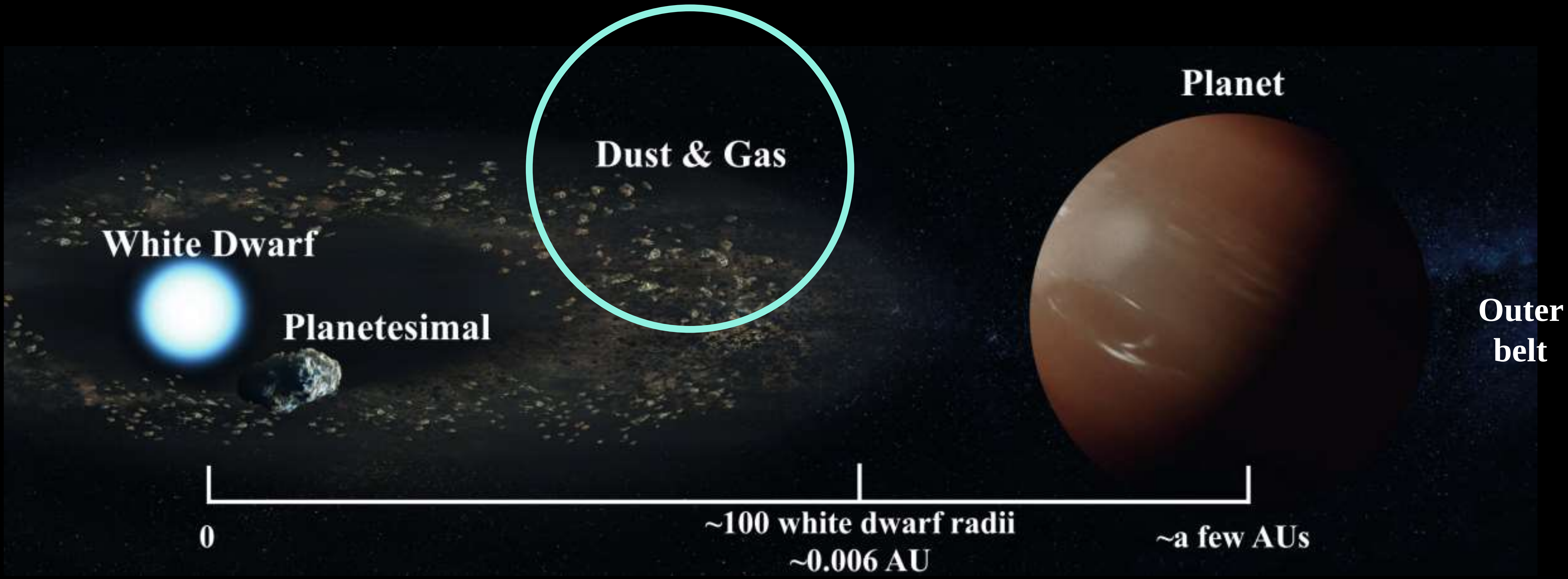


Manser et al. (2016, 2021)

Highest velocities tell you about the inner edge

Young eccentric disc that precesses due to general relativity

See talk by Felipe Lagos-Vilches (Tuesday 11:12) on modelling gas discs and fitting abundances with CLOUDY

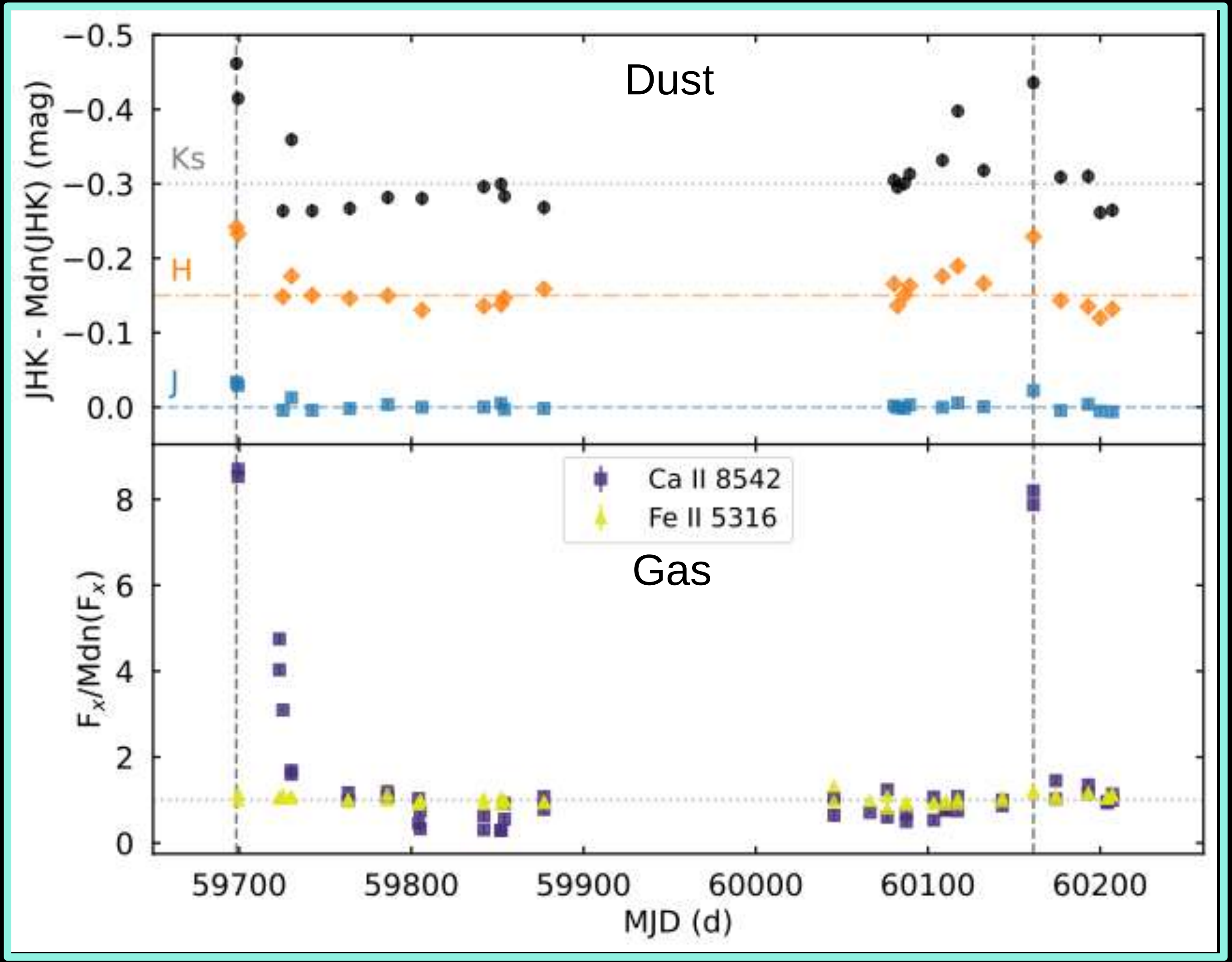


Xu and Bonsor (2021)

First study of simultaneous gas and dust variability

When there is significant dust emission there is also significant calcium gas emission

-> Common origin? Collisions?



Rogers (2024, in prep)

First study of simultaneous gas and dust variability

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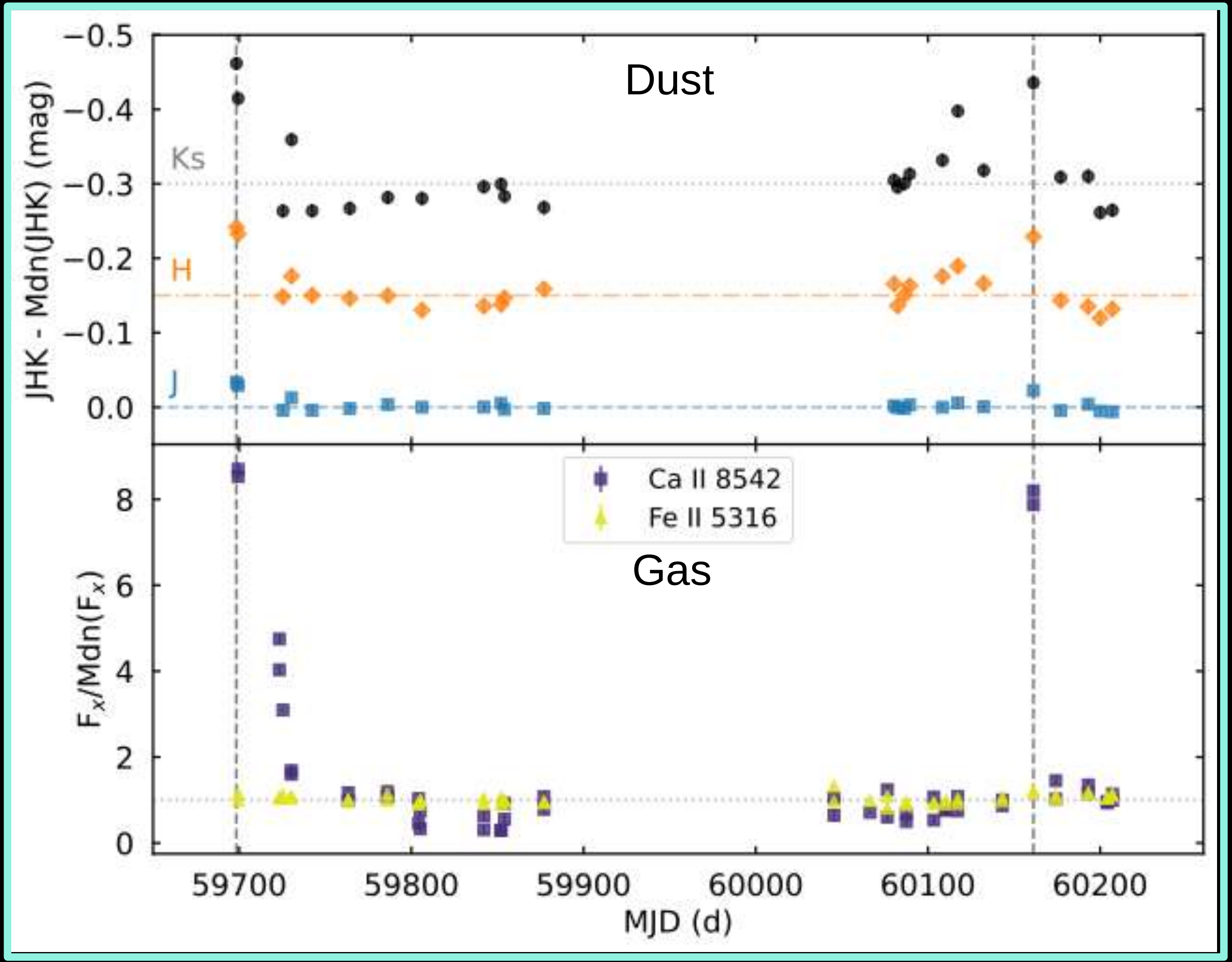
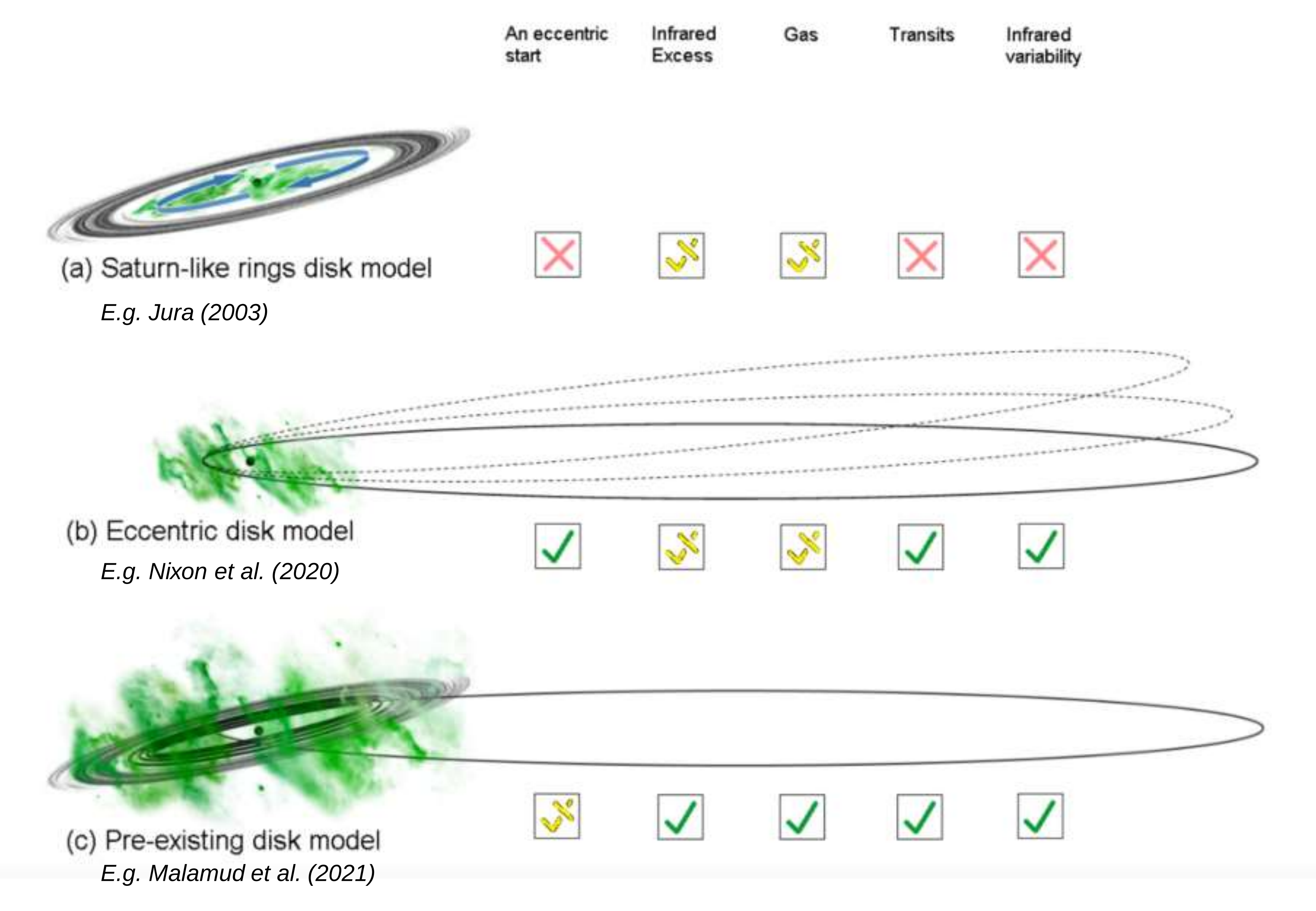
-> Common origin? Collisions?

We are clearly missing models of gas-dust interactions! See talk by Rafael Martinez-Brunner (Tuesday 16:12)



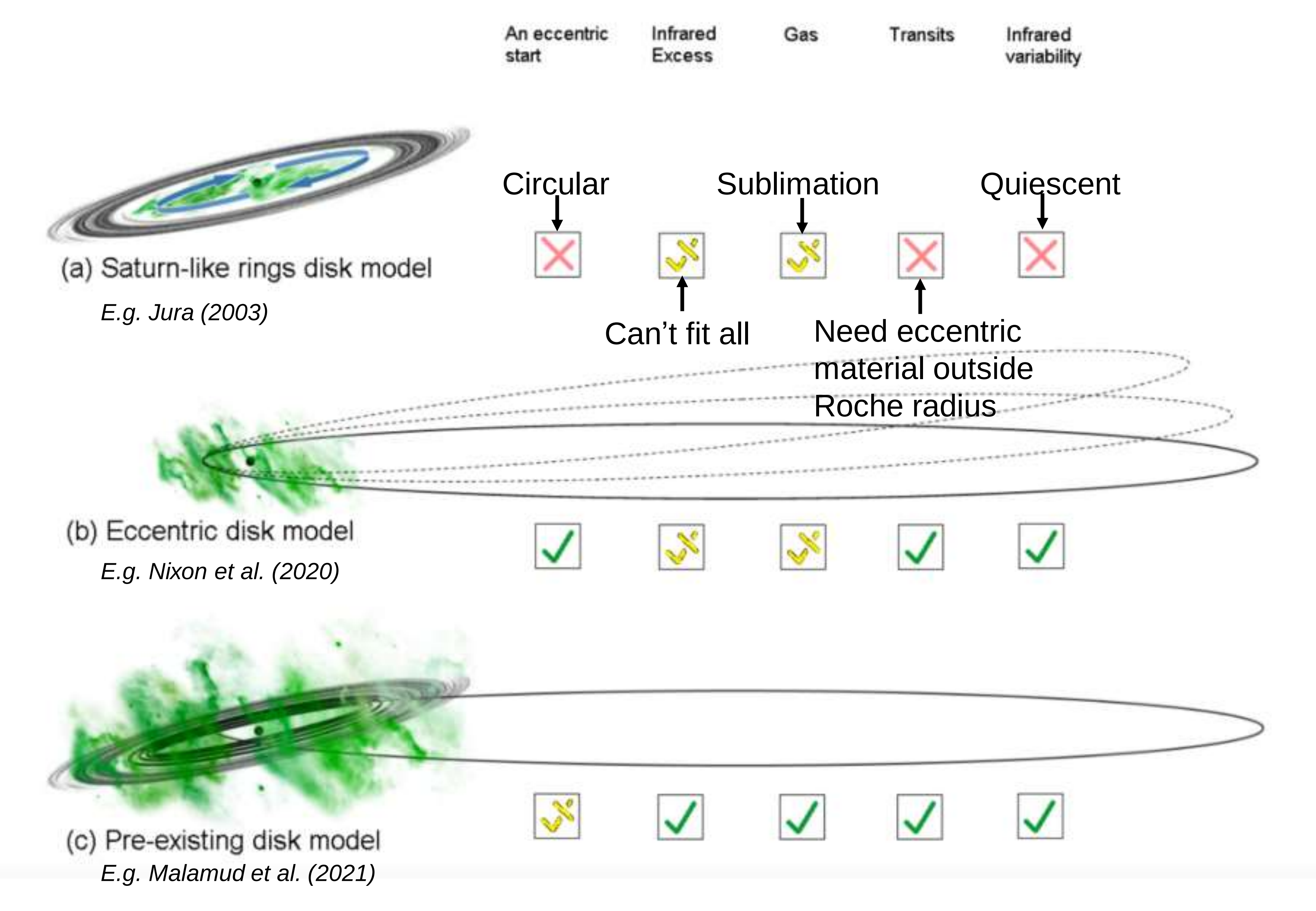
Rogers (2024, in prep)

Disc models to explain all



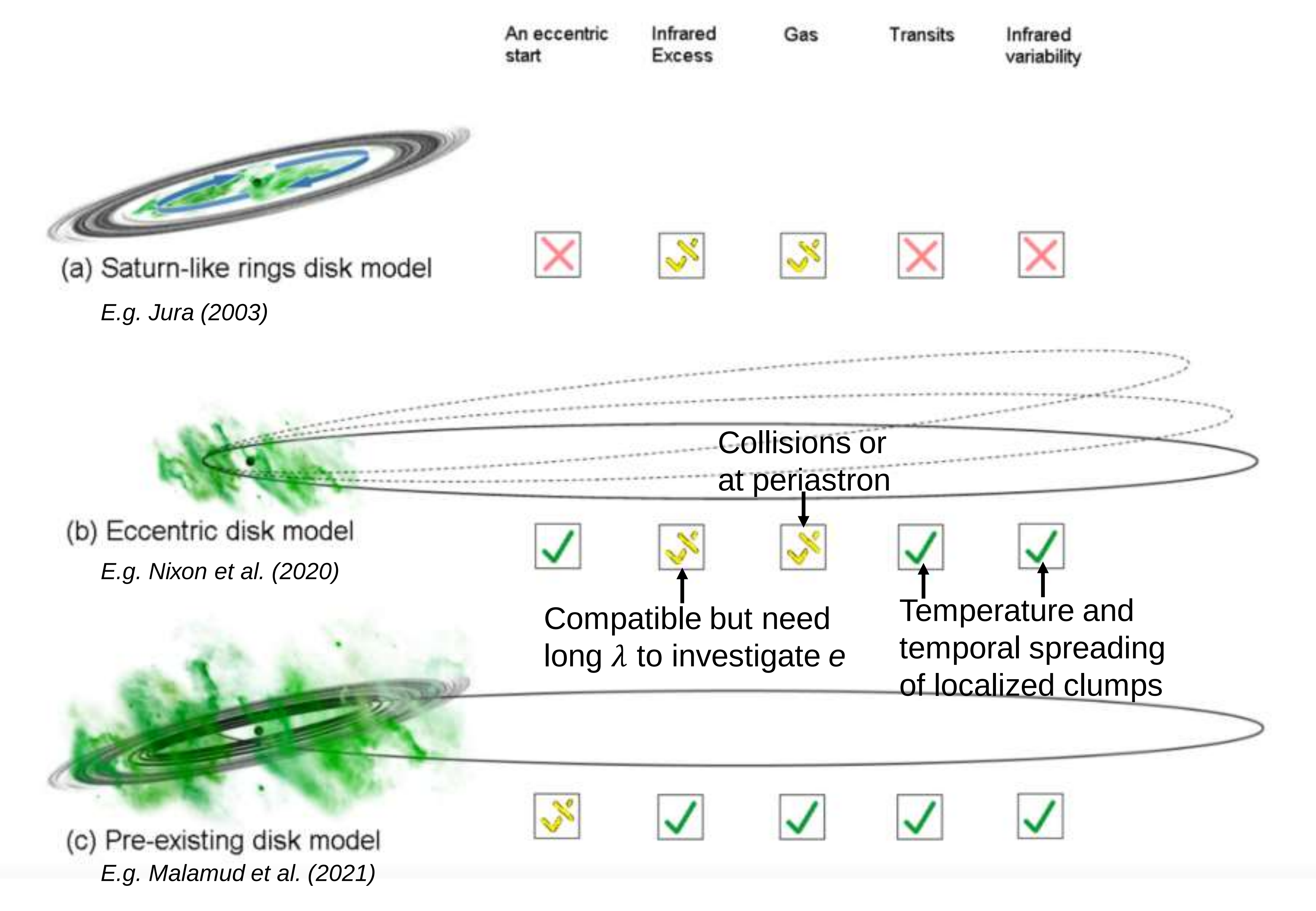
Malamud (2024)

Disc models to explain all



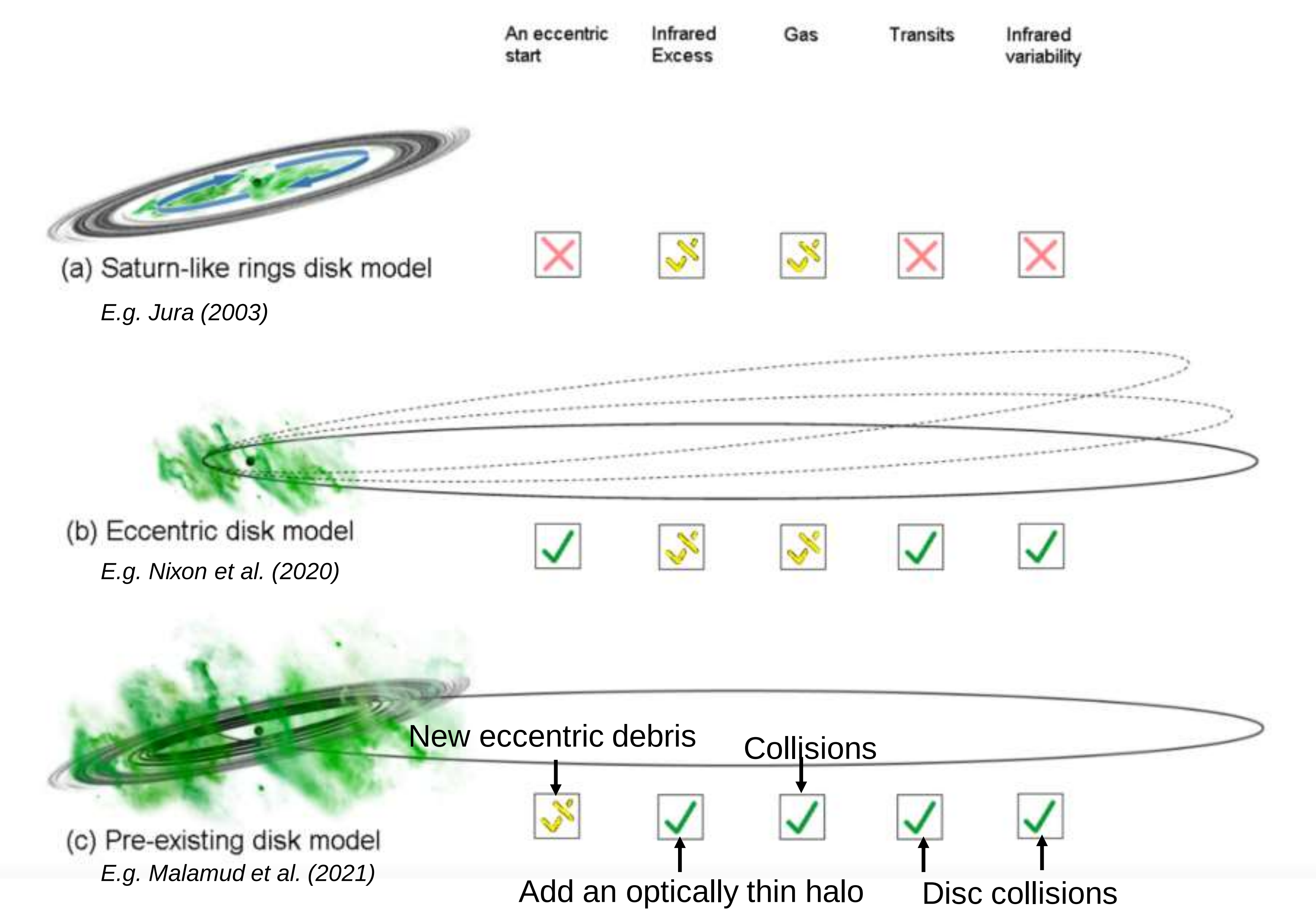
Malamud (2024)

Disc models to explain all



Malamud (2024)

Disc models to explain all



Malamud (2024)

White Dwarf Planetary Systems

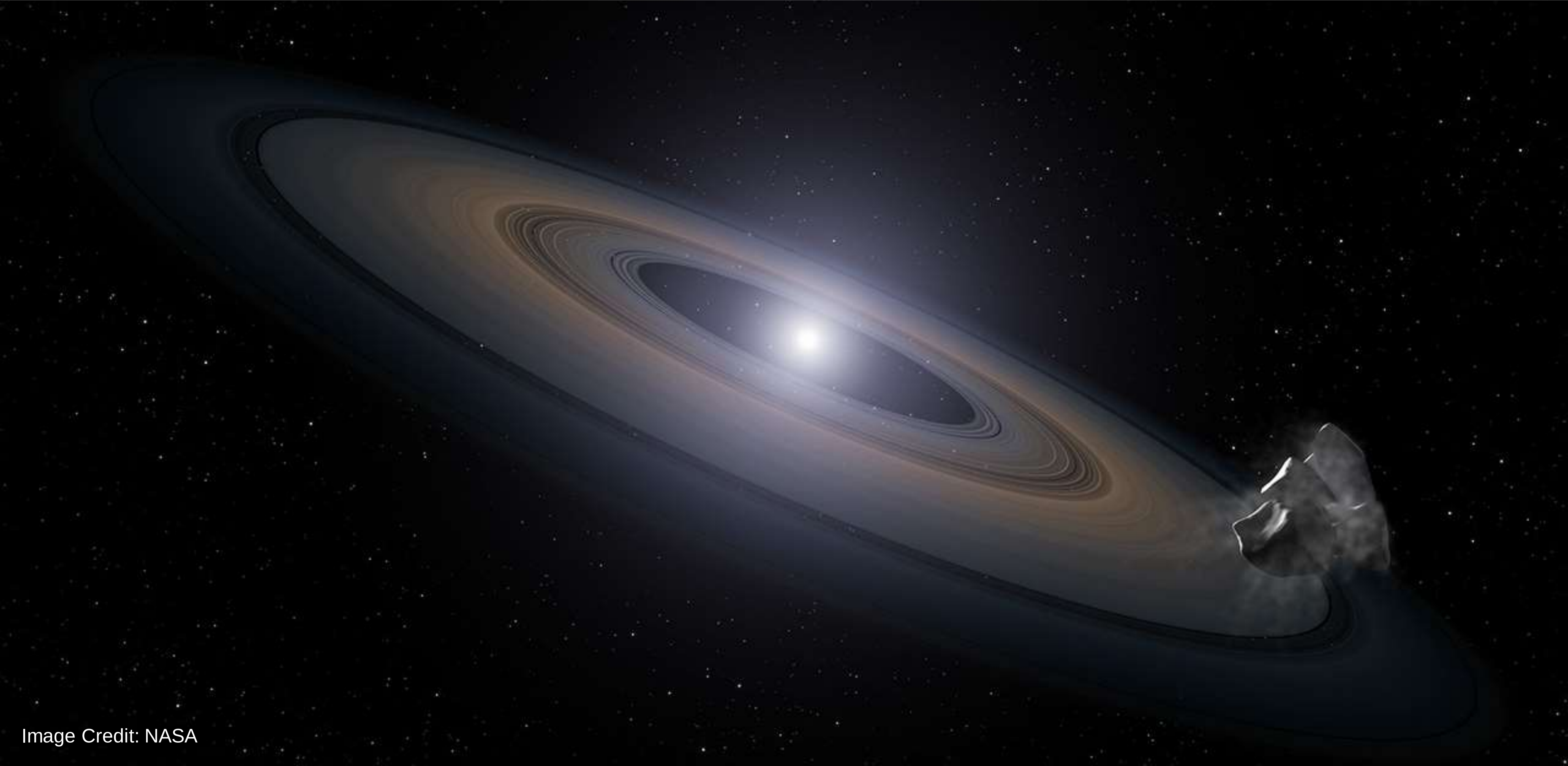


Image Credit: NASA

White Dwarf Planetary Systems

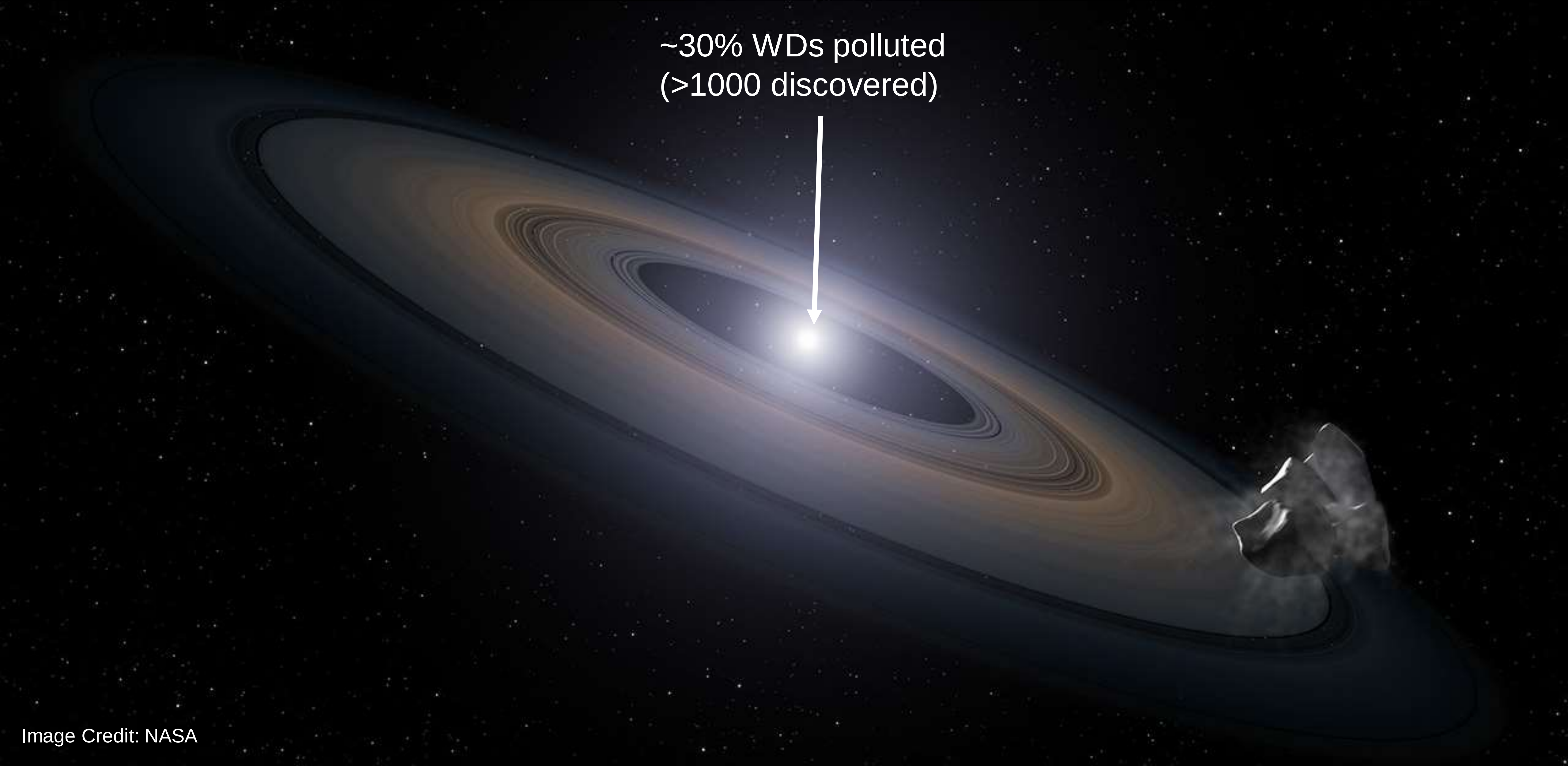


Image Credit: NASA

White Dwarf Planetary Systems

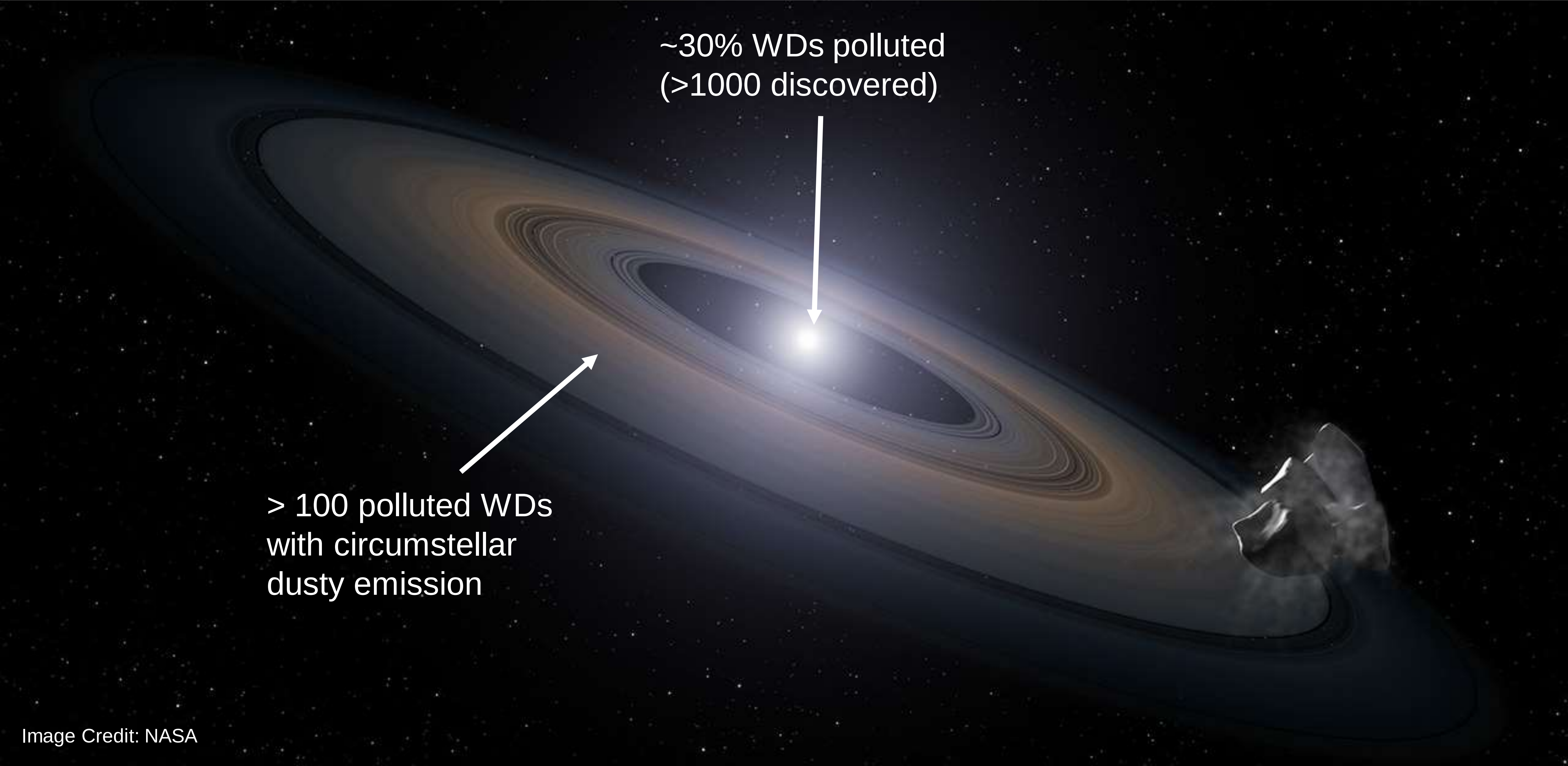


Image Credit: NASA

White Dwarf Planetary Systems

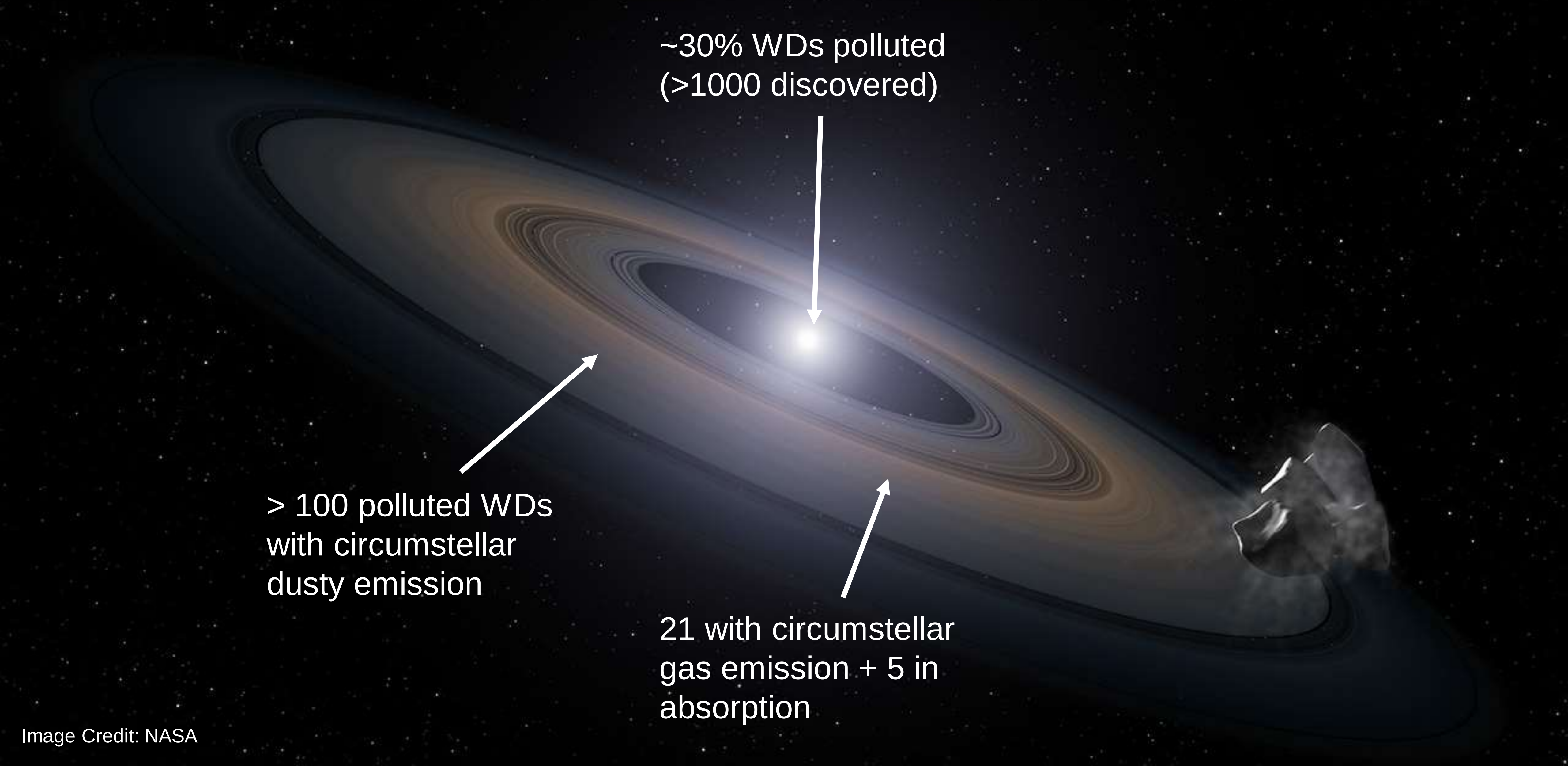


Image Credit: NASA

White Dwarf Planetary Systems

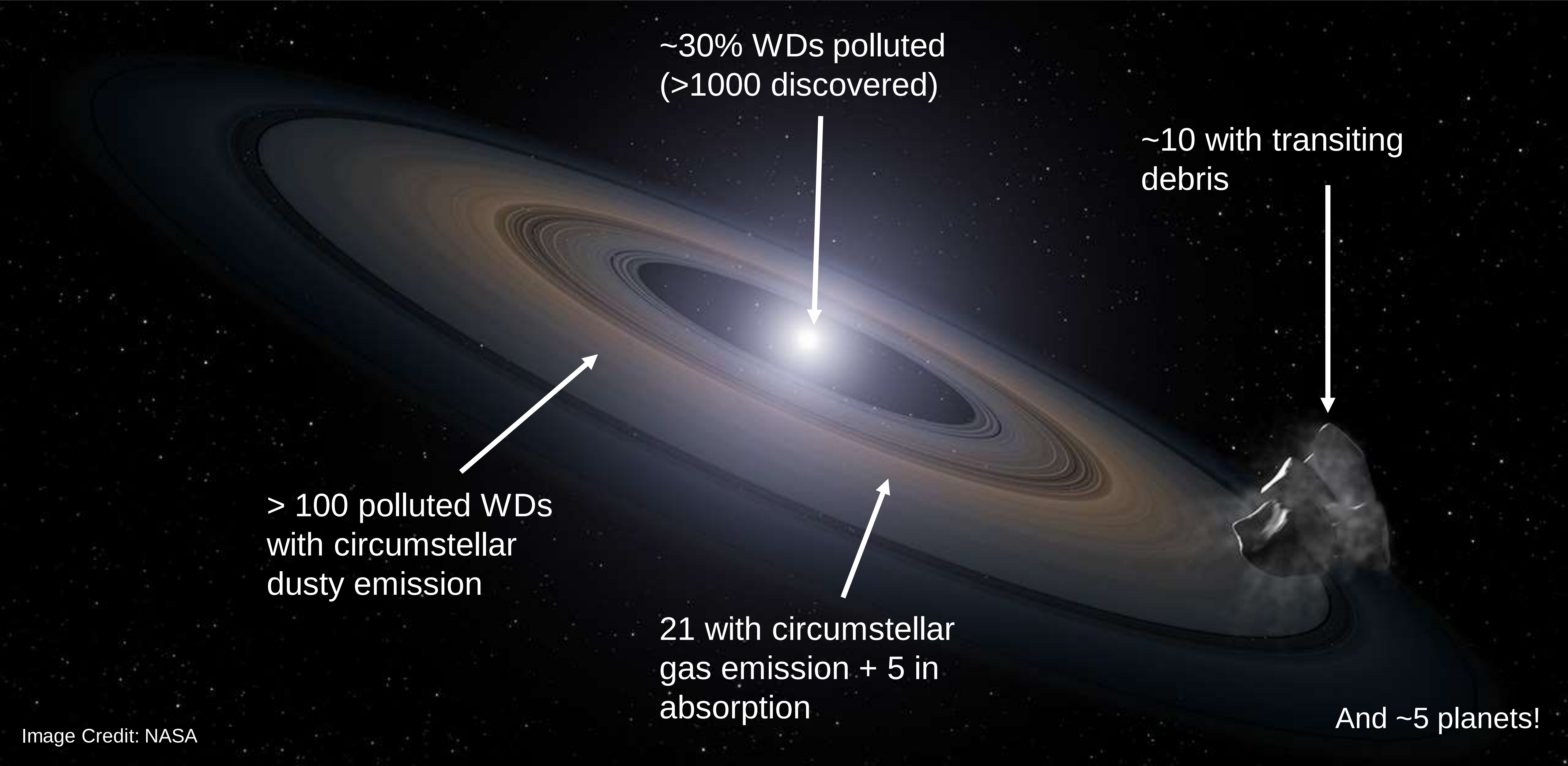
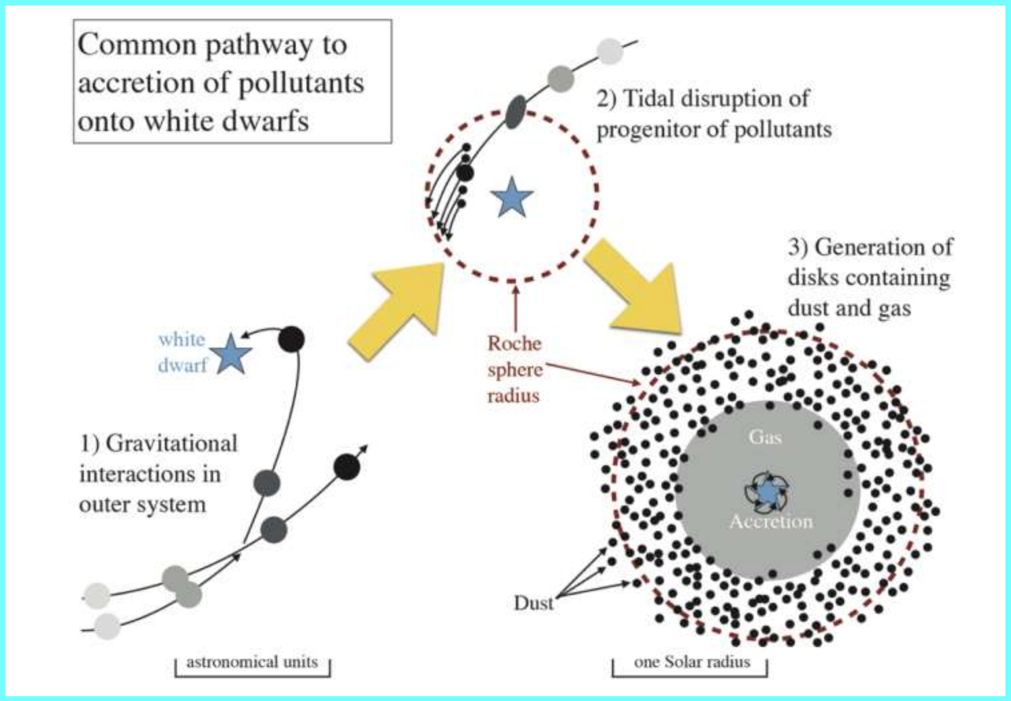
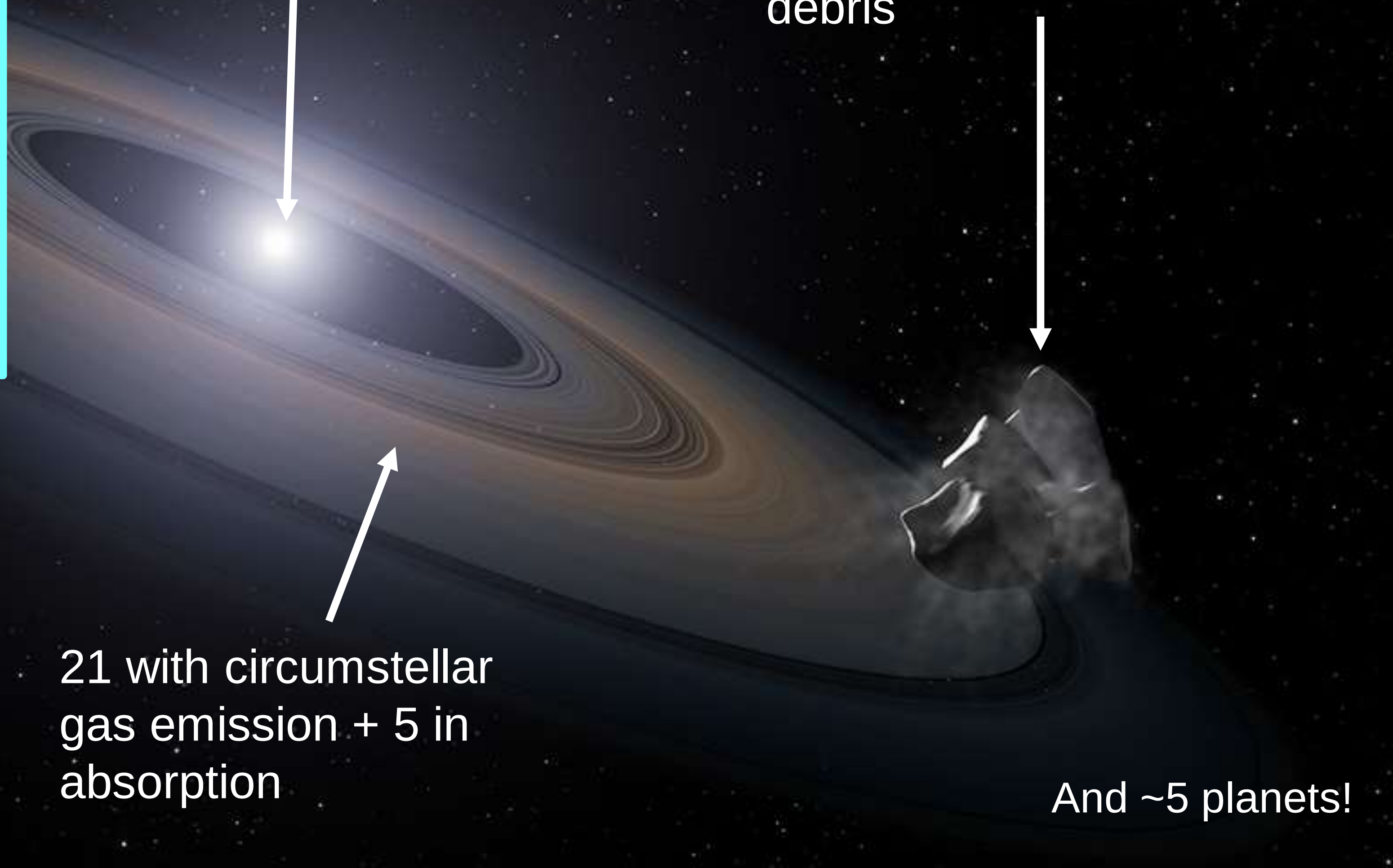


Image Credit: NASA

White Dwarf Planetary Systems





~30% WDs polluted (>1000 discovered)

~10 with transiting debris

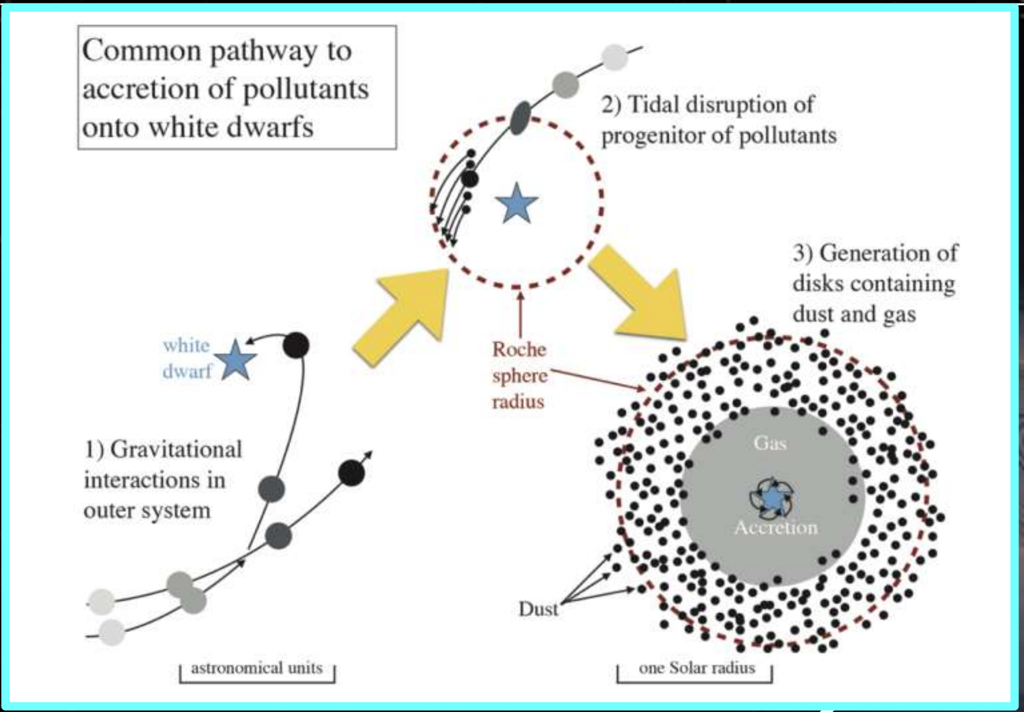
> 100 polluted WDs with circumstellar dusty emission

21 with circumstellar gas emission + 5 in absorption

And ~5 planets!

Image Credit: NASA

White Dwarf Planetary Systems



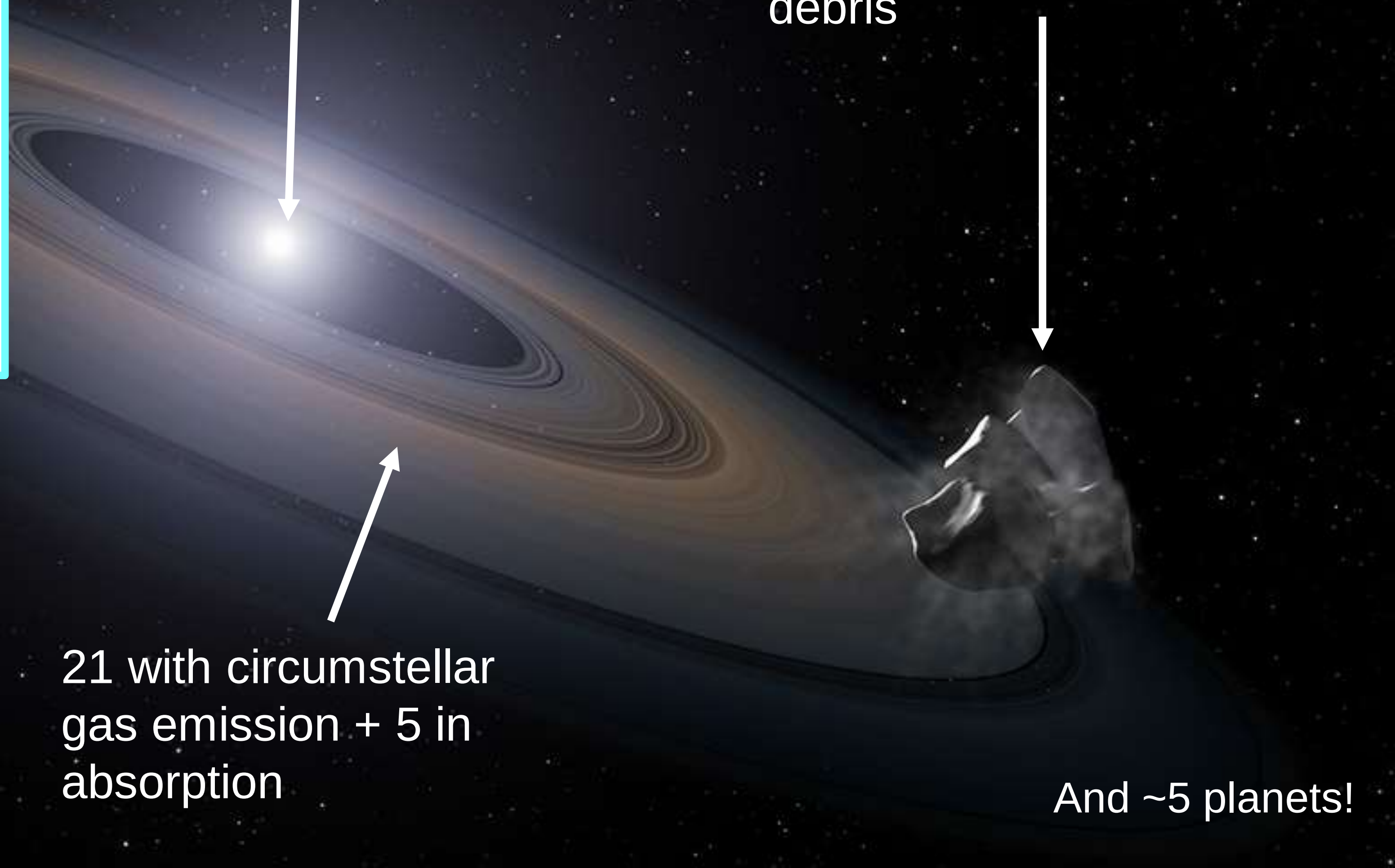


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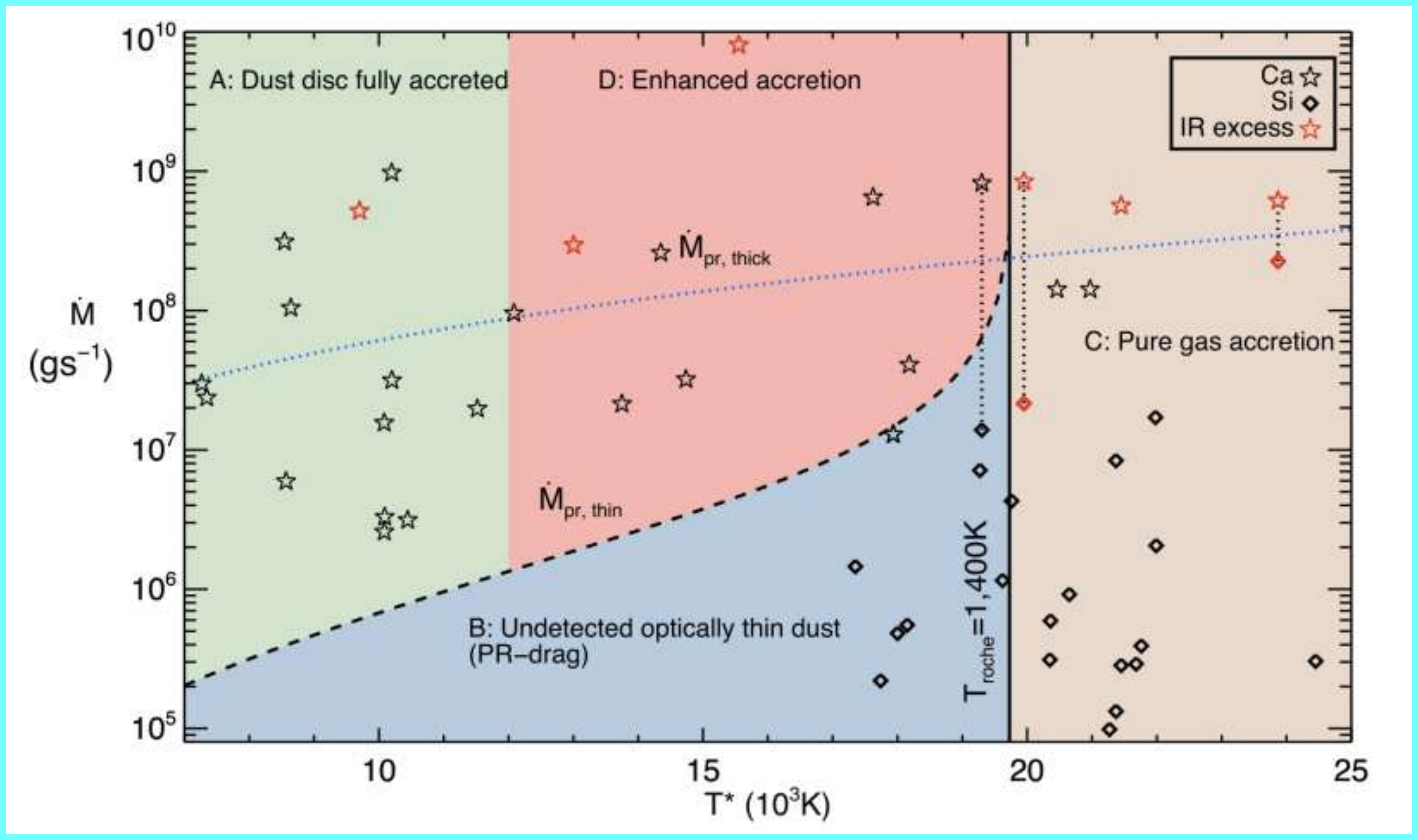
Image Credit: NASA

Why don't all PWDs have discs?

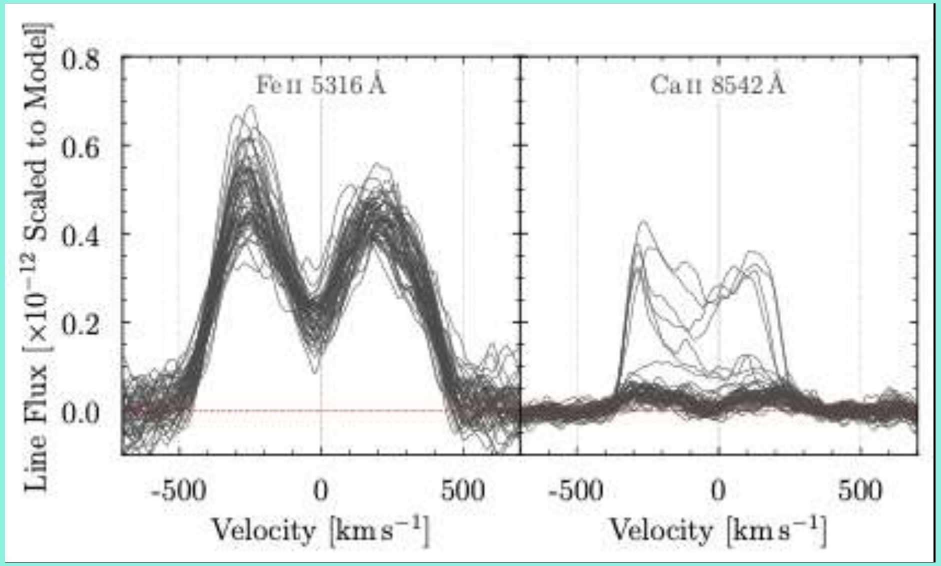


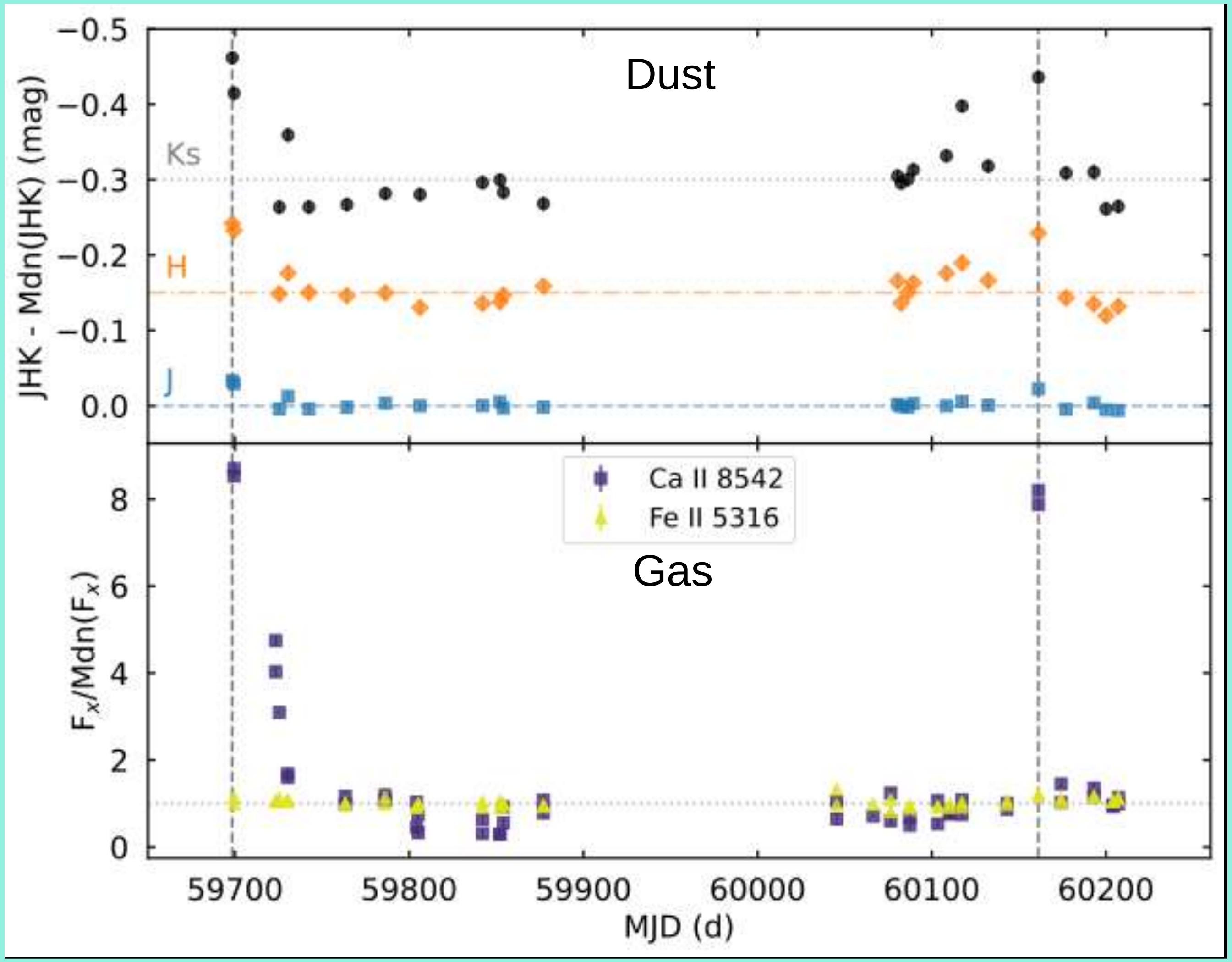
Bonsor et al. (2017)

First study of simultaneous gas and dust variability

When there is significant dust emission there is also significant calcium gas emission – common origin? Collisions?

Evolution of gas lines:





Rogers (2024, in prep)