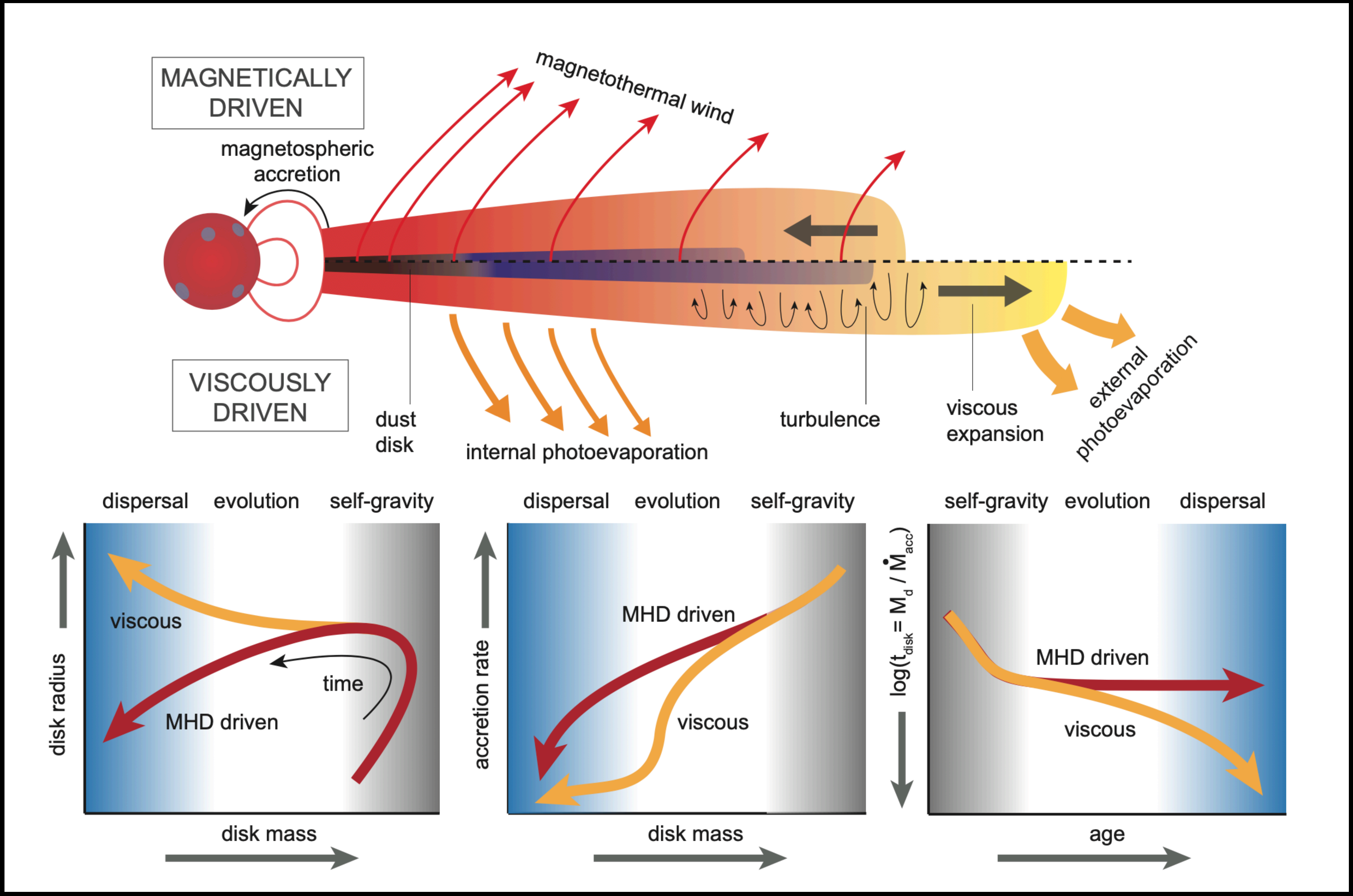
Disc population synthesis (review)



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Core2Disk III, Paris
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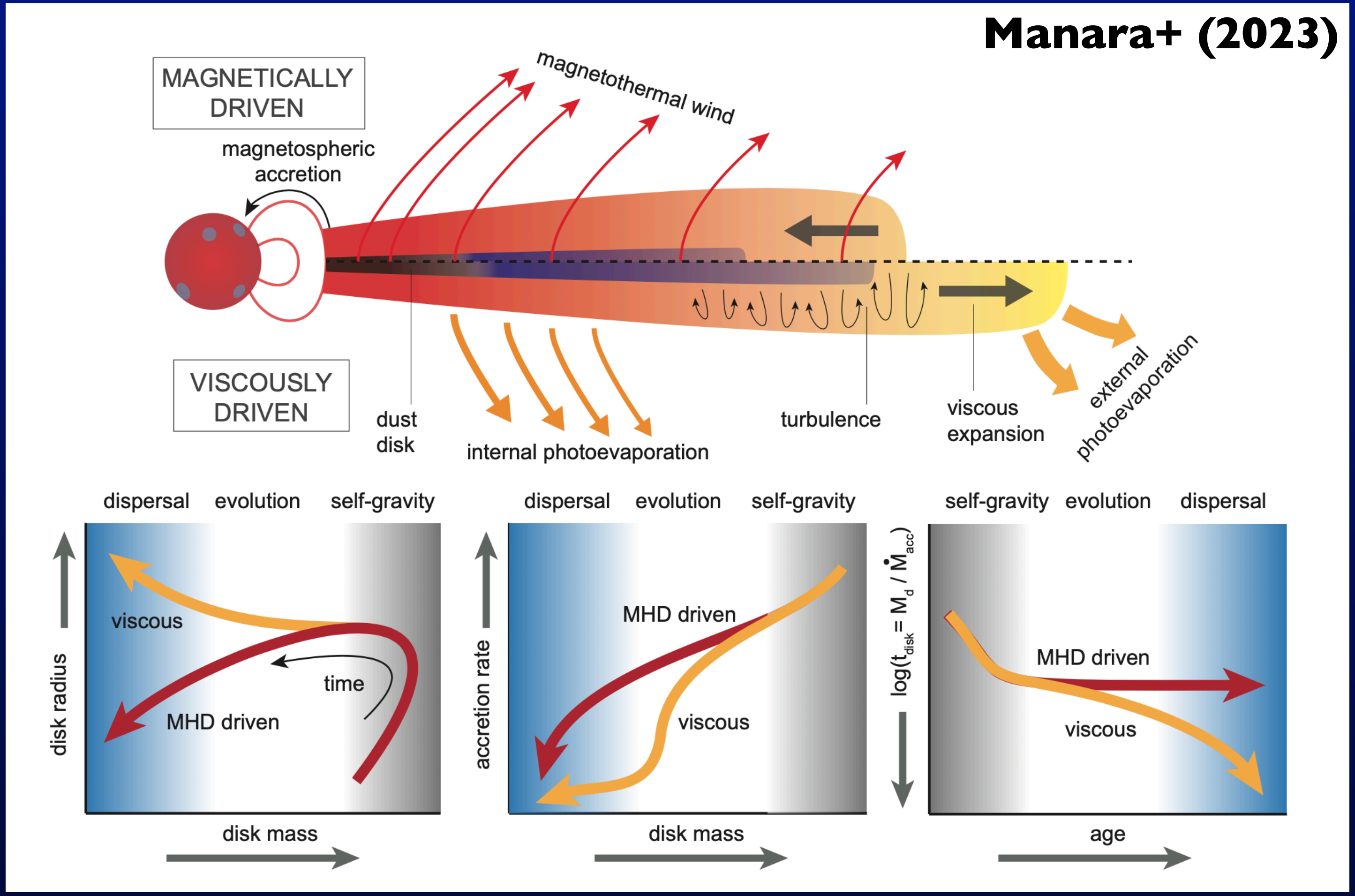
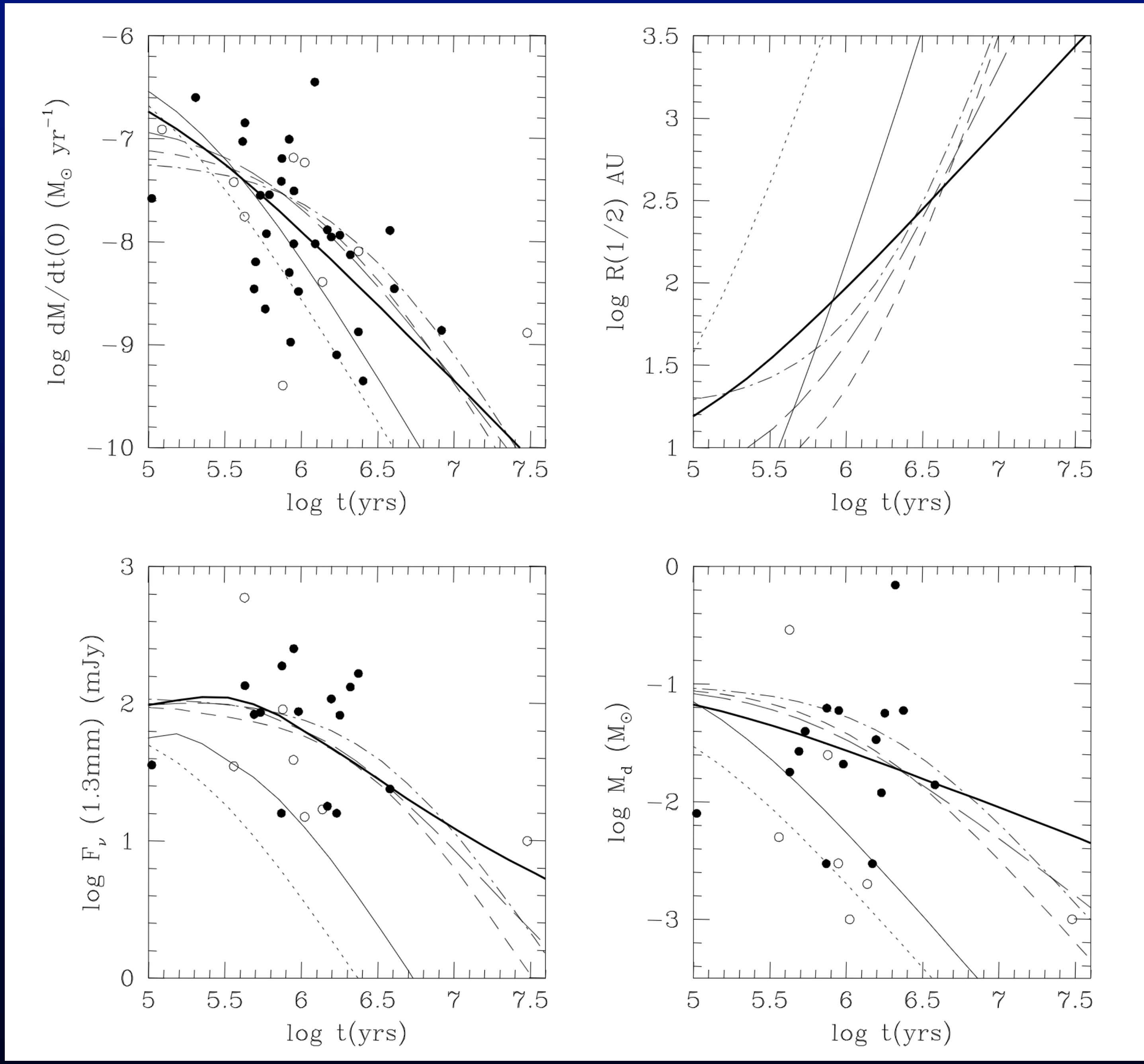
UNIVERSITY OF LEICESTER

What this talk ~~is~~ will try to be…



- We now have observational demographic data for large samples of protoplanetary discs (~$10^2 - 10^3$ objects).
- Broad aim is to build models which can reproduce / explain observed disc demographics / populations.
- Reviewed in detail by Manara et al. at PP7. Focus today is on where we go next….

Ancient history

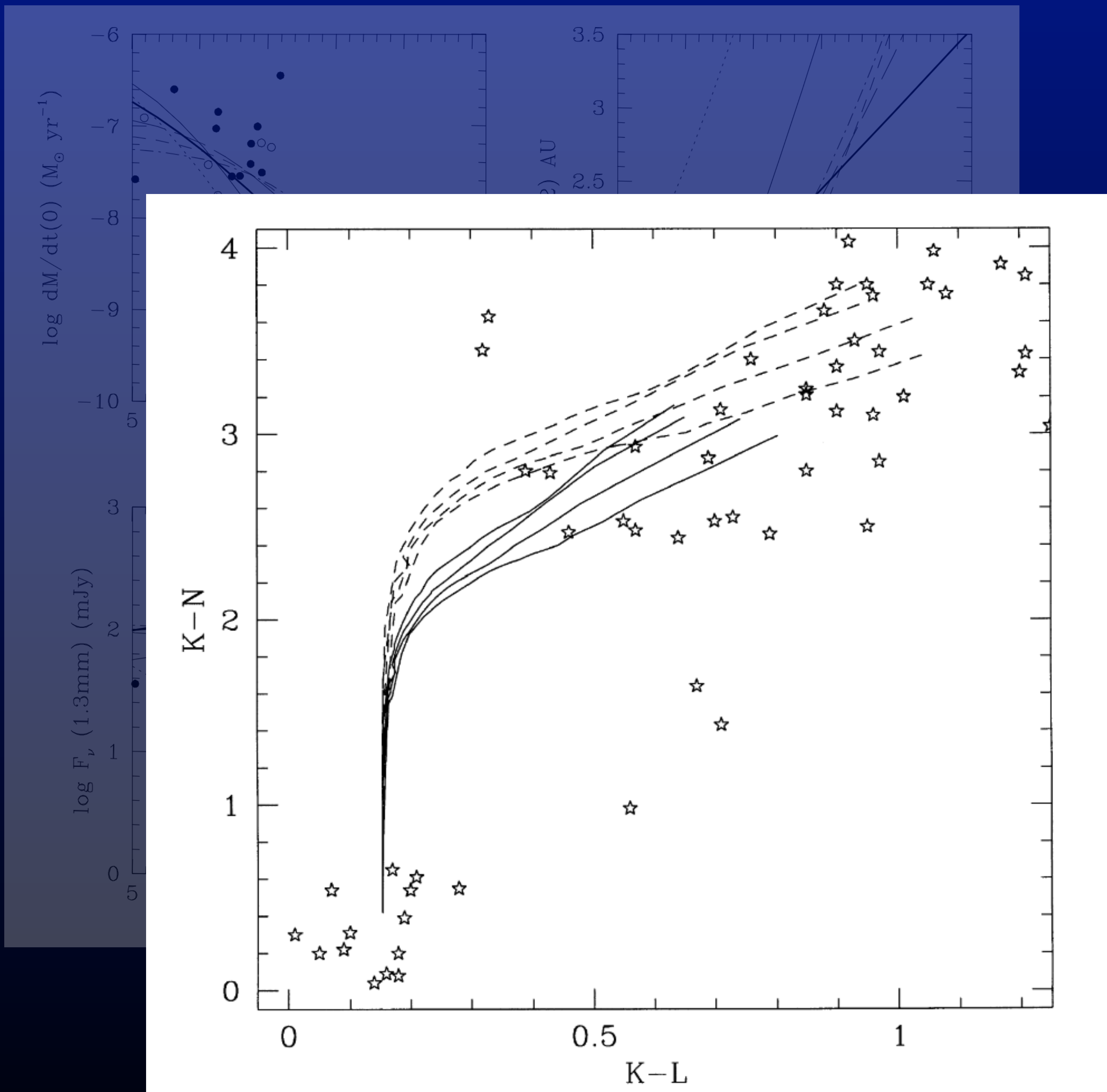


Hartmann+ (1998):
viscous accretion disc models

vs

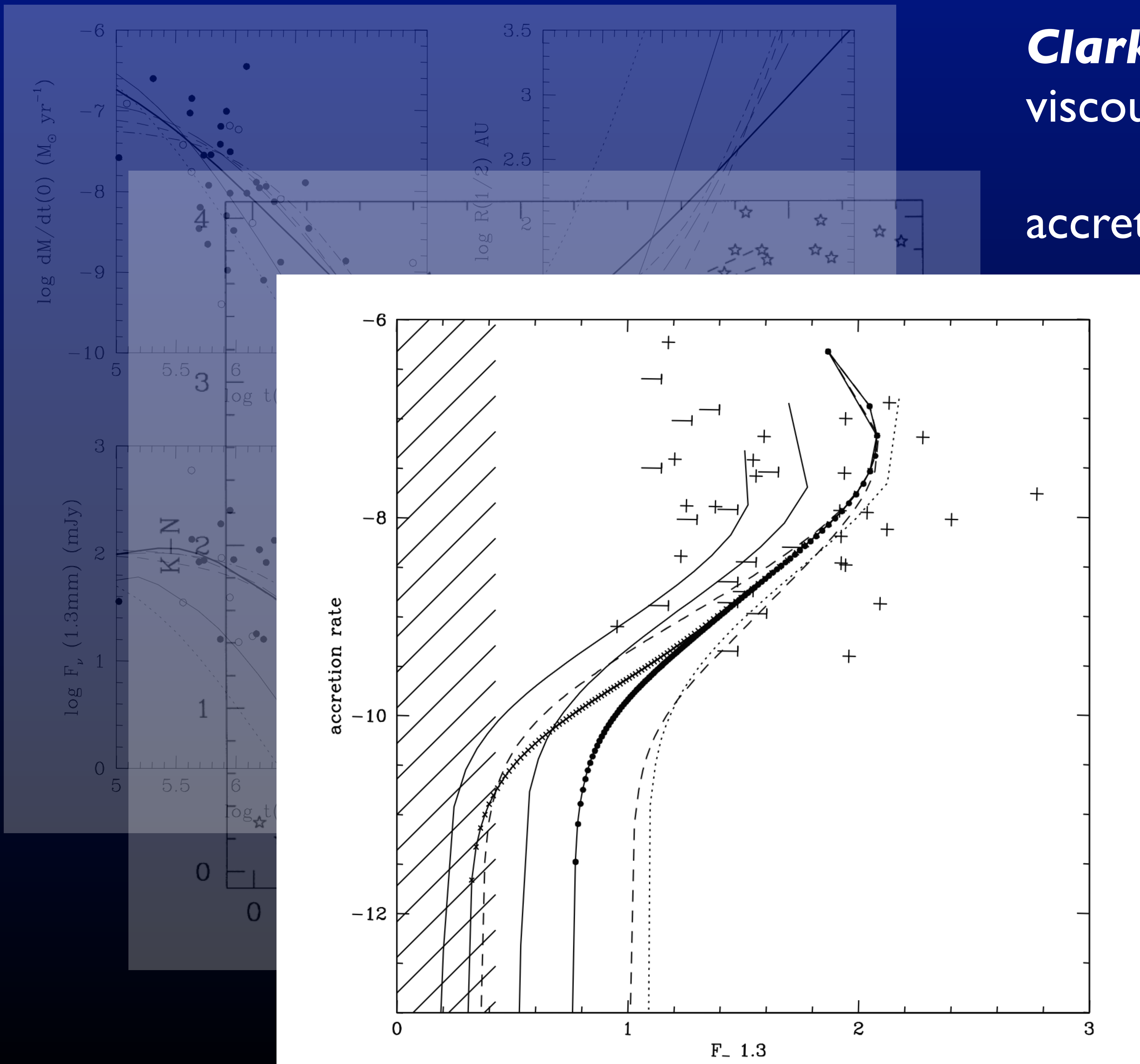
accretion rate; age; disc mass (size?)

Ancient history



Armitage+ (1999):
viscous discs w/B-spheres
vs
IR colours & stellar rotation

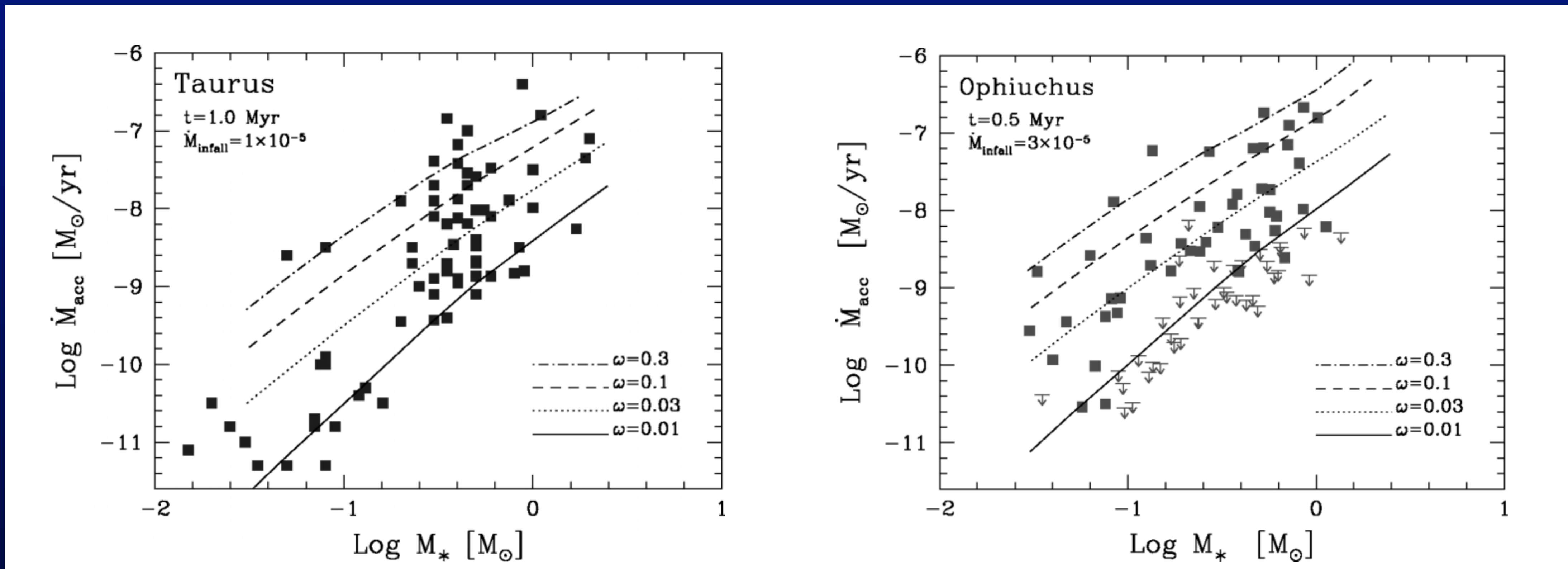
Ancient history



Clarke+ (2001):
viscous + photoevaporation
vs
accretion rates, IR colours, mm fluxes

See also Wood+ (2002), Matsuyama+ (2003), Armitage+ (2003), Takeuchi+ (2005), RDA+ (2006), etc.

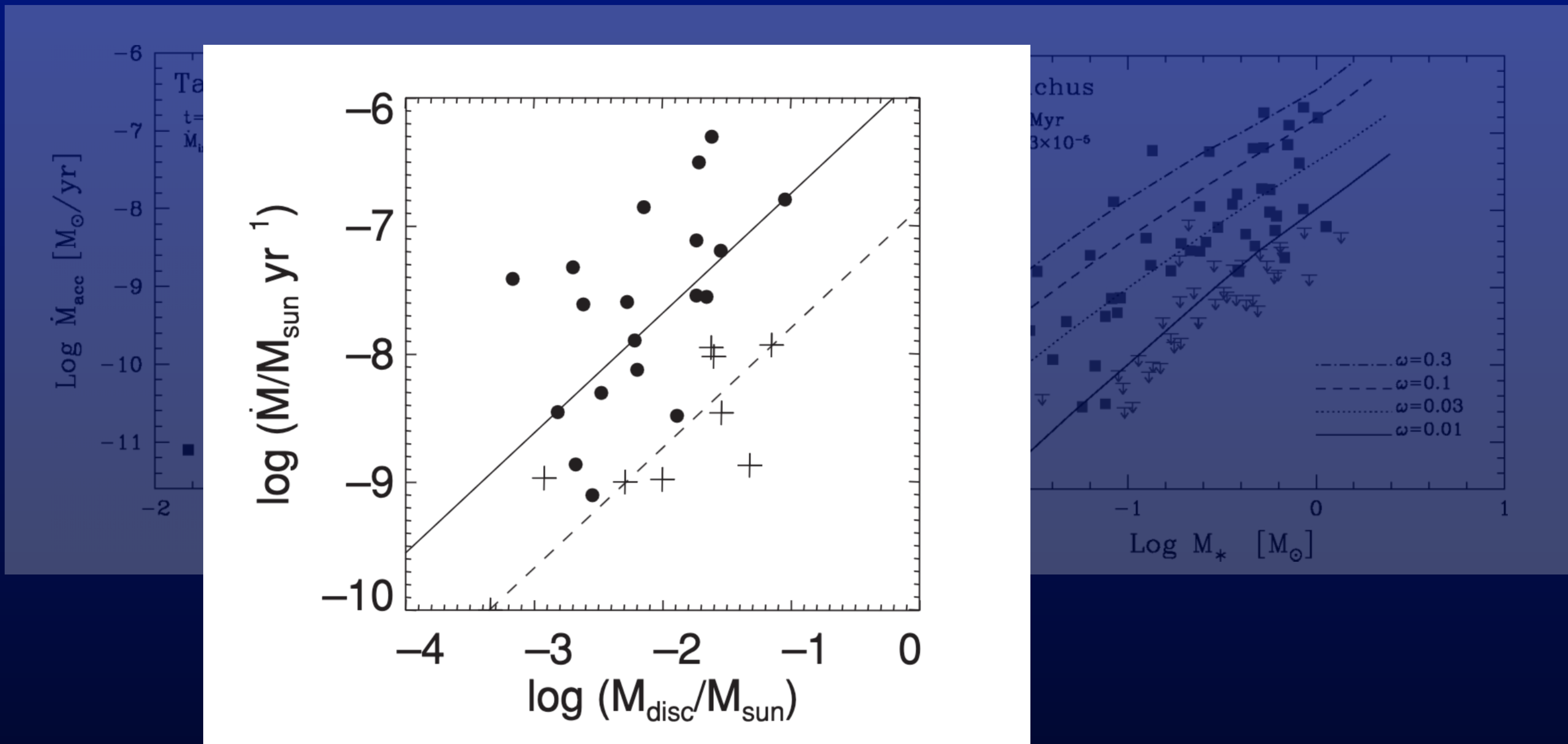
Slightly-less-ancient history



Scaling with stellar mass

Dullemond+ (2006), Mohanty+ (2005), Hartmann+ (2006), RDA & Armitage (2006), Clarke & Pringle (2006).

Slightly-less-ancient history

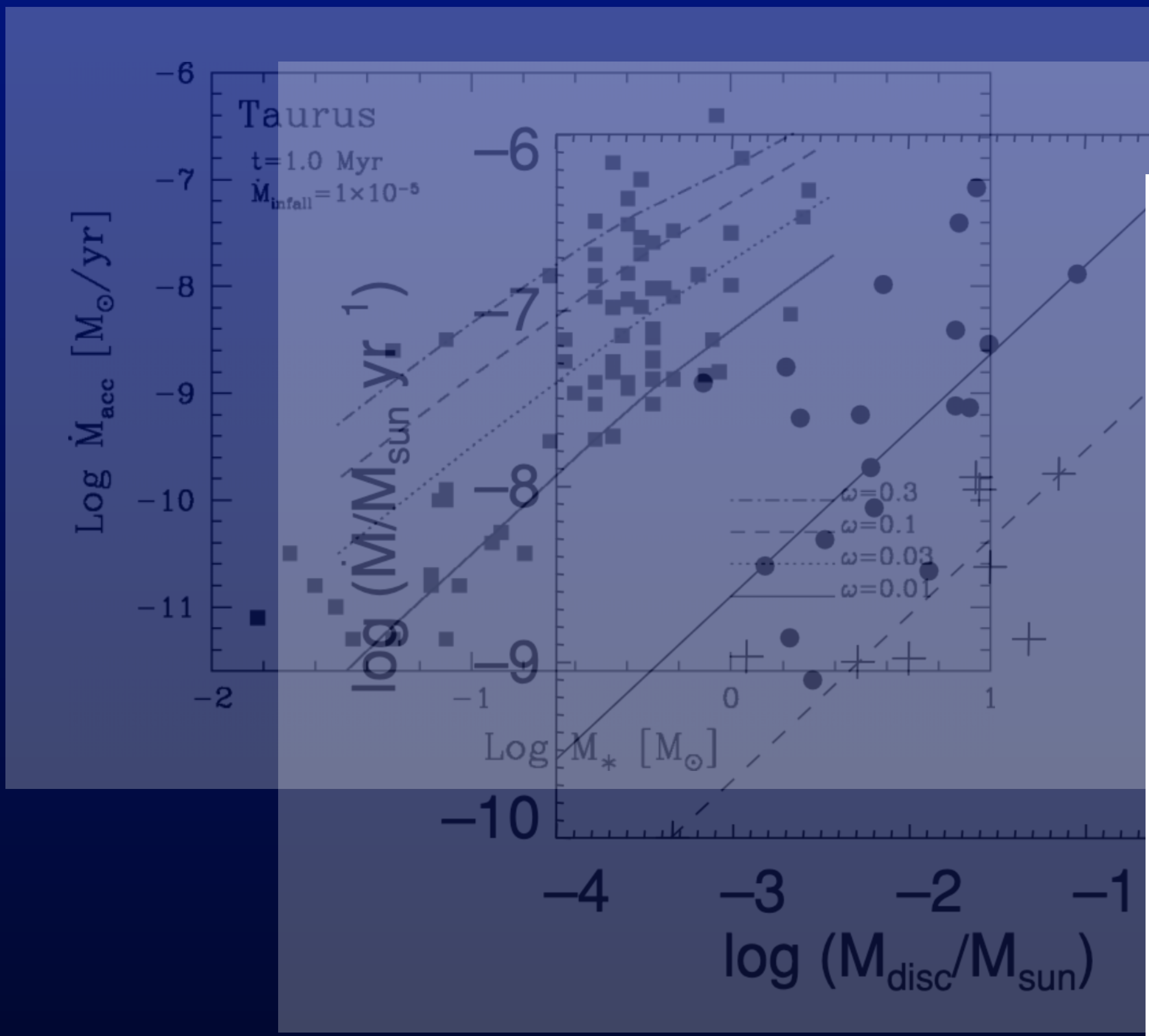


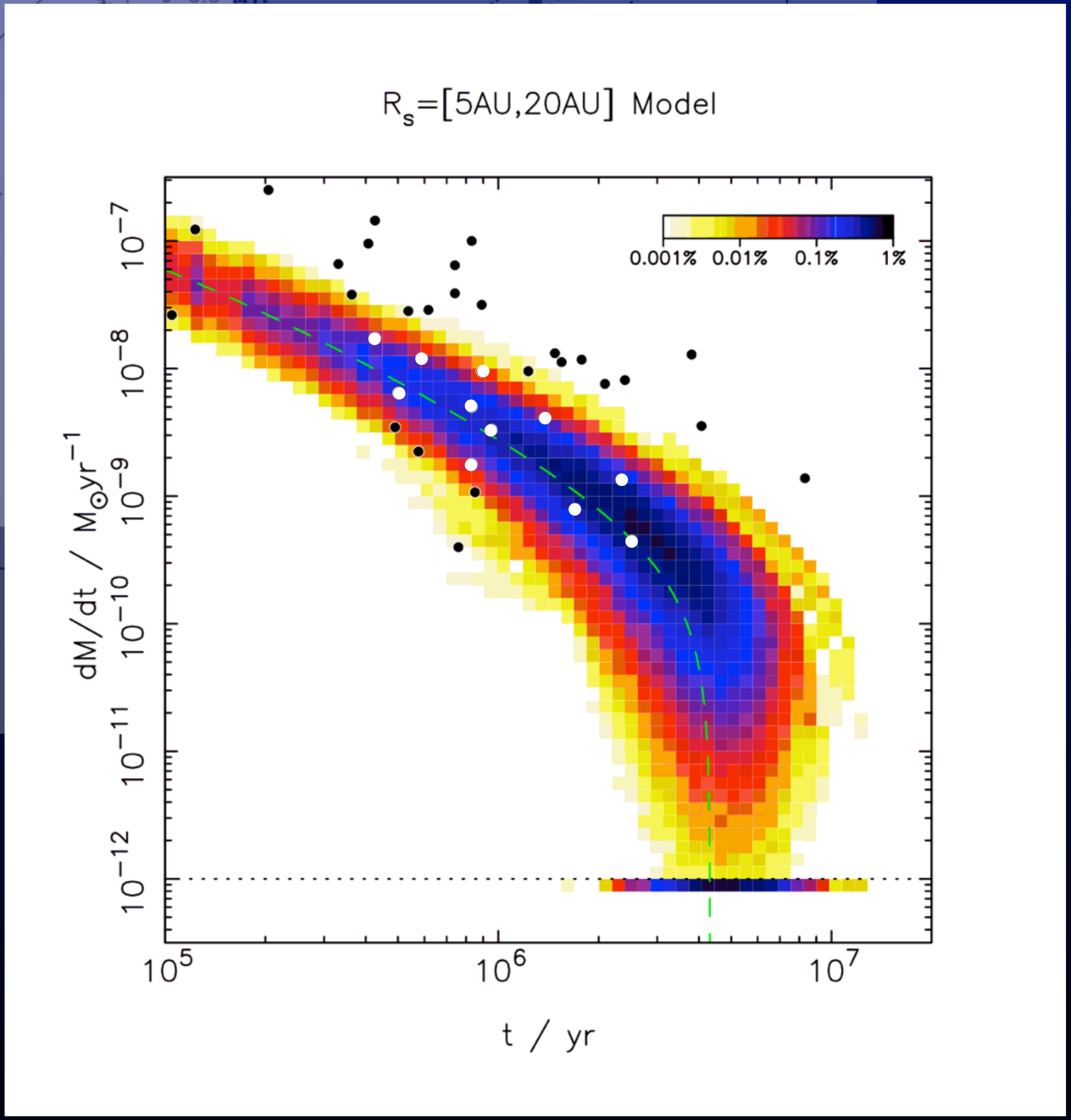
Mdisc-Mdot scalings (transitional discs)

Najita+ (2007), RDA & Armitage (2007),

Chiang & Murray-Clay (2007), etc.

Slightly-less-ancient history





Population models
RDA & Armitage (2009),
Owen+ (2011, 2012),
Köpferl+ (2013), etc.

What is population synthesis?

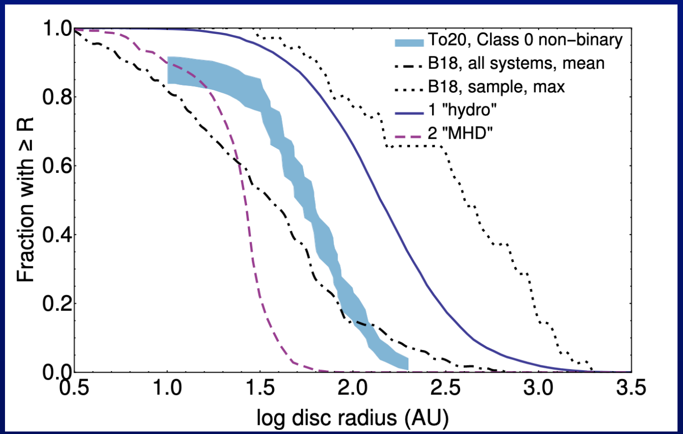
Disc model

(Simplified physics and/or initial conditions; usually 1-D)

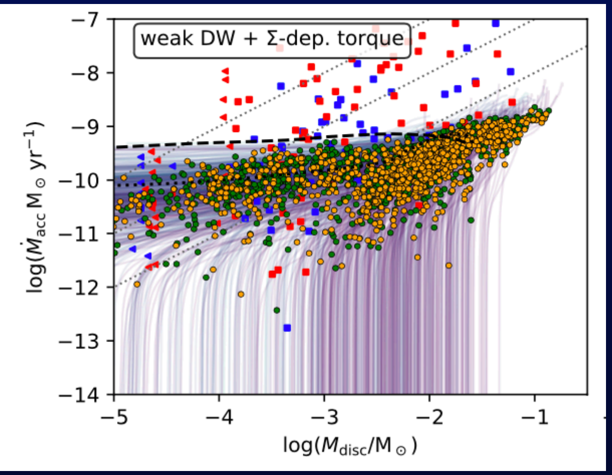
Time evolution

Synthetic observations

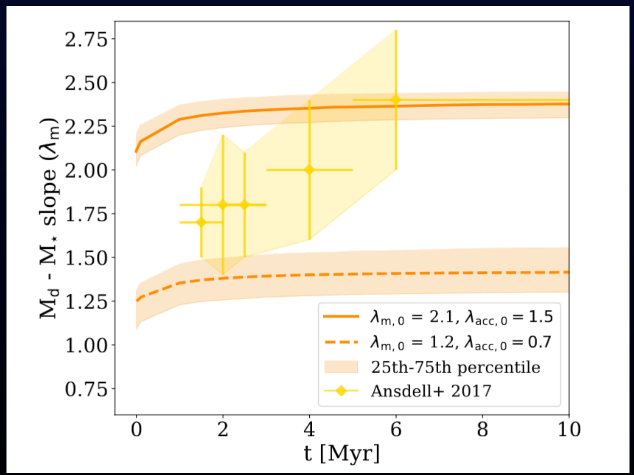
Randomly sampled input parameters



Schib+ (2021)



Weder+ (2023)



Somigliana+ (2022)

What is population synthesis?

The dream

- Well-understood physics.
- Relatively few free parameters.
- Statistically significant link between observable diagnostics and specific physical processes.

😇

Stellar population models (??)

Reality

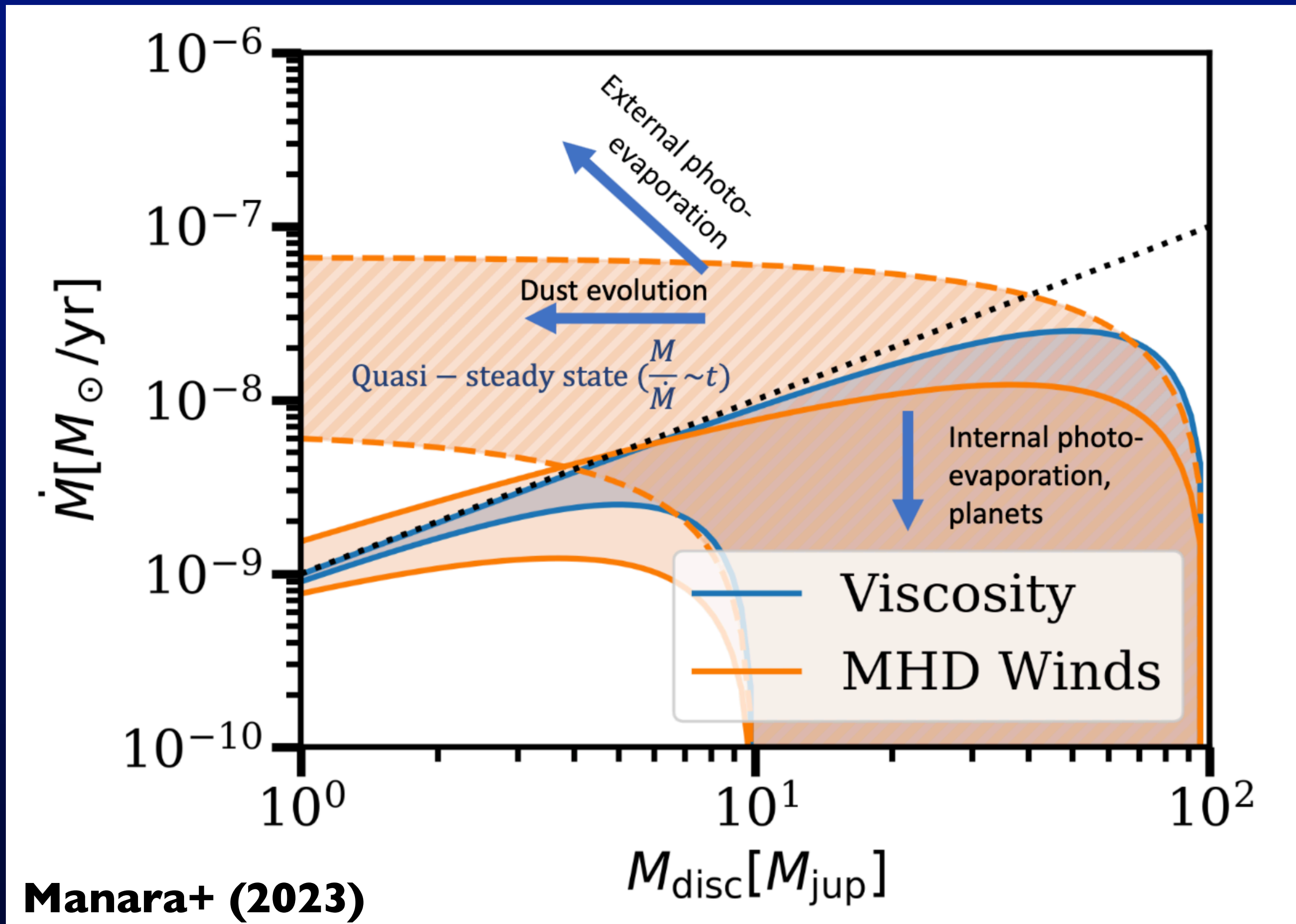
- Key physics not known and/or poorly understood.
- Large number of input parameters.
- Observables degenerate with parameters & assumptions.

🤪

Planet pop. synthesis

Galaxy formation

A tale of two…disc models

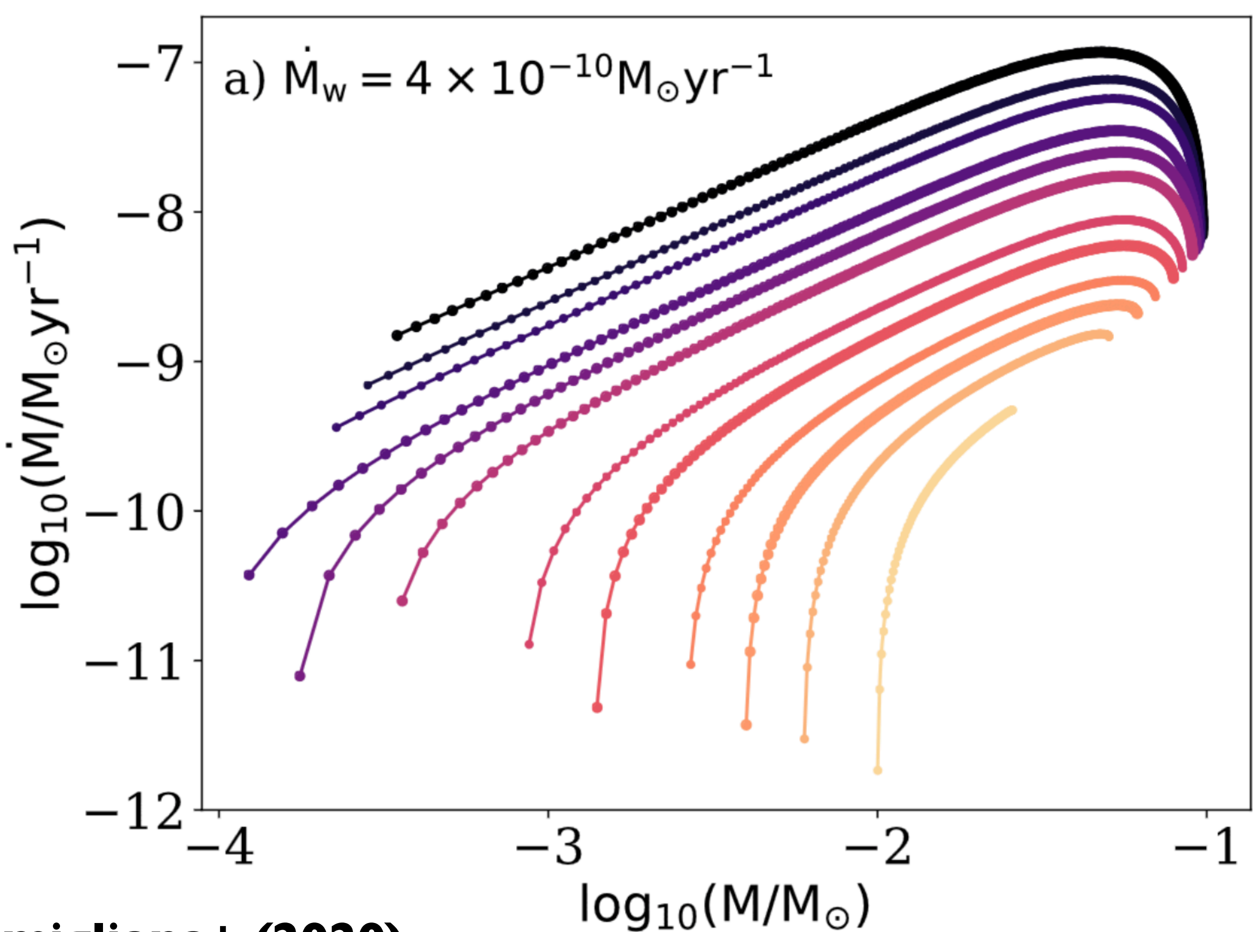


See also Jones+ (2012), Armitage+ (2013), Lodato+ (2017), Tabone+ (2022), Rosotti+ (2017), Coleman & Haworth (2022), Hasegawa+ (2022), etc.

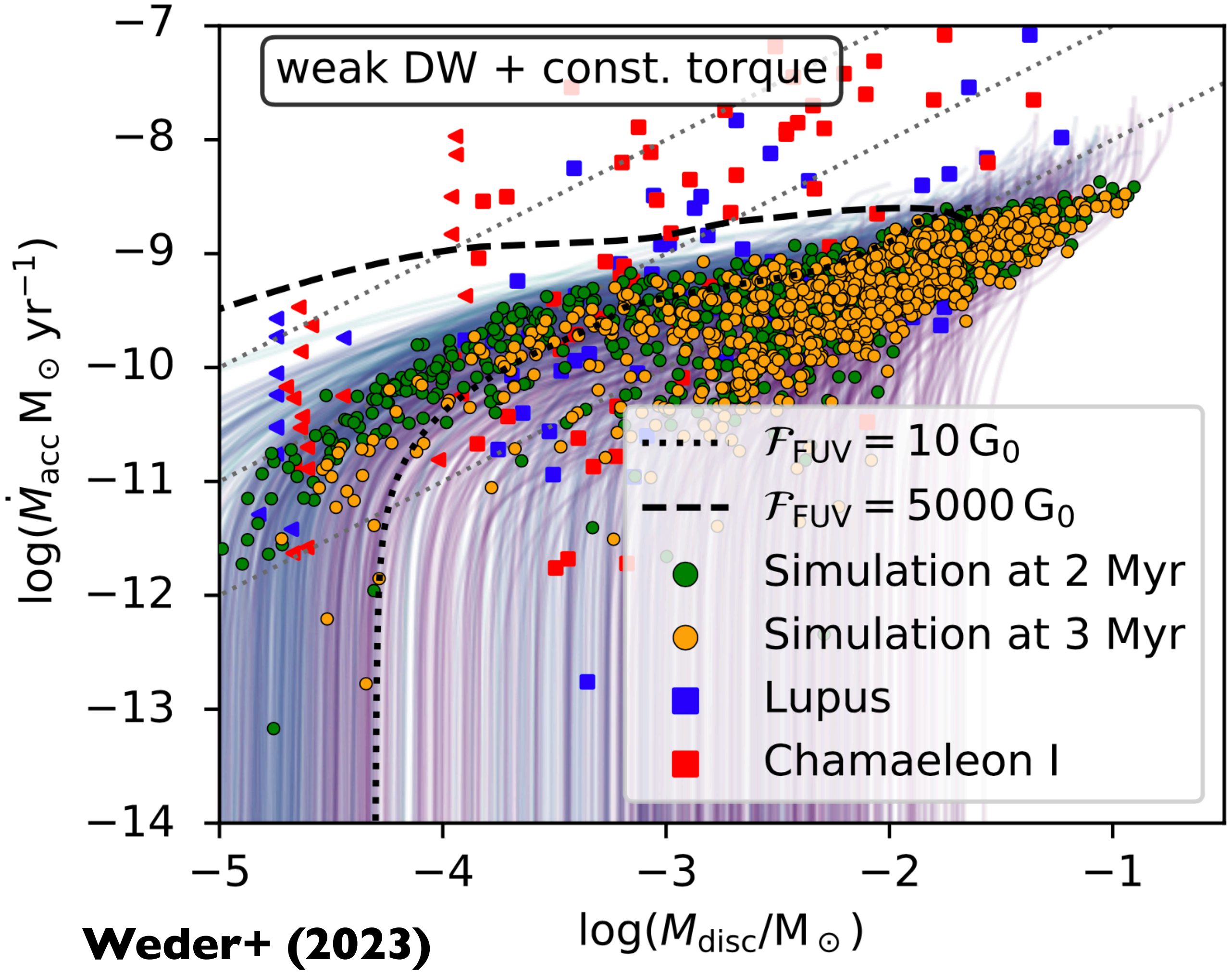
See talks by Somigliana, Weder & Toci

- We don't know if disc accretion/evolution is driven by turbulent transport (MRI), or by torques from (magnetised) winds.
- Common diagnostics: two-observable planes, compared to model tracks, isochrones, and/or populations.
- "Pure" viscous vs wind-driven models make distinct predictions.

Population synthesis: initial conclusions



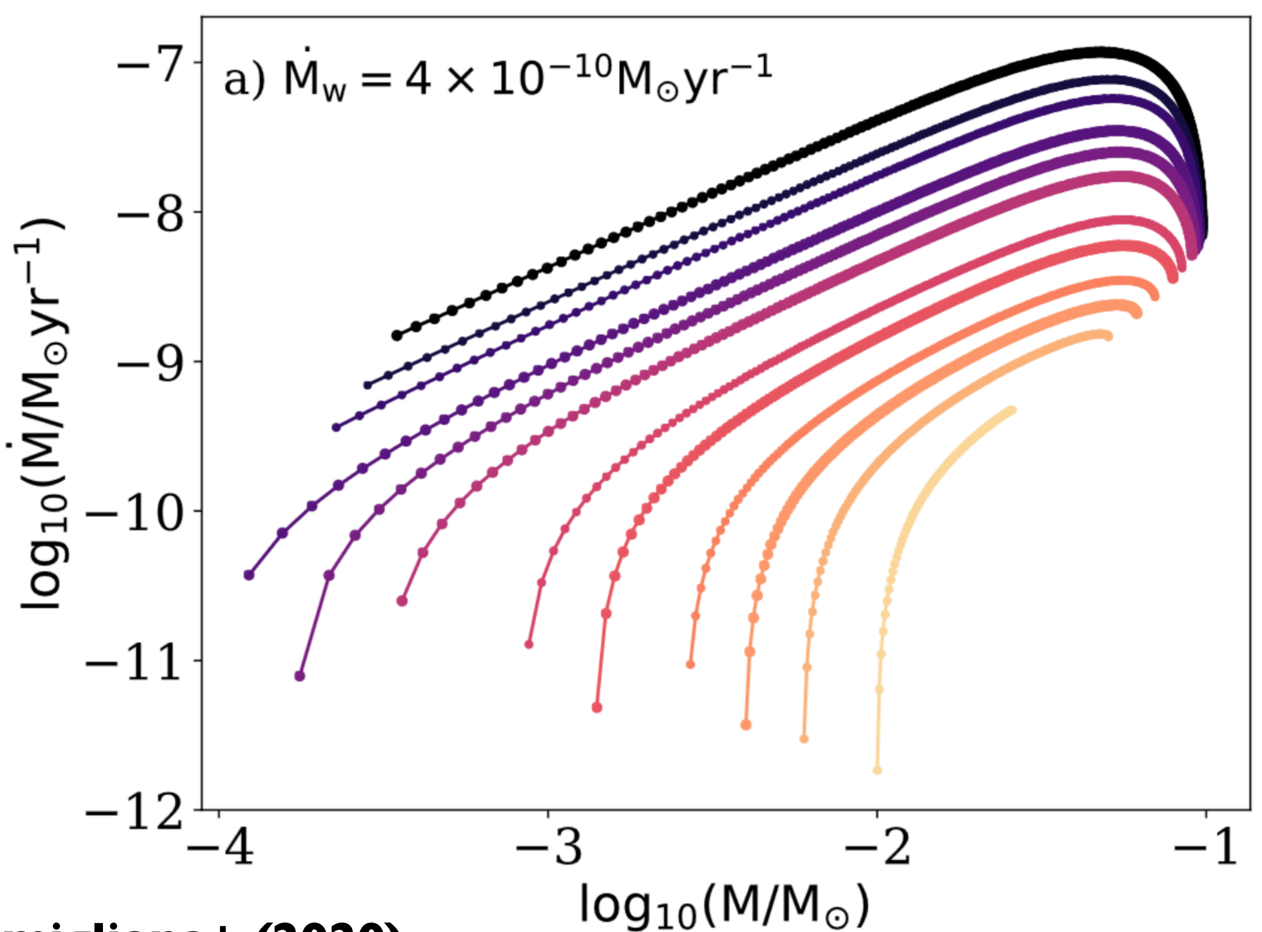
Somigliana+ (2020)



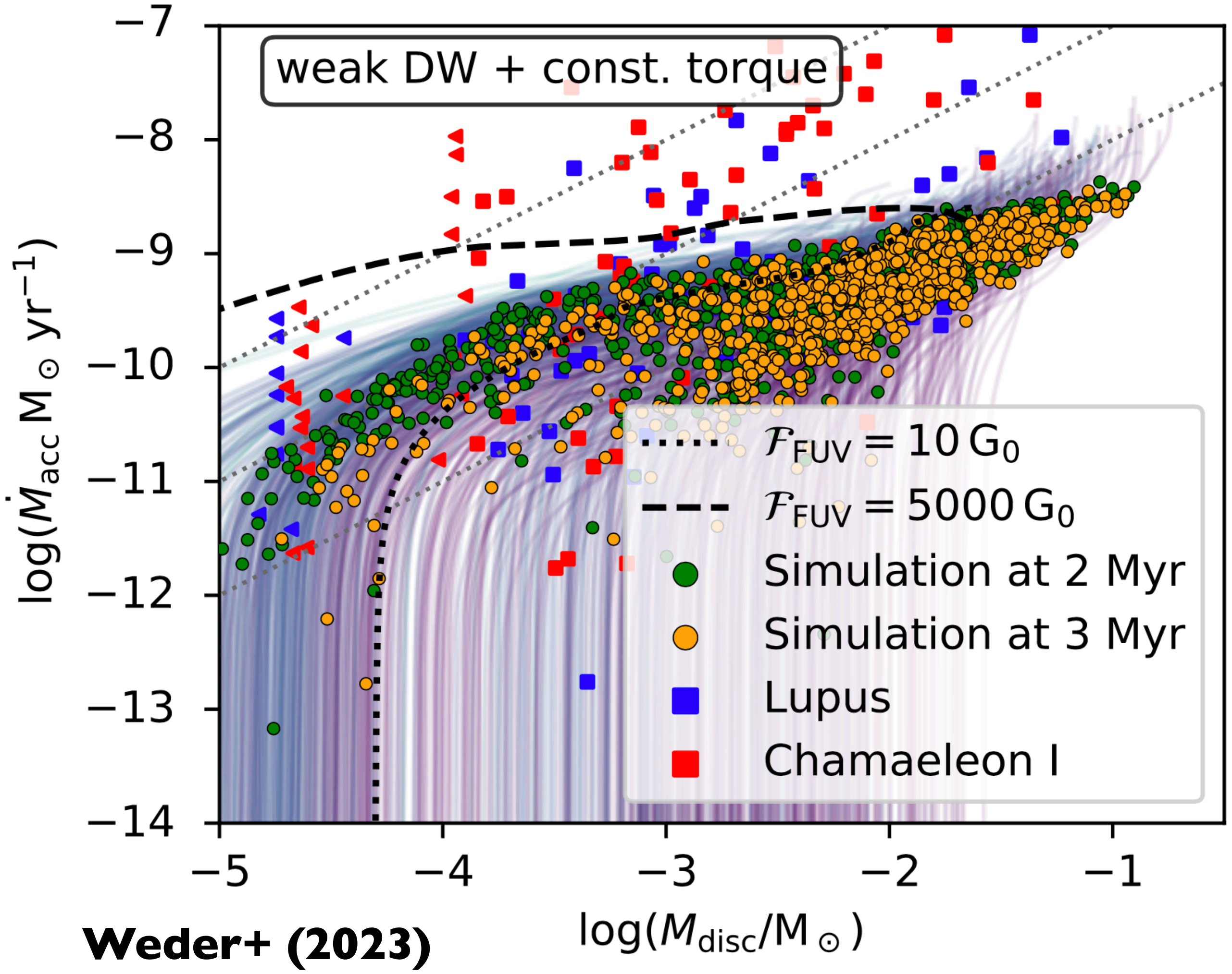
Weder+ (2023)

- Viscous ➡ long(ish) viscous time-scales, and modest photoevaporation rates (Lodato+ 2017; Somigliana+ 2020).
- Wind-driven ➡ weak winds with strong torques (Weder+ 2023).
- Wind-driven discs always retain "memory" of initial conditions; viscous discs do not (RDA+ 2023; Somigliana+ 2023).

A tale of two disc models, ***BUT***…



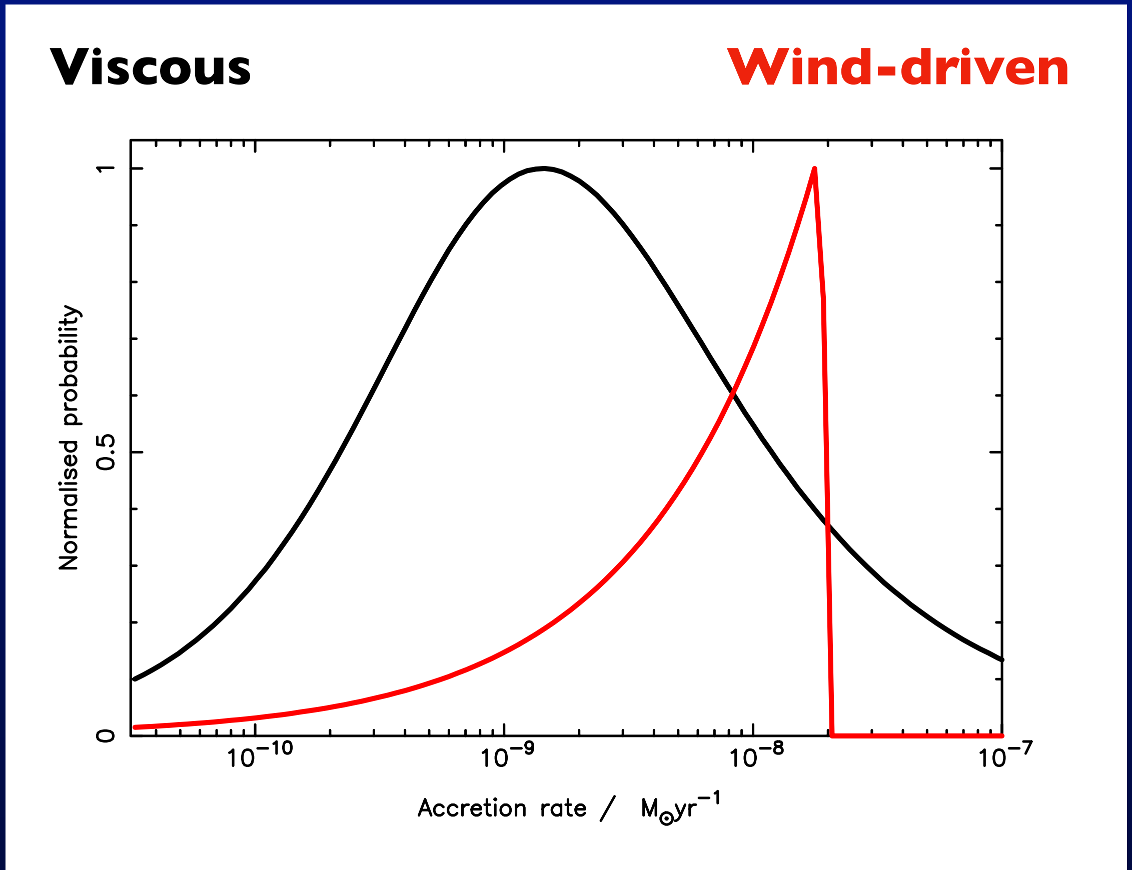
Somigliana+ (2020)

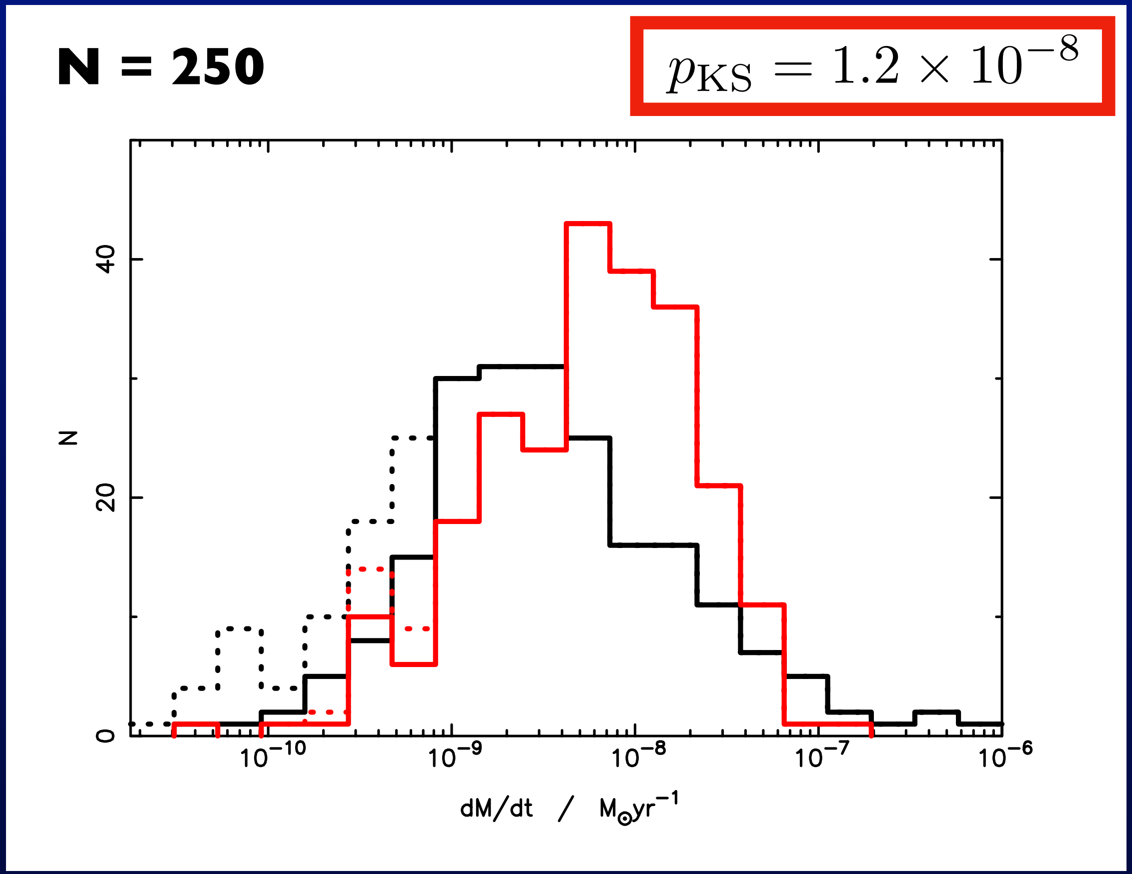


Weder+ (2023)

- Both scenarios ~consistent with current demographic data.
- Including more physics (infall, dust drift / evolution, photoevaporation, etc.) makes it harder to tell models apart.
- The "pure" viscous vs wind-driven distinction is too simple; in real discs both processes operate.

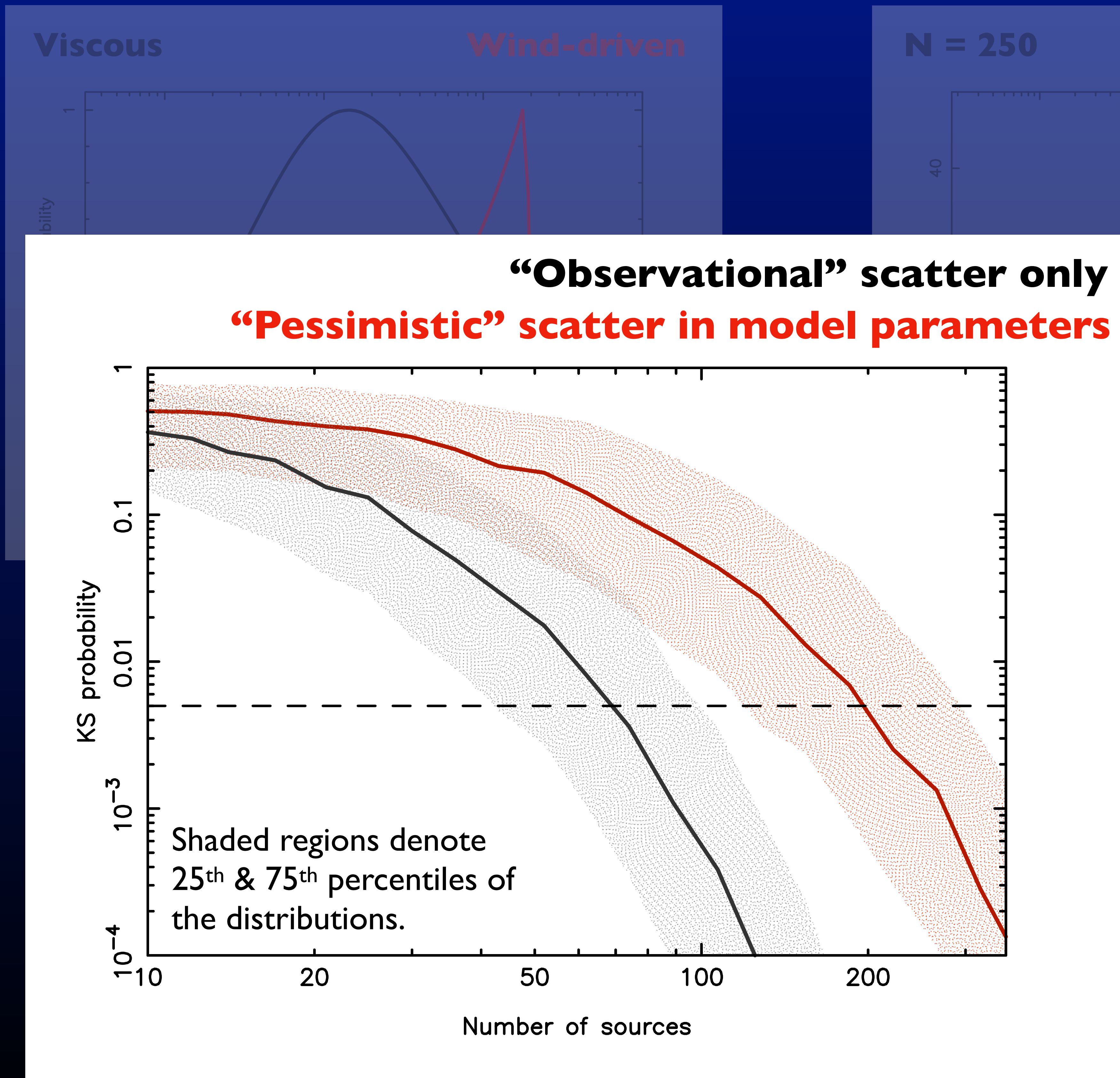
A statistical look at accretion rates

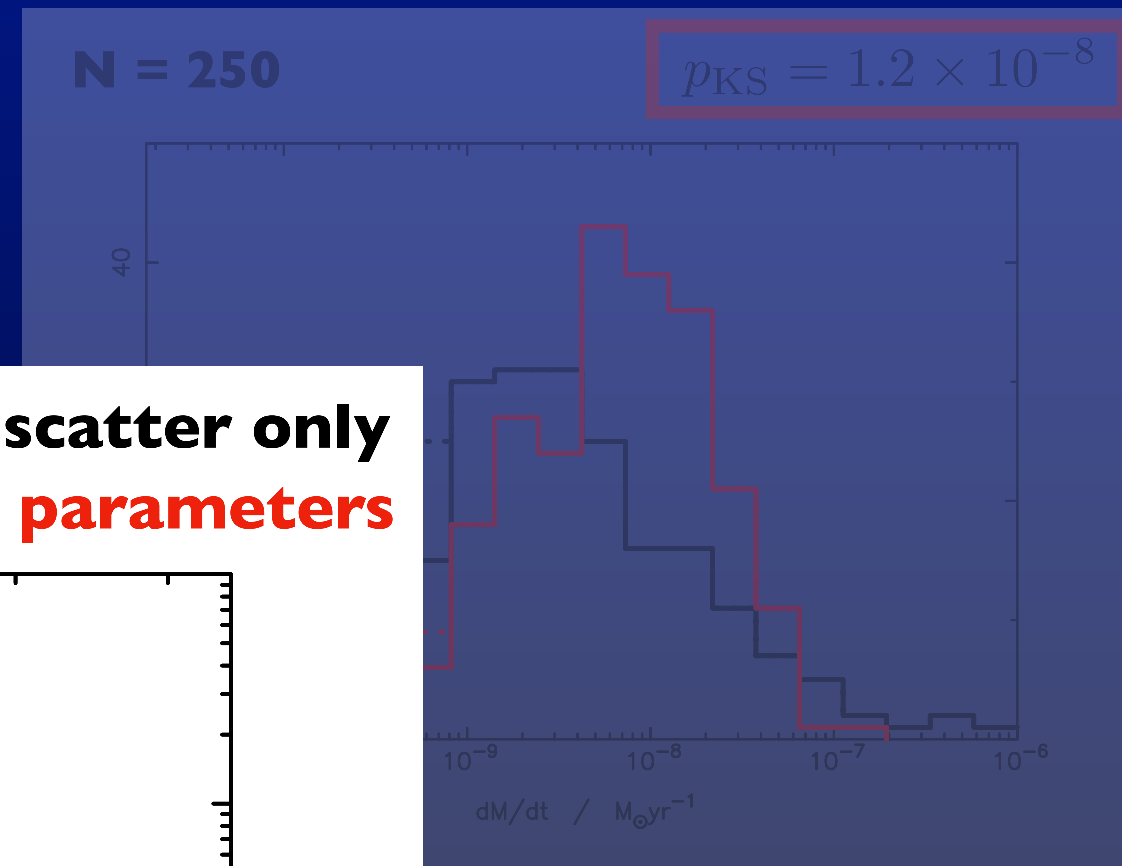




RDA+ (2023)

A statistical look at accretion rates

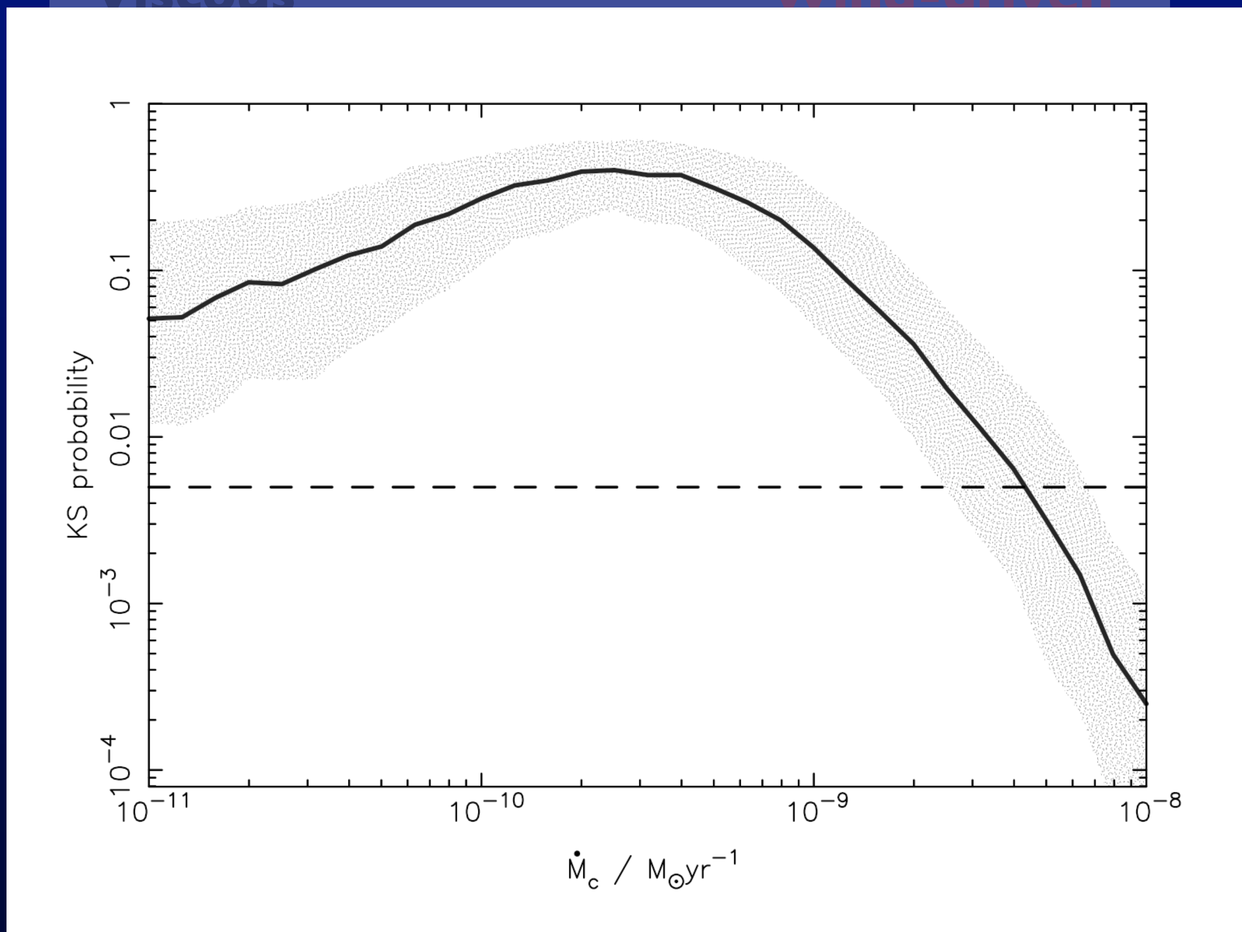


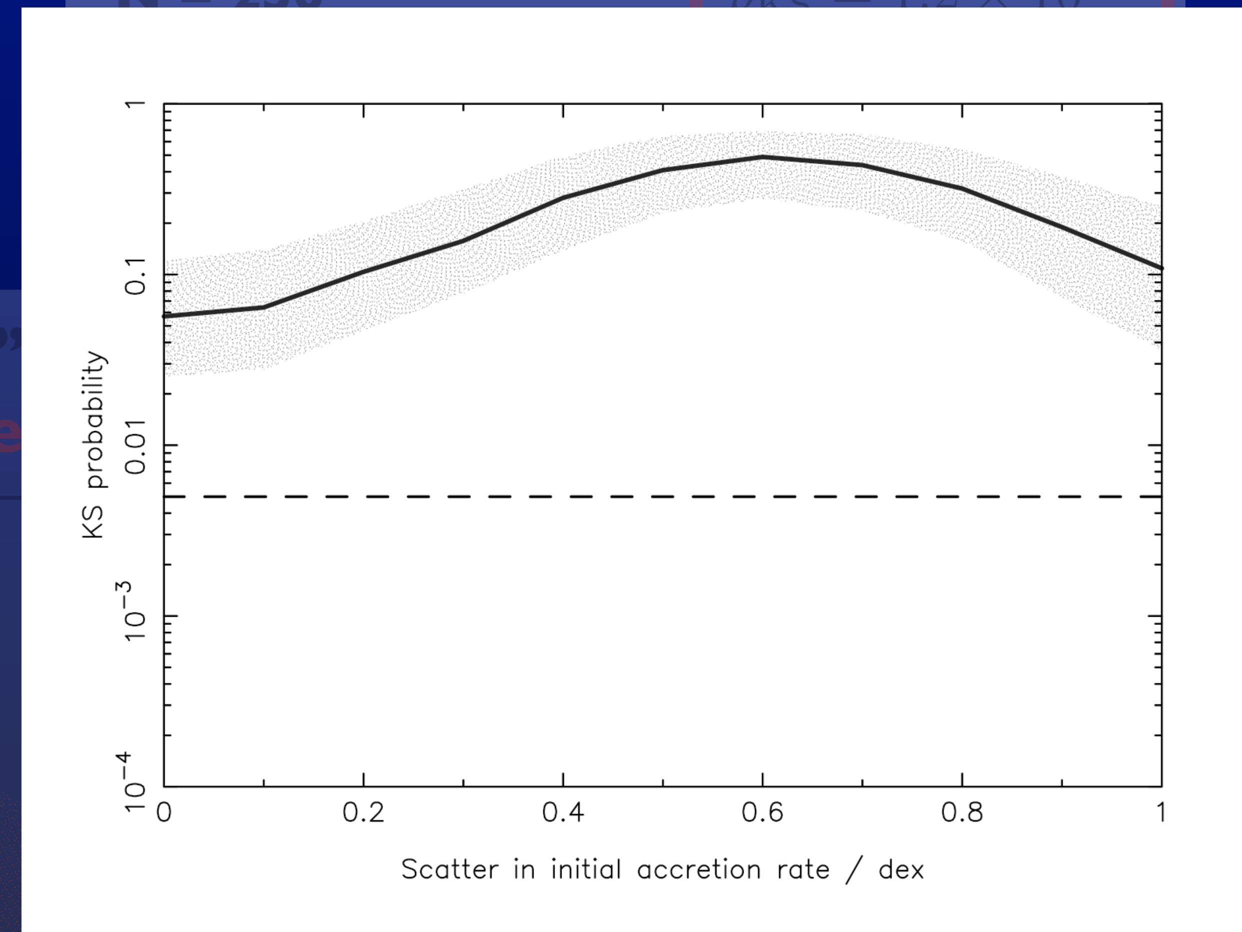


~300 objects should be(!) enough to distinguish between these models.

RDA+ (2023)

A statistical look at accretion rates





Observed sample (Manara+ PP7) is ~100 objects (0.3-1.2$M_\odot$).

So we cannot distinguish between the models (they both fit), and most parameters are not strongly constrained.

[But if accretion is viscous, there is a statistically significant preference for lower photoevaporation rates.]

RDA+ (2023)

So…where are we?

Successes

- Models able to reproduce demographic data relatively well.
- Starting to get useful constraints on some parameters.
- Model predictions becoming a useful guide for current/future observations.

Limitations

- Observations still suffer from significant systematics (especially ages and "total" disc masses).
- Models still highly simplified (1-D; gas-only; viscous or wind)
- *Many* degeneracies between model parameters.
- Limited statistical comparisons.
- Not much is really ruled out…

Where do we go next?

- "Hybrid" models, incorporating both turbulent/viscous and wind-driven accretion physics (e.g., Tong+, in prep).
- Initial conditions: what do the ICs in these models mean? and what can they tell us?
- More sophisticated statistical comparisons with observations.
- Improved treatments of dust dynamics / evolution.
- Sub-structures? (***If*** structures tell us about evolution…)
- Beyond 1-D models?

A data-driven approach?

Disc model

(Simplified physics and/or initial conditions; usually 1-D)

MCMC

"By the power of Bayes…"

Observations / population statistics

Posterior distributions of model / input parameters

Concluding thoughts

- Both wind-driven and viscous disc models are able to reproduce observed disc demographics / populations relatively well.
- Even simple models are very degenerate. Can reproduce data with wide ranges of physics, input parameters, & initial conditions.
- We have ~enough data to do statistics, but treatment of systematic uncertainties remains a major issue.
- ***What do we need to take this approach further?***