CONICYT Ministerio de Educación Gobierno de Chile
FONDECYT Fondo Nacional de Desarrollo Científico y Tecnológico
Centro de Astrofísica y Tecnologías Afines
INSTITUTO DE ASTROFÍSICA FACULTAD DE FÍSICA
NPF NÚCLEO MILENIO DE FORMACIÓN PLANETARIA

Lifetimes of protoplanetary disks in multiple star systems

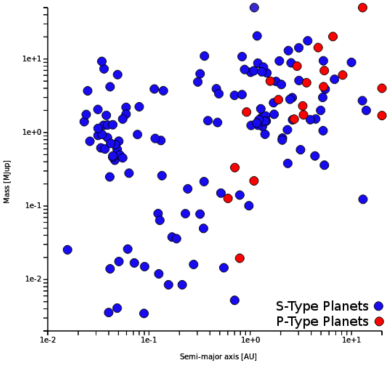
Great Barriers in Planet Formation
Palm Cove - Australia - July - 2019

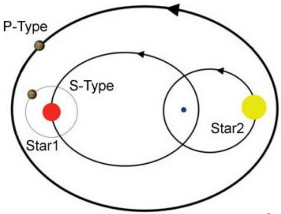
Instituto de Astrofísica - PUC
Núcleo Milenio de Formación Planetaria

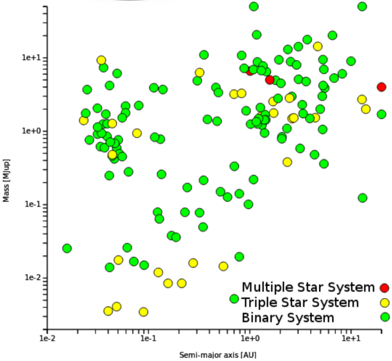
Ronco, M.P.
Fontecilla, C., Cuadra, J., Poblete, P., Cuello, N., Guilera, O.

Credit: J. Olofsson

Planets in Multiple Star Systems Do Exist !



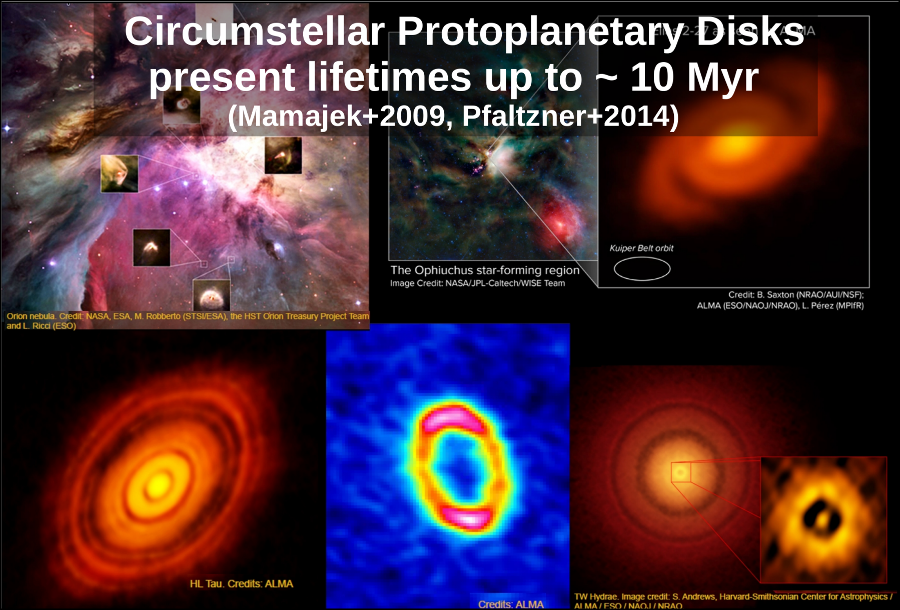




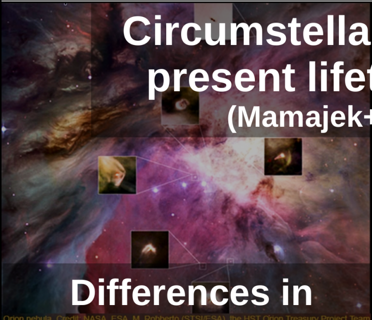
> 130 S-Type Planets
> 20 P-type Planets
> 30 Planets in multiple star systems

Protoplanetary disks: Planets birthplaces

Circumstellar Protoplanetary Disks present lifetimes up to ~ 10 Myr (Mamajek+2009, Pfaltzner+2014)

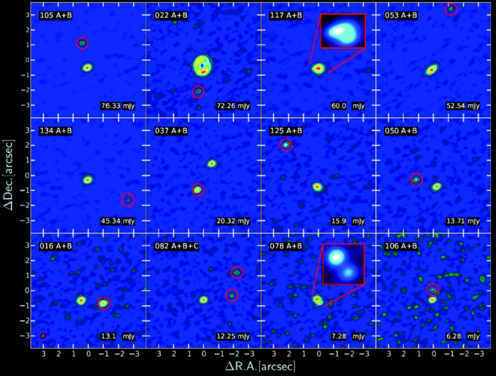


Circumstellar Protoplanetary Disks present lifetimes up to ~ 10 Myr (Mamajek+2009, Pfaltzner+2014)

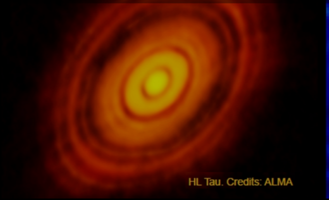


Orion nebula. Credit: NASA, ESA, M. Robberto (STScI/ESA), the HST Orion Treasury Project Team

Differences in Circumprimary and Circumbinary Disks



Cieza et al. 2019

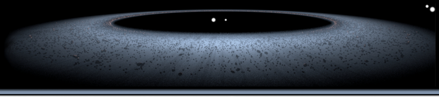


HL Tau. Credits: ALMA

Lucas Cieza and Megan Ansdell talks on Monday
Gaspar Duchene's talk today !

TW Hydrae. Image credit: S. Andrews, Harvard-Smithsonian Center for Astrophysics /

Motivation: HD 98800



HD 98800:

- Quadruple hierarchical system (Aa-Ab, Ba-Bb) in TW Hya
- Narrow circumbinary disk around Ba-Bb
- Age: ~ 7 - 10 Myr
- Lack of accretion signatures (Soderblom et al. 1996 – Muzerolle et al. 2000)

Ribas et al. 2018:

- VLA Disk detection at 5cm is compatible with free-free emision from photoionized material.
- $M_{gas} \sim 5M_J$
- <u>**Proposition:**</u> The disk is evolving due to photoevaporation.

Our Model: Only gas evolution version of PlanetaLP

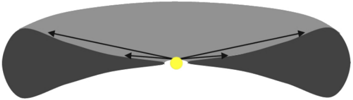
A standard 1D+1D viscous accretion disk

Vertical Structure of the Disk

$$\frac{\partial P}{\partial z} = -\rho \Omega^2 z,$$
$$\frac{\partial F}{\partial z} = \frac{9}{4} \rho \nu \Omega^2,$$
$$\frac{\partial T}{\partial z} = \nabla \frac{T}{P} \frac{\partial P}{\partial z}.$$

Boundary Conditions at the Disk surface

$$P_s = \frac{\Omega^2 H \tau_{\mathrm{ab}}}{\kappa_s},$$
$$F_s = \frac{3 \dot{M}_{\mathrm{st}} \Omega^2}{8\pi},$$



$$0 = 2\sigma \left(T_s^4 + T_{\mathrm{irr}}^4 - T_{\mathrm{b}}^4 \right) - \frac{9\alpha \Omega k (T_s^4 + T_{\mathrm{irr}}^4)^{1/4}}{8 \kappa_s \mu m_{\mathrm{H}}} - F_s,$$

Papaloizou & Terquem 1999; Alibert et al. 2005; Migaszewski 2015

Stellar Irradiation

$$T_{\mathrm{irr}} = T_\star \left[\frac{2}{3\pi} \left(\frac{R_\star}{R} \right)^3 + \frac{1}{2} \left(\frac{R_\star}{R} \right)^2 \left(\frac{H}{R} \right) \left(\frac{d \log H}{d \log R} - 1 \right) \right]^{0.5}$$

Hueso & Guillot 2005

Time Evolution of the Gas Surface Density:

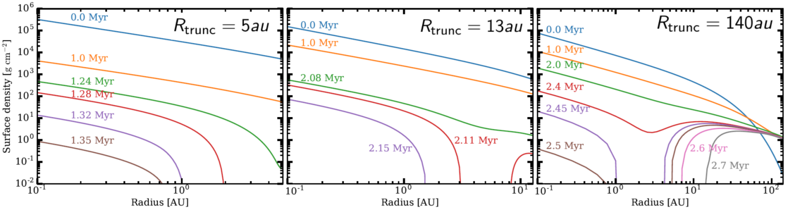
$$\frac{\partial \Sigma_{\mathrm{g}}}{\partial t} = \frac{3}{R} \frac{\partial}{\partial R} \left[R^{1/2} \frac{\partial}{\partial R} \left(\nu \Sigma_{\mathrm{g}} R^{1/2} \right) \right] + \dot{\Sigma}_{\mathrm{w}}(R)$$

X-Ray Photoevaporation
Owen et al. 2012

Viscosity $\nu = \alpha c_s^2 \Omega$ Shakura & Sunyaev 1973

Evolution of a Circumprimary Disk

Rosotti & Clarke 2018

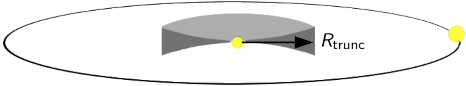


Giovanni Rosotti's talk

$$\frac{\partial \Sigma_{\rm g}}{\partial t} = \frac{3}{R}\frac{\partial}{\partial R}\left[R^{1/2}\frac{\partial}{\partial R}\left(\nu\Sigma_{\rm g}R^{1/2}\right)\right] + \dot{\Sigma}_{\rm w}(R),$$

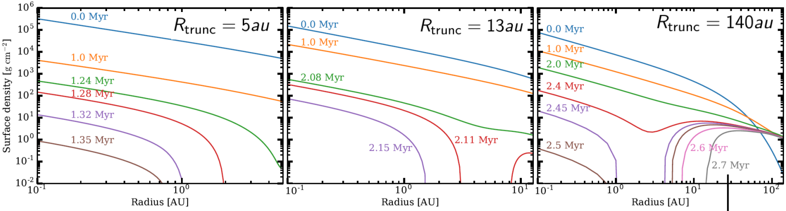
Zero flux condition at $R_{\rm trunc}(q, a)$ $\rightarrow \frac{\partial}{\partial R}\left(\nu\Sigma_{\rm g}R^{1/2}\right) = 0,$

Papaloizou & Pringle 1977
Bath & Pringle 1981;
Rosotti & Clarke 2018

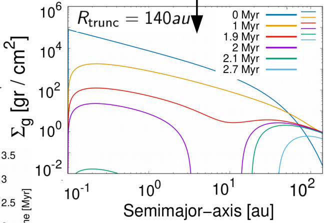


Evolution of a Circumprimary Disk

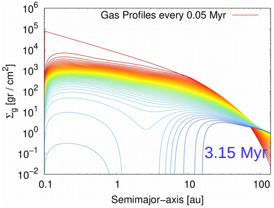
Rosotti & Clarke 2018

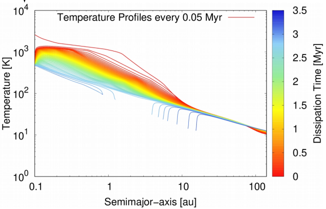


PlanetaLP (Isothermal version)
Test using the same viscosity model as Rosotti & Clarke (2018)

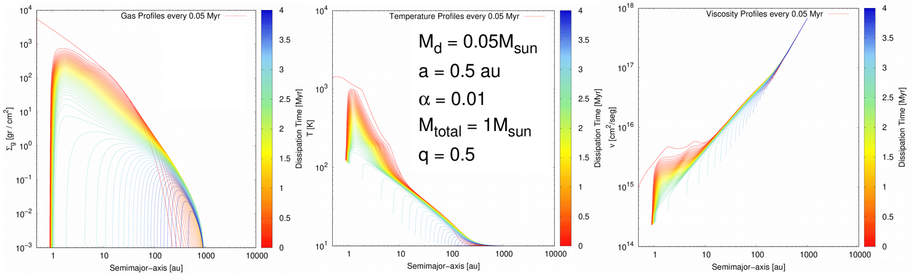


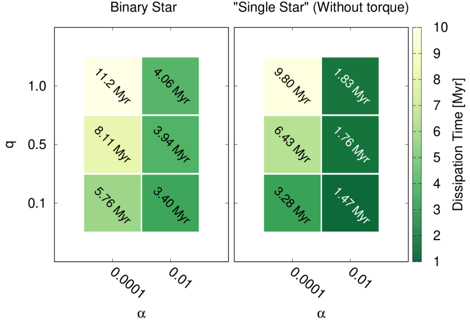
PlanetaLP
(Non-Isothermal version)
Ronco et al. In prep.





Evolution of a Circumbinary Disk



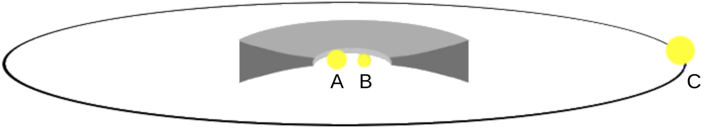


Dissipation timescales of circumbinary disks are higher than for single star systems

Alexander 2012

Gas Disk Evolution in Triple Star Systems

Which disk conditions would allow the existence of long-lived disks
In triple systems affected by X-Ray Photoevaporation ?

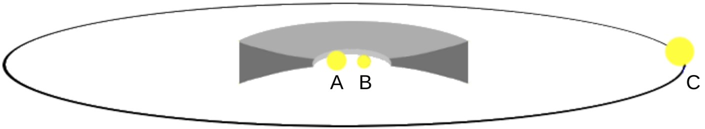


Stellar and Disk Parameters to explore:

- a (Inner binary separation)
- R_{trunc}
- $q = M_2/M_1$ and M_{tot}
- α
- M_{d}
- $e_{(\mathrm{A\text{-}B})}$, $e_{(\mathrm{A\text{-}B})\text{-}\mathrm{C}}$
- $i_{(\mathrm{A\text{-}B})}$, $i_{(\mathrm{A\text{-}B})\text{-}\mathrm{C}}$

Gas Disk Evolution in Triple Star Systems

Which disk conditions would allow the existence of long-lived disks
In triple systems affected by X-Ray Photoevaporation ?



Stellar and Disk Parameters to explore:

- a (Inner binary separ
- R_{trunc}
- $q =$ ... $_{\mathrm{tot}}$
- ... $_{\mathrm{d}}$
- $e_{(\text{A-B})}$, $e_{(\text{A-B})\text{-C}}$
- $i_{(\text{A-B})}$, $i_{(\text{A-B})\text{-C}}$

Population Synthesis in Progress
Ronco et al. in prep.

Stellar and Disk Parameters "Similar" to HD 98800

- a fixed at 0.5 au
- R_{trunc} 10 au
- $q = 0.857$ and $M_{\mathrm{tot}} = 1.3 M_{\odot}$
- $\alpha = 1.e^{-4}, 1.e^{-3}, 1.e^{-2}$
- $M_{\mathrm{d}} = 0.01 M_{\odot}, 0.05 M_{\odot}, 0.1 M_{\odot}$
- $e_{(\text{A-B})} = 0$, $e_{(\text{A-B})\text{-C}} = 0$
- $i_{(\text{A-B})} = 0$, $i_{(\text{A-B})\text{-C}} = 0$

Gas Disk Evolution in Triple Star Systems

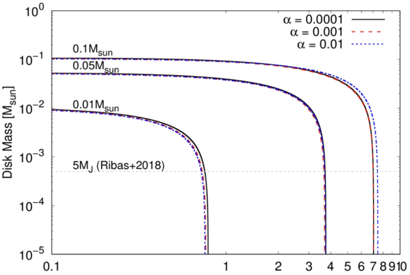
X-Ray Luminosities from
A theoretical model

$$L_X = L_X^{\star 1} + L_X^{\star 2} \simeq 2.64 \times 10^{30} [\mathrm{erg\ s^{-1}}]$$

Bae et al. (2013)

$$\boxed{L_X \big|_{(M=1.3M_\odot)} \simeq 3.42 \times 10^{30} [\mathrm{erg\ s^{-1}}]}$$

Only massive disks ($M_d > 0.1M_{sun}$) survive for more than 7 Myrs

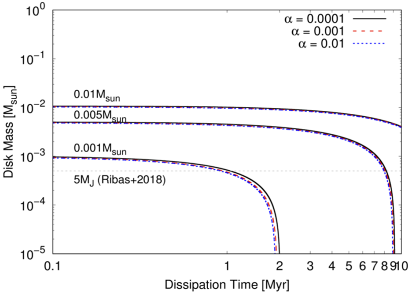


X-Ray Luminosity from
Observational estimations

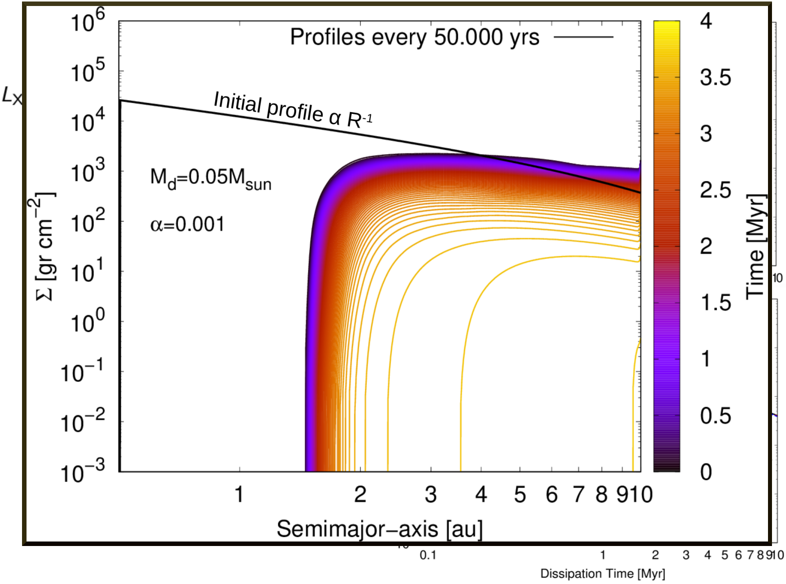
$$L_X = 1.4 \times 10^{29} [\mathrm{erg\ s^{-1}}]$$

Kastner et al. (2004)

Low-mass disks ($M_d \sim 0.005M_{sun}$) survive for more than 10 Myrs



Gas Disk Evolution in Triple Star Systems



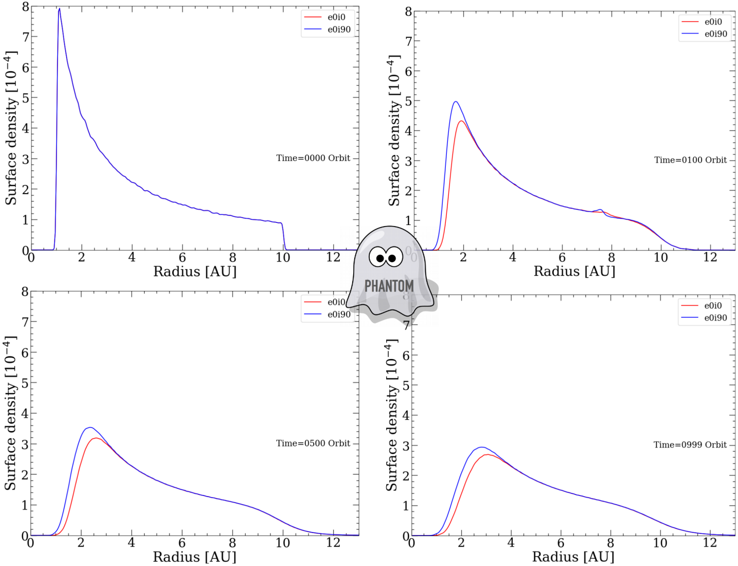
Gas Evolution in Multiple Systems

But ...

Kennedy et al. 2019

"A circumbinary protoplanetary disk in a polar configuration"

SPH Simulations by Pedro Poblete



Take Home Messages

- We present a 1D+1D Model for the gas disk evolution in 3 Star Systems.
- Work in Progress: Population synthesis to analyze long-term gas evolution exploring a wide range of disk and stellar parameters.
- For a disk "similar" to HD 98800: long-lived disks if $M_\mathrm{d} \gtrsim 0.05 M_\odot$ (theoretical way to compute L_X) - $M_\mathrm{d} \sim 0.005$ - half the MMSN (estimated L_X)
- Circumpolar configurations in a CBD do not seem to present significant differences in viscous accretion than for a coplanar case.

Whats next ?

- Include external photoevaporation
- Modeling of $e_{\text{Ba-Bb}} \neq 0$ and its effects on the disk (Kley+2019)
- Dust evolution + grain growth + Regions of planet formation ? (Drazkowska+2016)
- Back-reaction: possible mechanism to extend disk lifetimes ? (Dipierro+2019, Garate+2019).