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PHOTOEVAPORATION AND CLOSE ENCOUNTERS: HOW THE ENVIRONMENT IN CYGNUS OB2 AFFECTS THE EVOLUTION OF PROTOPLANETARY DISKS

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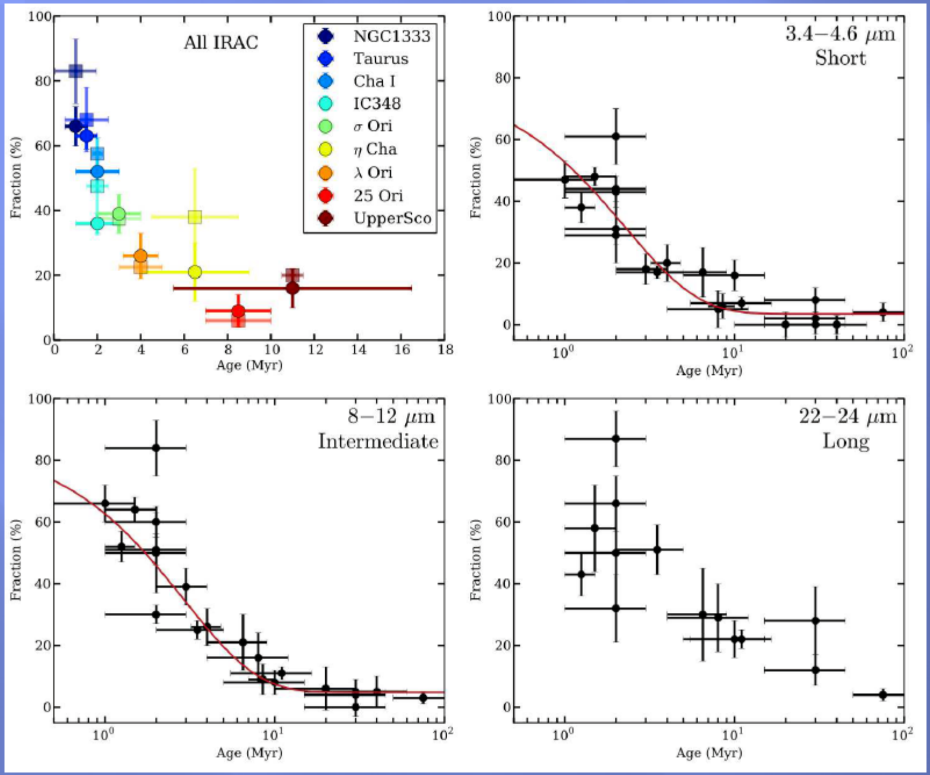
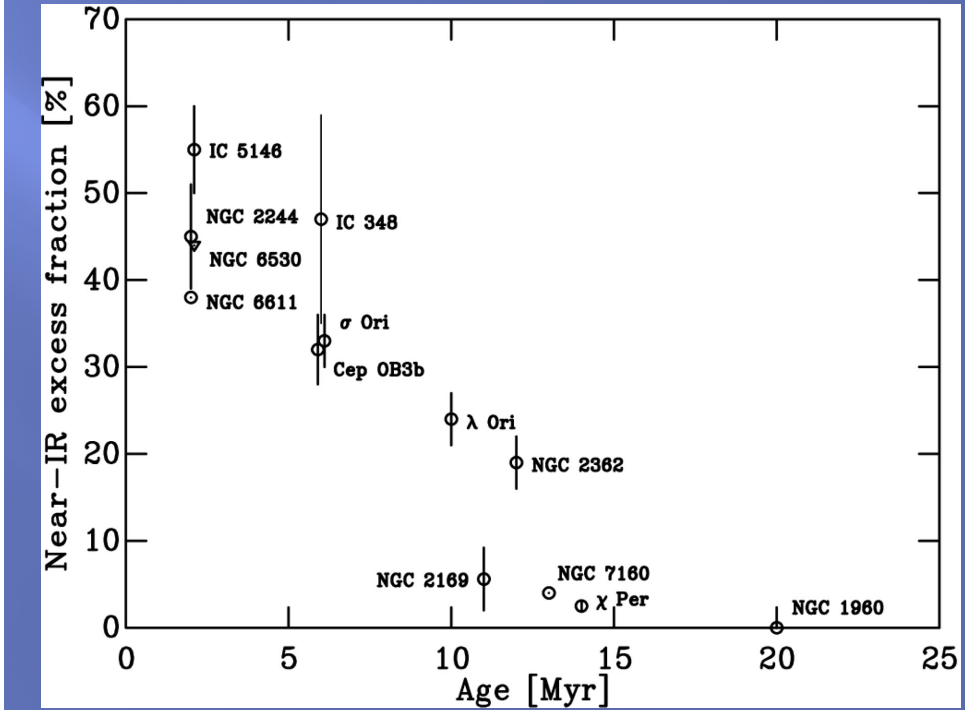
Disks dispersal timescale

Most *[Lada & Lada 2003]*/some *[Krujessen 2012]* of stars in our Galaxy form in clusters. Observational clues in disks dispersal timescale is provided by the decline of the fraction of cluster members with disks with the age of the parental cluster.





[i.e. Haish+ 2001, Hernandez+ 2007, Mamajek+ 2009, Bell+ 2013 Ribas+ 2015]

Environment feedback on disks evolution

Most of stellar clusters do not survive longer than 10 Myrs ***[Lada & Lada 2003].***
This means that typically protoplanetary disks which form in clusters evolve while the central star is still associated with the parental cluster, which can affect disks evolution.

Feedback from massive stars
($M > 7\,M_{\odot}$):

- **Externally induced disks photoevaporation**
- **Triggering of star formation**
- **Dissipation of protostellar envelopes**
- **Supernovae explosions and chemical enrichment**

Feedback from other cluster members

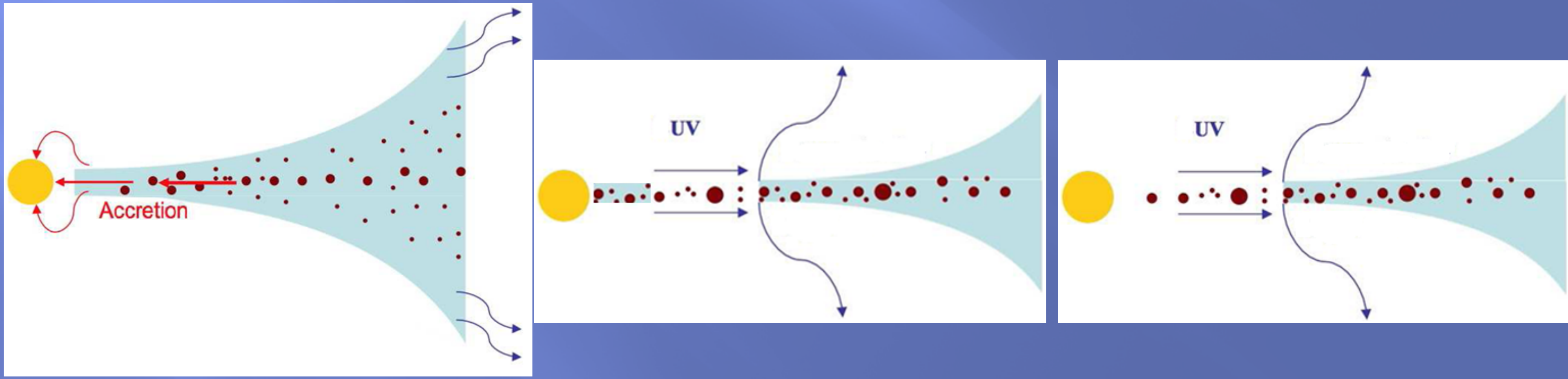
- **Close encounters and gravitational interaction**

DISKS PHOTOEVAPORATION

Disks photoevaporation

- **The gas in the disk is heated by incident FUV (6 eV < hv <13.6 eV, ~3000K), and EUV photons (hv > 13.6 eV , ~10^4K), that ionize and dissociate H_2 molecules. A photoevaporating flow of gas from the disk is created by the intense thermal pressure.**

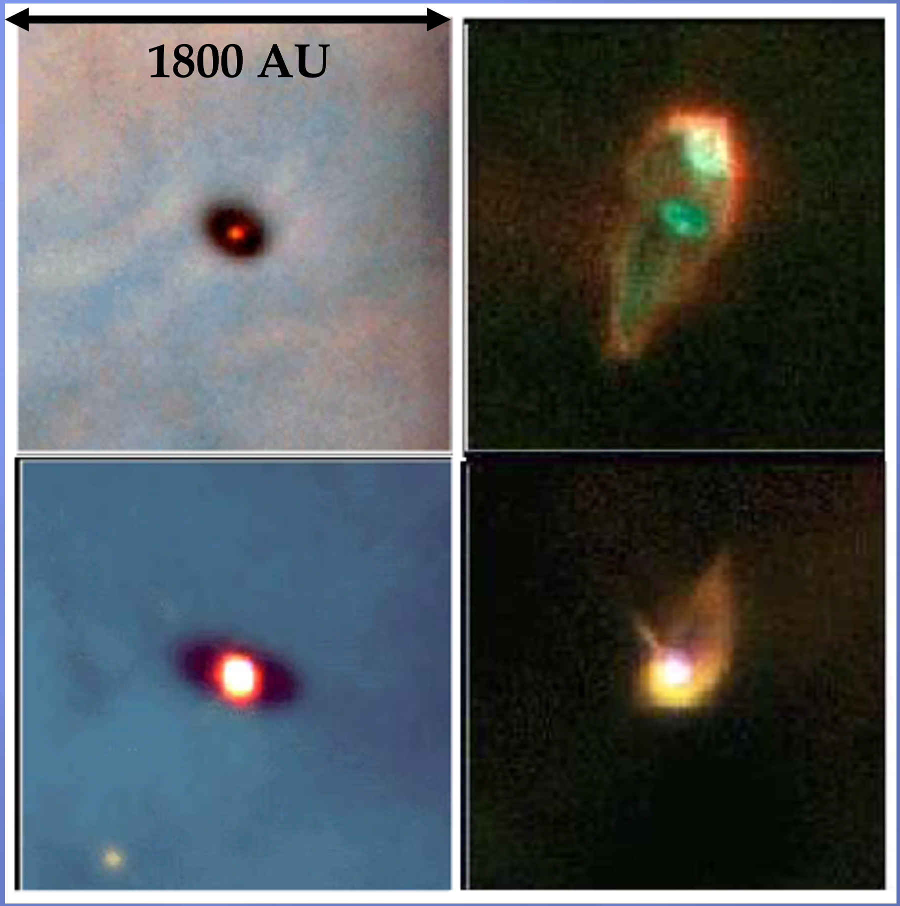
- **Together with viscous accretion, photoevaporation is proposed as the main mechanism for disks dispersal.**



Bally & Scoville 1982; *Johnstone*+. 1998, *Hollenbach*+. 1990, 1994, 2000; *Clarke*+ 2001, 2011, *Alexander*+, 2006, 2014; *Dullemond*+ 2007; *Ercolano*+ 2008, 2009, 2011; *Gorti & Hollenbach* 2009; *Armitage* 2011; *Owen et al.* 2012; *Koepferl*+ 2013

Can photoevaporation be induced by nearby O stars?

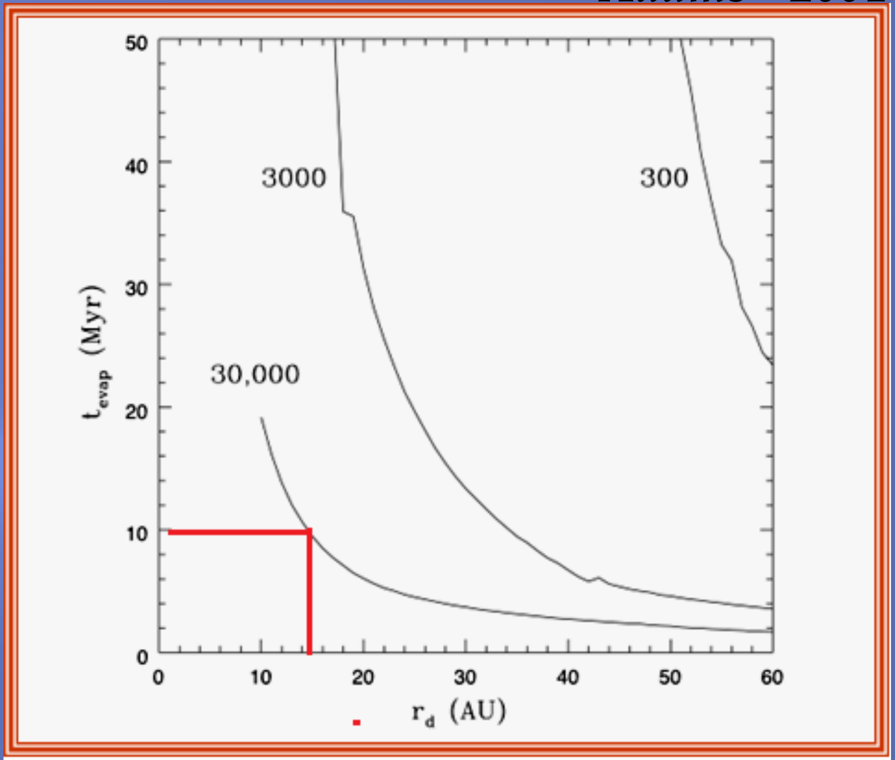
..it looks like the answer is yes:



HST observations of proplyds in the Orion Nebula Cluster

[O'dell & Wong 1996; Bally et al. 2000]

Adams+ 2004



Dissipation timescales for a 0.01 $M_\odot$ disk (M_{star}= 1 $M_\odot$) illuminated by FUV (in units of G_0).

In EUV regime disks closer to 0.5 pc to O stars can be dissipated in <10^6 yrs *[Johnstone+ 1998]*

Photoevaporation in clusters

In Low Mass clusters no feedback is expected. In fact, in IC 1795 *[Roccatagliata+ 2011]* **and IC 1396** *[Barentsen+ 2011]* **the disk fraction is constant across the clusters.**

In Intermediate Massive clusters a 10%-15% decline of disk fraction ONLY in the core of the cluster is observed in NGC 6611 *[Guarcello+ 2007, 2009, 2010]*, **Pismis 24** *[Fang+2012]*; **NGC 2244** *[Balog+ 2007]*; **NGC 6231** *[Damiani+ 2016]*

Disks destruction by photoevaporation in Trapezium-like environments is also proved by N-body simulations *[Scally & Clarke 2001]* **and ALMA observations [σ Orionis,** *Ansdell+ 2017***]**

No feedback is observed in 20 clusters included in the Mystix survey *[Richert et al. 2015]*

MOST OF THE STAR FORMING ENVIRONMENTS IN OUR GALAXY ARE SAFE FOR DISKS EVOLUTION

CLOSE ENCOUNTERS

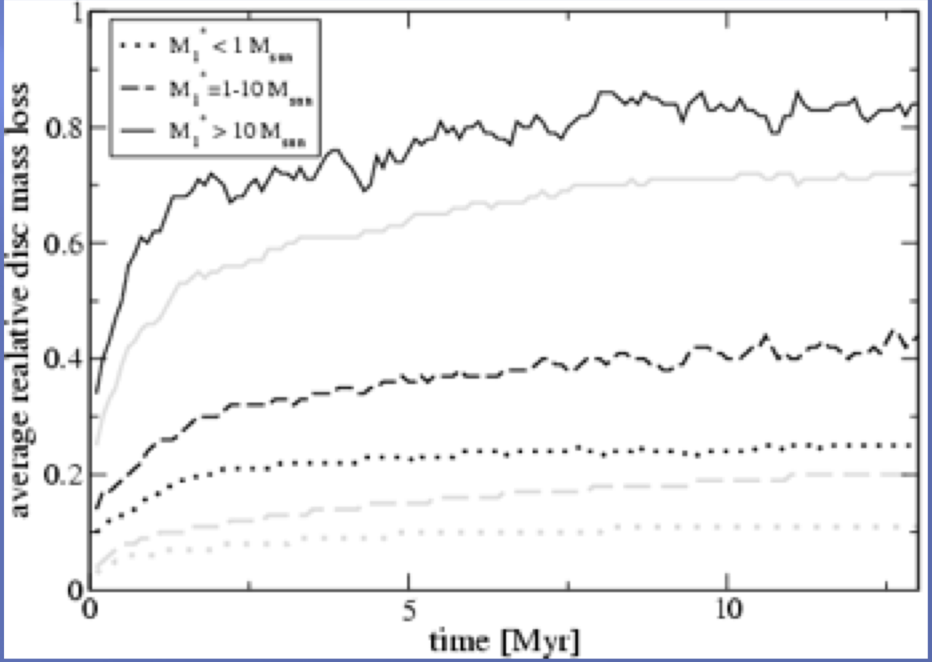
Close encounters

During the dynamical evolution of clusters, stars can get very close to each other.

It has been proposed that close encounter between a disk-bearing star and another star can have serious consequences on disk evolution *[i.e.: Clarke & Pringle 1993, Tamura+ 1998, Zapatero-Osorio+ 2000, Lucas & Roche 2000, Pfalzner+ 2005, 2006, Thies+ 2005, Adams+ 2006]*. **For instance:**

👍 **In Trapezium-like clusters, in 10 Myrs disks can loose between 80% and 30% of their initial mass by close encounters** *[Pfalzner+ 2006]*

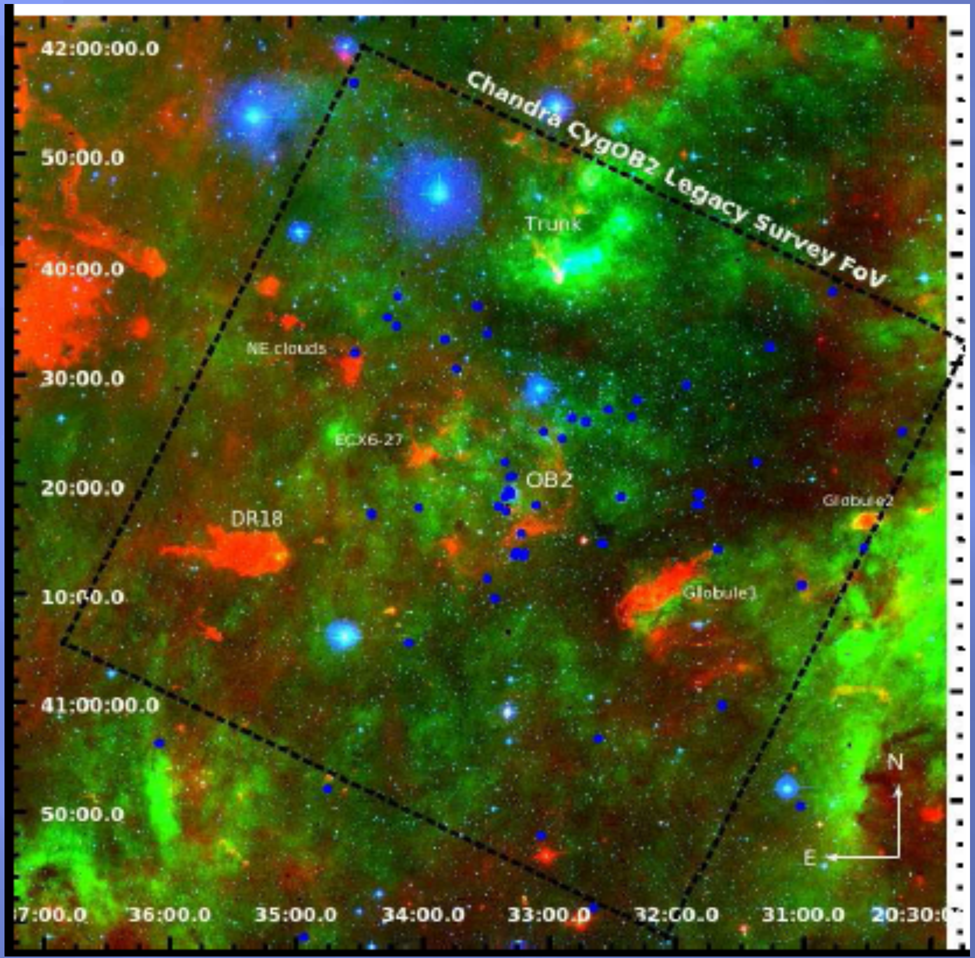
👎 **Recent study indicate that distant encounter do not have impact on angular momentum loss on disks in clusters** *[Winter+ 2018]*



Fraction of mass lost from disks in stars with different masses, in a Trapezium-like (black) and Orion-like(grey) cluster

CYGNUS OB2

Cygnus OB2



Combined r (blue); Hα (green); 8.0µm (red)

- **1.4kpc from the Sun** ***[Rygl+2012]*****; the next massive association (the Carina Nebula) is more than 1.5 times more distant.**
- **Identified massive stars:**
  - **52 O stars (•)**
  - **3 Wolf – Rayet stars**
  - **114 B stars**

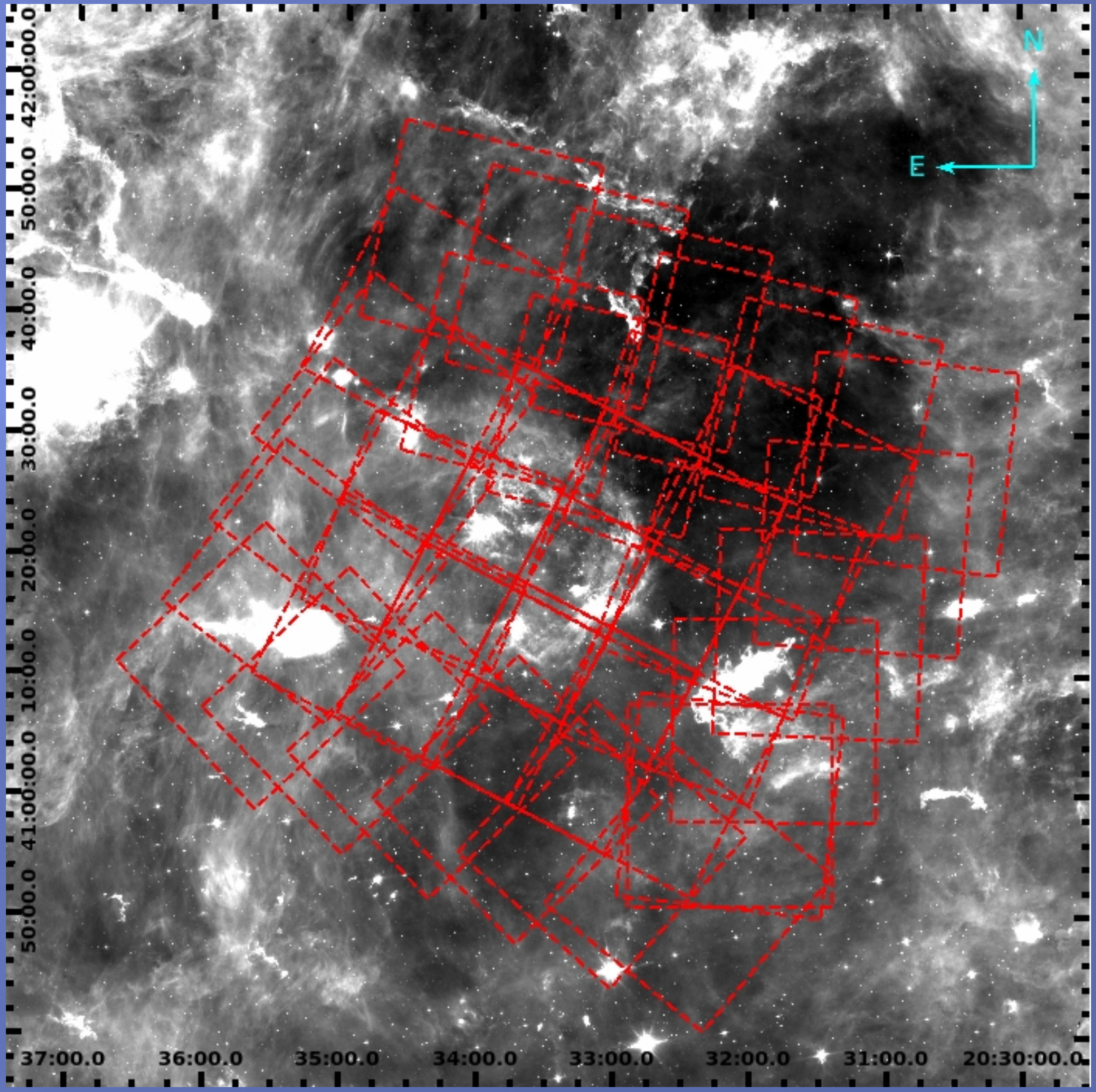
Among which two O3 stars, a candidate BHG, and various B supergiant ***[Wright+ 2015]***

- **The unidentified B population is larger** ***[Knodlseder 2000]***
- **Thousands of PMS stars 3-5 Myrs old** ***[i.e.: Wright & Drake 2009]***

CygOB2 is the best target in our Galaxy to study large scale star formation in presence of massive stars

The Chandra Cygnus OB2 Legacy Project

- **1.08 Msec Chandra/ACIS-I observation.** *[Drake+ 2016]*
- **36 pointings (30 ksec each) designed to have constant sensitivity in the central region.** *[Wright+ 2015]*
- **Estimated completeness 90% at 1 solar mass in the center** *[Wright+ 2015]*
- **X-ray catalog combined with deep optical and IR data** *[Guarcello+ 2015]*

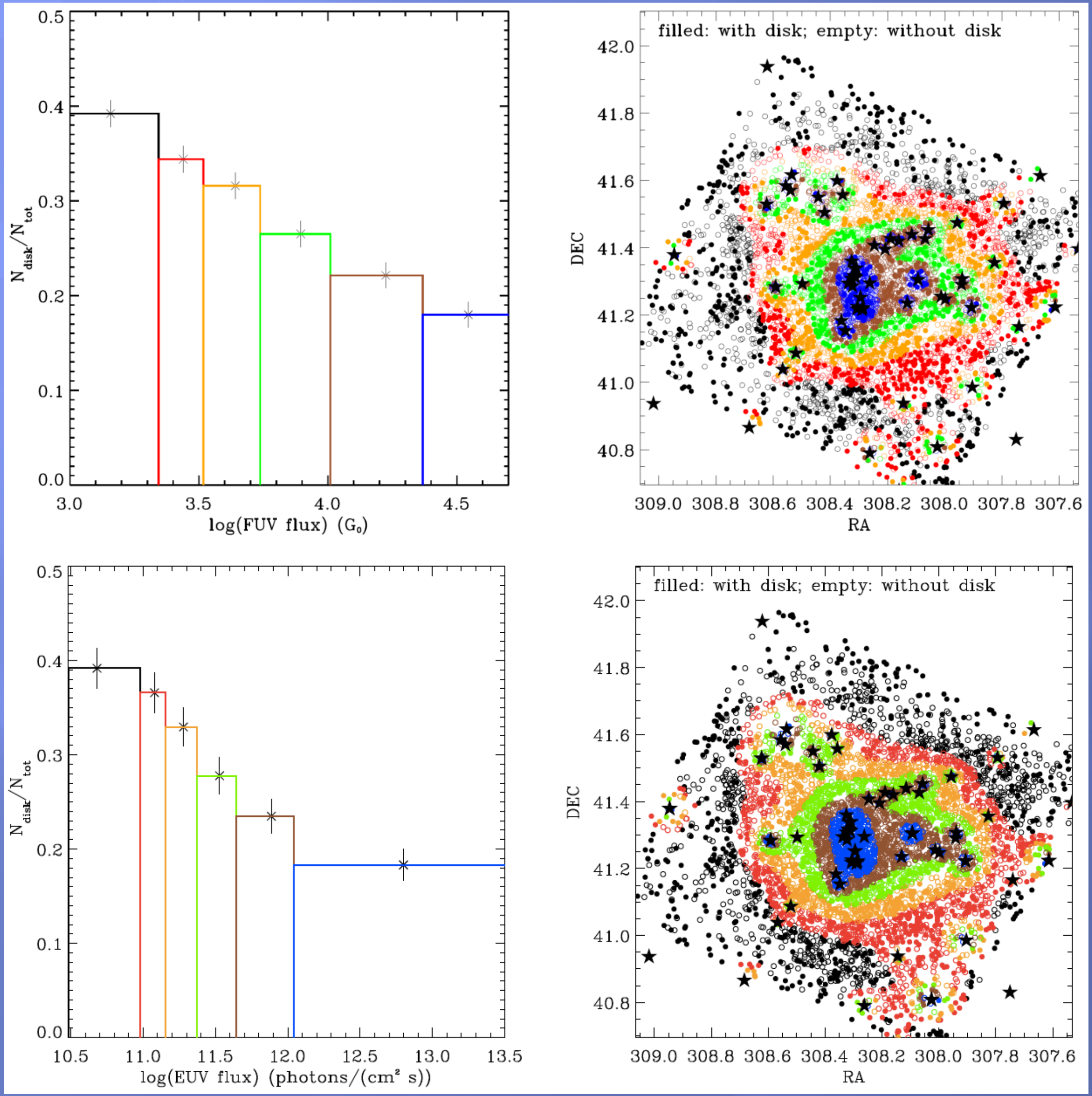


[8.0] image around CygOB2 with overplotted the survey observations

Membership and O-WR stars

- **7924 X-ray sources have been detected and validated** *[Wright+ 2014]*
- **6563 X-ray sources are classified as members using a Naïve Bayes estimate of probability of being member or contaminant (4246 candidate class III sources)** *[Kashyap+ 2018, Guarcello+2014]*
- **1843 stars with disks selected from optical and infrared photometry (439 X-ray sources)** *[Guarcello+ 2013]*
- **FUV and EUV fluxes emitted by O and WR stars are calculated using published tables** *[Parravano+ 2003, Martins+ 2005]*, **and projected across the field**
- **The disk fraction is calculated across the field and its correlation with local FUV field, EUV field, and stellar density studied**

Disk fraction vs. UV flux field



Disk fraction is observed to decline from ~40% to ≤ 20% as a function of local FUV and EUV fluxes

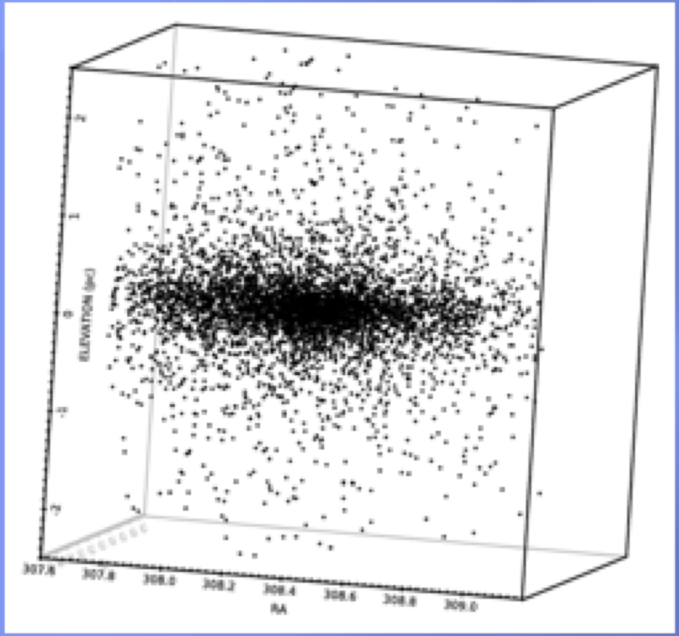
Possible Bias explored

- Inside out sequence of star formation
- Decrease of sensitivity in OIR images around massive stars
- 2D projection effect

Results

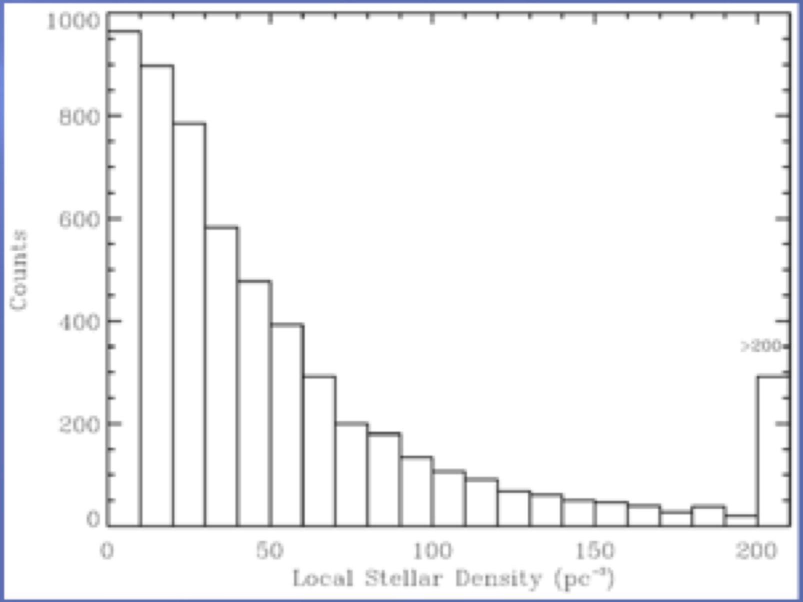
- Age difference of ~3 Myrs inner region vs. outskirt required to explain the DF decline. Only ≤1 Myr observed.
- The decline of DF is observed selecting members with J< 17, J< 16, J< 15; M> 0.4 $M_{\odot}$, M> 0.7 $M_{\odot}$, Fx >25% and 50% quantiles Fx distribution.
- Performed 5000 simulations of the 3D morphology of the association randomly defining the inclination of the branches connecting stars in MSTs. The decline of DF is always observed

Photoevaporation vs. close encounters



In the 5000 simulations, cubic stellar density is calculated from simulated 3D configurations of the association using equation defined for density particles in SPH simulations *[Whitworth+ 1995]*

Only about 15% of the members are surrounded by a local stellar density > 100 stars/pc^3, corresponding to about 1% chances of close encounters in 1 Myr *[Clarke & Pringle 1991]*



In Cygnus OB2 stellar density is typically low and photoevaporation dominates the feedback over close encounters

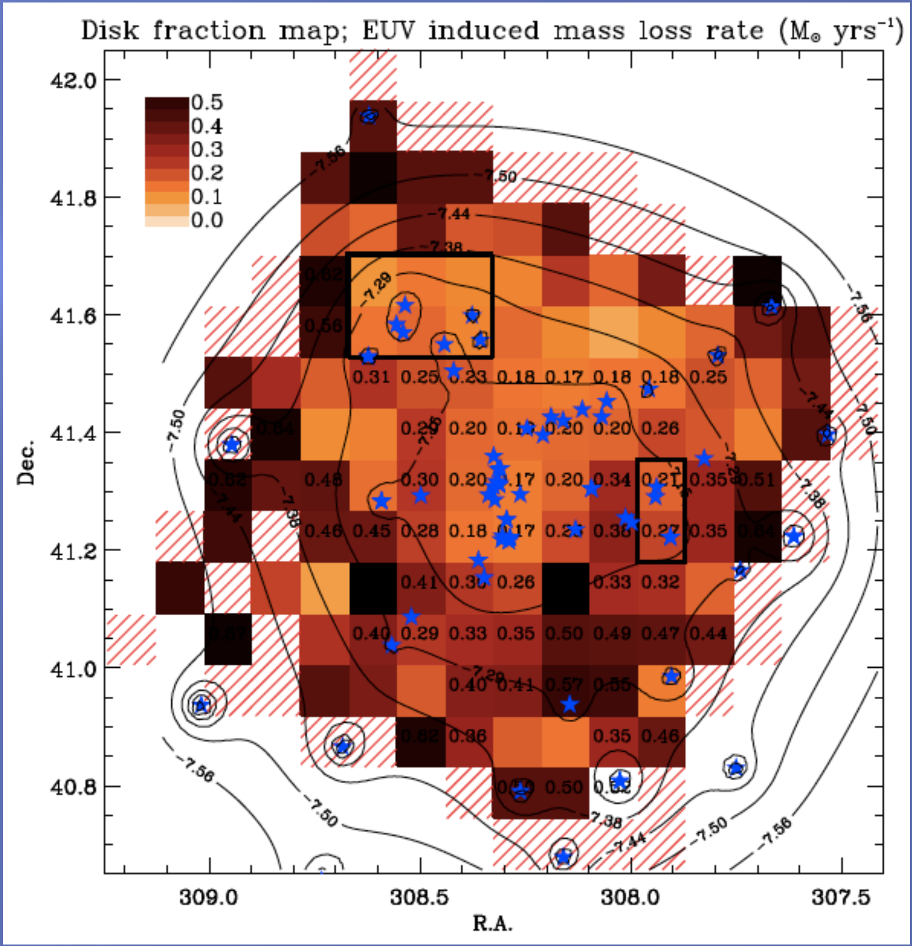
Mass loss rate induced by EUV radiation

EUV field calculated across the field and converted into Ṁ using:

$$\dot{M} \approx 9 \times 10^{-8} \left(\frac{L_{EUV}}{10^{49}\,s^{-1}} \right)^{1/2} \left(\frac{10^{17}\,cm}{d} \right) \left(\frac{r_d}{30\,AU} \right)^{3/2}$$

Adams+ 2010

The resulting Ṁ ranges from 1.5×10^{-8} $M_\odot$/yr to 3.9×10^{-7} $M_\odot$/yr.



This mass loss results in a total dissipation of a 0.05 $M_\odot$ disk in 3.3 and 0.1 Myrs, respectively .

For comparison, such mass loss rates are induced by Θ^1 Ori within 0.44 pc.

The O-WR population of CygOB2 really creates a hostile environment for disks, so.. .

Why do we still observe disks?

What shields the disks from EUV radiation?

- The equation for $\dot{M}$ does not account for the attenuation of EUV photons by the intracluster residual material

- To have disk lifetime larger by a factor 5 → F_{EUV} must decrease by a factor 25 → a similar extinction can be achieved with Av being about 1 for FUV and 1.4 for EUV *[using Cardelli+ 1989]* both corresponding to realistic density particles within the association

- Cygnus OB2 is almost clear of gas *[Schneider+ 2006]* but residual gas still present *[Drew+ 2005]* and significant dust in the outskirt *[Guarcello+ 2013]*

- Hydrogen column density (both Cygnus Rift and intra-association) larger than 10^{21} atoms/cm^2*[Schneider+ 2016],* large enough to be opaque to EUV radiation.

Conclusions

- Environments can impact disks evolution by externally induced disks photoevaporation and close encounters. This feedback is not important in most of the star forming environments in our Galaxy

- Cygnus OB2 is the closest massive association to our Sun, being the best target to study star formation in presence of massive stars.

- In CygOB2, disk fraction is observed to decrease as function of the local FUV and EUV fields.

- Stellar densities are not high enough to result in significant disks destruction by close encounters.

- Mass loss rate by EUV radiation is high enough to destroy disks in few Myrs across the association. Disks can survive only thanks to the attenuation of EUV radiation by intracluster material.