Gaia view of low-mass star formation

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The evolution of protoplanetary disks and their typical lifetime

Fraction of stars with optically thick disk

Age of the region [Myr]

$\tau_{\text{acc}} = 2.3$ Myr

$\tau_{\text{dust}} = 3.0$ Myr

(Fedele et al. 2010, Haisch et al. 2001, Hernandez et al. 2007, Bell et al. 2013)

(Adapted from Andre 2002)
Planets form in EVOLVING protoplanetary disks

(Thommes et al. 2008)
What is the driver of the evolution of protoplanetary disks?

**Viscous Evolution | Disk Winds**

- Turbulence
- Magnetic fields
- Dead zone
- ~100 au
- ~0.1 au

**Internal Photoevaporation**

- UV/X-ray
- ~1 au

**Effects of Environment - Stellar Clusters**

- Dynamical interactions
- Massive star (O.B)

**External photoevaporation**

- e.g., Alexander et al. 2014
- e.g., Lynden-Bell & Pringle 1974; Hartmann et al. 1998
- e.g., Armitage et al. 2013, Bai et al. (2014, 2015, 2016), Gressel et al. 2015
- e.g., Clarke 2007, Anderson et al. (2013), Facchini et al. (2016)
- e.g., Pfalzner et al., 2005; Clarke et al., 1993, 2008; Adams 2010
- e.g., Clarke 2007, Anderson et al. (2013), Facchini et al. (2016)
1 Spectroscopy:
- Stellar properties
- Mass accretion rates
- Wind properties

2 mm-interferometry:
- Disk mass
- Disk morphology
- Surface density

3 IR-interferometry & spectroscopy:
- Inner disk morphology
- Inner disk composition

4 Astrometry:
- Distances
- Kinematic membership
- Dynamical properties

Credit: ESO/H.H. Heyer
mm-interferometry:
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Credit: ESO/H.H. Heyer
The Chamaeleon-Musca complex seen with Gaia DR1

One of the closest star forming complex with hundreds of young stellar objects, many surrounded by disks (e.g., Luhman et al. 2004, 2008) and still accreting (e.g., Manara et al. 2016a, 2017).

The distances to the various clouds are still under debate.

Only 8 known members of the Chamaeleon I cloud are included in the TGAS catalog, 4 in common with Hipparcos.

Chamaeleon I: TGAS vs Hipparcos distances

TGAS parallaxes suggest that Chamaeleon I is further away than assumed.

NB: all distances are from Astraatmadja & Bailer-Jones (2016), assuming an anisotropic prior

Whittet et al. 1997
Chamaeleon I: TGAS distance using known members

\[ \text{distance}_{\text{Chamaeleon I, members}} = 189 \pm 9 \pm 10 \text{ [pc]} \]
TGAS distance using reddening turn-on

See Whittet et al. 1987, 1997
TGAS distance using reddening turn-on

See Whittet et al. 1987, 1997
TGAS distance using reddening turn-on

See Whittet et al. 1987, 1997
Chamaeleon I: TGAS distance using reddening turn-on

\[ \text{distance}_{\text{Chamaeleon I, reddening}} = 181 \pm 10 \pm 10 \text{ [pc]} \]
Chamaeleon II: TGAS distance using reddening turn-on

\[ \text{distance}_{\text{Chamaeleon II, reddening}} = 181 \pm 10 \pm 10 \ [\text{pc}] \]
# The Chamaeleon region seen with Gaia DR1

<table>
<thead>
<tr>
<th>Name</th>
<th>Distance [pc]</th>
<th>Old Distance [pc]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamaeleon I</td>
<td>181 ± 10 ± 10</td>
<td>160±15</td>
</tr>
<tr>
<td>Chamaeleon II</td>
<td>181 ± 10 ± 10</td>
<td>178±18</td>
</tr>
<tr>
<td>Chamaeleon III</td>
<td>199 ± 15 ± 13</td>
<td>~140 ?</td>
</tr>
<tr>
<td>Musca</td>
<td>&lt; 600</td>
<td></td>
</tr>
</tbody>
</table>

Corradi et al. (1997) hypothesis
Interface of the Local and Loop I Bubbles

King et al. (1979) hypothesis
STAR FORMATION
IN THE Gaia ERA

Data release 2:
dynamical effects
Detection of young stellar objects from IR-excess

1. Limited coverage of IR surveys
2. Low sensitivity to small IR-excess (e.g., diskless stars)

Chamaeleon I, Luhman et al. 2008

Ercolano & Pascucci 2017
Sparse populations in young regions

See also:
- Taurus, Gomez de Castro et al. 2015
- Vela OB2, Sacco et al. 2015
- Orion, Sanchez et al. 2014
- 30 Dor, De Marchi et al. 2011
Sparse populations in young regions

ORIGIN:
• different star formation sites
• dynamical interactions

EFFECTS:
• are we missing many young stars? (e.g., Pfalzner et al. 2015)
• wrong disk lifetime estimates? (e.g., Armitage & Clarke 1997)
• can we use this population to study dynamical evolution? (e.g., Allison et al. 2012)

HOW CAN WE FIND THIS SPARSE POPULATION?
Maximum likelihood kinematic membership

Zari, Brown, Manara, de Bruijne (Leiden, ESA)

Astrometric observables
$(\alpha, \delta, \pi, \mu_\alpha, \mu_\delta + RV)$

Model for cluster stars
$x, y, z, v_x, v_y, v_z, \sigma_v$

Model for field stars
$x, y, z, v_x, v_y, v_z, \sigma_v$

Cluster+field likelihood function
MLE

Cluster members selection

Cluster-only likelihood function
MLE

Cluster kinematics + improved parallaxes

See an application in poster
D6 by Difeng Guo

Detailed description of the method: Lindegren et al. (2000), de Bruijne (1999)
Gaia as a tool to detect sparse populations

Chamaeleon I-like cluster
($N\star=400$, $t_{\text{sim}}=5$ Myr, $R=2$ pc, $\alpha_{\text{vir}}=0.4$, $f_{\text{bin}}=0.2$, $D=1.6$)

Time

0 Myr 3 Myr 5 Myr

Zari, Manara, Brown, de Bruijne, Jilkova
Gaia as a tool to detect sparse populations

Chamaeleon I-like cluster
\((N_\star=400, \ t_{\text{sim}}=5 \ \text{Myr}, \ R=2 \ \text{pc}, \ \alpha_{\text{vir}}=0.4, \ f_{\text{bin}}=0.2, \ D=1.6)\)

Simulate observation with Gaia (\(G, \ V-I, \ \alpha, \ \delta, \ \pi, \ \mu_\alpha, \ \mu_\delta\))

Zari, Manara, Brown, de Bruijne, Jilkova
Gaia and young clusters: kinematical modelling

Single population code: determining the cluster motion

Zari, Manara, Brown, de Bruijne
Gaia and young clusters: kinematical modelling

Sub-virial model of a star forming region (Parker et al. 2014)

Zari, Manara, Brown, de Bruijne, Parker
Cluster+field code: assigning membership to cluster stars

>95% of cluster members recovered, <5% false positive
TAKE HOME

1. Gaia DR1: Refined distance and 3D structure of the Chamaeleon region

2. Gaia DR2: Kinematic-based membership in nearby young stellar clusters to test disk evolution

Carlo Felice Manara (ESA/ESTEC)