Insights into Young Star Cluster Astrophysics based on Chandra Observations

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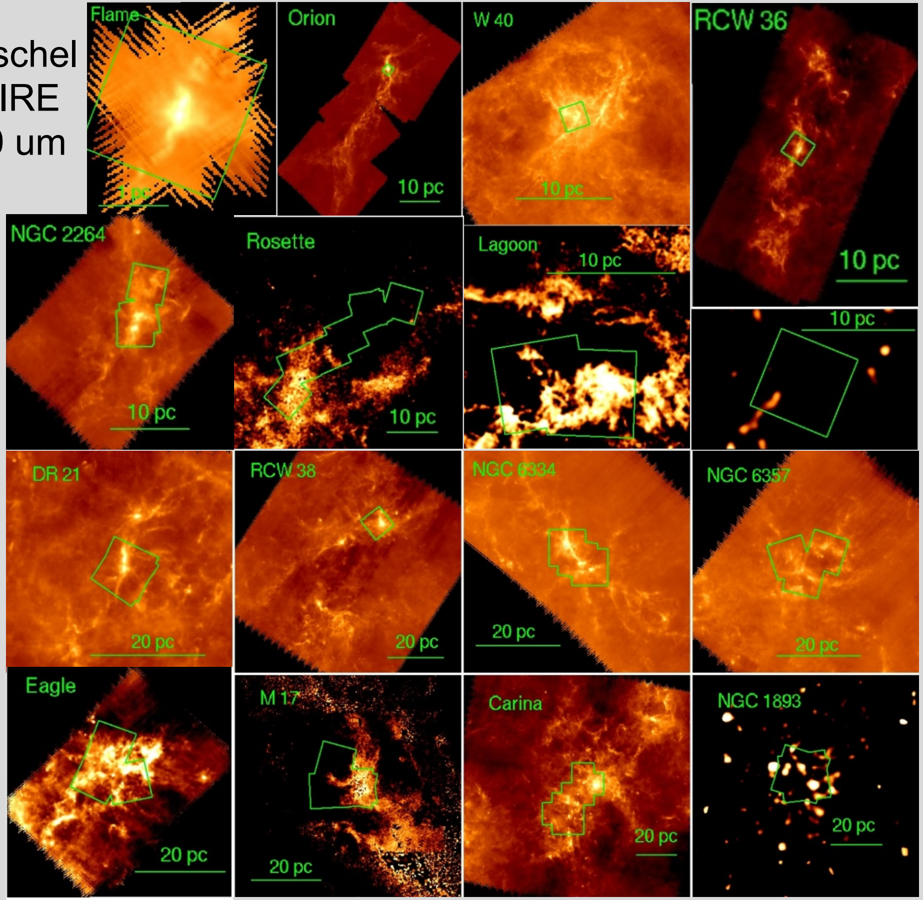
MYStIX & SFiNCs and Underlying Molecular Clouds

Massive Young Star-Forming Complex Study in Infrared and X-ray & Star Formation in Nearby Clouds

Herschel SPIRE 500 um



MYStIX (Feigelson et al. 2013, ApJS, 209, 26) and SFiNCs (Getman et al. 2017, ApJS, 229, 28) projects involve Chandra+2MASS+UKIDSS/UKIRT+ Spitzer & Gaia data for >40 star forming regions (D < 3 kpc).

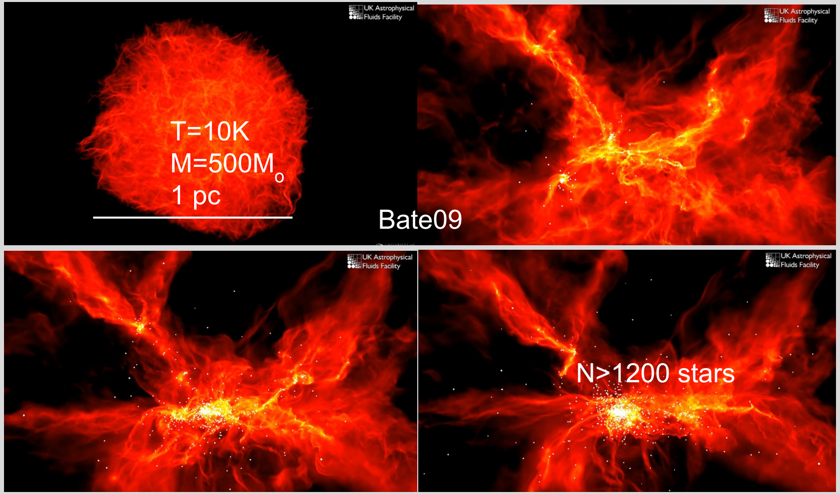
Topics in this talk: clustered star formation & early cluster dynamics.

Molecular clouds have diverse morphologies; filaments, shells (bubbles) are ubiquitous.

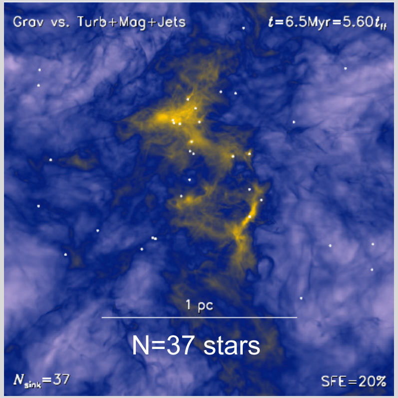
Theory: Monolithic and Hierarchical Star Formation

Gravity alone: monolithic; t_{sf}<1Myr
(Elmegreen 2000, AJ, 530, 277)

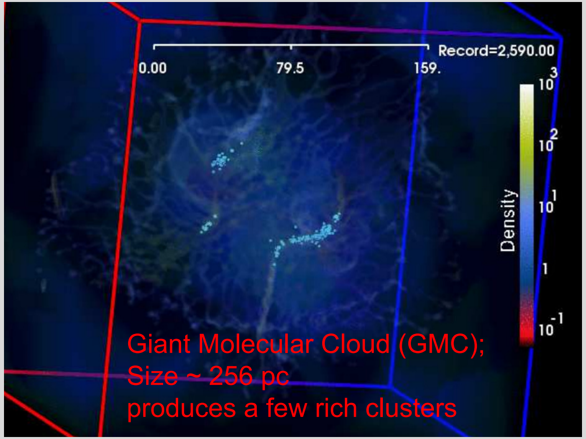
Gravity Turbulence: hierarchical; t_{sf}<1Myr
(Bate 2009, MNRAS, 392,590)



Gravity Turb Mag Jets: t_{sf}>1Myr (Federrath, 2015, MNRAS, 450, 4035)



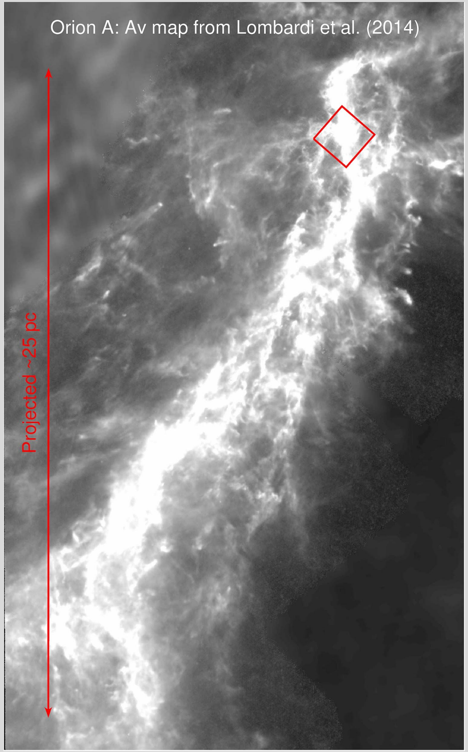
Global Hierarchical Gravitational Collapse (GHC) No global Turb/Mag Support
(Vazquez-Semadeni et al. 2017, 2019):

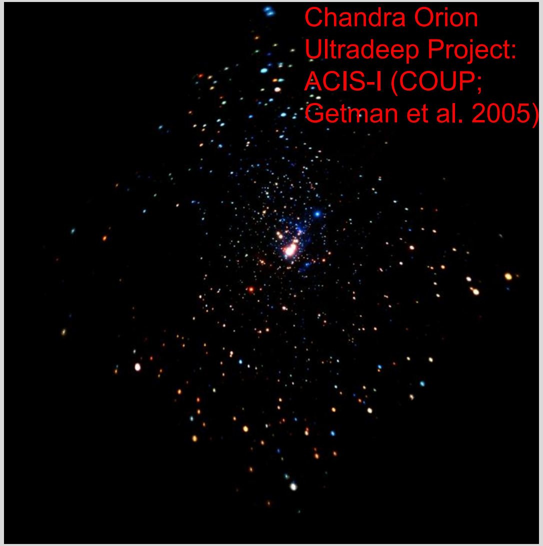


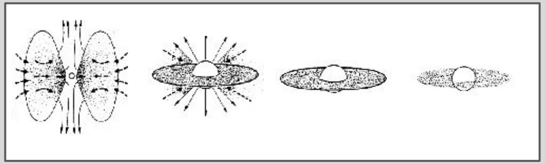
* GMC is produced by colliding Warm Neutral Medium streams on scales of >100 pc;
* Non-homologous, non-isotropic collapse of GMC slab naturally makes filaments (dt~10 Myr);
* Small stellar groups form non-coevally across filaments & fall towards central hub(s);
* Massive stars form last; radiative feedback destroys the central clump(s);
* Older stars inside in-falling groups have higher velocity dispersions to appear further away from the cluster center(s) leading to **cluster core-halo age gradients** (dt ~1 Myr/pc).

X-ray/IR/Gaia data reveal core-halo age gradients and global star-cloud contractions followed by cluster expansions =>

Source Extraction and Classification



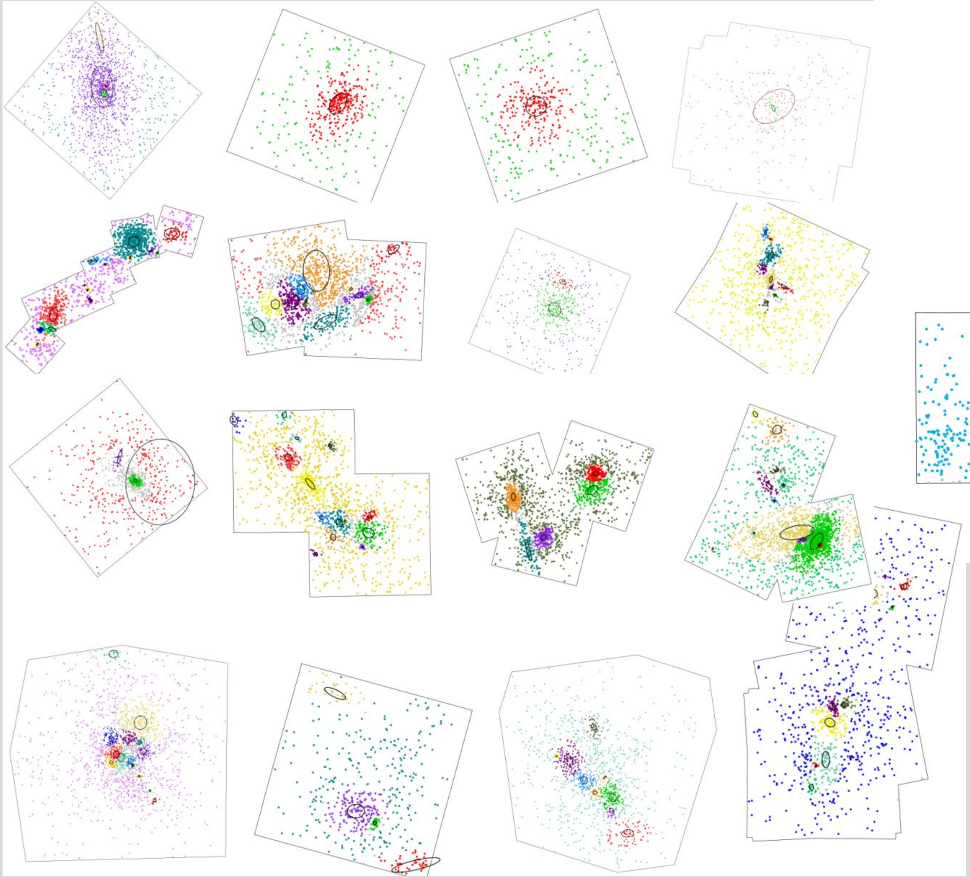


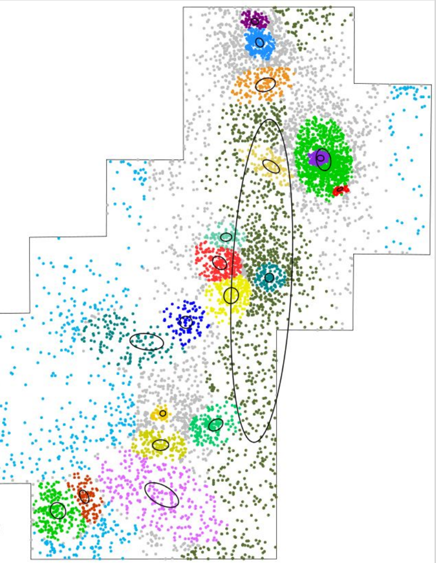


Acis-Extract (Broos, Townsley, et al. 2010, ApJ, 714, 1582) identifies and characterizes >100,000 X-ray point sources across MYStIX, and SFiNCs Chandra fields.

About >30,000 X-ray-selected + >10,000 IR-selected young stellar objects are identified (Broos et al. 2013, ApJS, 209, 32; Povich et al. 2013, ApJS, 209, 31; Getman et al. 2017, ApJS, 229, 28).

Identification of Stellar SubClusters

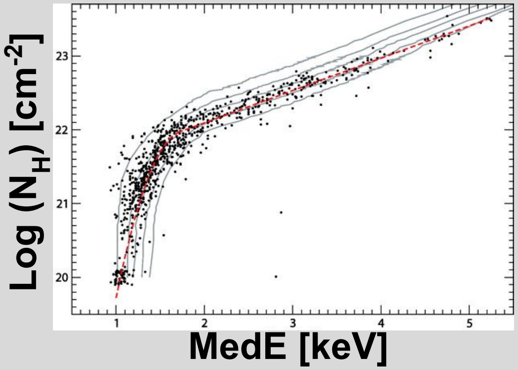




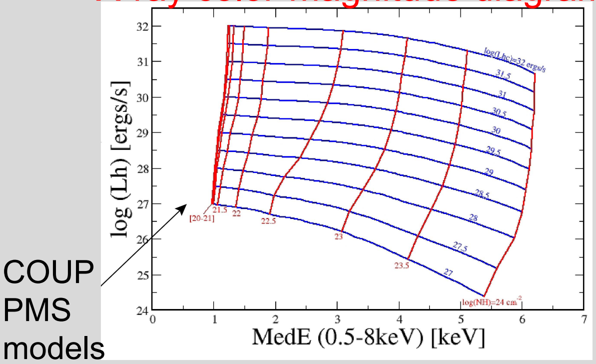
Multi-cluster fits with models of isothermal ellipsoids yield ~200 MYStIX/SFiNCs subclusters (Kuhn et al. 2014, ApJ, 787, 107; Getman et al. 2018, MNRAS, 477, 298).

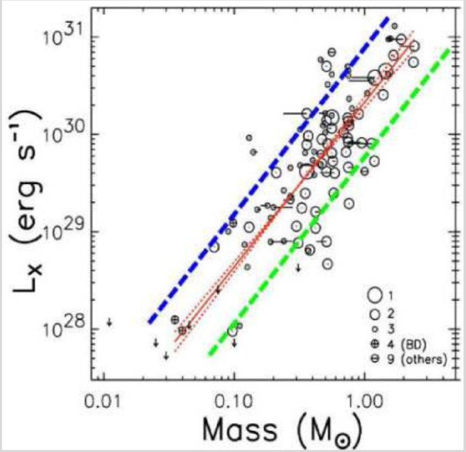
Inferred cluster properties: position of the center, core radius, ellipticity, ellipse orientation, central apparent stellar surface density.

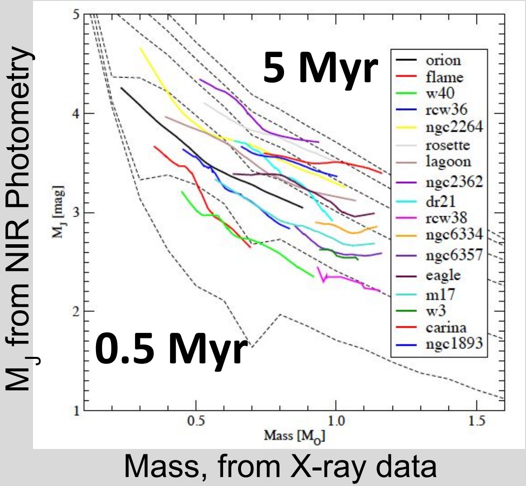
Stellar Absorptions, X-ray Luminosities, & Cluster Ages



X-ray color-magnitude diagram







Observed X-ray median energy is a surrogate for absorption and plasma temperature (Feigelson et al. 2005, ApJS, 160, 379).

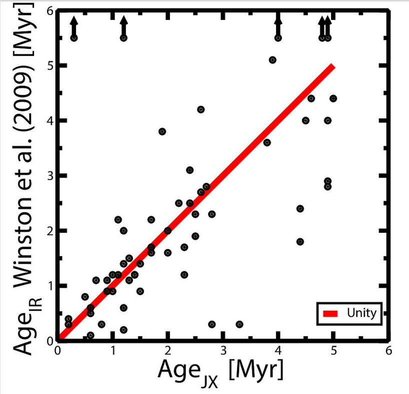
Stellar X-ray luminosities are derived using the color-magnitude approach (Getman et al. 2010, ApJ, 708, 1760).

X-ray luminosity is a surrogate for stellar mass (Telleschi et al. 2007, A&A, 468, 425).

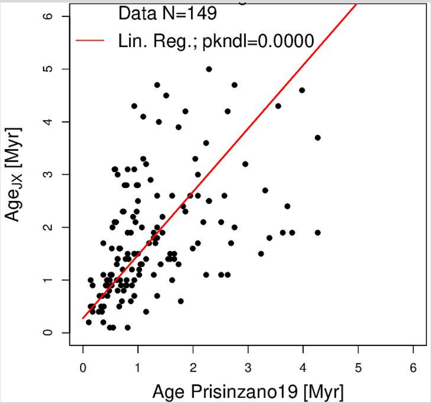
Cluster ages (Age_{JX}) are derived from the M_J-Mass diagram (analogue to HRD; Getman et al. 2014, ApJ, 787, 108).

Agreement with HRD Ages

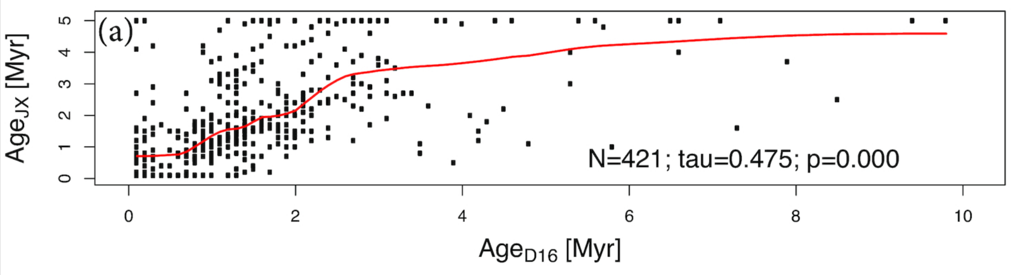
NGC 1333 & Serpens Main



Lagoon Nebula



Orion Nebula



Age$_{JX}$s are in good agreement with traditional HRD ages from near-IR and optical spectroscopy+photometry (Winston et al. 2009, AJ, 137, 4777; Da Rio et al. 2016, ApJ, 818, 59; Prisinzano et al. 2019, A&A, 623, 159).

Individual age estimates are highly uncertain and absolute ages are not known.

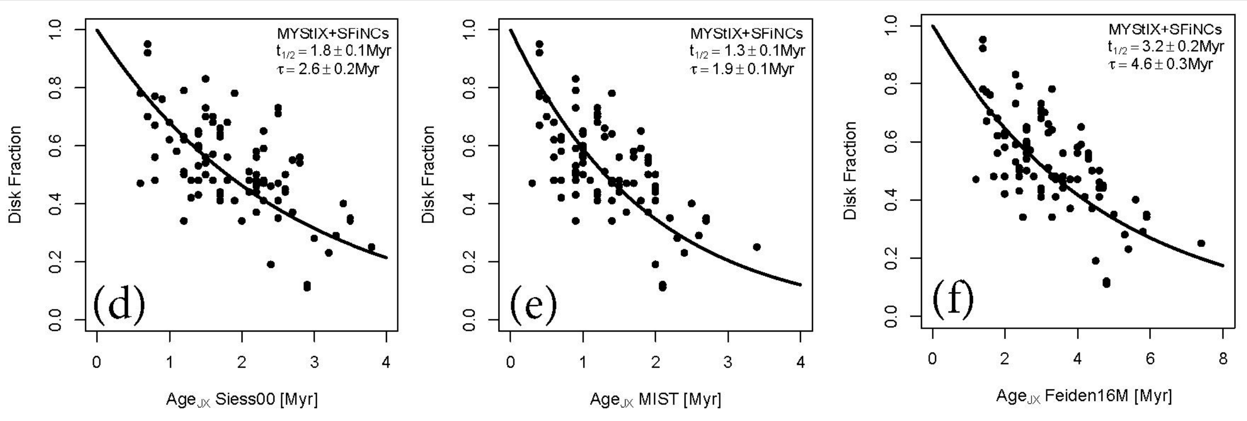
Homogeneous sets of median subcluster ages for MYStIX/SFiNCs are produced.

Consistency between Cluster Age$_{JX}$ and Disk Fraction

non-magnetic

magnetic

Disk Fraction

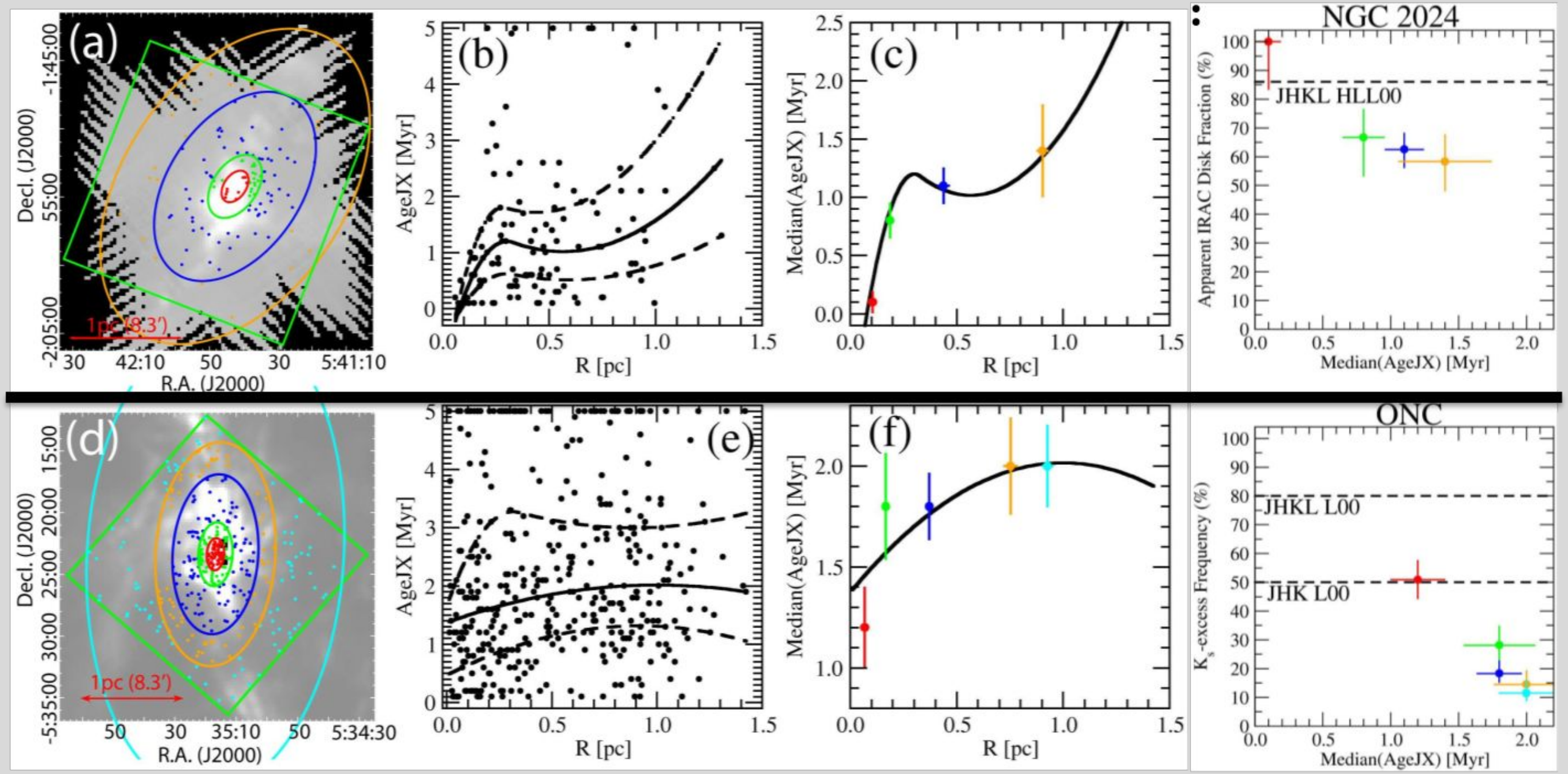


Age$_{JX}$

Disk longevity estimates are strongly affected by the choice of PMS evolutionary models: $t_{1/2}$~1.5Myr and $t_{1/2}$~3.5Myr for non-magnetic and magnetic models, respectively (Richert et al. 2018, MNRAS, 477, 5191).

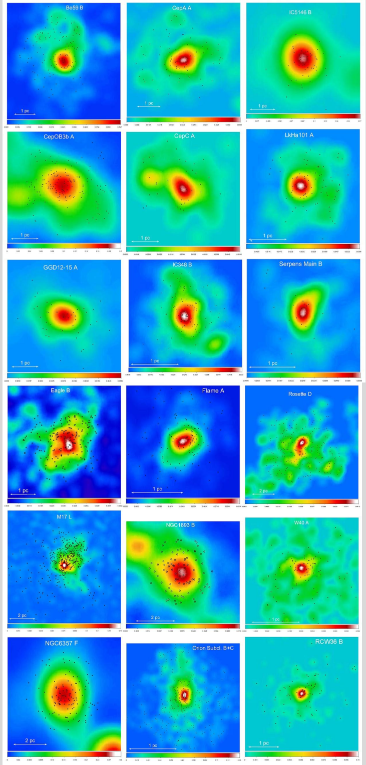
CORE-HALO Age Gradients in NGC 2024 and ONC (Getman et al. 2014, ApJ, 787, 109)

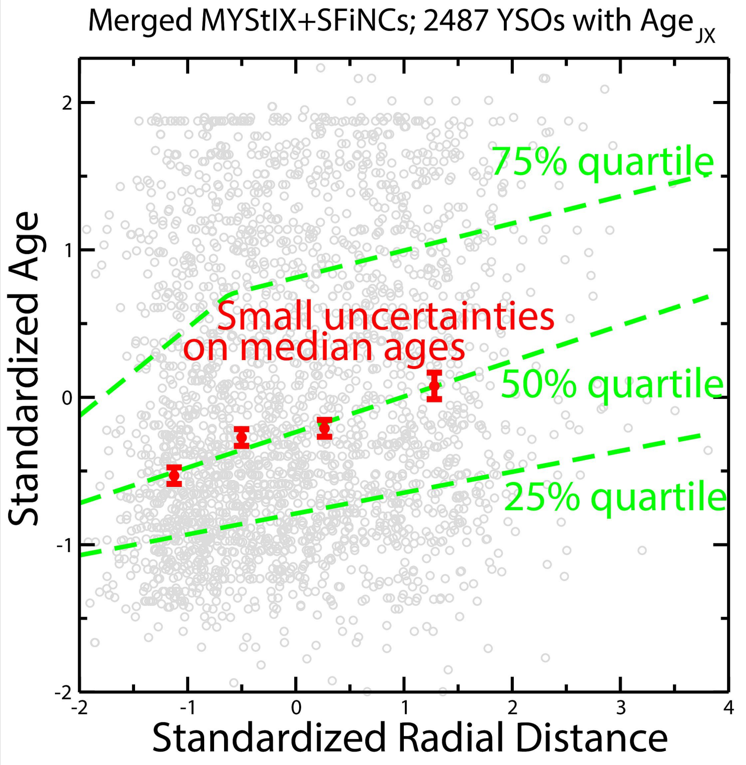
NGC 2024



ONC

Core-Halo Age Gradients in Numerous MYStIX/SFiNCs Clusters



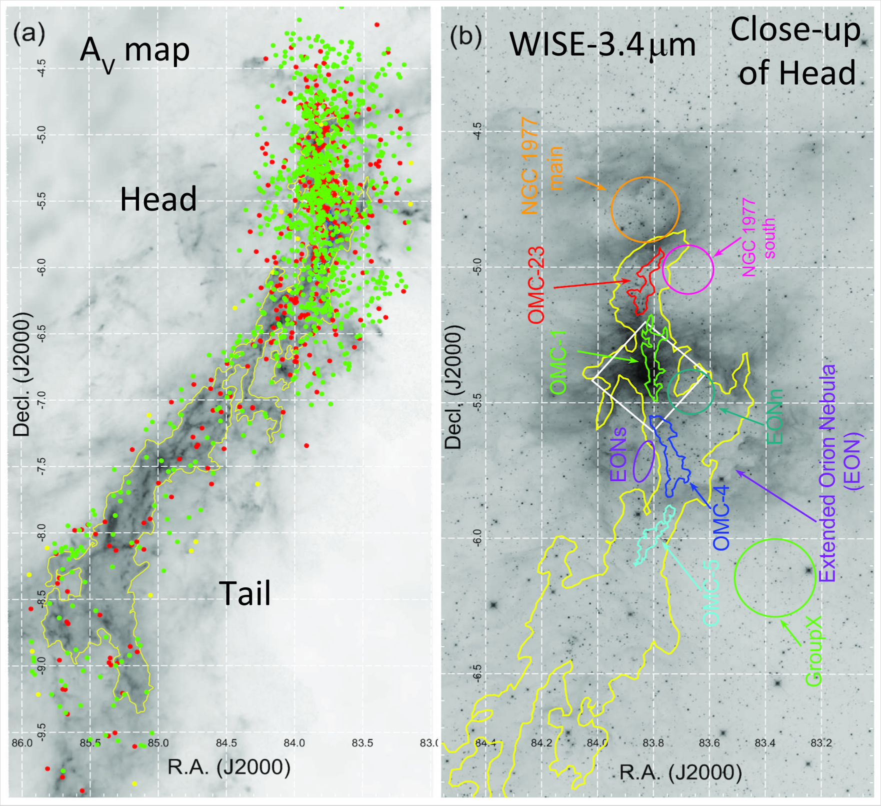


In isolated, rich, simple-morphology MYStIX/SFiNCs clusters, the cores have systematically younger ages than the halos.

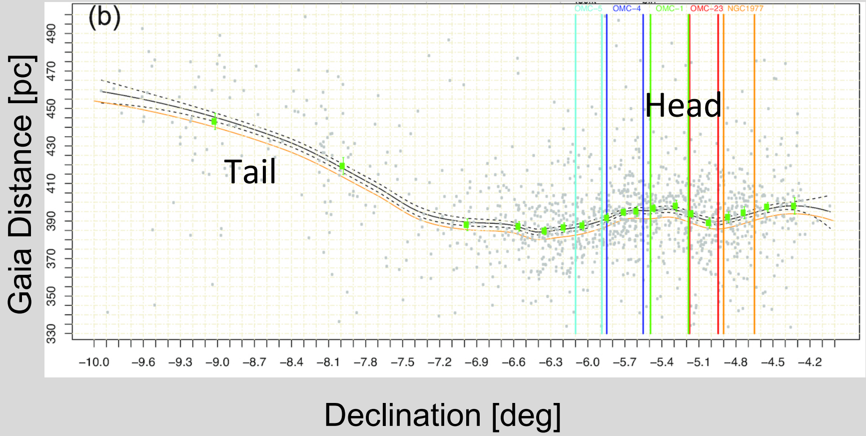
Observed gradient is ~1 Myr/pc (Getman et al. 2018,MNRAS, 476, 1213).

Requires combination of continued feeding of molecular material to give late star formation in core, plus dispersion of older stars during merging process (in support of GHC model!).

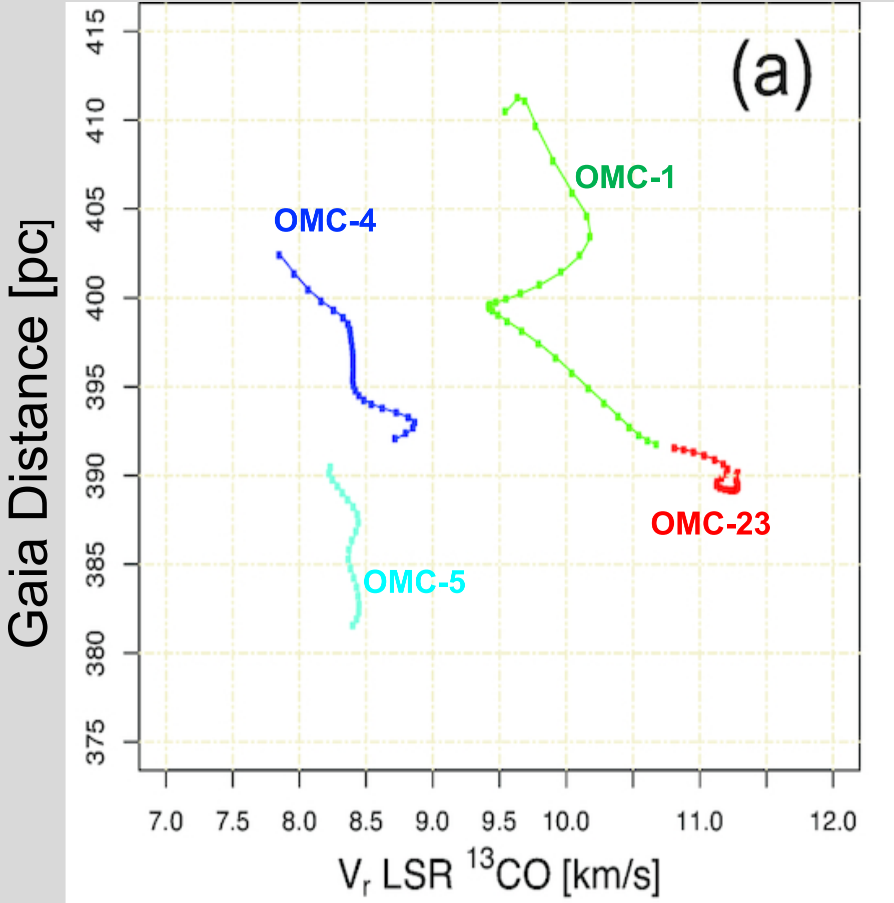
Gas-Star Contraction in Orion A



Using Gaia data and published ground-based star-cloud radial velocities (Getman et al. 2019, MNRAS, 488, 2977).



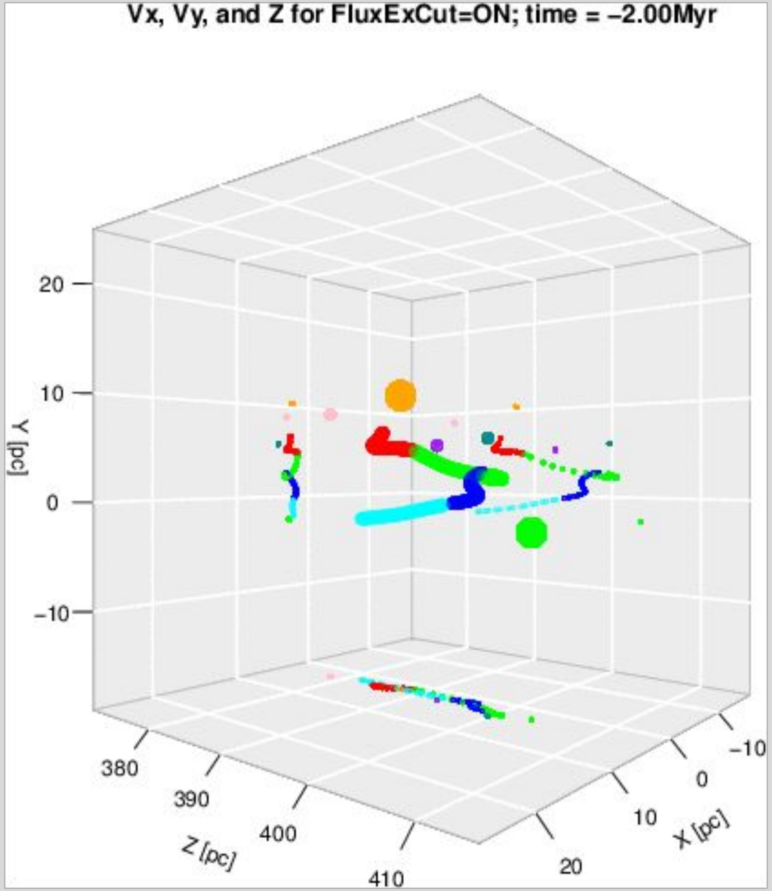
Global Gas Contraction in the Head of Orion A



More distant parts of the cloud move slower from the observer than closer parts of the cloud: **gas gravitational contractions.** Supports the GHC model.

Getman et al. 2019, MNRAS, 488, 2977

Star Contraction in the Head of Orion A

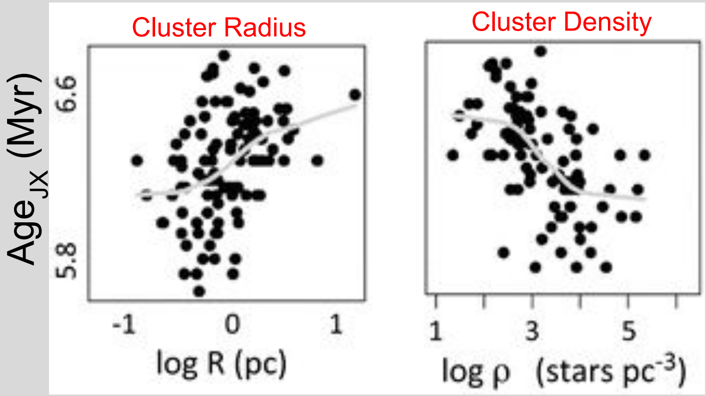


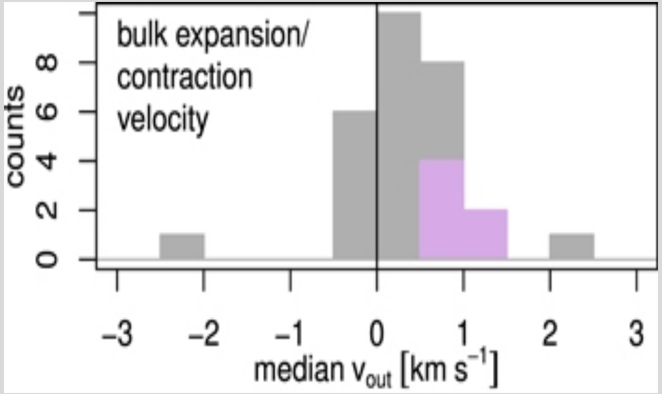
Runaway groups: NGC 1977, EON, GroupX.

Stars in the northern part of the Head (OMC-1/23) show tendency for a global contraction, in support of the GHC model.

Getman et al. 2019, MNRAS, 488, 2977

Cluster Expansion





Pre-Gaia evidence for cluster expansion from MYStIX & SFiNCs (Kuhn et al. 2015, ApJ, 812, 131; Getman et al. 2018, MNRAS, 477, 298).

Direct evidence for 2-D expansion of MYStIX & SFiNCs clusters from Gaia data (Kuhn et al. 2019, ApJ, 870, 32). Most clusters are probably unbound.

OB feedback removes molecular gas; weakening of gas gravitational potential causes cluster expansion.

Conclusions

MYStIX & SFiNCs core-halo age gradients and cluster/gas contraction measurements support the GHC model of hierarchical assembly of clusters from sub-clusters during filament infall, followed by cluster expansion to disperse stars into the Galaxy.