X-ray and IR Observations of Young Clusters

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With help from...

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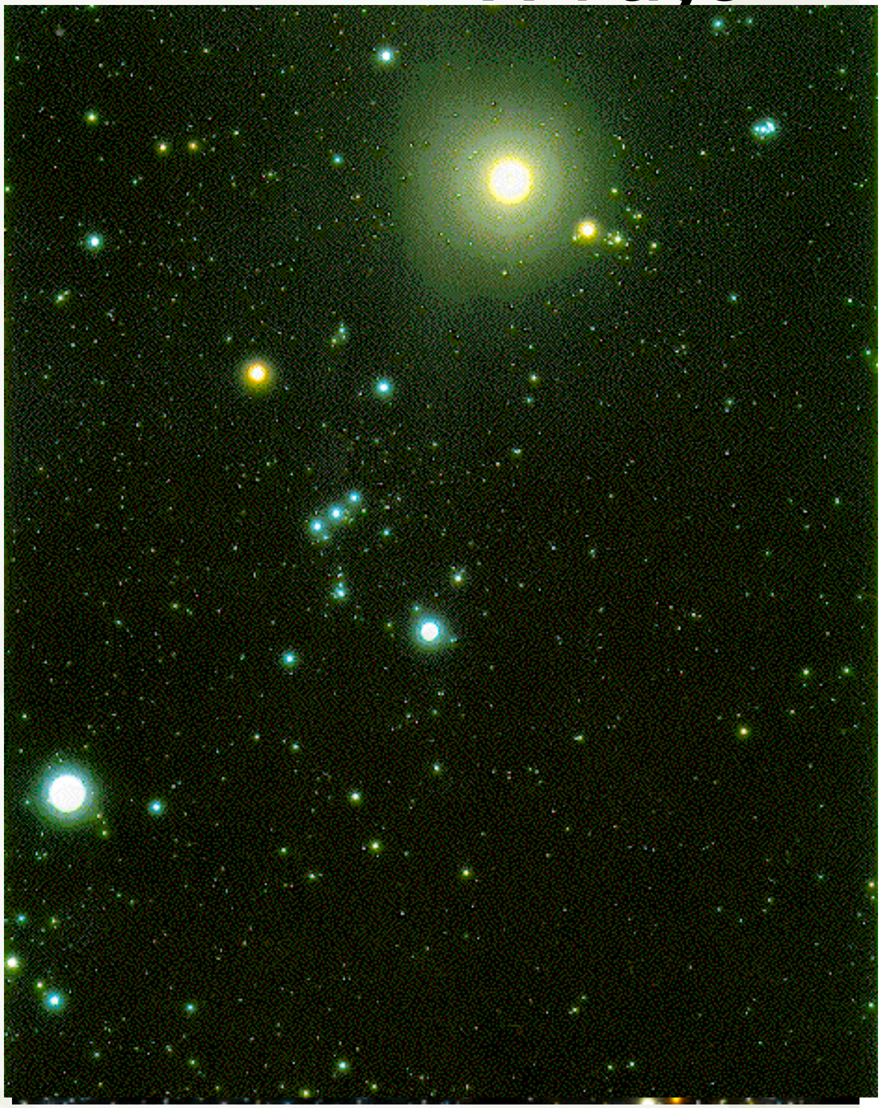
Why Bother Looking at Young Stars in X-rays

- Young stars are X-ray bright
  - HMS- High energy wind shocks?
  - LMS- Despite pedestrian 5000K, temperatures they have luminous hot coronae.
    - Insight into the interior workings of LMS.
- To identify young stars.
  - After stars lose their disks X-ray surveys are the only way to find young stellar objects
  - This has allowed us to understand the history of star formation in the galaxy.
- Direct observation of material accreting onto very young stars.
- X-rays are probably responsible for rapid heating and ionization of protoplanetary disks.



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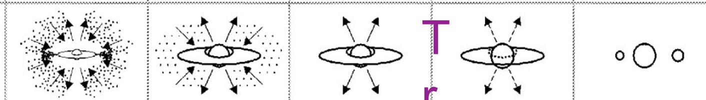
The program: Multiwavelength Studies of Nearby regions of Star Formation

PROPERTIES	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
SKETCH					
AGE (YEARS)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/INFRARED CLASS	Class 0	Class I	Class II	Class III	(Class III)
DISK	Yes	Thick	Thick	Thin or Non-existent	Possible Planetary System
X-RAY	?	Yes	Strong	Strong	Weak
THERMAL RADIO	Yes	Yes	Yes	No	No
NON-THERMAL RADIO	No	Yes	No ?	Yes	Yes

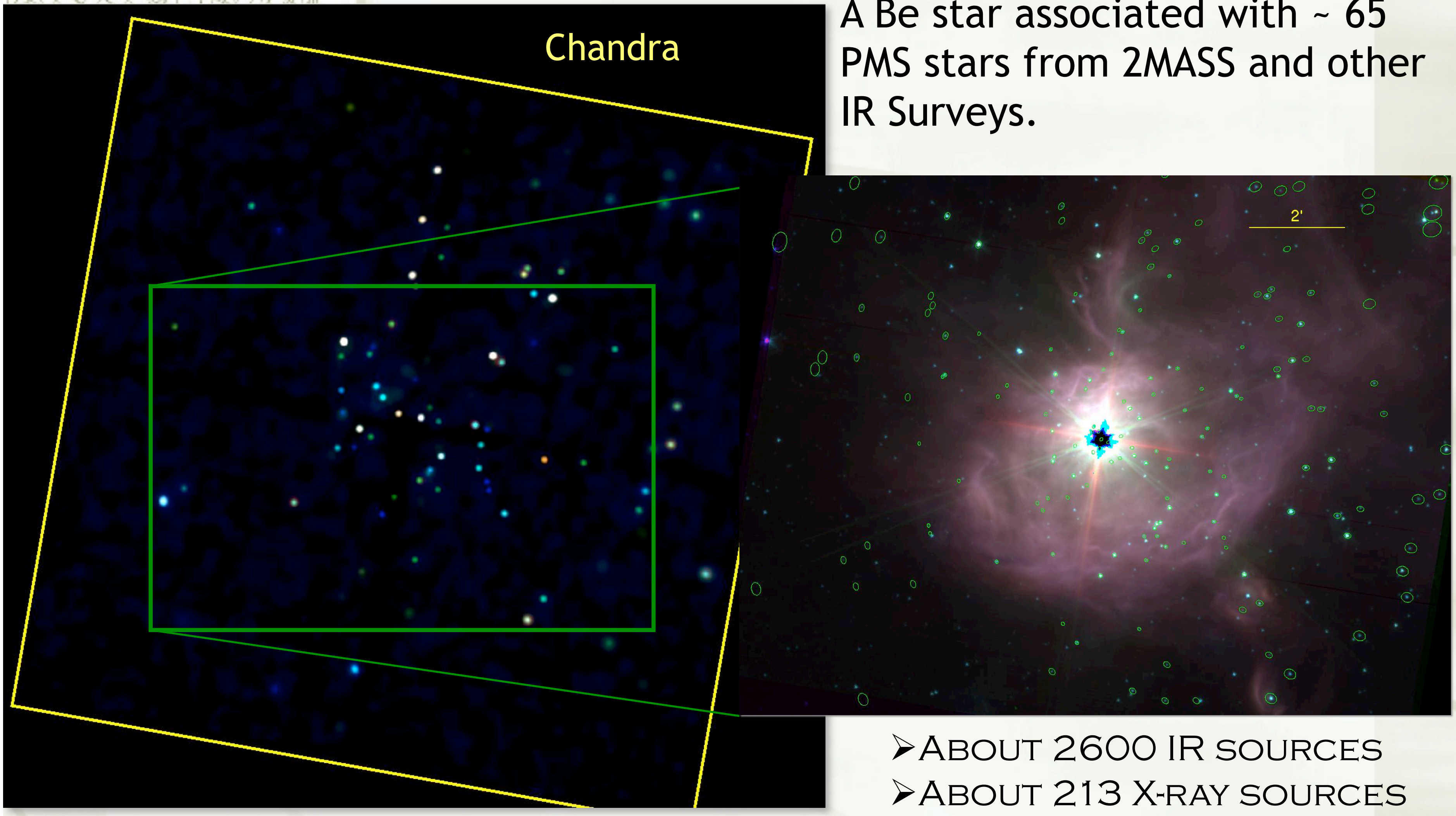
Transition

FEIGELSON & MONTMERLE 1999

- Goals
  - Cluster census
  - Transition disk timescales
  - Detect grain growth
  - X-rays from protostars
  - Effect of X-rays on planet forming disks
    - ➔ especially flares
  - X-ray effects on cluster morphology

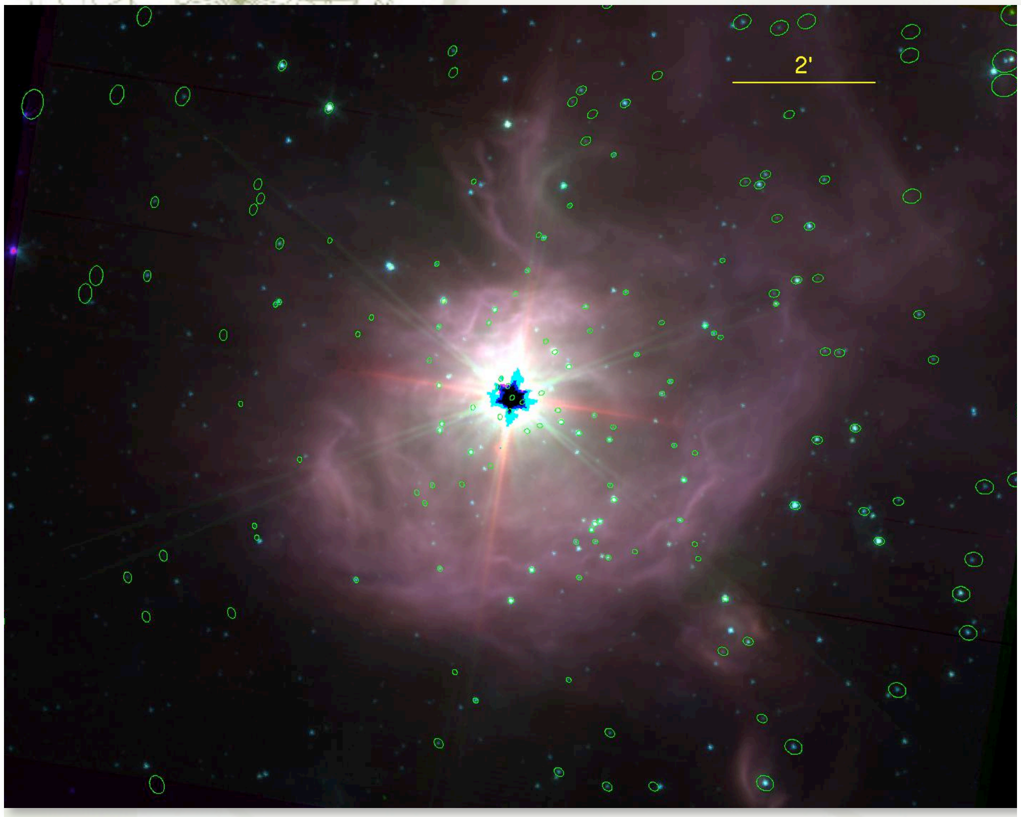
LkHα101 Cluster

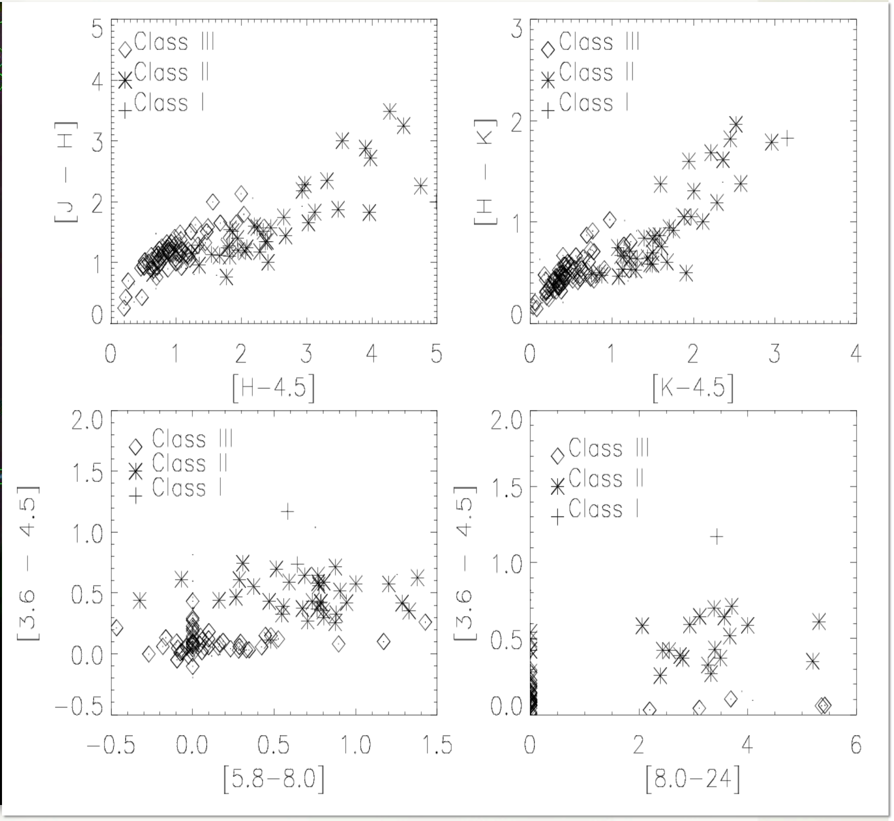
A Be star associated with ~ 65 PMS stars from 2MASS and other IR Surveys.



- About 2600 IR sources
- About 213 X-ray sources

Spitzer Data

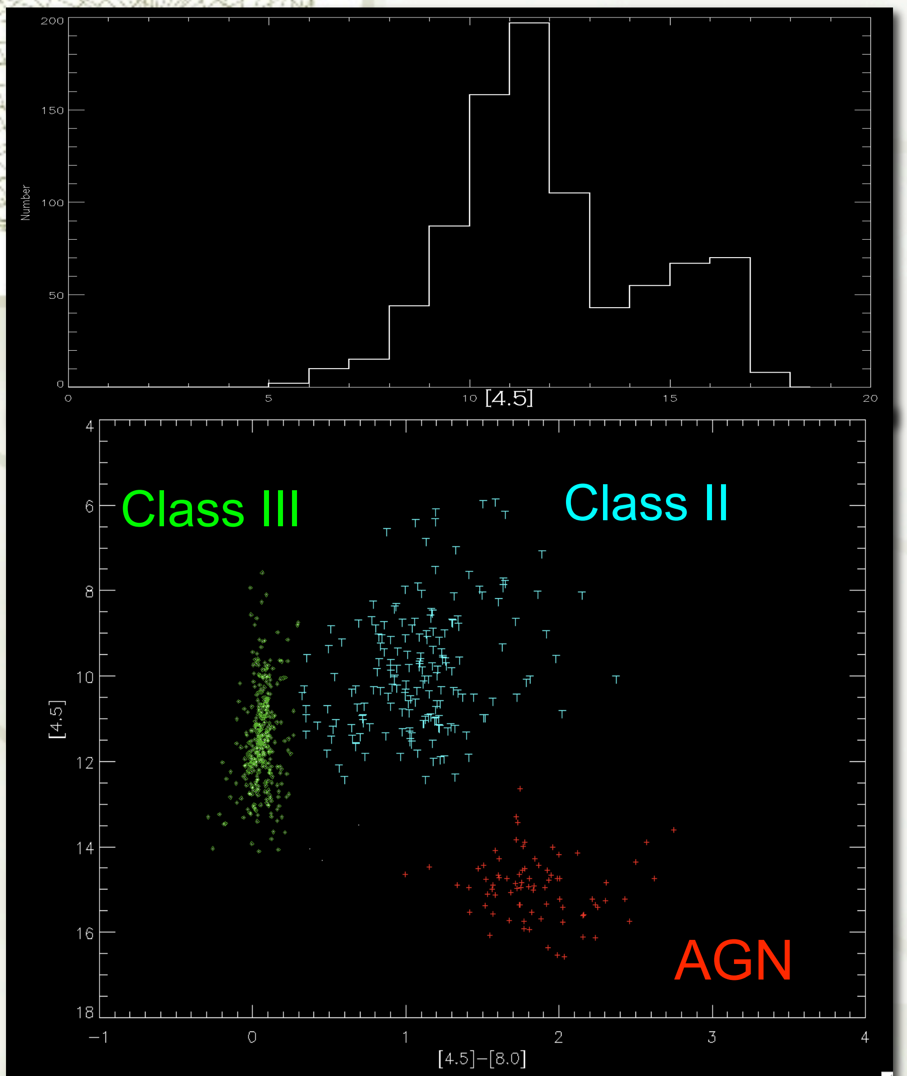




IR colors of X-ray sources

X-ray Decontamination

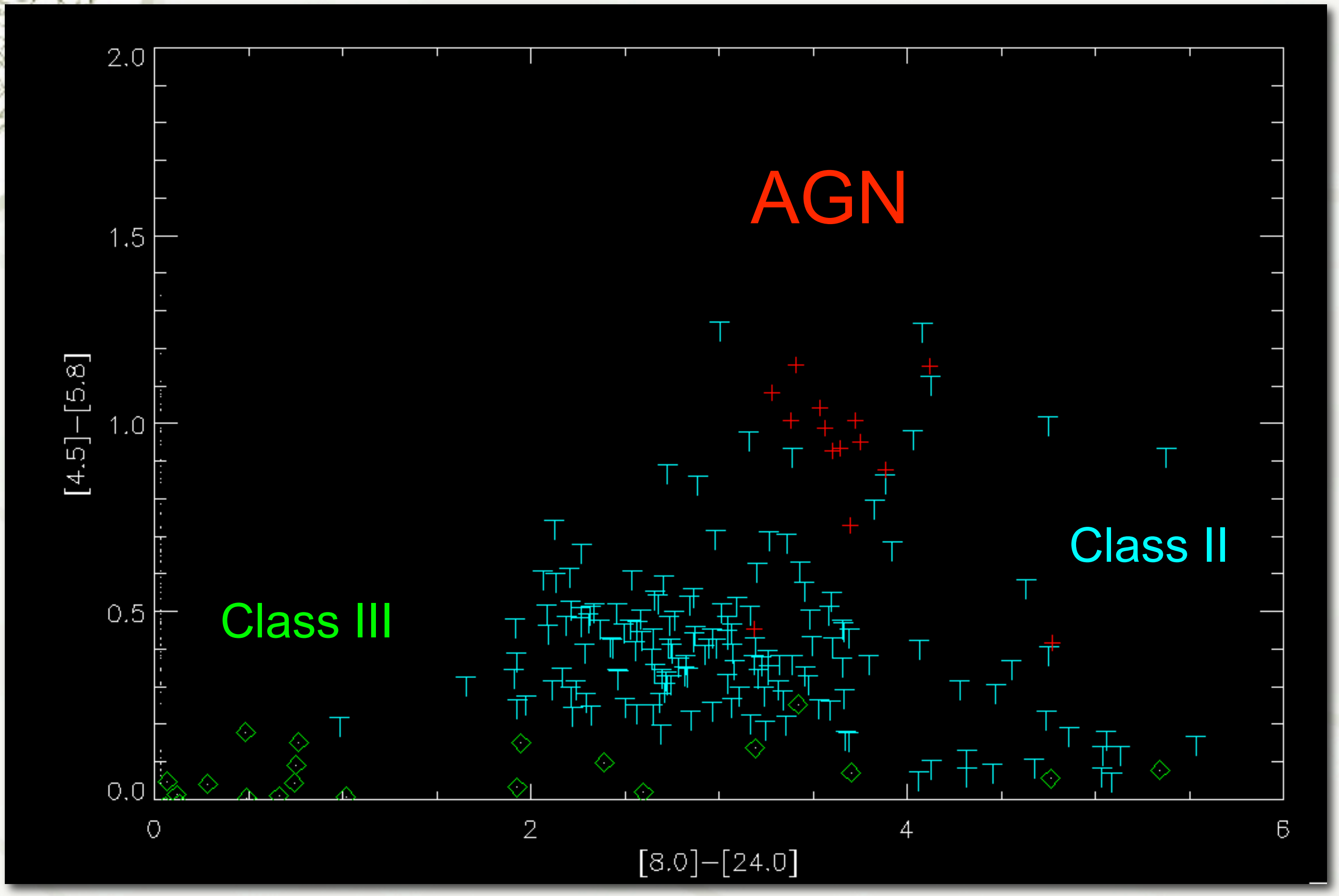
ORION A



The IRAC counterparts to the X-ray sources, clearly show contamination by IR faint sources. The IR colors can be used to distinguish X-ray sources which appear to be Class II sources from AGN as well as separating Class II and III sources.

X-ray Selection

Orion A



About 30 X-ray selected transition disks

Stellar Content

LkHα 101

Class	0/I	II	Trans.	III	Other PMS?	Total PMS Stars
X-Ray sources	5	41	5	65	26	~116
Spitzer Sources	16	94	9⅄	(142)*	(52)*	(261-313)*

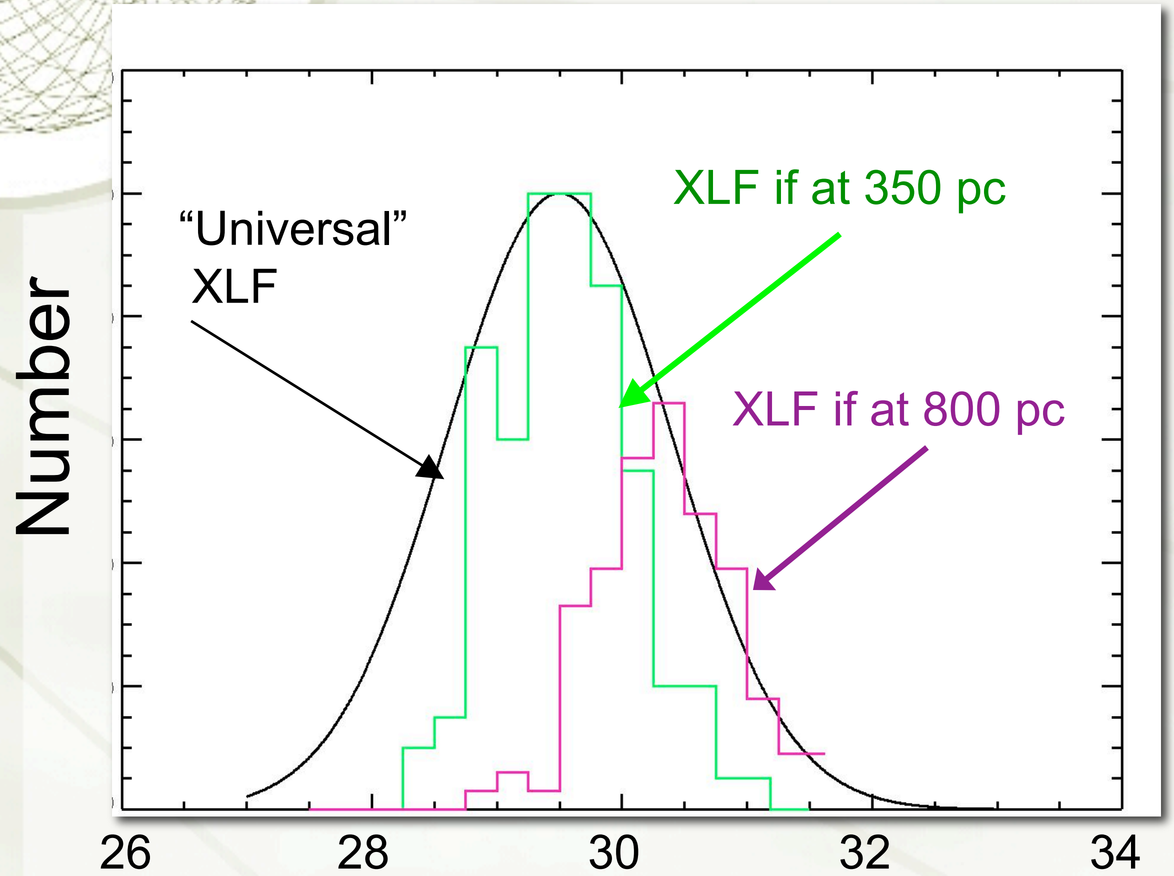
Orion A

Class	0/I	II	Trans.	III	Total PMS stars
X-Ray Sources	<10	220	31	390-520	~650-750
Spitzer Sources	140	550	65*-80⅄	(775-1035)*	(1530-1790)*

⅄From Spitzer Data

*Estimated after correction about 5%

Distance to LkHα 101



Concept from Feigelson and Getman (2005)

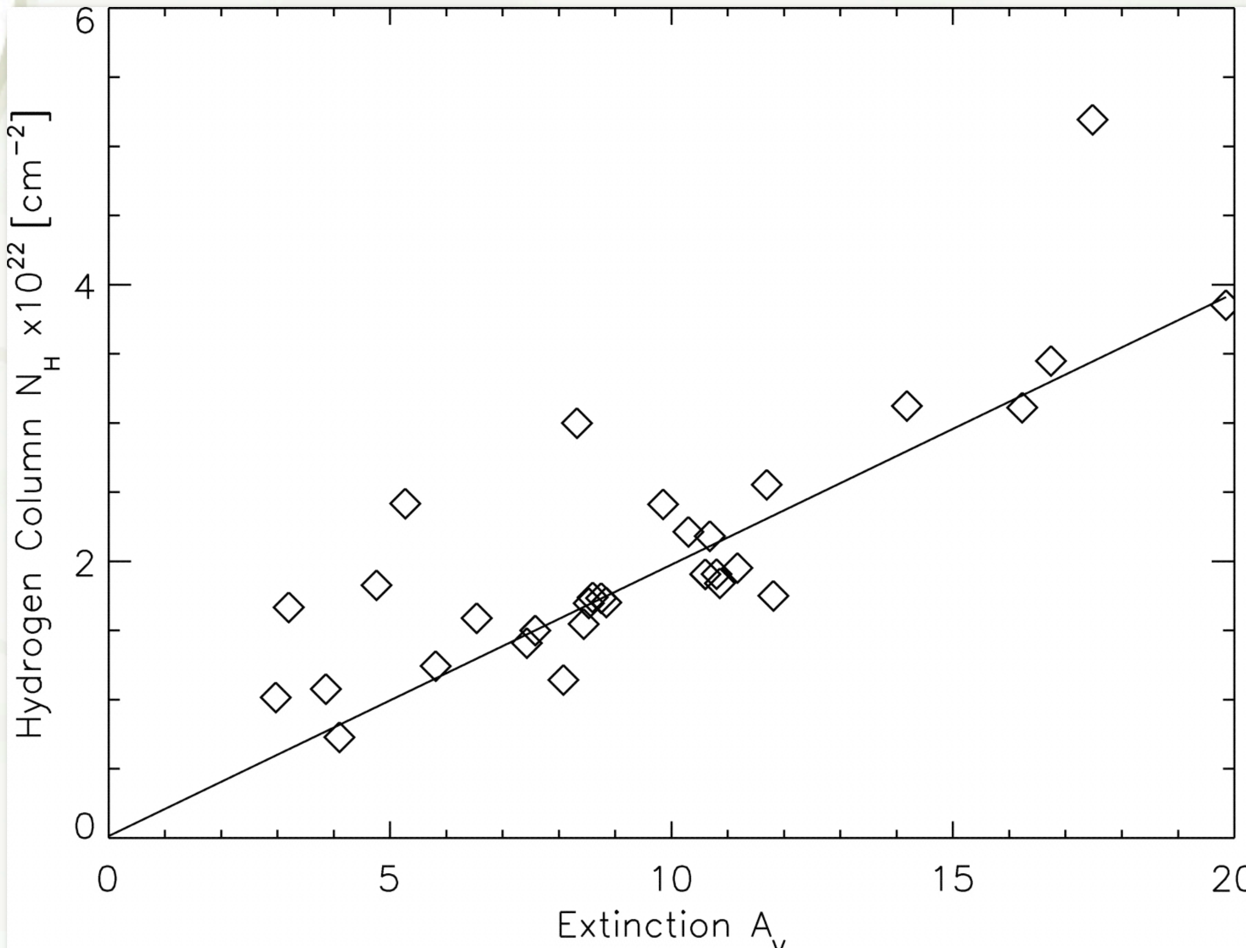
Fit implies cluster size:
300 pc ~ 200 stars

800pc ~ 350 stars

Best fit 550-700 pc
➢275-310 stars

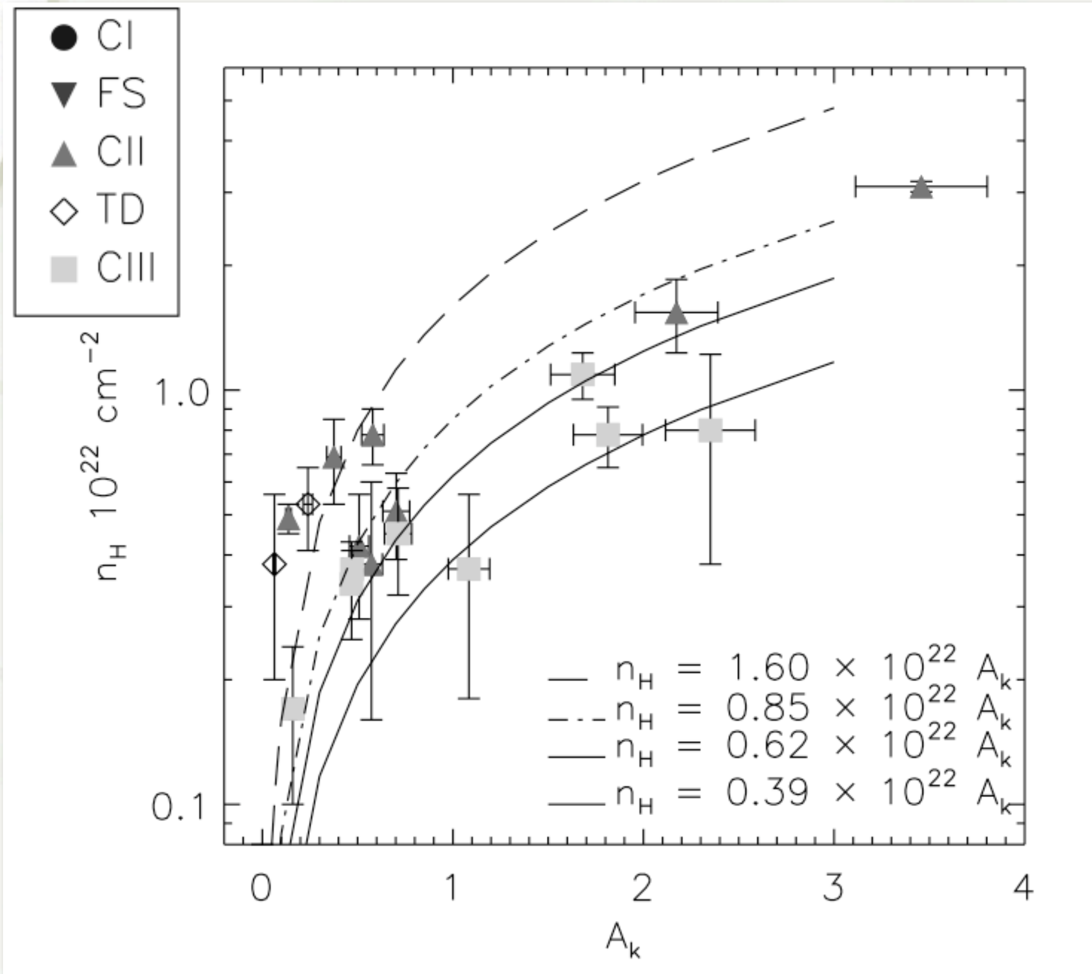
➢Consistent with Chandra+Spitzer estimate.

Grain Growth *(Wolk et al. 2006)*



RCW 38

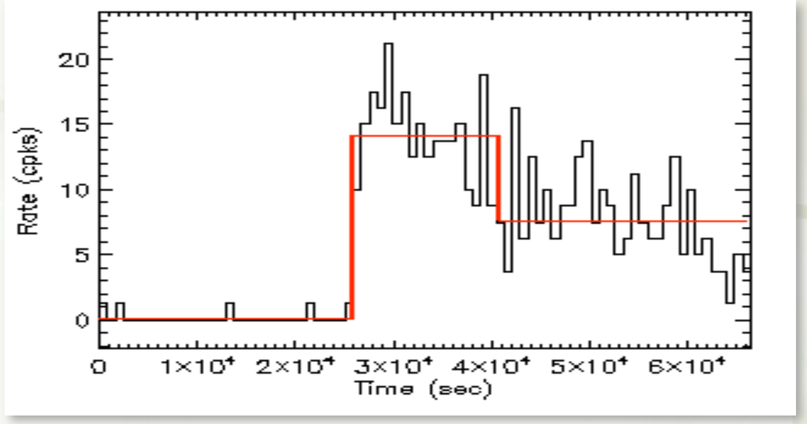
Grain Growth *(Winston et al. 2007)*

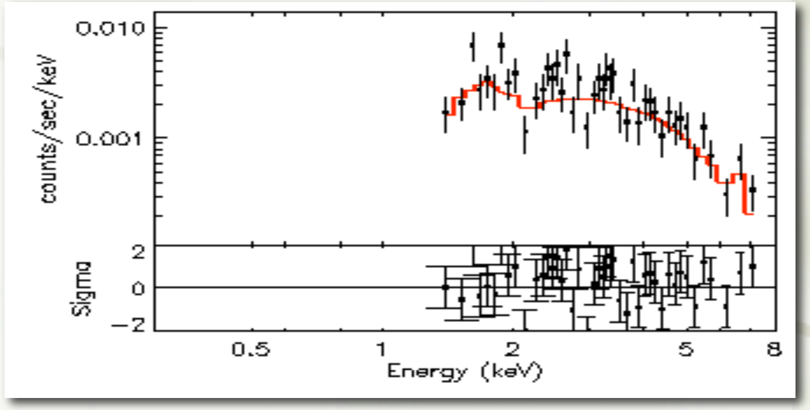


Serpens

Protostars

- Class I only
- Perhaps 100 detected (so far).
- Highly embedded, can only see the hard/hot X-rays.
- Some have detections of Fe I indicative of X-ray fluorescence





The largest flare seen in the X-ray observation, this object is about 12" from LkHα 101 (directly on a *Spitzer* diffraction spike). The X-ray spectrum shows ~2.3×10^{22} cm^{-2} absorption (~11 A_V) and a temperature (in flare) of about 6 keV.

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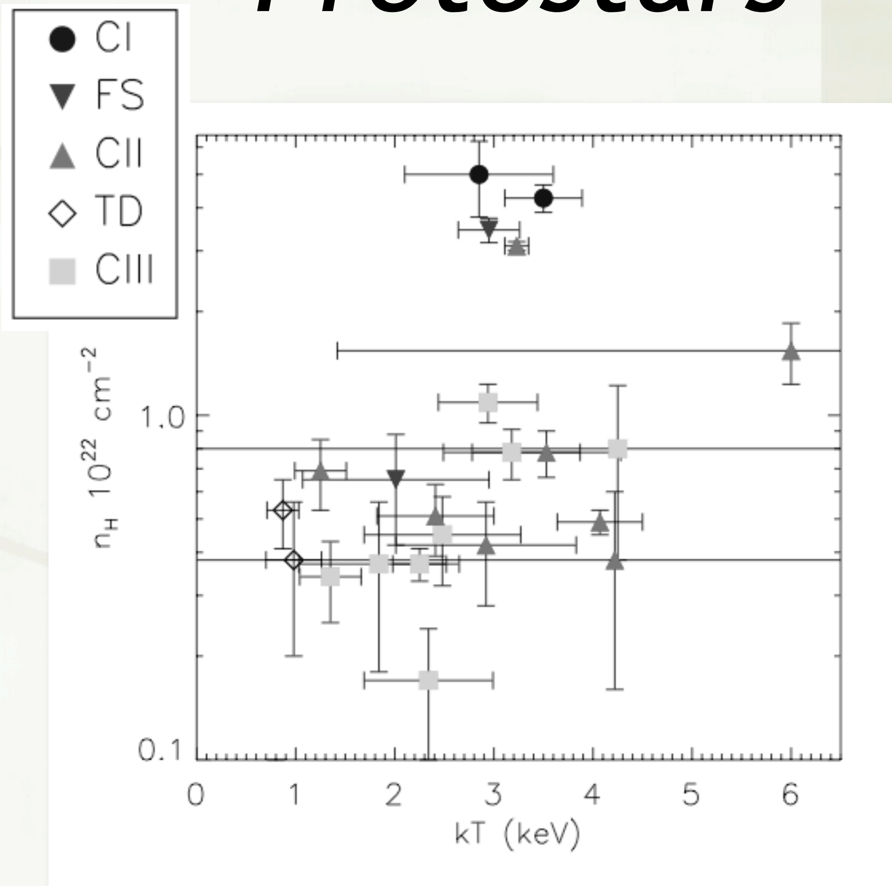
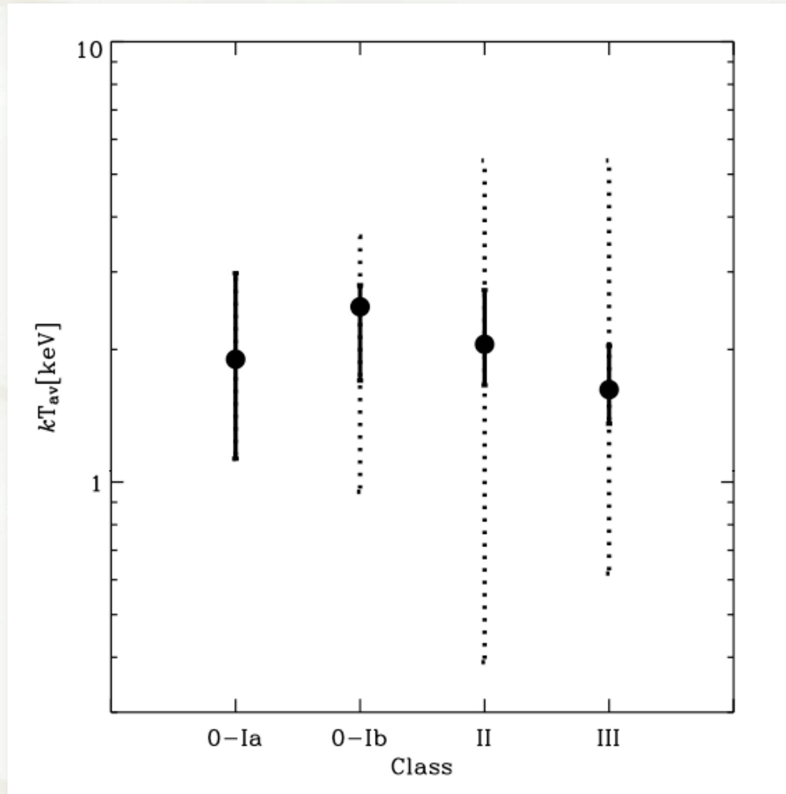


Serpens Winston et al. 2007

Protostars

- Class I only
- Perhaps 100 detected (so far)
- Highly embedded, can only see the hard/hot X-rays.
- Some have detections of Fe I indicative of X-ray fluorescence
- Trend towards peak temperature in Class "Ib"

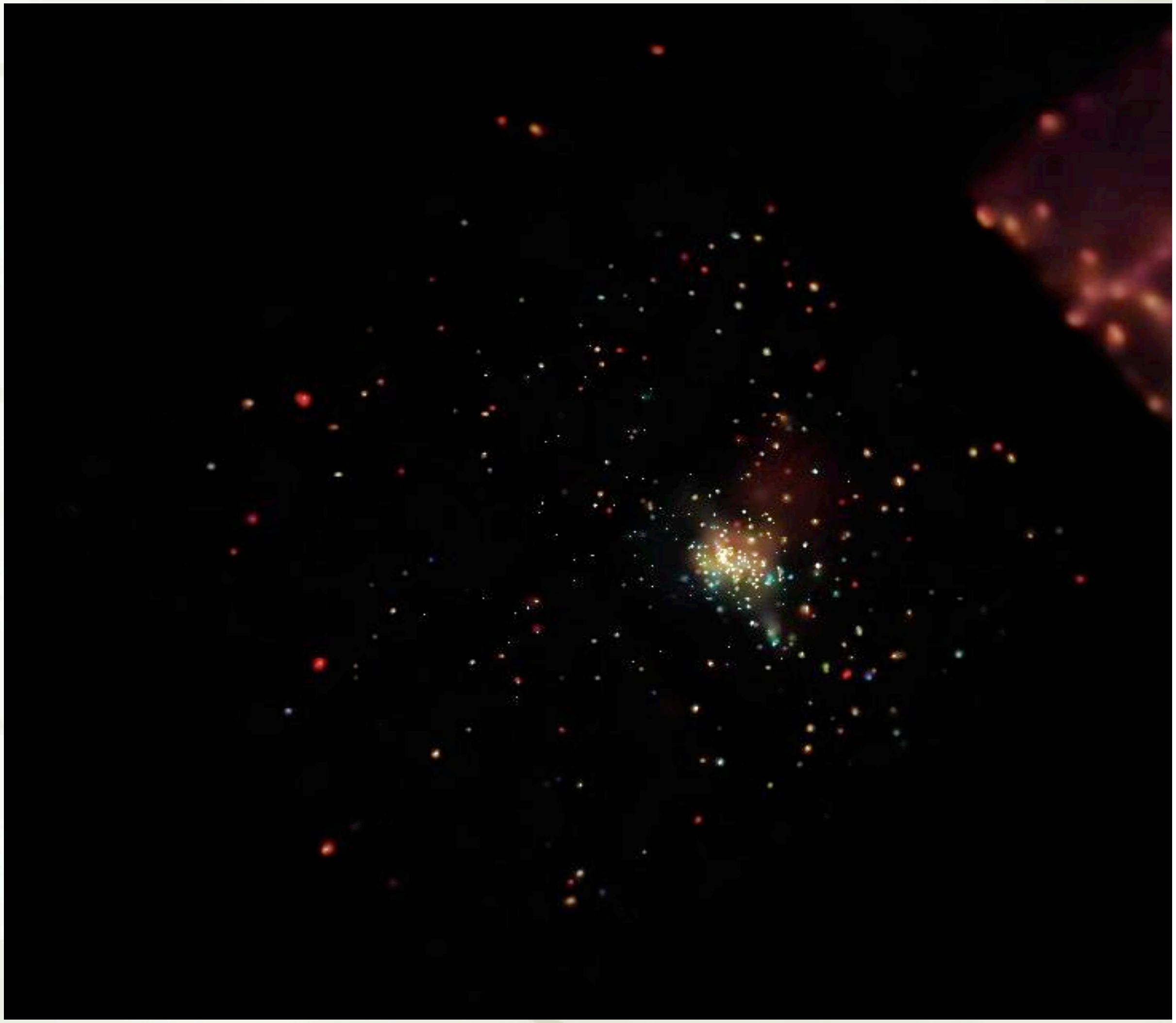


COUP Prisinzano et al. 2007

Morphology

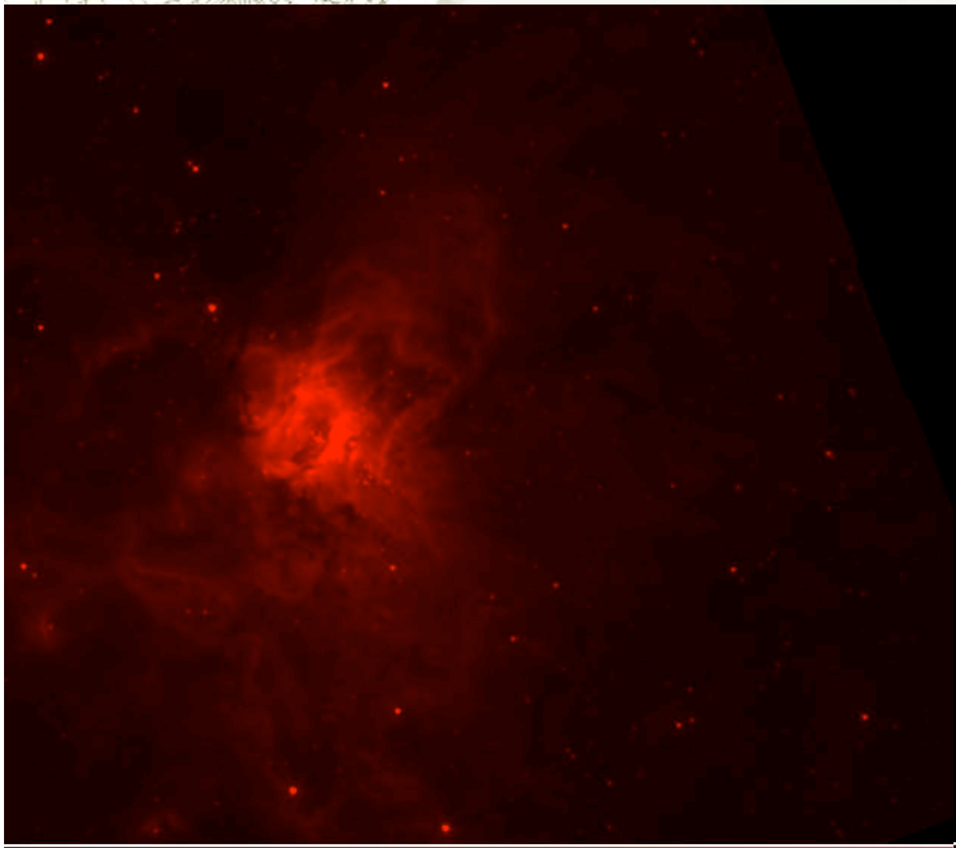
RCW 38

- *Massive SFR in the Sagittarius -Carinae arm.*
- D~1.7 kpc
- 10′~4.7 pc
- A face on version of the ONC with the molecular cap in place

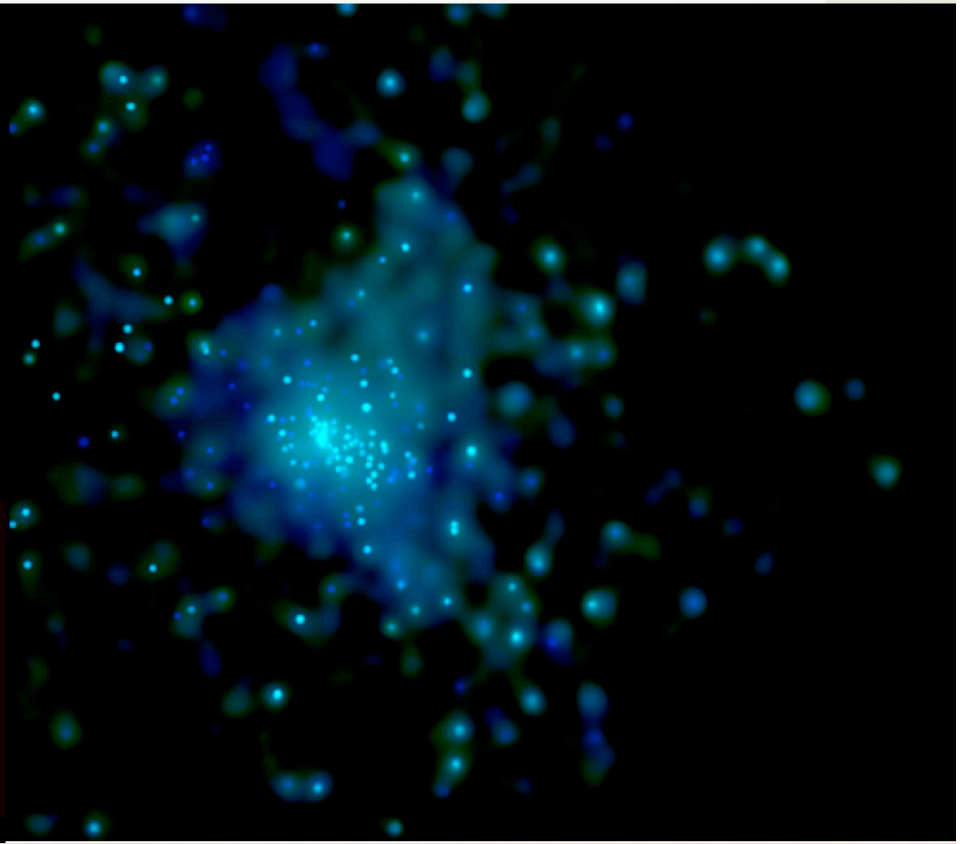


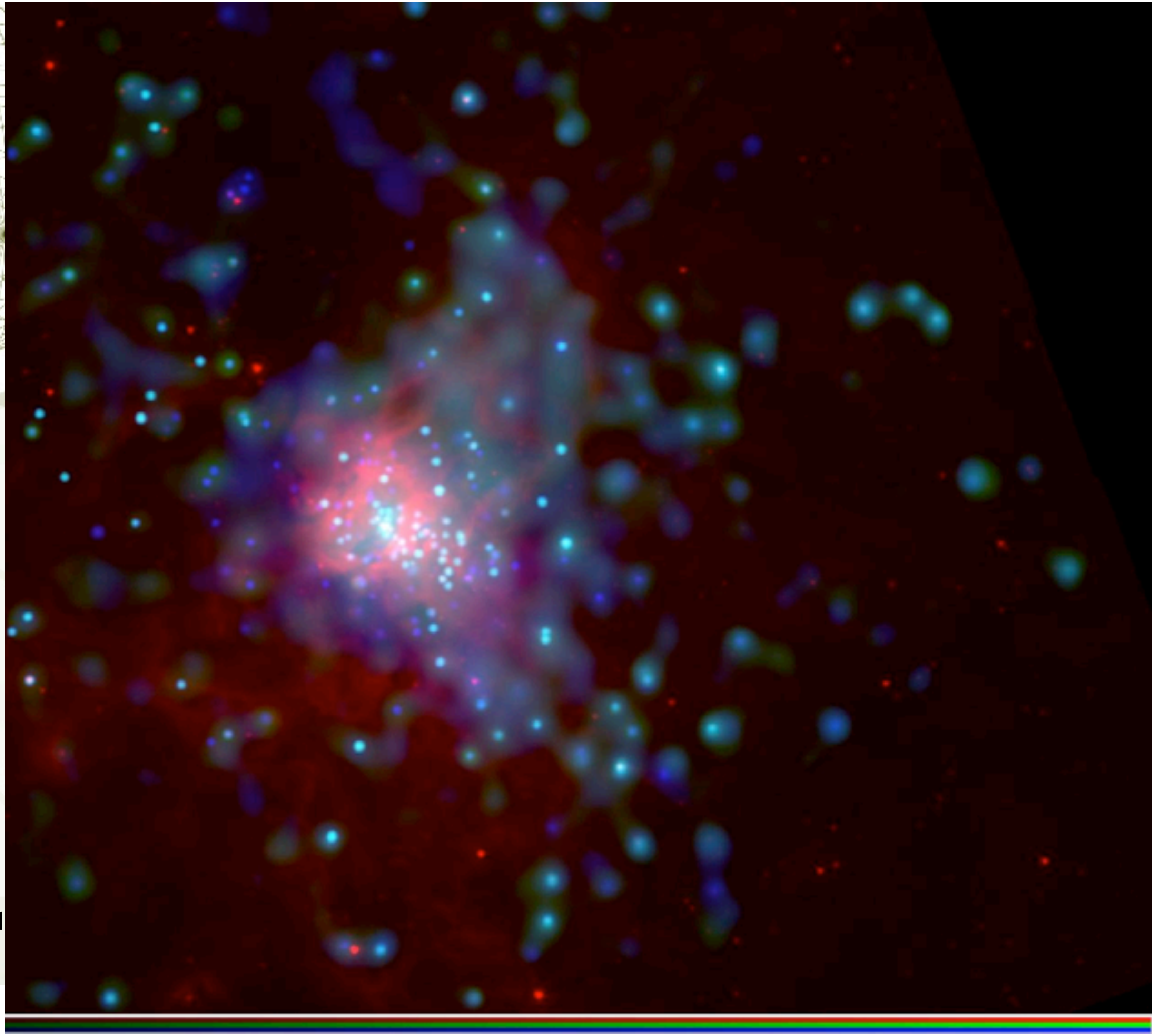
RCW 38 Morphology

8μm

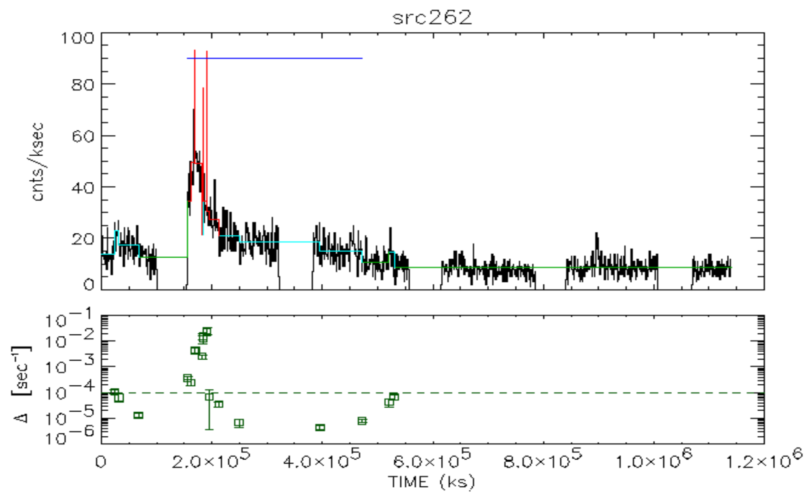


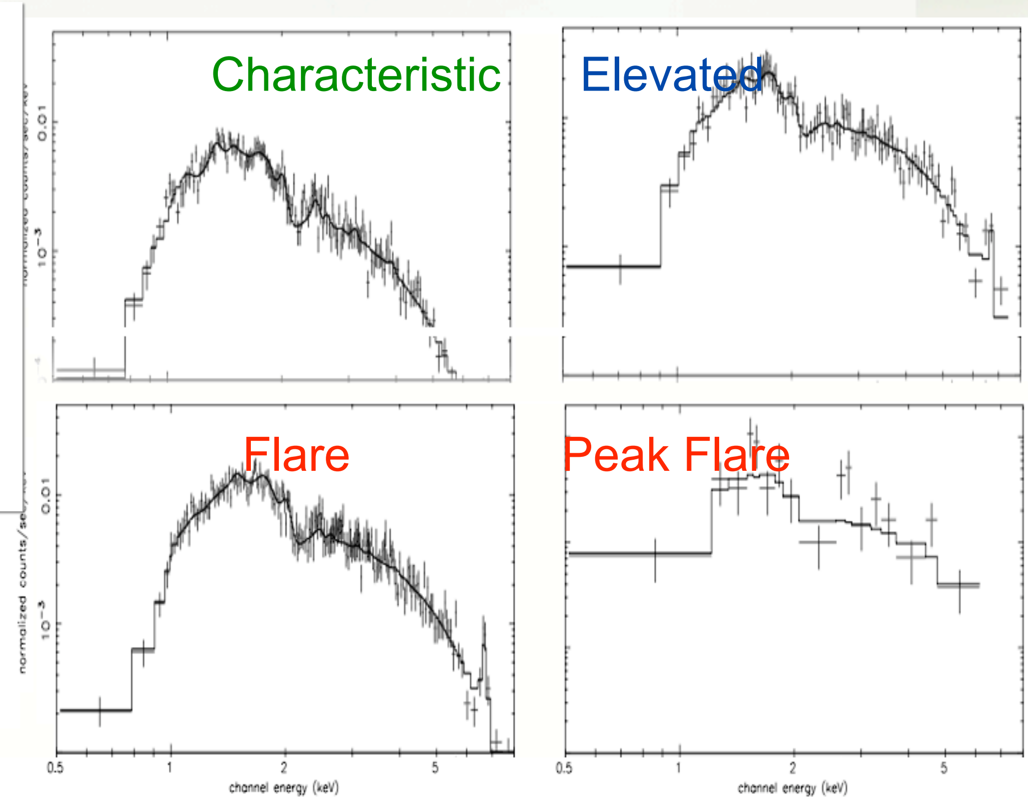
X-ray





X-Ray Spectrum of a Flaring Source





- YSOs are at the characteristic level 75% of the time. *Flares* are defined to rise rapidly above that level by a significant amount; the median rise is 3.5; only a few rise by factors of 10-100.
- During the COUP, 1-4 flares are observed on average for each source over a 10-day observing period, so the flare repetition time is about 1-2 per week.
- The spectrum always hardens during a flare, so their X-rays are more penetrating as well as more powerful.

Physical Process

- X-rays can be an important source of disk heating.
  - While total energy is small, hard X-rays can penetrate to near the midplane.
- Ionization rate for a sun-like YSO at 1 AU:

  $$\zeta = 10^{-8}\ s^{-1}$$

- 8-9 orders of magnitude > galactic cosmic ray Ionization:
  - X-rays can dominate out to 1000 AU
  - Caveat: ignoring attenuation of X-rays and the effects of cosmic ray transport.
- Nucleosynthesis…

Gounelle et al. (2001)

Reactions
$^{16}O(p, x)^{6}Li$
$^{16}O(p, x)^{7}Li$ or ^{7}Be
$^{16}O(p, x)^{10}B$
$^{16}O(p, x)^{10}Be$
$^{16}O(p, x)^{11}B$
$^{16}O(^{3}He, x)^{6}Li$
$^{16}O(^{3}He, x)^{7}Li$ or ^{7}Be
$^{16}O(^{3}He, x)^{10}B$
$^{16}O(^{3}He, x)^{10}Be$
$^{16}O(^{3}He, x)^{11}B$
$^{16}O(\alpha, x)^{10}Be$
$^{24}Mg(^{3}He, p)^{26}Al$
$^{25}Mg(^{3}He, pn)^{26}Al$
$^{27}Al(^{3}He, \alpha)^{26}Al$
$^{28}Si(^{3}He, p\alpha)^{26}Al$
$^{42}Ca(p, pn)^{41}Ca$
$^{40}Ca(\alpha, {}^{3}He)^{41}Ca$
$^{40}Ca(\alpha, {}^{3}H)^{41}Sc$
$^{40}Ca(^{3}He, 2p)^{41}Ca$
$^{50}Ti(p, n)^{50}V$
$^{51}V(p, 2n)^{50}V$
$^{52}Cr(p, 2pn)^{50}V$
$^{48}Ti(^{3}He, p)^{50}V$
$^{49}Ti(^{3}He, pn)^{50}V$
$^{50}Ti(^{3}He, p\ 2n)^{50}V$
$^{48}Ti(\alpha, pn)^{50}V$
$^{56}Fe(p, x)^{53}Mn$ or ^{53}Fe
$^{56}Fe(p, \alpha)^{53}Mn$
$^{53}Cr(p, n)^{53}Mn$
$^{138}Ba(p, n)^{138}La$

X-ray Studies of Star Formation

- The X-ray detection of over thousands of stars, including brown dwarf candidates. X-ray emission originates from Class 0, I, II, and III YSOs.
  - X-ray sources not associated with any optical/infrared counterpart can trace a yet-to-be-discovered stellar population of deeply embedded, relatively massive cluster members.
  - Changes in observed gas to dust ratios may be a sign of grain growth in dense regions.
- Diffuse emission has been detected in many regions of massive star formation.
  - 10^7 K plasma leads to:
    - 10^4K ionization fronts
    - 100 K dust
    - A bubble can clear dust
  - Less UV extinction
    - A bad place to be a disk
- (All PMS) stars are variable.
  - Young stars have both constant and flaring X-ray components.
  - X-rays can both heat protostellar disks and cause in situ nucleosynthesis.