

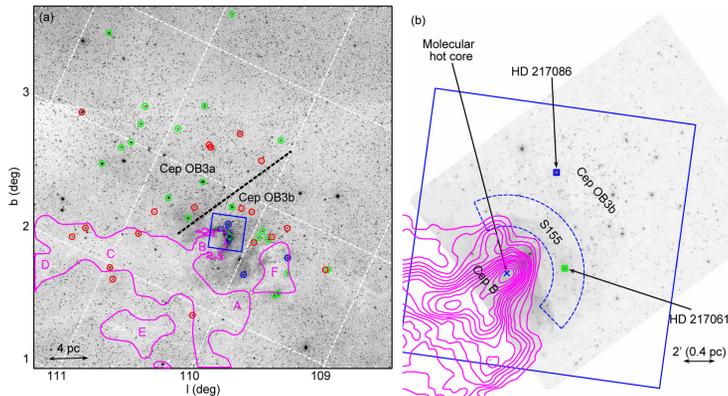
The Spitzer/Chandra view of the triggered star formation in the CepB/OB3b region

K. V. Getman (PSU), E. D. Feigelson (PSU), K. L. Luhman (PSU),
A. Sicilia-Aguilar (MPI), J. Wang (CfA), G. P. Garmire (PSU)

REFERENCES

1. Getman et al. 2009, ApJ, 699, 1454
2. CXO press release "Trigger-Happy Star Formation":
http://chandra.harvard.edu/press/09_releases/press_081209.html

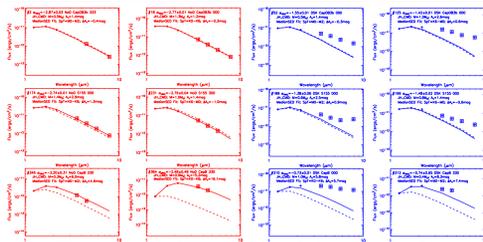
1. INTRODUCTION & SUMMARY In this very active star forming complex which consists of the molecular bright-rimmed cloud CepB, the nearby OB association CepOB3b, and the HII interface S155, our Spitzer-Chandra study discovers a several hundred young stellar members. The analyses of the identified nearly disk-unbiased and mass complete samples of young stars give several results. Our major finding is a spatio-temporal gradient of young stars from the hot molecular core toward the primary ionizing O star HD 217086. This strongly supports the radiation-driven implosion (RDI) model of triggered star formation in the region. The empirical estimate for the shock velocity of 1 km/s is very similar to theoretical models of RDI in shocked molecular clouds. The initial mass function (IMF) of the lightly obscured triggered population exhibits a standard Galactic field IMF shape. The unusually high apparent value of 70% star formation efficiency inferred from the ratio of star mass to current molecular gas mass indicates that most of the CepB molecular cloud has been already ablated or transformed to stars. Contrary to the current RDI simulations, our findings indicate that star formation triggering by HII region shocks is not restricted to a single episode but can continue for millions of years. Other results include: (1) agreement of the disk fractions, their mass dependency, and fractions of transition disks with other clusters; (2) confirmation of the youthfulness of the embedded Cep B cluster; (3) confirmation of the effect of suppression of time-integrated X-ray emission in disk-bearing versus diskless systems.



2. CEPHEUS REGION Cep B is a molecular core located at the edge of the Cepheus giant molecular cloud at a distance around 725 pc. A handful of embedded young stars were found in Cep B from previous radio continuum and infrared studies. The unobscured stellar OB association Cep OB3 lies around Cep B; the younger subgroup, CepOB3b, lies closest to the cloud. The interface between the CepB and CepOB3b is delineated by the optically bright HII region S155, where cloud material is ionized and heated by the radiation of the O7 star HD 217086 and B1 star HD 217061. Large-scale DSS image of the CepB/OB3 environs (panel a in the figure above) and the close up of the Cep B showing 20'x15' IRAC image in the 4.5 μ m band with the 17'x17' Chandra ACIS-I field outlined in blue (panel b).

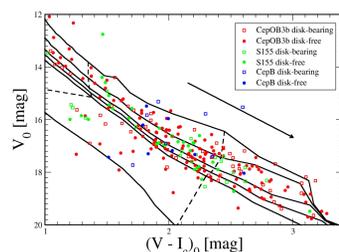
3. DISK CLASSIFICATION

In our Chandra-ACIS and Spitzer-IRAC images of the region we identify >600 pre-main sequence (PMS) stars. We base the PMS disk classification of these stars on a comparison of their infrared (IR) spectral energy distributions (SEDs) with the template SEDs of PMS stars in the well studied IC 348 cluster. IR SEDs for 6 representative disk-free (Class III) and 6 disk-bearing (Class II) Cepheus stars are shown in the figure.



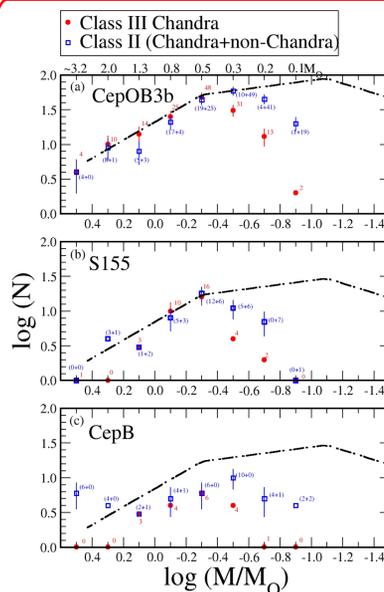
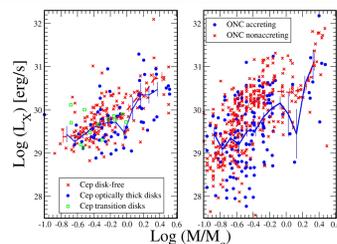
4. STELLAR AGES from OPTICAL DATA

From the V- and I_c-band color-magnitude diagram for the Chandra X-ray PMS stars using the optical photometry from Mayne et al. (2007) we find an average age of 2-3 Myr for the Cep OB3b stars (red+green) and <1-2 Myr for the embedded Cep B stars (blue).



5. X-RAY DETECTION EFFICIENCY IS HIGHER FOR DISKLESS STARS

Both, the L_x-M relationship and the suppression of X-ray emission in accreting versus nonaccreting PMS systems, are seen in the Cep OB3b star sample (left panel). These are somewhat different than the relationships present in the Orion COUP stars (right panel). The differences are attributed to the truncation effect of the Cepheus data due to the lower than COUP's sensitivity of the Chandra Cepheus observation.

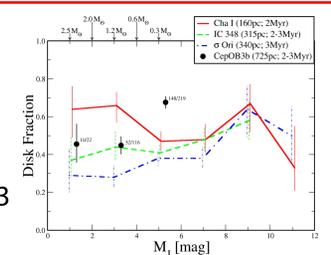


6. INITIAL MASS FUNCTION (IMF)

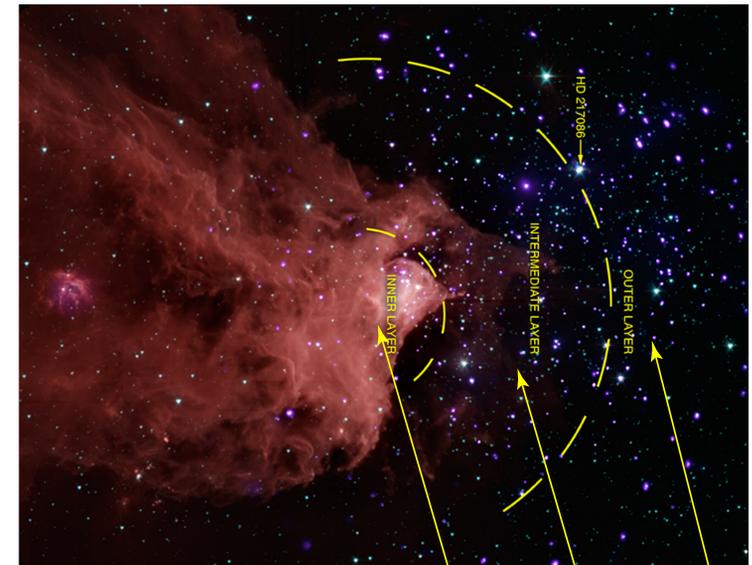
For a given mass, the X-ray detection efficiency of Class III stars is somewhat higher than that of Class II stars (see 5). To compensate for this effect, in the IMF and the disk evolution analyses, we use the disk-bearing stellar sample that is the combination of the Chandra and non-Chandra (=only Spitzer detected) IR-excess PMS stars while retaining the diskless sample as purely composed of X-ray stars. Our IMF analysis shows that the combined Chandra+non-Chandra CepOB3b and S155 stellar samples follow the Galactic field shape IMF with mass completeness limits of 0.5 Mo. Whereas the Cep B stellar population may be complete only somewhere above 1 Mo. We estimate the total Cepheus population within the ACIS-I field to be >1000 stars down to 0.1 Mo.

7. DISK EVOLUTION: MASS DEPENDENCE

We find no significant difference of disk fraction on mass in the rich Cep OB3b Chandra+non-Chandra-selected sample above its completeness limit of 0.5 Mo. This agrees with the lack of mass dependence in the >0.2 Mo regime seen in the 2-3 Myr old IC 348 and σ Ori clusters.

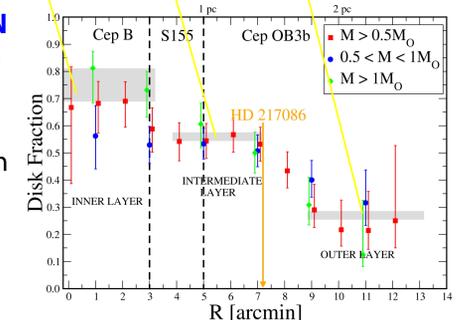


Combined Chandra (violet) and Spitzer (red-green-blue) image of the Cep B/Cep OB3b region.



8. SPATIAL GRADIENTS OF DISK FRACTION

We find that the disk fractions fall from 80% to 30% across the S155 HII region in the direction from the molecular cloud towards the ionizing star HD 217086. Combined with our finding on stellar ages (see 4) this gives the spatio-temporal gradient of Cepheus PMS stars from the center of the cloud toward HD 217086.



9. IMPLICATIONS FOR TRIGGERED STAR FORMATION

The Cepheus region now possesses all of the observational features of an RDI triggered star formation region: A) The presence of exciting star(s) and a molecular cloud surrounded by an ionized rim facing the exciting stars (Minchin et al. 1992; Beuther et al. 2000). B) The presence of a dense molecular core close to the rim (Yu et al. 1996; Beuther et al. 2000). C) The spatio-temporal gradient of young stars oriented toward the exciting star(s) (this work).

*From the age gradient of Cepheus stars we estimate the shock velocity of 1 km/s. This agrees with empirical estimates obtained for a number of other shocked bright-rimmed clouds and with theoretical predictions. *In section 6 we show that the IMF of the Cep OB3b / S155 triggered populations exhibits a standard Galactic field shape. *While the theoretical calculations of RDI triggering involve small globules and a single episode of triggering, the 2-3 Myr range of stellar ages found in the Cep B/ Cep OB3b region (see 4) implies repeated or continuing star formation over millions of years when the RDI mechanism occurs in a large molecular cloud.