St Andrews/Cambridge node on $\overline{\text{MSFR}}$

July 16, 2003

1 Objectives:

a) Understand the environmental influences in galaxies that lead to bursts of star formation, and how these affect the star formation efficiency and the initial mass function for stars.

b) Combine our hydrodynamical star formation codes with state of the art radiative transfer codes, in order to connect our simulated systems with observations and to assess the role of feedback.

We propose a suite of simulations modeling the response of the ISM to a time dependent galactic potential, in order to examine differences in star formation between isolated and interacting galaxies. We will run simulations at a variety of resolutions: large scale simulations will delineate the morphology and spatial distribution of massive star forming regions and follow temporal variations in the global star formation rate, intermediate level simulations will follow the assembly of gas into clusters and associations, to be compared with the luminosity functions of OB associations and HII regions, and small scale, high resolution simulations, will follow the formation of individual stars within Giant Molecular Clouds, thus allowing direct comparison with determinations of the IMF. We also propose to combine these latter simulations with radiative transfer modules, with the aim of facilitating comparison with observations and of addressing the role of feedback in limiting the efficiency of star formation. We will rely heavily on the observational expertise provided by the Network in order to interpret the results of our simulations.

2 Originality, timeliness

The link between the galactic environment and the star forming properties of galaxies has not previously been explored by simulations with the capacity to resolve the formation of individual stars. We are well placed to undertake this next stage, given our recent experience of fully resolved modeling of star formation in turbulent molecular clouds. We stress that, in the highest resolution studies, neither the star formation rate nor the IMF is put into the code by prescription, but instead follows from the hydrodynamic simulation of self-gravitating turbulent flows. We will also for the first time model isolated spiral galaxies using realistic time dependent potentials derived from the Nbody studies of Jerry Sellwood; our pilot studies suggest that the star formation history and morphology is markedly different in this case compared with the usually assumed case of a rigidly rotating long lived spiral mode. Our research will re-examine whether isolated galaxies should be regarded as quiescent, quasi-steady systems and will contrast with the situation of interacting systems.

Our simulations of cluster formation in a realistic galactic environment will incorporate a code we have newly developed to model feedback from ionising radiation in hydrodynamic simulations, as well as codes designed to follow feedback of mechanical energy from stellar winds.

The timeliness derives from the development of such codes and the ability to run computationally intensive simulations, using a new generation of supercomputers such as the UK's Astrophysical Fluid Facility (UKAFF).

3 work plan

We are proposing to employ a postdoctoral researcher and a PhD student, both of whom would be based in St Andrews, but who would in both cases make regular visits to Cambridge in order to receive training in the a the parts of the project led by the Cambridge team (specifically the incorporation of realistic potentials for isolated galaxies, the low resolution study of the interaction between spiral arms and the ISM and the use of a recently developed module for incorporating ionising radiation in hydrodynamic simulations). St Andrews would lead the portions of the project concerned with the high resolution simulation of molecular clouds, the use of state of the art Monte Carlo radiative transfer codes and the modeling of feedback from stellar winds.

PhD student:

3.1 year 1

Global ISM simulations subject to a time dependent galactic potential, corresponding to the cases of isolated spiral galaxies and galaxies undergoing minor and major interactions.

3.2 year 2

Extraction of observational diagnostics (time dependence of star formation rate, spatial distribution of star forming centres etc.). Comparison with observations of isolated and interacting galaxies.

Setting up of medium resolution simulations of patches of the ISM subject to the time varying potentials provided by spiral arm passage or interactions.

3.3 year 3

Medium resolution simulations used to explore the assembly of self-gravitating systems. Extraction of 'cluster' mass spectrum, to be compared with the luminosity functions of HII regions, OB associations and Super Star Clusters. Examination of how results depend on galactic environment.

Postdoctoral researcher

3.4 year 1

Gain familiarity with hydrodynamic codes for the high resolution simulation of molecular clouds. Run codes for isolated cloud (subject to no background potential variations) as control case. Derive observable properties of resulting stellar systems using Monte Carlo radiative transfer codes on snapshots of the cloud generated by the hydrodynamic code.

3.5 year 2

Incorporate newly developed modules for including the hydrodynamic effects of ionising radiation and stellar winds in star formation simulations. Study relative roles of positive versus negative feedback.

3.6 year 3

Repeat the above in the case of clouds subject to the time varying potentials generated in isolated and interacting galaxies, as provided by the large scale simulations produced by the PhD student. This study will yield important results on how the IMF and the efficiency of star formation can be expected to vary as a function of environment.

4 Training

This research programme will familiarise the young researchers with state of the art numerical codes, developed by the St Andrews/Cambridge teams and elsewhere, and allow them to develop extensive experience in programming, numerical modeling as well as developing the required techniques to analyse the results from the simulations.

5 Expertise

5.1 St Andrews

The University of St Andrews involves an active group of astronomers with areas of research that span from galactic dynamics and cosmology to searches for extrasolar planets and stellar magnetic fields. The areas of relevance for this proposal include studies of star formation using numerical simulations (Ian Bonnell), radio observations of molecular clouds (Jane Greaves), the propagation of radiation in young stellar systems and the ISM (Kenny Wood), the dynamics of self-gravitating discs (Ken Rice) and galactic dynamics (HongSheng Zhao and Steve Vine).

5.2 IoA, Cambridge

The Institute of Astronomy is a world leading institution with expertise in nearly every branch of astronomy. Activities at the IOA that are relevant to those of the broader Network include those of the large Stellar Populations Group, headed by Gerry Gilmore, with long standing interests in the star formation histories of the Milky Way and other galaxies, and the dynamics of galaxies and star clusters. In addition, Steven Smartt is leading high profile investigations on the progenitors of supernovae. Other relevant expertise is provided by Chris Tout (stellar evolution) and Sverre Aarseth (pioneering developer of Nbody simulations). Close collaborations on observational projects exist between the IOA and Sheffield (and UCL...and where else in Network.... mention Roberto?).

5.3 Violent star formation

The proposed work plan of this node utilises the combined expertise of the researchers in St Andrews and Cambridge. Of primary importance is the experience of Ian Bonnell and Cathie Clarke in using numerical simulations as a tool to study star formation. This includes recent work modeling the formation of stellar clusters and massive stars, as well as the the first-ever fully resolved simulations of multiple star formation. A number of ongoing projects that are highly relevant have been instigated recently include:

- the inclusion of winds from massive stars (IAB, St Andrews)
- the development of a new algorithm for the implementation of feedback from ionising radiation in star formation simulations (CJC, Cambridge)

- a parallel project to incorporate the effect of radiation pressure on dust in simulations of massive star formation (CJC, Cambridge)
- a first examination of gas dynamics in realistic galactic potentials (CJC, Cambridge)
- the development of an adaptive method in order to increase numerical resolution in regions of interest.

There is a a long history of collaborations between the St Andrews and Cambridge groups. Cathie Clarke and Ian Bonnell have coauthored numerous papers on the hydrodynamics of cluster and binary star formation. Currently, the two groups are involved in incorporating the feedback algorithms developed in Cambridge into the St Andrews cluster formation simulations.

5.4 Publications

- The hierarchical formation of a stellar cluster. by Ian A. Bonnell, Matthew R. Bate and Stephen G. Vine. 2003, MNRAS, in press.
- A New Algorithm for Radiative Feedback and its Application to the Formation of Massive Stars, R.G. Edgar and C.J. Clarke, 2003 MNRAS 340,841
- The formation of a star cluster: predicting the properties of stars and brown dwarfs, by M. R. Bate, I. A. Bonnell and V. Bromm. 2003, MNRAS, 339, 577
- Galactic porosity and a star formation threshold for the escape of ionizing radiation from galaxies, Clarke, C.J. and Oey, M.S., MNRAS 337,1299
- Accretion in stellar clusters and the IMF. by I. A. Bonnell, C. J. Clarke, Matthew R. Bate and J. E. Pringle, 2001. MNRAS, 324, 573.

5.5 People: St Andrews

- Ian Bonnell 15 %
- Kenny Wood 5 %
- Hong-Sheng Zhao 5 %
- Jane Greaves 5 %
- Ken Rice 5 %
- Steve Vine 5 %

5.6 People: IoA Cambridge

- Cathie Clarke 10 %
- Gerry Gilmore 5 %
- Steve Smartt 5 %
- Sverre Aarseth 5 %
- Chris Tout 5 %

6 Management

CJC: CJC has extensive experience of training young researchers, having to date supervised 11 PhD students, mainly on topics related to the hydrodynamic simulation of star formation. In addition, CJC has been the team leader of the Cambridge node of the FP5 Network "The Formation of Young Stellar Clusters" and has employed two postdoctoral researchers in this connection.

IAB has significant experience in training researchers and in supervising PhD students. He presently has 2 PhD students and 2 postdoctoral researchers studying the hydrodynamics of star formation, the formation of massive stars and the formation of planetary systems.