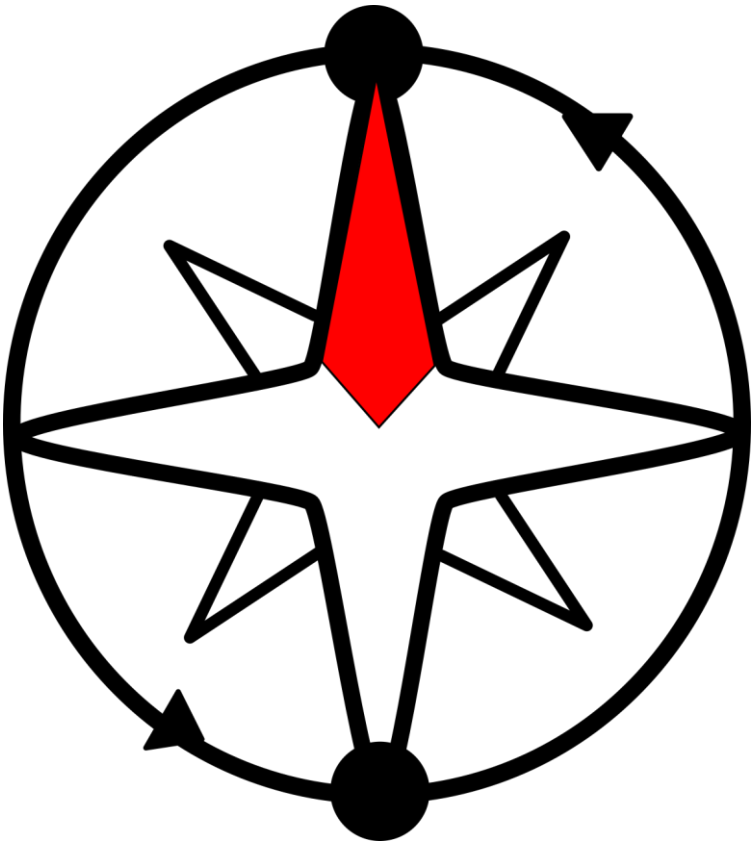
COMPACT OBJECT MERGERS: POPULATION ASTROPHYSICS AND STATISTICS

COMPAS is a platform for the exploration and study of populations of compact binaries formed through isolated binary evolution (Stevenson et al., 2017). COMPAS population synthesis code is flexible, fast and modular, allowing rapid simulation of binary star evolution. The complete COMPAS suite includes the population synthesis code together with a collection of tools for sophisticated statistical treatment of the synthesised populations.



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Revision History

Date	Version	Description	Author
2012-2019		Original COMPAS manual	Team COMPAS
1 September 2019	0.1	Initial draft	Jeff Riley
20 September 2019	0.2	Updated compilation requirements	Jeff Riley
1 October 2019	0.3	Added (minimal) CHE documentation	Jeff Riley
21 October 2019	0.4	Added Grids documentation	
		Added Programming Style and Conventions	
		Added Appendices A-E	
		Reformatted for User Guide, Developer Guide etc.	Jeff Riley
18 December 2019	0.5	Updated Grids documentation for kick values	Jeff Riley

User Guide

To do: Introductory text here...

COMPAS Input

COMPAS provides wide-ranging functionality and affords users much flexibility in determining how the synthesis and evolution of stars (single or binary) is conducted. Users configure COMPAS functionality via the use of program options and configuration files, described below.

Program Options

To do: How should we list these? Alphabetically in function-related groups?

To do: document all program options...

allow-rlof-at-birth	boolean to indicate that binaries that have one or both stars in RLOF at birth are allowed to evolve. For binaries that have one or both stars in RLOF at birth, the following actions are taken before evolution of the binary begins: • the masses of the constituent stars are equilibrated • the attributes of the constituent stars are recalculated based on the new masses • the orbit is circularised • the semi-major axis is recalculated • angular momentum is conserved
allow-touching-at-birth	boolean to indicate that binaries that are touching at birth are allowed to evolve. Note that one of the first checks in the BaseBinaryStar::Evolve() function is to check for stars touching and, if they are, the binary is flagged as a merger (both 'StellarMerger' and 'StellarMergerAtBirth' flags are set true) and evolution is stopped. Setting this program option allows such binaries to be included in population statistics.
chemically-homogeneous-evolution	enable/disable Chemically Homogeneous Evolution. Options are {NONE, PESSIMISTIC, OPTIMISTIC}
grid	grid filename (see Grids section below)
logfile-BSE-be-binaries	filename for BSE Be Binaries log file
logfile-BSE-common-envelopes	filename for BSE Common Envelopes log file
logfile-BSE-detailed-output	filename for BSE Detailed Output log file
logfile-BSE-double-compact-objects	filename for BSE Double Compact Objects log file
logfile-BSE-pulsar-evolution	filename for BSE Pulsar Evolution log file
logfile-BSE-rlof-parameters	filename for BSE RLOF Parameters log file
logfile-BSE-supernovae	filename for BSE Supernovae log file
logfile-BSE-system-parameters	filename for BSE System Parameters log file
logfile-SSE-parameters	filename for SSE Parameters log file

logfile-definitions	the name of the file containing log file record specifications
logfile-delimiter	the field delimiter for log file records. Options are {TAB, SPACE, COMMA}
logfile-name-prefix	the string to be prepended to all log file names
log-classes	string classes to determine which log records to write
log-level	numeric indicator to determine which log records to write
debug-classes	string classes to determine which debug statements to write
debug-level	numeric indicator to determine which debug statements to write
debug-to-file	boolean to indicate if debug statements should also be written to file
print-bool-as-string	causes boolean values to be printed as “TRUE” or “FALSE” instead of “1” or “0”
single-star-mass-max	the maximum mass for single star evolution
single-star-mass-min	the minimum mass for single star evolution
single-star-mass-steps	the number of steps for single star evolution

Grids

Grid functionality allows users to specify a grid of initial values for both Single Star Evolution (SSE) and Binary Star Evolution (BSE).

For SSE, users can supply a text file that contains initial mass values and, optionally, metallicity values, and COMPAS will evolve individual stars with those initial values (one star per record).

For BSE, users can supply a text file that contains initial mass and metallicity values for the binary constituent stars, as well as the initial separation or orbital period, and eccentricity, of the binary (one binary star per record of initial values).

Grid File Format

Grid files are comma-separated text files, with column headers denoting the meaning of the data in the column (with an exception for SSE Grid files – see below for details).

Grid files may contain comments. Comments are denoted by the hash/pound character ('#'). The hash character and any text following it on the line in which the hash character appears is ignored. The hash character can appear anywhere on a line - if it is the first character then the entire line is a comment and ignored, or it can follow valid characters on a line, in which case the characters before the hash are processed, but the hash character and any text following it is ignored. Blank lines are ignored.

Notwithstanding the exception for SSE Grid files mentioned above, the first non-comment, non-blank line in a Grid file must be the header record. The header record is a comma-separated list of strings that denote the meaning of the data in each of the columns in the file.

Data records follow the header record. Data records, with an exception for SSE data files described below, are comma-separated lists of non-negative floating-point numbers. Any data field that contains a negative number, or characters that do not convert to floating-point numbers, is considered an error and will cause processing of the Grid file to be abandoned – an error message will be displayed.

Data records are expected to contain the same number of columns as the header record. If a data record contains more columns than the header record, data beyond the number of columns in the header record is ignored. If a data record contains fewer columns than the header record, missing data values (by position) are set equal to 0.0 – a warning message will be displayed.

BSE Grid File

Header Record

The BSE Grid file header record must be a comma-separated list of strings taken from the following list (case is not significant):

Header String	Column meaning
Mass_1	mass value to be assigned to the primary star, in $M_\odot$
Mass_2	mass value to be assigned to the secondary star, in $M_\odot$
Metallicity_1	metallicity value to be assigned to the primary star
Metallicity_2	metallicity value to be assigned to the secondary star
Separation	separation of the stars – the semi-major axis value to be assigned to the binary, in *AU*
Eccentricity	eccentricity value to be assigned to the binary
Period	orbital period value to be assigned to the binary, in *days*
Kick_Velocity_1	value to be used as the (drawn) kick velocity for the primary star should it undergo a supernova event, in *kms^-1*
Kick_Theta_1	value to be as the angle between the orbital plane and the 'z' axis of the supernova vector for the primary star should it undergo a supernova event, in *radians*
Kick_Phi_1	value to be used as the angle between 'x' and 'y', both in the orbital plane of the supernova vector, for the primary star should it undergo a supernova event, in *radians*
Kick_Mean_Anomaly_1	value to be used as the mean anomaly at the instant of the supernova for the primary star should it undergo a supernova event – should be uniform in [0, 2pi] (not range checked)
Kick_Velocity_2	value to be used as the (drawn) kick velocity for the secondary star should it undergo a supernova event, in *kms^-1*
Kick_Theta_2	value to be as the angle between the orbital plane and the 'z' axis of the supernova vector for the secondary star should it undergo a supernova event, in *radians*
Kick_Phi_2	value to be used as the angle between 'x' and 'y', both in the orbital plane of the supernova vector, for the secondary star should it undergo a supernova event, in *radians*
Kick_Mean_Anomaly_2	value to be used as the mean anomaly at the instant of the supernova for the secondary star should it undergo a supernova event – should be uniform in [0, 2pi] (not range checked)

All header strings **in bold** in the table above are required in the header record, with the exception of Separation and Period: one of Separation and Period *must* be present, but both *may* be present.

The header strings not in bold in the table above (the kick-related header strings) are not mandatory. However, if one of the kick-related header strings is present, then *all must* be present.

The order of the columns in the BSE Grid file is not significant.

Data Record

See the general description of data records above.

As for the header record, only one of Separation and Period is required to be present, but both may be present. The period may be used to calculate the separation of the binary. If the separation is present it is used as the value for the semi-major axis of the binary, regardless of whether the period is present (Separation has precedence over Period). If the period is present, but separation is not, the separation is calculated form the masses of the stars and the period given.

Also as for the header record, the kick-related values are not mandatory, but if one of the kick-related values is given, then all must be given.

SSE Grid File

Header Record

The SSE Grid file header record must be a comma-separated list of strings taken from the following list (case is not significant):

Header String	Column meaning
Mass	$M_{\odot}$ mass value () to be assigned to the star
Metallicity	metallicity value to be assigned to the star

The SSE Grid file is only required to list Mass values for each star, with Metallicity values being optional. If the Metallicity column is omitted, the metallicity value assigned to the star is the user-specified value for metallicity via the program options (OPTIONS→Metallicity()).

If the Metallicity column is omitted from the SSE Grid file, the header is optional: if there is only one column of data in the SSE Grid file it is assumed to be the Mass column, and no header is required (though may be present). If the Metallicity column header is present, the the Mass column header is required.

The order of the columns in the SSE Grid file is not significant.

Data Record

See the general description of data records above. As for the header record, only Mass is required to be present, but Metallicity may also be present. If the Metallicity is omitted, the metallicity value assigned to the star is the user-specified value for metallicity via the program options (OPTIONS→Metallicity()).

AIS Input Files

To do: document these (only one?)

COMPAS Output

COMPAS defines several standard log files that may be produced depending upon the simulation type (Single Star Evolution (SSE), or Binary Star Evolution (BSE), and the value of various program options. The standard log files are:

- SSE Parameters log file
- BSE System Parameters log file
- BSE Detailed Output log file
- BSE Double Compact Objects log file
- BSE Common Envelopes log file
- BSE RLOF Parameters log file
- BSE Supernovae log file
- BSE Pulsar Evolution log file
- BSE Be Binaries log file

Standard Log File Record Specifiers

Each standard log file has an associated log file record specifier that defines what data are to be written to the log files. Each record specifier is a list of known properties that are to be written as the log record for the log file associated with the record specifier. Default record specifiers for each of the standard log files are shown in Appendix G – Default Log File Record Specifications. The standard log file record specifiers can be defined by the user at run-time (see Standard Log File Record Specification below).

When specifying known properties, the property name must be prefixed with the property type. The current list of valid property types available for use is:

- STAR_PROPERTY
- STAR_1_PROPERTY
- STAR_2_PROPERTY
- SUPERNOVA_PROPERTY
- COMPANION_PROPERTY
- BINARY_PROPERTY
- PROGRAM_OPTION

The stellar property types (all types except BINARY_PROPERTY AND PROGRAM_OPTION) must be paired with properties from the stellar property list, the binary property type BINARY_PROPERTY with properties from the binary property list, and the program option type PROGRAM_OPTION with properties from the program option property list.

Standard Log File Record Specification

The standard log file record specificiers can be changed at run-time by supplying a definitions file via program option ‘logfile-definitions’ (see Program Options above).

The syntax of the definitions file is fairly simple. The definitions file is expected to contain zero or more log file record specifications, as explained below.

For the following specification:

`::=`	means "expands to" or "is defined as"
`{ x }`	means (possible) repetition: x may appear zero or more times
`[ x ]`	means x is optional: x may appear, or not
`<name>`	is a term (expression)
`"abc"`	means literal string "abc"
`|`	means "or"
`#`	indicates the start of a comment

Logfile Definitions File specification:

```
<def_file>   ::= { <rec_spec> }

<rec_spec>   ::= <rec_name> <op> "{" { [ <props_list> ] } "}" <spec_delim>

<rec_name>   ::= "SSE_PARMS_REC"       |                      # SSE only
                 "BSE_SYSPARMS_REC"    |                      # BSE only
                 "BSE_DCO_REC"         |                      # BSE only
                 "BSE_SNE_REC"         |                      # BSE only
                 "BSE_CEE_REC"         |                      # BSE only
                 "BSE_RLOF_REC"        |                      # BSE only
                 "BSE_BE_BINARIES_REC" |                      # BSE only
                 "BSE_PULSARS_REC"     |                      # BSE only
                 "BSE_DETAILED_REC"                           # BSE only

<op>         ::= "=" | "+=" | "-="

<props_list> ::= <prop_spec> [ <prop_delim> <props_list> ]

<prop_spec>  ::= <prop_type> "::" <prop_name> <delim>

<spec_delim> ::= " " | EOL

<prop_delim> ::= "," | <spec_delim>

<prop_type>  ::= "STAR_PROPERTY"      |                      # SSE only
                 "STAR_1_PROPERTY"    |                      # BSE only
                 "STAR_2_PROPERTY"    |                      # BSE only
                 "SUPERNOVA_PROPERTY" |                      # BSE only
                 "COMPANION_PROPERTY" |                      # BSE only
                 "BINARY_PROPERTY"    |                      # BSE only
                 "PROGRAM_OPTION"                            # SSE or BSE

<prop_name>  ::= valid property name for specified property type
                 (see definitions in constants.h)
```

The file may contain comments. Comments are denoted by the hash/pound character ('#'). The hash character and any text following it on the line in which the hash character appears is ignored by the

parser. The hash character can appear anywhere on a line - if it is the first character then the entire line is a comment and ignored by the parser, or it can follow valid symbols on a line, in which case the symbols before the hash character are parsed and interpreted by the parser.

A log file specification record is initially set to its default value (see Appendix G – Default Log File Record Specifications). The definitions file informs the code as to the modifications to the default values the user wants. This means that the definitions log file is not mandatory, and if the definitions file is not present, or contains no valid record specifiers, the log file record definitions will remain at their default values.

The assignment operator given in a record specification (<op> in the file specification above) can be one of "=", "+=", and "-=". The meanings of these are:

> "=" means that the record specifier should be assigned the list of properties specified in the braced-list following the "=" operator. The value of the record specifier prior to the assignment is discarded, and the new value set as described.

> "+=" means that the list of properties specified in the braced-list following the "+=" operator should be appended to the existing value of the record specifier. Note that the new properties are appended to the existing list, so will appear at the end of the list (properties are printed in the order they appear in the list).

> "-=" means that the list of properties specified in the braced-list following the "-=" operator should be subtracted from the existing value of the record specifier.

Example Log File Definitions File entries:

```
SSE_PARMS_REC = { STAR_PROPERTY::RANDOM_SEED,
                  STAR_PROPERTY::RADIUS, STAR_PROPERTY::MASS,
                  STAR_PROPERTY::LUMINOSITY }


BSE_PULSARS_REC += { STAR_1_PROPERTY::LUMINOSITY
                     STAR_2_PROPERTY::CORE_MASS
                     BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRIME_RSOL
                     COMPANION_PROPERTY::RADIUS }

BSE_PULSARS_REC -= { SUPERNOVA_PROPERTY::TEMPERATURE }

BSE_PULSARS_REC += { PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_NS,
                     BINARY_PROPERTY::ORBITAL_VELOCITY }
```

A full example Log File Record Specifications File is shown in Appendix H.
The record specifications in the definitions file are processed individually in the sequence they appear in the file, and are cumulative: for record specifications pertaining to the same record name, the output of earlier specifications is input to later specifications.

For each record specification:

- Properties requested to be added to an existing record specification that already exist in that record specification are ignored. Properties will not appear in a record specification twice.

- Properties requested to be subtracted from an existing record specification that do not exist in that record specification are ignored.

Note that neither of those circumstances will cause a parse error for the definitions file – in both cases the user's intent is satisfied.

Standard Log File Format

Each standard log file consists three header records followed by data records. Header records and data records are delimiter separated fields, with the delimiter being that specified by the `logfile-delimiter` program option (COMMA, TAB or SPACE), and the fields as specified by the log file record specifier.

The header records for all files are:

Header record 1: Column Data Type Names
Header record 2: Column Units (where applicable)
Header record 3: Column Headings

Column Data Type Names are taken from the set {BOOL, INT, FLOAT, STRING}, where

BOOL — the data value will be a boolean value. Boolean data values will be recorded in the log file in either numerical format (1 or 0, where 1 = TRUE and 0 = FALSE), or string format ('TRUE' or 'FALSE'), depending upon the value of the `print-bool-as-string` program option.

INT — the data value will be an integer number

FLOAT — the data value will be a floating-point number

STRING — the data value will be a text string

Column Units is a string indicating the units of the corresponding data values (e.g. 'Msol*AU^2*yr^-1', 'Msol', 'AU', etc.). The Column Units value may be blank where units are not applicable, or may be one of:

'Count' — the data value is the total of a counted entity
'State' — the data value describes a state (e.g. 'Disbound' state is 'TRUE' or 'FALSE')
'Event' — the data value describes an event status (e.g. 'Simultaneous_RLOF' is 'TRUE')

Column Headings are string labels that describe the corresponding data values. The heading strings for stellar properties of constituent stars of a binary will have appropriate identifiers appended. That is, heading strings for:

STAR_1_PROPERTY::*properties* will have "_1" appended
STAR_2_PROPERTY::*properties* will have "_2" appended
SUPERNOVA_PROPERTY::*properties* will have "_SN" appended
COMPANION_PROPERTY::*properties* will have "_CP" appended

Data types, units, and column headings for stellar properties are listed in Appendix D, and Appendix E for binary properties.

Developer Guide

To do: Introductory text here…

Class Hierarchy

The main class for single star evolution is the **Star** class.

The Star class is a wrapper that abstracts away the details of the star and the evolution. Internally the Star class maintains a pointer to an object representing the star being evolved, with that object being an instance of one of the following classes:

MS_lte_07
MS_gt_07
CH
HG
FGB
CHeB
EAGB
TPAGB
HeMS
HeHG
HeGB
HeWD
COWD
ONeWD
NS
BH
MR

which track the phases from Hurley et al. 2000, with the exception of the CH class for Chemically Homogeneous stars, which is not described in Hurley et al. 2000.

Three other SSE classes are defined:

BaseStar
MainSequence
GiantBranch

These extra classes are included to allow inheritance of common functionality.

The BaseStar class is the main class for the underlying star object held by the Star class. The BaseStar class defines all member variables, and many member functions that provide common functionality. Similarly, the MainSequence and GiantBranch classes provide repositories for common functionality for main sequence and giant branch stars respectively.

The inheritance chain follows the phases described in Hurley et al. 2000 (again, with the exception of the CH, not described by Hurley et al. 2000), and is as follows:

```
Star
  BaseStar → MainSequence → ( MS_lte_07   )
```

```
                                ( MS_gt_07    ) → CH
                                ( GiantBranch ) → HG → FGB → CheB → EAGB →

→ TPAGB → HeMS → HeHG → HeGB → HeWD → COWD → OneWD → NS → BH → MR
```

CH (Chemically Homogeneous) stars inherit from MS_gt_07 because (in this implementation) they are just (large) main sequence stars that have a static radius.

HG (Hertzsprung Gap) stars inherit from the GiantBranch because they share the Giant Branch Parameters described in Hurley et al. 2000, section 5.2.

Each class in the inheritance chain has its own set of member functions that calculate various attributes of the star according to the phase the class represents (using the equations and parameters from Hurley et al. 2000 where applicable).

Evolution Model

The stellar evolution model is driven by the Evolve() function in the Star class which evolves the star through its entire lifetime by doing the following:

DO:

1. calculate time step
   calculate the giant branch parameters (as necessary)
   calculate the timescales
   choose time step

2. save the state of the underlying star object

3. DO:
   a) evolve a single time step

   b) if too much change
      revert to the saved state
      reduce the size of the time step

   UNTIL timestep not reduced

4. resolve any mass loss
   a) update initial mass (mass0)
   b) update age after mass loss
   c) apply mass transfer rejuvenation factor

5. evolve to the next stellar type if necessary

WHILE the the underlying star object is not one of: { HeWD, COWD, ONeWD, NS, BH, MR }

Evolving the star through a single time step (step 3a above) is driven by the UpdateAttributesAndAgeOneTimestep() function in the BaseStar class which does the following:

1. check if the star should be a massless remnant

2. check if the star is a supernova

if evolution on the phase should be performed

3. evolve the star on the phase – update stellar attributes
4. check if the star should evolve off the current phase to a different stellar type

else

5. ready the star for the next time step

Evolving the star on its current phase, and off the current phase and preparing to evolve to a different stellar type, is handled by two functions in the BaseStar class: EvolveOnPhase() and ResolveEndOfPhase().

The EvolveOnPhase() function does the following:

1. Calculate Tau

2. Calculate CO Core Mass
3. Calculate Core Mass
4. Calculate He Core Mass

5. Calculate Luminosity
6. Calculate Radius

7. Calculate Envelope Mass

8. Calculate Perturbation Mu
9. Perturb Luminosity and Radius

10. Calculate Temperature

11. Resolve possible envelope loss

Each of the calculations in the EvolveOnPhase() function is performed in the context of the star evolving on its current phase. Each of the classes implements their own version of the calculations (via member functions) – some may inherit functions from the inheritance chain, while others might just return the value unchanged if the calculation is not relevant to their stellar type.

The ResolveEndOfPhase() function does the following:

1. Resolve possible envelope loss

2. Calculate Tau

3. Calculate CO Core Mass
4. Calculate Core Mass
5. Calculate He Core Mass

6. Calculate Luminosity
7. Calculate Radius

8. Calculate Envelope Mass

9. Calculate Perturbation Mu
10. Perturb Luminosity and Radius

11. Calculate Temperature

12. Evolve star to next phase

Each of the calculations in the ResolveEndOfPhase() function is performed in the context of the star evolving off its current phase to the next phase.

The remainder of the code (in general terms) supports these main driver functions.

Class Hierarchy

The main class for single star evolution is the **BinaryStar** class. The BinaryStar class is a wrapper that abstracts away the details of the binary star and the evolution. Internally the BinaryStar class maintains a pointer to an object representing the binary star being evolved, with that object being an instance of the BaseBinaryStar class.

The BaseBinaryStar class is the main class for the underlying binary star object held by the BinaryStar class. The BaseBinaryStar class defines all member variables that pertain specifically to a binary star, and many member functions that provide binary-star specific functionality. Internally the BaseBinaryStar class maintains pointers to the two BinaryConstituentStar class objects that constitute the binary star.

The BinaryConstituentStar class inherits from the Star class, so objects instantiated from the BinaryConstituentStar class inherit the characteristics of the Star class, particularly the stellar evolution model. The BinaryConstituentStar class defines member variables and functions that pertain specifically to a constituent star of a binary system but that do not (generally) pertain to single stars that are not part of a binary system (there are some functions that are defined in the BaseStar class and its derived classes that deal with binary star attributes and behaviour – in some cases the stellar attributes that are required to make these calculations reside in the BaseStar class so it is easier and cleaner to define the functions there).

The inheritance chain is as follows:

```
BinaryStar → BaseBinaryStar

(Star → )       BinaryConstituentStar (star1)
(Star → )       BinaryConstituentStar (star2)
```

Evolution Model

The binary evolution model is driven by the Evolve() function in the BaseBinaryStar class which evolves the star through its entire lifetime by doing the following:

```
if (touching OR secondary too small)
        STOP = true
else
        calculate initial time step
        STOP = false

DO WHILE !STOP AND !max iterations:

        evolve a single time step
                evolve each constituent star a single time step (see SSE evolution)

        if  (disbound OR touching OR Massless Remnant)
                STOP = true
        else
                evaluate the binary
                        calculate lambdas if necessary
                        calculate zetas if necessary

                        calculate mass transfer
                        calculate winds mass loss

                        if common envelope
                                resolve common envelope
                        else if supernova
                                resolve supernova
                        else
                                resolve mass changes

                        evaluate supernovae
                        resolve tides
                        calculate total energy and angular momentum
                        update magnetic field and spin: both constituent stars

                if (disbound OR touching OR merger)
                        STOP = true
                else
                        if NS+BH
                                resolve coalescence

                                if AIS exploratory phase
                                        calculate DCO Hit

                                STOP = true
                        else
                                if (WD+WD OR max time)
                                        STOP = true
                                else
                                        if NOT max iterations
                                                calculate new time step
```

OBJECT IDENTIFIERS

All objects (instantiations of a class) are assigned unique object identifiers of type OBJECT_ID (unsigned long int - see constants.h for the typedef). In the original COMPAS code, all binary star objects were assigned unique object ids – this is just an extension of that so that all objects created in the COMPAS code are assigned unique ids. The purpose of the unique object id is to aid in object tracking and debugging.

As well as unique object ids, all objects are assigned an object type (of type OBJECT_TYPE – see constants.h for the enum class declaring OBJECT_TYPE), and a stellar type where applicable (of type STELLAR_TYPE – see constants.h for the enum class declaring STELLAR_TYPE).

Objects should expose the following functions:

```
OBJECT_ID       ObjectId() const      { return m_ObjectId; }
OBJECT_TYPE     ObjectType() const    { return m_ObjectType; }
STELLAR_TYPE    StellarType() const   { return m_StellarType; }
```

If any of the functions are not applicable to the object, then they must return "*::NONE (all objects should implement ObjectId() correctly).

Any object that uses the Errors service (i.e. the SHOW_* macros) ***must*** expose these functions: the functions are called by the SHOW_* macros (the Errors service is described later in this document).

SERVICES

A number of services have been provided to help simplify the code. These are:

- Program Options
- Random Numbers
- Logging and Debugging
- Error Handling

The code for each service is encapsulated in a singleton object (an instantiation of the relevant class). The singleton design pattern allows the definition of a class that can only be instantiated once, and that instance effectively exists as a global object available to all the code without having to be passed around as a parameter. Singletons are a little anti-OO, but provided they are used judiciously are not necessarily a bad thing, and can be very useful in certain circumstances.

PROGRAM OPTIONS

A Program Options service is provided encapsulated in a singleton object (an instantiation of the Options class).

The Options class member variables are private, and public getter functions have been created for the program options currently used in the code.

The Options service can be accessed by referring to the Options::Instance() object. For example, to retrieve the value of the "quiet" program option, call the Quiet() getter function:

```
bool quiet = Options::Instance()→Quiet();
```

Since that could become unwieldy, there is a convenience macro to access the Options service. The macro just defines "OPTIONS" as "Options::Instance()", so retrieving the value of the "quiet" program option can be written as:

```
bool quiet = OPTIONS→Quiet();
```

The Options service must be initialised before use. Initialise the Options service by calling the Initialise() function:

```
COMMANDLINE_STATUS programStatus = OPTIONS->Initialise(argc, argv);
```

(see constants.h for details of the COMMANDLINE_STATUS type)

RANDOM NUMBERS

A Random Number service is provided, with the gsl Random Number Generator encapsulated in a singleton object (an instantiation of the Rand class).

The Rand class member variables are private, and public functions have been created for random number functionality required by the code.

The Rand service can be accessed by referring to the Rand::Instance() object. For example, to generate a uniform random floating point number in the range [0, 1), call the Random() function:

```
double u = Rand::Instance()→Random();
```

Since that could become unwieldy, there is a convenience macro to access the Rand service. The macro just defines "RAND" as "Rand::Instance()", so calling the Random() function can be written as:

```
double u = RAND→Random();
```

The Rand service must be initialised before use. Initialise the Rand service by calling the Initialise() function:

```
RAND->Initialise();
```

Dynamically allocated memory associated with the gsl random number generator should be returned to the system by calling the Free() function:

```
RAND→Free();
```

before exiting the program.

The Rand service provides the following public member functions:

void Initialise()

Initialises the gsl random number generator. If the environment variable GSL_RNG_SEED exists, the gsl random number generator is seeded with the value of the environment variable, otherwise it is seeded with the current time.

void Free()

Frees any dynamically allocated memory.

unsigned long int Seed(const unsigned long p_Seed)

Sets the seed for the gsl random number generator to p_Seed. The return value is the seed.

unsigned long int DefaultSeed()

Returns the gsl default seed (gsl_rng_default_seed)

double Random(void)

Returns a random floating point number uniformly distributed in the range [0.0, 1.0)

double Random(const double p_Lower, const double p_Upper)

Returns a random floating point number uniformly distributed in the range [p_Lower, p_Upper), where p_Lower <= p_Upper.

(p_Lower and p_Upper will be swapped if p_Lower > p_Upper as passed)

double RandomGaussian(const double p_Sigma)

Returns a Gaussian random variate, with mean 0.0 and standard deviation p_Sigma

int RandomInt(const int p_Lower, const int p_Upper)

Returns a random integer number uniformly distributed in the range [p_Lower, p_Upper), where p_Lower <= p_Upper.

(p_Lower and p_Upper will be swapped if p_Lower > p_Upper as passed)

int RandomInt(const int p_Upper)

Returns a random integer number uniformly distributed in the range [0, p_Upper), where 0 <= p_Upper. Returns 0 if p_Upper < 0.

LOGGING & DEBUGGING

A logging and debugging service is provided encapsulated in a singleton object (an instantiation of the Log class).

The logging functionality was first implemented when the Single Star Evolution code was refactored, and the base-level of logging was sufficient for the needs of the SSE code. Refactoring the Binary Star Evolution code highlighted the need for expanded logging functionality. To provide for the logging needs of the BSE code, new functionality was added almost as a wrapper around the original, base-level logging functionality. Some of the original base-level logging functionality has almost been rendered redundant by the new functionality implemented for BSE code, but it remains (almost) in its entirety because it may still be useful in some circumstances.

When the base-level logging functionality was created, debugging functionality was also provided, as well as a set of macros to make debugging and the issuing of warning messages easier. A set of logging macros was also provided to make logging easier. The debug macros are still useful, and their use is encouraged (rather than inserting print statements using std::cout or std::cerr).

When the BSE code was refactored, some rudimentary error handling functionality was also provided in the form of the Errors service - an attempt at making error handling easier. Some of the functionality provided by the Errors service supersedes the DBG_WARN* macros provided as part of the Log class, but the DBG_WARN* macros are still useful in some circumstances (and in fact are still used in various places in the code). The LOG* macros are somewhat less useful, but remain in case the original base-level logging functionality (that which underlies the expanded logging functionality) is used in the future (as mentioned above, it could still be useful in some circumstances). The Errors service is described later in this document.

The expanded logging functionality introduces Standard Log Files - described later in this document.

Base-Level Logging

The Log class member variables are private, and public functions have been created for logging and debugging functionality required by the code.

The Log service can be accessed by referring to the Log::Instance() object. For example, to stop the logging service, call the Stop() function:

```
Log::Instance()→Stop();
```

Since that could become unwieldy, there is a convenience macro to access the Log service. The macro just defines “LOGGING” as “Log::Instance()”, so calling the Stop() function can be written as:

```
LOGGING→Stop();
```

The Log service must be initialised before logging and debugging functionality can be used. Initialise logging by calling the Start() function:

LOGGING→Start(

outputPath,	- location of logfiles
logfilePrefix,	- prefix for logfile names (can be blank)
logLevel,	- logging level (integer) (see below)
logClasses,	- array of enabled logging classes (strings) (see below)
debugLevel,	- debug level (integer) (see below)
debugClasses,	- array of enabled debug classes (strings) (see below)
debugToLogfile,	- flag (boolean) indicating whether debug statements should also be written to log file
errorsToLogfile,	- flag (boolean) indicating whether error messages should also be written to log file
delimiter	- string (usually single character) to be used as the default field delimiter in log file records

)

Start() returns nothing (void function).

The Log service should be stopped before exiting the program – this ensures all open log files are flushed to disk and closed properly. Stop logging by calling the Stop() function:

LOGGING→Stop()

Stop() flushes any closes any open log files.
Stop() returns nothing (void function).

The Log service provides the following public member functions:

void Start(

outputPath,	- location of logfiles- the directory in which log files will be created
logfilePrefix,	- prefix for logfile names (can be blank)
logLevel,	- logging level (integer) (see below)
logClasses,	- array of enabled logging classes (strings) (see below)
debugLevel,	- debug level (integer) (see below)
debugClasses,	- array of enabled debug classes (strings) (see below)
debugToLogfile,	- flag (boolean) indicating whether debug statements should also be written to log file
errorsToLogfile,	- flag (boolean) indicating whether error messages should also be written to log file
delimiter	- string (usually single character) to be used as the default field delimiter in log file records

)

Initialises the logging and debugging service. Logging parameters are set per the program options specified (using default values if no options are specified by the user). Log files to which debug statements and error messages will be created and opened if required.

void Stop()

Stops the logging and debugging service. All open log files are flushed to disk and closed (including and Standard Log Files open - see description of Standard Log Files later in this document).

bool Enabled()

Returns a boolean indicating whether the Log service is enabled – true indicates the Log service is enable and available; false indicates the Log service is not enable and so not available.

int Open(

logFileName,	- the name of the log file to be created and opened. This should be the filename only – the path, prefix and extensions are added by the logging service. If the file already exists, the logging service will append a version number to the name if necessary (see *append* parameter below).
append,	- flag (boolean) indicating whether the file should be opened in append mode (i.e. existing data is preserved) and new records written to the file appended, or whether a new file should be opened (with version number if necessary).
timeStamps,	- flag (boolean) indicating whether timestamps should be written with each log file record.
labels	- flag (boolean) indicating whether a label should be written with each log record. This is useful when different types of logging data is being written to the same log file file.
delimiter	- (optional) string (usually single character) to be used as the field delimiter in this log file. If *delimiter* is not provided the default delimiter is used (as parameter to Start()).

)

Opens a log file. If the append parameter is true and a file name *logFilename* exists, the existing file will be opened and the existing contents retained, otherwise a new file will be created and opened (not a Standard Log File - see description of Standard Log Files later in this document).

New log files are created at the path specified by the *outputPath* parameter passed to the Start() function.

The filename is prefixed by the *logfilePrefix* parameter passed to the Start() function.

The file extension is based on the *delimiter* parameter passed to the Start() function: if the delimiter is TAB or SPACE, the file extension is ".txt"; if the delimiter is COMMA the file extension is ".csv".

If a file with the name as given by the *logFilename* parameter already exists, and the *append* parameter is false, a version number will be appended to the filename (before the extension).

The log file identifier (integer) is returned to the caller - a value of -1 indicates the log file was not opened successfully. Multiple log files can be open simultaneously – referenced by the identifier returned.

bool Close(
  logFileId, - the identifier of the log file to be closed (as returned by Open())
)

Closes the log file specified by the *logFileId* parameter. If the log file specified by the *logFileId* parameter is open, it is flushed to disk and closed. The function returns a boolean indicating whether the file was closed successfully.

bool Write(
  logFileId, - the identifier of the log file to be written

  logClass, - string specifying the log class to be associated with the record to be written. Can be blank.

  logLevel, - integer specifying the log level to be associated with the record to be written.

  logString, - the string to be written to the log file.
)

Writes an unformatted record to the specified log file. If the Log service is enabled and the specified log file is active, and the log class and log level passed are enabled (see discussion of log classes and levels), the string is written to the file.

The function returns a boolean indicating whether the record was written successfully. If an error occurred the log file will be disabled.

bool Put(

logFileId,	- the identifier of the log file to be written
logClass,	- string specifying the log class to be associated with the record to be written. Can be blank.
logLevel,	- integer specifying the log level to be associated with the record to be written.
logString,	- the string to be written to the log file.

)

Writes a minimally formatted record to the specified log file. If the Log service is enabled and the specified log file is active, and the log class and log level passed are enabled (see discussion of log classes and levels), the string is written to the file.

If labels are enabled for the log file, a label will be prepended to the record. The label text will be the *logClass* parameter.

If timestamps are enabled for the log file, a formatted timestamp is prepended to the record. The timestamp format is *yyyymmdd hh:mm:ss*.

The function returns a boolean indicating whether the record was written successfully. If an error occurred the log file will be disabled.

bool Debug(

debugClass,	- string specifying the debug class to be associated with the record to be written. Can be blank.
debugLevel,	- integer specifying the debug level to be associated with the record to be written.
debugString,	- the string to be written to stdout (and optionally to file)

)

Writes *debugString* to stdout and, if logging is active and so configured (via program option debug-to-file), writes *debugString* to the debug log file.

The function returns a boolean indicating whether the record was written successfully. If an error occurred writing to the debug log file, the log file will be disabled.

bool DebugWait(

debugClass,	- string specifying the debug class to be associated with the record to be written. Can be blank.
debugLevel,	- integer specifying the debug level to be associated with the record to be written.
debugString,	- the string to be written to stdout (and optionally to file)

)

Writes *debugString* to stdout and, if logging is active and so configured (via program option debug-to-file), writes *debugString* to the debug log file, then waits for user input.

The function returns a boolean indicating whether the record was written successfully. If an error occurred writing to the debug log file, the log file will be disabled.

bool Error(

errorString,	- the string to be written to stdout (and optionally to file)

)

Writes *errorString* to stdout and, if logging is active and so configured (via program option errors-to-file), writes *errorString* to the error log file, then waits for user input.

The function returns a boolean indicating whether the record was written successfully. If an error occurred writing to the error log file, the log file will be disabled.

void Squawk(

squawkString,	- the string to be written to stderr

)

Writes *squawkString* to stderr.

void Say(

sayClass,	- string specifying the log class to be associated with the record to be written. Can be blank.
sayLevel,	- integer specifying the log level to be associated with the record to be written.
sayString,	- the string to be written to stdout

)

Writes *sayString* to stdout.

The filename to which debug records are written when Start() parameter “debugToLogfile” is true is declared in constants.h – see the LOGFILE enum class and associate descriptor map LOGFILE_DESCRIPTOR. Currently the name is ‘Debug_Log’.

Extended Logging

The Logging service was extended to support standard log files for Binary Star Evolution (SSE also uses the extended logging). The standard log files defined are:

- SSE Parameters log file
- BSE System Parameters log file
- BSE Detailed Output log file
- BSE Double Compact Objects log file
- BSE Common Envelopes log file
- BSE RLOF Parameters log file
- BSE Supernovae log file
- BSE Pulsar Evolution log file
- BSE Be Binaries log file

The Logging service maintains information about each of the standard log files, and will handle creating, opening, writing and closing the files. For each execution of the COMPAS program that evolves binary stars, one (and only one) of each of the log file listed above will be created, except for the Detailed Output log in which case there will be one log file created for each binary star evolved.

The Log service provides the following public member functions specifically for managing standard log files:

void LogSingleStarParameters(Star, Id**)**
void LogBinarySystemParameters(Binary**)**
void LogDetailedOutput(Binary, Id**)**
void LogDoubleCompactObject(Binary**)**
void LogCommonEnvelope(Binary**)**
void LogRLOFParameters(Binary**)**
void LogSupernovaDetails(Binary**)**
void LogPulsarEvolutionParameters(Binary**)**
void LogBeBinary(Binary**)**

Each of the BSE functions is passed a pointer to the binary star for which details are to be logged, and in the case of the Detailed Output log file, an integer identifier (typically the loop index of the binary star) that is appended to the log file name.

The SSE function is passed a pointer to the single star for which details are to be logged, and an integer identifier (typically the loop index of the star) that is appended to the log file name.

Each of the functions listed above will, if necessary, create and open the appropriate log file. Internally the Log service opens (creates first if necessary) once at first use, and keeps the files open for the life of the program.

The Log service provides a further two functions to manage standard log files:

bool CloseStandardFile(LogFile**)**

Flushes and closes the specified standard log file. The function returns a boolean indicating whether the log file was closed successfully.

bool CloseAllStandardFiles()

Flushes and closes all currently open standard log files. The function returns a boolean I indicating whether all standard log files were closed successfully.

Standard log file names are supplied via program options, with default values declared in constants.h.

Logging & Debugging Macros

Logging Macros

The following macros are provide for logging:

LOG(id, …)
Writes log record to log file specified by “id”. Use:

LOG(id, string)	writes “string” to log file specified by “id”
LOG(id, level, string)	writes “string” to log file specified by “id” if “level” is <= “id” in Start()
LOG(id, class, level, string)	writes “string” to log file specified by “id” if “class” is in “logClasses” in Start() and if “level” is <= “logLevel” in Start()

default “class” is “”; default “level” is 0

Examples:

```
LOG(SSEfileId, “This is a log record”);
LOG(OutputFile2Id, “The value of x is “ << x << “ km”);
LOG(MyLogfileId, 2, “Log string”);
LOG(SSEfileId, “CHeB”, 4, “This is a CHeB only log record”);
```

LOG_ID(id, …)
Writes log record prepended with calling function name to log file. Use:

LOG_ID(id)	writes name of calling function to log file specified by "id"
LOG_ID(id, string)	writes "string" prepended with name of calling function to log file specified by "id"
LOG_ID(id, level, string)	writes "string" prepended with name of calling function to log file specified by "id" if "level" is <= "logLevel" in Start()
LOG_ID(id, class, level, string)	writes "string" prepended with name of calling function to log file specified by "id" if "class" is in "logClasses" in Start() and if "level" is <= "logLevel" in Start()

default "class" is ""; default "level" is 0

Examples:

```
LOG_ID(Outf1Id)
LOG_ID(Outf2Id, "This is a log record");
LOG_ID(MyLogfileId, "The value of x is " << x << " km");
LOG_ID(OutputFile2Id, 2, "Log string");
LOG_ID(CHeBfileId, "CHeB", 4, "This is a CHeB only log record");
```

LOG_IF(id, cond, …)
Writes log record to log file if the condition given by "cond" is met. Use:

LOG_IF(id, cond, string)	writes "string" to log file specified by "id" if "cond" is true
LOG_IF(id, cond, level, string)	writes "string" to log file specified by "id" if "cond" is true and if "level" is <= "logLevel" in Start()
LOG_IF(id, cond, class, level, string)	writes "string" to log file specified by "id" if "cond" is true and if "class" is in "logClasses" in Start() and if "level" is <= "logLevel" in Start()

"cond" is any logical statement and is required; default "class" is ""; default "level" is 0

Examples:

```
LOG_IF(MyLogfileId, a > 1.0, "This is a log record");
LOG(SSEfileId, (b == c && a > x), "The value of x is " << x << " km");
LOG(CHeBfileId, flag, 2, "Log string");
LOG(SSEfileId, (x >= y), "CHeB", 4, "This is a CHeB only log record");
```

LOG_ID_IF(id, ...)

Writes log record prepended with calling function name to log file if the condition given by “cond” is met. Use: see LOG_ID(id, …) and LOG_IF(id, cond, …) above.

The logging macros described above are provided in a verbose variant. The verbose macros function the same way as their non-verbose counterparts, with the added functionality that the log records written to the log file will be reflected on stdout as well. The verbose logging macros are:

LOGV(id, ...)
LOGV_ID(id, ...)
LOGV_IF(id, cond, ...)
LOGV_ID_IF(id, cond, …)

A further four macros are provided that allow writing directly to stdout rather than the log file. These are:

SAY(…)
SAY_ID(…)
SAY_IF(cond, …)
SAY_ID_IF(cond, ...)

The SAY macros function the same way as their LOG counterparts, but write directly to stdout instead of the log file. The SAY macros honour the logging classes and level.

Debugging Macros

A similar set of macros is also provided for debugging purposes.

The debugging macros write directly to stdout rather than the log file, but their output can also be written to the log file if desired (see the debugToLogfile parameter of Start(), and the debug-to-file program option described above).

A major difference between the logging macros and the debugging macros is that the debugging macros can be defined away. The debugging macro definitions are enclosed in an #ifdef enclosure, and are only present in the source code if #DEBUG is defined. This means that if #DEBUG is not defined (#undef), all debugging statements using the debugging macros will be removed from the source code by the preprocessor before the source is compiled. Un-defining #DEBUG not only prevents bloat of unused code in the executable, it improves performance. Many of the functions in the code are called hundreds of thousands, if not millions, of times as the stellar evolution proceeds. Even if the debugging classes and debugging level are set so that no debug statement is displayed, just checking the debugging level every time a function is called increases the run-time of the program. The suggested us is to enable the debugging macros (#define DEBUG) while developing new code, and disable them (#undef DEBUG) to produce a production version of the executable.

The debugging macros provided are:

DBG(…)	analgous to the LOG(…) macro
DBG_ID(…)	analgous to the LOG_ID(…) macro
DBG_IF(cond, …)	analgous to the LOG_IF(…) macro
DBG_ID_IF(cond, …)	analgous to the LOG_ID_IF(…) macro

Two further debugging macros are provided:

DBG_WAIT(…)
DBG_WAIT_IF(cond, …)

The DBG_WAIT macros function in the same way as their non-wait counterparts (DBG(…) and DBG_IF(cond, …) with the added functionality that they will pause execution of the program and wait for user input before proceeding.

A set of macros for printing warning message is also provided. These are the DBG_WARN macros:

DBG_WARN(...)	analgous to the LOG(…) macro
DBG_WARN_ID(...)	analgous to the LOG_ID(…) macro
DBG_WARN_IF(...)	analgous to the LOG_IF(…) macro
DBG_WARN_ID_IF(...)	analgous to the LOG_ID_IF(…) macro

The DBG_WARN macros write to stdout via the SAY macro, so honour the logging classes and level, and are not written to the debug or errors files.

Note that the “id” parameter of the “LOG” macros (to specify the logfileId) is not required for the DBG macros (the filename to which debug records are written is declared in constants.h – see the LOGFILE enum class and associate descriptor map LOGFILE_DESCRIPTOR).

ERROR HANDLING

An error handling service is provided encapsulated in a singleton object (an instantiation of the Errors class).

The Errors service provides global error handling functionality. Following is a brief description of the Errors service (full documentation coming soon...):

Errors are defined in the error catalog in constants.h (see ERROR_CATALOG). It could be useful to move the catalog to a file so it can be changed without changing the code, or even have multiple catalogs provided for internationalisation – a task for later.

Errors defined in the error catalog have a scope and message text. The scope is used to determine when/if an error should be printed.

The current values for scope are:

NEVER	the error will not be printed
ALWAYS	the error will always be printed
FIRST	the error will be printed only on the first time it is encountered anywhere in the program
FIRST_IN_OBJECT_TYPE	the error will be printed only on the first time it is encountered anywhere in objects of the same type (e.g. Binary Star objects)
FIRST_IN_STELLAR_TYPE	the error will be printed only on the first time it is encountered anywhere in objects of the same stellar type (e.g. HeWD Star obejcts)
FIRST_IN_OBJECT_ID	the error will be printed only on the first time it is encountered anywhere in an object instance
FIRST_IN_FUNCTION	the error will be printed only on the first time it is encountered anywhere in the same function of an object instance (i.e. will print more than once if encountered in the same function name in different objects)

The Errors service provides methods to print both warnings and errors - essentially the same thing, but warning messages are prefixed with "WARNING:", whereas error messages are prefixed with "ERROR:".

Errors and warnings are printed by using the macros defined in ErrorsMacros.h. They are:

Error macros:

SHOW_ERROR(error_number)
Prints "ERROR: " followed by the error message associated with "error_number" (from the error catalog)

SHOW_ERROR(error_number, error_string)
Prints "ERROR: " followed by the error message associated with "error_number" (from the error catalog), and appends "error_string"

SHOW_ERROR_IF(cond, error_number)
If "cond" is TRUE, prints "ERROR: " followed by the error message associated with "error_number" (from the error catalog)

SHOW_ERROR_IF(cond, error_number, error_string)
If "cond" is TRUE, prints "ERROR: " followed by the error message associated with "error_number" (from the error catalog), and appends "error_string"

Warning macros:

SHOW_WARN(error_number)
Prints "WARNING: " followed by the error message associated with "error_number" (from the error catalog)

SHOW_WARN(error_number, error_string)
Prints "WARNING: " followed by the error message associated with "error_number" (from the error catalog), and appends "error_string"

SHOW_WARN_IF(cond, error_number)
If "cond" is TRUE, prints "WARNING: " followed by the error message associated with "error_number" (from the error catalog)

SHOW_WARN_IF(cond, error_number, error_string)
If "cond" is TRUE, prints "WARNING: " followed by the error message associated with "error_number" (from the error catalog), and appends "error_string"

Error and warning message always contain:

The object id of the calling object
The object type of the calling object
The stellar type of the calling object (will be "NONE" if the calling object is not a star-type object)
The function name of the calling function

Any object that uses the Errors service (i.e. the SHOW_* macros) must expose the following functions:

```
OBJECT_ID       ObjectId() const      { return m_ObjectId; }
OBJECT_TYPE     ObjectType() const    { return m_ObjectType; }
STELLAR_TYPE    StellarType() const   { return m_StellarType; }
```

These functions are called by the SHOW_* macros. If any of the functions are not applicable to the object, then they must return "*::NONE (all objects should implement ObjectId() correctly).

The filename to which error records are written when Start() parameter “errorsToLogfile” is true is declared in constants.h – see the LOGFILE enum class and associate descriptor map LOGFILE_DESCRIPTOR. Currently the name is ‘Error_Log’.

FLOATING-POINT COMPARISONS

Floating-point comparisons are inherently problematic. Testing floating-point numbers for equality, or even inequality, is fraught with problems due to the internal representation of floating-point numbers: floating-point numbers are stored with a fixed number of binary digits, which limits their precision and accuracy. The problems with floating-point comparisons are even more evident if one or both of the numbers being compared are the results of (perhaps several) floating-point operations (rather than comparing constants).

To avoid the problems associated with floating-point comparisons it is (almost always) better to do any such comparisons with a tolerance rather than an absolute comparison. To this end, a floating-point comparison function has been provided, and (almost all of) the floating-point comparisons in the code have been changed to use that function. The function uses both an absolute tolerance and a relative tolerance, which are both declared in constants.h. Whether the function uses a tolerance or not can be changed by #define-ing or #undef-ing the "COMPARE_WITH_TOLERANCE" flag in constants.h (so the change is a compile-time change, not run-time).

The compare function is defined in utils.h and is implemented as follows:

```
static int Compare(const double p_X, const double p_Y) {
#ifdef COMPARE_WITH_TOLERANCE
   return (fabs(p_X - p_Y) <= max(FLOAT_TOLERANCE_ABSOLUTE,
                                  FLOAT_TOLERANCE_RELATIVE *
                                  max(fabs(p_X),
                                      fabs(p_Y)))) ? 0 : (p_X < p_Y ? -1 : 1);
#else
    return (p_X == p_Y) ? 0 : (p_X < p_Y ? -1 : 1);
#endif
```

If COMPARE_WITH_TOLERANCE is defined, p_X and p_Y are compared with tolerance values, whereas if COMPARE_WITH_TOLERANCE is not defined the comparison is an absolute comparison.

The function returns an integer indicating the result of the comparison:

-1	indicates that p_X is considered to be less than p_Y
0	indicates p_X and p_Y are considered to be equal
+1	indicates that p_X is considered to be greater than p_Y

The comparison is done using both an absolute tolerance and a relative tolerance. The tolerances can be defined to be the same number, or different numbers. If the relative tolerance is defined as 0.0, the comparison is done using the absolute tolerance only, and if the absolute tolerance is defined as 0.0 the comparison is done with the relative tolerance only.

Absolute tolerances are generally more effective when the numbers being compared are small – so using an absolute tolerance of (say) 0.0000005 is generally effective when comparing single-digit numbers (or so), but is less effective when comparing numbers in the thousands or millions. For comparisons of larger numbers a relative tolerance is generally more effective (the actual tolerance is wider because the relative tolerance is multiplied by the larger absolute value of the numbers being compared).

There is a little overhead in the comparisons even when the tolerance comparison is disabled, but it shouldn't be prohibitive.

CONSTANTS FILE – constants.h

Brief documentation – more details to come…

As well as plain constant values, many distribution and prescription identifiers are declared in constants.h. In the original code there swer just declared as (mostly) integer constants. These have been changed to enum classes, with each enum class having a corresponding map of labels. The benefit is that the values of a particular (e.g.) prescription are limited to the values declared in the enum class, rather than any integer value, so the compiler will complain if an incorrect value is inadvertently used to reference that prescription.

For example, the Common Envelope Lambda Prescriptions are declared in constants.h thus:

```
enum class CE_LAMBDA_PRESCRIPTION: int {
     FIXED, LOVERIDGE, NANJING, KRUCKOW, DEWI
};

const std::unordered_map<CE_LAMBDA_PRESCRIPTION, std::string>
CE_LAMBDA_PRESCRIPTION_LABEL = {
    { CE_LAMBDA_PRESCRIPTION::FIXED,     "LAMBDA_FIXED" },
    { CE_LAMBDA_PRESCRIPTION::LOVERIDGE, "LAMBDA_LOVERIDGE" },
    { CE_LAMBDA_PRESCRIPTION::NANJING,   "LAMBDA_NANJING" },
    { CE_LAMBDA_PRESCRIPTION::KRUCKOW,   "LAMBDA_KRUCKOW" },
    { CE_LAMBDA_PRESCRIPTION::DEWI,      "LAMBDA_DEWI" }
};
```

Note that the values allowed for variables of type `CE_LAMBDA_PRESCRIPTION` are limited to `FIXED`, `LOVERIDGE`, `NANJING`, `KRUCKOW` and `DEWI` – anything else will cause a compiler error.

The unordered map `CE_LAMBDA_PRESCRIPTION_LABEL` is indexed by `CE_LAMBDA_PRESCRIPTION` and declares a string label for each `CE_LAMBDA_PRESCRIPTION`. The strings declared in `CE_LAMBDA_PRESCRIPTION_LABEL` are used by the Options service to match user input to the required `CE_LAMBDA_PRESCRIPTION`. These strings can also be used if an English description of the value of a variable is required: instead of just printing an integer value that maps to a `CE_LAMBDA_PRESCRIPTION`, the string label associated with the prescription can be printed.

Stellar types are also declared in constants.h via an enum class and associate label map. This allows stellar types to be referenced using symbolic names rather than an ordinal number. The stellar types enum class is STELLAR_TYPE, and is declared as:

```
enum class STELLAR_TYPE: int {
    MS_LTE_07,
    MS_GT_07,
    HERTZSPRUNG_GAP,
    FIRST_GIANT_BRANCH,
    CORE_HELIUM_BURNING,
    EARLY_ASYMPTOTIC_GIANT_BRANCH,
    THERMALLY_PULSING_ASYMPTOTIC_GIANT_BRANCH,
    NAKED_HELIUM_STAR_MS,
    NAKED_HELIUM_STAR_HERTZSPRUNG_GAP,
    NAKED_HELIUM_STAR_GIANT_BRANCH,
    HELIUM_WHITE_DWARF,
    CARBON_OXYGEN_WHITE_DWARF,
    OXYGEN_NEON_WHITE_DWARF,
    NEUTRON_STAR,
    BLACK_HOLE,
    MASSLESS_REMNANT,
    STAR,
    BINARY_STAR,
    NONE
};
```

Ordinal numbers can still be used to reference the stellar types, and because of the order of definition in the enum class the ordinal numbers match those given in Hurley et al. 2000.

The label map STELLAR_TYPE_LABEL can be used to print text descriptions of the stellar types, and is declared as:

```
const std::unordered_map<STELLAR_TYPE, std::string> STELLAR_TYPE_LABEL = {
 { STELLAR_TYPE::MS_LTE_07,                          "Main_Sequence_<=_0.7" },
 { STELLAR_TYPE::MS_GT_07,                           "Main_Sequence_>_0.7" },
 { STELLAR_TYPE::HERTZSPRUNG_GAP,                    "Hertzsprung_Gap" },
 { STELLAR_TYPE::FIRST_GIANT_BRANCH,                 "First_Giant_Branch" },
 { STELLAR_TYPE::CORE_HELIUM_BURNING,                "Core_Helium_Burning" },
 { STELLAR_TYPE::EARLY_ASYMPTOTIC_GIANT_BRANCH,
 "Early_Asymptotic_Giant_Branch" },{ STELLAR_TYPE::THERMALLY_PULSING_ASYMPTOTIC_GIANT_BRANCH,
 "Thermally_Pulsing_Asymptotic_Giant_Branch" },
 { STELLAR_TYPE::NAKED_HELIUM_STAR_MS,               "Naked_Helium_Star_MS" },
 { STELLAR_TYPE::NAKED_HELIUM_STAR_HERTZSPRUNG_GAP,  "Naked_Helium_Star_Hertzsprung_Gap" },
 { STELLAR_TYPE::NAKED_HELIUM_STAR_GIANT_BRANCH,     "Naked_Helium_Star_Giant_Branch" },
 { STELLAR_TYPE::HELIUM_WHITE_DWARF,                 "Helium_White_Dwarf" },
 { STELLAR_TYPE::CARBON_OXYGEN_WHITE_DWARF,          "Carbon-Oxygen_White_Dwarf" },
 { STELLAR_TYPE::OXYGEN_NEON_WHITE_DWARF,            "Oxygen-Neon_White_Dwarf" },
 { STELLAR_TYPE::NEUTRON_STAR,                       "Neutron_Star" },
 { STELLAR_TYPE::BLACK_HOLE,                         "Black_Hole" },
 { STELLAR_TYPE::MASSLESS_REMNANT,                   "Massless_Remnant" },
 { STELLAR_TYPE::STAR,                               "Star" },
 { STELLAR_TYPE::BINARY_STAR,                        "Binary_Star" },
 { STELLAR_TYPE::NONE,                               "Not_a_Star!" }
};
```

PROGRAMMING STYLE AND CONVENTIONS

Everyone has their own preferences and style, and the nature of a project such as COMPAS will reflect that. However, there is a need to suggest some guidelines for programming style, naming conventions etc. Following is a description of some of the elements of programming style and naming conventions used to develop COMPAS v2. These may evolve over time.

Object-Oriented Programming

COMPAS is written in C++, an object-oriented programming (OOP) language, and OOP concepts and conventions should apply throughout the code. There are many texts and web pages devoted to understanding C++ and OOP – following is a brief description of the key OOP concepts:

Abstraction

For any entity, product, or service, the goal of abstraction is to handle the complexity of the implementation by hiding details that don't need to be known in order to use, or consume, the entity, product, or service. In the OOP paradigm, hiding details in this way enables the consumer to implement more complex logic on top of the provided abstraction without needing to understand the hidden implementation details and complexity. (There is no suggestion that consumers shouldn't understand the implementation details, but they shouldn't need to in order to consume the entity, product, or service).

Abstraction in C++ is achieved via the use of *objects* – an object is an instance of a *class*, and typically corresponds to a real-world object or entity (in COMPAS, usually a star or binary star). An object maintains the state of an object (via class member variables), and provides all necessary means of changing the state of the object (by exposing public class member functions (methods)). A class may expose public functions to allow consumers to determine the value of class member variables ("getters"), and to se the value of class member variables ("setters").

Encapsulation

Encapsulation binds together the data and functions that manipulate the data in an attempt to keep both safe from outside interference and accidental misuse. An encapsulation paradigm that does not allow calling code to access internal object data and permits access through functions only is a strong form of abstraction. C++ allows developers to enforce access restrictions explicitly by defining class member variables and functions as *private*, *protected*, or *public*. These keywords are used throughout COMPAS to enforce encapsulation.

There are very few circumstances in which a consumer should change the value of a class member variable directly (via the use of a setter function) – almost always consumers should present new situational information to an object (via a public member function), and allow the object to respond to the new information. For example, in COMPAS, there should be almost no reason for a consumer of a star object to directly change (say) the radius of the star – the consumer should inform the star object of new circumstances or events, and allow the star object to respond to those events (perhaps changing the value of the radius of the star). Changing a single class member variable directly introduces the possibility that related class member variables (e.g. other attributes of stars) will not be changed accordingly. Moreover, developers changing the code in the future should, in almost all cases, expect that the state of an object is maintained consistently by the object, and that there should be no unexpected side-effects caused by calling non class-member functions. In short, changing the state of an object outside the object is potentially unsafe and should be avoided where possible.

Inheritance

Inheritance allows classes to be arranged in a hierarchy that represents *is-a-type-of* relationships. All *non-private* class member variables and functions of the parent (base) class are available to the child (derived) class (and, therefore, child classes of the child class). This allows easy re-use of the same

procedures and data definitions, in addition to describing real-world relationships in an intuitive way. C++ allows multiple inheritance – a class may inherit from multiple parent classes.

Derived classes can define additional class member variables (using the *private*, *protected*, and *public* access restrictions), which will be available to any descendent classes (subject to inheritance rules), but will only be available to ancestor classes via the normal access methods (getters and setters).

Polymorphism

Polymorphism means *having many forms*. In OOP, polymorphism occurs when there is a hierarchy of classes and they are related by inheritance.

Following the discussion above regarding inheritance, in the OOP paradigm, and C++ specifically, derived classes can override methods defined by ancestor classes, allowing a derived class to implement functions specific to its circumstances. This means that a call to a class member function will cause a different function to be executed depending on the type of object that invokes the function. Descendent classes of a class that has overridden a base class member function inherit the overridden function (but can override it themselves).

COMPAS makes heavy use of inheritance and polymorphism, especially for the implementation of the different stellar types.

Programming Style

The goal of coding to a suggested style is readability and maintainability – if many developers implement code in COMPAS with their own coding style, readability and maintainability will be more difficult than if a consistent style is used throughout the code. Strict adherence isn't really necessary, but it will make it easier on all COMPAS developers if the coding style is consistent throughout.

Comments

An old, but good, rule-of-thumb is that any file that contains computer code should be about one-third code, one-third comments, and one-third white space. Adhering to this rule-of-thumb just makes the code a bit easier on the eye, and provides some description (at least of the intention) of the implementation.

Braces

The placement of braces in C++ code (actually, any code that uses braces to enclose scope) is a contentious issue, with may developers having long-held, often dogmatic preferences. COMPAS (so far) uses the K&R style ("the one true brace style") - the style used in the original Unix kernel and Kernighan and Ritchie's book *The C Programming Language*.

The K&R style puts the opening brace on the same line as the control statement:

```
while (x == y) {
    something();
    somethingelse();
}
```

Note also the space between the keyword *while* and the opening parenthesis, and the closing parenthesis and the opening brace.

Indentation

There is ongoing debate in the programming community as to whether indentation should be achieved using spaces or tabs (strange, but true…). The use of spaces is more common. COMPAS (so far) has a mix of both – whatever is convenient (pragmatism is your friend...).

COMPAS uses an indentation size of 4 spaces.

Function Parameters

In most cases, function parameters should be input only – meaning that the values of function parameters should not be changed by the function. Anything that needs to be changed and returned to the caller should be returned as a functional return. There are a few exceptions to this in COMPAS – all were done for performance reasons, and are documented in the code.

To avoid unexpected side-effects, developers should expect (in most cases) that any variables they pass to a function will remain unchanged – all changes should be returned as a functional return.

Performance & Optimisation

In general COMPAS developers should code for performance – within reason. Bear in mind that many functions will be called many, many thousands of times (in some cases, millions) in one execution of the program.

- Avoid calculating values inside loops that could be calculated once outside the loop.
- Try to use constants where possible.
- Use multiplication in preference to functions such as *pow()* and *sqrt()* (note that *pow()* is very expensive computationally; *sqrt()* is expensive, but much less expensive than *pow()*).
- Don't optimise to the point that readability and maintainability is compromised. Bear in mind that most compilers are good at optimising, and are very forgiving of less-than-optimally-written code (though they are not miracle workers...).

Naming Conventions

COMPAS (so far) uses the following naming conventions:

- all variable names should be in camelCase – don't use underscore_to_separate_words
- function names should be in camelCase, beginning with an uppercase letter. Function names should be descriptive.
- class member variable names are prefixed with "m_", and the character immediately following the prefix should be uppercase (in most cases – sometimes, for well-known names or words that are always written in lowercase, lowercase might be used)
- local variable names are just camelCase, beginning with a lowercase letter (again, with the caveat that sometimes, for well-known names or words that are always written in uppercase, uppercase might be used)
- function parameter names are prefixed with "p_", and the character immediately following the prefix should be uppercase (again, with the caveat that sometimes, for well-known names or words that are always written in lowercase, lowercase might be used)

COMPILATION & REQUIREMENTS

Use the supplied Make file (Makefile) to compile the COMPAS code.

The current requirements are:

Compiler:	CPP/g++ version 7.2.0 or greater (Requires C+11 compliance)
BOOST:	Known to work with version 1.67.0.0ubuntu1
GNU Scientific Library (gsl):	Known to work with version 2.5

Appendix A – Log File Record Specification: Stellar Properties

Following is the list of stellar properties available for inclusion in log file record specifiers:

To do: add descriptions for each of the properties

AGE
ANGULAR_MOMENTUM
BINDING_ENERGY_AT_COMMON_ENVELOPE
BINDING_ENERGY_FIXED
BINDING_ENERGY_NANJING
BINDING_ENERGY_POST_COMMON_ENVELOPE
BINDING_ENERGY_PRE_COMMON_ENVELOPE
BINDING_ENERGY_LOVERIDGE
BINDING_ENERGY_LOVERIDGE_WINDS
BINDING_ENERGY_KRUCKOW
CO_CORE_MASS
CO_CORE_MASS_AT_COMMON_ENVELOPE
CO_CORE_MASS_AT_COMPACT_OBJECT_FORMATION
CORE_MASS
CORE_MASS_AT_COMMON_ENVELOPE
CORE_MASS_AT_COMPACT_OBJECT_FORMATION
DRAWN_KICK_VELOCITY
DT
DYNAMICAL_TIMESCALE
DYNAMICAL_TIMESCALE_POST_COMMON_ENVELOPE
DYNAMICAL_TIMESCALE_PRE_COMMON_ENVELOPE
ECCENTRIC_ANOMALY
ENV_MASS
ERROR
EXPERIENCED_ECSN
EXPERIENCED_PISN
EXPERIENCED_PPISN
EXPERIENCED_RLOF
FALLBACK_FRACTION
HE_CORE_MASS
HE_CORE_MASS_AT_COMMON_ENVELOPE
HE_CORE_MASS_AT_COMPACT_OBJECT_FORMATION
HYDROGEN_POOR
HYDROGEN_RICH
ID
INITIAL_STELLAR_TYPE
INITIAL_STELLAR_TYPE_NAME
IS_ECSN
IS_RLOF
IS_SN
IS_USSN
KICK_VELOCITY
LAMBDA_AT_COMMON_ENVELOPE
LAMBDA_DEWI
LAMBDA_FIXED
LAMBDA_KRUCKOW
LAMBDA_KRUCKOW_BOTTOM

LAMBDA_KRUCKOW_MIDDLE
LAMBDA_KRUCKOW_TOP
LAMBDA_LOVERIDGE
LAMBDA_LOVERIDGE_WINDS
LAMBDA_NANJING
LUMINOSITY
LUMINOSITY_POST_COMMON_ENVELOPE
LUMINOSITY_PRE_COMMON_ENVELOPE
MASS
MASS_0
MASS_LOSS_DIFF
MASS_TRANSFER_CASE_INITIAL
MASS_TRANSFER_DIFF
MDOT
MEAN_ANOMALY
METALLICITY
MZAMS
NUCLEAR_TIMESCALE
NUCLEAR_TIMESCALE_POST_COMMON_ENVELOPE
NUCLEAR_TIMESCALE_PRE_COMMON_ENVELOPE
OMEGA
OMEGA_BREAK
OMEGA_ZAMS
ORBITAL_ENERGY_POST_SUPERNOVA
ORBITAL_ENERGY_PRE_SUPERNOVA
PULSAR_MAGNETIC_FIELD
PULSAR_SPIN_DOWN_RATE
PULSAR_SPIN_FREQUENCY
PULSAR_SPIN_PERIOD
RADIAL_EXPANSION_TIMESCALE
RADIAL_EXPANSION_TIMESCALE_POST_COMMON_ENVELOPE
RADIAL_EXPANSION_TIMESCALE_PRE_COMMON_ENVELOPE
RADIUS
RANDOM_SEED
RECYCLED_NEUTRON_STAR
RLOF_ONTO_NS
RUNAWAY
RZAMS
STELLAR_TYPE
STELLAR_TYPE_NAME
STELLAR_TYPE_PREV
STELLAR_TYPE_PREV_NAME
SUPERNOVA_KICK_VELOCITY_MAGNITUDE_RANDOM_NUMBER
SUPERNOVA_PHI
SUPERNOVA_THETA
TEMPERATURE
TEMPERATURE_POST_COMMON_ENVELOPE
TEMPERATURE_PRE_COMMON_ENVELOPE
THERMAL_TIMESCALE
THERMAL_TIMESCALE_POST_COMMON_ENVELOPE
THERMAL_TIMESCALE_PRE_COMMON_ENVELOPE
TIME

TIMESCALE_MS
TOTAL_MASS_AT_COMPACT_OBJECT_FORMATION
TRUE_ANOMALY
ZETA_HURLEY
ZETA_HURLEY_HE
ZETA_NUCLEAR
ZETA_SOBERMAN
ZETA_SOBERMAN_HE
ZETA_THERMAL

As described in Standard Log File Record Specifiers, when specifying known properties in a log file record specification record, the property name must be prefixed with the property type.

The current list of valid stellar property types available for use is:

- STAR_PROPERTY
- STAR_1_PROPERTY
- STAR_2_PROPERTY
- SUPERNOVA_PROPERTY
- COMPANION_PROPERTY

For example, to specify the property TEMPERATURE for an individual star being evolved in SSE, use:

    STAR_PROPERTY::TEMPERATURE

To specify the property TEMPERATURE for the primary star in a binary star being evolved in BSE, use:

    STAR_1_PROPERTY::TEMPERATURE

To specify the property TEMPERATURE for the supernova star in a binary star being evolved in BSE, use:

    SUPERNOVA_PROPERTY::TEMPERATURE

Appendix B – Log File Record Specification: Binary Properties

Following is the list of binary properties available for inclusion in log file record specifiers:

To do: add descriptions for each of the properties

BE_BINARY_CURRENT_COMPANION_LUMINOSITY
BE_BINARY_CURRENT_COMPANION_MASS
BE_BINARY_CURRENT_COMPANION_RADIUS
BE_BINARY_CURRENT_COMPANION_TEFF
BE_BINARY_CURRENT_DT
BE_BINARY_CURRENT_ECCENTRICITY
BE_BINARY_CURRENT_ID
BE_BINARY_CURRENT_NS_MASS
BE_BINARY_CURRENT_RANDOM_SEED
BE_BINARY_CURRENT_SEPARATION
BE_BINARY_CURRENT_TOTAL_TIME
CIRCULARIZATION_TIMESCALE
COMMON_ENVELOPE_ALPHA
COMMON_ENVELOPE_AT_LEAST_ONCE
COMMON_ENVELOPE_EVENT_COUNT
DIMENSIONLESS_KICK_VELOCITY
DISBOUND
DOUBLE_CORE_COMMON_ENVELOPE
DT
ECCENTRICITY
ECCENTRICITY_AT_DCO_FORMATION
ECCENTRICITY_INITIAL
ECCENTRICITY_POST_COMMON_ENVELOPE
ECCENTRICITY_PRE_2ND_SUPERNOVA
ECCENTRICITY_PRE_COMMON_ENVELOPE
ECCENTRICITY_PRIME
ERROR
ID
IMMEDIATE_RLOF_POST_COMMON_ENVELOPE
LUMINOUS_BLUE_VARIABLE_FACTOR
MASS_1_FINAL
MASS_1_POST_COMMON_ENVELOPE
MASS_1_PRE_COMMON_ENVELOPE
MASS_2_FINAL
MASS_2_POST_COMMON_ENVELOPE
MASS_2_PRE_COMMON_ENVELOPE
MASS_ENV_1
MASS_ENV_2
MASSES_EQUILIBRATED
MASS_TRANSFER_TRACKER_HISTORY
MERGES_IN_HUBBLE_TIME
OPTIMISTIC_COMMON_ENVELOPE
ORBITAL_VELOCITY
ORBITAL_VELOCITY_PRE_2ND_SUPERNOVA
RADIUS_1_POST_COMMON_ENVELOPE
RADIUS_1_PRE_COMMON_ENVELOPE
RADIUS_2_POST_COMMON_ENVELOPE

RADIUS_2_PRE_COMMON_ENVELOPE
RANDOM_SEED
RLOF_CURRENT_COMMON_ENVELOPE
RLOF_CURRENT_EVENT_COUNTER
RLOF_CURRENT_ID
RLOF_CURRENT_RANDOM_SEED
RLOF_CURRENT_SEPARATION
RLOF_CURRENT_STAR1_MASS
RLOF_CURRENT_STAR2_MASS
RLOF_CURRENT_STAR1_RADIUS
RLOF_CURRENT_STAR2_RADIUS
RLOF_CURRENT_STAR1_RLOF
RLOF_CURRENT_STAR2_RLOF
RLOF_CURRENT_STAR1_STELLAR_TYPE
RLOF_CURRENT_STAR1_STELLAR_TYPE_NAME
RLOF_CURRENT_STAR2_STELLAR_TYPE
RLOF_CURRENT_STAR2_STELLAR_TYPE_NAME
RLOF_CURRENT_TIME
RLOF_PREVIOUS_EVENT_COUNTER
RLOF_PREVIOUS_SEPARATION
RLOF_PREVIOUS_STAR1_MASS
RLOF_PREVIOUS_STAR2_MASS
RLOF_PREVIOUS_STAR1_RADIUS
RLOF_PREVIOUS_STAR2_RADIUS
RLOF_PREVIOUS_STAR1_RLOF
RLOF_PREVIOUS_STAR2_RLOF
RLOF_PREVIOUS_STAR1_STELLAR_TYPE
RLOF_PREVIOUS_STAR1_STELLAR_TYPE_NAME
RLOF_PREVIOUS_STAR2_STELLAR_TYPE
RLOF_PREVIOUS_STAR2_STELLAR_TYPE_NAME
RLOF_PREVIOUS_TIME
RLOF_SECONDARY_POST_COMMON_ENVELOPE
ROCHE_LOBE_RADIUS_1
ROCHE_LOBE_RADIUS_2
ROCHE_LOBE_RADIUS_1_POST_COMMON_ENVELOPE
ROCHE_LOBE_RADIUS_2_POST_COMMON_ENVELOPE
ROCHE_LOBE_RADIUS_1_PRE_COMMON_ENVELOPE
ROCHE_LOBE_RADIUS_2_PRE_COMMON_ENVELOPE
ROCHE_LOBE_TRACKER_1
ROCHE_LOBE_TRACKER_2
SECONDARY_TOO_SMALL_FOR_DCO
SEMI_MAJOR_AXIS_AT_DCO_FORMATION
SEMI_MAJOR_AXIS_INITIAL
SEMI_MAJOR_AXIS_POST_COMMON_ENVELOPE
SEMI_MAJOR_AXIS_PRE_2ND_SUPERNOVA
SEMI_MAJOR_AXIS_PRE_2ND_SUPERNOVA_RSOL
SEMI_MAJOR_AXIS_PRE_COMMON_ENVELOPE
SEMI_MAJOR_AXIS_PRIME
SEMI_MAJOR_AXIS_PRIME_RSOL
SIMULTANEOUS_RLOF
STABLE_RLOF_POST_COMMON_ENVELOPE
STELLAR_MERGER

STELLAR_MERGER_AT_BIRTH
STELLAR_TYPE_1_POST_COMMON_ENVELOPE
STELLAR_TYPE_1_PRE_COMMON_ENVELOPE
STELLAR_TYPE_2_POST_COMMON_ENVELOPE
STELLAR_TYPE_2_PRE_COMMON_ENVELOPE
STELLAR_TYPE_NAME_1_POST_COMMON_ENVELOPE
STELLAR_TYPE_NAME_1_PRE_COMMON_ENVELOPE
STELLAR_TYPE_NAME_2_POST_COMMON_ENVELOPE
STELLAR_TYPE_NAME_2_PRE_COMMON_ENVELOPE
SUPERNOVA_STATE
SURVIVED_SUPERNOVA_EVENT
SYNCHRONIZATION_TIMESCALE
SYSTEMIC_VELOCITY
TIME
TIME_TO_COALESCENCE
TOTAL_ANGULAR_MOMENTUM_PRIME
TOTAL_ENERGY_PRIME
WOLF_RAYET_FACTOR
ZETA_RLOF_ANALYTIC
ZETA_RLOF_NUMERICAL
ZETA_STAR_COMPARE

As described in Standard Log File Record Specifiers, when specifying known properties in a log file record specification record, the property name must be prefixed with the property type.

Currently there is a single binary property type available for use: BINARY_PROPERTY.

For example, to specify the property SEMI_MAJOR_AXIS_PRE_COMMON_ENVELOPE for a binary star being evolved in BSE, use:

```
BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRE_COMMON_ENVELOPE
```

Appendix C – Log File Record Specification: Program Options

A small subset of all program options is available for inclusion in log file record specifiers. This list may be expanded over time. The current list of program options available is:

To do: add descriptions for each of the program options

KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_BH
KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_NS
KICK_VELOCITY_DISTRIBUTION_SIGMA_FOR_ECSN
KICK_VELOCITY_DISTRIBUTION_SIGMA_FOR_USSN
RANDOM_SEED

As described in Standard Log File Record Specifiers, when specifying known properties in a log file record specification record, the property name must be prefixed with the property type.

Currently there is a single program option property type available for use: PROGRAM_OPTION.

For example, to specify the program option property property RANDOM_SEED, use:

PROGRAM_OPTION::RANDOM_SEED

Appendix D – Stellar Property Header Details

Property	Type	Heading	Units
AGE	DOUBLE	'Age'	'Myr'
ANGULAR_MOMENTUM	DOUBLE	'Ang_Momentum'	'Msol*AU^2*yr^-1'
BINDING_ENERGY_AT_COMMON_ENVELOPE	DOUBLE	'Binding_Energy@CE'	'ergs'
BINDING_ENERGY_FIXED	DOUBLE	'BE_Fixed'	'ergs'
BINDING_ENERGY_NANJING	DOUBLE	'BE_Nanjing'	'ergs'
BINDING_ENERGY_POST_COMMON_ENVELOPE	DOUBLE	'Binding_Energy>CE'	'ergs'
BINDING_ENERGY_PRE_COMMON_ENVELOPE	DOUBLE	'Binding_Energy<CE'	'ergs'
BINDING_ENERGY_LOVERIDGE	DOUBLE	'BE_Loveridge'	'ergs'
BINDING_ENERGY_LOVERIDGE_WINDS	DOUBLE	'BE_Loveridge_Winds'	'ergs'
BINDING_ENERGY_KRUCKOW	DOUBLE	'BE_Kruckow'	'ergs'
CO_CORE_MASS	DOUBLE	'Mass_CO_Core'	'Msol'
CO_CORE_MASS_AT_COMMON_ENVELOPE	DOUBLE	'Mass_CO_Core@CE'	'Msol'
CO_CORE_MASS_AT_COMPACT_OBJECT_FORMATION	DOUBLE	'Mass_CO_Core@CO'	'Msol'
CORE_MASS	DOUBLE	'Mass_Core'	'Msol'
CORE_MASS_AT_COMMON_ENVELOPE	DOUBLE	'Mass_Core@CE'	'Msol'
CORE_MASS_AT_COMPACT_OBJECT_FORMATION	DOUBLE	'Mass_Core@CO'	'Msol'
DRAWN_KICK_VELOCITY	DOUBLE	'Drawn_Kick_Velocity'	'kms^-1'
DT	DOUBLE	'dT'	'Myr'
DYNAMICAL_TIMESCALE	DOUBLE	'Tau_Dynamical'	'Myr'
DYNAMICAL_TIMESCALE_POST_COMMON_ENVELOPE	DOUBLE	'Tau_Dynamical>CE'	'Myr'
DYNAMICAL_TIMESCALE_PRE_COMMON_ENVELOPE	DOUBLE	'Tau_Dynamical<CE'	'Myr'
ECCENTRIC_ANOMALY	DOUBLE	'Eccentric_Anomaly'	
ENV_MASS	DOUBLE	'Mass_Env'	'Msol'
ERROR	INT	'Error'	
EXPERIENCED_ECSN	BOOL	'Experienced_ECSN'	'Event'
EXPERIENCED_PISN	BOOL	'Experienced_PISN'	'Event'
EXPERIENCED_PPISN	BOOL	'Experienced_PPISN'	'Event'
EXPERIENCED_RLOF	BOOL	'Experienced_RLOF'	'Event'
FALLBACK_FRACTION	DOUBLE	'Fallback_Fraction''	
HE_CORE_MASS	DOUBLE	'Mass_He_Core'	'Msol'
HE_CORE_MASS_AT_COMMON_ENVELOPE	DOUBLE	'Mass_He_Core@CE'	'Msol'
HE_CORE_MASS_AT_COMPACT_OBJECT_FORMATION	DOUBLE	'Mass_He_Core@CO'	'Msol'
HYDROGEN_POOR	BOOL	'Hydrogen_Poor'	'State'
HYDROGEN_RICH	BOOL	'Hydrogen_Rich'	'State'
ID	INT	'ID'	
INITIAL_STELLAR_TYPE	INT	'Stellar_Type_ZAMS'	
INITIAL_STELLAR_TYPE_NAME	STRING	'Stellar_Type_ZAMS'	
IS_ECSN	BOOL	'USSN'	'State'
IS_RLOF	BOOL	'RLOF'	'State'
IS_SN	BOOL	'SN'	'State'
IS_USSN	BOOL	'ECSN'	'State'
KICK_VELOCITY	FLOAT	'Kick_Velocity'	'kms^-1'
LAMBDA_AT_COMMON_ENVELOPE	FLOAT	'Lambda@CE'	
LAMBDA_DEWI	FLOAT	'Dewi'	
LAMBDA_FIXED	FLOAT	'Lambda_Fixed'	
LAMBDA_KRUCKOW	FLOAT	'Kruckow'	
LAMBDA_KRUCKOW_BOTTOM	FLOAT	'Kruckow_Bottom'	
LAMBDA_KRUCKOW_MIDDLE	DOUBLE	'Kruckow_Middle'	
LAMBDA_KRUCKOW_TOP	FLOAT	'Kruckow_Top'	
LAMBDA_LOVERIDGE	FLOAT	'Loveridge'	
LAMBDA_LOVERIDGE_WINDS	FLOAT	'Loveridge_Winds'	
LAMBDA_NANJING	FLOAT	'Lambda_Nanjing'	
LUMINOSITY	FLOAT	'Luminosity'	'Lsol'
LUMINOSITY_POST_COMMON_ENVELOPE	FLOAT	'Luminosity>CE'	'Lsol'
LUMINOSITY_PRE_COMMON_ENVELOPE	FLOAT	'Luminosity<CE'	'Lsol'
MASS	FLOAT	'Mass'	'Msol'
MASS_0	FLOAT	'Mass_0'	'Msol'
MASS_LOSS_DIFF	FLOAT	'dmWinds'	'Msol'
MASS_TRANSFER_CASE_INITIAL	INT	'MT_Case'	
MASS_TRANSFER_DIFF	FLOAT	'dmMT'	'Msol'
MDOT	FLOAT	'Mdot'	'Msol yr^-1'
MEAN_ANOMALY	FLOAT	'Mean_Anomaly'	
METALLICITY	FLOAT	'Metallicity'	
MZAMS	FLOAT	'MZAMS'	'Msol'

Property	Type	Heading	Units
NUCLEAR_TIMESCALE	FLOAT	'Tau_Nuclear'	'Myr'
NUCLEAR_TIMESCALE_POST_COMMON_ENVELOPE	FLOAT	'Tau_Nuclear>CE'	'Myr'

NUCLEAR_TIMESCALE_PRE_COMMON_ENVELOPE	FLOAT	'Tau_Nuclear<CE'	'Myr'
OMEGA	FLOAT	'Omega'	'yr^-1'
OMEGA_BREAK	FLOAT	'Omega_Break'	'yr^-1'
OMEGA_ZAMS	FLOAT	'Omega_ZAMS'	'yr^-1'
ORBITAL_ENERGY_POST_SUPERNOVA	FLOAT	'Orbital_Energy>SN'	'Msol^2AU^-1'
ORBITAL_ENERGY_PRE_SUPERNOVA	FLOAT	'Orbital_Energy<SN'	'Msol^2AU^-1'
PULSAR_MAGNETIC_FIELD	FLOAT	'Pulsar_Mag_Field'	'Tesla'
PULSAR_SPIN_DOWN_RATE	FLOAT	'Pulsar_Spin_Down'	'rad/s^2'
PULSAR_SPIN_FREQUENCY	FLOAT	'Pulsar_Spin_Freq'	'rad/s'
PULSAR_SPIN_PERIOD	FLOAT	'Pulsar_Spin_Period'	'ms'
RADIAL_EXPANSION_TIMESCALE	FLOAT	'Tau_Radial'	'Myr'
RADIAL_EXPANSION_TIMESCALE_POST_COMMON_ENVELOPE	FLOAT	'Tau_Radial>CE'	'Myr'
RADIAL_EXPANSION_TIMESCALE_PRE_COMMON_ENVELOPE	FLOAT	'Tau_Radial<CE'	'Myr'
RADIUS	FLOAT	'Radius'	'Rsol'
RANDOM_SEED	INT	'SEED'	
RECYCLED_NEUTRON_STAR	BOOL	'Recycled_NS'	'Event'
RLOF_ONTO_NS	BOOL	'RLOF->NS'	'Event'
RUNAWAY	BOOL	'Runaway'	'Event'
RZAMS	FLOAT	'RZAMS'	'Rsol'
STELLAR_TYPE	INT	'Stellar_Type'	
STELLAR_TYPE_NAME	STRING	'Stellar_Type'	
STELLAR_TYPE_PREV	INT	'Stellar_Type_Prev'	
STELLAR_TYPE_PREV_NAME	STRING	'Stellar_Type_Prev'	
SUPERNOVA_KICK_VELOCITY_MAGNITUDE_RANDOM_NUMBER	FLOAT	'SN_Kick_VM_Rand'	
SUPERNOVA_PHI	FLOAT	'SN_Phi'	
SUPERNOVA_THETA	FLOAT	'SN_Theta'	
TEMPERATURE	FLOAT	'Teff'	'Tsol'
TEMPERATURE_POST_COMMON_ENVELOPE	FLOAT	'Teff>CE'	'Tsol'
TEMPERATURE_PRE_COMMON_ENVELOPE	FLOAT	'Teff<CE'	'Tsol'
THERMAL_TIMESCALE	FLOAT	'Tau_Thermal'	'Myr'
THERMAL_TIMESCALE_POST_COMMON_ENVELOPE	FLOAT	'Tau_Thermal>CE'	'Myr'
THERMAL_TIMESCALE_PRE_COMMON_ENVELOPE	FLOAT	'Tau_Thermal<CE'	'Myr'
TIME	FLOAT	'Time'	'Myr'
TIMESCALE_MS	FLOAT	'tMS'	'Myr'
TOTAL_MASS_AT_COMPACT_OBJECT_FORMATION	FLOAT	'Mass_Total@CO'	'Msol'
TRUE_ANOMALY	FLOAT	'True_Anomaly(psi)'	
ZETA_HURLEY	FLOAT	'Zeta_Hurley'	
ZETA_HURLEY_HE	FLOAT	'Zeta_Hurley_He'	
ZETA_NUCLEAR	FLOAT	'Zeta_Nuclear'	
ZETA_SOBERMAN	FLOAT	'Zeta_Soberman'	
ZETA_SOBERMAN_HE	FLOAT	Zeta_SoberMan_He'	
ZETA_THERMAL	FLOAT	'Zeta_Thermal'	

Appendix E – Binary Property Header Details

Property	Type	Heading	Units
BE_BINARY_CURRENT_COMPANION_LUMINOSITY	FLOAT	'Companion_Lum'	'Lsol'
BE_BINARY_CURRENT_COMPANION_MASS	FLOAT	'Companion_Mass'	'Msol'
BE_BINARY_CURRENT_COMPANION_RADIUS	FLOAT	'Companion_Radius'	'Rsol'
BE_BINARY_CURRENT_COMPANION_TEFF	FLOAT	'Companion_Teff'	'Tsol'
BE_BINARY_CURRENT_DT	FLOAT	'dT'	'Myr'
BE_BINARY_CURRENT_ECCENTRICITY	FLOAT	'Eccentricity'	
BE_BINARY_CURRENT_ID	INT	'ID'	
BE_BINARY_CURRENT_NS_MASS	FLOAT	'NS_Mass'	'Msol'
BE_BINARY_CURRENT_RANDOM_SEED	INT	'SEED'	
BE_BINARY_CURRENT_SEPARATION	FLOAT	'Separation'	'Rsol'
BE_BINARY_CURRENT_TOTAL_TIME	FLOAT	'Total_Time'	'Myr'
CIRCULARIZATION_TIMESCALE	FLOAT	'Tau_Circ'	'Myr'
COMMON_ENVELOPE_ALPHA	FLOAT	'CE_Alpha'	
COMMON_ENVELOPE_AT_LEAST_ONCE	BOOL	'CEE'	'Event'
COMMON_ENVELOPE_EVENT_COUNT	INT	'CE_Event_Count'	'Count'
DIMENSIONLESS_KICK_VELOCITY	FLOAT	'Kick_Velocity(uK)'	
DISBOUND	BOOL	'Disbound'	'State'
DOUBLE_CORE_COMMON_ENVELOPE	BOOL	'Double_Core_CE'	'Event'
DT	FLOAT	'dT'	'Myr'
ECCENTRICITY	FLOAT	'Eccentricity'	
ECCENTRICITY_AT_DCO_FORMATION	FLOAT	'Eccentricity@DCO'	
ECCENTRICITY_INITIAL	FLOAT	'Eccentricity_0'	
ECCENTRICITY_POST_COMMON_ENVELOPE	FLOAT	'Eccentricity>CE'	
ECCENTRICITY_PRE_2ND_SUPERNOVA	FLOAT	'Eccentricity<2ndSN'	
ECCENTRICITY_PRE_COMMON_ENVELOPE	FLOAT	'Eccentricity<CE'	
ECCENTRICITY_PRIME	FLOAT	'Eccentricity'	
ERROR	INT	'Error'	
ID	INT	'ID'	
IMMEDIATE_RLOF_POST_COMMON_ENVELOPE	BOOL	'Immediate_RLOF>CE'	'Event'
LUMINOUS_BLUE_VARIABLE_FACTOR	FLOAT	'LBV_Multiplier'	
MASS_1_FINAL	FLOAT	'Core_Mass_1'	'Msol'
MASS_1_POST_COMMON_ENVELOPE	FLOAT	'Mass_1>CE'	'Msol'
MASS_1_PRE_COMMON_ENVELOPE	FLOAT	'Mass_1<CE'	'Msol'
MASS_2_FINAL	FLOAT	'Core_Mass_2'	'Msol'
MASS_2_POST_COMMON_ENVELOPE	FLOAT	'Mass_2>CE'	'Msol'
MASS_2_PRE_COMMON_ENVELOPE	FLOAT	'Mass_2<CE'	'Msol'
MASS_ENV_1	FLOAT	'Mass_Env_1'	'Msol'
MASS_ENV_2	FLOAT	'Mass_Env_2'	'Msol'
MASSES_EQUILIBRATED	BOOL	'Equilibrated'	'Event'
MASS_TRANSFER_TRACKER_HISTORY	INT	'MT_History'	
MERGES_IN_HUBBLE_TIME	BOOL	'Merges_Hubble_Time'	'State'
OPTIMISTIC_COMMON_ENVELOPE	BOOL	'Optimistic_CE'	'State'
ORBITAL_VELOCITY	FLOAT	'Orbital_Velocity'	'kms^-1'
ORBITAL_VELOCITY_PRE_2ND_SUPERNOVA	FLOAT	'Orb_Velocity<2ndSN'	'kms^-1'
RADIUS_1_POST_COMMON_ENVELOPE	FLOAT	'Radius_1>CE'	'Rsol'
RADIUS_1_PRE_COMMON_ENVELOPE	FLOAT	'Radius_1<CE'	'Rsol'
RADIUS_2_POST_COMMON_ENVELOPE	FLOAT	'Radius_2>CE'	'Rsol'
RADIUS_2_PRE_COMMON_ENVELOPE	FLOAT	'Radius_2<CE'	'Rsol'
RANDOM_SEED	INT	'SEED'	
RLOF_CURRENT_COMMON_ENVELOPE	BOOL	'CEE'	'State'
RLOF_CURRENT_EVENT_COUNTER	INT	'Event_Counter'	'Count'
RLOF_CURRENT_ID	INT	'ID'	
RLOF_CURRENT_RANDOM_SEED	INT	'SEED'	
RLOF_CURRENT_SEPARATION	FLOAT	'Separation'	'Rsol'
RLOF_CURRENT_STAR1_MASS	FLOAT	'Mass_1'	'Msol'
RLOF_CURRENT_STAR2_MASS	FLOAT	'Mass_2'	'Msol'
RLOF_CURRENT_STAR1_RADIUS	FLOAT	'Radius_1'	'Rsol'
RLOF_CURRENT_STAR2_RADIUS	FLOAT	'Radius_2'	'Rsol'
RLOF_CURRENT_STAR1_RLOF	BOOL	'RLOF_1'	'State'
RLOF_CURRENT_STAR2_RLOF	BOOL	'RLOF_2'	'State'
RLOF_CURRENT_STAR1_STELLAR_TYPE	INT	'Type_1'	
RLOF_CURRENT_STAR1_STELLAR_TYPE_NAME	STRING	'Type_1'	
RLOF_CURRENT_STAR2_STELLAR_TYPE	INT	'Type_2'	
RLOF_CURRENT_STAR2_STELLAR_TYPE_NAME	STRING	'Type_2'	

Property	Type	Heading	Units
RLOF_CURRENT_TIME	FLOAT	'Time'	'Myr'
RLOF_PREVIOUS_EVENT_COUNTER	INT	'EventCounter_Prev'	'Count'
RLOF_PREVIOUS_SEPARATION	FLOAT	'Separation_Prev'	'Rsol'

RLOF_PREVIOUS_STAR1_MASS	FLOAT	'Mass_1_Prev'	'Msol'
RLOF_PREVIOUS_STAR2_MASS	FLOAT	'Mass_2_Prev'	'Msol'
RLOF_PREVIOUS_STAR1_RADIUS	FLOAT	'Radius_1_Prev'	'Rsol'
RLOF_PREVIOUS_STAR2_RADIUS	FLOAT	'Radius_2_Prev'	'Rsol'
RLOF_PREVIOUS_STAR1_RLOF	BOOL	'RLOF_1_Prev'	'Event'
RLOF_PREVIOUS_STAR2_RLOF	BOOL	'RLOF_2_Prev'	'Event'
RLOF_PREVIOUS_STAR1_STELLAR_TYPE	INT	'Type_1_Prev'	
RLOF_PREVIOUS_STAR1_STELLAR_TYPE_NAME	STRING	'Type_1_Prev'	
RLOF_PREVIOUS_STAR2_STELLAR_TYPE	INT	'Type_2_Prev'	
RLOF_PREVIOUS_STAR2_STELLAR_TYPE_NAME	STRING	'Type_2_Prev'	
RLOF_PREVIOUS_TIME	FLOAT	'Time_Prev'	'Myr'
RLOF_SECONDARY_POST_COMMON_ENVELOPE	BOOL	'RLOF_Secondary>CE'	'Event'
ROCHE_LOBE_RADIUS_1	FLOAT	'RocheLobe_1/a'	
ROCHE_LOBE_RADIUS_1_POST_COMMON_ENVELOPE	FLOAT	'RocheLobe_1>CE'	'Rsol'
ROCHE_LOBE_RADIUS_1_PRE_COMMON_ENVELOPE	FLOAT	'RocheLobe_1<CE'	'Rsol'
ROCHE_LOBE_RADIUS_2	FLOAT	'RocheLobe_2/a'	
ROCHE_LOBE_RADIUS_2_POST_COMMON_ENVELOPE	FLOAT	'RocheLobe_2>CE'	'Rsol'
ROCHE_LOBE_RADIUS_2_PRE_COMMON_ENVELOPE	FLOAT	'RocheLobe_2<CE'	'Rsol'
ROCHE_LOBE_TRACKER_1	FLOAT	'Radius_1/RL'	
ROCHE_LOBE_TRACKER_2	FLOAT	'Radius_2/RL'	
SECONDARY_TOO_SMALL_FOR_DCO	BOOL	'Secondary<<DCO'	'State'
SEMI_MAJOR_AXIS_AT_DCO_FORMATION	FLOAT	'Separation@DCO'	'AU'
SEMI_MAJOR_AXIS_INITIAL	FLOAT	'Separation'	'AU'
SEMI_MAJOR_AXIS_POST_COMMON_ENVELOPE	FLOAT	'Separation>CE'	'AU'
SEMI_MAJOR_AXIS_PRE_2ND_SUPERNOVA	FLOAT	'Separation<2ndSN'	'AU'
SEMI_MAJOR_AXIS_PRE_2ND_SUPERNOVA_RSOL	FLOAT	'Separation<2ndSN'	'Rsol'
SEMI_MAJOR_AXIS_PRE_COMMON_ENVELOPE	FLOAT	'Separation<CE'	'AU'
SEMI_MAJOR_AXIS_PRIME	FLOAT	'Separation'	'AU'
SEMI_MAJOR_AXIS_PRIME_RSOL	FLOAT	'Separation'	'Rsol'
SIMULTANEOUS_RLOF	BOOL	'Simultaneous_RLOF'	'Event'
STABLE_RLOF_POST_COMMON_ENVELOPE	BOOL	'Stable_RLOF>CE'	'State'
STELLAR_MERGER	BOOL	'Merger'	'Event'
STELLAR_MERGER_AT_BIRTH	BOOL	'Merger_At_Birth'	'Event'
STELLAR_TYPE_1_POST_COMMON_ENVELOPE	INT	'Stellar_Type_1>CE'	
STELLAR_TYPE_1_PRE_COMMON_ENVELOPE	INT	'Stellar_Type_1<CE'	
STELLAR_TYPE_2_POST_COMMON_ENVELOPE	INT	'Stellar_Type_2>CE'	
STELLAR_TYPE_2_PRE_COMMON_ENVELOPE	INT	'Stellar_Type_2<CE'	
STELLAR_TYPE_NAME_1_POST_COMMON_ENVELOPE	STRING	'Stellar_Type_1>CE'	
STELLAR_TYPE_NAME_1_PRE_COMMON_ENVELOPE	STRING	'Stellar_Type_1<CE'	
STELLAR_TYPE_NAME_2_POST_COMMON_ENVELOPE	STRING	'Stellar_Type_2>CE'	
STELLAR_TYPE_NAME_2_PRE_COMMON_ENVELOPE	STRING	'Stellar_Type_2<CE'	
SUPERNOVA_STATE	INT	'Supernova_State'	'State'
SURVIVED_SUPERNOVA_EVENT	BOOL	'Survived_SN_Event'	'State'
SYNCHRONIZATION_TIMESCALE	FLOAT	'Tau_Sync'	'Myr'
SYSTEMIC_VELOCITY	FLOAT	'Systemic_Velocity'	'kms^-1'
TIME	FLOAT	'Time'	'Myr'
TIME_TO_COALESCENCE	FLOAT	'Coalescence_Time'	'Myr'
TOTAL_ANGULAR_MOMENTUM_PRIME	FLOAT	'Ang_Momentum_Total'	'Msol*AU^2*yr^-1'
TOTAL_ENERGY_PRIME	FLOAT	'Energy_Total'	'Msol*AU^2*yr^-2'
WOLF_RAYET_FACTOR	FLOAT	'WR_Multiplier'	
ZETA_RLOF_ANALYTIC	FLOAT	'Zeta_RLOF_Analytic'	
ZETA_RLOF_NUMERICAL	FLOAT	'Zeta_RLOF_Numerical'	
ZETA_STAR_COMPARE	FLOAT	'Zeta_Star_Compare'	

Appendix F – Program Option Header Details

Property	Type	Heading	Units
KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_BH	DOUBLE	'Sigma_Kick_CCSN_BH'	'kms^-1'
KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_NS	DOUBLE	'Sigma_Kick_CCSN_NS'	'kms^-1'
KICK_VELOCITY_DISTRIBUTION_SIGMA_ECSN_BH	DOUBLE	'Sigma_Kick_ECSN'	'kms^-1'
KICK_VELOCITY_DISTRIBUTION_SIGMA_USSN_BH	DOUBLE	'Sigma_Kick_USSN'	'kms^-1'
RANDOM_SEED	INT	'SEED (ProgramOption)'	

Appendix G – Default Log File Record Specifications

Following are the default log file record specifications for each of the standard log files. These specifications can be over-ridden by the use of a log file specifications file via the `logfile-definitions` program option.

SSE Parameters

```
const ANY_PROPERTY_VECTOR SSE_PARAMETERS_REC = {

   STAR_PROPERTY::AGE,
   STAR_PROPERTY::DT,
   STAR_PROPERTY::TIME,
   STAR_PROPERTY::STELLAR_TYPE,
   STAR_PROPERTY::METALLICITY,
   STAR_PROPERTY::MASS_0,
   STAR_PROPERTY::MASS,
   STAR_PROPERTY::RADIUS,
   STAR_PROPERTY::RZAMS,
   STAR_PROPERTY::LUMINOSITY,
   STAR_PROPERTY::TEMPERATURE,
   STAR_PROPERTY::CORE_MASS,
   STAR_PROPERTY::CO_CORE_MASS,
   STAR_PROPERTY::HE_CORE_MASS,
   STAR_PROPERTY::MDOT,
   STAR_PROPERTY::TIMESCALE_MS

};
```

BSE System Parameters

```
const ANY_PROPERTY_VECTOR BSE_SYSTEM_PARAMETERS_REC = {

   BINARY_PROPERTY::ID,
   BINARY_PROPERTY::RANDOM_SEED,
   STAR_1_PROPERTY::MZAMS,
   STAR_2_PROPERTY::MZAMS,
   STAR_1_PROPERTY::MASS_0,
   STAR_2_PROPERTY::MASS_0,
   BINARY_PROPERTY::SEMI_MAJOR_AXIS_INITIAL,
   BINARY_PROPERTY::ECCENTRICITY_INITIAL,
   STAR_1_PROPERTY::SUPERNOVA_KICK_VELOCITY_MAGNITUDE_RANDOM_NUMBER,
   STAR_1_PROPERTY::SUPERNOVA_THETA,
   STAR_1_PROPERTY::SUPERNOVA_PHI,
   STAR_1_PROPERTY::MEAN_ANOMALY,
   STAR_2_PROPERTY::SUPERNOVA_KICK_VELOCITY_MAGNITUDE_RANDOM_NUMBER,
   STAR_2_PROPERTY::SUPERNOVA_THETA,
   STAR_2_PROPERTY::SUPERNOVA_PHI,
   STAR_2_PROPERTY::MEAN_ANOMALY,
   STAR_1_PROPERTY::OMEGA_ZAMS,
   STAR_2_PROPERTY::OMEGA_ZAMS,
   PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_NS,
   PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_BH,
   PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_FOR_ECSN,
   PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_FOR_USSN,
   BINARY_PROPERTY::LUMINOUS_BLUE_VARIABLE_FACTOR,
   BINARY_PROPERTY::WOLF_RAYET_FACTOR,
   BINARY_PROPERTY::COMMON_ENVELOPE_ALPHA,
   STAR_1_PROPERTY::METALLICITY,
   STAR_2_PROPERTY::METALLICITY,
   BINARY_PROPERTY::SECONDARY_TOO_SMALL_FOR_DCO,
   BINARY_PROPERTY::DISBOUND,
   BINARY_PROPERTY::STELLAR_MERGER,
   BINARY_PROPERTY::STELLAR_MERGER_AT_BIRTH,
   STAR_1_PROPERTY::INITIAL_STELLAR_TYPE,
   STAR_1_PROPERTY::STELLAR_TYPE,
   STAR_2_PROPERTY::INITIAL_STELLAR_TYPE,
   STAR_2_PROPERTY::STELLAR_TYPE,
   BINARY_PROPERTY::ERROR

};
```

BSE Detailed Output

```
const ANY_PROPERTY_VECTOR BSE_DETAILED_OUTPUT_REC = {

    BINARY_PROPERTY::ID,
    BINARY_PROPERTY::RANDOM_SEED,
    BINARY_PROPERTY::DT,
    BINARY_PROPERTY::TIME,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRIME_RSOL,
    BINARY_PROPERTY::ECCENTRICITY_PRIME,
    STAR_1_PROPERTY::MZAMS,
    STAR_2_PROPERTY::MZAMS,
    STAR_1_PROPERTY::MASS_0,
    STAR_2_PROPERTY::MASS_0,
    STAR_1_PROPERTY::MASS,
    STAR_2_PROPERTY::MASS,
    STAR_1_PROPERTY::ENV_MASS,
    STAR_2_PROPERTY::ENV_MASS,
    STAR_1_PROPERTY::CORE_MASS,
    STAR_2_PROPERTY::CORE_MASS,
    STAR_1_PROPERTY::HE_CORE_MASS,
    STAR_2_PROPERTY::HE_CORE_MASS,
    STAR_1_PROPERTY::CO_CORE_MASS,
    STAR_2_PROPERTY::CO_CORE_MASS,
    STAR_1_PROPERTY::RADIUS,
    STAR_2_PROPERTY::RADIUS,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_1,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_2,
    BINARY_PROPERTY::ROCHE_LOBE_TRACKER_1,
    BINARY_PROPERTY::ROCHE_LOBE_TRACKER_2,
    STAR_1_PROPERTY::OMEGA,
    STAR_2_PROPERTY::OMEGA,
    STAR_1_PROPERTY::OMEGA_BREAK,
    STAR_2_PROPERTY::OMEGA_BREAK,
    STAR_1_PROPERTY::INITIAL_STELLAR_TYPE,
    STAR_2_PROPERTY::INITIAL_STELLAR_TYPE,
    STAR_1_PROPERTY::STELLAR_TYPE,
    STAR_2_PROPERTY::STELLAR_TYPE,
    STAR_1_PROPERTY::AGE,
    STAR_2_PROPERTY::AGE,
    STAR_1_PROPERTY::LUMINOSITY,
    STAR_2_PROPERTY::LUMINOSITY,
    STAR_1_PROPERTY::TEMPERATURE,
    STAR_2_PROPERTY::TEMPERATURE,
    STAR_1_PROPERTY::ANGULAR_MOMENTUM,
    STAR_2_PROPERTY::ANGULAR_MOMENTUM,
    STAR_1_PROPERTY::DYNAMICAL_TIMESCALE,
    STAR_2_PROPERTY::DYNAMICAL_TIMESCALE,
    STAR_1_PROPERTY::THERMAL_TIMESCALE,
    STAR_2_PROPERTY::THERMAL_TIMESCALE,
    STAR_1_PROPERTY::NUCLEAR_TIMESCALE,
    STAR_2_PROPERTY::NUCLEAR_TIMESCALE,
    STAR_1_PROPERTY::ZETA_THERMAL,
    STAR_2_PROPERTY::ZETA_THERMAL,
    STAR_1_PROPERTY::ZETA_NUCLEAR,
    STAR_2_PROPERTY::ZETA_NUCLEAR,
    STAR_1_PROPERTY::ZETA_SOBERMAN,
    STAR_2_PROPERTY::ZETA_SOBERMAN,
    STAR_1_PROPERTY::ZETA_SOBERMAN_HE,
    STAR_2_PROPERTY::ZETA_SOBERMAN_HE,
    STAR_1_PROPERTY::ZETA_HURLEY,
    STAR_2_PROPERTY::ZETA_HURLEY,
```

```
    STAR_1_PROPERTY::ZETA_HURLEY_HE,
    STAR_2_PROPERTY::ZETA_HURLEY_HE,
    STAR_1_PROPERTY::MASS_LOSS_DIFF,
    STAR_2_PROPERTY::MASS_LOSS_DIFF,
    STAR_1_PROPERTY::MASS_TRANSFER_DIFF,
    STAR_2_PROPERTY::MASS_TRANSFER_DIFF,
    BINARY_PROPERTY::TOTAL_ANGULAR_MOMENTUM_PRIME,
    BINARY_PROPERTY::TOTAL_ENERGY_PRIME,
    STAR_1_PROPERTY::LAMBDA_NANJING,
    STAR_2_PROPERTY::LAMBDA_NANJING,
    STAR_1_PROPERTY::LAMBDA_LOVERIDGE,
    STAR_2_PROPERTY::LAMBDA_LOVERIDGE,
    STAR_1_PROPERTY::LAMBDA_KRUCKOW_TOP,
    STAR_2_PROPERTY::LAMBDA_KRUCKOW_TOP,
    STAR_1_PROPERTY::LAMBDA_KRUCKOW_MIDDLE,
    STAR_2_PROPERTY::LAMBDA_KRUCKOW_MIDDLE,
    STAR_1_PROPERTY::LAMBDA_KRUCKOW_BOTTOM,
    STAR_2_PROPERTY::LAMBDA_KRUCKOW_BOTTOM,
    STAR_1_PROPERTY::METALLICITY,
    STAR_2_PROPERTY::METALLICITY,
    BINARY_PROPERTY::MASS_TRANSFER_TRACKER_HISTORY,
    STAR_1_PROPERTY::PULSAR_MAGNETIC_FIELD,
    STAR_2_PROPERTY::PULSAR_MAGNETIC_FIELD,
    STAR_1_PROPERTY::PULSAR_SPIN_FREQUENCY,
    STAR_2_PROPERTY::PULSAR_SPIN_FREQUENCY,
    STAR_1_PROPERTY::PULSAR_SPIN_DOWN_RATE,
    STAR_2_PROPERTY::PULSAR_SPIN_DOWN_RATE,
    STAR_1_PROPERTY::RADIAL_EXPANSION_TIMESCALE,
    STAR_2_PROPERTY::RADIAL_EXPANSION_TIMESCALE

};
```

BSE Double Compact Objects

```
const ANY_PROPERTY_VECTOR BSE_DOUBLE_COMPACT_OBJECTS_REC = {

    BINARY_PROPERTY::ID,
    BINARY_PROPERTY::RANDOM_SEED,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_INITIAL,
    BINARY_PROPERTY::ECCENTRICITY_INITIAL,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRE_2ND_SUPERNOVA,
    BINARY_PROPERTY::ECCENTRICITY_PRE_2ND_SUPERNOVA,
    BINARY_PROPERTY::ORBITAL_VELOCITY_PRE_2ND_SUPERNOVA,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_AT_DCO_FORMATION,
    BINARY_PROPERTY::ECCENTRICITY_AT_DCO_FORMATION,
    STAR_1_PROPERTY::METALLICITY,
    STAR_2_PROPERTY::METALLICITY,
    STAR_1_PROPERTY::MZAMS,
    STAR_1_PROPERTY::MASS_0,
    STAR_1_PROPERTY::TOTAL_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_1_PROPERTY::HE_CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_1_PROPERTY::CO_CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_1_PROPERTY::CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_1_PROPERTY::HE_CORE_MASS_AT_COMMON_ENVELOPE,
    STAR_1_PROPERTY::CO_CORE_MASS_AT_COMMON_ENVELOPE,
    STAR_1_PROPERTY::CORE_MASS_AT_COMMON_ENVELOPE,
    STAR_1_PROPERTY::KICK_VELOCITY,
    STAR_1_PROPERTY::SUPERNOVA_THETA,
    STAR_1_PROPERTY::SUPERNOVA_PHI,
    STAR_1_PROPERTY::MASS,
    STAR_1_PROPERTY::INITIAL_STELLAR_TYPE,
    STAR_1_PROPERTY::STELLAR_TYPE,
    STAR_2_PROPERTY::MZAMS,
    STAR_2_PROPERTY::MASS_0,
    STAR_2_PROPERTY::TOTAL_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_2_PROPERTY::HE_CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_2_PROPERTY::CO_CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_2_PROPERTY::CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
    STAR_2_PROPERTY::HE_CORE_MASS_AT_COMMON_ENVELOPE,
    STAR_2_PROPERTY::CO_CORE_MASS_AT_COMMON_ENVELOPE,
    STAR_2_PROPERTY::CORE_MASS_AT_COMMON_ENVELOPE,
    STAR_2_PROPERTY::KICK_VELOCITY,
    STAR_2_PROPERTY::SUPERNOVA_THETA,
    STAR_2_PROPERTY::SUPERNOVA_PHI,
    STAR_2_PROPERTY::MASS,
    STAR_2_PROPERTY::INITIAL_STELLAR_TYPE,
    STAR_2_PROPERTY::STELLAR_TYPE,
    BINARY_PROPERTY::TIME_TO_COALESCENCE,
    BINARY_PROPERTY::TIME,
    BINARY_PROPERTY::LUMINOUS_BLUE_VARIABLE_FACTOR,
    PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_NS,
    PROGRAM_OPTION::KICK_VELOCITY_DISTRIBUTION_SIGMA_CCSN_BH,
    BINARY_PROPERTY::COMMON_ENVELOPE_ALPHA,
    BINARY_PROPERTY::WOLF_RAYET_FACTOR,
    BINARY_PROPERTY::RLOF_SECONDARY_POST_COMMON_ENVELOPE,
    STAR_1_PROPERTY::MASS_TRANSFER_CASE_INITIAL,
    STAR_2_PROPERTY::MASS_TRANSFER_CASE_INITIAL,
    STAR_1_PROPERTY::ORBITAL_ENERGY_PRE_SUPERNOVA,
    STAR_1_PROPERTY::ORBITAL_ENERGY_POST_SUPERNOVA,
    STAR_2_PROPERTY::ORBITAL_ENERGY_PRE_SUPERNOVA,
    STAR_2_PROPERTY::ORBITAL_ENERGY_POST_SUPERNOVA,
    BINARY_PROPERTY::COMMON_ENVELOPE_AT_LEAST_ONCE,
    STAR_1_PROPERTY::LAMBDA_AT_COMMON_ENVELOPE,
    STAR_2_PROPERTY::LAMBDA_AT_COMMON_ENVELOPE,
```

```
    BINARY_PROPERTY::ECCENTRICITY_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ECCENTRICITY_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_1_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_1_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_2_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_2_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::OPTIMISTIC_COMMON_ENVELOPE,
    BINARY_PROPERTY::MERGES_IN_HUBBLE_TIME,
    BINARY_PROPERTY::DOUBLE_CORE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::BINDING_ENERGY_AT_COMMON_ENVELOPE,
    STAR_2_PROPERTY::BINDING_ENERGY_AT_COMMON_ENVELOPE,
    STAR_1_PROPERTY::RECYCLED_NEUTRON_STAR,
    STAR_2_PROPERTY::RECYCLED_NEUTRON_STAR,
    STAR_1_PROPERTY::IS_USSN,
    STAR_2_PROPERTY::IS_USSN,
    STAR_1_PROPERTY::EXPERIENCED_ECSN,
    STAR_2_PROPERTY::EXPERIENCED_ECSN,
    STAR_1_PROPERTY::EXPERIENCED_PISN,
    STAR_2_PROPERTY::EXPERIENCED_PISN,
    STAR_1_PROPERTY::EXPERIENCED_PPISN,
    STAR_2_PROPERTY::EXPERIENCED_PPISN

};
```

BSE Common Envelopes

```
const ANY_PROPERTY_VECTOR BSE_COMMON_ENVELOPES_REC = {

    BINARY_PROPERTY::ID,
    BINARY_PROPERTY::RANDOM_SEED,
    BINARY_PROPERTY::TIME,
    BINARY_PROPERTY::COMMON_ENVELOPE_ALPHA,
    STAR_1_PROPERTY::LAMBDA_AT_COMMON_ENVELOPE,
    STAR_2_PROPERTY::LAMBDA_AT_COMMON_ENVELOPE,
    STAR_1_PROPERTY::BINDING_ENERGY_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::BINDING_ENERGY_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ECCENTRICITY_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ECCENTRICITY_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_1_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_1_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_2_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ROCHE_LOBE_RADIUS_2_POST_COMMON_ENVELOPE,
    STAR_1_PROPERTY::MZAMS,
    BINARY_PROPERTY::MASS_1_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::MASS_ENV_1,
    BINARY_PROPERTY::MASS_1_FINAL,
    BINARY_PROPERTY::RADIUS_1_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::RADIUS_1_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::STELLAR_TYPE_1_PRE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::STELLAR_TYPE,
    STAR_1_PROPERTY::LAMBDA_FIXED,
    STAR_1_PROPERTY::LAMBDA_NANJING,
    STAR_1_PROPERTY::LAMBDA_LOVERIDGE,
    STAR_1_PROPERTY::LAMBDA_LOVERIDGE_WINDS,
    STAR_1_PROPERTY::LAMBDA_KRUCKOW,
    STAR_1_PROPERTY::BINDING_ENERGY_FIXED,
    STAR_1_PROPERTY::BINDING_ENERGY_NANJING,
    STAR_1_PROPERTY::BINDING_ENERGY_LOVERIDGE,
    STAR_1_PROPERTY::BINDING_ENERGY_LOVERIDGE_WINDS,
    STAR_1_PROPERTY::BINDING_ENERGY_KRUCKOW,
    STAR_2_PROPERTY::MZAMS,
    BINARY_PROPERTY::MASS_2_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::MASS_ENV_2,
    BINARY_PROPERTY::MASS_2_FINAL,
    BINARY_PROPERTY::RADIUS_2_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::RADIUS_2_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::STELLAR_TYPE_2_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::STELLAR_TYPE,
    STAR_2_PROPERTY::LAMBDA_FIXED,
    STAR_2_PROPERTY::LAMBDA_NANJING,
    STAR_2_PROPERTY::LAMBDA_LOVERIDGE,
    STAR_2_PROPERTY::LAMBDA_LOVERIDGE_WINDS,
    STAR_2_PROPERTY::LAMBDA_KRUCKOW,
    STAR_2_PROPERTY::BINDING_ENERGY_FIXED,
    STAR_2_PROPERTY::BINDING_ENERGY_NANJING,
    STAR_2_PROPERTY::BINDING_ENERGY_LOVERIDGE,
    STAR_2_PROPERTY::BINDING_ENERGY_LOVERIDGE_WINDS,
    STAR_2_PROPERTY::BINDING_ENERGY_KRUCKOW,
    BINARY_PROPERTY::MASS_TRANSFER_TRACKER_HISTORY,
    BINARY_PROPERTY::STELLAR_MERGER,
    BINARY_PROPERTY::OPTIMISTIC_COMMON_ENVELOPE,
    BINARY_PROPERTY::COMMON_ENVELOPE_EVENT_COUNT,
    BINARY_PROPERTY::DOUBLE_CORE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::IS_RLOF,
```

```
    STAR_1_PROPERTY::LUMINOSITY_PRE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::TEMPERATURE_PRE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::DYNAMICAL_TIMESCALE_PRE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::THERMAL_TIMESCALE_PRE_COMMON_ENVELOPE,
    STAR_1_PROPERTY::NUCLEAR_TIMESCALE_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::IS_RLOF,
    STAR_2_PROPERTY::LUMINOSITY_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::TEMPERATURE_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::DYNAMICAL_TIMESCALE_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::THERMAL_TIMESCALE_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::NUCLEAR_TIMESCALE_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::ZETA_STAR_COMPARE,
    BINARY_PROPERTY::ZETA_RLOF_ANALYTIC,
    BINARY_PROPERTY::SYNCHRONIZATION_TIMESCALE,
    BINARY_PROPERTY::CIRCULARIZATION_TIMESCALE,
    STAR_1_PROPERTY::RADIAL_EXPANSION_TIMESCALE_PRE_COMMON_ENVELOPE,
    STAR_2_PROPERTY::RADIAL_EXPANSION_TIMESCALE_PRE_COMMON_ENVELOPE,
    BINARY_PROPERTY::IMMEDIATE_RLOF_POST_COMMON_ENVELOPE,
    BINARY_PROPERTY::SIMULTANEOUS_RLOF
};
```

BSE RLOF Parameters

```
const ANY_PROPERTY_VECTOR BSE_RLOF_PARAMETERS_REC = {

   BINARY_PROPERTY::RLOF_CURRENT_ID,
   BINARY_PROPERTY::RLOF_CURRENT_RANDOM_SEED,
   BINARY_PROPERTY::RLOF_CURRENT_STAR1_MASS,
   BINARY_PROPERTY::RLOF_CURRENT_STAR2_MASS,
   BINARY_PROPERTY::RLOF_CURRENT_STAR1_RADIUS,
   BINARY_PROPERTY::RLOF_CURRENT_STAR2_RADIUS,
   BINARY_PROPERTY::RLOF_CURRENT_STAR1_STELLAR_TYPE,
   BINARY_PROPERTY::RLOF_CURRENT_STAR2_STELLAR_TYPE,
   BINARY_PROPERTY::RLOF_CURRENT_SEPARATION,
   BINARY_PROPERTY::RLOF_CURRENT_EVENT_COUNTER,
   BINARY_PROPERTY::RLOF_CURRENT_TIME,
   BINARY_PROPERTY::RLOF_CURRENT_STAR1_RLOF,
   BINARY_PROPERTY::RLOF_CURRENT_STAR2_RLOF,
   BINARY_PROPERTY::RLOF_CURRENT_COMMON_ENVELOPE,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR1_MASS,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR2_MASS,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR1_RADIUS,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR2_RADIUS,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR1_STELLAR_TYPE,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR2_STELLAR_TYPE,
   BINARY_PROPERTY::RLOF_PREVIOUS_SEPARATION,
   BINARY_PROPERTY::RLOF_PREVIOUS_EVENT_COUNTER,
   BINARY_PROPERTY::RLOF_PREVIOUS_TIME,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR1_RLOF,
   BINARY_PROPERTY::RLOF_PREVIOUS_STAR2_RLOF,
   STAR_1_PROPERTY::ZETA_THERMAL,
   STAR_1_PROPERTY::ZETA_NUCLEAR,
   STAR_1_PROPERTY::ZETA_SOBERMAN,
   STAR_1_PROPERTY::ZETA_SOBERMAN_HE,
   STAR_1_PROPERTY::ZETA_HURLEY,
   STAR_1_PROPERTY::ZETA_HURLEY_HE,
   STAR_2_PROPERTY::ZETA_THERMAL,
   STAR_2_PROPERTY::ZETA_NUCLEAR,
   STAR_2_PROPERTY::ZETA_SOBERMAN,
   STAR_2_PROPERTY::ZETA_SOBERMAN_HE,
   STAR_2_PROPERTY::ZETA_HURLEY,
   STAR_2_PROPERTY::ZETA_HURLEY_HE,
   BINARY_PROPERTY::ZETA_RLOF_ANALYTIC,
   BINARY_PROPERTY::ZETA_RLOF_NUMERICAL

};
```

BSE Supernovae

```
const ANY_PROPERTY_VECTOR BSE_SUPERNOVAE_REC = {

   BINARY_PROPERTY::ID,
   BINARY_PROPERTY::RANDOM_SEED,
   SUPERNOVA_PROPERTY::DRAWN_KICK_VELOCITY,
   SUPERNOVA_PROPERTY::KICK_VELOCITY,
   SUPERNOVA_PROPERTY::FALLBACK_FRACTION,
   BINARY_PROPERTY::ORBITAL_VELOCITY,
   BINARY_PROPERTY::DIMENSIONLESS_KICK_VELOCITY,
   SUPERNOVA_PROPERTY::TRUE_ANOMALY,
   SUPERNOVA_PROPERTY::SUPERNOVA_THETA,
   SUPERNOVA_PROPERTY::SUPERNOVA_PHI,
   SUPERNOVA_PROPERTY::IS_ECSN,
   SUPERNOVA_PROPERTY::IS_SN,
   SUPERNOVA_PROPERTY::IS_USSN,
   SUPERNOVA_PROPERTY::EXPERIENCED_PISN,
   SUPERNOVA_PROPERTY::EXPERIENCED_PPISN,
   BINARY_PROPERTY::SURVIVED_SUPERNOVA_EVENT,
   SUPERNOVA_PROPERTY::MZAMS,
   COMPANION_PROPERTY::MZAMS,
   SUPERNOVA_PROPERTY::TOTAL_MASS_AT_COMPACT_OBJECT_FORMATION,
   COMPANION_PROPERTY::MASS,
   SUPERNOVA_PROPERTY::CO_CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
   SUPERNOVA_PROPERTY::MASS,
   SUPERNOVA_PROPERTY::EXPERIENCED_RLOF,
   SUPERNOVA_PROPERTY::INITIAL_STELLAR_TYPE,
   SUPERNOVA_PROPERTY::STELLAR_TYPE,
   BINARY_PROPERTY::SUPERNOVA_STATE,
   SUPERNOVA_PROPERTY::STELLAR_TYPE_PREV,
   COMPANION_PROPERTY::STELLAR_TYPE_PREV,
   SUPERNOVA_PROPERTY::CORE_MASS_AT_COMPACT_OBJECT_FORMATION,
   SUPERNOVA_PROPERTY::METALLICITY,
   BINARY_PROPERTY::COMMON_ENVELOPE_AT_LEAST_ONCE,
   BINARY_PROPERTY::STABLE_RLOF_POST_COMMON_ENVELOPE,
   SUPERNOVA_PROPERTY::RLOF_ONTO_NS,
   BINARY_PROPERTY::TIME,
   BINARY_PROPERTY::ECCENTRICITY_PRE_2ND_SUPERNOVA,
   BINARY_PROPERTY::ECCENTRICITY,
   BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRE_2ND_SUPERNOVA_RSOL,
   BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRIME_RSOL,
   BINARY_PROPERTY::SYSTEMIC_VELOCITY,
   SUPERNOVA_PROPERTY::HYDROGEN_RICH,
   SUPERNOVA_PROPERTY::HYDROGEN_POOR,
   COMPANION_PROPERTY::RUNAWAY

};
```

BSE Pulsar Evolution

```
const ANY_PROPERTY_VECTOR BSE_PULSAR_EVOLUTION_REC = {

    BINARY_PROPERTY::ID,
    BINARY_PROPERTY::RANDOM_SEED,
    BINARY_PROPERTY::DISBOUND,
    STAR_1_PROPERTY::MASS,
    STAR_2_PROPERTY::MASS,
    STAR_1_PROPERTY::STELLAR_TYPE,
    STAR_2_PROPERTY::STELLAR_TYPE,
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_PRIME_RSOL,
    BINARY_PROPERTY::MASS_TRANSFER_TRACKER_HISTORY,
    STAR_1_PROPERTY::PULSAR_MAGNETIC_FIELD,
    STAR_2_PROPERTY::PULSAR_MAGNETIC_FIELD,
    STAR_1_PROPERTY::PULSAR_SPIN_FREQUENCY,
    STAR_2_PROPERTY::PULSAR_SPIN_FREQUENCY,
    STAR_1_PROPERTY::PULSAR_SPIN_DOWN_RATE,
    STAR_2_PROPERTY::PULSAR_SPIN_DOWN_RATE,
    BINARY_PROPERTY::TIME,
    BINARY_PROPERTY::DT

};
```

BSE Be Binaries

```
const ANY_PROPERTY_VECTOR BSE_BE_BINARIES_REC = {

    BINARY_PROPERTY::BE_BINARY_CURRENT_ID,
    BINARY_PROPERTY::BE_BINARY_CURRENT_RANDOM_SEED,
    BINARY_PROPERTY::BE_BINARY_CURRENT_DT,
    BINARY_PROPERTY::BE_BINARY_CURRENT_TOTAL_TIME,
    BINARY_PROPERTY::BE_BINARY_CURRENT_NS_MASS,
    BINARY_PROPERTY::BE_BINARY_CURRENT_COMPANION_MASS,
    BINARY_PROPERTY::BE_BINARY_CURRENT_COMPANION_LUMINOSITY,
    BINARY_PROPERTY::BE_BINARY_CURRENT_COMPANION_TEFF,
    BINARY_PROPERTY::BE_BINARY_CURRENT_COMPANION_RADIUS,
    BINARY_PROPERTY::BE_BINARY_CURRENT_SEPARATION,
    BINARY_PROPERTY::BE_BINARY_CURRENT_ECCENTRICITY

};
```

Appendix H – Example Log File Record Specifications File

Following is an example log file record specifications file. COMPAS can be configured to use this file via the `logfile-definitions` program option.

This file (`COMPAS_Output_Definitions.txt`) is also delivered as part of the COMPAS github repository.

```
# sample standard log file specifications file

# the '#' character and anything following it on a single line is considered a comment
# (so, lines starting with '#' are comment lines)

# case is not significant
# specifications can span several lines
# specifications for the same log file are cumulative
# if a log file is not specified in this file, the default specification is used


# SSE Parameters

# start with the default SSE Parameters specification and add ENV_MASS

sse_parms_rec += { STAR_PROPERTY::ENV_MASS }

# take the updated SSE Parameters specification and add ANGULAR_MOMENTUM

sse_parms_rec += { STAR_PROPERTY::ANGULAR_MOMENTUM }

# take the updated SSE Parameters specification and subtract MASS_0 and MDOT

sse_parms_rec -= { STAR_PROPERTY::MASS_0, STAR_PROPERTY::MDOT }


# BSE System Parameters

bse_sysparms_rec = {                          # set the BSE System Parameters specification to:
    BINARY_PROPERTY::ID,                      # ID of the binary
    BINARY_PROPERTY::RANDOM_SEED,             # RANDOM_SEED for the binary
    STAR_1_PROPERTY::MZAMS,                   # MZAMS for Star1
    STAR_2_PROPERTY::MZAMS                    # MZAMS for Star2
}

# ADD to the BSE System Parameters specification:
# SEMI_MAJOR_AXIS_INITIAL for the binary
# ECCENTRICITY_INITIAL for the binary
# SUPERNOVA_THETA for Star1 and SUPERNOVA_PHI for Star1

bse_sysparms_rec += {
    BINARY_PROPERTY::SEMI_MAJOR_AXIS_INITIAL,
    BINARY_PROPERTY::ECCENTRICITY_INITIAL,
    STAR_1_PROPERTY::SUPERNOVA_THETA, STAR_1_PROPERTY::SUPERNOVA_PHI
}

bse_sysparms_rec += {                             # ADD to the BSE System Parameters specification:
    SUPERNOVA_PROPERTY::IS_ECSN,                  # IS_ECSN for the supernova star
    SUPERNOVA_PROPERTY::IS_SN,                    # IS_SN for the supernova star
    SUPERNOVA_PROPERTY::IS_USSN,                  # IS_USSN for the supernova star
    SUPERNOVA_PROPERTY::EXPERIENCED_PISN,         # EXPERIENCED_PISN for the supernova star
    SUPERNOVA_PROPERTY::EXPERIENCED_PPISN,        # EXPERIENCED_PPISN for the supernova star
    BINARY_PROPERTY::SURVIVED_SUPERNOVA_EVENT,    # SURVIVED_SUPERNOVA_EVENT for the binary
    SUPERNOVA_PROPERTY::MZAMS,                    # MZAMS for the supernova star
    COMPANION_PROPERTY::MZAMS                     # MZAMS for the companion star
}

# SUBTRACT from the BSE System Parameters specification:
# RANDOM_SEED for the binary
# ID for the binary
bse_sysparms_rec -= {                       # SUBTRACT from the BSE System Parameters specification:
    BINARY_PROPERTY::RANDOM_SEED,           # RANDOM_SEED for the binary
    BINARY_PROPERTY::ID                     # ID for the binary
}


# BSE Double Compas Objects
```

```
# set the BSE Double Compact Objects specifivation to MZAMS for Star1, and MZAMS for Star2

BSE_DCO_Rec = {STAR_1_PROPERTY::MZAMS,STAR_2_PROPERTY::MZAMS}

# set the BSE Double Compact Objects specification to empty - nothing will be printed
# (file will not be created)

BSE_DCO_Rec = {}


# BSE Supernovae

BSE_SNE_Rec = {}               # set spec empty - nothing will be printed (file will not be created)


# BSE Common Envelopes

BSE_CEE_Rec = {   }            # set spec empty - nothing will be printed (file will not be created)


# BSE RLOF Properties

BSE_RLOF_Rec= {}               # set spec empty - nothing will be printed (file will not be created)


# BSE Be Binaries

BSE_BE_Binaries_Rec ={}        # set spec empty - nothing will be printed (file will not be created)


# BSE Pulsars

# line ignored (comment).  BSE Pulsars specification will be default

# BSE_Pulsars_Rec= { STAR_1_PROPERTY::MASS, STAR_2_PROPERTY::MASS }


# BSE Detailed Output

BSE_Detailed_Rec={}            # set spec empty - nothing will be printed (file will not be created)
```