GaiaHub 1.0.0 documentation:

Introduction:

GaiaHub (Gaia-Hubble proper motion pipeline) is a program that combines Gaia Catalogs with images taken by the Hubble Space Telescope (HST) to construct the proper motions (PMs) of astrophysical objects with greater precision and accuracy than can be achieved with Gaia alone.

It achieves this by using the HST images as the first epoch and Gaia as the second epoch, this increases the time baseline available and therefore increases the precision and accuracy of the measurements. For faint stars (G>17), the longer time baseline afforded by combining HST and Gaia provides higher precision than is possible using Gaia alone. GaiaHub is most useful for targets with distances between 50 kpc and 150 kpc, as below this Gaia can use bright stars which are saturated in HST images and therefore adding HST produces a relatively small improvement, and above this Gaia sees very few stars and therefore is not useful as a second epoch.

For more details on GaiaHub and examples of usage please see del Pino et al. 2022 (ApJ submitted).

Technical limitations:

GaiaHub requires an HST image to act as the first epoch. The pipeline can work with ACS/WFC andWFC3/UVIS _flc images, as well as with ACS/HRC _flt exposures. Both _flt and _flc images preserve the unresampled pixel data for optimal PSF fitting. WFPC2 and WFC3/IR data are not supported because the astrometric precision reachable with these data is generally lower than what is possible with the other imagers above. If an appropriate HST image exists from before Gaia DR1 was released, then GaiaHub will perform better than HST alone, with more HST images and a greater time baseline improving performance.

Licenses and Copyrights:

Installing the software:

-Hardware requirements:

GaiaHub runs in a bash shell.

Installing GaiaHub requires ~2.5 GB of hard drive space.

The memory requirements to run GaiaHub depend on the number of HST images to be analyzed, but in general each HST image will use ~200 MB of memory. Therefore we do not consider hardware issues to be a problem for the vast majority of users.

-Software requirements:

GaiaHub runs in python and fortran and should work on any machine that has the capacity to run code in these languages. The prerequisite modules for the running of GaiaHub will be checked for and installed or updated during the installation process which will be detailed below. GaiaHub will ask for permission before doing this. You will need a fortran compiler to install GaiaHub.

If you do not want to alter your python environment, we recommend setting up a dedicated conda environment.

The Fortran code will be compiled as part of the installation process, the details of this will be laid out during the installation section of this document.

-Obtaining GaiaHub:

GaiaHub is stored on Github at the directory: https://github.com/AndresdPM/GaiaHub

To obtain GaiaHub you will first need to clone the repository, this can be done via the command:
git clone

There are further instruction on the GitHub directory to assist you.

-Installation:

To install GaiaHub from Github you must first uncompress the archive.

Then a new directory will appear wherever you are called GaiaHub-Master, enter this directory and run the python code install_GaiaHub.py to begin the installation process.

GaiaHub will first confirm that it requires 2.5 GB of space to install, that it requires several python packages and recommends setting up a dedicated conda environment if you do not want to alter your python environment.

If you continue GaiaHub will by default install in the directory GaiaHub-Master. You can accept this or provide an alternate directory.

Next GaiaHub will need to compile 2 Fortran codes. As mentioned previously you will need to obtain a fortran complier if your computer does not already have one. By default the compiler used is “gfortran” which can be obtained at https://gcc.gnu.org/fortran/ , however you can use a different compiler if you wish to.

Once Fortran has been compiled GaiaHub will download and install the requisite python modules. Then GaiaHub will download the PSF and geometric distortion libraries required to run the HST image analysis.

Finally GaiaHub will offer to set up an alias allowing you to call GaiaHub with the command gaiahub in future within the bash shell.

After installation you may need to open a new terminal window or restart your computer to use GaiaHub, depending on your settings.

-Using GaiaHub

Inputs:

GaiaHub uses a large number of keywords to enable customization, once GaiaHub is installed you can find a list using,

gaiahub --help

For standard use we advise,

gaiahub --name “insert_target_name” —use_members

This will derive the proper motions of the target only using stars that GaiaHub considers to be members of the target, ignoring foreground and background objects.

Outputs:

Once GaiaHub has finished running it will output a bulk proper motion estimate for the target alongside a series of files and images for diagnostic purposes or to allow the user to examine the output more closely.

These output files include:

The HST images used.
The Gaia Source catalog, with the extra columns containing PMs, HST magnitudes, errors, etc.
A summary of the sources in the Gaia catalog, along with properties derived for the matched sources in the HST images.
The proper motion and sigma proper motion diagrams for each iteration of the GaiaHub software.
A series of diagrams for the target:
  A CMD
  A vector point diagram
  A PM comparison between Gaia and GaiaHub
  Errors detected by GaiaHub against source magnitude, color and position to allow the user to examine them for systematic errors.
A footprint with highlighted sources from the GaiaHub
The footprint searched for HST images
Finally, a log of the bulk proper motions.

Expected Runtime:

The expected runtime for GaiaHub will vary widely based on the amount of data used, the number of options used and whether this is the first execution on a specific set target. Of these the most impactful is if this is the first execution, as during the first execution GaiaHub has to download all the data and run the detection of sources in the HST image, these results will be stored locally allowing faster runtime on subsequent executions. The exact speed of the download will depend on the users internet connection and computer. In test cases it was found that after all the data is downloaded, it should take a few minutes for an execution of GaiaHub to complete.

Systematic errors:

GaiaHub does not attempt to resolve the systematic errors for all possible targets. The systematic errors for both Gaia and HST are complex and depend on multiple factors which are not easily corrected for in advance. For an average target the systematics are likely to be around ~0.06 mas/yr for R.A. and ~0.034 mas/yr for Decl.. However, this is for a general target and other targets may have significantly larger or smaller systematic errors, which will require more careful examination by the user.