Allegato N. 1

Career options: remarks on astrophysics in particular and physics in general

General Remarks

The most frequent option for students completing a course of study in astrophysics is to enter a PhD program and follow the traditional academic/research track. This means specializing rather soon in either theoretical or observational problems, and usually not taking an instrumentation track. Employment follows in a university context or government research lab (in Europe, this usually means an observatory or research institute such as as one of the Max Planck centers, Saclay, CERN, Rutherford-Appleton, etc.) or one of the observatories (INAF, ESO, Obs. de Paris, IRAM, Bonn, Westerbork, TNG, VLA/VLBA/VLBI, etc.) This list broadens rapidly when astroparticle physics is included. Another possibility is working in space research, *e.g.* ESA, CNES, ASI, JPL, GSFC, involved with satellite projects. This generally means working, at least in part, in a support context (the same is true for international facilities, especially ESO, where pure research posts are less frequently available). Alternatively, there are industrial possibilities, especially in optics, detectors, software and systems, image processing, etc.

First Degree Students (NO, years 1-3)

For students at the end of the 3rd year of the NO, the dominant future terminal option is (or should be) teaching. In astronomy, earth/space science is a major option for high school - there's currently a possibility of this in the laurea didattica (overseen by geology/earth science) - but the thrusts of this option are mainly the geology and environmental components. There could be more physics and astrophysics if the courses were restructured from their current formulation. It's certainly worth the effort to examine this, astronomy has proven to be a very attractive inducement for students in school to get interested in physical science rather than pure (geological) phenomenology and taxonomy[1].

Training in classical positional astronomy, along with some experience with planetarium work, would be extremely useful for future teachers (and we could link here with the new planetarium in Firenze, that has close ties with Arcetri, for training). The *Giornale di Astronomia* provides a good overview of the usual activities and needs of this sort of training, so does *Mercury* (Astronomical Society of the Pacific).

Specialist Degree Students

For laurea specialistica students, the path is much more traditional and the training should consequently reflect this. In both physics in general, and astrophysics in particular, industry and teaching are again important options. The intellectual flexibility developed by physicists, relative to engineers, is an important ingredient in their comparative employability outside the academic setting: being able to work with messy data, infer results from first principles instead of simply applying standard formulations (in short, the ability to synthesize and abstract), have proven strong attractors for private sector employers.

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[1] It's particularly important that students in Pisa, during the third year, are exposed to material that can translate into classroom skills. Physics teaching is becoming inadequate in high schools to meet future needs and produce students with appropriate backgrounds to enter quickly into university work; Pisa is a major source for the teachers and *mus*t take its role seriously in this area.

In this regard, a wide range of experience in “real world” problems is most helpful. Despite first impressions, astrophysics provides this in abundance; the observer finds herself often working with large and varied data sets, being required to understand a broad range of instruments (both detectors and optical systems), being able to model a variety of data (especially at many wavelengths) and dealing with extreme problems of low S/N, complex backgrounds, and calibration problems. Imaging and spectroscopy, also polarimetry, come into play and are the core of the training. On top of this, writing and using complex analysis tools in a variety of computational environments are essential skills (there are few fields where data mining is so widely used or so well developed, much modern research is accomplished without either new experiments or even new observations because of projects such as the Virtual Observatories and the Sloane Digital Sky Survey and the space data archives).

Of particular note is the role played by space-based research: satellite observatories are central, but also particle experiments. And one of the most important requirements is a familiarity with aperture synthesis instruments and interferometry.

For theorists, strong training in dealing with observations is essential. The converse can be said for observers but that is still much less developed (and there is a real need for more training in instrumentation). The foundations of astrophysical training remain atomic and molecular processes, radiative transfer, statistical mechanics, classical gravitational dynamics, nuclear physics, hydrodynamics, plasma physics and MHD, and -depending on the problems of interest - also substantial exposure to GRT, cosmology, and particle physics.

A philosophical remark

There is a strong prejudice in the non-astrophysics community, and even among those in the business, concerning the appropriate training of an “astrophysicist”. Some of these preconceptions are addressed here, but a broad brush remark seems appropriate: fundamental questions lurk in all areas, even those that appear to be the most classical, and often students are drawn to some of these. Extrasolar planets are fast becoming a (perhaps *the*) major research area of the next decade (look at the NASA/ESA “Origins” programs) but the background required to make advances in this field is severely limited by curricular changes in the past 20 years (when was the last time celestial mechanics was required?). Solar physics, especially space weather, has again become important yet this field practically died during the 1990s. Stellar physics has been declared moribund among a large portion of the American community, even at the risk of producing nonsense in the literature. Some of the same problems faced in material sciences, especially nucleation and surface physics, dominate some areas of astrophysics yet are almost unaddressed in standard curricula. So at the risk of a negative reaction from you, the reader, I'll remark that unless the training is broad *and* deep in many areas -- and this applies equally to physics as astrophysics (think of the biological revolution now being proclaimed) -- there is a risk of producing a self-limiting cadre of future researchers without proper attention to the diversity of the field.

From the other side of the Pond

The American experience may be illustrative. Only about 25% of recent PhD recipients obtain permanent academic employment. About 1/2 remain in long term - but limited term - contract positions (postdocs, research support) - with the rest going into government (mainly defense-related) work. Consequently, note that in some areas - *i.e.* nuclear astrophysics, imaging and interferometry, hydrodynamic and turbulence modeling - there are private sector possibilities. Recall too the growth of econophysics, driven by statistical mechanics and stochastics, and modeling complex systems (for instance, traffic, percolation/forest fire problems, disease modeling, etc.).