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Naval Observatory Vector Astrometry Software (NOVAS) Version 3.1: Fortran, C, and Python Editions

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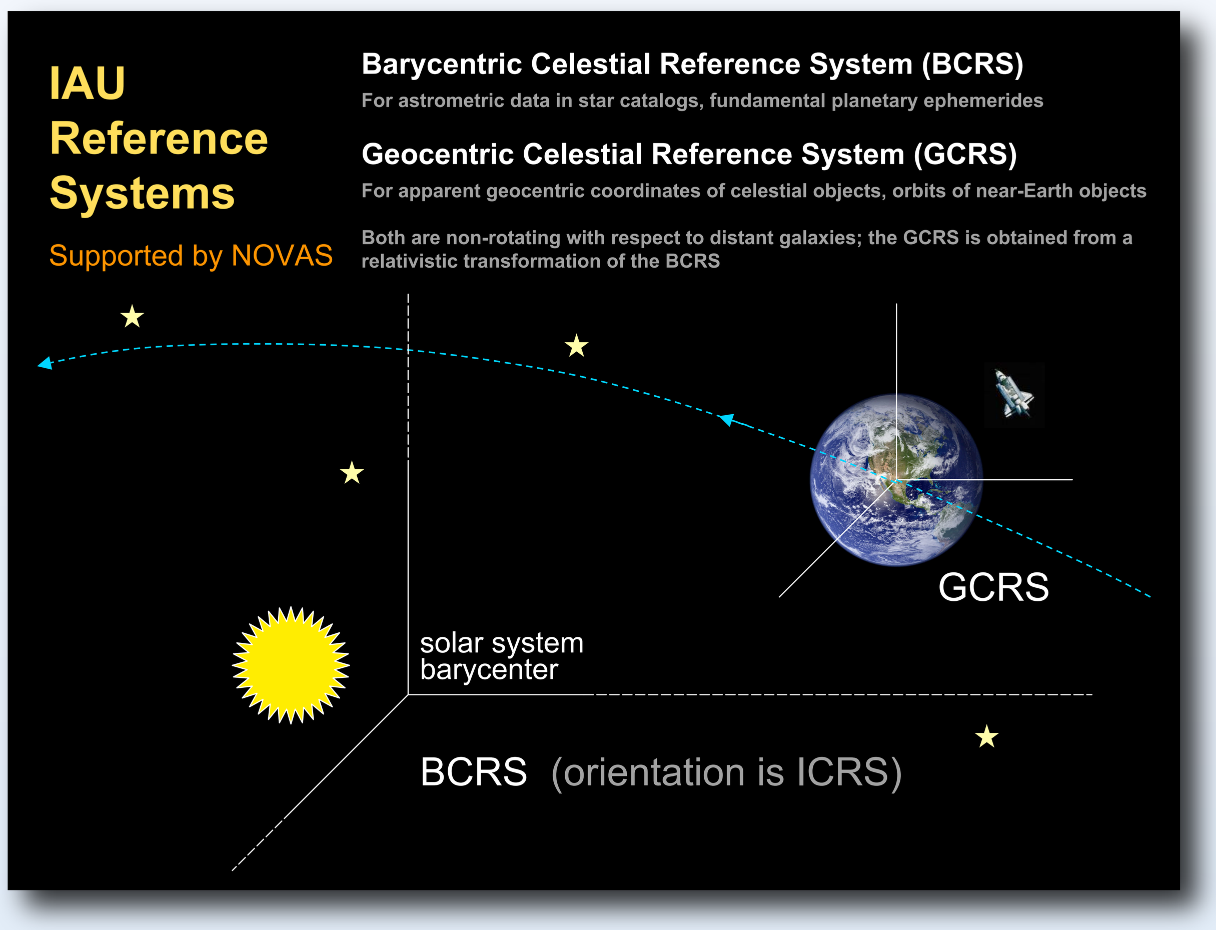
What is NOVAS?

The Naval Observatory Vector Astrometry Software (NOVAS) is a free source-code library for computing various commonly needed quantities in positional astronomy. The code is available in Fortran, C, and Python. The Fortran version was first released in the late 1970s, but has been updated periodically to use new, more accurate models that represent the evolving standards of the international astronomical and geodetic communities. The C edition was first introduced in 1996 and provides the same functionality and accuracy. A Python edition is now available.

NOVAS can supply, in one or two subroutine or function calls, the instantaneous celestial position of any star or planet in a variety of coordinate systems. NOVAS also provides access to all of the "building blocks" that go into such computations — single-purpose subroutines/ functions for common astrometric algorithms, such as those for precession, nutation, aberration, parallax, etc. NOVAS calculations are accurate at the sub-milliarcsecond level. The NOVAS package is an easy-to-use facility that can be incorporated into data reduction programs, telescope control systems, and simulations. NOVAS is used in the production of the U.S. parts of *The Astronomical Almanac*.

The algorithms used in NOVAS are based on a vector and matrix formulation that is rigorous and consistent with recent recommendations by the International Astronomical Union (IAU).



NOVAS is available from
http://aa.usno.navy.mil/software/novas/

NOVAS 3.1 is available for download from the U.S. Naval Observatory's website (URL above), in Fortran, C, and Python editions, each with its own User's Guide.

Also available for download at the same URL:

USNO Circular 181, which provides information on the nutation and precession models implemented in NOVAS.

USNO Circular 179, which explains the current IAU paradigm of reference systems, times scales, and Earth orientation modeling, with algorithms and reprints of relevant IAU resolutions.

About the Python Edition

A major addition to NOVAS in version 3.1 is NOVAS Py, an extension module for the Python programming language. This Python edition borrows its underlying computational code from the C edition and implements nearly all its features.

Why Python?

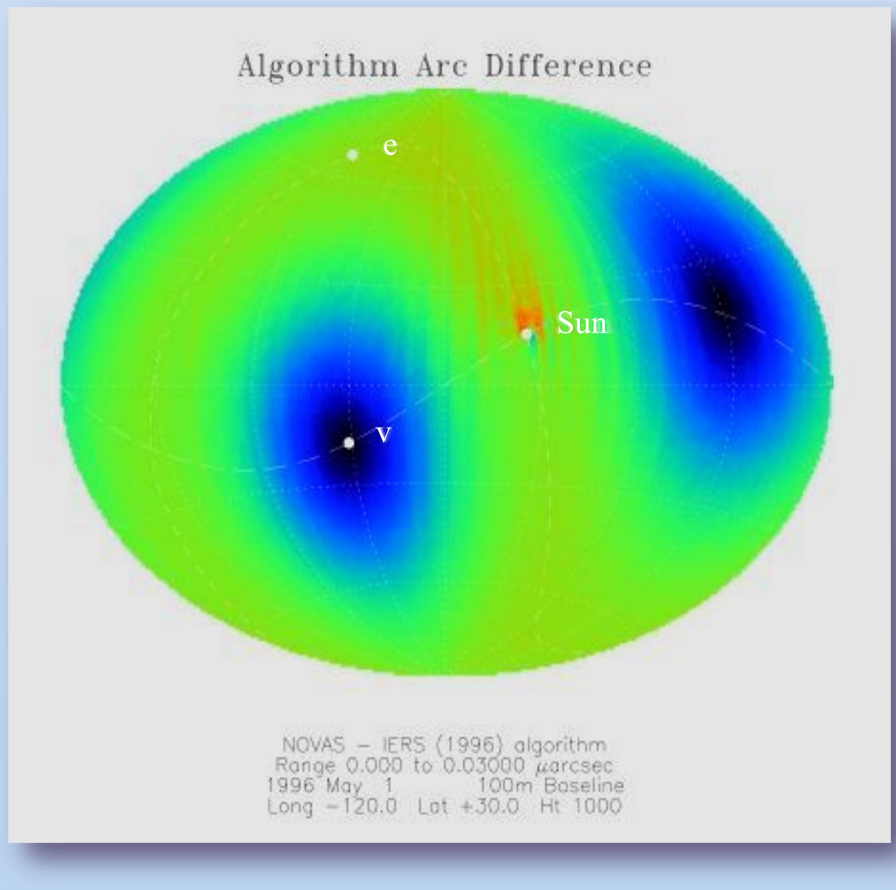
Python (http://www.python.org) is a powerful, cross-platform, open-source programming language that is easy to learn and has excellent code readability. Python is interpreted, uses dynamic typing, supports multiple programming paradigms — object-oriented, procedural, functional — and can be used interactively. It ships with a number of modules that provide tools for a variety of application domains, and a large and increasing number of third-party modules are available. Python is already widely used in the astronomy community and is still rapidly gaining popularity, in many cases replacing tools like IDL, Matlab, and Mathematica.

Implementing NOVAS in Python opens up the library to much greater ease of use in web applications, quick calculations, and rapid development of large and complex software products.

How Python is Implemented in NOVAS

The current (3.1) release of NOVAS Py is a wrapper around NOVAS C using Python's built-in ctypes library. The function calls in the Python edition are an almost one-to-one match with the function calls in the C edition. We are currently investigating the possibility of providing a native Python edition of NOVAS with array handling provided by NumPy (http://numpy.scipy.org), which would increase usability and efficiency in cases where a user needs to process large catalogs of objects.

Validation of Algorithms: One Example



The diagram above is an all-sky map showing the arc differences between star positions (a grid of artificial stars at infinity) computed using two different sets of algorithms for the gravitational deflection of light due to the Sun and relativistic stellar aberration. One set of algorithms was the spatial-domain formulation used in NOVAS, and the other was the time-domain "consensus delay model" used for high-precision astrometric and geodetic VLBI experiments by the IERS (International Earth Rotation and Reference Systems Service).

The positions of the Sun, the ecliptic pole (e), and the apex of the observer's instantaneous velocity (v) are indicated. The full range of color, from black to red, represents differences of 0 to 0.025 µas. (Figure 4 from Kaplan, 1998, AJ, 115, 361.) For all practical purposes, the results are identical.

This is just one of the tests performed to verify the accuracy of NOVAS. Other tests include comparisons with SOFA results and internal consistency checks. The latter are useful because many computations in NOVAS can be done in several ways, using independent algorithms.

What Are the Most Significant Features of NOVAS?

Easy to Use: The most frequently requested quantities, such as the apparent coordinates of celestial objects, can be obtained from only one or two subroutine or function calls — no long sequences of calls are needed. The User's Guides for both Fortran and C editions of NOVAS are comprehensive and detailed, with sample calculations and results.

Accurate: The computations are all based on a vector/matrix formulation (no spherical trigonometry) and have been checked against alternative software and independent algorithms, with compatibility at the microarcsecond level. (The external accuracy of some of the models used is several orders of magnitude worse, but is the best available at this time and far exceeds any practical requirements.)

Uses International Standards: NOVAS incorporates IAU values for constants, definitions of celestial and terrestrial reference systems, and models for precession, nutation, and Earth rotation. NOVAS can directly use data published daily by the International Earth Rotation and Reference Systems Service (IERS).

Stars and Solar System Objects Treated Similarly: All celestial objects, inside or outside the solar system, are treated similarly. NOVAS operates on "absolute" position and velocity vectors in 3-space (in units of au and au/day, respectively), with respect to the solar system barycenter, for both stars and planets. This allows for a unified approach to the calculations, regardless of the distance of the object of interest.

Compatibility of Fortran, C, and Python Editions: The Fortran, C, and Python editions of NOVAS use the same algorithms. In full-accuracy mode, differences in the results from the Fortran and C editions of NOVAS (for the same calculation and input) should not exceed 6×10^{-8} arcseconds (3×10^{-13} radians) for solar system bodies and 7×10^{-10} arcseconds (3×10^{-15} radians) for stars. Thus, there are no practical applications for which a change of the source code language would produce a significant change in results.

NOVAS Models: Precession and Nutation

During its 3-decade history, NOVAS has always incorporated the models of precession and nutation recommended by the IAU. There have been three generations of these models: Newcomb and Woolard (used through 1983); Lieske et al. and Wahr (1984-2003); and Capitaine et al. and Mathews et al. (2003-present). The latter two models, which were adopted by the IAU in 2006 and 2000, respectively, are used in NOVAS 3.0 and 3.1.

The two figures below illustrate the significant improvement in our knowledge of Earth orientation during this time. The first (from Kaplan, 1985, Ph.D. thesis), shows observational residuals in the Earth's obliquity with respect to the Newcomb-Woolard models; the second (from Capitaine et al., 2009, Celest. Mech. Dyn. Astr., 103, 179), shows similar data for the current models. The accuracy of the models has increased by about two orders of magnitude.