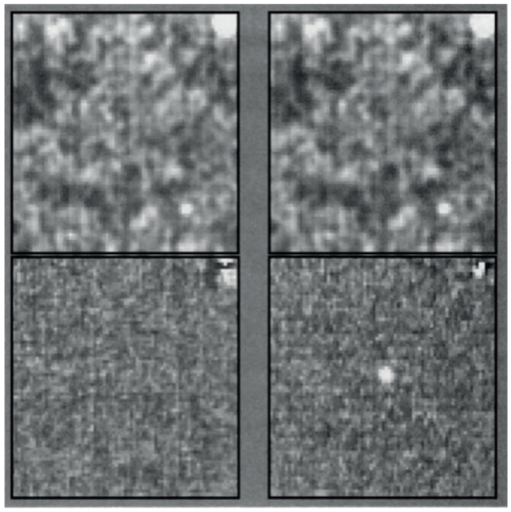
Discovered at the VATT

The Vatican Advanced Technology Telescope (VATT) has produced a number of important scientific results over its 25 year history. Some of its most important programs may well those be going on right now, whose true significance will only be revealed in hindsight! But even limiting our look to research projects that are now essentially completed, there have already been a number of significant findings coming from the VATT.

How do you judge what is significant? One way is to see what scientific papers have been written based on VATT results, and how often those papers have been cited by subsequent work that relies on VATT discoveries. You can track this at a NASA website called the Astrophysics Data System which records every scientific paper published in major journals in the field of astrophysics, and how often they have been cited. Here are some of the areas of research where, according to this NASA site, the VATT has made a big impact:



The Andromeda Galaxy (image from Wikipedia) is too large to fit into the VATT field of view.

But concentrating on small areas of this galaxy, detailed images from the VATT (bottom images from Tomaney and Crotts) could be compared to find momentary bursts of light.

The top images show the raw data at two different times; the bottom images subtract the average of that region from each image above. The bright spot on the right is a momentary gravitational lens event.

MACHOs:

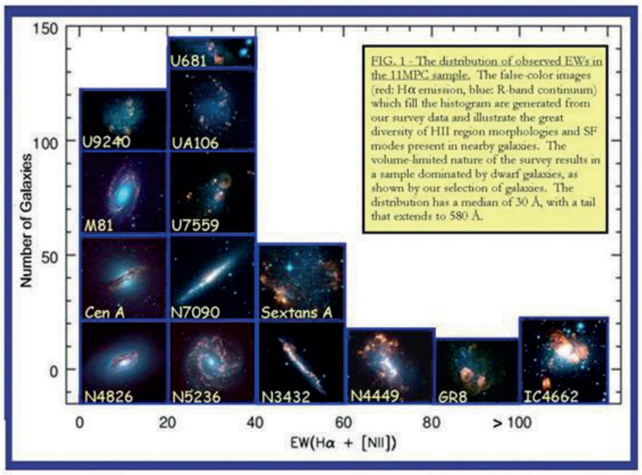
A mysterious source of gravitational attraction, dubbed "Dark Matter," was first hinted at in the 1930s in studies of the motions of distant galaxies. By the 1980s, Dark Matter's existence was not only well established, but a number or arguments showed that it was a completely unexpected type of material, different from ordinary atoms. Two candidate materials were proposed, with the whimsical acronyms of MACHOs (Massive Compact Halo Objects) and WIMPs (Weakly Interacting Massive Particles). The great thing about these proposals was that they could be tested. And in one of its very first programs, the VATT was instrumental in testing, and eliminating, the MACHO hypothesis.

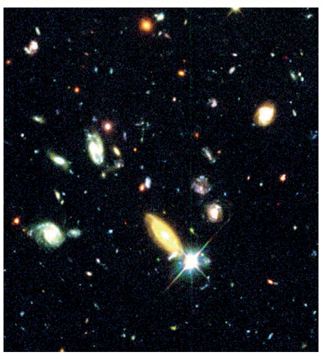
If there were indeed many "MACHOs", massive but compact objects orbiting in the halos around a galaxy, would we be able to see them? Not directly; by definition, they would be dark and compact. But their gravity should cause a number of "microlensing" events, momentarily focusing the light of any star lined up exactly opposite to them from us. Two astronomers from Columbia University, Austin Tomaney and Arlin Crotts, assisted by Specola astronomers Fr. Chris Corbally and Fr. Richard Boyle, surveyed the nearby Andromeda Galaxy to look for these flashes of light. Their results, published in the *Astronomical Journal* in 1996, showed conclusively that while such microlensing events were indeed observed, they were far too few to account for the Dark Matter known to exist in the Andromeda Galaxy. This work has been cited more than 160 times since its publication.

The Evolution of Galaxies:

In the mid 1990s, the world of astronomy was astounded by the "Hubble Deep Field" image, made when the Hubble Space Telescope was directed to image a seemingly "empty" piece of space.

By exposing its camera for many days, a remarkable number of faint, very distant, and thus very old, galaxies came to light. Yet, ironically, a full analysis of this image required another bit of science that no one had done yet: a similar set of images, at a similar resolution, of galaxies much closer to us in space and time. Only then could one see just what was the same, and what had changed, in galaxy morphology over the age of the universe.





The 11HUGS survey of galaxies imaged galaxies of all types located within 11 megaparsecs of Earth to compare their characteristics to far distant galaxies like these, to the left, from the Hubble Space Telescope Deep Field.

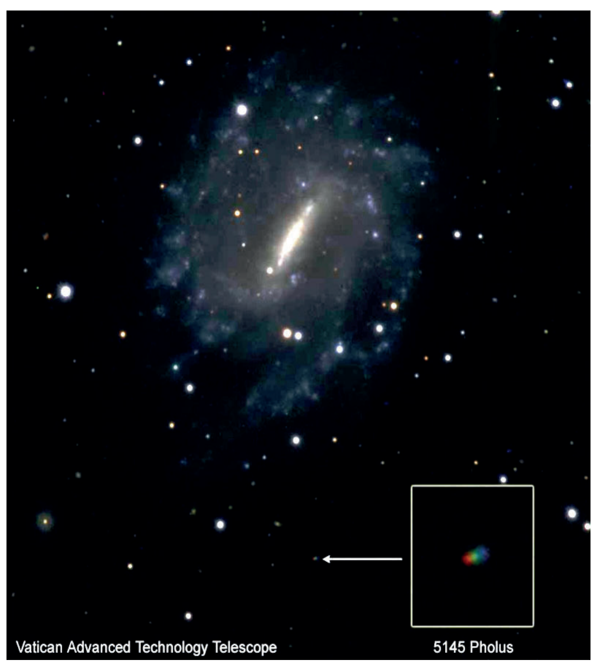
In order to create this comparison set of images, the VATT was employed in several surveys of the colors and morphologies of local galaxies. Robert Kennicutt of the Carnegie Institute set up the "11HUGS" (*11 Megaparsecs H-alpha Ultraviolet Galactic Survey*) team, which included Fr. José Funes, to make these observations. A 2009 overview paper of their work by Janice Lee and collaborators (including Fr. Funes) citing VATT data has been referenced more than 350 times. Meanwhile, companion work by Violet Taylor, a student of Rogier Windhorst at Arizona State University, and collaborators has been cited more than 75 times.

Kuiper Belt Object Colors:

Kuiper-belt objects (KBOs) are an ancient reservoir of comets beyond Neptune's orbit. First discovered in the mid 1990s, the most basic question about these faint and distant objects was to characterize what was there: were they all the same, or did they come in different populations? Because they are so small and distant, the only data we have are their orbits and their average colors. Beginning in the late 1990s, Steve Tegler at Northern Arizona University and Bill Romanishin from the University of Oklahoma collaborated with Br. Guy Consolmagno on a 15 year program of observations to measure KBO colors using the VATT.

These objects are faint (a million times fainter than the faintest star visible to the naked eye) and appear to move in the sky quickly enough that you cannot image them for more than five minutes before their images start to blur. The VATT and its CCD camera were the ideal system; with its sharp seeing it could concentrate the faint light onto a few pixels, while its field of view was sufficient to ensure that suitable comparison stars would be imaged alongside the object.

The result of a key 2000 paper published in *Nature* (with more than 130 citations) is that these objects come in two distinct color groups. Some of these objects were found to have the reddest optical colors in the solar system, while the others are gray: their surfaces reflect sunlight without absorbing any particular color. Follow up work at the VATT showed how these colors were connected to the nature of their orbits. All of the objects that have near-circular orbits larger than Pluto's orbit have extremely red surfaces; but of those objects whose orbits have been perturbed in inclination or eccentricity, about half are gray.



The centaur 5145 Pholus orbits from Saturn out to beyond Neptune; it was one of hundreds of trans-Neptunian objects surveyed in three colors.This is a composite of images taken with red, green, and blue filters: notice the colored dots marking its passage in front of a distant galaxy.

Among the solar system objects discovered and tracked at the VATT was a pair of asteroids in orbit about each other whose colors and orbits conned them with the important asteroid 4 Vesta, shown here in a NASA image from the Dawn Spacecraft.

Extending the Inventory of the Solar System:

Fr. Richard Boyle and his colleagues have been using the VATT for more than twenty years in their survey of open star clusters. This work is ongoing, and its ultimate significance is still developing. But in the meanwhile, with all that time at the telescope, they have had the opportunity to go "fishing" for discoveries closer to home.

Since 2009 Fr. Richard Boyle and collaborators K. Cernis and V. Laugalys at the Vilnius Observatory in Lithuania have been doing astrometry on asteroids and trans-Neptunian objects. As a result of their observations, over a hundred new asteroids and KBOs have been discovered at the VATT. One in particular is large enough to be nearly dwarf-planet sized. Following IAU conventions that such objects are named for deities related to creation, they have named it *Praamzius* for the goddess of creation in Lithuanian mythology.

Meanwhile, in 2001-2003, Bill and Elizabeth Ryan from New Mexico Tech and their collaborator C. T. Martinez from the University of New Mexico used the VATT to observe asteroid 3782 Celle, which has been associated both dynamically and spectroscopically with the Vesta asteroid family — the likely source of the basaltic achondrite meteorite family.

During the 2002-2003 run, dips in the brightness of this asteroid gave clear evidence that Celle is actually a binary system with an average bulk density of 2.2 grams per cubic centimeter, much less than the density of the basaltic meteorite fragments. This indicates that at least one, if not both, of the binary components has a highly fractured internal structure. This finding has important implications for understanding how fragments may have been broken off from their original parent body and re-accumulated into a binary system.

Other highly cited papers:

There are many other widely cited papers based on observations made at the VATT. Among the most cited works (citation counts as of January 2020):

G. Hallinan and collaborators, including Fr. Boyle, "Periodic Bursts of Coherent Radio Emission from an Ultracool Dwarf", in *The Astrophysical Journal*, 2007 (135 citations)

E. M. Corsini and collaborators, including Fr. Funes, "Dark matter in early-type spiral galaxies: the case of NGC 2179 and of NGC 2775", in *Astronomy and Astrophysics*, 1999 (76 citations).

Liese van Zee and collaborators, "Stellar Populations of Dwarf Elliptical Galaxies: UBVRI Photometry of Dwarf Elliptical Galaxies in the Virgo Cluster", in *The Astronomical Journal*, 2004 (75 citations)

E. Flaccomio and collaborators, "BVRI photometry of the star-forming region NGC 2264: the initial mass function and star-forming rate", in *Astronomy and Astrophysics,* 1999 (61 citations)

Krzysztof Stanek and collaborators, "Rapid UBVRI Follow-up of the Highly Collimated Optical Afterglow of GRB 010222", in *The Astrophysical Journal,* 2001 (51 citations)

K. G. Strassmeier and collaborators, including Fr. Gabor, "PEPSI: The high-resolution échelle spectrograph and polarimeter for the Large Binocular Telescope", in *Astronomische Nachrichten*, 2015 (45 citations)

Anne J. Verbiscer and collaborators, "Near-infrared spectra of the leading and trailing hemispheres of Enceladus", in *Icarus*, 2006 (43 citations).

A Brief History of the VATT

In the early 1980s, fleeing light pollution at its site in Castel Gandolfo outside of Rome, the Vatican Observatory opened an office at the University of Arizona solely with the idea of taking advantage of the large number of telescopes in the area accessible by astronomers affiliated with the University.

The idea that the Specola would be a participant with its own telescope first began in March, 1985, when a large mirror was spun-cast by what is now the Richard F. Caris Mirror Laboratory at Steward Observatory. This mirror, a 1.8-m diameter dish with an f/1.0 focus, was offered to the Vatican Observatory to be the heart of a joint new telescope project with Steward Observatory.

Once the decision was made to build a telescope around this mirror, the history of the VATT began.

In the fall of 1986, the Vatican Observatory Foundation was incorporated and the design of the telescope began. In February 1990, the telescope mount was delivered by L&F Industries to a test facility near Tucson. In the fall of 1990, the facility's contractor, T.L. Roof, began site clearing on Mount Graham. In November 1991, polishing of the primary mirror was completed by the Mirror Lab. In May 1992, polishing of the secondary mirror was completed by the Space Optics Research Laboratory. In October 1992, the telescope mount and dome were installed on Mount Graham.

In September 1993, first light was obtained with the primary mirror; this was followed by the telescope's dedication that same month. July 1994 saw first light with the secondary mirror. In January 1995, scientific observations began.

During the years immediately following 1995, the principal effort of the technical team went into further tuning and stabilization of the telescope's very complex systems. Facility instrumentation was limited to CCD cameras, first one on loan from Columbia University and later a 2K camera from Steward's Imaging Technology Laboratory (ITL).

The scientific capabilities were enhanced by the brief appearances of visitor instrumentation: these included, in 1996, a low-resolution optical spectrograph provided by the Planetary Science Institute of Tucson and the Arcetri (Italy) Near-Infrared Camera; and from late 2002 through 2003, CorMASS, a low-resolution infrared slit spectrograph.

The original 2K CCD camera was replaced in 2007 by a 4K imager, courtesy of ITL, which was capable of covering the whole 12 arcminute telescope field of view. In 2009 the National University of Ireland Galway located its Ultra Fast Imager (GUFI) at VATT; the agreement with NUI Galway continues to the present.

In the fall of 2010, after a development time nearly comparable with the history of VATT, a medium-resolution optical slit spectrograph, VATTSpec, was installed. In 2018, the original 4K imager was replaced by a new imager chip of similar dimensions from ITL.

In the twenty five years since first light, the telescope has had several major upgrades. In December 1998, the Vatican Observatory Foundation was awarded a Science Initiative Grant by The Kresge Foundation; the engineering projects completed under this grant in 2000 significantly improved the performance of VATT, most obviously in its imaging. In the summer of 2008 came the installation of new networking and computing equipment, provided through a grant from Hewlett Packard. As a result, the stability of the telescope's networking, and so the efficiency of observations, increased enormously.

At the present time, the VATT is undergoing its most significant upgrade since its first light.

First, the VATT is becoming a robotic telescope, capable of being operated remotely without a human presence necessary at the mountaintop. This involves intensive upgrading of virtually all of the telescope's infrastructure; much of this work has been funded by a generous grant from The Papal Foundation.

And second, this robotization is coordinated with that for the Steward Observatory's other medium-sized telescopes, the 90-inch Bok telescope on Kitt Peak and the 61-inch Kuiper telescope on Mt. Bigelow. When all three are robotic, with each telescope employing a different instrument, simultaneous observations in different modes for the same program will be possible. This will make the three telescopes into a powerful and unique consortium: Arizona Robotic Telescope Network (ARTN).

The Alice P. Lennon Telescope and the Thomas J. Bannan Astrophysics Facility were made possible thanks to the generous support of many donors to the Vatican Observatory Foundation, most notably major donations from the Lennon and Bannan families.