I. COVER

Program for Science Vanguard Research Program (SVRP)

Mid-Term Report

Title of Proposal (Chinese)：

宇宙的時變現象—台灣參與泛星計畫暨以掩星技術清點太陽系外圍小型天體之數量(3/4)

Title of Proposal (English)：

Cosmic Variability --- Taiwan's Participation in the Pan-STARRS Project and Population of Small Bodies in Outer Solar System by Stellar Occultation

Principal Investigator (Chinese)：

陳文屏

Principal Investigator (English)：

Wen-Ping Chen

Participating Institutions:

National Central University,
National Hsing Hua University,
National Taiwan Normal University,
Academia Sinica.

Overall Duration: Month 08 Year 2010 - Month 07 Year 2014
Report Duration: Month 08 Year 2012 - Month 05 Year 2013

Date **2013 May 23**

II. BASIC INFORMATION OF THE PROGRAM

Program Title: (in English & Chinese)
Cosmic Variability --- Taiwan's Participation in the Pan-STARRS Project and Population of Small Bodies in Outer Solar System by Stellar Occultation
宇宙的時變現象—台灣參與泛星計畫暨以掩星技術清點太陽系外圍小型天體之數量(3/4)

Principal Investigator		
	Name	Wen-Ping Chen/ 陳文屏
	Tel:	+886-3-422-3424
	Fax:	+886-3-426-2304
	E-mail	wchen@astro.ncu.edu.tw

	Expenditures* (in NT$1,000)	
	Projected	Actual
99	10834	9840
100	10550	9550
101	11042	10060
102	7263	9780

Serial No.	Project Title	Principal Investigator	Title	Affiliation
Sub-Project 1	Solar System Studies/ 太陽系	(in English & Chinese)	(in English & Chinese)	(in English & Chinese)
Sub-Project 2	Energetic Transient Phenomena/ 高能瞬變現象			
Sub-Project 3	Photometric Monitoring for Accreting Binaries/ 吸積雙星之光度監測			
Sub-Project 4	Galactic Open Clusters and Young Stellar Population/銀河系疏散星團與年輕恆星			
Sub-Project 5	Exoplanet and RR Lyrae Variables in the Milky Way/ 系外行星與天琴座 RR 變星			
Sub-Project 6	Matter and Light: Survey of Dark Halos through Weak Lensing and Study of Galaxy Evolution via Rest-frame Colors and Morphologies/ 星系演化			
Sub-Project 7	Variability Study of AGN and Starburst Galaxies/ 活躍星系核			
Sub-Project 8	Structure Formation/宇宙大尺度結構形成			
Sub-Project 9	Data Processing, Storage and Distribution/ 資料處理與分配			

Program Director/Principle Investigator Signature: ______________________________

III. (Form 3) Executive Summary on Research Outcomes of this Program

1. Description of the Program

This Vanguard Program consists of two projects, the Panoramic Survey Telescope And Rapid Response System (Pan-STARRS) and the Taiwanese-American Occultation Survey (TAOS). Pan-STARRS has built its first telescope system (PS1), a 1.8 m telescope located in Haleakala in Hawaii, equipped with a 1.4 giga-pixel camera using the state-of-art orthogonal transfer array detectors. The PS1 team in Taiwan consists of astronomers and engineers at National Central University (NCU), National Tsing Hua University (NTHU), Institute of Astronomy and Astrophysics of Academia Sinica (ASIAA), and National Taiwan Normal University (NTNU). PS1 patrols the entire observable sky from Hawaii (3 pi solid angle) with a cadence of one day to a couple of weeks. The primary goals are to detect and characterize celestial objects varying in brightness (e.g., variable stars, supernovae, gamma-ray burst counterparts) or in position (e.g., comets, asteroids, near-Earth objects, trans-Neptunian objects). The main part of this report focuses on the progress of the PS1 project.

TAOS operates its 4 telescopes, each of a 0.5 m aperture equipped with a 2K times 2 K CCD camera, located at Lulin Observatory in Taiwan. The TAOS collaboration includes mainly members at ASIAA, NCU, Harvard-Smithsonian Center for Astrophysics (CfA), and Yonsei University. While ASIAA is building TAOS2, the expanded version of TAOS, to be sited in Mexico, TAOS continues to gather data in a routine way. The TAOS results are summarized briefly at the end.

2. Status of the PS1

The PS1 system, with its wide field optics and a complex imaging device, had a long shakedown period. Eventually the sky survey started in May 2010 and as of the writing of this report (May 2013), each patch of the entire observable sky (3 pi solid angle) has been observed repeatedly in several bands for three years. PS1 carries out several surveys. The general 3-pi survey takes up slightly more than half of the telescope time (56%). Then there is the Medium-Deep (MD) survey using a total of 25% time. Other surveys are relatively small in terms of time consumption, for example the solar-system key project along the ecliptic using essentially no filter (5%), and the monitoring of M31 (2%, every night during the season when M31 is high).

Figure 1a depicts the sky coverage of the 3 pi survey as of May 2013. The entire observable sky has been visited at least a few dozen times per filter. In particular, the *y* band data is the first sky map at this wavelength (1 micron). For the PS1 operations, about 35% of night time was lost due to bad weather, and the overall duty cycle (open shutter for science versus total clear time) was 53%. Figure 1b illustrates the location of the MD fields.

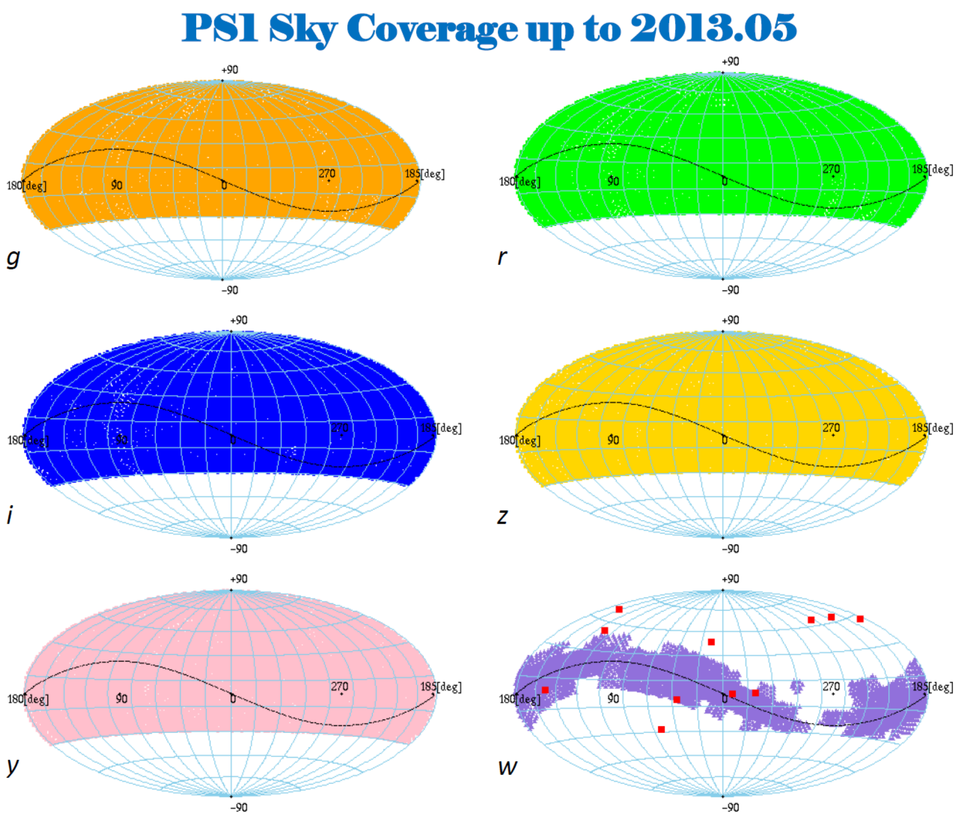

Figure 1 --- The sky coverage to date of the PS1 3-pi survey, from upper left to right at grizy and the w band. The Medium Deep (MD) fields are marked as red squares in the w band image

.

One critical development is that the US Air Force Research Lab since December 2011 has lifted the requirement for *MAGIC* (a software to remove streaks in the images caused by artificial satellites) to pre-run every raw PS1 image. This increases tremendously the data reduction efficiency, and hence timely discoveries. An administrative change of the PS1 consortium in Taiwan (PS1TW) is the replacement of the groups of National Cheng Kung University (NCKU) and of National Taiwan University (NTU) by those OF NTNU and ASIAA. The co-Is at NCKU (one person) and NTU (two) originally signed up to use the PS1 data, respectively, for Galactic structure and for variability of active galactic nuclei, pulled out because PS1 was delayed so they decided to work on something else. Meanwhile, Lihwai Lin graduated from NTU and moved to ASIAA. She is now leading the merging galaxies and large-scale structure project at ASIAA. In the past 3 years, NTNU hired new faculty members, who expressed interest to work with Lin. The NTNU colleagues brought in expertise not only on science but on data analysis and management. The PS1 Science Consortium (PS1SC) and the Board both approved our request of the change-over of the member institutions. The other PS1TW member institutions at NCU (astronomy and computer science) and at NTHU remain the same. There are 12 scientific key projects in the PS1SC: KP1 (Inner Solar System, within the orbit of Jupiter); KP2 (Outer Solar System); KP3 (Low-Mass Stars, Brown Dwarfs and Young Stars); KP4 (Exoplanets by Stellar Transits); KP5 (Milky Way Structure and Local Group); KP6 (M31); KP7 (Massive Stars and SN Progenitors); KP8 (Cosmology with Variable Stars and Explosive Transients); KP9 (Galaxies); KP10 (AGNs and High Redshift Quasars); KP11 (Cosmological Lensing), and KP12 (Large-Scale Structure of the Universe). The PS1TW members participate actively in KPs 1, 2, 3, 5, 6, 8, and 12. PS1TW meets once every 4-5 weeks at NCU to present results and to exchange experience in handling the PS1 data. The entire consortium PS1SC meets once to twice a year (Queens 2010 August; Hawaii 2011 May; Hawaii 2012 January) to learn of the project status and for KP collaborators to discuss face to face. Such workshop meetings require extensive travel time and funding but are essential to maximize scientific interactions. We occasionally also invited PS1 scientists to visit Taiwan, the latest being Prof. Kenneth Chambers, who visited NCU from May 21 to 24, 2013, giving tutorials on the PSPS (database interface) to Taiwan colleagues.

PS1 images taken every night are processed almost immediately, via high-performance computing facility in Maui, by the *Image Processing Pipeline* (IPP), a PS1-specific analysis package. Photometric and positional information for each detected source is extracted for comparison with that measured at previous epochs. Those with positional changes are sent to the *Moving Object Processing System* (MOPS) for orbital linkage. Those with brightness changes, such as supernovae, counterparts of gamma-ray bursts, or flare stars, etc. will be winnowed out by various working groups. At NCU, we download data products, essentially daily, as they become available. A total of 200 TB worth of data (star/galaxy catalogues and a small fraction of MD FITS images) are in the NCU depository.

The photometry and astrometry of the PS1 observations, either of the 3-pi or the MD surveys, needs to be tied down self-consistently of the entire sky. Scientific outcomes in this initial state tend to be quick results, e.g. on supernova and near-Earth object discoveries or follow-up studies. The PS1SC observations are expected to end by January 2014. One development in the last 6 months is the partnership of the the Space Telescope Science Institute (STScI), which will handle the archive after 2014, with a grace period of 1 year for the science consortium members. The PSPS database interface is being ingested of the vast amount of data. Here in Taiwan, we are in the process of negotiating with the High Performance Computing Institute to host one backup copy of the entire data store at NCU. Currently it amounts to about 350 TB worth of data.

On the personnel, Neelam Panwar continued her second year of postdoc in the project. Chien-Hsiu Lee terminated his contrast in January, and now works in Germany (still on the PS1 project). Juei-Hwa Hu starts her appointment in May 2013, working on star clusters.

The following summarizes the progress made by each PS1TW group using semi-calibrated data, organized by the key project science subjects.

Progress and Achievements of Key Projects

(1) <u>Solar System</u> (*Ip, Kinoshita, Abe, YT Chen, E Lin, ZY Lin*)

Detecting and characterizing near-Earth objects (NEOs) are the prime goal of the PS1. Objects in the inner solar system provide crucial clue to the origin and evolution of our planetary system. Asteroids and comets that have survived since the early solar system have experienced numerous collisions that influenced their thermal histories and orbital properties. Thus, the physical nature (size, shape, density, composition and orbital distribution) of these small bodies is fundamental to understanding how our solar system has evolved. The orbital distribution of NEOs have been investigated. The disruption phenomena of NEOs to generate “fragmented families” were proposed (Schunová et al. 2012), which is confronted by in-situ spacecraft measurements, such as those by *HAYABUSA* (e.g., Abe et al. 2006). A rare phenomenon of the Earth impactor was simulated by using a spacecraft re-entry with the impact speed higher than 12 km/s (Abe et al. 2011). Active asteroids (asteroid Phaethon as a parent of Geminid meteor shower) and main belt comets are of importance to know the origin of comets and asteroids (Hsieh et al. 2012a, Hsieh et al. 2012b).

We (NCU) have been contributing to the developments of the MOPS pipeline used to discover, identify and determine the orbit of the NEOs together with other classes of asteroids, and comets. About 550,000 asteroids are catalogued to date and ~9,000 of them are NEOs. In order for an asteroid to be catalogued, the asteroid must be observed by several observatories in different time zones to determine a reliable orbit. Most newly found NEOs are sub-km in size so are very faint. They are observable only when they approach the Earth during a short time period, typically a few days to a few weeks. PS1 as a patrol facility does not recover its own discoveries and rely on complementary follow-up observations to secure a discovery. A network of telescopes with a wide longitudinal coverage is needed. To make a quick follow-up observation, we have established the MOPS Alert System to inform our community of an NEO discovery immediately. The NCU team has been using the Tenagra II 32”(~0.81 m) telescope in Arizona, USA and the Lulin One-meter telescope (LOT) in Taiwan to follow up PS1 NEO discoveries.

PS1 is considered the most poweful tool for asteroid discoveries (Figure 2). The total number of newly discovered NEOs detected by PS1 to date (as of 2012 April) is 287, among which 25 are Potentially Hazardous Objects (PHOs), a subset of NEOs, whose orbits come close to that of the Earth within 0.05 AU (~20 Moon distances). PHO collisions to Earth occur infrequently, but the threat is large when averaged over time. A total of 7 comets have been discovered by PS1. Our follow-up efforts of PS1 NEO candidates have succeeded in determining their orbits. About 50 of PS1 NEO candidates have turned into NEO discoveries (4 of them were new comets) by our follow-up observations that were recognized through the Minor Planet Center (MPC) under the International Astronomical Union (IAU), for example;

```
MPEC 2011-Q08 : 2011 QE2 http://www.minorplanetcenter.net/iau/mpec/K11/K11Q08.html
MPEC 2011-N15 : 2011 MD5 http://www.minorplanetcenter.net/iau/mpec/K11/K11N15.html
MPEC 2011-M33 : 2011 MT http://www.minorplanetcenter.net/iau/mpec/K11/K11M33.html
MPEC 2011-H07 : 2011 GX65 http://www.minorplanetcenter.net/iau/mpec/K11/K11H07.html
```

Our contribution to the discovery of NEOs has been encouraged by the approval of the *NASA NEOO (Near-Earth Objects Observations) program* (selected NASA proposal: R. Wainscoat, R. Jedicke including S. Abe et al. *11-NEOO11-0016*).

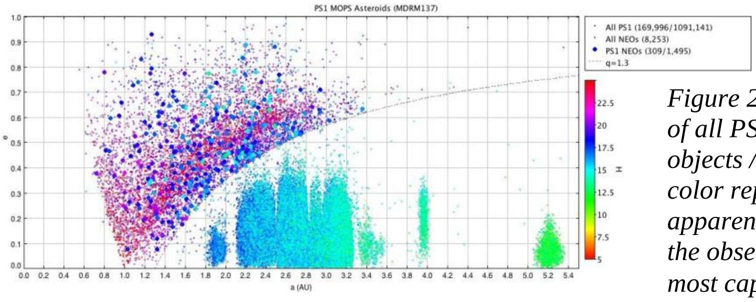

Figure 2 --- The semimajor axis 'a) versus the eccentricity 'e" of all PS1 detected asteroids as of 2012 January. Number of objects / number of observations by PS1 are indicated. The color represents its absolute magnitude H, defined as the apparent V-magnitude if it were 1 AU from both the Sun and the observer at a zero phase angle. PS1 is considered the most capable telescope in the world for NEO discoveries.

We published our first PS1TW paper in 2010 (Wang et al. 2010). A showcase project now is to monitor the activity of comet 29P/Schwassmann-Wachmann (Figure 3). It is an active Centaur with a near-circular orbital beyond Jupiter. This project monitors 29P from early 2010 to now using PS1, the LOT and Tenagra II telescope. Images in Figure 3 show two main results: (1) 29P is not always in the outburst state. We could use the images to estimate the outburst frequency. (2) The shape of the coma could be influenced by the relative location between 29P and the observer. For example, the coma seen in June 2011 is similar to that in May 2012. We are developing the coma model to explain the shape variation of 29P.

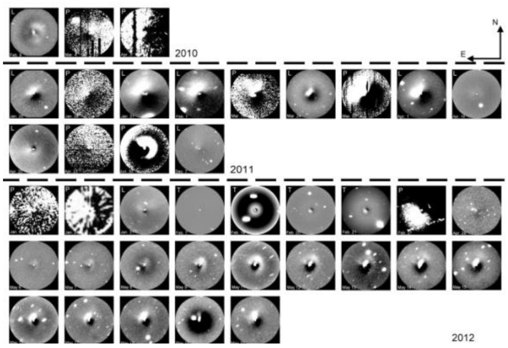

Figure 3 --- Images processed by subtracting the azimuthal average profile. In all images, taken from 2010 to 2012, north is to the up, and east to the left, with a field of view of 200 x 200 pixels. Images taken after 29 April 2012 were obtained at the Tenagra observatory.

In addition, there are two subprojects led by PS1TW members: development of an Outer Solar System (OSS) analysis pipeline, and long period comet (LPC). The IPP produces photometry and astrometry of stars and galaxies. The MOPS is tailored to detect fast moving objects, i.e., those in the inner solar system. Either IPP or MOPS, however, would produce too high a false positive rate for OSS objects. PhD students Charles Yin-Tung Chen and Ed Hsin-Wen Lin (both of NCU) has been working with Matt Holman and other OSS scientists at the Harvard-Smithsonian Center for Astrophysics to develop a new algorithm to filter out false positives, e.g., those near the detector edge (Figure 4). The algorithm forms the backbone of the OSS analysis pipeline. For the LPCs, we used the JPL ephemeris tool for known LPCs to simulate the discovery rate. On average, the PS1 OSS pipeline can identify slow moving objects as LPC candidates with at least a one-month arc, a time scale commensurable with PS1 observations. We expect to discovery some 10 comets each year with the PS1 data.

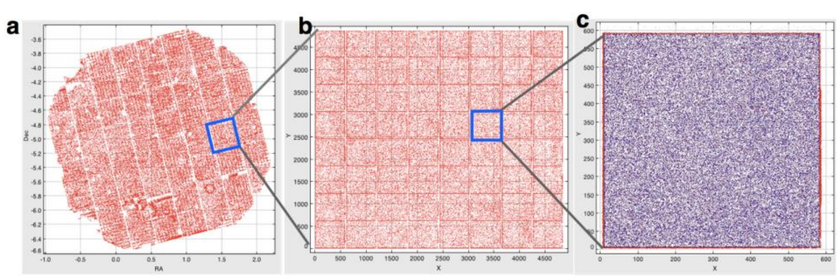

Fig. 4 --- Detections of PS1 in (a) the whole facal plane, (b) one chip, and (c) one cell. In (b) one sees a lot of false positives near the cell edges. After applying the edge 'cleaner', we were able to cut them off, as seen in (c). The blue dots present the remaining detections after applying the filtering algorithm; red dots are false positives near the cell edge.

Regarding papers, Edward Lin has a draft of paper close to submission: "*Pan-STARRS 1 observations of an unusual active Centaur P/2011 S1(Gibbs)*".

(2) <u>Galactic Star Clusters and Young Stars</u> (*WP Chen, Panwar, Chiang, CC Lin, CD Lee*)

We have used the PS1 photometry and proper motion data to identify and characterize low-mass members in star clusters. The sample of open clusters is largely incomplete, limited to within about 1 kpc in the solar neighborhood because of excessive extinction in the Galactic plane and because of lack of systematic surveys. With PS1, we expect to produce the most comprehensive sample of cluster member list for thousands of open clusters out to about 3 kpc down to ~0.3 solar masses. For nearby clusters, even substellar objects may be detected. Our sample will provide information of the origin of stellar mass at the lowest end of the main sequence and of brown dwarfs. The spatial distribution will serve to diagnose the dynamical evolution of a star cluster, such as the effects of mass segregation, stellar evaporation, tidal stripping.

The PS1 photometry is being calibrated and accurate proper motions await the completion of the project when there will be a 3.5-year baseline. In developing the analysis pipeline, we carried out a pilot program to identify uncharted star clusters using 2MASS data and this resulted in a few candidates, including a cluster within the Camelopardalis OB1 association (Figure 5). Characterization by PS1, *WISE*, of this cluster Gℓ144.9+0.4 indicates extreme youth (< 1 Myr), a distance of ~1 kpc, with at least a couple of dozen members. This paper has been submitted in May 2013.

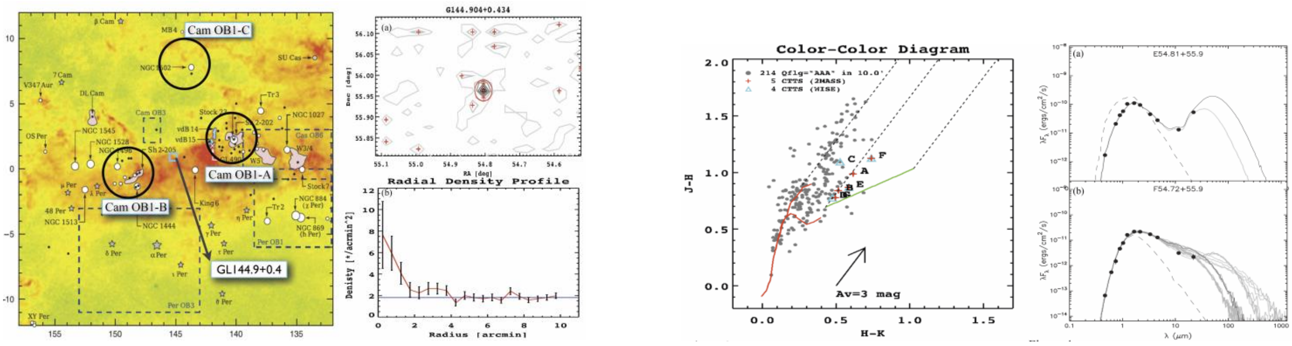

Figure 5--- (Left) a newly found star cluster in the molecular cloud complex within Cam OB1, stellar density map, and the radial density profile. (Right) Using infrared colors, young star candidates were selected, a couple of which show spectral energy distributions of young stars with copious circumstellar dust.

Figure 6 demonstrates another application of PS1 data on Praesepe (M44), a very nearby (170 pc) and intermediate-age (800 Myr) cluster as the target to study its very low-mass members. Combining the PS1 magnitudes data and PPMXL proper motions, we have identified a total of more than 900 member candidates, with the lowest mass being less than 0.1 $M_\odot$. Furthermore, the spatial distribution is segregated for different stellar masses, even for the substellar population (Figure 6). Some candidates found by other groups with photometric criteria alone were excluded from the member list on the basis of proper motions. Our sample of stars and brown dwarfs is the most comprehensive in terms of sky coverage and depth, with both photometric and proper motion data. This paper is being submitted. Neelam Panwar, one of the PS1TW postdocs at NCU, has been working on this project, in addition to her study of star formation in H II regions. A paper has been submitted to the MNRAS in May 2013.

Regarding papers, Chien-Chen Lin submitted a paper "*Characterization of the Young Open Cluster G144.9+0.4 in the Camelopardalis OB1 Association*" in May 2013. A paper has been submitted to the MNRAS by Panwar in May 2013. Chen, W. P. is leading a paper "*Characterization of the Lowest-mass Stars in the Praesepe Star Cluster*", ready for submission in late May, 2013 (see Figure 6).

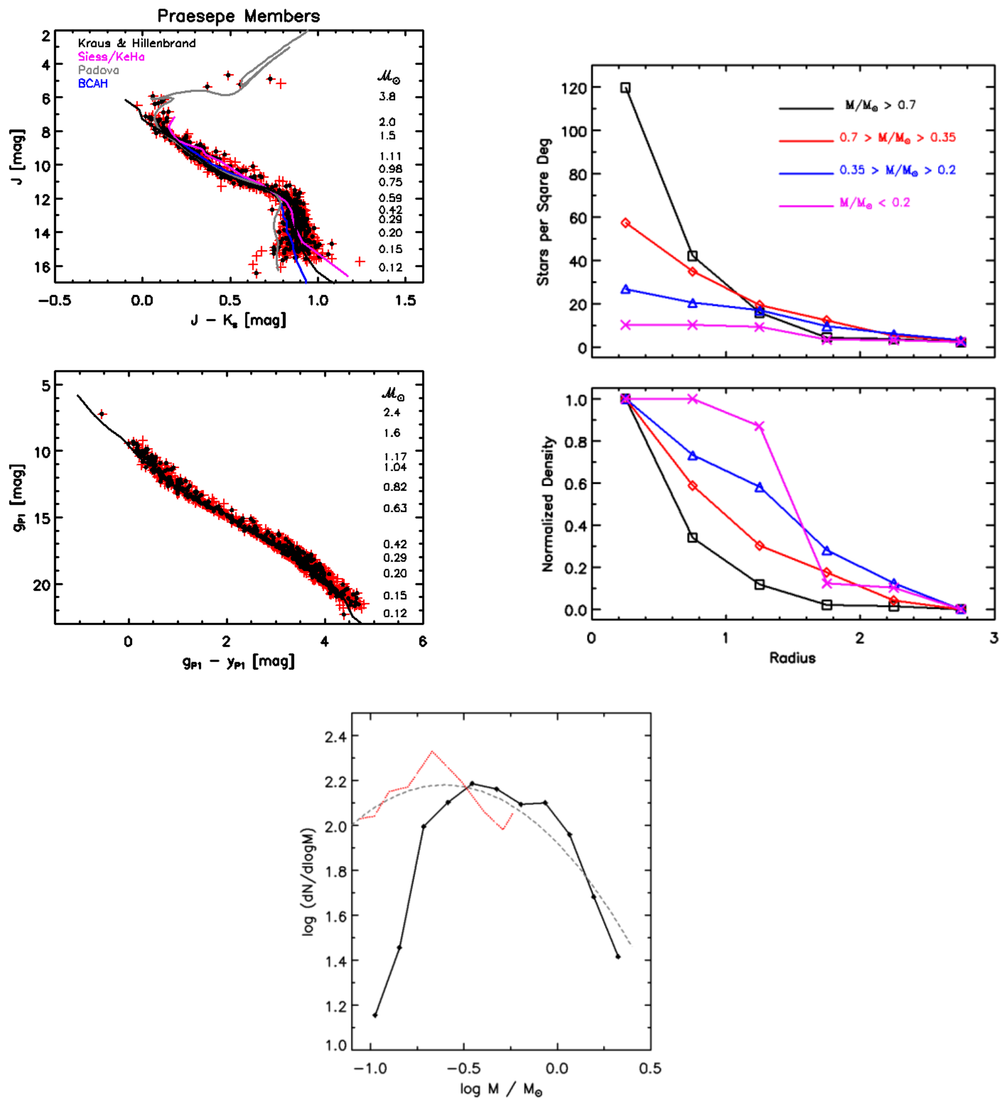

Figure 6--- (Upper Left) 2MASS J versus J-Ks and PS1 g versus g-r diagram color-magnitude diagrams for the Praesepe members down to the hydrogen burning limit. (Upper Right) More massive stars have a number density falling off faster than those of lower masses, indicating mass segregation. The least massive sample has been tidally stripped. (Bottom) The mass function of Praesepe, showing a consisitency with disk population (dashed line) and the field stars (dotted line).

We will also use the PS1 data to identify young stars with abrupt brightness variations when data at enough epochs become available. These variations are caused either by an intermittent accretion from the circumstellar disk onto the young stellar surface or by obscuration of starlight by a dust clump in the disk. As a pilot study, we monitored GM Cephei, a sun-like young star in the young (4 Myr) cluster Trumpler 37. An occultation lasting for a month, with a possible recurrence time scale of a year, has been observed (see Figure 7), signifying the first step of disk inhomogeneity in transition between grain growth in molecular clouds and planetesimal formation (Chen et al. 2012). The data were taken mostly by the LOT and Tenagra II. We expect this kind of variable stars to be common and we will use the PS1 data set to search for these abrupt variables yet uncatalogued.

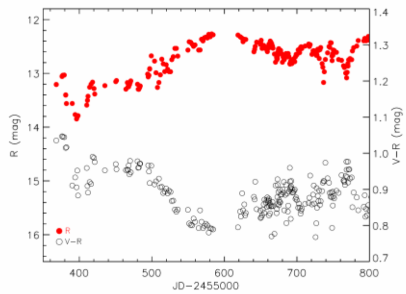

Figure 7 --- The R-band light curve (left y-axis) and the V-R color variations (right y-axis, redder to the top) of GM Cep from mid-2010 to mid-2011. Note the occultation event at the beginning and that the star became blue when faintest and brightest.

(3) <u>PAndromeda Project</u> (*Ngeow*, *CH Lee*)

This is one of the key projects, led by the German group at MPE, to monitor the Andromeda galaxy

M31 in the *r* and *i* bands with daily cadence duration five months per year. Chien-Hsu Lee got a PhD from MPE and now has been a PS1TW postdoc at NCU since October 2011 used this unique PAndromeda data set to study pulsating stars in M31. He continues to collaborate with the German group and initiated a couple of subprojects on his own.

Microlensing --- Lee et al. (2012) have detected six microlensing events in the bulge of M31, where one of the events (PAnd-3) is likely to be a MACHO event (Lee et al. 2012). We are now processing the data covering the disk of M31 to search for microlensing candidates.

Cepheids --- Lee and his collaborators have searched for Cepheids with period up to 100 days and found more than a hundred Cepheid candidates. With this sample, they expect to fine tune the period-luminosity relation of M31 Cepheid for distance determinations.

Eclipsing binaries --- Lee is a member of the MPE collaboration to conduct a comprehensive photometric study of the eclipsing binaries in M31. They have applied the box-fitting method to search for eclipsing binary candidates and determine their periods. The physical parameters of the candidates are characterized by fitting the Wilson-Devinney model. The results will be drafted up within a couple of months

(4) Transient Phenomena (*Urata, Kong, LJ Huang*)

In the past 1.5 years, the group at NTHU led by Albert Kong has been using PS1 data to follow up high-energy transients discovered by other instruments such as *MAXI*, *RXTE*, *Swift*, and *Fermi*. In particular, the focus is to look for the optical quiescent emission. This is important as the optical properties of the quiescent emission can determine the nature of the companion star in an accreting binary system. It will also provide crucial information (e.g. optical magnitude) for follow-up studies with large telescopes in the future. Kong et al. (2010a) discovered a quiescent optical counterpart for the black hole binary MAXI J1659-152 which has the shortest orbital period among all black hole binaries. It is an unexpected discovery as the counterpart seems to be brighter than predicted and this source has been widely discussed in a few recent papers. Because the PS1 detection is very marginal, we recently obtained a deep image with the CFHT and confirmed the PS1 observation. A paper has been published, Kong "*Optical Emission of the Black Hole X-Ray Transient MAXI J1659-152 during Quiescence*", 2012, ApJ, 760, L27.

The second effort by Kong’s group is XTE J1728-295 (Kong et al. 2010b). Unfortunately, the source is too faint for PS1. Using PS1 data, however, we discovered an early outburst of Swift J1836.6+0341 (Li et al. 2011), which showed an optical outburst two months before the X-ray outburst. Follow-up observations are required to understand the nature of the source.

The CosmicExplosion Lab of NCU (led by Yuji Urata) and Kuiyun Huang (ASIAA) are working on various transients such as Gamma-Ray Bursts (e.g. Huang et al 2012 in prep as a PS1 lite paper), ultra-luminous SNe (e.g. Pastorello et al. 2010), unusual optical transients using both Taiwan's projects (LOT, Pan-STARRS, CFHT, Subaru and SMA) and international resources. We have submitted one PS1 lite paper and been preparing several drafts based on the PS1 discoveries. Here we highlight the mostly completed topic for which we used PS1 and Subaru (Suprime-Cam and Hyper-Suprime-Cam) to discover the unusually long and luminous optical transient (Urata et al. submitted). The transient showed an absolute magnitude brighter than −19 mag lasting for approximately 300 d in the rest frame, which is significantly longer than typical supernovae or ultra-luminous optical transients. The total radiated energy during our observation was 2×10^{52} ergs, comparable to energetic Fermi GRBs (Urata et al. 2012). The light curves and color evolution are inconsistent with any known supernova types. We suggest that the transient may be either a unique and peculiar supernova or a new type of event at an intermediate redshift. The ultra-deep Subaru images allowed us to characterize the faint host galaxy, crucial to the understanding of the origin and occurrence rate of this kind of transients. Given the luminosity function of various types of galaxies, the fraction of faint galaxies, such as the host galaxy of SDF-05M05, is expected to increase with redshift. This may make detections of luminous events rare in nearby Universe but common toward higher redshift (e.g., $z \gtrsim 0.5$). The apparent magnitudes at higher redshift will be as faint as the current event, ~22-23 mag, well within the limiting magnitudes of the PS1 MD data. However, the slow evolution and the presence of a faint host galaxy make it difficult to detect and classify these optical transients. Therefore, coordinated long-term monitoring with large telescopes (e.g. CFHT, Subaru) is needed. In particular, a synergy between PS1 (very wide sky coverage) and the sky survey by the Subaru Hyper-Suprime-Cam (wide field, very deep) should prove highly rewarding.

(5) Large-Scale Structure , (*LH Lin, Foucaud, Hashimoto, Jian, CW Chen*)

The primary science interest of the group led by Lihwai Lin is to study the environment effects on the galaxy evolution out to z ~ 1. The MD survey of the 10 fields shall reach a depth of 26.0 mag in *gri*, 25 mag in *z*, and 24.0 mag in *y* (AB, 2" aperture) after 3.5 years of operation. The combination of the filter, depth, and field size of MDS will eventually yield a large galaxy sample on the order of 10 million galaxies with exquisite photometric redshifts, enabling the search for groups and clusters of galaxies, the measurement of local galaxy density, and the determination of the clustering amplitude of galaxies. All these measurements will allow us to probe the relationship between the galaxy property and environments. Below we summarize the major progress made over the last two years, and outline the science papers that are under preparation.

Stacking status in the Medium Deep Fields

To have an independent check of the stacking procedure of IPP and to allow a better control on the quality of the final stacks, we have been stacking the Medium Deep Fields using our own pipeline. To avoid the processing of a very large number of frames, we have based our stacks on the IPP intermediate "nightly" stacks, which are typically stacking 8 warped frames in the different filters taken during a given night. We assumed here that the conditions are fairly constant throughout the night. All nightly stacks produced by IPP between May 2010 and December 2011, were used. Typically 10-15 of such frames for the fields in the spring and 20-25 in the fall were processed for each filter (slightly less for the *y* band). The total exposure time varies from 10 ksec to 48 ksec.

The pipeline developed for the processing by S. Foucaud, is based on the "Astromatic" software (http://www.astromatic.net): SCAMP, SWarp, and SExtractor. First, images are grouped per field, band and skycells. Then a first quality control process helps rejecting skycell images with very low sky coverage (typically on the border of the PS1 field-of-view, or for which masking has been very extensive) or very high extinction (preventing detection of stars). Then the astrometric solution is recomputed on the base of the SDSS-DR7 catalog when available (i.e. except MD01 and MD02), using the SCAMP software. The typical residual from astrometric solution is below 0.1". Finally using the same star catalog an internal photometric calibration is computed. At this stage a final quality control assessment is made, and all images with bad astrometric solution (>1") or with high extinction (>0.3mag) are rejected. In total less than 10% of the images are rejected during the two steps of quality control. Finally images in each field, band, and skycell are stacked with a median algorithm using SWarp. A skybackground removal algorithm with a kernel of 128 pixels (optimized for distant galaxies) is applied during the process. A final absolute photometric calibration is then made using once again the SDSS-DR7 catalog.

Several campaigns of observations have been conducted with the CFHT MEGACAM to cover the PS1 MD fields, mainly combining efforts from the CFHTLS and Eugene Magnier from the IfA. All MD fields are covered in u*-band to various depths. We have downloaded the calibrated images from the CADC Archive system. We then follow a similar process as the PS1 images, applying a two-level quality control, and computing astrometric and internal photometric solutions using SCAMP and the SDSS-DR7 catalog as reference. Images in each field are then stacked with a 4-sigma clipped mean algorithm using SWarp (modified by S. Foucaud for this purpose). A sky background removal algorithm with a kernel of 128 pixels is applied during the process. A final absolute photometric calibration is made using once again the SDSS-DR7 catalog. Master catalogs based on the *i*-band objects are generated by running SExtractor in a dual mode.

Data quality assessment

We have set up an image assessment pipeline to examine the quality of MD field stacks produced by our own and by the PS1 IPP team, by measuring the FWHM and distortion (quantified by the axis ratio and position angles) of PSF, the depth, and the detection completeness for each 'skycell' of a given stacked image (each MD field is composed of on the order of 70-100 skycells). The average seeing is around 0.9"~1.2", with sharper PSFs in longer wavelengths. The point sources are in general round with axial ratio ~0.96 with no obvious preferential position angles, suggesting there is no obvious distortion appearing in our stacks. To measure the depth, objects detected in each band were masked based on segmentation maps from Source Extractor. From the unmasked sky region, we randomly selected 1000 sky areas with radius 1” and calculated the fluxes enclosed within the circles. The depth was defined as 5 times the flux fluctuation within the sky apertures. Our depth analysis shows the current MD fields reach 24.5-25 mag in *griz* and 22.5-23 mag in *y*. The averaged seeing and depth distributions in various bandpasses for our stacks are given in Table 1 (subscripted “TW”). The results for IPP stacks are also shown for comparison (subscripted 'IPP'). The better seeing in IPP stacks compared to that of our stacks is partially due to the fact that the former stacks have applied a seeing cut in the frames going into the final stacks.

	g	*r*	*i*	*z*	*y*	*u*
Seeing_{TW} (“)	1.20	1.06	1.04	1.01	1.02	0.8
Seeing_{IPP} (“)	1.09	0.98	0.93	0.88	0.90	N/A
Depth_{TW} (mag)	24.8	24.7	24.6	24.1	22.6	25.5
Depth_{IPP} (mag)	25.0	24.9	24.7	24.1	22.8	N/A

Development of group/cluster finder: Probability Friend-of-Friend method (PFOF)

A group finder method, called Probability Friend-of-Friend (PFOF), was developed with the purpose to identify groups and clusters of galaxies in a photometric redshift sample (Liu et al., 2008). Using the PanStarrs galaxy mock catalogs generated by the Durham group with simulated photometric redshift error σz, we have tested the PFOF performance in terms of the 'purity' and 'completeness' for various cases, including galaxy samples with σ_z ranging from 0 to 0.07. In addition, we have also applied PFOF to the PS1 MD04 field which overlaps with the COSMOS field using two sources of photometric redshift catalogs: one is based on PS1 *grizy* photometry with $\sigma_z \sim 0.045$, and the other is from the COSMOS photometric redshift catalog with $\sigma_z \sim 0.01$ obtained from 30-bands photometry (Ilbert et al. 2009). These two catalogs allow us to evaluate how the PFOF performance varies with different photo-z uncertainties. The group candidates are then calibrated with the public zCOSMOS group catalog (Knobel et al. 2009) and matched to the known X-ray identified groups (George et al. 2011). The preliminary results are shown in Figure 8.

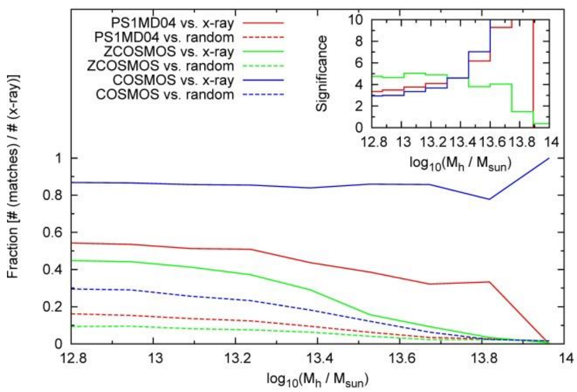

Figure 8--- The recovery rate of X-ray clusters as a function of group mass for PS1 MD04 (in red) COSMOS (in blue) and zCOSMOS (in green) optical groups. The dashed lines are for the control sample with the same density of X-ray clusters but with randomized locations. The ratio between the solid and the dashed lines, a measure of the significance of the recovery rate,

Regarding papers, one has been submitted: Jian et al. 2013, "*Probability Friends-of-Friends (PFOF) Group Finder: Performance Study and Observational Data Applications on Photometric Surveys*", submitted to ApJ, (arXiv:1305.1891). Another paper is in preparation: Lin et al. 2013, "*Pan-STARRS 1: The Role of Environment in the Star Formation Rate versus Stellar Mass Relation out to z ～1*", with a draft ~40% complete. Foucaud is preparing two papers: (1) Foucaud et al. 2013, "*Pan-STARRS1 Medium Deep Survey: Data quality and evolution of galaxy luminosity functions since z ~1*", 60% complete, and (2) Foucaud et al. 2013, "*Pan-STARRS1 Medium Deep Survey: Galaxy clustering and Halo occupation Models to z~1*", with the analysis started, likely to be a letter.

(6) Data Management

The data server is located at NCU, managed by J. K. Guo, who is in charge of data download, hardware and software maintenance, and users support. An in-house interface has been developed to query PS1 measurements (given the coordinates of an object and a search radius) along with other data bases commonly used, e.g., the 2MASS, SDSS, etc. A separate command can fetch (from the image server in Hawaii) postage-stamp images of the patch of sky of interest. A fraction of the data, namely of the MD fields including all object catalogs and some images, are stored also at NTNU, as a part of the community data depository center. Figure 9 shows the disk arrays and the schematic of the query interface. To date, a total of some 350 TB worth of data have been stored. A new server machine was purchased in 2013.

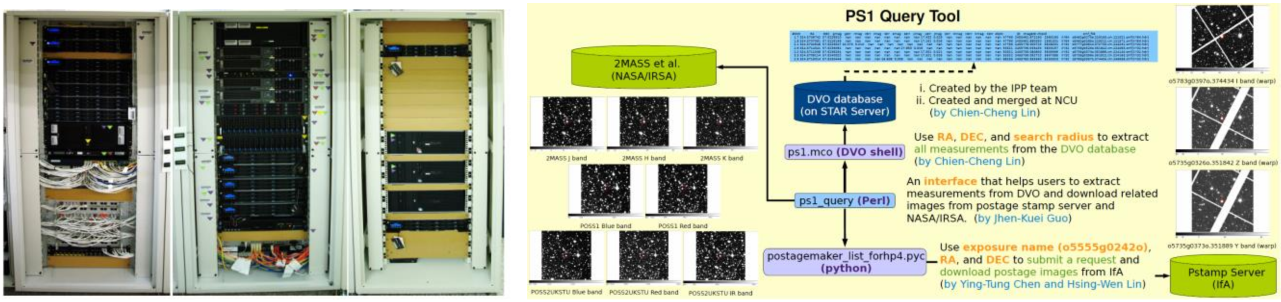

Figure 9--- The PS1TW "Star" data server at NCU with storage disk arrays and the schematic of the interface to query the PS1 data along with other databases.

(7) <u>Education and Public Outreach</u>

2010 December 18, 19 --- A teachers' workshop was held on major frontier astronomy projects carried out by Taiwanese scientists and engineers. A total of nearly 200 high school and elementary teachers were briefed on AMLA and Pan-STARRS. A special lecture on exoplanets was scheduled. There were parallel sessions to brain-storm the educational moduli, textbook and classroom materials. The event was financially support in part by the ALMA-U project and the response was overwhelmingly positive.

2011 May International Astronomical Search Consortium --- Using PS1 images, high school and college students from 7 countries, including Taiwan, participated in a campaign to search for uncharted asteroids. Some 18 students in Taiwan from 3 high schools joined this campaign and excelled, finding 4 out of 22.

2012 March/April International Astronomical Search Consortium --- Another such a campaign, this time with 40 schools from 7 countries, including 5 schools in Taiwan. We did even better this time, discovering 16 out of the total 59. The results were well covered in the news media, e.g., by TV and newspapers.

2013 March/April International Astronomical Search Consortium --- Another such a campaign, this time with 6 schools from Taiwan, contributing a total of 25 discoveries.

Status on the Taiwanese-American Occultation Survey (TAOS)

So far TAOS has published 10 papers, with the latest 5 in 2010, summarizing the system performance, analysis techniques, or scientific results. The scientific paper by Bianco et al. (2010) reported data collected from 2005 to July 2008, consisting of 443 data runs, equivalent to 5 x 10^5 star-hour exposures or 8.5 x 10^9 photometric measurements (Figure 10). In comparison, data up to September 2011 amount to 2016 data runs=1.2×10^6 star-hour exposures or 2.1×10^{10} photometric measurements. Data have been analyzed, and we expect a paper drafted in the second half of 2012.

All our scientific papers (about TNOs in general or about Sedna-like objects) so far report on upper limits, owing to the lack of positive detection by TAOS (Figure 11). The latest paper has been accepted for publication in the *Astronomical Journal*. The trans-Neptunian region appears not to be highly populated. Our multi-telescope system is crucial to beat down the false positives. To date, TAOS is still the only one of its kind in the TNO study, and the NCU group remains in charge of site support of the TAOS telescope systems, plus night-time technical assistance when needed. The next generation TAOS

2 is being built, with a larger telescope size (1.3 m versus 0.5 m), improved data acquisition (frame-transfer or CMOS), and a better site (Mexico), should have a sensitivity 100 times better.

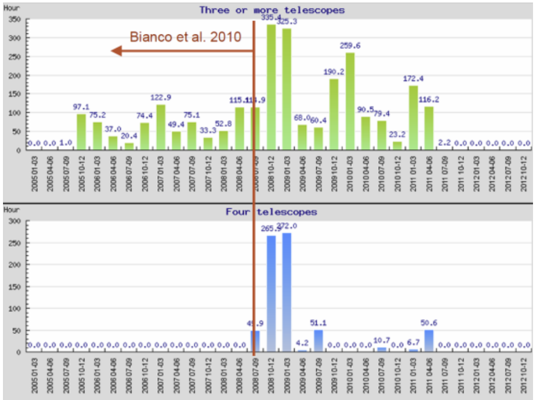

Figure 10 --- Data collected by TAOS. Addition of the 4th telescope is expected to improve noticeably the statistical significance of any possible event.

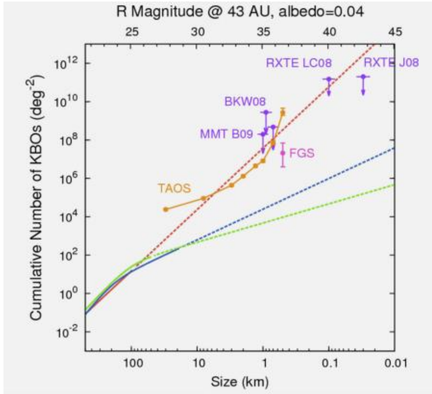

Figure 11 --- Number density of TNOs estimated by different experiments. Downward arrows show upper limits.

References (those derived from the PS1 or TAOS data are each marked with an asterisk)

Abe, S., et al. 2006, Sci, 312, 1344
Abe, S., et al. 2011, PASJ, 63, 1011
Chen, W. P., et al. 2012, ApJ, 751, 118*
George, M. R., et al. 2011, ApJ, 742, 125
Goldman, B., et al. 2012, submitted*
Hsieh, H., et al. 2012a, ApJL, 748, L15*
Hsieh, H., et al. 2012b, AJ, 143, 104*
Ilbert, O., et al. 2009, ApJ, 690, 1236
Knobel, C., et al. 2009, ApJ, 697, 1842
Kong, A. et al. 2010a, ATel, 2976*
Kong, A., et al. 2010b, ATel, 3011*
Kong A. 2012, ApJL, 760, L27*
Lee, C.-H., et al. 2012, AJ, 143, 89*
Li, K. L., et al. 2011, ATel, 3708*
Liu, H. B., et al. 2008, ApJ, 681, 1046
Pastorello, A., et al. 2010 ApJL, 724, L16*
Schunová, E., Et al. 2012, Icarus, 220, 1050*
Urata, Y., et al. 2012b, ApJL, 748, L4
Urata, Y., et al. 2012, ApJL, 760, L11*
Wang, J. H., et al. 2010, AJ, 139, 2003*
Zhang, Z. W., et al. 2013, AJ, accepted*

Publications (PS1 data and TAOS only since 2008)

Refereed Journal Papers

Bianco, F., et al., 2010, AJ, 139, 1499
Chen, W. P., et al. 2012, ApJ, 751, 118
Hsieh, H., et al. 2012a, ApJL, 748, L15
Hsieh, H., et al. 2012b, AJ, 143, 104
Kim, D., et al. 2010, AJ, 139, 757
Lee, C.-H., et al. 2012, AJ, 143, 89
Lehner, M., et al. PASP, 121, 138
Lehner, M., et al. 2010, PASP, 122, 959
Lin, C. L., et al. 2009, PASP, 121, 359
Liu, H. B., et al. 2008, ApJ, 681, 1046
Mondal, S., et al. 2010, AJ, 139, 2026
Urata, Y., et al. 2012b, ApJL, 748, L4
Urata, Y., et al. 2012, ApJL, submitted
Wang, J. H., et al. 2009, AJ, 138, 1893
Wang, J. H., et al. 2010, AJ, 139, 2003
Zhang, Z. W., et al., 2008, ApJL, 685, L157
Zhang, Z. W., et al. 2009, PASP, 121, 1429

A total of about 40 Communications or Short Reports (Minor Planet Electronic Circulars, Central Bureau Electronic Telegrams, ATel)

IV. APPENDIX I:

CURRICULUM VITA — Wen Ping Chen

Address	Graduate Institute of Astronomy, National Central University 300 Jhongda Road, Jhongli 32001, Taiwan Telephone: +886-3-422-3424 Facsimile: +886-3-426-2304 e-mail: `wchen@astro.ncu.edu.tw` url: `http://www.astro.ncu.edu.tw`
Personal	Born Nov. 22, 1958, Taiwan; married with two children
Education	Ph D, 1990, Astronomy, Stony Brook University, USA B S, 1980, Physics, National Central University, Taiwan
Employment and Scholar Visits	2005.01 ~ 2005.06, Visiting Scientist, Academia Sinica, Institute of Astronomy and Astrophysics, Taiwan 2004 till now, Professor, NCU/Astronomy 2000 ~ 2003, Director, NCU/Astronomy 1992 ~ 2004, Associate Professor, NCU/Astronomy 1996.07 ~ 1996.12, Visiting Scientist, Harvard-Smithsonian Center for Astrophysics, USA 1990 ~ 1992, Carnegie Fellow, Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, USA
Membership, Academic Posts and Awards	International Astronomical Union Astronomical Society, ROC, President, 2005~2008 Chinese Physics Society (Taiwan) NCU Distinguished Professorship, since 2008 NCU Outstanding Teaching Award, 2007 NCU Outstanding Research Award, 2006
Research Expertise	Multiwavelength Observational Astronomy; Star and Planet Formation; Young Stellar Objects and Star Clusters; Stellar Variability; Small Solar-System Objects

PUBLICATION LIST (only Pan-STARRS- and TAOS-related papers in the last 5 years are listed.)

Refereed Papers

Time Delay between Images of the Lensed Quasar UM 673, Koptelova, E., Chen, W. P., Chiueh, T., et al. 2012, *Astron. & Astrophy.*, 544, 51

A Possible Detection of Occultation by A Proto-planetary Clump in GM Cephei, Chen, W. P. Hu, C. L. and the YETI collaboration, 2012, *Astrophy. J.*, 751, 118

Observational and Dynamical Characterization of Main-Belt Comet P/2010 R2 (La Sagra), Hsieh, Henry, H., Yang, B., Haghighipour, N., et al. (Pan-STARRS Collaboration, including Abe, S., Chen, W. P., Ip, W., Kinoshita, D. from NCU), 2012, *Astron. J.*, 143, 104

Discovery of Main-Belt Comet P/2006 VW139 by Pan-STARRS 1, Hsieh, Henry, Yang B., Haghighipour, N., et al. (Pan-STARRS Inner Solar System Consortium, including Abe, S., Cheng, Y. C., Chen, W. P., Ip, W. H., and Kinoshita, D. from NCU), 2012, *Astrophy. J. Lett.*, 748, L15

Discovery of Variable Stars in the Field of the Galactic Open Cluster NGC 7039, Hu, Juei-Hwa, Chen, Hui-Chen, Chen, Ying-Tung, et al. 2011, *Pub. Astron. Soc. Pac.*, 123, 671

The TAOS Project: Statistical Analysis of Multi-Telescope Time Series Data, Lehner, M. J., Coehlo, N. K., Z.-W. Zhang, et al. 2010, *Pub. Astron. Soc. Pac.*, 122, 959

The Taiwanese-American Occultation Survey: stellar variability II. Discovery of 15 Variable Stars, Soumen Mondal, C. C. Lin, W. P. Chen, et al. 2010, *Astron. J.* 139, 2026

Searching for Sub-Kilometer TNOs Using Pan-STARRS Video Mode Lightcurves: Preliminary Study and Evaluation using Engineering Data, Wang, J. H., Protopapas, P., Chen, W. P., et al. 2010, *Astron. J.*, 139, 2003

The TAOS Project: Upper Bounds on the Population of Small KBOs and Tests of Models of Formation and Evolution of the Outer Solar System, F. B. Bianco, Z.-W. Zhang, M. J. Lehner, et al. 2010, *Astron. J.*, 139, 1499

The Taiwan-America Occultation Survey Project Stellar Variability I. Detection of Low-Amplitude Delta Scuti Stars and a Revised Catalog of All Known Delta Scuti Stars, Kim, D. -W., Protopapas, P., Alcock, C., et al. 2010, *Astron. J*., 139, 757

The TAOS Project: High-Speed Crowded Field Aperture Photometry, Zhang, Z.-W., Kim, D.-W., Wang, J.-H., et al. 2009, *Pub. Astron. Soc. Pacific*, 121, 1429

Upper Limits on the Number of Small Bodies in Sedna-like orbits by the TAOS Project, J.-H. Wang, M. J. Lehner, Z.-W. Zhang, et al. 2009, *Astron. J*. 138, 1893

A Close Binary Star Resolved from Occultation by 87 Sylvia, Lin, C. L., Zhang, Z. W., Chen, W. P. (The TAOS Consortium), 2009, *Pub. Astron. Soc. Pacific*, 121, 359

The Taiwanese-American Occultation Survey: The Multi-Telescope Robotic Observatory, Lehner, M. J.; Wen, C. -Y.; Wang, J. -H.; et al. 2009, *Pub. Astron. Soc. Pacific*, 121, 138

First Results from the Taiwanese-American Occultation Survey, Zhang, Z. W., Bianco, F. B., Lehner, M. J., Coehlo, et al. *Astrophy. J. Lett.*, 685, L157

Biography of Wing-Huen Ip

Date of birth: March 10, 1947
Birth place: Nanjing, China
Married to Ta An Diana Ma; two daughters: Ihan Anita and Ifan Betina
Current position: Vice President
Professor of Astronomy and Space Science, National Central University, Taiwan

Education and Professional Experiences:

1965-1969 BA (Physics), Chinese University of Hong Kong, New Asia College
1969-1970 MA (Physics), University of Pittsburgh
1970-1974 PhD (Applied Physics and Information Science), University of California, San Diego
1974-1975 Postdoctoral Researcher (APIS), University of California, San Diego
1975-1978 Assistant Research Physicist, University of California, San Diego
1978-1991 Max-Planck-Institut fuer Aeronomie, Germany, Staff Scientific Member
1991-1992 Chief Scientist, National Space program Office, National Science Council, Taiwan
1993-1998 Staff Scientific Member, Max-Planck-Institut fuer Aeronomie
1997 Visiting Professor, Dept. of Aerospace Engineering, University of Southern California
1997 Visiting Scientist, Dept. of Electrical and Computing Eng., Univ. of California, San Diego
1997 Distinguished Visiting Scientist, NASA Jet Propulsion Laboratory
1998- 2004 Dean of Science, National Central University
1998-present Professor of Astronomy and Space Science, National Central University, Taiwan
2004 Lee Kuo-Ting Chair Professor, National Central University
2006-2009 Vice President, National Central University
2009- Vice Chancellor, University System of Taiwan

Award(s) and Honor(s):

Full member, International Academy of Astronautics (1998)
Outstanding Scholar Award, Foundation for the Adv. of Outstanding Scholarship, Taiwan (1998-2003)
Fellow, Physical Society of Republic of China (2002)
Eminent NRC(Canada)-NSC(Taiwan) Researcher (2006)
National Professorship of Ministry of Education, Taiwan (2006)
The laurels for team achievement award to Cassini-Huygens project team,
International Academy of Astronautics (2006)
Fellow, American Geophysical Union (2007)
Honorary Member, Asia Oceania Geosciences Society (2008)
NASA Exceptional Public Service Medal (2009)
Axford Medal, Asia Oceania Geosciences Society (2011)

Academic Services:

Co-Chair, Joint NASA-ESA Study Team of the Cassini Mission
Member, Joint NASA-ESA Study Team of the CRAF mission
European Editor, Journal of Geophysical Research-Space Physics (1990-1992)
Executive Editor, Planetary and Space Science (1998-2001)
Editorial Board Member, Space Science Review (1998-2001)
Chair, National COSPAR Committee, Taiwan, (1998-2002)
Chair, Chinese Astronomical Society, Taiwan (2002-2004)
President, Asia Oceania Geosciences Society (2004-2006)
Member, Trustee Board (Basic Science), International Academy of Sciences (2007-present)
Scientific Editor, Research in Astronomy and Astrophysics (2008-present)

Selected Referred Journal Papers:

1. Ip, W.-H., Planetary and Space Science, 63, 83 (4/2012)
2. Haider, S. A.; Lal, Shyam; Ip, Wing-Huen; Barabash, Stas,Planetary and Space Science, 63, 1 (4/2012)
3. Müller, Joachim; Simon, Sven; Wang, Yung-Ching; et al., Icarus, 218, 666 (3/2012)
4. Hsieh, Henry H.; Yang, Bin; et al. Astrophysical Journal Letters, 748, L15 (3/2012)
5. Cheng, K.-S.; Chernyshov, D. O.; Dogiel, V. A.; et al., Astrophysical Journal, 746, 116 (2/2012)
6. Lin, Z.-Y.; Lara, L. M.; Vincent, J. B.; Ip, W.-H., Astronomy & Astrophysics, 537, 101 (1/2012)
7. Wang, Y.-C.; Müller, J.; Ip, W.-H.; Motschmann, U., Icarus, 216, 415 (12/2011)
8. Wang, Y.-C.; Ip, W.-H., Icarus, 216, 387 (12/2011)
9. Coradini, A.; Capaccioni, F.; Erard, S.; Arnold, G.;et al. Science, 334, 492 (2011)
10. Sierks, H.; Lamy, P.; Barbieri, C.; et al. Science, 334, 487 (2011)
11. Milillo, A.; Orsini, S.; Hsieh, K. C.; et al. Journal of Geophysical Research, 116, 7229 (7/2011)
12. Hu, Juei-Hwa; Chen, Hui-Chen; et al. the Astron. Soc. of the Pac. 123, 904, 671 (2011)
13. Chen, Y.-J.; Nuevo, M.; Chu, C.-C.; Adv. in Space Res., 47, 1633 (2011)
14. Cheng, K.-S.; Chernyshov, D. O.; Dogiel, V. A.; Astrophysical J. Letters, 731, L17 (2011)
15. Tseng, Wei-Ling; Ip, Wing-Huen, Icarus, 212, 294 (2011)
16. Lara, L. M.; Lin, Z.-Y.; Rodrigo, R.; Ip, W.-H., Astronomy and Astrophysics, 525, A36 (2011)
17. Wing-Heun Ip, "A Revisit of the Phobos Events", Chinese Journal of Space Science, (2011)
18. Lin, H.-W.; Kavelaars, J. J.; Ip, W.-H.; Pub. of the Astron. Soc. of the Pac., 122, 1030 (2010)
19. Wang, Y.-C.; Mueller, J.; Motschmann, U.; Ip, W.-H., Icarus, 209, 46 (2010)
20. Gulkis, S.; Keihm, S.; Kamp, L., et al. Planetary and Space Science, 58, 1077 (2010)
21. Chernyshov, D. O.; Cheng, K.-S.; Dogiel, V. A.; Ko, C.-M.; Ip, W.-H., 403, 817 (2010)
22. Coradini, A.; Grassi, D.; Capaccioni, F.; et al. J. of Geophysical Research, 115, E4, E04004 (2010)
23. Ip, Wing-Huen, Proceedings of the International Astronomical Union, IAUS, 269, 87 (2010)
24. Tseng, W.-L., Ip, W.-H., Johnson, R. E., et al., Icarus, 206, 382 (2010)
25. Chassefière, E., Maria, J.-L., et al. (including Ip, W.), Planetary and Space Science, 58, 201, (2010)
26. Keller, H. U., Barbieri, C., et al. (including Ip, W.-H.), Science, 327, 190 (2010)
27. Mendis, A. and Ip, W.-H., Physics Today, 63, 070000, (2010)
28. Wang, Y.-C., Mueller, J., Motschmann, U., and Ip, W.-H., Icarus, 209, 46 (2010)

Reports (including both WP Chen and W. H. Ip)

1. Knoefel, A., Nishiyama, K., Urakawa, S., et al. 2012, Minor Planet Electronic Circulars, 71
2. Abe, S., Guo, J. K., Panwar, N., et al. 2012, Minor Planet Electronic Circulars, 52
3. Schwartz, M., Abe, S., Guo, J. K., et al. 2012, Minor Planet Circulars, 77699, 1
4. McMillan, R. S., Abe, S., Guo, J. K., et al. 2011, Minor Planet Electronic Circulars, 54
5. Buzzi, L., McMillan, R. S., Sakamoto, T., et al. 2011, Minor Planet Electronic Circulars, 40
6. Buzzi, L., McMillan, R. S., Kowalski, R. A., et al. 2011, Minor Planet Electronic Circulars, 30
7. Bressi, T. H., Abe, S., Guo, J. K., et al. 2011, Minor Planet Electronic Circulars, 32
8. Schwartz, M., Abe, S., Guo, J. K., et al. 2011, Minor Planet Circulars, 77266, 8
9. Bacci, P., Tesi, L., Fagioli, G., et al. 2011, Minor Planet Electronic Circulars, 69
10. McMillan, R. S., Urakawa, S., Sakamoto, T., et al. 2011, Minor Planet Electronic Circulars, 56
11. Abe, S., Guo, J. K., Panwar, N., & Chen, W. P. 2011, Minor Planet Circulars, 76683, 5
12. Buzzi, L., Draginda, A., Tholen, D. J., et al. 2011, Minor Planet Electronic Circulars, 108
13. Buzzi, L., McMillan, R. S., Woodworth, D., et al. 2011, Minor Planet Electronic Circulars, 107
14. Bacci, P., Tesi, L., Fagioli, G., et al. 2011, Minor Planet Electronic Circulars, 90
15. Bressi, T. H., Woodworth, D., Tholen, D. J., et al. 2011, Minor Planet Electronic Circulars, 84
16. Bressi, T. H., McMillan, R. S., Abe, S., et al. 2011, Minor Planet Electronic Circulars, 83
17. Micheli, M., Guo, J. K., Panwar, N., Chen, W. P., & Williams, G. V. 2011, Central Bureau Electronic Telegrams, 2874, 1
18. Woodworth, D., Tholen, D. J., Wainscoat, R. J., et al. 2011, Minor Planet Electronic Circulars, 2
19. Schwartz, M., Holvorcem, P. R., Abe, S., Guo, J. K., & Chen, W. P. 2011, Minor Planet Circulars, 75442, 5
20. Eglitis, I., Cernis, K., Tesi, L., et al. 2011, Minor Planet Electronic Circulars, 51
21. Blythe, M., Spitz, G., Brungard, R., et al. 2011, Minor Planet Electronic Circulars, 20
22. Eglitis, I., Cernis, K., Bilkina, B., et al. 2011, Minor Planet Electronic Circulars, 11
23. Schwartz, M., Holvorcem, P. R., Abe, S., Guo, J. K., & Chen, W. P. 2011, Minor Planet Circulars, 75199, 5
24. Abe, S., Guo, J. K., Chen, W. P., Schwartz, M., & Holvorcem, P. R. 2011, Minor Planet Circulars, 75108, 35
25. Buzzi, L., Ierman, G., Pettarin, E., et al. 2011, Minor Planet Electronic Circulars, 11
26. Tesi, L., Bacci, P., Fagioli, G., et al. 2011, Minor Planet Electronic Circulars, 31
27. Tesi, L., Bacci, P., Fagioli, G., et al. 2011, Minor Planet Electronic Circulars, 23
28. Holmes, R., Linder, T., Hoette, V., et al. 2011, Minor Planet Electronic Circulars, 10
29. Schwartz, M., Guo, J. K., Chen, W. P., et al. 2011, Minor Planet Circulars, 74892, 6
30. Abe, S., Guo, J. K., & Chen, W. P. 2011, Minor Planet Circulars, 74774, 35
31. Abe, S., Guo, J. K., Chen, W. P., et al. 2011, Minor Planet Electronic Circulars, 64
32. McMillan, R. S., Holmes, R., Linder, T., et al. 2011, Minor Planet Electronic Circulars, 50
33. Gilmore, A. C., Kilmartin, P. M., Abe, S., et al. 2011, Minor Planet Electronic Circulars, 46
34. Abe, S., Guo, J. K., Chen, W. P., et al. 2011, Minor Planet Electronic Circulars, 33
35. Schwartz, M., Ory, M., Abe, S., et al. 2011, Minor Planet Circulars, 74497, 7
36. Denneau, L., Wainscoat, R., Hsieh, H., et al. 2011, Central Bureau Electronic Telegrams, 2874, 1