The 2.5m Wide-Field Survey Telescope (WFST): Goals and Status

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• Sensitivity
• angular resolution
• wavelength resolution
• wavelength range
• time resolution

A powerful data acquisition facility in terms of both observation depth and sky coverage wide field of view, large aperture, high throughput

Providing the required temporal resolution for the discovery and monitoring of the variable universe.
New Frontier: Multi-Messenger Astronomy

Variable Universe: a natural lab for studying extreme physics

Current generation GW detectors locate GW events over a large sky area, demanding followup at a survey speed of $>600 \text{ deg}^2/\text{hr}$.
New Frontier: Time-Domain Astronomy

- Gravitational Events
- Supernova
  - SN Physics
  - Extreme Physics
  - SN Cosmology
- Gamma-ray Bursts
- Binary of Compact obj.
- Tidal Disruption Event
- Variables and Binaries
- AGNs
- Unknown Events

Small Telescopes: Monitoring of Bright objects!

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Ω</th>
<th>CCD (Gpix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDSS</td>
<td>5.9</td>
<td>0.12</td>
</tr>
<tr>
<td>Pan-STARRS1</td>
<td>13.5</td>
<td>1.02</td>
</tr>
<tr>
<td>LSST</td>
<td>308</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Much of the Solar System is still unknown.
1. Discovery of *Kuiper Belt Objects (KBOs)* at the edge of Solar System, won 2012 Shaw Prize.
2. Since 2015, accumulating evidence supports the prediction of *Planet X*.

Mapping the outer solar system requires a survey over 15,000 deg$^2$, to a depth of >22 mag.

Dwarf Planets and KBOs in the outer part, fainter than 21-22 mag.
Mapping substructures of the Milky Way to understand the formation and accretion history demands a full coverage of the sky to a depth of $r > \sim 24 - 25$ mag.

Ivezic+12
Search for remnants of 1\textsuperscript{st}-generation objects and their analogs; Missing satellites? Scattering stars and GCs in the Local Group?
### Requirements by Science Drivers

<table>
<thead>
<tr>
<th>Science Requirement</th>
<th>Near-Field &amp; Milky Way</th>
<th>Solar System objects</th>
<th>Time-Domain Astronomy</th>
<th>Technical Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>20,000deg$^2$</td>
<td>&gt;10,000deg$^2$</td>
<td>20,000deg$^2$</td>
<td>FOV $\Phi \geq 3$deg</td>
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<tr>
<td>Depth</td>
<td>r&lt;25</td>
<td>W&lt;24</td>
<td>r&lt;23</td>
<td>Aper D $\geq 2.5$m</td>
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<tr>
<td>Peroid</td>
<td>5 yr</td>
<td>1 yr</td>
<td>Highcadence</td>
<td>FOV $\Phi \geq 3$deg</td>
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<tr>
<td>Photometry</td>
<td>High 0.1%</td>
<td>1%</td>
<td>high 0.1%</td>
<td>High Quality (80%&lt;0.4”)</td>
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<td>Astrometry</td>
<td>high(0.033”=1/10pix)</td>
<td>0.1”</td>
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<tr>
<td>Waveband</td>
<td>ugriz</td>
<td>Broad W</td>
<td>ugriz</td>
<td>ugrizW</td>
</tr>
</tbody>
</table>

**A Wide-Field Imaging Survey Facility:**

- $D \geq 2.5$m, FOV $\Phi \geq 3$deg, high accuracy, broad band
The 2.5m Wide-Field Survey Telescope

- Aperture: 2.5m
- Mount: Altazimuth
- Optics: primary-focus assembly
- Focus length: 6.2m
- Field of View: $\Phi=3\text{deg}$ ($6.55^\circ$)
- Etendue ($A\Omega$): 29.3
- Image Quality: $80\%<0.4''$
- Pixel scale: 0.33''
- Plate scale: 10um/pixel
- Camera: $27k \times 27k$
- Window: 320-1028nm
- Filters: $u,g,r,i,z,W$ + Narrow
- Depth: $g=23\text{m @30s}$
A Primary-Focus System with ADC

Camera (1.5t)

Credit: Ming Liang

• The telescope (lens+mirror coating+detector) is optimized to have high UV (320-390nm) throughput;
• ADC is the key element to yield high quality image with the super-wide filter (410-850nm=g+r+i), resulting in a higher sensitivity
A Powerful Survey Machine

- Flat focal plane
- Distortion-free
- 1pix = 0.33"
- Exp 30+5s, 9hrs/night, 925 pointings cover 6000 deg2
- Each 27Kx27K (16bits) = 1.458 GB
- 1.3 TB per night
- 33 TB per month
- 400 TB per year
- 2.3 PB raw data 6 yrs
• The camera is comprised of the mosaic CCD chips, a rolling shutter, filters and filter switch mechanism, and an image rotator.

• A total of 9 pieces of 9K×9K E2V CCD chips with 10 μm×10 μm pixels fills the 300 mm×300 mm focal plane. three 4K×2K chips are used for wavefront sensors and one additional chip is used as guiding sensors.

• The CCD chips, the RAFT structures, and the readout electronics are housed in a cryogenic dewar (working temperature of -100ºC).
Why WFST? 2π Optical Imaging Survey

- WFST will map the 2π sky every 3 nights
- detect moving objects and variables and transients
- The survey over 6 years reaches $r=25.1$ (5σ), being the deepest 2π Survey in the Northern sky

- Synergy with LSST in panoramic view of the solar system, the Milky Way, and the Local Group; moving and variables objects
WFST (AΩ = 29.3) is a powerful survey machine, with a cost only 1/50 of LSST.
WFST Characteristics

- **High sensitivity**
  - Large effective collection area (D=2.5m)
  - Less scattering background light
  - High **UV** throughput + high-altitude site @ >4000m
  - the W (g+r+i) filter

- **High quality imaging (seeing-limited)**
  - With atmospheric dispersion corrector (ADC)
  - With distortion corrector (distortion <0.1% at edges)
  - Homogeneity of image quality (80%<0.4”)

- **High Survey Power**
  - $A\Omega=29.3$ (Pan-STARRS1: 13.5, SDSS: 5.9/25.3, LSST: 308)
  - Survey speed 6000□°/night @ 30s exposure.
Key Science Goals

- **New Frontier**: Time-domain Astronomy
  - Time-domain: discover unknown events
  - Extreme physics: GW EM counterparts, Gamma-ray Bursts, Tidal Disruptions, etc

- **Solar System Objects**: Panoramic view & dynamics
  - Panoramic view: main-belt asteroids, comets, Trojans, ...
  - Search and monitor Near-Earth Objects

- **MW & Local Group**: Structure and Formation History
  - Complete Survey of nearby low-mass stars within 100pc
  - Stellar composition and structure to $R = 30kpc$
  - Near-field cosmology: ultra-faint dwarfs and clusters
The Deepest Northern Sky $2\pi$ Survey with high-quality ugriz deep images ($r < 25.1$) and photometric catalogs

- Reference catalogs of astrometry, parallax and proper motion for $r < 23$ stars

- Catalogs of orbital and physical parameters for one million solar system objects

- Light curves with time scale from hours to 2-3 years for $r < 23$ variables, AGNs and transients

- 30s exp.: ugriz = [22.3, 22.9, 22.8, 22.0, 21.0]
- 50min exp.: ugriz = [24.6, 25.2, 25.1, 24.3, 23.3]
Why 2.5 meters?

• **Science requirements and Performance**
  – 23m @short exposure (30s): spectroscopic followup by 6-10m telescopes
  – 25-26m @long exposure, targets for TMT, JWST

• **Balance between gain and cost**
  – Total cost: < 30M USD
  – Collection area ~ D^2: (4m/2.5m)^2 = 2.5 (1mag)
  – cost ~ D^{3-4}: (4m/2.5m)^{3.5} = 5.2

WFST is a powerful survey machine. The 6-year Survey will yield the deepest optical multi-band Imaging of the Northern Sky, providing the legacy database for multiple purpose research.
Time Domain Astronomy in the Era of LSST

• LSST is a flagship facility for time-domain astronomy, but **NOT** a terminator to other wide-field telescopes.

• There will be huge space for TDA and other research fields.

• The 2.5m Wide-Field Survey Telescope is complementary to LSST in **sky accessibility and science**.
  – Solar system objects & Milky Way & Local group
  – Dedicated surveys include
    • Monitoring of **bright** objects
    • Semi-simultaneous multi-band survey
    • 24 hr **global monitoring** observation
    • **High-cadence** survey

• With your own “LSST”, you can develop **core technologies** in mining big data.
Optical Observatories
Site: Lenghu, Qinghai
Funded by University of Science and Technology of China (USTC)!
Expected first light 2022 (commissioning), starting survey in 2023
WFST: A Northern Sky Surveyor

- **New Frontiers**: Time-domain Astronomy
  - discover unknown events
  - Extreme physics: GW EM counterparts, Gamma-ray Bursts, Tidal Disruptions, etc

- **Solar System Objects**: Panoramic view & dynamics
  - Panoramic view: main-belt asteroids, comets, Trojans, ...
  - Search and monitor Near-Earth Objects

- **Near-field Cosmology**:
  - Stellar composition and structure
  - Archaeology in LG: ultra-faint dwarfs