Impact Assessment Efforts from Astronomical Communities in China

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Xinglong Observatory

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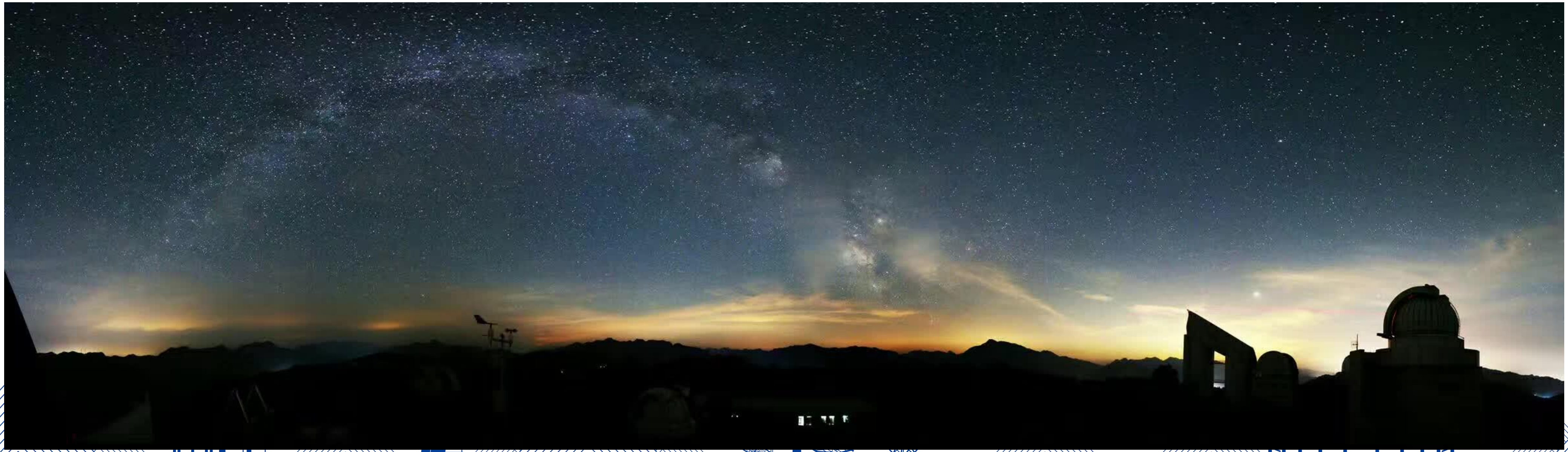
The Xinglong Observatory of National Astronomical Observatories, CAS (NAOC; IAU code 327, coordinates: 40° 23′39″ N, 117° 34′30″ E) was founded in 1968. At present, it is one of most primary observing stations of NAOC. As the largest optical astronomical observatory site in the continent of Asia, it harbors more than ten telescopes with an effective aperture greater than 50 cm.



80cm telescope and Mini Sitian (MST)

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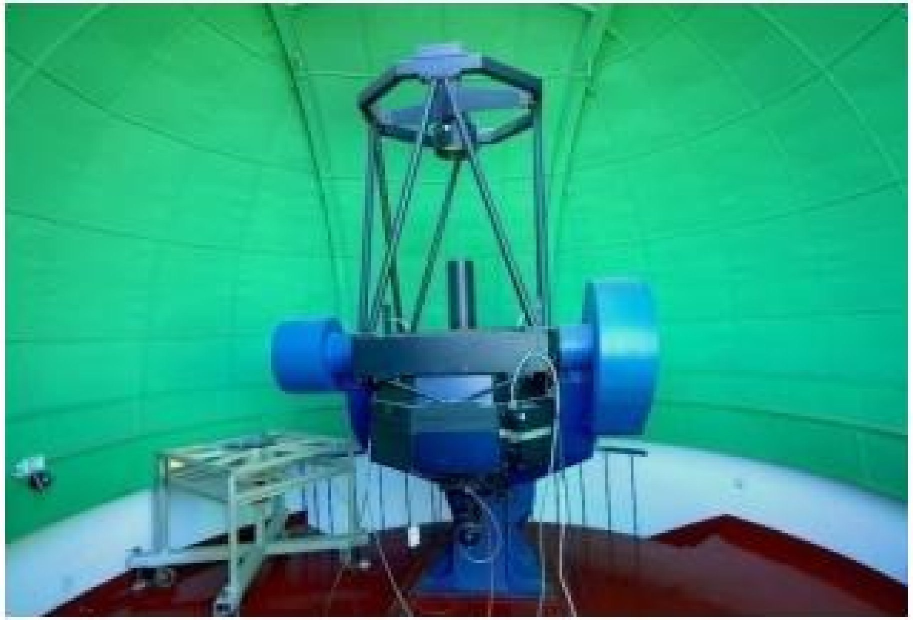
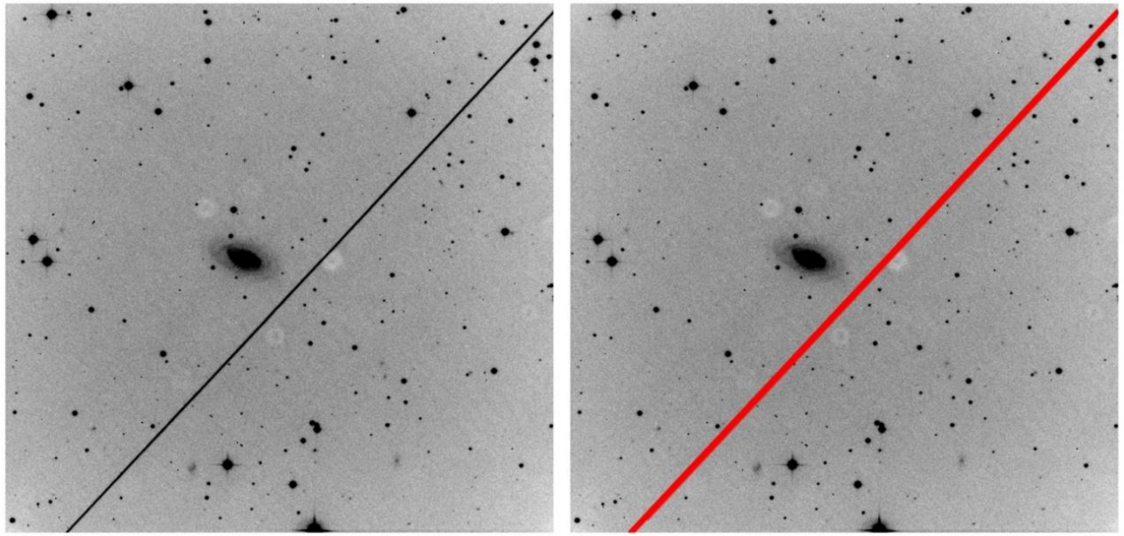
- The 80cm telescope has an aperture of 80 cm and a focal length of 8 meters. It features a classic Cassegrain system and an equatorial mount.

- The MST is composed of three 30 cm catadioptric Schmidt telescopes: mini-001 (hereafter MST1), mini-002 (hereafter MST2) and mini-003 (hereafter MST3).

Overview of the MST telescope array



80cm Telescope at Xinglong Observatory



Satellite trails detected in the captured images

WWT Platform & Module Overview

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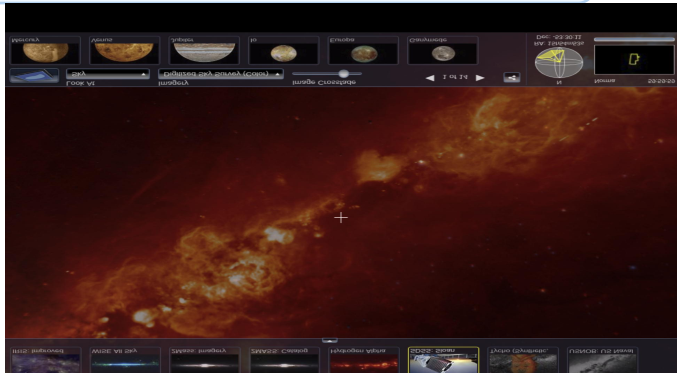
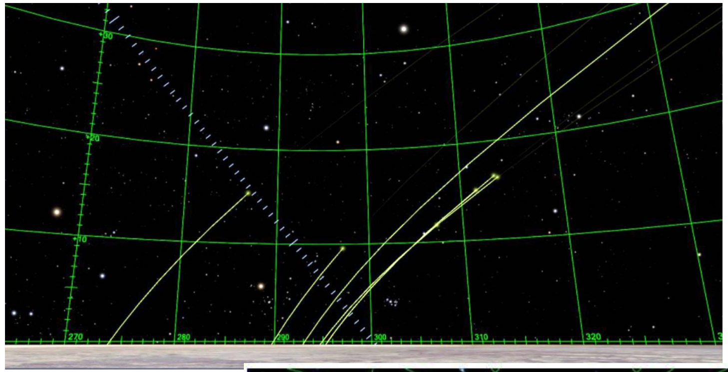
WorldWide Telescope (WWT) platform and its two newly developed astronomical observation modules



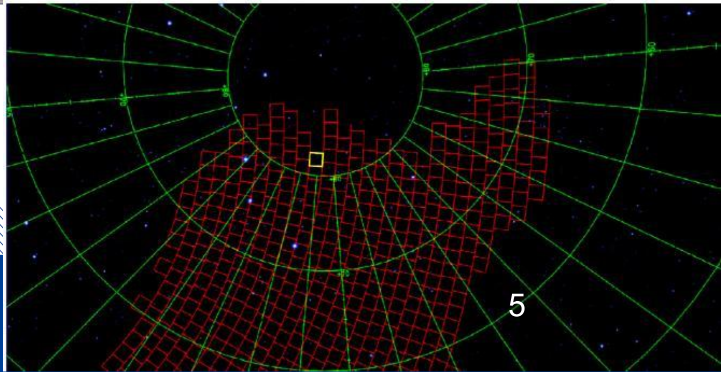
WWT Platform Foundation

- Open-source astronomical data visualization software developed by Microsoft Research
- Maintained by American Astronomical Society and China-VO team with powerful space-time simulation capabilities
- Supports satellite orbit display via TLE data loading and geometric marker import



Newly Developed Modules

- **Sats Tracker**: Simulates satellite visibility periods for astronomical observations
- **Obs Simulator**: Visualizes telescope observation plans and field of view coverage
- Both modules enhance satellite impact assessment on astronomical observations



Application cases

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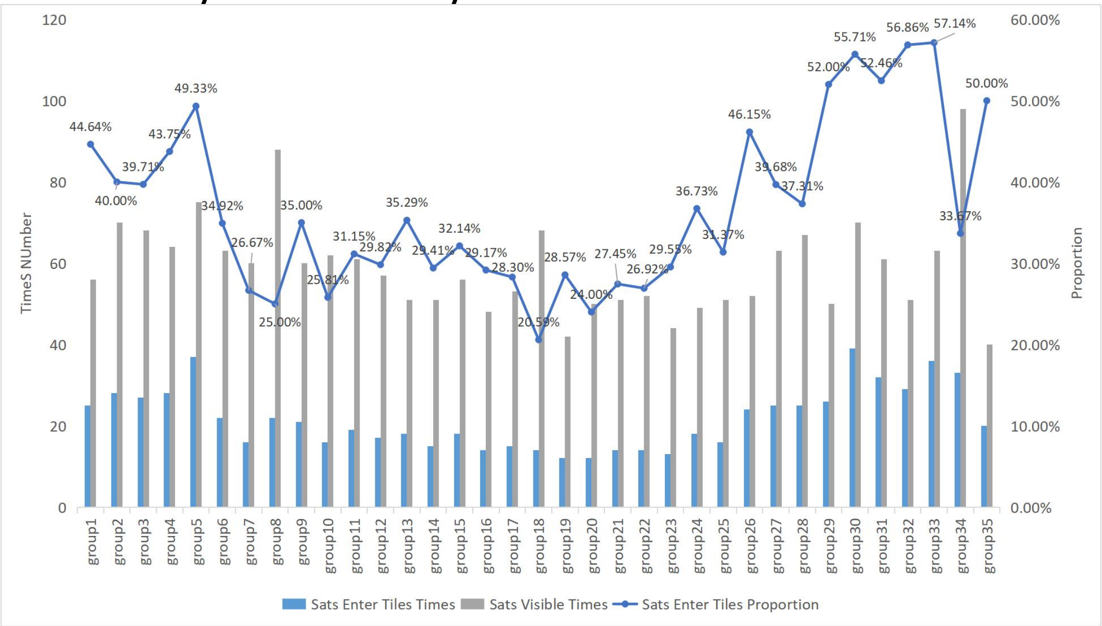
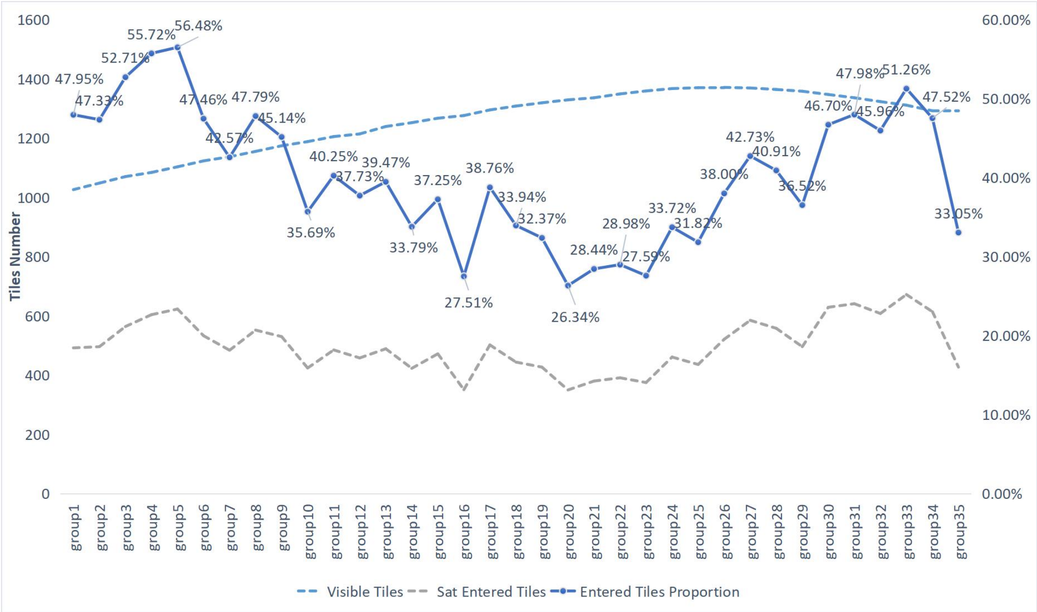
Analyzing the impact of starlink satellites on assessing influence on search for GW electromagnetic counterpart at NAOC Altay Observatory





Visible satellites VS Satellites entered the observable tiles (in each 10 min bins)

Observable tiles VS Tiles will be affected by satellites (in each month)

- During May-August, more than 90% of the observable tiles are swept by satellites.
- In other months, an average of 80% of the observation tiles are passed by the satellites.
- 36.75% of visible satellites entered the GW observation tiles on average.

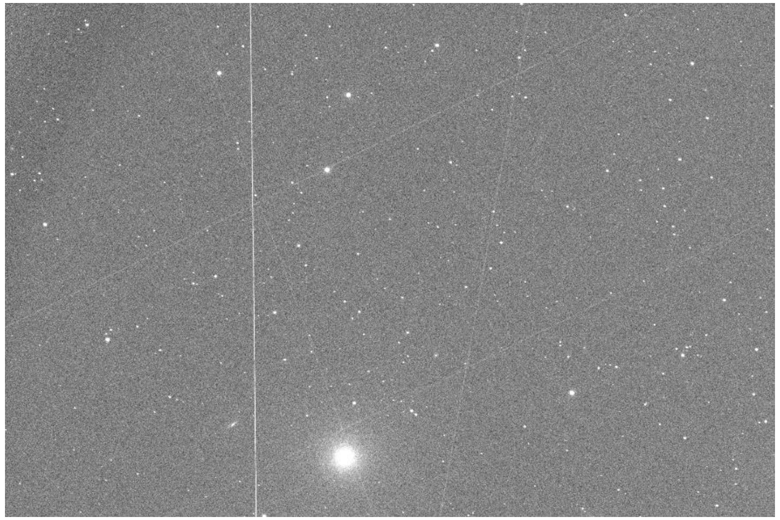
- 40.2% of tiles were affected and would generate trail if they were observed.
- 1.22 trails in each affected tile on average

Application cases

- In this simulation, the impact of Starlink on imaging can be eliminated by avoiding the affected observation tile, or pausing observation for a few seconds when a satellite passes through the tile.

- Under the typical exposure time of 60s, its image on the corresponding pixel element on the CCD is equivalent to the image of a 17.5-magnitude static point-like object.

- When 42,000 Starlink satellites in orbit, the average grids that affected by satellites in 10-min bin is 85.13%, the maximum is 99.88%, and an average of 4.77 trails will be left. **It is more necessary to adjust the observation plan to avoid the influence of satellites.**



Mini-SiTian Image

LAMOST

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a special active reflecting Schmidt telescope.

Astronomical spectroscopy plays a very important role in exploring these questions and the optical spectra contain abundant physical information of distant celestial objects, and acquiring spectra of a large number of celestial objects is desperately needed in astronomy.

The combination of large aperture, wide field of view and 4000 fibers makes LAMOST the most powerful optical spectroscopic survey instrument in the world. Its scientific goals focus on the structure and evolution of our Galaxy, galaxies and cosmology and multi-band identification. The Galactic spectroscopic survey will produce a spectroscopic database of millions of stars.

Figure 1 LAMOST

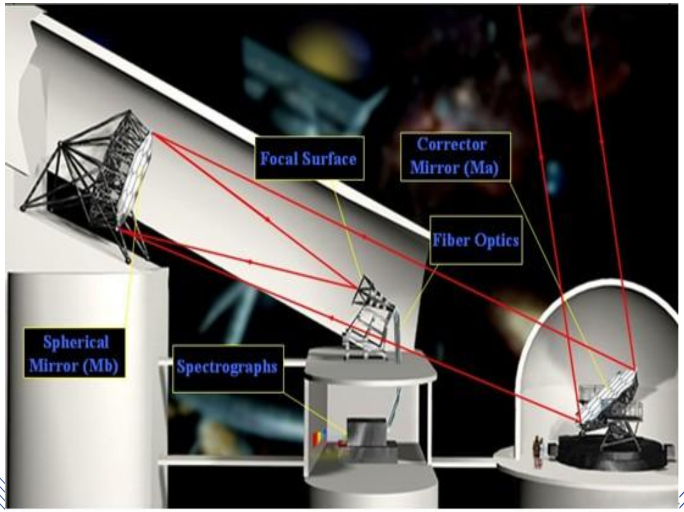
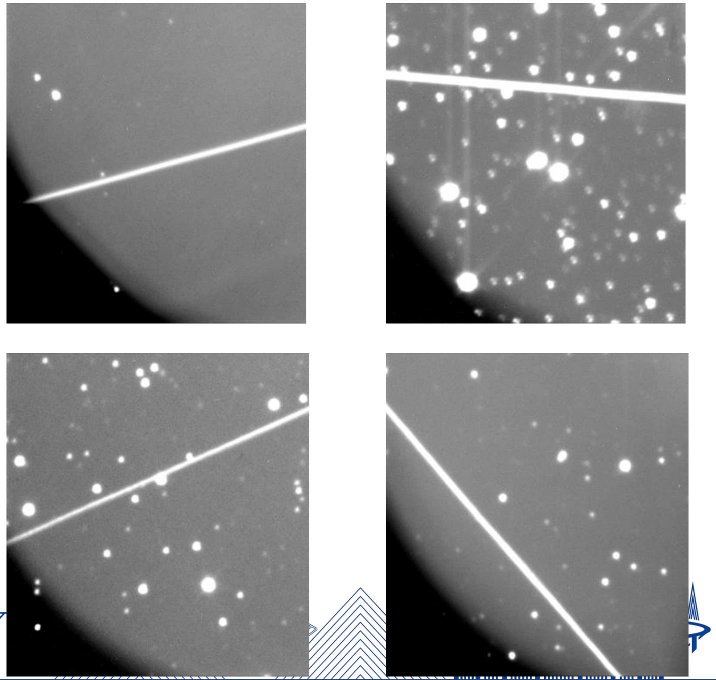


Figure 2 LAMOST overview

Impact on LAMOST

- As the global number of LEO satellites rapidly increases, satellite streaks frequently appear in LAMOST's observational images, especially during dusk and dawn when sunlight reflects strongly from satellite surfaces.
- Based on Hu et al. (2024), LAMOST recorded 427 satellite trails in early 2023, showing that satellite contamination is already common. Interference is strongest during dusk and dawn due to stronger sunlight reflection.



Impacts on LAMOST spectroscopic sky survey

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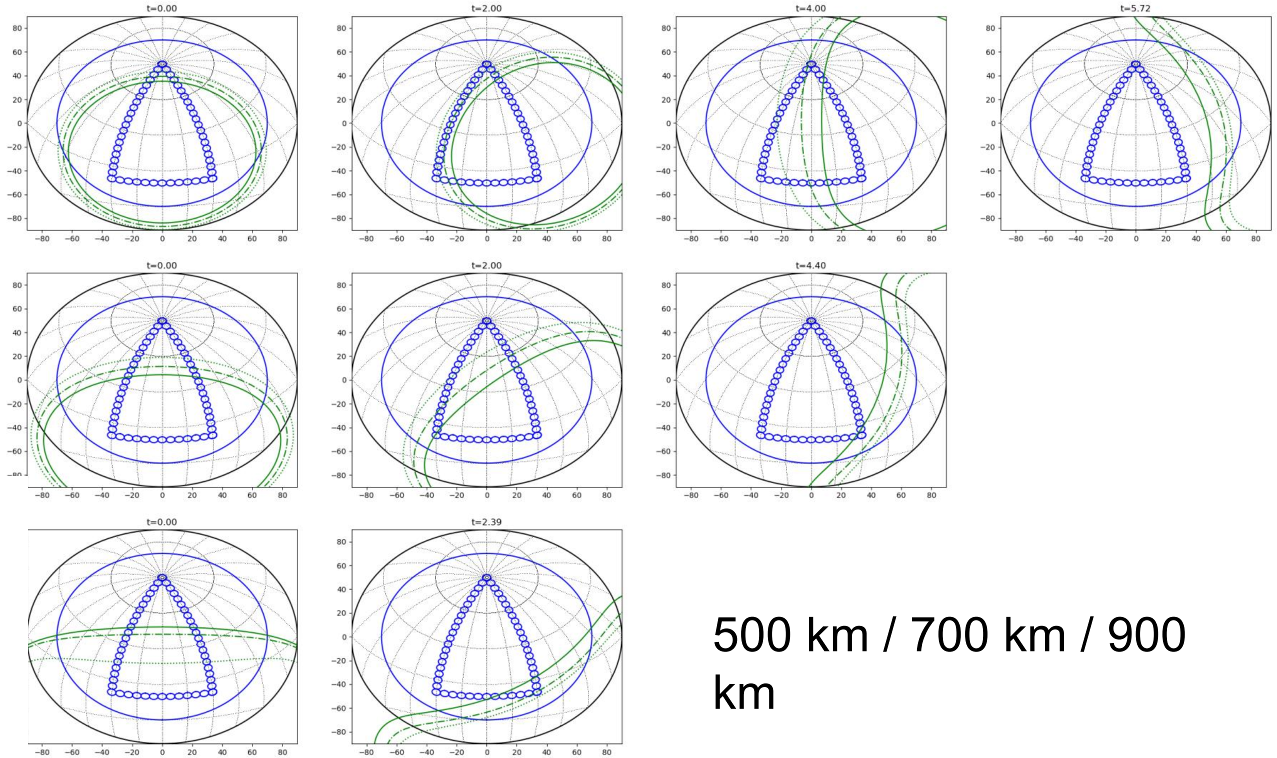
- In a 3.3″ fiber, a satellite produces an effect equivalent to that of a 15.6 mag object.

- **As long as a satellite is visible to the naked eye, its impact on photometry and spectroscopy cannot be ignored.**



How to avoid this?

Observations can only be conducted in the direction of Earth’s umbra!

For LAMOST, the observable sky area is reduced by half, and the available observing time is reduced by more than half.

500 km / 700 km / 900 km

Satellite RFI mitigation of FAST

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- A satellite RFI monitoring software for the Five-hundred-meter Aperture Spherical radio Telescope (FAST) has been developed, which includes a satellite database, an observation module, and a monitoring module.
- The impact of satellite constellations on FAST has also undergone a preliminary evaluation. Based on the transmission parameters of satellites, a new software is under development to establish propagation models and estimate potential RFI of satellite constellations.

A satellite RFI monitoring software

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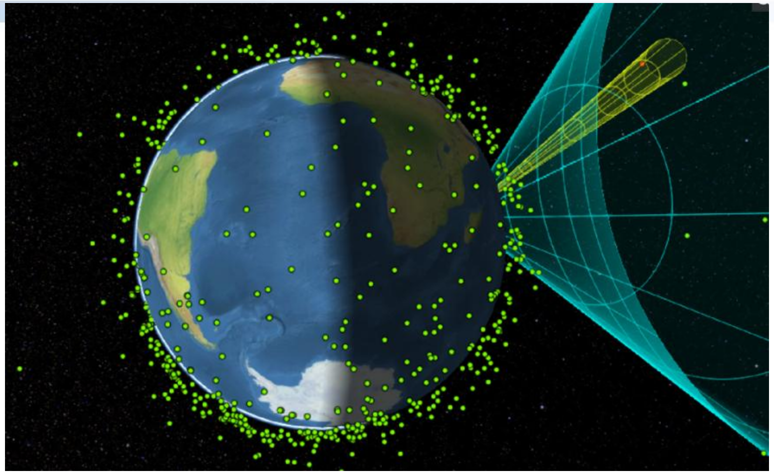
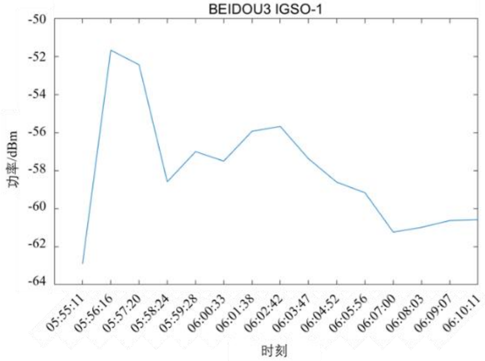
ID	SourceName	ObserveMode	Feed	FocusRatio	StartDateTime	ObjectDateTime	DutationTime/Angle ONDurationTime	Delay	RA TargetNumber	DEC	StartRA ON	EndRA OFF	StartDEC ON	EndDEC OFF
210	DEC+120542-8	DecDriftWithAngle	1.05G-1.45G(MB)	0.4621	2024-01-30 01:26:00		7200	Allow	+11:23:00.00	+12:05:42.30				
211	DEC+045218-b	MultiBeamOTF	1.05G-1.45G(MB)	0.4621	2024-01-30 03:38:00		23.4	Allow	+10:50:00.00	+04:52:18.30	+10:50:00.00	+11:50:00.00	+04:52:18.30	+04:52:18.30
212	DEC+552606-a	MultiBeamOTF	1.05G-1.45G(MB)	0.4621	2024-01-30 04:50:00		23.4	Allow	+12:30:00.00	+55:26:06.30	+12:30:00.00	+13:30:00.00	+55:26:06.30	+55:26:06.30
213	source_14	OnOff	1.05G-1.45G(MB)	0.4621	2024-01-30 06:02:00		120	Allow			+14:51:54.57	+14:51:08.37	+05:19:34.20	+05:19:34.20
214	source_54	OnOff	1.05G-1.45G(MB)	0.4621	2024-01-30 06:27:30		120	Allow			+14:53:33.89	+14:52:24.20	+48:41:55.60	+48:41:55.60
215	DEC+030357-b	MultiBeamOTF	1.05G-1.45G(MB)	0.4621	2024-01-30 06:53:00		23.4	Allow	+14:20:00.00	+03:03:57.30	+14:20:00.00	+16:20:00.00	+03:03:57.30	+03:03:57.30
216	l15.0_b10.75_0	OnOff	1.05G-1.45G(MB)	0.4621	2024-01-30 09:08:00		600	Allow			+17:41:08.60	+17:41:02.54	-10:51:55.60	-10:54:27.40
217	l15.0_b10.75_1	OnOff	1.05G-1.45G(MB)	0.4621	2024-01-30 09:33:30		600	Allow			+17:41:08.44	+17:41:14.50	-10:57:00.60	-10:54:28.80
218	l15.0_b11.25_0	OnOff	1.05G-1.45G(MB)	0.4621	2024-01-30 09:59:00		600	Allow			+17:37:38.25	+17:37:32.17	-10:21:27.60	-10:23:59.20

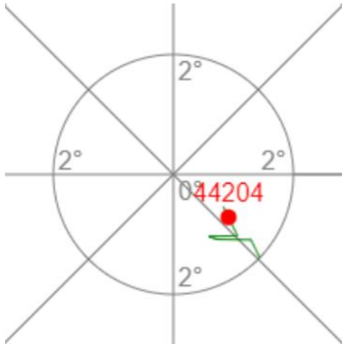
序号	场景	卫星编号	卫星名称	进入时间	方位(度)	仰角(度)	距离(千米)	离开时间	方位(度)	仰角(度)	距离(千米)	时长(秒)
1	显示	52984	COSMOS 2557	2024-01-30 02:41:51	174.077	78.039	19251.770	2024-01-30 02:47:32	175.550	74.477	19321.2265	340.61
2	显示	44204	BEIDOU-3 IGSO-1	2024-01-30 06:02:00	137.369	62.792	36321.998	2024-01-30 06:05:29	139.277	62.385	36338.9667	209.80
3	显示	40938	BEIDOU-3S IGSO-	2024-01-30 10:37:26	199.766	51.737	37158.169	2024-01-30 10:44:45	201.785	52.998	37084.4956	438.09
4	显示	44793	BEIDOU-3 M22	2024-01-30 17:06:54	354.866	68.162	21871.159	2024-01-30 17:10:20	357.263	66.988	21910.9222	206.34
5	显示	46826	NAVSTAR 80	2024-01-30 17:52:54	357.779	66.896	20541.354	2024-01-30 18:01:07	4.056	70.148	20430.8794	493.78
6	显示	43057	GSAT0217	2024-01-30 17:53:27	358.485	66.785	23638.682	2024-01-30 18:03:44	3.798	70.231	23526.3607	617.03
7	显示	38251	BEIDOU-2 M4	2024-01-30 18:32:50	2.091	54.919	22482.682	2024-01-30 18:40:33	6.451	53.091	22580.8851	463.32
8	显示	43648	BEIDOU-3 M15	2024-01-30 19:35:22	349.096	53.819	22499.521	2024-01-30 19:43:09	354.327	53.481	22518.5902	466.98

Observation plan (top) and the corresponding satellites transit lists (bottom) (Wang et al. 2024)



3D display of the FAST main beam and satellite transit trajectory (Wang et al. 2024)





Power intensity during transit of BDS-3 IGSO-1 satellite (left) and the predicted angle distance between FAST beam center and BDS-3 IGSO-1 satellite during the OnOff observation mode (right) (Wang et al. 2024)

Starlink Impacts on Radio Astronomy

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Starlink does not offer services in China, and their satellite downlinks are inactive when they are above China. So, Starlink's impact on radio astronomical observations in China are limited.

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CrossMark

Artificial Satellite Trails Detection Using U-Net Deep Neural Network and Line Segment Detector Algorithm

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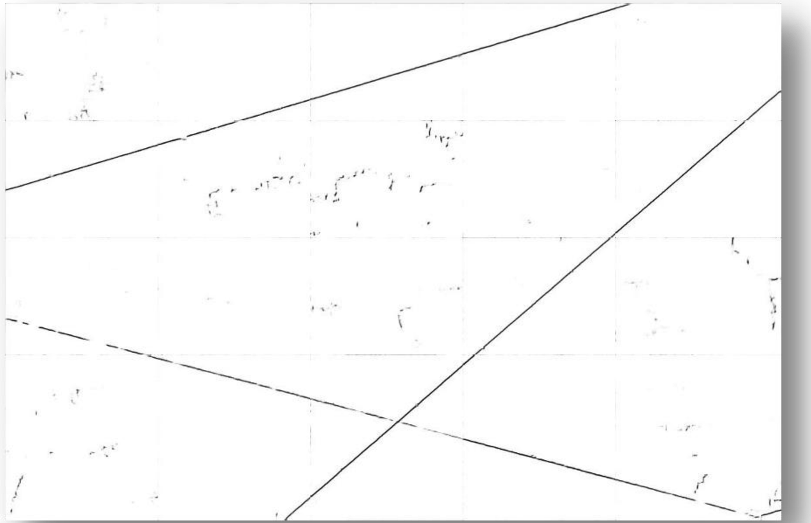
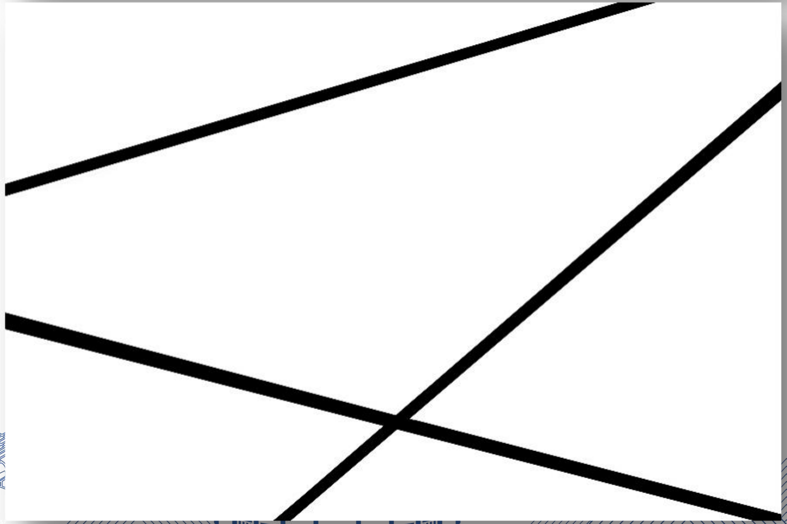
Trails Detection Using U-Net and LSD





Observation schedule optimization

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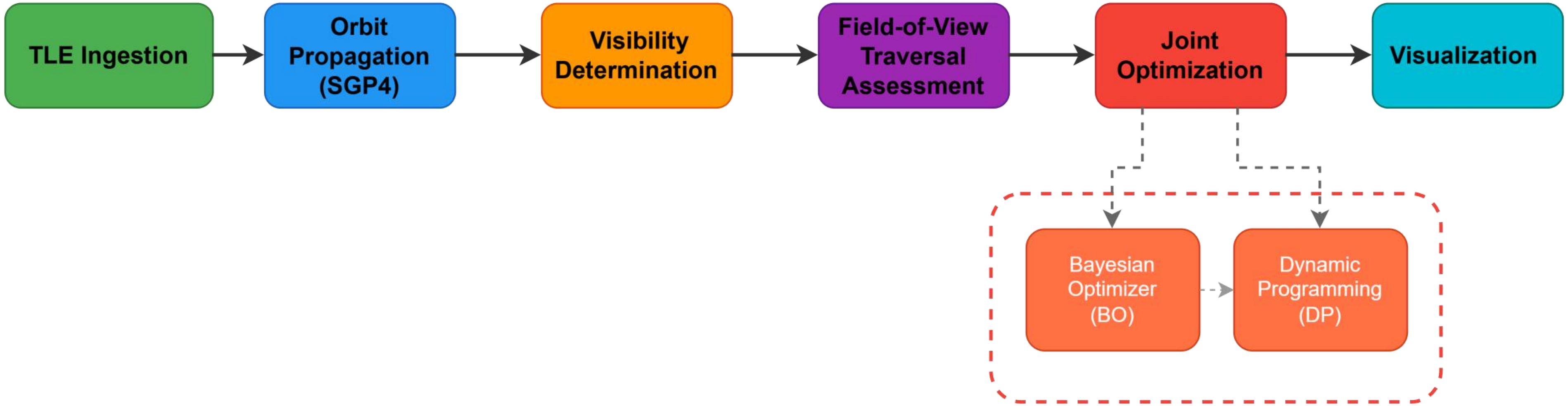
Motivation & Framework Overview

- Avoiding bright satellite trails requires not only reactive avoidance but also strategic planning across time and sky regions. To achieve this, we developed a BO-DP framework that combines Bayesian Optimization and Dynamic Programming, enabling joint spatial–temporal optimization for telescope scheduling.



Objectives:

1) Automatically generate optimal sky regions and observation time windows within a given night.
2) For a fixed region, automatically plan the best observation schedule.

Summary

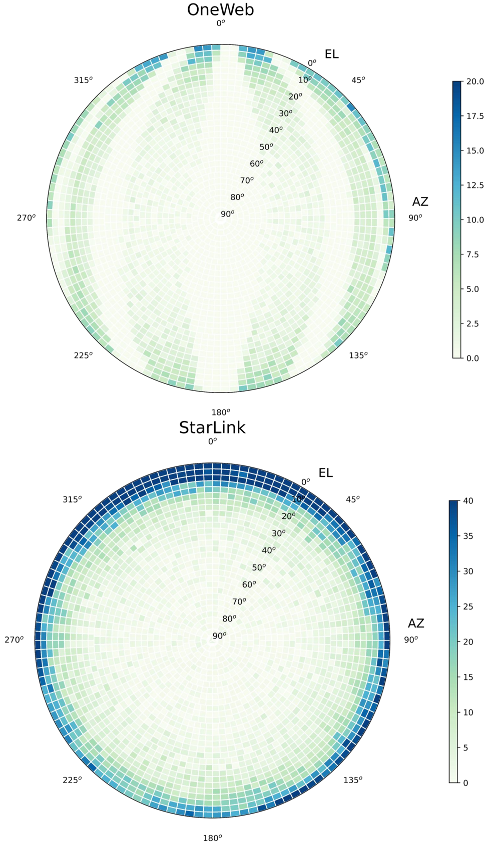
- Astronomy is an important science that drives the progress of human civilization and social development, and the Dark and Quiet Sky should be effectively protected.

- The industrial and societal value of satellite constellations is beyond doubt, but the increasingly severe negative impacts they bring to astronomical observations require full attention.

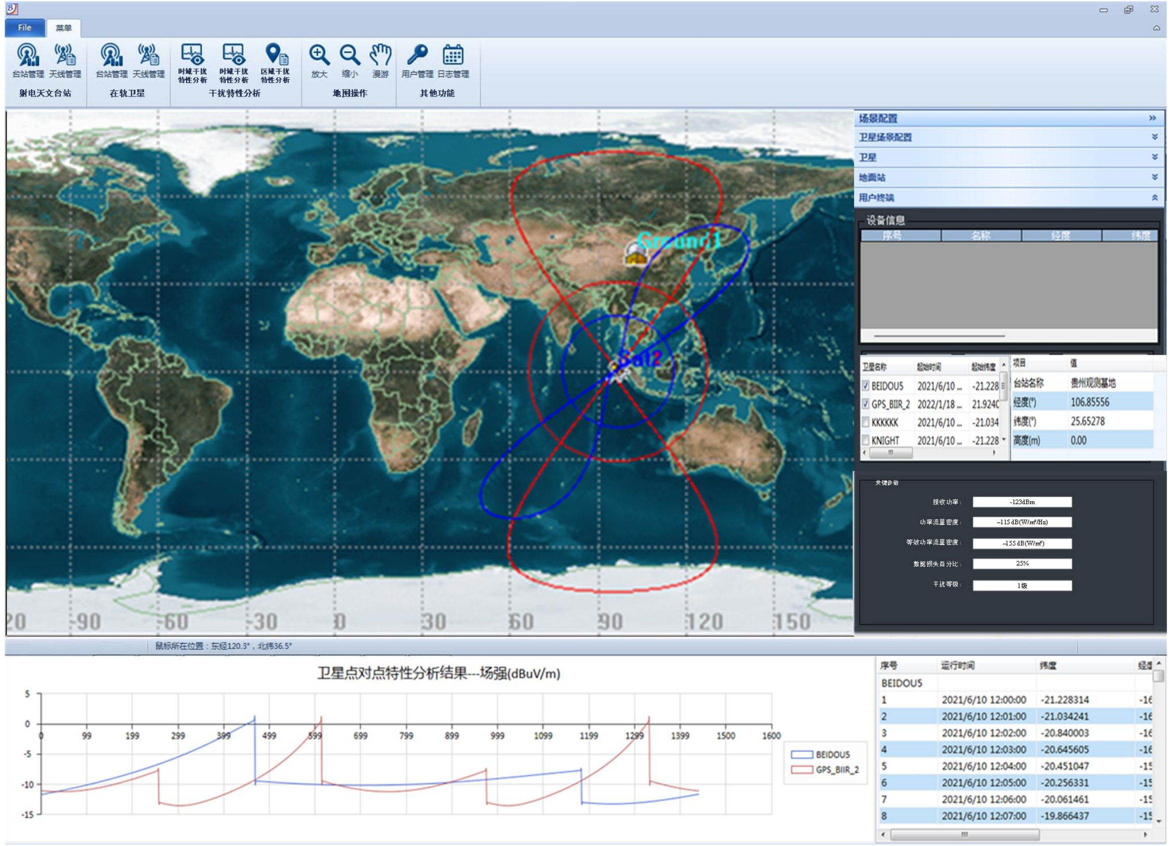
- To achieve sustainable development for humanity, the United Nations should play a more significant coordinating role.

Backup Slides

RFI evaluation of satellite constellations



Distribution of OneWeb (top) and StarLink (bottom) satellite constellations in the FAST sky area within 2000 s (Wang et al. 2024)



Preliminary software interface for estimating potential RFI of satellite constellations

GEO satellites as bright signal sources

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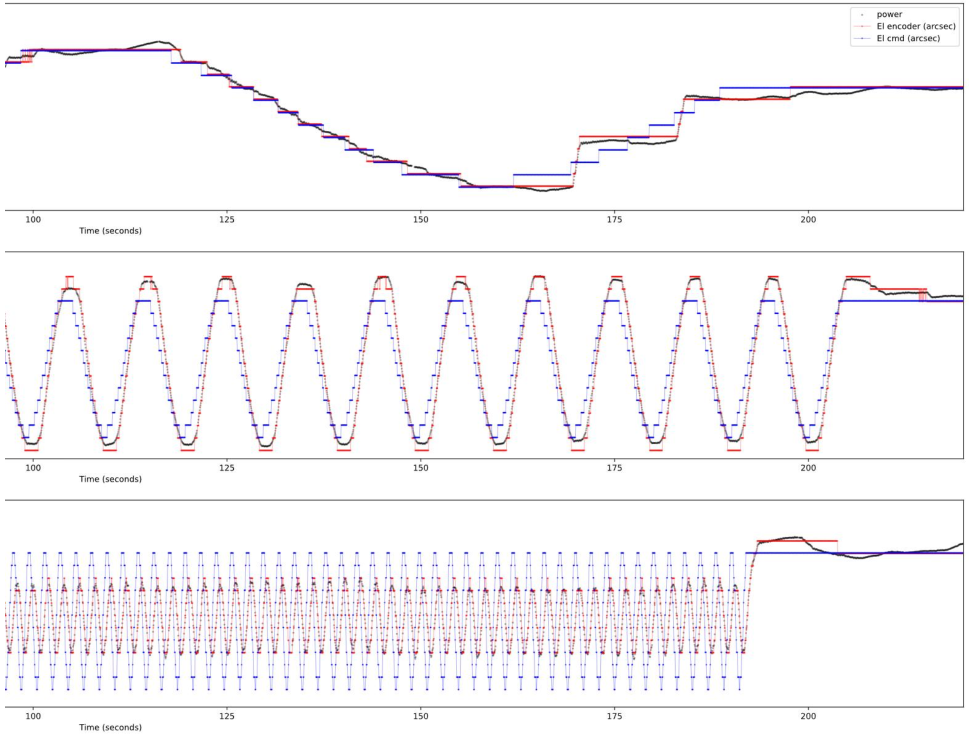
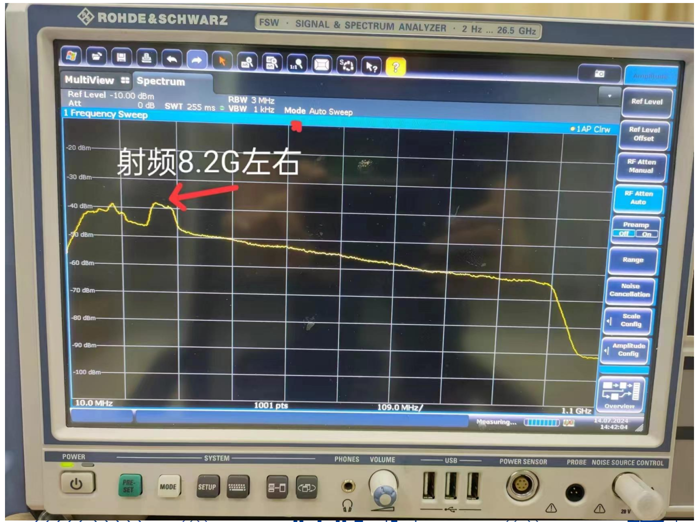
Pointing detection using half-beam tracking method

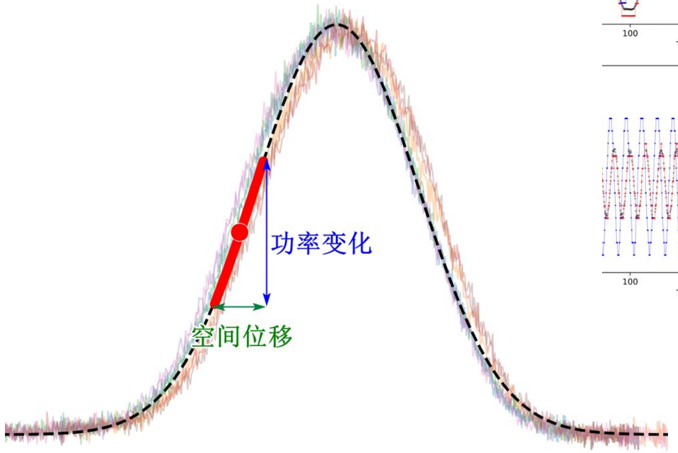
- Pointing the telescope to the satellite at the half-beam point
- Convert the signal power variations into spatial variations using the beam profile.
- Detect oscillations between the beam direction and the encoder-indicated direction



Encoder-indicated direction: red
Power-indicated direction: black



The X-band beacon of a GEO satellite

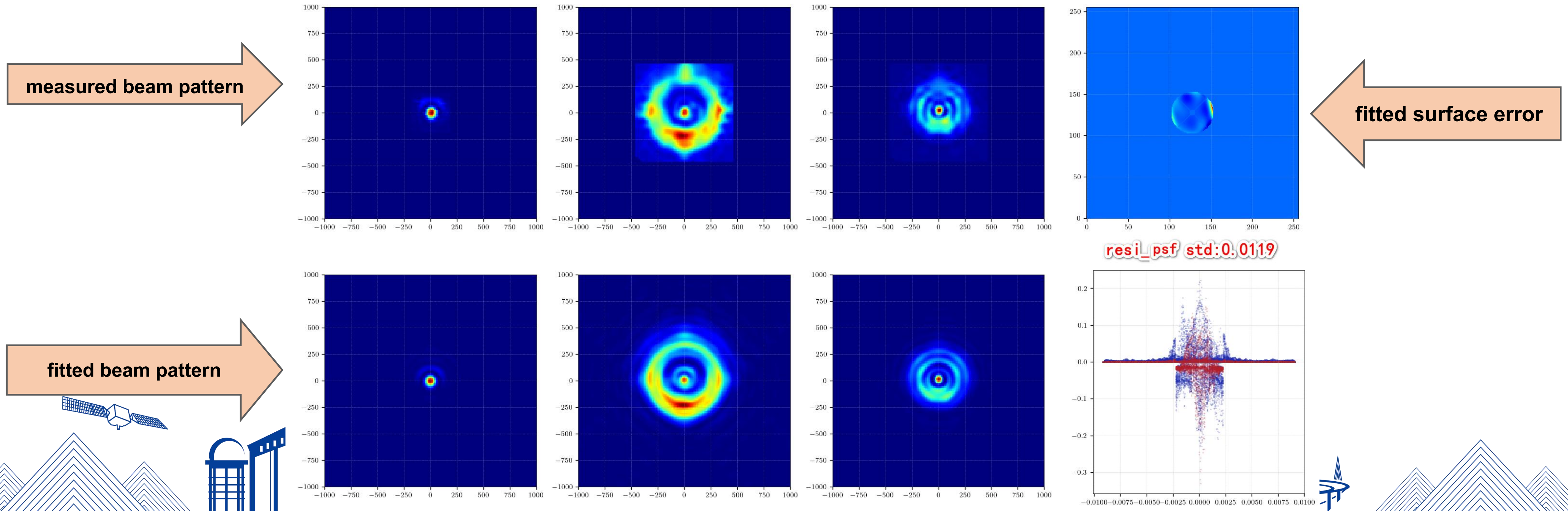


Relations of power variations and spatial variations

GEO satellites as bright signal sources

Radio Telescope Surface Error Measurement

- High-precision measurement of far-field beam pattern using satellite
- Calculate surface error from pattern data



Meridian radio telescope pointing calibration

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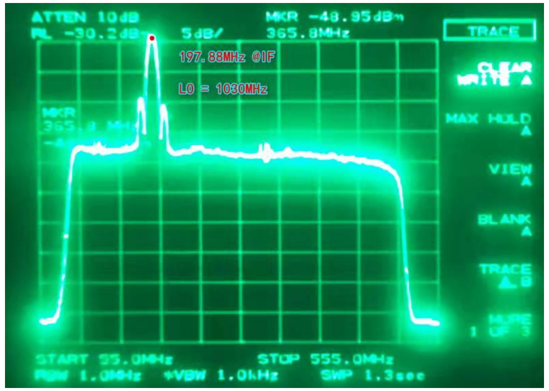
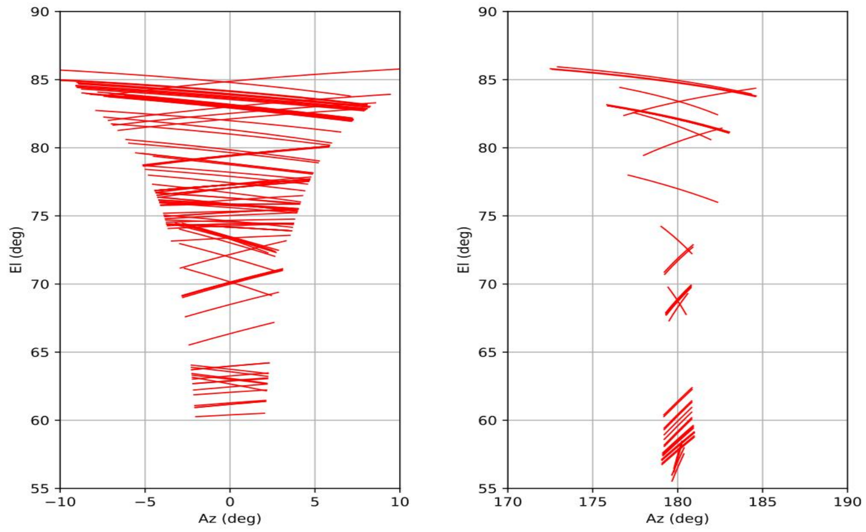
- **Satellites**: Multiple motion directions provide 2D pointing data via drift scans
- **Radio Sources**: Drift scans limited to RA direction only
https://doi.org/10.1155/aa/8503450

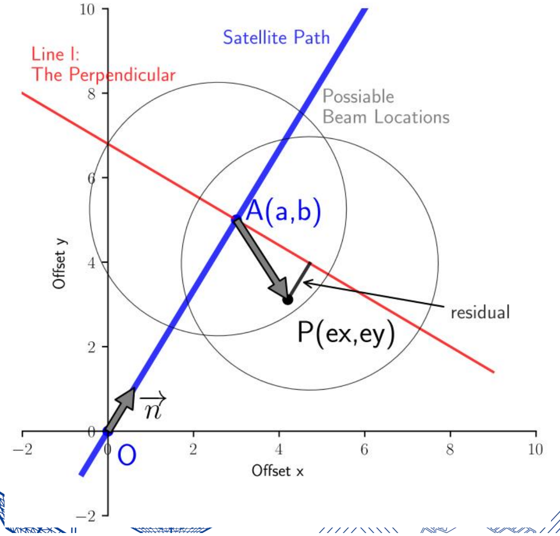
25 meters meridian radio telescope



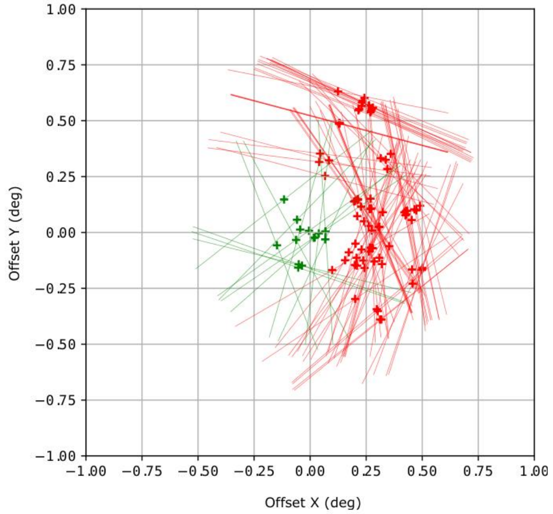
Spectrum of the satellites



Satellite Trajectory



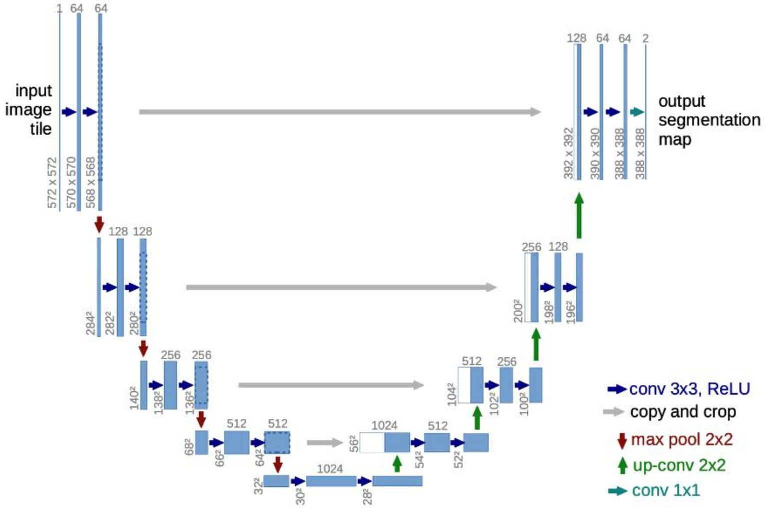
Principle of Pointing Measurement



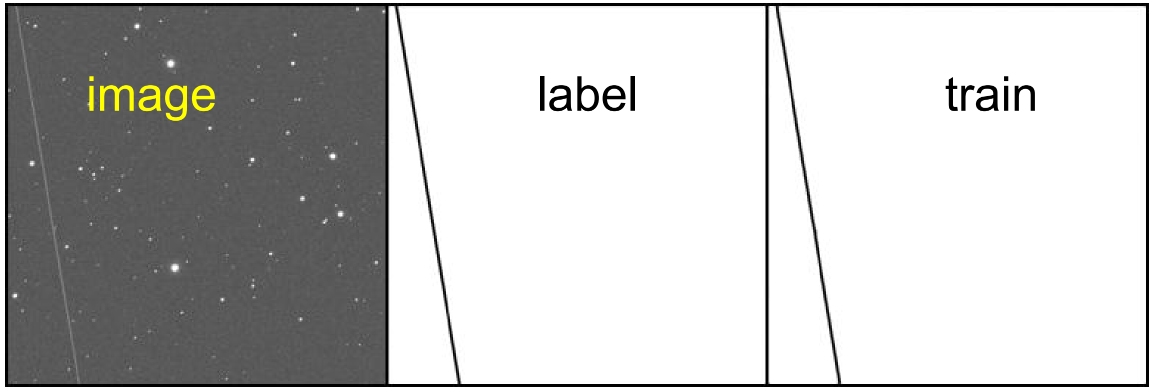
Pointing before an after Correction

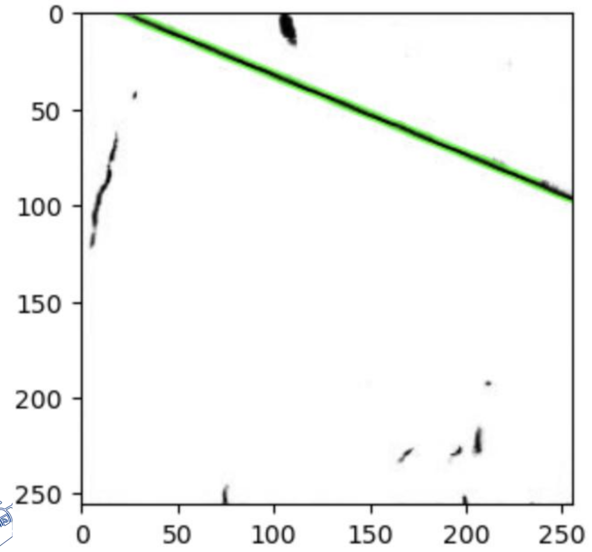
U-Net and LSD

- Combine the U-Net deep neural network for image segmentation with the Line Segment Detector algorithm：
  - U-Net (Ronneberger et al. 2015)：



- LSD：a linear-time algorithm capable of achieving subpixel accuracy by computing gradient magnitudes and directions across all pixels in an image (Grompone von Gioi et al. 2010, 2012).



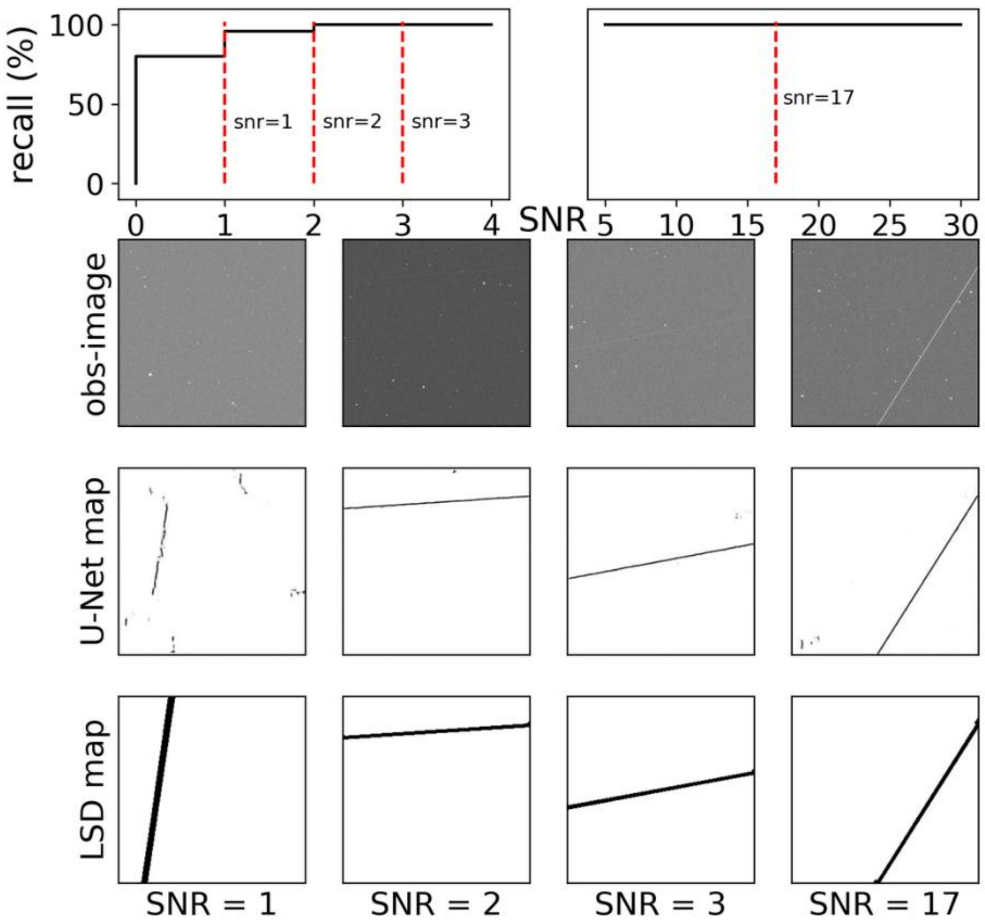


U-Net and LSD

1. Simulated data：For trails with a SNR greater than 3, the detection rate exceeds 99%.
2. Real observational data：
   a. precision：74.56%
   b. recall：79.57%

Threshold	TP	FP	FN	Recall	Precision
0	1372	27559	116	92.20%	4.74%
0.12	1184	404	304	79.57%	74.56%
0.14	1136	60	352	76.34%	94.98%
0.20	994	5	494	66.80%	99.50%
0.39	735	2	753	49.40%	99.73%
0.78	410	0	1078	27.55%	100%

Note. The threshold values in the table represent the ratio of the minimum line length in LSD to the side length of the image.



Observation Optimization Steps

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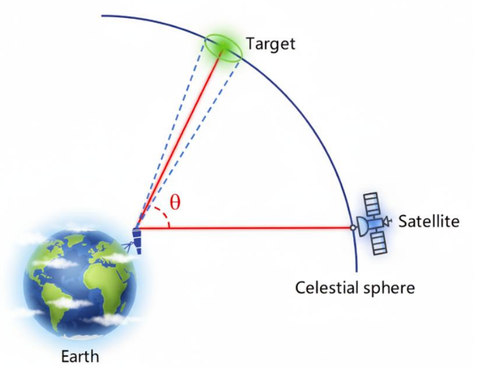
Step 1 – Satellite Risk Heatmap

We first model the spatio-temporal distribution of LEO using orbital data and reflection geometry. This produces a risk heatmap that quantifies the probability and intensity of satellite interference for each sky region and time slot.



Step 2 – Bayesian Optimization

BO constructs a surrogate probabilistic model linking observation quality with satellite risk and sky geometry. It iteratively selects the most promising sky regions, balancing exploration and exploitation to maximize expected observation gain.

Step 3 – Dynamic Programming

Given BO's spatial results, DP optimizes observation timing by dividing the night into decision stages and solving a recursive relation:

$$DP[t][k] = \max\{DP[t\text{-}1][k], \max\_\{s\in\Omega(t)\}\ [DP[s-\Delta g][k-1] + Q(s,t)]\}$$