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Search for gravitational wave probes – A self-supervised learning for pulsars based on signal contexts

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Contents

Background

1. Five-hundred-meter Aperture Spherical radio Telescope (FAST)

- All radiation energy received by radio telescopes from the universe over the past 70 years cannot be flipped a page.
- Detect Gravitational Waves at nanohertz used Pulsar Timing Array succeed 2023.
  (Xu et al 2023 Res. Astron. Astrophys. 23 075024 DOI: 10.1088/1674-4527/acdfa5)
  Different from the ground-based laser detection method (LIGO and Virgo, 2015)

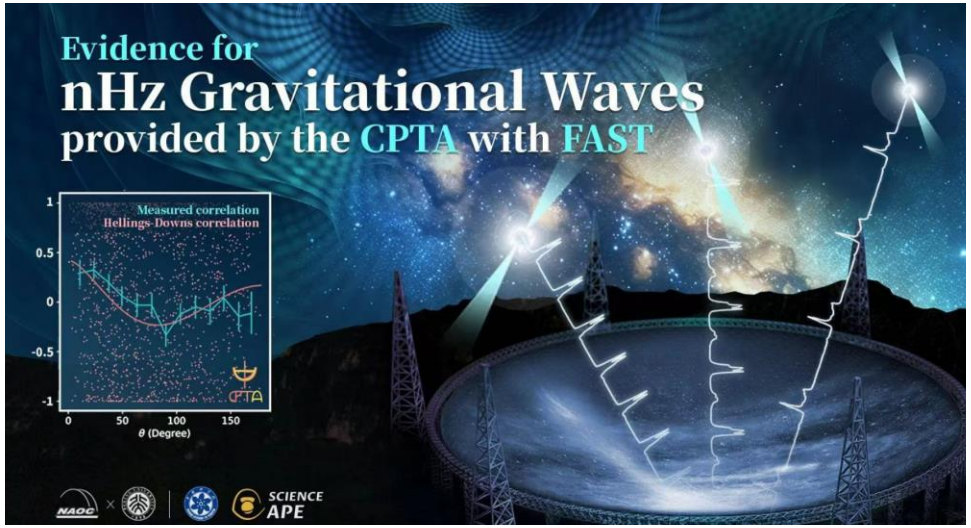


Fig 2. nHz GW provided by PTA with FAST.

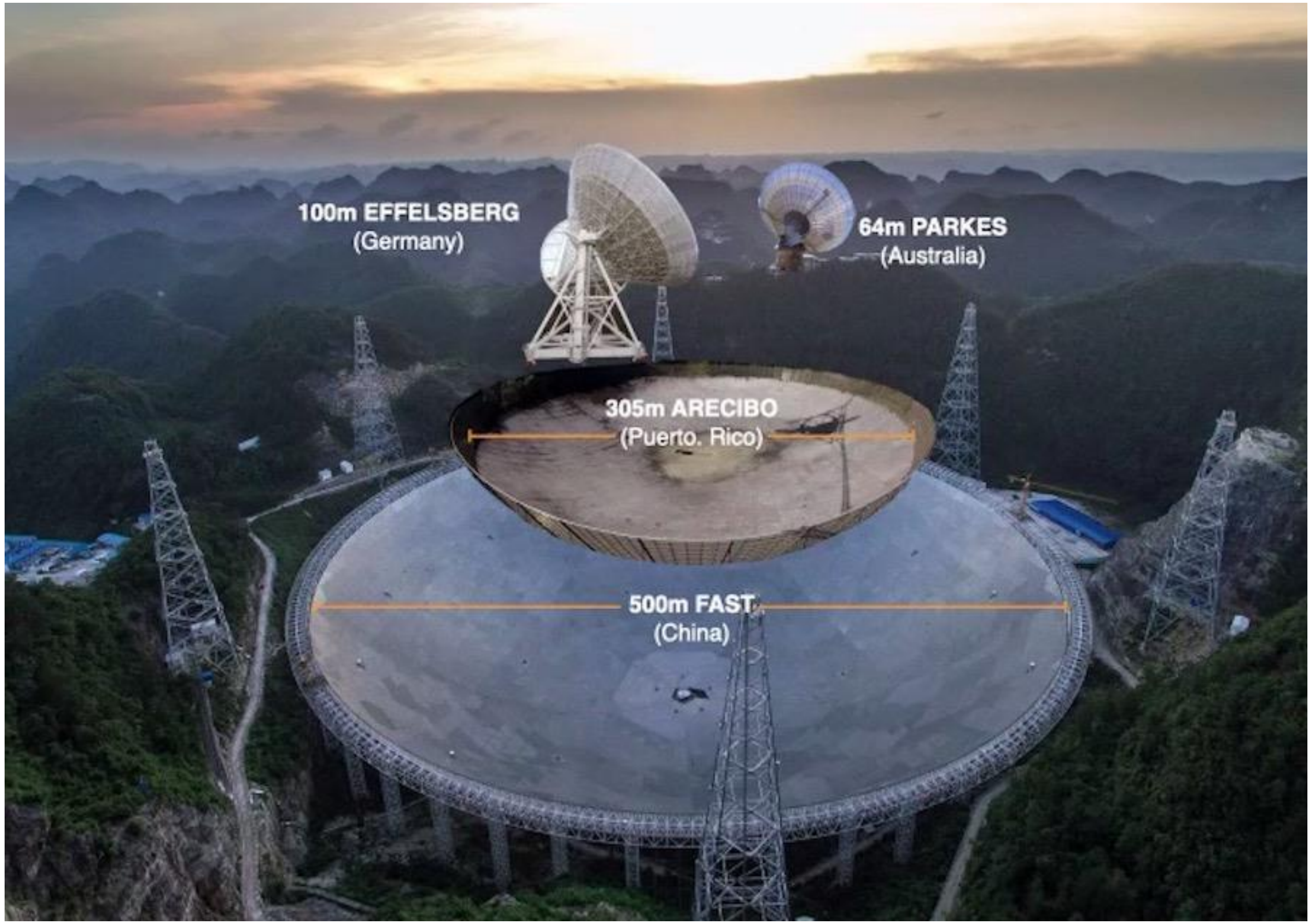


Fig 1. FAST, Arecibo, Effelesberg and Parkes telescopes.

Background

2. The motivations of searching pulsars

1, Need More pulsars as GWs probes to become pulsar timing array.

2, Meaningful for astrophysics science, application of AI for science.
Pulsar studies won Nobel prizes in Physics twice.

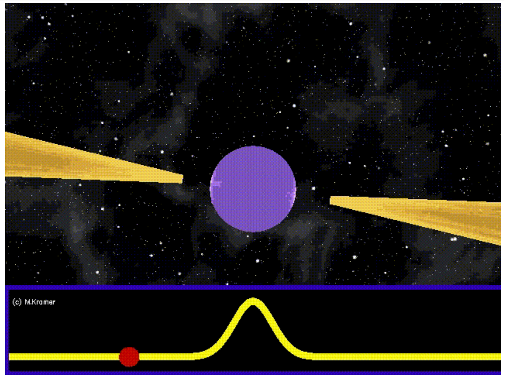


Fig 3. pulsar and its pulse signal

3, Challenges of deep learning: small example study, self-supervised learning, big data processing.

A systematic scientific engineering for 8 years. Our team has proposed a series of improvements for pulsar searching.

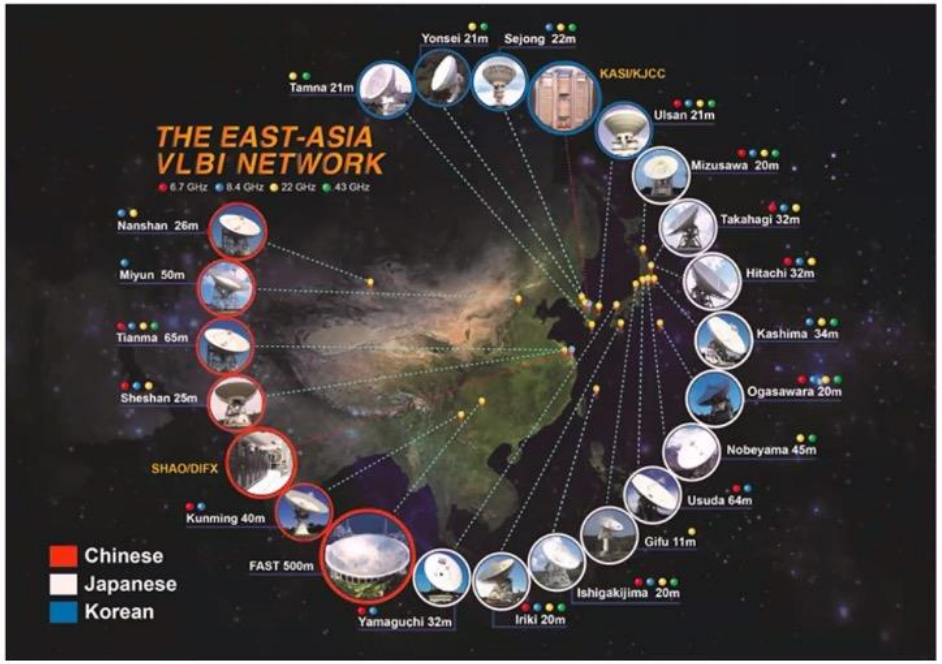


Fig 5. Telescope Array can become a larger telescope by VLBI network (the technology won Nobel Prize).
Pulsar Timing Array is a detected network in the universe.

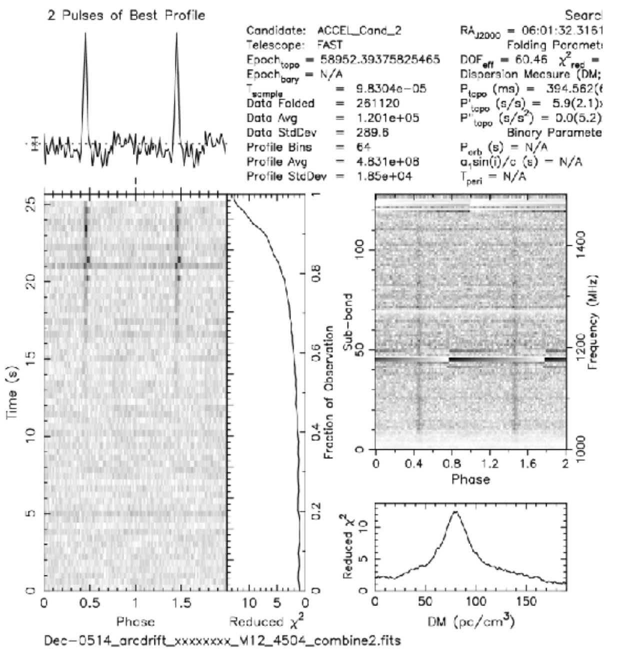
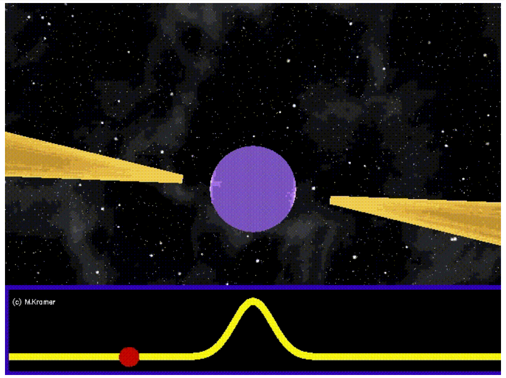


Fig 4. Classical pulsar profile and image

Background

3. Pulsar searching

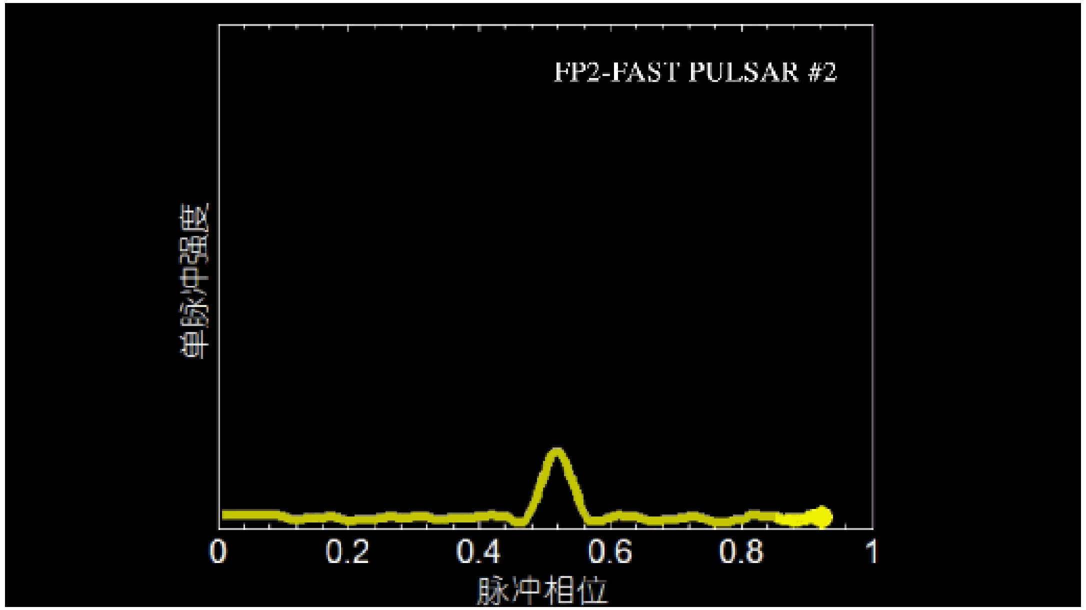


Two main strategies:

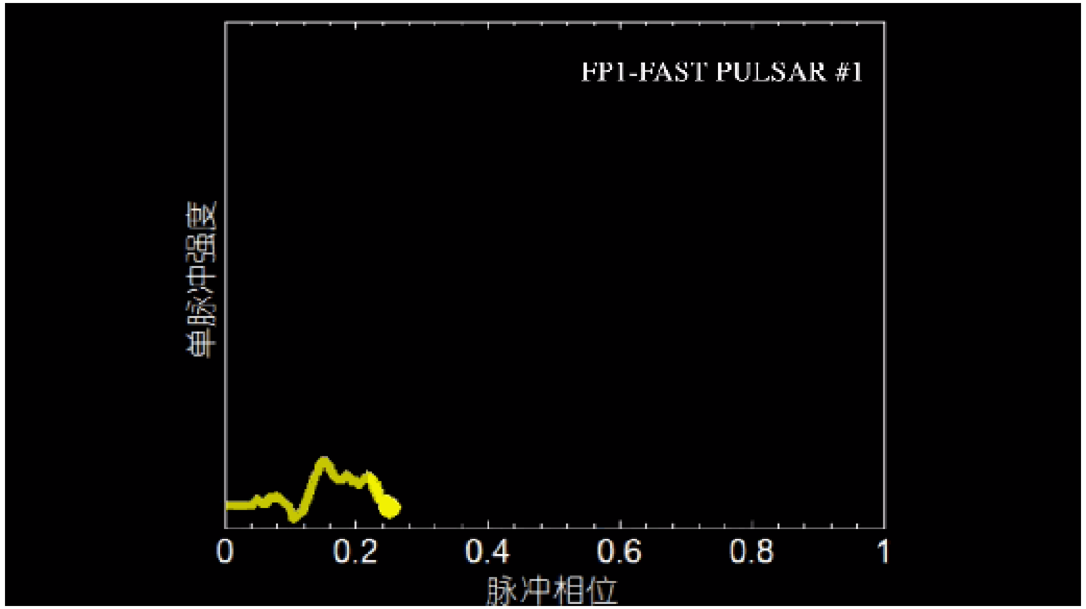
1, Period search (left): folding period signal to strength weak signals; need longer observation.

2, Single pulse search (right): depending on a small number of stronger signals; need higher sensitive observation.

Low frequency pulsars are seriously disturbed by temporal noise, which is unfavourable to the searching. Propose a new method combine two strategies.



Period search



Single pulse search

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Tasks and Dataset

Two training Tasks:

PPTA Profile Prediction Auxiliary Task

NACL Negative Augmentation Contrastive Learning

Dataset: CRAFTS-drift scan dataset, which contains
1,835 training samples including 837 pulsar signals and 998 noise signals,
13,647 test samples including 326 pulsar signals and 13,321 noise signals.

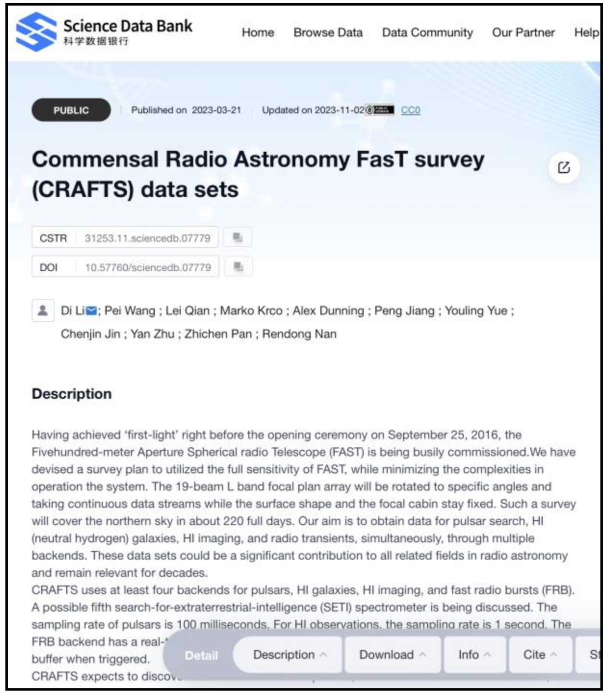
Notice: (1) unlabeled (2) unbalanced (3) baseline model (PICS-ResNet) training by labeled and balanced samples comes from other telescope.

Train			Test		
Pos.	Neg.	Total	Pos.	Neg.	Total
837	998	1835	326	13321	13647

CRAFTS
The Commensal Radio Astronomy FAST Survey
FAST多科学目标同时扫描巡天

Li et al. 2018 IEEE MW

Science Data Bank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Commensal Radio Astronomy FasT survey (CRAFTS) data sets

CSTR 31253.11.sciencedb.07779
DOI 10.57760/sciencedb.07779

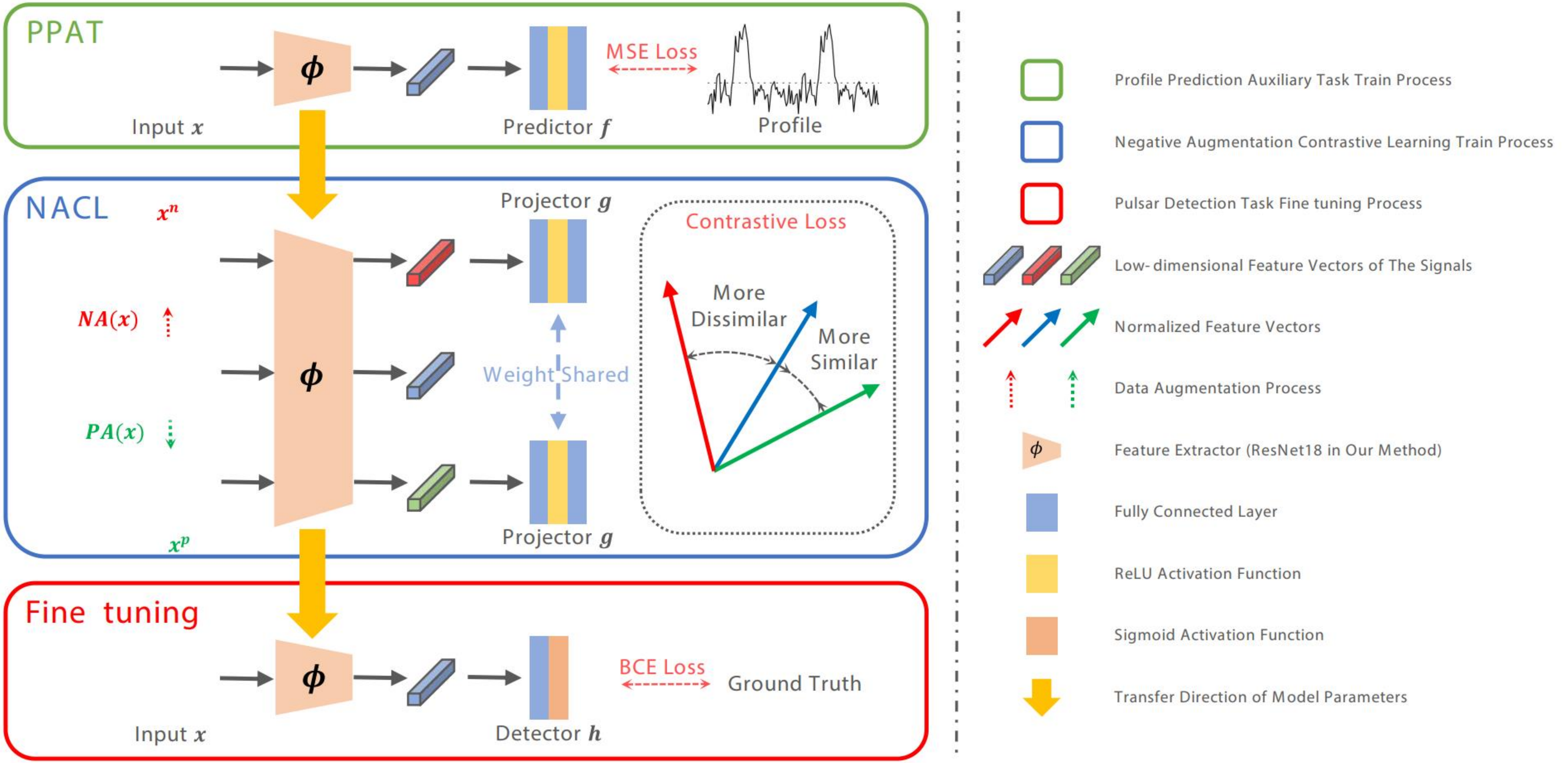
Di Li; Pei Wang ; Lei Qian ; Marko Krco ; Alex Dunning ; Peng Jiang ; Youling Yue ; Chenjin Jin ; Yan Zhu ; Zhichen Pan ; Rendong Nan

Description

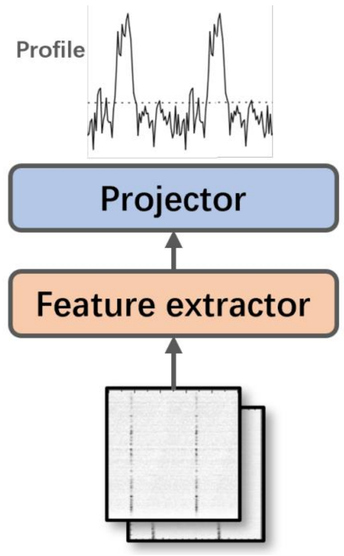
Having achieved 'first-light' right before the opening ceremony on September 25, 2016, the Fivehundred-meter Aperture Spherical radio Telescope (FAST) is being busily commissioned.We have devised a survey plan to utilized the full sensitivity of FAST, while minimizing the complexities in operation the system. The 19-beam L band focal plan array will be rotated to specific angles and taking continuous data streams while the surface shape and the focal cabin stay fixed. Such a survey will cover the northern sky in about 220 full days. Our aim is to obtain data for pulsar search, HI (neutral hydrogen) galaxies, HI imaging, and radio transients, simultaneously, through multiple backends. These data sets could be a significant contribution to all related fields in radio astronomy and remain relevant for decades.
CRAFTS uses at least four backends for pulsars, HI galaxies, HI imaging, and fast radio bursts (FRB). A possible fifth search-for-extraterrestrial-intelligence (SETI) spectrometer is being discussed. The sampling rate of pulsars is 100 milliseconds. For HI observations, the sampling rate is 1 second. The FRB backend has a real-
buffer when triggered.
CRAFTS expects to disco

Detail Description Download Info Cite

Training Pipeline



Training Pipeline



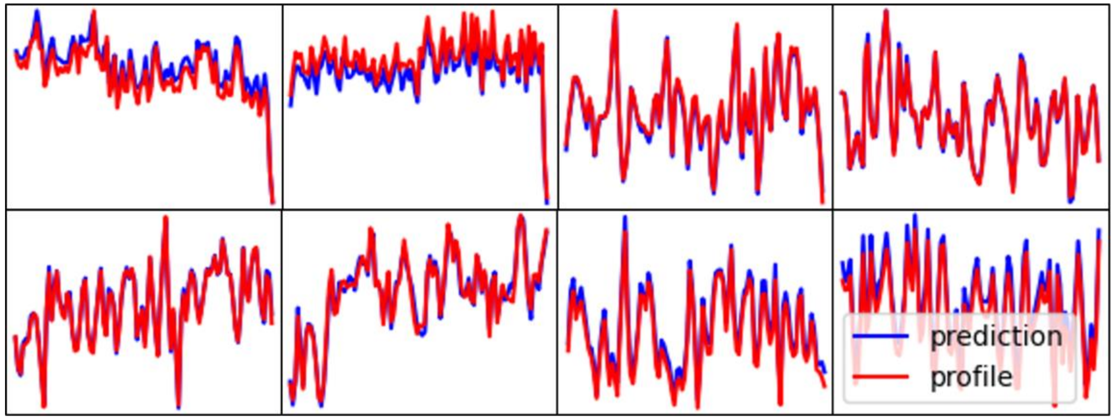


Fig 7. **PPAT** Blue lines represent the profile ground truth, while the red lines represent the prediction.

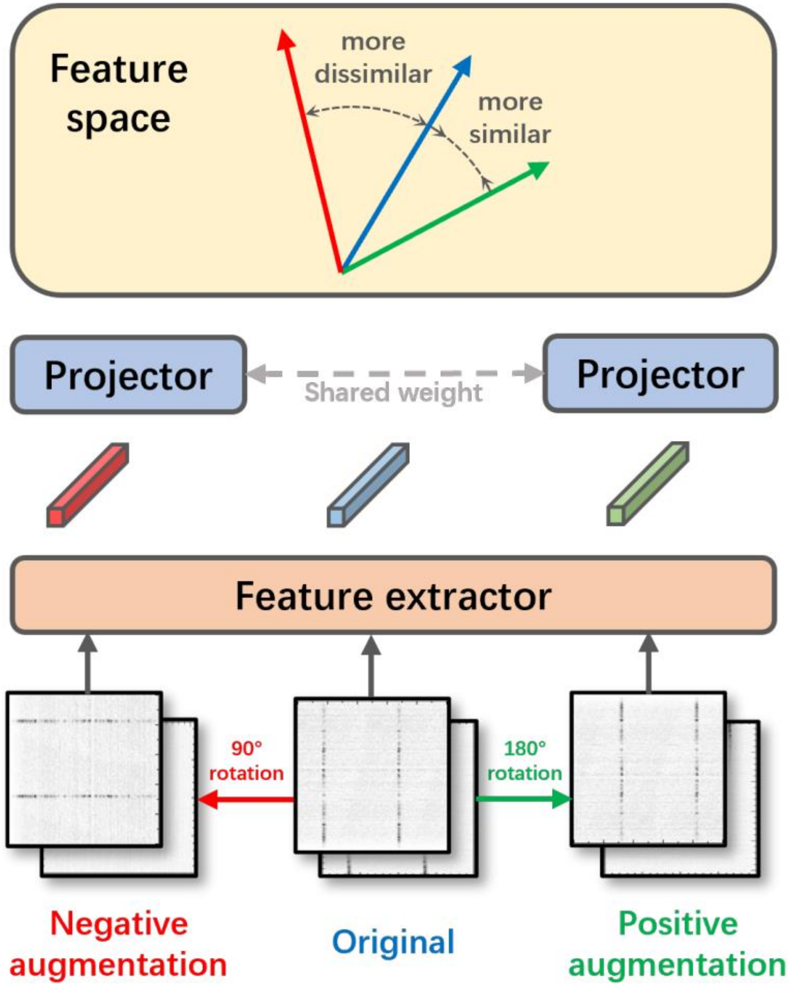


Fig 8. **NACL** Negative augmentation contrastive learning increases discrimination.

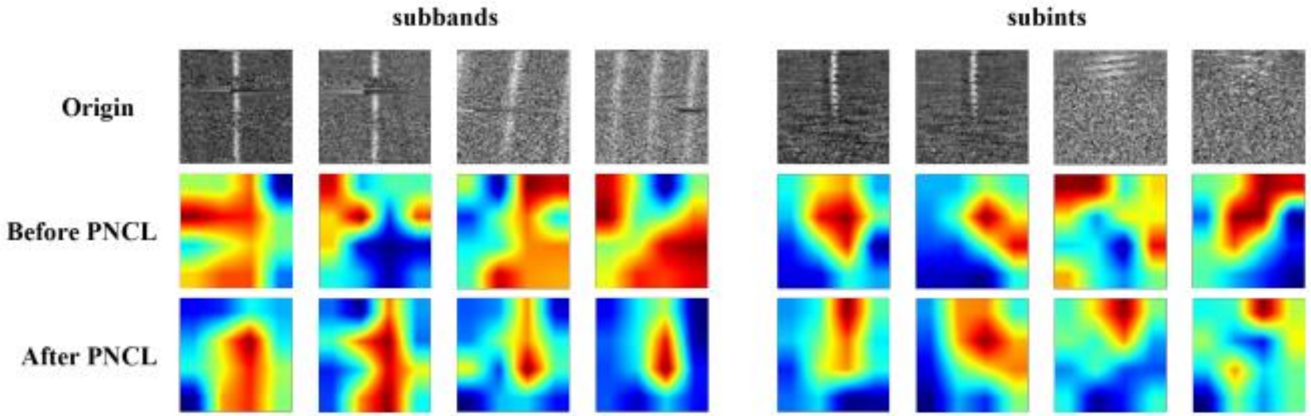


Fig 9. **Visualization** Grad-CAM of ResNet18 third layer in downstream pulsar detection task.

Results

The results of experiments

Both self-supervised tasks PPAT and NACL can improve the baseline method, which can be observed in the improvement of recall, AUC and the decrease of FPR.

Method	Signals	Recall	FPR	AUC
PICS[12]	All folded signals	0.9587	0.2039	0.9050
PICS-ResNet[13]	All folded signals	0.9610	0.1606	0.9133
SA-ResNet[14]	subbands+subints+DM	0.9863	0.0283	0.9734
baseline	subband+subint	0.9808	0.0892	0.9316
only PPAT (ours)	subband+subint	0.9818	0.0353	0.9678
only NACL (ours)	subband+subint	0.9826	0.0265	0.9729
both (ours)	subband+subint	**0.9878**↑	**0.0211**↓	**0.9803**↑

Results

The results of

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both (ours)	subband+subint	**0.9878**↑	**0.0211**↓	**0.9803**↑

One More Thing: if pretrain PPAT first, it will be better.

Order	Recall	FPR
PPAT+NACL	**0.9878**	**0.0211**
NACL+PPAT	0.9820	0.0294

Results

We find 32 new pulsars and 2 more Fast Radio Bursts

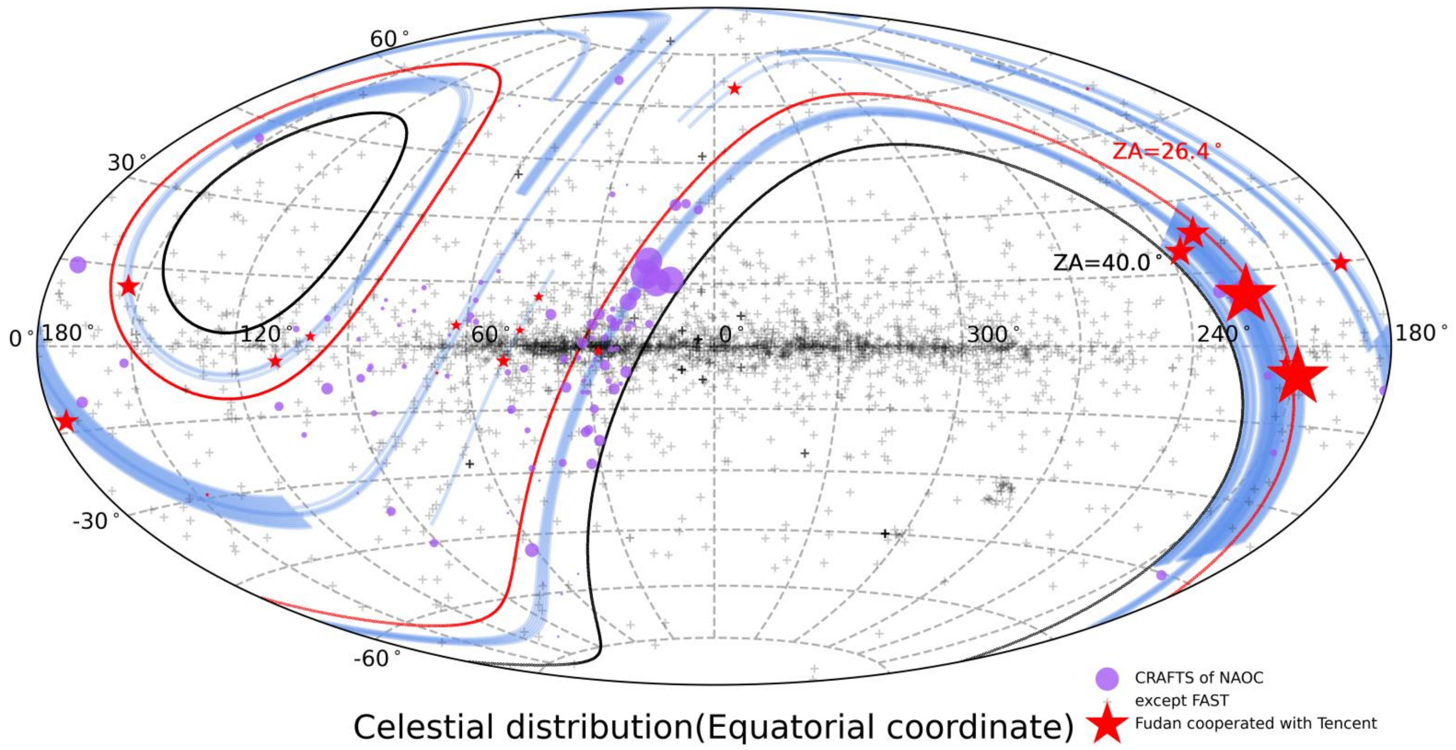

Fig 10. The sky map of the new pulsars find by our team.

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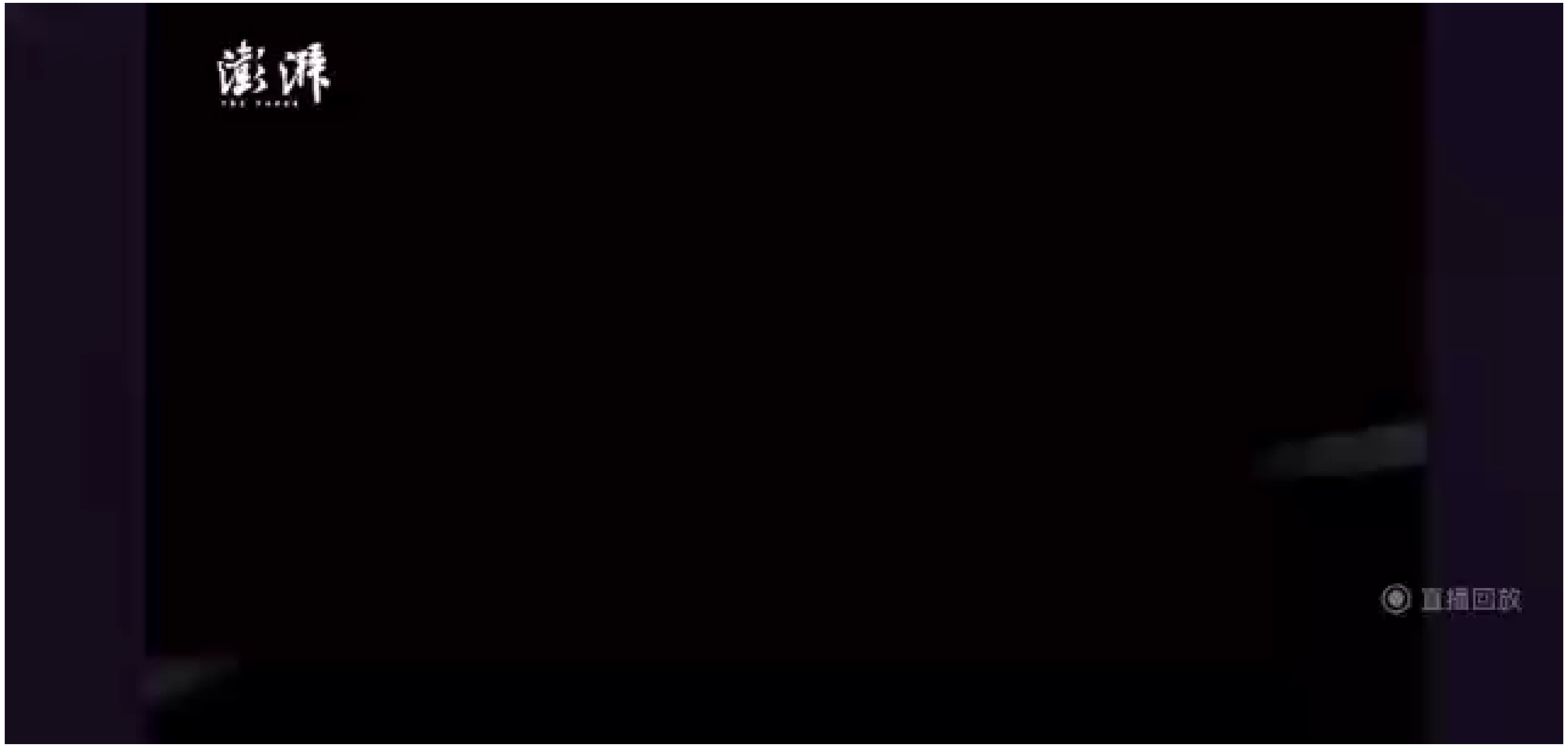
Pulsars, the heartbeat of the universe

The voices of pulsars detected by FAST.



Wang et al. Listen the Universe: Sonification Recipes of Pulsars Base on Artifficial Intelligence (in prep.)

Thank you!