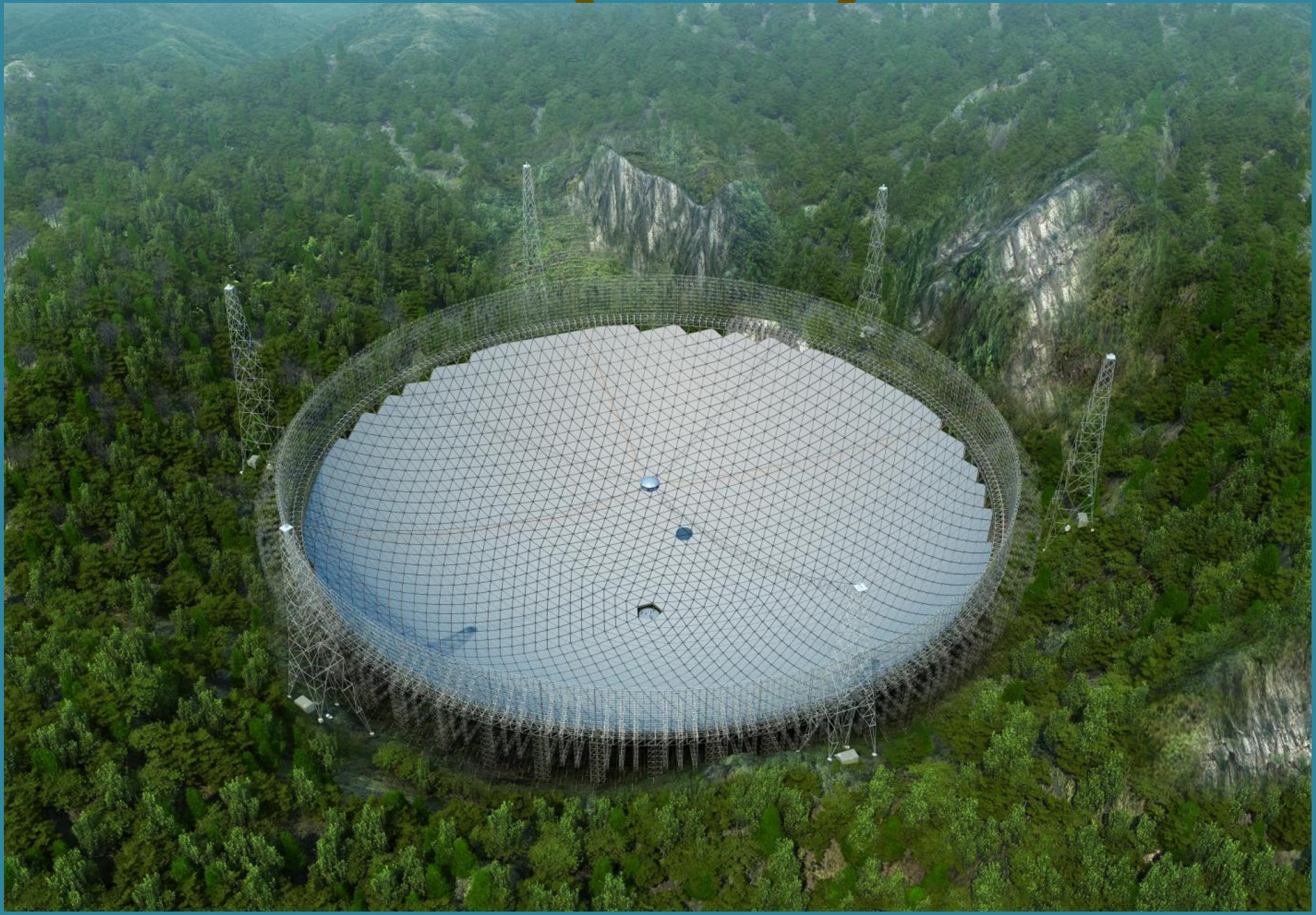
FAST Project and its Science Goals

Five hundred meter Aperture Spherical radio Telescope



Zhu, Ming (on behalf of the FAST team)
National Astronomical Observatories
Chinese Academy of Sciences

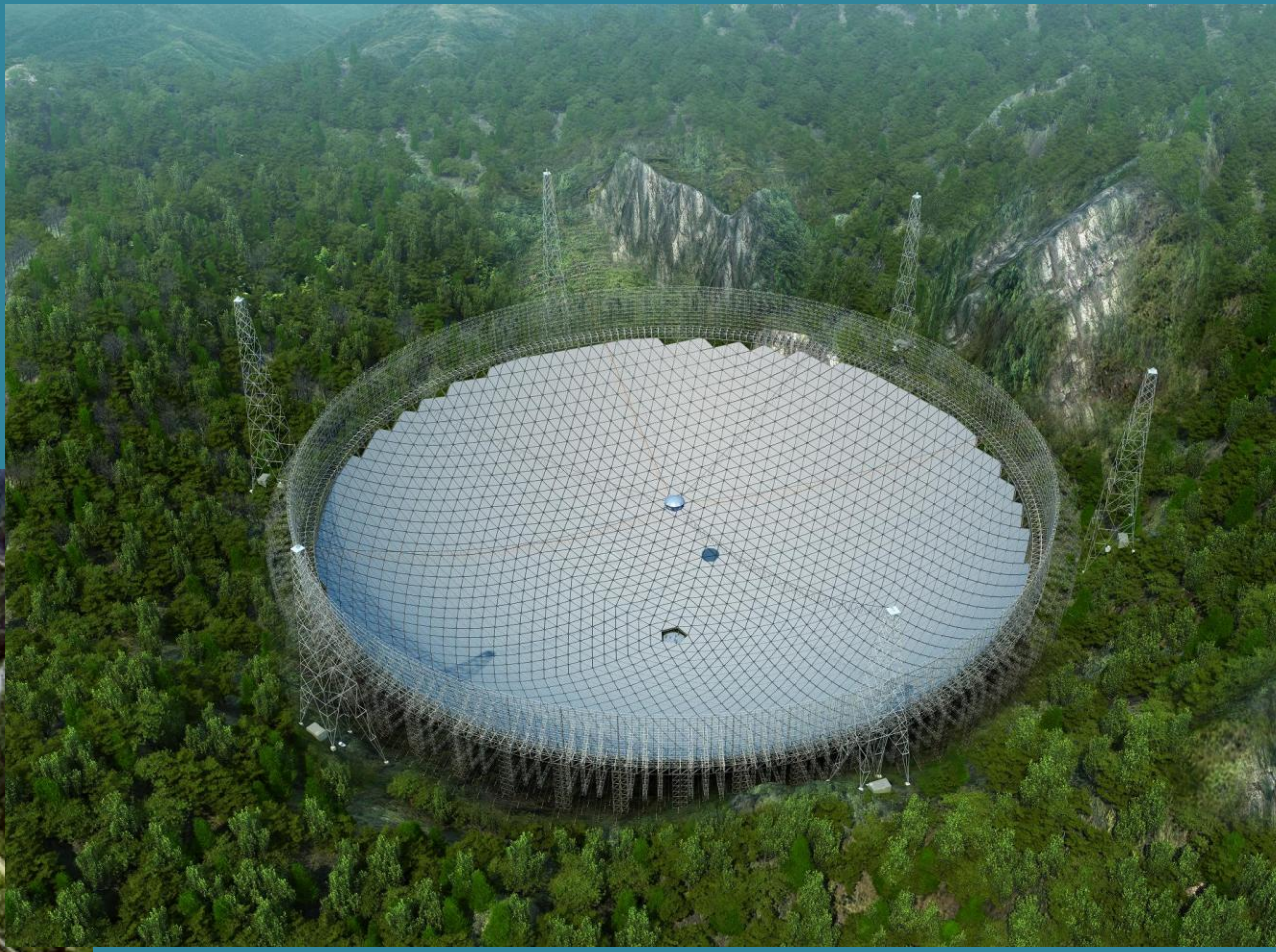
2011 Nov 7th

content

- Introduction to the FAST project
- General technical specifications
- Critical technologies
- FAST Science

Five hundred meter Aperture Spherical Telescope

- Unique Karst depression as the site
- Active main reflector
- Cable - parallel robot feed support



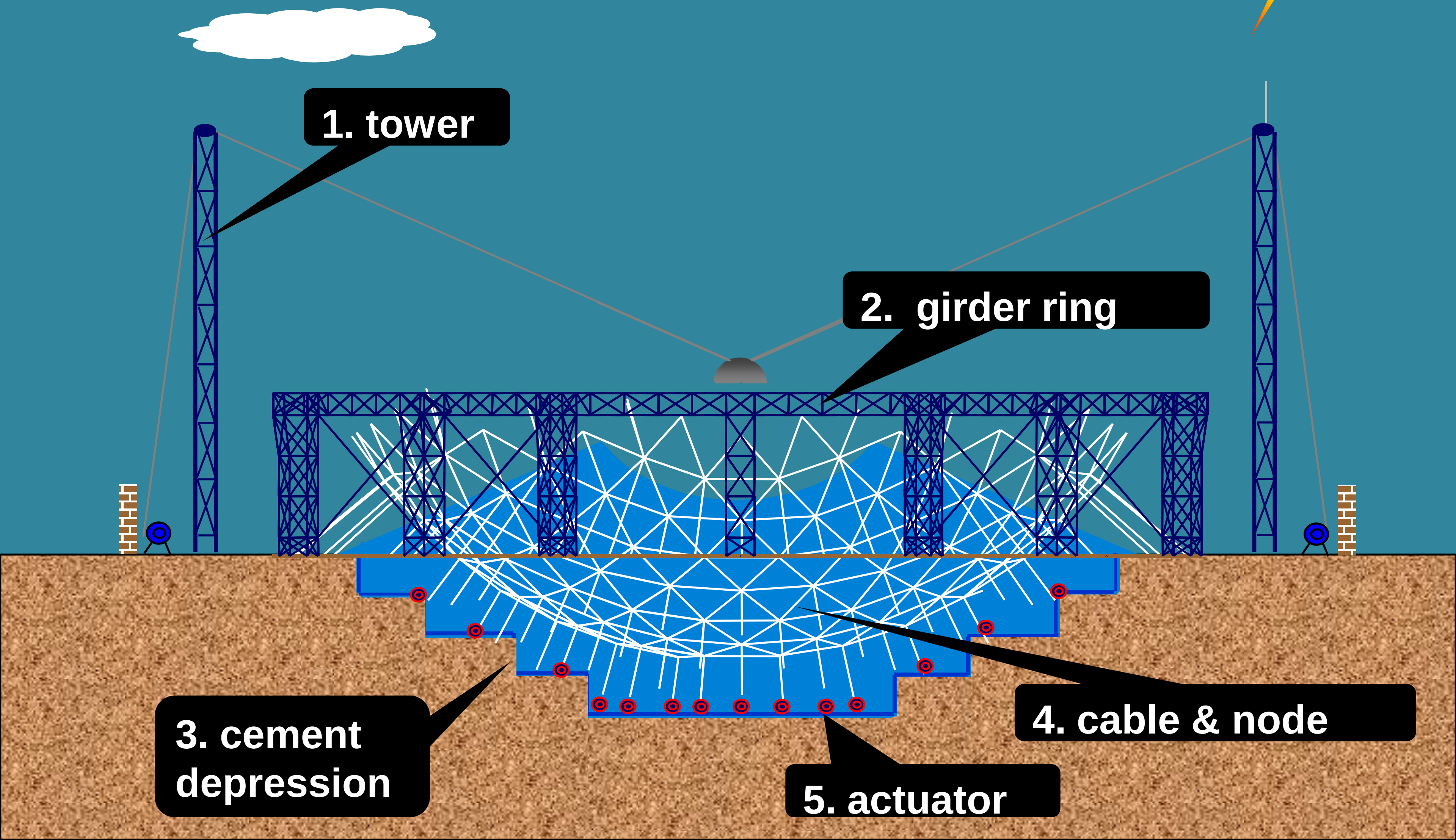
Site Surveying in Guizhou

Location: N25.647222º E106.85583°

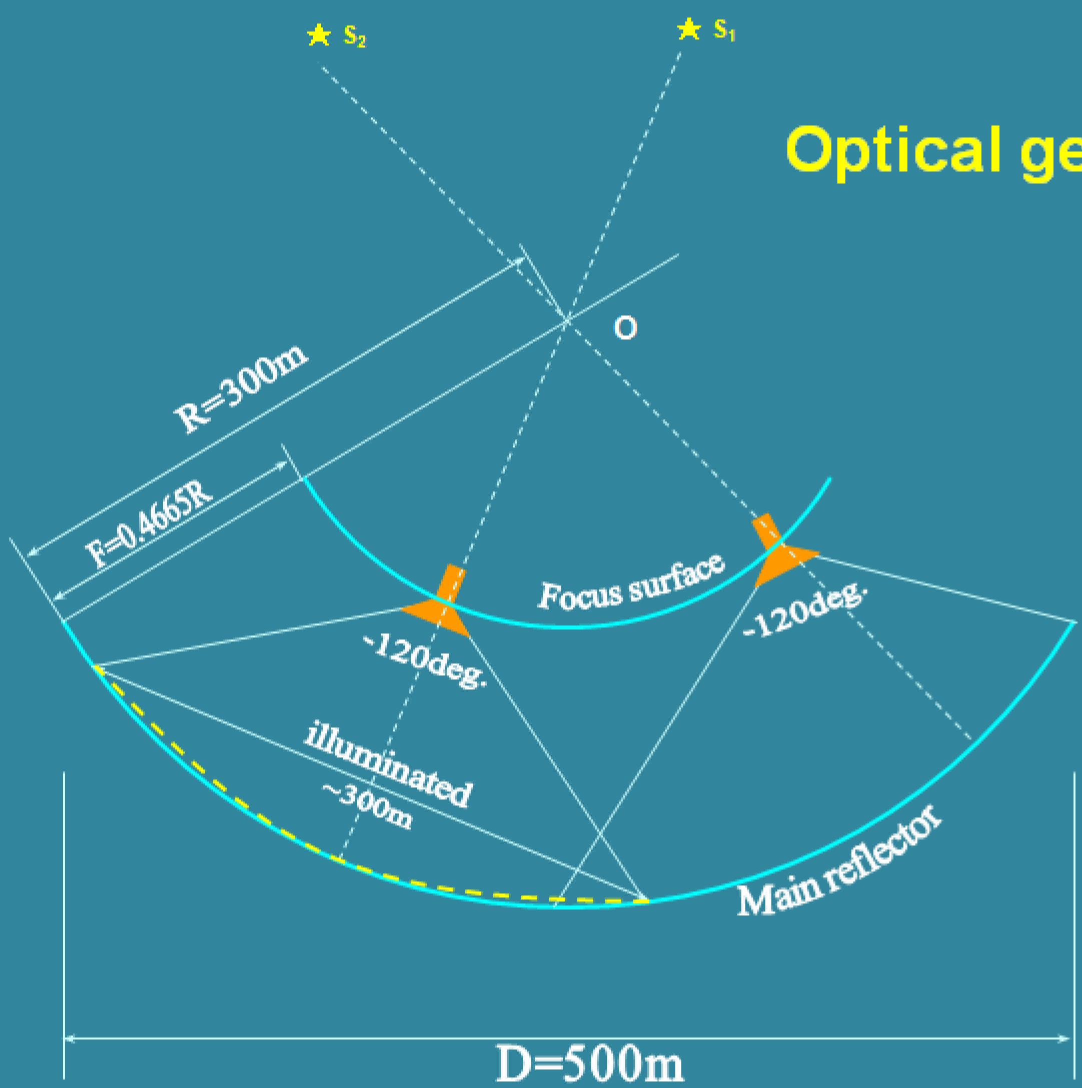
Site: the Karst region in south Guizhou Province


Quick Bird Fly Oct. 6, 2005

FAST model construction process



Optical geometry



2. General Technical Specification

Spherical reflector：Radius～300m, Aperture～500m, Opening angle 110~120°

Illuminated aperture：D_{ill}=300m

Focal ratio：f/D =0.467

Sky coverage：zenith angle 40° (up to 60° with efficiency loss) tracking hours 0~6h

Frequency：70M ~ 3 GHz（up to 8GHz in future upgrading）

Sensitivity (L-Band)：A/T~2000, T~20 K

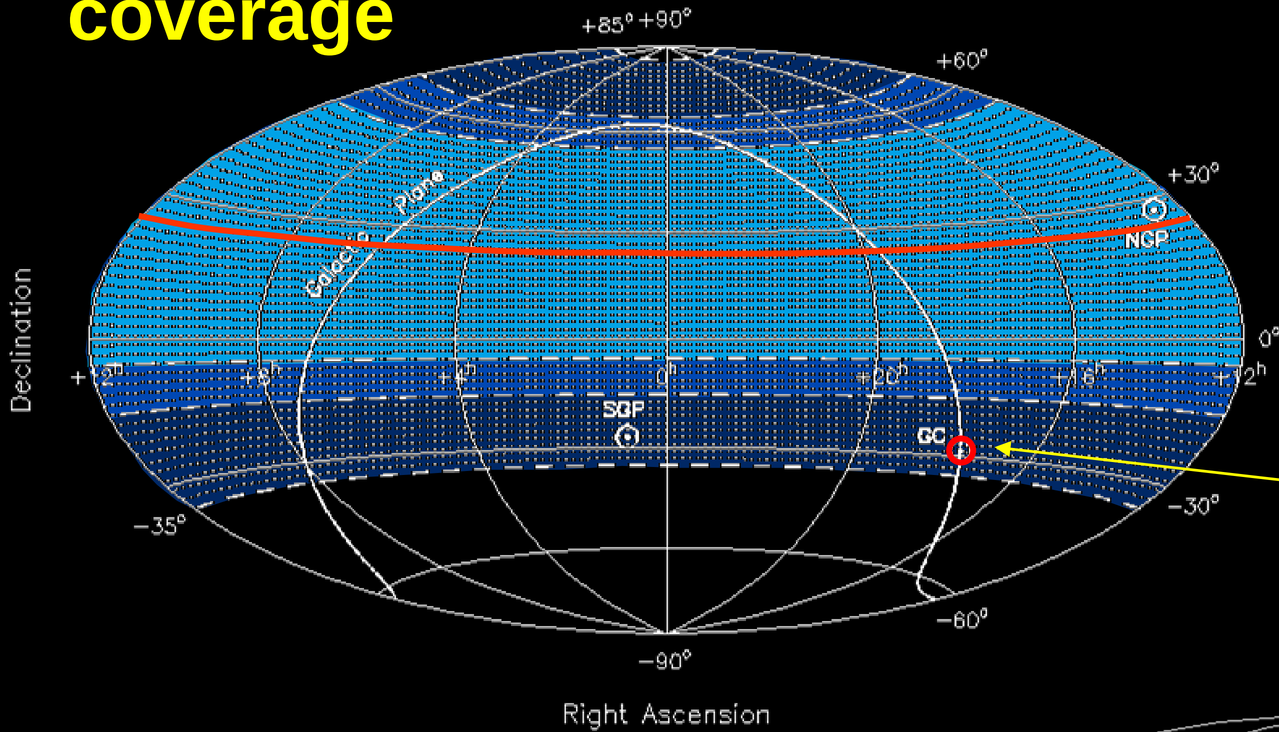
Resolution (L-Band)：2.9′

Multi-beam (L-Band)：19, beam number of future FPA >100

Slewing：<10min

Pointing accuracy：8″

Opening angle - sky coverage



Sky coverage

ZA 30 deg

ZA 40 deg

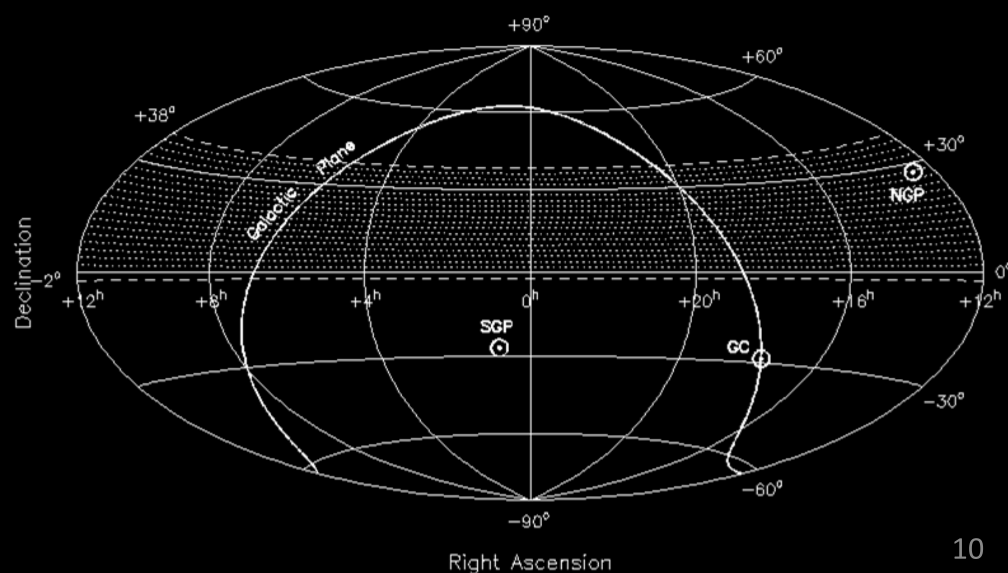
ZA 60 deg

FAST Zenith

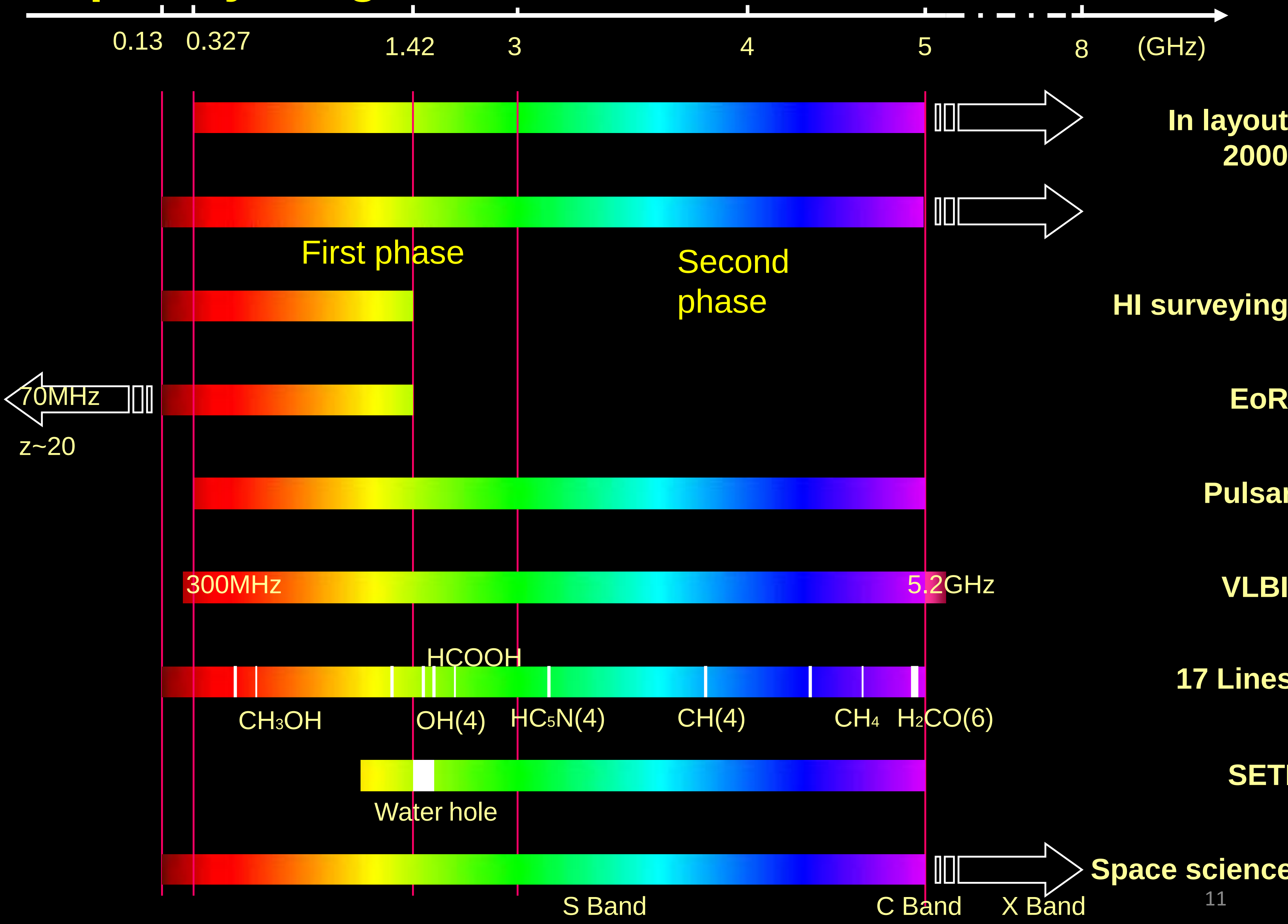
ZA 56 deg

Sky coverage

FAST vs. Arecibo

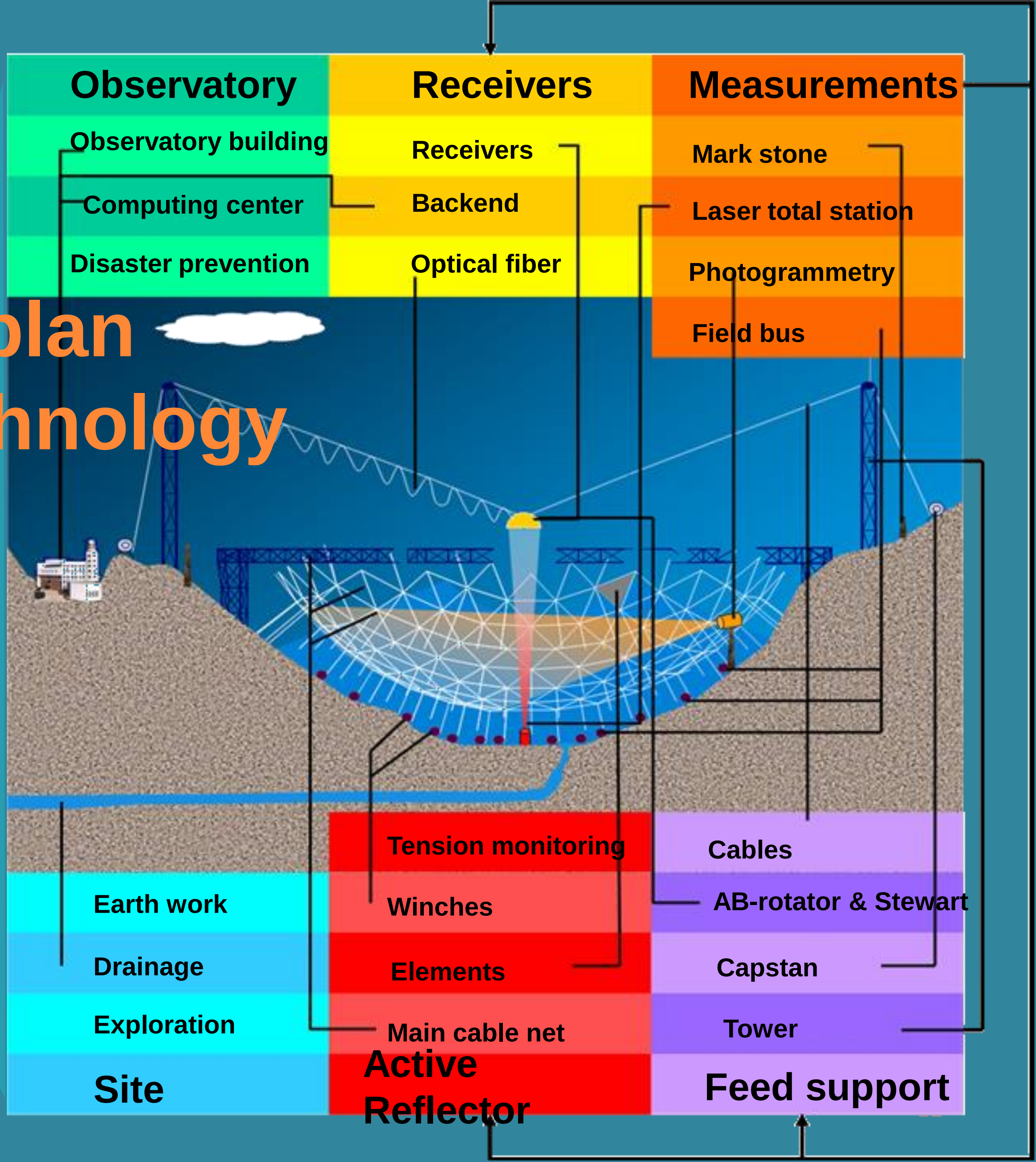


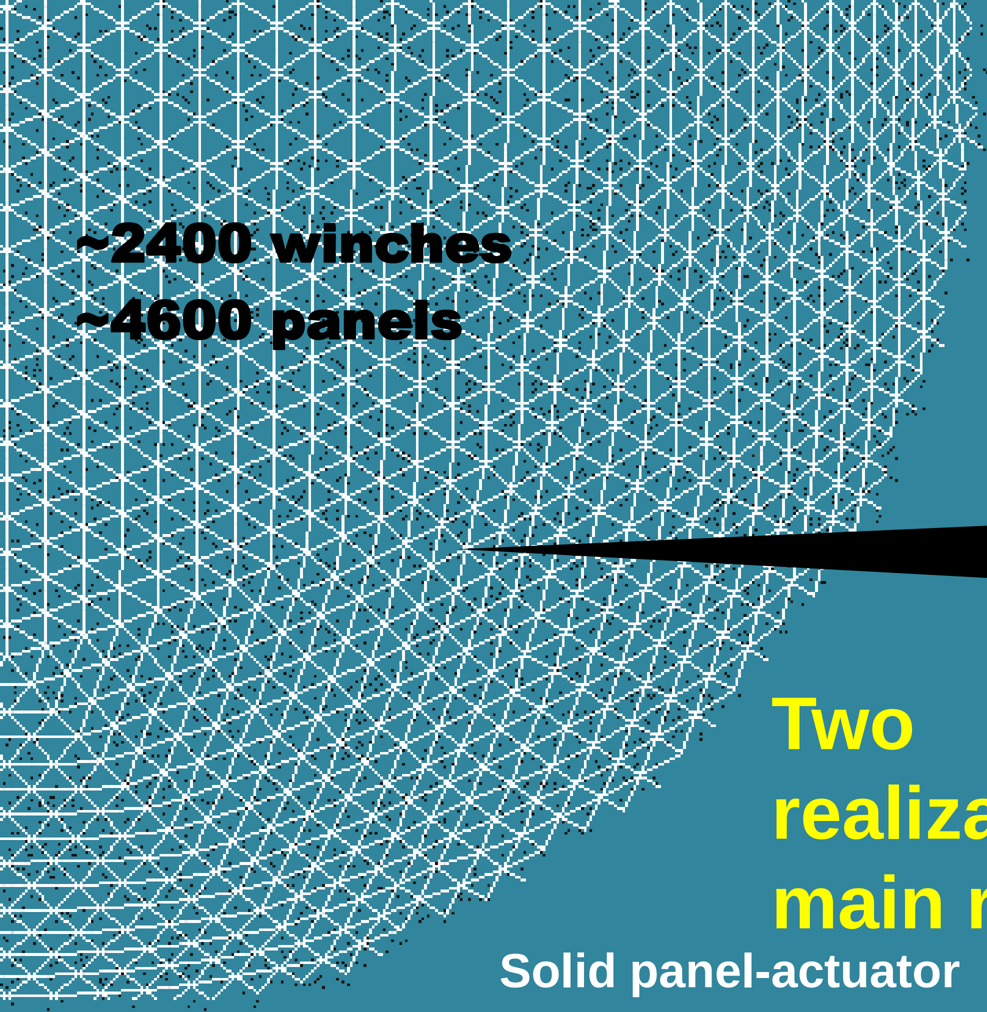
Frequency range

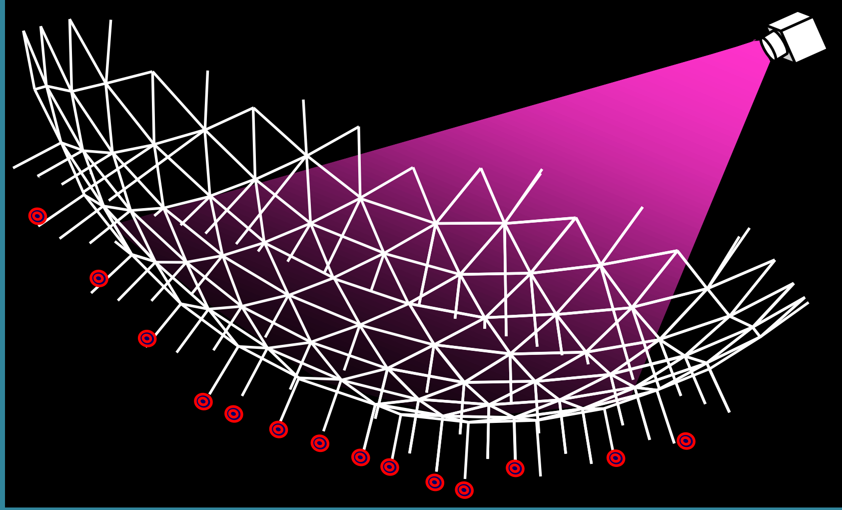


3.Technical plan – critical technology

Site
Active Reflector
Feed support
Measurements
Receivers
Observatory



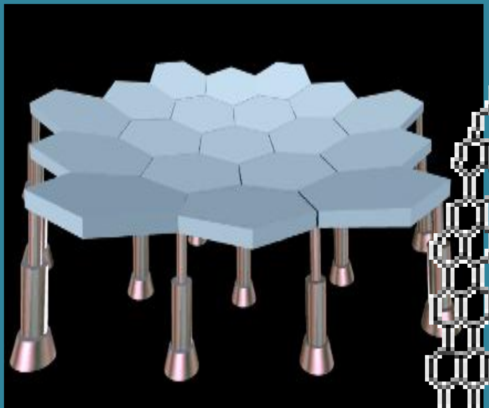


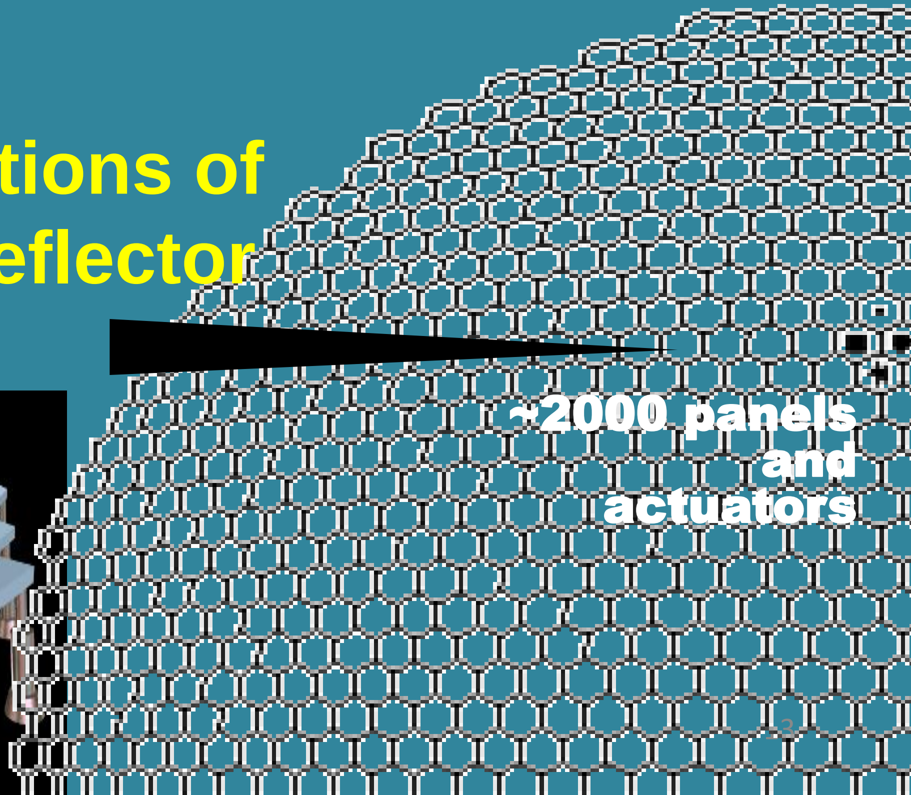


daptive cable-mesh

Two realizations of main reflector

Solid panel-actuator

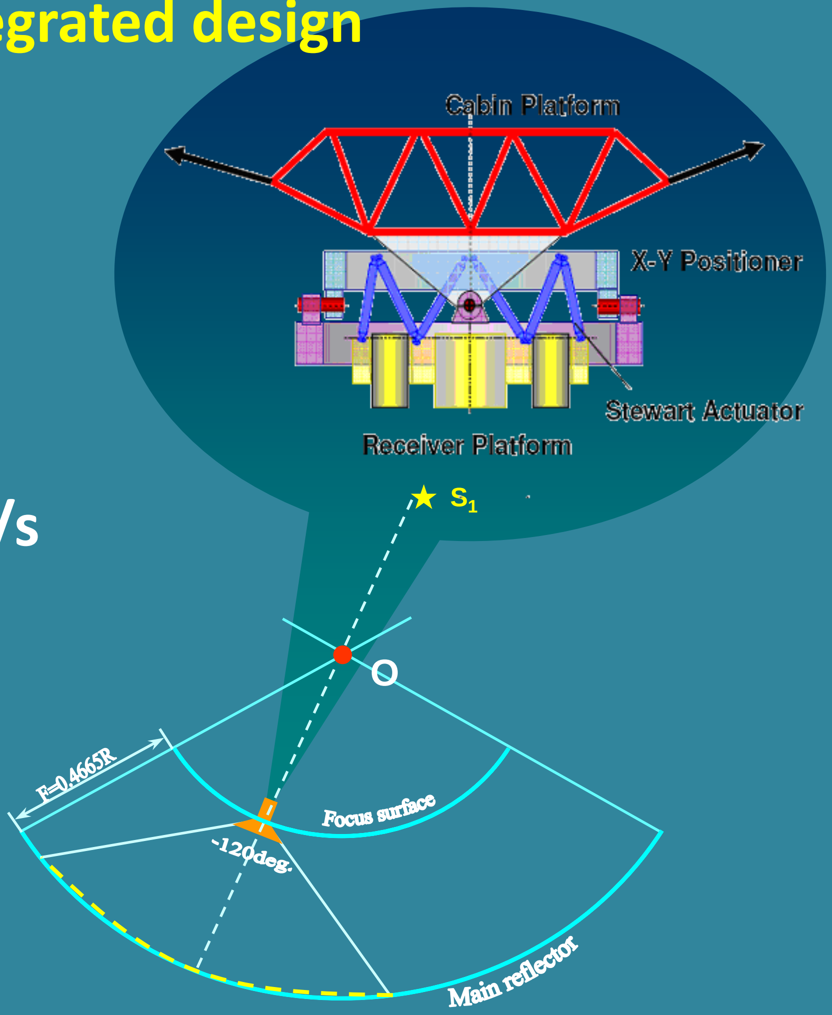




Feed Support

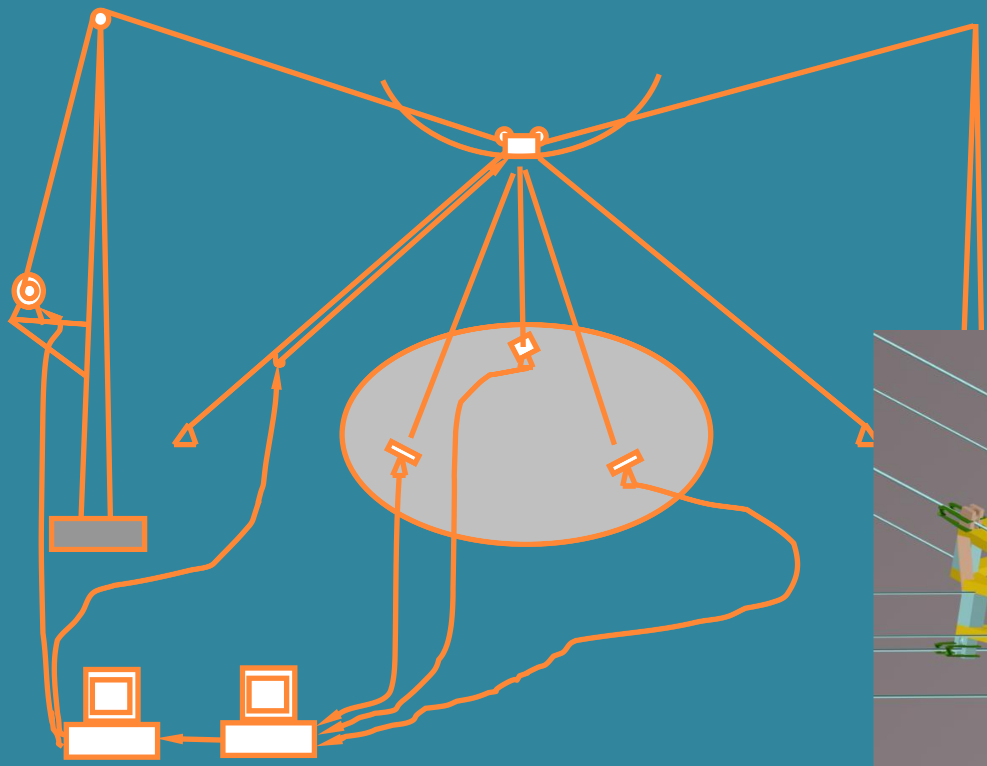
mechanical-electronic-optical integrated design

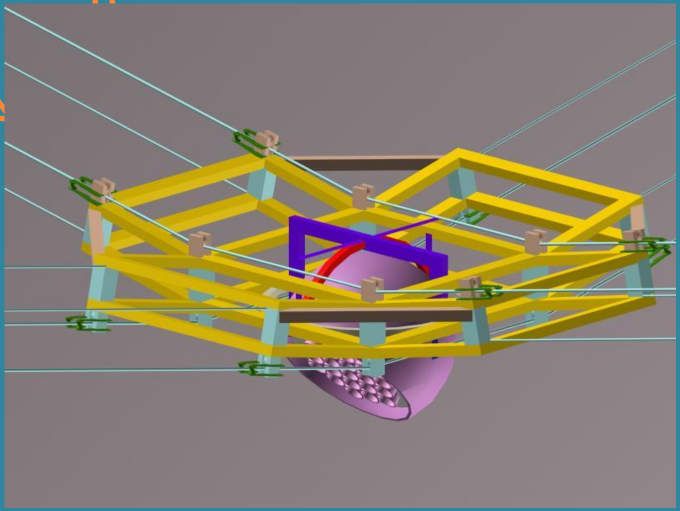
- Focal cap diameter 206m
- Cabin in total ~30t
- Load on lower plate ~3t
- Maximum tracking 11.6mm/s
- Slewing 400mm/s
- Position error <10mm
- Pointing accuracy 8”



Three main parts of cabin suspension

- **Cable network - first adjustable system**
- **Stewart - secondary adjustable system**
- **Close loop control**



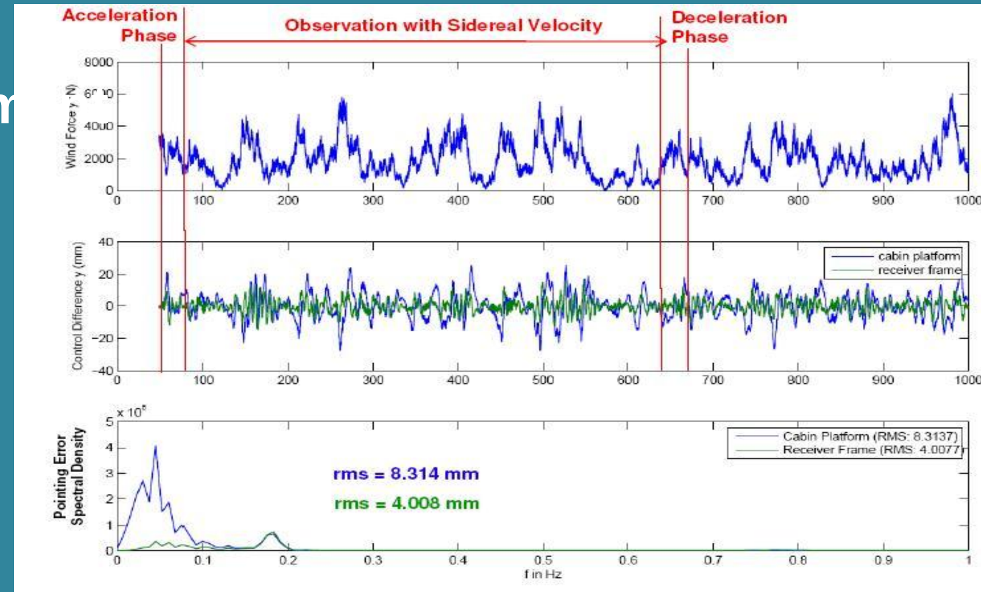


Prime focus position control

Experiment on the cable supporting system

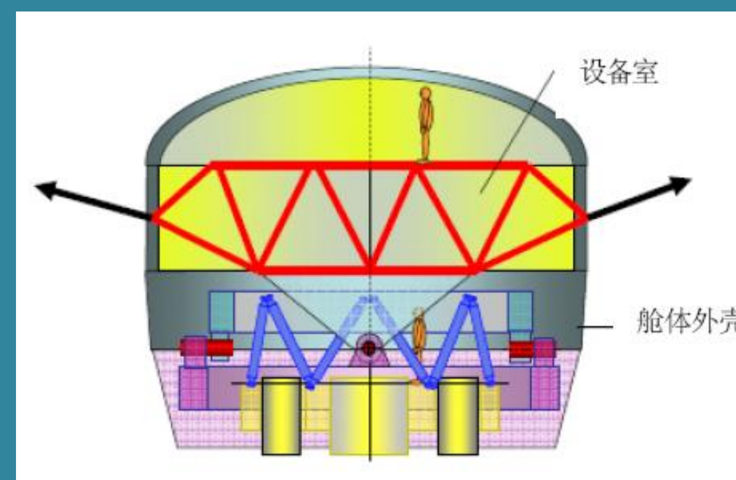

2002 9 2

- under the wind 8m/s, 1st adjustm
  reaches control accuracy 8mm
- as the stabilizer is switched on
  accuracy 4mm
- spectra - 0.18Hz



Total weight of cabin ~ 30t

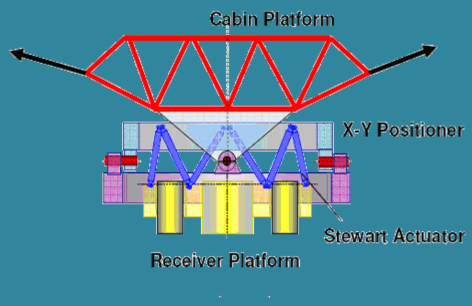
receivers	4
Stabilized platform	2
actuators	1,5
X-Y Frames	4
Y- positioner base	4
cladding	8
Top frame – star truss	4
total	27,5



Measurement – precise, quick and in long distance

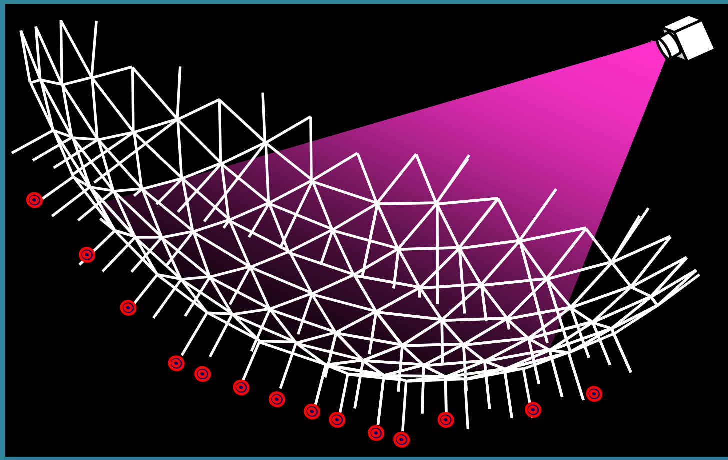
Task 1: 3-D spatial positions of focus cabin

- Large working range up to 300 m
- Errors ~1 mm
- Sampling rate > 10 Hz

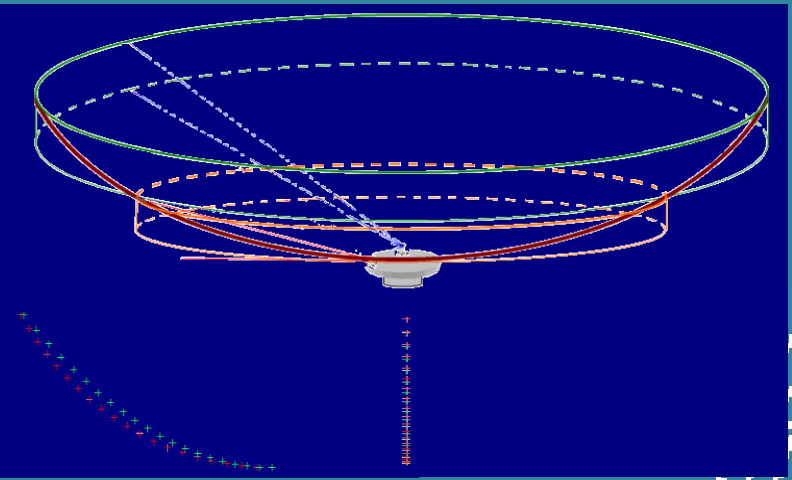


Task 2: profiles of main reflector

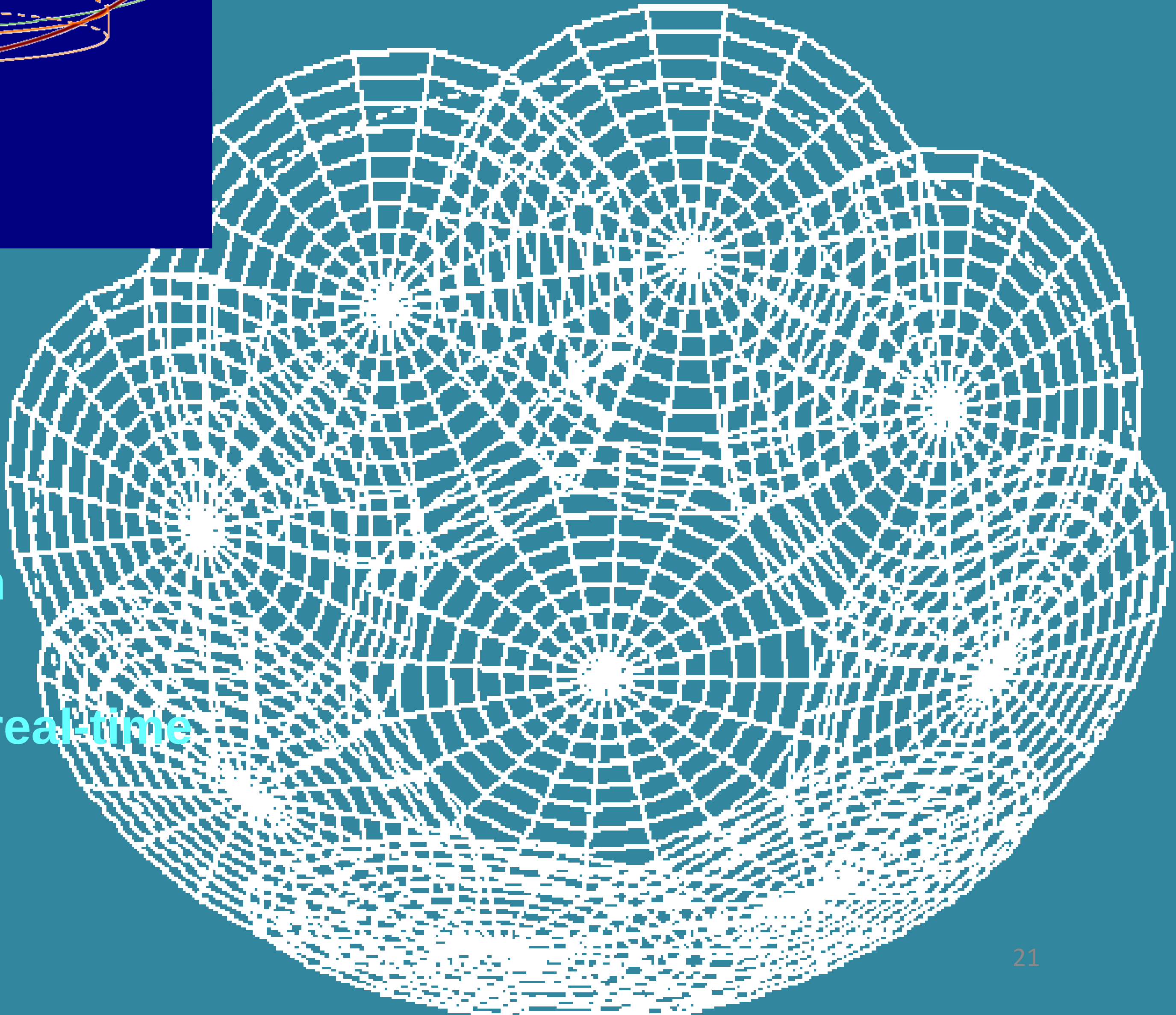
- Number of targets ~2400
- ~1000 in illuminated area
- Accuracy 1~2mm
- Sampling interval 10 sec ~ few min




CCD：20Hz；0.5cm
DGPS：10Hz；1cm
2002/10/10 11:04am
Laser Tracker：1KHz；0.05mm
IMU：0.1°
Measuring
21 10:45 AM
Total station

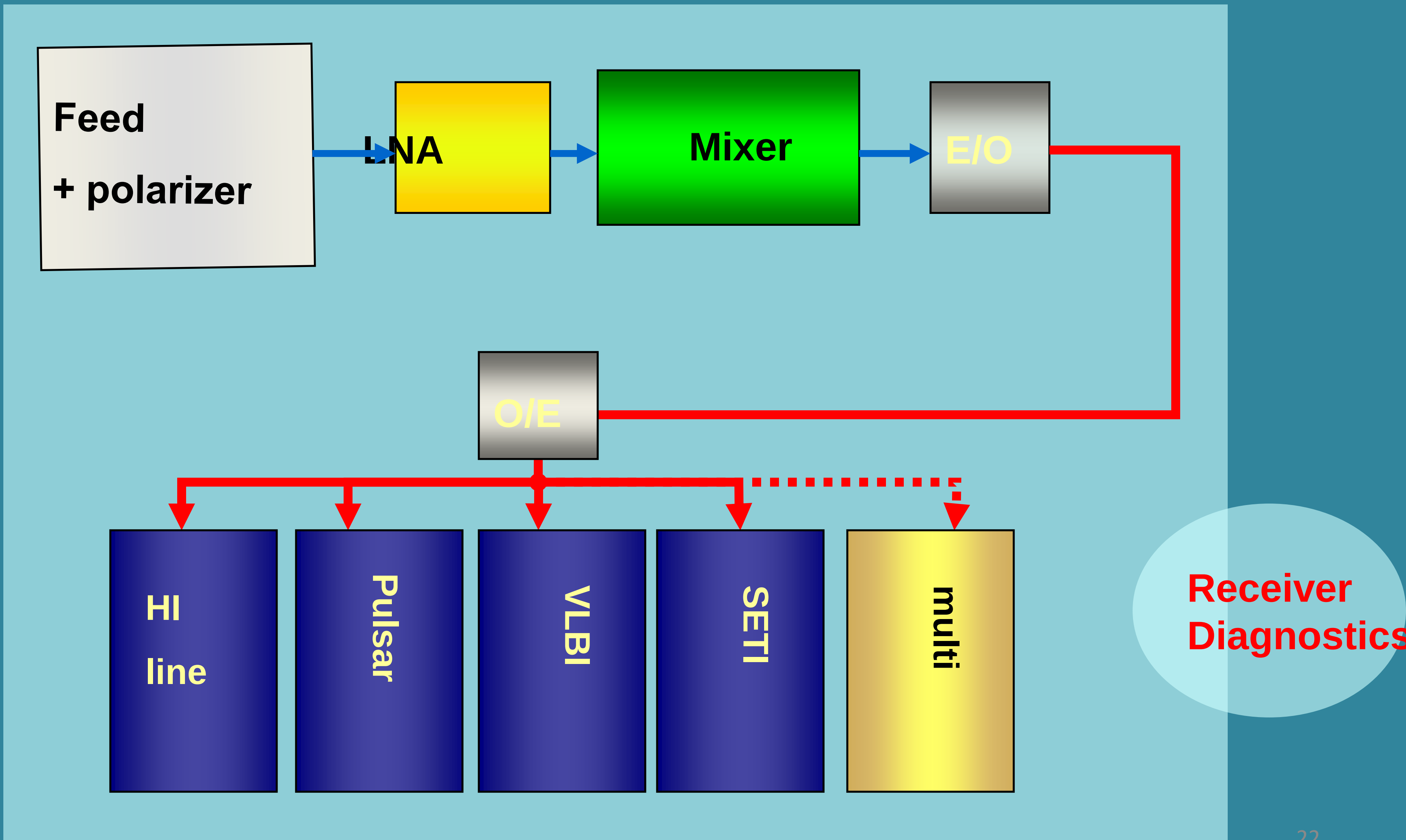


Photogrammetry
Surveying reflector profile



1000 nodes within
illuminated area
to be scanned in real-time
period ~ 1 min

Receiver -- Schematic Diagram



9 sets of FAST receivers NAOC - JBO

No	Band (GHz)	Beams	Pol.	Cryo Tsys(K)	Science
1	0.07 – 0.14	1	RCP LCP	no 1000	High-z HI(EoR),PSR, VLBI, Lines
2	0.14 – 0.28	1	RCP LCP	no 400	High-z HI(EoR),PSR, VLBI, Lines
3	0.28 – 0.56	1 or multi	RCP LCP	no 150	High-z HI(EoR),PSR, VLBI, Lines Space weather, Low frequency DSN
4	0.56 – 1.02	1 or multi	RCP LCP	yes 60	High-z HI(EoR),PSR, VLBI, Lines Exo-planet science
5	0.320 – 0.334	1	RCP LCP	no 200	HI,PSR,VLBI Early sciences
6	0.55 – 0.64	1	RCP LCP	yes 60	HI,PSR,VLBI Early Sciences
7	1.15 – 1.72	1 L wide	RCP LCP	yes 25	HI,PSR,VLBI,SETI,Lines
8	1.23 – 1.53	19 Lnarrow multibeam	RCP LCP	yes 25	HI and PSR survey, Transients
9	2.00 – 3.00	1	RCP/ LCP	yes 25	PTA, DSN, VLBI, SETI

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FAST sciences

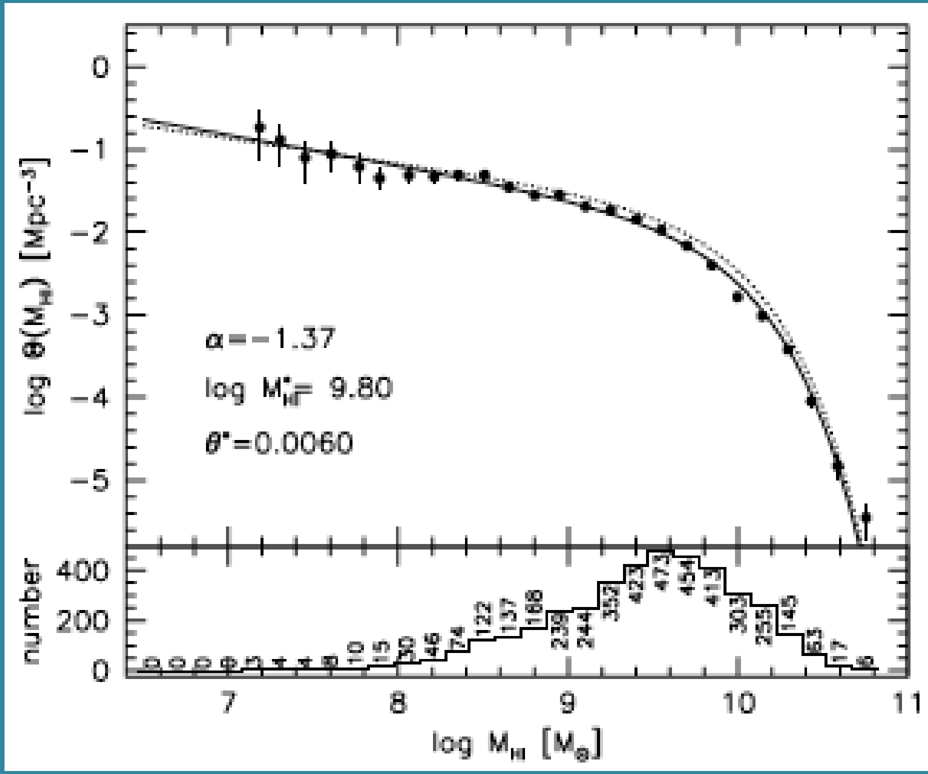
- Neutral Hydrogen line (HI) survey
- Pulsar research
- VLBI network
- Molecular line study (including recombination lines, masers)
- Search for Extraterrestrial Intelligence (SETI)

Key HI Science Questions

- How do the HI properties of low-mass galaxies compare in different environments at z ~ 0?
  – An all FAST sky HI survey
- How is gas accreted from the IGM onto galaxies?
  – Map HI in the cosmic web
- How does the HI content of galaxies change from z = 0 – 1?
  – An HI Deep Field

What are the HI properties of low-mass galaxies at z ~ 0?

- Recent measurements of the HI mass function (HIMF) are based on few to no detections of galaxies with $M_{HI} < 10^7\ M_{\odot}$.
- It is unclear how the slope of the HIMF changes in different environments.
- Need more detections of a wider range of M_{HI} over a larger volume of space.



HIPASS: Zwaan et al. 2005

A FAST all-sky HI survey

- Using a 19 beam L-band receiver, one can map 2.3π sterradians FAST sky at 20 sec per beam in under 4000 hours.
- This will yield about 3 million detections with $M_{HI} < 10^{11}$ $M_{\odot}$ out to z ~ 0.15 in a range of environments including Virgo, Coma, Hydra, Ursa Major clusters and Shapley supercluster plus neighboring voids.
- About 2000 detections will have $M_{HI} < 10^{7}$ $M_{\odot}$ with D < 15 Mpc.
- The number of detections is an order of magnitude larger than expected for any planned surveys with Arecibo or ASKAP.

Duffy et al **Number of galaxies to be detected per day (18h) using FAST 19 beams with different san range**

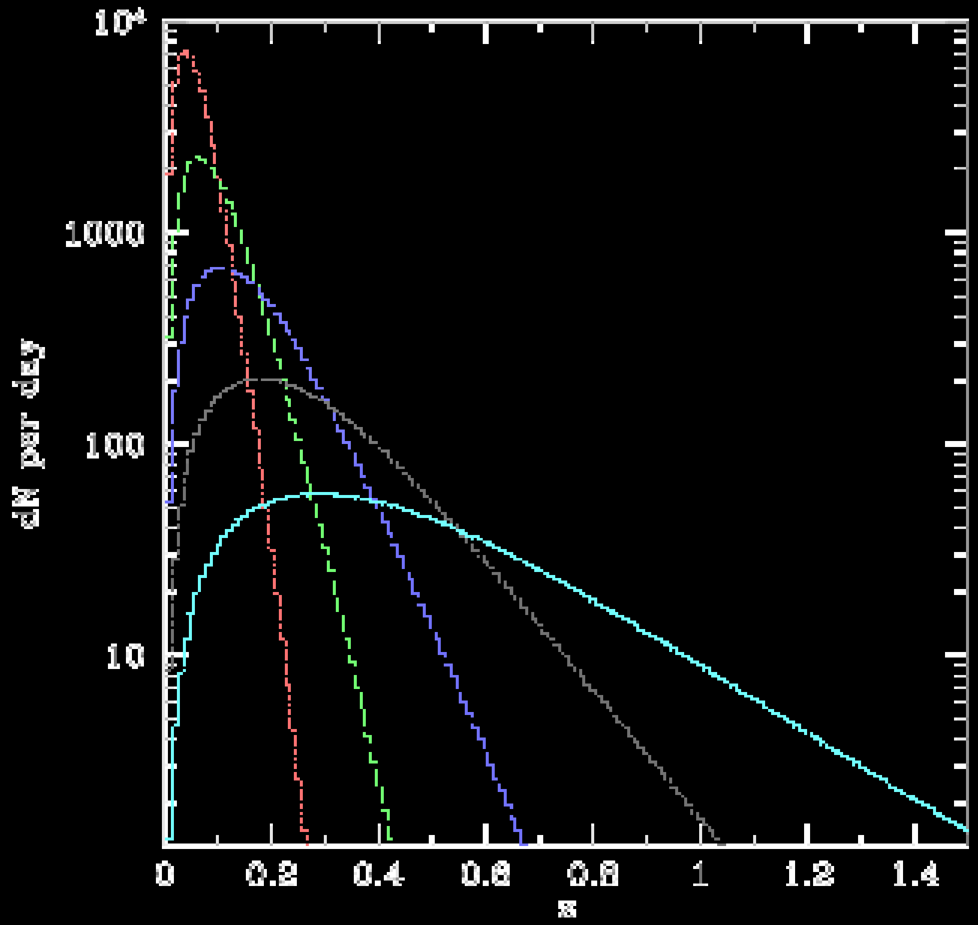
---- 6 sec

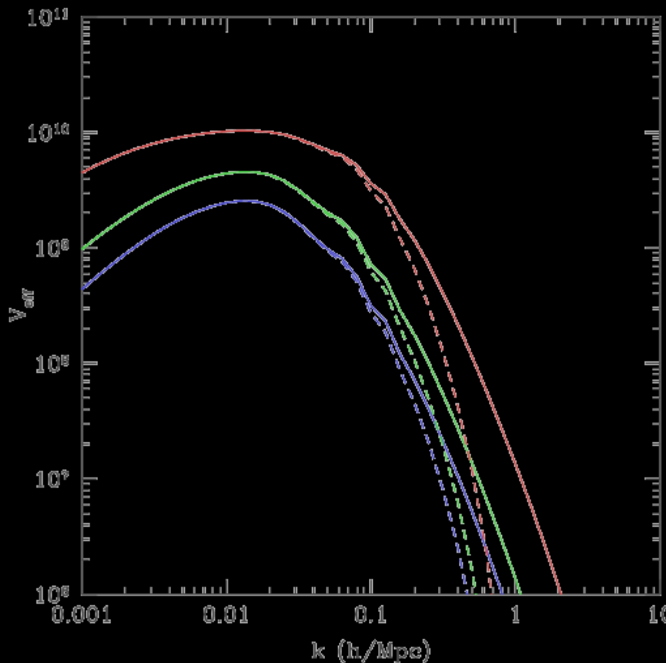
---- 60 sec

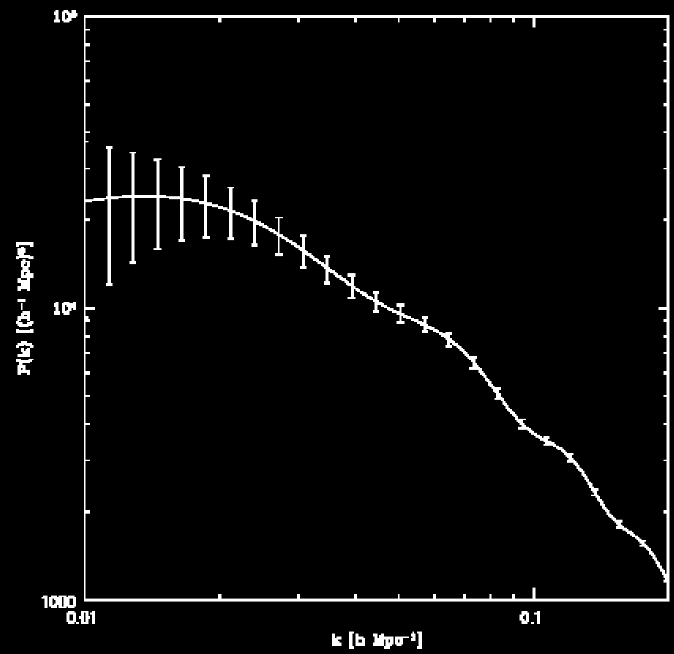
---- 600 sec

---- 6000 sec

---- 60000 sec







Xuelei Chen V_{eff} **vs scale ¼ sky coverage survey by FAST**

---- 6 s 44 days

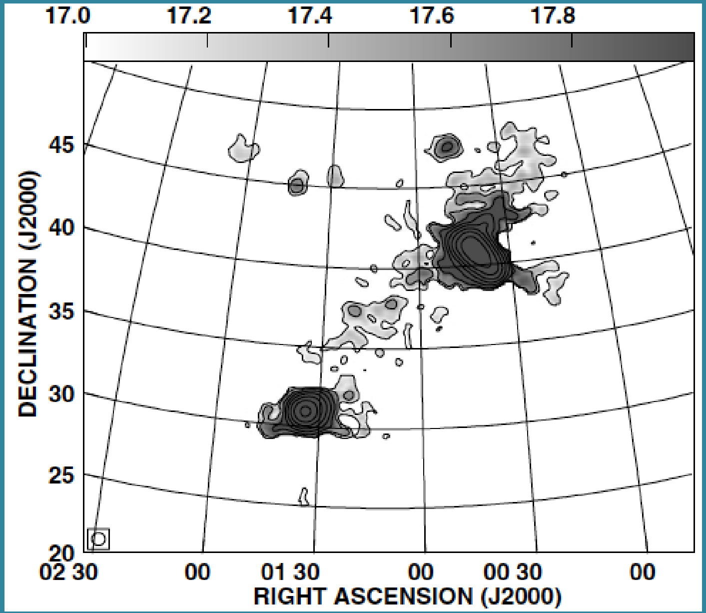
---- 12 s 88 days

---- 1 min 440 days

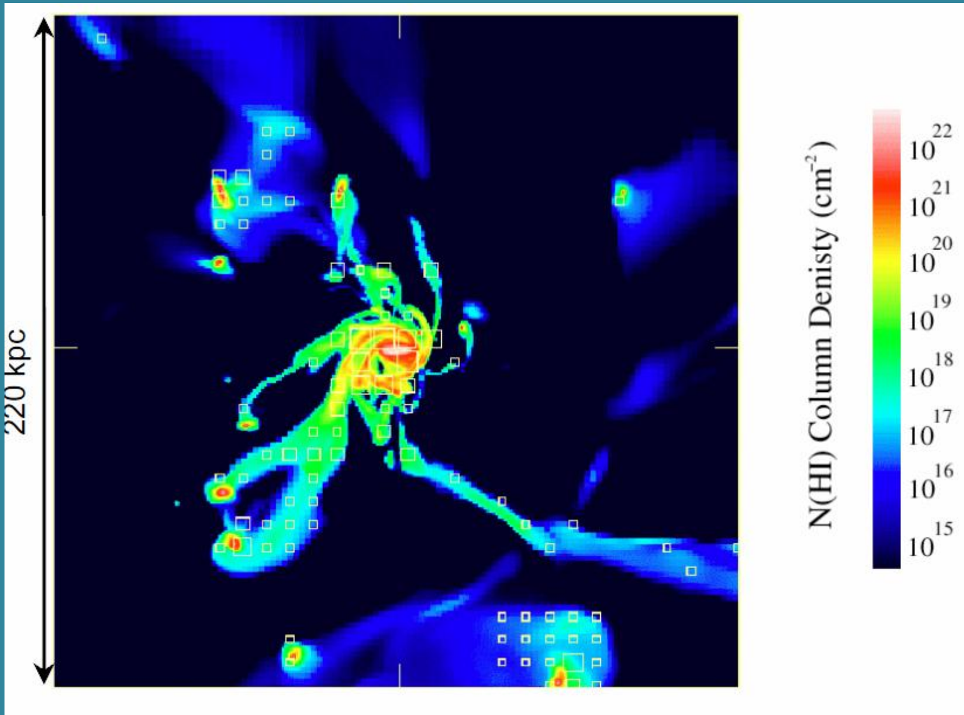
Duffy et al

How is gas accreted from the IGM onto galaxies?

- Is the low N_{HI} gas seen around M 31 and M 33 fuel for star formation being accreted from the “cosmic web” or is it indicative of past tidal interactions?
- We need to map this HI around many galaxies in different environments to determine origin.

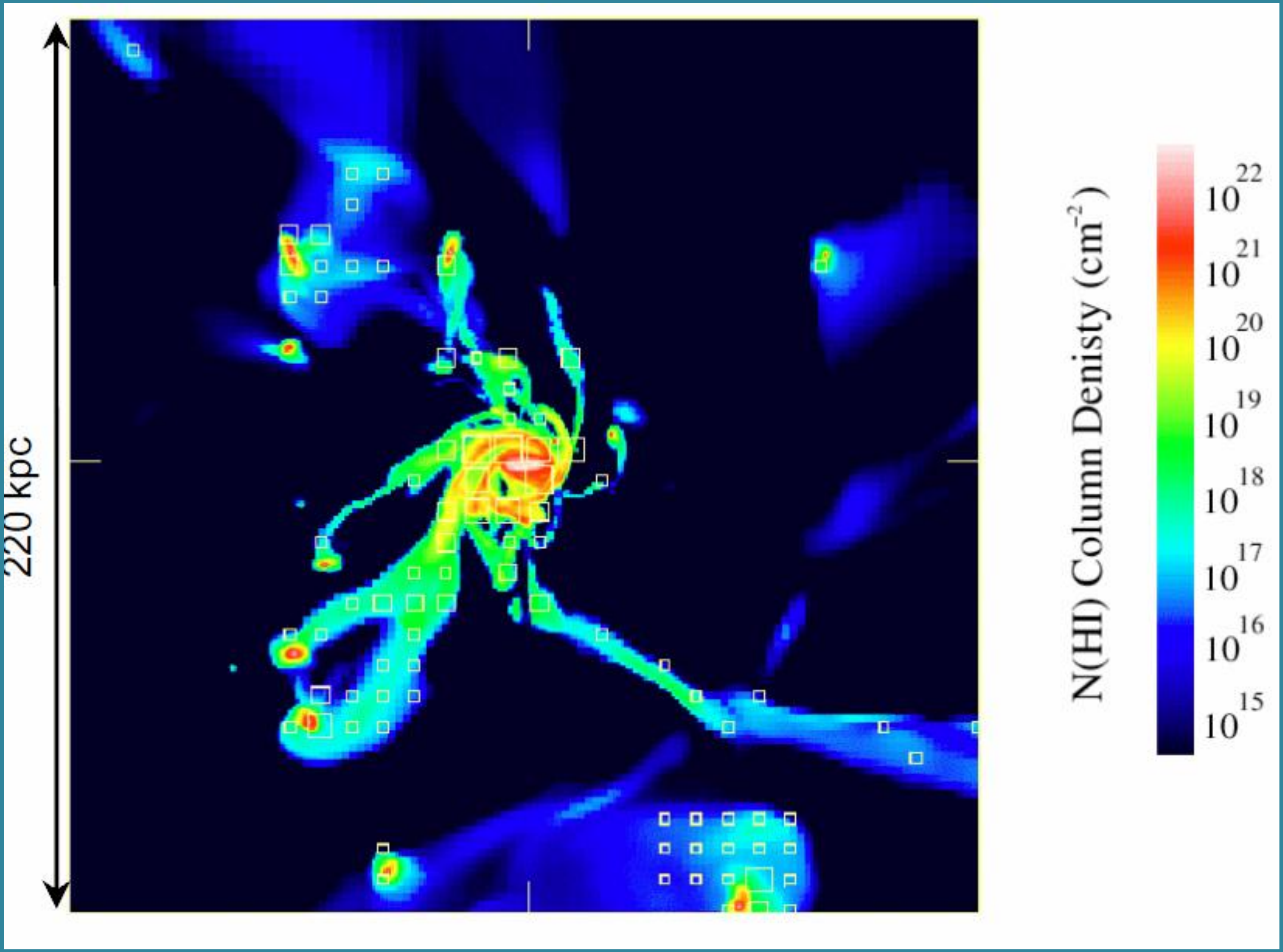


Braun &Thilker 2004

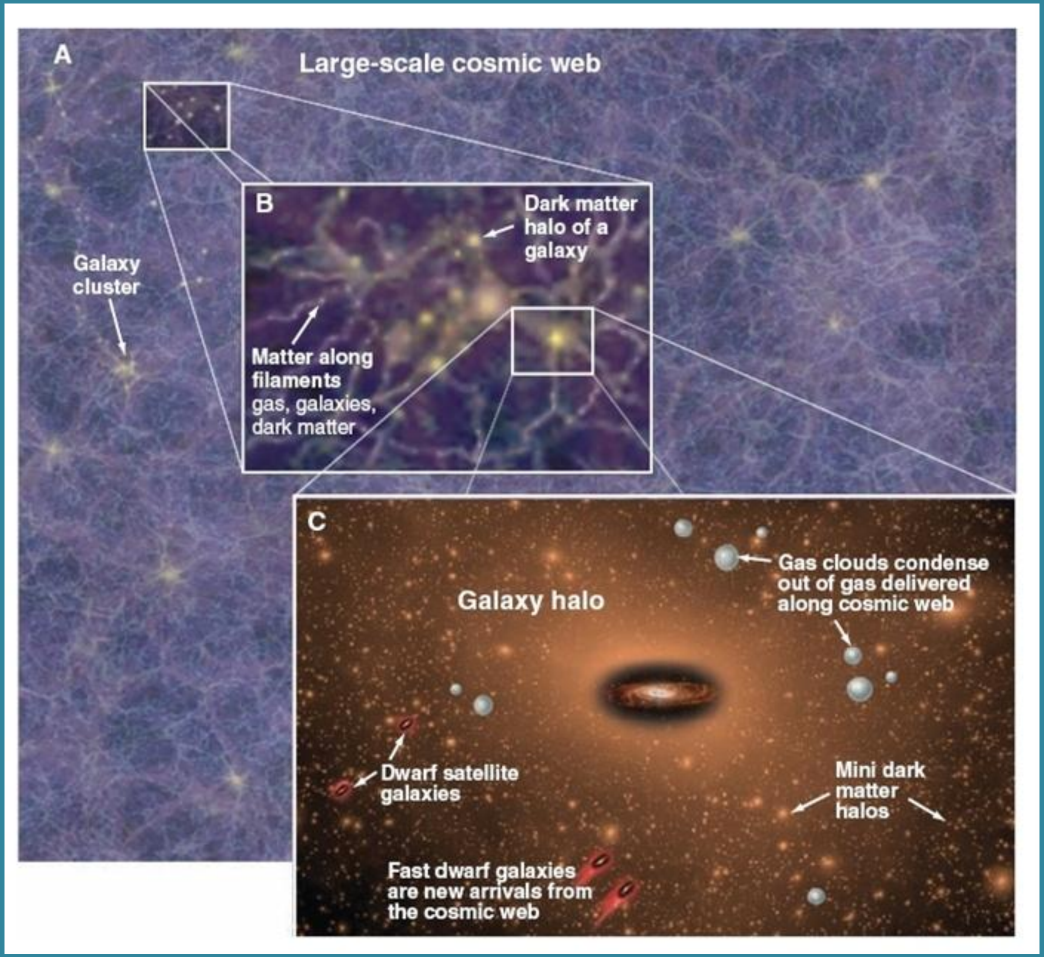


ΛCDM COSMOLOGICAL GALAXY SIMULATIONS

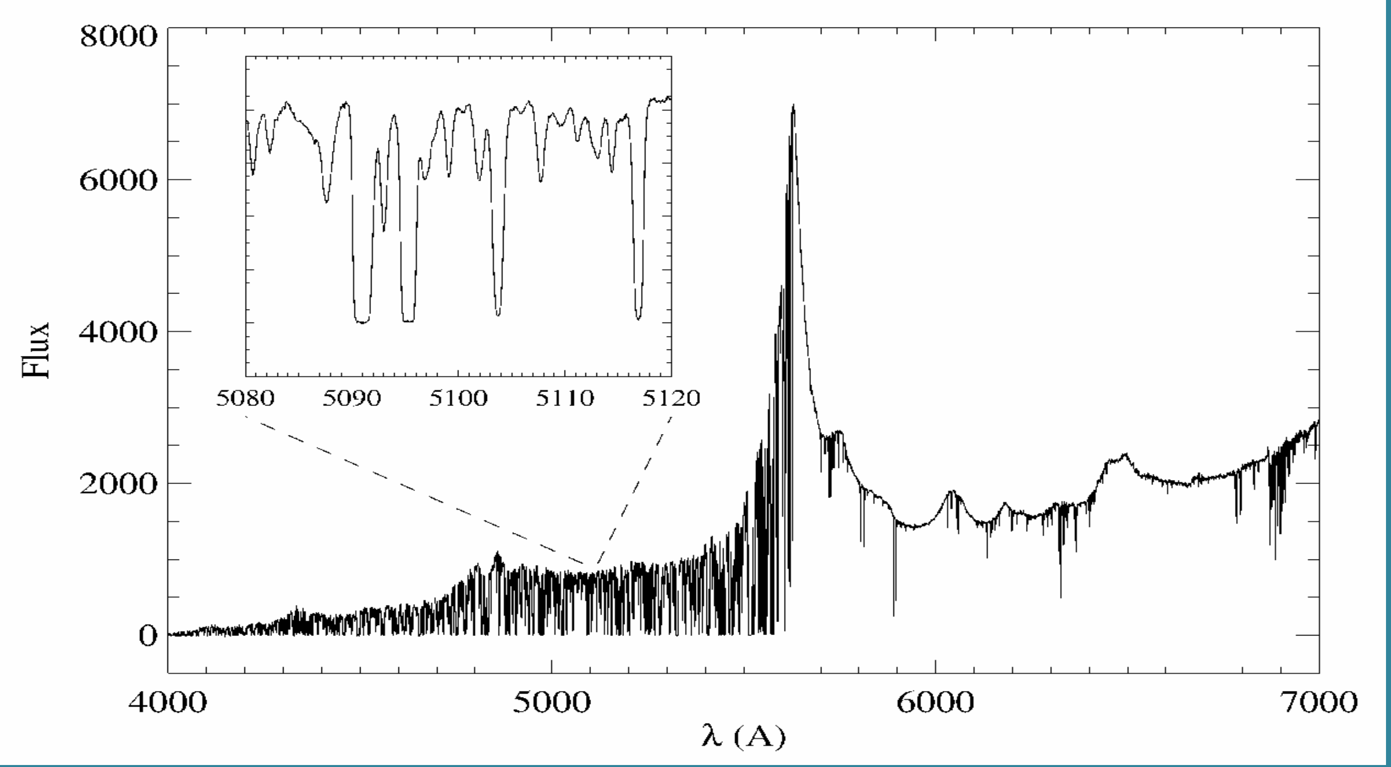
Kacprzak et al. 2010



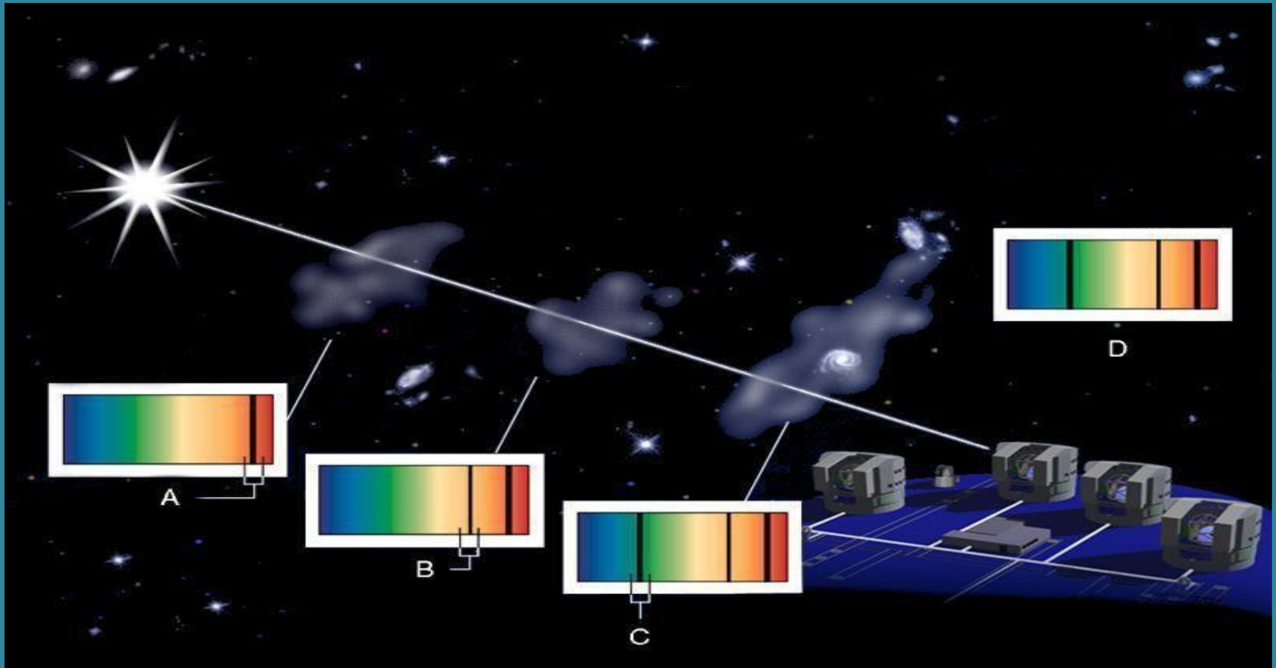
Cosmic web



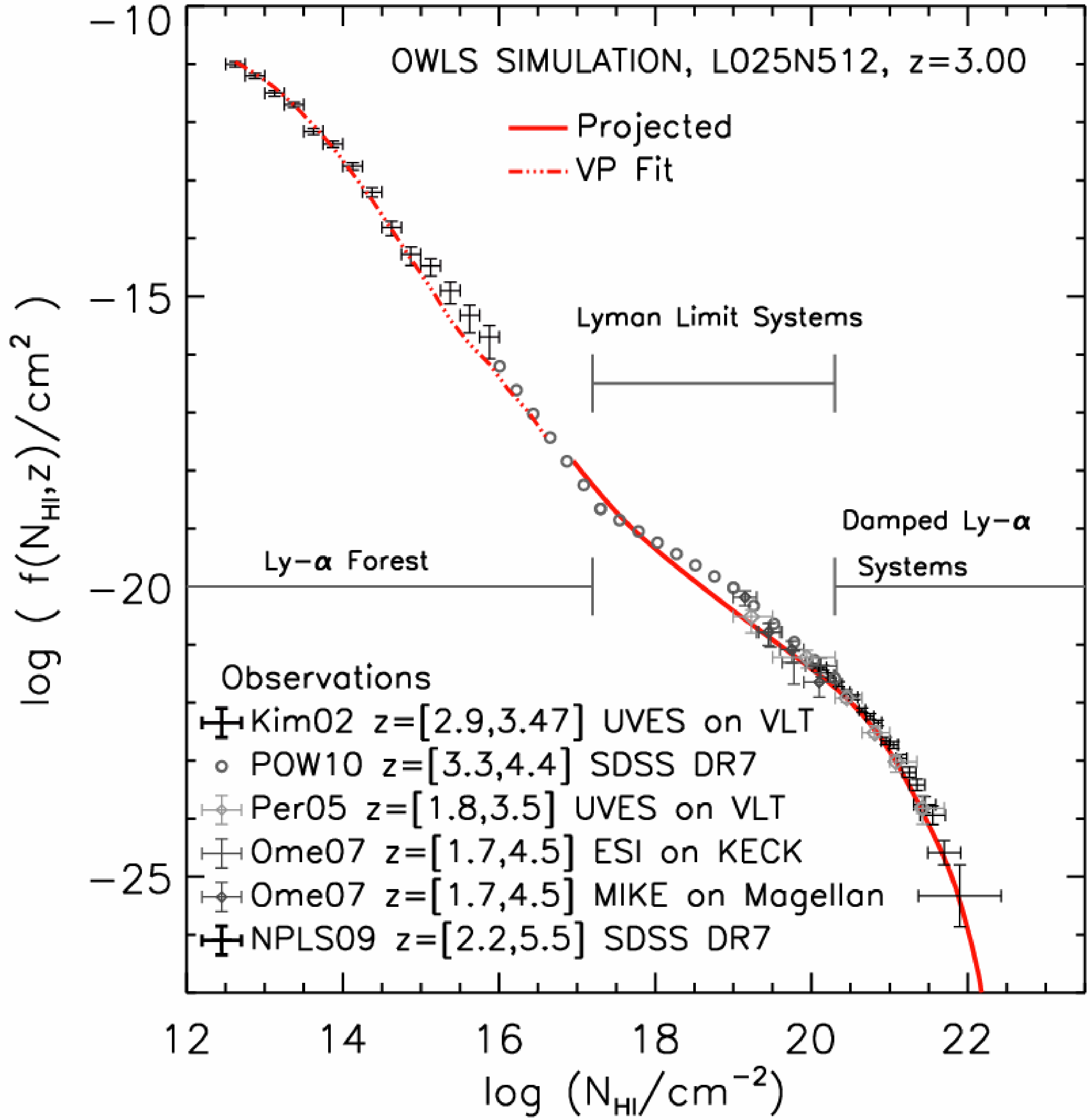
Ibata and Lewis (2008) Sciences 319, 50



8000
6000
4000
2000
0
Flux
5080
5090
5100
5110
5120
4000
5000
6000
7000
λ (A)

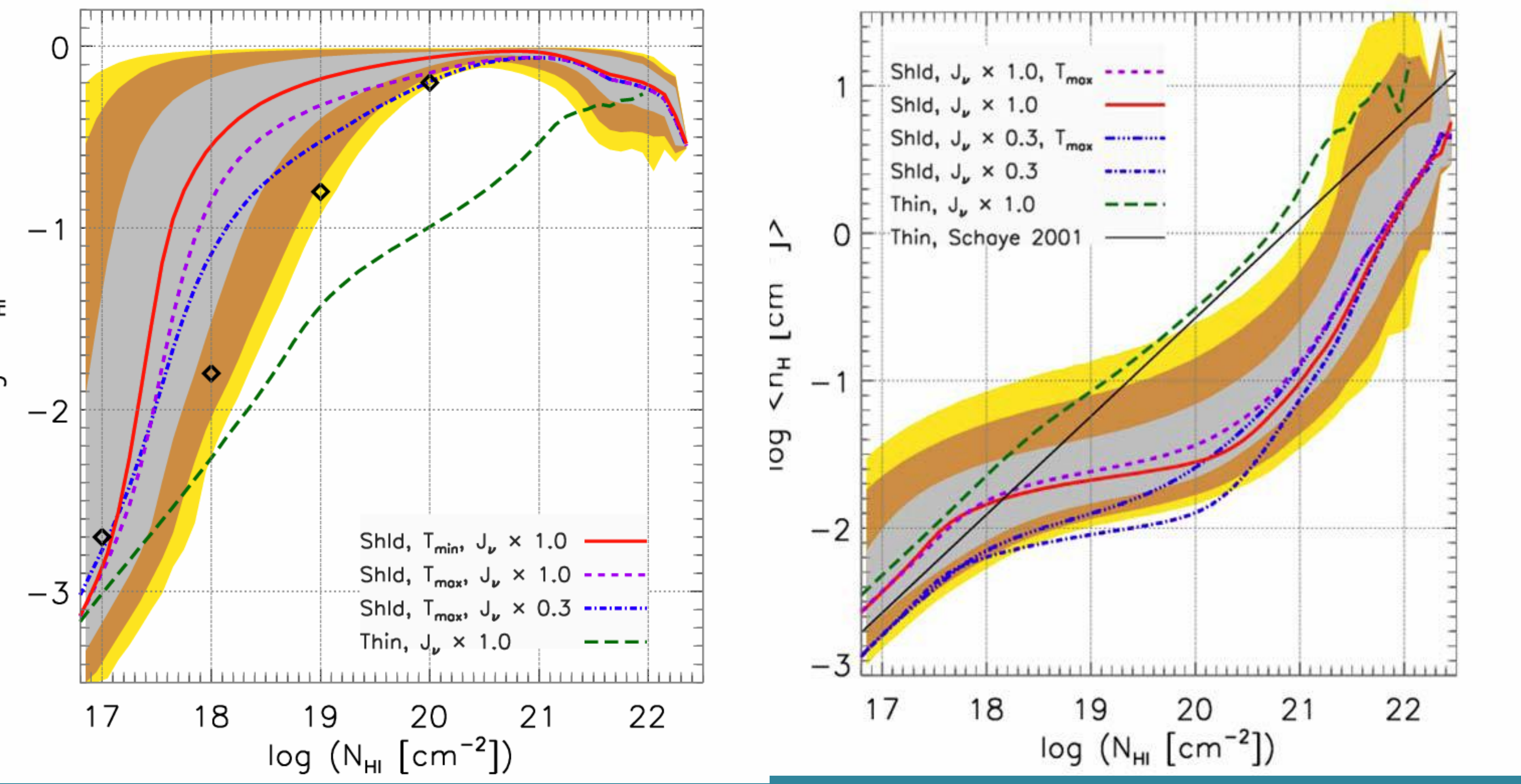


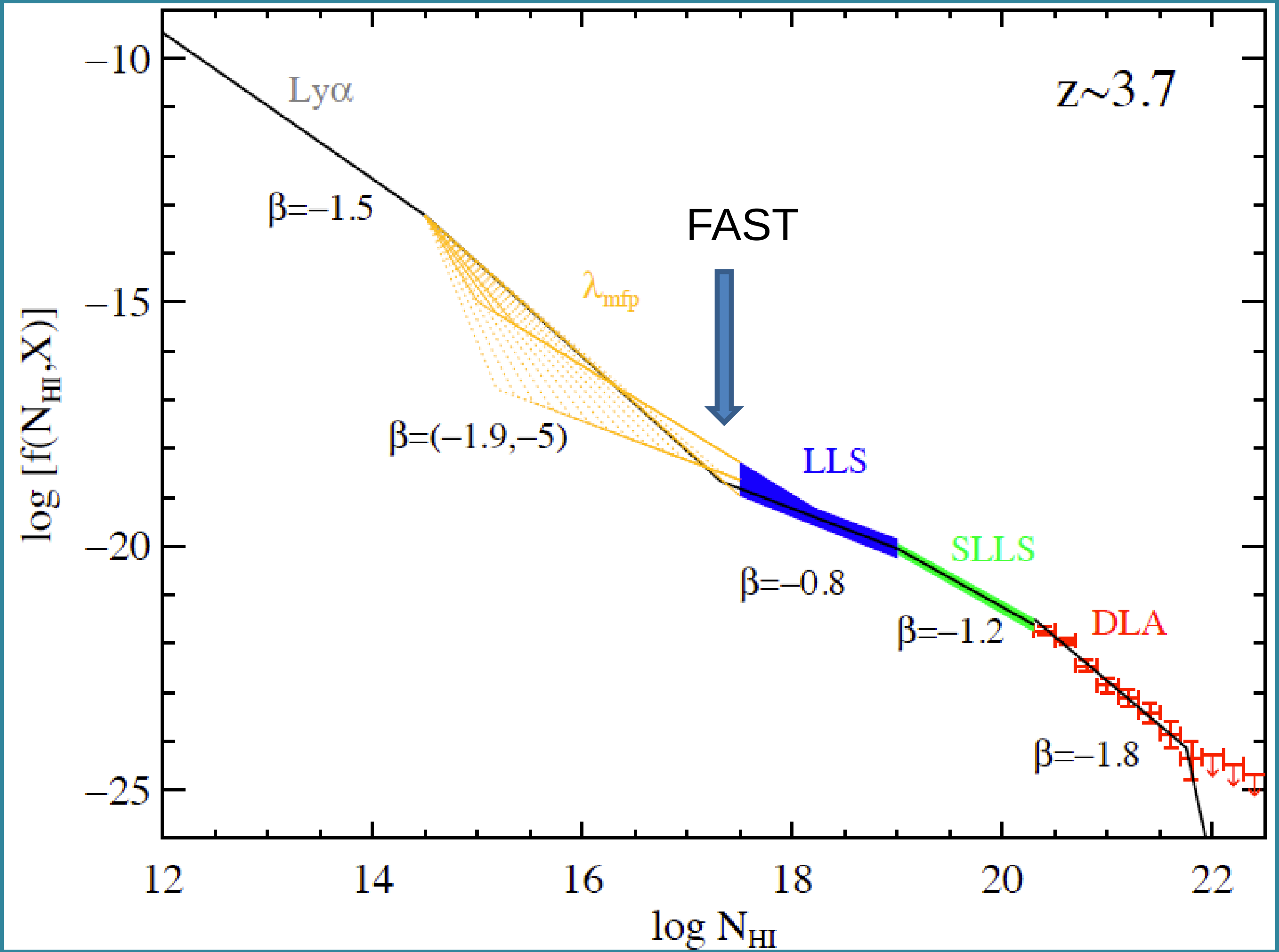
A
B
C
D



OWLS SIMULATION, L025N512, z=3.00
Projected
VP Fit
Lyman Limit Systems
Damped Ly−α
Systems
Ly−α Forest
Observations
Kim02 z=[2.9,3.47] UVES on VLT
POW10 z=[3.3,4.4] SDSS DR7
Per05 z=[1.8,3.5] UVES on VLT
Ome07 z=[1.7,4.5] ESI on KECK
Ome07 z=[1.7,4.5] MIKE on Magellan
NPLS09 z=[2.2,5.5] SDSS DR7
−10
−15
−20
−25
12
14
16
18
20
22
log (f(N_HI,z)/cm²)
log (N_HI/cm⁻²)

Volume density vs. N(HI) and neutrual factoin vs. N(HI)





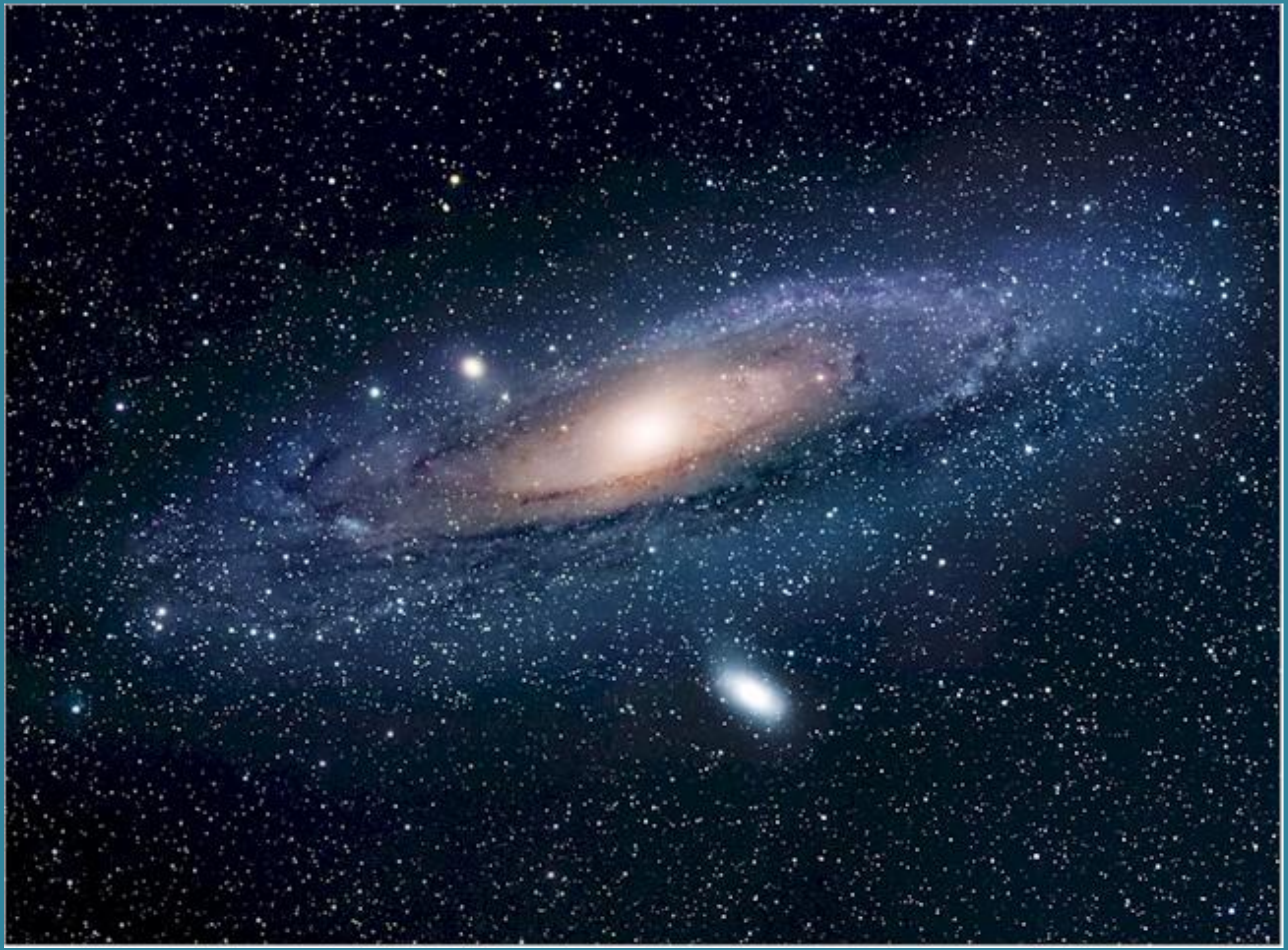
WALLABY:
NHI~2x10^19 cm-2
DINGO deep:
NHI~2.6x 10^18 cm-2
DINGO u-deep:
NHI~1.2x10^18 cm-2

Prochaska et al. 2010

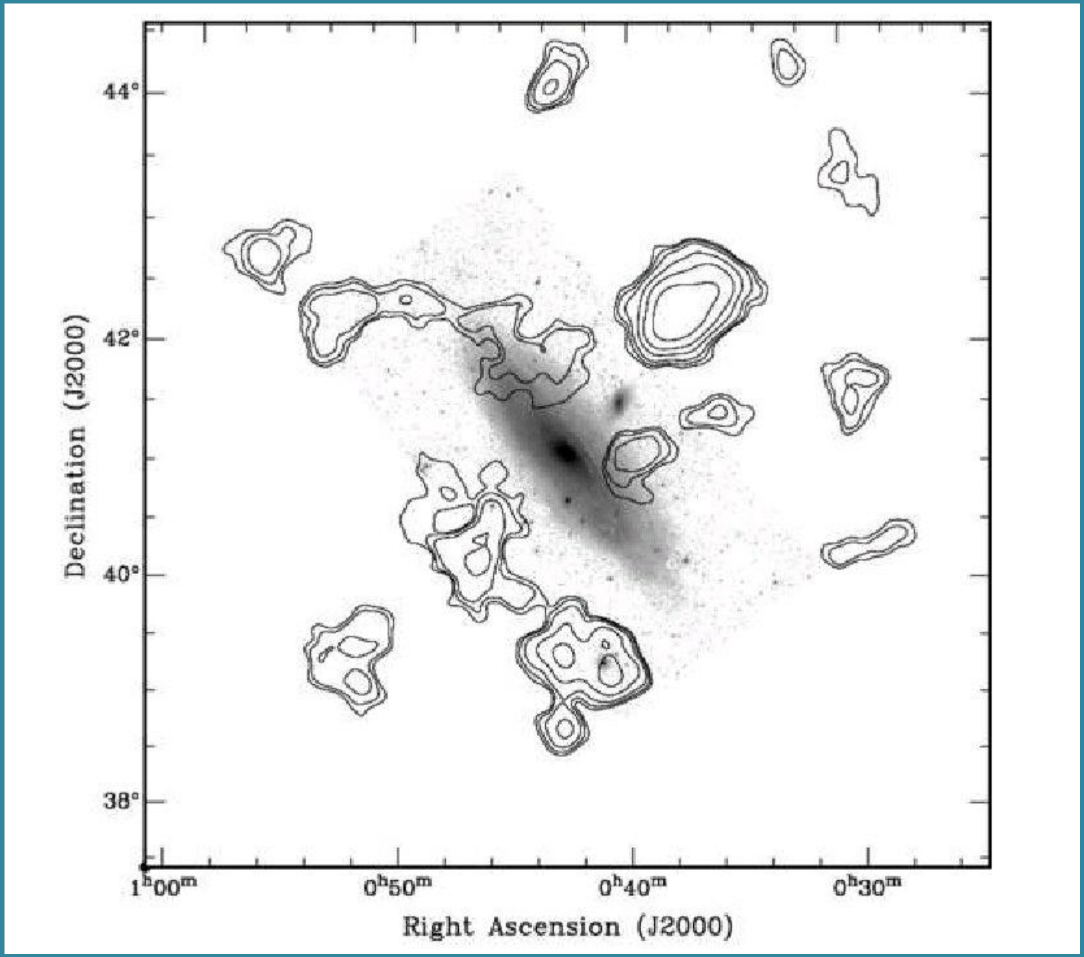
Proposed Survey 2

- To map a 4 square degree area, with an integration time of 10 minute per beam, in 10 hours we can reach a 3σ sensitivity of 1.5×10^{17} cm^{-2} per 2.1 km/s channel.
- The beamsize of FAST has the same linear extent as the GBT at 3x the distance. T_{sys} is better than Arecibo.
- Select regions of different environments,
  - void, big galaxies, clusters …

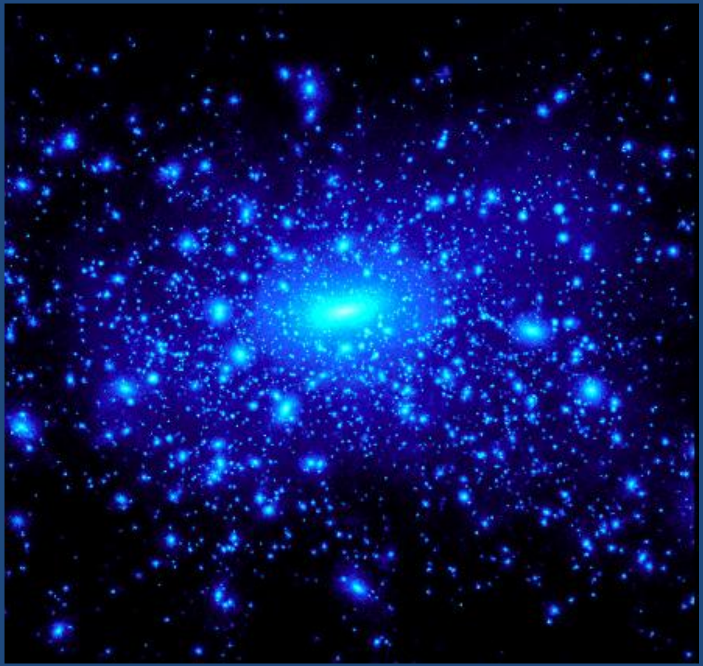
M31

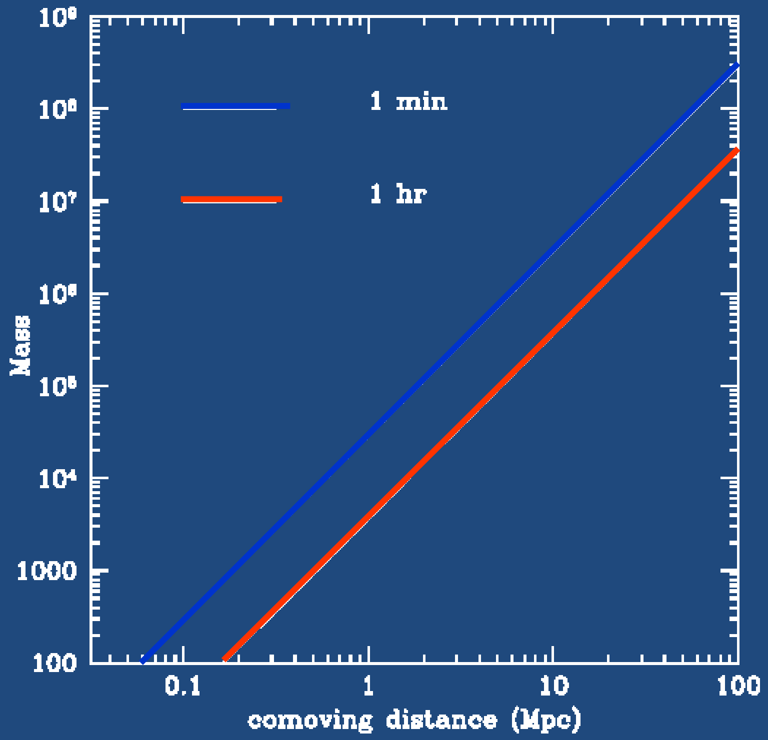


HI map of M31



Braun & Thilker 2003



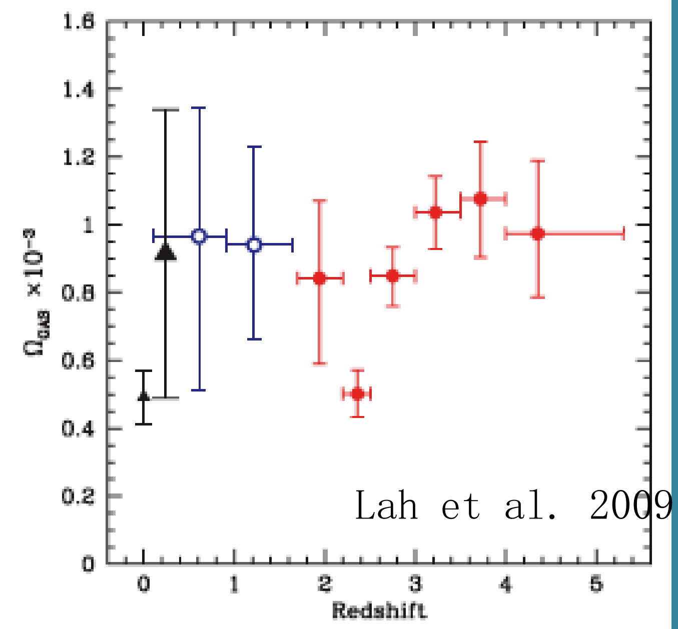


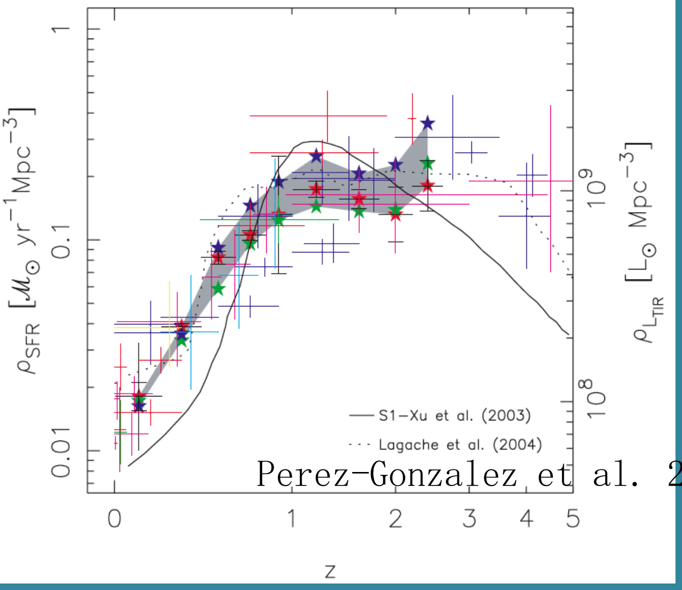
Kravtsov - Simulation on dark matter distribution in a normal galaxy

Xuelei Chen – Estimated FAST detection sensitivity of 1 min & 1 h
Line width 30km/s,S/N -10

How does HI content evolve from z = 0 – 1?

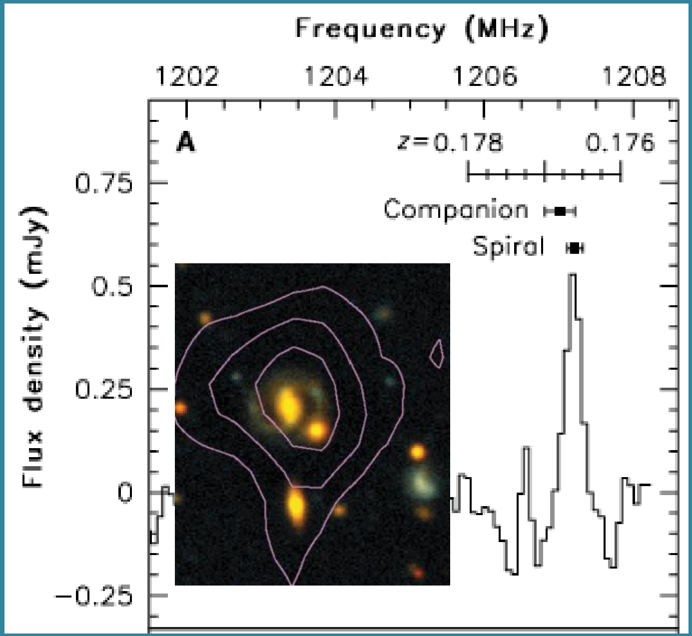
- Studies of Damped Lyman α absorbers show Ω_{HI} is roughly flat with z, but SFR increases by factor of 10x to z = 1. How do we reconcile these trends?
- Most distant HI-rich galaxies detected at z ~ 0.2 (Zwaan et al. 2001, Verheijen et al. 2007, Catinella et al. 2008).
- Stacking has detected HI statistically at z ~ 0.37 (Lah et al. 2007, 2009).
- 21 cm intensity mapping of a large-scale filament with the GBT produced a detection at z ~ 0.8 (Chang et al. 2010).
- Gravitational lensing may also help in detection of individual galaxies.

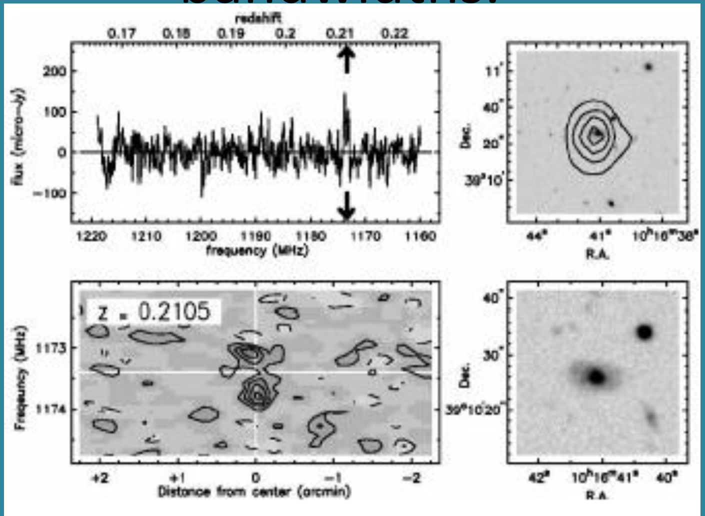


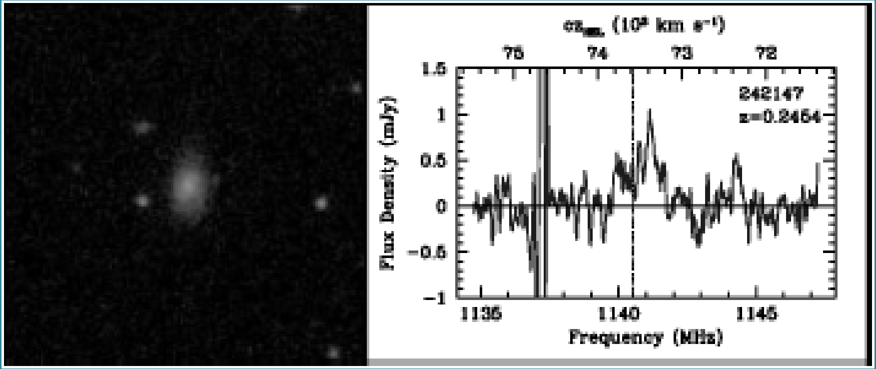


HI emission at z~ 0.2

The most distant individual detections of HI emission are at z ~ 0.2 by Zwaan et al. (2001), Verheijen et al. (2007), and Catinella et al. (2008) using WSRT and Arecibo. These are limited by sensitivity and receiver bandwidths.

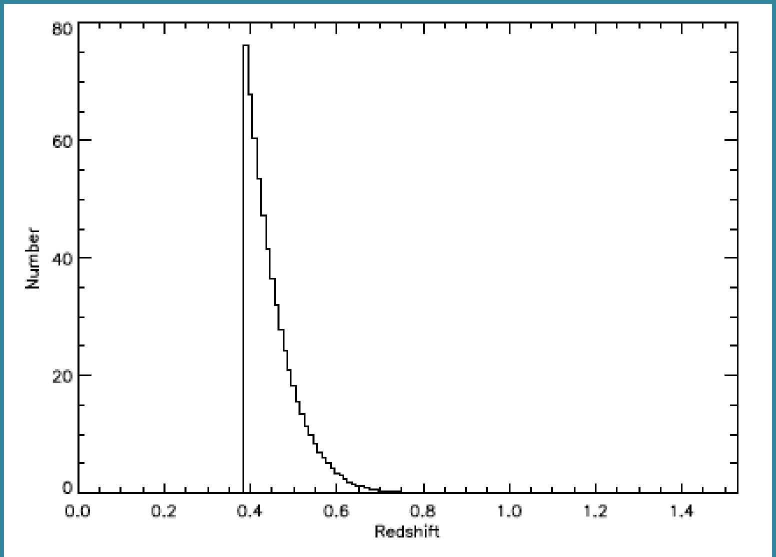


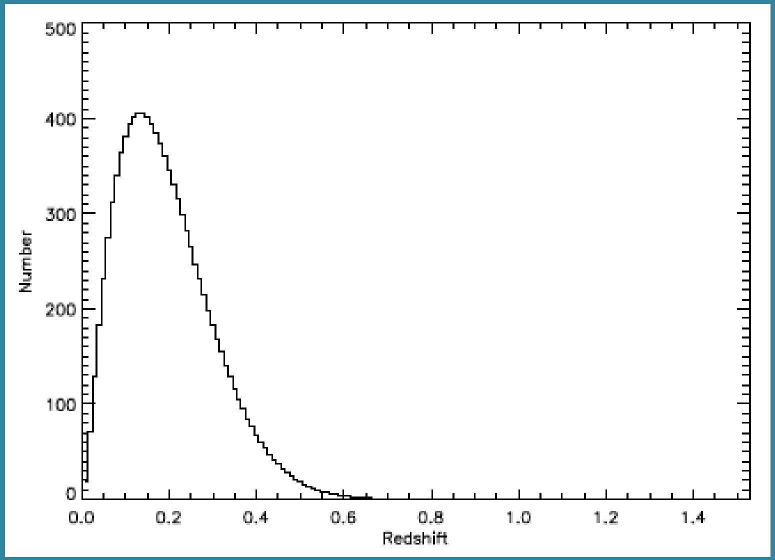




An HI Deep Field

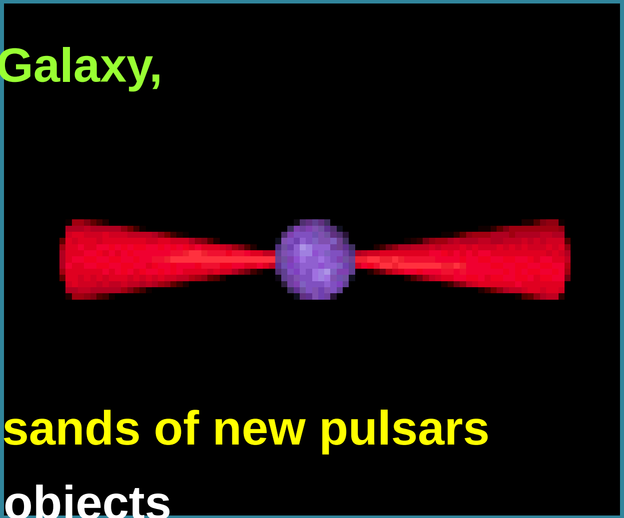
- A survey of a 1 square degree region with a single pixel receiver at 40 hours per beam will take about 5000 hours.
- The survey could detect 10000 galaxies at $z \leq 0.66$ in a wide range of environments. This is twice the number of galaxies that the planned SKA pathfinder deep fields expect to have.

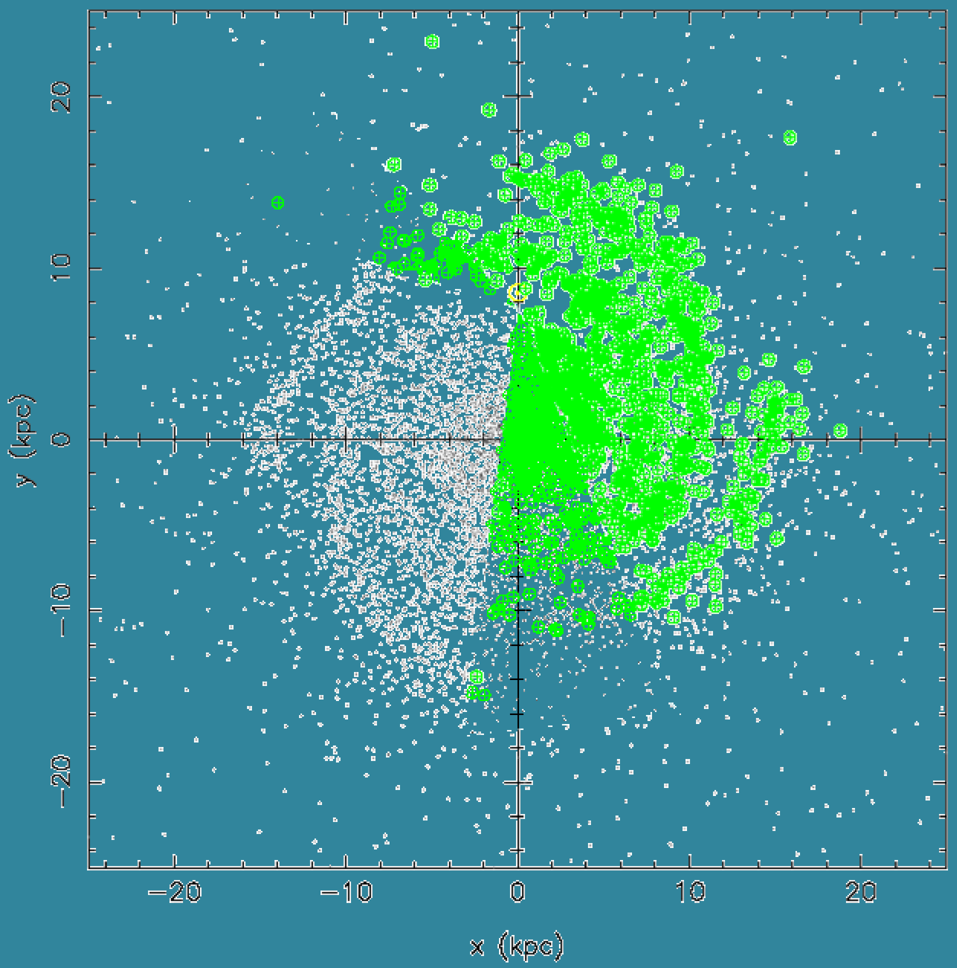




FAST Pulsar Survey

There are ~ 2 X 10^4 detectable pulsars in the Galaxy, half is in FAST sky

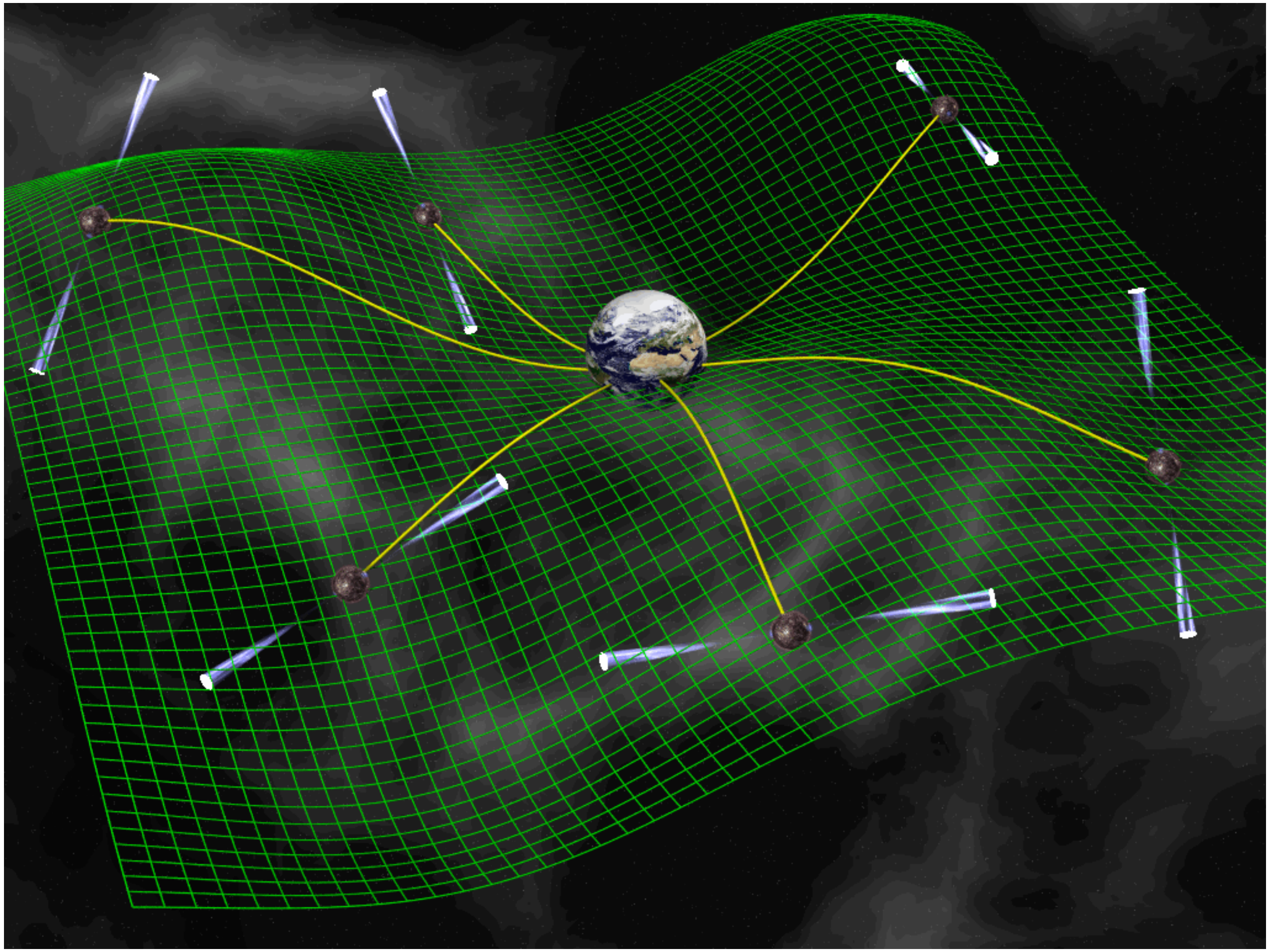




~ Thousands of new pulsars

- **Rare objects**
  Exotic stars – quark matter
  Pulsar-BH binary
  ….
- **Stellar evolution before SN**
- **ISM map of unprecedented details**

Pulsar timing arrays to detect long-wavelength gravitational waves



Telescope requirements: Sensitivity at low frequencies and Sky Coverage

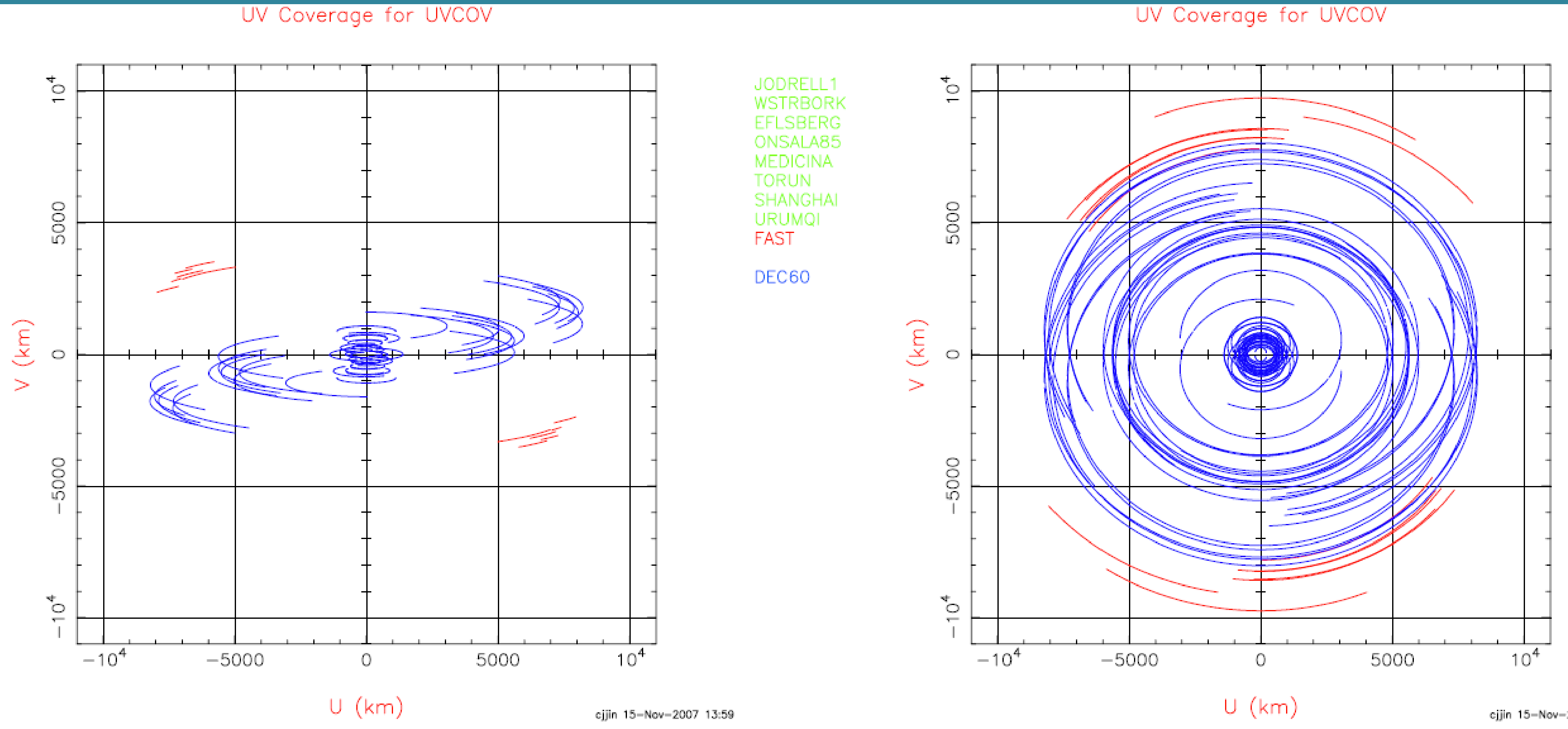
Sensitivity at low frequencies

- Collecting area (FAST wins easily)
- System noise temperature (Must have good receivers)
- Bandwidth (Must have good pulsar backends)
- Available tracking time (Arecibo < FAST < GBT)

Sky Coverage

- Declination range (Arecibo < FAST < GBT)
- Instantaneous field of view for surveys $SS \propto (N\ \Omega)\ \Delta\nu (A\ /\ T)^2$

The simulated uv-coverage of EVN+FAST for sources of Declination 10 and 60 degree



Search for binary SMBH

- Galaxy mergers yield inspiraling, binary, and recoiling black holes that may be detectable with high resolution VLBI search for off-nuclear and binary SMBHs

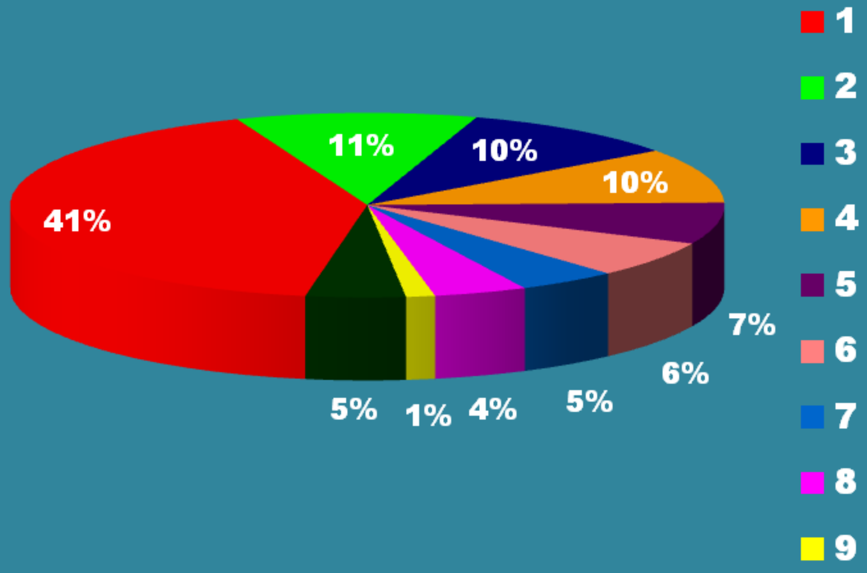
- FAST+VLBI

Current status of FAST project

Total budget ~ 688 millions ¥

Construction started in March 2011, earthwork are expected to completed in Sept 2012

First light expected in 2016



- Eartwork- Main reflector
- Feed support
- Receivers
- Measurement and control
- Infrastructures
- Design
- Observatory and facilities
- Site exploration
- Contingency

Summary

- FAST has very high sensitivity and large coverage of the northern sky
- Good for searching for weak signals, low surface density structures
- FAST has the potential to make great contribution to HI and pulsar studies and VLBI observations

- First light expected in 2016

Website: fast.bao.ac.cn