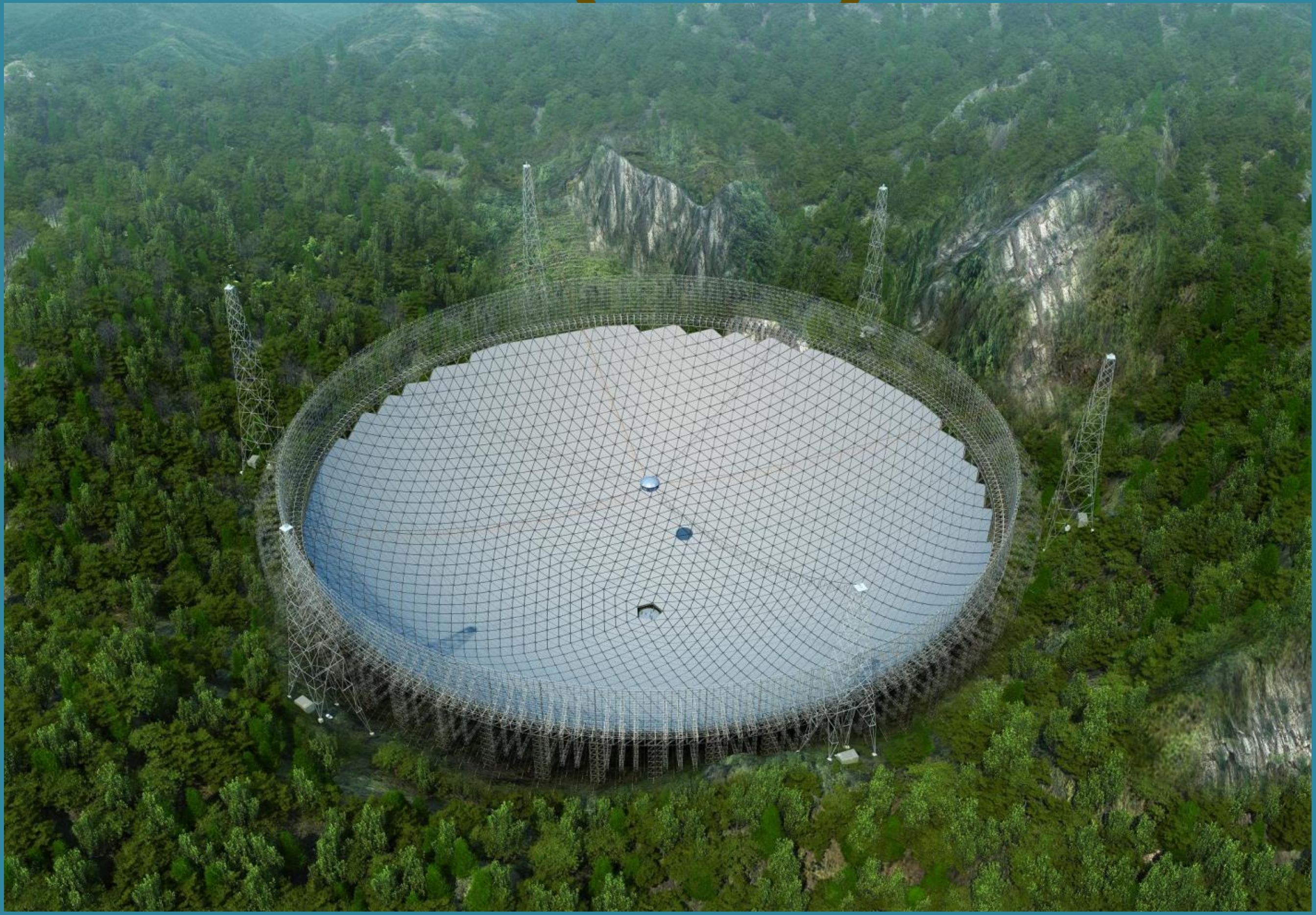
HI survey with the Future FAST Telescope
Five hundred meter Aperture Spherical radio Telescope



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

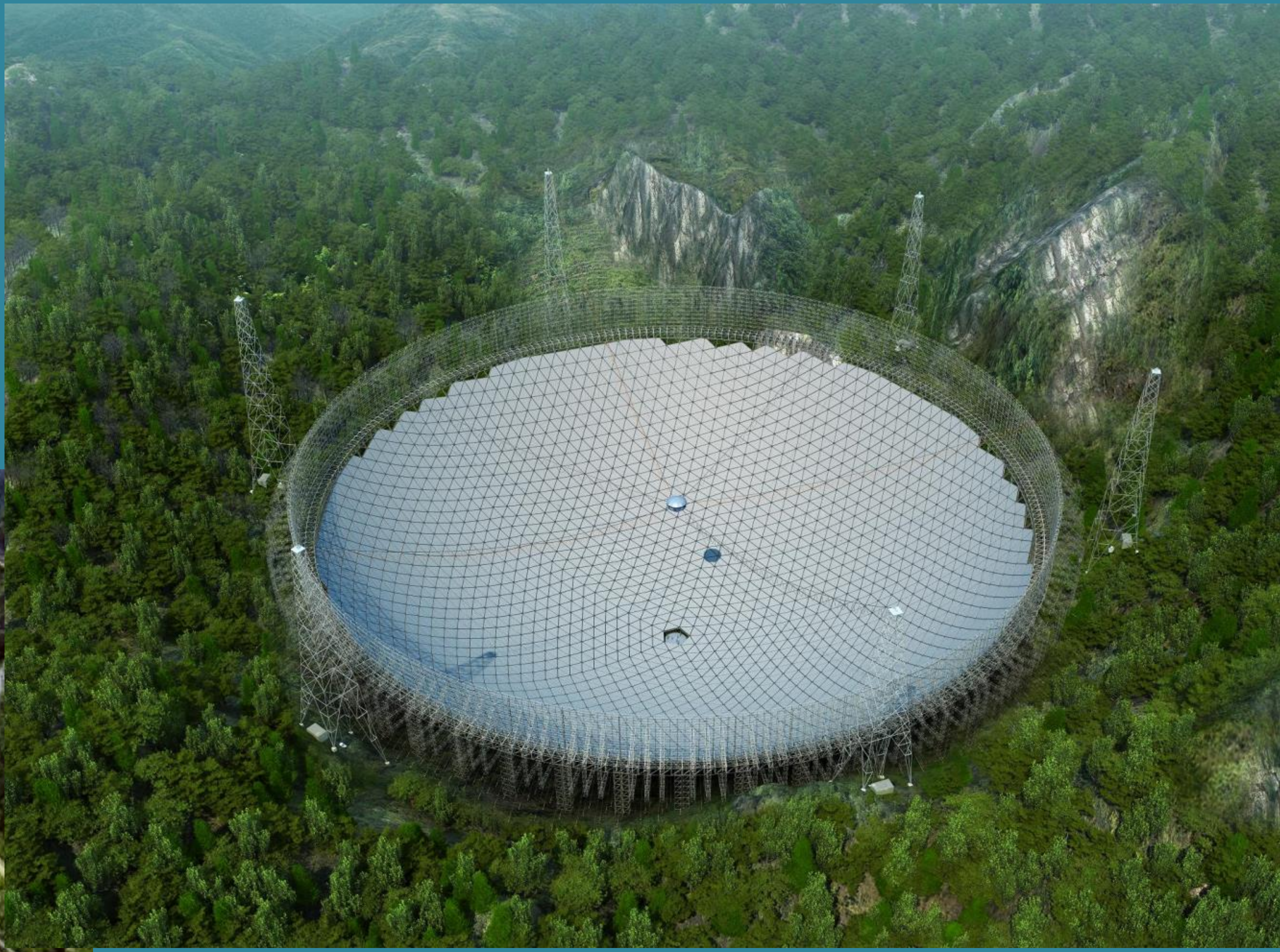
2013 June 20

FAST Science Group

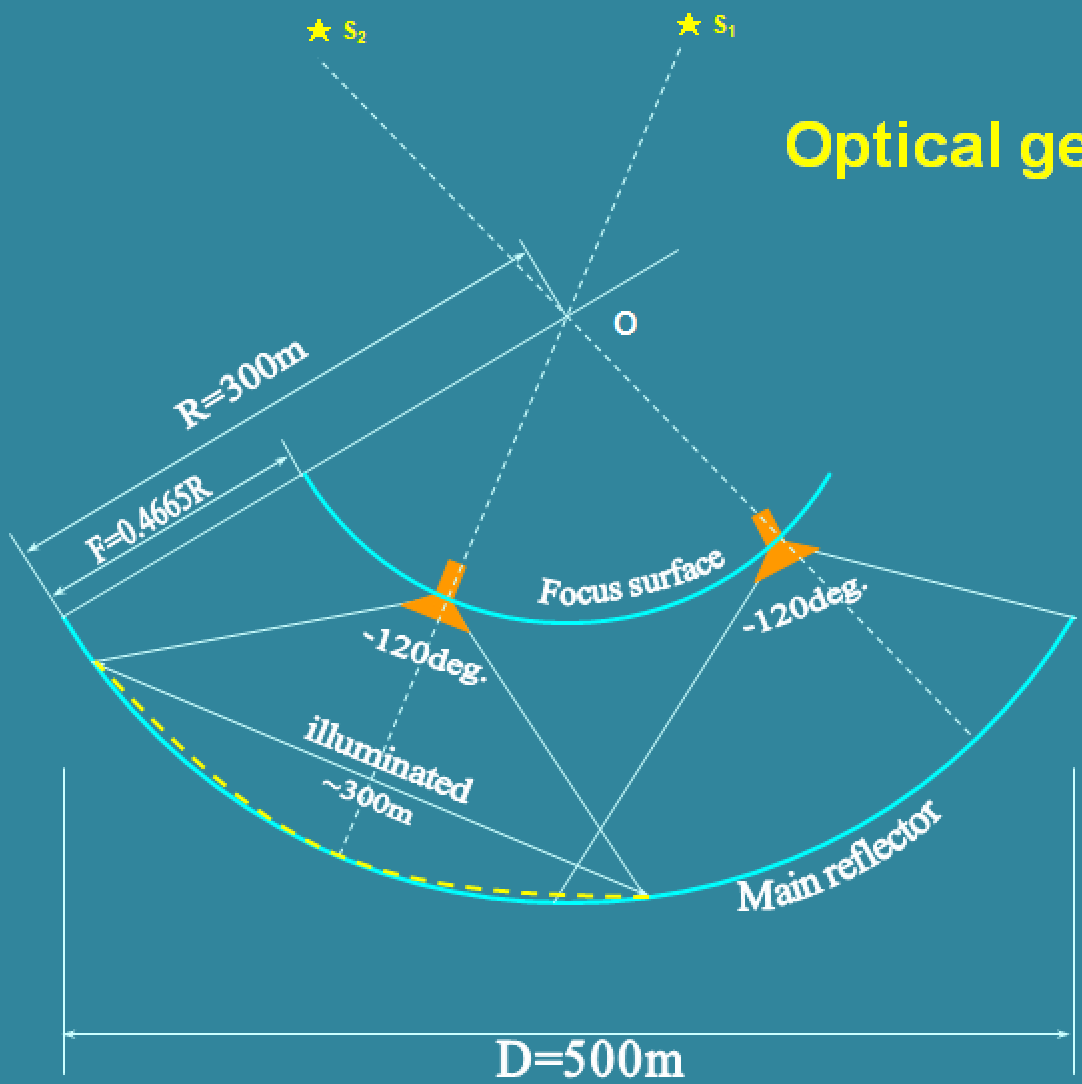
- HI survey—galaxy and cosmology
  - Ming Zhu, Li Xiao, Rurong Chen + students
- HI survey of the Milky Way, Molecular Line study
  - Lei Qian , Huixian Li + students
- Pulsar survey
  - Youlin Yue, Chenmin Zhang + students
- Data reduction system

Five hundred meter Aperture Spherical Telescope

- Unique Karst depression as the site
- Active main reflector
- Cable driving receiver cabin--light weight



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

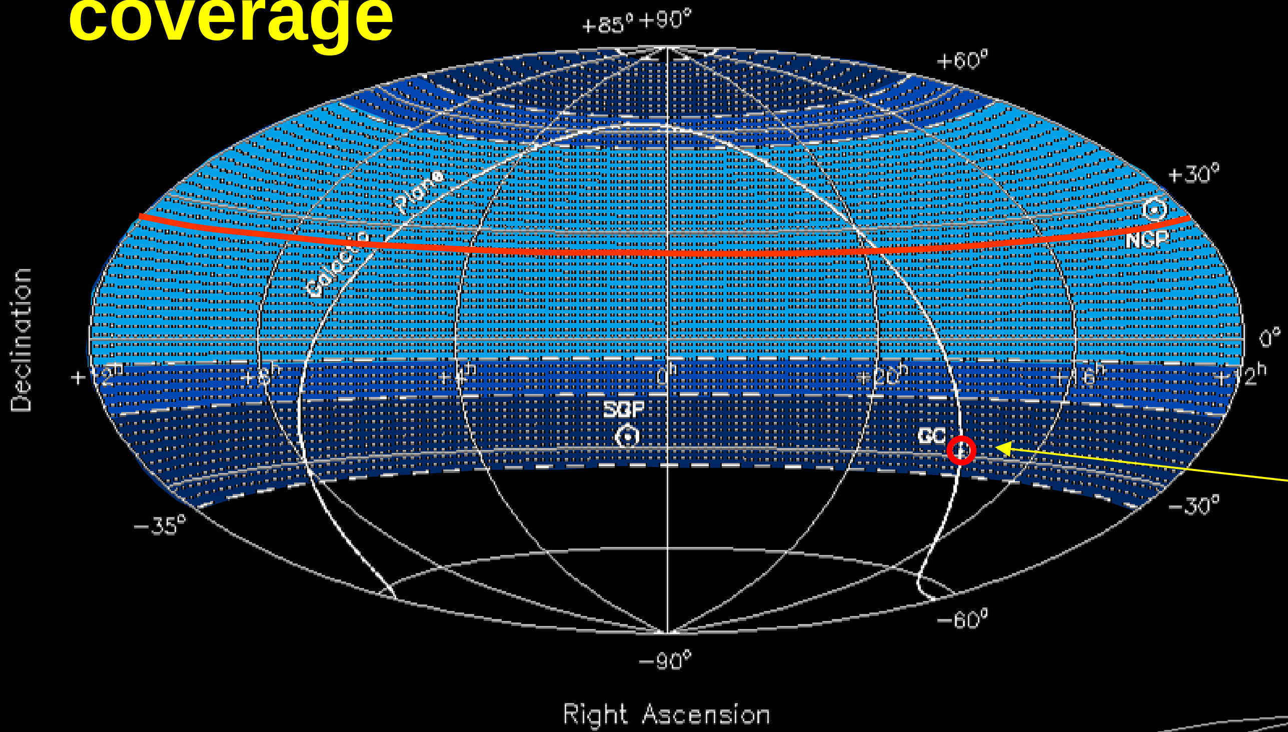
Resolution (L-Band)：2.9′

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

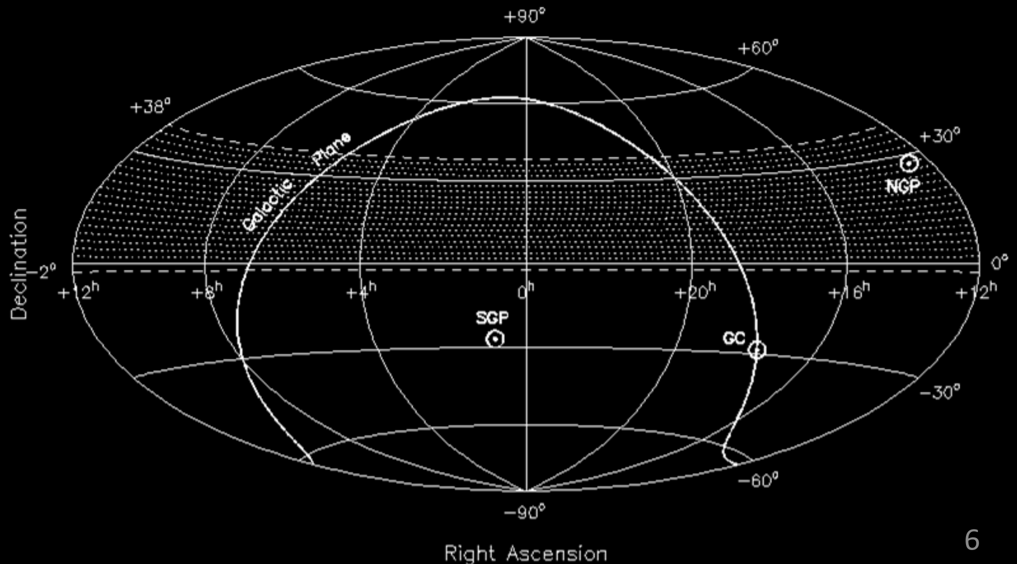
ZA 60 deg

FAST Zenith

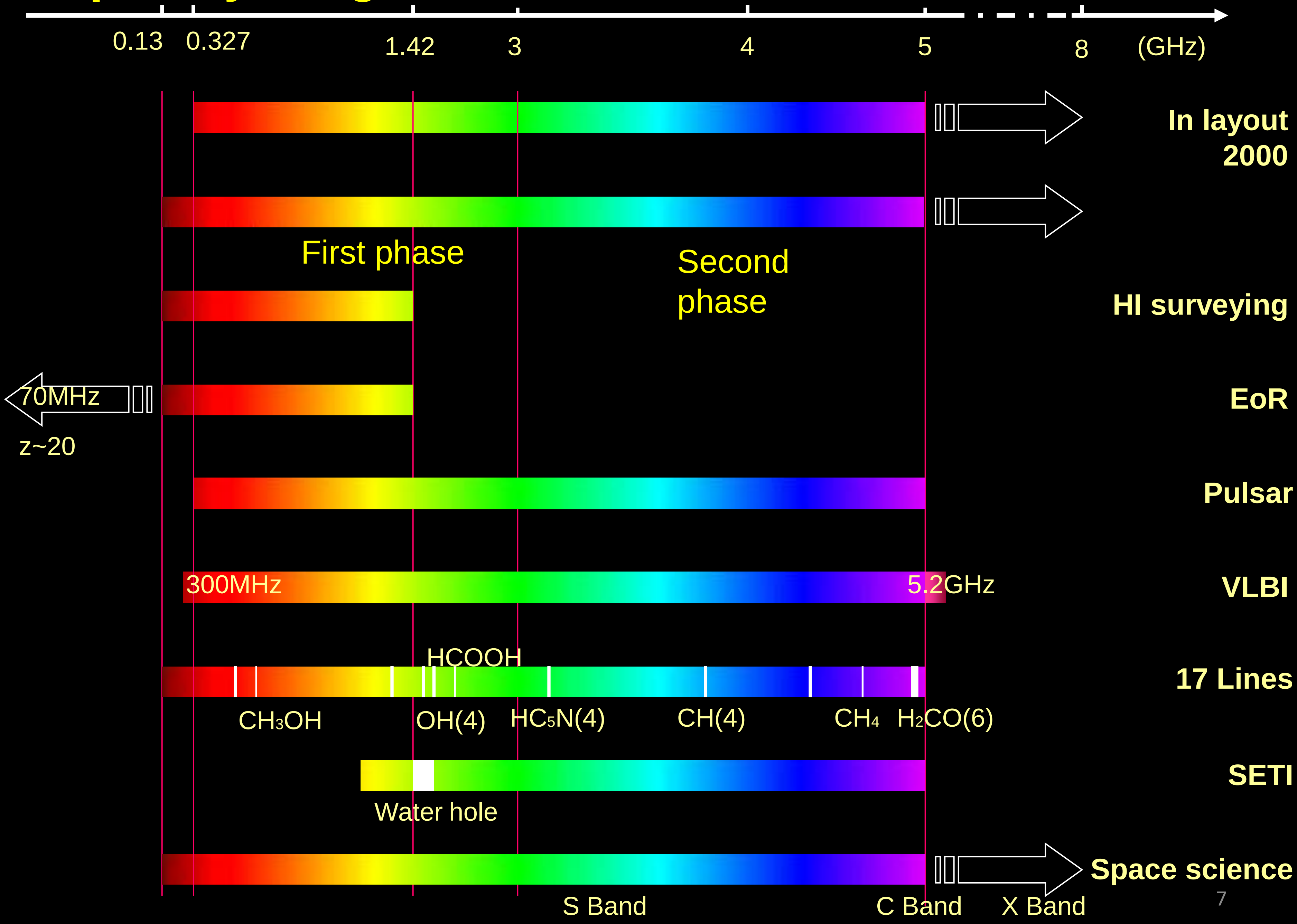
ZA 56 deg

Sky coverage

FAST vs. Arecibo



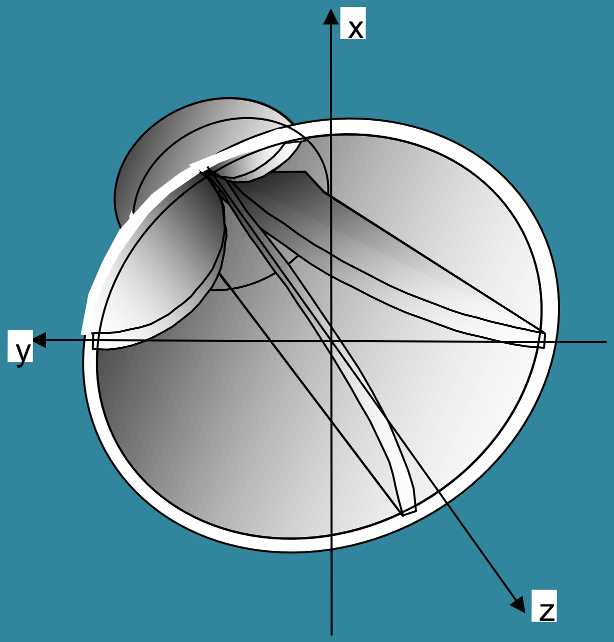
Frequency range

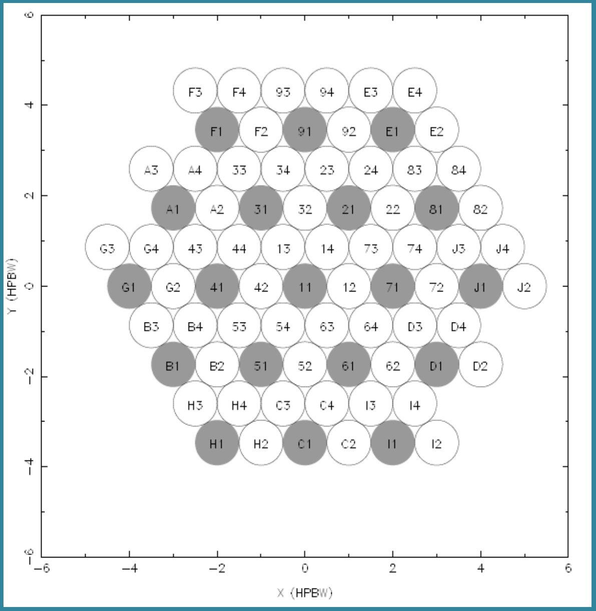


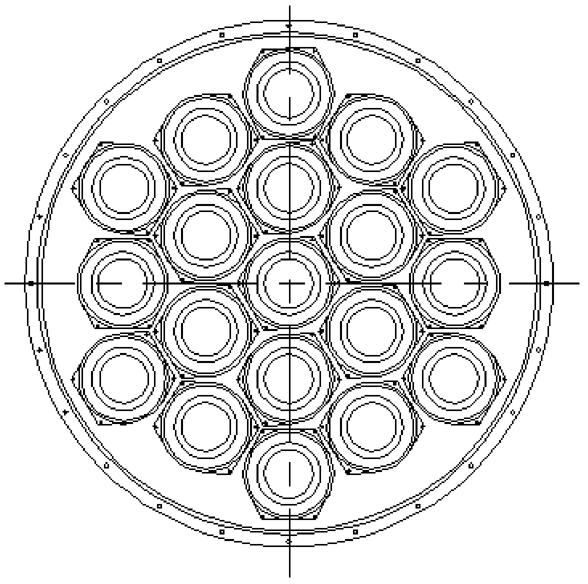
9 sets of FAST receivers NAOC - JBO

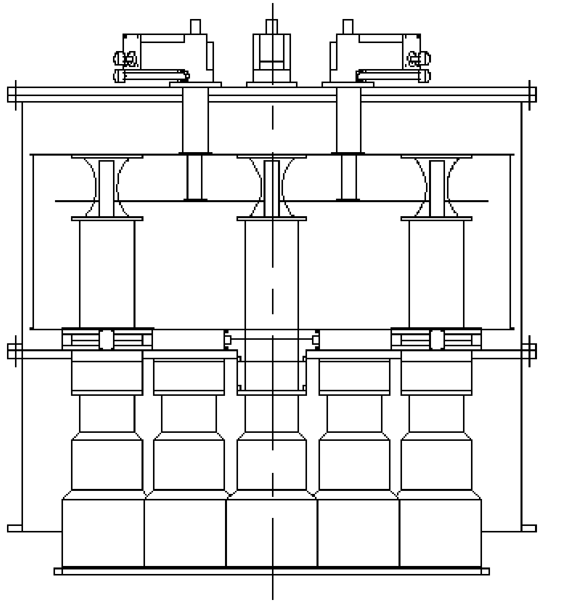
No	Band (GHz)	Beams	Pol.	Cryo Tsys(K)	Science
1	0.07 – 0.14	1	RCP LCP	no 1000	High-z HI(EoR),PSR, VLBI, Lines
2	0.14 – 0.28	1	RCP LCP	no 400	High-z HI(EoR),PSR, VLBI, Lines
3	0.28 – 0.56	1 or multi	RCP LCP	no 150	High-z HI(EoR),PSR, VLBI, Lines Space weather, Low frequency DSN
4	0.56 – 1.02	1 or multi	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	1.05 – 1.45	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

L-band Multi-beam receivers and its prototyping









Major Science Drives

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

Key HI projects with FAST

- HI proterties in the local universe and search for dark galaxies: all sky survey
- Cosmic Webs: Deep mapping of nearby spiral galaxies
- Mini halo search and missing satellite problems: HVCs and local group
- Galaxy Evolution, HI at high z

Sensitivity

$$\Delta S_\nu = \frac{2kT_{sys}}{A_{eff}\sqrt{\Delta\nu t}} = 1.2\frac{A_{eff}/T}{2000\mathrm{m}^2K^{-1}}\left(\frac{\Delta\nu t}{\mathrm{MHz\,sec}}\right)^{-1/2}\mathrm{mJy}$$

For HI emission,

$$\int S_\nu d\nu = 0.255 \times \frac{(1+z)}{4\pi(d_L/Mpc)^2}\left(\frac{M_{HI}}{10^6 M_\odot}\right)\mathrm{Jy\,MHz}$$

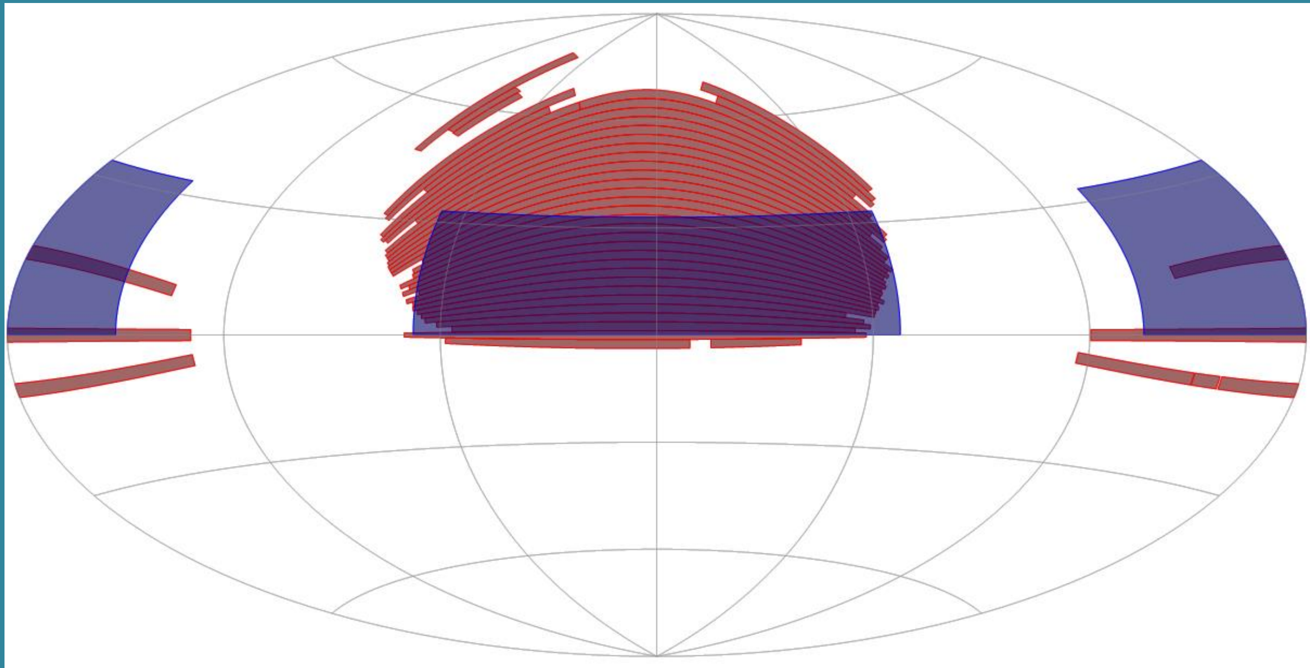
$$S_\nu = 4.25 \times \frac{(1+z)^2}{(d_L/\mathrm{Mpc})^2}\left(\frac{M_{HI}}{10^6 M_\odot}\right)\left(\frac{\Delta V}{\mathrm{kms}^{-1}}\right)^{-1}\mathrm{Jy}$$

$$\frac{M_{HI}}{M_\odot} = 0.235 \times \frac{(d_L/\mathrm{Mpc})^2}{(1+z)^2}\left(\frac{\Delta V}{\mathrm{kms}^{-1}}\right)\left(\frac{S}{\mu\mathrm{Jy}}\right)$$

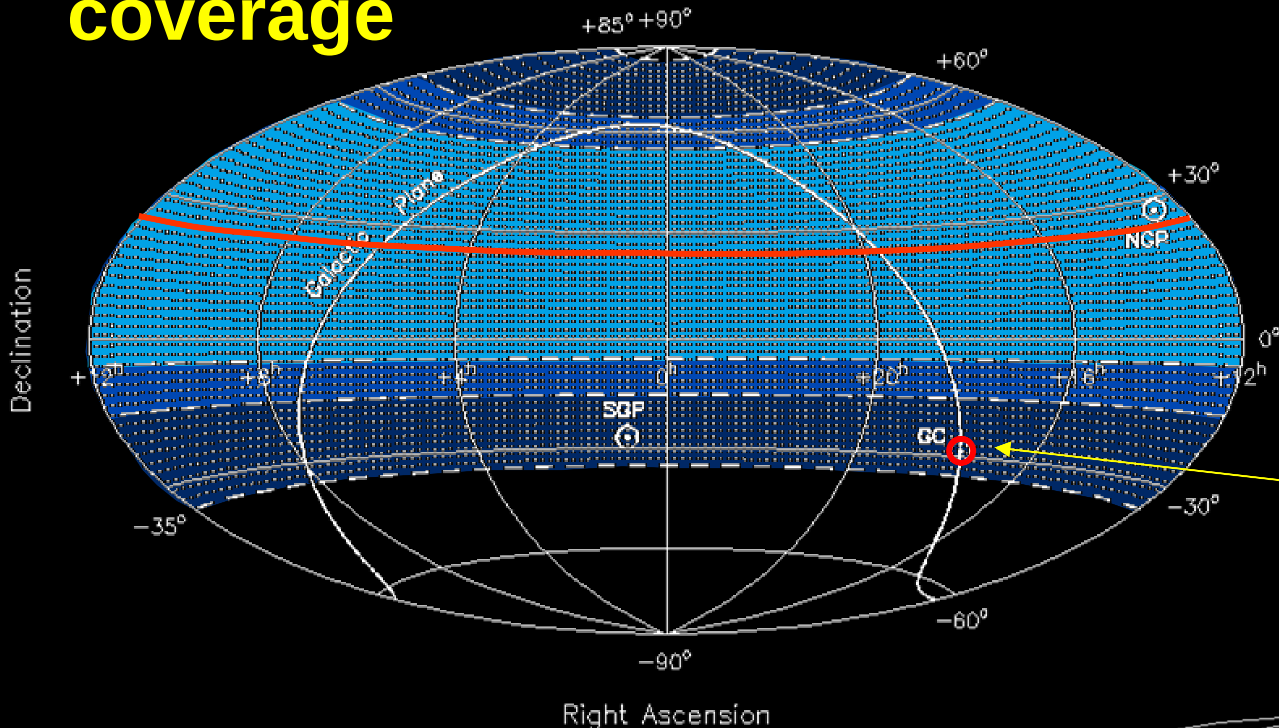
FAST all-sky HI survey

- Using a 19 beam L-band receiver to map 2π sterradians FAST sky at 23 sec per beam at 0.7 mJy, doable in 2 yrs,
  - Expect about 0.5 million galaxies (Duffy et al. 2008, 2013) with $M_{HI} < 10^{11} M_{\odot}$ out to z ~ 0.25 in a range of environments including Coma, Hydra, Ursa Major, Persues-Pisces supercluster plus neighboring voids.
- Large HI database for T-F relation, peculiar velocity study of the local universe with a larger volume.
- Extend ALFALFA

Sky coverage



Opening angle - sky coverage



Sky coverage

ZA 30 deg

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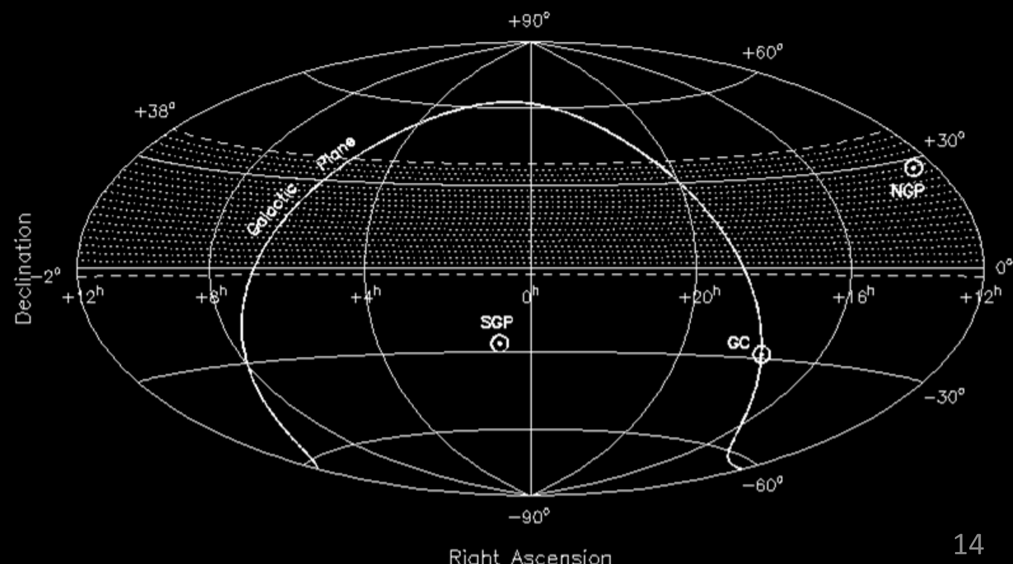
FAST Zenith

ZA 56 deg

Sky coverage

FAST vs. Arecibo

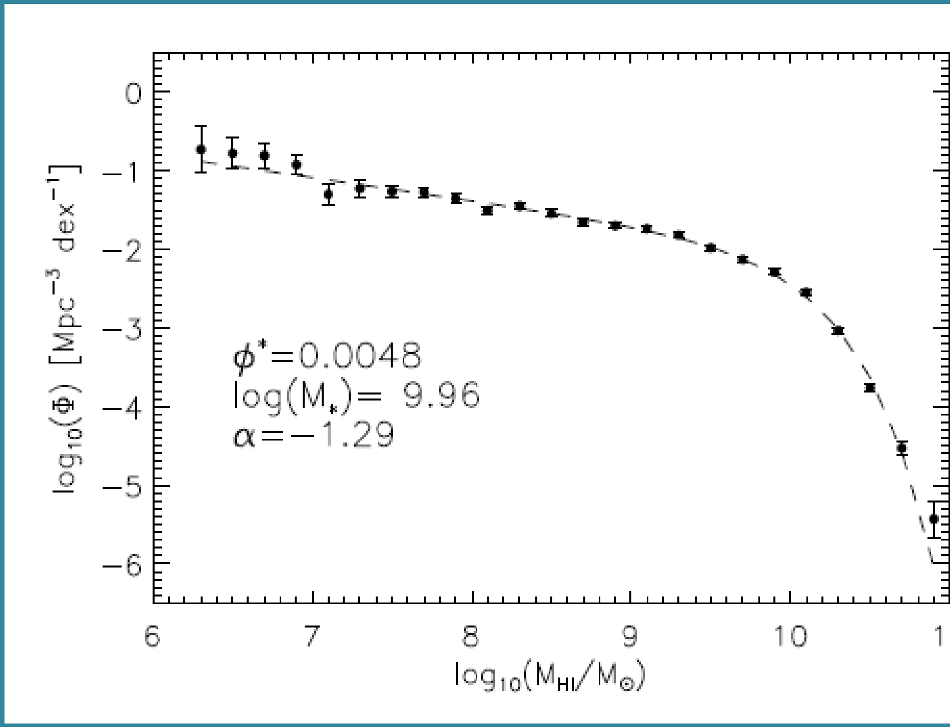


What are the HI properties of low-mass galaxies at z ~ 0?

- Recent measurements of the HI mass function (HIMF) are based on a few detections of galaxies with $M_{HI} < 10^7 M_{\odot}$.
- It is unclear how the slope of the HIMF changes in different environments

HIMF flatten for groups/clusters?

- Need more detections of a wider range of M_{HI} over a larger volume of space.



HIMF from ALFALFA (Haynes et al. 2011)

Duffy et al (2008)

Number of galaxies to be detected per day (18h) using FAST 19 beams with different integration time

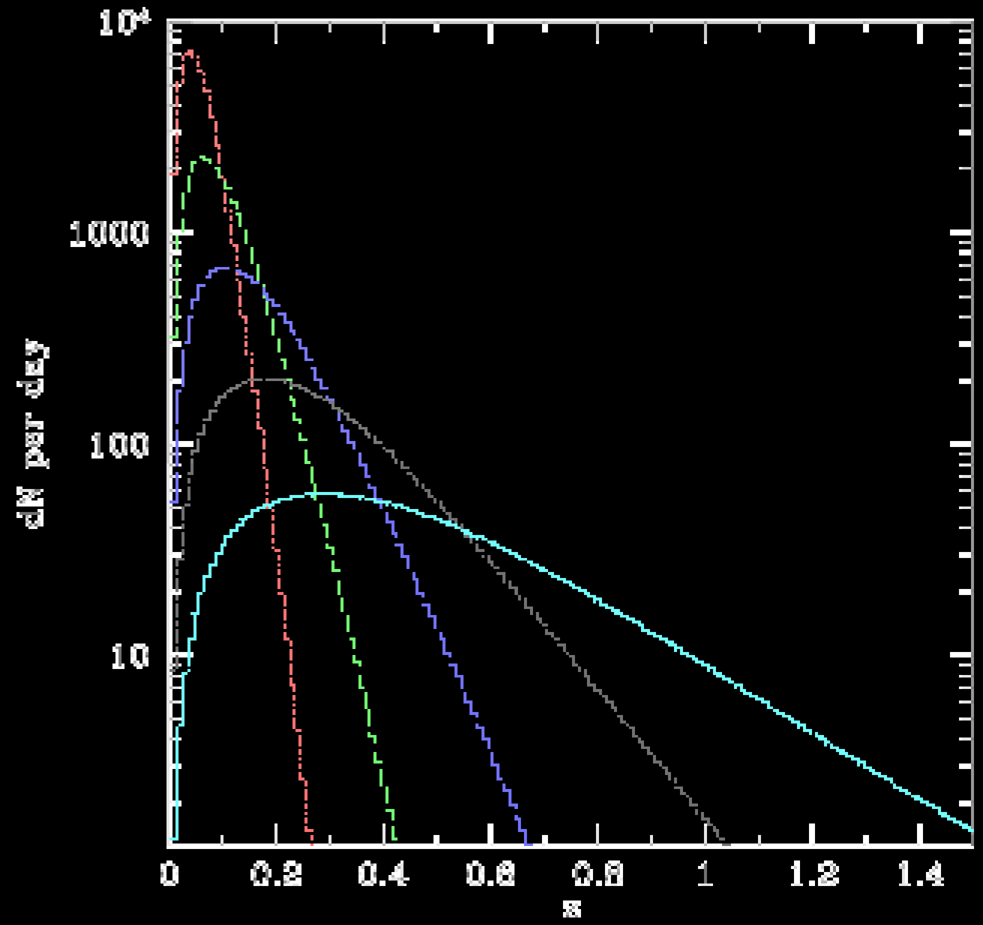
---- 6 sec

---- 60 sec

---- 600 sec

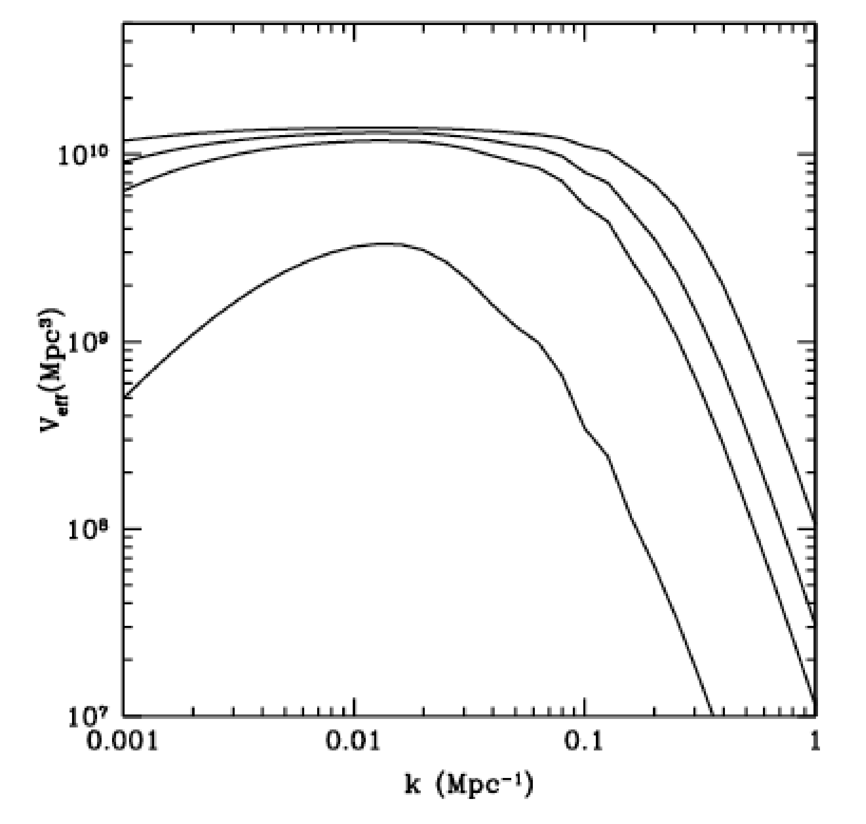
---- 6000 sec

---- 60000 sec

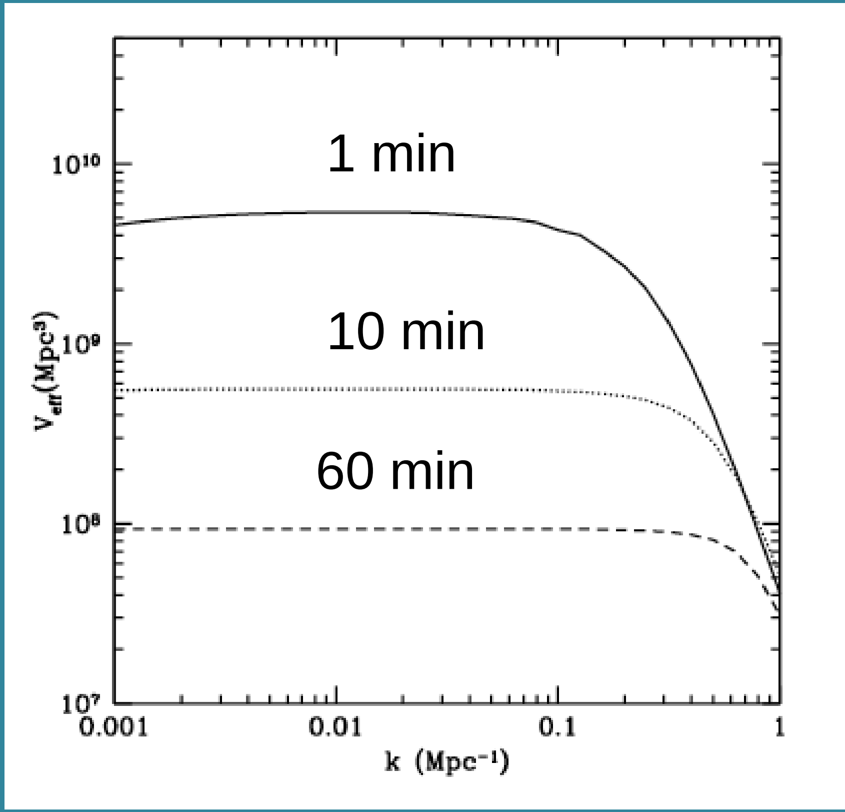


Survey Effective Volume

$$V_{eff}(\vec{k}) = \int d^3r \left[\frac{n_{eff}(r)W(k)P(k)}{n_{eff}(r)W(k)P(k)+1}\right]^2$$



V_{eff} for FAST observation 1sec, 12sec, 24sec, 60sec (19 beams)



V_{eff} for a FAST survey of total integration time 90 days

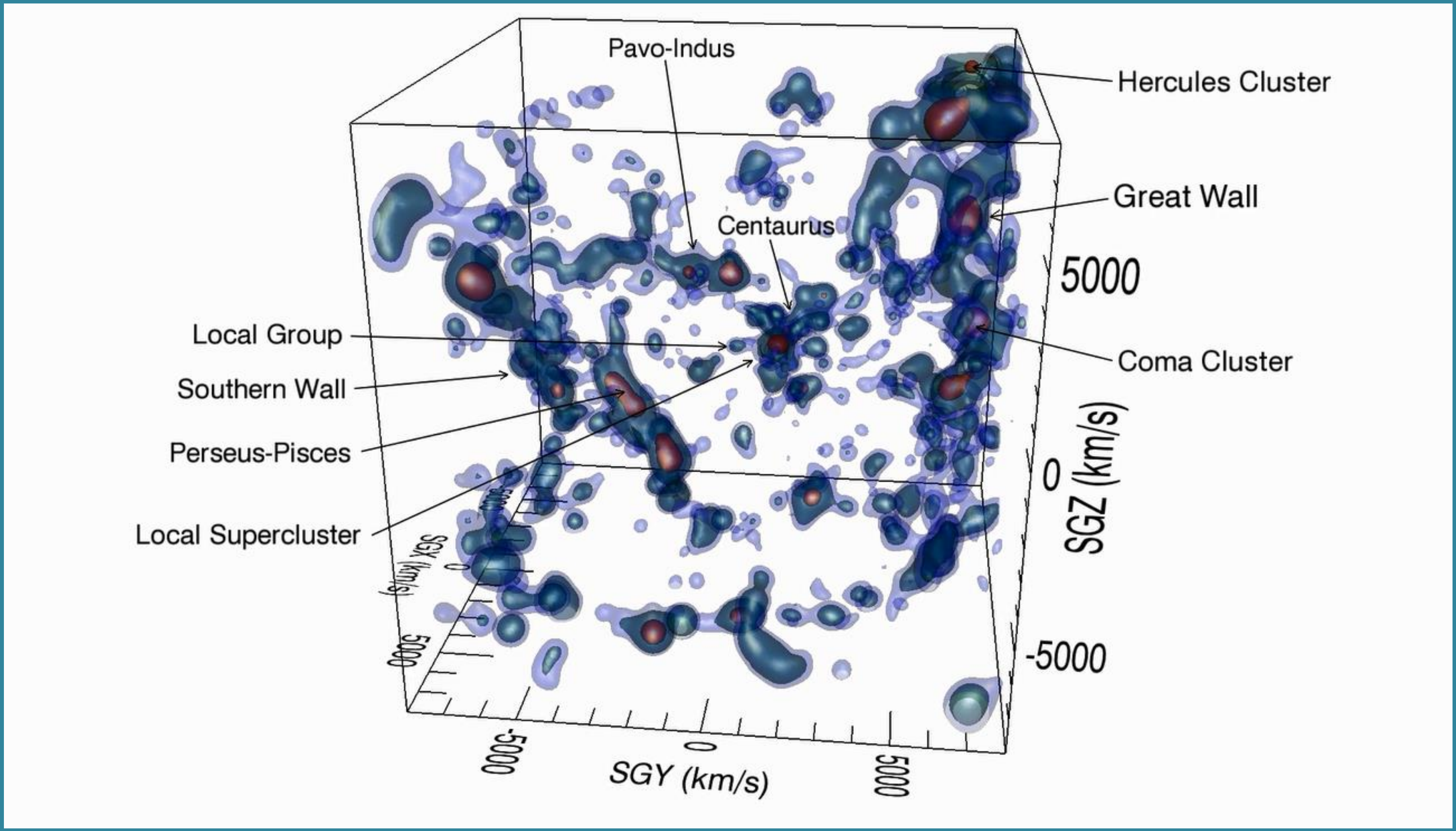
Measure the Peculiar Velocity using TFR

- Tully-Fisher relation provides the redshift independent distances for spirals
- Peculiar velocities can be estimated from these redshift independent distances

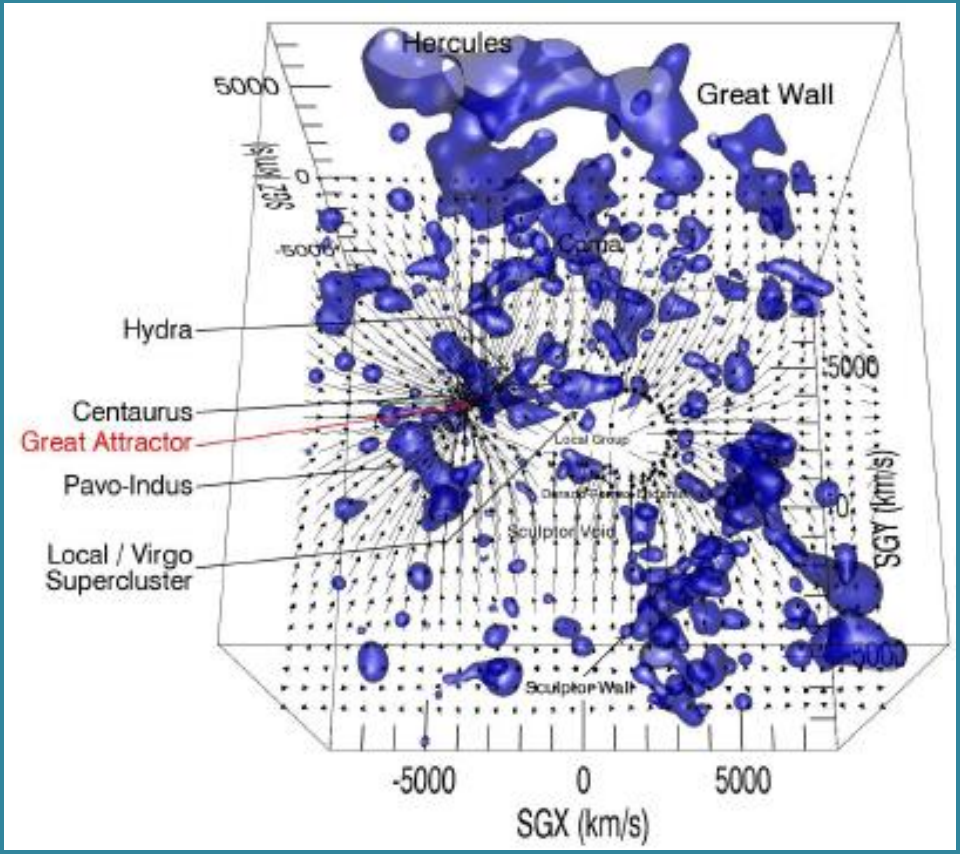
$$v_{pec} = cz - H_0 r$$

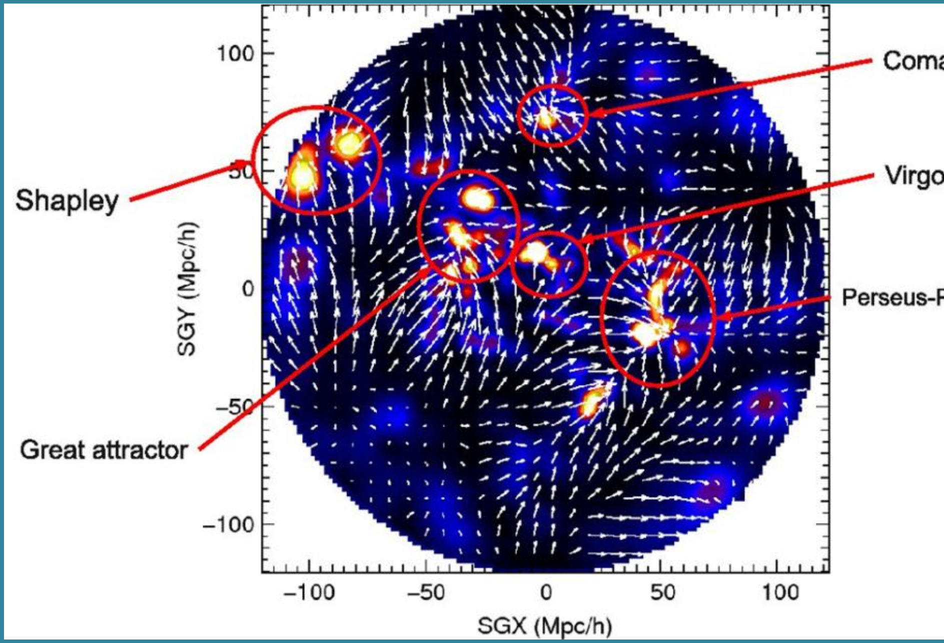
- Using the peculiar velocity field to trace mass in the local universe, Gravitational mass (visible matter + dark matter)

Mass distribution in the local Universe



➢ Peculiar Velocity, Tully-Fisher relation studies

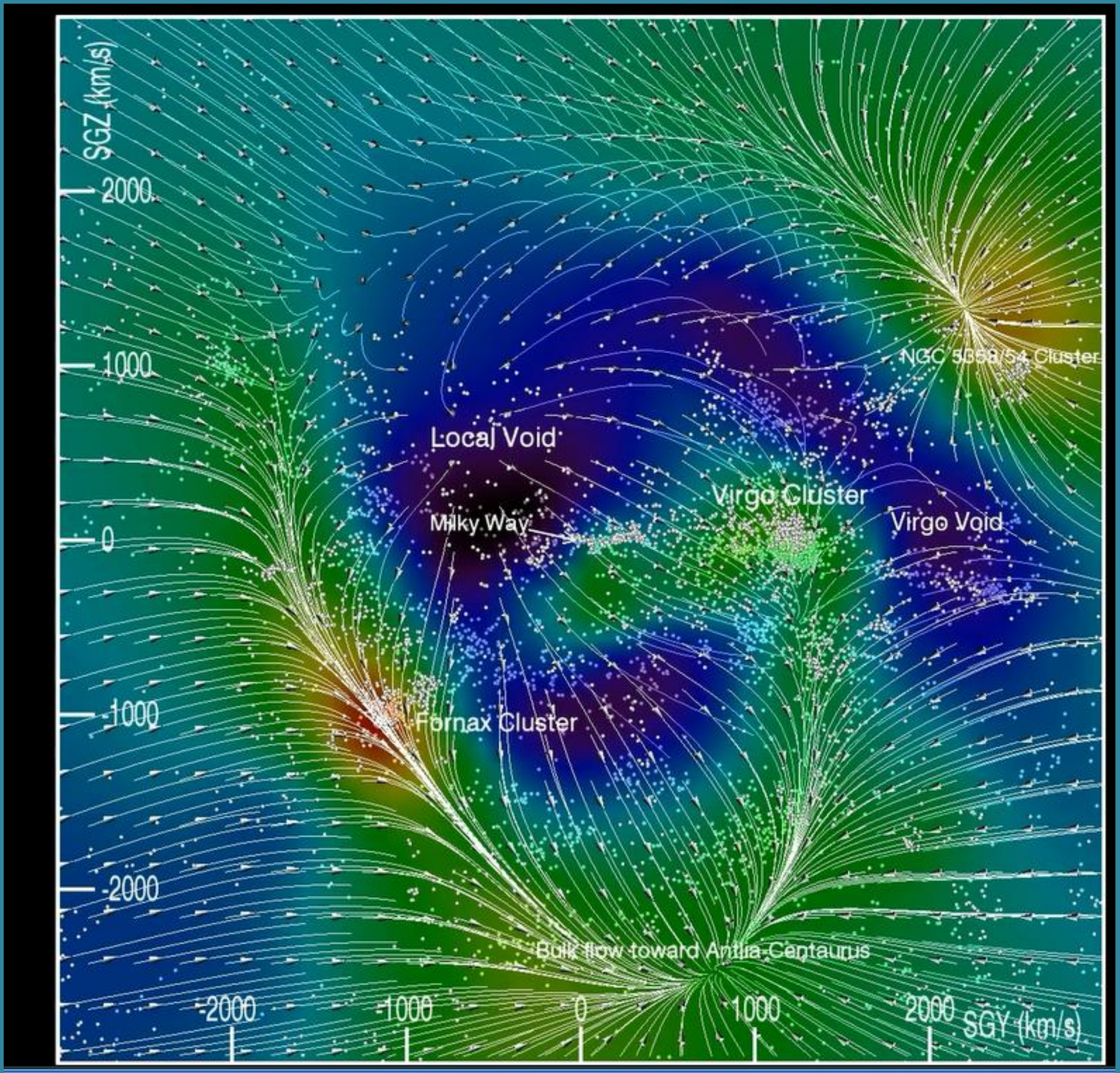




2MRS (Lavaux et al. 2010)

V8+ cosmicflow (Pomarede et al. 2012 IAU)

Cosmic Flows   Courtois et al. 2013



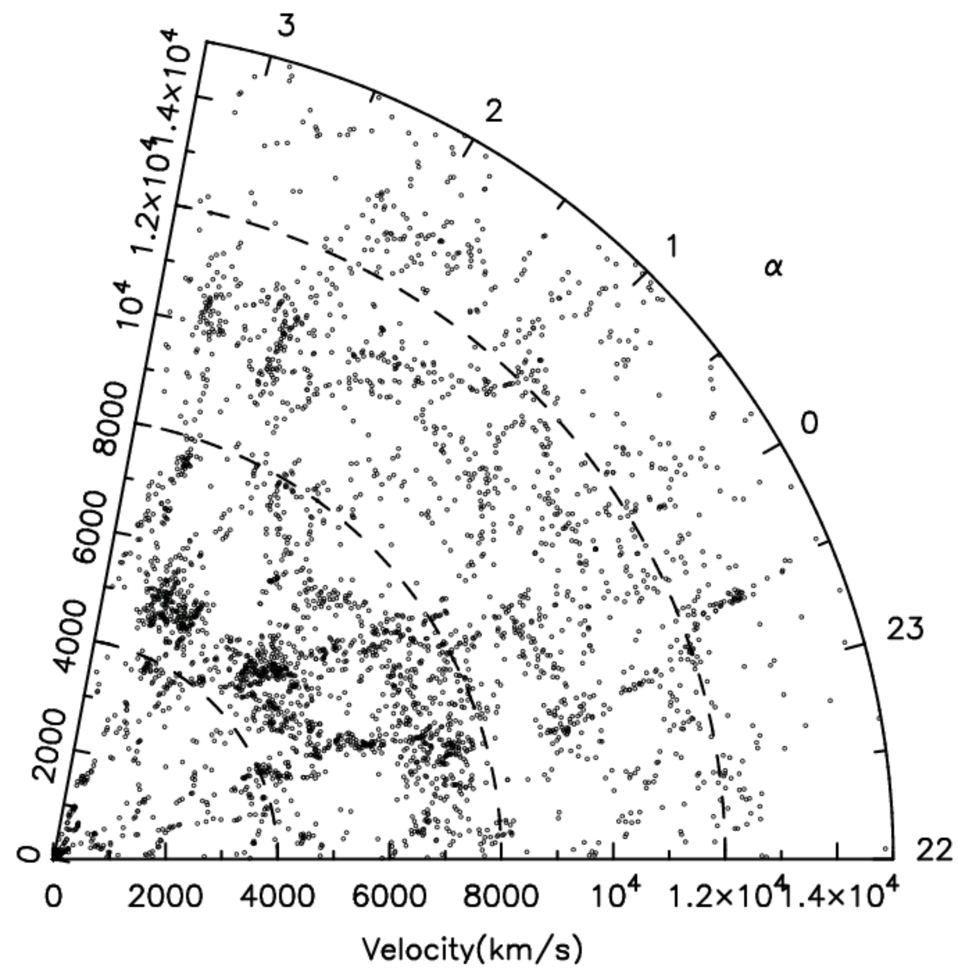
The Pisces-Perseus supercluster
L. Xiao et al.

Width 5-10h^{-1} Mpc

Redshift depth: 250-500 km/s

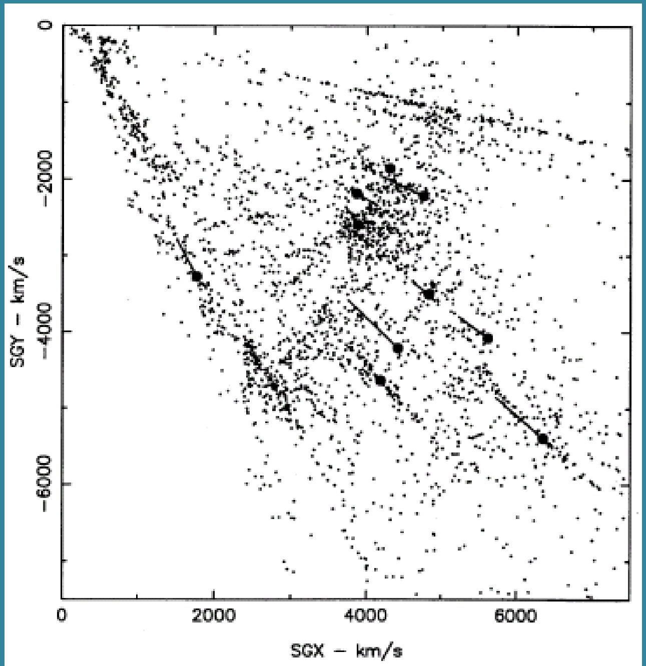
Distance: 5000 km/s

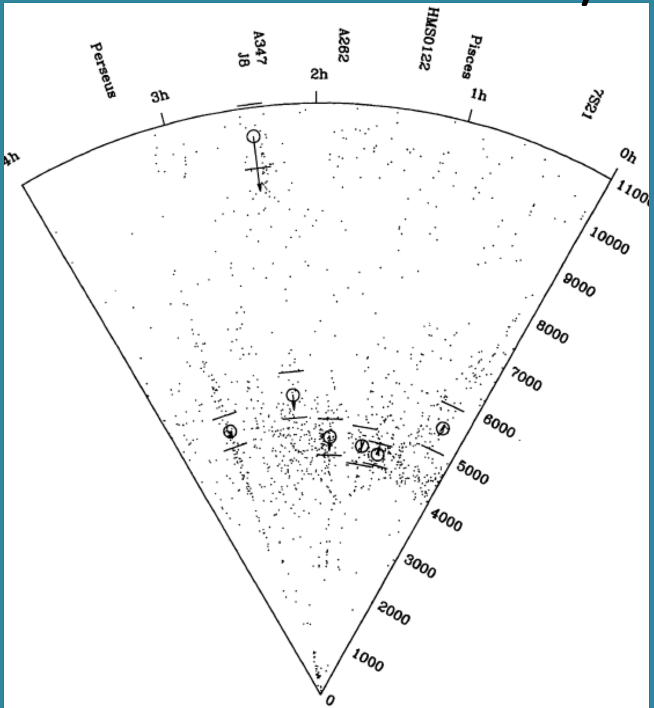
- **TF-relation to derive the peculiar velocity field of PPS**
- **Find loose groups, and the clustering effect**
- **Properties of Galaxies in Cluster and field galaxies**
- **Comparing with numerical simulation to predict FAST survey results**



Infall towards PPS

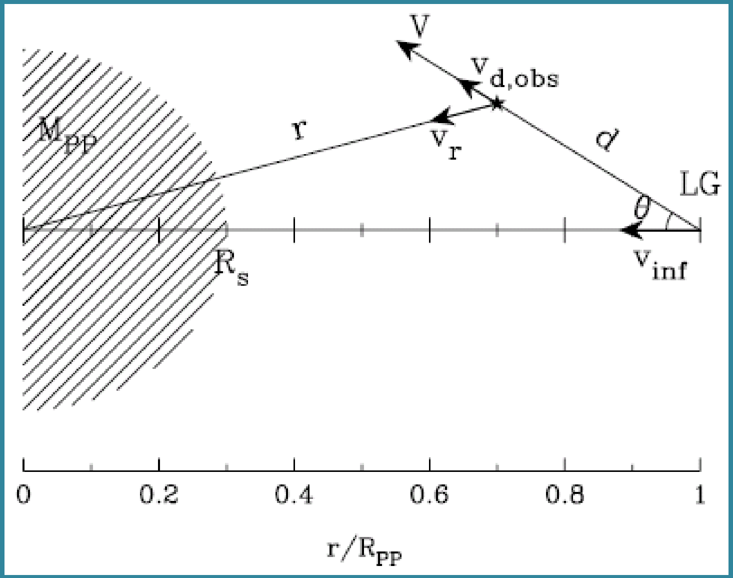
- r-band 355 TF galaxies (Willick 1991; Courteau et al. 1993)
  - join the bulk flow ~350 km/s
- 21 cluster TF sample (Han & Mould 1992)
- 16 cluster inverse FP sample (Hudson et al. 1997)
  - Infall in the backside, bulk motion 420±280 km/s

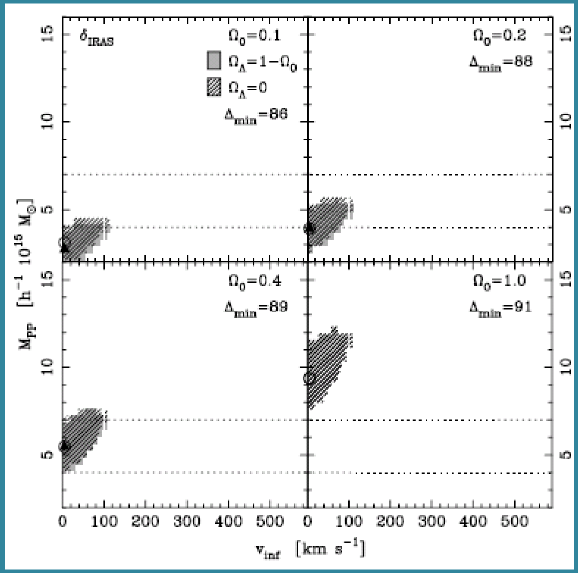




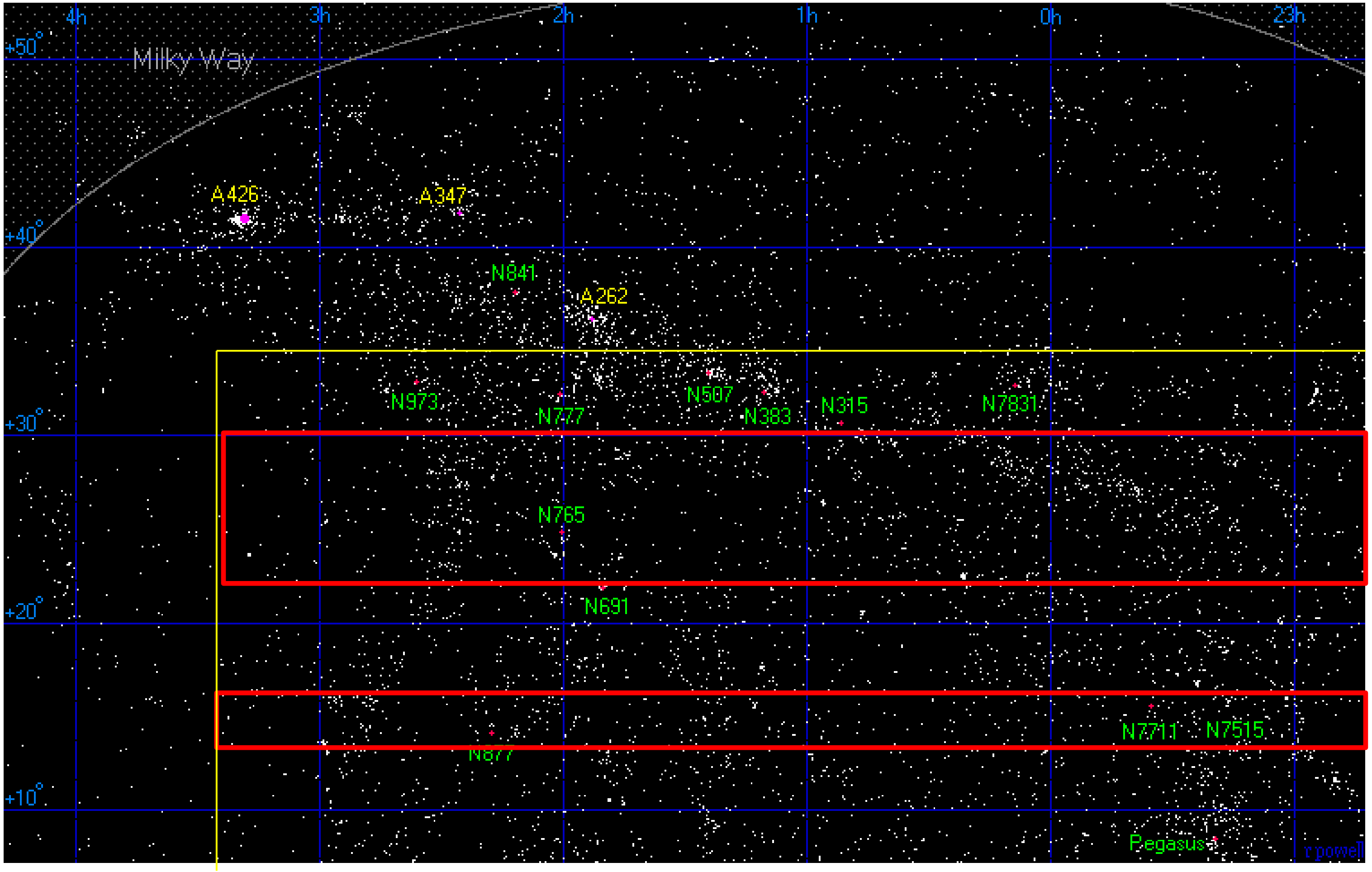
Infall towards PPS

- POTENT reconstruction of ρ and PV field (Mark III)
  - PPS at rest to LG (Dekel et al. 1999)
  - regions between PPS and LG infall towards PPS
- Monte-Carlo analysis (da Costa et al. 1996)
  - infall towards PPS, GA less dominant
- Tolman-Bondi model fit KLUN catalog (Hanski et al. 2001)
  - Vinf <100 km/s

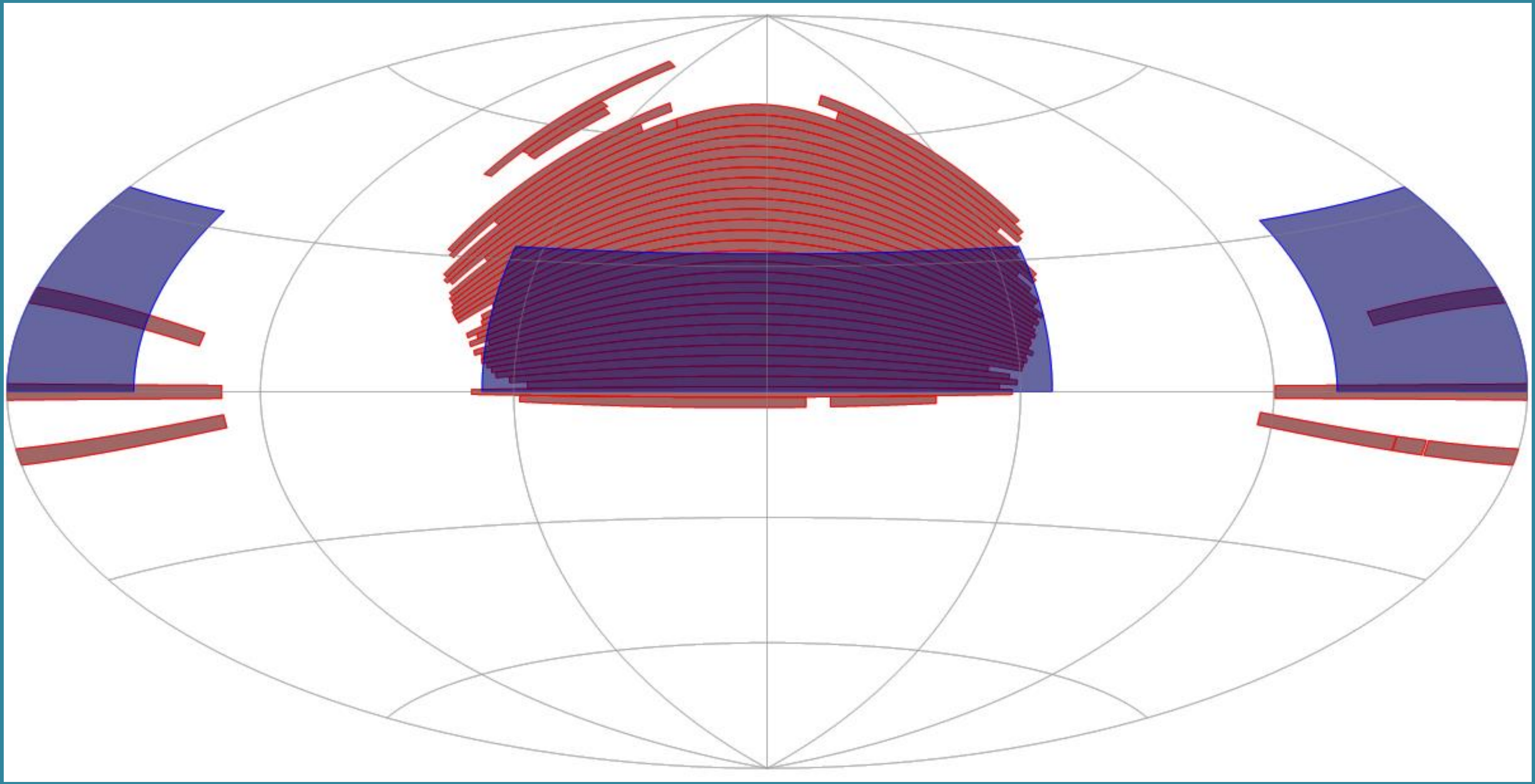




The Pisces-Perseus supercluster



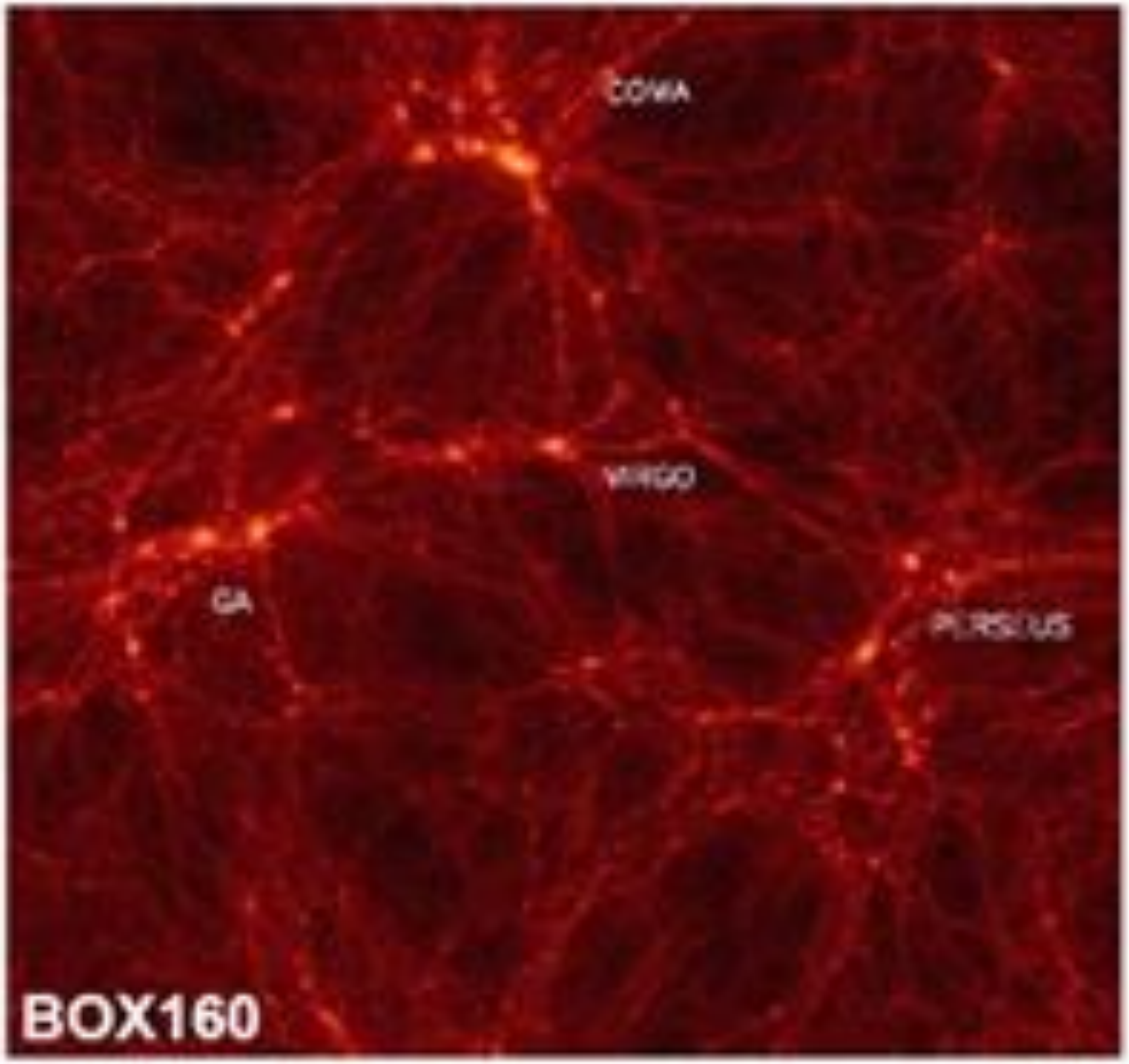
- Early Science plan: Extend ALFALFA Sky coverage



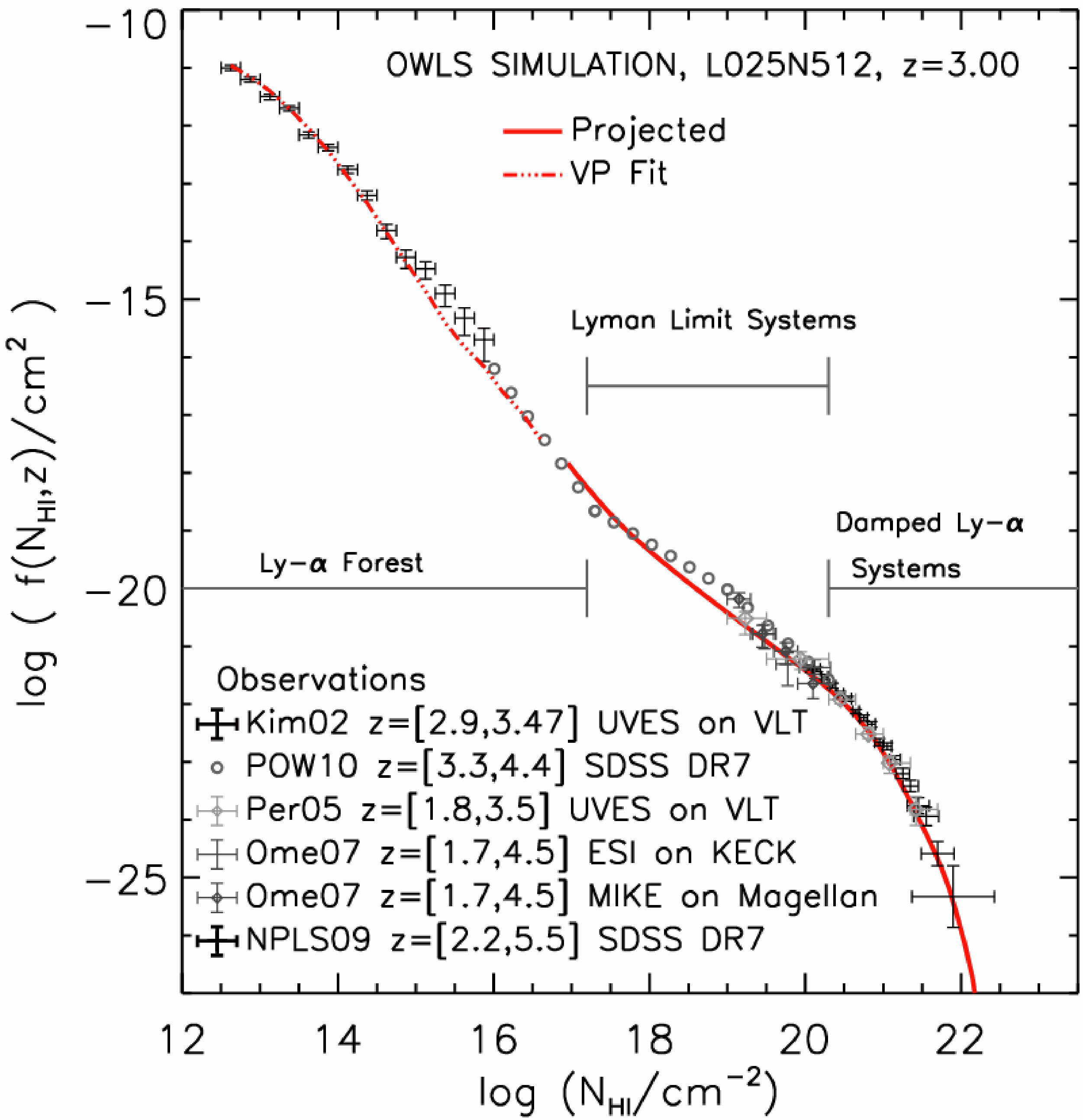
Mapping diffuse HI at 10^17

- Gas accreting onto galaxies
- Tracing pass interactions
- Mapping the cosmic web
- Gas in void
- Gas in groups and clusters,
  e.g. tails, filaments etc.

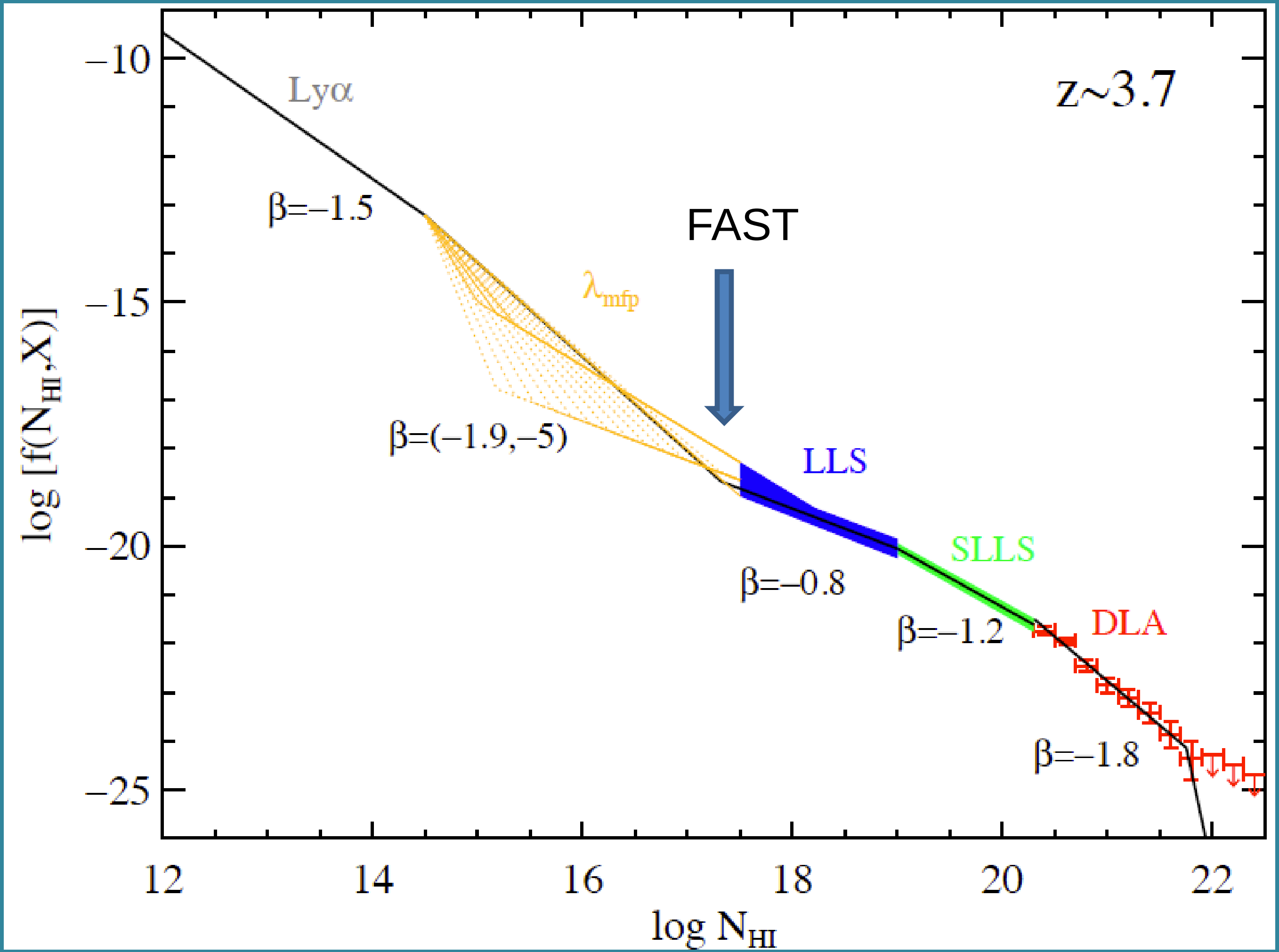
HI as a probe of Large Scale Structure



e.g. Gottlöber, Hoffman, Yepes (2010)



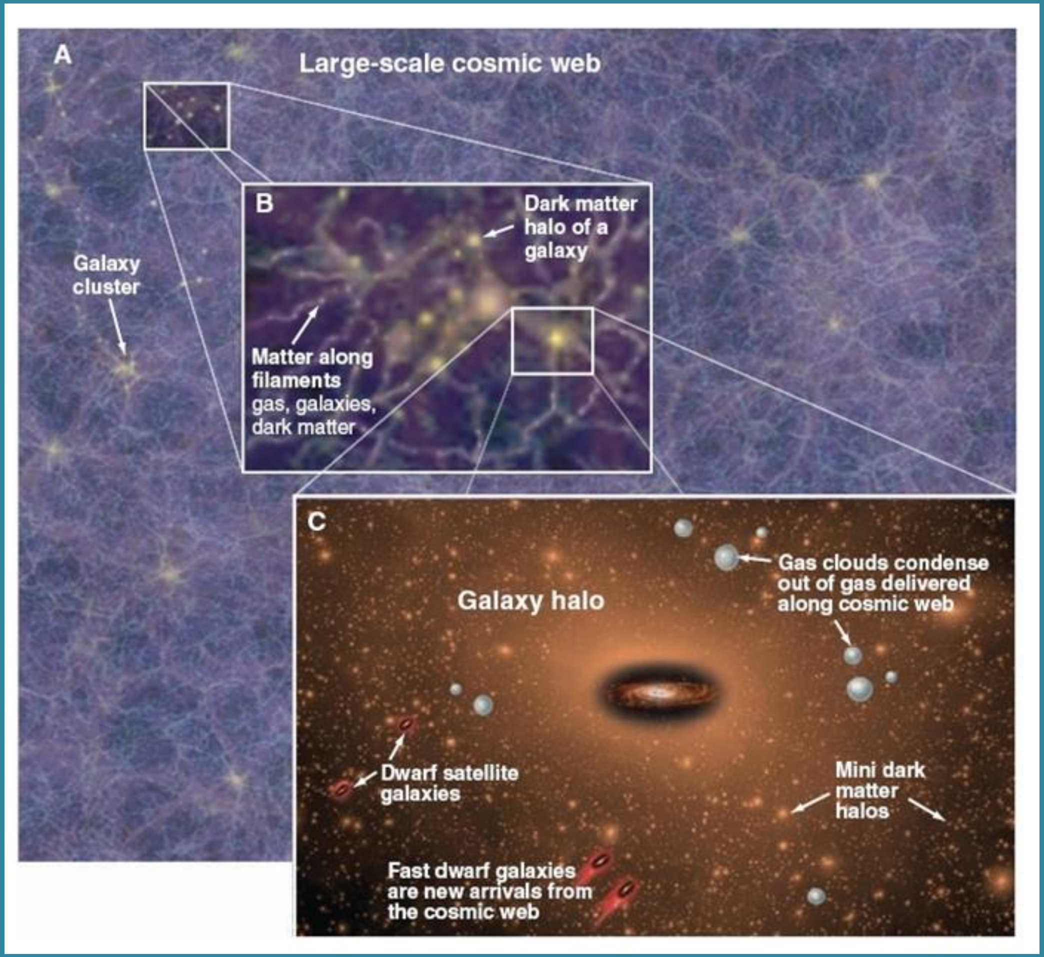
OWLS SIMULATION, L025N512, z=3.00
Projected
VP Fit
Lyman Limit Systems
Damped Ly−α Systems
Ly−α Forest
Observations
Kim02 z=[2.9,3.47] UVES on VLT
POW10 z=[3.3,4.4] SDSS DR7
Per05 z=[1.8,3.5] UVES on VLT
Ome07 z=[1.7,4.5] ESI on KECK
Ome07 z=[1.7,4.5] MIKE on Magellan
NPLS09 z=[2.2,5.5] SDSS DR7
log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



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

Cosmic web



Ibata and Lewis (2008) Sciences 319, 50

LETTER

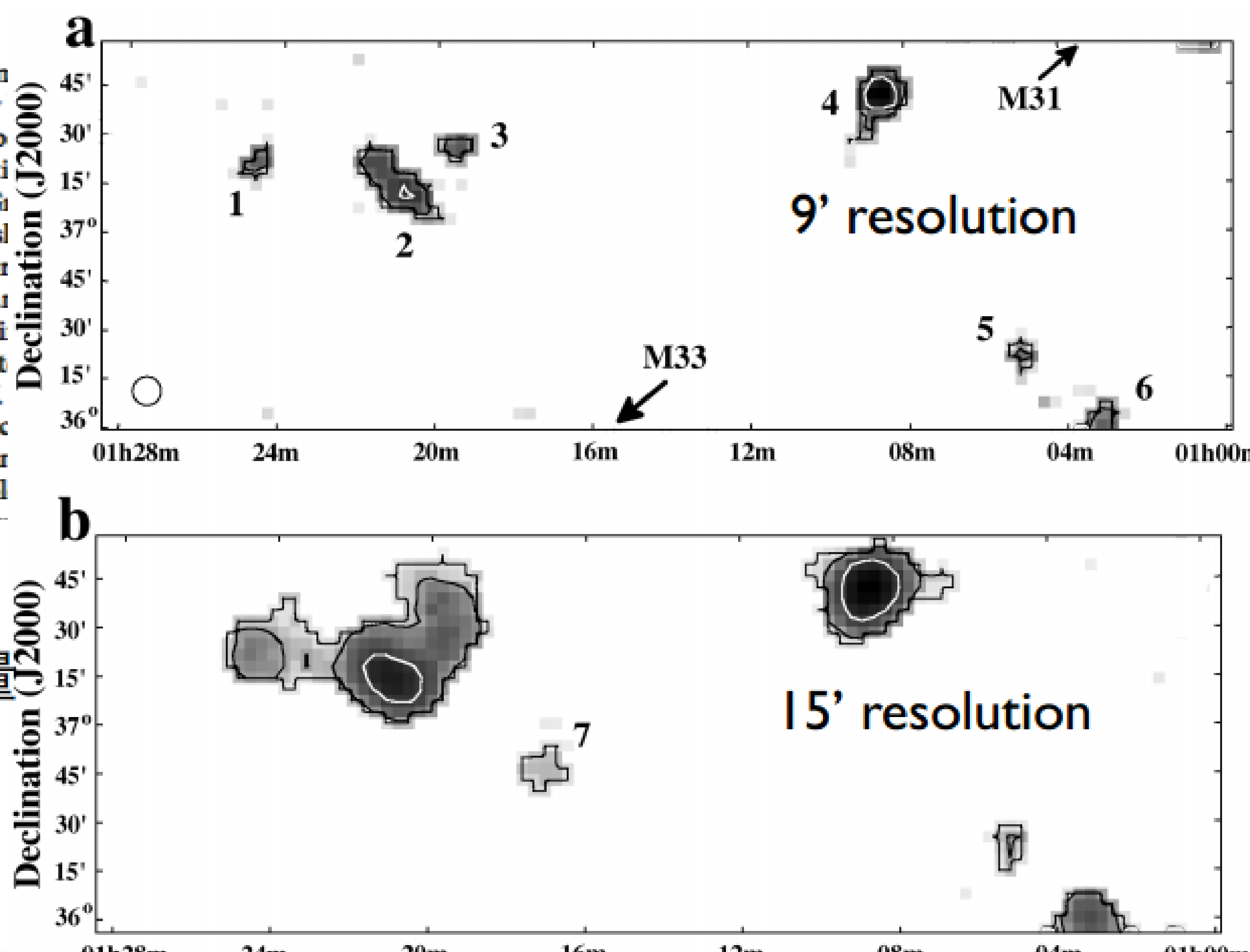
NATURE May 9, 2013

doi:10.1038/nature12082

Discrete clouds of neutral gas between galaxies M31 and M33

Spencer A. Wolfe[1], D. J. Pisano[1], Felix J. Lockman[2], Stacy S. McGaugh[3] & Edward J. Shaya[4]

Spiral galaxies must acquire gas to n
star formation beyond the next few
material may be the gas that resides b
standing of the state and distributi
Radio observations[3] of the Local G
hydrogen gas extending from the disl
to M33. This feature has been interpr
ent of a condensing intergalactic filaı
formation in M31 and M33, but si
feature could also result from an int
within the past few billion years (ref.
vations showing that about 50 per c
clouds, with the rest distributed in aı
The clouds have velocities comparabl

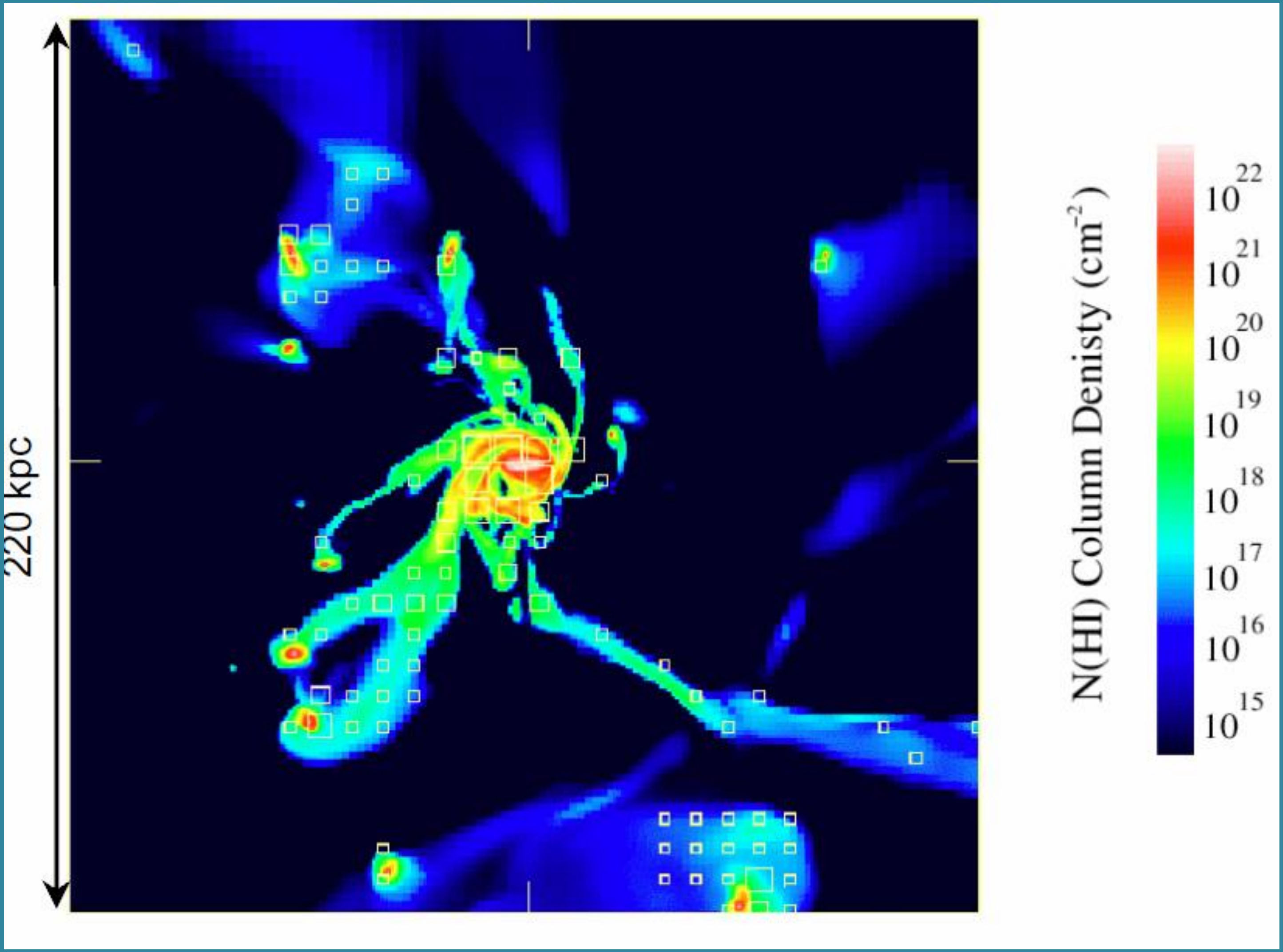


log(MHI): 4.6-5.6 太阳质量

size: <3 - 6.4 kpc

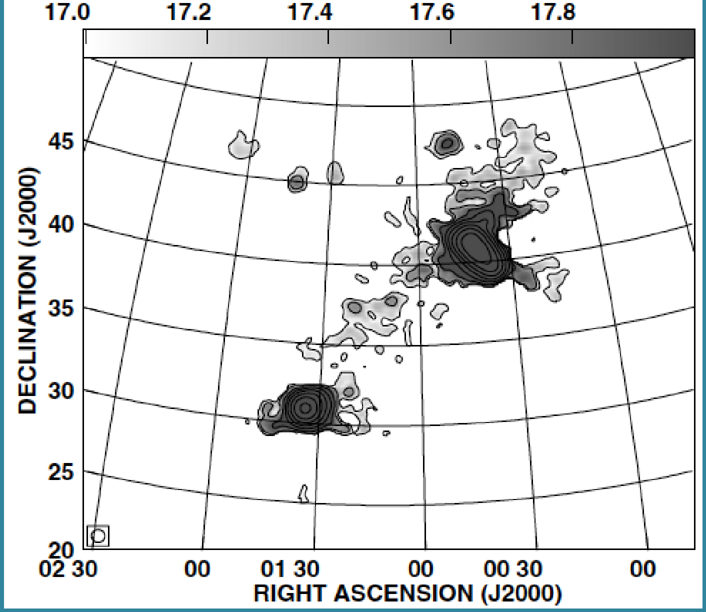
ΛCDM COSMOLOGICAL GALAXY SIMULATIONS

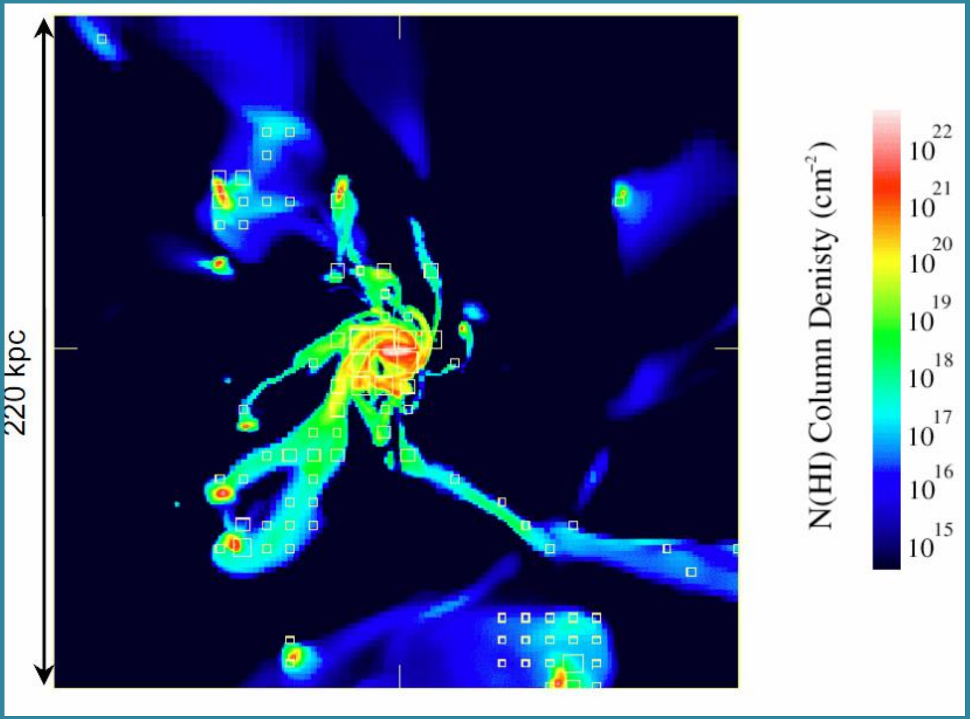
Kacprzak et al. 2010



Gas accretion from the IGM onto galaxies?

- low N_{HI} gas seen around M 31 and M 33



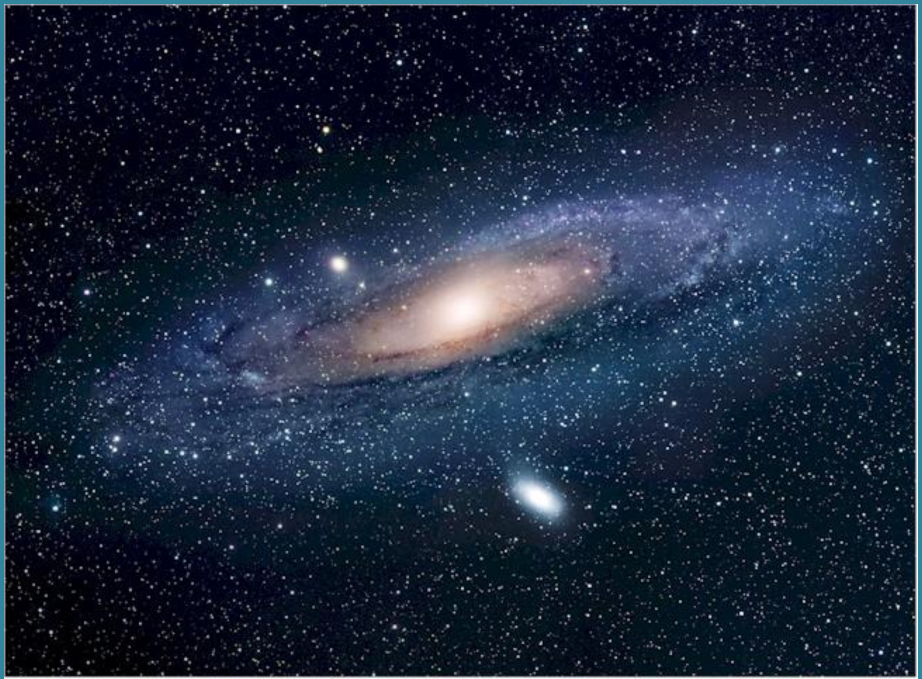


Braun &Thilker 2004

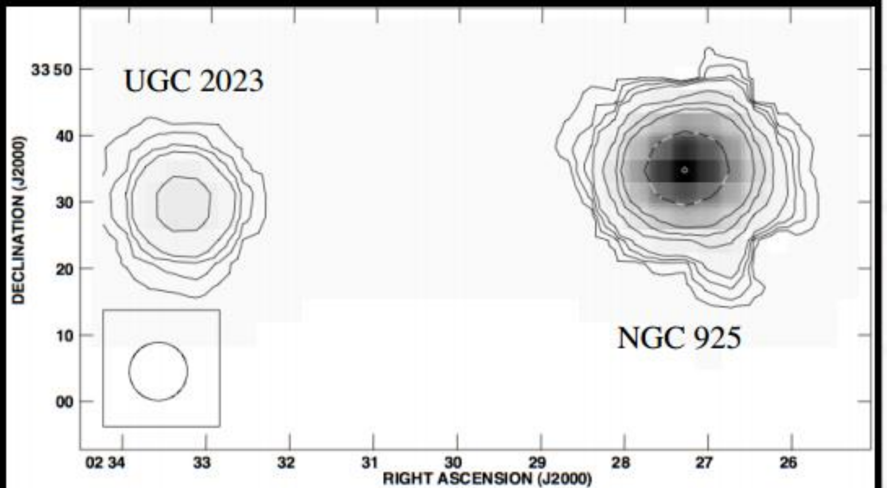
Deep mapping of Nearby Galaxies

- 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 $1.5 \times 10^{17}\ cm^{-2}$ per 2.1 km/s channel.

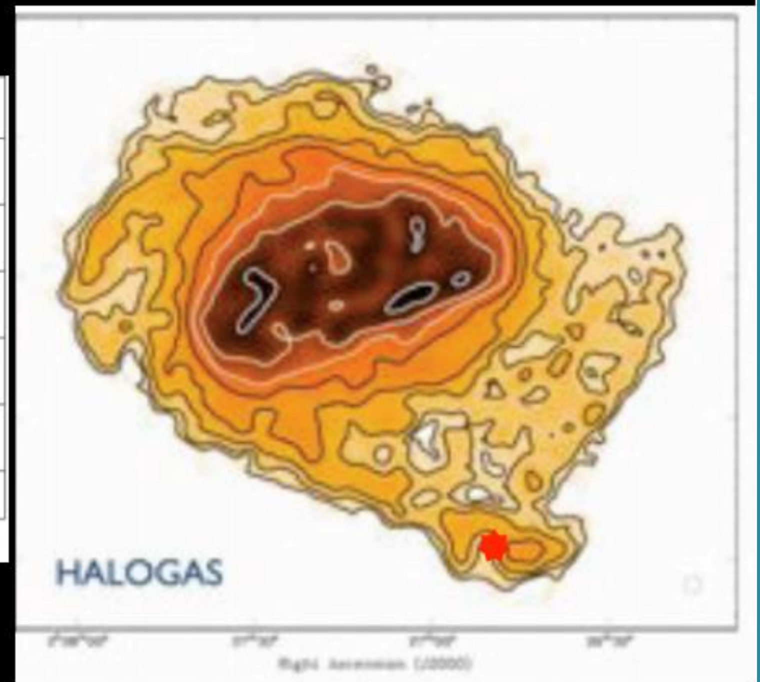
- Select regions of different environments,
  - void, big galaxies, clusters …



NGC 925



Preliminary reduction yields 3σ, 20 km/s sensitivity $\sim 10^{18}$ cm^{-2}.
Can see the tidal features near NGC 925, but no connection with companion.
Absence of low N_{HI} features probably real, but may be due to distance of source.



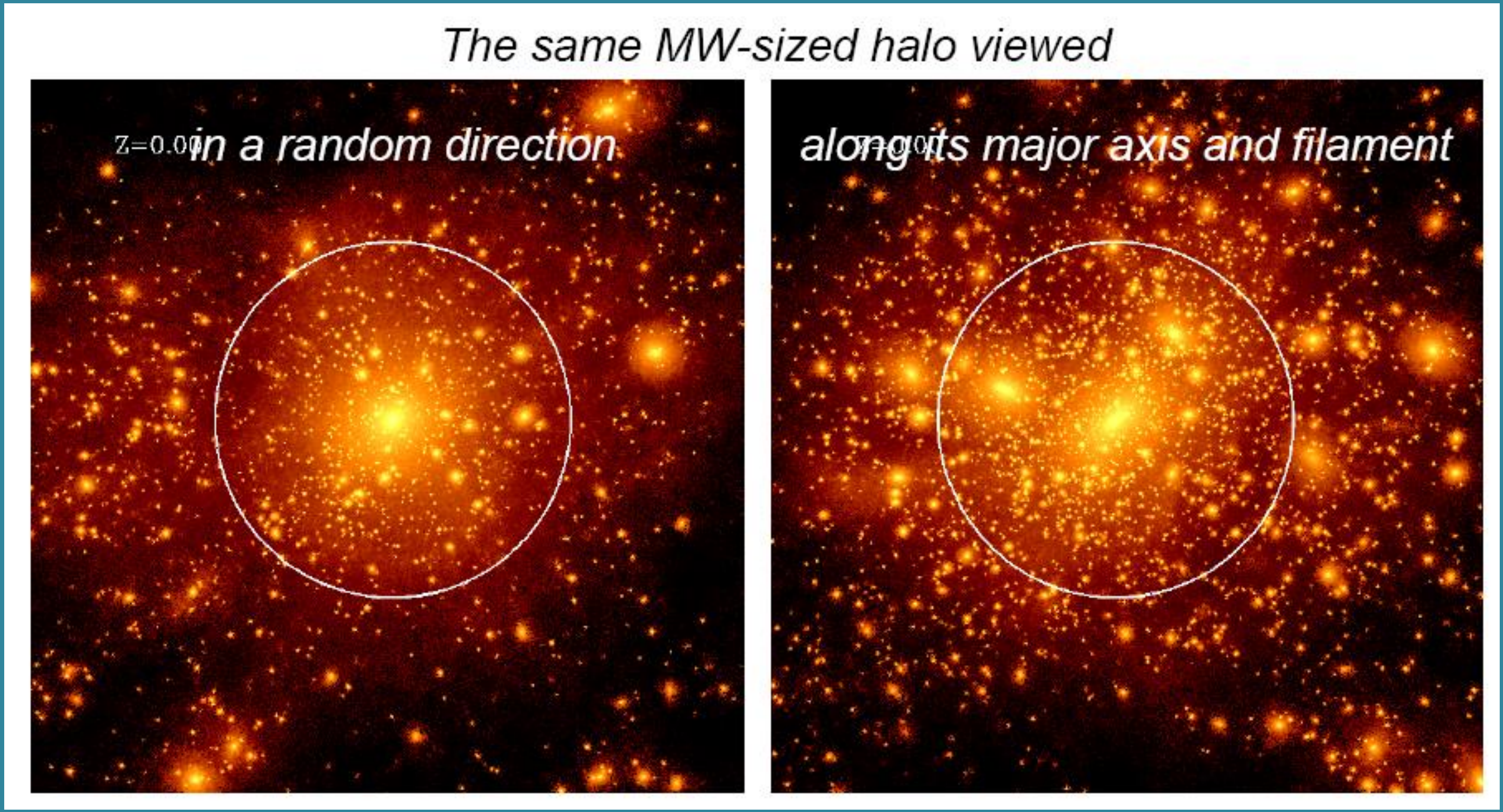
Contours at 1, 3, 6, 10...600x10^{18} cm^{-2}.
See signs of extended HI around NGC 925, but no filamentary structures.

Image Credit: D.J. Pisano

Key HI projects with FAST

3. Mini halo search and missing satellite problems: HVCs and local group

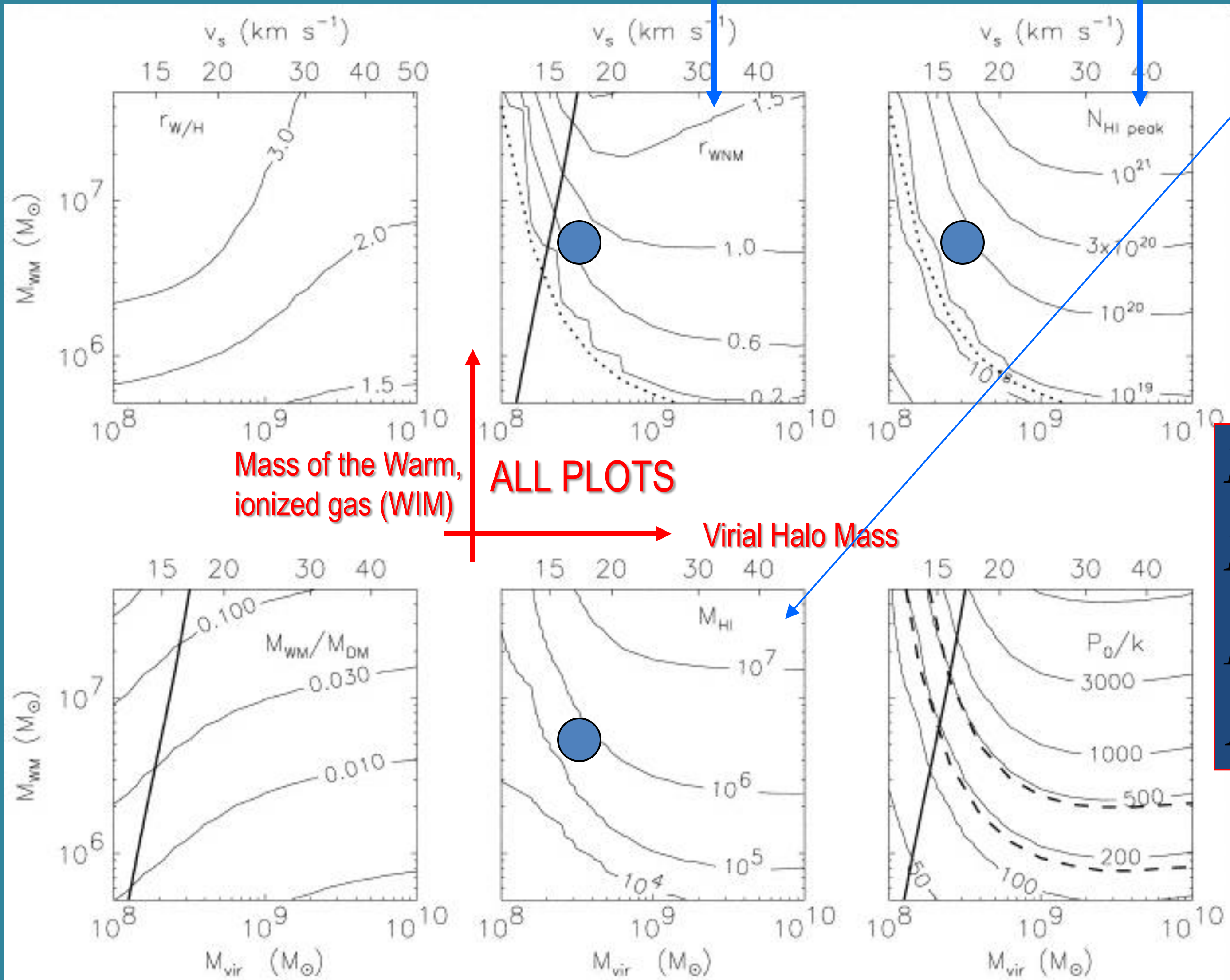
Searching for the dark halos, substructure, and filaments



Kravtsov, Irvine workshop, 2007

Contours of HI (WNM) radius (kpc)   HI column density   HI Mass

Sternberg, McKee & Wolfire 2002



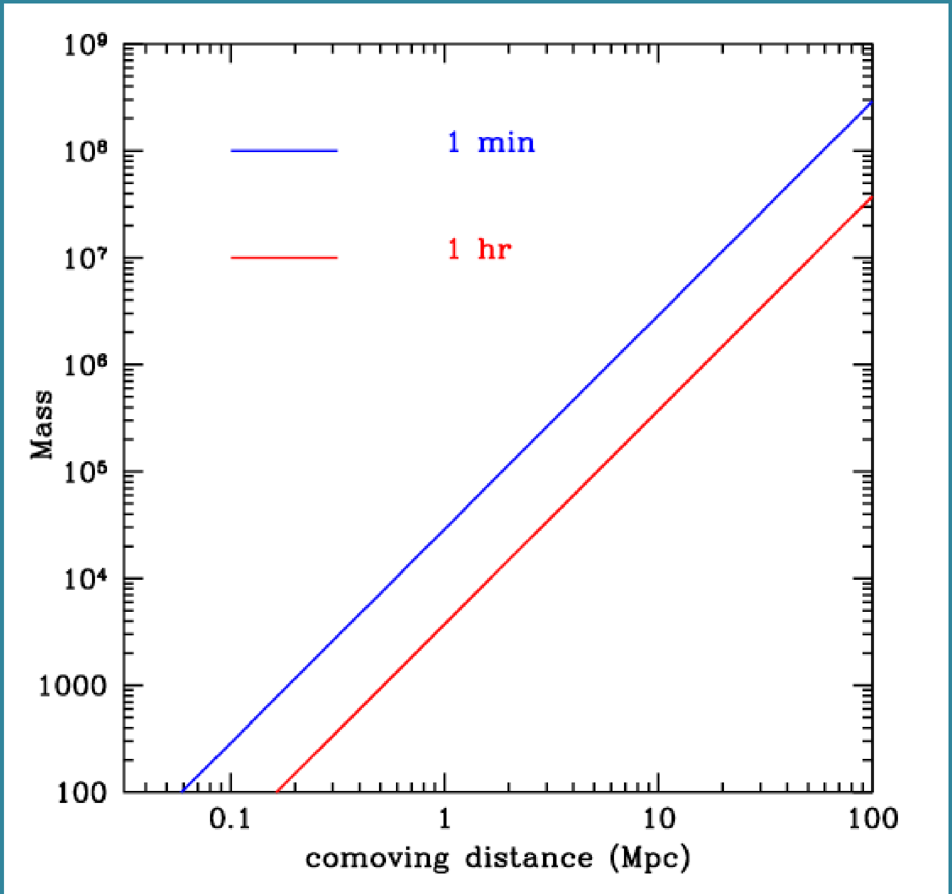
A plausible model for a baryon-poor minihalo:

$$M_{halo} = 3\times10^8 M_{sun}$$
$$M_{baryon} = 5\times10^6 M_{sun}$$
$$M_{HI} = 3\times10^5 M_{sun}$$
$$R_{HI} = 0.7 kpc$$

FAST can detect this kind of object out to 3-4 Mpc

Nearby faint sources

assume v=30 km/s, S/N =10



by **Matthew Francis** - Jan 3 2013, 9:00pm +0800

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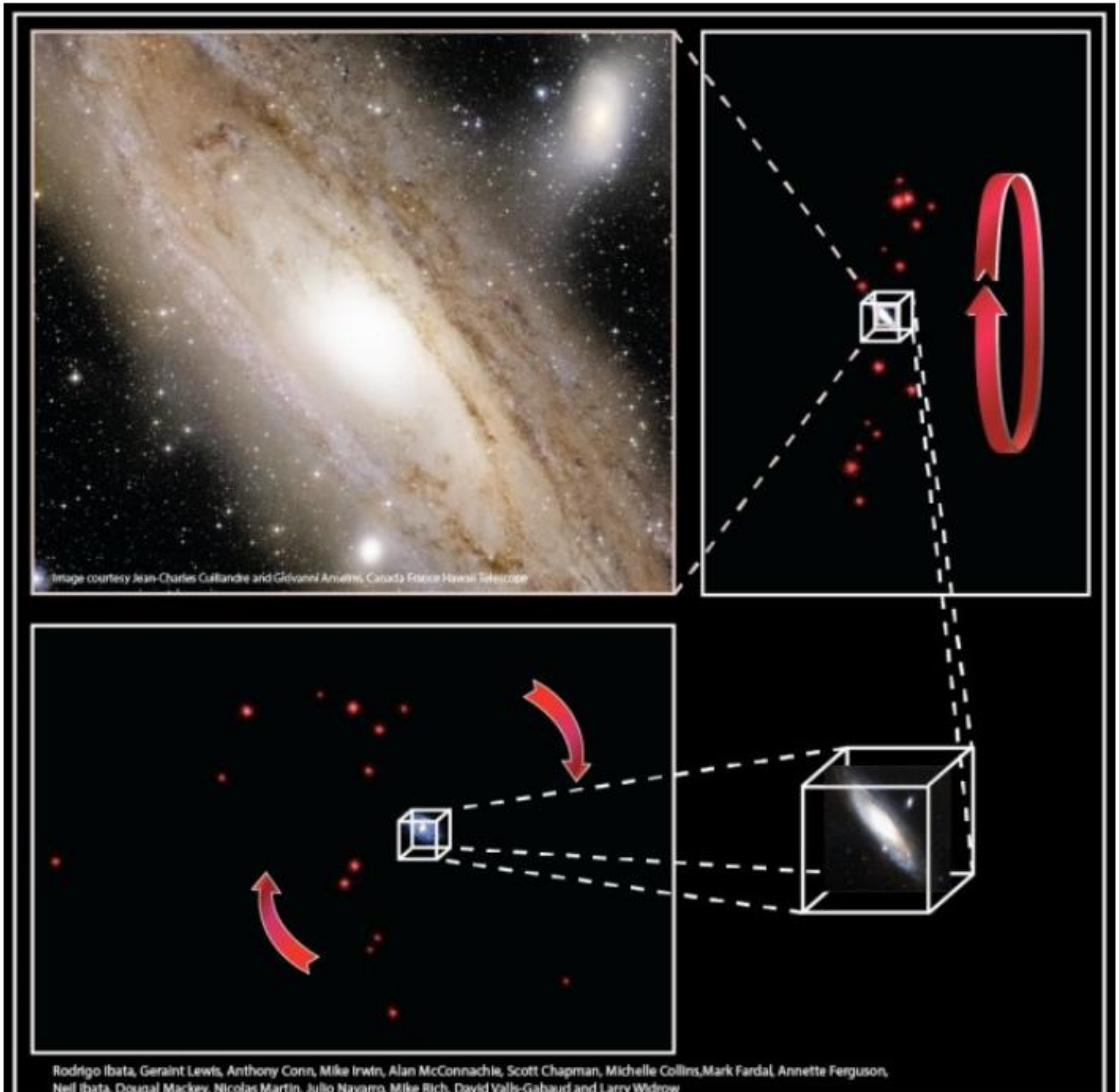


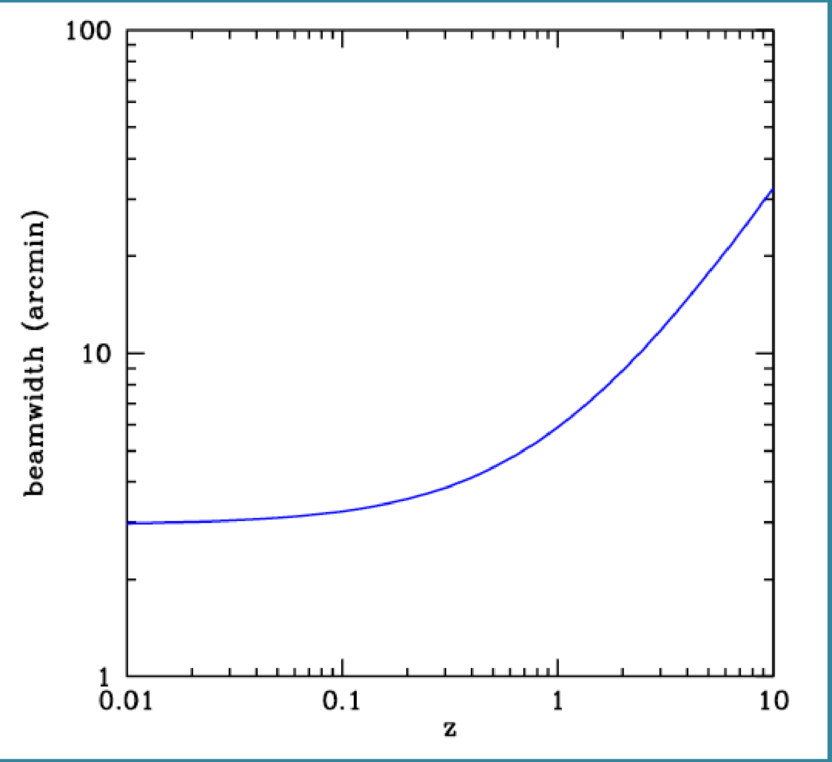
Ibata et al.
Nature, 2013

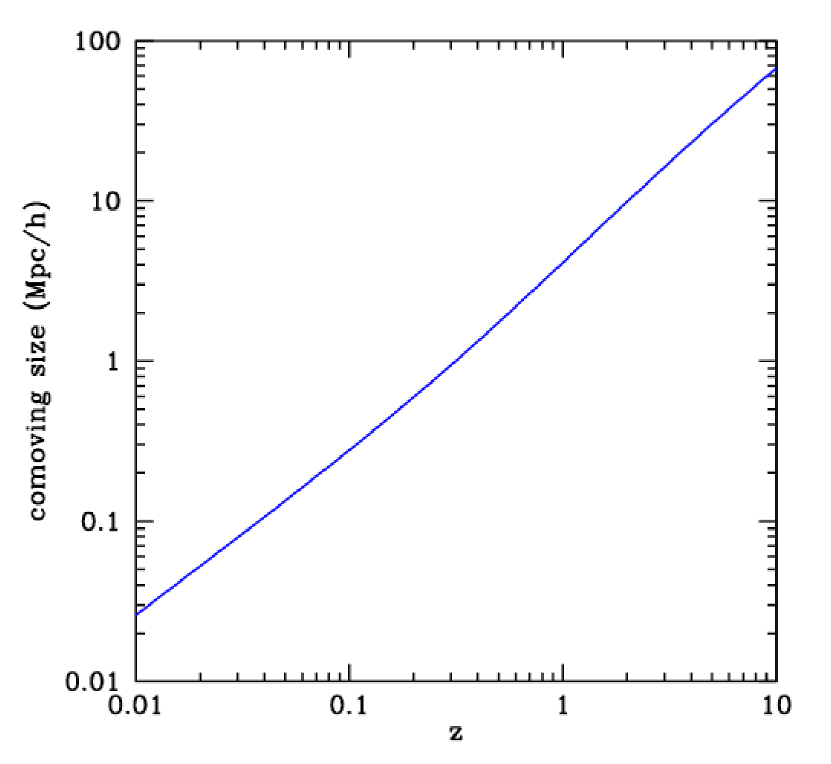
Key HI projects with FAST

4. Galaxy Evolution, HI at high z

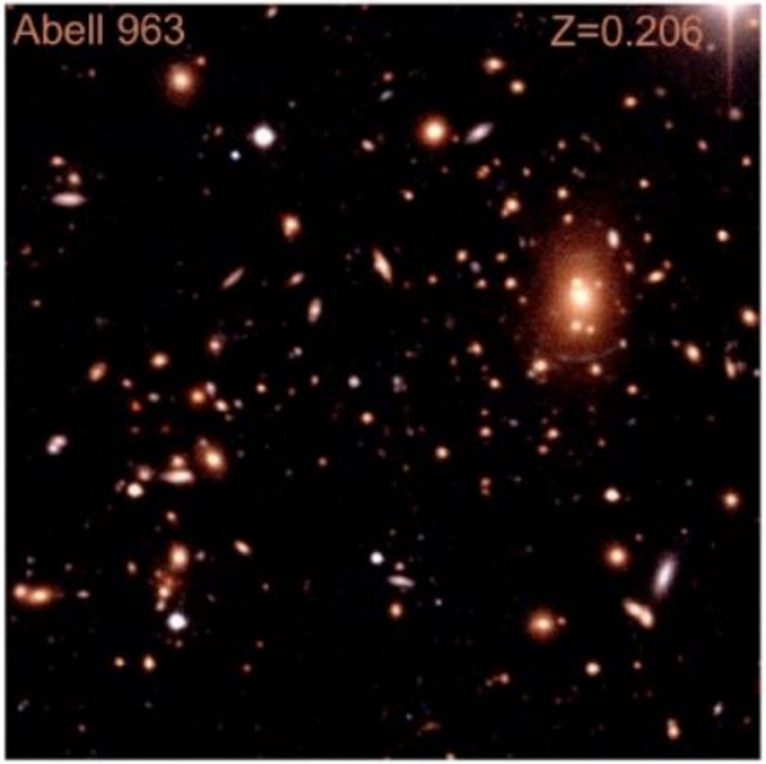
Beam width

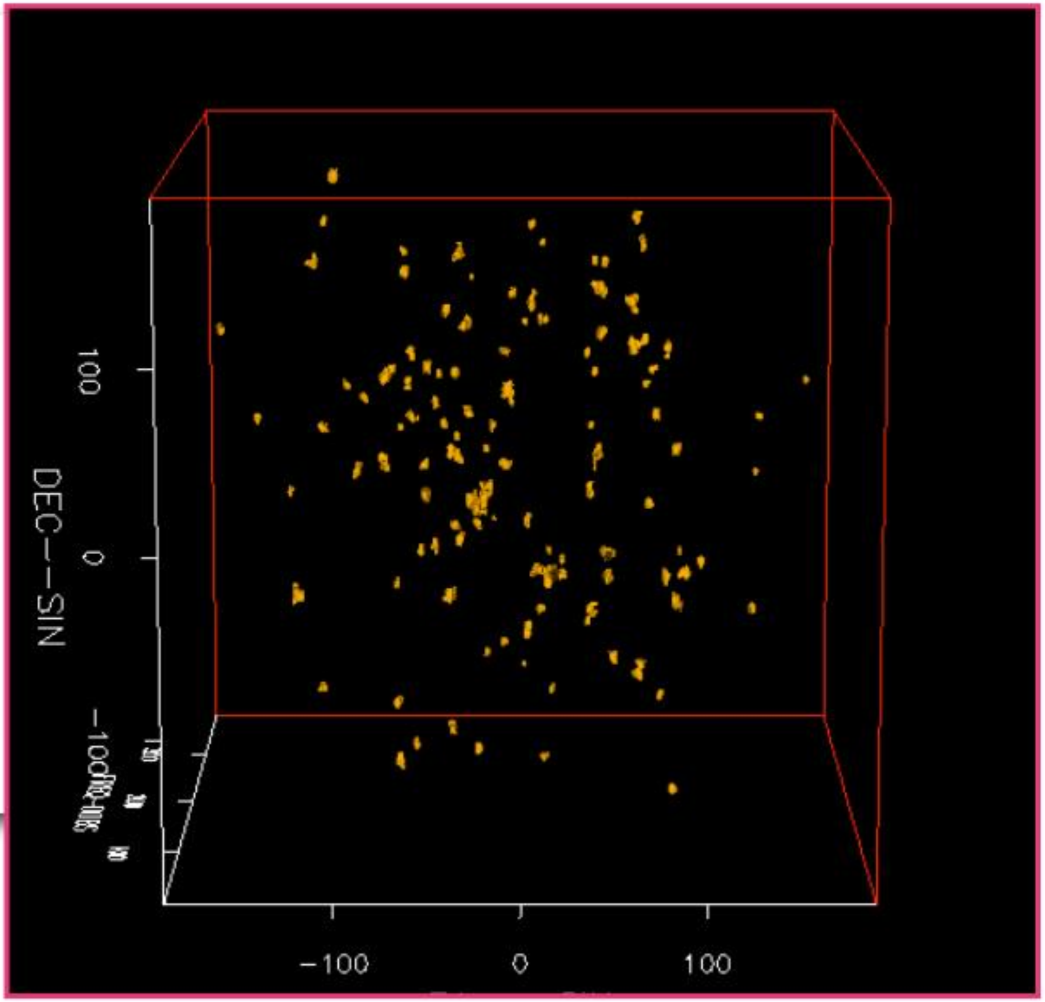
$$\theta \sim \frac{21(1+z)\ \text{cm}}{30000\ \text{cm}} \sim 3(1+z)\,\text{arcmin}$$





Another example of less resolved data: Abell 936





1404 hour integration with WSRT imaging HI emission out to z = 0.2

Deshev, Verheijen, van Gorkom et al. 2012

Image courtesy of T. Van der Hulst,

FAST can detect the cluster as a whole in 10 hrs

Summary

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

- First light expected in 2016

Website: fast.bao.ac.cn