FAST
Science and Data Reduction

Ming Zhu
FAST science group,NAOC
2016-5-10

Complete by 2016-09-26?


Quick Bird Fly Oct. 6, 2005

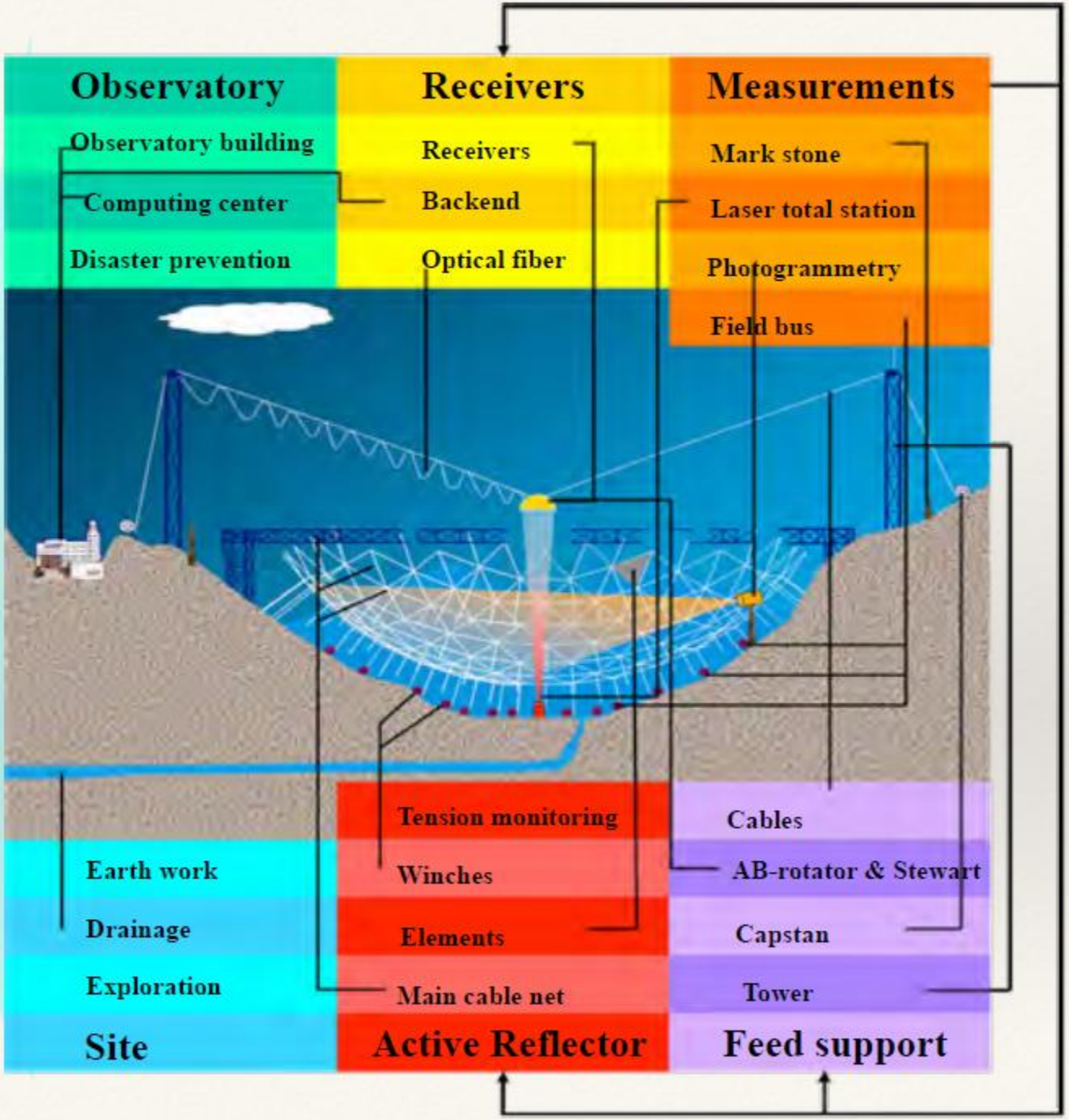
radio973.bao.ac.cn

6 Subsystems

	Site
I	Active Reflector
II	Feed support
III	Measurements
IV	Receivers
	Observatory

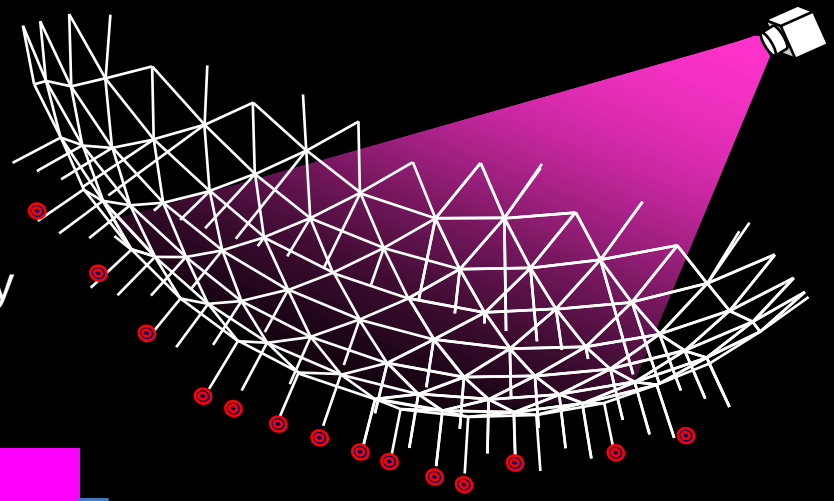
667,230,000 RMB

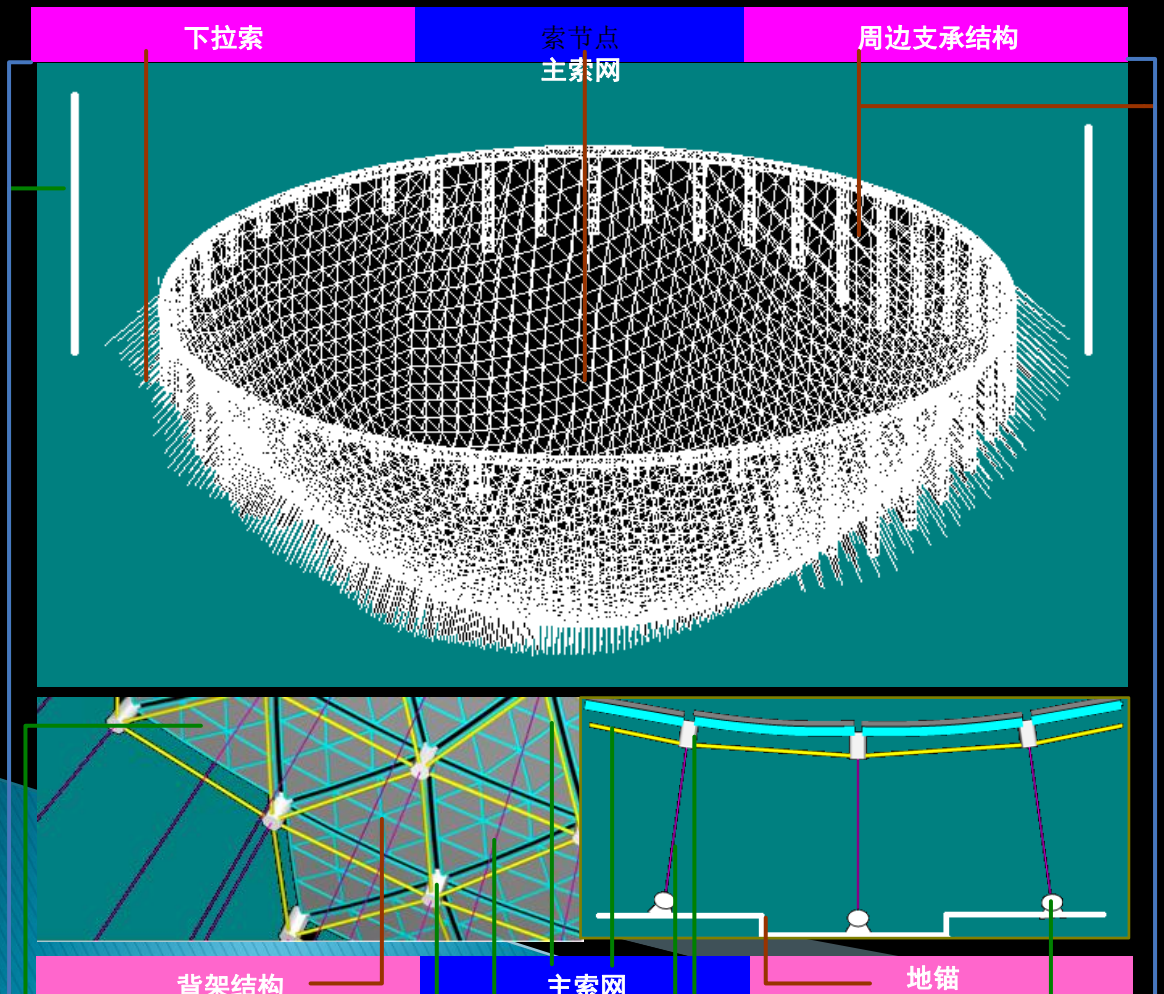
1,149,590,000 RMB



Structure of active reflector

- 500m girder built around hills supported by
- 50 pillars
- Backup consists of ~7000 steel strands
- actuated by ~2300 down tied cables driven by
- winches anchored into ground
- Errors 5.0 mm r.m.s in total

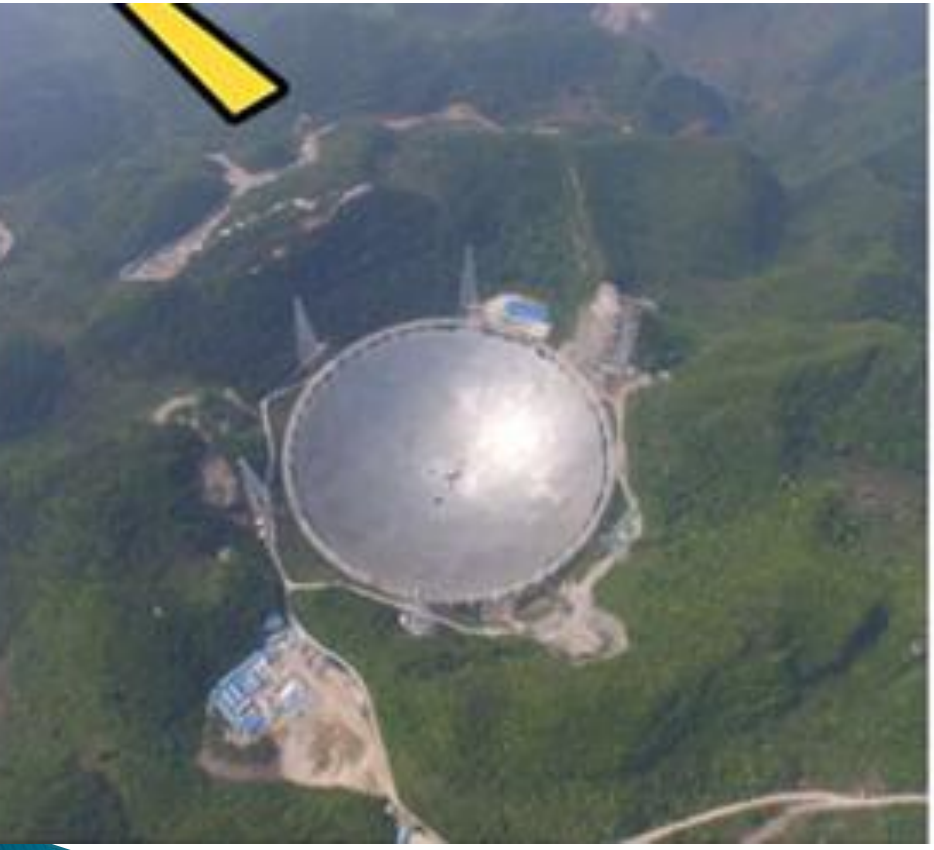




I. Active Reflector: Cable Mesh

III. Focal Cabin

On site data processing center



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

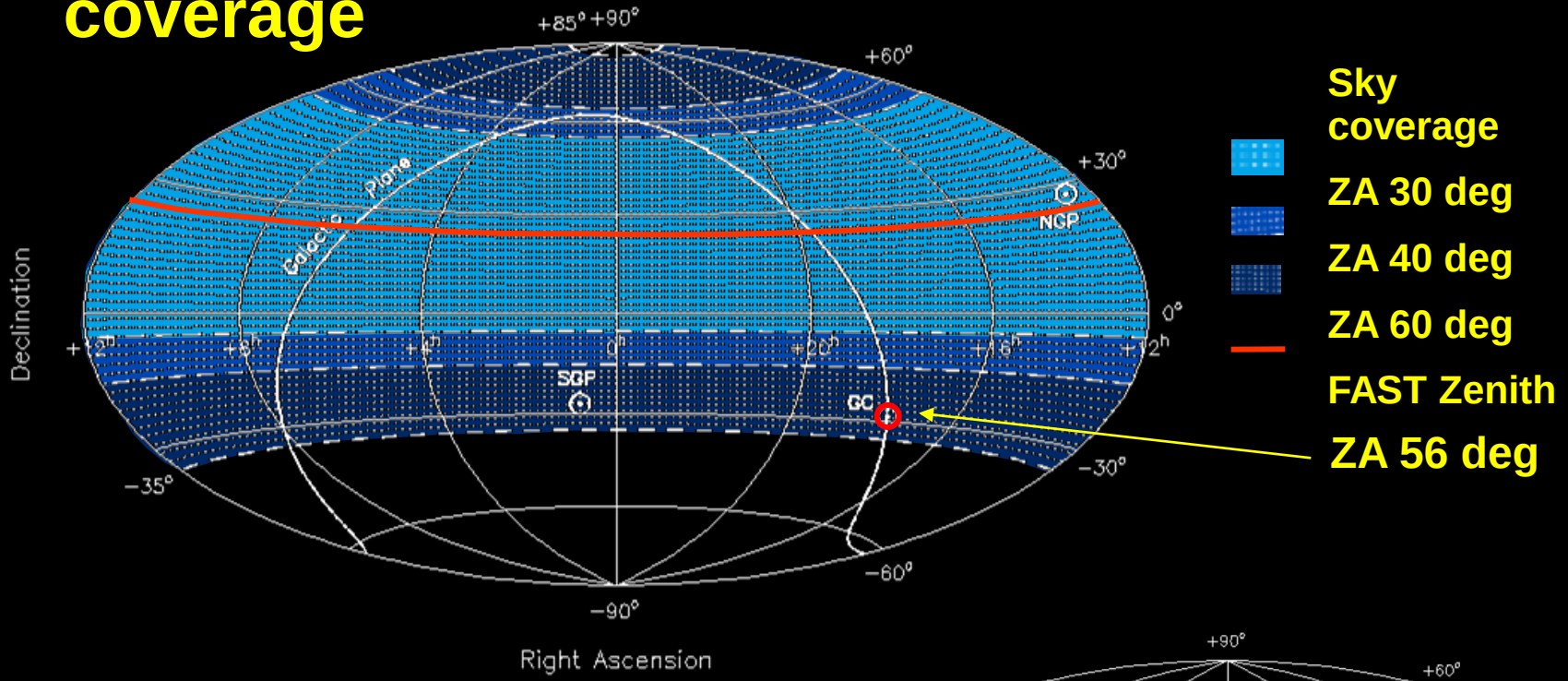
Resolution (L-Band)：2.9′

Multi-beam (L-Band)：19 beam

Slewing：<10min

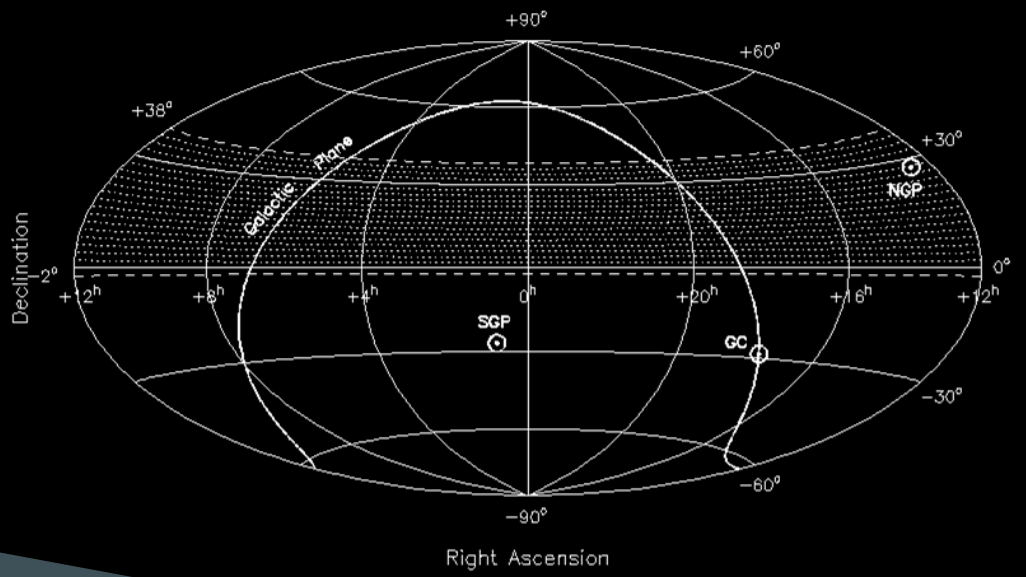
Pointing accuracy：8″

Opening angle - sky coverage

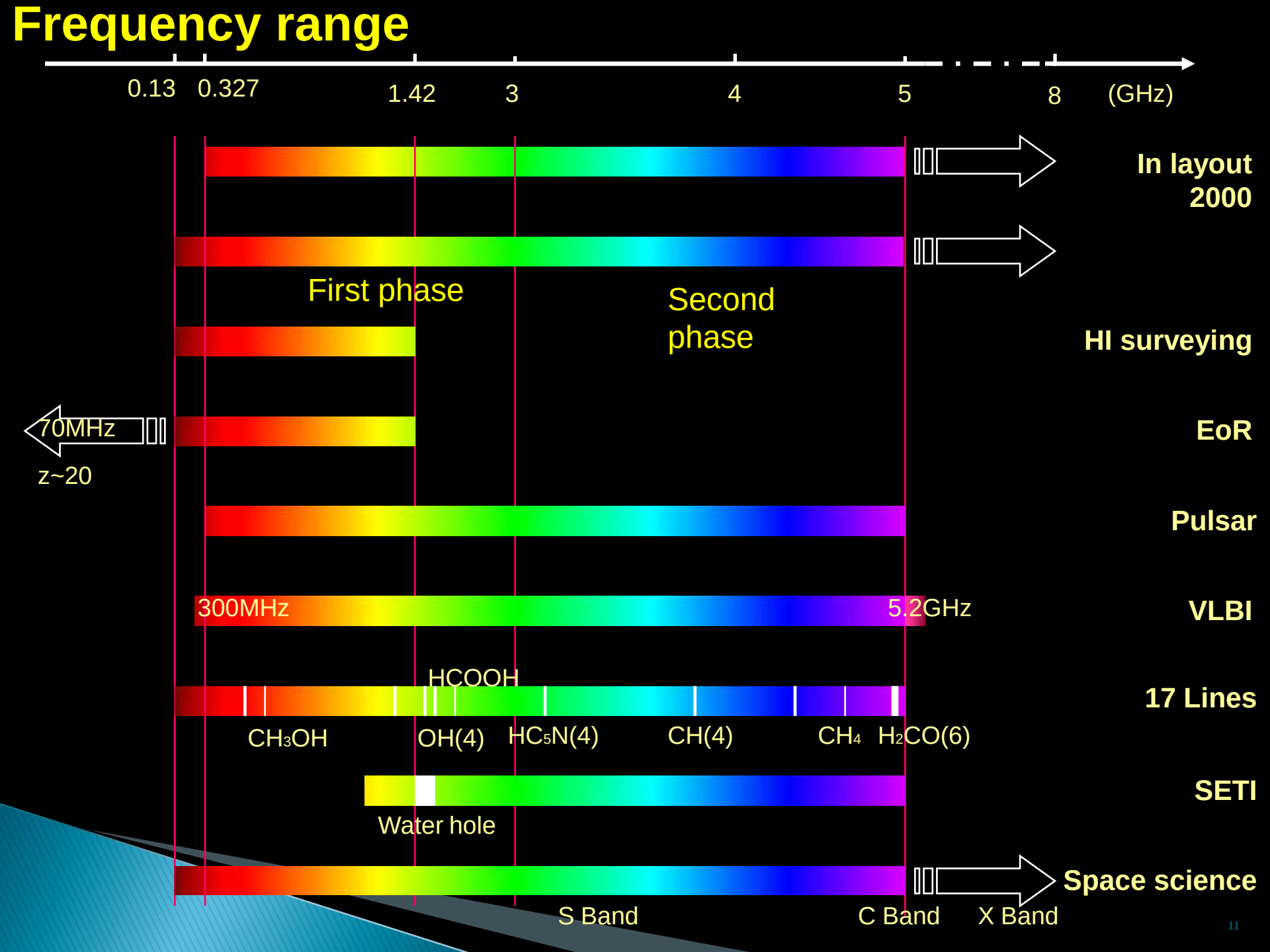


Sky coverage

FAST vs. Arecibo



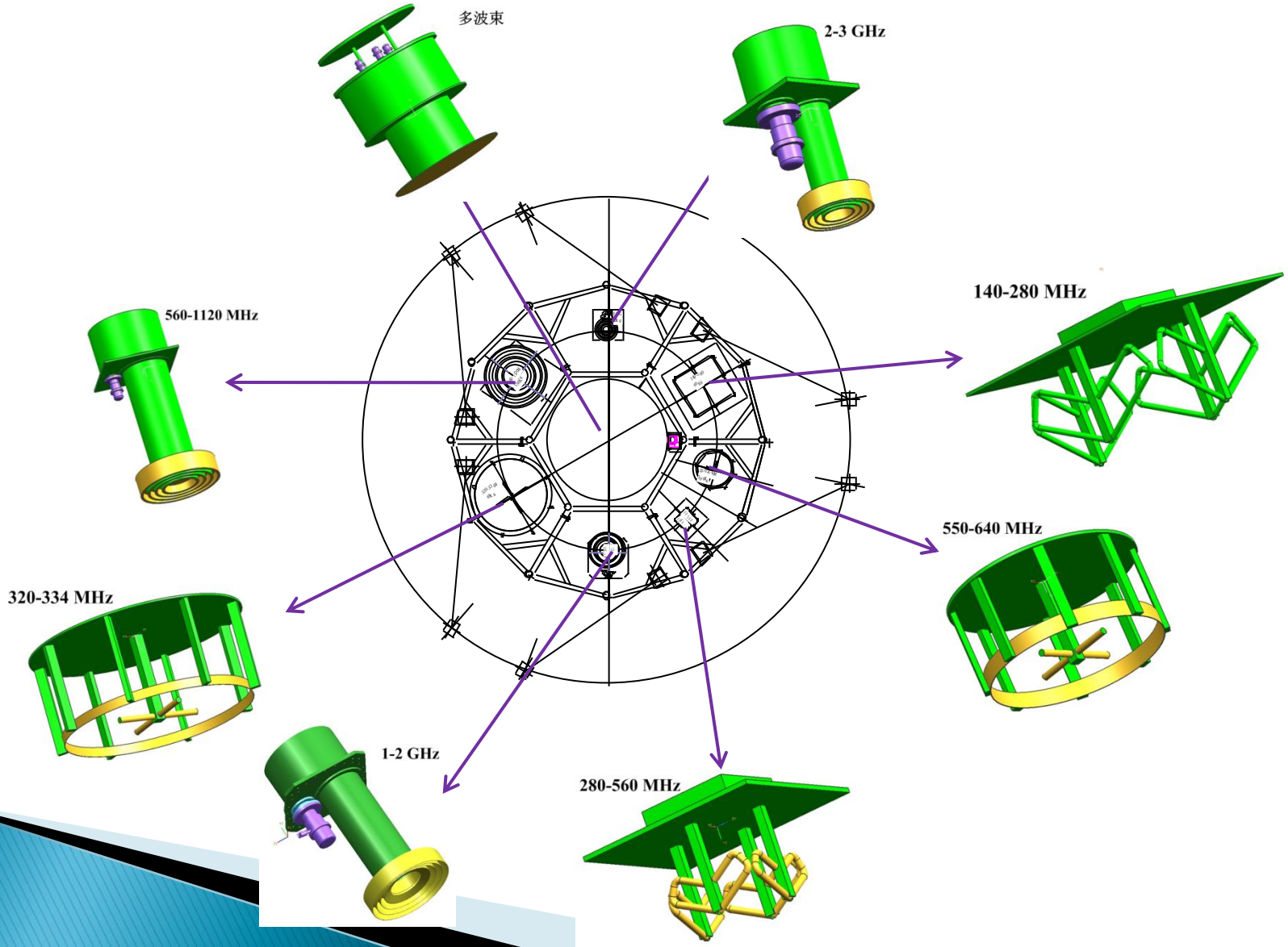
Frequency range



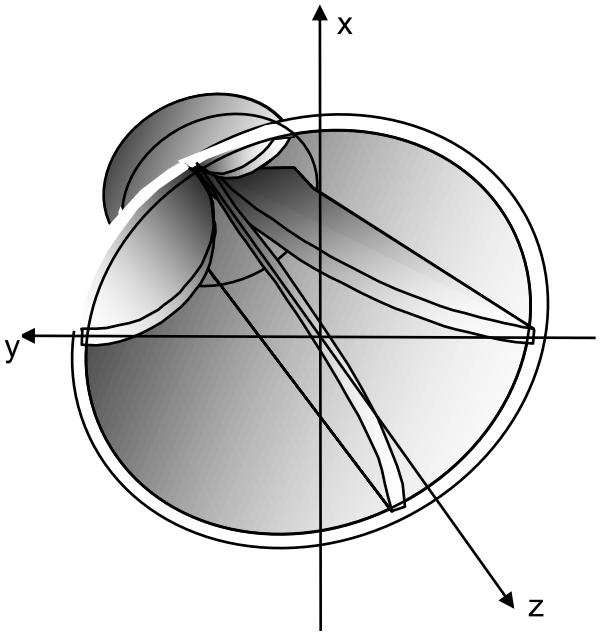
7 sets of frontend

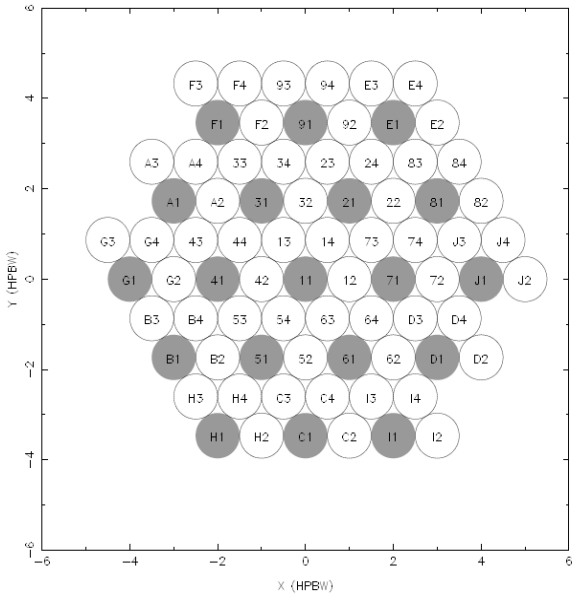
IV. Receiver System

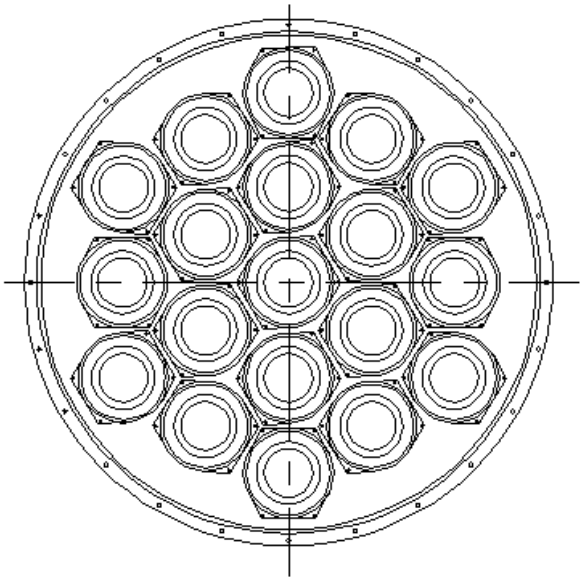
No.	Frequency range[a] (MHz)	Number of Beams	Polarization Mode[b]	System Temperature[c]
1	70-140	1	RCP & LCP	1000
2	140-280	1	RCP & LCP	400
3	270-1620	1	RCP & LCP	35
4	560-1020	1	RCP & LCP	60
5	1100-1900	1	RCP & LCP	25
6	1050-1450	19	X & Y linear	25
7	2000-3000	1	RCP & LCP	25

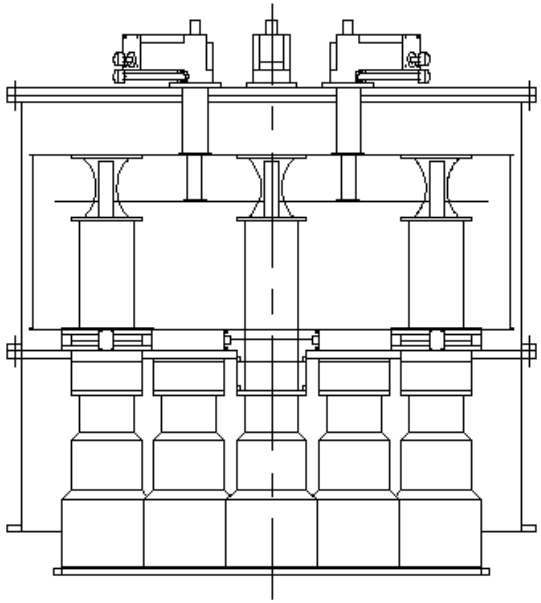

多波束
2-3 GHz
560-1120 MHz
140-280 MHz
320-334 MHz
550-640 MHz
1-2 GHz
280-560 MHz

L-band Multi-beam receivers and its prototyping

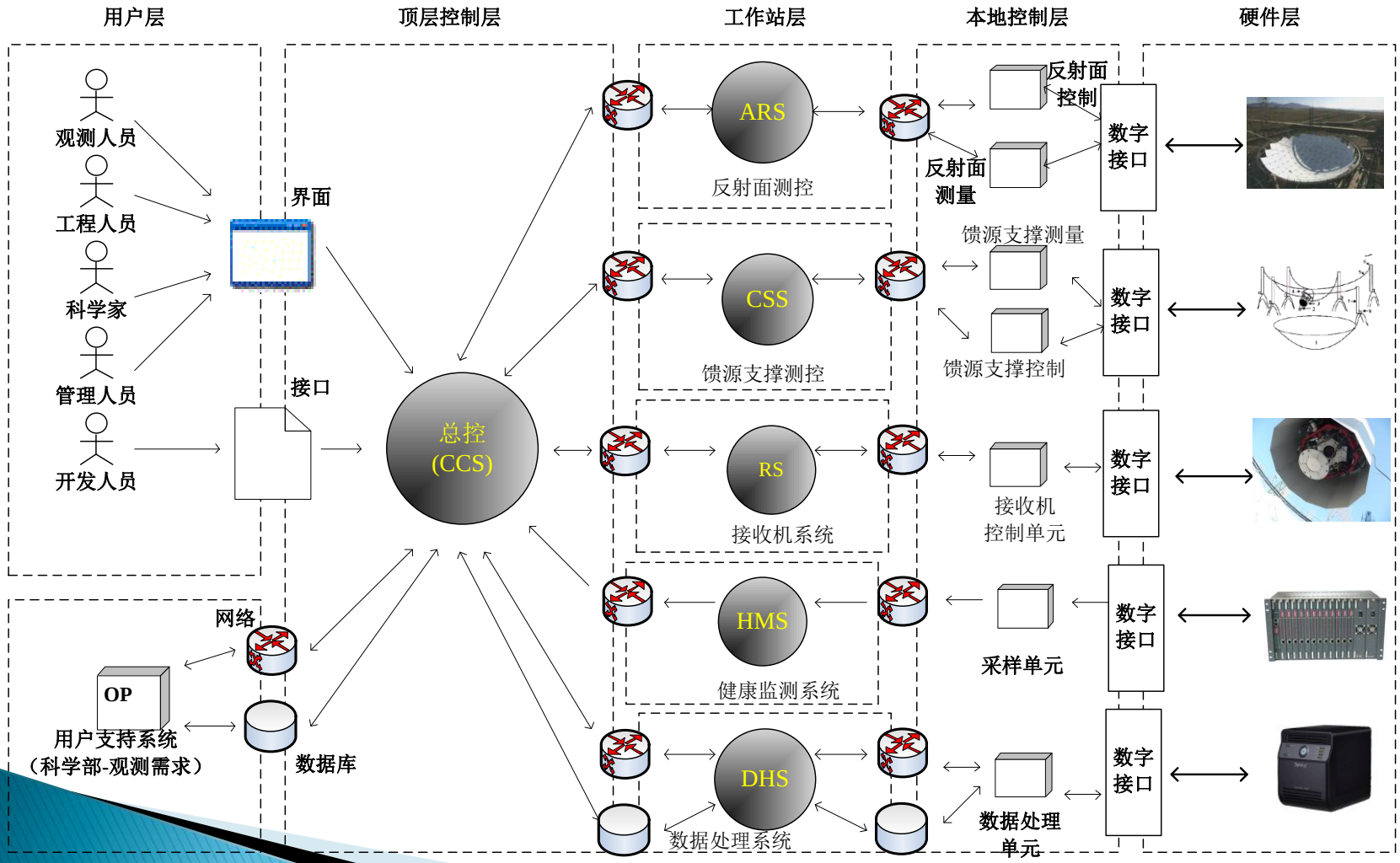




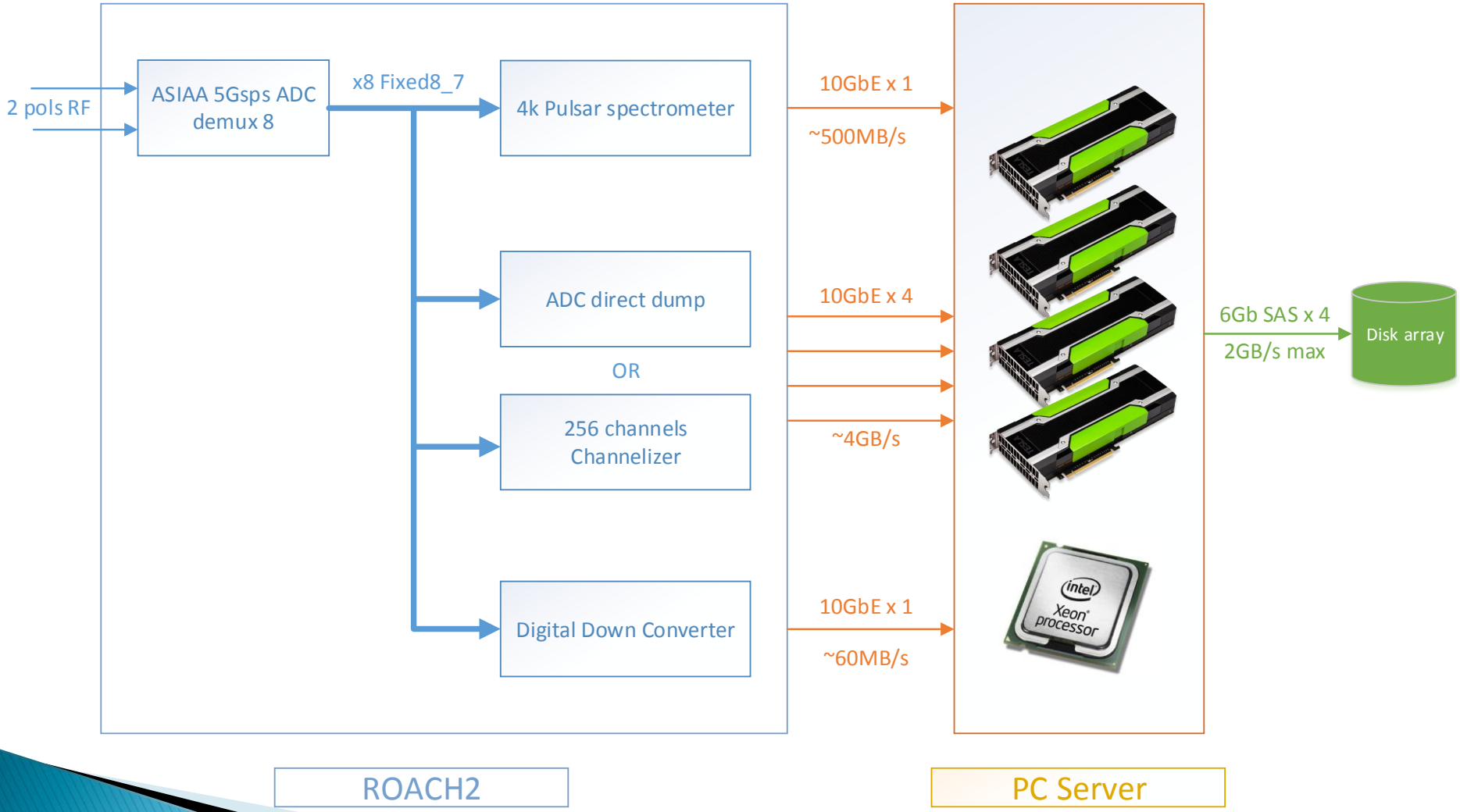




Telescope Control system



Example of hardware assembly



Data Challenges

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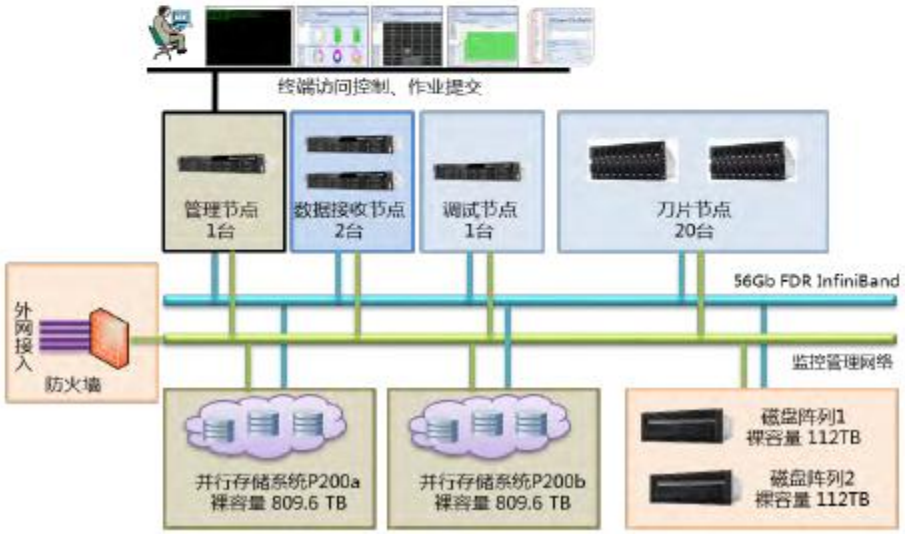
FAST data rate: 1TB/hr

- 3PB/yr容量：与LSST规模相当，10x 大亚湾
- 1P flops：10x 国台老虎集群

随时改装，异地管理，高性能计算，远程同步

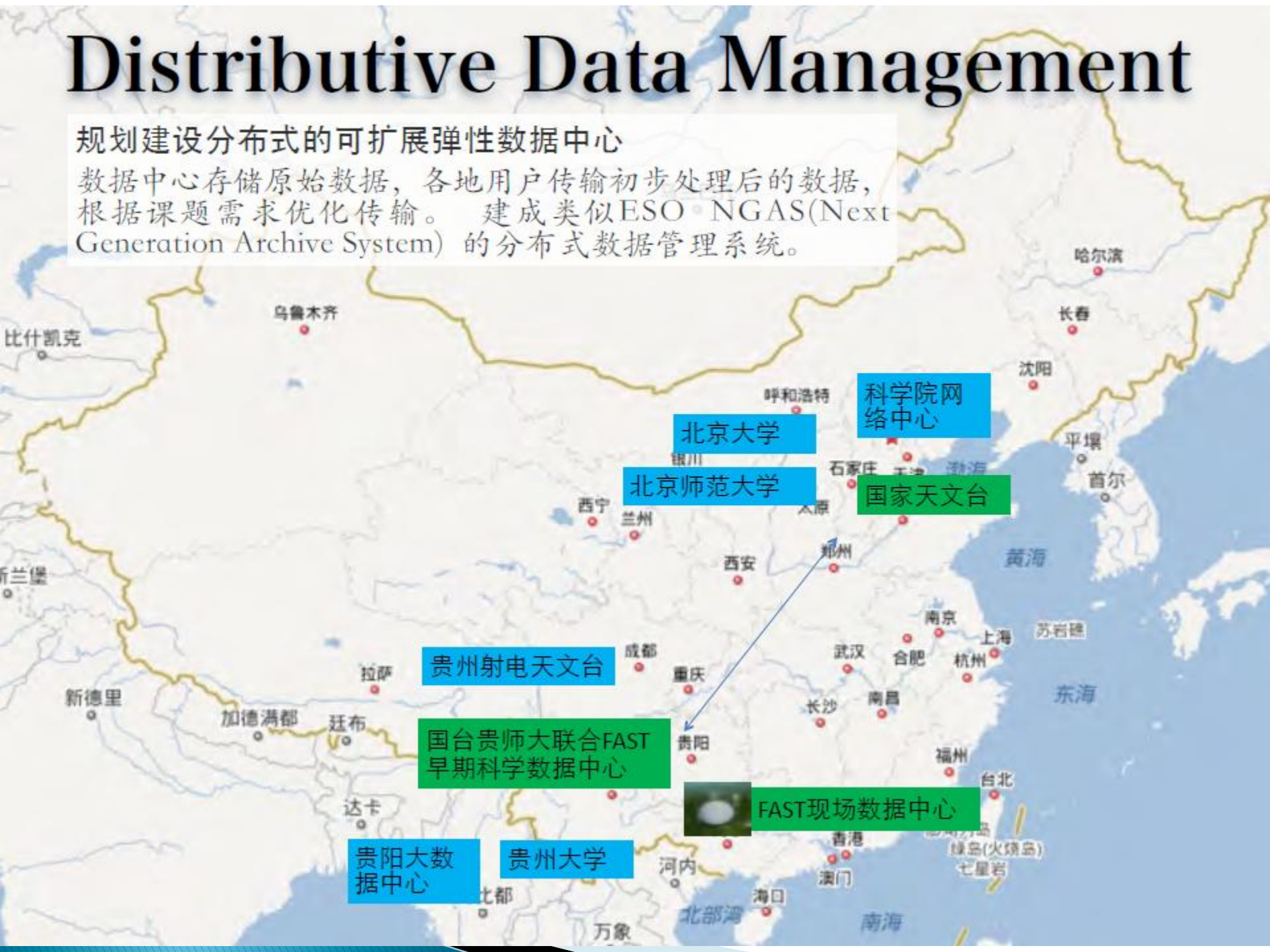


Guizhou Normal University

Distributive Data Management

规划建设分布式的可扩展弹性数据中心

数据中心存储原始数据，各地用户传输初步处理后的数据，根据课题需求优化传输。 建成类似ESO NGAS(Next Generation Archive System) 的分布式数据管理系统。



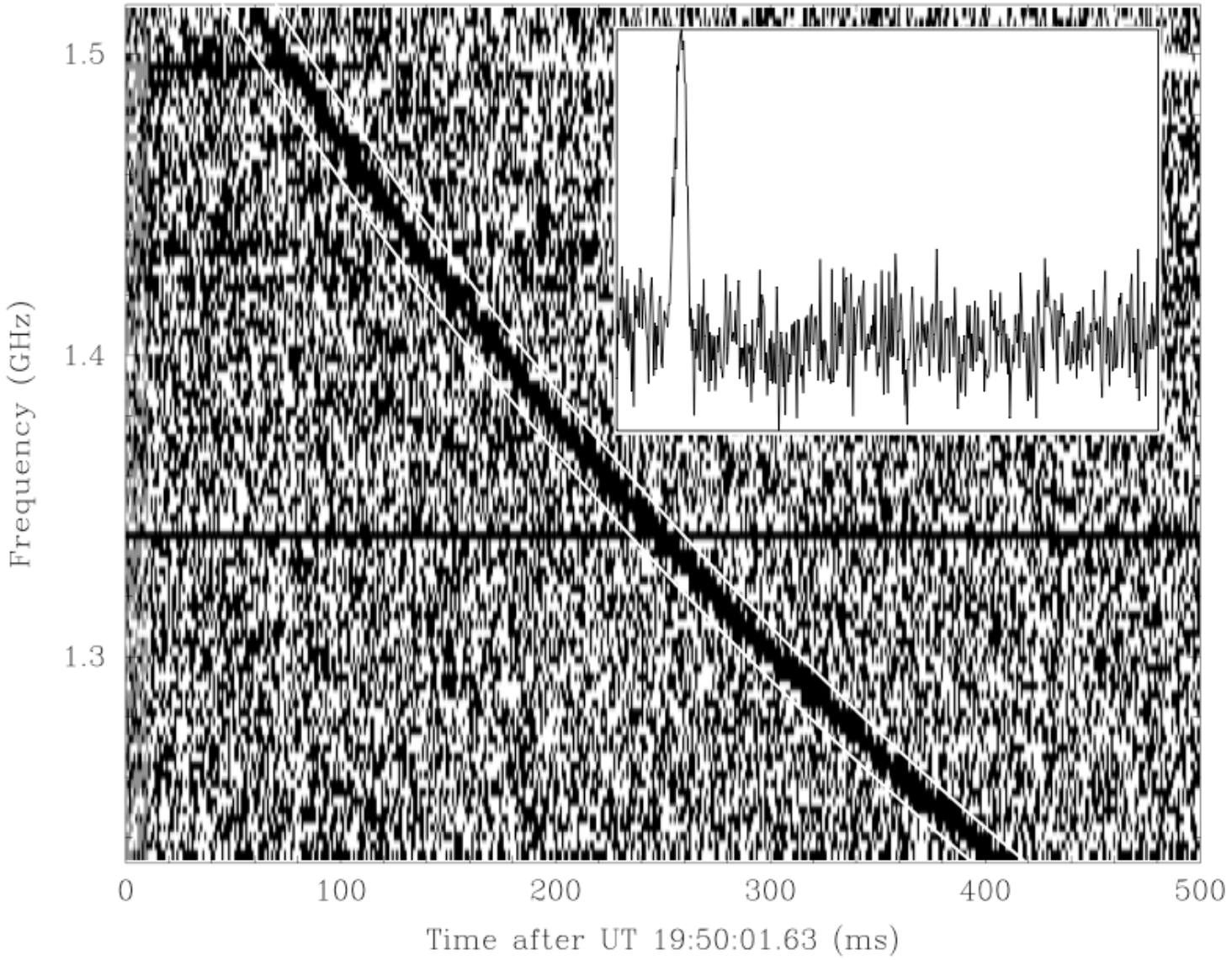
FAST sciences

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

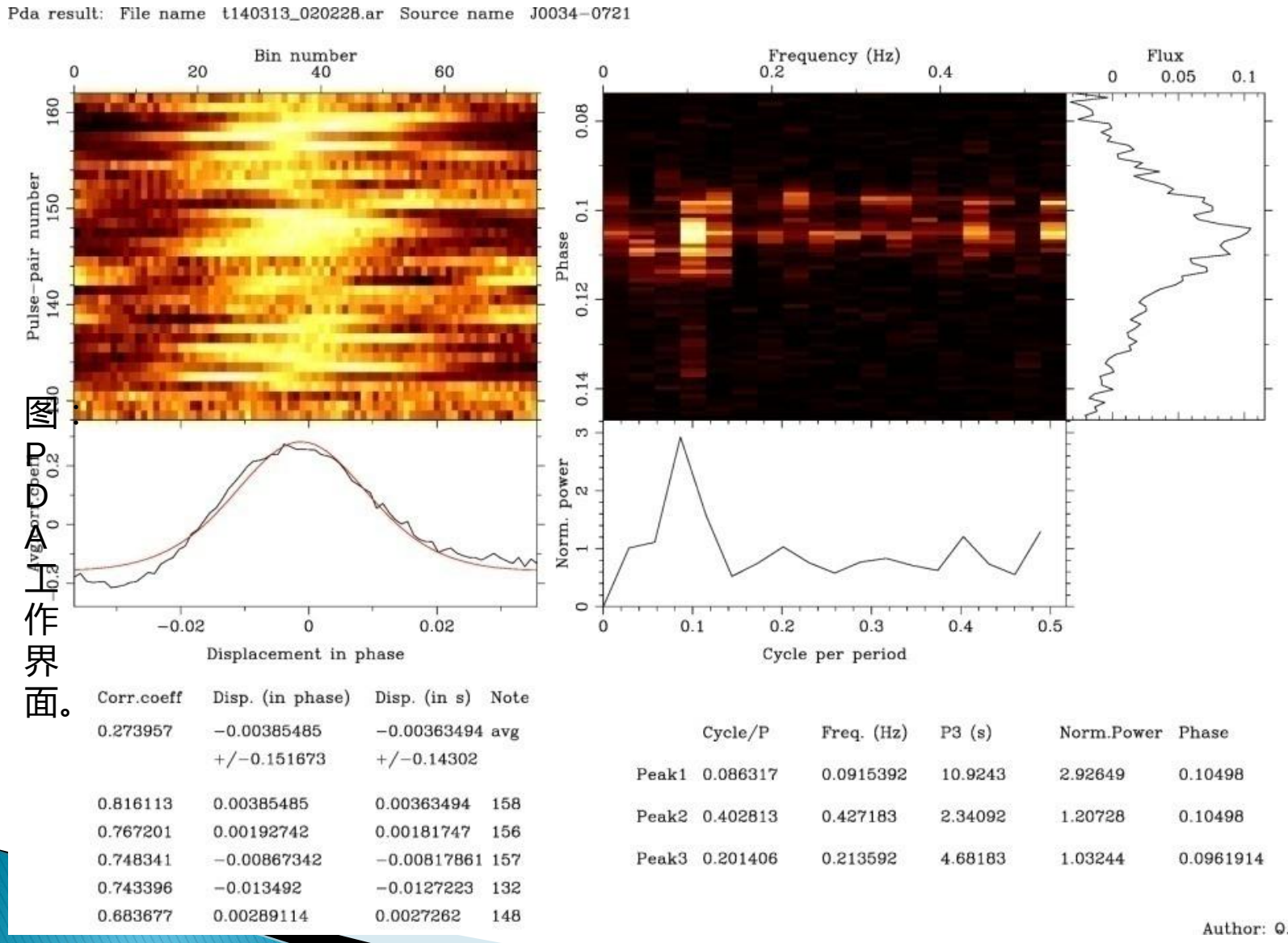
HI studies with FAST

- Extent of HI Disk - truncation
- Extended rotation curve to extreme large distance
- Cold Dark Matter Satellite (ΛCDM)
- HI Mass Function
- Voids
- Surveying Milky Way (FV, Magellanic Stream …)
- HI gas in high redshift galaxies
- HI gas in galaxy clusters and groups
- High z OH megamaser

Lorimer Burst (FRB 010824)
(Lorimer et al 2007)



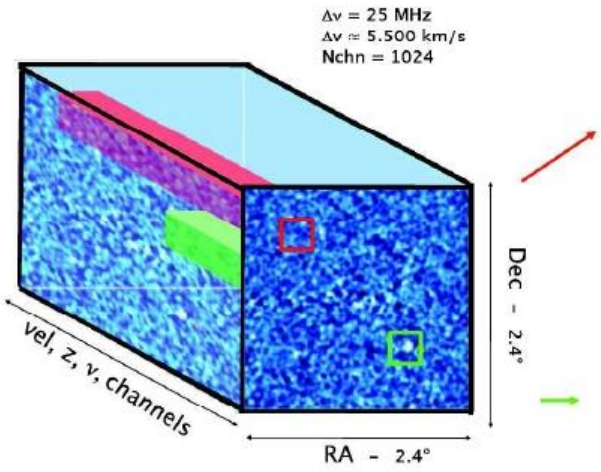
Pulsar data analysis tools

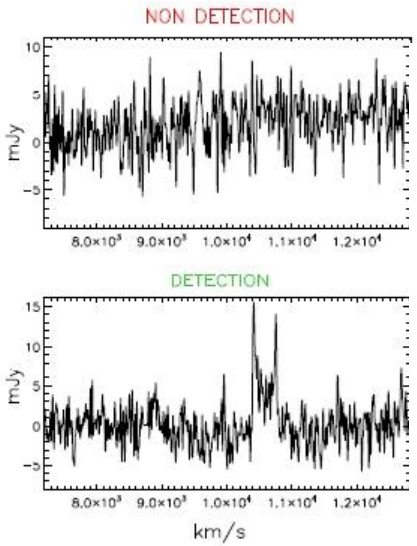


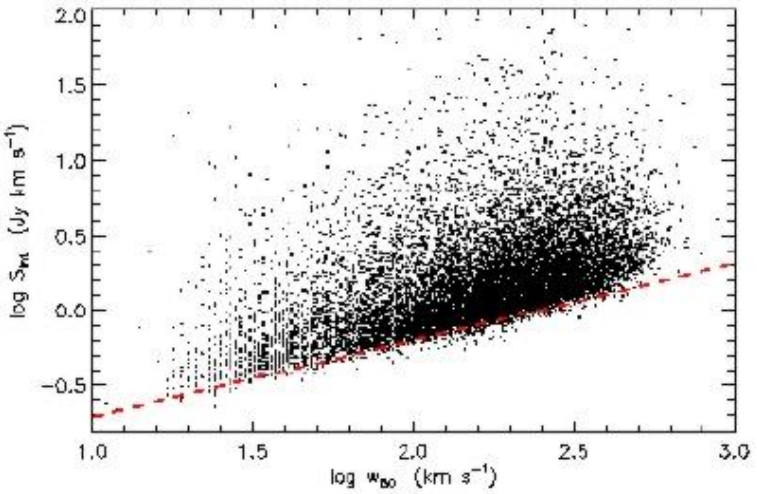
图：PDA工作界面。

HI survey data reduction

- Based on Arecibo ALFALFA survey

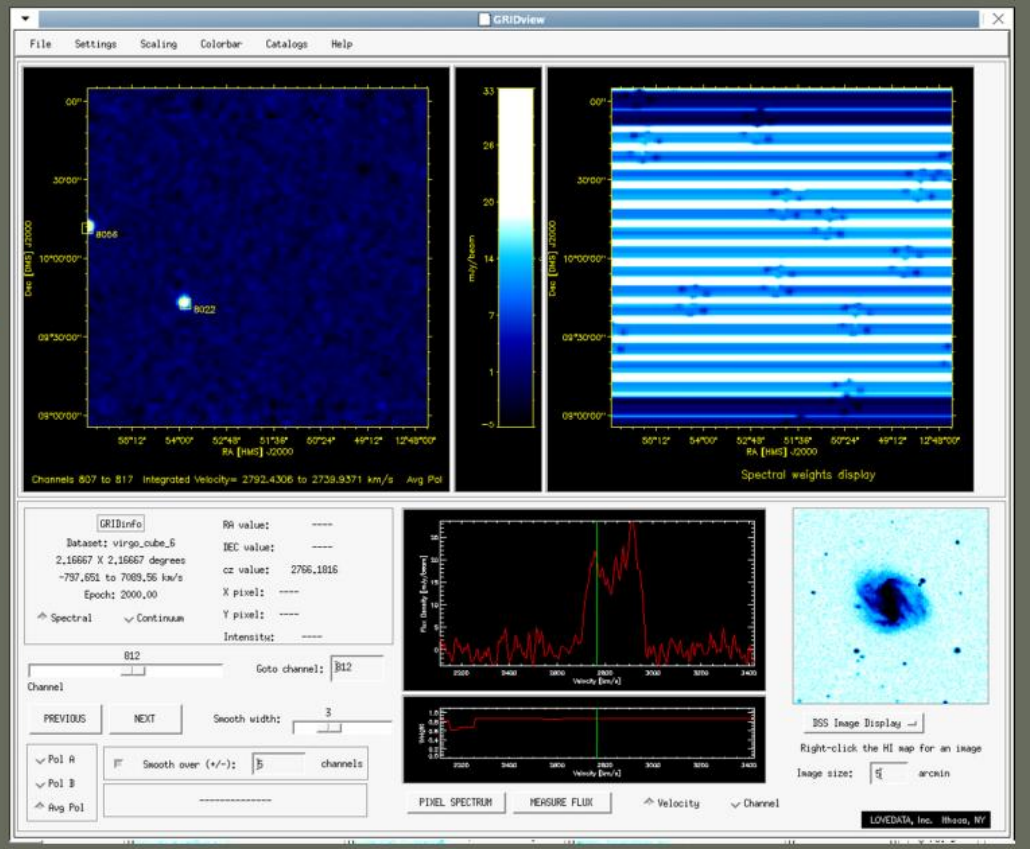


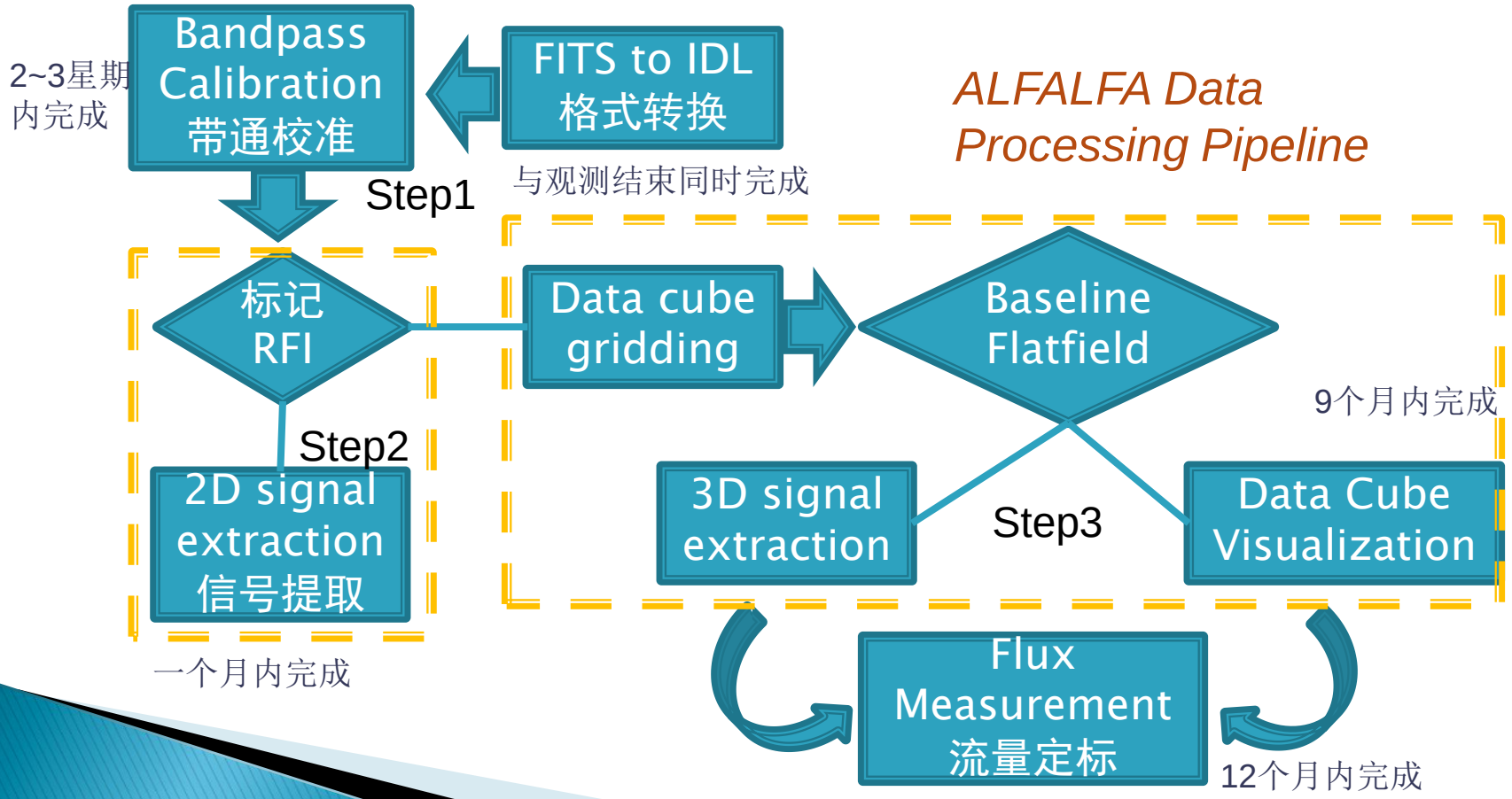


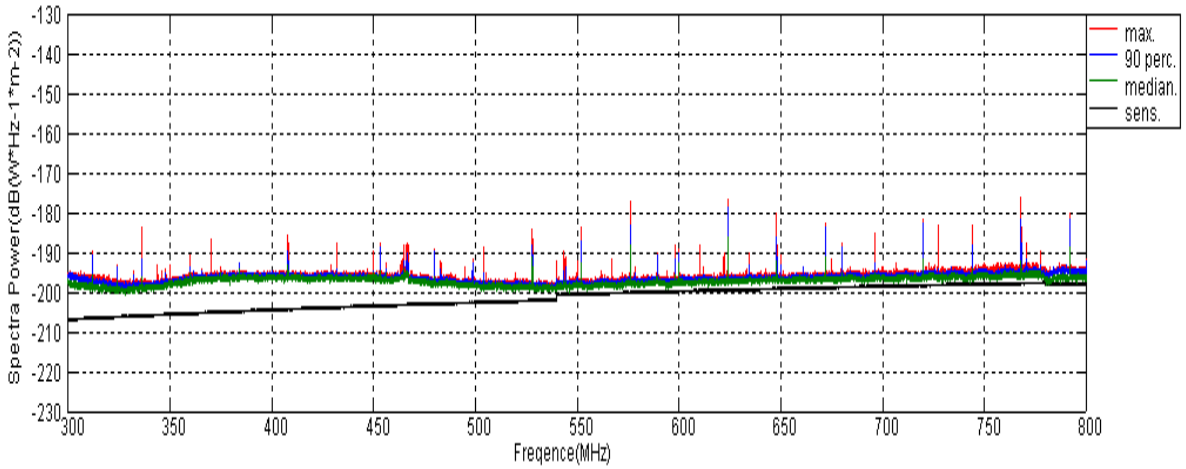


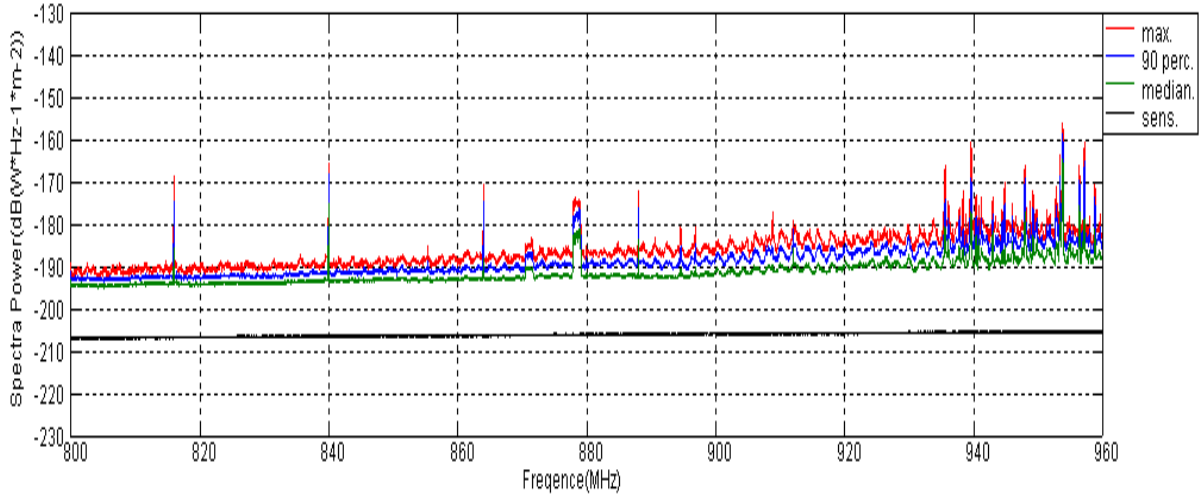
Data cube and link with SDSS

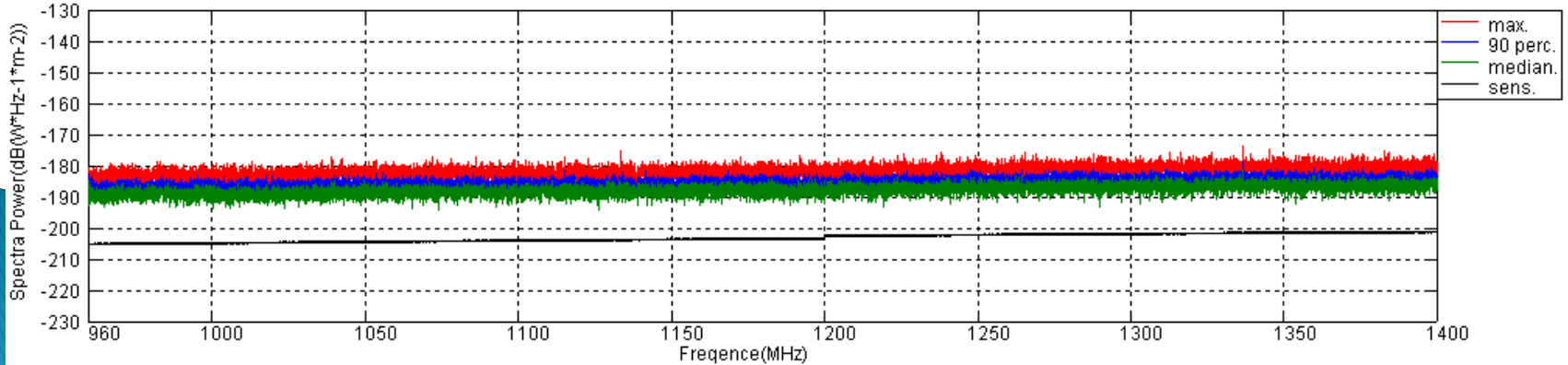
- *Data cubes and corresponding 3D catalogs are examined in GRIDview.*
- *The upper left display is a channel map; at upper right is the corresponding weights map.*
- *Controls allow user to view channel or integrated maps at different velocities.*
- *DSS, DSS2, Sloan, NVSS images can be fetched.*
- *NED and other on-line catalogs – including internal ones – can be accessed and overplotted*

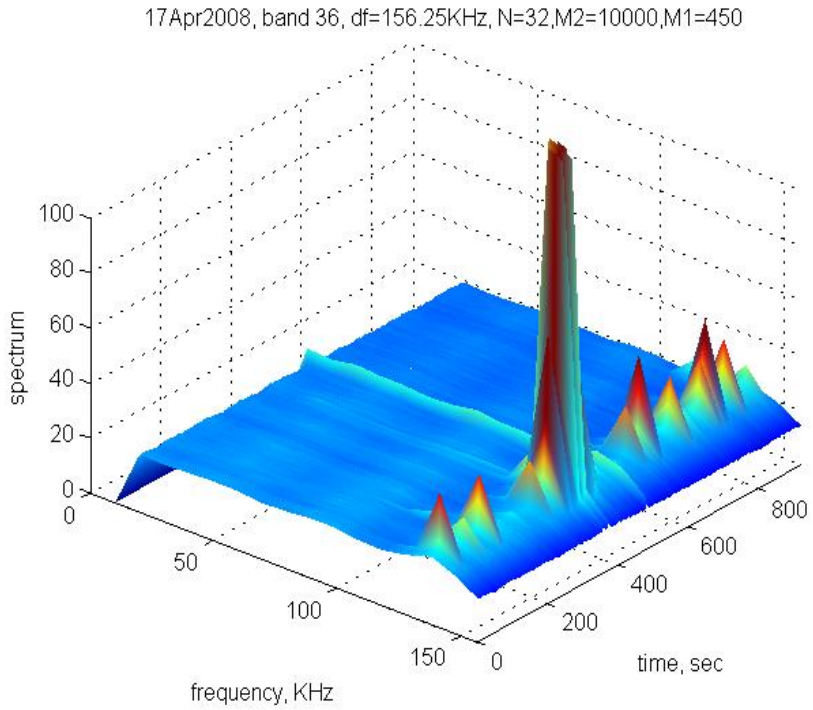


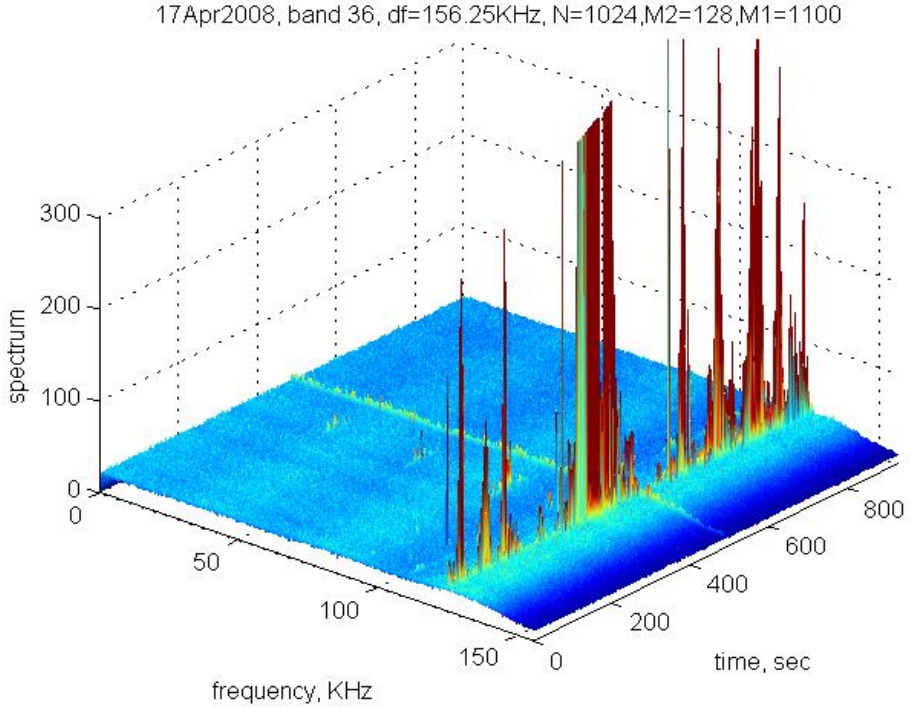

ALFALFA Data Processing Pipeline
2~3星期内完成
Bandpass Calibration 带通校准
FITS to IDL 格式转换
与观测结束同时完成
Step1
标记 RFI
Data cube gridding
Baseline Flatfield
9个月内完成
Step2
2D signal extraction 信号提取
一个月内完成
3D signal extraction
Step3
Data Cube Visualization
Flux Measurement 流量定标
12个月内完成

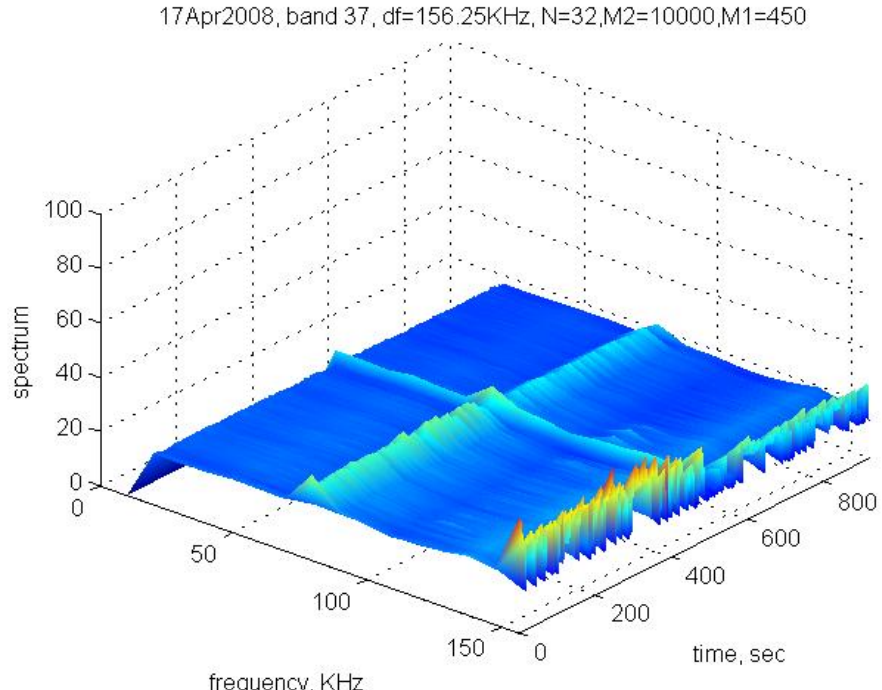

Spectra Power(dB(W*Hz-1*m-2))
-130
-140
-150
-160
-170
-180
-190
-200
-210
-220
-230
300
350
400
450
500
550
600
650
700
750
800
Freqence(MHz)
max.
90 perc.
median.
sens.

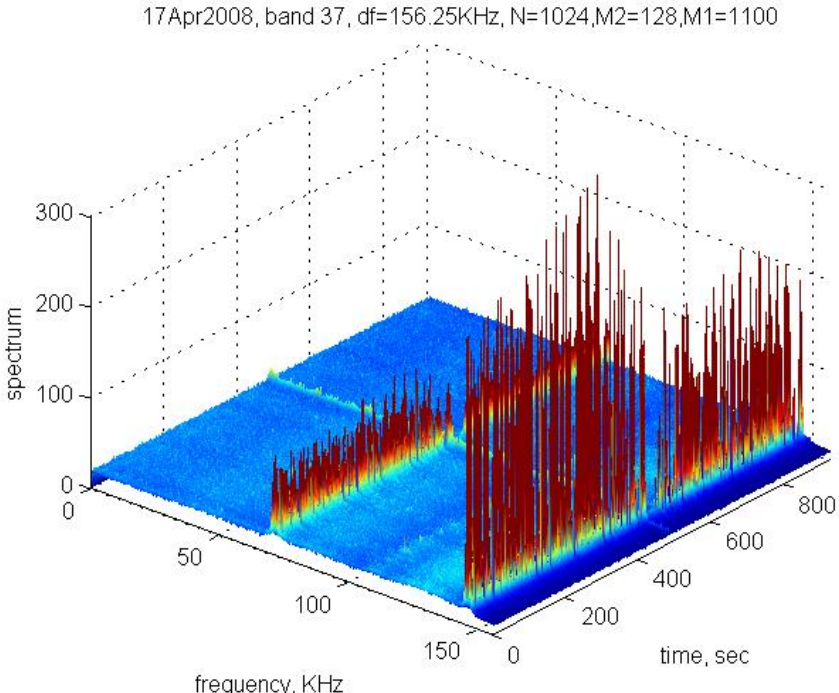

Spectra Power(dB(W*Hz-1*m-2))
-130
-140
-150
-160
-170
-180
-190
-200
-210
-220
-230
800
820
840
860
880
900
920
940
960
Freqence(MHz)
max.
90 perc.
median.
sens.


Spectra Power(dB(W*Hz-1*m-2))
-130
-140
-150
-160
-170
-180
-190
-200
-210
-220
-230
960
1000
1050
1100
1150
1200
1250
1300
1350
1400
Freqence(MHz)
max.
90 perc.
median.
sens.


17Apr2008, band 36, df=156.25KHz, N=32,M2=10000,M1=450
spectrum
frequency, KHz
time, sec


17Apr2008, band 36, df=156.25KHz, N=1024,M2=128,M1=1100
spectrum
frequency, KHz
time, sec

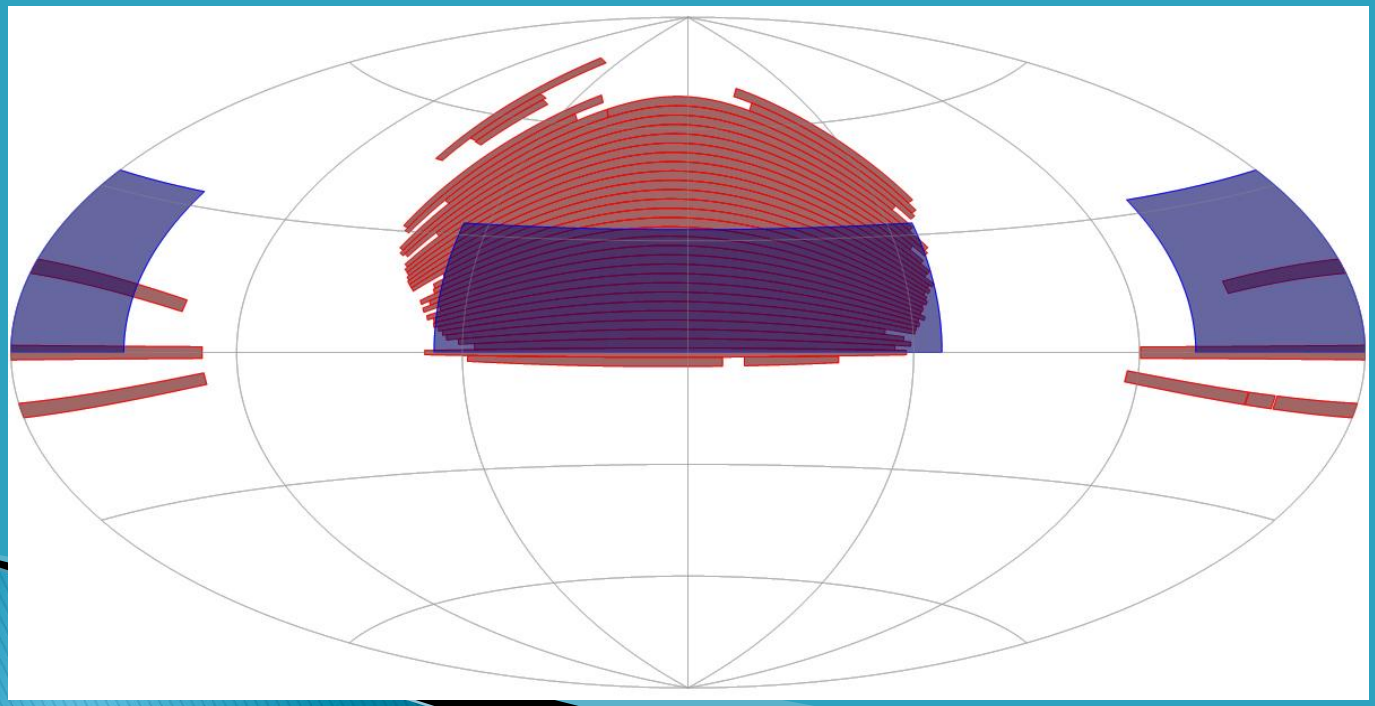

17Apr2008, band 37, df=156.25KHz, N=32,M2=10000,M1=450
spectrum
frequency, KHz
time, sec


17Apr2008, band 37, df=156.25KHz, N=1024,M2=128,M1=1100
spectrum
frequency, KHz
time, sec

FAST all-sky HI survey

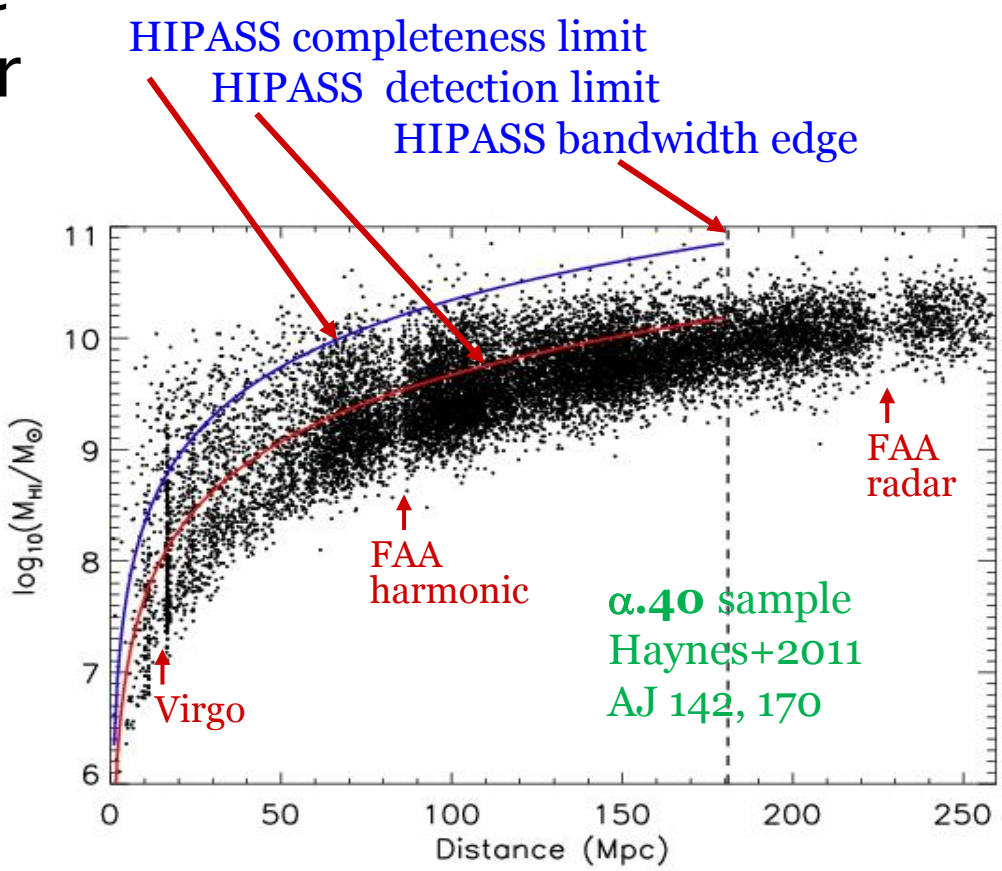
Using a 19 beam L-band receiver to map the FAST sky at 20- 40 sec per beam, doable in 1-2 yrs.

Expect about 1 million detections (Duffy et al. 2008, 2012) with $M_{HI} < 10^{11}\ M_{\odot}$ out to $z \sim 0.15$ in a range of environments including Coma, Hydra, Ursa Major, Persues-Pisces supercluster plus neighboring voids.

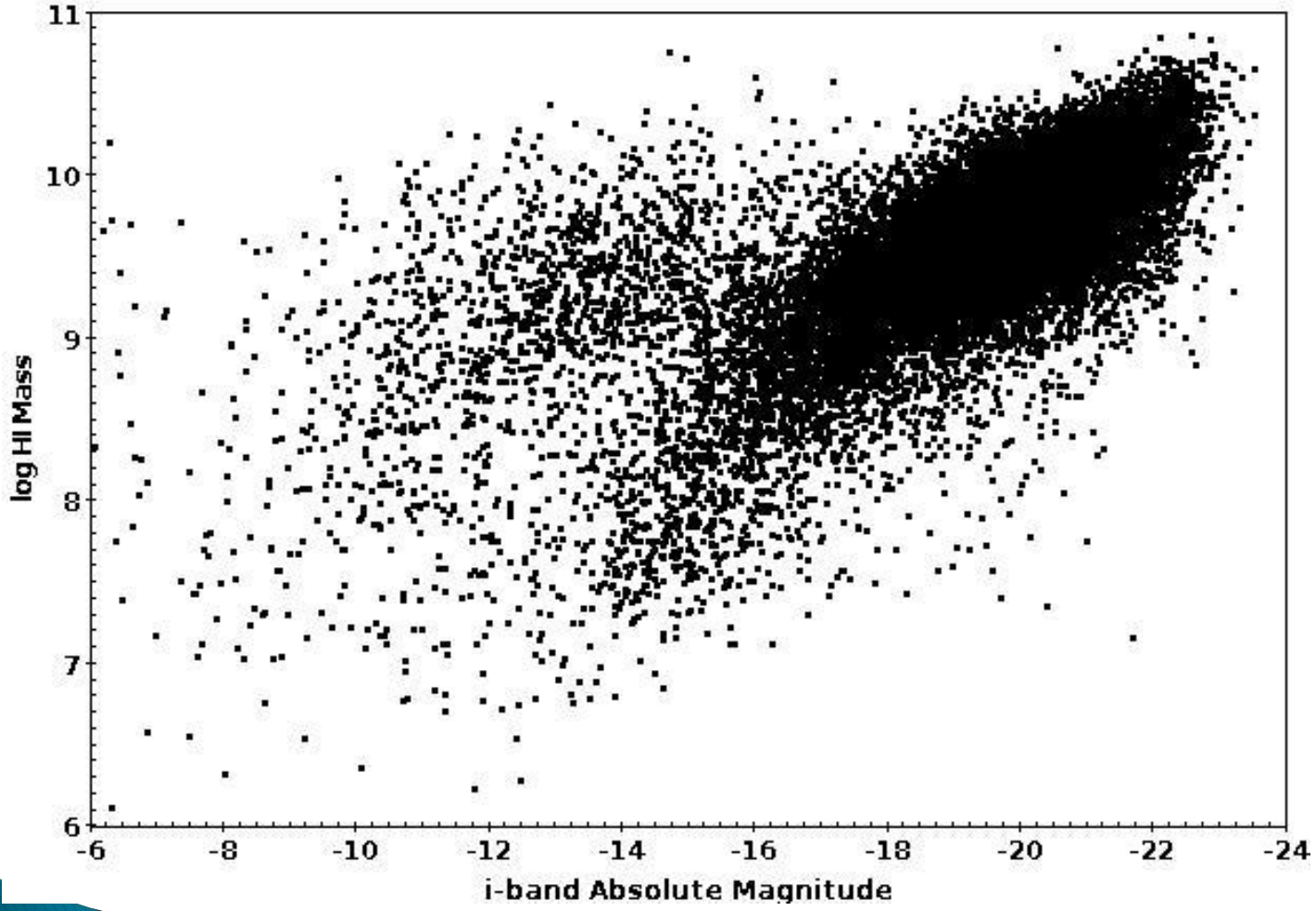


ALFALFA 40% catalog

- Census of HI in the Local Universe over cosmologically significant volume
  - 15000+ detections in 40% of final area
  - 70% are new detections



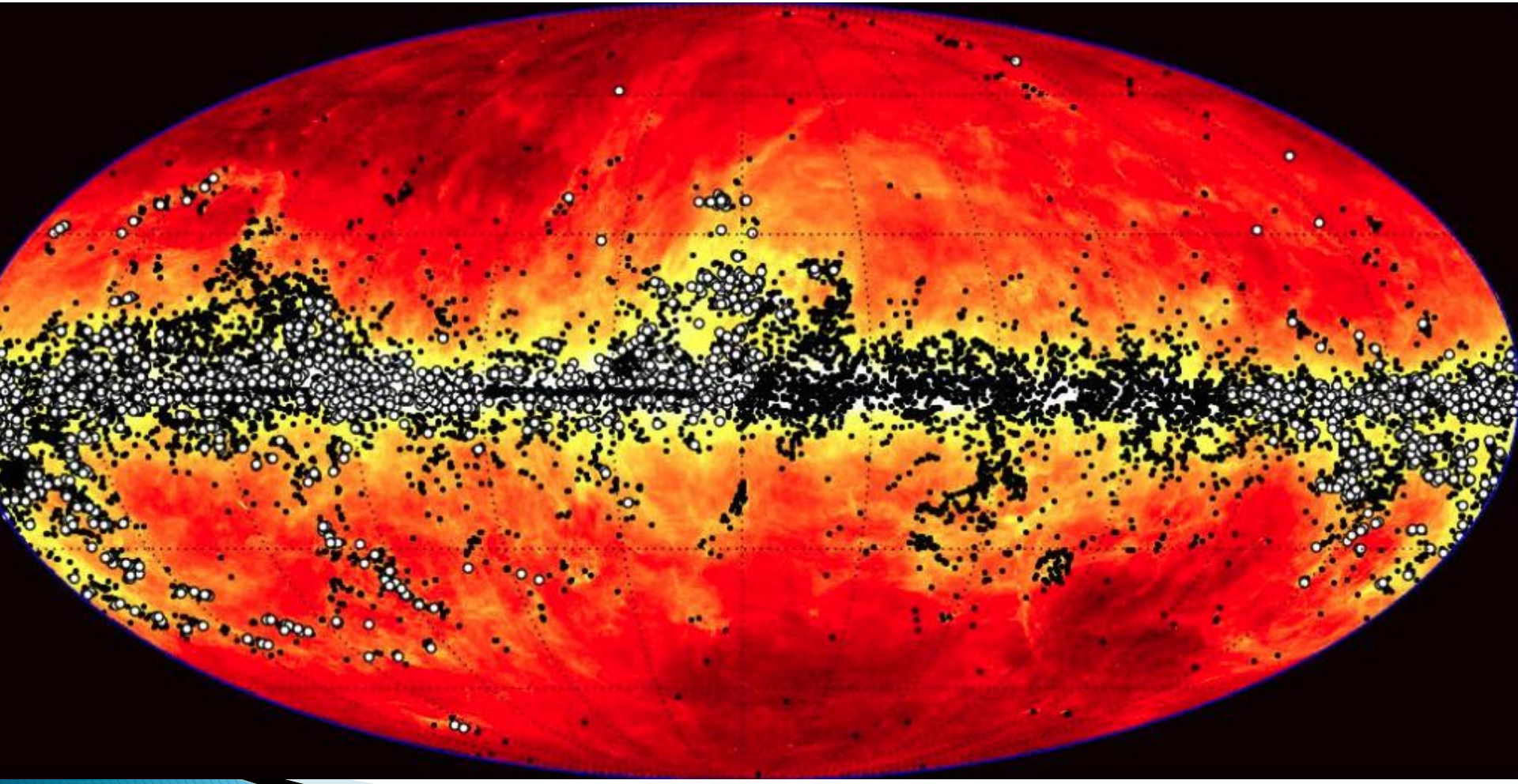
ALFALA –SDSS data crossmatch



- Above
- M*~ 5 x 10^8 M□
- HI mass scales with stellar mass
- for SF galaxies

(Credit Martha Haynes)

Future All sky HI maps



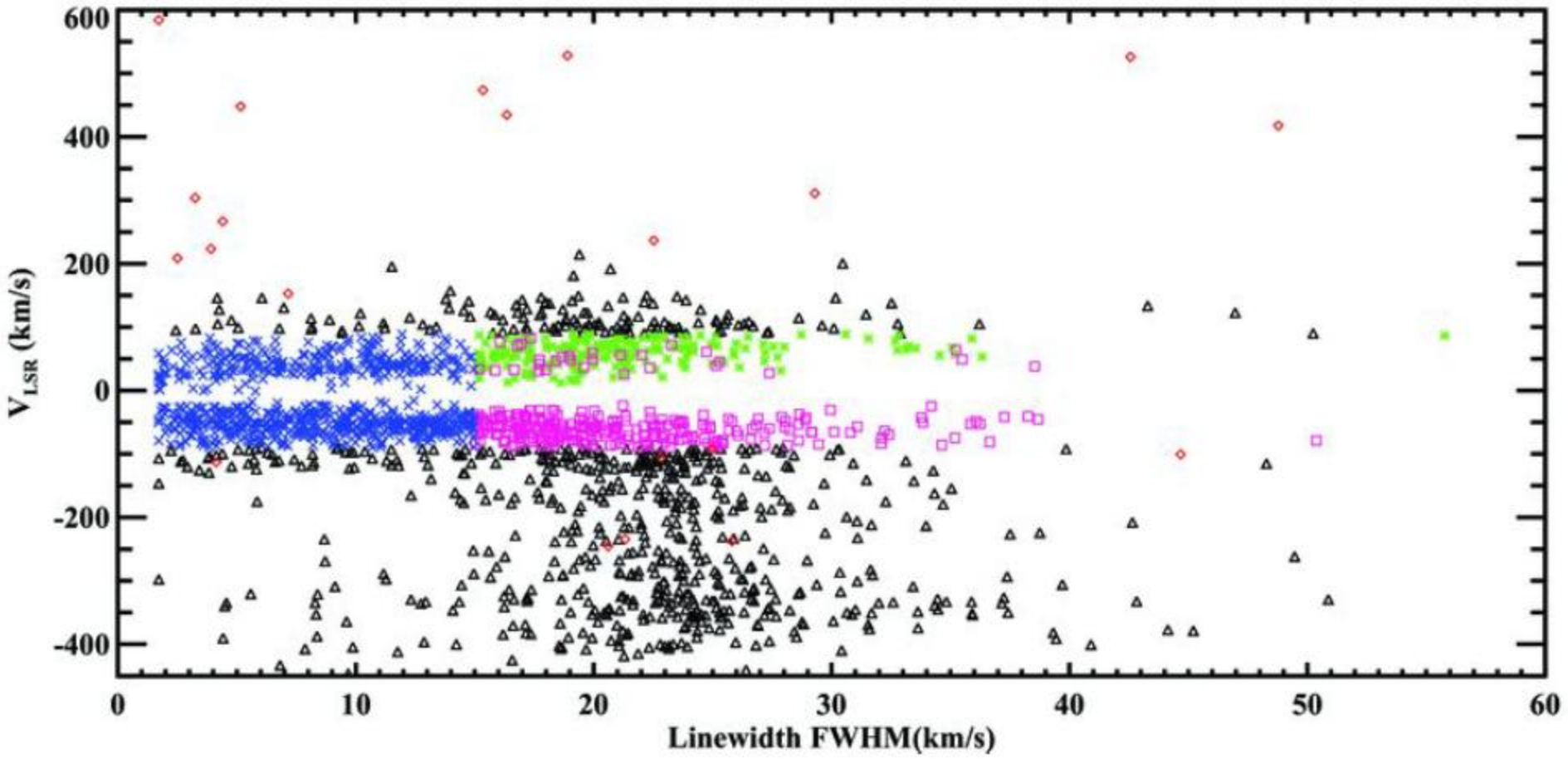


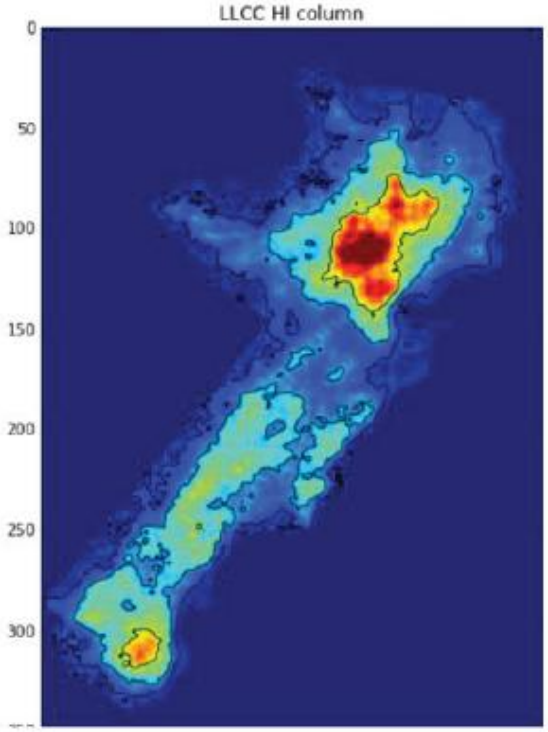
Figure 7. Line width and V_{LSR} distributions for all clouds. The differently colored symbols correspond to the five populations—HVCs (black triangles), galaxy candidates (red diamonds), cold LVCs (blue Xs), warm LVCs (pink open squares), and warm Q3 LVCs (green filled squares). This plot best illustrates where the populations are separated. See Figure 9 for the velocity and line width distribution for each population.

(A color version of this figure is available in the online journal.)

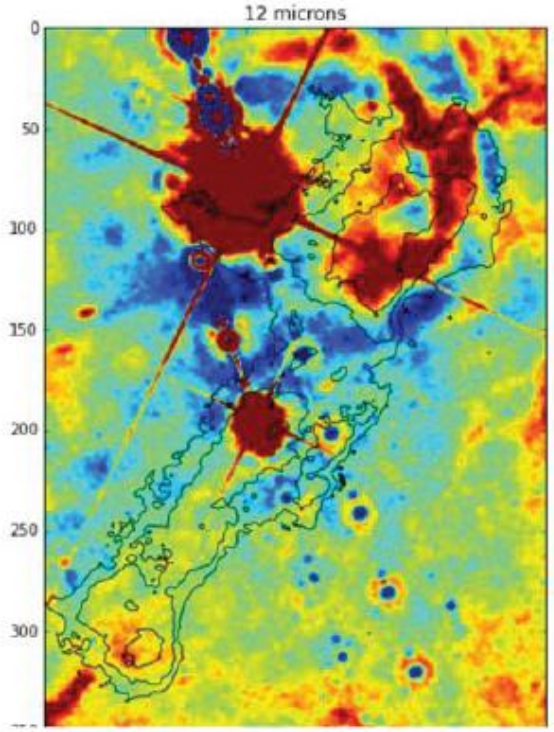
Carl Heiles 2015

This cloud is deficient in 12 micron emission, which is produced by tiny grains (PAHs). It is <u>not</u> deficient in ordinary grains. <u>Conclusion: it's just the PAHs—not all the grains—that heat the ordinary diffuse ISM</u>!

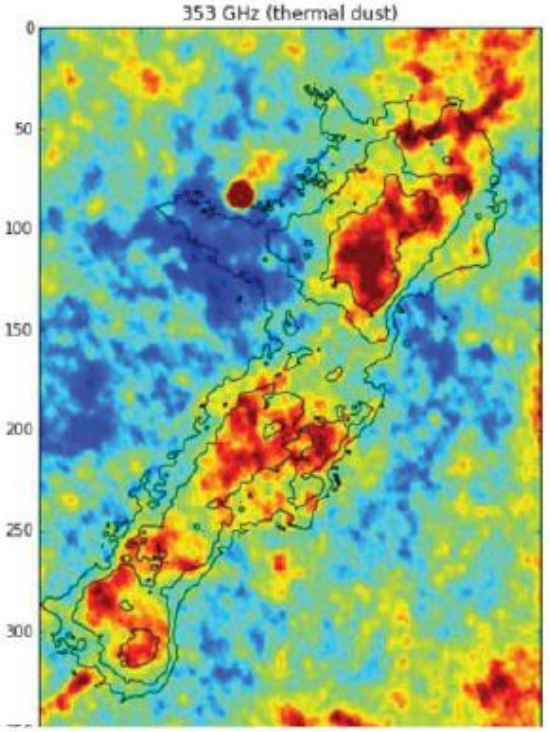
21-cm line HI



12 micron PAHs



353 GHz thermal dust



Carl Heiles 2015

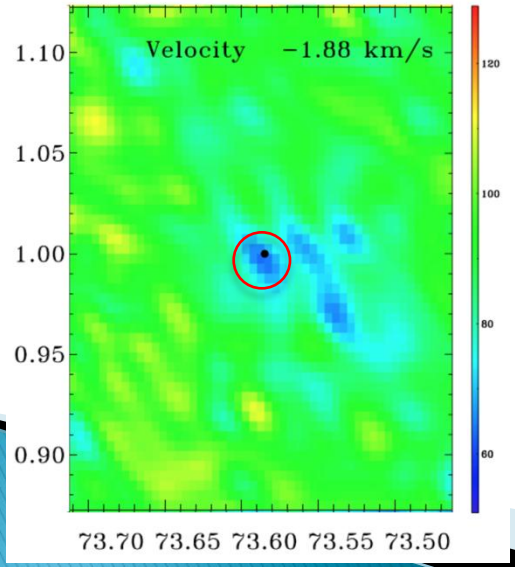
HISA as a tool to constrain T,N,n (D. Li et al. 2015

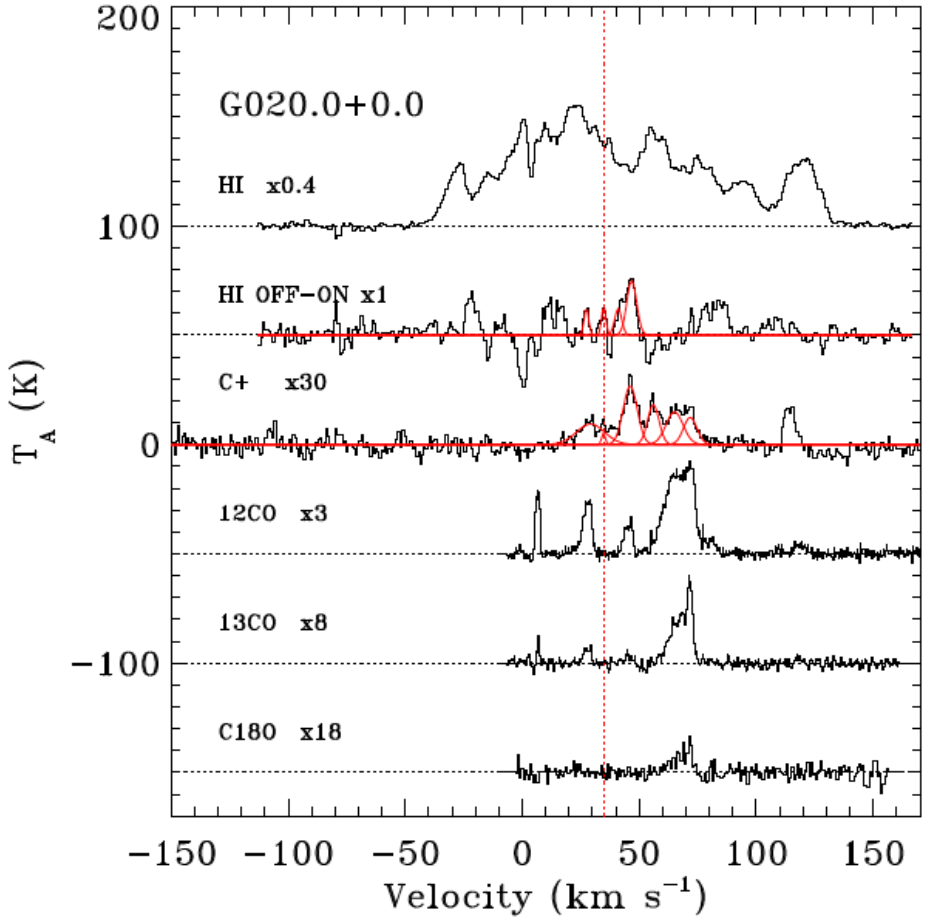
HISA: HI self-absorption

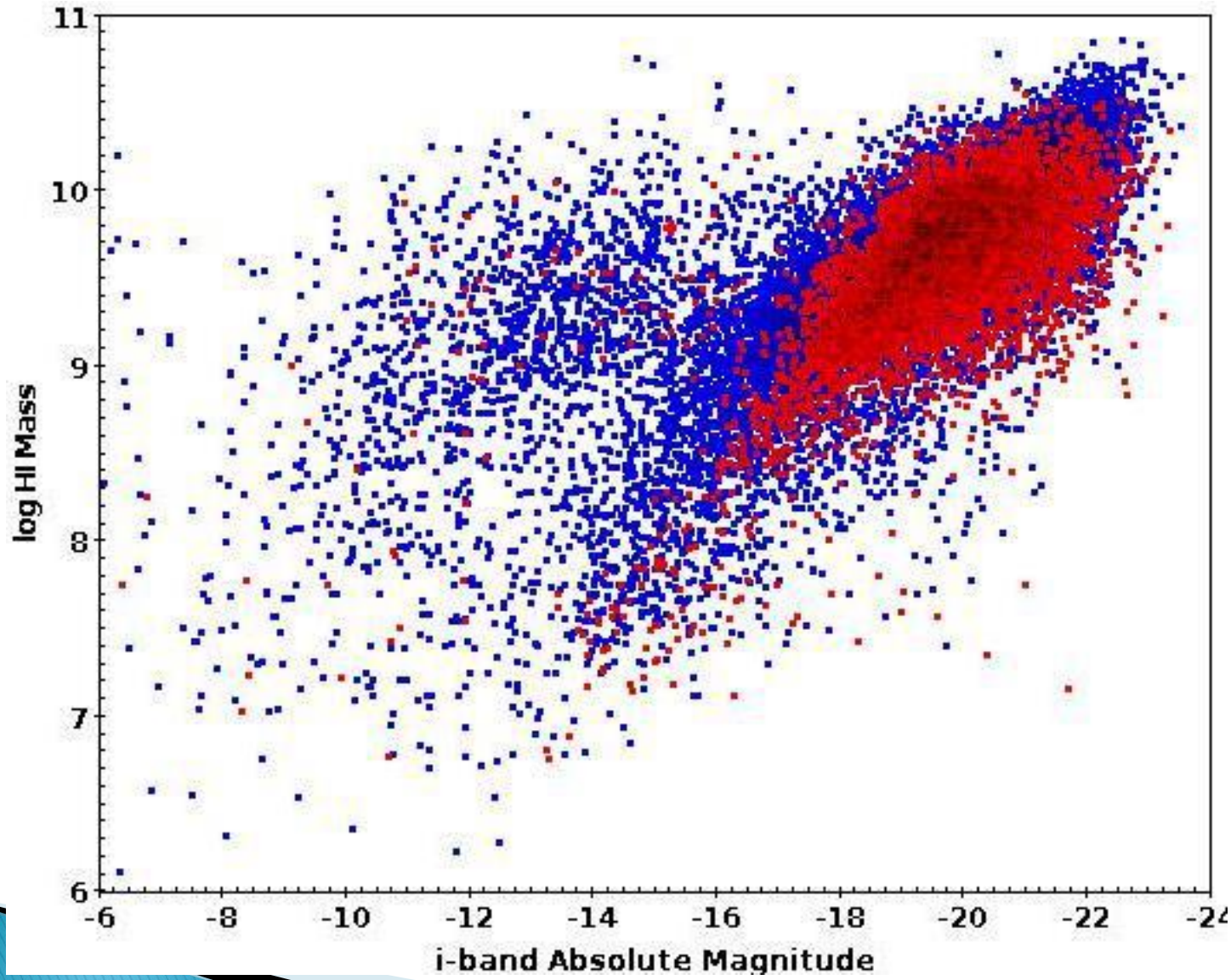
$$T_s = T_c + \frac{p \cdot T_{HI} - [T_{ab}/(1-e^{-\tau})]}{1-\tau_f}$$

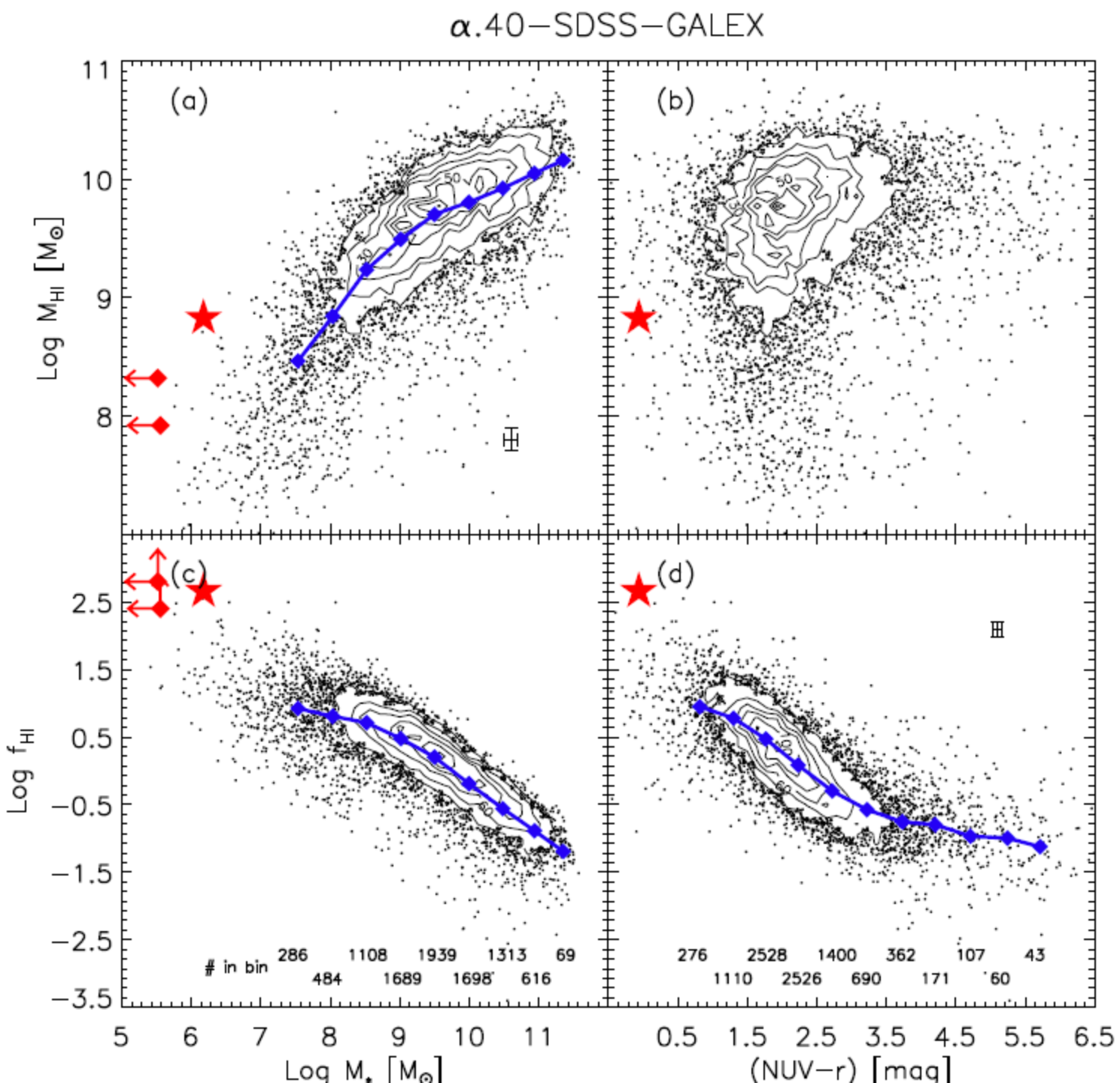
$$N(HI) = 1.94 \times 10^{18} \tau \Delta v T_s \ cm^{-2}$$

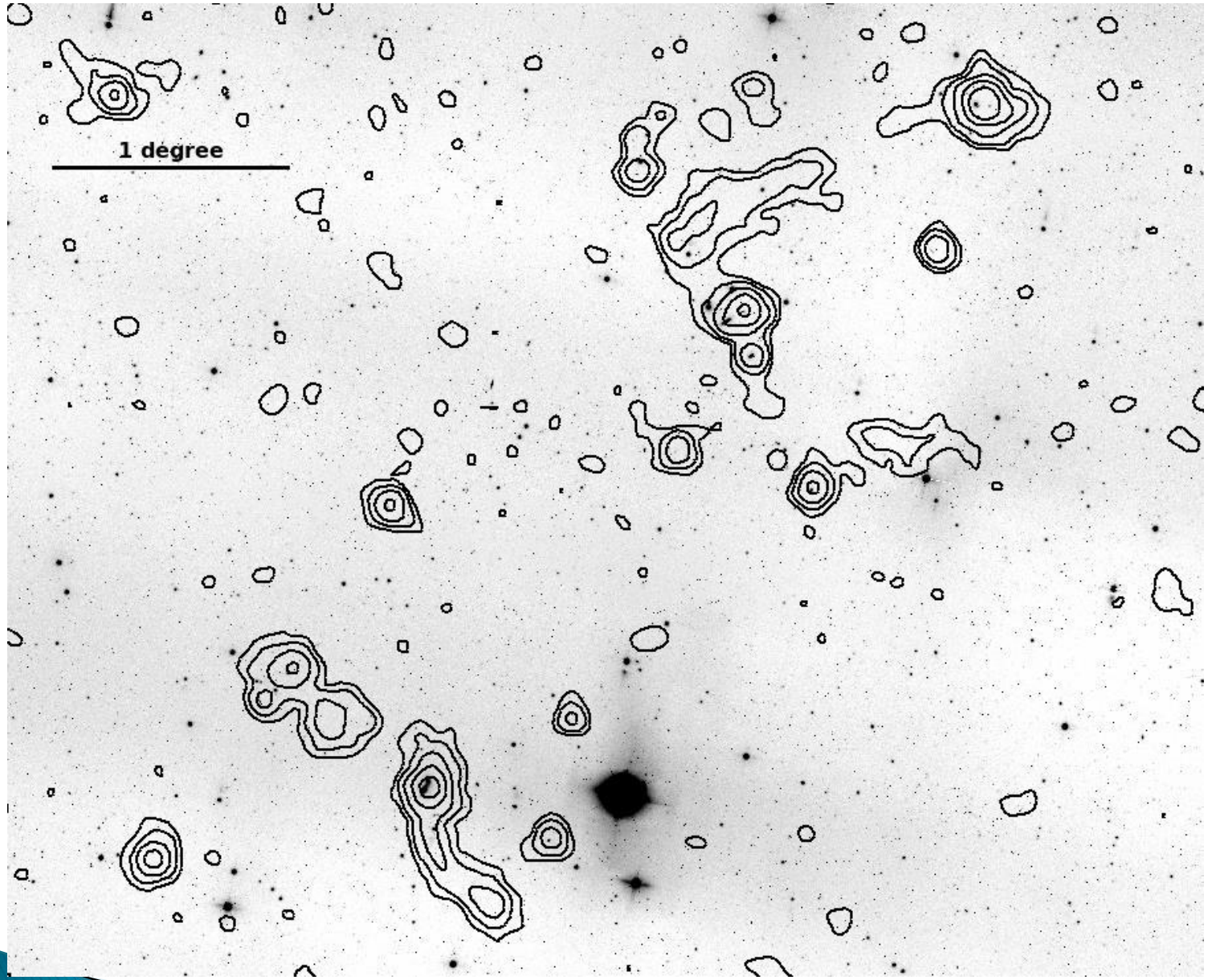
$$n = N(HI)/d$$





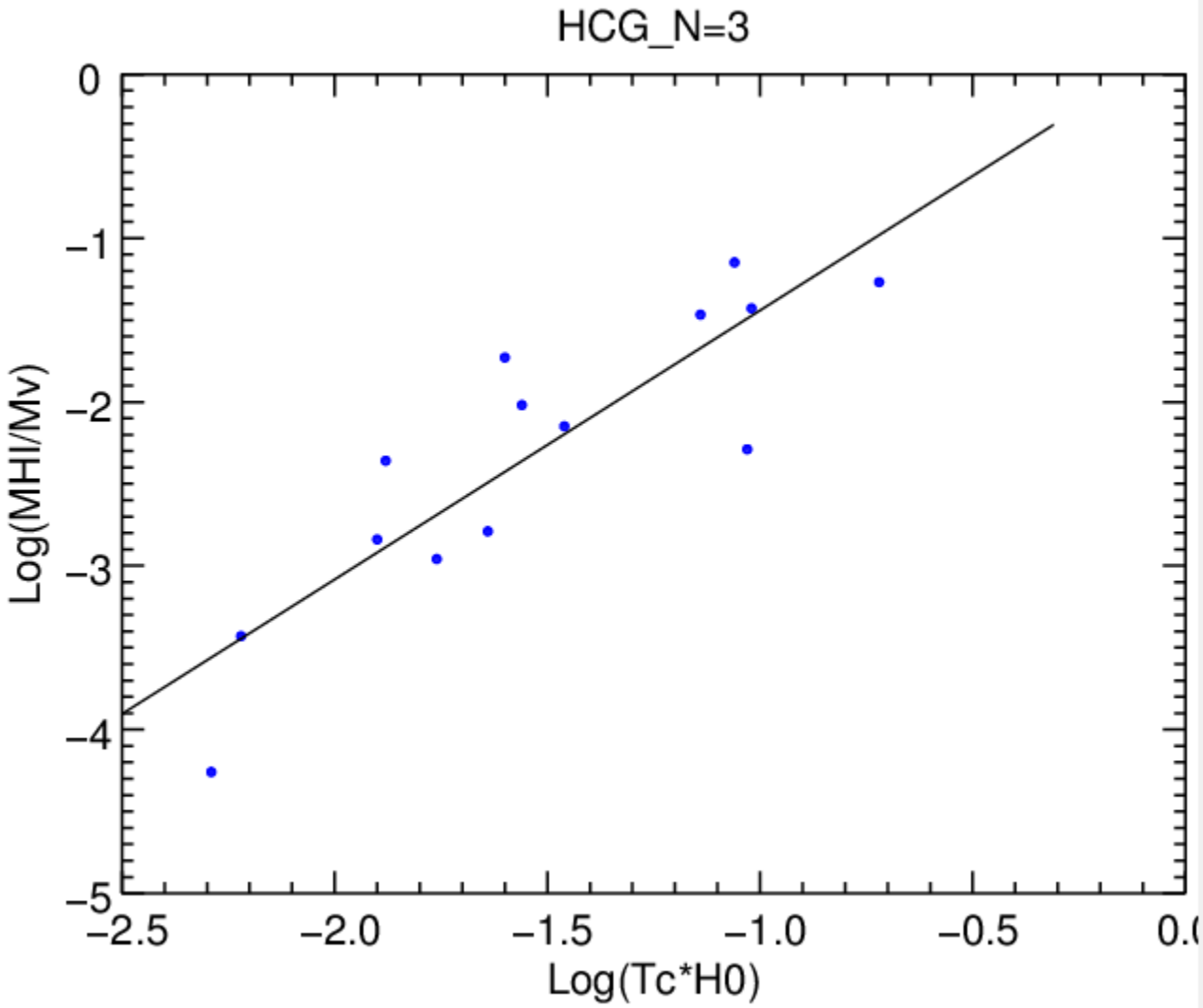

log HI Mass
11
10
9
8
7
6
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
i-band Absolute Magnitude


α.40−SDSS−GALEX
(a)
(b)
(c)
(d)
Log M_{HI} [$M_\odot$]
Log f_{HI}
Log M_* [$M_\odot$]
(NUV−r) [mag]
in bin
286 1108 1939 1313 69
484 1689 1698 616
276 2528 1400 362 107 43
1110 2526 690 171 60



Luke Leisman+ 2015 in prep
(Courtesy of M. Haynes)

Galaxy Groups and Clusters



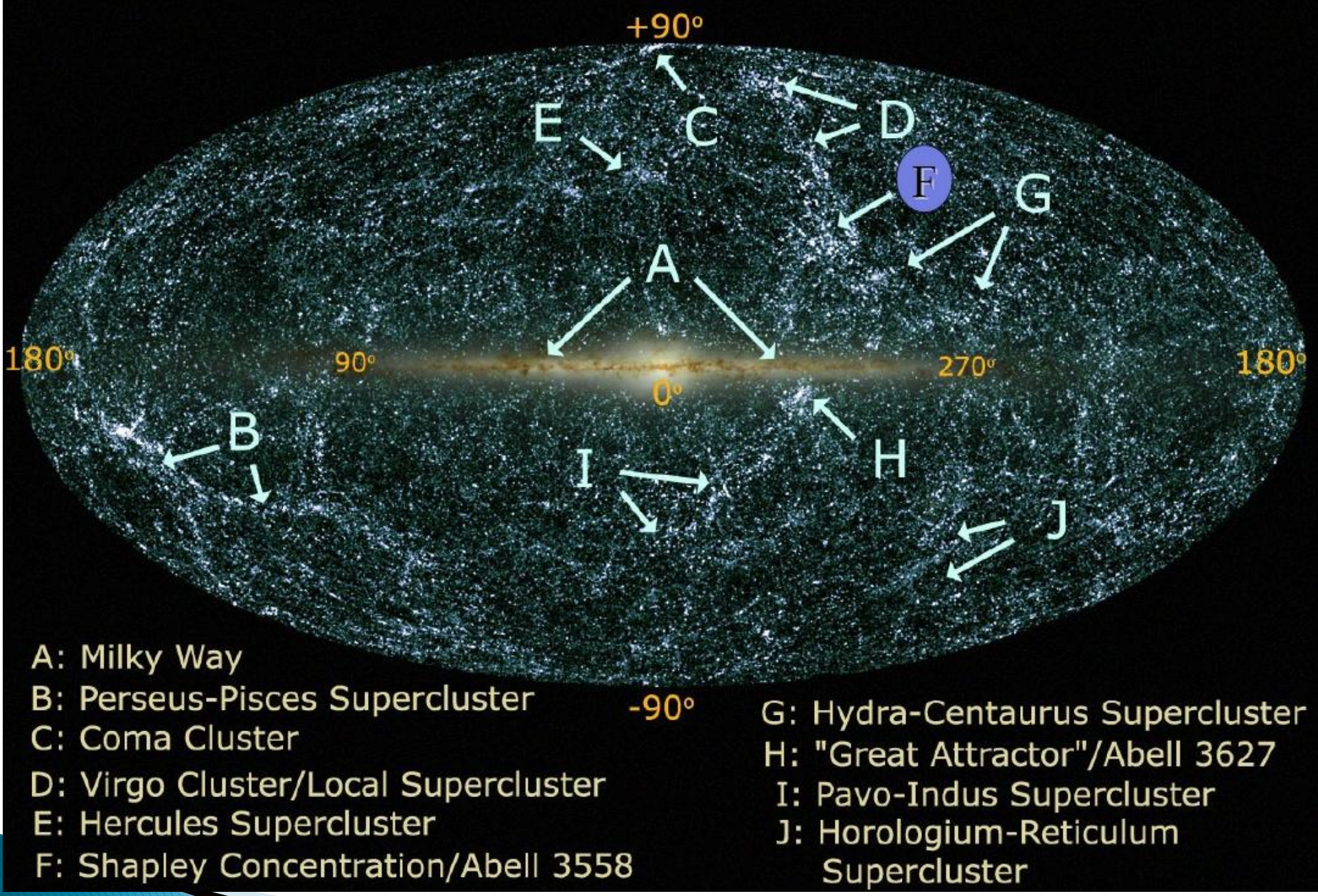
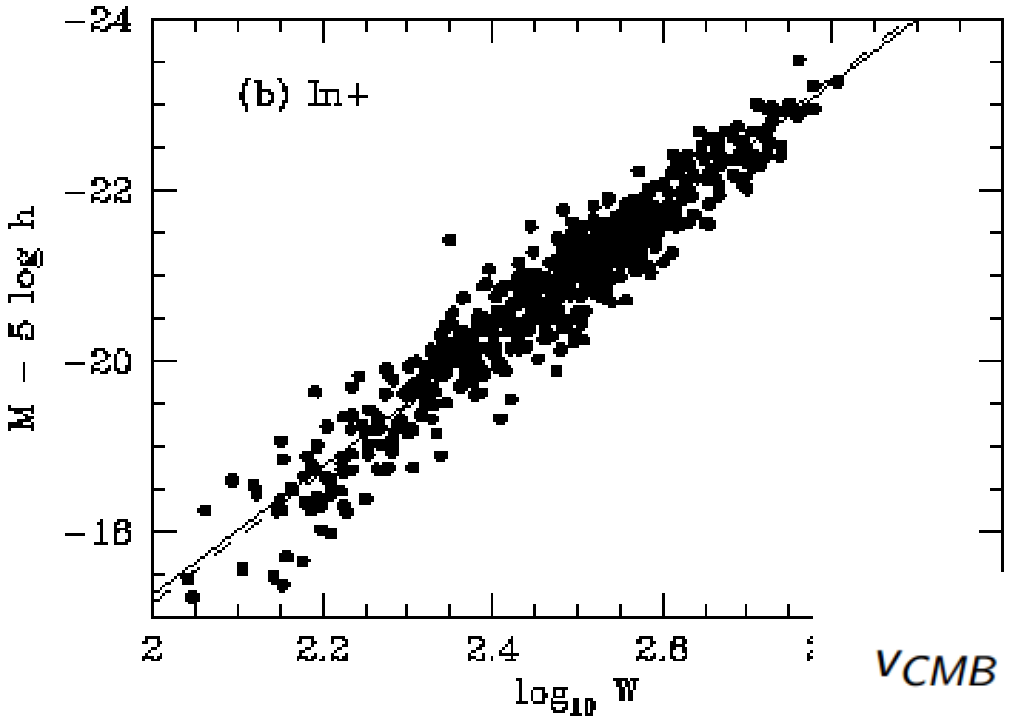


Image Credit: O. Lahav

Tully-Fisher 关系定星系距离及本速度场（Peculiar Velocity



Tully & Fisher 1977

$$v_{CMB} = H_0 \times d + v_{peculiar\ radial} \quad (1)$$

$$m - M = 5log_{10}(d(Mpc)) + 25 \quad (2)$$

Accurate HI + photometry

1. m $\leftrightarrow$ Photometry Observations
2. M $\leftrightarrow$ Tully-Fisher relation: $L \propto v_{HI}^{\alpha}$
   Calibrations (Tully & Fisher 1977)

$\hookrightarrow$ **d** $\rightarrow$ $v_{peculiar\ radial}$ $\rightarrow$ Cosmic Flows

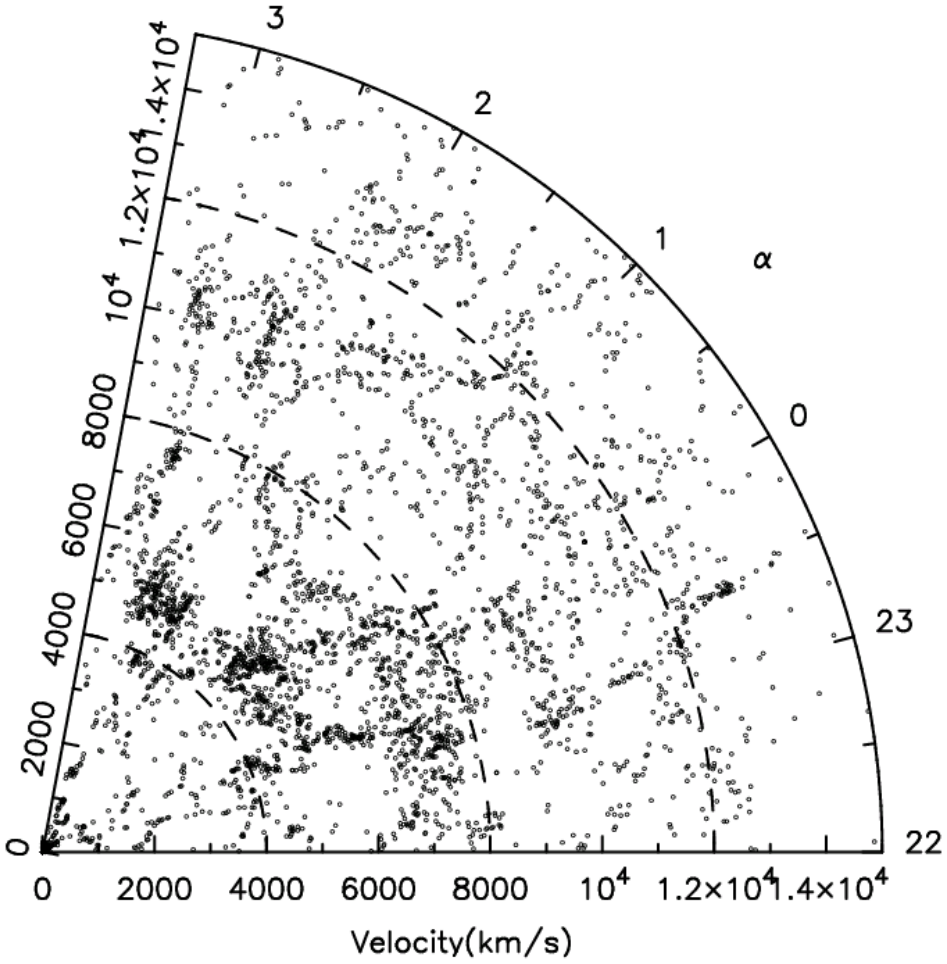
The Pisces-Perseus supercluster
L. Xiao et al.

Width 5-10h^{-1} Mpc

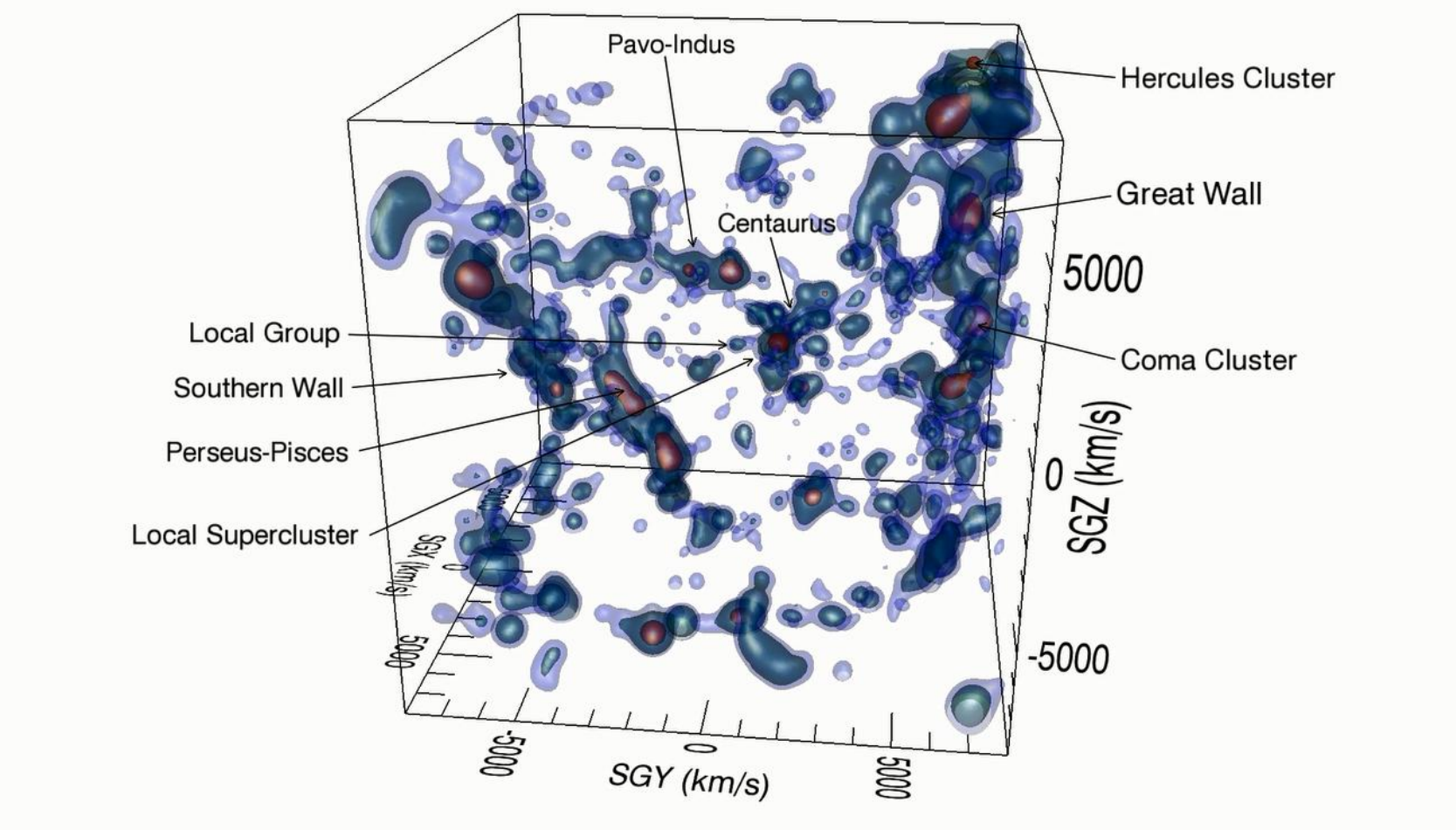
Redshift depth: 250-500 km/s

Distance: 5000 km/s

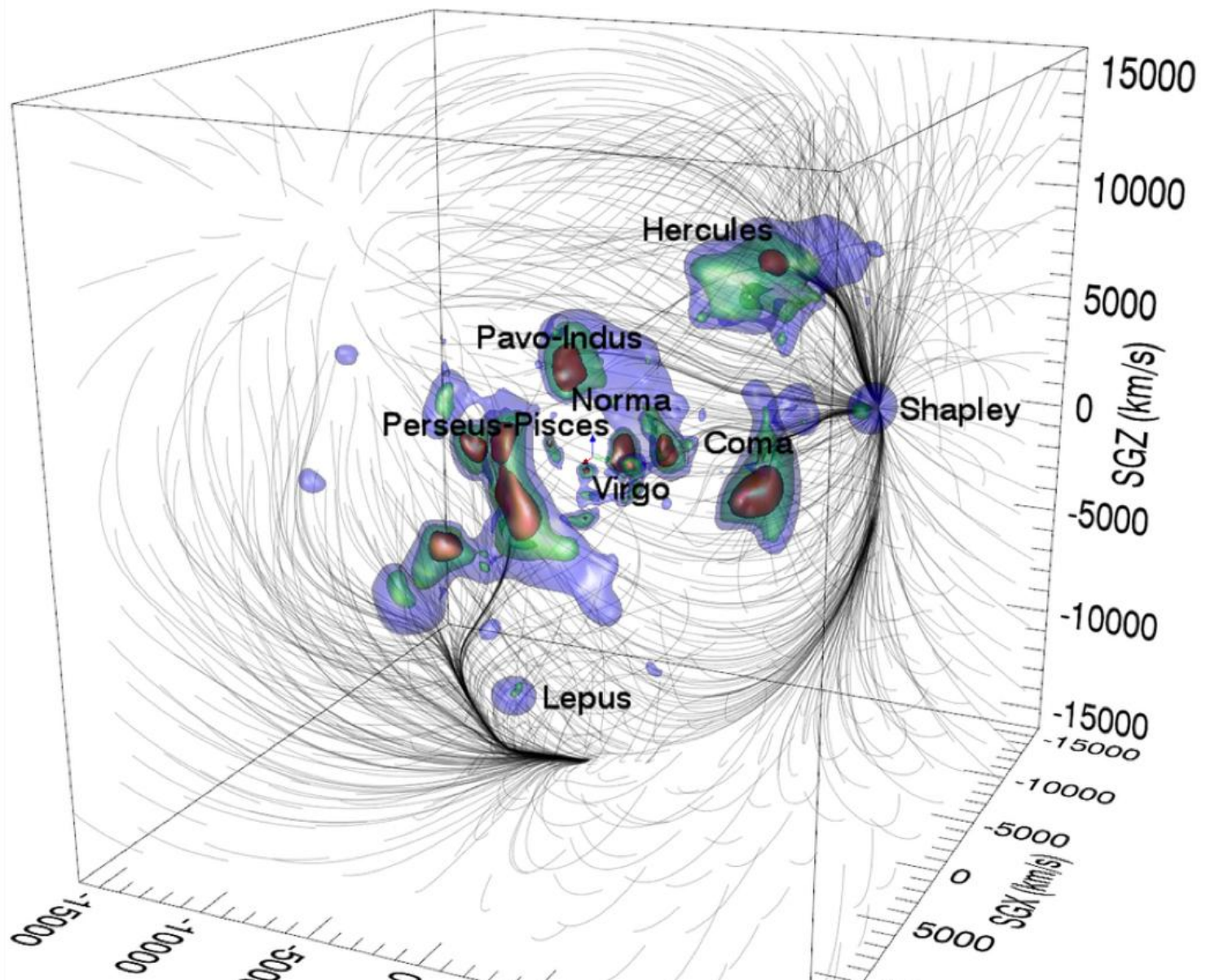
- TF-relation to derive the peculiar velocity field of PPS
- Find loose groups, and the clustering effect
- Properties of Galaxies in Cluster and field galaxies
- Comparing with numerical simulation to predict FAST survey results



Mass distribution in the local Universe

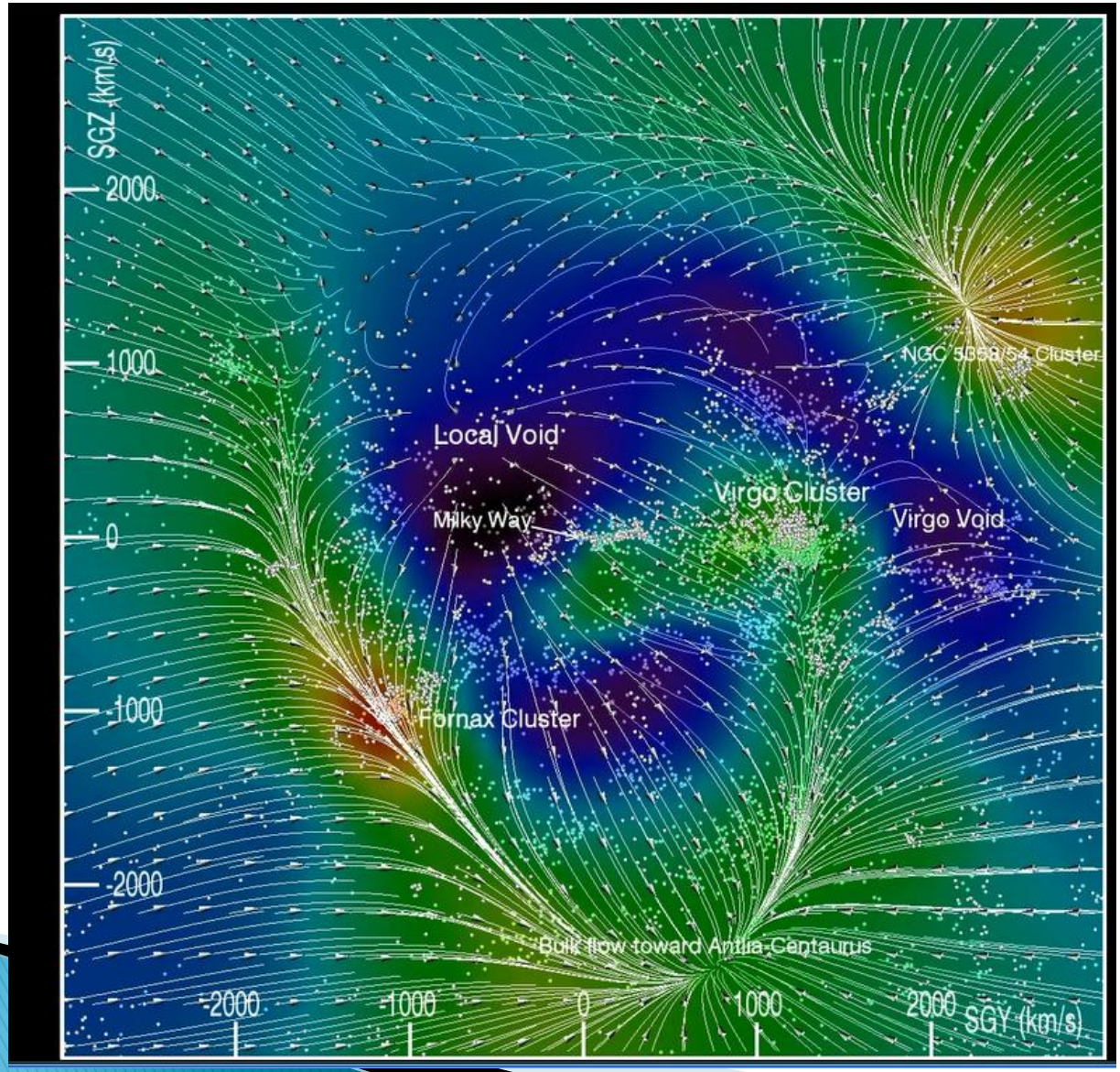


Tully et al 2014, Nature



Cosmic flow and Velocity field

Courtois et al. 2013

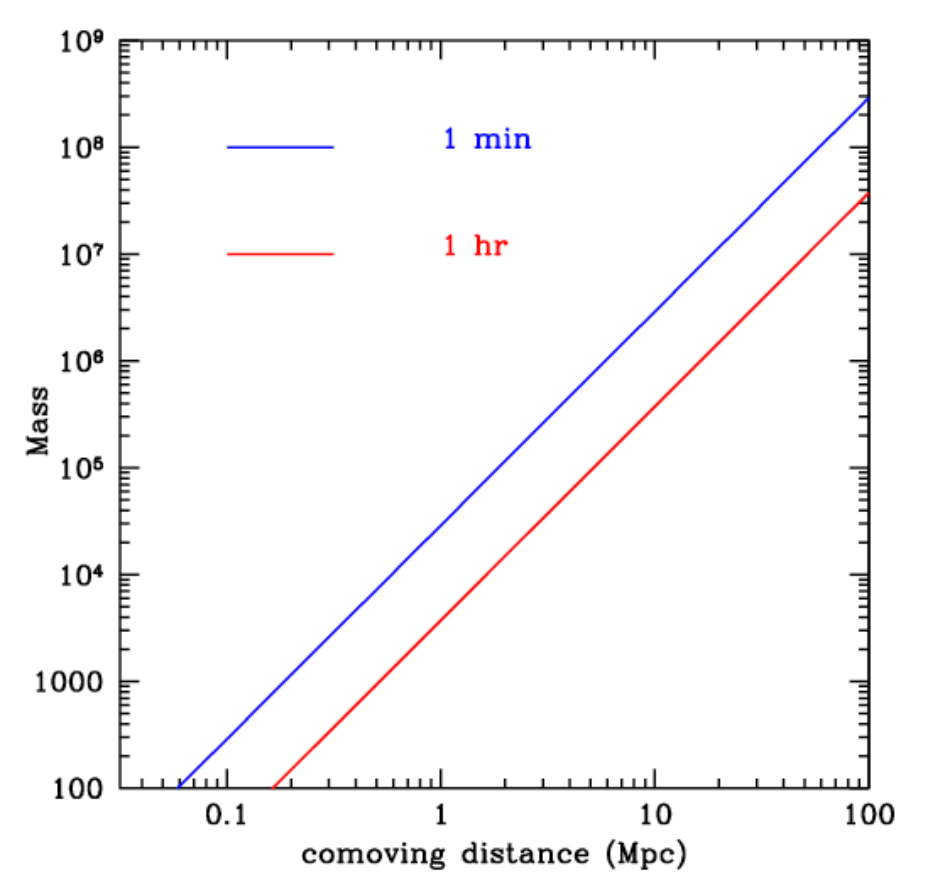


Mapping diffuse HI at 10^17

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

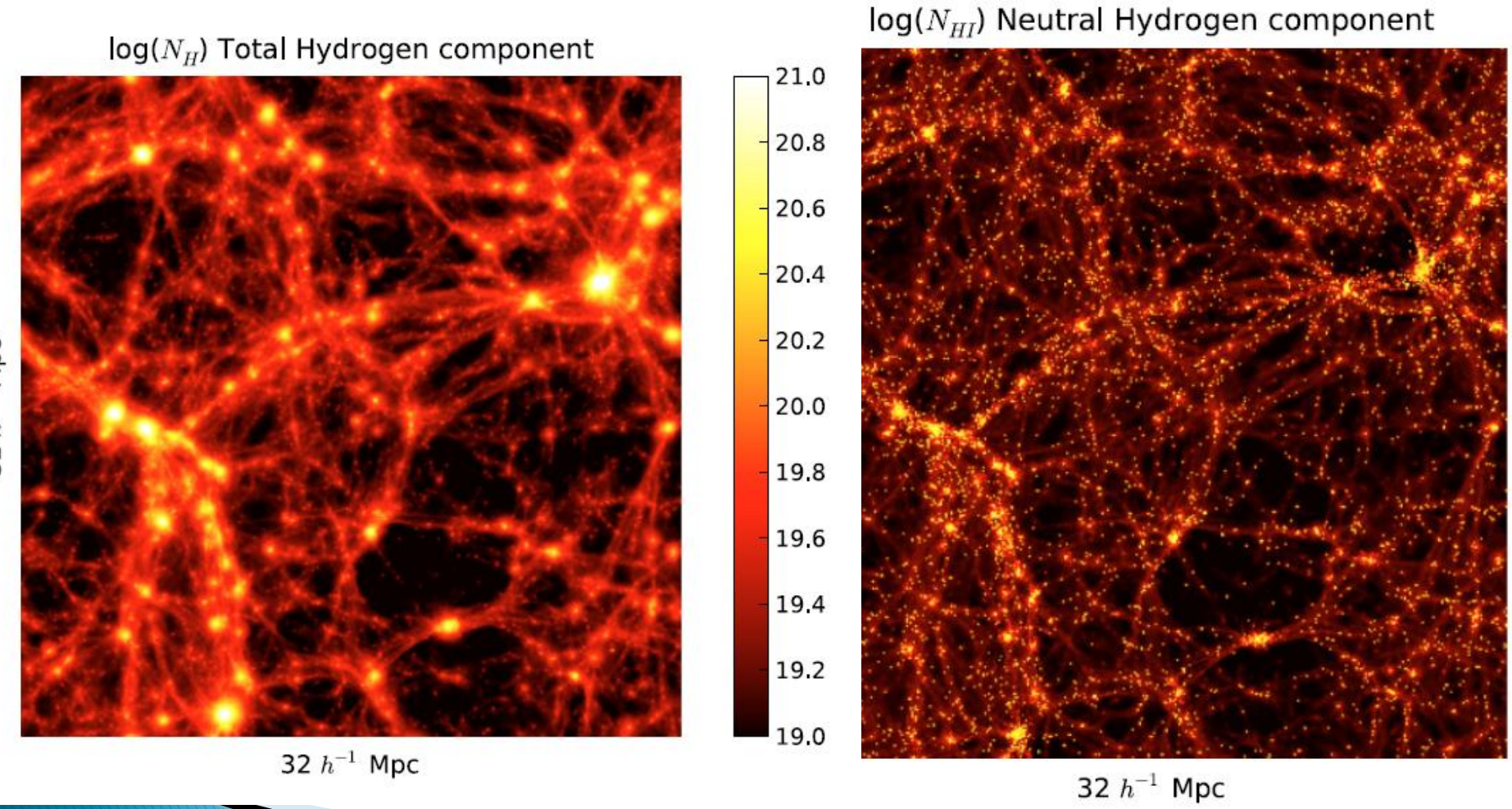
Nearby faint sources-missing saterllites

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

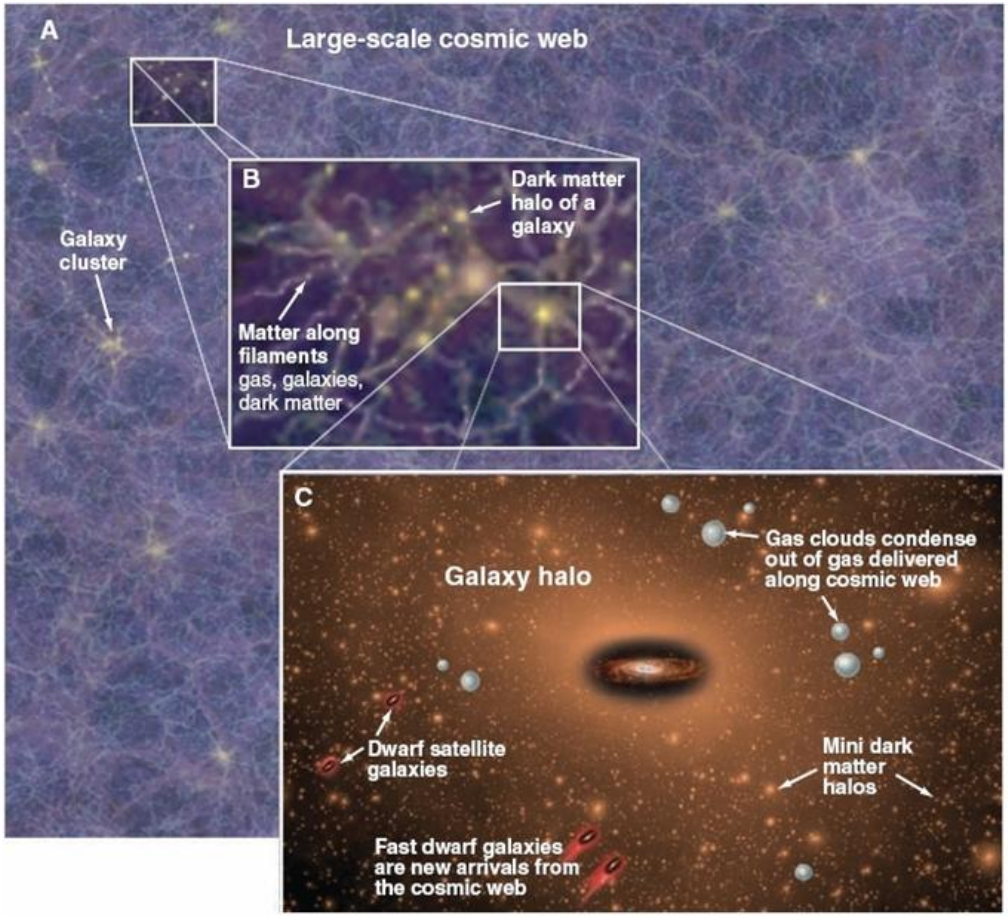


HI view of the Cosmic Web

Popping et al. (2009)



Cosmic web



Ibata and Lewis (2008) Sciences 319, 50

FAST data interoperability

- Data products
  - Level 0 and level 1, currently FITS
  - Level 2 and higher need to be developed by science teams
  - Multi-dimentional data cubes, more than catalogs
  - Time domain data, e.g. pulsar
  - Requirements similar to SKA1 and pathfinders

- VO tools
  - Datalink, crossmatch, link to theoretical models
  - Visualization , footprints
  - Use China-VO tools for data access