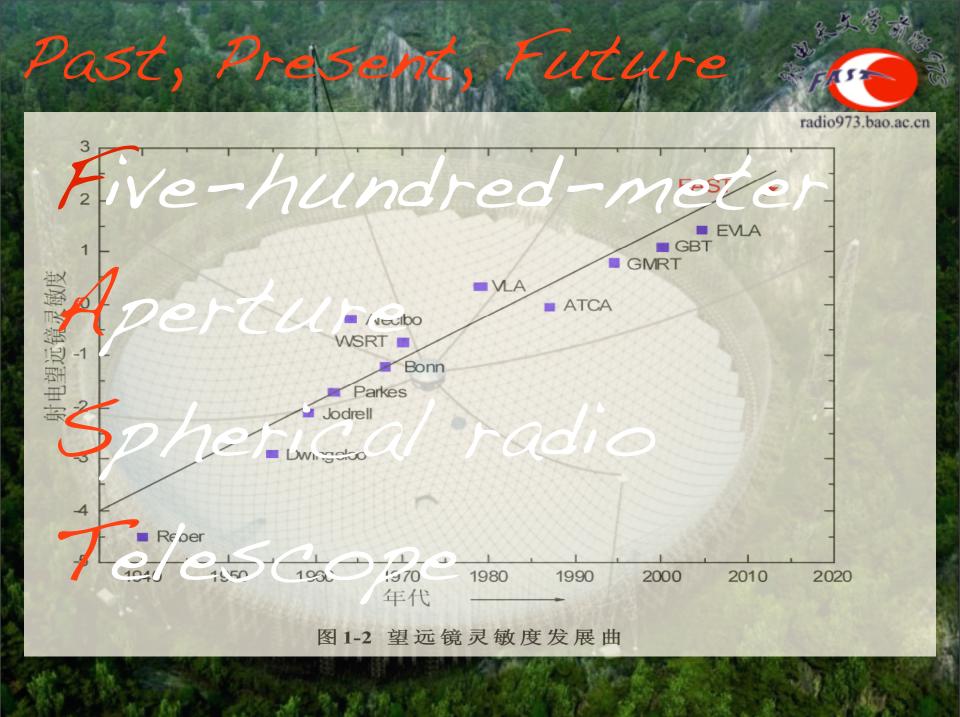
# The Promise of a Giant Radio Telescope



radio973.bao.ac.cn



#### Fully Steerable Telescopes





GBT 140foot

Effelsberg -



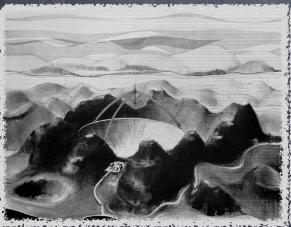


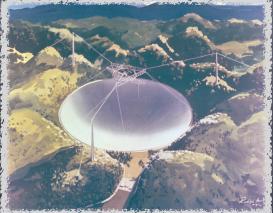
#### Arecibo: Dream of a Giant



William Gordon proposed the project around 1958 to Advanced Research Projects Agency (ARPA)

- Construction between1960-1963
- Total cost: \$9.3M









1959

1960.2

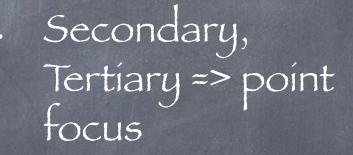
1963

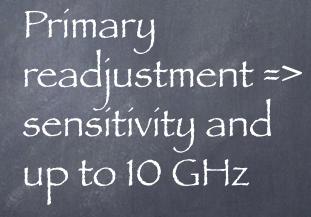
# Spherical Optics

### Arecibo Upgrade









Ground Screen => cleaner beam

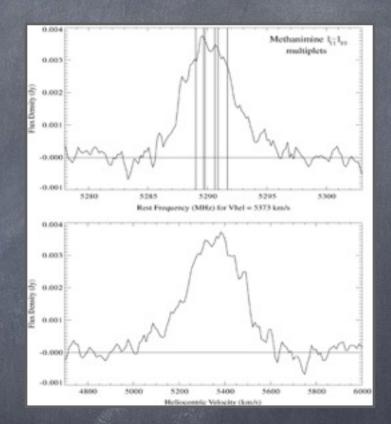


#### Pre-biotic Molecules in Galaxies









2008 Arecibo detects CH<sub>2</sub>NH (pre-biotic) in Arp 220

Arecibo望远镜

# Revolutionary Results



- 1965: The fist measurement of 59 days Mercury spin rate.
- 1960s: First images of surface of Venus.
- 1974: The first pulsar in a binary system was discovered (1974), leading to a Nobel Prize for astronomers Russell Hulse and Joseph Taylor (1993).
- 1982: Discovery of Millisecond Pulsar
- Late 1980s: Distribution of gas galaxies and large scale filamentary structures.
- 1990: The first exoplanets were discovered around Pulsar B1257+12
- 1997: Lunar surface ice in polar regions
- 2008: Detection of pre-biotic molecules in galaxies
- 2011: increase the known gaseous galaxies by ~ 10 fold
- Now: the major timing machine for gravitational wave detection, solving missing satellite problem, search for extraterrestrial intelligence, map the ISM Milkyway ....

#### Hulse-Taylor Pulsar Survey



Sept. 1972: JHT proposal to NSF: A High Sensitivity Survey to Detect New Pulsars (\$33,557)

"It would be of (very) high significance to find even one example of a pulsar in a binary system, for measurement of its parameters could yield the pulsar mass, an extremely important number."

- 2 × 32 × 250 kHz filter bank receiver
- Modcomp II/25 "mini-computer"

  memory 16k words

  32-channel multiplexer, A/D

  8k real-to-complex FFT in 1.9 s
- 2-d digital search (Period, Dispersion)
   Fast TREE algorithm for DM
   Incoherent harmonic summing for P



# Giant Single Dish: Why?









- -Galaxy Evolution
- ISM and Star Formation
- Maser and Spectroscopy
- Planetary and Exoplanet







#### World's largest telescope under construction

China has begun building the biggest radio telescope in the world, the Five-hundredmeter Aperture Spherical Telescope (FAST). Sitting in a natural bowl-shaped depression in a remote region of Guizhou province, southwestern China, FAST is due to be completed in 2014.

China's National Astronomical Observatories will use the exquisite resolution of the 700-million-yuan



Proper to before the a national course mine Milliant make therein treat has paid to



#### Radio Astronomers Go for High Gain With Mammoth Telescope

Construction is about to commence until e-model's hipped-single-clair scalls intewage, which will have also also are mostly because with a company and during palastics.

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Figure Service Special Instruments date date for Broady 1990s, when previously in the pre-By two opining up to the caption social by 1964, principality from China prigod and-

Science

MAAAS

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# «New Scientist》

"Open the giant eye to the radio sky"

#### A BIG EYE ON THE SKY

500-meter aperture spherical radio telescope (FAST)

Surveys neutral hydrogen in the Milky way and other Finds out where extraterrestrial life might exist in

Detects new galactic and extragalactic pulsars Finds and researches the first shining stars

space

Detects dark energy and helps us understand the evolution of galaxies

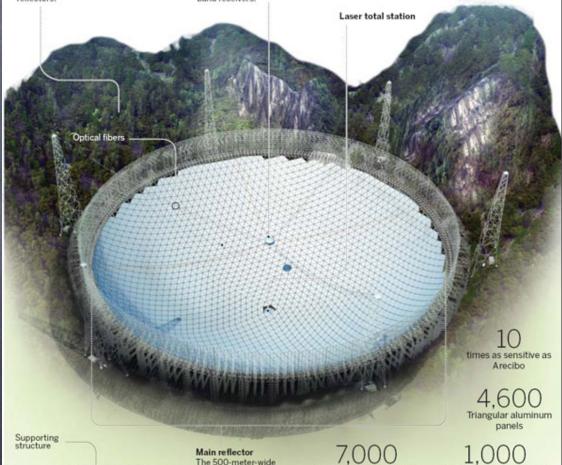
#### Karst valley depression

Main cable net

A natural limestone depression in southern Guizhou province creates a cradle for the telescope's main

#### Receiver Cabin

A lightweight focus cabin is powered by cables and operated by a robot. The cabin contains multiple-beam and multipleband receivers.



active main reflector

directly corrects for spherical aberration.

Tie-down cables

The number of pulsars in

the Milky Way Galaxy it will

detect in less than a year

The number of light years

into space FAST will enable

scientists to detect the signal



#### 6 Subsystems

Site

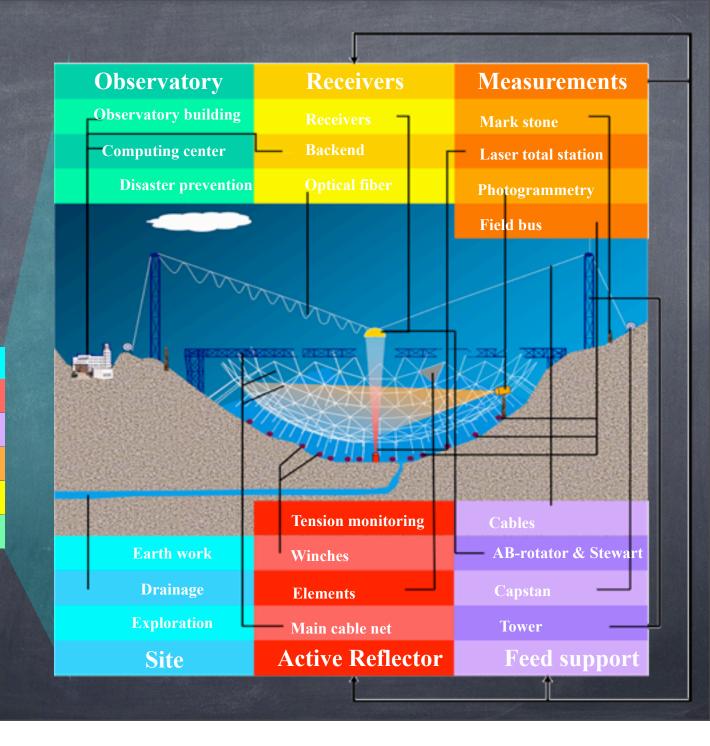
**Active Reflector** 

Feed support

Measurements

Receivers

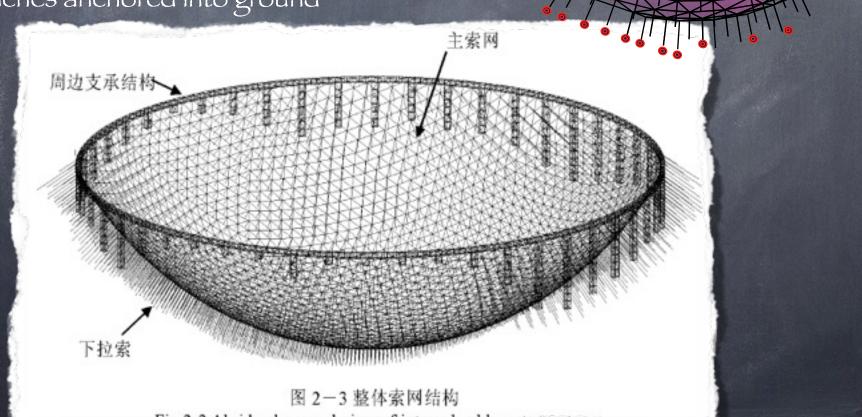
**Observatory** 



#### Active Reflectors

本 FATTE TO

- 500m girder built around hills
- 50 pillars
- Backup consists of 7000 steel strands
- 2300 down tied cables driven by
- winches anchored into ground



#### Reflector and prototyping

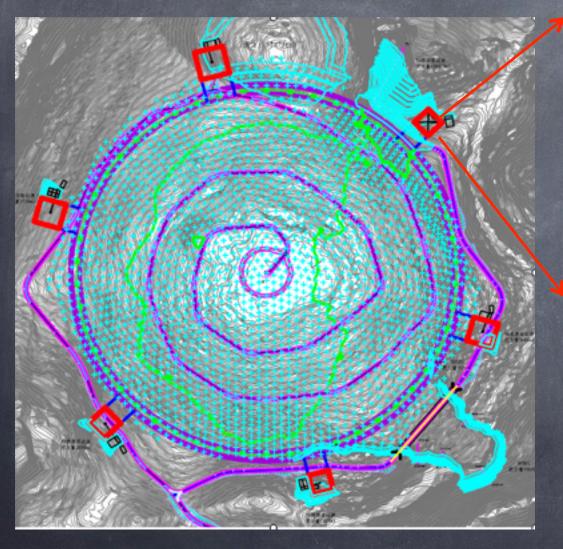




- triangular panels, side ~11m, manufacturing error ~ 2.0 mm weight ~10kg/m²
- backup: single rear rib, spatial truss, suspended by cable
  skin: perforated aluminum sheet, expended mesh, or welded stand less steel

#### Tower Base Layout









# Girder "Ring"

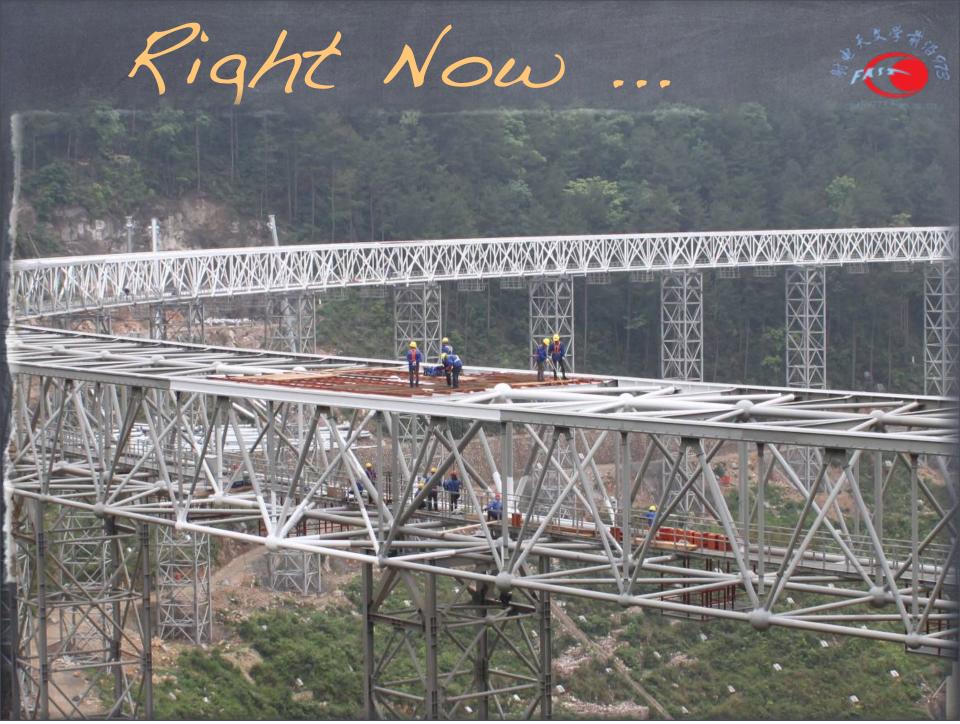


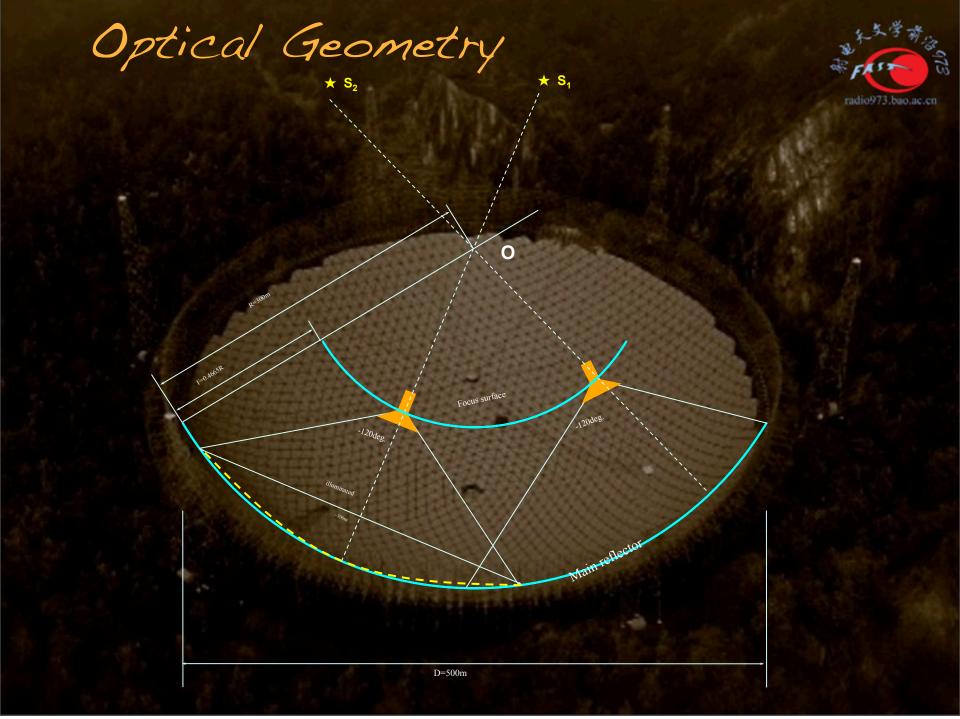


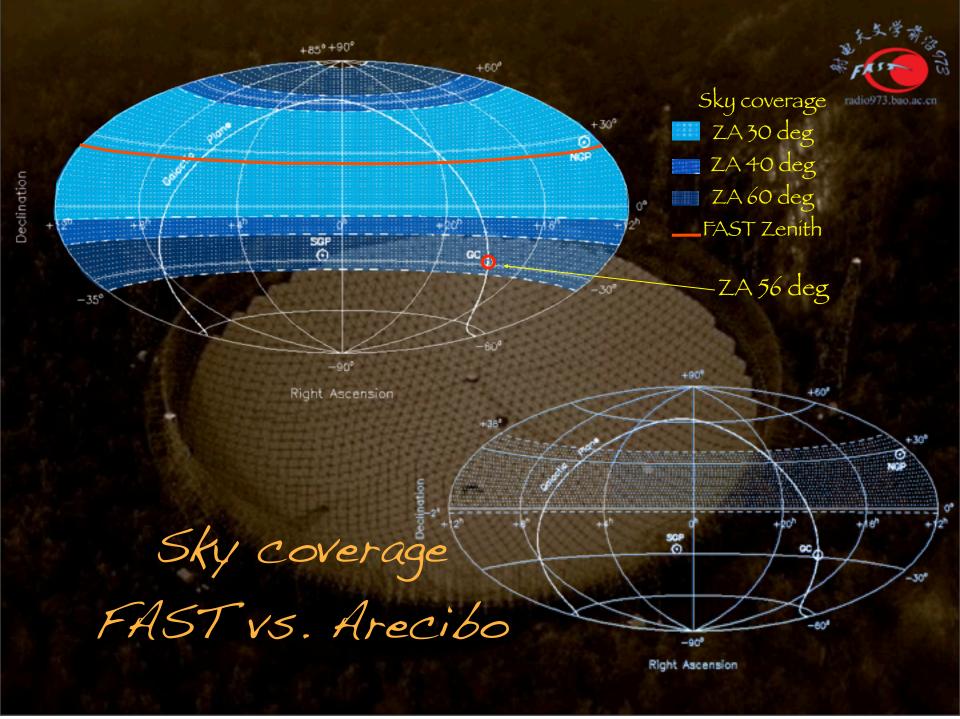
Monday, May 19, 14



Monday, May 19, 14







#### Technical Specification



Spherical reflector: Radius~300m, Aperture~500m Illuminated aperture : D<sub>11</sub>=300m

Focal ratio : f/D = 0.467

Sky coverage: zeníth angle 40° up to 60° with efficiency loss, tracking hours: 6h

Frequency: 70MHz - 3 GHz, up to 8GHz after upgrade 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"

# Observables



#### 70MHz~3GHz Complete Coverage

- a) Pulsar
- b) HI 21cm Hyperfine transition

$$f = 1$$
,  $g_F = 3$  (statistical weight, 2F+1)  
 $f = 0$ ,  $g_F = 1$ 

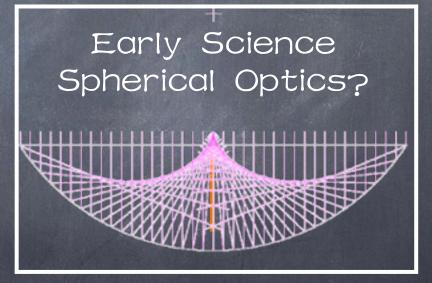
Frequency: 1420.405 751 7667 MHz (±0.001 Hz!)

c) Other atomic and molecular lines, radio continuum, maser

# Possible Discoveries a) special pulsars: pulsar-blackhole system, detection of extra-galactic pulsar beyond LMC

b) HI Disks and halos in dark galaxies and diffuse HI

c) New content of the ISM including new molecules, especially prebiotic ones
High redshift masers



other) First detection of radio emission of exoplanet

#### Early Science: Challenge



#### Main Technical Difficulties

Error Budget ~5mm

Light Path ~ 150m/300m

beam shape, calibration, and EMC control

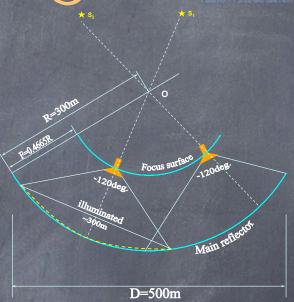
Early Science Targets

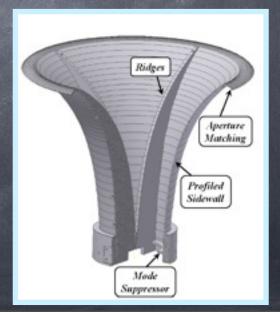
Low Frequency
Point Source

Time/Frequency Domain Characteristic

An Ultra-wide Band Recevier

Lí, Nan, Pan 2012, IAUS291





# Key Early Sciences

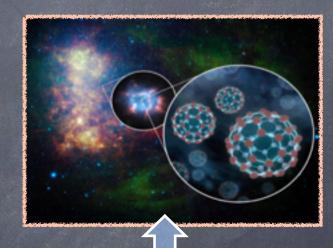


a) Pulsar Search in Nearby Galaxies and Globular Clusters M31 is out of Arecibo Coverage

Planetary Nebular: C<sub>60</sub>和C<sub>70</sub>

Cami et al. 2010, Science 329, 1180

b) OH Mega-Maser Search FAST 2.3xArecibo Sky; growing IR Galaxy catalogues

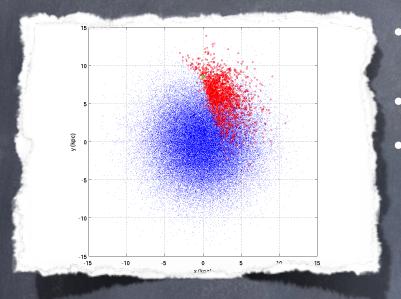


C) Orion Spectral Line Survey Orion is out of Arecibo Sky; Herschel Orion Source Model

Radio Detection of cosmic carbon structures?

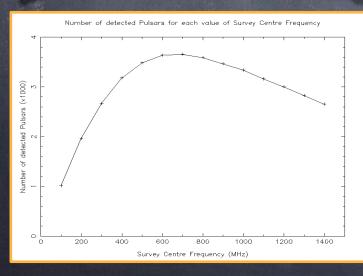
#### a) FAST Drift Scan Surveys

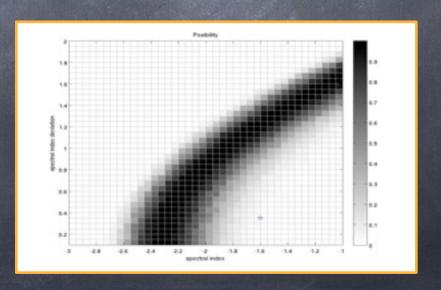




- Drift scan whole FAST sky (~58%) whole sky)
- ~2000 pulsars, 300 MSP
- +5year timing => 3 x improvement over current IPTA

Yue et al. 2014 in prep. (RAA) - FAST special issue





# 6) OH Mega-maser Search



FAST (Nan, Li, Jin et al. 2011, IJMPD, 20, 1)

- 3 better raw sensitivity
- o ~ 10 higher surveying speed
- $\circ$ 2-3 times sky coverage  $\sim$ 15°< $\delta$ <65°

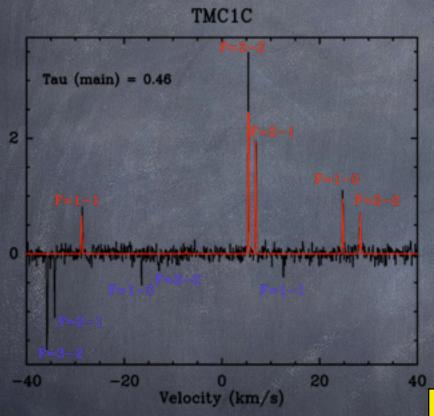
Expectations of FAST:

Zhang et al. 2014 in prep. (RAA) - FAST special issue

- Numbers of OHM: 10~20 times? N>1000
- oHigh z OHM: OHM to z 2; Giga-M: to z 4
- ©Lensed OHM at z>1

#### 9) Carbon-Chain Molecules





Li & Goldsmith 2012, ApJ

#### HC<sub>3</sub>N 2-1 18.2 GHz

GBT

A&A 553, A119 (2013) DOI: 10.1051/0004-6361/201220822 © ESO 2013 Astronomy Astrophysics

#### Formation and evolution of interstellar filaments Hints from velocity dispersion measurements\*,\*\*

D. Arzoumanian<sup>1,2</sup>, Ph. André<sup>1</sup>, N. Peretto<sup>1</sup>, and V. Könyves<sup>1,2</sup>

small along the crest of the filament (cf. right panel of Fig. 5), with an average velocity dispersion  $(0.25 \pm 0.03) \, \mathrm{km} \, \mathrm{s}^{-1}$ . This is consistent with previous observations of a few low-density filaments showing that these structures have velocity dispersions close to the thermal velocity dispersion  $\sim 0.2 \, \mathrm{km} \, \mathrm{s}^{-1}$  for  $T = 10 \, \mathrm{K}$  (cf. Hily-Blant 2004; Hily-Blant & Falgarone 2009) and which do not vary much along their length (Hacar & Tafalla 2011; Pineda et al. 2011). Recently, Li & Goldsmith (2012) studied the Taurus B213 filament and found that it is characterized by a coherent velocity dispersion of about  $\sim 0.3 \, \mathrm{km} \, \mathrm{s}^{-1}$ .

These results suggest that the velocity dispersion observed at a single position toward a filament provides a reasonably good estimate of the velocity dispersion of the entire filament<sup>5</sup>. Nevertheless mapping observations of a broader sample

Arzoumanian et al.: Li & Goldsmith (2012) ... Taurus B213 filament is characterized by a coherent dispersion ...

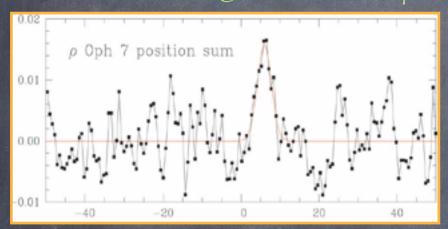
 $<sup>^5</sup>$  An interstellar filament is an elongated structure characterized by small column density variations along its crest (less than a factor of 3; see Fig. 3-left). Therefore, the velocity dispersion variations induced by the trend  $\sigma_{\rm tot} \propto \Sigma_0^{0.5}$  found in Sect. 5 below for supercritical filaments remain small («2) along a given filament.

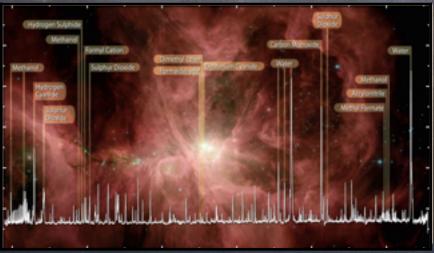
# *c*)

#### Exploring Low Freg. Radio Spectrum



Goldsmith, Li, Bergin et al. 2002, ApJ



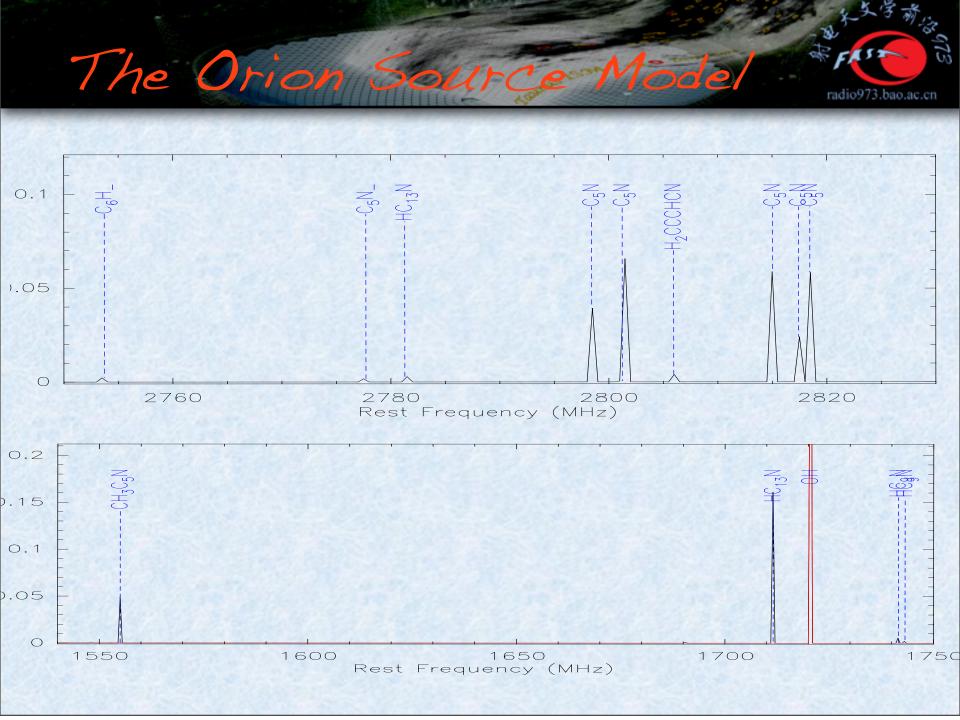


HIFTENNIGETER (BORN, April)

#### New Molecules

??? Lí, Qín, Bergín in prep. (RAA) - FAST special issue

- Carbon chains
- Negative lons
- Nano-Diamonds and PAH?



#### FAST Special Issue



#### Clarify FAST Science Goals and Technical Requirements

=> (RAA) Special Issue: ISM, Pulsar, Galaxy Surveys, Cosmology, Spectroscopy, etc.

42 proposalsFirst authors from 5 countries

■Co-authors from most of the national radio observatories

> Research in Astron. Astrophys. 2013 Vol. 0 No. XX, 000-000

Simulation of millisecond pulsar population and FAST sensitivity on gravitational wave detection

Y.L. Yac, K.J. Lee, D.R. Lorimer, F.A. Jenet and D. Li

National Astronomical Observatories, CAS; shortlenences.cm

Abstract A new simulation millisecond pulsar (MSP) population using PSRPOP is carried out to estimate FAST sensitivity on gravitational wave detection. The simulation is based on three large sky coverage pulsar surveys: Parkes multi-beam survey, Parkes 70cm survey and Green Bank North Celestial Cap (GBNCC) survey. We found that MSP has



#### 973 Science Teams



Observers lead, collaborating with theorists, modeling experts, and instrumentalists, work toward a concrete definition of FAST key programs and early science goals.

- · Pulsar Observations and Theories (Xu@PKU)
- From Atoms to Star: ISM and Star Formation (Li@ NAOC)
- . Galaxy Evolution and Structures (Zhu@NAOC)
- . Cosmology and Dark Matter (Zhu@BNU)
- . Radio Spectroscopy and Masers (Wang@SHAO)
- . Multi-beam System and VLBI (Jin@NAOC)

#### 2013.5.14: NRAO

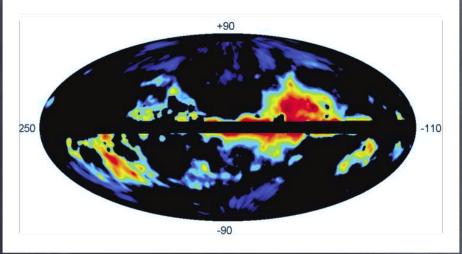


5月14日,国家天文合合长严俊与美国射电天文合合长Anthony Beasley签署了国家天文合与美国国家射电天文合合作备忘录 (MoV)。双方的合作覆盖射电天文学科学与技术研究的罗个领域,特别是大天线及相关设备的建造运行技术和FAST与GBT、JVLA等NRAO所属设备的协同观测计划。

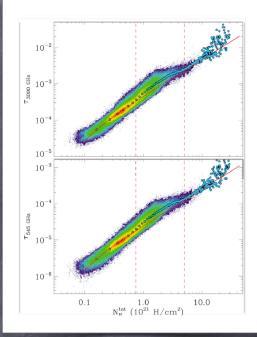


# Dark Molecular Gas?

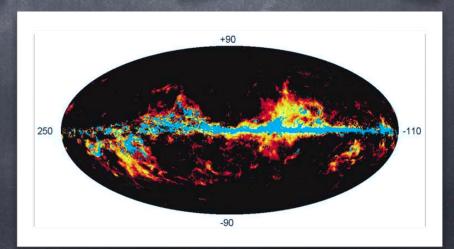
IRAS [IRAS – (HI + X\*CO)]



Planck
Dust vs[HI+X\*CO]

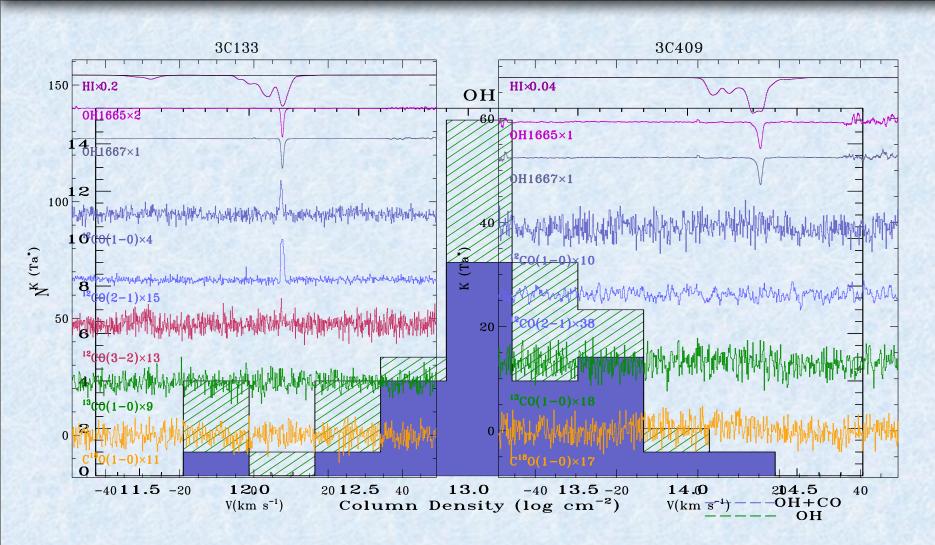


EGRET gamma rays
[CR/H-nuclei] interaction
Gerier et al. 2005 Science



#### Arecibot Delinghat CSO





Xu, Li, Heiles 2014, in prep.

"When we were talking about building [the telescope] back in the late '50s, we were told by eminent authorities it couldn't be done. We were in the position of trying to do something that was impossible, and it took a lot of guts. . . . We were young enough that we didn't know we couldn't do it. But we were in the right place at the right time and had the right idea and the right preparation."

William Gordon, 2003