中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

The Promise of a Giant Telescope

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FAST
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Di Li
Chief Scientist, Radio Division, NAOC


Five-hundred-meter
Aperture
Spherical radio
Telescope
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Past, Present, Future

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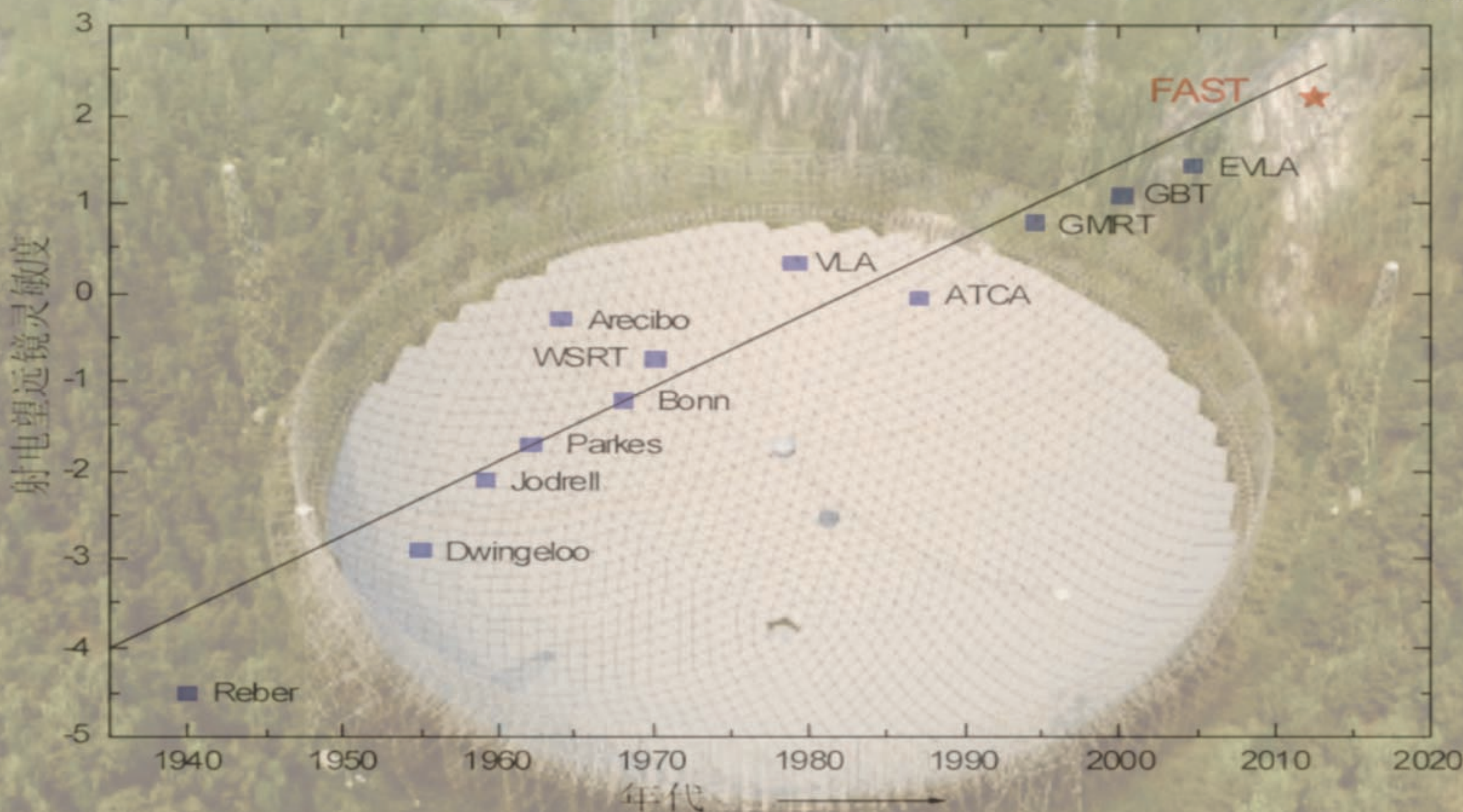


图 1-2 望远镜灵敏度发展曲

Outline

1. Motivation for a Large Single Dish
2. The Key Technical Aspects of FAST
3. Science Cases of FAST
4. A "Fundamental Science" (973) proposal to prepare for FAST
5. Summary

Discovery of Hydrogen

Harold Irwin Ewen (Doc H.I. Ewen) and Purcell 1951

Transit telescope designed to have the Galactic Center pass through its beam

Receiver system built with $500. grant plus military surplus parts

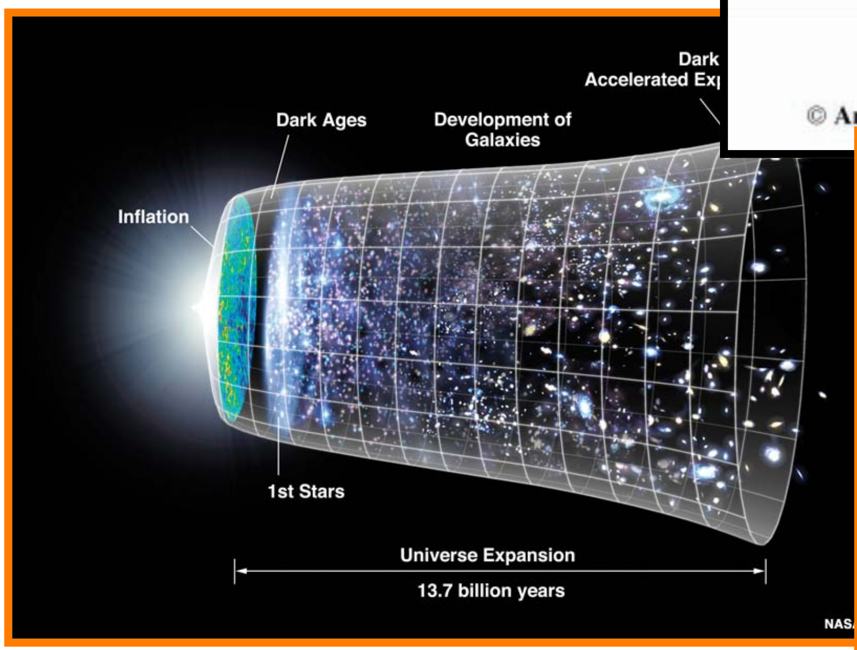
Detection of interstellar Gas

waveguide connected to the horn antenna

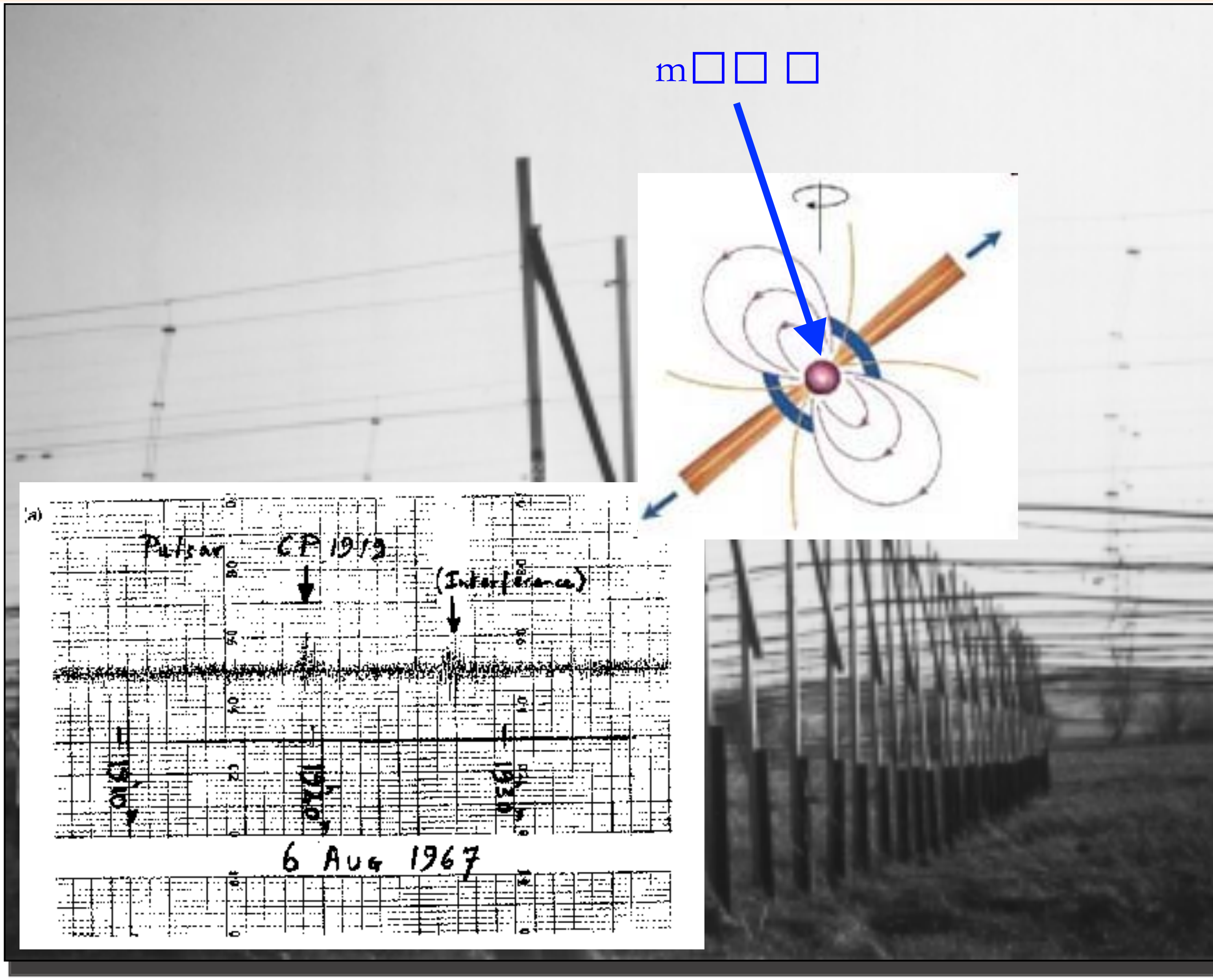
Discovery of CMB

A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE
AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and



Discovery of Pulsar



Bell and Hewish 1967

The Birth of a True Giant!

- W pposed the project around 1958 to rch Projects Agency (ARPA)

- Const betw

- Operated by National Astronomy and Ionosphere Center (NAIC) through

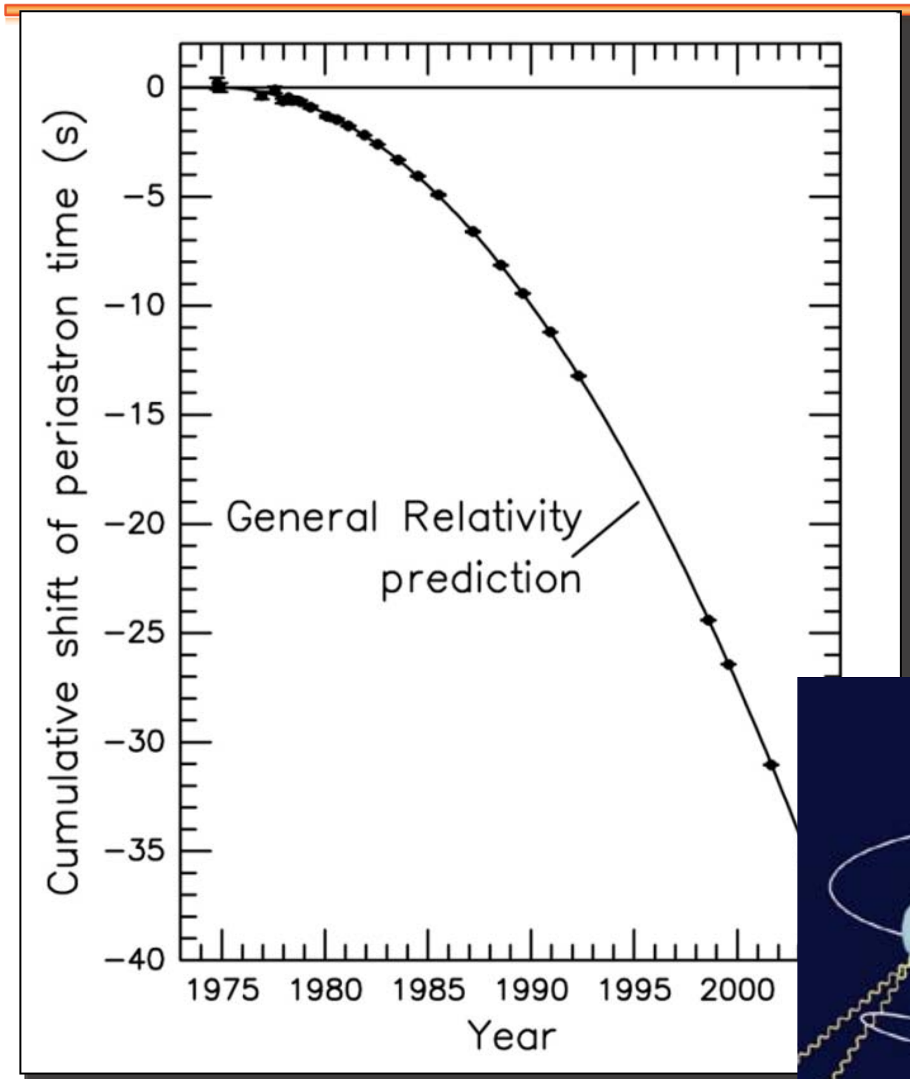
Cornell University

SRI/USRA

Triumph of the Giant

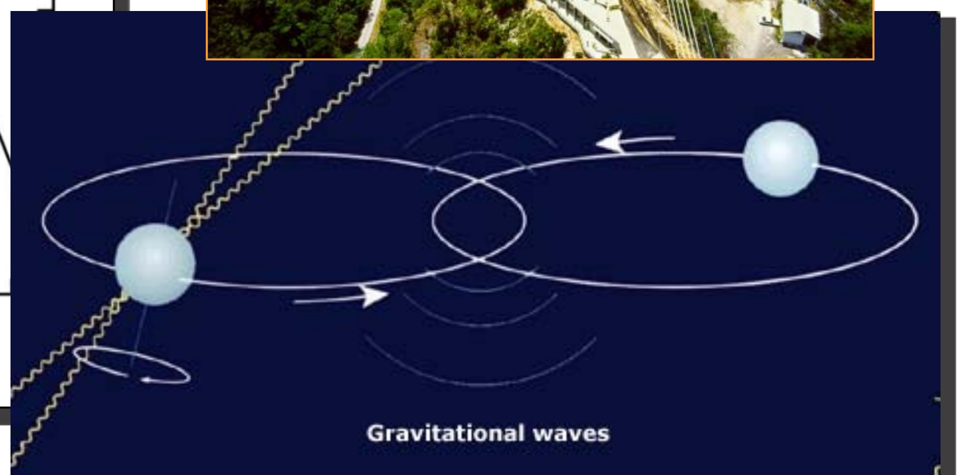
- Pettengill et al. Mercury rotation rate 1964
- Lovelace et al. Crab Pulsar – 33 msec periodicity; neutron star
- Hulse & Taylor 1974 PSR B1913+16, binary pulsar
- Backer et al. 1983 PSR B1937+21, millisecond pulsar
- Map HI Galaxy Distribution 1980s
- Direct imaging of asteroids 1989-1990s
- Wolszczan first exoplanets 1990

Pulsar in a Binary System



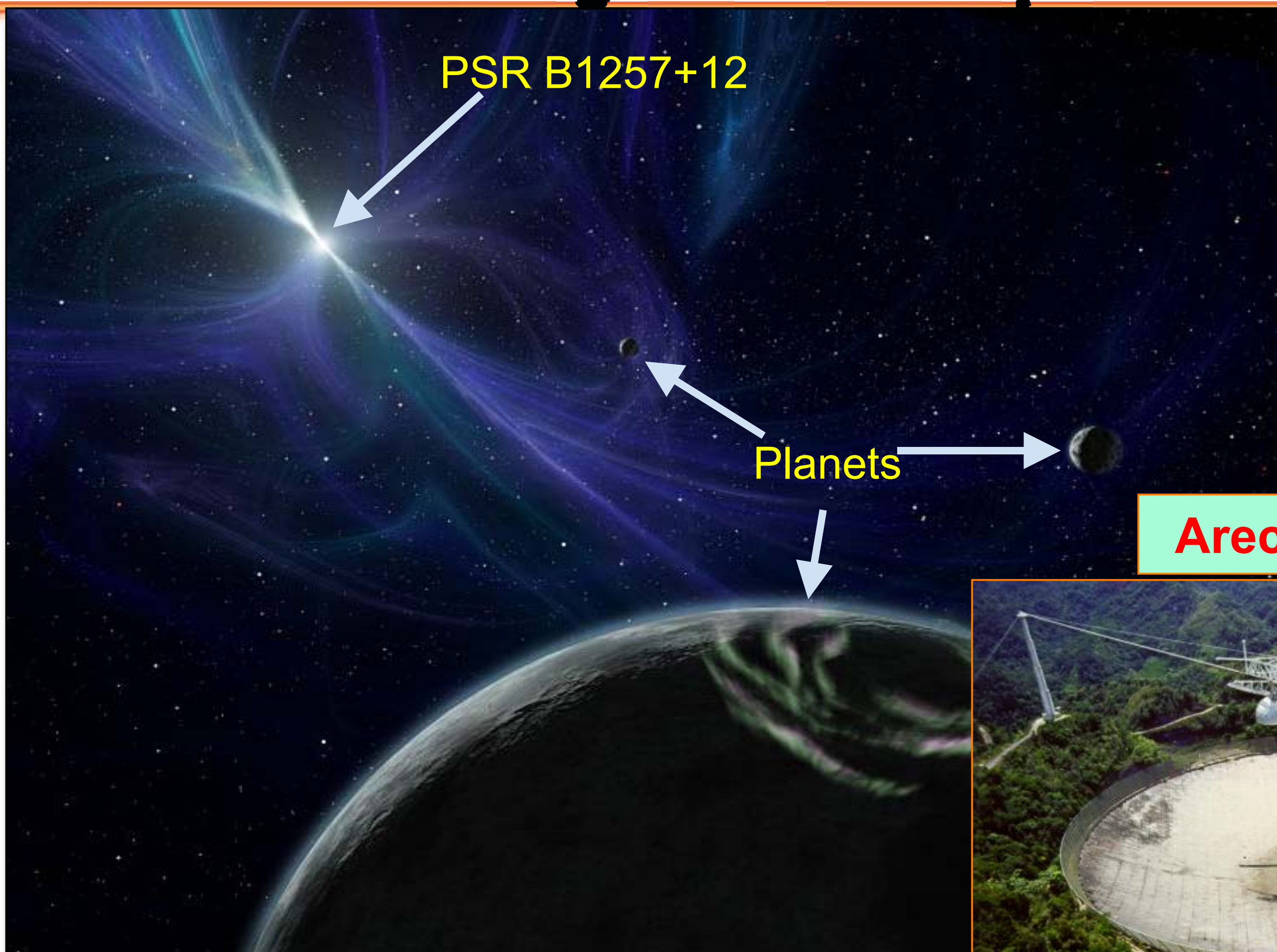
GR Testing Case

Arecibo望□ □



脉冲双星

Discovery of Exoplanet

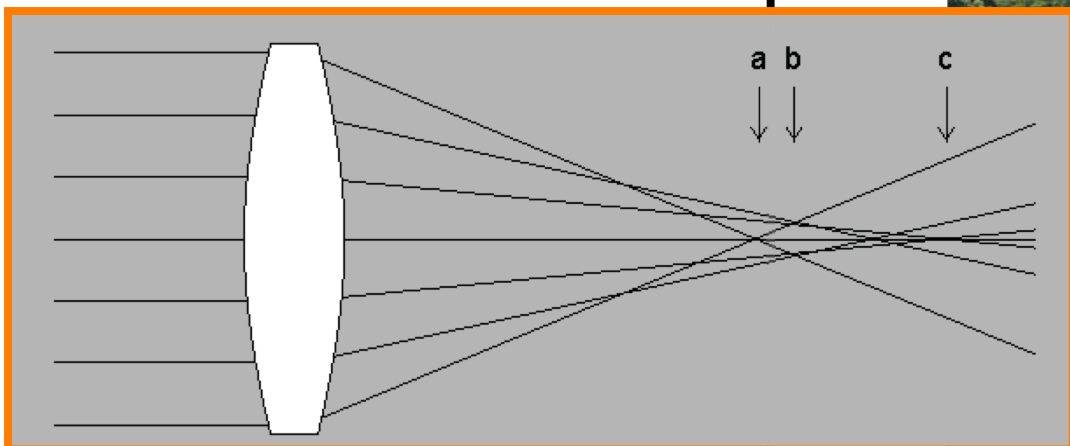


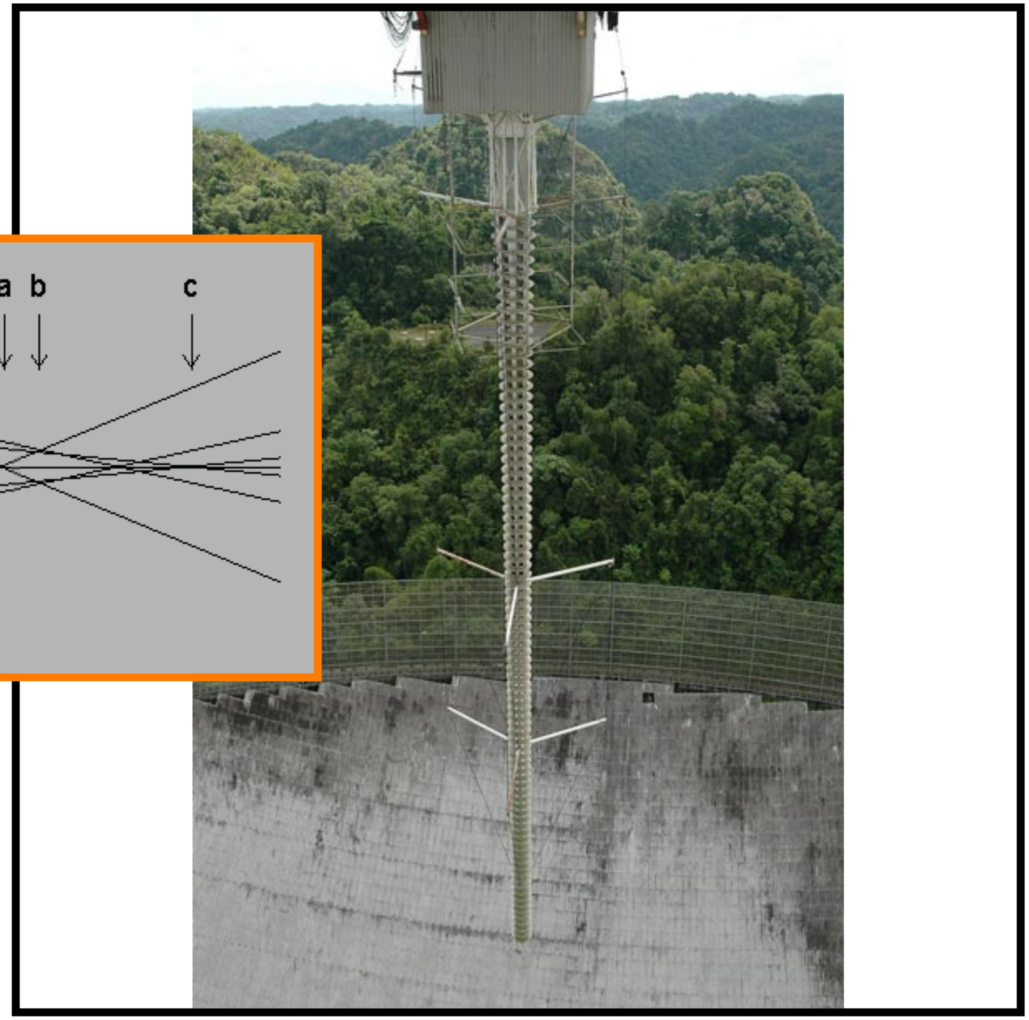
Arecibo望□ □

First Discoveries of Exoplanets

1990 @ Arecibo, around PSR B1257＋12

Spherical Design





Upgraded

- Secondary, Tertiary => point focus
- Primary readjustment => sensitivity and up to 10 GHz
- Ground Screen => cleaner beam

Pre-Biotic Molecules in Galaxies

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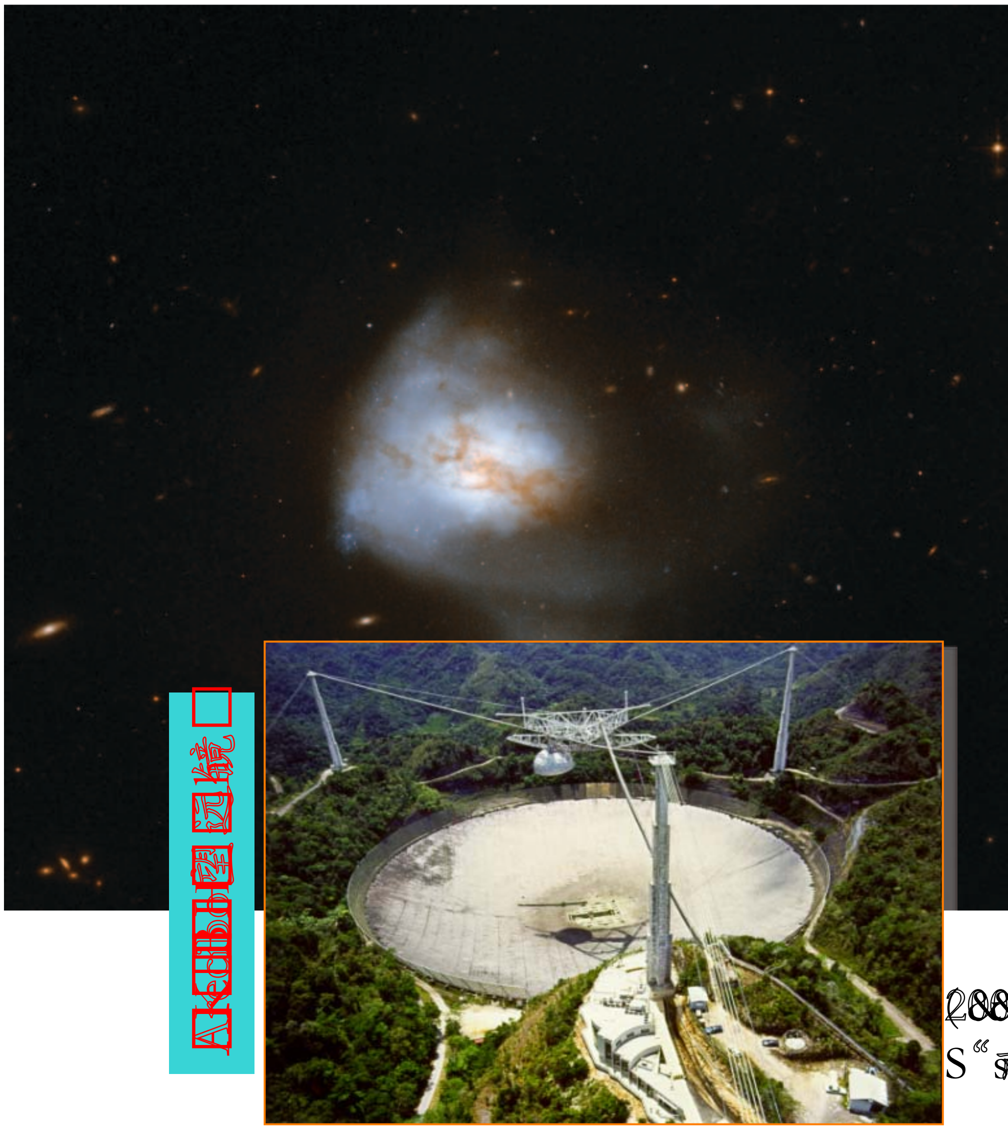
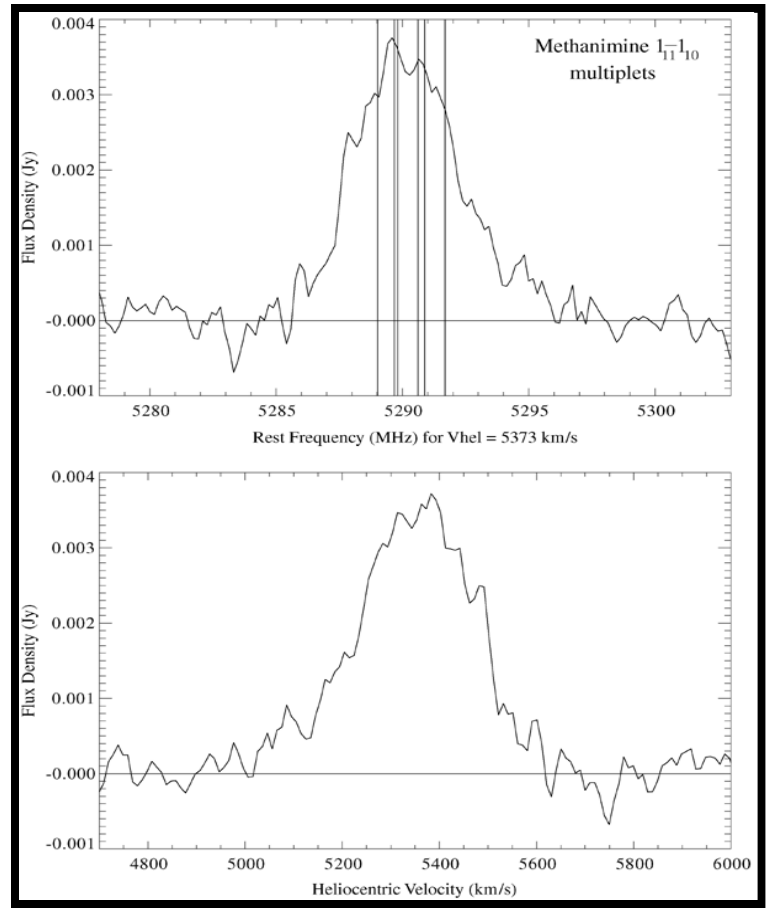


Arecibo望远镜



2008: Arecibo望远镜在Arp 220中发现了“前生命” (pre-biotic) 分子CH_2NH

Fully Steerable Telescopes

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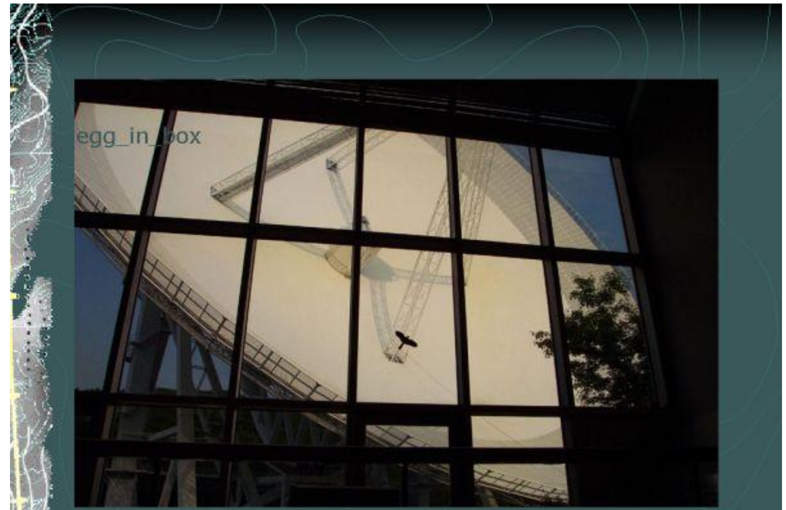

Outline

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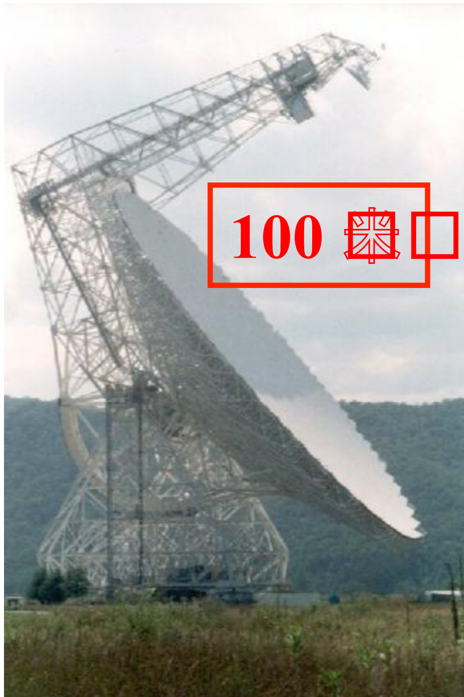
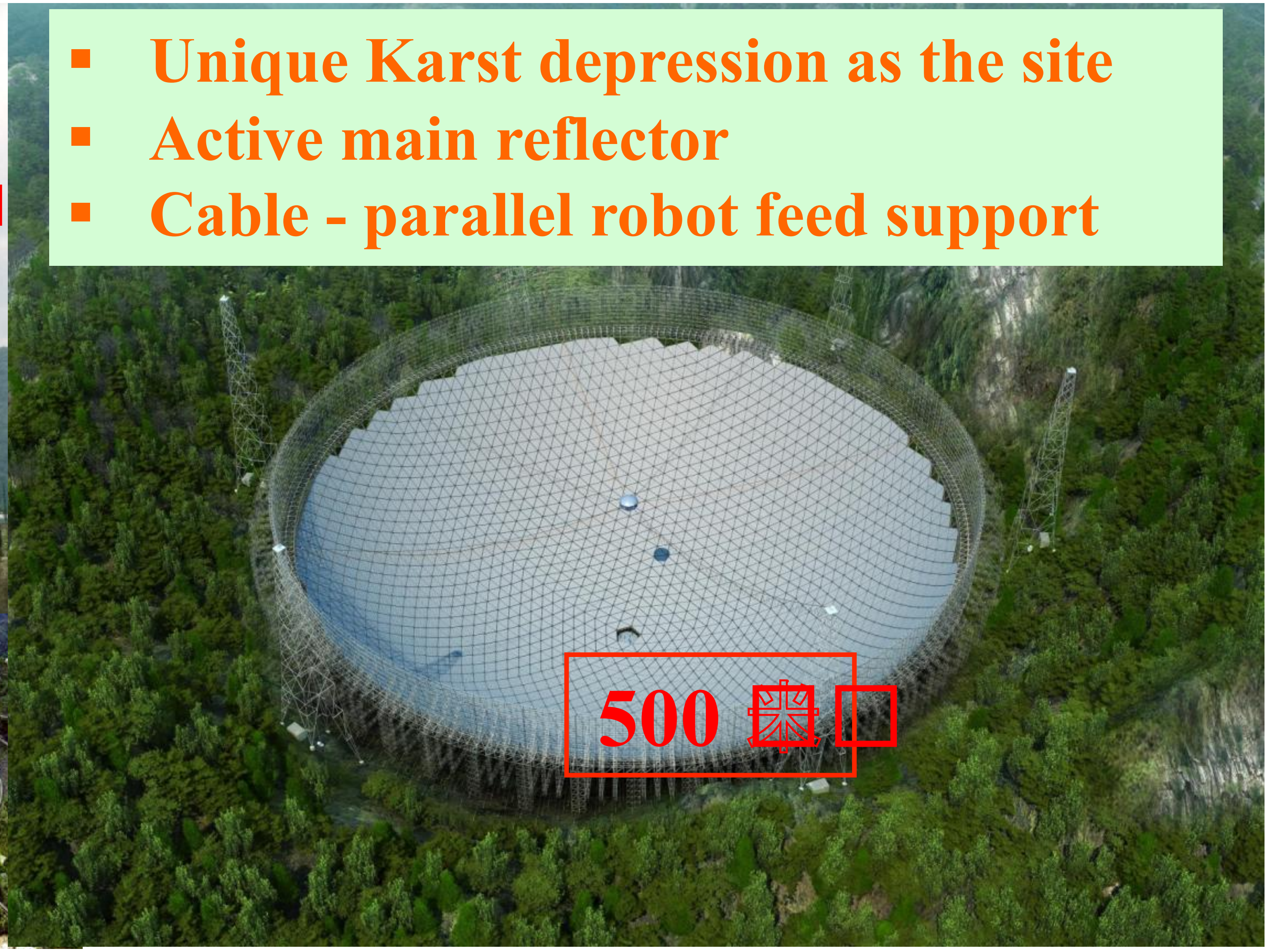
Five-hundred-meter Aperture Spherical radio Telescope (FAST)

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





"World's Largest Telescope"

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Published online 4 February 2009 | *Nature* **457**, 648 (2009) | doi:10.1038/457648d

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- Space and astronomy

Stories by keywords
- FAST
- Radio telescopes

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News in Brief

World's largest telescope under construction

China has begun building the biggest radio telescope in the world, the Five-hundred-meter 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 (US$102-million) facility to identify distant pulsars and galaxies in the low-gigahertz range of the radio spectrum.

FAST will unseat the Arecibo radio telescope in Puerto Rico as the biggest single eye on the sky — although it will not be able to match the resolution of multiple-antenna telescopes such as the Very Large Array in New Mexico and the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile (currently under construction). ■

World's largest telescope under construction

China has begun building the biggest radio telescope in the world, the Five-hundred-meter 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

FAST Site in Guizhou

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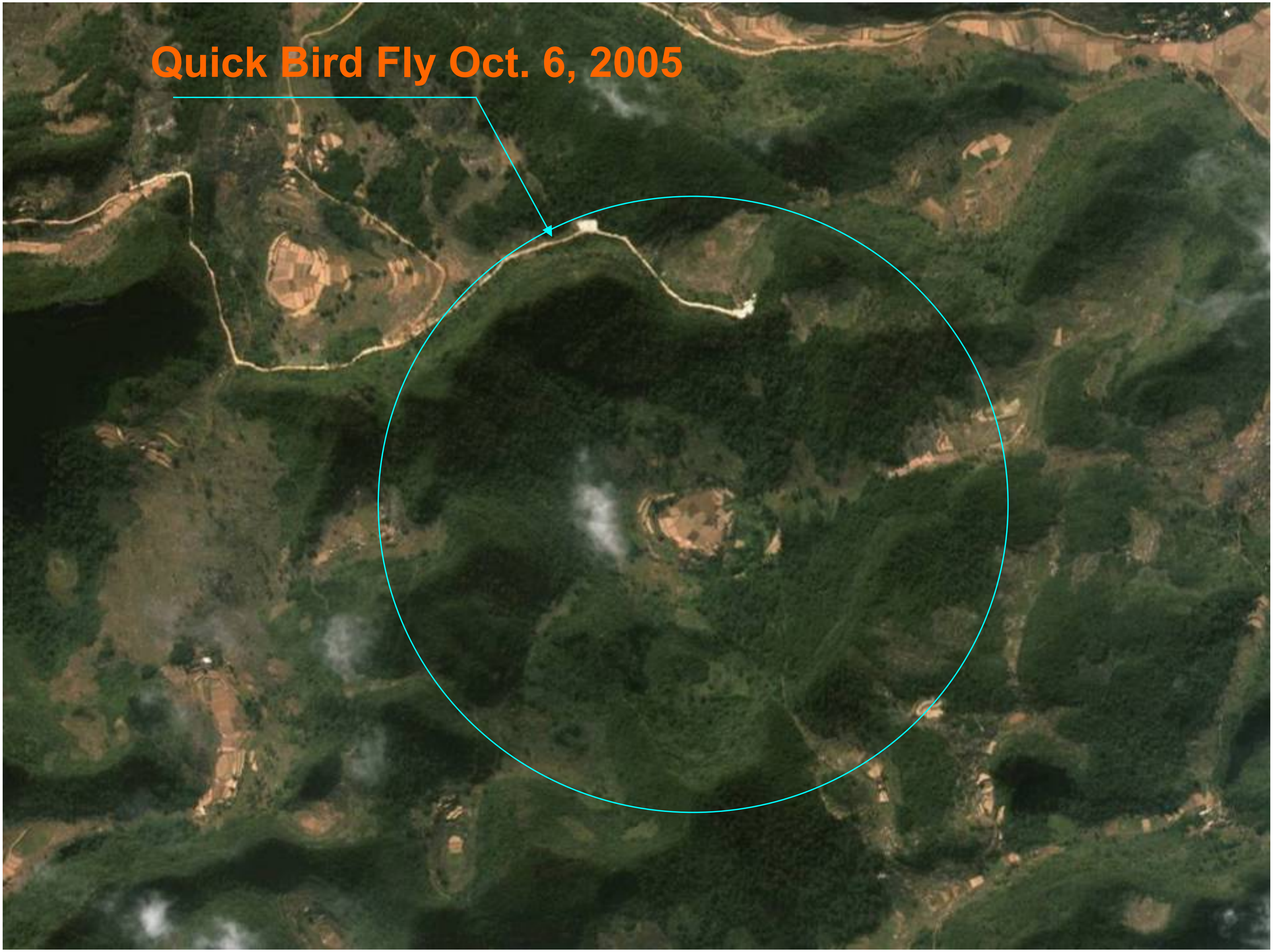
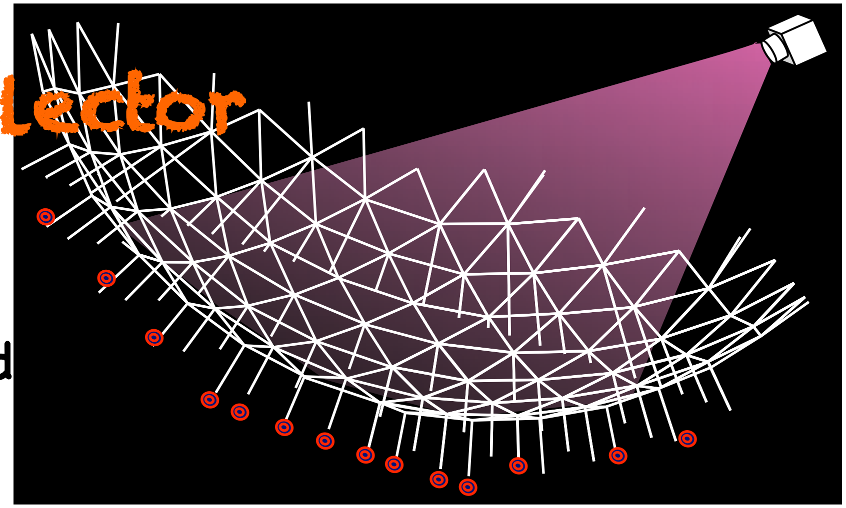
Location: N25.647222º E106.85583°

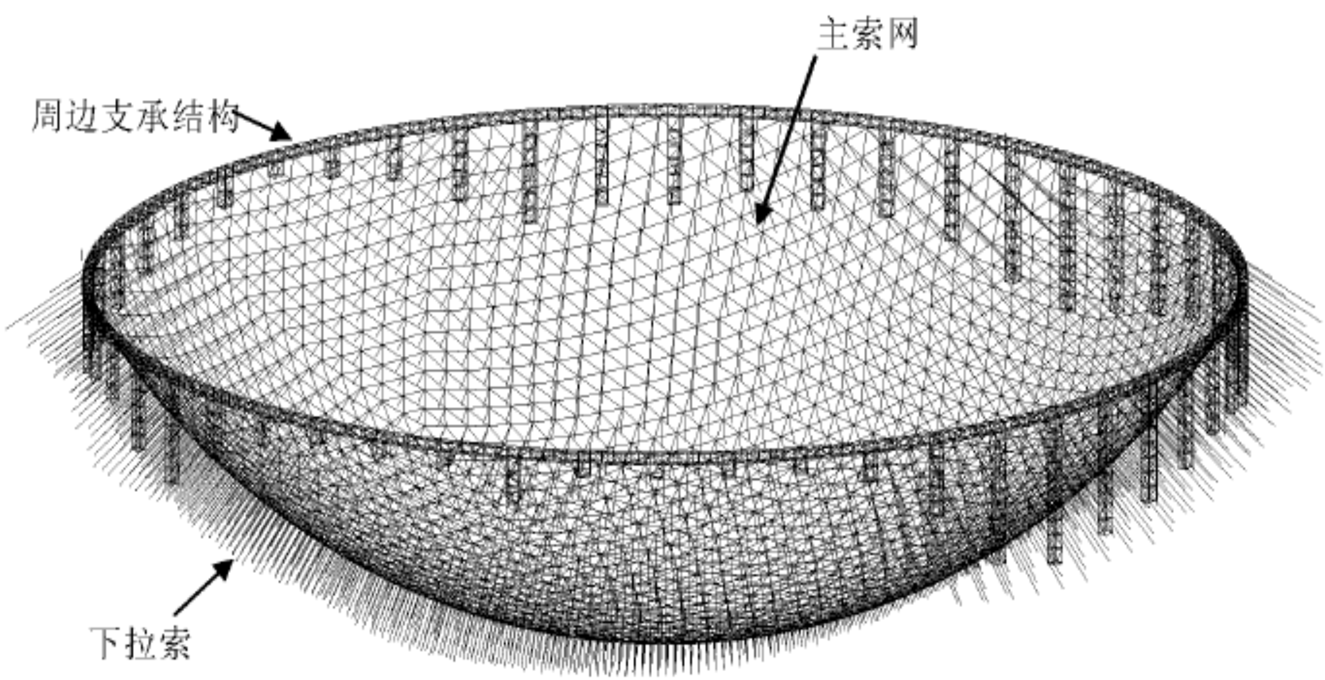
Site: the Karst region in south Guizhou Province


Quick Bird Fly Oct. 6, 2005

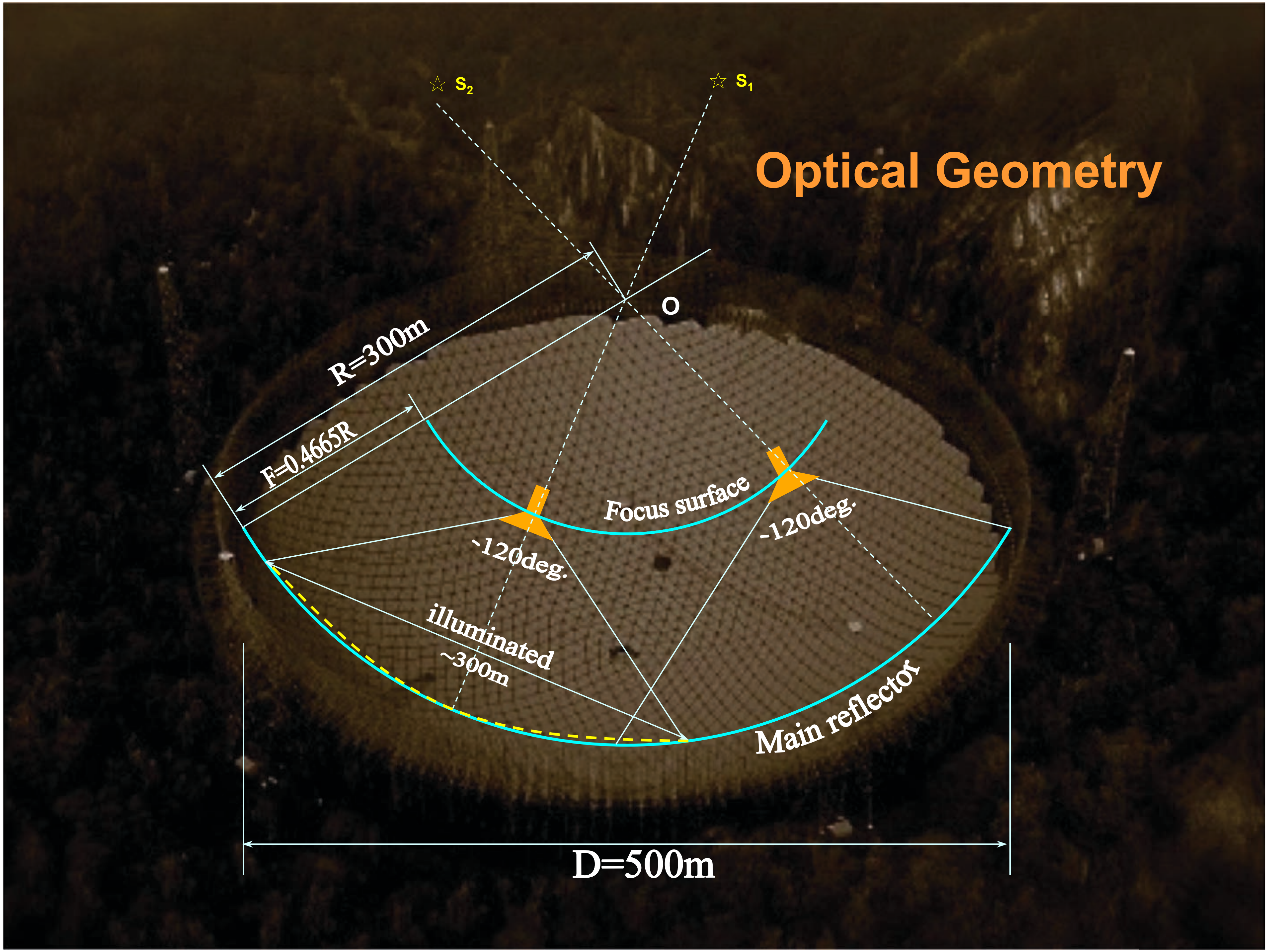
Structure of active reflector

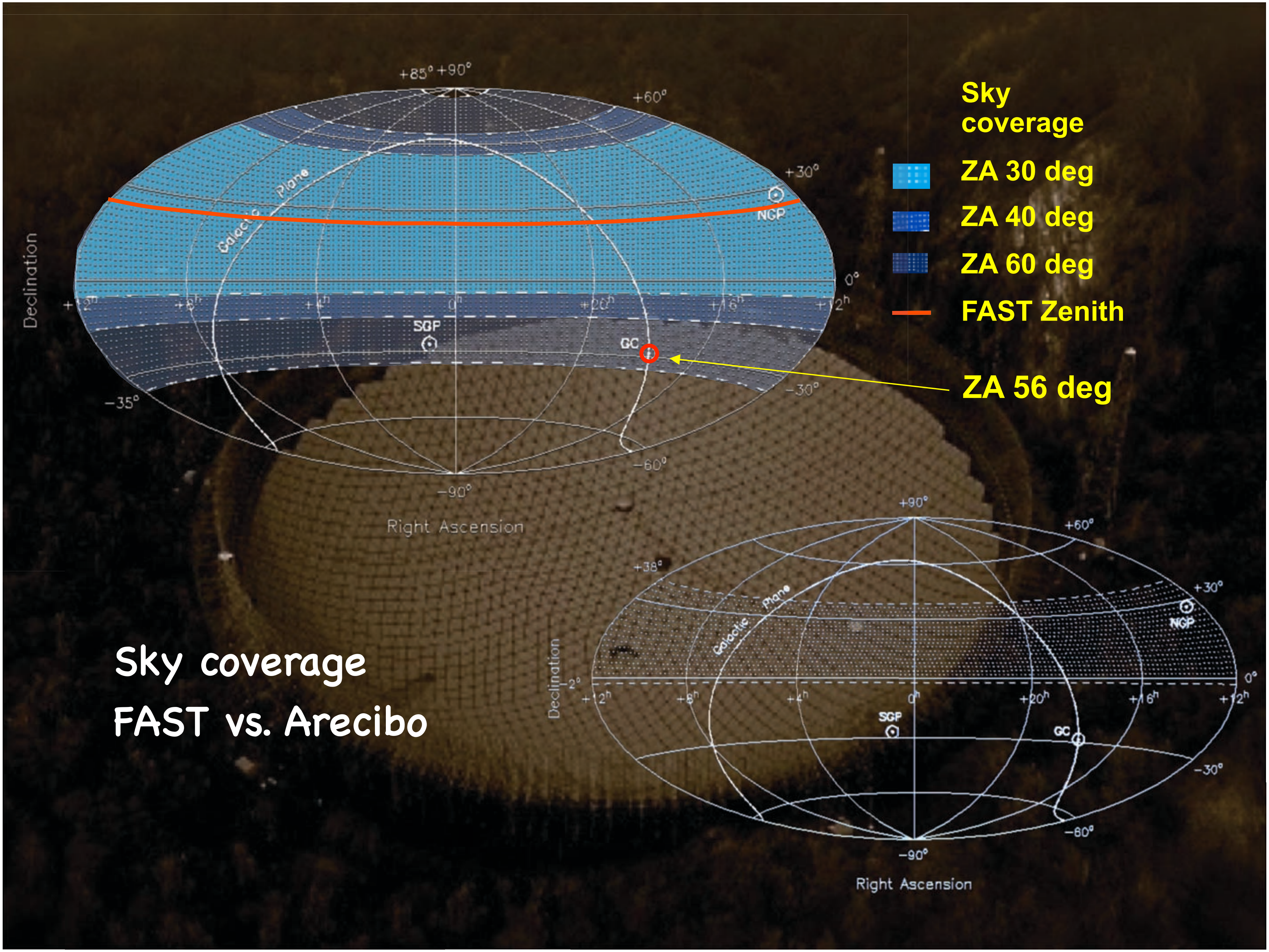
- 500m girder built around hills
- 50 pillars
- Backup consists of ~7000 steel strand
- 2300 down tied cables driven by
- winches anchored into ground



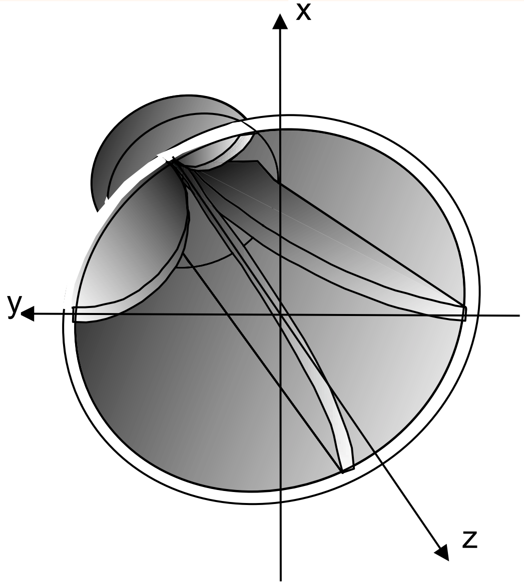


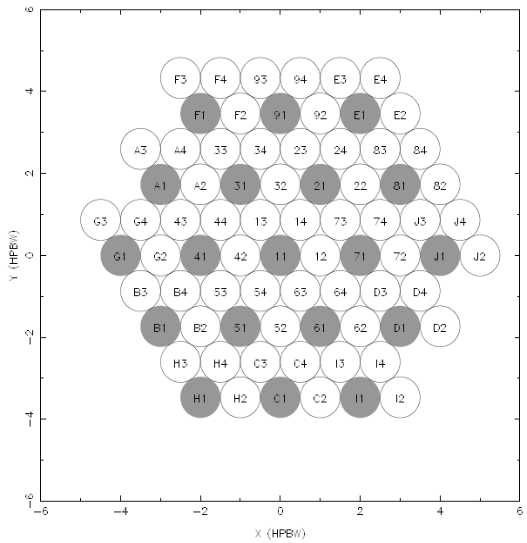
Optical Geometry

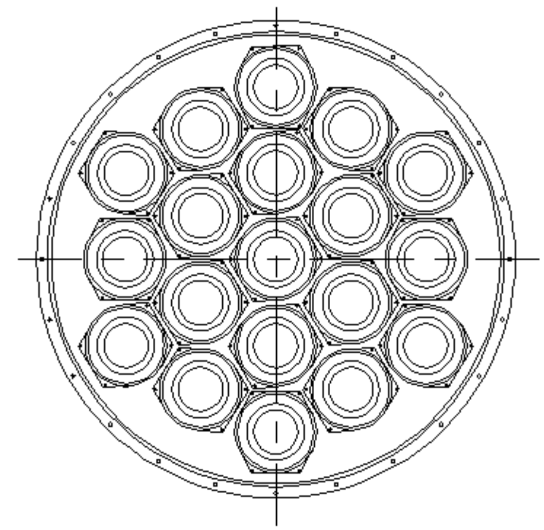


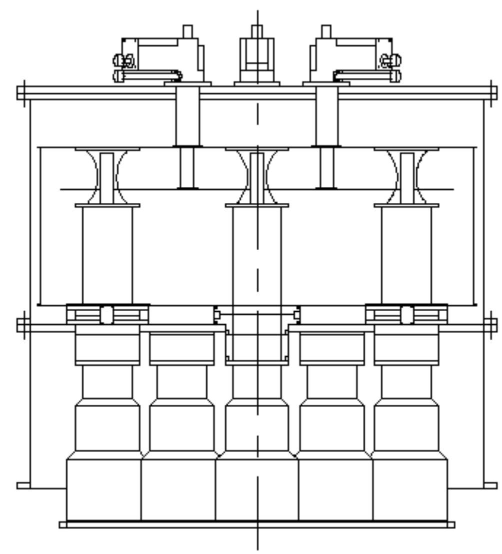

Sky coverage
ZA 30 deg
ZA 40 deg
ZA 60 deg
FAST Zenith
ZA 56 deg
+85° +90°
+60°
+30°
0°
-30°
-35°
-60°
-90°
Galactic Plane
NGP
SGP
GC
Declination
Right Ascension
+38°
-2°
Sky coverage
FAST vs. Arecibo

L-band receiver Array









Technical Specification

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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″

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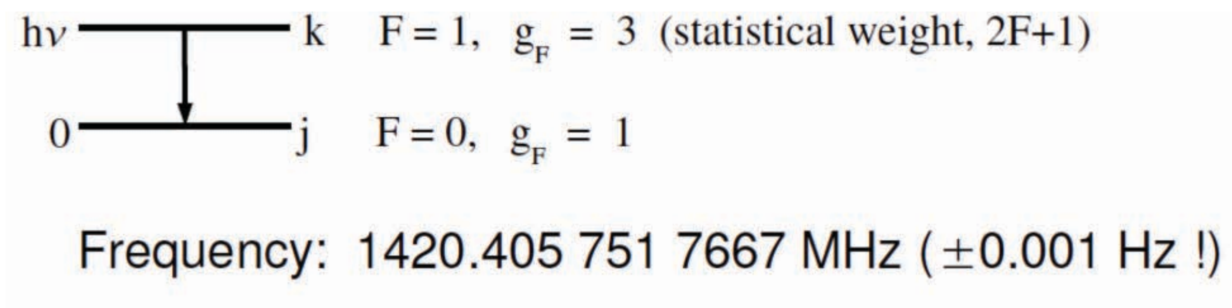
Observables

70MHz～3GHz Complete Coverage

- HI 21cm Hyperfine transition



- Pulsar
- Many more atomic and molecular lines, radio continuum, maser
- Planetary radio emission

Major Topics

(1)Galaxy Evolution and Cosmology:
sensitive measurement of HI universe

(2)ISM and Star Formation:
spectroscopic tracers of physics and chemistry

(3)Compact Objects and Gravitational Wave: PTA, pulsar physics, state of matter

(4)Planetary Radio Emission

Possible Discoveries

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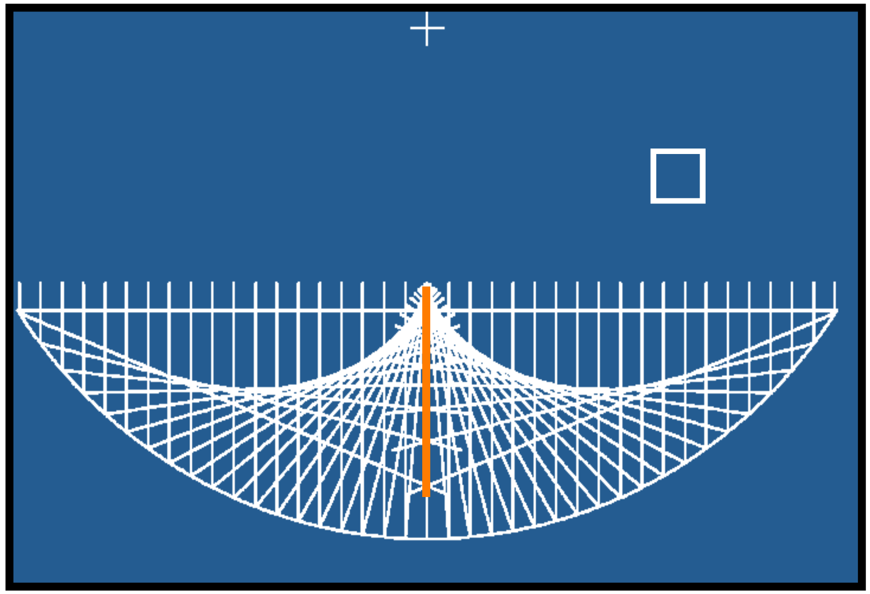
- New content of the ISM including new molecules, especially prebiotic ones
- High redshift masers
- HI Disks and halos in dark galaxies



- special pulsars:

pulsar-blackhole system, first extra-galactic pulsar

- first detection of radio emission of exoplanet

FAST Overview

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International Journal of Modern Physics D
Vol. 20, No. 3 (2011) 1–36

DOI: 10.1142/S0218271811019335

World Scientific
www.worldscientific.com

THE FIVE-HUNDRED-METER APERTURE SPHERICAL RADIO TELESCOPE (FAST) PROJECT

RENDONG NAN[*,†,§], DI LI[*,‡,¶], CHENGJIN JIN[*], QIMING WANG[*],
LICHUN ZHU[*], WENBAI ZHU[*], HAIYAN ZHANG[*,†],
YOULING YUE[*] and LEI QIAN[*]

[*]*National Astronomical Observatories,*
Chinese Academy of Sciences,

Budget of FAST project

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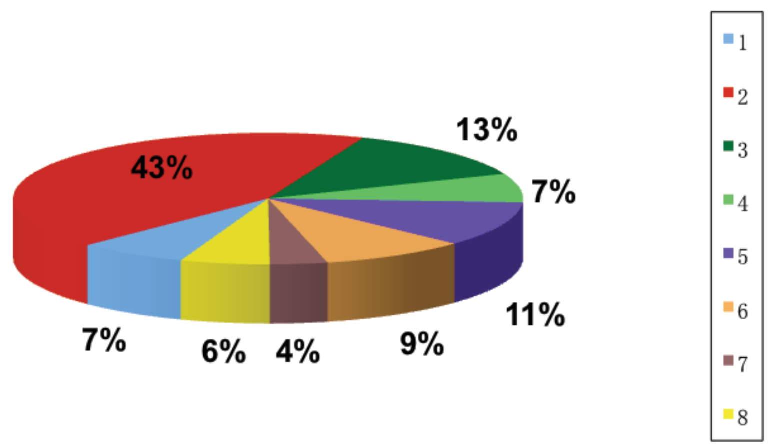
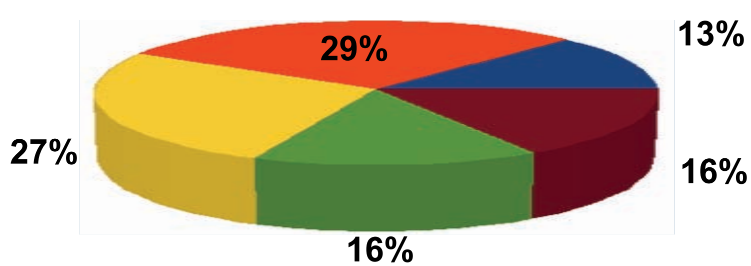
Total budget ~ ¥ 667 millions approved

Total budget pie



- Site
- Reflector
- Feed support
- Measurement
- Receivers
- Observatory
- Others
- Contingency

Budget pie of reflector



- Cable mesh
- Back structure of reflector element
- Surface Panel
- Girder ring and other supporting structure
- Actuator

Outline

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"Frontiers in Radio Astronomy and FAST"

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FAST

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- 2011.3: Construction Start for FAST
- 2016.9: FAST first light
- 2020至2024: SKA phase I and phase II

Fundamental Science Proposal (973):2012～2016

five science teams plus one receiver group, define key FAST programs and early science, train >30 graduate students and young radio astronomers

right idea, right talent, right techniques→ window of oppurtunity

973 Science Teams

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

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

1) Galaxy and Cosmology

FAST HI Galaxy Survey:

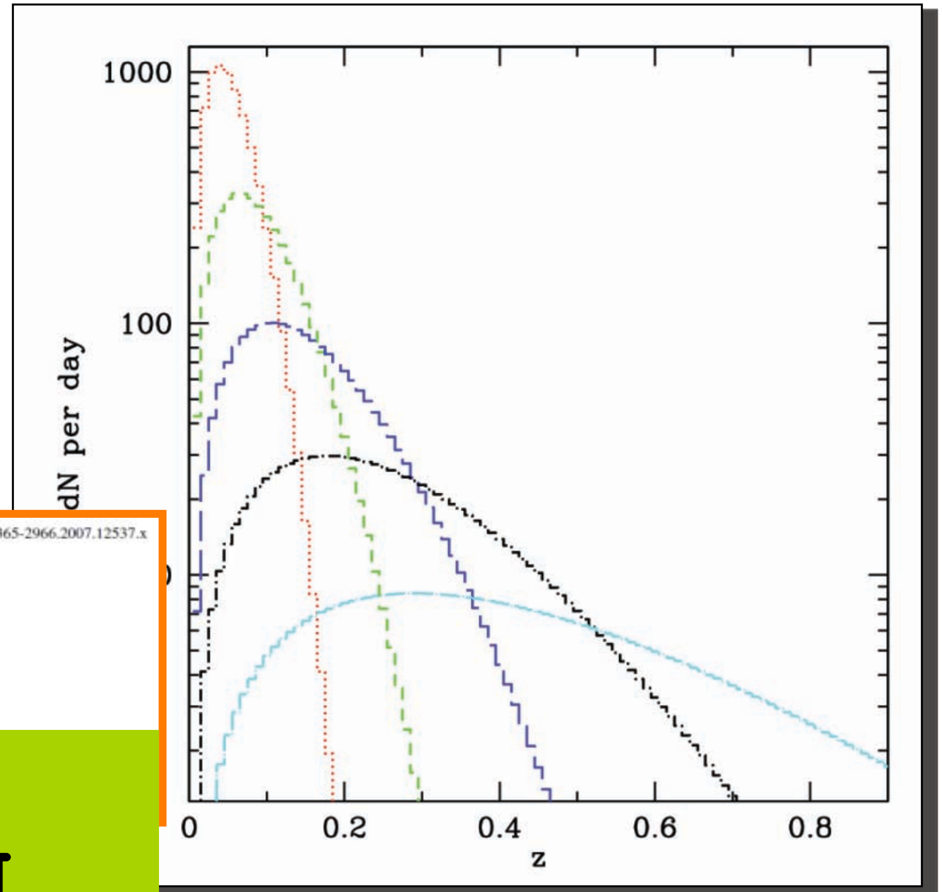
1000 per day

Mon. Not. R. Astron. Soc. 383, 150–160 (2008) doi:10.1111/j.1365-2966.2007.12537.x

Galaxy redshift surveys selected by neutral hydrogen using the Five-hundred metre Aperture Spherical Telescope

Alan R. Duffy,[1,2★] Richard A. Battye,[1] Rod D. Davies,[1] Adam Moss[3]
and I
[1]Jodrell
[2]Leiden
[3]Depart

973: prepare survey methods, understand HI mass function



□ 分模式

---- 6 sec ---- 60 sec ---- 600 sec

--- 6000 sec --- 60000 sec

1) Missing Satellite Problem

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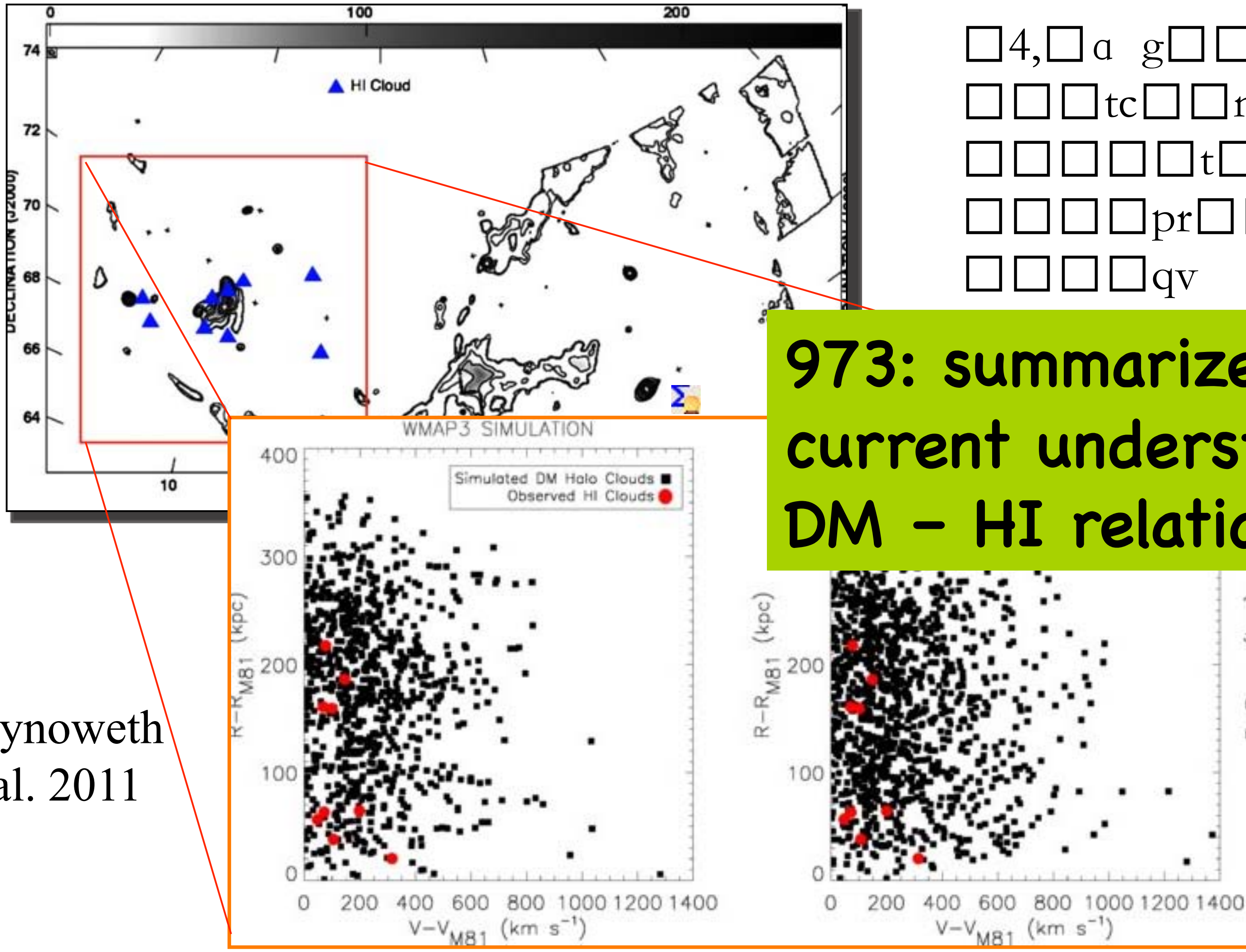
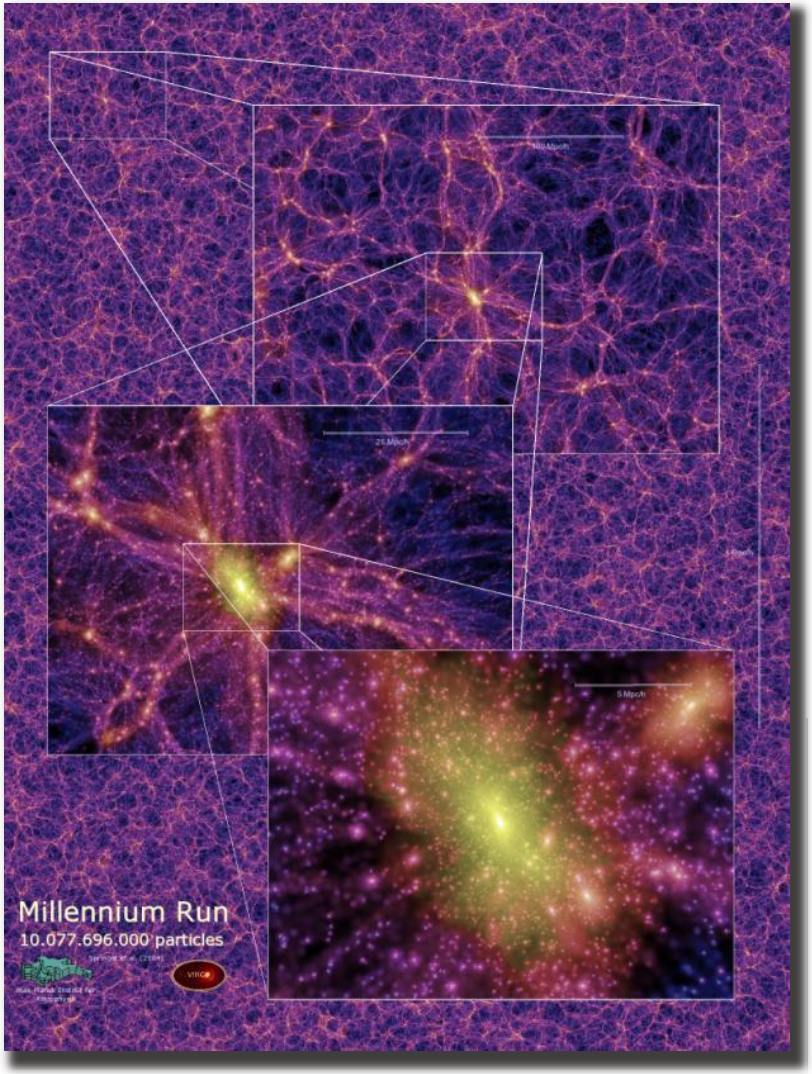
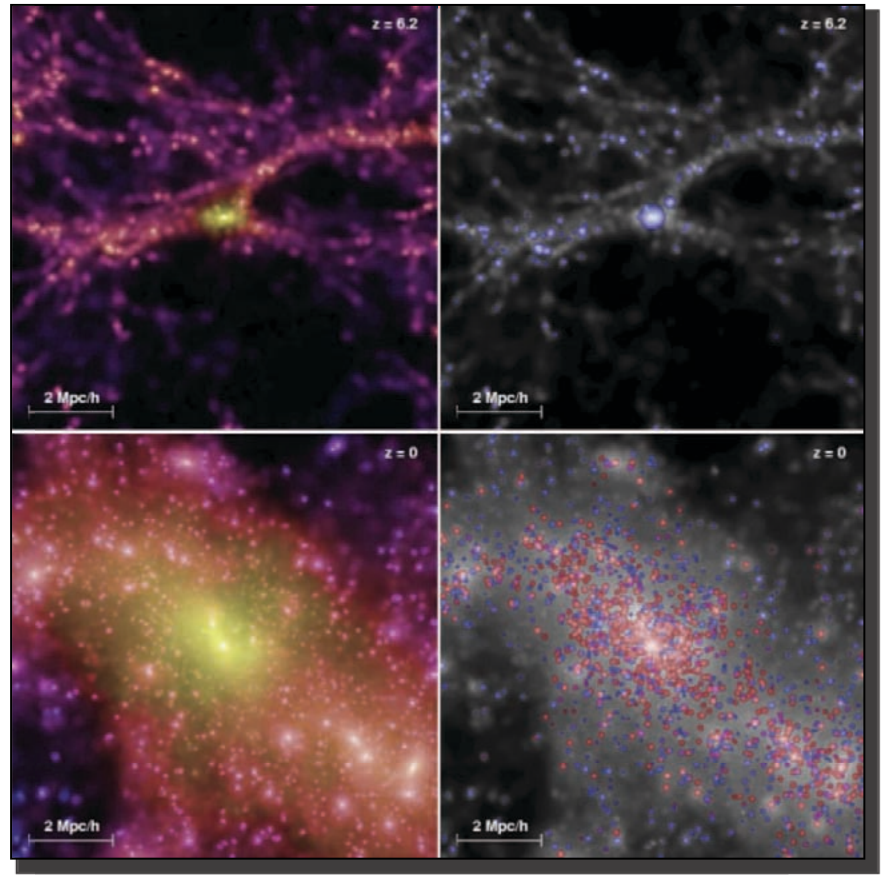


973: summarize the current understanding of DM – HI relationship

Chynoweth et al. 2011

2) Star Formation: 点亮暗宇宙





*(Springel et al. 2005, **Nature**)*

Treatment of SF

- "Semi-Analytic"

The Millennium simulation – Virgo Consortium

Collisionless dark matter particle +

Analytic equations of cooling, star formation, and feedback.

- "Dissipative"

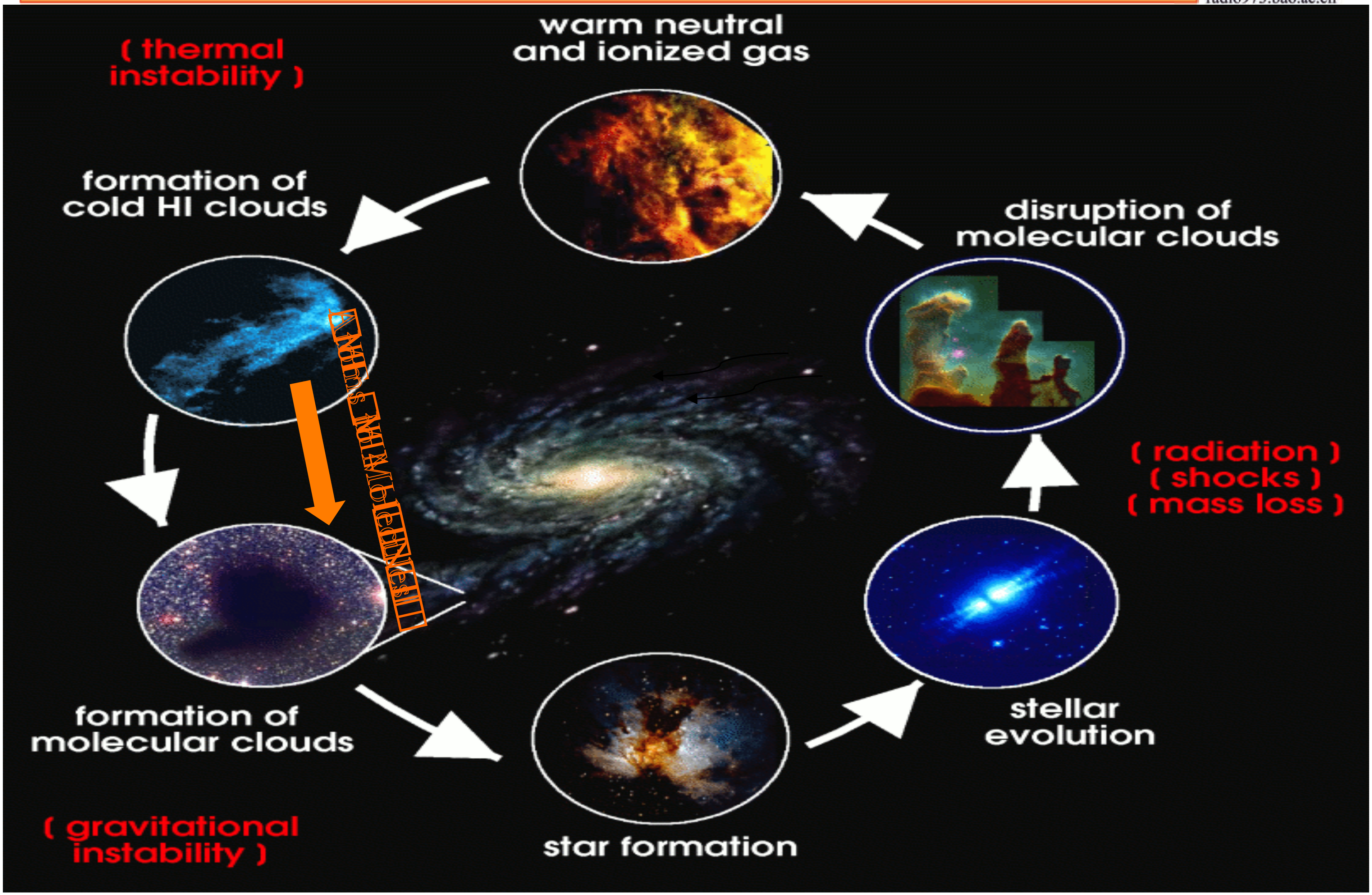
Hydrodynamic Simulations

Overwhelmingly Large Simulations (OWLS)

(Schaye et al. 2009 MNRAS)

Dark matter particles + gas particles + parametric treatment of star formation.

2) Life Cycle of ISM



2) HINSA Reveals Cold HI

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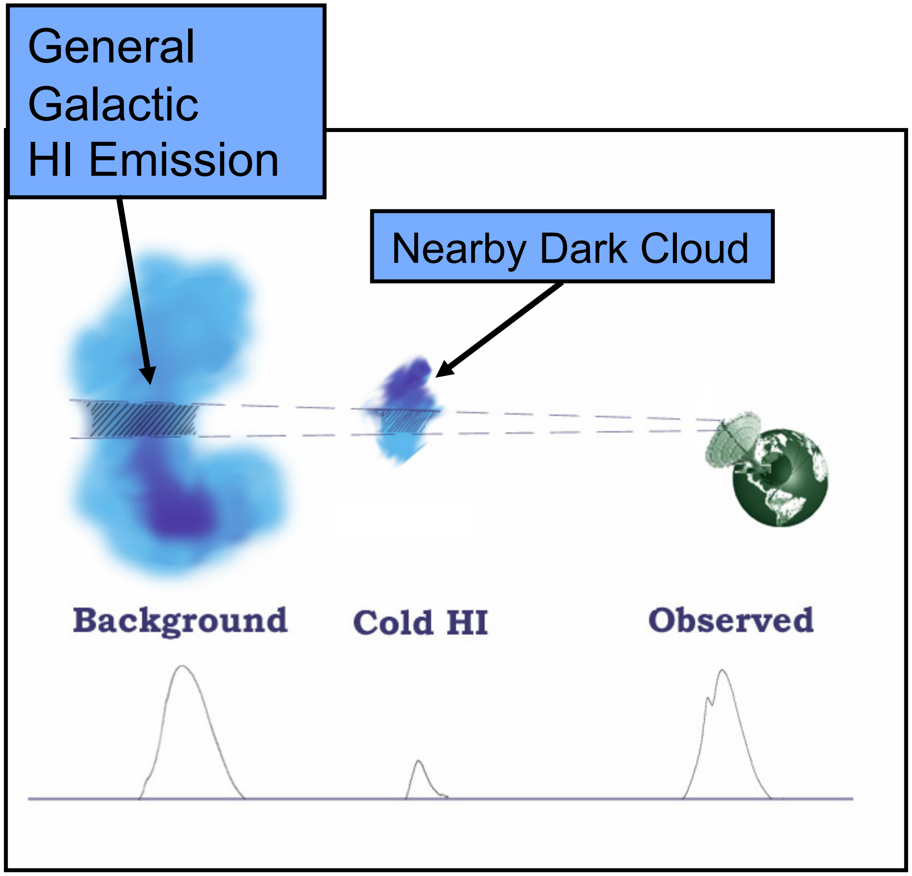

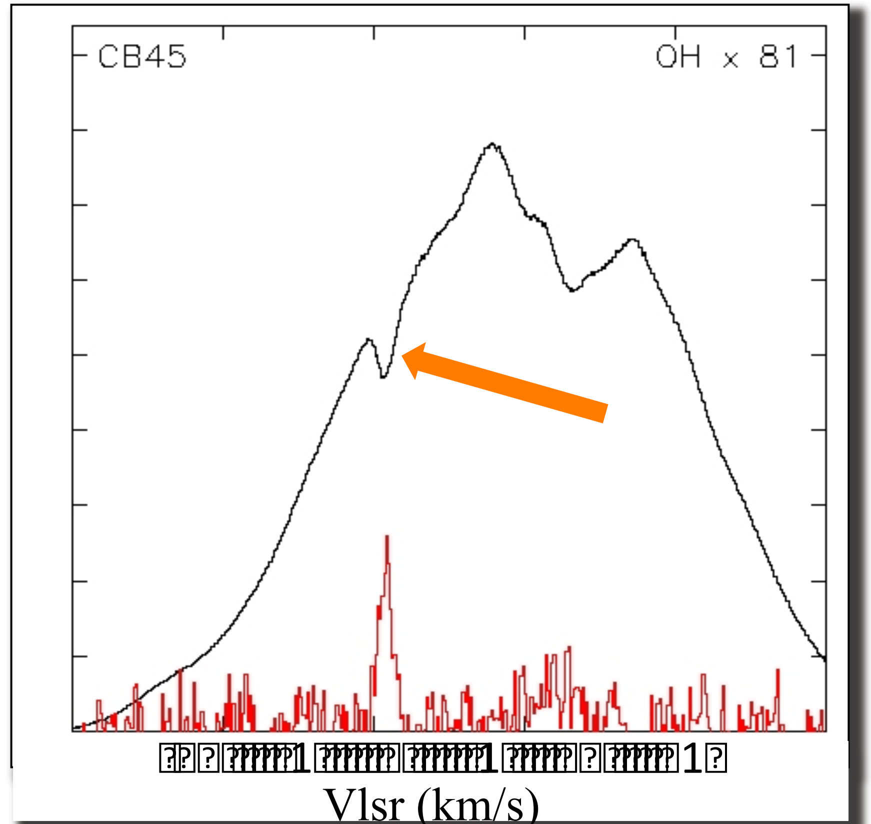

(Li & Goldsmith 2003)

HI Narrow Self Absorption (HINSA)

Atoms (HI) to Molecules (H_2)

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Fractional Abundance of HI

$$x_1(t) = 1 - \frac{2k'n_0}{2k'n_0 + \zeta_{H_2}}\left[1 - \exp\left(\frac{-t}{\tau_{H\,I \to H_2}}\right)\right].$$

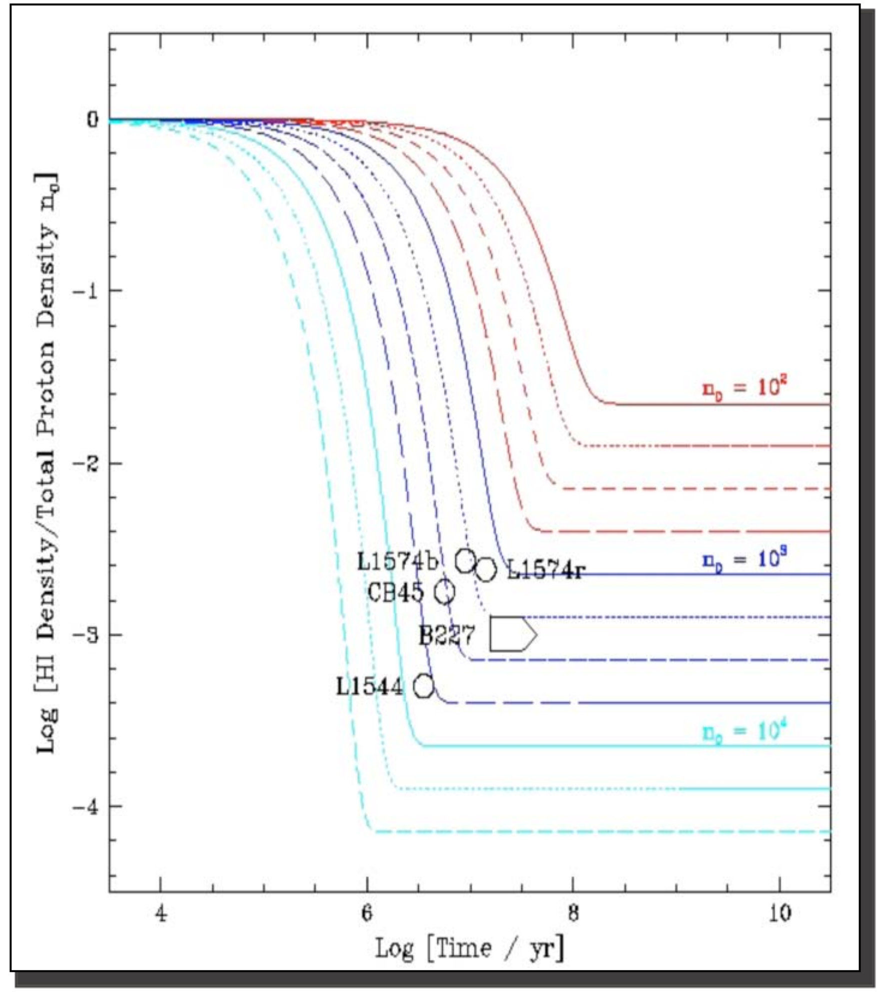
Characteristic Time Scale

$$\tau_{H\,I \to H_2} = \frac{1}{2k'n_0}. \qquad T = 1.3\times10^9 \text{ yr}/n_0$$

Steady-State Abundance of HI

$$x_1 \to \frac{\zeta_{H_2}}{2k'n_0} \quad \text{or} \quad n_{H\,I} \to \frac{\zeta_{H_2}}{2k'}.$$

Molecular Cloud Age: $>10^7$ yr



(Goldsmith & Li 2005)

SF Time Scale

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年度天文及天体物理综述

Theory of Star Formation

Christopher F. McKee[1] and Eve C. Ostriker[2]

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[2]Department of Astronomy, University of Maryland, College Park, Maryland 20742; email: ostriker@astro.umd.edu

Annu. Rev. Astron. Astrophys. 2007. 45:565–687

The *Annual Review of Astronomy and Astrophysics* is online at astro.annualreviews.org

This article's doi: 10.1146/annurev.astro.45.051806.110602

0066-4146/07/0922-0565$20.00

Key Words

accretion, galaxies, giant molecular clouds, gravitational collapse, HII regions, initial mass function, interstellar medium, jets and outflows, magnetohydrodynamics, protostars, star clusters, turbulence

Abstract

We review current understanding of star formation, outlining an overall theoretical framework and the observations that motivate it. A conception of star formation has emerged in which turbulence plays a dual role, both creating overdensities to initiate gravitational contraction or collapse, and countering the effects of gravity in these overdense regions. The key dynamical processes involved in star formation—turbulence, magnetic fields, and self-gravity—are highly nonlinear and multidimensional. Physical arguments are used to identify and explain the features and scalings involved in star formation, and results from numerical simulations are used to quantify these effects. We divide star formation into large-scale and small-scale regimes and review each in turn. Large scales range from galaxies to giant molecular clouds (GMCs) and their substructures. Important problems include how GMCs form and evolve, what determines the star formation rate (SFR), and what determines the initial mass function (IMF). Small scales range from dense cores to the protostellar systems they beget. We discuss formation of both low- and high-mass stars, including ongoing accretion. The development of winds and outflows is increasingly well understood, as are the mechanisms governing angular momentum transport in disks. Although outstanding questions remain, the framework is now in place to build a comprehensive theory of star formation that will be tested by the next generation of telescopes.

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A potentially more robust clock is provided by observations of cold HI in cores (Goldsmith & Li 2005)

easily be destroyed, however, and it is likely that they remain intact until they merge with other cores to become supercritical. Simulations have not yet afforded sufficient statistics to determine the mean time to collapse or dispersal as a function of core properties and cloud turbulence level, or whether there is a threshold density above which ultimate collapse is inevitable.

Observationally, core lifetimes can be estimated by using chemical clocks or from statistical inference. The formation of complex molecules takes $\sim 10^5$ years at typical core densities, but this clock can be reset by events that bring fresh C and C^+ into the core, such as turbulence or outflows (Langer et al. 2000). A potentially more robust clock is provided by observations of cold HI in cores: Goldsmith & Li (2005) infer ages of $10^{6.5-7}$ years for five dark clouds from the low observed values of the H^0/H_2 ratio. These age estimates would be reduced if clumping is significant and hence the time-averaged molecule formation rate is accelerated, but, as in the case of complex molecules, they would be increased if turbulent mixing were effective in bringing in fresh atomic hydrogen. In simulations of molecule formation in a turbulent (and therefore clumpy) medium, Glover & Mac Low (2007) find that H_2 formation is indeed accelerated when compared with the nonturbulent case, although the atomic fractions they found are substantially greater than those observed by Goldsmith & Li (2005). If confirmed, these ages, which are considerably greater than a free-fall time, would suggest that these dark clouds are quasi-equilibrium structures.

Statistical studies of core lifetimes are based on comparing the number of starless cores with the number of cores with embedded YSOs and the number of visible T Tauri stars (TTSs). The ages of the cores (starless and with embedded YSOs) can then be inferred from the ages of the T Tauri population, provided that most of the observed starless cores will eventually become stars. The results of several such studies have been summarized by Ward-Thompson et al. (2007), who conclude that lifetimes are typically $3 - 5t_{ff}$ for starless cores with densities $n_{H_2} = 10^{3.5} - 10^{5.5}$ cm^{-3}. This is not consistent with dynamical collapse, nor is it consistent with a long period ($>5t_{ff}$) of

H_2 Formation and SF


nature Vol 465|3 June 2010

RESEARCH HIGHLIGHTS

GEOPHYSICS

Glaciers going, going...

Geophys. Res. Lett. doi:10.1029/2010GL042616 (2010)

As much as half of the glacial retreat documented in the Swiss Alps in recent decades could be due to natural cycles in the North Atlantic climate.

Matthias Huss at the Swiss Federal Institute of Technology in Zurich and his co-authors combined field data with computer modelling to develop a 100-year record of glacier surface mass balance from 1908 to 2008. The team compared their records with global climate data as well as with regional climate trends relating to multidecadal oscillations in Atlantic Ocean surface temperatures.

The findings may help to sharpen predictions of the impact of future climate change on glaciers, the authors say. J.T.

ASTRONOMY

Clouds with an H_2 lining

Astrophys. J. 715, 1370–1382 (2010)

Stars are born inside giant clouds of gas. Figuring out where such clouds begin and end is tricky because their main component, molecular hydrogen (H_2), is often too cold to be seen by telescopes.

Paul Goldsmith and his colleagues at NASA's Jet Propulsion Laboratory in Pasadena, California, have used the orbiting Spitzer Space Telescope to find the edge of a nearby molecular cloud. By detecting emissions from transitions in the rotational states of molecular hydrogen, they found hints of a warm layer of H_2 on the surface of the cloud. The team suggests that the properties of the hot edge could be related to circulation of gas within the cloud. G.B.

ECOLOGY

What's that whale?

Genome Res. doi:10.1101/gr.102954.109 (2010)

Killer whales consist of several species, not just one, according to a genetic study.

Different populations or 'ecotypes' of killer whale (*Orcinus orca*) vary in traits such as body size, social structure and preferred prey. Yet analyses of fragments of their mitochondrial DNA — which is inherited only from the mother and is often studied to delineate species — have revealed very low levels of genetic diversity between ecotypes, probably because of low mutation rates.

Phillip Morin of the National Marine Fisheries Service in La Jolla, California, and his colleagues examined the entire mitochondrial genome of 139 whales from the North Pacific, North Atlantic and Southern oceans. The authors found enough genetic variation to suggest renaming three of the ecotypes as separate species and classifying the rest as subspecies until more data become available. L.O.-S.

NANOMANUFACTURING

Petite pottery

Nano Lett. doi:10.1021/nl100824d (2010)

Polymer nanofibres can be spun into free-standing, hollow cylinders that look as if they might have been shaped on a tiny pottery wheel. Ho-Young Kim at Seoul National University, L. Mahadevan at Harvard University in Cambridge, Massachusetts, and their co-workers used an electric field to tease a nanometre-scale jet of polyethylene oxide solution from a capillary tube. The jet dried in mid-air and, in less than a second, coiled up into a spool a few micrometres in diameter (pictured) as it hit a sharp stainless steel tip 2 millimetres below the capillary tube.

Such structures could be used in nanometre-scale magnets, bioscaffolds or nanochannels, the researchers suggest. R.V.N.

PHYSIOLOGY

Marathon metabolites

Science Trans. Med. 2, 33ra37 (2010)

An analysis of 210 blood metabolites has yielded indicators of physical fitness.

Robert Gerszten and Gregory Lewis at Massachusetts General Hospital in Boston and their colleagues analysed blood samples taken from 70 people before and after a ten-minute run on a treadmill. The researchers found that, across the group, the levels of 21 metabolites changed during the run. Some of these metabolites are linked to cardiovascular fitness and faster running times in the Boston Marathon. Furthermore, fit volunteers showed signs of having more efficient fat metabolism than less fit individuals.

Feeding cultured cells a mixture of five of the 21 metabolites — glycerol, niacinamide, glucose-6-phosphate, pantothenate and succinate — rapidly boosted expression of the NUR77 protein, which controls glucose and lipid metabolism in muscles. H.L.

For a longer story on this research, see go.nature.com/g5P4Pb

GENOMICS

Transposition trends

Genome Res. doi:10.1101/gr.106419.110 (2010)

Researchers have mapped the genomic locations of almost every member of a family of human retrotransposons — short DNA segments thought to make up as much as one-third of the genome. These elements — which can affect physical traits — copy and then paste themselves back into the genome at various locations. Despite their abundance, they are not as well studied as other forms of genomic variation.

AM. CHEM. SOC.

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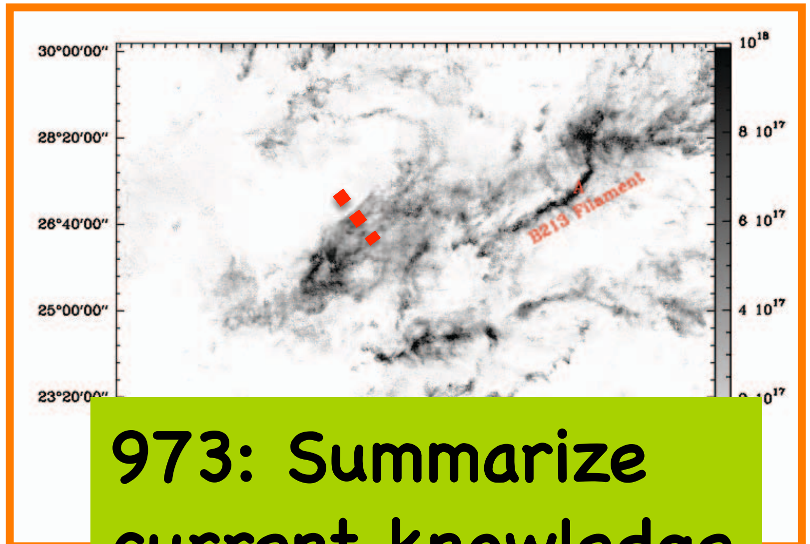
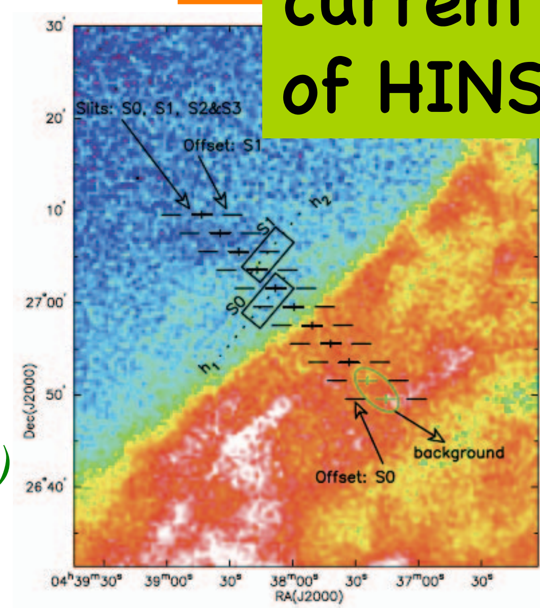
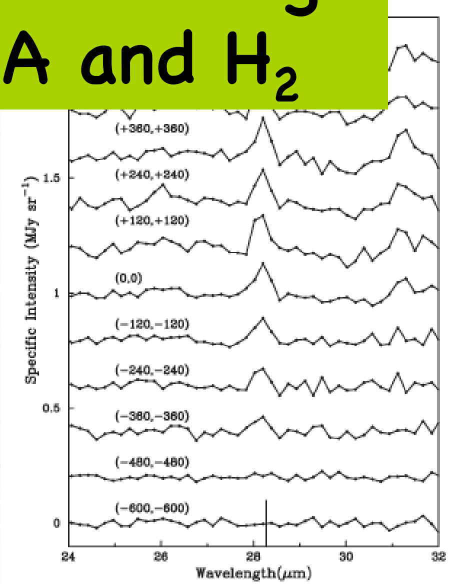
detects warm H_2 around dark clouds

(Goldsmith, Velusamy, Li & Langer 2010)



973: Summarize current knowledge of HINSA and H_2





Implications for Sim.

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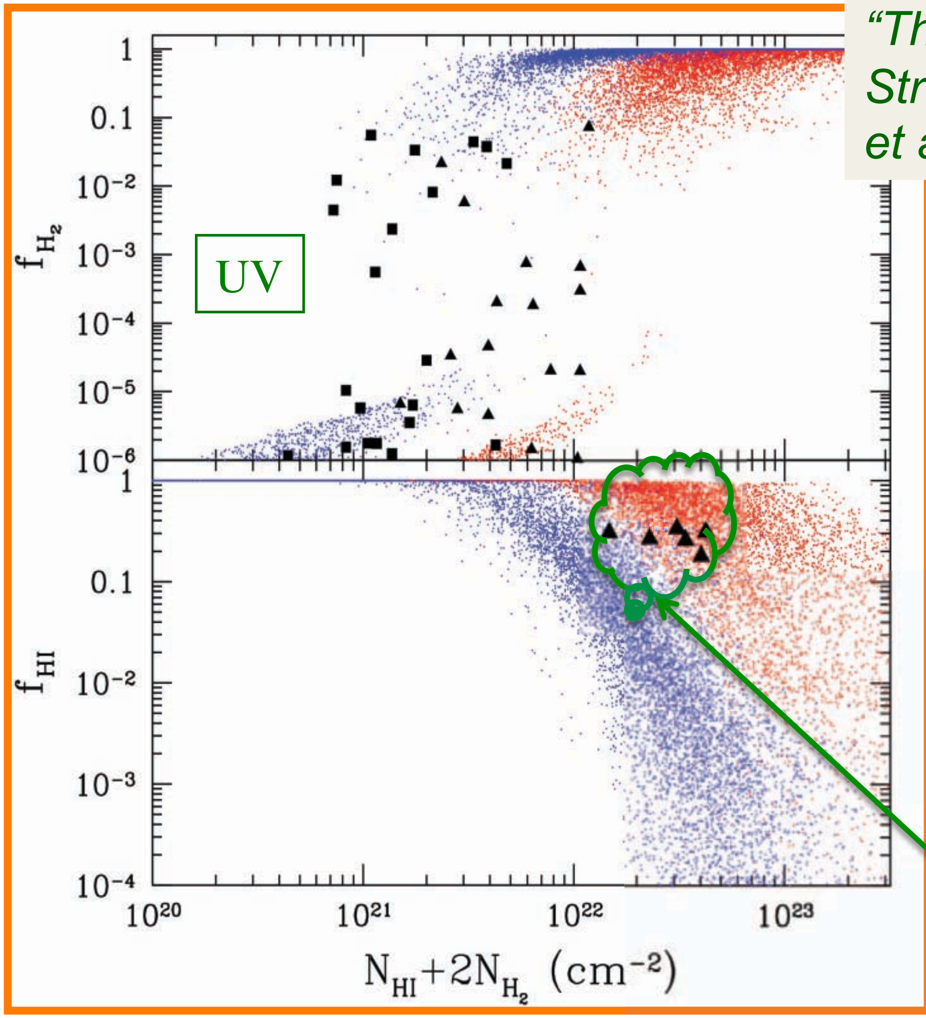
N. Gnedin & A. Kravtsov 2010



"The Impact of Baryon Physics on the Structure of High-redshift Galaxies", Zemp et al. 2012

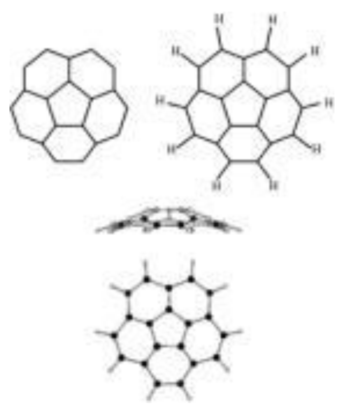
The atomic-to-molecular transition ... is rather sharp and shifts to higher densities with decreasing dust-to-gas ratio and/or increasing FUV flux.

Consequently, star formation is concentrated to higher gas surface density regions, resulting in steeper slope and lower amplitude of the KS relation at a given gas surface density, in less dusty and/or higher FUV flux environments.

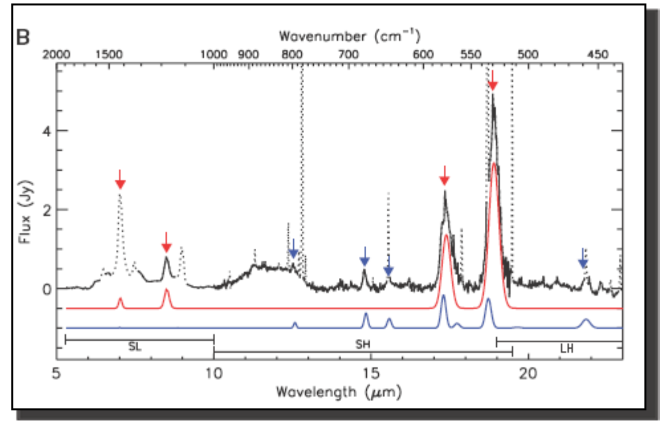
Goldsmith & Li 2005

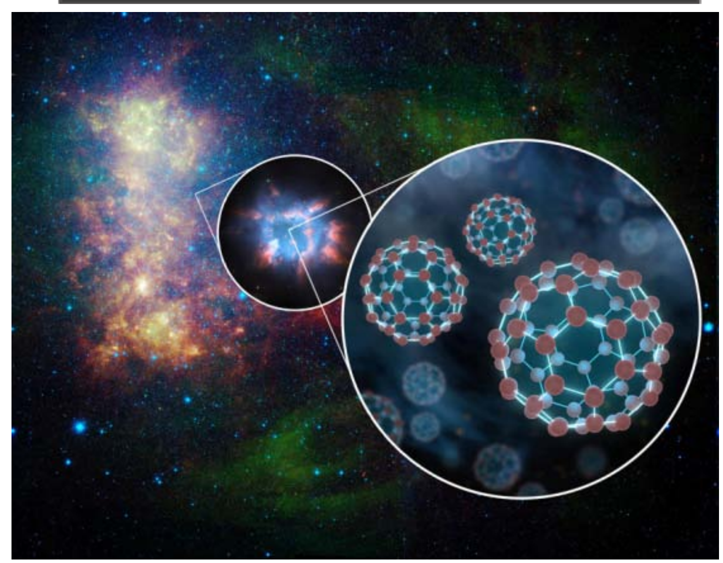
2) ISM: New Components

- more than 140 interstellar molecules detected
- Orion nebula, the primary target for space spectroscopy, is out of Arecibo coverage
- FAST: complete line survey in low frequency radio bands
- Search for "Prebiotic" and large organic molecules (*Nan, Li, Jin et al. IJMPD 2011*)



C_{60} & C_{70} (Buckyballs) in Space





Cami et al. 2010, **Science** 329, 1180

3) Pulsar Surveys

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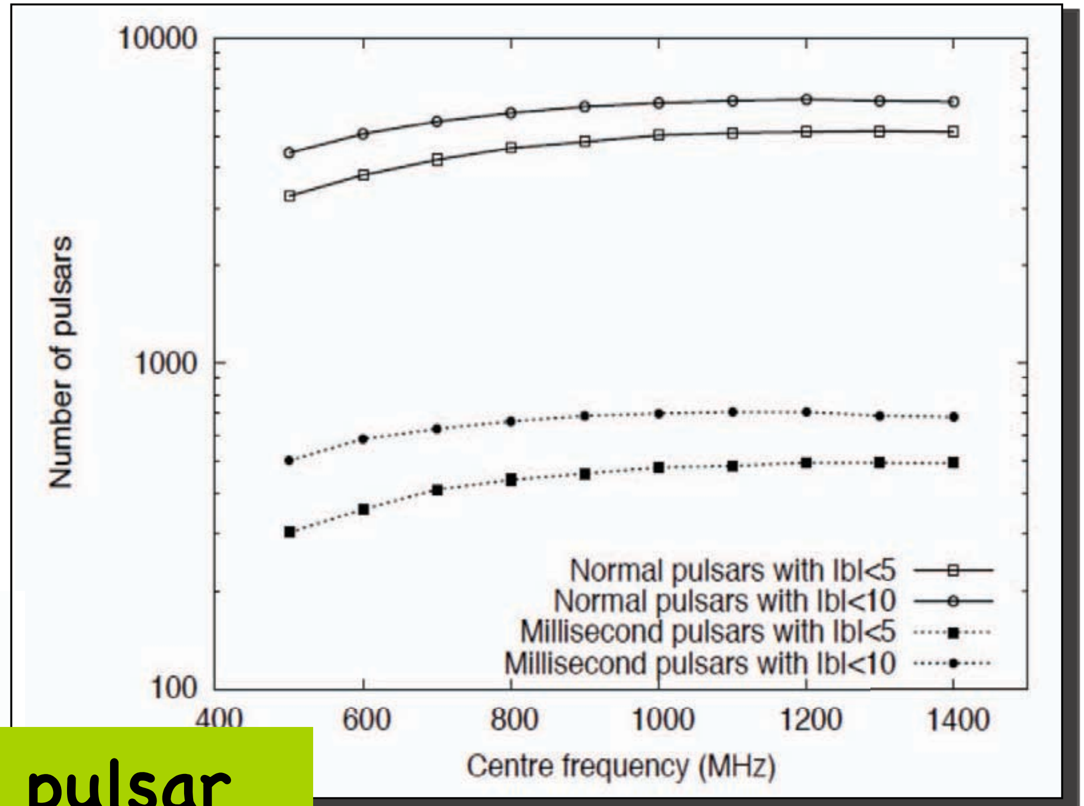
FAST：

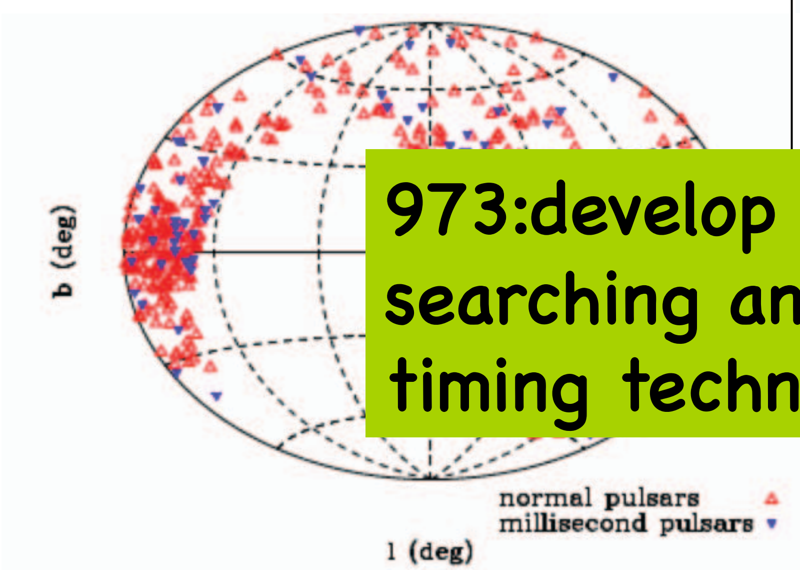
~4000 Pulsar

~300 MSP

Survey time：200d

Integration：600s





973:develop pulsar searching and timing techniques

Astronomy & Astrophysics

Pulsar science with the Five hundred metre Aperture Spherical Telescope

R. Smits[1], D. R. Lorimer[2,3], M. Kramer[1,4], R. Manchester[5], B. Stappers[1], C. J. Jin[6], R. D. Nan[6], and D. Li[7]

3) Pulsar-BH System

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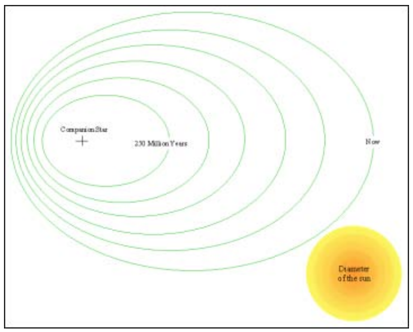
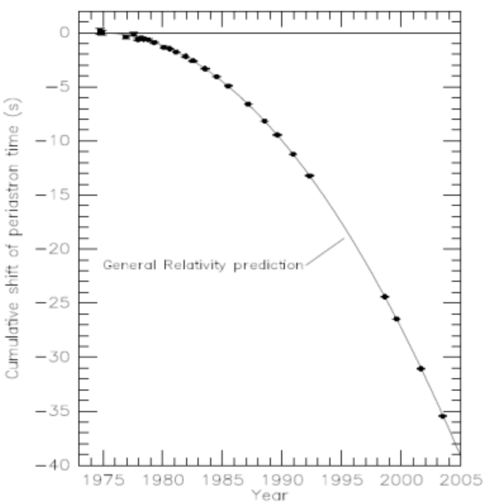
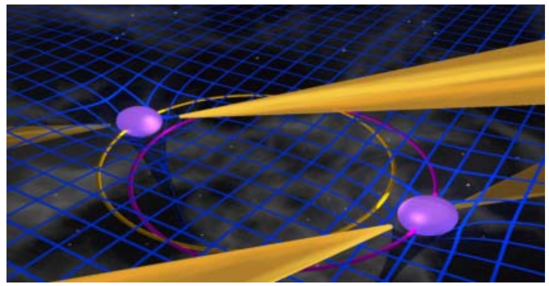
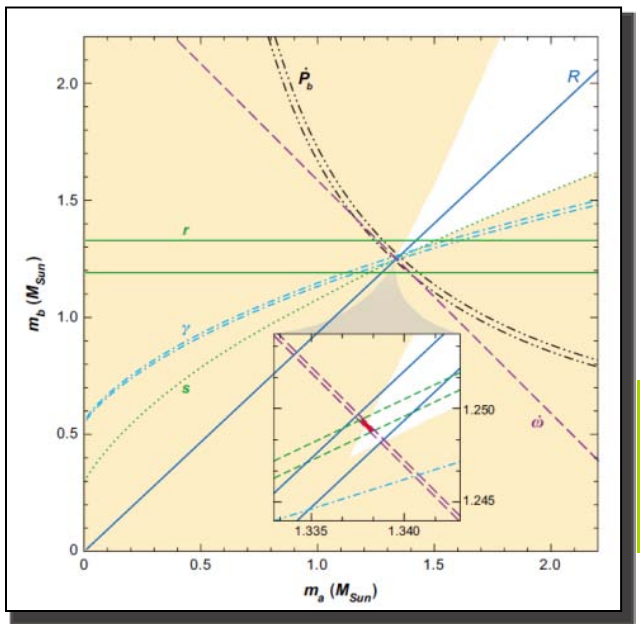
Pulsar-Neutron Star (1974)
PSR B1913+16
□ 接□ □ 引力波
在0.2%精度□ □ 相□ □
1993年□ □ 尔□





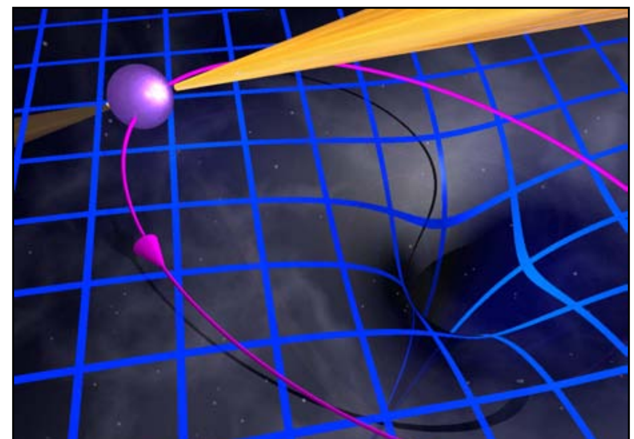
Pulsar-Pulsar (2004)
PSR J0737-3039A/B
在0.05%精度□ □ 相□ □





Pulsar-BH

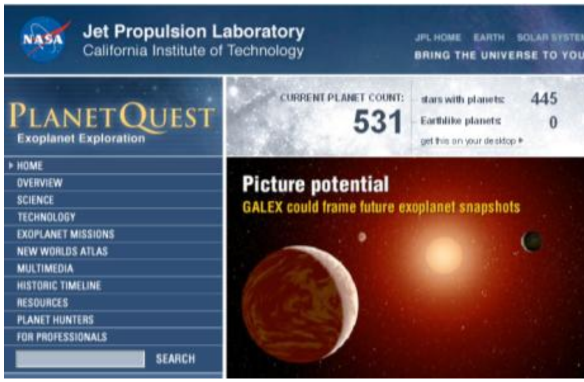
BH physics and precise measurement of GR effects

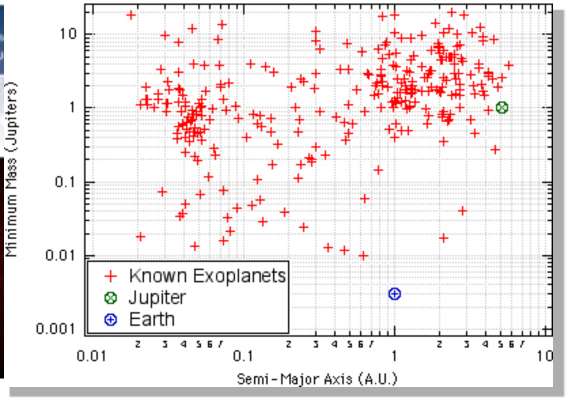


973: move beyond acceleration search

Kramer & Stairs, 2008, A&A

4) Planetary Radio Emission



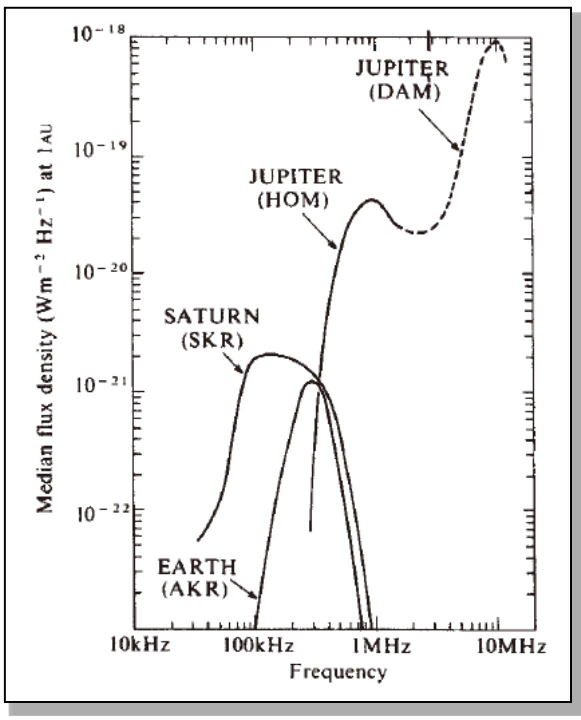


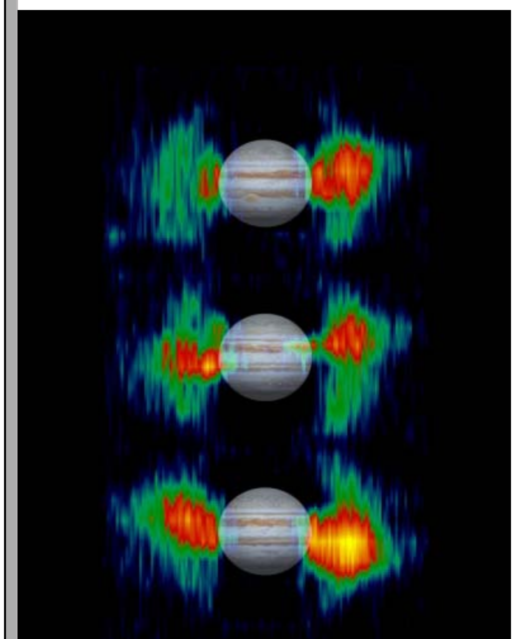
FAST high sensitivity

=>

time modulation signal?

(Li 2009, EGU invited talk)

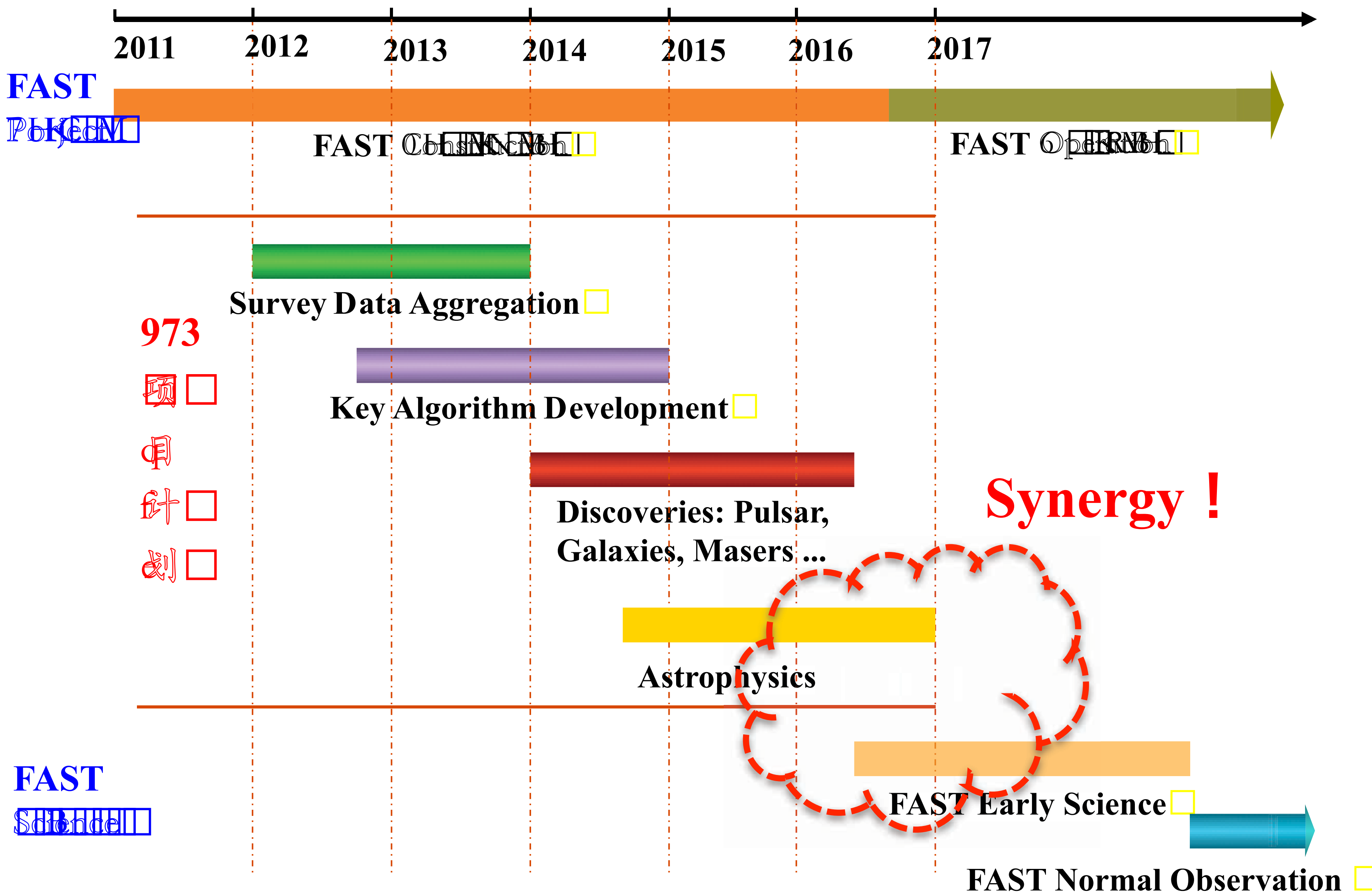




973:verify method, model and targets

Desch & Kaiser, 1984, Nature

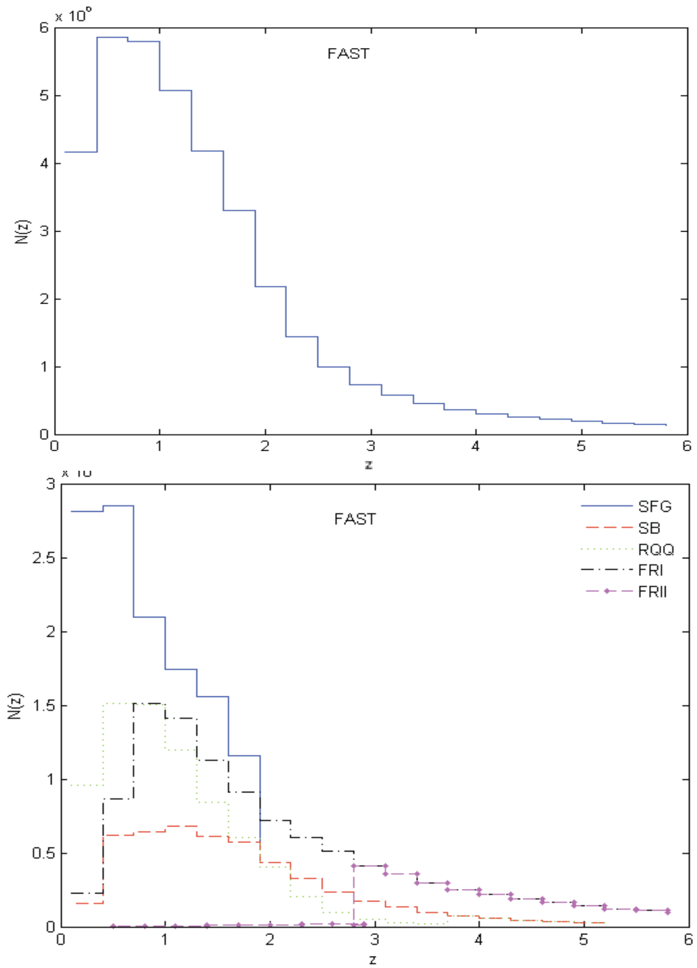
Planning Diagram

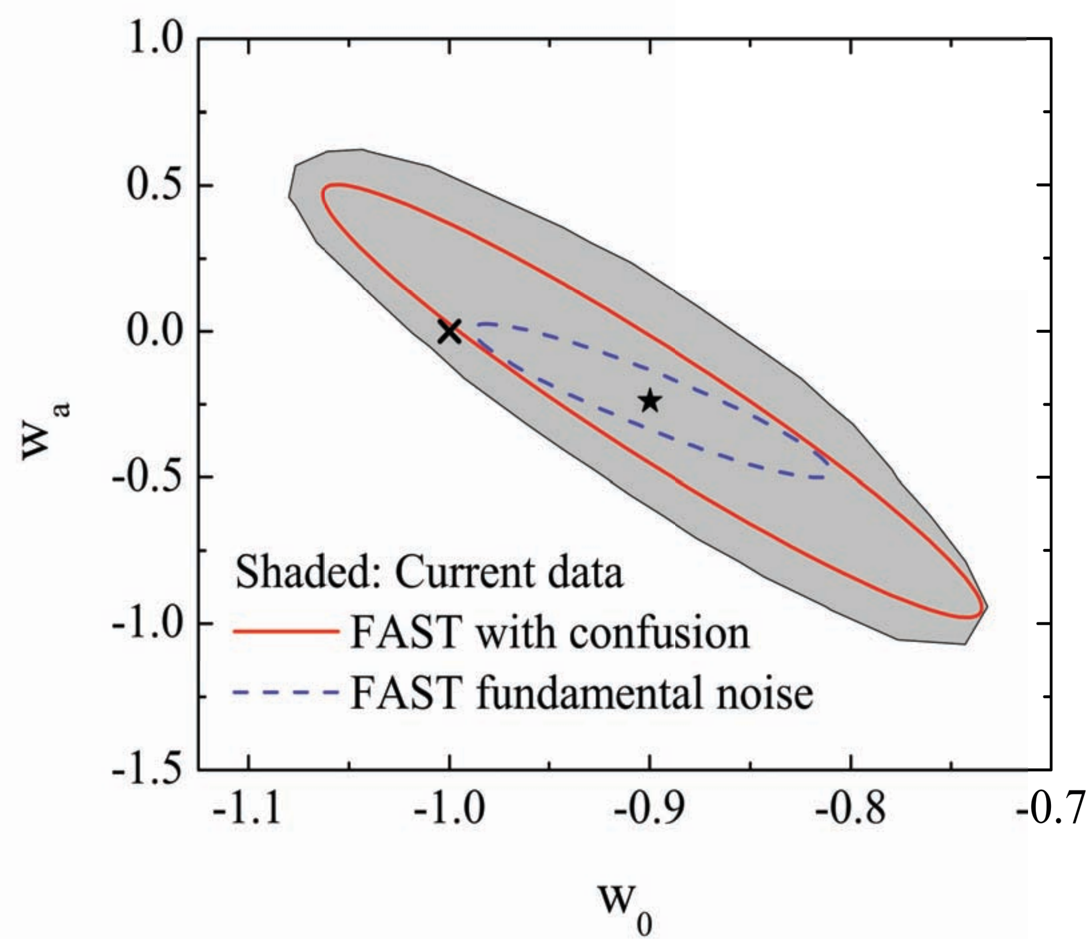


Outline

1. Motivation for a Large Single Dish
2. The Key Technical Aspects of FAST
3. Science Cases of FAST
4. 973: What Now?
5. Summary

FAST Survey + Two-point-corr.





(Yue, Li, Zhao, & Zhang 2012)

WISE BCD

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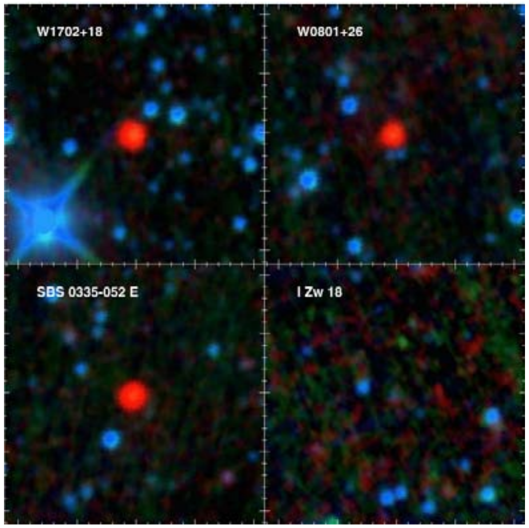

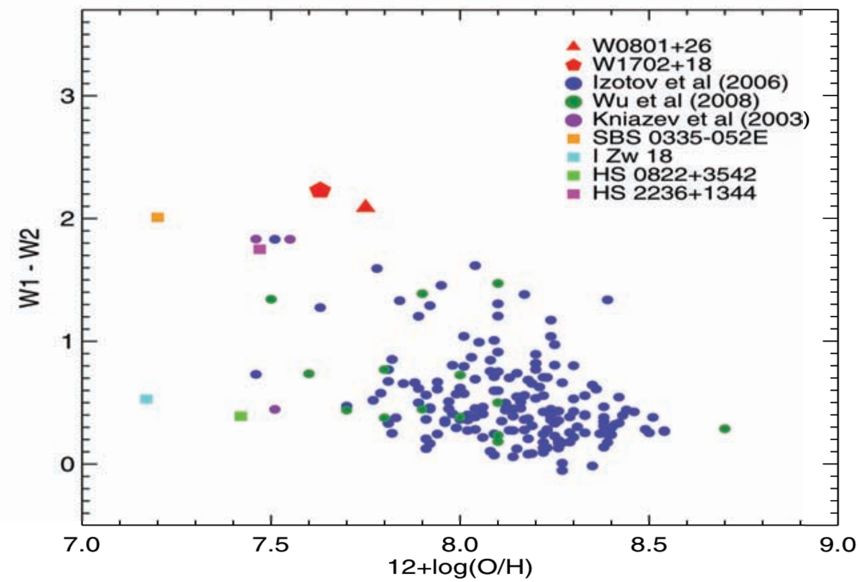

Proposal Title: HI Content of Mid-IR Bright, Low Metallicity Blue Compact Dwarf Galaxies

ABSTRACT:

We propose to measure the HI contents of four selected nearby metal-poor blue compact dwarf galaxies (BCDs) using ALFA on Arecibo Telescope. These BCDs, selected by their red and bright mid-infrared emission using WISE mid-infrared data, are undergoing a starburst phase in the low metallicity environments, possibility their first major episode of star formation. It is a mystery why the gas in these systems has remained in a relatively pristine sate with little metal enrichment in their early star formation cycles over the Hubble time, but recently have they exhibited active star formation. The proposed observations will probe the neutral gas as the fuel resource of the current intensive star formation activity, and provide the essential first step toward the further understanding of gas dynamics in these systems.

Name	Institution	E-mail	Phone	Student
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Di Li	Radio Astronomy Division, National Astronomical Observatory, China	dili@nao.cas.cn	1-818-292-6780	no

3) FAST-Drift Scan

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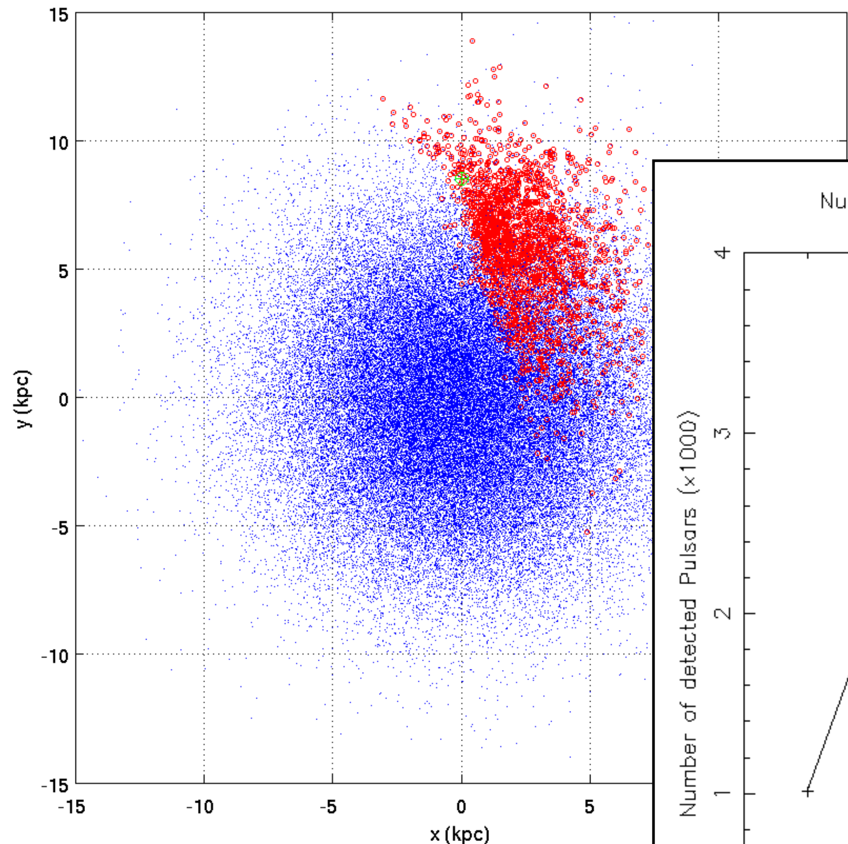
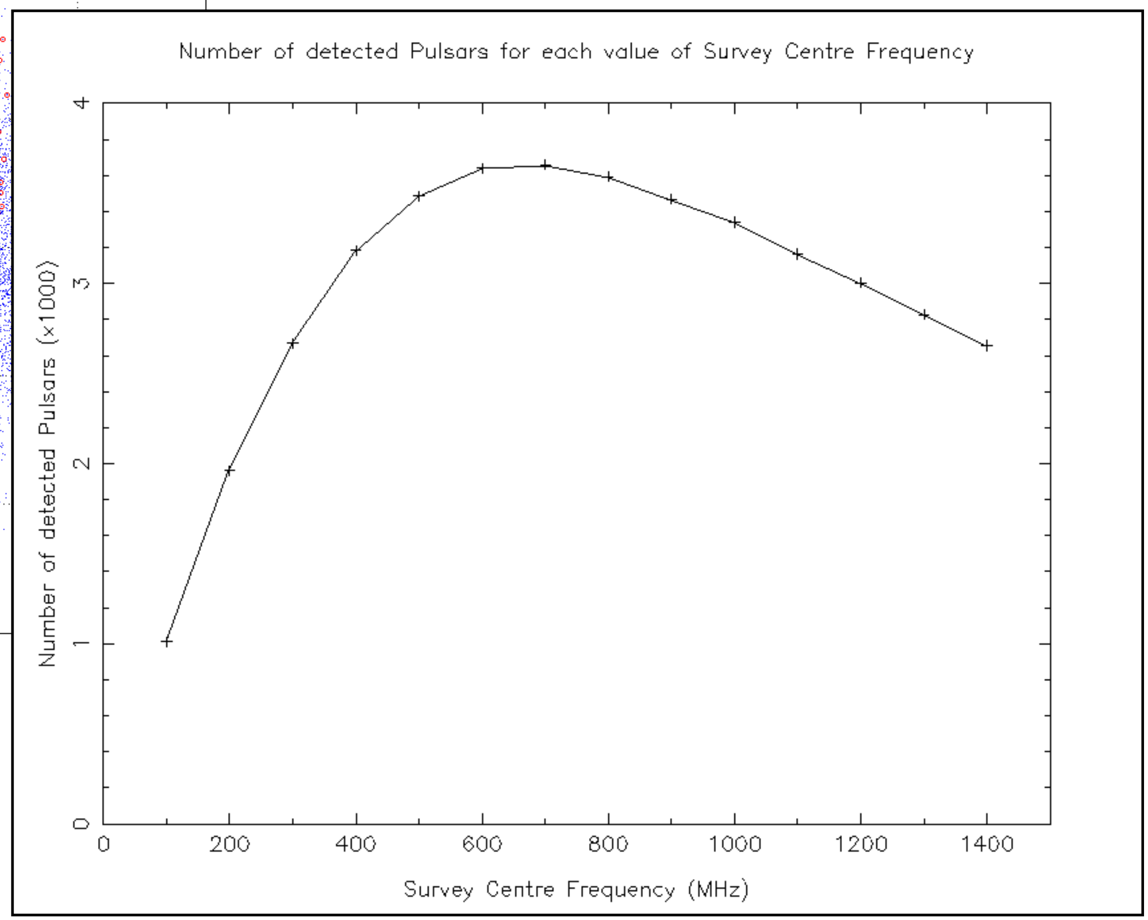
Yue, Li, Li, Jenet, Lorimer, Xu, 2012, in prep





The case for a
low frequency array =>

Probe HI-H_2 Transition

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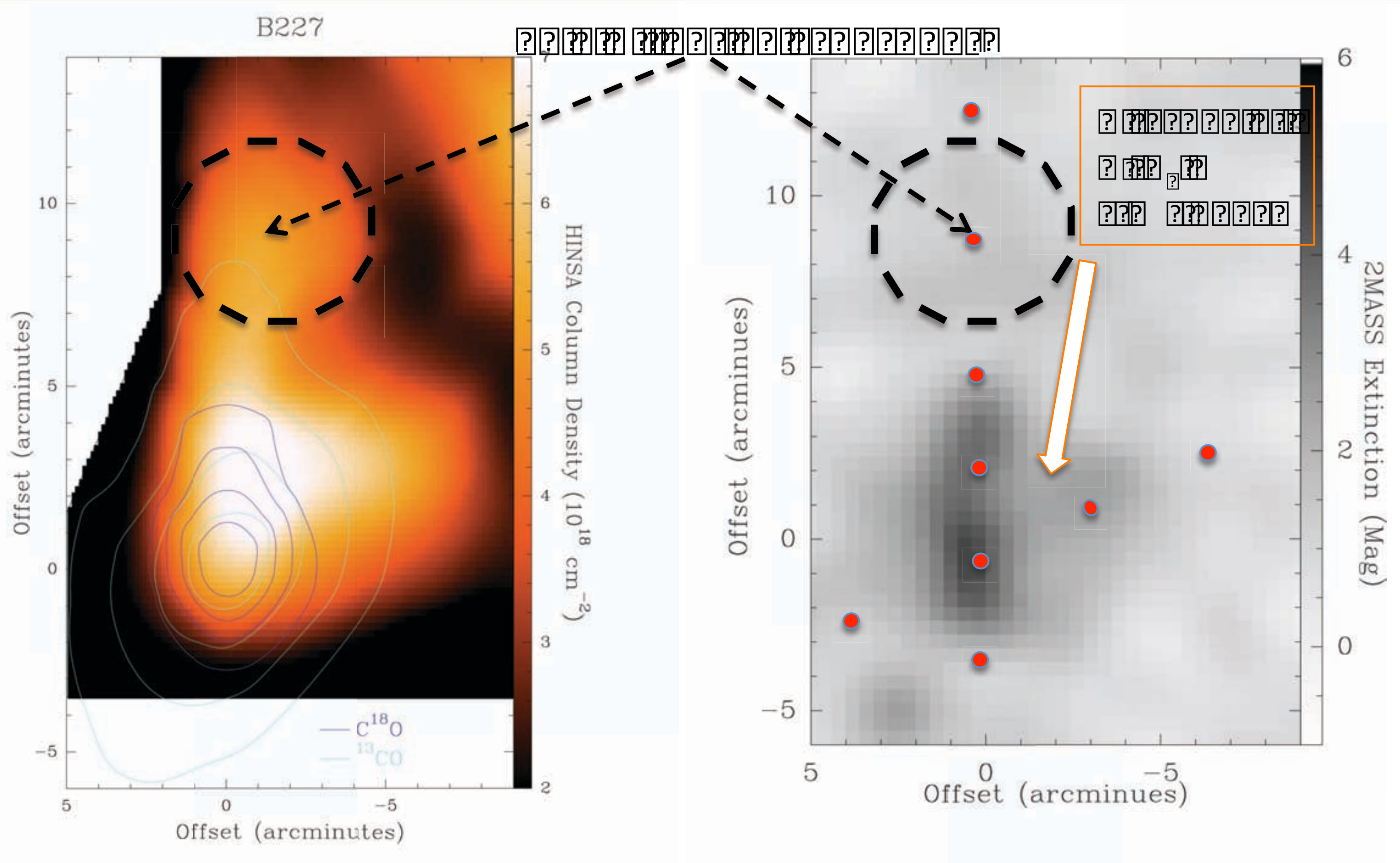

Herschel OT1 Program: *Isolated Dark Clouds with Signs of On Going H2 Formation*

Arecibo proposal: *A Sensitive Survey of HI Absorption in Planck Cores*

Planck Cores

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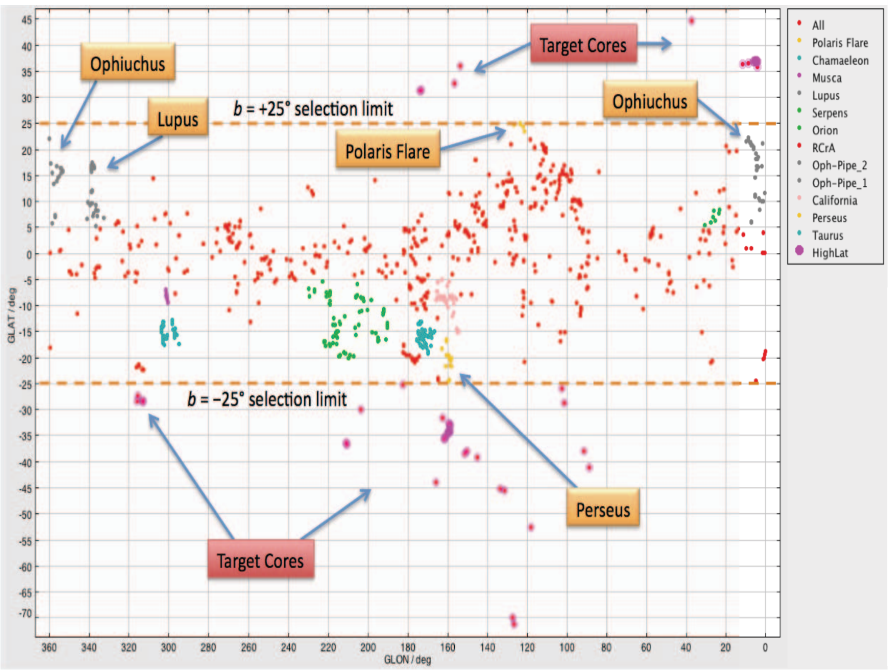

ARECIBO OBSERVATORY

Gas emissions in Planck cold dust cores

—A Survey of the J=1-0 Transitions of ^{12}CO, ^{13}CO, and C^{18}O

Yuefang Wu[1], Tie Liu[1], Fanyi Meng[2], Di Li[3], Sheng-Li Qin[3,4], Bing-Gang Ju[5]

Received ______________; accepted ______________

Submitted to ApJ

Proposal Title: Reveal the Transition from Atomic to Molecular ISM - A Sensitive Survey of HI Absorption in Planck Cores

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Pei Zuo

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Ms. Yue, Nannan; Beijing Normal Univ.; yuenannan@mail.bnu.edu.cn

射电波段前沿天体物理课题及FAST早期科学研究(973)

Radio Astronomy

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本站首页 项目介绍 课题设置 项目成员 专家成员 课题进展 项目成果 973会议 学者来访 招聘启事 学术资源 项目管理

本站首页

500米口径球面射电望远镜(Five-hundred-meter Aperture Spherical radio Telescope,简称FAST)是目前中国天文科学界正式立项并实施建设的国家重大科技基础设施，将成为世界上最大的单孔径射电望远镜。作为一个在关键技术指标上处于国际前沿的科学设备，FAST蕴藏着巨大的发现机遇，具有对天文学产生重大影响的潜力。FAST的立项及开建受到国际科学界和媒体的广泛关注，在《自然》杂志、《天空和望远镜》杂志及《纽约时报》都有报道。

FAST将于2016年在贵州建成。在FAST投入运行之前的五年时间里，中国射电天文界有义务利用现有设备,在与FAST相关的领域取得国际领先的成果,并为FAST运行作科学上的准备。我们只有培养足够的射电天文人才并且储备足够的创新思想，才可能在拥有自主建设的国际最先进的观测设备后，由中国科学家主导取得重大成果。

973指南中的"重要科学前沿领域"包含了"基于国家重大科学工程开展的前沿科学研究"的方向。本项目围绕FAST这一国家重大科学工程开展研究。计划在未来五年内调动中国及国际天文界力量，完成几十个具体的射电前沿研究课题，推动FAST科研人才培养及储备。综合考虑FAST相关领域及国内现有人才，本项目设置六个相互依赖并互相促进的研究课题：

1. 脉冲星射电观测与理论研究;
2. 从原子到恒星：星际介质及恒星形成的射电研究;
3. 星系结构与星系演化;
4. 宇宙学和暗物质;
5. 射电光谱和脉泽源;
6. 低频多波束接收机和VLBI的设计预研。

这六个课题通过FAST的观测技术有机结合在一起，力图在多波段观测、基础理论及仪器设计等方面取得成果。本项目建议的首席科学家李菂研究员是中国科学院国家天文台射电天文研究部首席科学家、FAST项目科学家，美国Arecibo望远镜多波束巡天恒星形成课题的首席及美国宇航局多个观测项目的首席，有能力领导该项目。

项目动态

- 李菂研究员带赴Arecibo望远镜观测Planck Cores中的中性氢自吸收线
- 李菂研究员应邀参加NANOGrav/PIRE及咨询会议介绍FAST概况并讨论合作
- "射电波段的前沿天体物理课题及FAST早期科学研究"973项目启动会
- FAST早期科学研究（973）网站启动

项目动态存档

- May 2012
- April 2012
- January 2012

June 2012

M	T	W	T	F	S	S
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4	5	6	7	8	9	10
11	12	13	14	15	16	17
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25	26	27	28	29	30	

« May

News Photo Gallery

射电天文学前沿973

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Future FAST Site @ 2016