中国科学院国家天文台

NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

Radio Spectroscopy from Ground to Space

李菂

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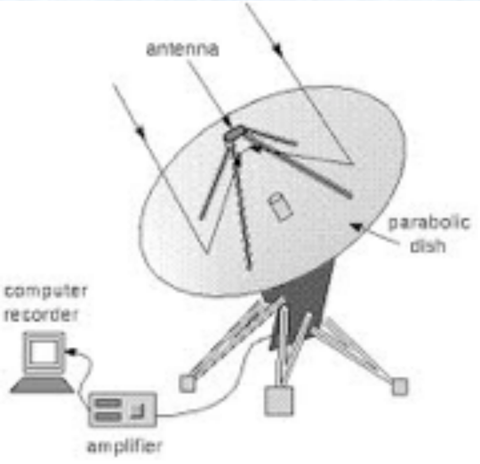
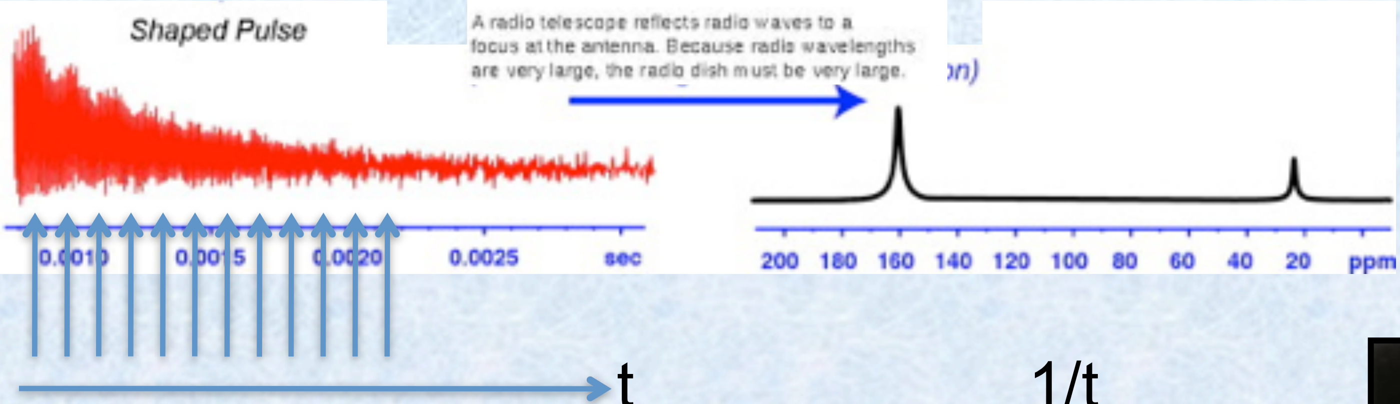
Time Series



A radio telescope reflects radio waves to a focus at the antenna. Because radio wavelengths are very large, the radio dish must be very large.



Discovery of Hydrogen

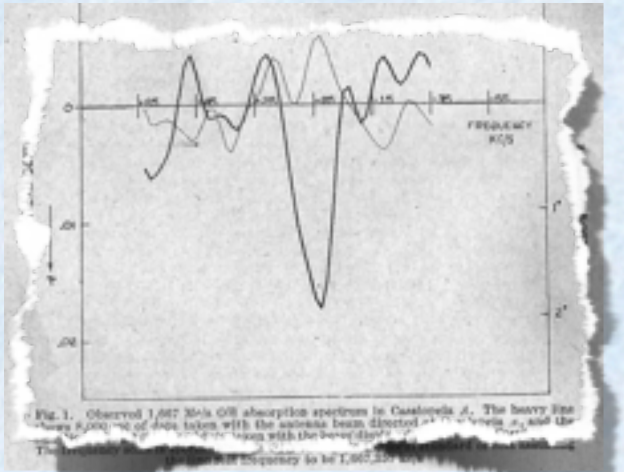
Harold Irwin Ewen (Doc H.I. Ewen) and Purcell 1951

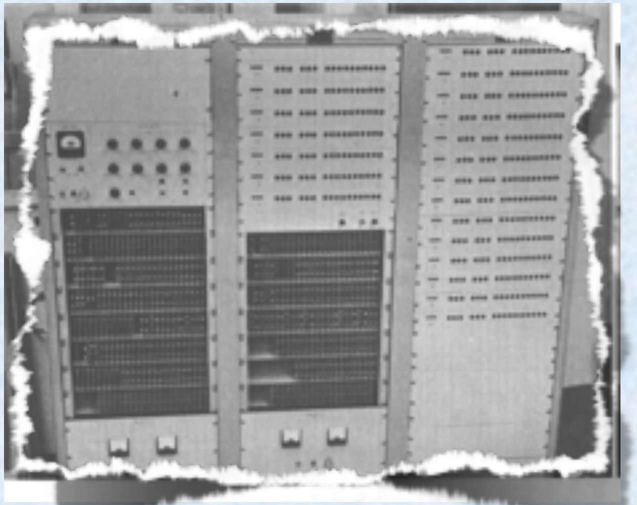
Transit telescope designed to have the Galactic Center pass through its beam

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

Discover the Molecules

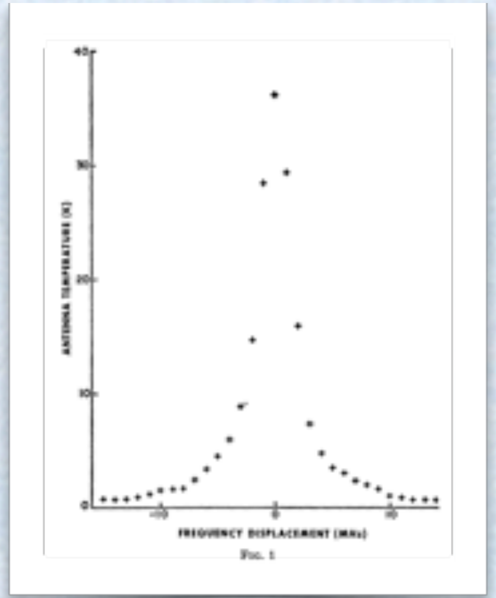
OH

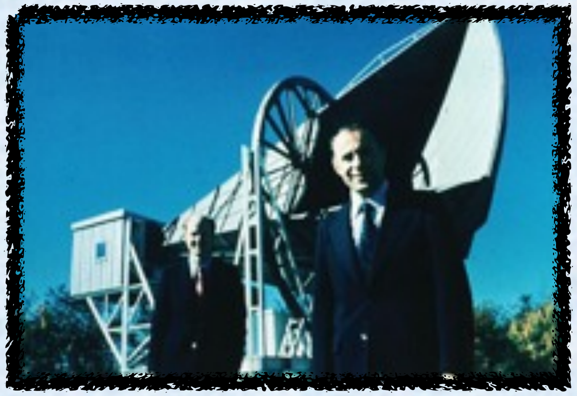




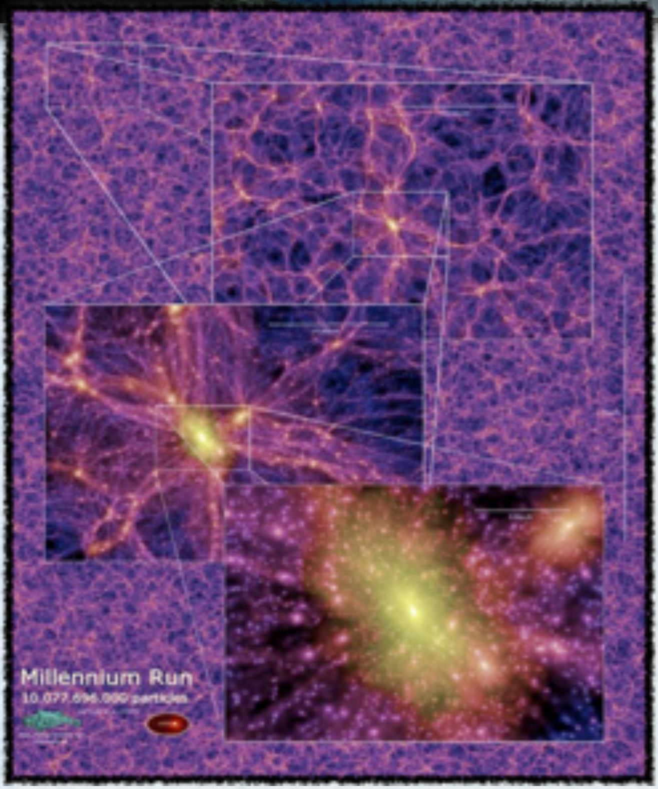
Weinreb et al. 1963 Nature

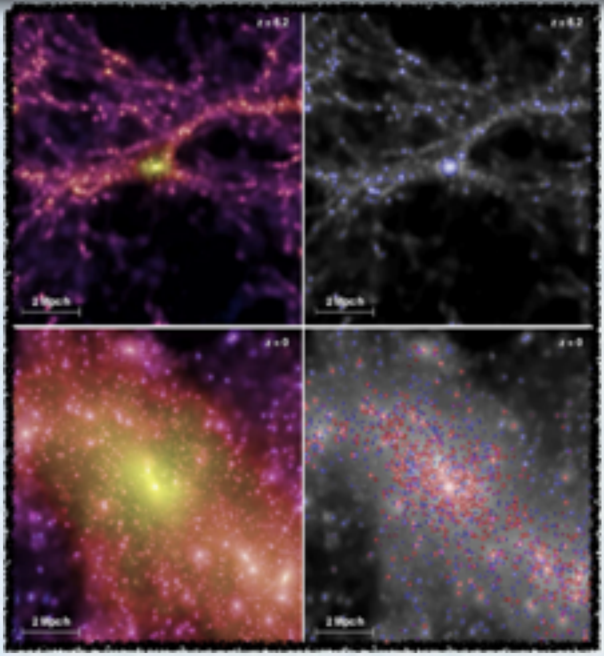
CO





Penzias, Jefferts, Wilson 1970, ApJL





(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 + gas particles + parametric treatment of star formation.

Stars and Molecules

Complex Processes involving gravity, radiation, turbulence, magnetic field, and feedback

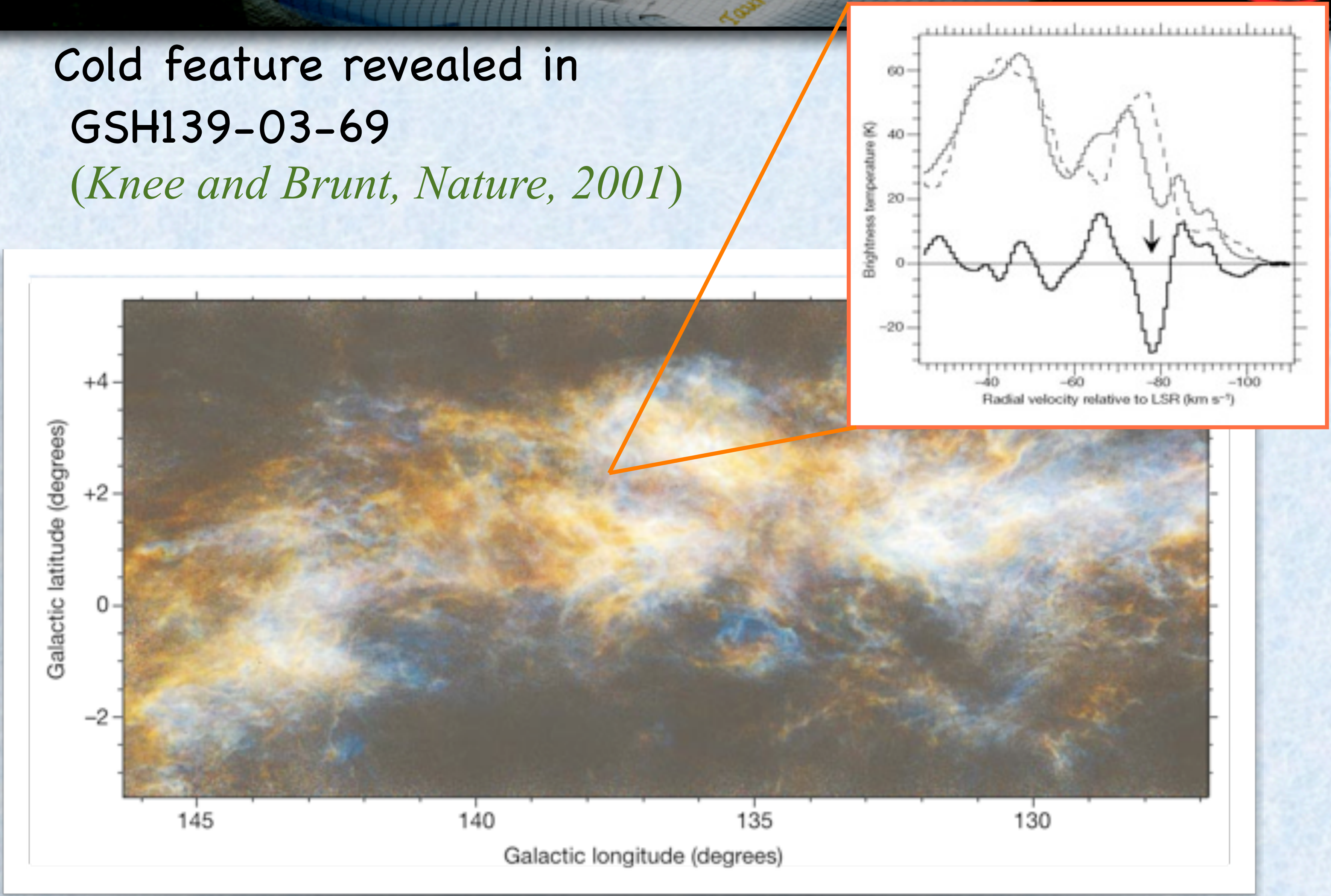
> *"I write about molecules with considerable diffidence, having not yet rid myself of the tradition that "atoms are physics, but molecules are chemistry"*
>
> *---A.S. Eddington*

- Gas accretion
- Energy dissipation
- Heating / cooling
- Chemical evolution
- Environmental and/or Initial Conditions

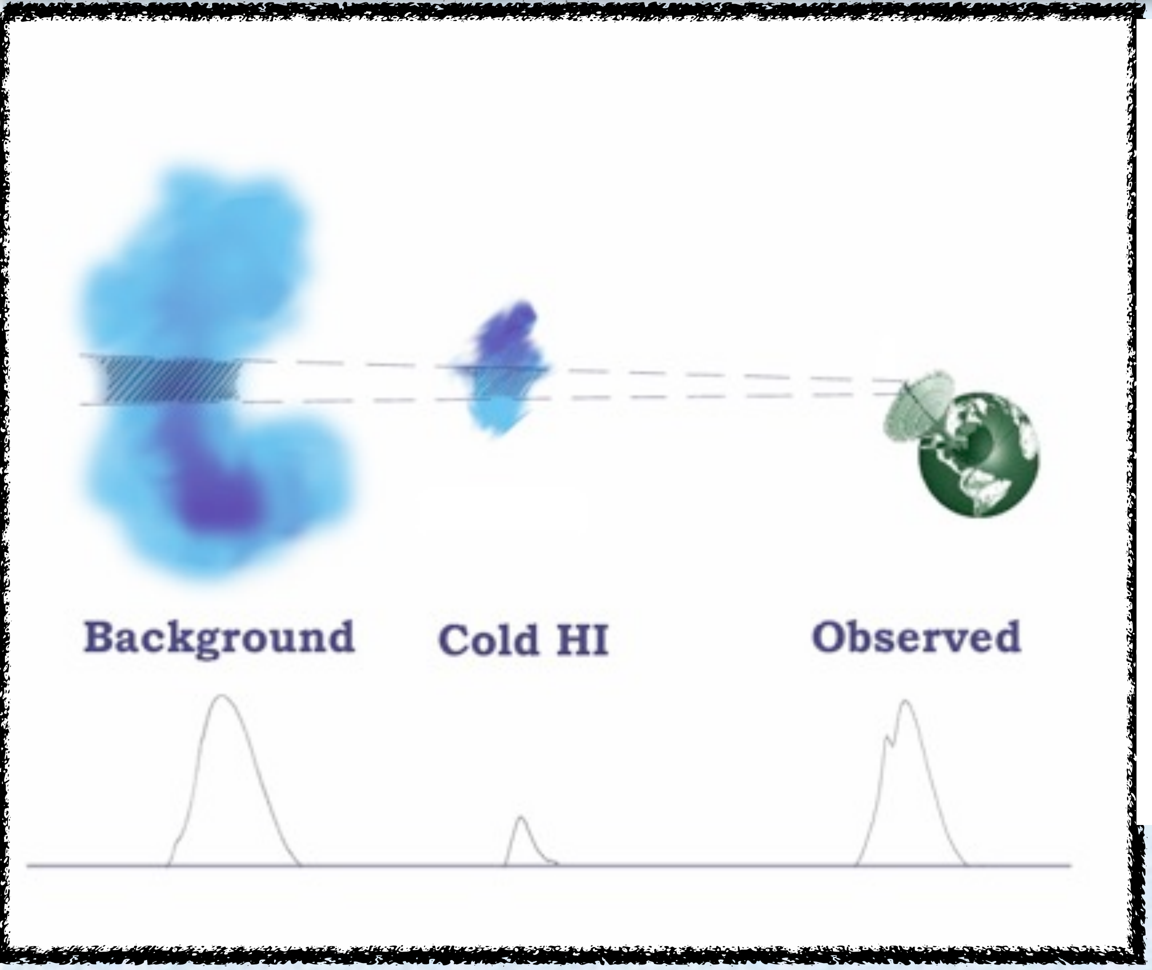
Discovery of Massive Cold HI Clouds

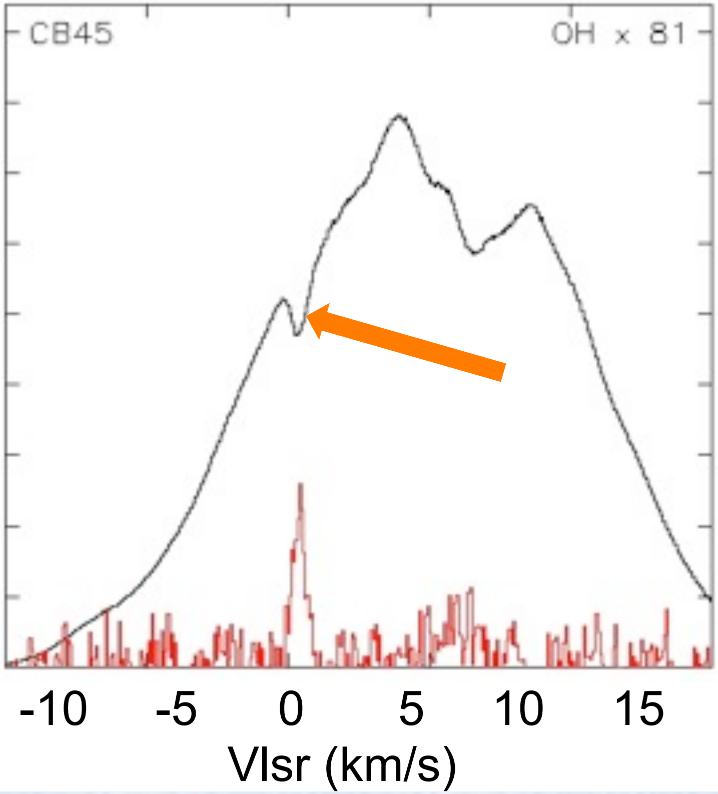
Cold feature revealed in GSH139-03-69

(Knee and Brunt, Nature, 2001)



Discovery of Cold HI in Molecular Clouds



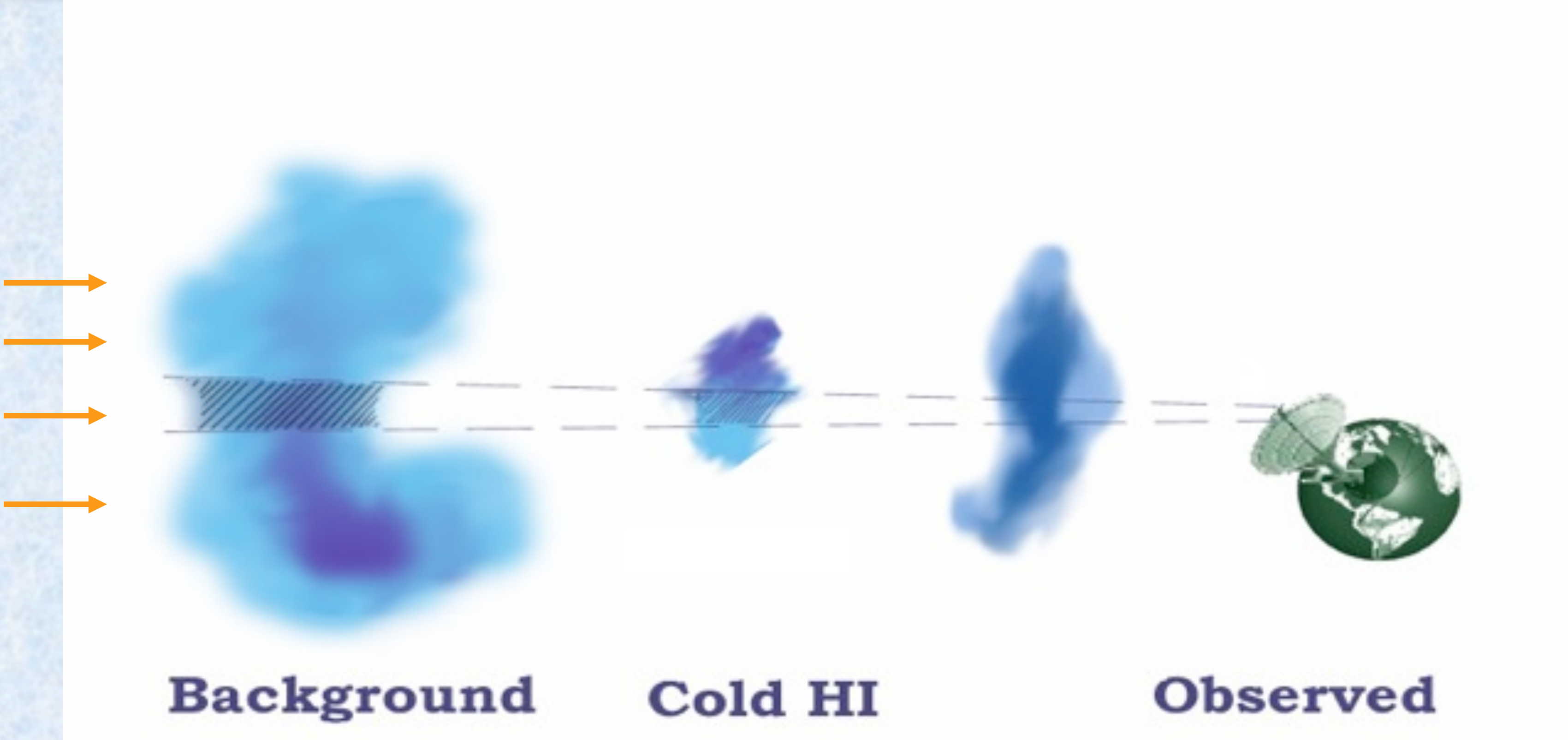


(Li & Goldsmith 2003 ApJ)

HI Narrow Self Absorption

HINSA

Three-Component Radiative Transfer



T_c

T_b τ_b

T_x τ

T_f τ_f

T_R T_{HI}

Column Density of HI

- Total HI column density derived from optical depth of the 21cm line:

$$N(HINSA) = 1.8 \times 10^{18} \Delta V(km/s)\tau_0 T_k\ cm^{-2}$$

- Average HI column density:

$7.2\text{x}10^{18}\ \text{cm}^{-2}$

- If using $C^{18}O$, the abundance $[HI/H_2]$ is 0.15%
- Under the standard model, this corresponds to a cloud size ~ 1pc, about 24′ at Taurus distance

Molecular Cloud Formation

- H_2 Formation On Dust Grains

Production rate ($s^{-1}cm^{-3}$)

$$R_{H_2} = \frac{1}{2} n_g n_1 \sigma v S \eta$$

$$R_{H2} = 2.1\times10^{-18} n n_1 \sqrt{T}$$

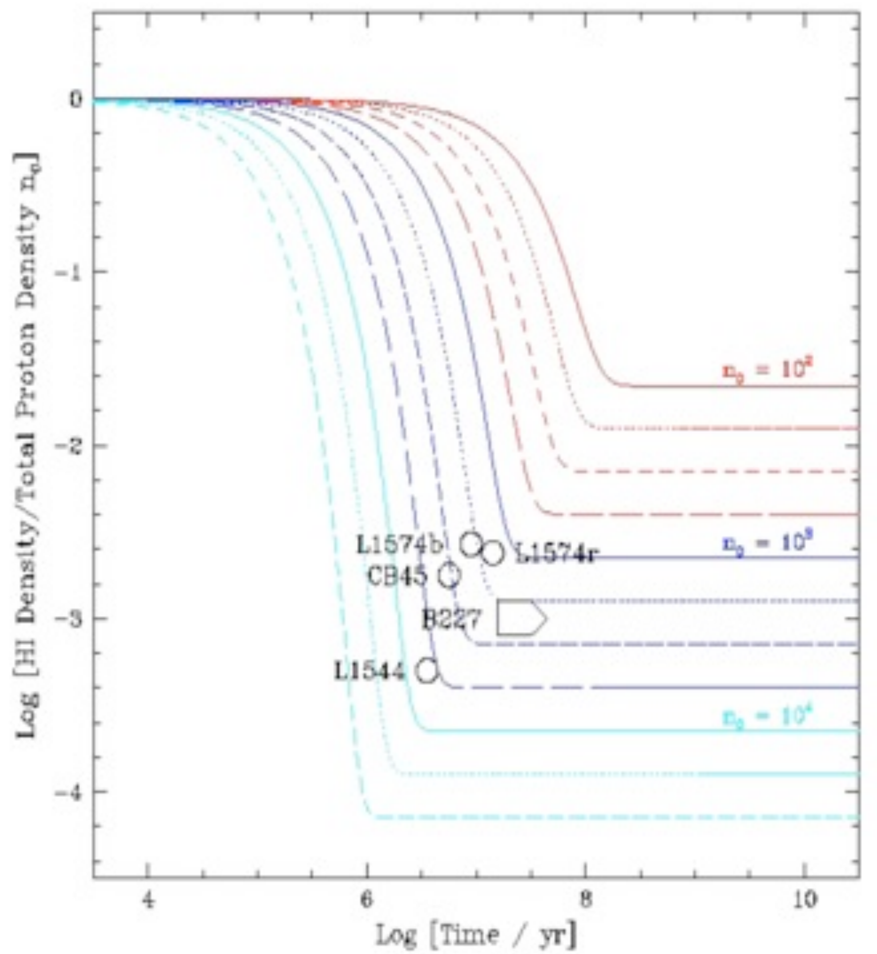
- H_2 Dissociation By Cosmic Rays
  - Destruction Rate(cm^{-3} s^{-1})

(Hollenbach & Salpeter 1970; Buch & Zhang 1991)

$$D_{H_2} = \xi n_2,$$

where $\xi \approx 3\times10^{-17} s^{-1}$

is the cosmic ray ionization rate.



(Goldsmith and Li 2005 ApJ; Krco et al. 2010 ApJ)

Chemical Clock

年度天文及天体物理综述

Theory of Star Formation

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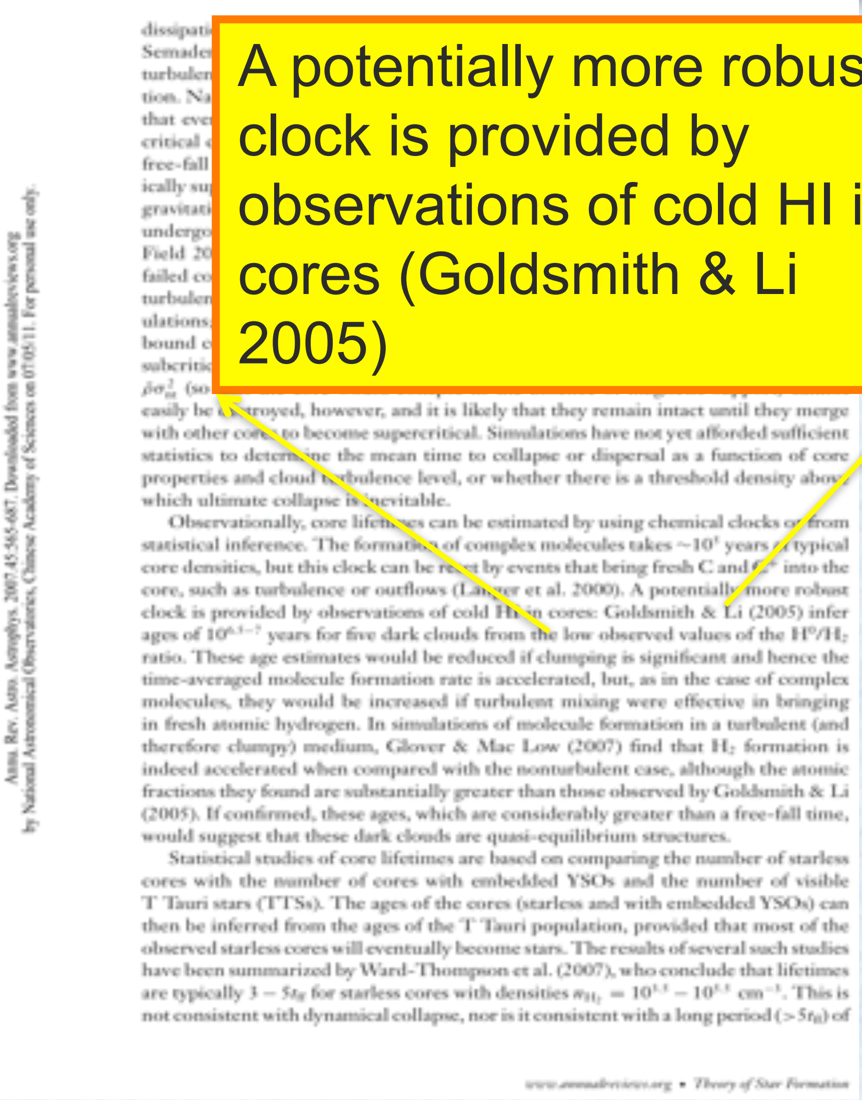
0066-4146/07/0922-0565$20.00

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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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.

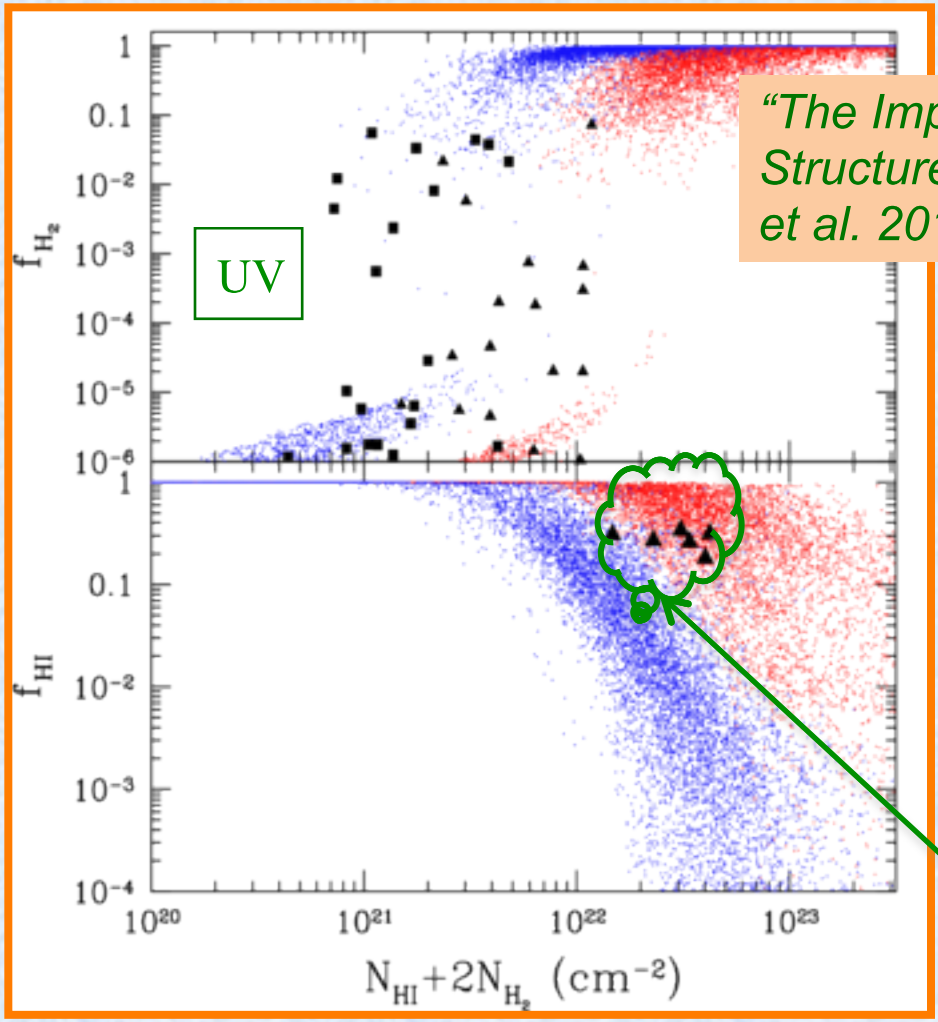
Observationally, core lifetimes can be estimated by using chemical clocks or from statistical inference. The formation of complex molecules takes ~10^5 years at typical core densities, but this clock can be reset by events that bring fresh C and C^+ into the core, such as turbulence or outflows (Langer 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 $n_{H_2} = 10^{4.5} - 10^{5.5}$ cm^{-3}. This is not consistent with dynamical collapse, nor is it consistent with a long period ($>5t_{ff}$) of

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

HINSA Constrains CosmologicalSimulations

N. Gnedin & A. Kravtsov 2010



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

density

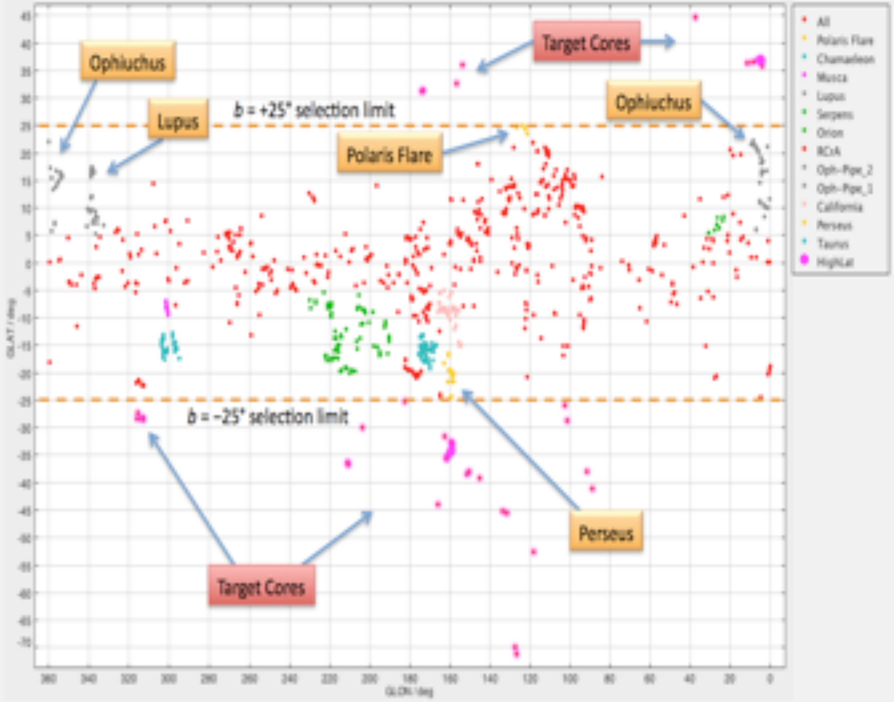
atter

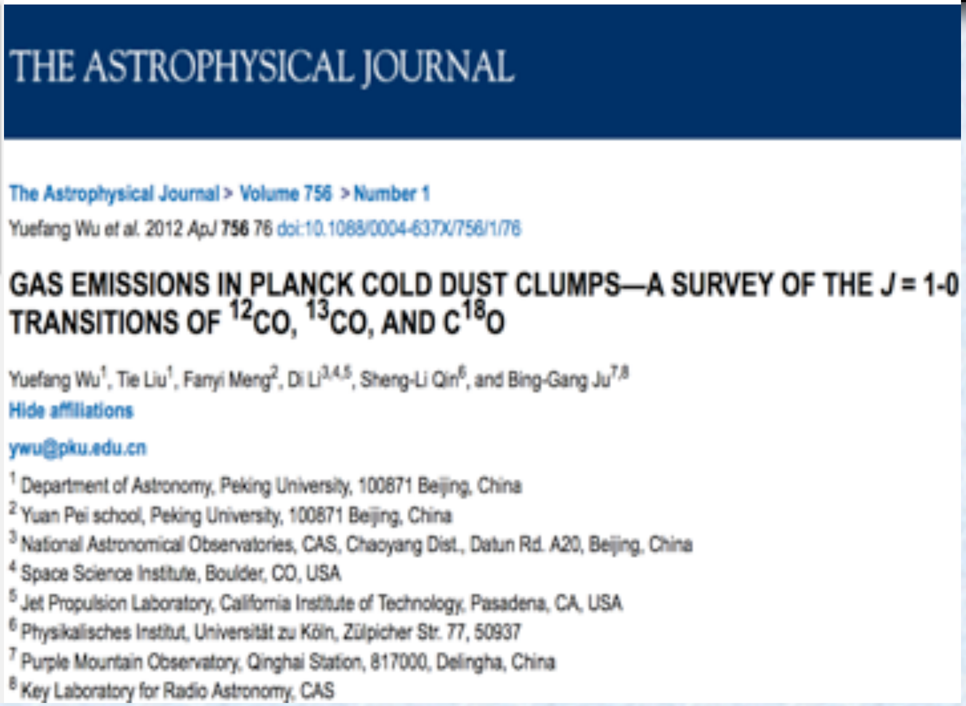
but is rather sharp and shifts to higher densities with decreasing dust-to-gas ratio and/or increasing FUV flux.

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

Planck Cores





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Yuefang Wu et al. 2012 ApJ 756 76 doi:10.1088/0004-637X/756/1/76

GAS EMISSIONS IN PLANCK COLD DUST CLUMPS—A SURVEY OF THE $J = 1\text{-}0$ TRANSITIONS OF ^{12}CO, ^{13}CO, AND C^{18}O

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[8] Key Laboratory for Radio Astronomy, CAS

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

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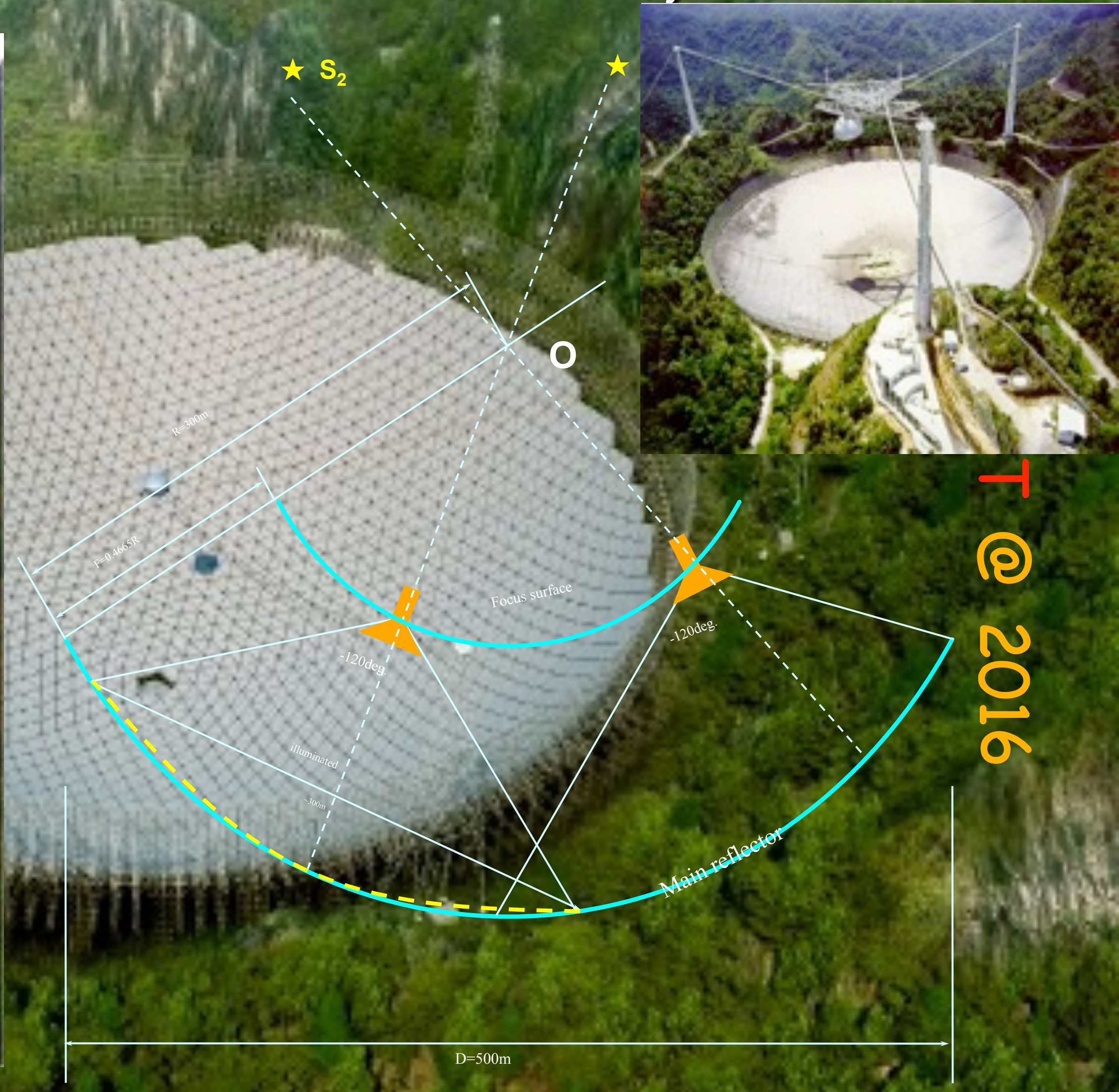
Five-hundred-meter Aperture Spherical radio Telescope

FAST Site @ Nov 29, 2009



T @ 2016

Past, Present, Future

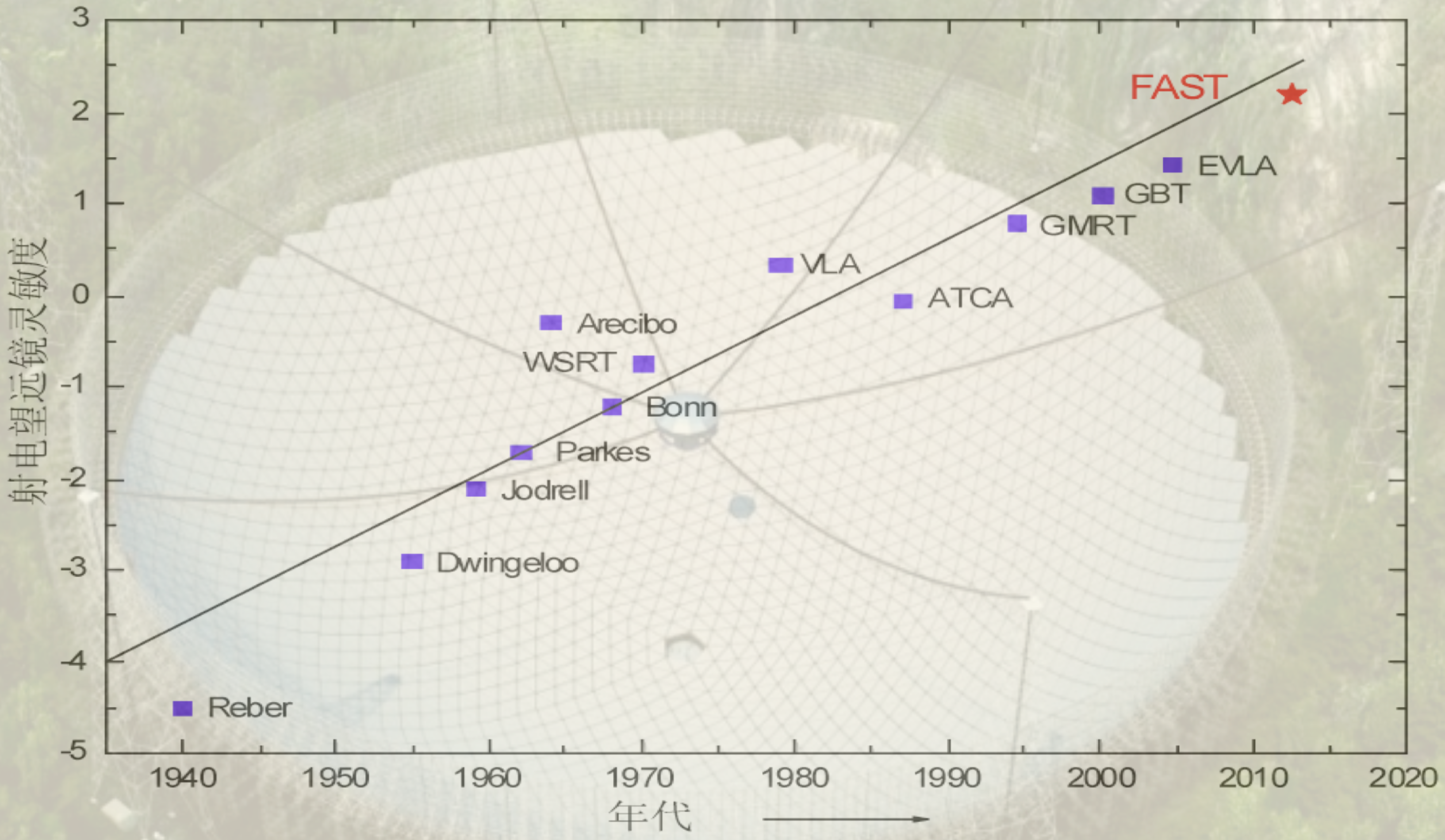


图 1-2 望远镜灵敏度发展曲

FAST Science Preparation

- **Pulsar detection:** time domain analysis, observation
- **Nearby universe:** multiwavelength surveys, HI mass function
- **Cosmology:** HI power spectrum detection and analysis
- **ISM and star formation:** HINSA, maser recombination lines, molecular emission
- Understand nonthermal **planetary** radio emission

FAST Maser Sciences

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

- ➡ 3 better raw sensitivity
- ➡ ~10 higher surveying speed
- ➡ 2-3 times sky coverage $-14^\circ < \delta < 66^\circ$

Expectations of FAST:

- •Numbers of OHM: 10~20 times? N>1000
- •High z OHM: OHM to z~2; Giga-M: to z~4

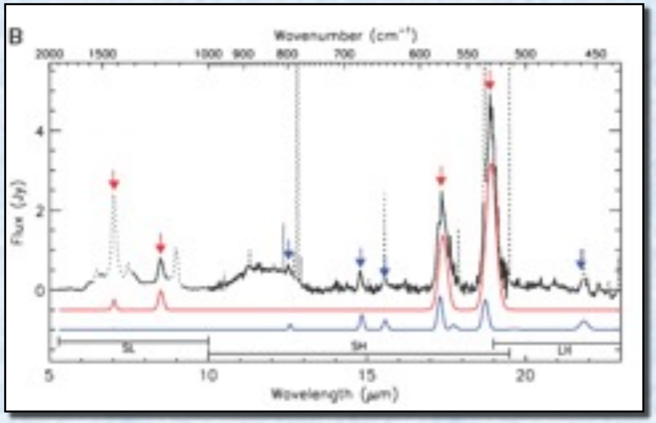
  R3: 0.56 – 1.02 GHz R4: 0.28 – 0.56 GHz
- •Lensed OHM at z>1

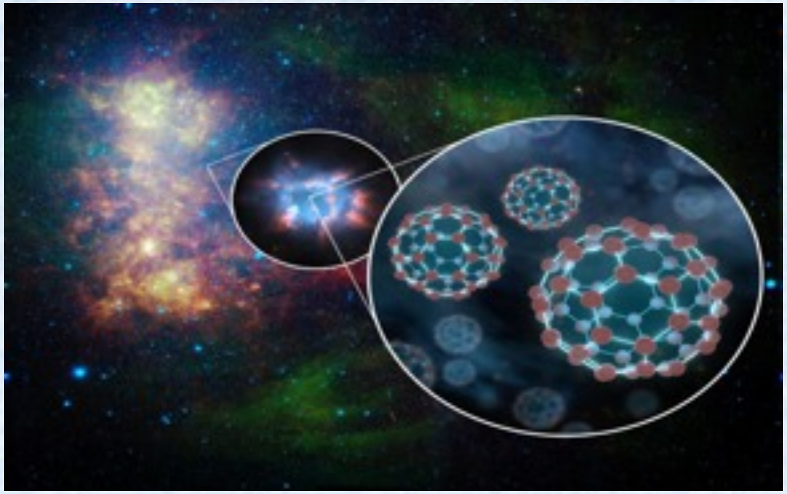
(Zhang, Li, Wang 2012, IAU 287)

Molecular Universe

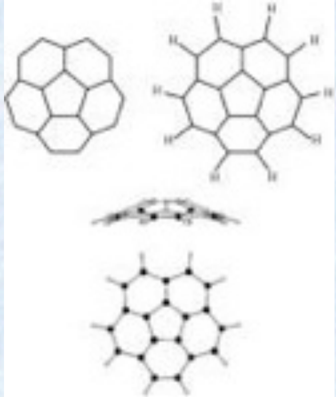
- Over 140 molecules discovered
- One of the richest sepctroscopic source-Orion Nebular is out of Arecibo Sky
- Comprehensive Line Survey in the FAST bands
- Search for pre-biotic molecules (Nan, Li, Jin et al. 2011)

C_{60}和C_{70}(Buckyballs)Discovered in Planetary Nebular

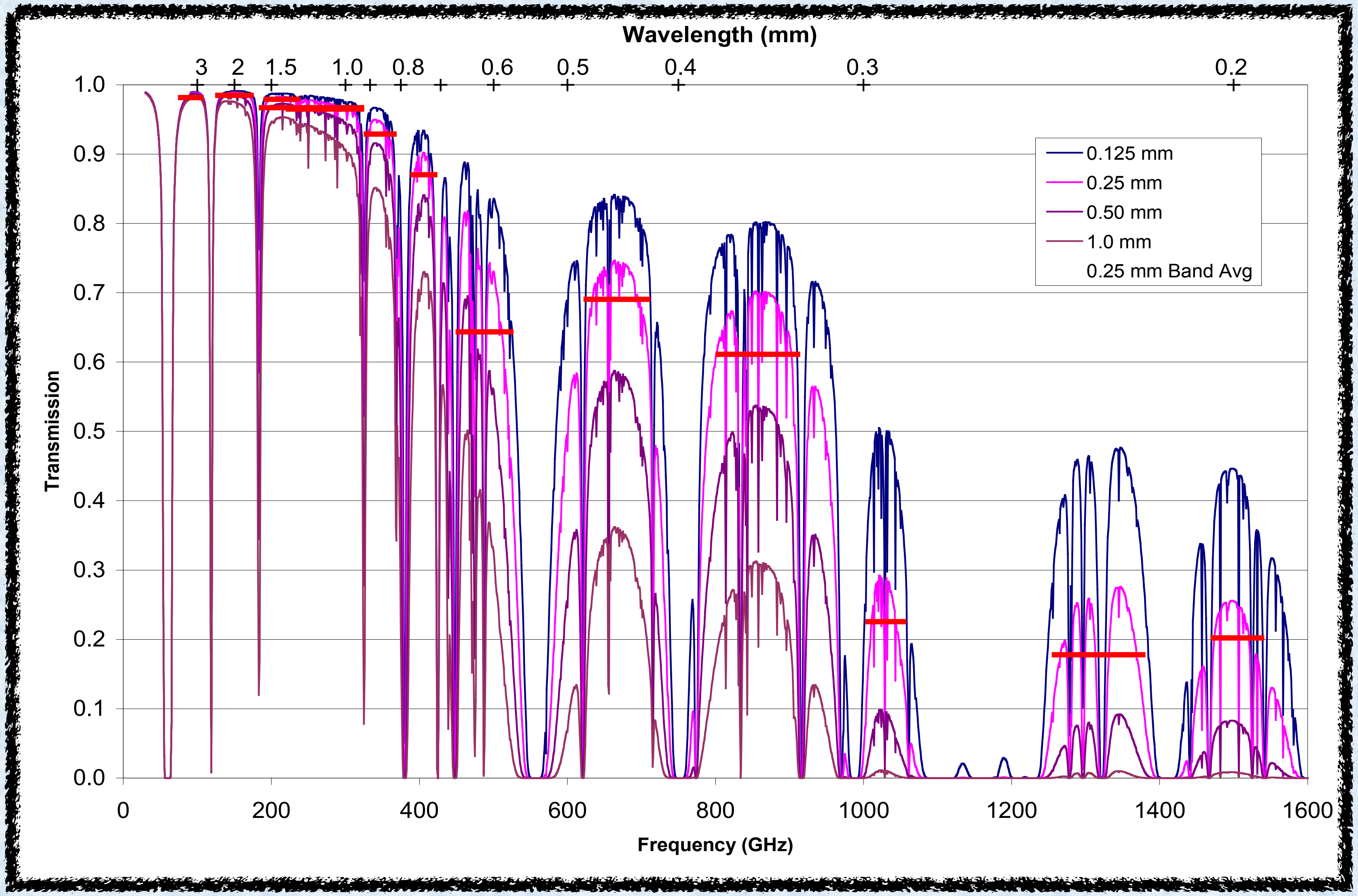




Cami et al. 2010, **Science** 329, 1180



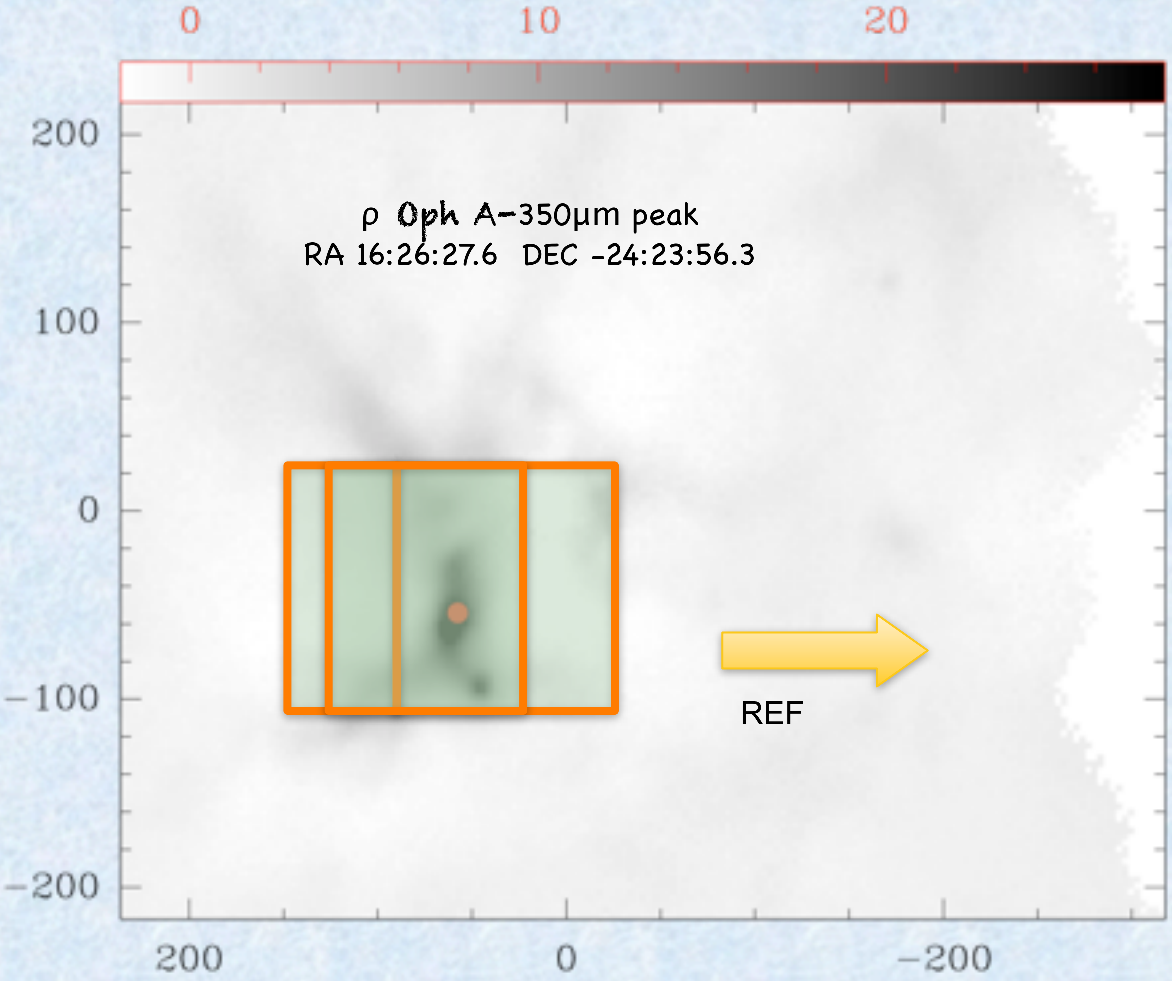
Atmospheric Transmission



Stratospheric Observatory for Infrared Astronomy

SOFIA

SOFIA “On-the-Fly”

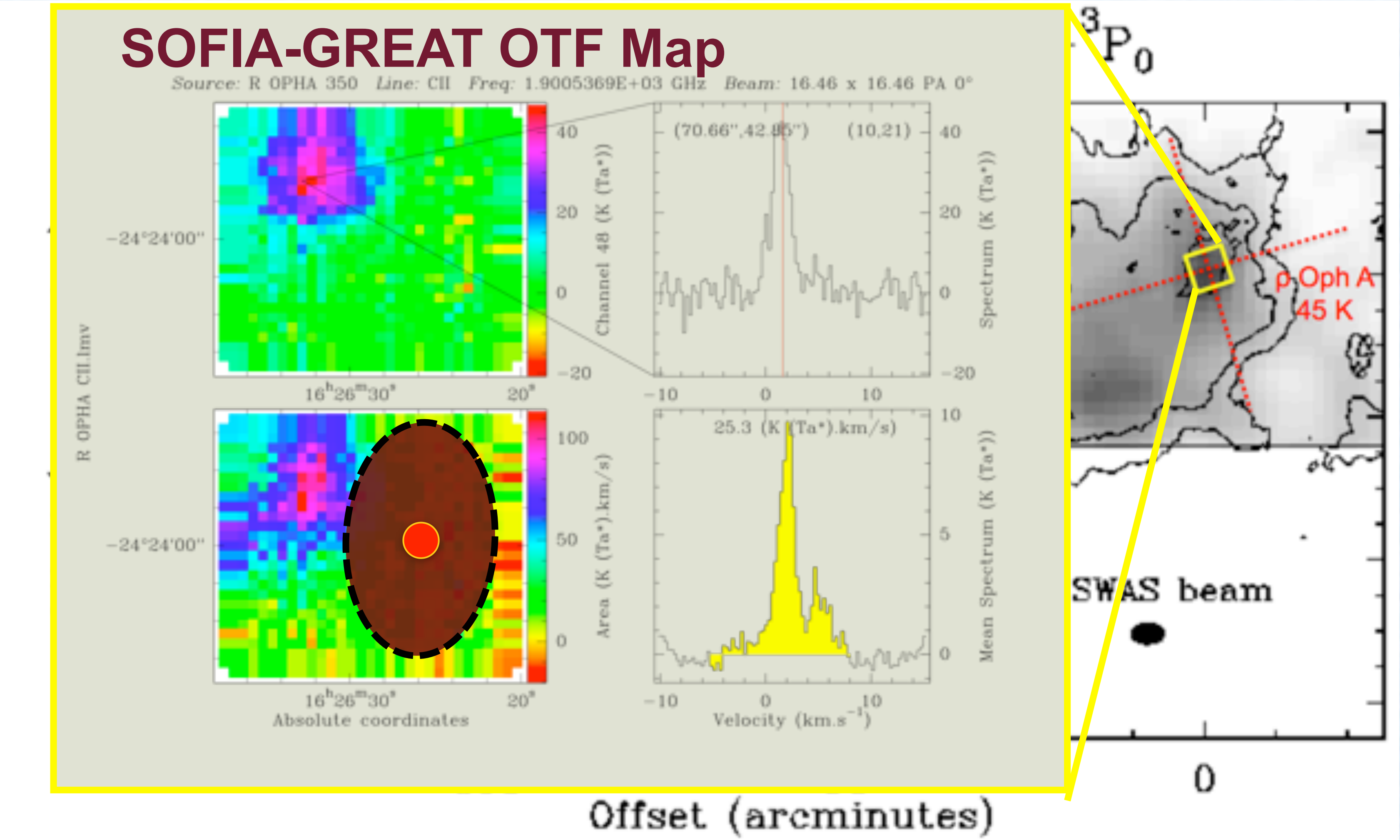


OTF in THz

GREAT

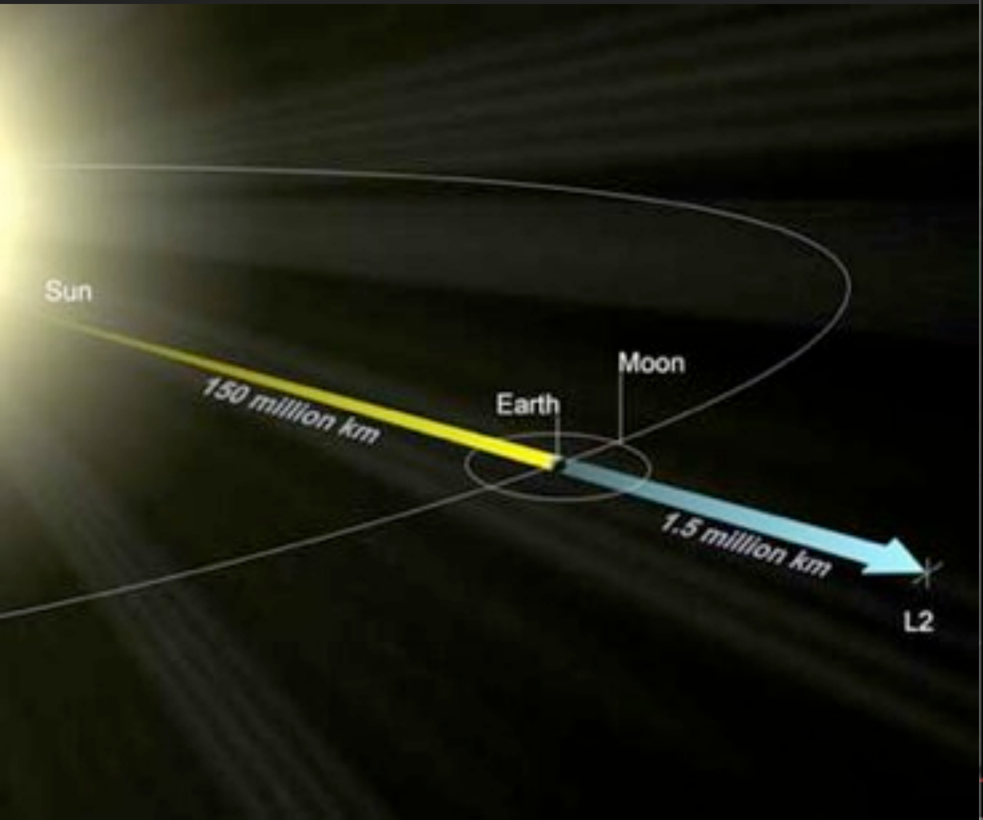
1st Ref
2nd Ref

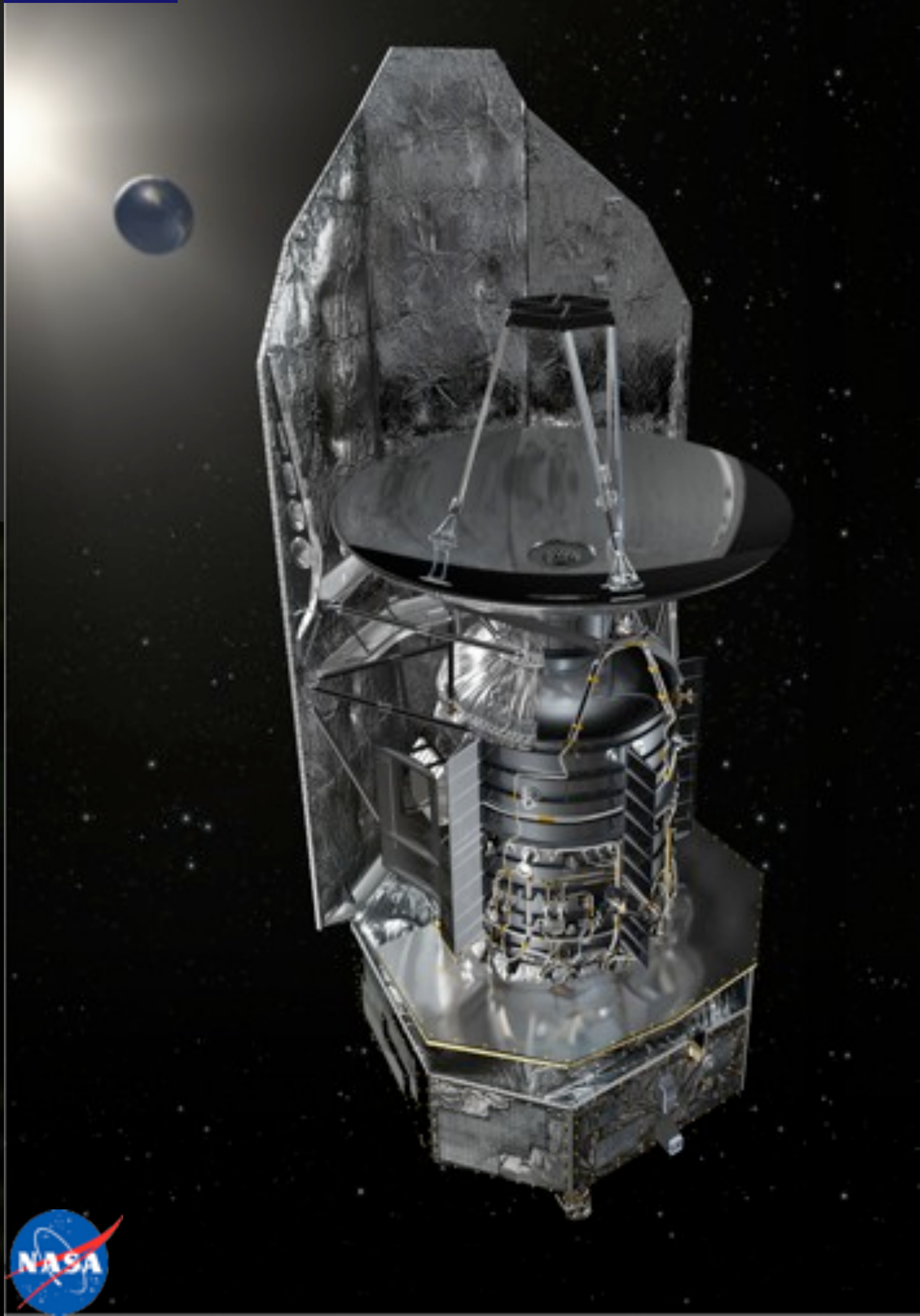
Where is Carbon?



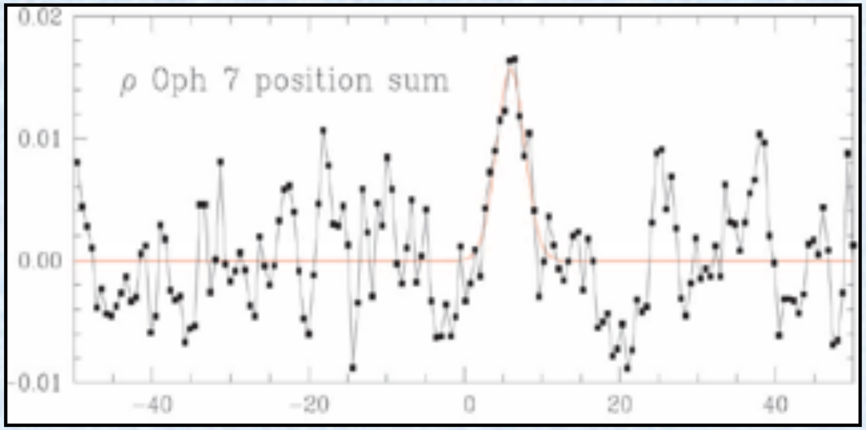
SOFIA-GREAT OTF Map

Herschel – 2nd Generation Submm Space Mission

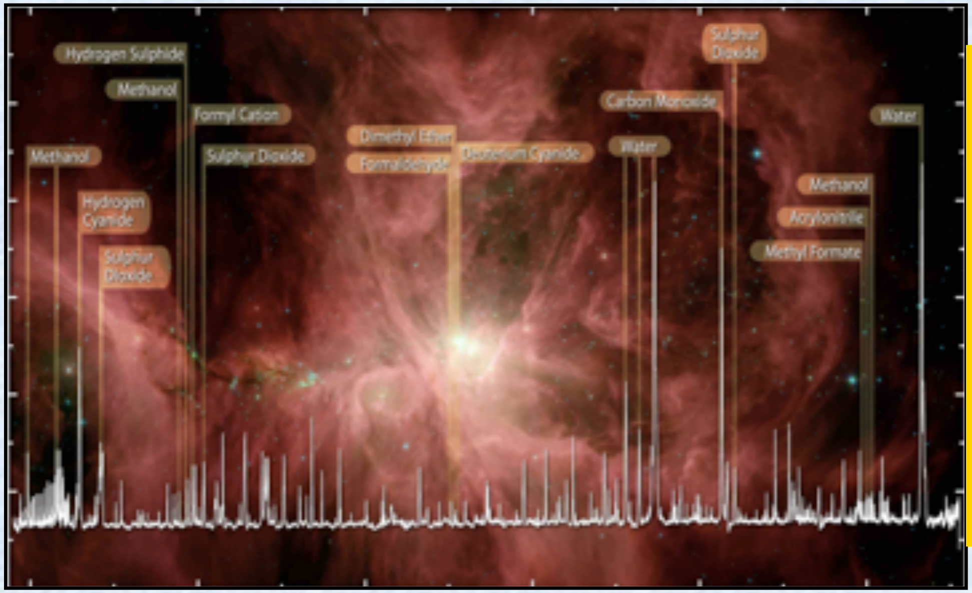




Discover O2 in Space



Goldsmith, Li, Bergin et al. 2002, ApJ）



丰富的星际气体光谱

Herschel巡天计划 HEXOS

Herschel 发现新分子,

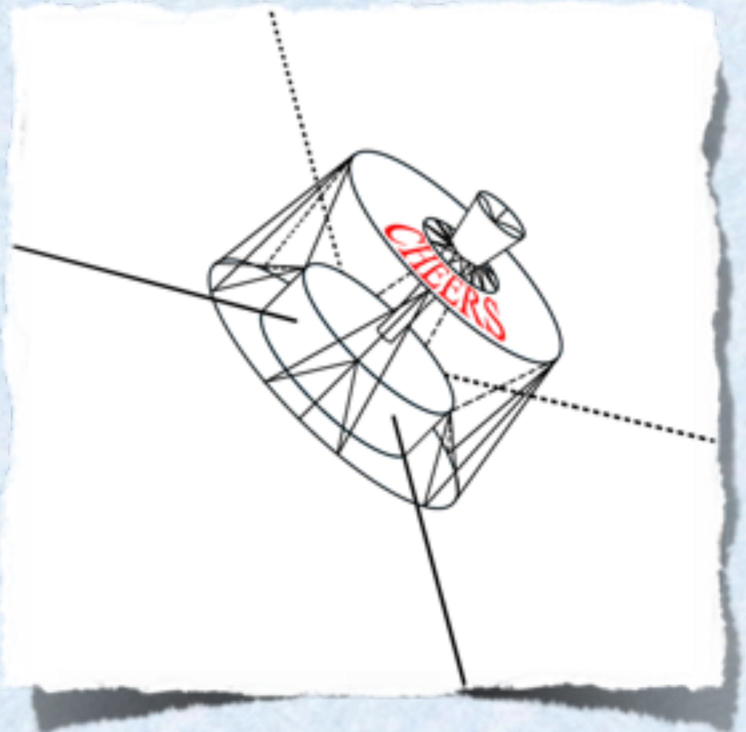
例如 Lis...Li(6) ... et al. 2010,

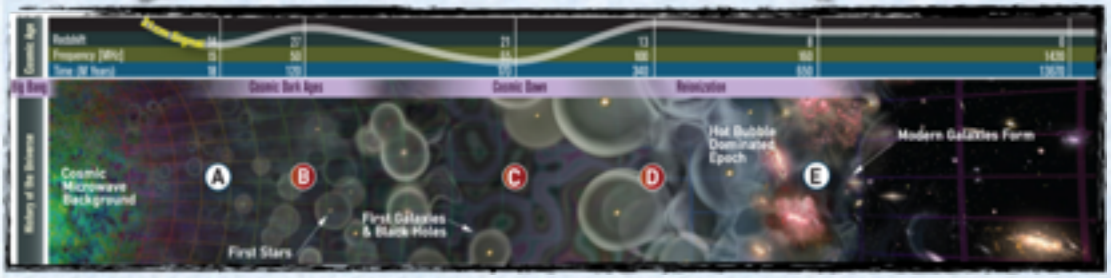
“Herchel/HIFI Discovery of Interstellar Chloronium (H_2Cl+)”, A&A

and many more

COME: the Future?

COsmology and Molecule Explorer





Universe

@Beginning
cosmological HI spectrum,
recombination ripple

@Now
Reveal faint
molecular universe

Opportunities

- CAS International Fellows from Developing Countries
  - Senior Fellow
  - Junior Fellow ~$25K per year
- FAST Fellow
  - $30K per year
  - Housing subsidy
  - Travel Grant
  - Funding authorization
- East Asian Center of Astronomy (EACOA)
  - Postdoctoral fellow ~$60 K per year
  - within 5 years of PhD