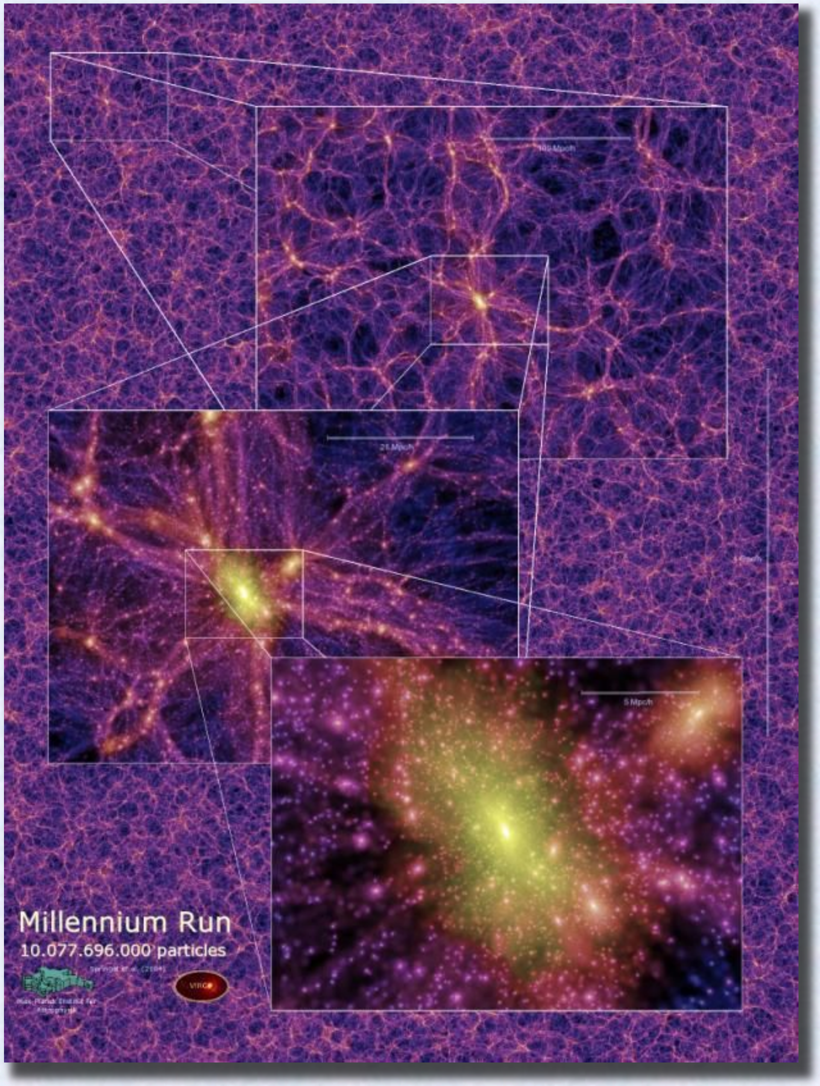
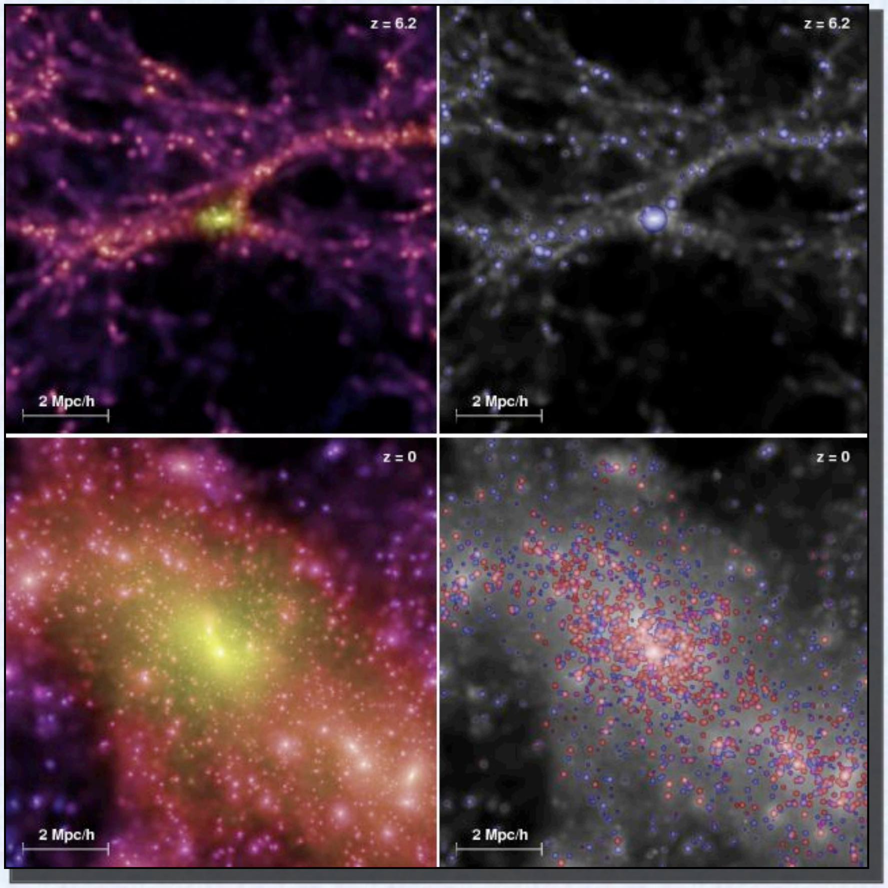
Tracing the Transition Phase of ISM

Di Li

SOFIA Tel-Talk, Jan 2012

Lighting up the Dark Universe





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

Treatment of Galaxy and Star Formation

- "Semi-Analytic" Approach

The Millennium simulation – Virgo Consortium

Collisionless dark matter particle +

Analytic equations of cooling, star formation, and feedback.

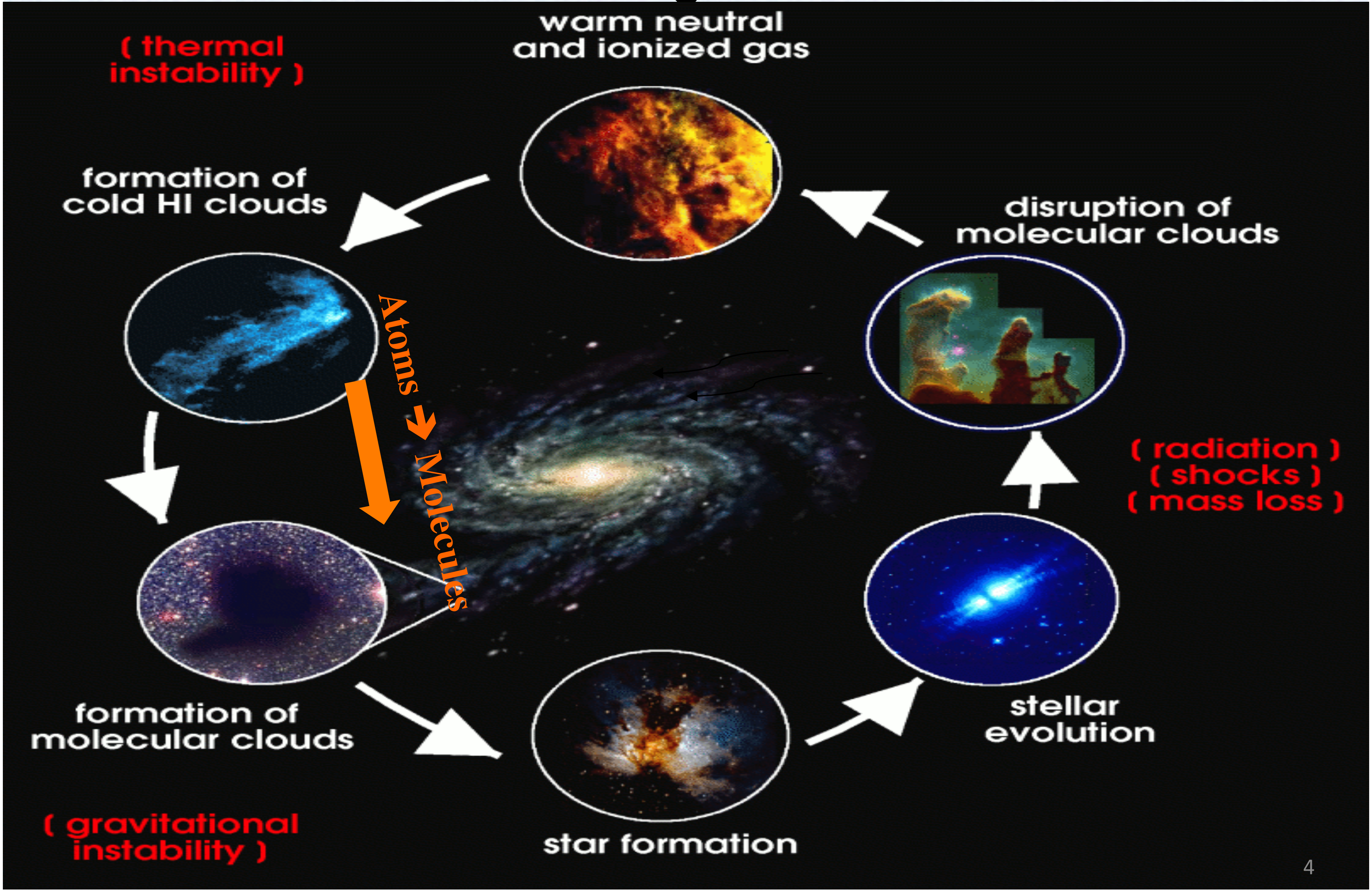
- "Dissipative" Hydrodynamic Simulations

Overwhelmingly Large Simulations (OWLS)

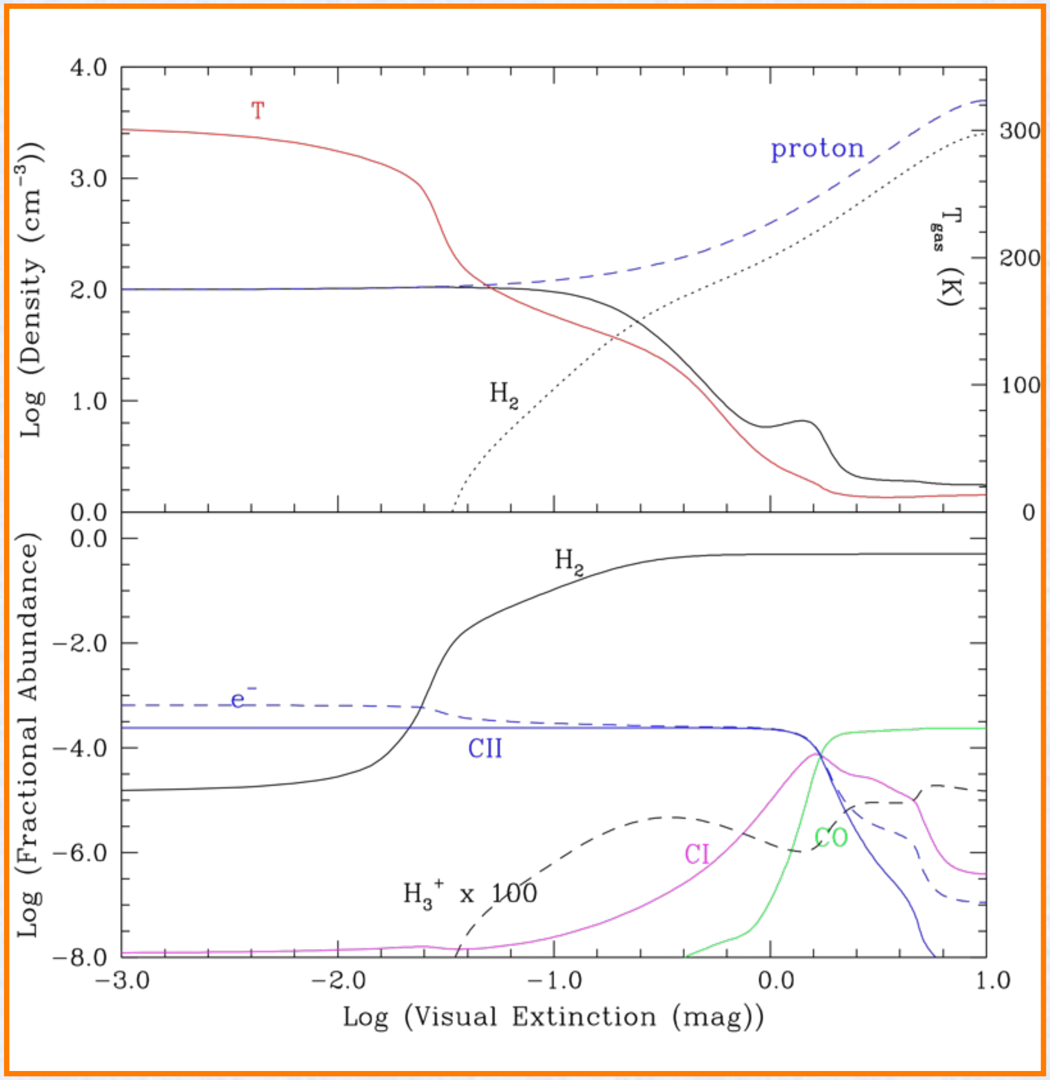
(Schaye et al. 2009 MNRAS)

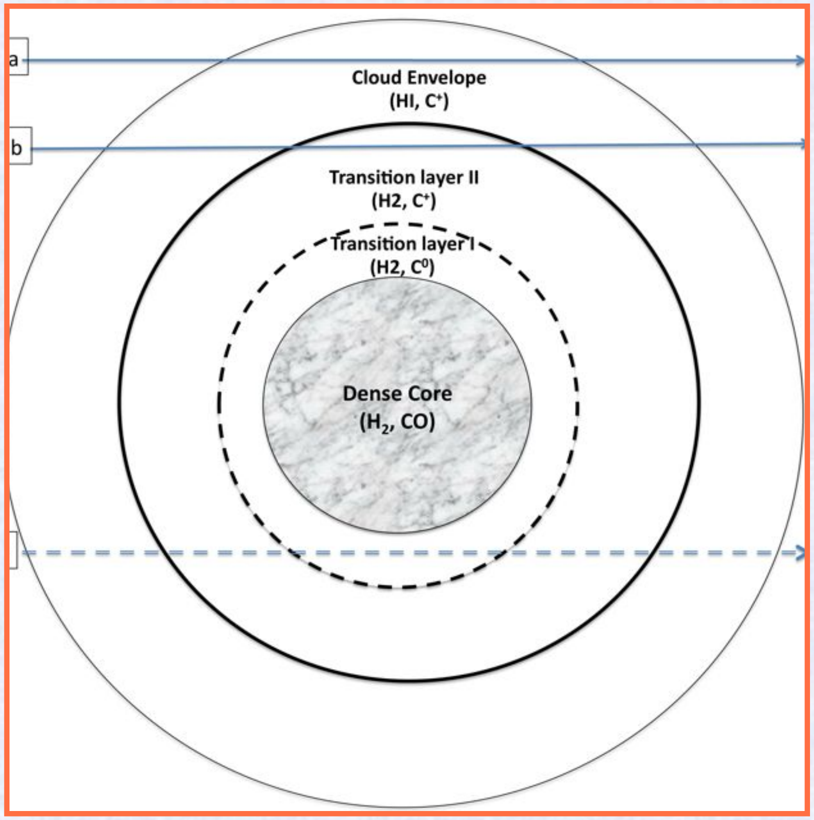
Dark matter particles + gas particles + parametric treatment of star formation.

The Life Cycle of ISM

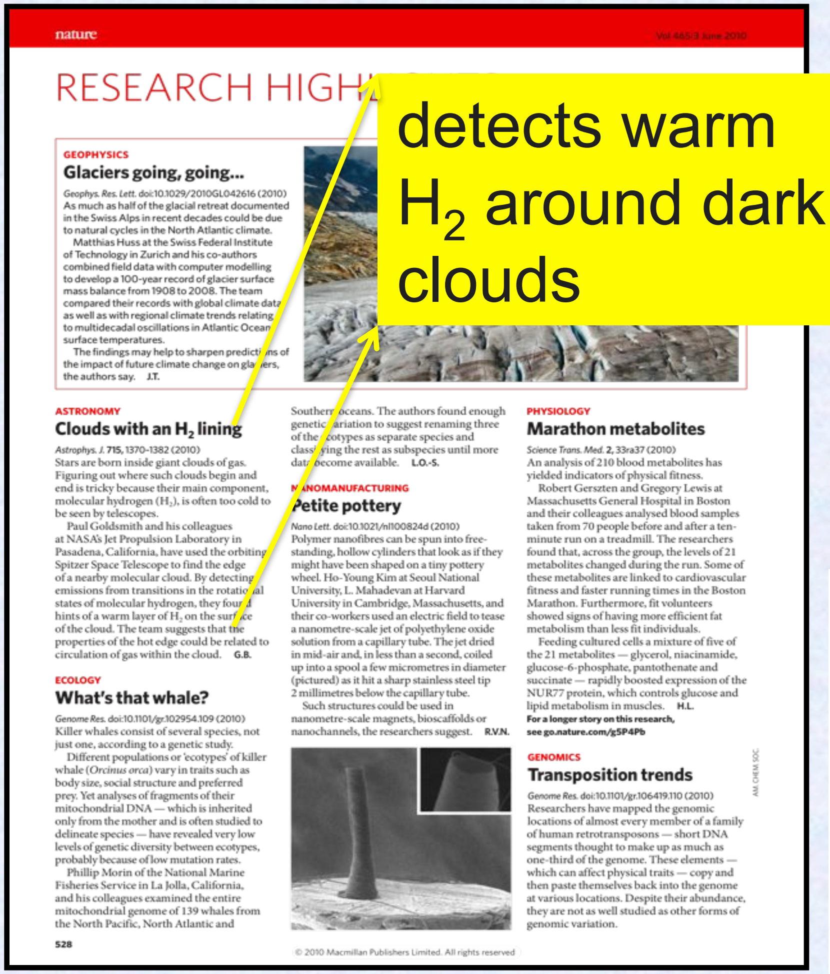


The Transition Phase





H_2 Formation and SF



nature Vol 465|3 June 2010

RESEARCH HIGH

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)

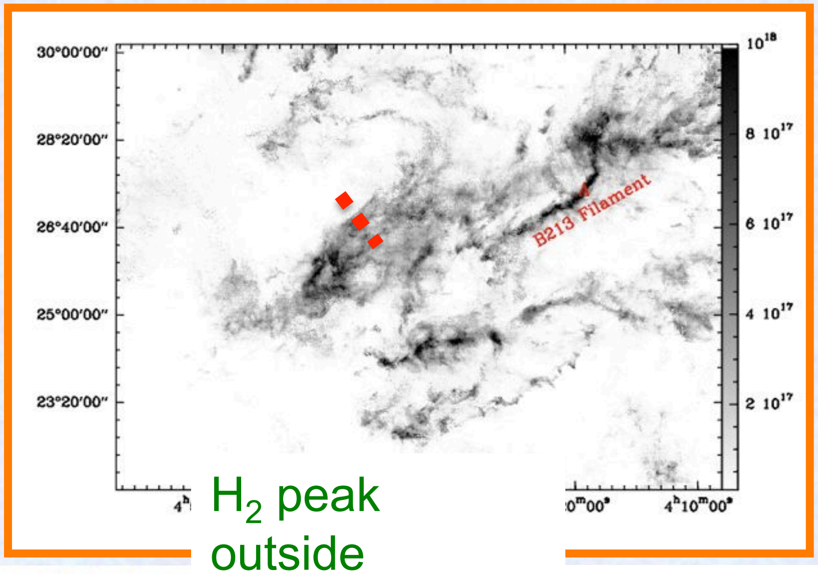
Researchers have mapped the genomic locations of almost every member of a family of human retrotransposons — short DNA segments thought to make up as much as one-third of the genome. These elements — which can affect physical traits — copy and then paste themselves back into the genome at various locations.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

AM. CHEM. SOC.

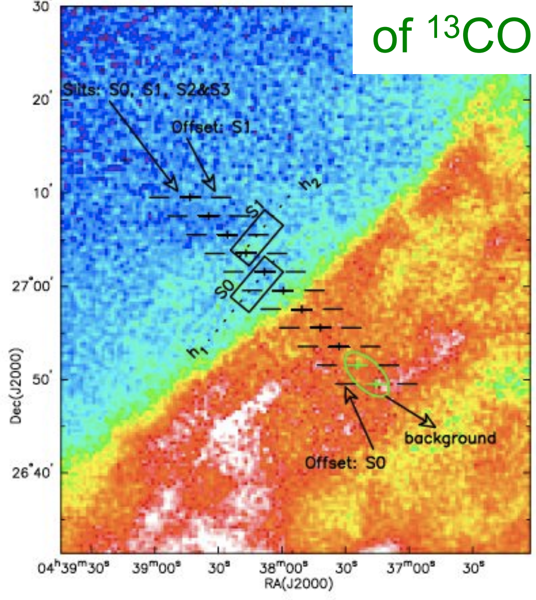
528

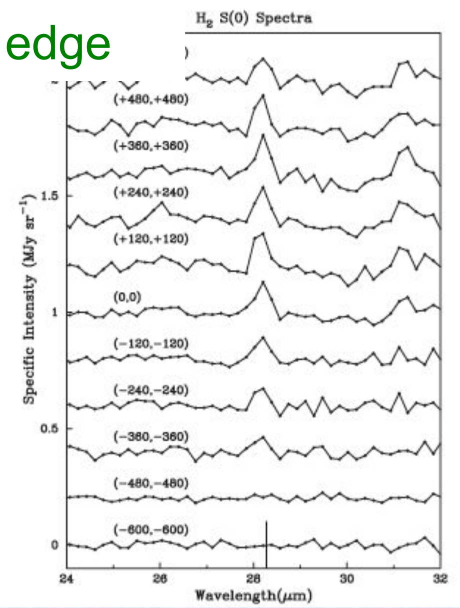
detects warm H_2 around dark clouds

(Goldsmith, Velusamy, Li & Langer 2010)

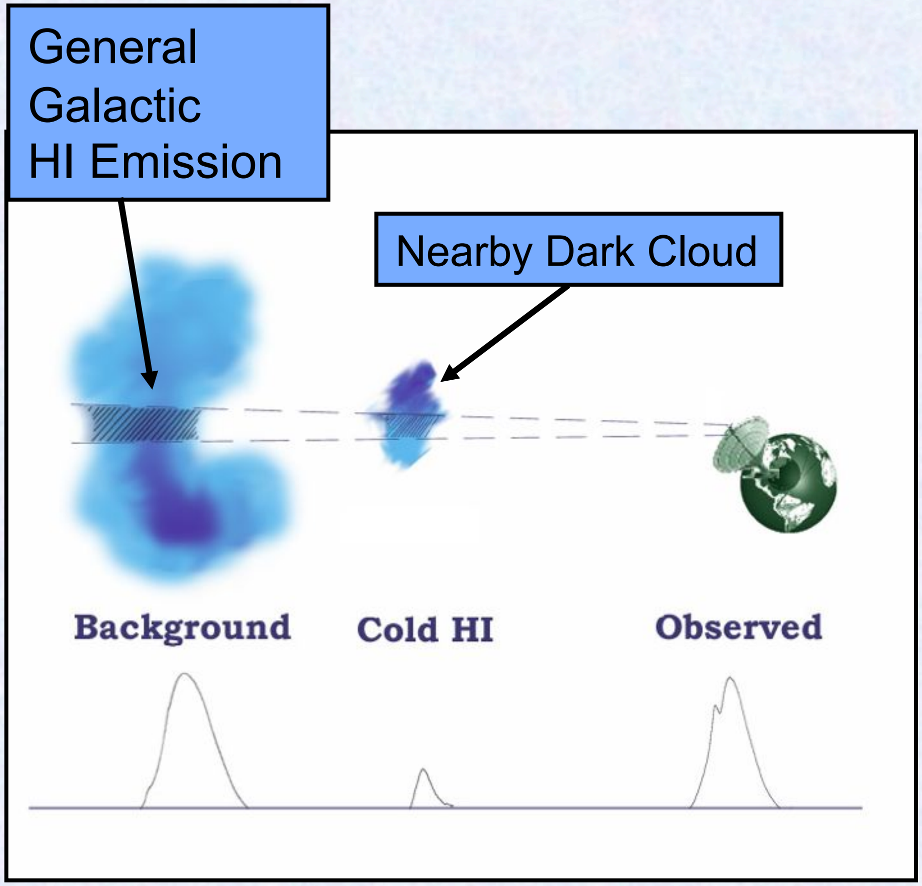


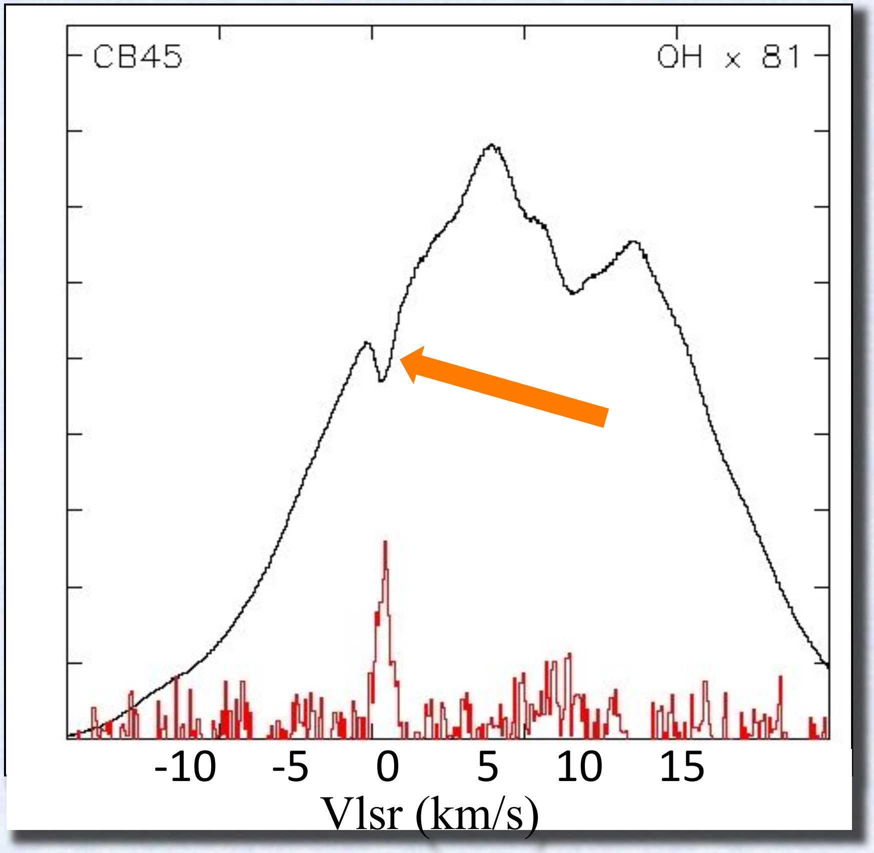
H_2 peak outside of ^{13}CO edge





HINSA Reveals Cold HI





(Li & Goldsmith 2003)

HI Narrow Self Absorption (HINSA)

Atoms (HI) to Molecules (H_2)

Fractional Abundance of HI

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

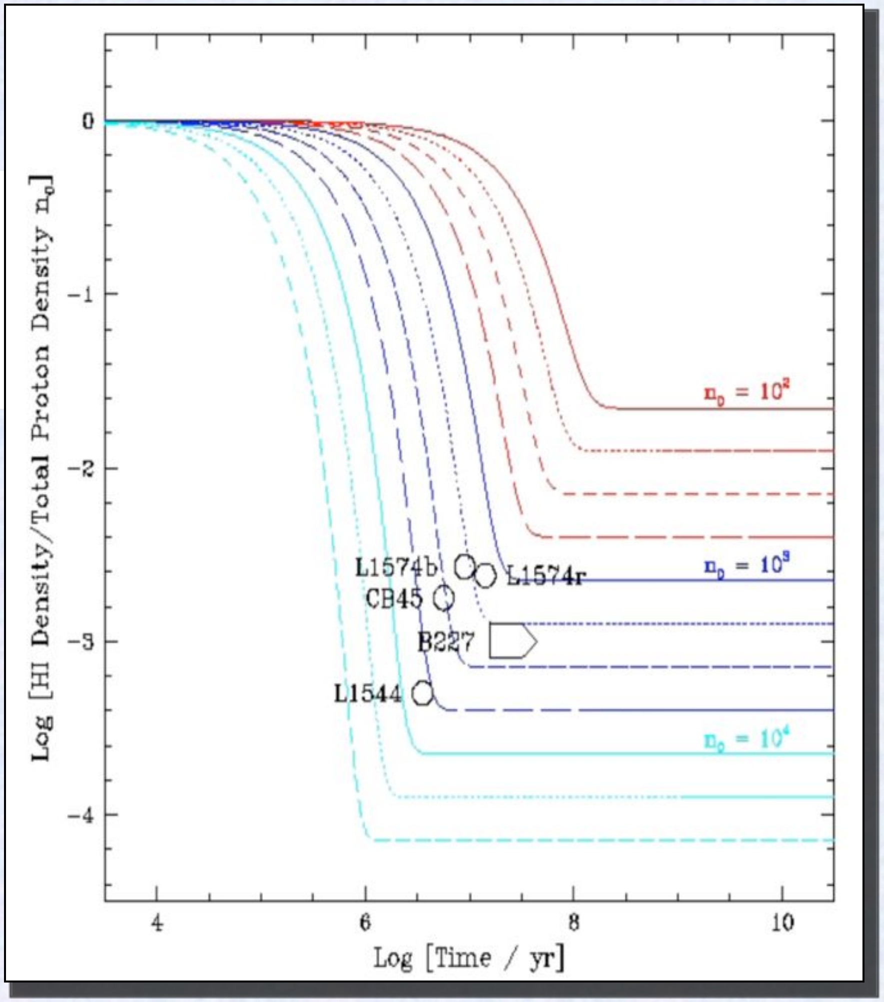
Characteristic Time Scale

$$\tau_{\mathrm{H\,I}\rightarrow\mathrm{H_2}} = \frac{1}{2k'n_0}.$$

$T = 1.3 \times 10^9$ yr/n_0

Steady-State Abundance of HI

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



Molecular Cloud Age： $>10^7$ yr

(Goldsmith & Li 2005)

SF Time Scale

年度天文及天体物理综述

Theory of Star Formation

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

[1]Departments of Physics and Astronomy, University of California, Berkeley, California 94720; email: cmckee@astro.berkeley.edu

[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

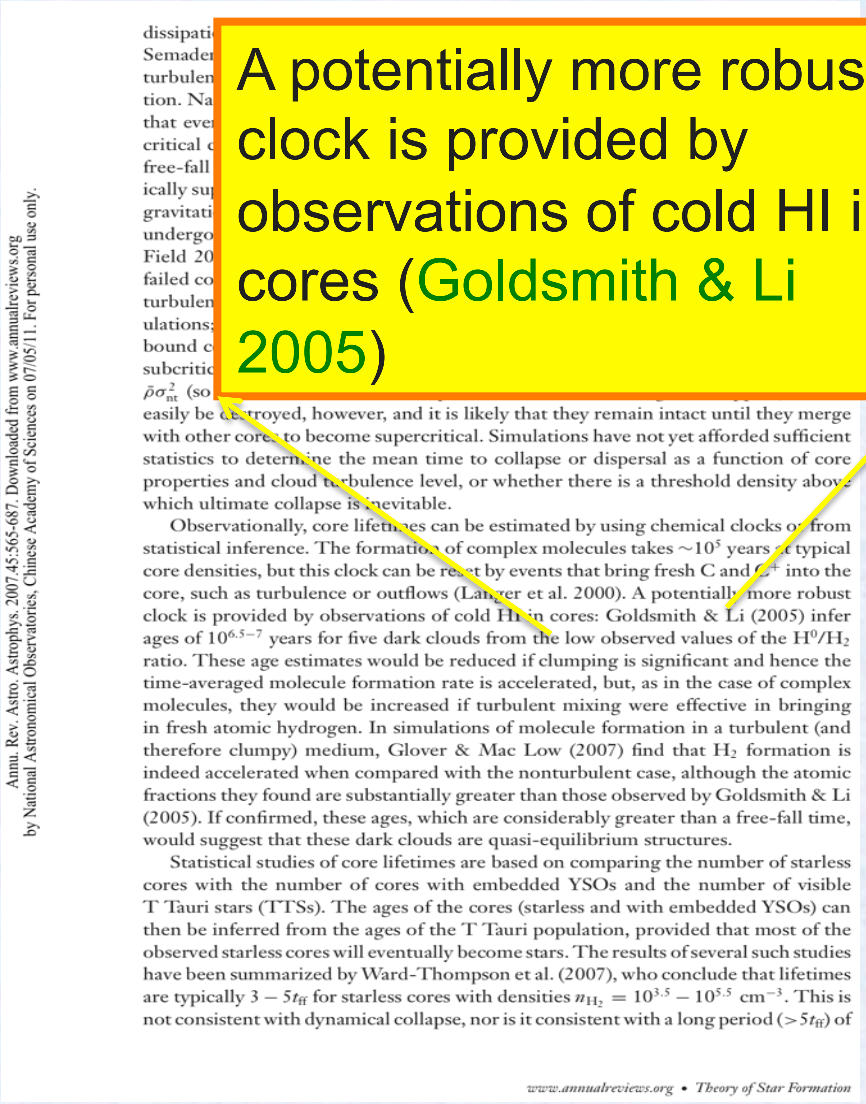
0066-4146/07/0922-0565$20.00

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.



dissipati
Semader
turbulen
tion. Na
that ever
critical c
free-fall
ically su
gravitati
undergo
Field 20
failed co
turbulen
ulations;
bound c
subcritic
$\bar{\rho}\sigma_{\rm nt}^2$ (so

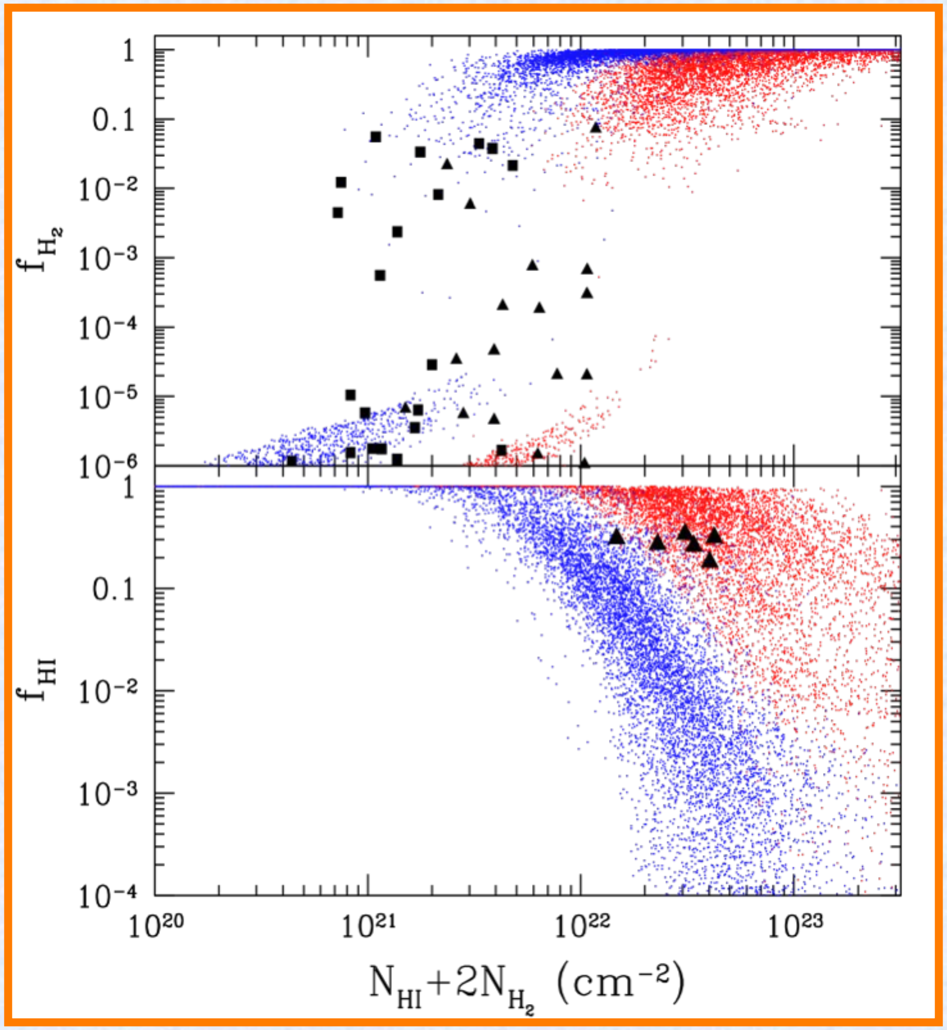
easily be destroyed, however, and it is likely that they remain intact until they merge with other cores to become supercritical. Simulations have not yet afforded sufficient statistics to determine the mean time to collapse or dispersal as a function of core properties and cloud turbulence level, or 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 $3 - 5t_{\rm ff}$ for starless cores with densities $n_{\rm H_2} = 10^{3.5} - 10^{5.5}$ cm^{-3}. This is not consistent with dynamical collapse, nor is it consistent with a long period ($>5t_{\rm ff}$) of

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

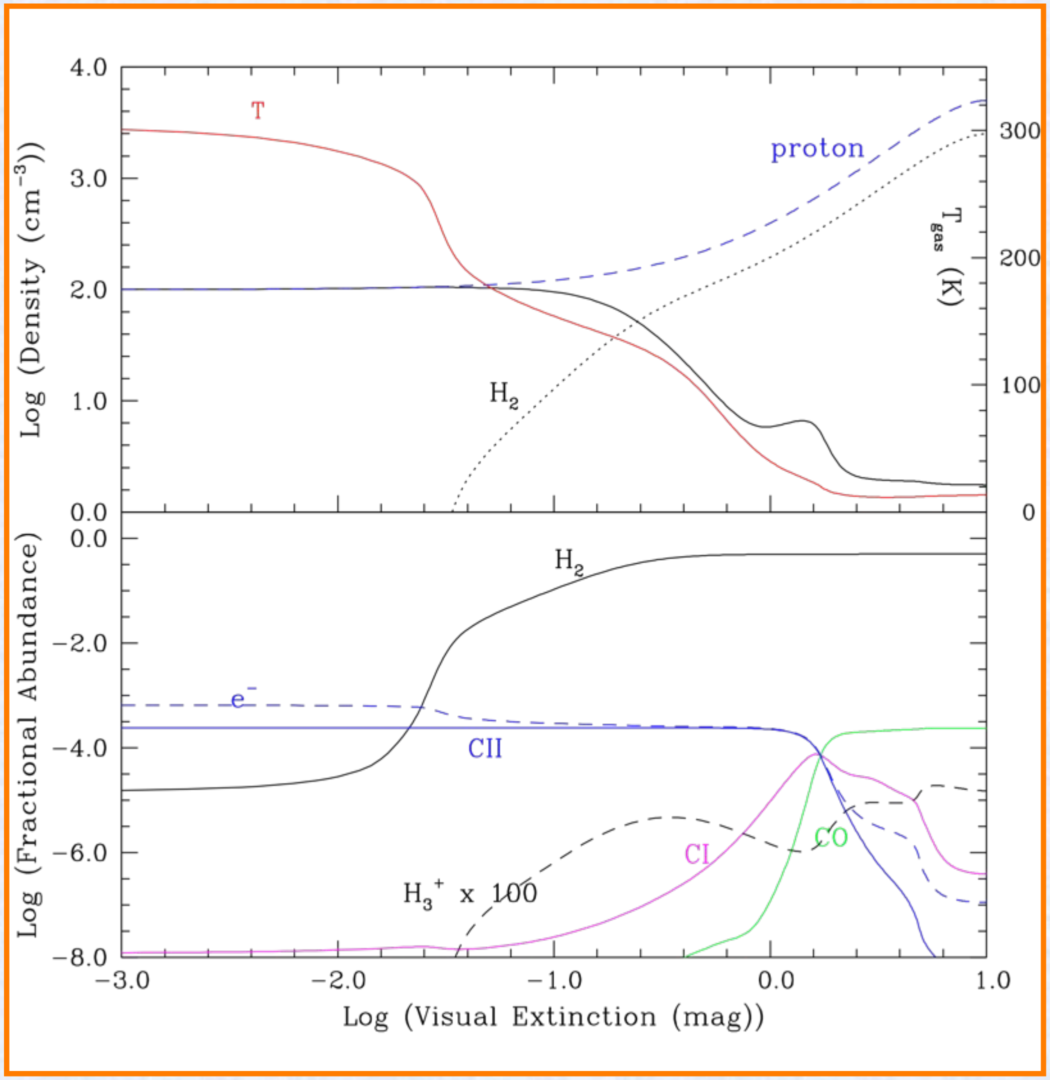
Implications of HINSA

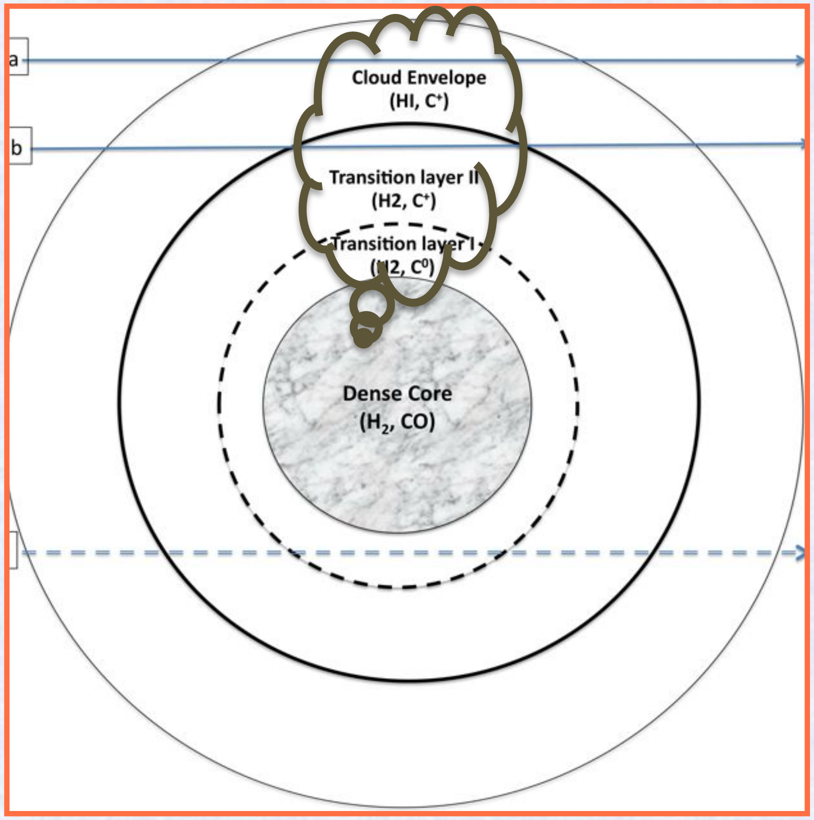


N. Gnedin & A. Kravtsov 2010

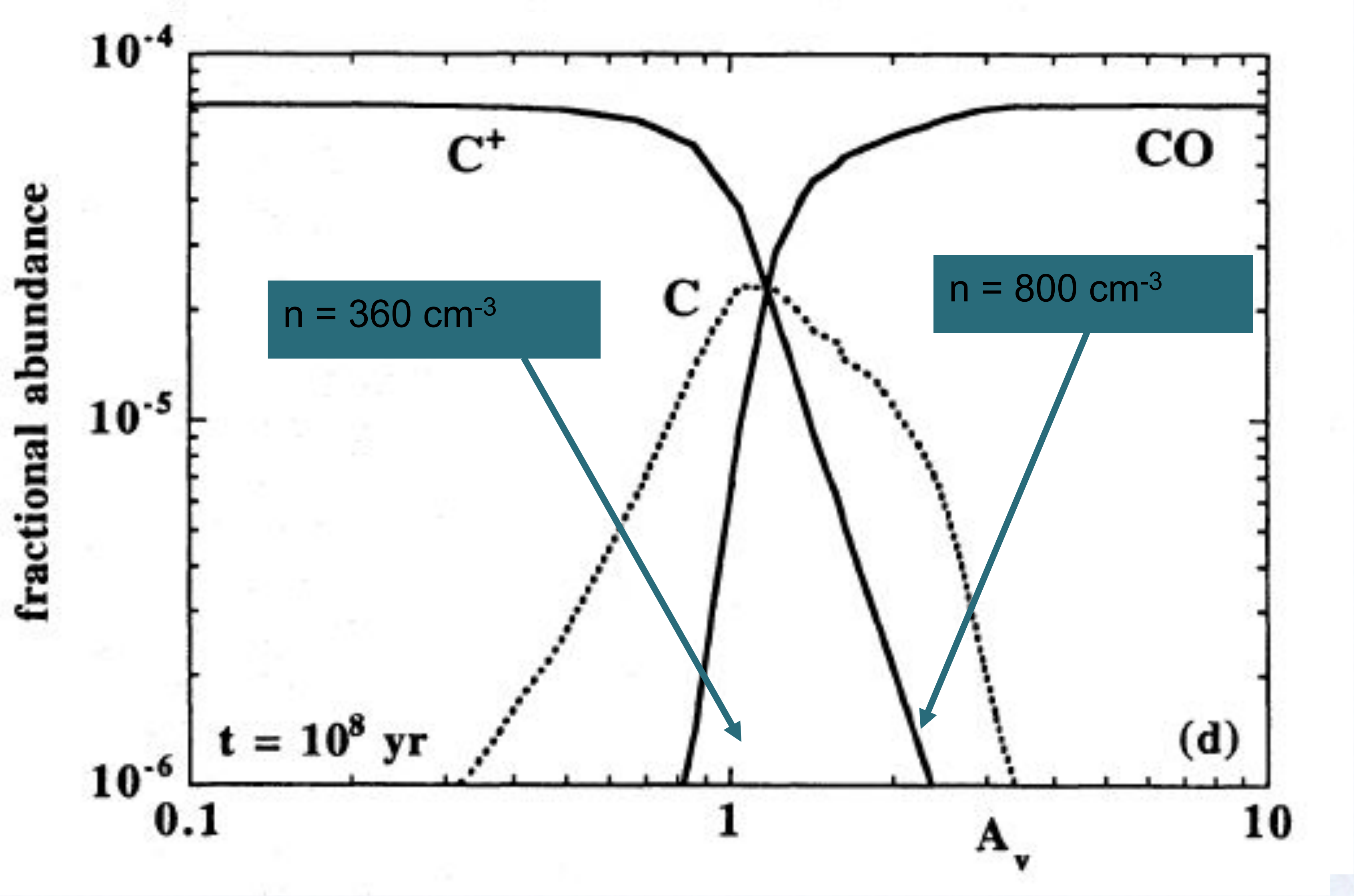
The atomic-to-molecular transition as a function of gas density or column density has a large scatter but is rather sharp and shifts to higher densities with decreasing dust-to-gas ratio and/or increasing FUV flux. Consequently, star formation is concentrated to higher gas surface density regions, resulting 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.

The Transition Phase





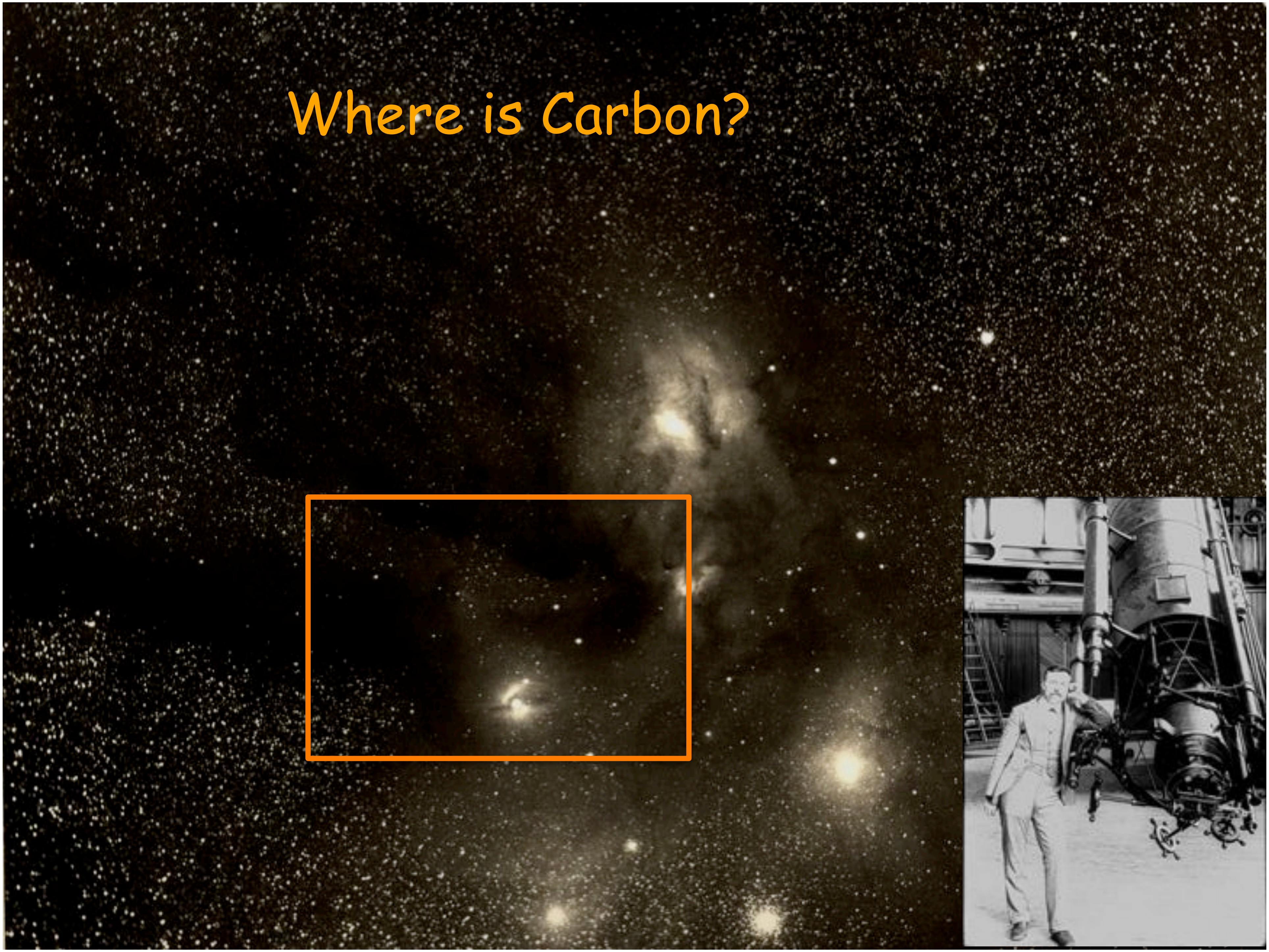
Carbon in A_v and Time



n = 360 cm^{-3}

n = 800 cm^{-3}

Where is Carbon?



Telescopes

The Submillimeter Pathfinder Missions – SWAS and ODIN

SWAS

54 x 68cm offset Cass antenna

Passively cooled front end with 2 fixed tuned Schottky 2nd harmonic mixers at 490 GHz and 555 GHz

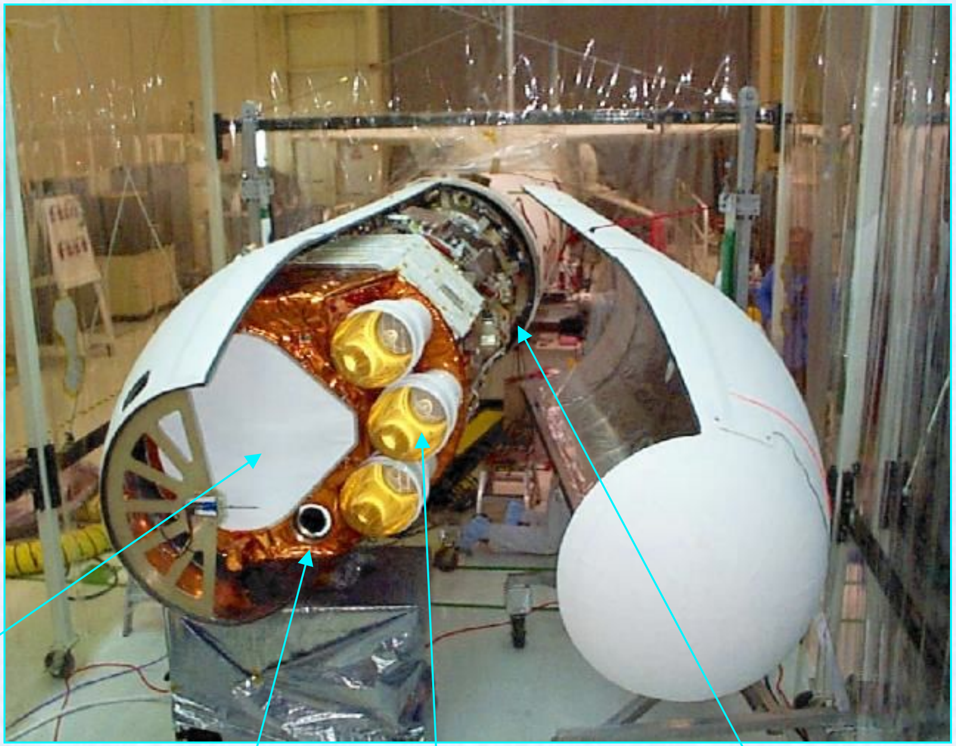
AOS backend

Observe O_2, CI, H_2O, $H_2{}^{18}O$, and ^{13}CO

Launched 5 Dec 1998

Operated until 21 July 2004

Beam Width
= 3′ x 5′



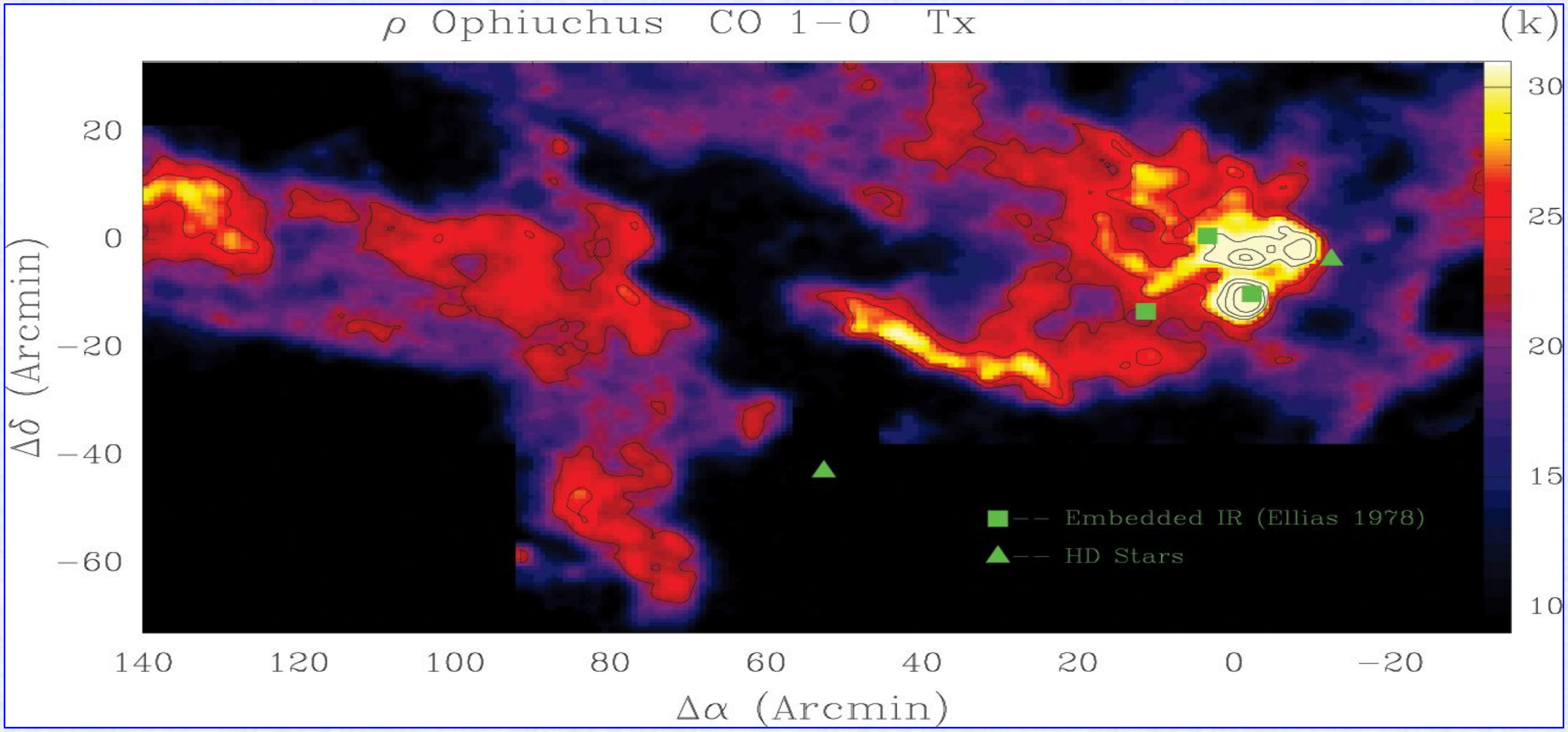
Teflon Aperture Cover

Star Tracker

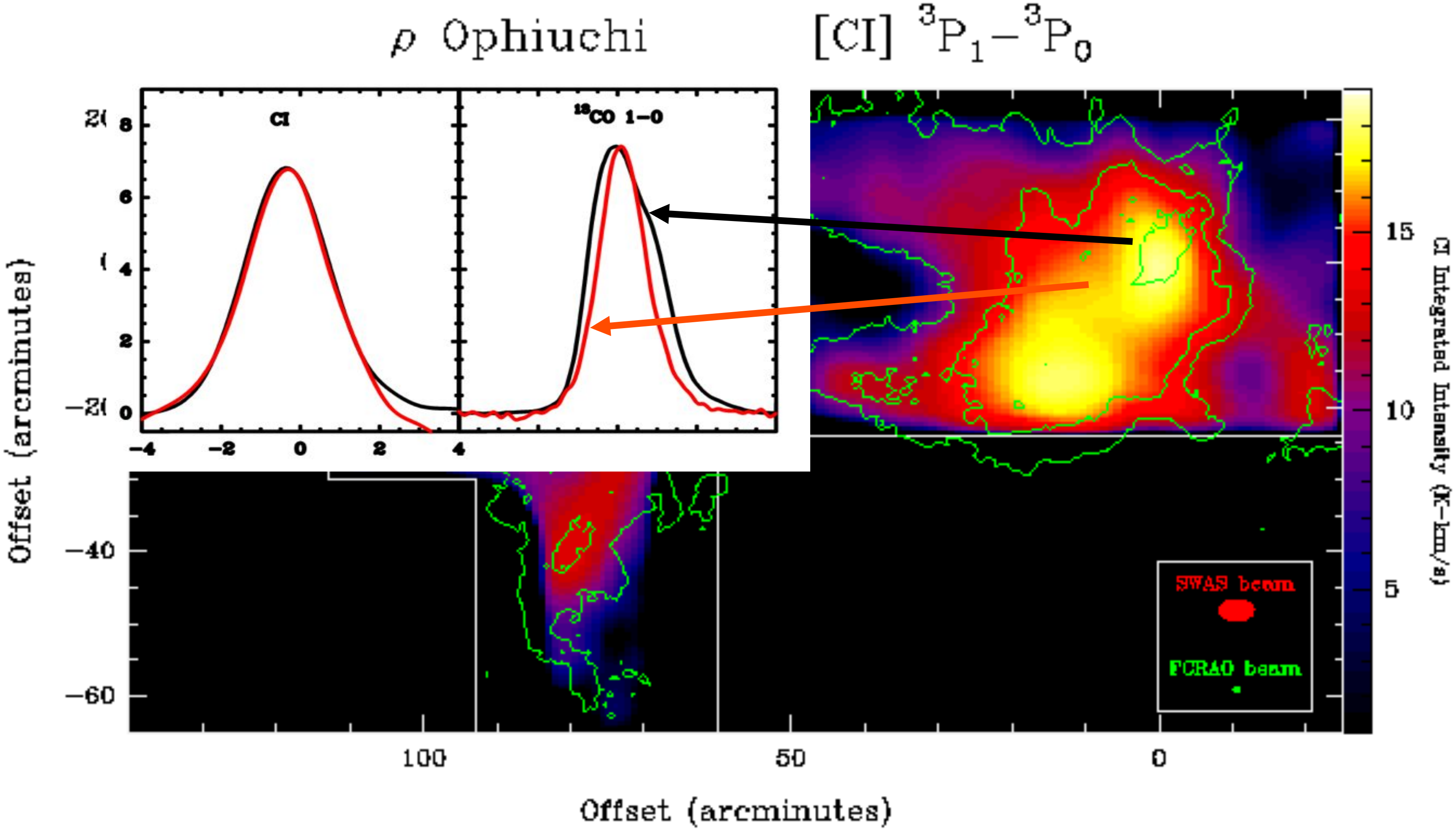
Winston Cone Thermal Radiators

Pegasus XL Launch Vehicle

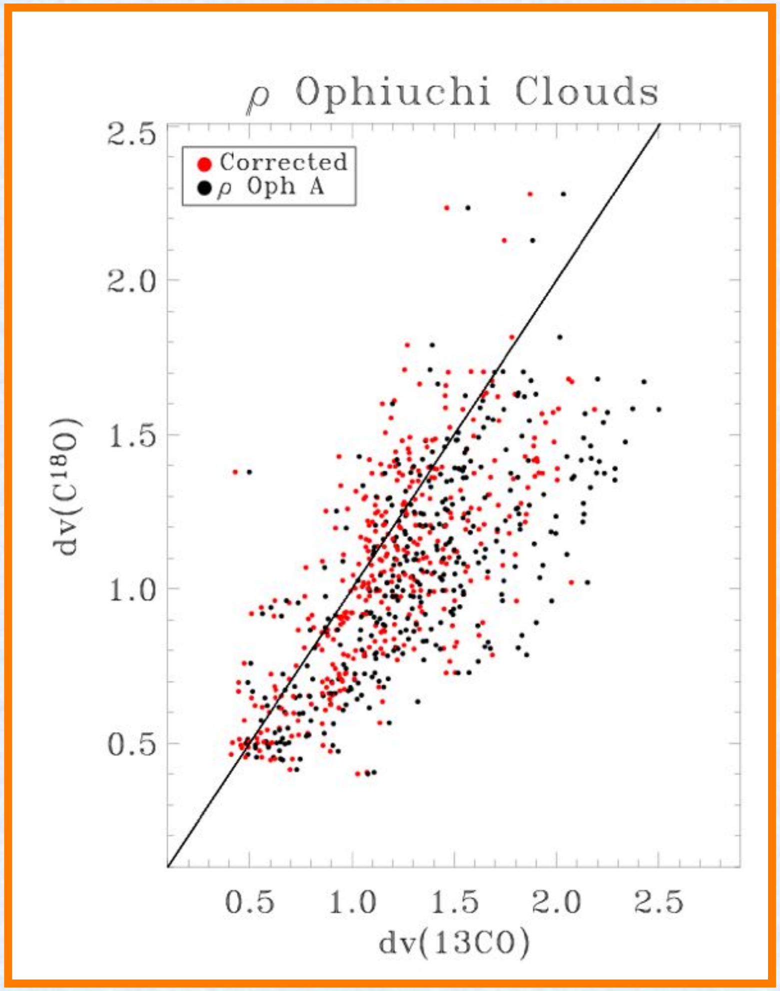
Temperature Structure

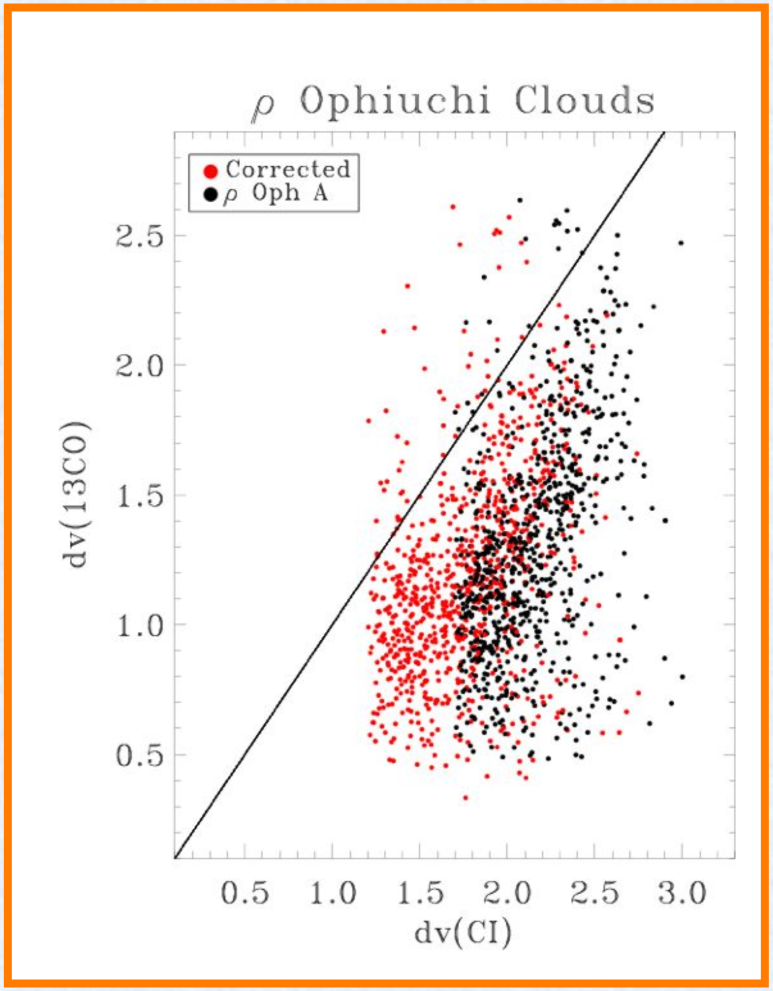


Carbon in ρ Ophiuchi Clouds



Turbulence Structure

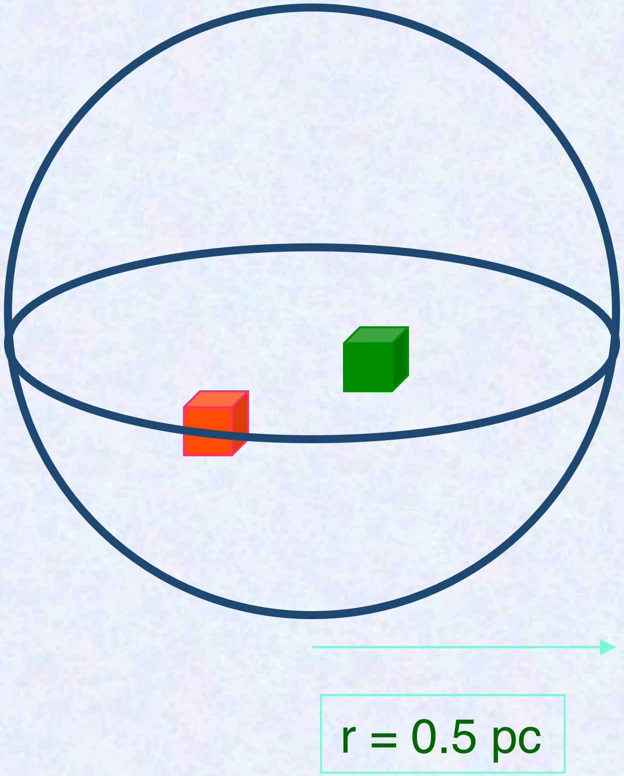




Clump-Interclump: Model Fit

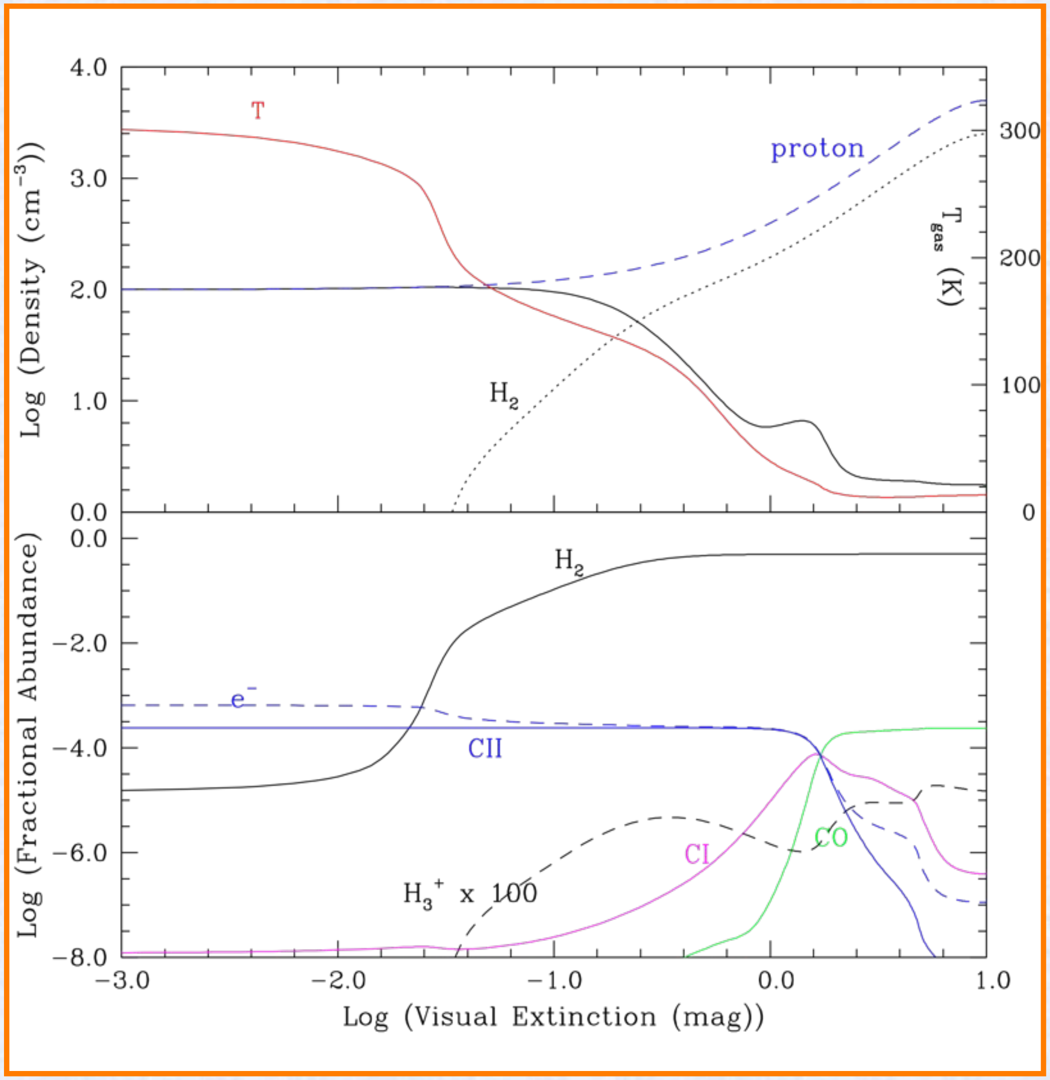
Model; V_{mic}=0.2 km/s; f_b = 0.35

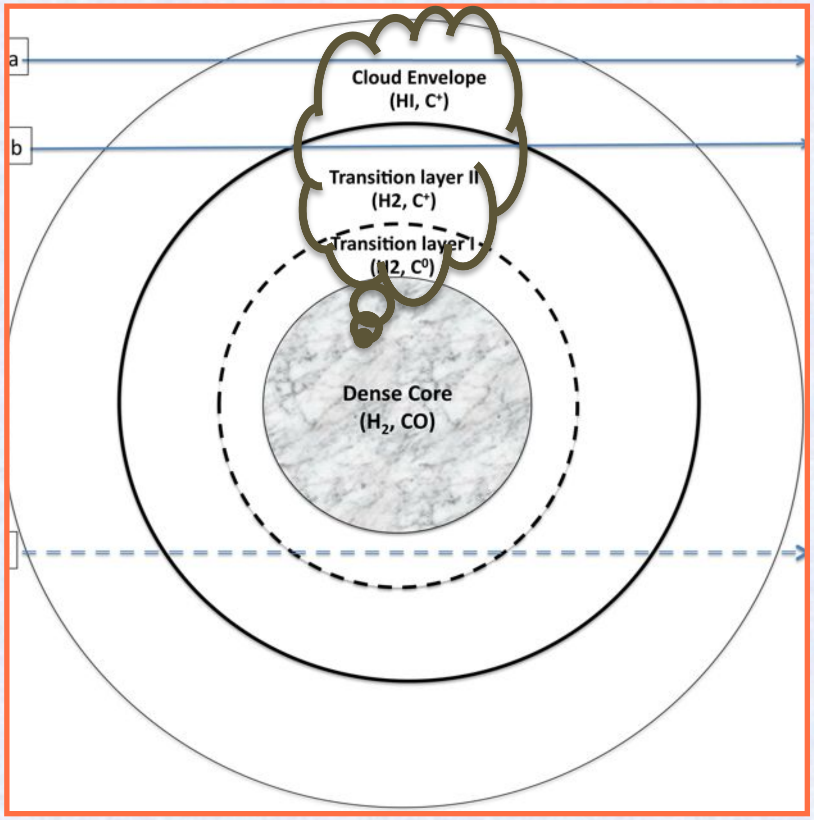
	$n(H_2)$ Cm^{-3}	$[CI]/[H_2]$	$[^{13}CO]/[H_2]$	V_{mac} Km/s
Clump	$4x10^4$	$1x10^{-6}$	$2x10^{-6}$	0.72
Inter-clump	$2x10^3$	10^{-4}	10^{-6}	1.5
	offset			
Clump	$5x10^3$	$1x10^{-6}$	$2x10^{-6}$	0.57
Inter-clump	$1.5x10^3$	10^{-4}	10^{-6}	1.5



Li et al. in Prep

The Transition Phase

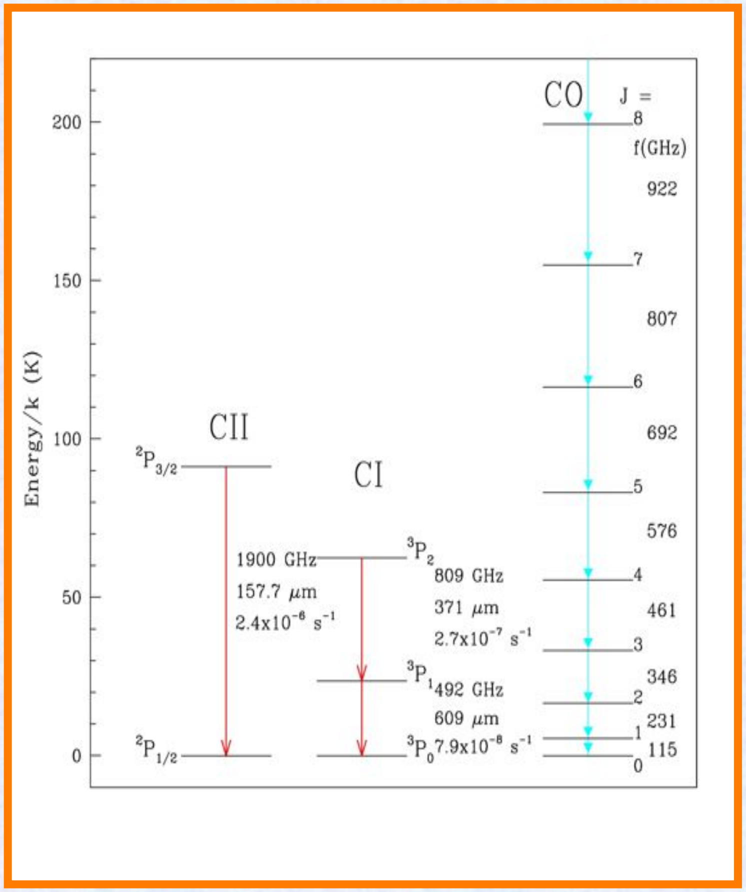




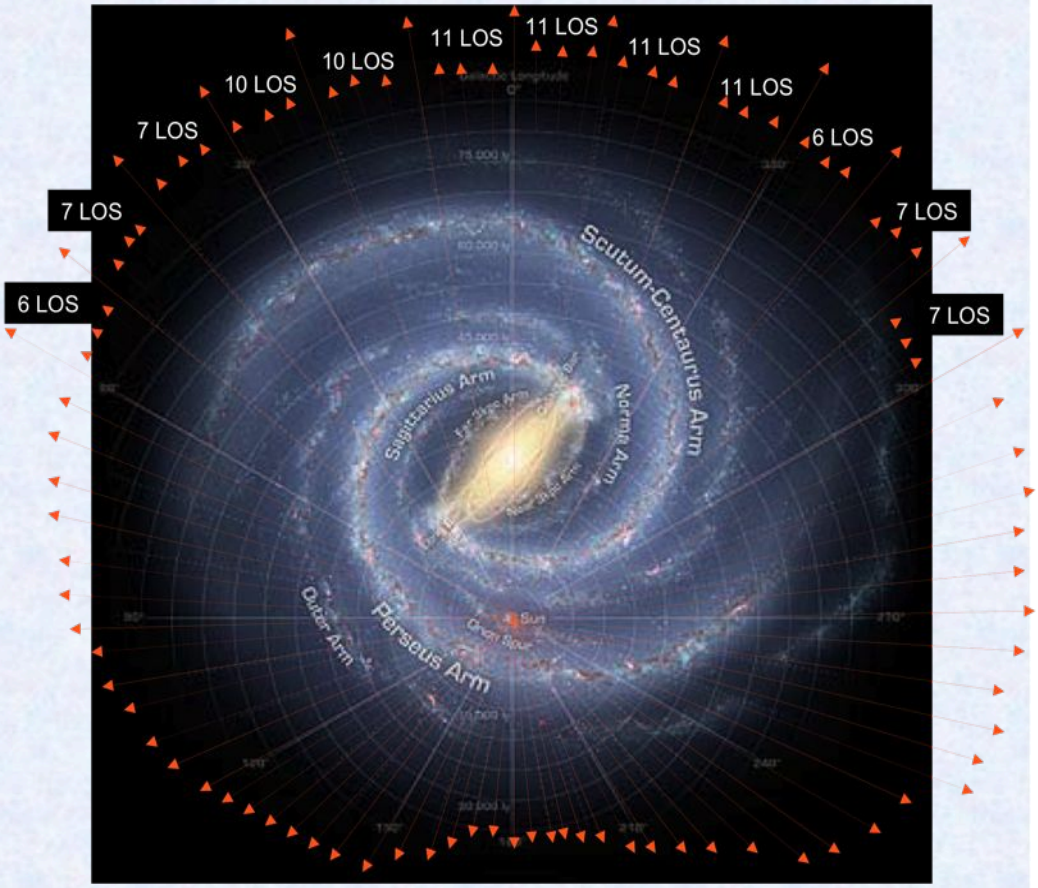
Galactic Observations of the Terahertz CII Line (GOT C+)

Herschel OTKP – GOTC+

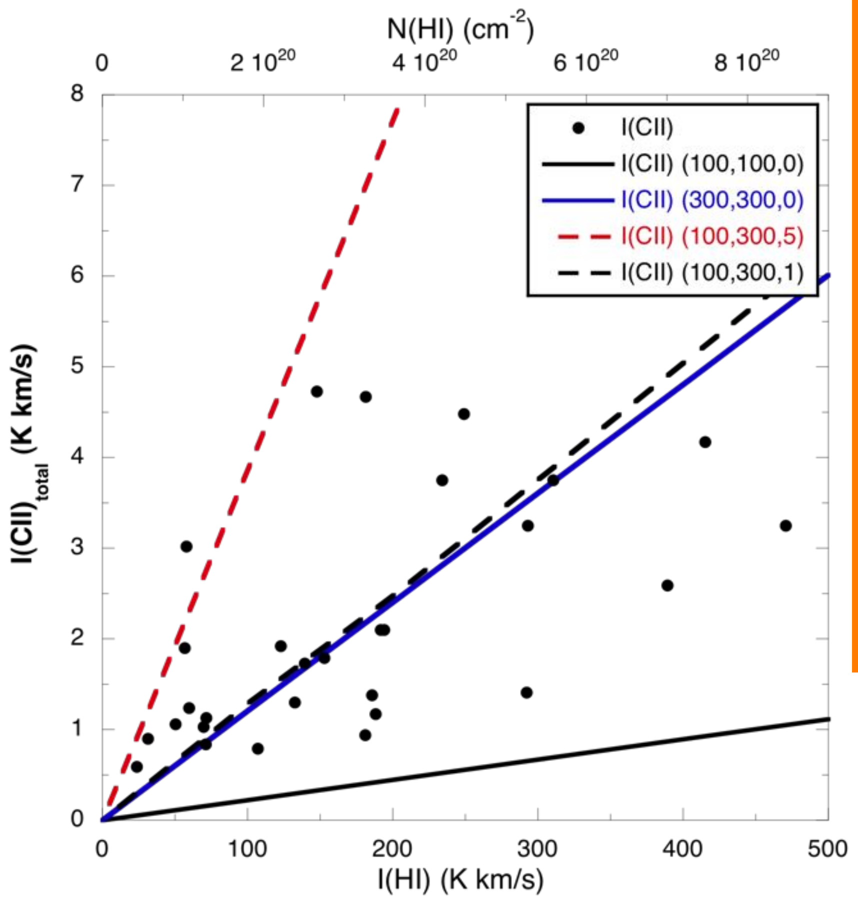
Langer, Goldsmith, Li, Velusamy & Yorke

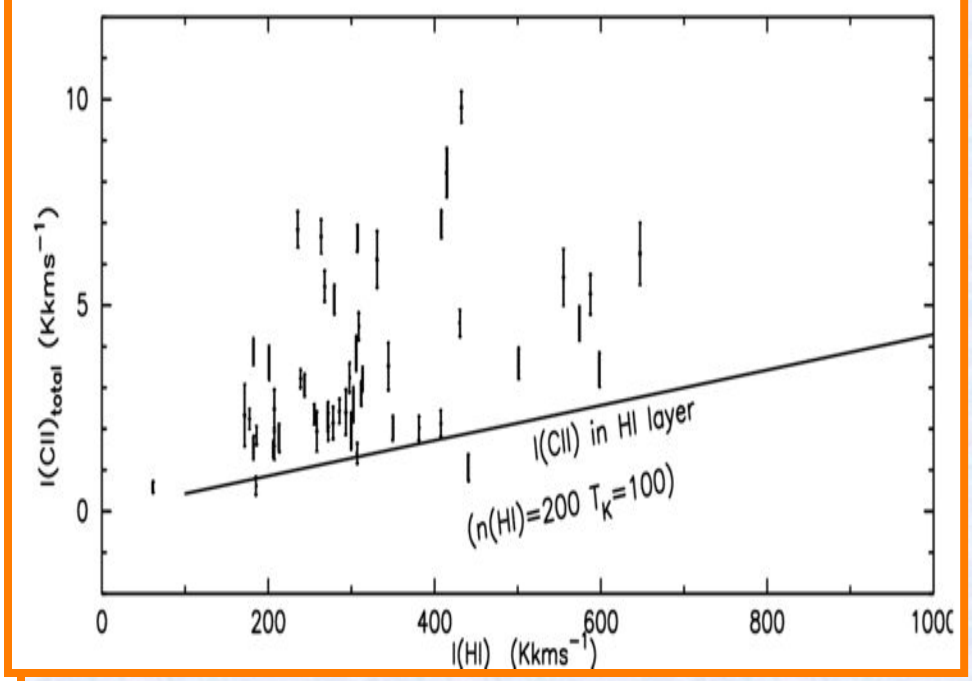


CII Galactic Plane Survey



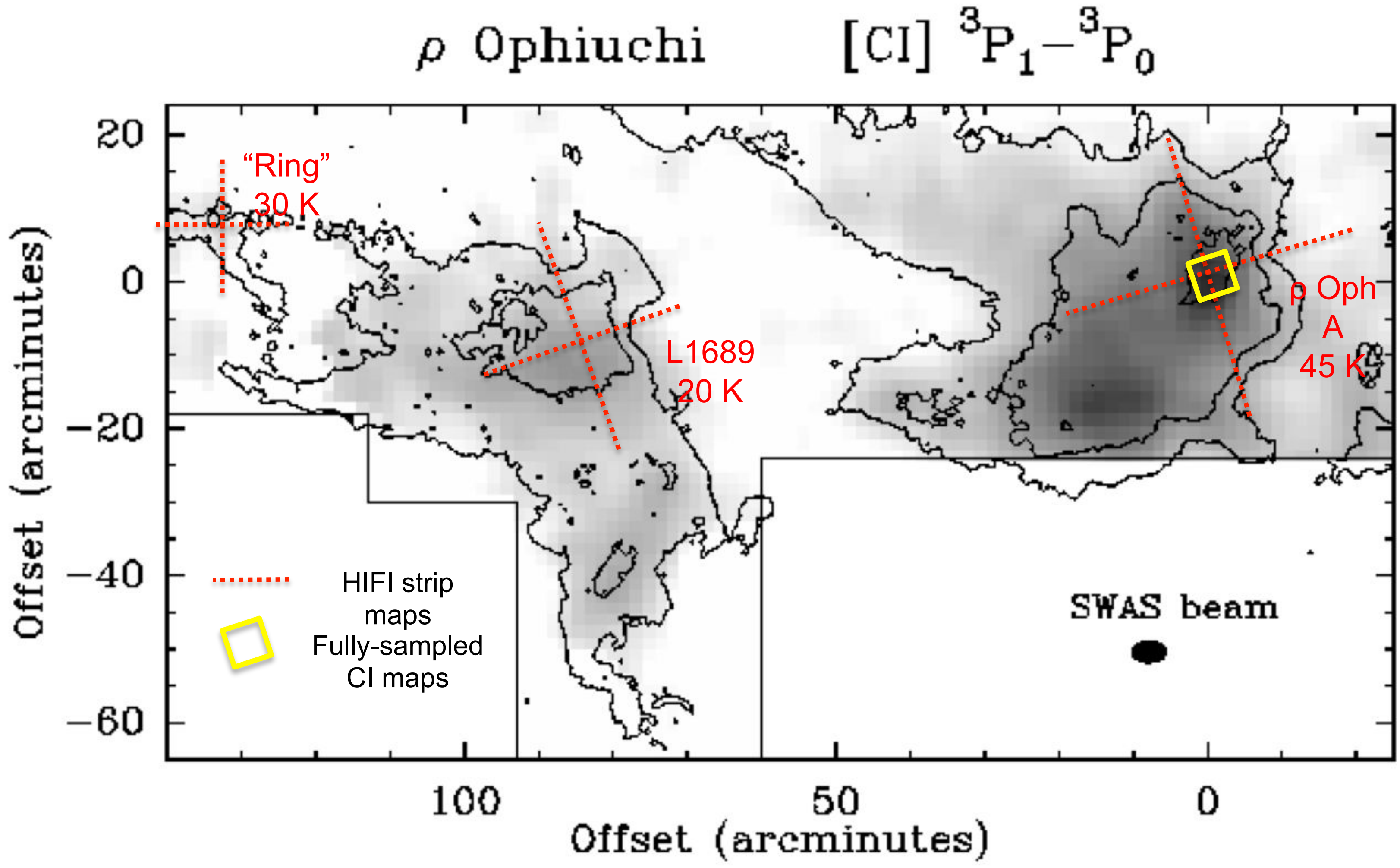
Counting Carbon





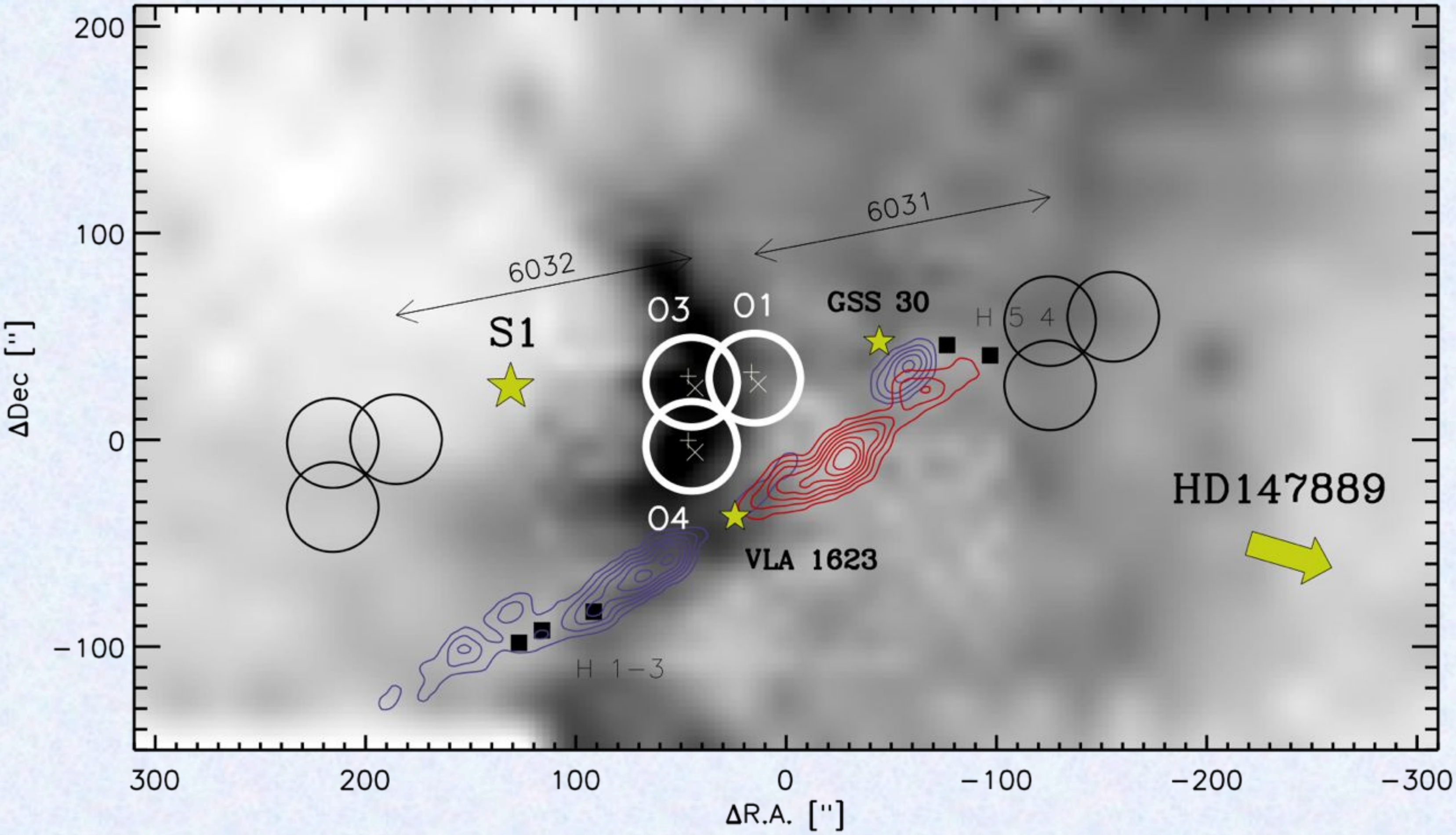
Substantial fraction of C+ cannot be explained by pure atomic gas excitaion -- "Dark H_2 Gas"

Herschel and GREAT



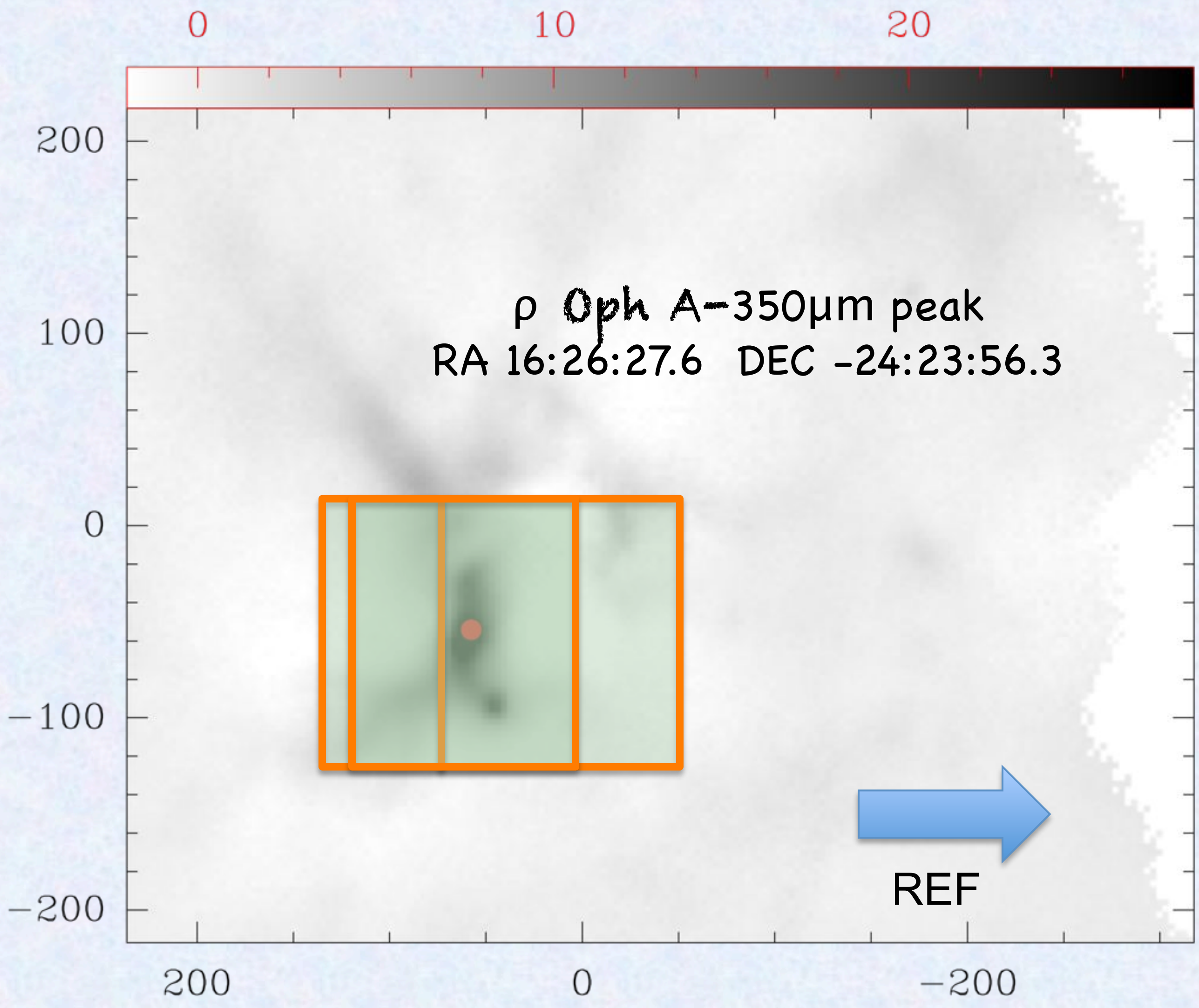
Fly with SOFIA

ρ Oph A Region



(Liseau et al. 2011)

OTF and REFs



ρ Oph A–350μm peak
RA 16:26:27.6 DEC -24:23:56.3

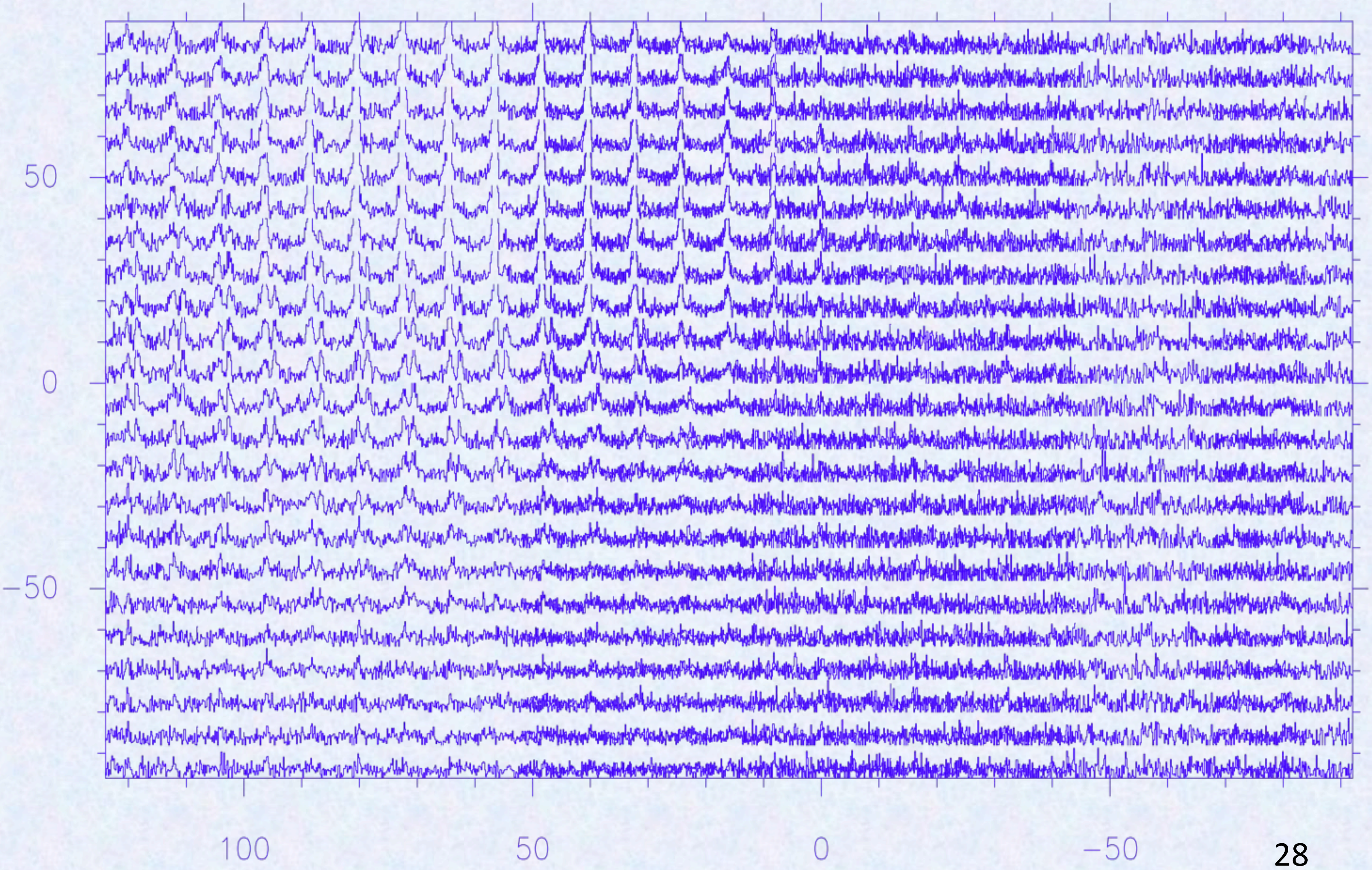
REF

Data Reduction

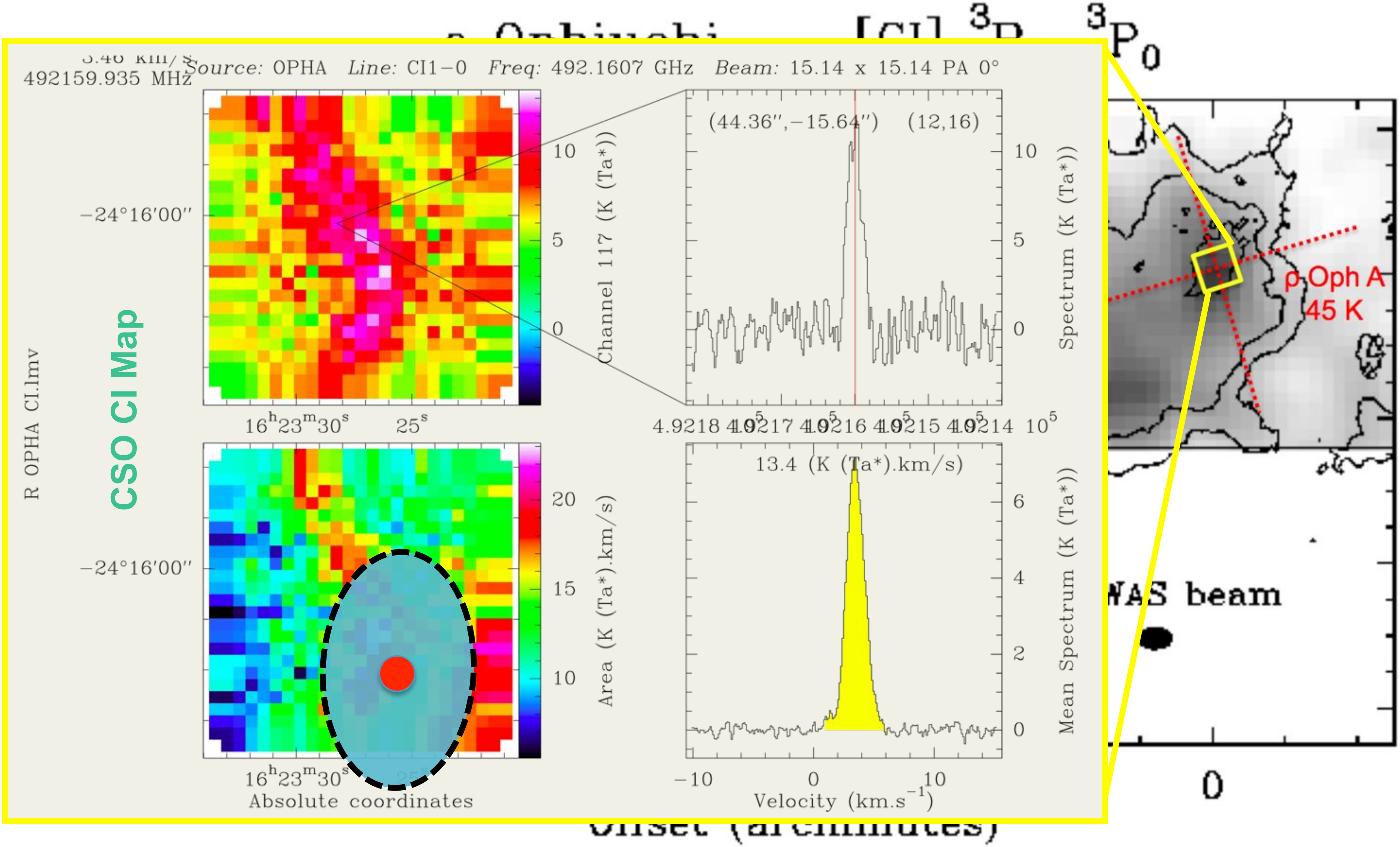
Miguel Requena Torres & Rolf Gusten,
GREAT TEAM

- "Kosma Calibrator" => Tsys
- Flagging spikes and bad pixels
- Remove standing wave
- Regridding => Data cubes for each line

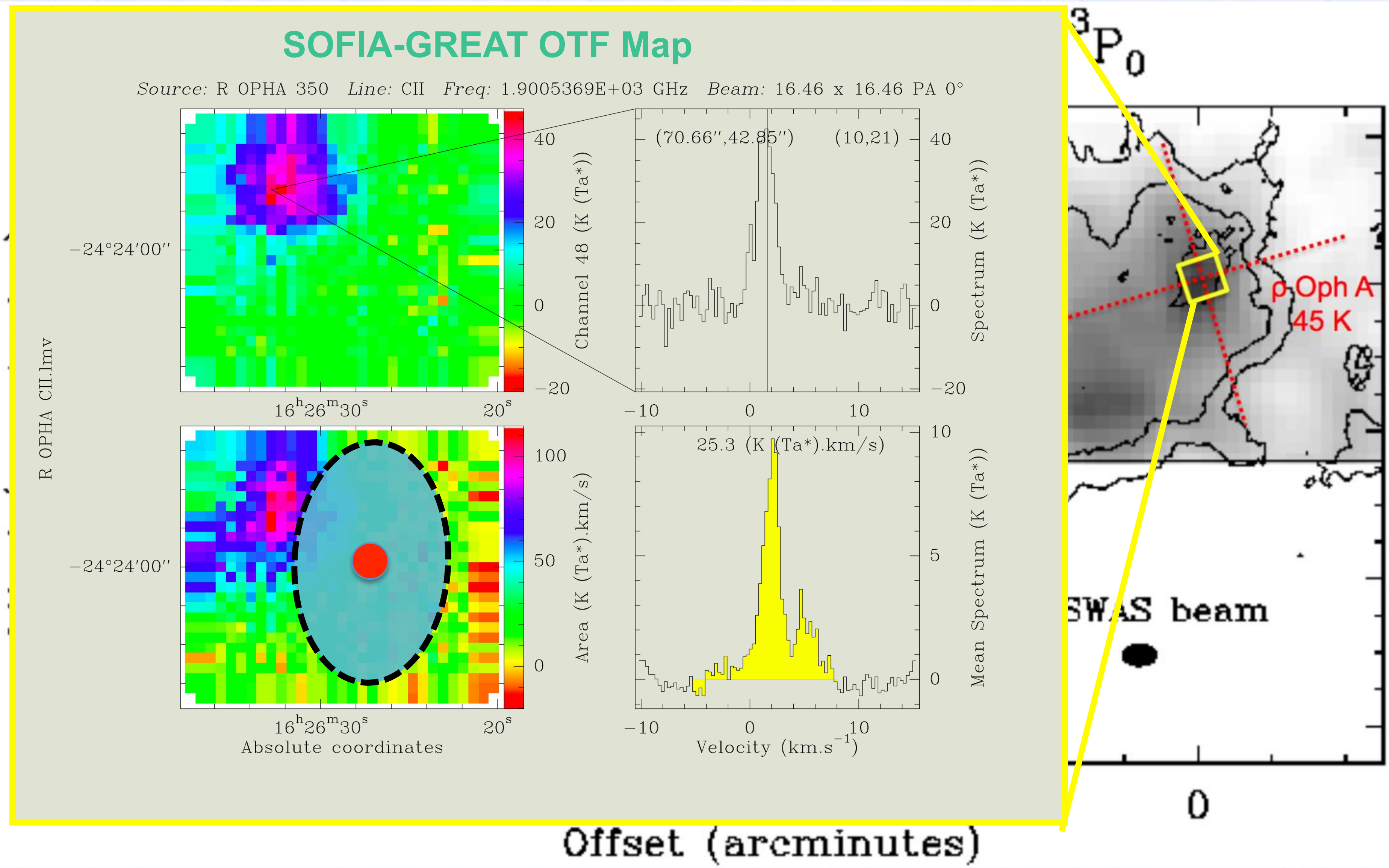
Spectra Array



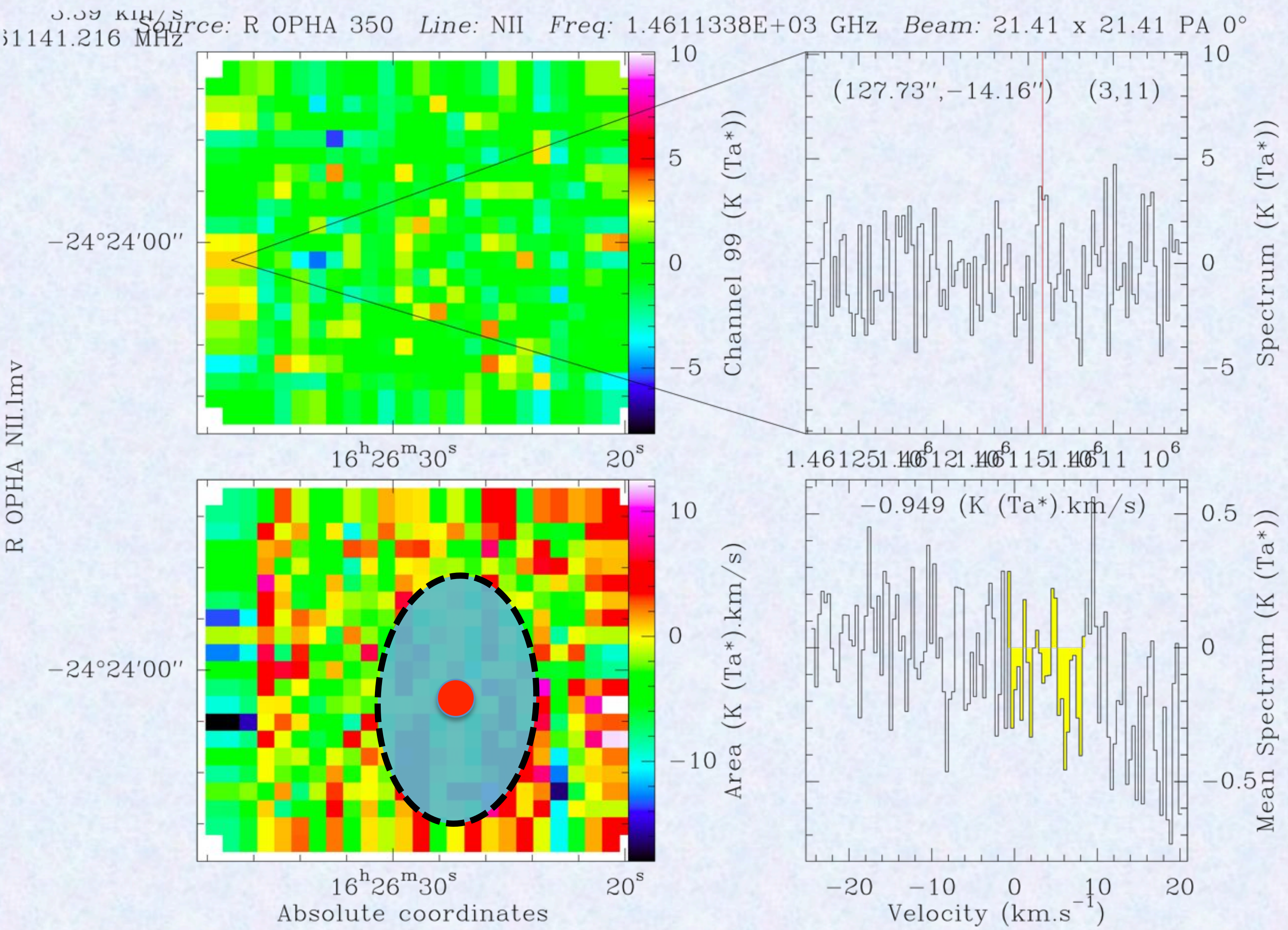
Resolving the Transition: CI



Resolving the Transition: CII

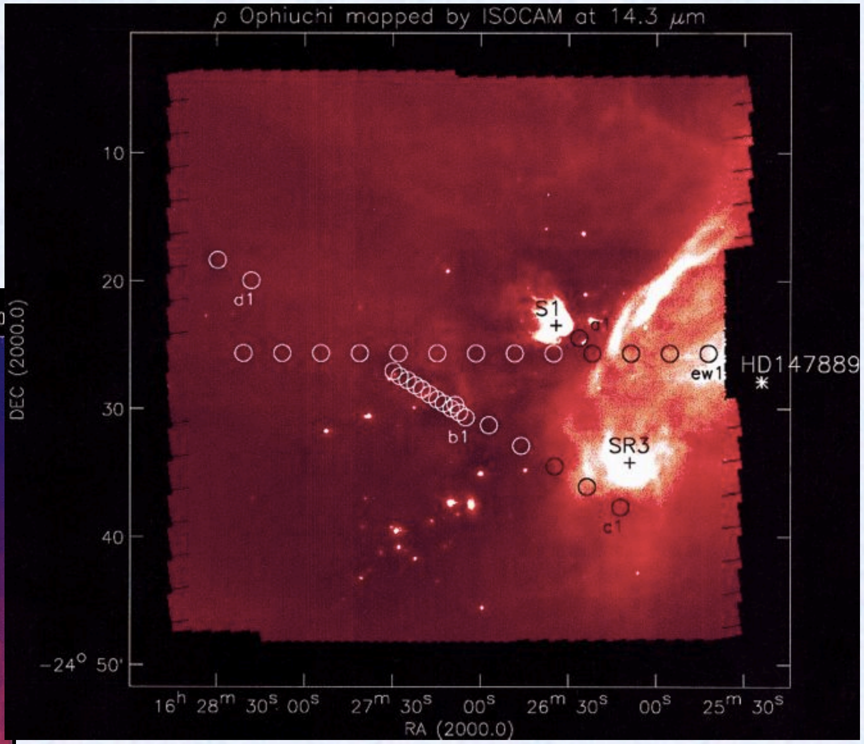


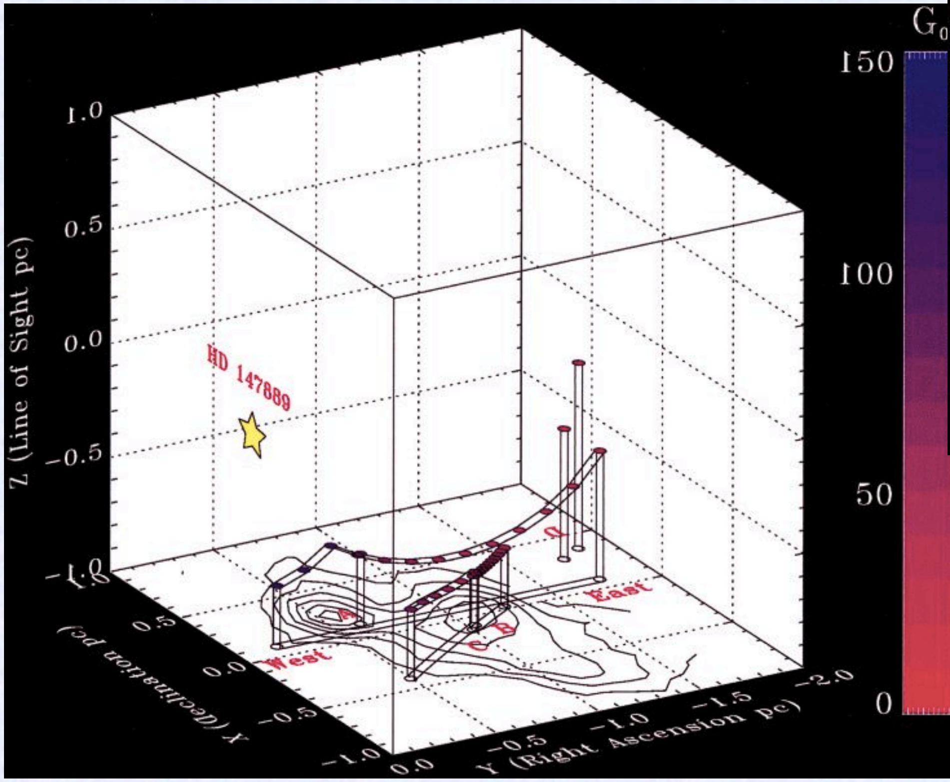
Resolving the Transition: NII?



The Environment of ρ Oph A

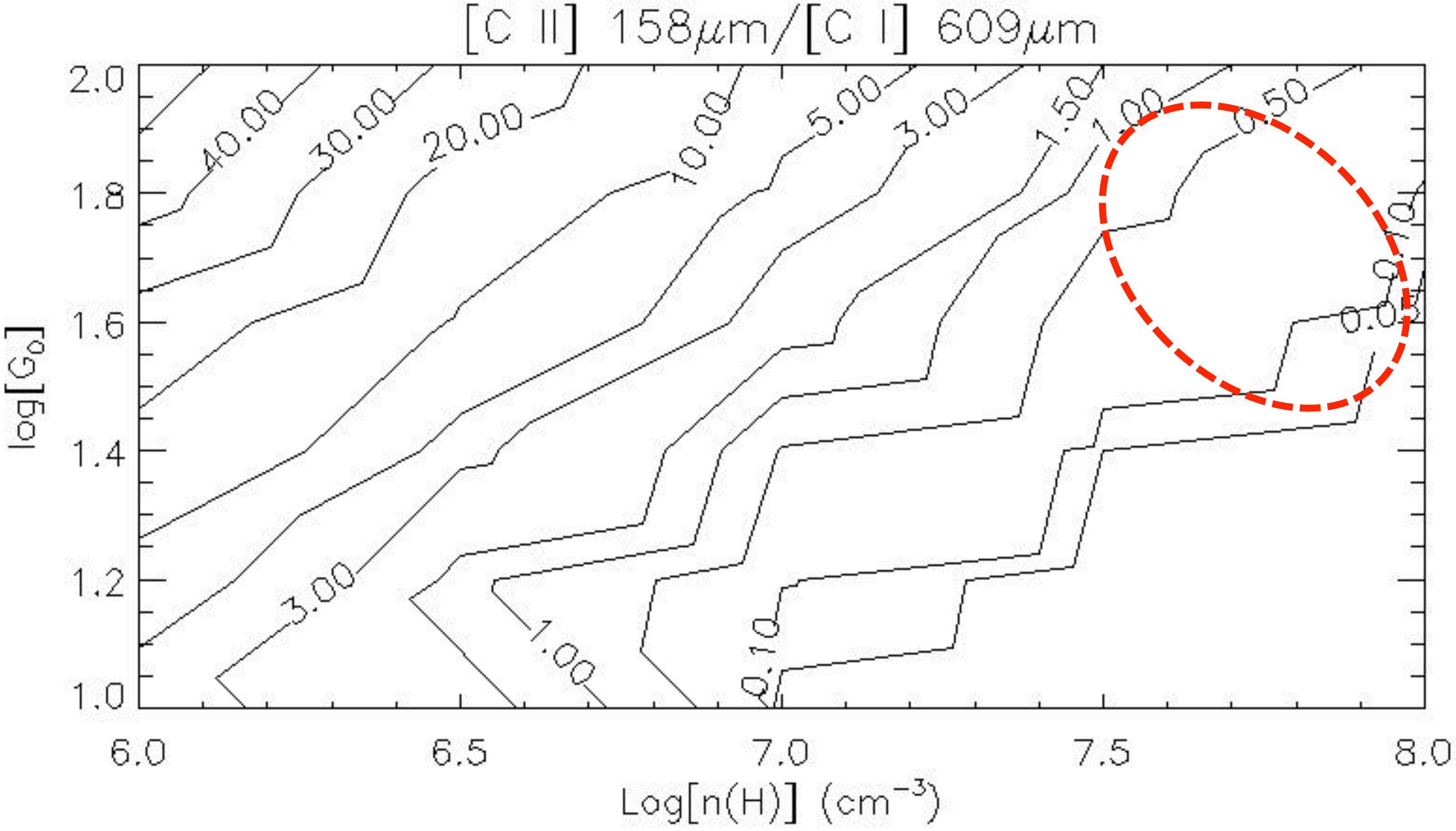
(Liseau et al. 1999)



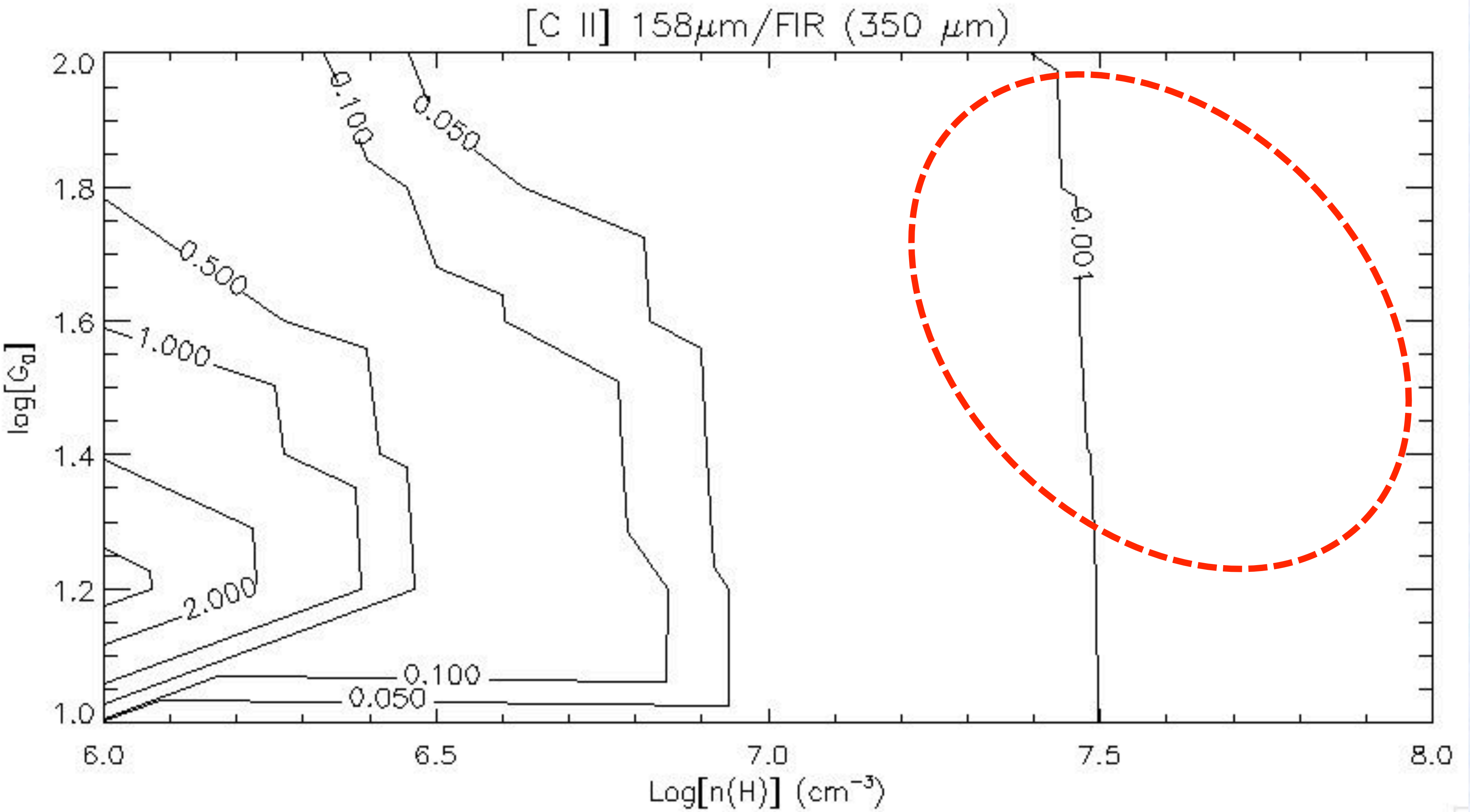


CLOUDY?

(Kauffmann et al. 1999)



CLOUDY Cont.


[C II] 158μm/FIR (350 μm)
log[G_0]
Log[n(H)] (cm^-3)
2.0
1.8
1.6
1.4
1.2
1.0
6.0
6.5
7.0
7.5
8.0
0.100
0.050
0.500
1.000
2.000
0.100
0.050
0.001

Conclusions

- Study of H_2 in UV and IR continues to surprise us with complexity of excitation state, OPR, and role in astrochemistry
- Atomic H in molecular clouds is a very powerful tool suggesting that they are not "young" but that it takes millions of years to convert primarily atomic hydrogen clouds to 99.9% molecular form
- Atomic carbon does not show limb brightening, rather, seems to be mixed with CO. Further examination of the turbulence suggests CI is in a low density inter-clump medium.
- Ongoing and future observations of CII by GREAT and Herschel will improve our understanding of the structure of clouds, their physical conditions, and reveal important parameters of the atomic to molecular transition of the ISM.