Submillimeter Line Spectroscopy with SOFIA

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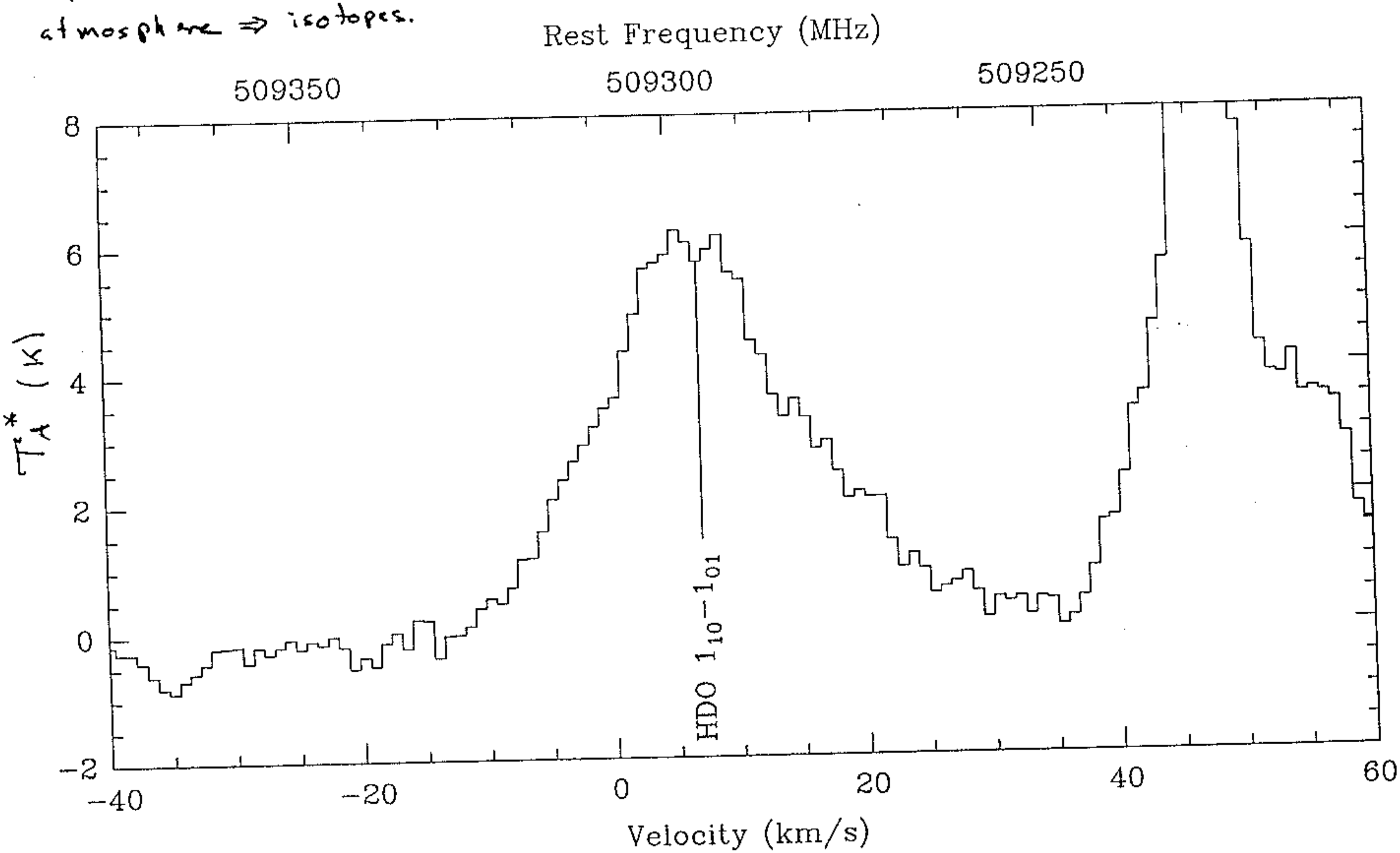
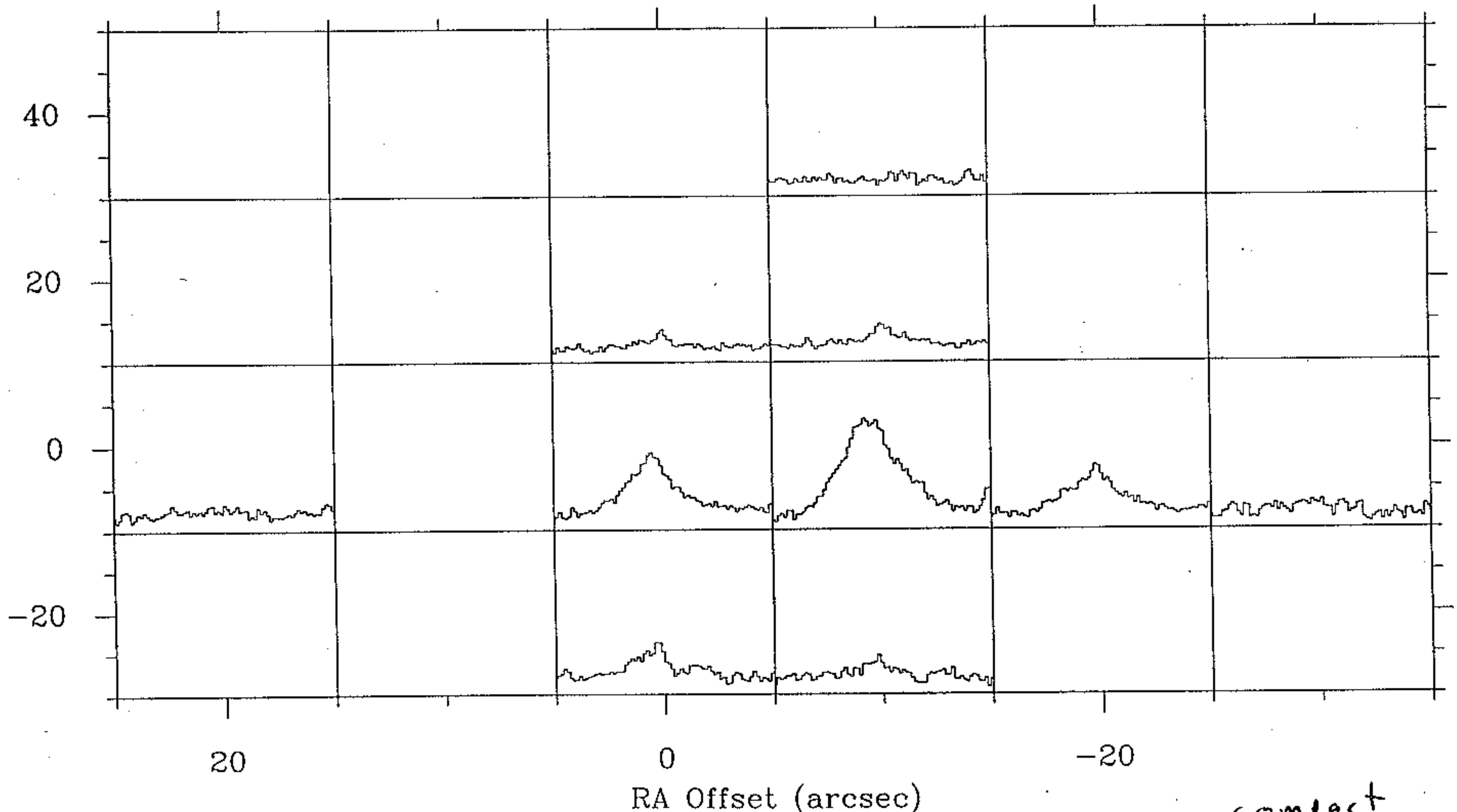
1170; 3 ORIIRC2 HDO110-101 CSO 500MHz 2 -10.000 0.0 Eq 209

22 GHz - Cheung et al 1969
(maser)
atmosphere ⇒ isotopes.

E_{lower} = 22 K
(1st detection)



HDO $1_{10}-1_{01}$ in Orion Hot Core (Irc2) ~14" resolution



compact

<u>HDO</u>

- detected toward hot cores
- $T_x \sim 200$ K
- source is compact, even in low-excitation lines (464 GHz $1_{01}-0_{00}$ ground state; Schulz et al. 1991)

- HDO abundance is high
- $HDO/H_2O \sim 100$ D/H
- difficult for gas-phase chemistry
- HDO released from grains?

- What about H_2O? Abundance in "ordinary" molecular cloud gas? Need low-excitation line (ground state)

SWAS $1_{10}-1_{01}$ 557 GHz

KAO $H_2^{18}O$ 547 GHz

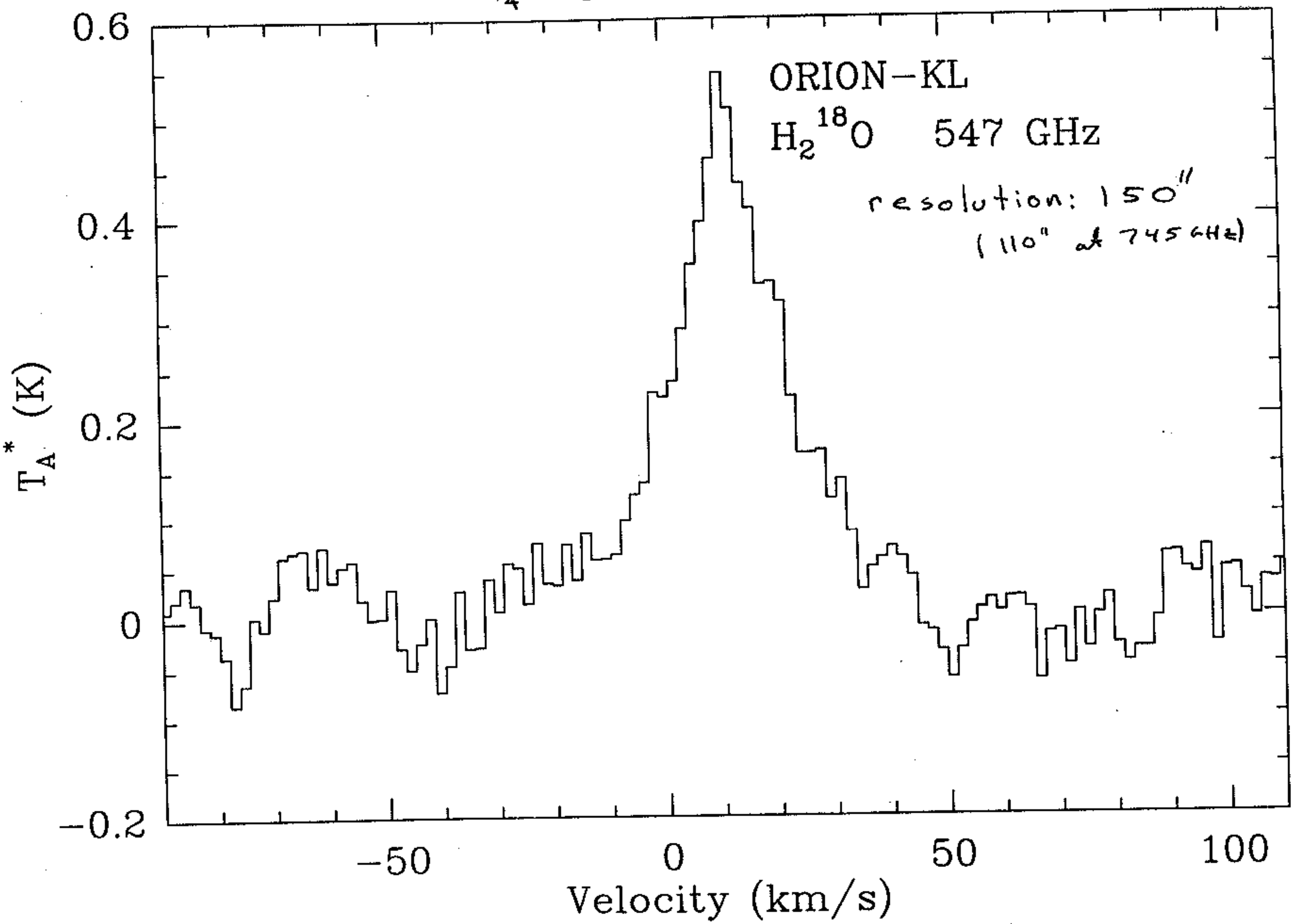
$1_{10} - 1_{01}$ (ortho) ground state

Feb. 1994

KAO

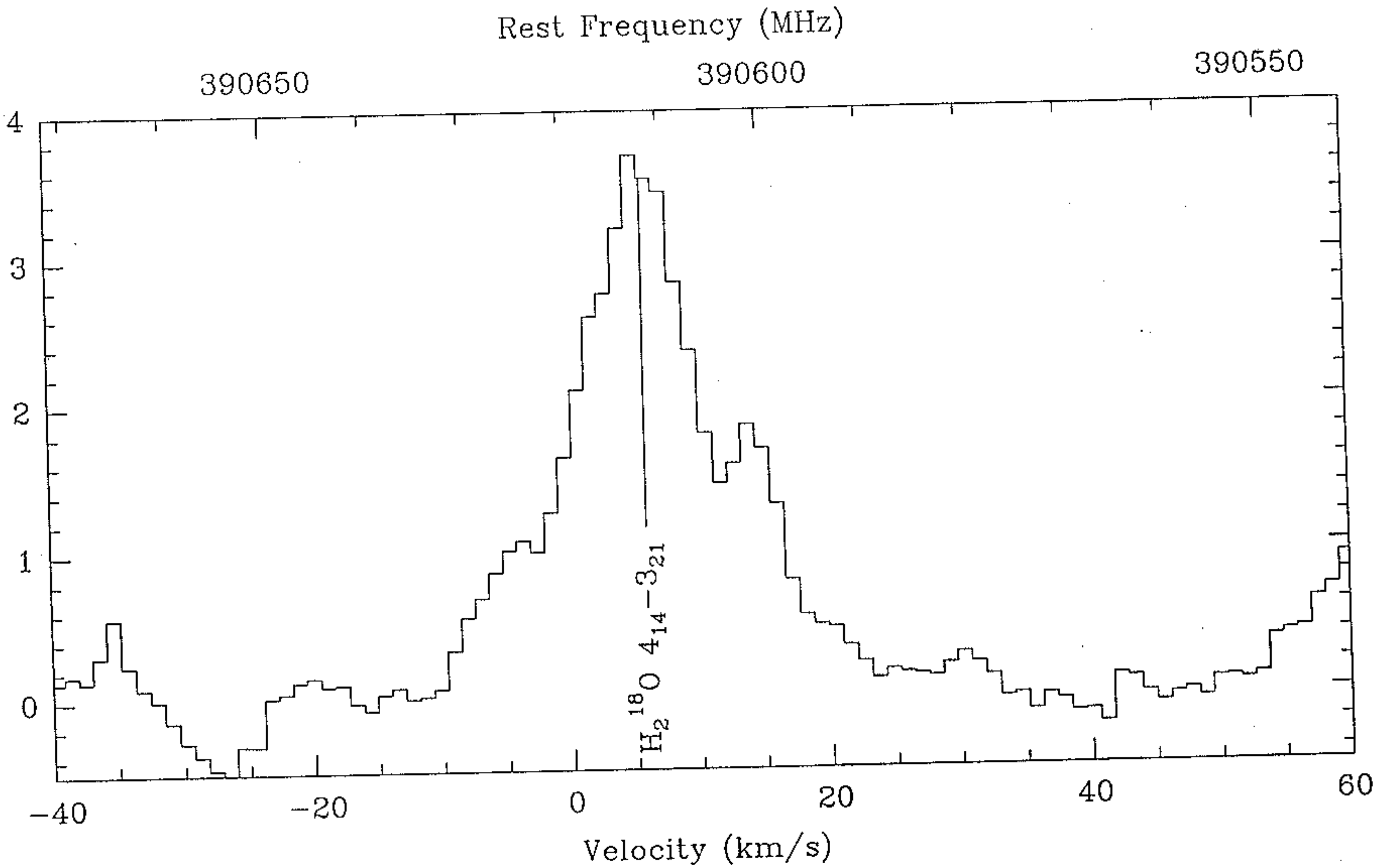
+ $2_{11} - 2_{02}$ (para) 745 GHz, $E_{lower} \sim 100$ K

$T_A^* \sim 0.6$ K



Feb. 1999

1325; 3 ORIIRC2 H2180414-321 CSO 500MHz 2 0.0 0.0 Eq 185



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Also: Gensheimer et al. 1996,

Jacq et al. 1990

IRAM 30m

203 GHz $3_{13}-2_{20}$ 12"

(but... heavy line confusion)

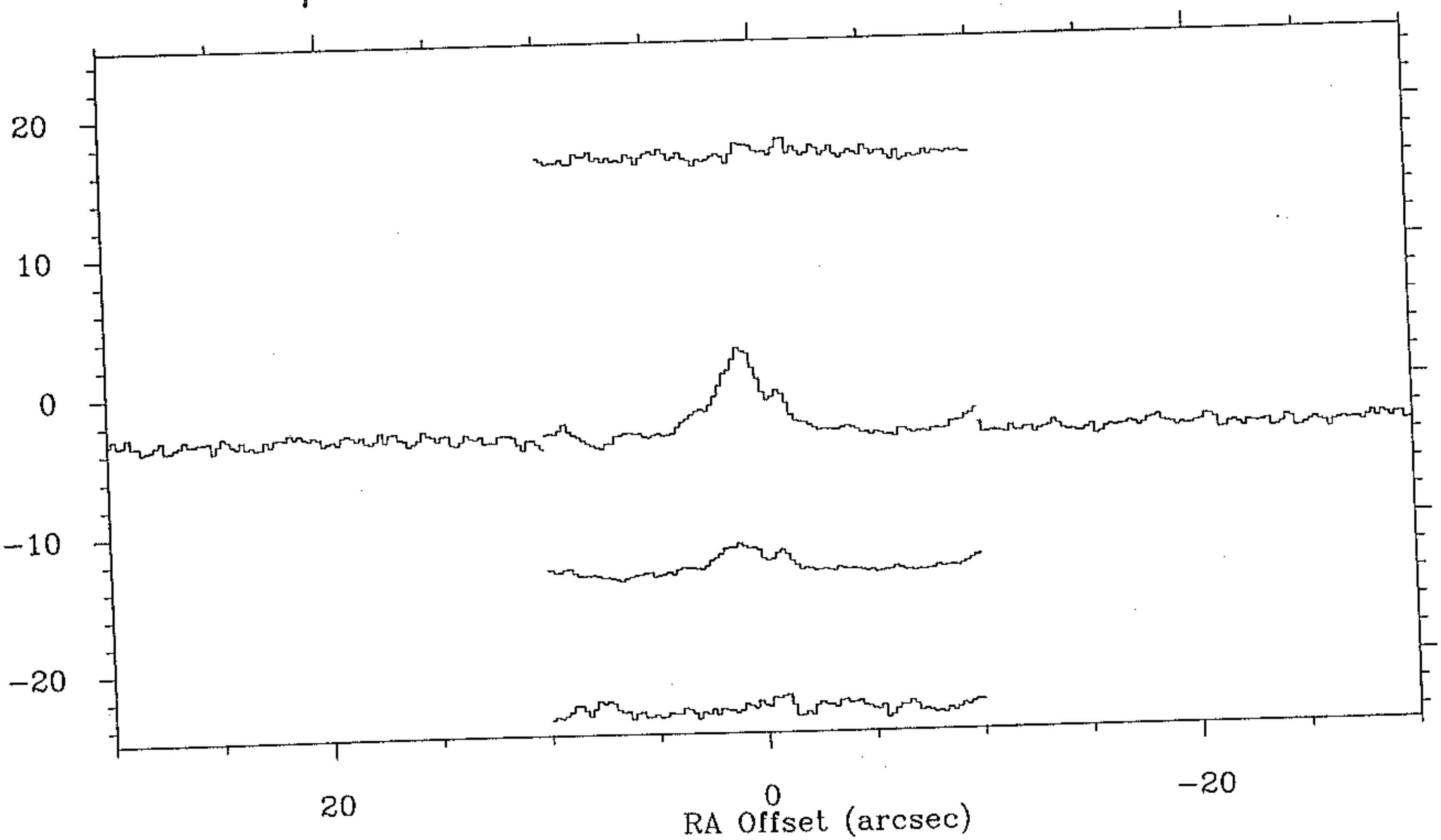
391 GHz

$4_{14}-3_{21}$

resolution: 18"

E_{lower} ~300 K

$H_2^{18}O$ in Orion Hot Core (Irc2)



Interstellar Water

WATER SPECIES IN ORION

Species	Transition	Frequency (GHz)	E_{low} (K)	T_{mb} (K)	LTE (K)	Telescope
$H_2{}^{18}O$	$3_{13} - 2_{20}$	203	194	2.8–10	3.8	IRAM
$H_2{}^{18}O$	$5_{15} - 4_{22}$	322	452	0.6	0.7	CSO
$H_2{}^{18}O$	$4_{14} - 3_{21}$	391	303	5.8	6.8	CSO
$H_2{}^{18}O$	$1_{10} - 1_{01}$	547	34	0.55	1.2	KAO
$H_2{}^{18}O$	$2_{11} - 2_{02}$	745	100.6	0.65	0.83	KAO
HDO	$1_{10} - 1_{01}$	509	22.3	11.	9.	CSO
* D_2O	$2_{11} - 2_{02}$	404	51.6	1.4	1.4	CSO

Assumptions:

* tentative

$N(H_2{}^{18}O) = 1 \times 10^{16}$ cm^{-2}

$N(HDO) = 1 \times 10^{15}$ cm^{-2}

$N(D_2O) = 1 \times 10^{14}$ cm^{-2}

$10''$ source size, 200 K excitation temperature, LTE

All $H_2{}^{18}O$ lines produced by "hot core"?

Need SOFIA!!

3 × better angular resolution (or more!)

Santa Cruz, 1999

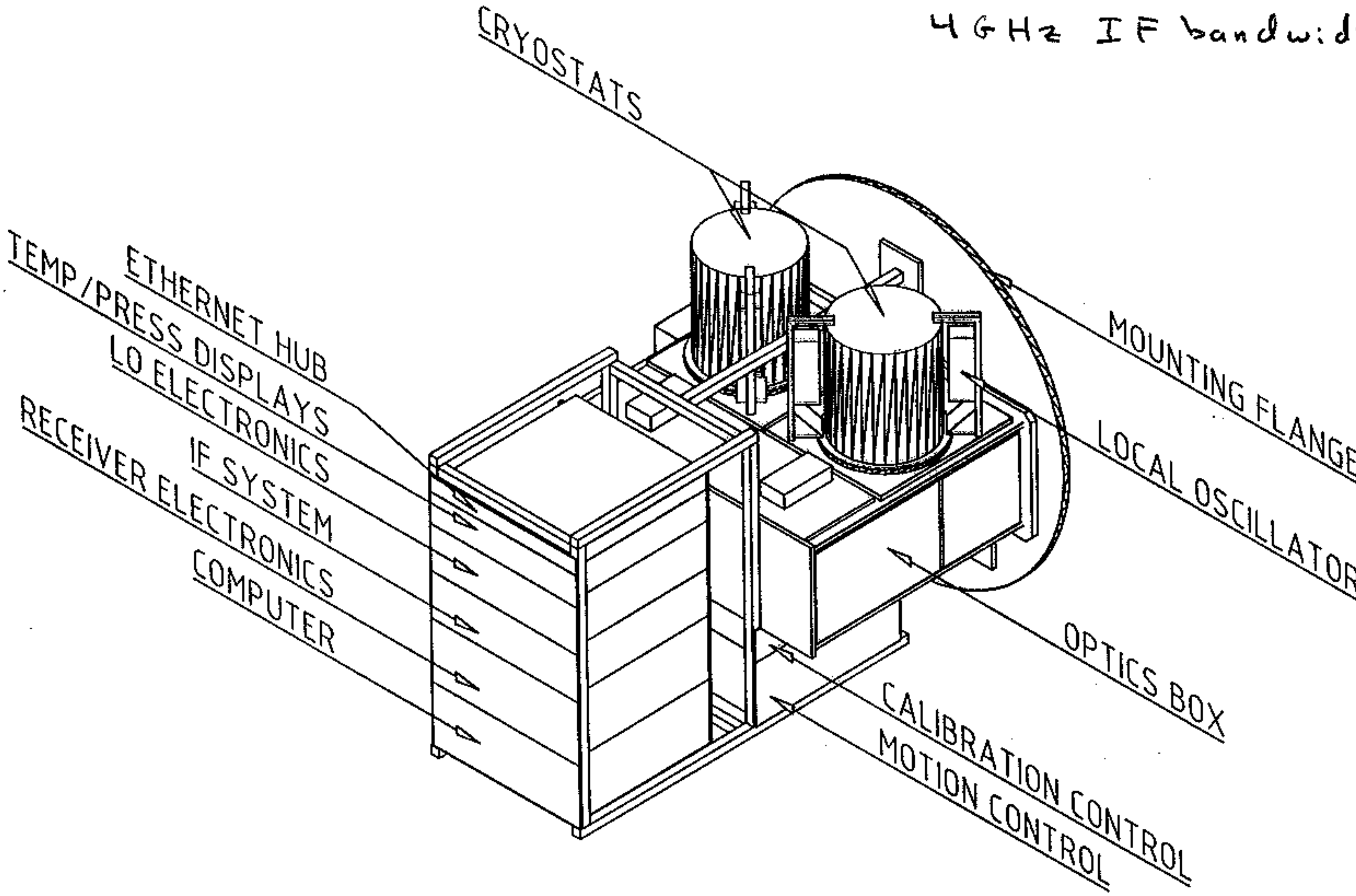
10 × better sensitivity

⇒ mapping

500 – 2000 GHz (eventually)

7 bands; 4 available per flight

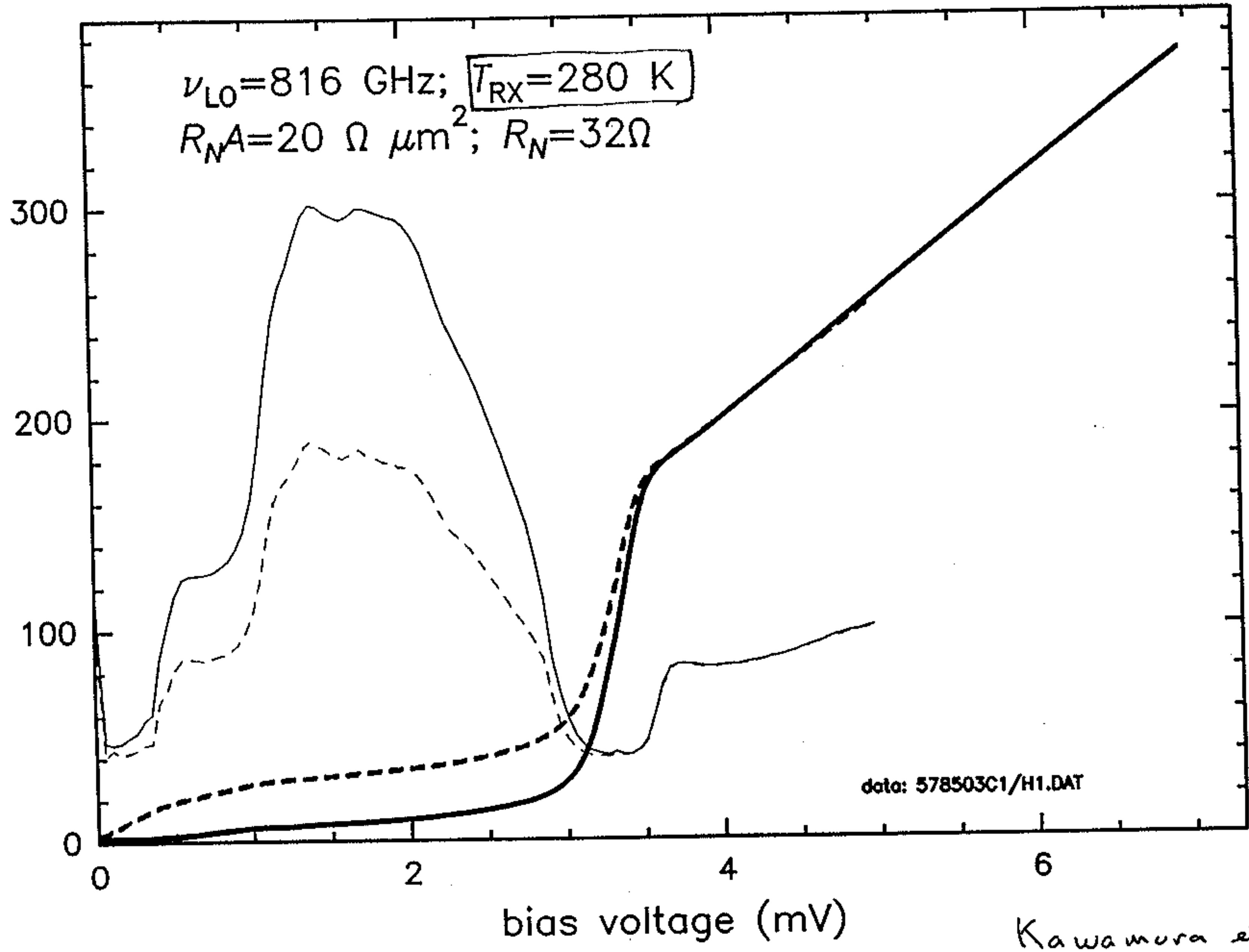
4 GHz IF bandwidth



CAltech Submm Interstellar Medium Investigations Receiver

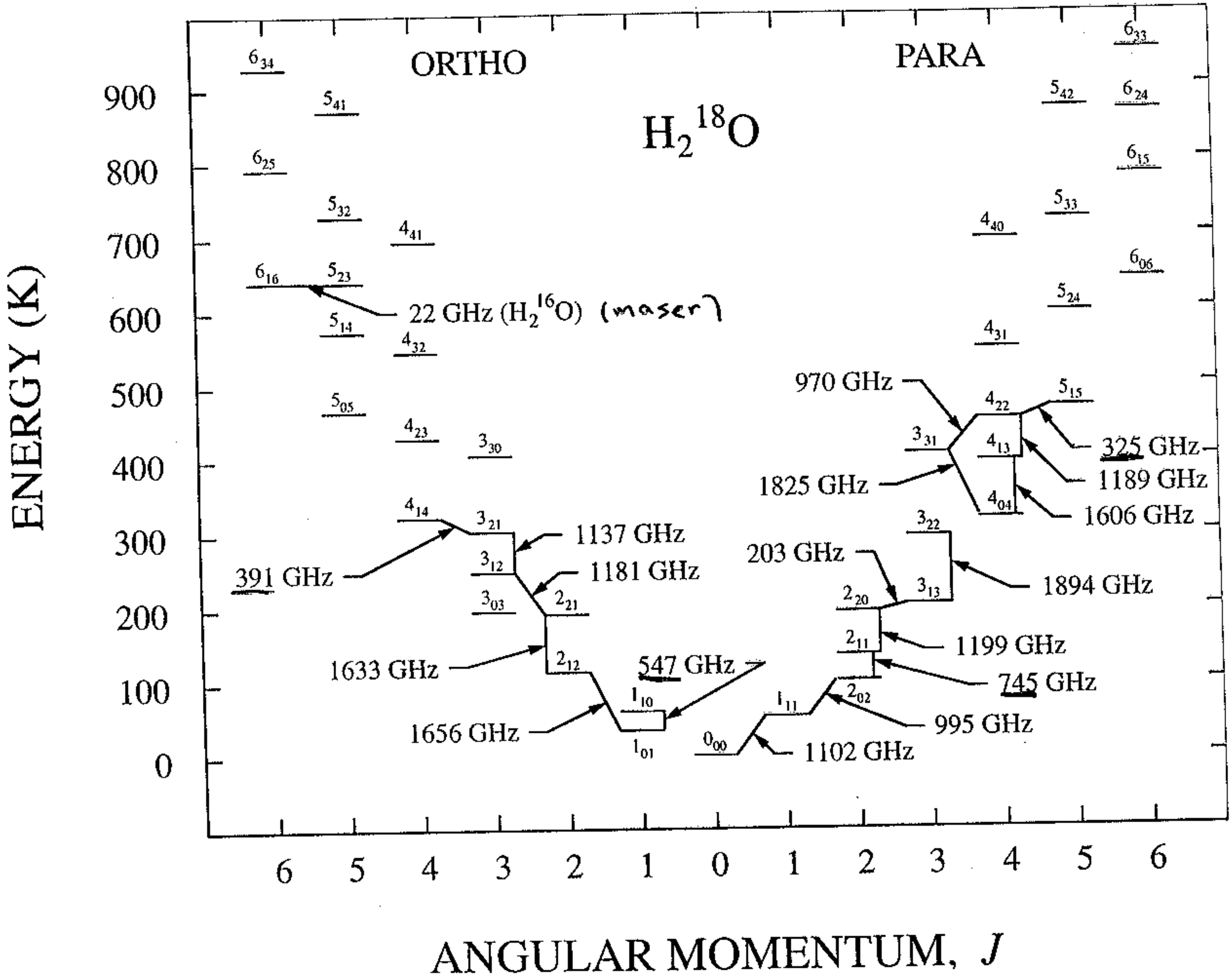
"CASIMIR"

NbTiN SIS mixer
NbTiN/AlN/Nb junction

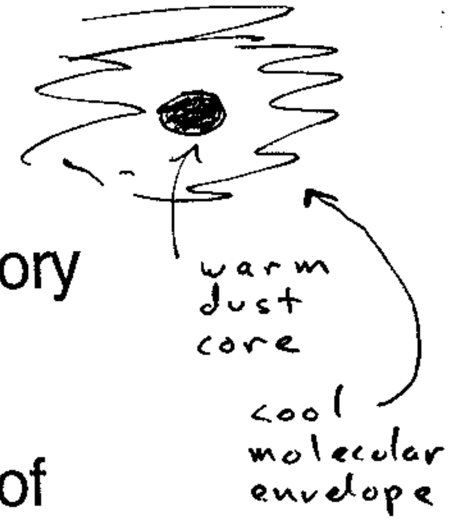


Kawamura et al.
1999

$H_2{}^{18}O$ with SOFIA



H_2O abundance in "quiescent" gas:



SOLUTION:

$H_2{}^{18}O$ + NASA Kuiper Airborne Observatory

- Observe the 1_{10} - 1_{01} **ground-state** transition of ortho-$H_2{}^{18}O$ at 547 GHz, in *absorption.*
- Dipole moment: μ = 1.85 D ; $n_{crit} \approx 10^8$ cm^{-3} .
- Molecular envelopes surrounding dense cores

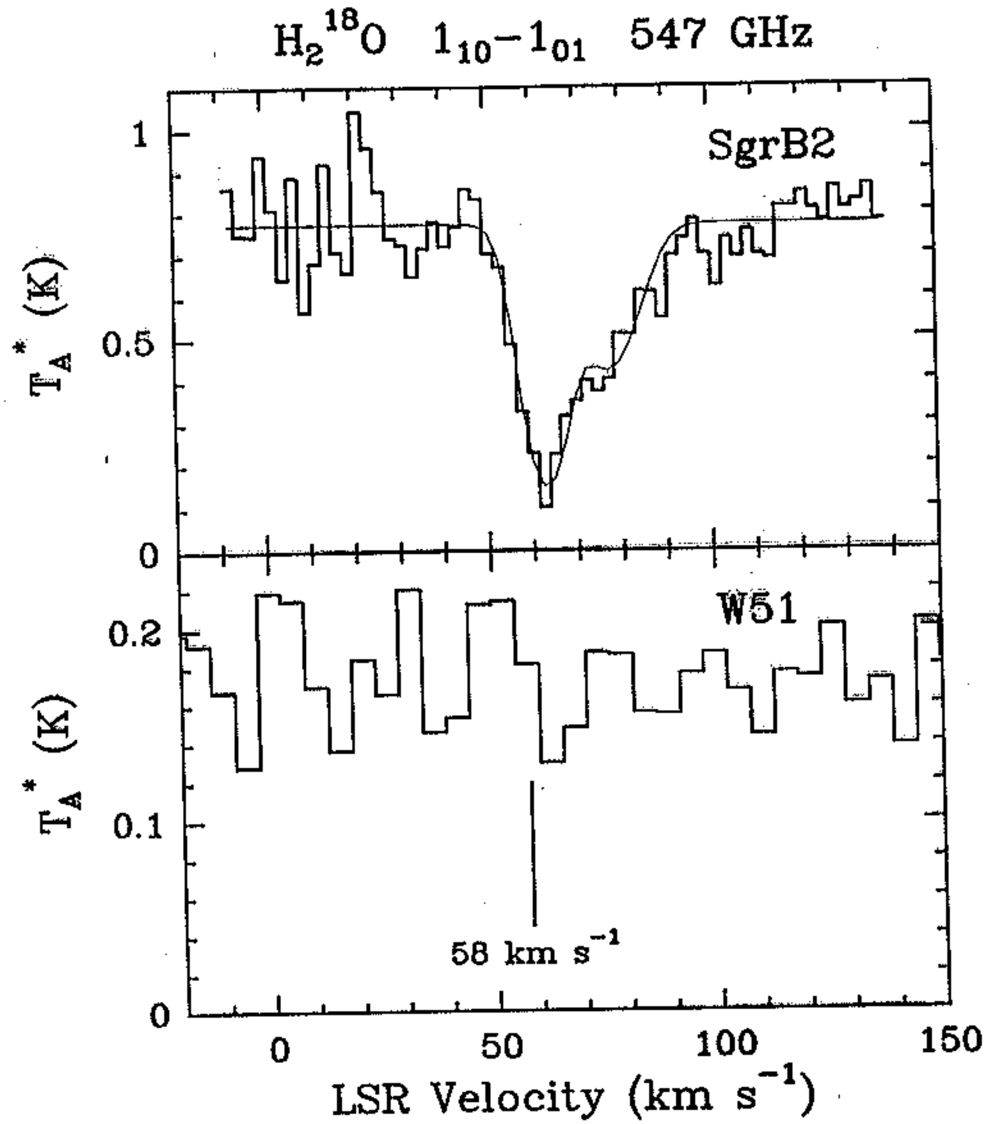
  $T_{gas} \sim$ 20-30 K

  $n_{H2} \sim$ few x 10^3 cm^{-3}

  $N_{H2} \sim$ few x 10^{23} cm^{-2}
- Virtually all ortho-H_2O in this envelope must be in the 1_{01} ground state, and so is sampled by our measurement.

Abundance of Water in Molecular Clouds

KAO



$\frac{H_2O}{O} \lesssim 0.03\%$!

$\frac{H_2O}{H_2} \sim 3 \times 10^{-7}$ Sgr B2

$\lesssim 4 \cdot 10^{-7}$ W51

Note: $H_2{}^{18}O$ is <u>ideal</u>

$H_2{}^{16}O$ extremely optically thick!

RADIATIVE TRANSFER MODELING

- spherical cloud model: (Lis + Goldsmith)

$$n(r) = \left[0.22 + 8.6\left(\frac{1\ \mathrm{pc}}{r}\right)^2\right] \times 10^4\ \mathrm{cm}^{-3} \quad \text{and} \quad T_{\mathrm{dust}}(r) = \sqrt{\frac{1\ \mathrm{pc}}{r}} \times 40\ \mathrm{K}$$

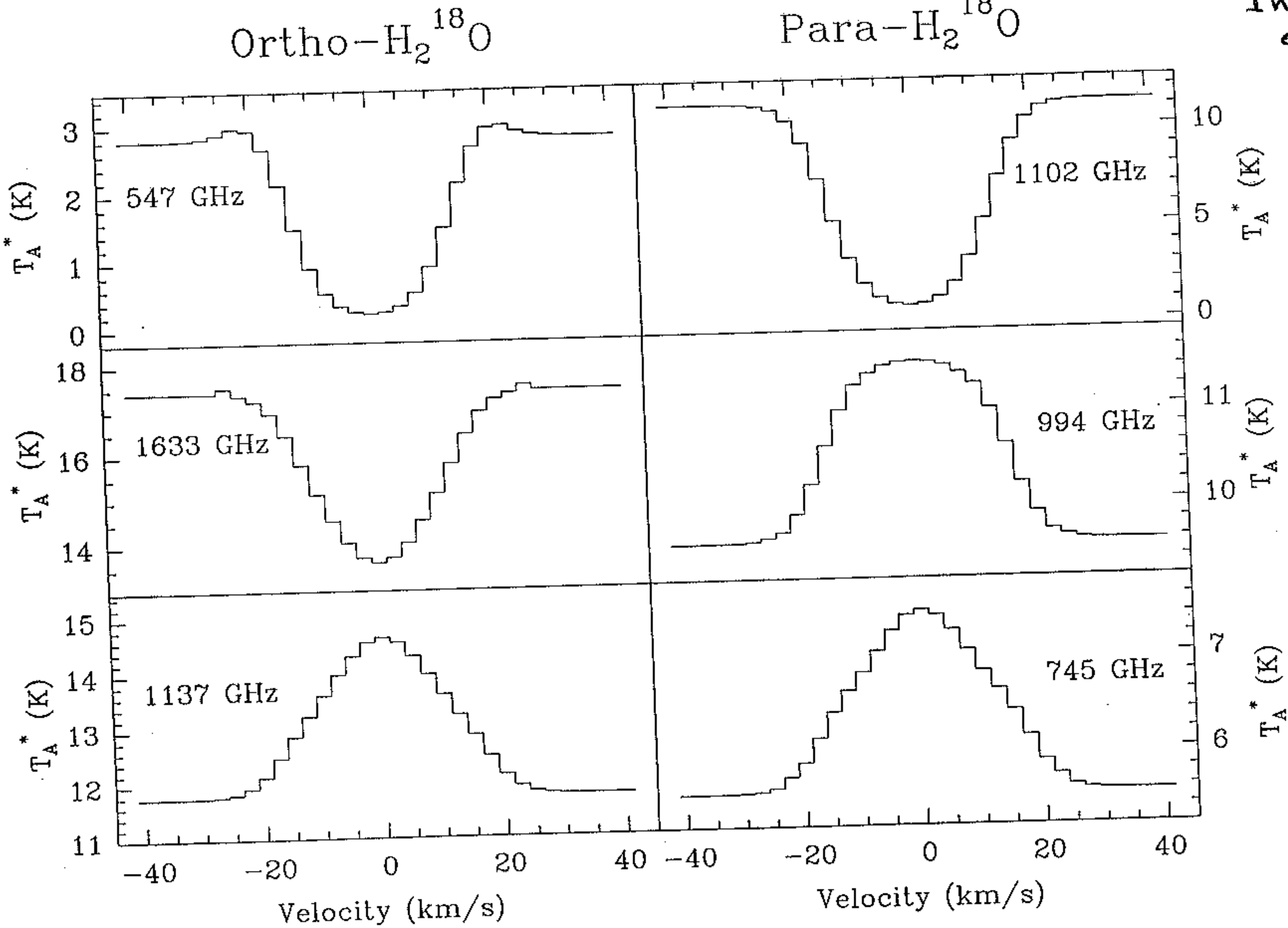
(reproduces mm + submm dust continuum data)

- 200 radial shells
- 22 rotational levels (ortho & para); ~55 transitions each
- statistical equilibrium - transitions due to collisions & emission & absorption of radiation
- radiative transfer - include absorption & emission by molecules & dust Excitation dominated by dust
- use "accelerated lambda iteration" method developed to calculate stellar atmospheres (Rybicki & Hummer 1991)

simultaneously reproduces 203, 391, + 547 GHz lines

"hot core": $H_2O/H_2 \sim$ few $\cdot 10^{-6}$; envelope $\sim 3 \cdot 10^{-7}$

SgrB2 Radiative Transfer Model



Increasing excitation ↓