COMPLEX ORGANIC MOLECULES in the HOT CORINOS of SUN-LIKE PROTOSTARS

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HOW ALL THIS STARTED: ONCE UPON A TIME ...

LOW MASS STARS FORM FROM CONDENSATIONS INSIDE MOLECULAR CLOUDS, THE PRE-STELLAR CORES:



- NO SOURCE OF HEATING
- COLD (<10K)
- **DENSE** (>10⁵cm⁻³)



THE GRAIN MANTLE FORMATION

→ HEAVY-ELEMENT BEARING MOLECULES CONDENSANTION ONTO THE GRAIN SURFACES

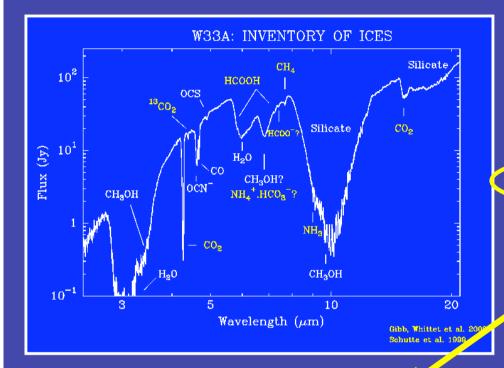
Bergin et al. 2002

 $C^{18}O(1-0)$ $N_{0}H^{+}(1-0)$ CS (3-2) 100 50 ∆ð [‴] -50-100-150-100-100150-50 15050 100 Δα ["] Δα ["] Δα ["'

→ FORMATION OF MANTLES OF ICED WATER SPRINKLED WITH OTHER MOLECULES



THE GRAIN MANTLE COMPOSITION



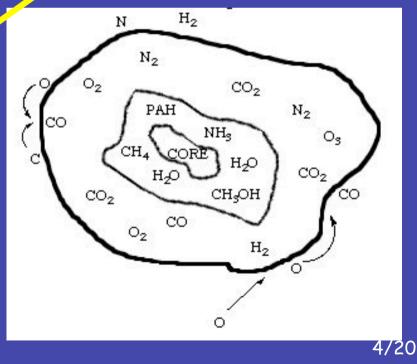
BUT WHAT OTHER TRACE MOLECULES ARE TRAPPED IN THE ICES ?

OBSERVABLE WHEN EVAPORATED OFF...



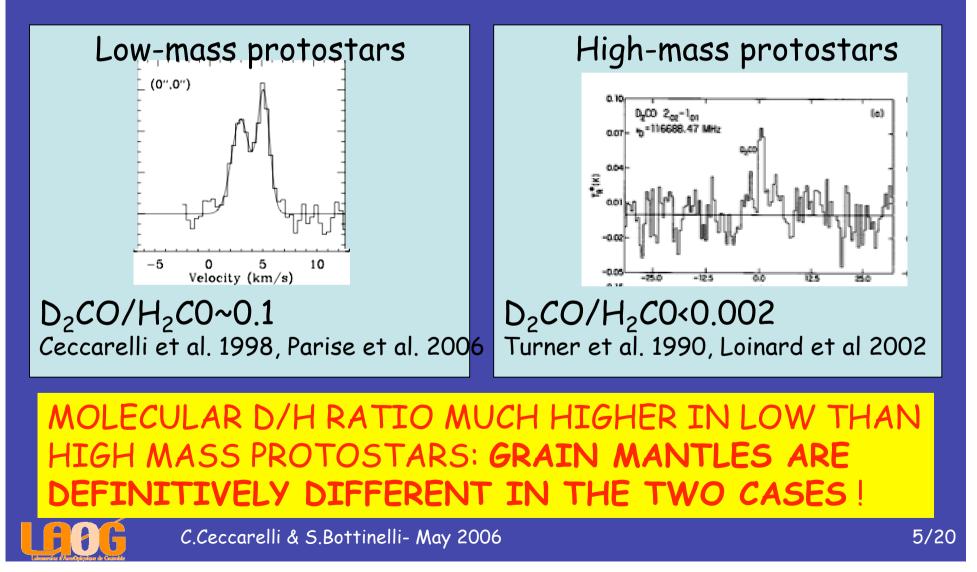
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NIR OBSERVATIONS MEASURE THE MOST ABUNDANT MANTLE COMPONENTS, WITH ABUNDANCES >10⁻⁶: H_2O , CO, CO_2 , CH_4 , NH_3 , OCS, CH_3OH , H_2CO , HCOOH



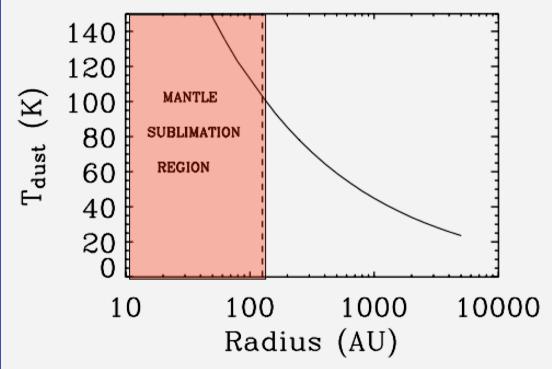
ICES IN LOW AND HIGH MASS PROTOSTARS

HEAVY-ELEMENT DEPLETION → LARGE DEUTERATION (-> Kristensen et al. POSTER 18)



WHEN THE ICES BOIL OFF

ONCE THE PROTOSTAR IS FORMED, THE LUMINOSITY FROM THE COLLAPSING MATERIAL HEATS UP THE SURROUNDINGS



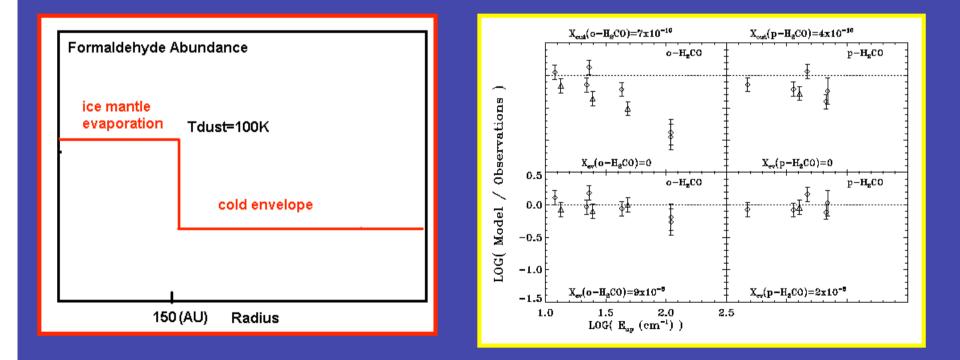
... LOW MASS PROTOSTARS HAVE AN HOT CORE INSIDE



EVIDENCES OF MANTLE SUBLIMATION

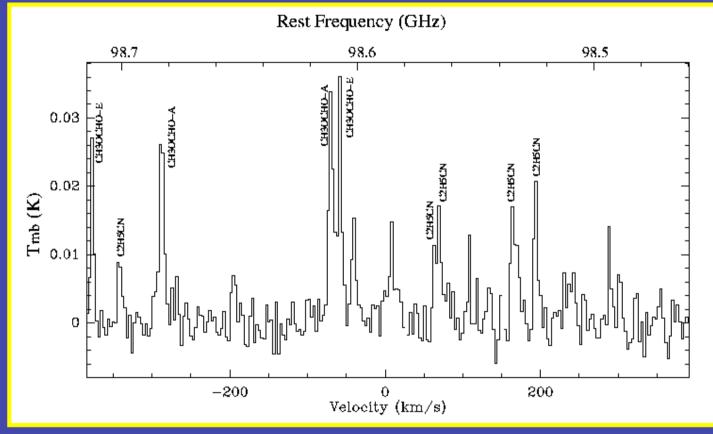
THE JUMP IN THE ABUNDANCE OF "MANTLE" MOLECULES: H_2O , H_2CO and CH_3OH

(Ceccarelli et al. 2000a,b; Maret et al. 2002, 2004, 2005; Schoier et al. 2002, 2004; Jorgensen et al. 2004, 2005)



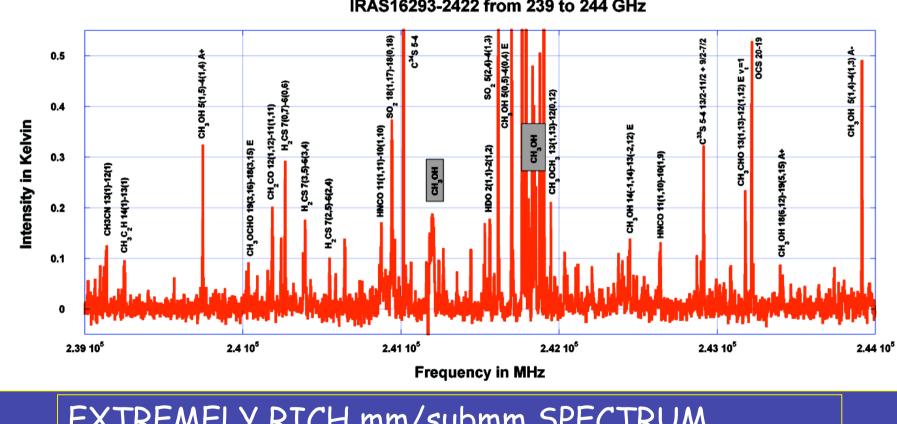
THE EXISTENCE OF COMPLEX MOLECULES

IRAS16293-2422 (Ceccarelli et al. 2000; Cazaux et al. 2003)



FORMIC ACID, ACETALDEHYDE, METHYL FORMATE, ACETIC ACID, METHYL CYANIDE, ETHYL CYANIDE, PROPINE.....

BUT HOW COMPLEX ARE COMPLEX MOLECULES? IRAS16293-2422 SPECTRAL SURVEY IN THE IRAM (90, 150 and 250 GHz), JCMT (350 GHz) and APEX (450 GHz) BANDS (van Dishoeck et al. 1995; Caux et al. 2006 -> POSTER 5)



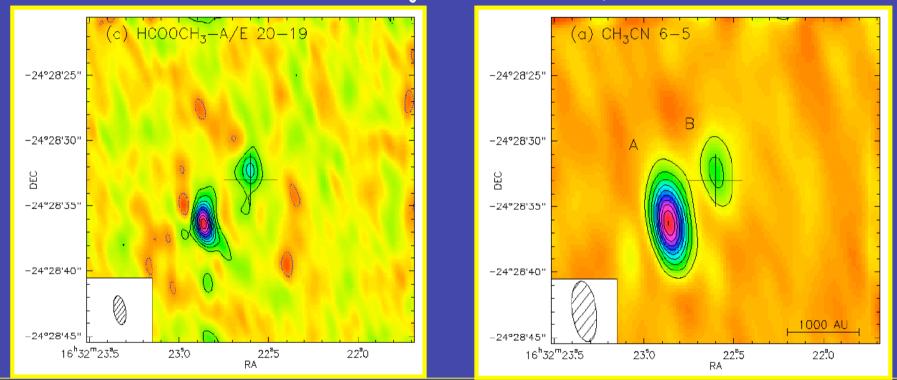
IRAS16293-2422 from 239 to 244 GHz

EXTREMELY RICH mm/submm SPECTRUM...



WHERE ARE COMPLEX MOLECULES FOUND ?

IRAS16293-2422 (Kuan et al. 2004; Bottinelli et al. 2004b; Chandler et al. 2005; Remijan & Hollis 2006)



→ CONCENTRATED IN TWO R≤150 AU SPOTS
→ POSSIBLE DIFFERENT CHEMISTRY AT WORK (NEED ALMA TO SETTLE THE ISSUE)

but listen to Jorgensen's talk for alternative interpretations C.Ceccarelli & S.Bottinelli- May 2006

 $\frac{10}{20}$

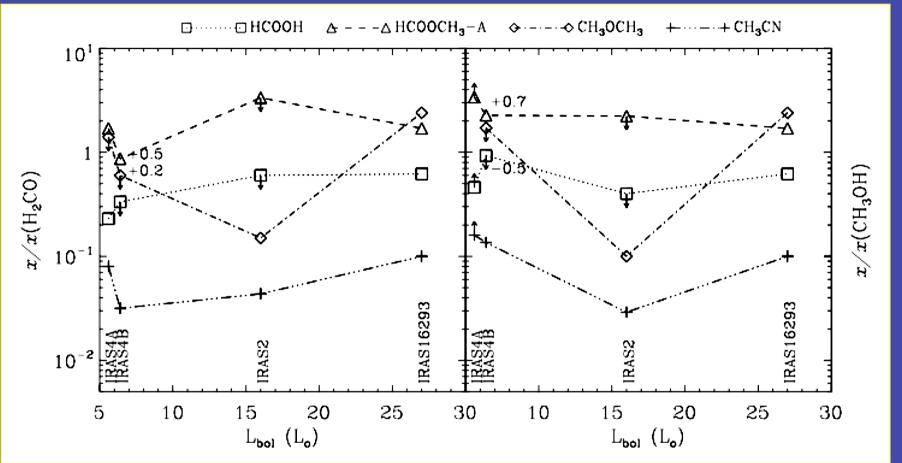
ARE HOT CORINOS AND COMPLEX MOLECULES A COMMON CHARACTERISTIC OF SUN-LIKE PROTOSTARS ?

Source	Molecules	Ref.
IRAS16293-2422	HCOOH, CH_3CHO , CH_3OCHO , CH_3OCH_3 , HCOOCH ₃ , CH_3CN , C_2H_5CN , CH_3CCH	Cazaux et al. 2003 ; Kuan et al. 2004; Bottinelli et al. 2004b; Remijan & Hollis 2006
NGC1333-IRAS4A	$HCOOH, HCOOCH_3, CH_3CN$	Bottinelli et al. 2004a
NGC1333-IRAS4B	$HCOOCH_3$, CH_3CN	Bottinelli et al. 2006, Sakai et al. 2006
NGC1333-IRAS2A	CH_3CN , CH_3OCH_3	Jorgensen et al. 2005; Bottinelli et al. 2006

→ COMPLEX MOLECULES DETECTED IN THE HOT CORINOS WHERE THEY WERE SEARCHED FOR



COMPLEX MOLECULES in HOT CORINOS (1/2) Bottinelli et al. 2006

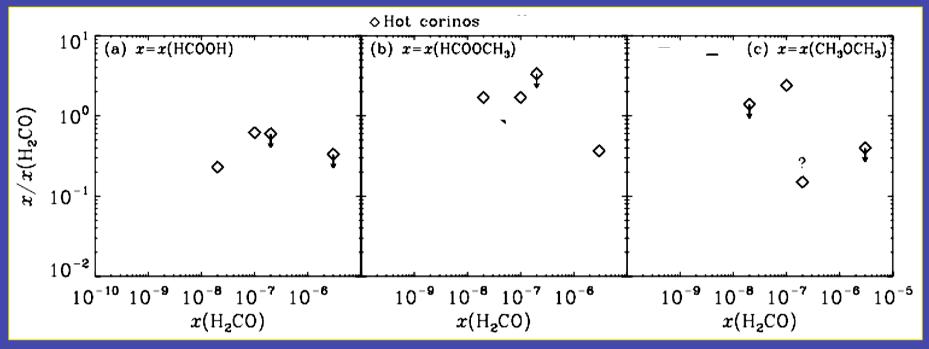


→ NO CLEAR DEPENDENCE ON THE SOURCE LUMINOSITY and/or ANY OTHER SOURCE PROPRIETY



COMPLEX MOLECULES in HOT CORINOS (2/2)

Bottinelli et al. 2006

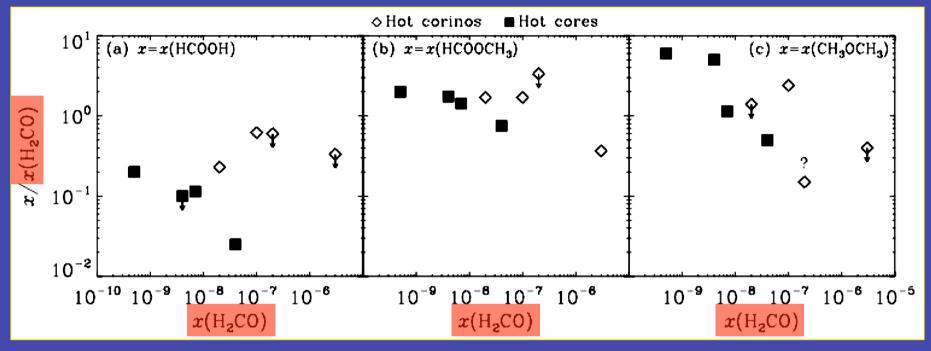


→ NO CLEAR DEPENDENCE ON THE H_2CO and/or CH₃OH ABUNDANCE (OVER 2 ORDERS OF MAGNITUDES) → HCOOH, HCOOCH₃ and CH₃OCH₃ HAVE ABUNDANCES COMPARABLE TO H₂CO and CH₃OH



HOT CORINOS versus HOT CORES

Bottinelli et al. 2006

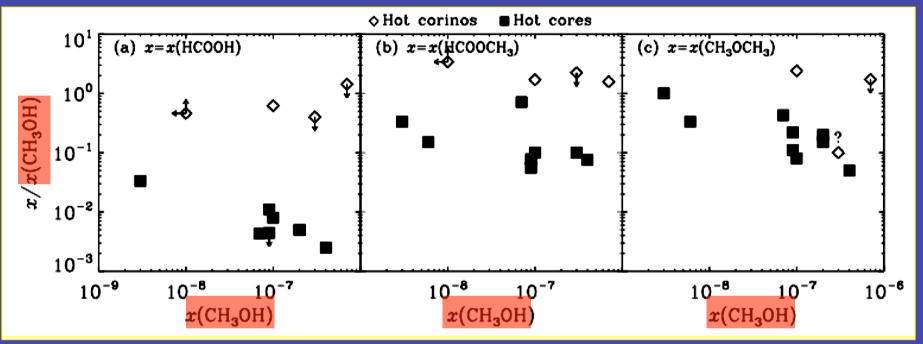


→ HCOOH/ H_2CO LARGER IN HOT CORINOS THAN IN HOT CORES → HCOOCH₃ and CH₃OCH₃ / H_2CO COMPARABLE



HOT CORINOS versus HOT CORES

Bottinelli et al. 2006



→ HCOOH, HCOOCH₃ and CH_3OCH_3 / CH_3OH LARGER IN HOT CORINOS THAN IN HOT CORES (BUT THE STATISTICS IS POOR...)



WHY COMPLEX MOLECULES ARE DIFFERENT IN HIGH AND LOW MASS PROTOSTARS ?

- → MANTLE COMPOSITION ? MANTLES IN HIGH AND LOW MASS PROTOSTARS ARE DIFFERENT (e.g. MOLECULAR DEUTERATION)
- → X-RAY IRRADIATION ? CONVERSELY TO HIGH MASS, LOW MASS PROTOSTARS ARE STRONG X-RAYS EMITTERS

→ IMPORTANCE OF THE INTERMEDIATE MASS PROTOSTARS CASE (Fuente et al. 2005a,b; -> POSTER 10)



HOT CORINOS versus GC CLOUDS

Study by Requena-Torres et al. 2006 (-> POSTER 23)

→ GALACTIC CENTER MOLECULAR CLOUDS SHOW SIMILAR HCOOH, HCOOCH₃ and CH_3OCH_3 / CH_3OH RATIOS INDEPENDENT THAN HOT CORES

→ AND THEYARE INDIPENDENT ON X(CH₃OH), LIKE HOT CORES AND CORINOS

→ ARE HCOOH, HCOOCH₃ and CH_3OCH_3 FORMED ON THE **GRAIN SURFACES** (AND SPUTTERED BY THE SHOCKS)?

→ X-RAYS PERMEATE THE REGION: DO THEY PLAY ANY ROLE IN THIS COMEDY ?



SUMMARY

→ HOT CORINOS SEEM TO BE A COMMON PHASE IN THE SUN-LIKE STAR FORMATION

→ THE ABSOLUTE ABUNDANCE OF THE OBSERVED COMPLEX MOLECULES DO NOT DEPEND ON THE LUMINOSITY

→ HCOOH, HCOOCH₃ and CH₃OCH₃ ABUNDANCES ARE COMPARABLE TO THOSE OF H₂CO AND CH₃OH BUT DO NOT DEPEND ON THEM

→ ARE COMPLEX MOLECULES FORMED ON THE GRAIN SURFACES? ARE X-RAYS INVOLVED? IF YES, WHEN? HOW?..... waiting for Erik the Red (Herbst)'s talk!

BUT THE STATISTICS IS BY FAR TOO POOR!



LA VIE EN ROSE: ALMA

→ SENSITIVITY: MANY MORE HOT CORINOS, MANY MORE COMPLEX MOLECULES

→ SPATIAL RESOLUTION: ORIGIN OF COMPLEX MOLECULES AND MEASURE OF EMITTING SIZES



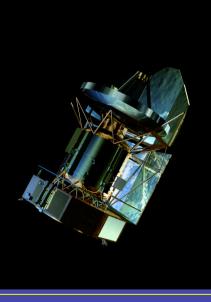
INCREASE STATISTICS = BEAT IGNORANCE



LA VIE EN ROSE : (and don't forget) HSO HIFI

→ SPECTRAL LINE SURVEYS IN THE 500-2000 GHz INTERVAL OF LOW, INTERMEDIATE AND HIGH MASS PROTOSTARS

→ HSO HIFI GT KEY PROGRAM OF ~300 hrs



INCREASE STATISTICS = BEAT IGNORANCE



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