A Formaldehyde Deep Field with the EVLA:
A Powerful New Probe of Galaxy Evolution (and Cosmology?)

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Outline

Formaldehyde (H$_2$CO)

A Formaldehyde Deep Field: Why?

Formaldehyde in the Local Universe

Formaldehyde versus Redshift

A Formaldehyde Deep Field: How?
Galactic $\text{H}_2\text{CO}$

**Dark Clouds:**

- “Anomalous” $\text{H}_2\text{CO}$ absorption
  
  (e.g. Palmer et al. 1969)

- Absorption in multiple cm lines

- No radio continuum source!
H$_2$CO: The DASAR

Light (Microwave) Amplification by Stimulated Emission of Radiation

Inversion: “Heating” of lines $T_x >> T_{kin}$

Pump required: Chemical, collisional, radiative

Darkness* Amplification** by Stimulated Absorption of Radiation

Anti-Inversion: “Cooling” of lines $T_x < T_{CMB}$

Pump required: Collisions with H$_2$

*Not really dark.
**Not a true amplification.

Townes et al (1953)
H$_2$CO Absorption in Dark Clouds

- “Anomalous absorption” in Galactic dark clouds (Palmer et al 1969)
  \[ \Rightarrow T_{\text{ex}} < T_{\text{CMB}} \]

- 2 cm lines also observed in absorption against CMB
  \[ \Rightarrow \text{“Anti-inversion” due to collisional pumping (Evans et al 1975)} \]
  \[ \Rightarrow \text{cm line ratio proxy for } n(\text{H}_2) \]

- 2 mm emission observed in Galactic dark clouds (Evans & Kutner 1976)
  \[ \Rightarrow \text{gastrophysics} \]
Galactic H\textsubscript{2}CO

Dark Clouds:
- “Anomalous” H\textsubscript{2}CO absorption
  (e.g. Palmer \textit{et al.} 1969)
- Absorption in multiple cm lines
- No radio continuum source!

1. Can H\textsubscript{2}CO be observed in other galaxies?
   - Can “anomalous” H\textsubscript{2}CO absorption be observed in galaxy-scale analogs of Dark Clouds?
   - How does H\textsubscript{2}CO behave at high redshift? (Ben Zeiger)
H$_2$CO Absorption Against the CMB
H$_2$CO: The DASAR

The CMB is the ultimate illumination source:

- Behind everything
- Everywhere
- Uniform on arcsec scales

$H_2CO$ absorption against the CMB offers an unrivaled probe of dense molecular gas, independent of redshift!

A $H_2CO$ deep field would produce immediate precise redshifts and positions of a mass-limited survey of star-forming galaxies, automatically omitting AGN.
Anti-Inversion Driven by Collisions

- Collisions are with H$_2$
- Anti-inversion persists over 2-3 decades in density
- Anti-inversion is significant for the first 4-5 K-doublet lines
Line Ratio Depends Weakly on Kinetic Temperature

- Line ratio is a sensitive probe of in-situ density, $n(H_2)$
- Line ratio is insensitive to Kinetic Temperature
Density Thresholds

Mangum et al. 2008

Graph showing density thresholds and transitions in molecular lines.
Density Thresholds

Mangum et al. 2008
The H$_2$CO Densitometer

What is the “density” of a galaxy?

Density regimes measured by H$_2$CO are \textit{in-situ!} (not \textit{n$_{\text{crit}}$})
Dense Gas Mass and Star Formation

Mangum et al 2008
Extended Illumination: PKS 1830-211

PKS 1830-211:
- Einstein ring at $z = 0.89$
- HI and OH absorption
- CO, HCN, HCO$^+$,... absorption
- Molecular isotope absorption
- H$_2$CO absorption

Chengalur, deBruyn, & Narasimha 1999
Patnaik et al. 1994
Nair et al. 1993

Wiklind & Combes
H$_2$CO $2_{11}-1_{10}$

Menten et al. 1999
Formaldehyde in PKS 1830-211

![Graphs showing IRAM 30m and GBT observations of formaldehyde in PKS 1830-211.](image)
Line Temperature vs Redshift

- How does $T_{ex}$ depend on redshift?

- Combine local galaxies (Mangum et al 2008) with two gravitational lenses

- $T_{\text{line}}$ grows (negatively) with redshift

- $T_{ex} \sim 0.5 T_{\text{CMB}}$ at $z=0$ (with large scatter)

- $T_{ex} - T_{\text{CMB}} \sim -1.4 - z$

See Zeiger Poster!
Anti-Inversion versus Redshift

- The rest-frame temperature decrement increases with redshift.
- The observed temperature decrement is nearly independent of redshift!
- Absorption is redshift-independent.
Source Size versus Redshift, Beam Size

- Array resolution depends on redshift and line

- Assume a 10 kpc size scale (cf Chapman et al 2004)

- Size $\sim$ constant for $0.8 < z < 3$
Instantaneous Redshift Coverage

- Large coverage for C-band
- $z = 0.81 - 6.24$
- Commensal observations
EVLA Formaldehyde Deep Field

Let’s do something new!

cm lines of \( \text{H}_2\text{CO} \) absorb CMB photons

- Redshifts
- Positions
- Dense Gas SF tracer
- Multiple lines give \( n(\text{H}_2) \)

Detectability *independent* of redshift!

Surveys are *mass-limited*.

**Also:**
\( \text{H}_2\text{CO} + \text{NH}_3 \) make density and temperature maps!