Using H_3^+ and H_2D^+ as probes of star-forming regions

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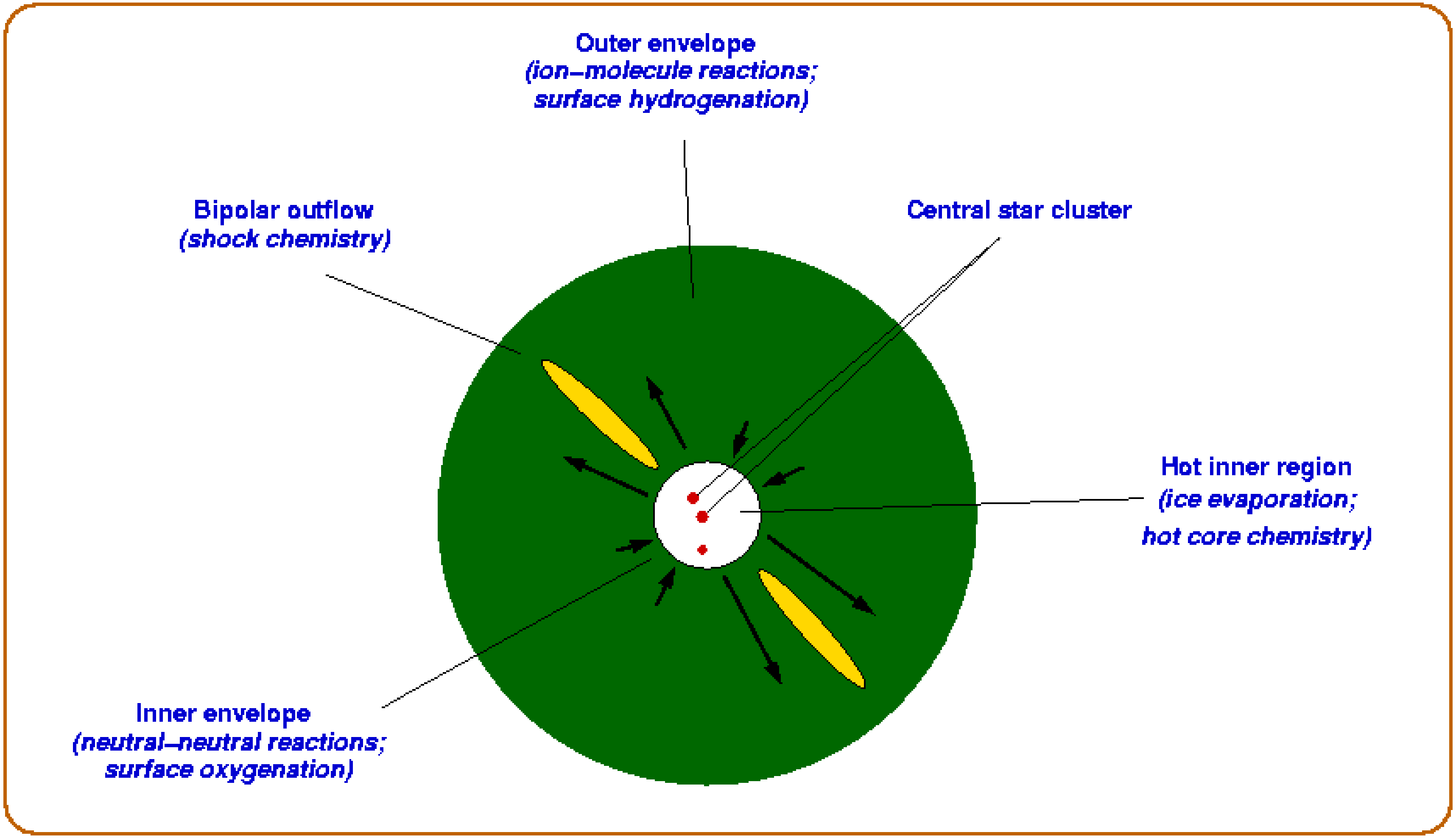
Outline

- Models of star-forming regions
- Measuring molecular abundances
- Cosmic-ray ionization rate
- Chemistry and dynamics of pre-stellar cores
- Future directions

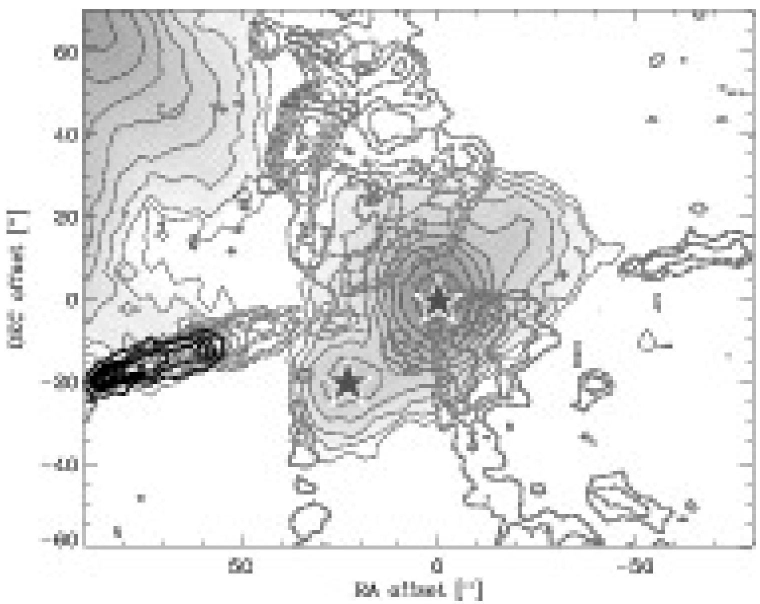
H_3^+ is great, but to understand its message, we need other molecules too

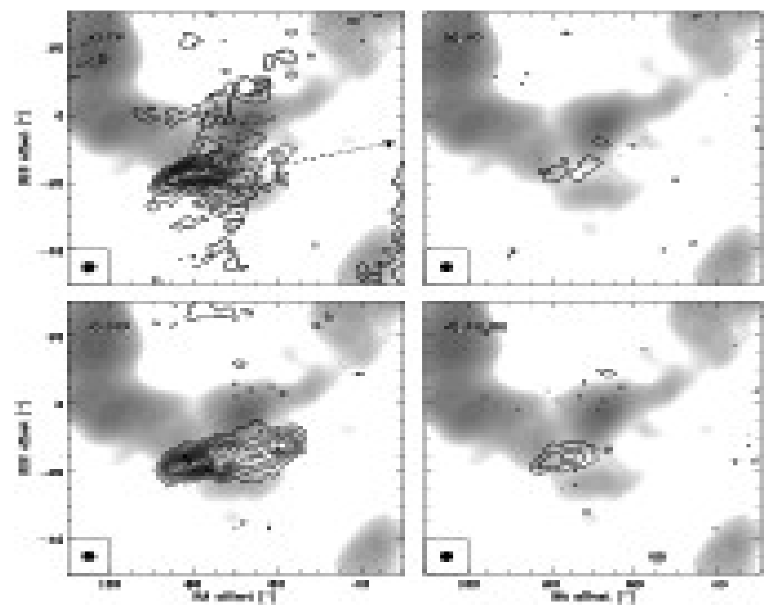
Star-forming regions: Great chemical diversity



Need non-local radiative transfer programs
and models with temperature and density gradients

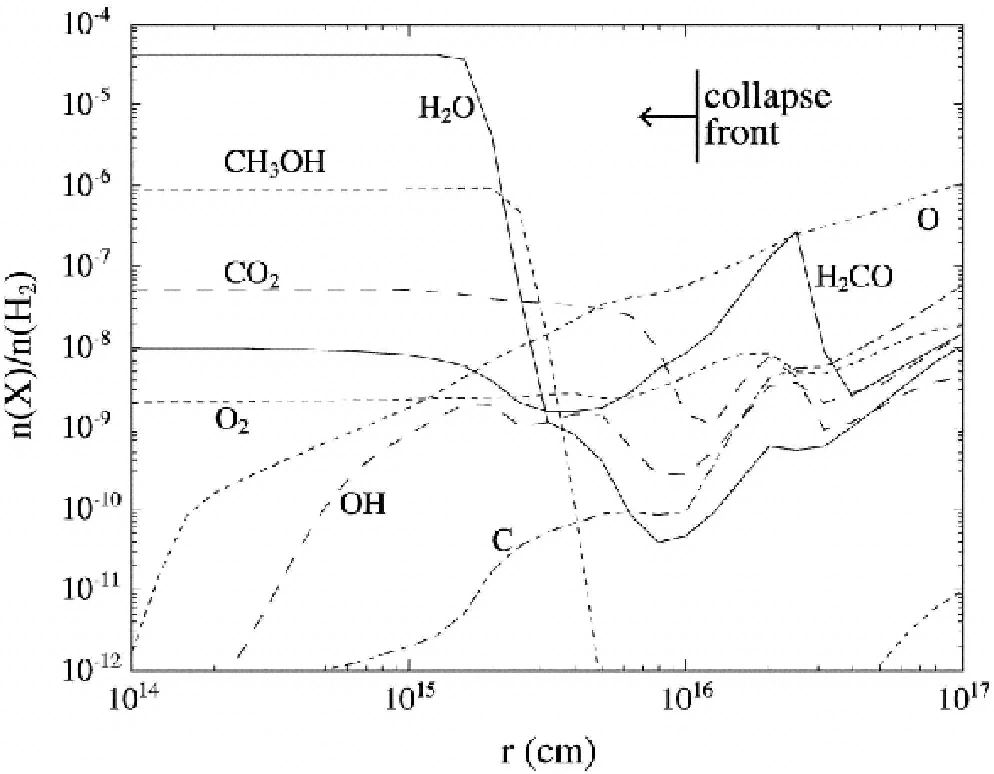
For example: OVRO & BIMA maps of NGC 1333 IRAS 2A





Jørgensen et al 2004: CS, SO, SiO & CH_3OH on N_2H^+

Modern models: chemistry + dynamics

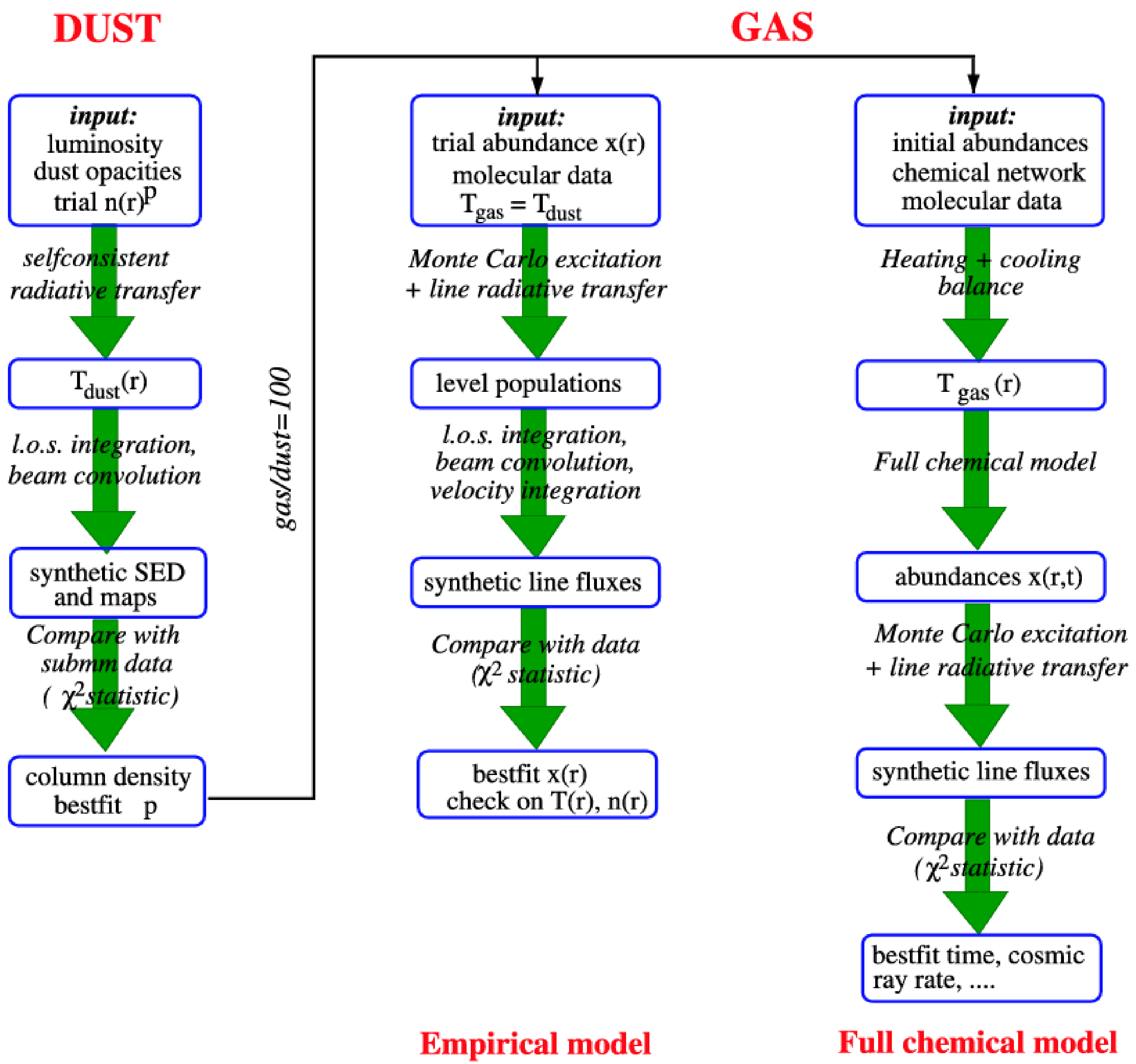


Collapsing envelope:

31 shells, 207 species, 2337 reactions

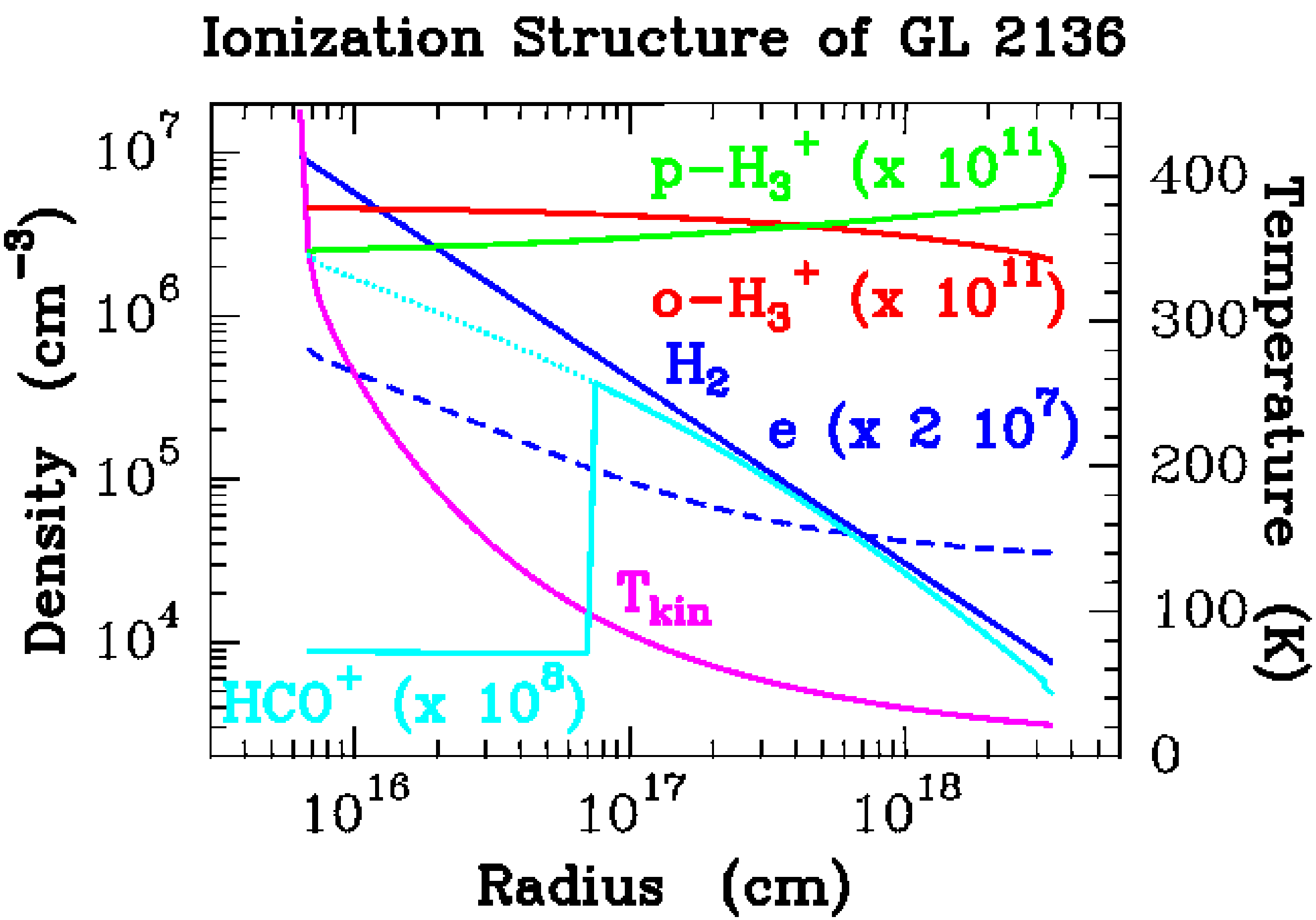
Rodgers & Charnley 2003

Measuring molecular abundances



Doty et al 2004

Probing the cosmic-ray ionization rate



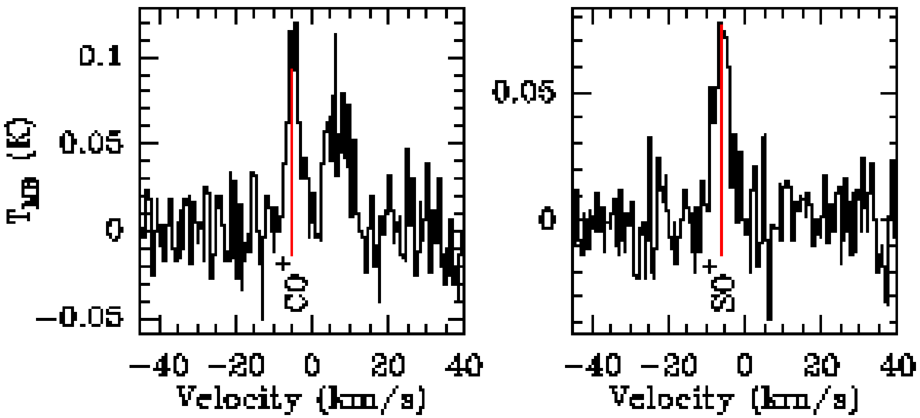
Dense clouds: $\zeta \sim 3 \times 10^{-17}\ s^{-1}$ (Van der Tak & van Dishoeck 2000)

Diffuse clouds: 10 x higher (McCall et al 2003; Le Petit et al 2004)

Factor ~10 variation possibly linked to column density

Intervening translucent clouds contribute ~half of H_3^+ absorption

Close to high-mass stars: X-rays contribute to ionization



Detection of CO^+ and SO^+ toward AFGL 2591

Stäuber et al 2005

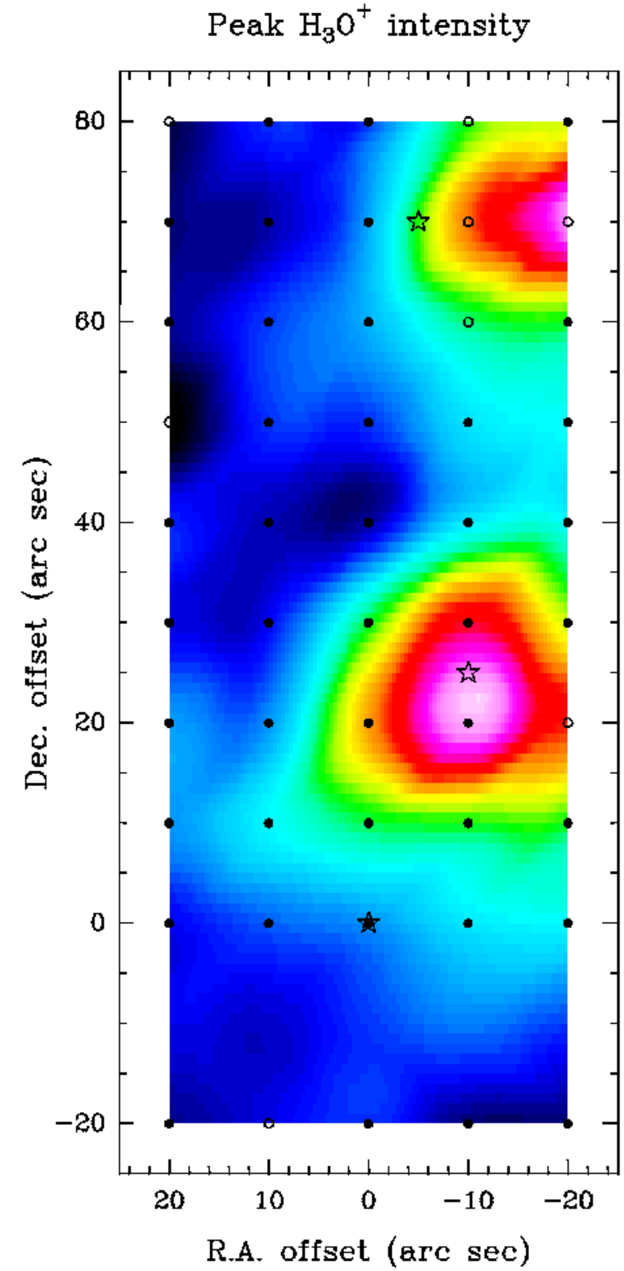
If we cannot see H_3^+:

Use other ions as substitutes

Example: APEX 364 GHz map of SgrB2

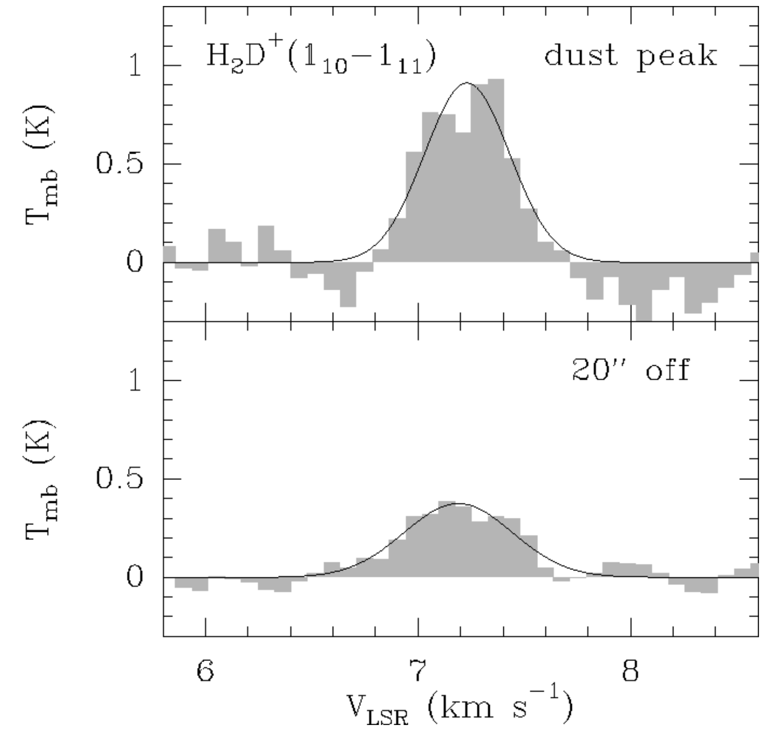
Use H_3O^+ / H_2O ratio to constrain CR rate

Data indicate $\zeta \sim 10^{-18}$ s^{-1}
(FvdT et al 2006)
10 x lower than in Solar neighbourhood
(FvdT & EvD 2000)
and 1000 x lower than diffuse GC gas
(Oka et al 2005)
but similar to centers of pre-stellar cores
(Caselli et al 2002)



Using H_2D^+ as chemical filter

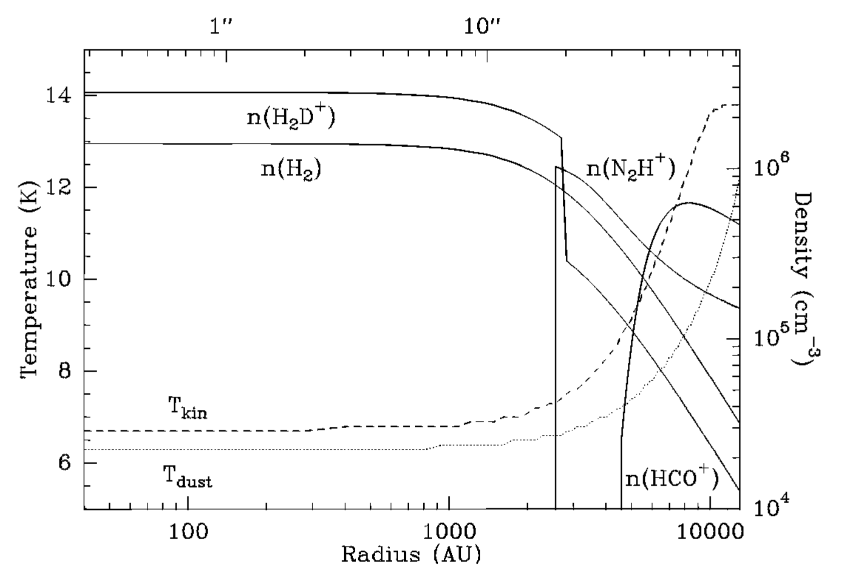
Formation of H_2D^+ from HD + H_3^+ enhanced at $T < 20$ K; destruction by CO, O, N_2 inhibited at $n > 10^5$ cm^{-3} *(talk Roberts)*



Use H_2D^+ to filter out cold, dense gas, where all elements >He are frozen out

Data indicate x~10^{-9} : major charge carrier (Caselli et al 2003)

~100 x stronger than in cores with stars (Stark et al 1999, 2004)



Abundance uncertain through spatial distribution *(talk Vastel)* & collisional

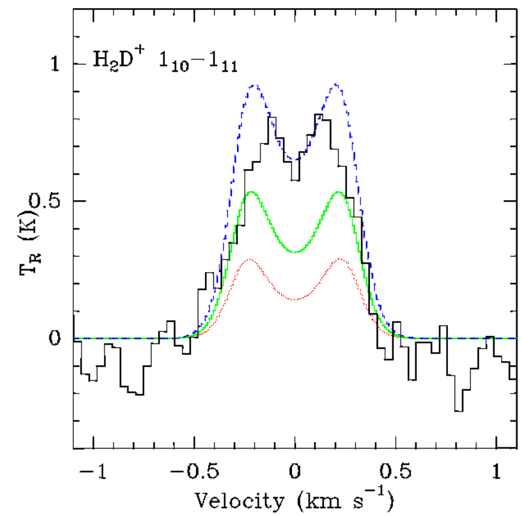
Kinematics of molecular ions toward the pre-stellar core L1544

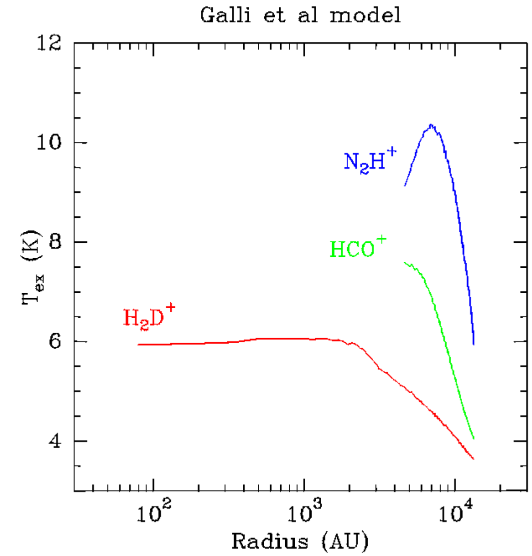
Double-peaked line profile like HCO^+ and N_2H^+ (but probes smaller radii)

Several changes to model needed:

1. density does not flatten off
2. gas temperature does not decrease
3. infall velocity increases inward
4. motion outer layers < thermal speed

(Van der Tak et al 2005)





Future directions

- Submillimeter interferometry (ALMA)
  - sensitive high-resolution H_2D^+ images
  - disk chemistry *(talk Ceccarelli)*
- Terahertz spectroscopy: APEX, *Herschel*
  - H_2D^+ 372, 1370 GHz
  - D_2H^+ 692 GHz
- Mid-infrared spectroscopy (VLT/CRIRES)
  - velocity-resolved H_3^+ spectra
  - isotopic species
- Laboratory / theory: