Tracing planetesimal formation using carbon depletion

Universiteit Leiden
The Netherlands

Ardjan Sturm (sturm@strw.leidenuniv.nl)
Leiden Observatory

Sterrewacht Leiden

Background

Recent observations show that protoplanetary disks are regularly depleted in carbon and oxygen by orders of magnitude.

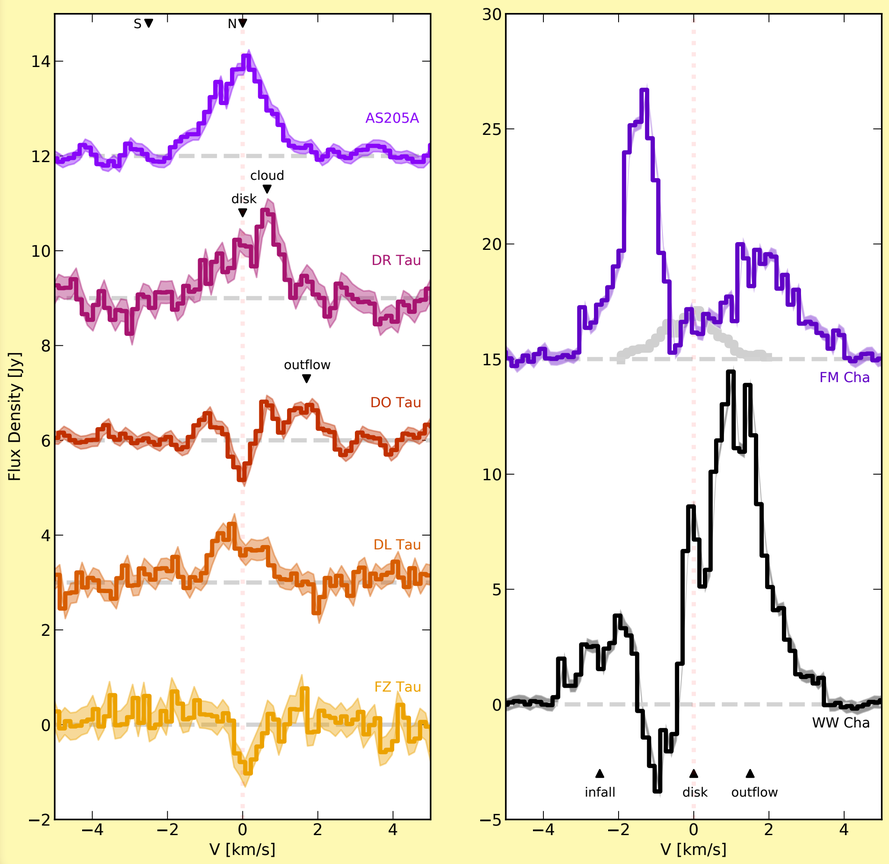
Modeling shows that this can only be explained by a combination of (Krijt et al. 2020):

-- Freezeout of CO on grains in the outer disk
-- Efficient vertical mixing
-- Grain growth, locking the ices in the midplane
-- Chemical evolution locking C and O in less volatile species
-- Radial drift transporting the C and O inwards

Inside the CO snowline or ultimately the dust sublimation rim, C and O are released, creating a local enhancement above ISM abundances.

Unless dust trapping or planetesimal formation stops radial drift!

Observations



We observed 7 disks in the weak [CI] line at 492 GHz using the ACA to get reliable measurments of the bulk elemental C gas abundance.

First succesful ALMA [CI] survey in protoplanetary disks!

6/7 sources are detected. Most of the sources have extended cloud/outflow emission.

For 4 of the sources we can determine the disk component.

Results/Conclusions

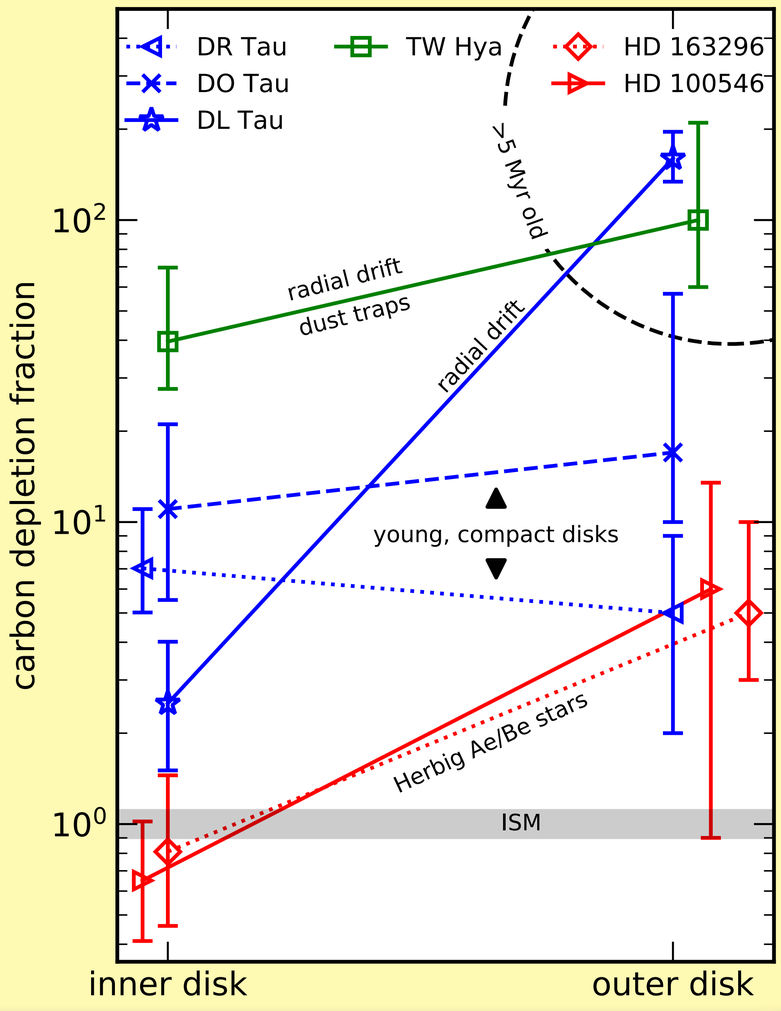
The system-wide carbon depletion factors are consistent with the ages of the systems. DL Tau is much older, thus more depleted in carbon.

Comparing our results with inner disk carbon abundance tracers (McClure 2019) we observe three scenarios:

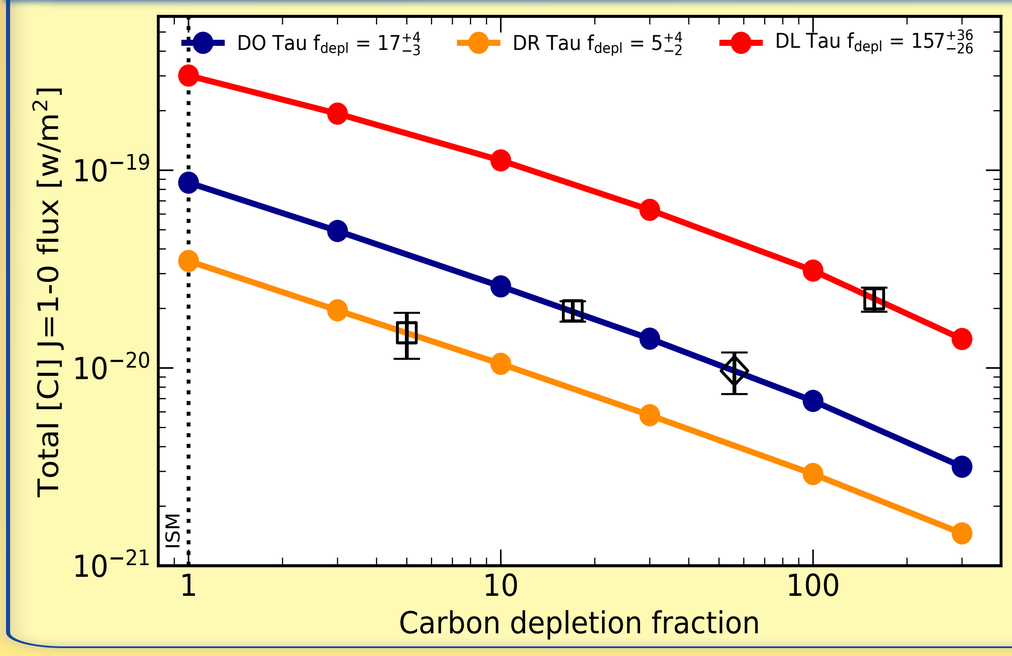
1. Inner disk less depleted --> radial drift releases CO inside snowline
2. Inner disk similarly depleted as outer disk --> efficient trapping of solids in the outer disk (planetesimal formation?)
3. Almost no depletion in warm disks with small area below CO snow surface

Interestingly:
DO Tau and DR Tau efficient dust locking, but compact disks without substructure (pebble/planetesimal formation?). DL Tau no efficient dust locking, but has three pressure maxima or continuum rings outside CO snowline!

DL Tau second disk ever to be observed being depleted in carbon more than 2 orders of magnitude. DL Tau's disk is very similar to TW Hya, has similar radial carbon abundance pattern.



modeling



Modeling of three sources in Taurus:
-- Using physical/chemical DALI models
-- Fitting the disk structure using the SED and [CI] and CO isotopolog lines
-- Determine the C/H ratio from the total line fluxes

DO Tau and DR Tau are weakly depleted in carbon and oxygen by a factor of 17^{+4}_{-3} and 5^{+4}_{-2}, respectively

DL Tau is strongly depleted in elemental carbon abundances by a factor of 157^{+36}_{-26}

References: Krijt et al. 2020, ApJ, 899, 134; McClure 2019, A&A, 632, 32