Zooming in on the Formation of Protoplanetary Disks

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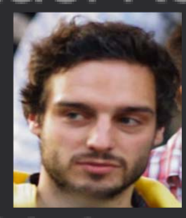


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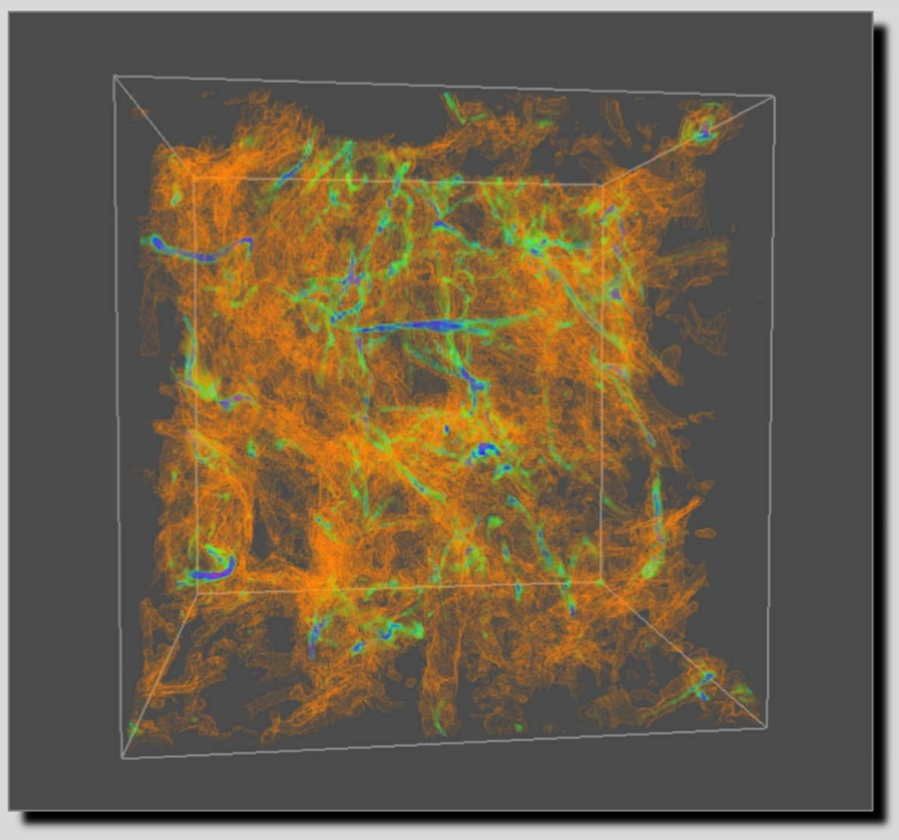
STARPLAN

Introduction: We use the adaptive mesh refinement code RAMSES [1,2] to model the formation of proto-planetary disks in a realistic star formation environment, with resolution scaling over 29 'levels of refinement' (powers of two); about 9 orders of magnitude, covering a range from an outer scale of 40 pc to an inner scale of 0.015 AU. Done for one case so far; a larger study will follow.



The purpose of this procedure is to characterize the typical properties of accretion disks around solar mass protostars, with as few free parameters as possible. This is a vast improvement over models where initial and boundary conditions have to be chosen arbitrarily. Here, the initial and boundary conditions follow instead from the well-observed statistical properties of the interstellar medium [3,4,5,..]. The idea is similar to studying galaxy formation starting from calibrated cosmic micro-wave background fluctuations.

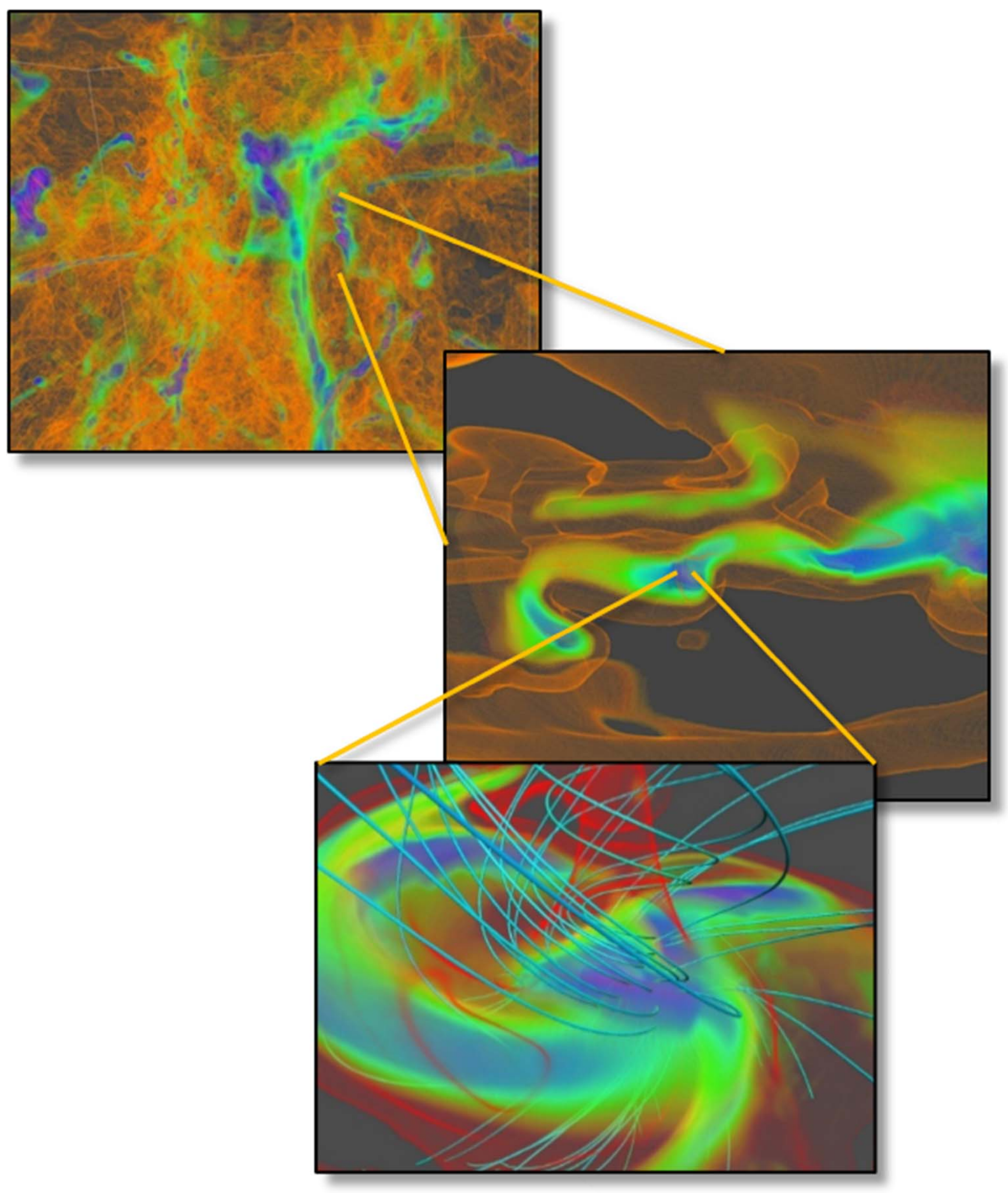
Method

Three step simulations:

Step 1: follows individual star formation in a 40 pc GMC model over about 10 Myr, using 16 levels (smallest cell size ~120 AU)

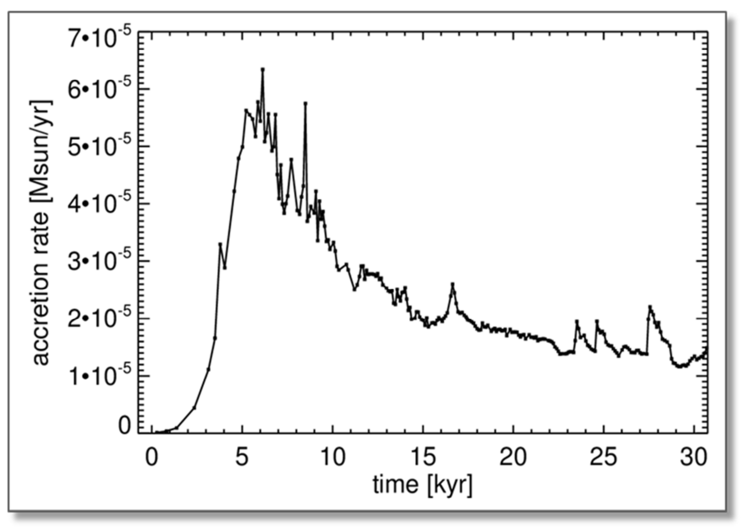
Step 2: follows the accretion process of a selected solar mass star over about 0.2 Myr, using 22 levels (smallest cell size ~ 2 AU)

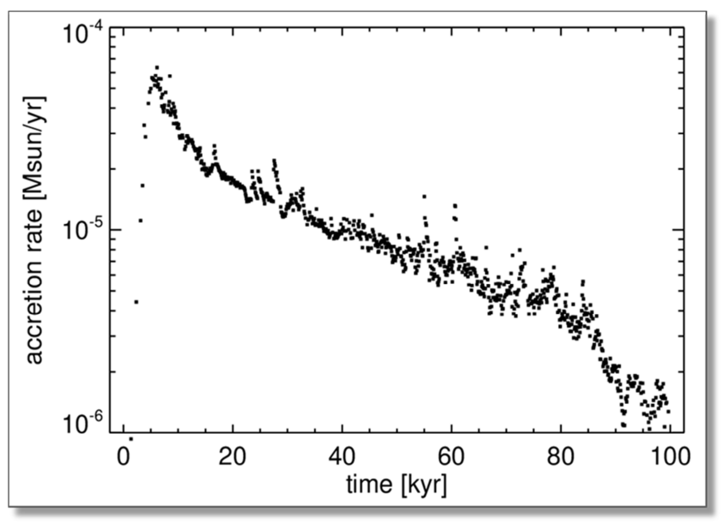
Step 3: follows the detailed dynamics over time intervals of a few hundred years, using 29 levels (smallest cell size ~ 0.015 AU)

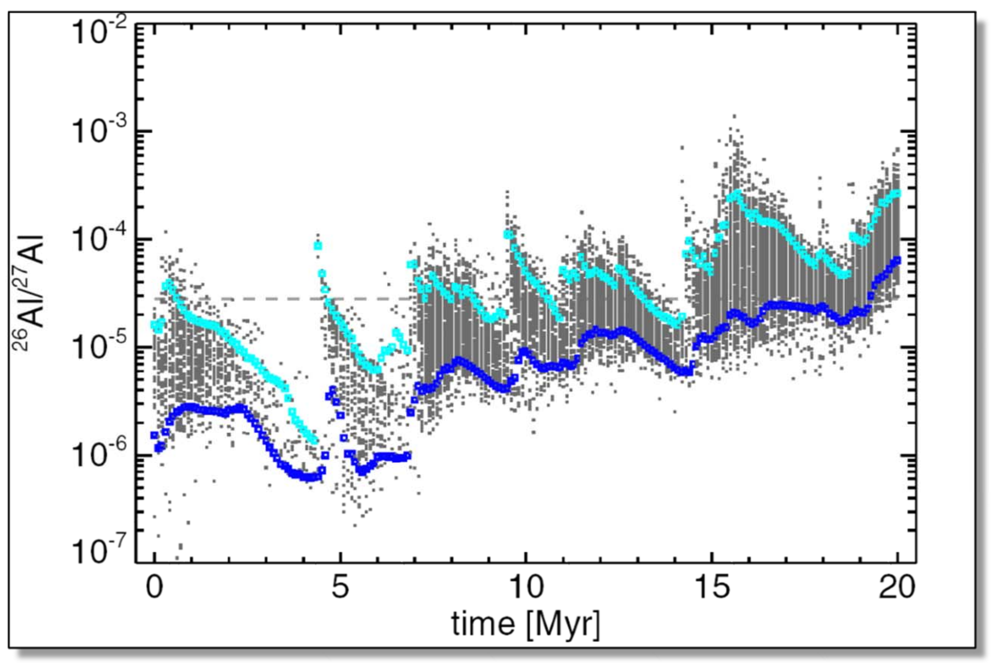


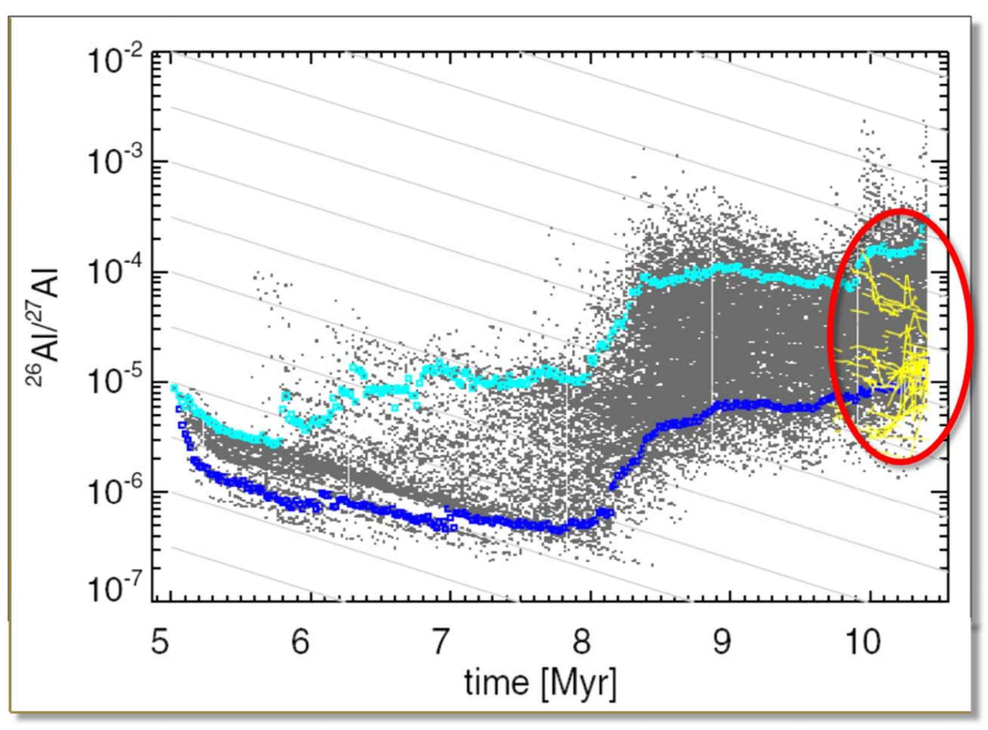
Results of this first case study

Over a time interval of 5-6 kyr the accretion rate grows to a maximum of about $6 \cdot 10^{-5}$ solar masses per year, and then starts to decline, with fluctuations mainly due to re-arrangements of the magnetic field. Henceforth the accretion rate decays essentially exponentially with time, reaching 10^{-6} solar masses per year in about 100 kyr (we have seen other cases with both shorter and longer time scales). The radial mass profile scales similar to free-fall accretion (cf. adjacent poster), with the magnetic field carrying away excess angular momentum and energy.









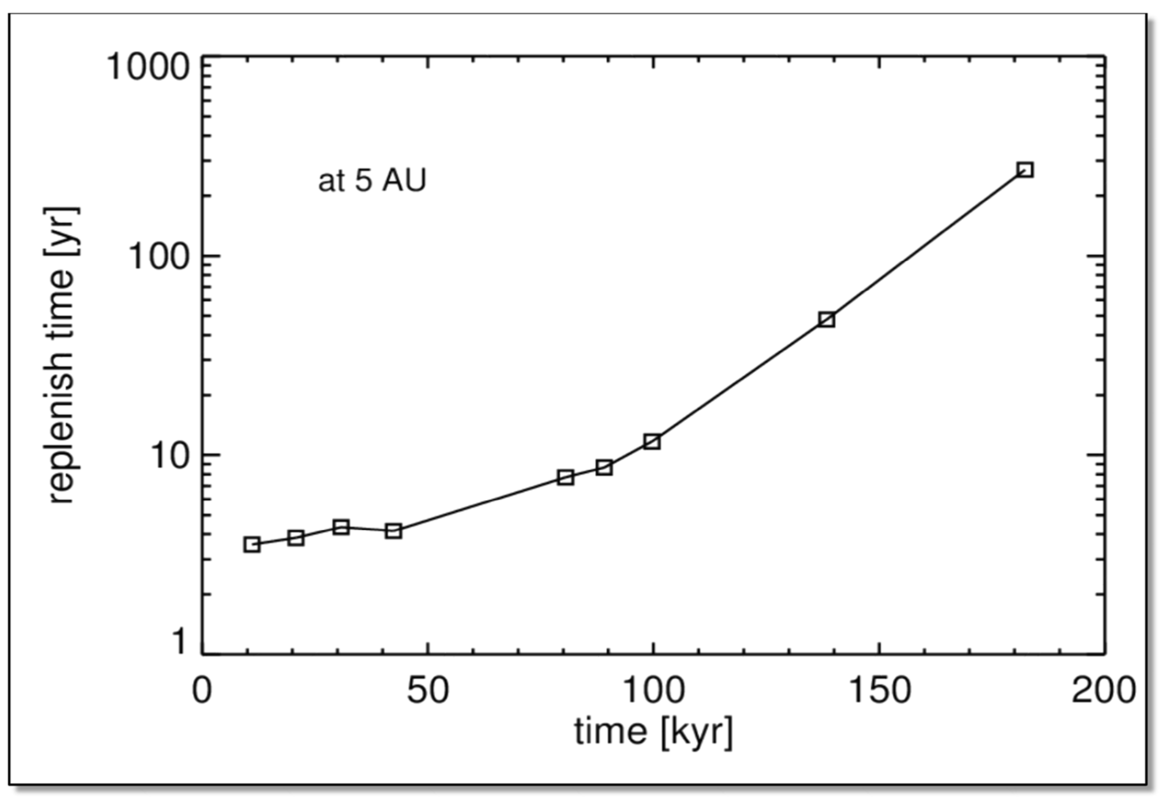
Transport of SLRs

As a byproduct of this type of modeling, which starts out from a supernova driven interstellar medium, we can follow the transport of short-lived radionuclides (SLRs), from the time of ejection by supernovae until they become part of proto-planetary disks.

As shown by Vasileiades et al. [6] the transport time is on average short enough to be consistent with initial abundance of 26Al in the Solar System derived from cosmochemistry. Of particular interest is to characterize the amount of variation with time of the SLR abundance during the lifetime of PP-disks surrounding solar mass stars.

Disk Replenishment Times

A remarkable property of the system is the rapid turn-around of mass: The disk replenishment time, defined as the mass of the disk (here out to 5 AU) divided by the mass accretion rate is initially much smaller than the disk life time, with the ratio increasing as the accretion rate drops faster than the mass of the disk.



See also other posters with results from our RAMSES models of star formation:

1G021: Tracing Protostellar Evolution Using Gas Kinematics, Christian Brinch
1H009: Understanding Disk Formation, Søren Frimann
1H004: Accretion and Formation of Protostellar Systems, Troels Haugbølle
1H003: Zooming in on Proto-Planetary Disks, Michael Küffmeier

References

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2. Fromang, S., Hennebelle, P., Teyssier, R. 2006, J. Comp. Physics, **218**, 44
3. Larson 1979, MNRAS **186**, 479
4. Larson 1981, MNRAS **194**, 809
5. Solomon, P.M., Sanders, D.B., Rivolo, A.R. 1985, ApJ **292**, 19L
6. Vasileiades, A, Nordlund, Å, Bizzarro, M 2013, ApJ **769**, 8L