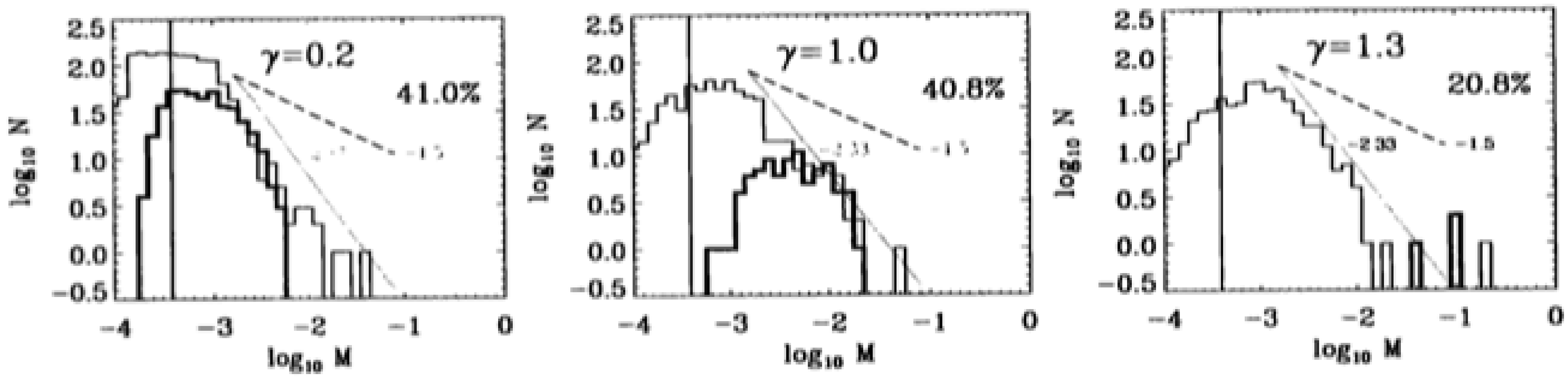
Black hole formation and growth: Expectations for ALMA

Dominik Schleicher
Leiden Observatory (ESO fellow)

Collaborators:
R. Banerjee (Heidelberg), S. Glover (Heidelberg),
Rainer Beck (Bonn), R. Klessen (Heidelberg),
M. Spaans (Groningen), S. Sur (Heidelberg)

The role of the equation of state



- Li, Klessen & MacLow (2005): Equation of state determines fragmentation properties $\gamma_{\rm eff} = 1 + \frac{d\log T}{d\log\rho}$
- H_2 cooling suppressed by soft-UV radiation (Omukai 2001)
- Lyman Alpha photons (if estimated with escape-probability method) cannot escape cloud in a free-fall time (Spaans & Silk 2005)
- Additional cooling via chemical reactions (Glover & Savin 2009)

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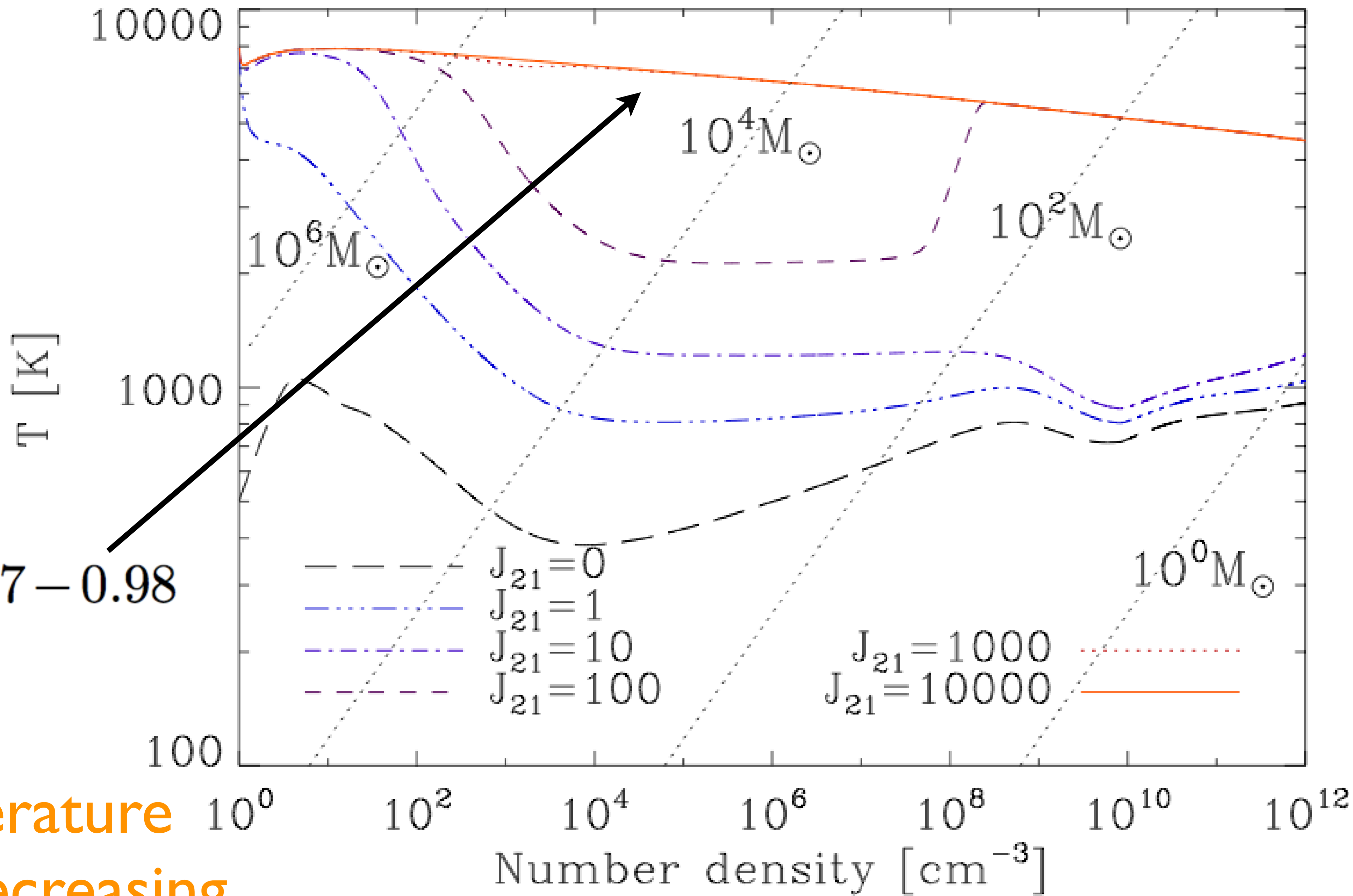
Results from a one-zone model



$\gamma_{\rm eff} = 0.97 - 0.98$

Temperature keeps decreasing with density

Schleicher, Spaans & Glover (2010)

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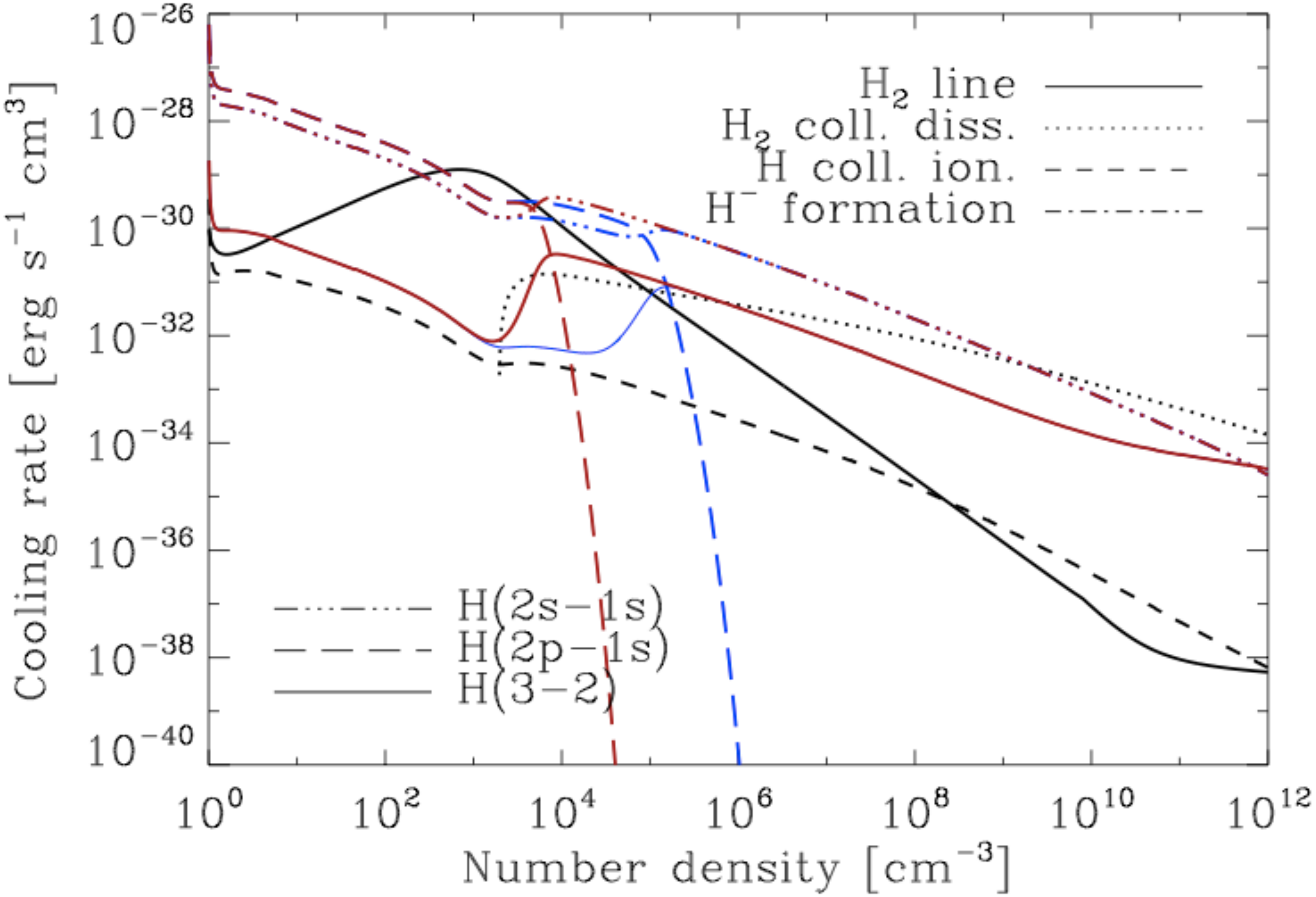
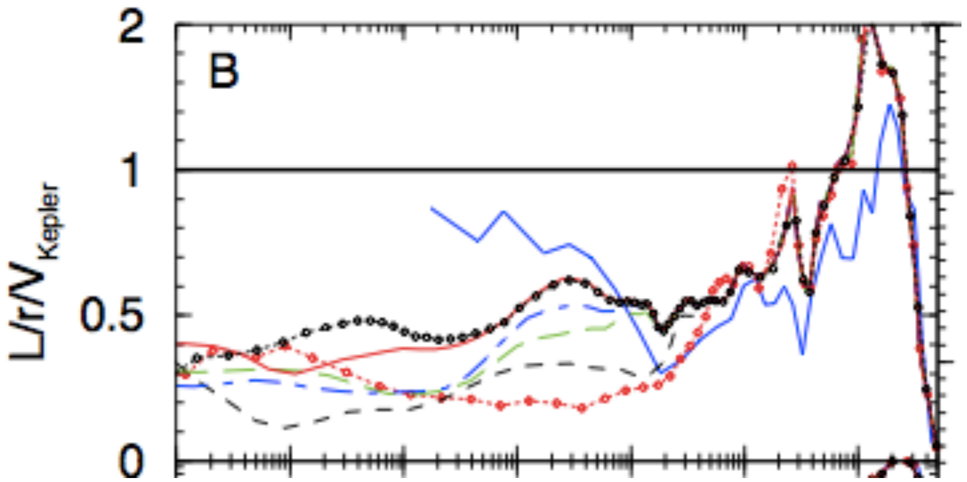
Cooling mechanisms



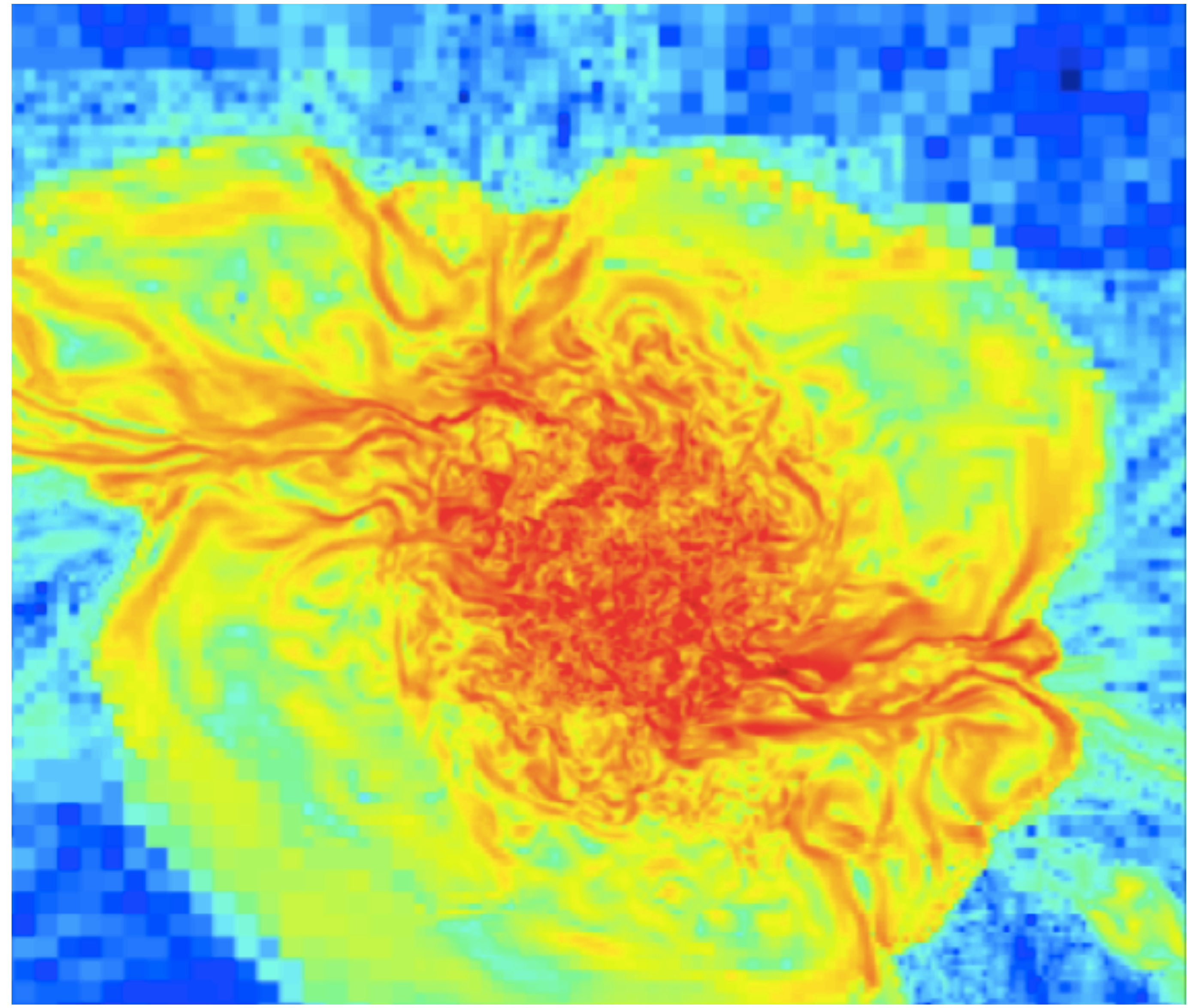
Additional cooling from (2s-1) and (3-2) transition; chemical cooling

Schleicher, Spaans & Glover (2010)

Turbulence during first star formation



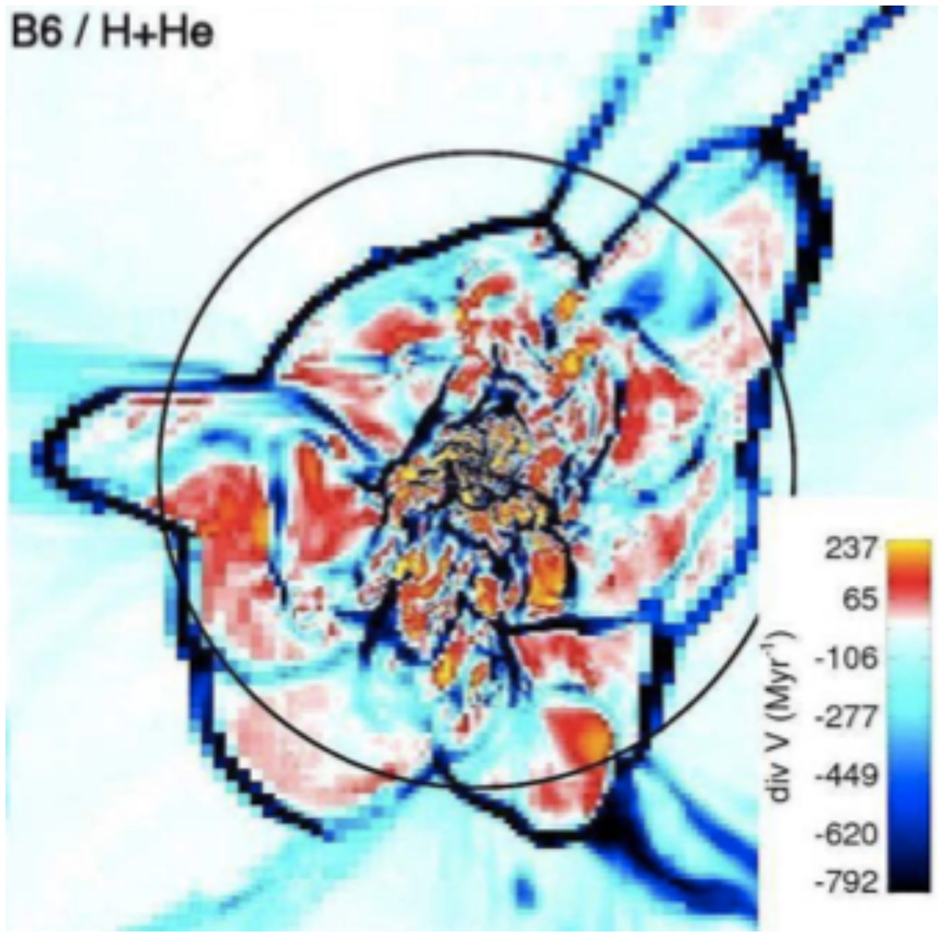
Abel, Bryan & Norman
(Science, 2002)



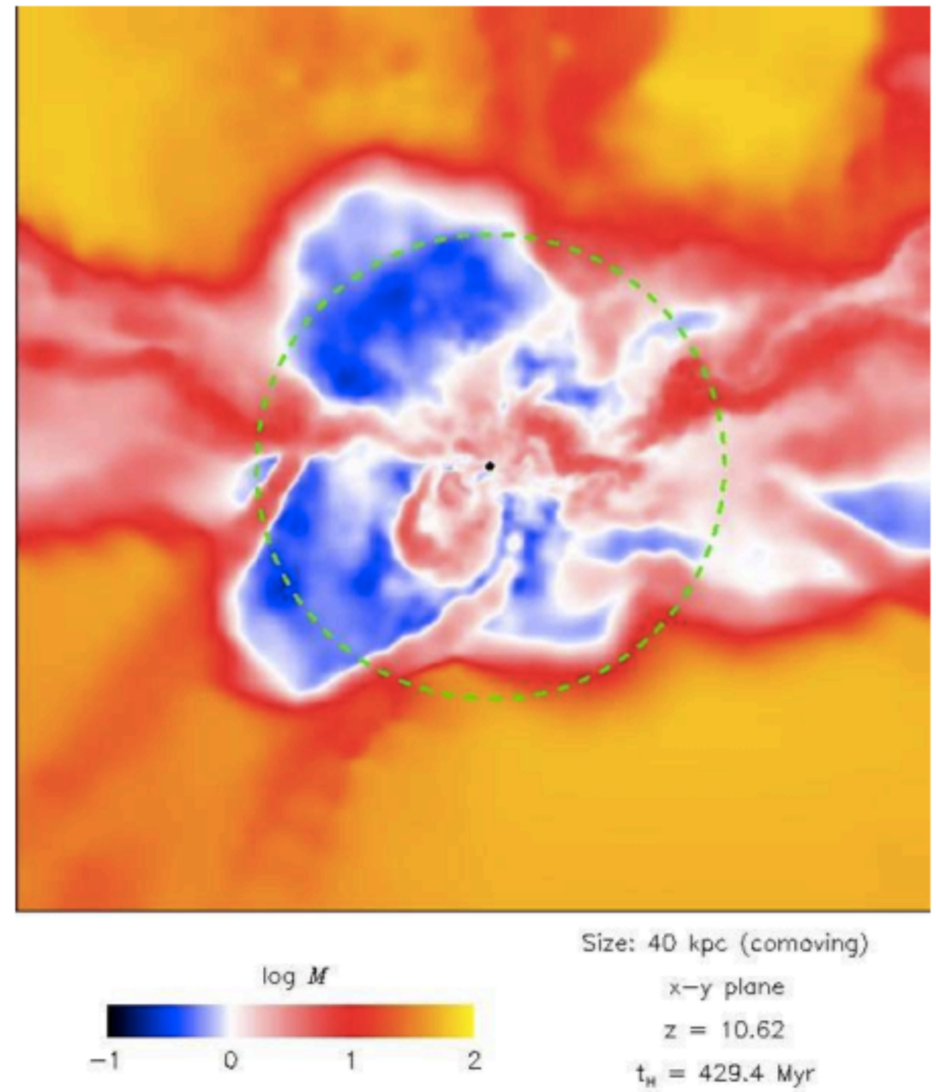
Courtesy Zhao, Turk & Abel

Subsonic, turbulent structures
in the first minihalos

Turbulence in the first galaxies



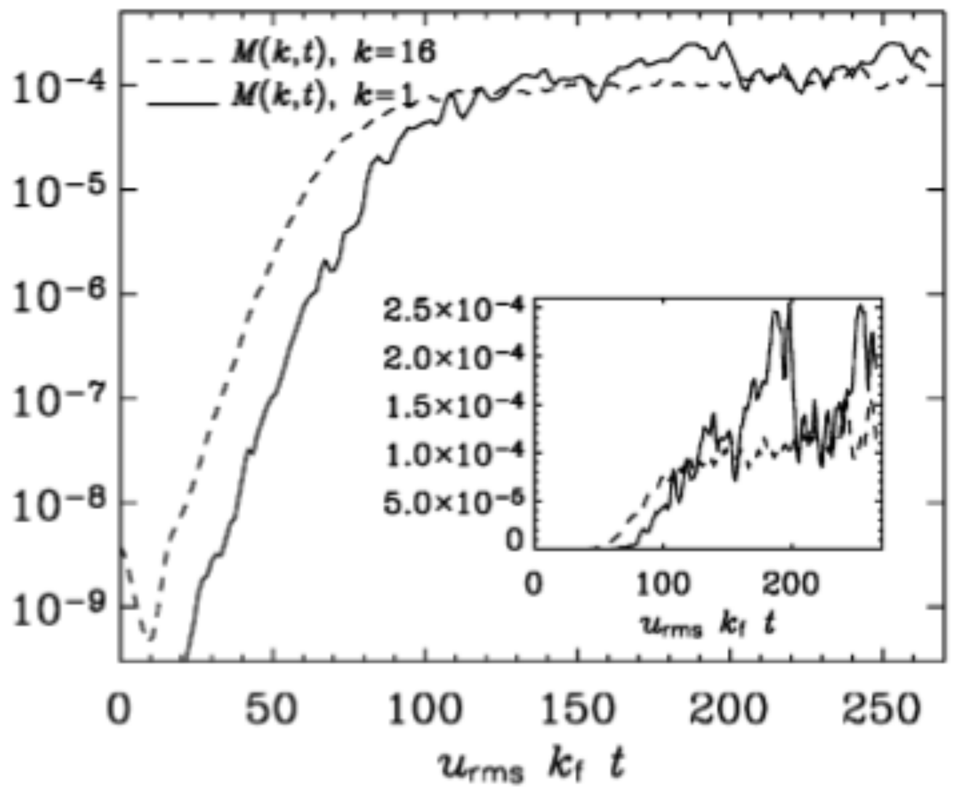
Divergence of velocity field,
Wise & Abel (2007)



Supersonic Mach numbers
(Greif et al. 2008)

Presence of highly supersonic turbulence in the first galaxies

The small-scale dynamo



Turbulent amplification of magnetic fields: Haugen et al. (2004); Brandenburg & Subramanian (2005)

- The small-scale dynamo rapidly amplifies magnetic fields on the eddy-turnover timescale.
- Saturation at about 10% equipartition with kinetic energy.
- Injection of turbulent energy on Jeans scale, then power-law (Kolmogorov / Burger)

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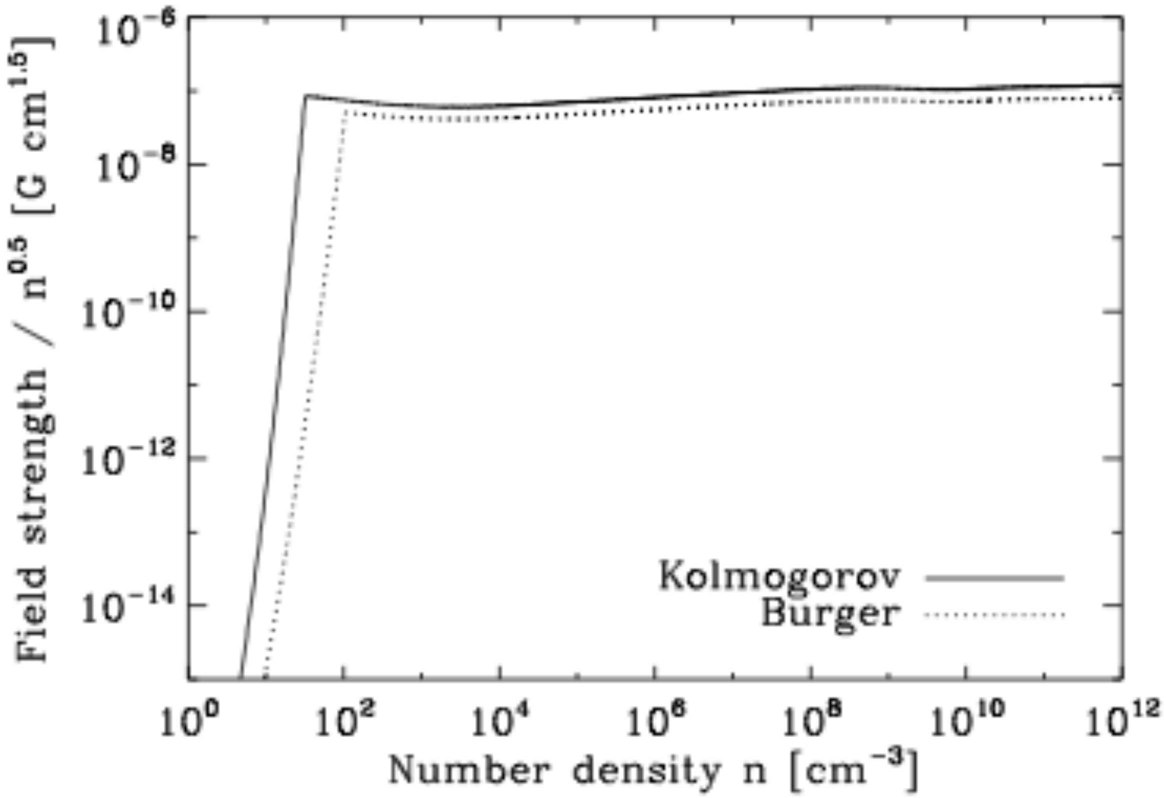
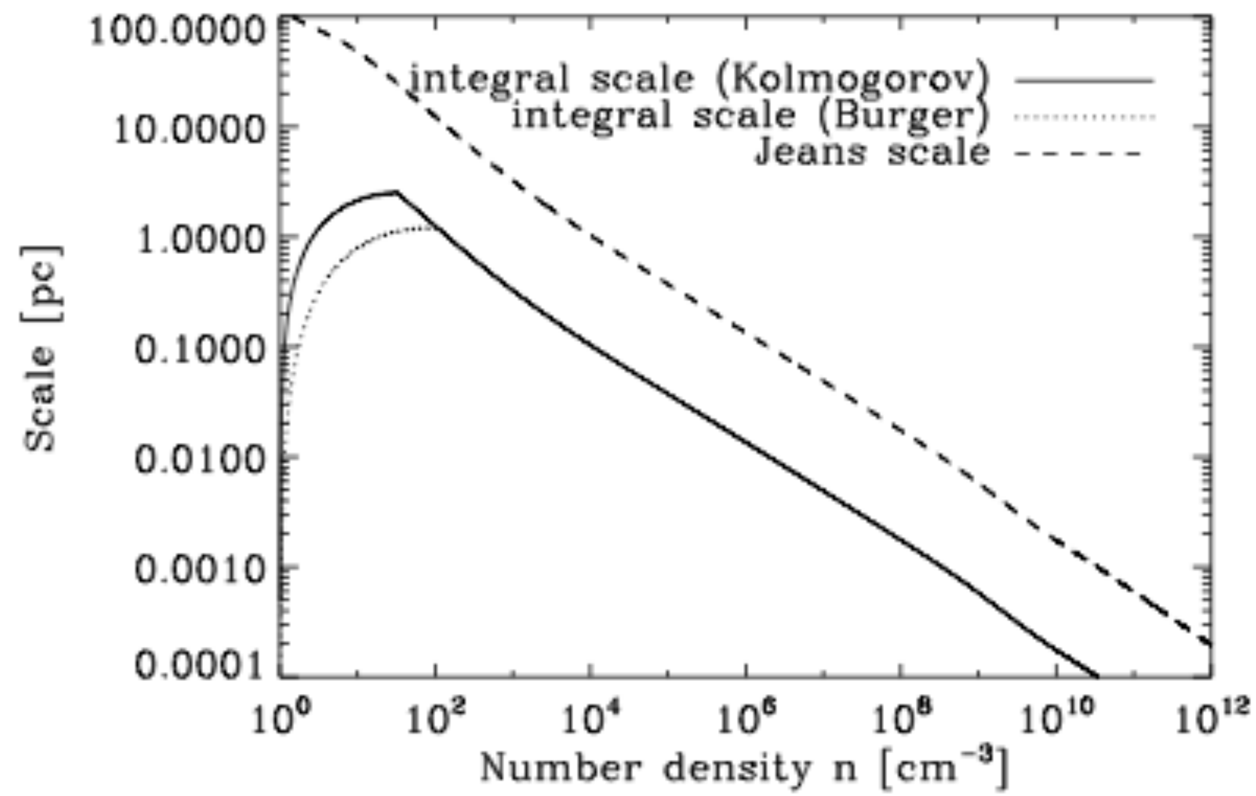
Magnetic field growth during protostellar collapse

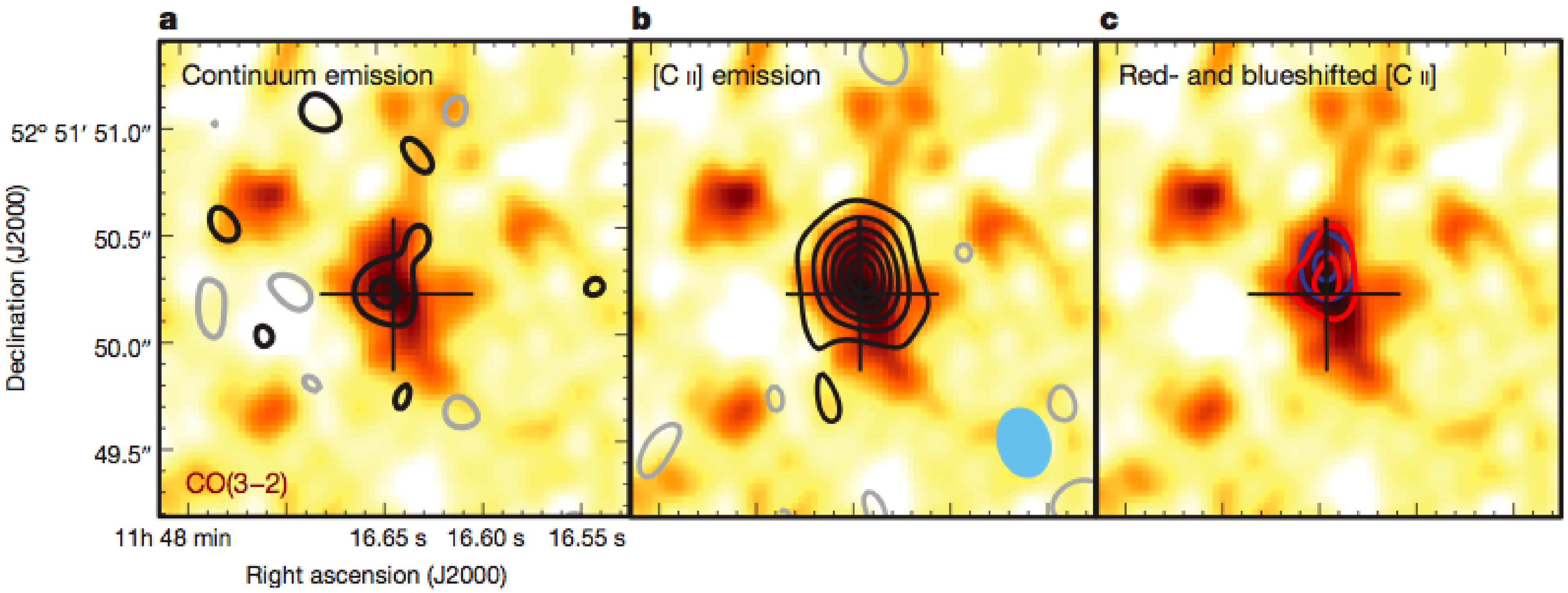




Magnetic fields may help forming more massive clumps; see Talks Klessen/Machida for MHD effects and suppression of binaries

Schleicher, Banerjee, Sur, Arshakian, Klessen, Beck & Spaans (2010)

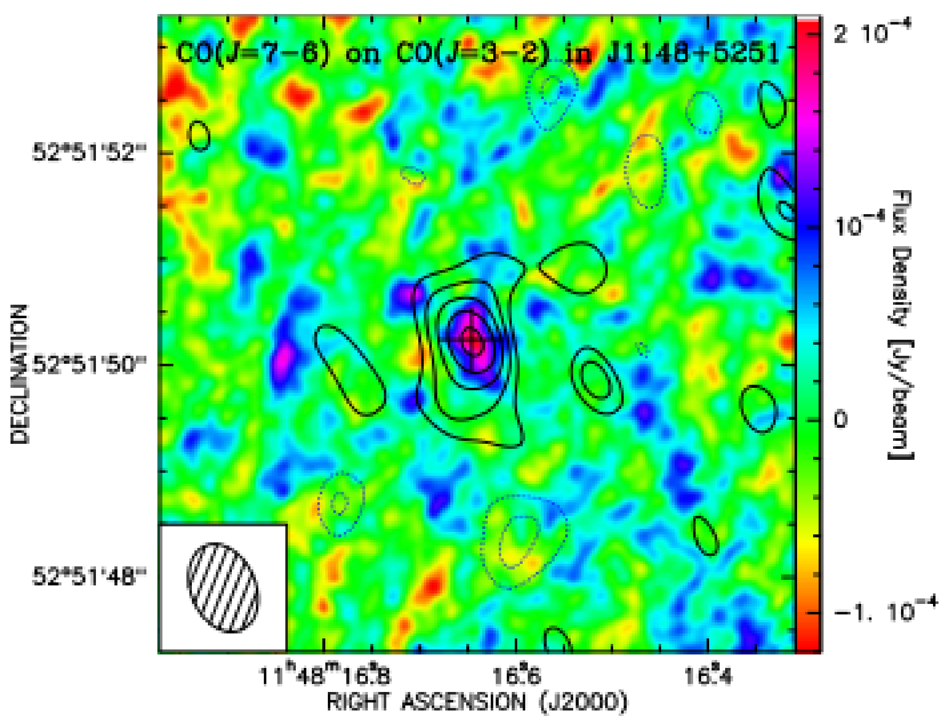
The z=6.42 quasar



A kilo-parsec scale starburst at z=6.42

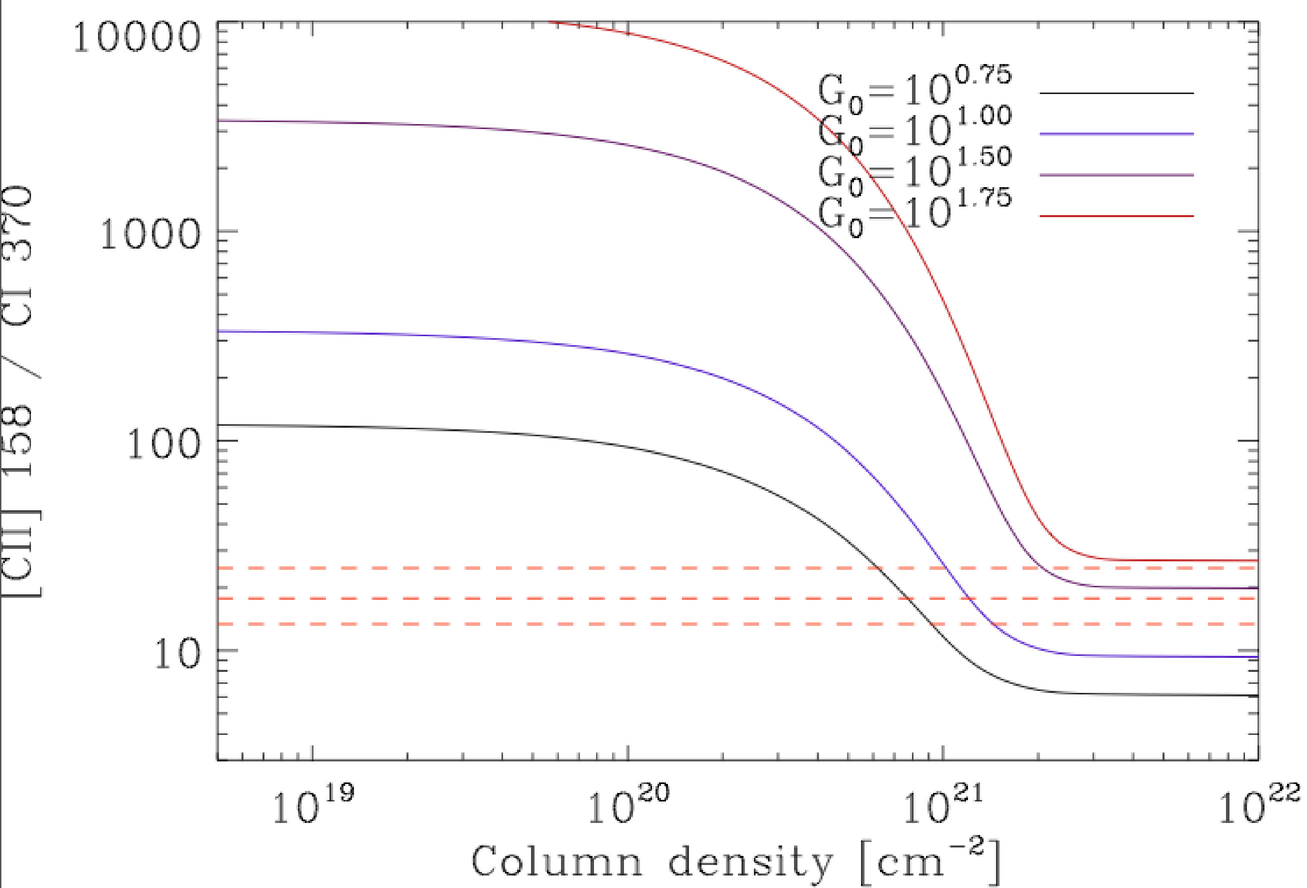
Walter et al. 2009

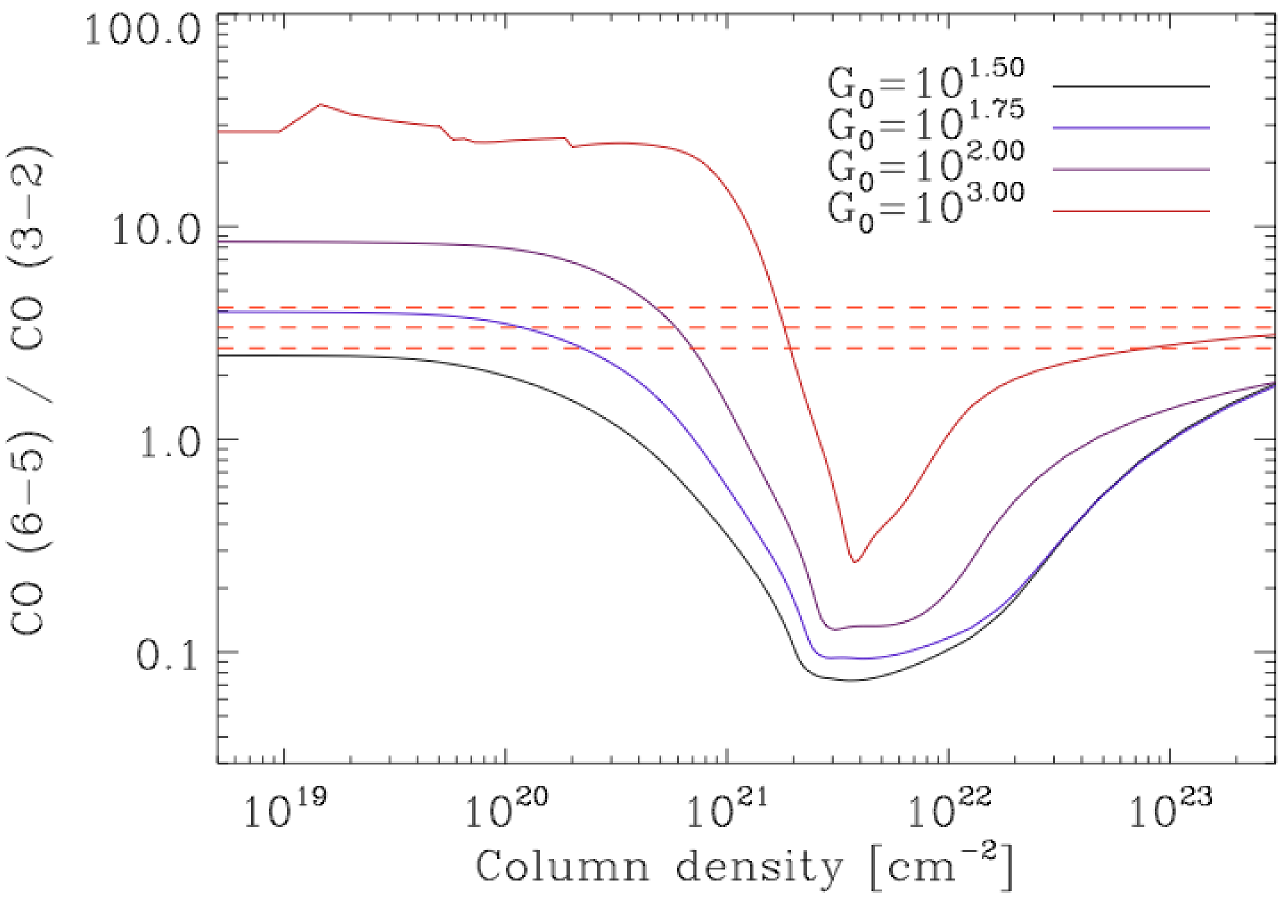
	$S_\nu dv$ [Jy km s^{-1}]	L' [10^9 K km s^{-1} pc^2]	Ref.
CO(J=1→0)	<0.11	<143	1
CO(J=3→2)	0.20 ± 0.02	29.9 ± 2.7	2
CO(J=6→5)	0.67 ± 0.08	25.0 ± 3.0	1
CO(J=7→6)	0.63 ± 0.06	17.2 ± 1.8	1,3
HCN(J=2→1)	<0.006	<3.3	4
HCO$^+$(J=2→1)	<0.018	<10	5
$H_2O(J_{K_aK_c}=2_{12}\rightarrow1_{01})$	<0.69	<4.4	3
C I($^3P_2\rightarrow^3P_1$)	0.22 ± 0.05	6.0 ± 1.3	3
[C II]($^3P_{3/2}\rightarrow^3P_{1/2}$)	3.9 ± 0.3	19.0 ± 1.6	6,7
[N II]($^3P_1\rightarrow^3P_0$)	<0.47	<4.0	8



Riechers et al. 2009

Modelling the z=6.42 quasar





Low-density gas (~10^3 cm^{-3})

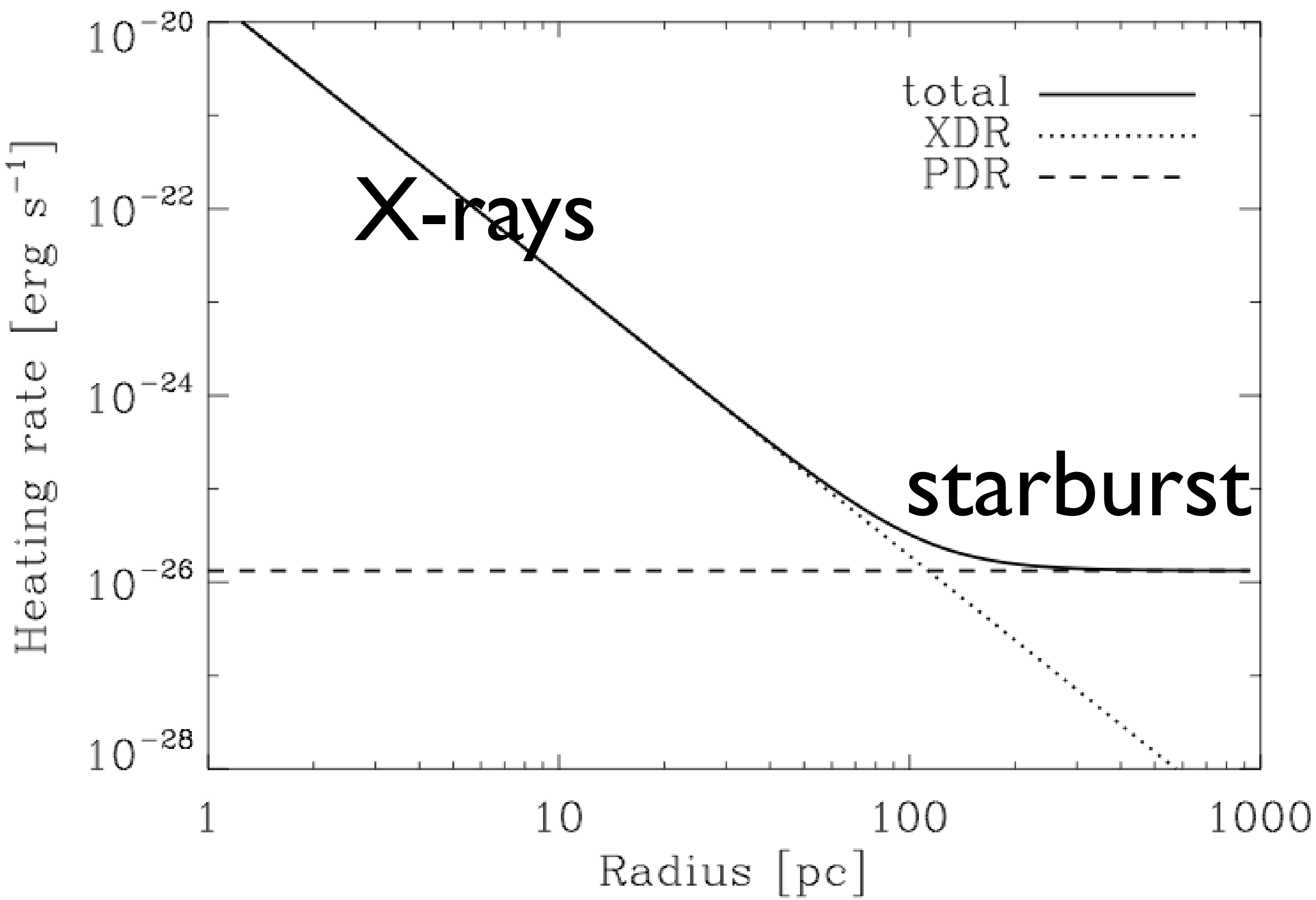
Higher-density gas exposed to stronger radiation field?

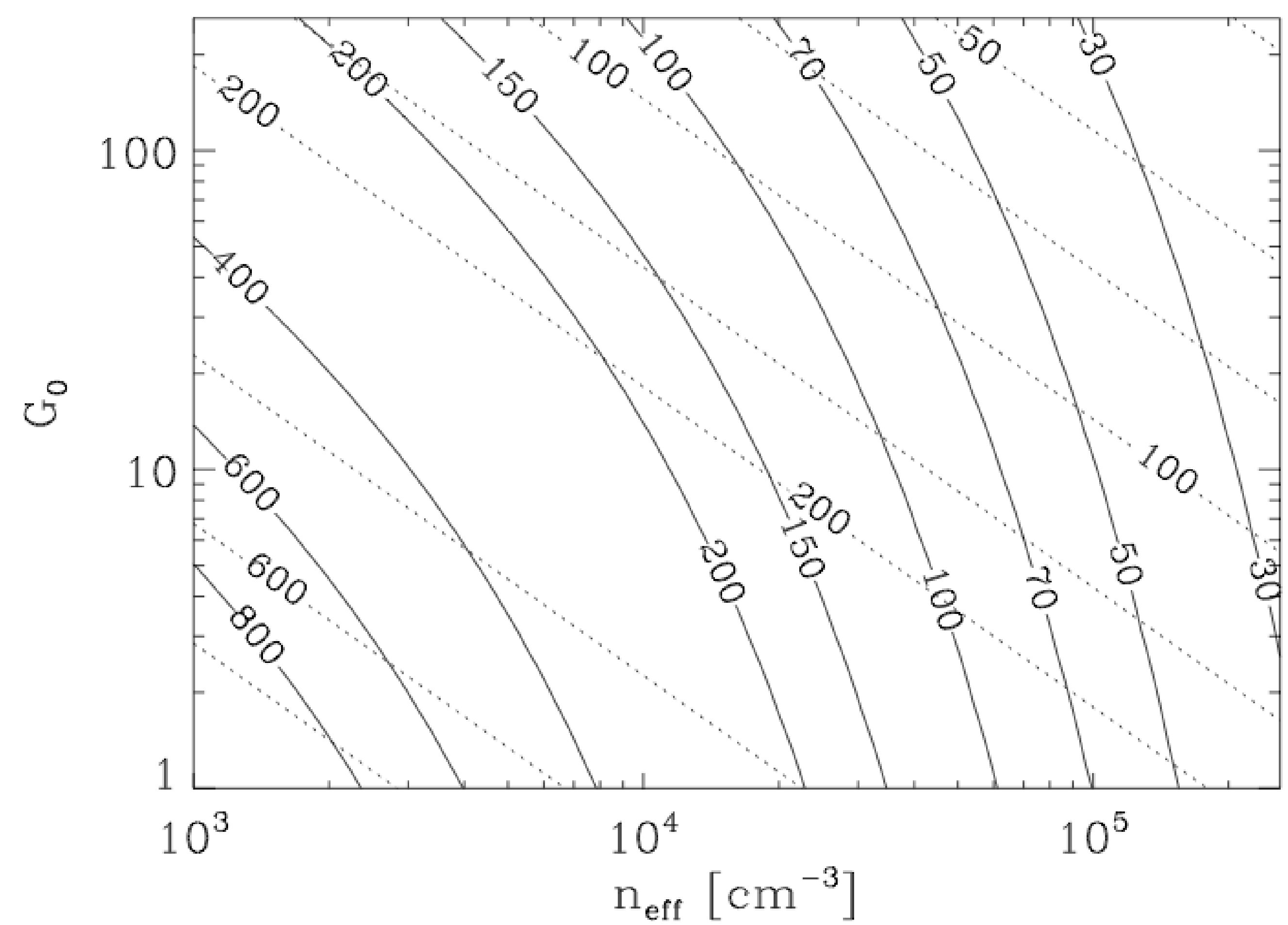
High-density gas (~10^4 cm^{-3})

Interpretation: Star-formation started just recently and occurs in high-density gas; radiation trapped mostly inside the clouds

 Schleicher, Spaans & Klessen (2010)

Expectations for ALMA: The central X-ray dominated region





Heat input as a function of scale ($M_{BH}=10^7\ M_{solar}$, 3% of L_{Edd} in X-rays, $G_0=10$)

Expected sizes for the central XDR in pc

Schleicher, Spaans & Klessen (2010)

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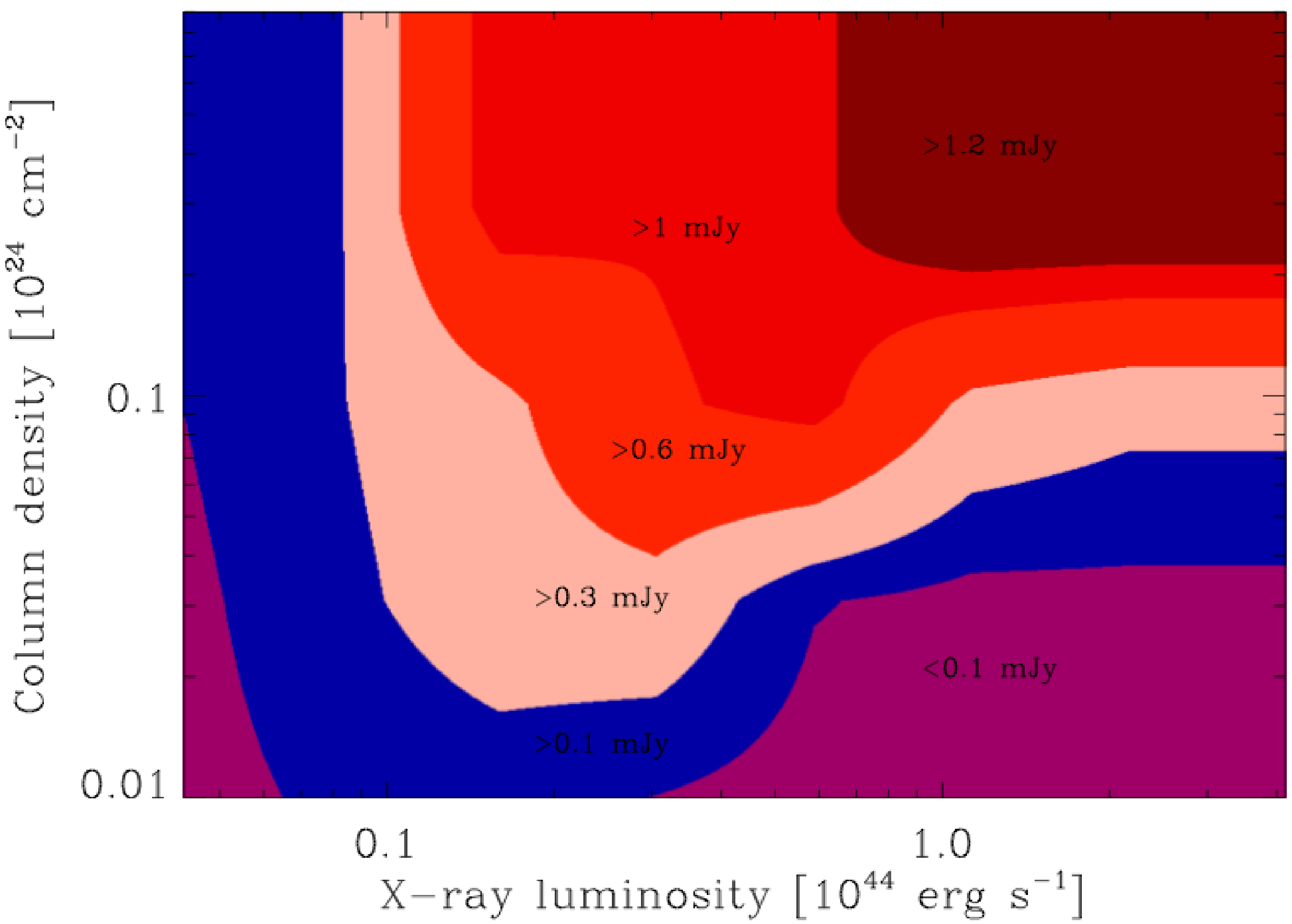
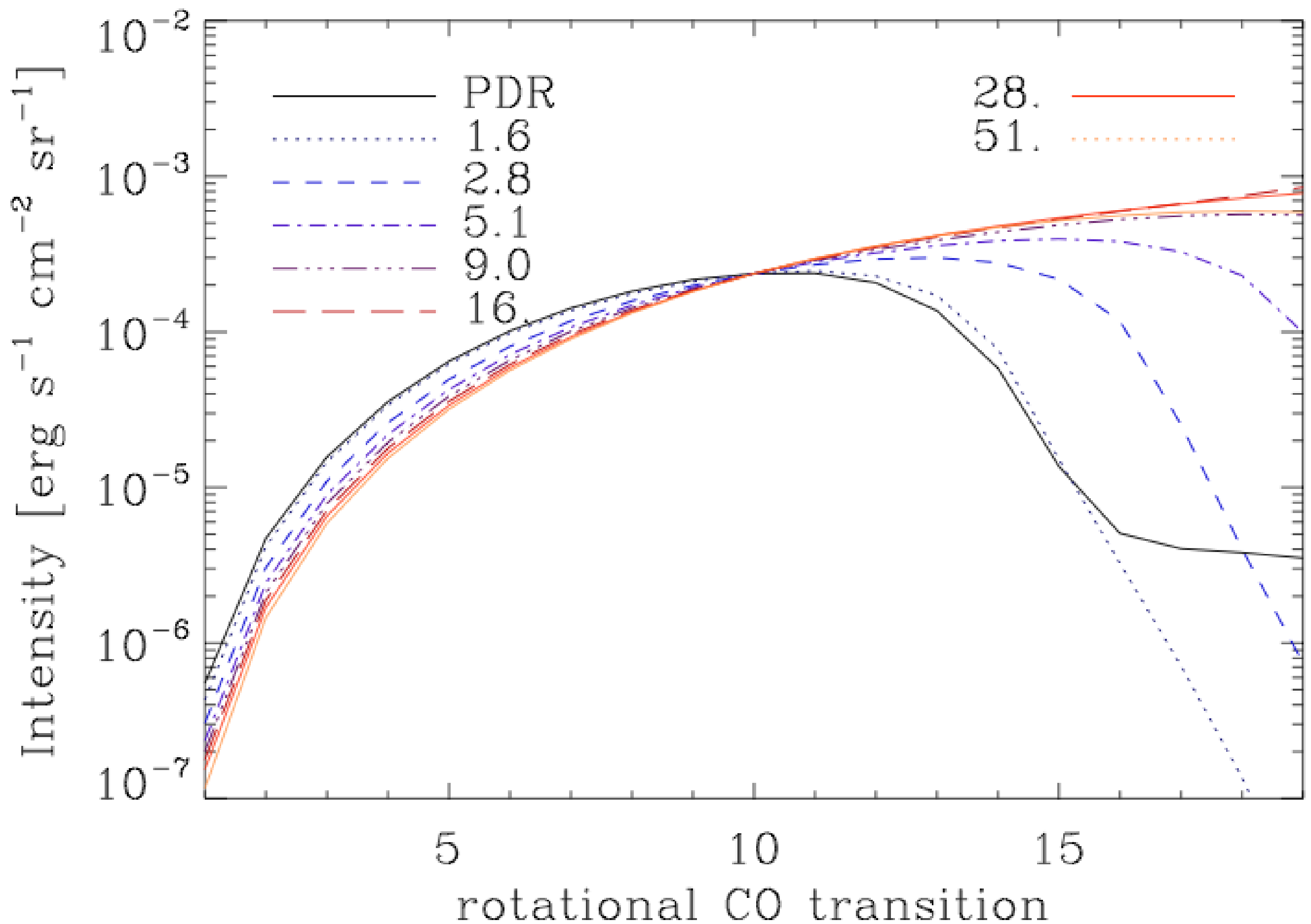
Expected flux in (14-13) CO, z=8



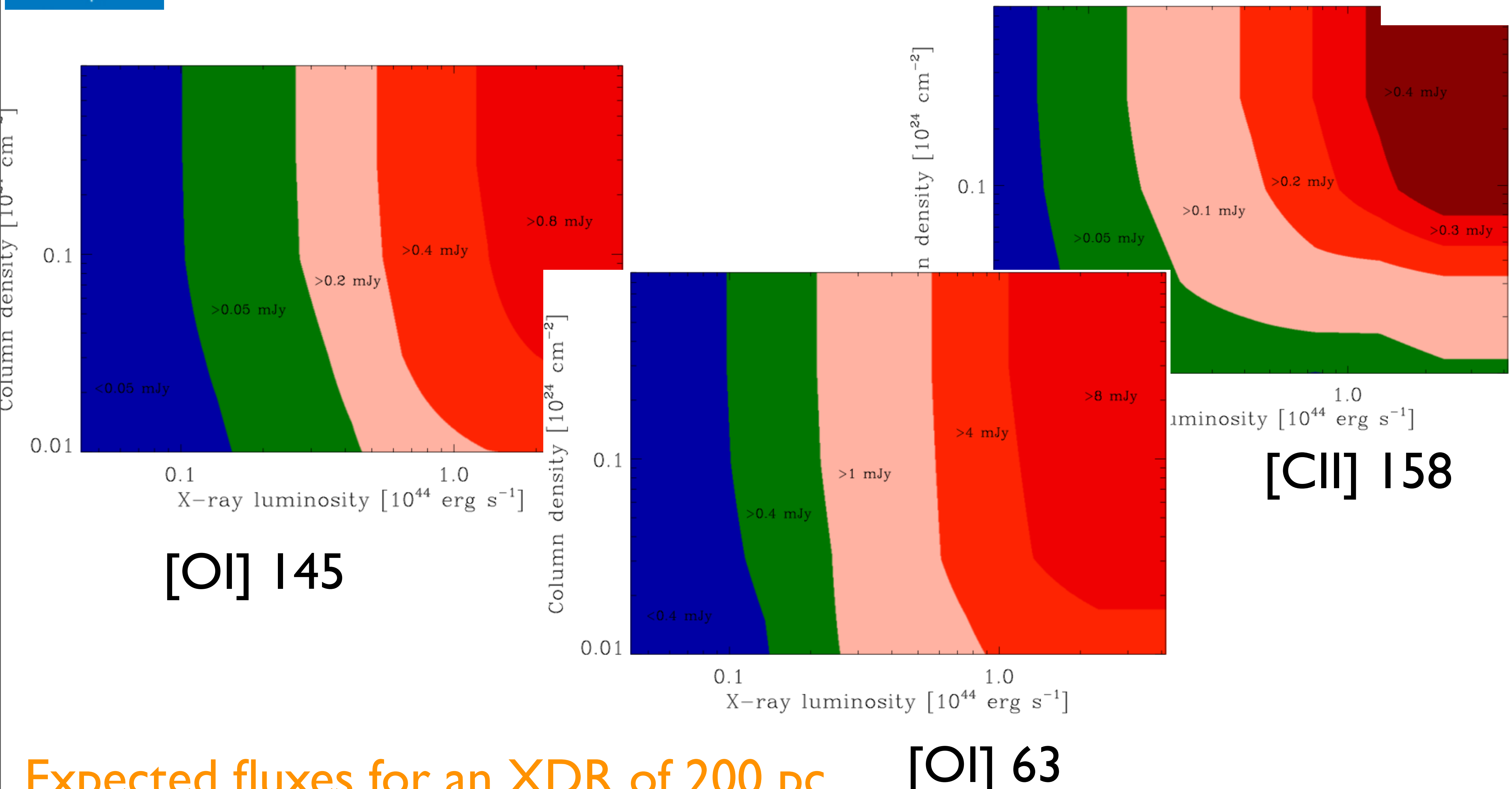


Expected flux for an XDR of 200 pc at z=8, with 10^5 cm^{-3} density clouds filling the projected surface

Diagnostic power of CO lines to discriminate between XDRs and PDRs

 Schleicher, Spaans & Klessen (2010)

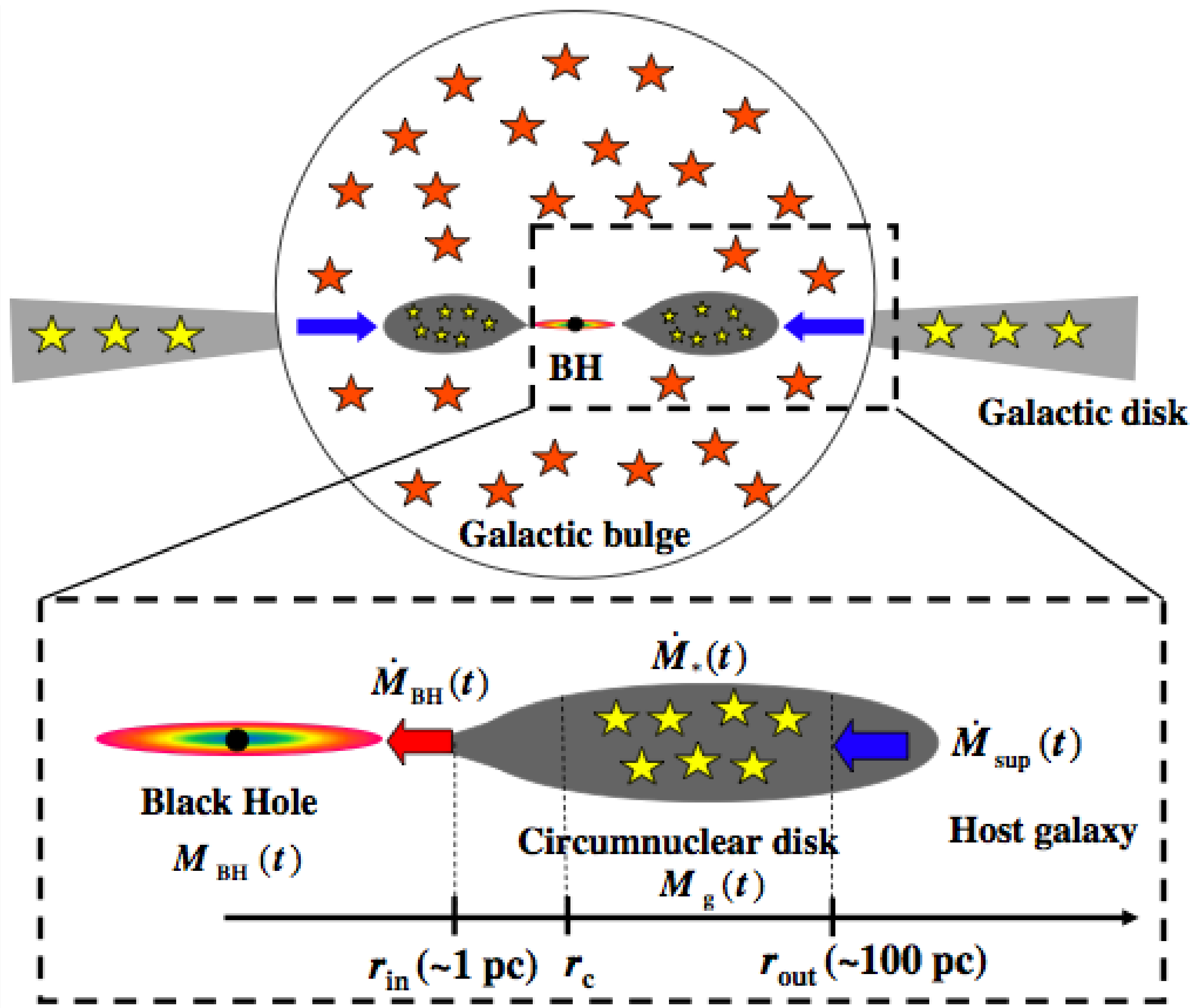
Fluxes in fine-structure lines



Expected fluxes for an XDR of 200 pc at z=8, with 10^5 cm^{-3} density clouds filling the projected surface

 Schleicher, Spaans & Klessen (2010) D. Schleicher

Towards probing the growth of high-z black holes with ALMA



Kawakatu & Wada (2008)

- The central XDRs are postulated to harbor circumnuclear disks
- Gravitational instabilities lead to star formation and turbulence
- Turbulent accretion feeds the central black hole
- Radiation feedback from the black hole affects the chemistry in the environment

Dominik Schleicher