PROPERTIES, DYNAMICS, & SPECTRAL SIGNATURES OF CLOUDS IN AGN

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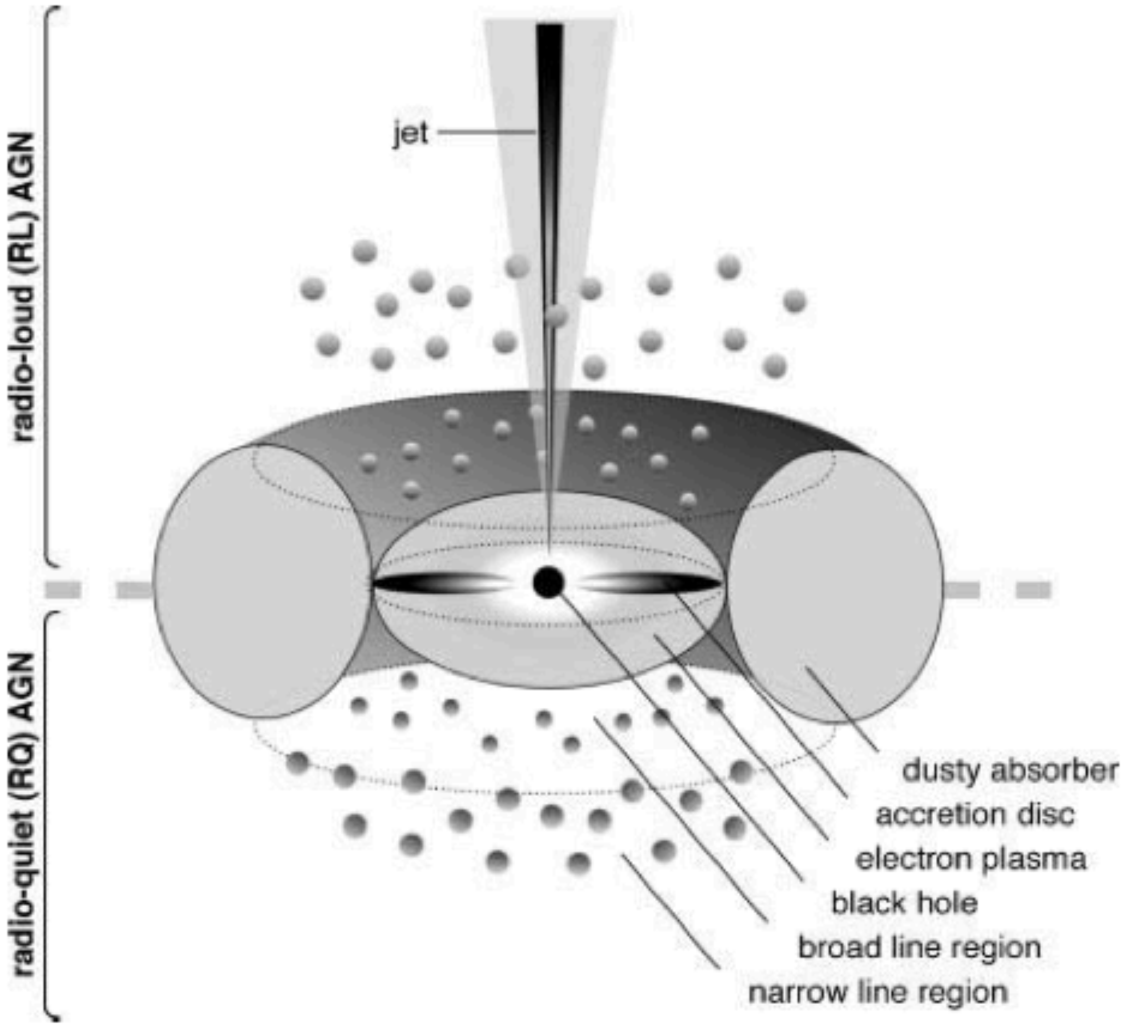
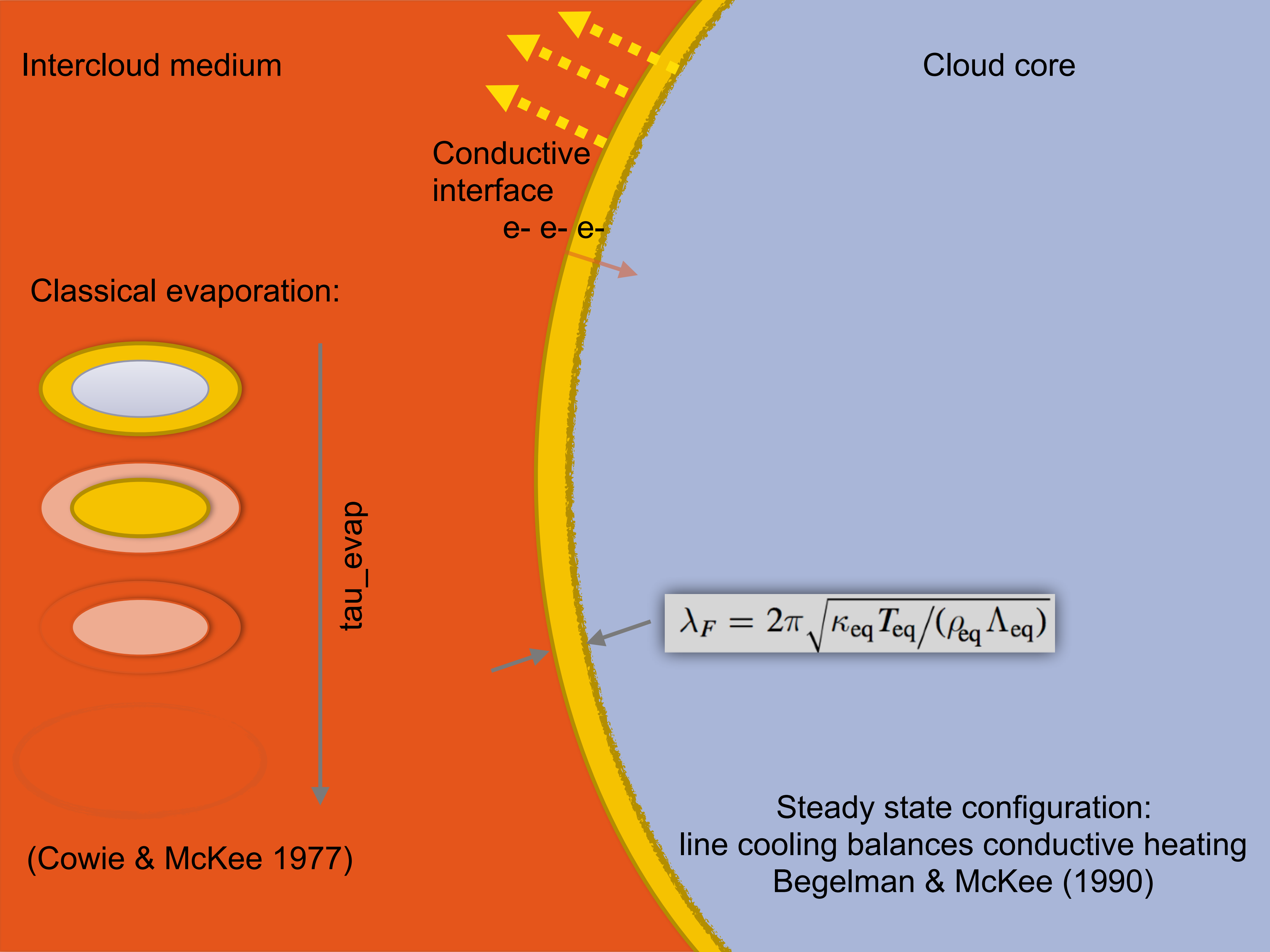
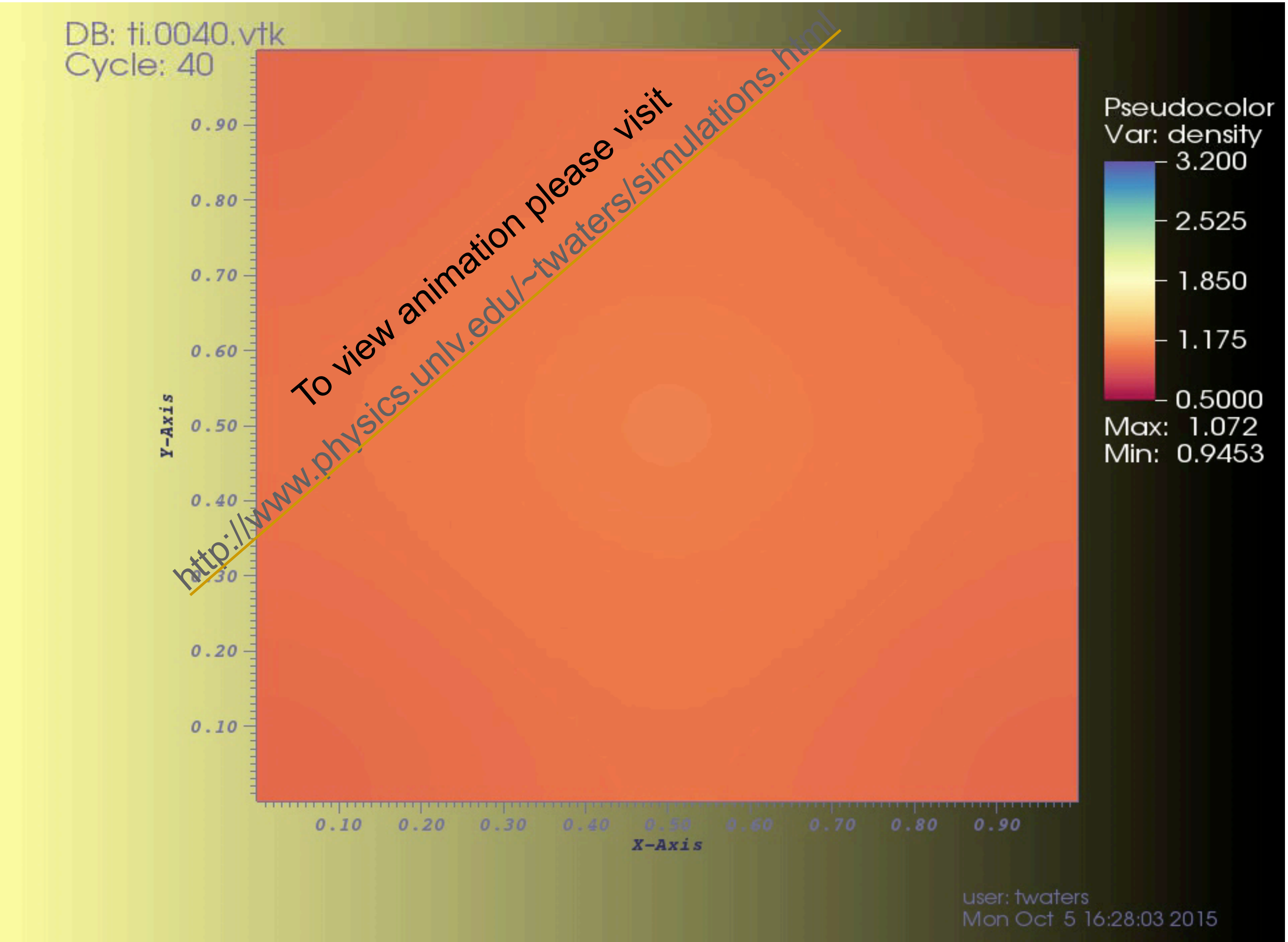


Figure credit: Active Galactic Nuclei, Wiley 2012

	COMMON VIEW		LOCAL SIMULATIONS	
Property	**Single cloud**	**Global distribution**	**Single cloud**	**Global distribution**
Equilibrium state	Static vs. evolving vs. evaporating	Confined vs. outflowing		
Formation/ Regeneration	Thermal instability vs. blobs uplifted from the disk	orbiting blobs vs. condensing clumps (bloated star winds?)		
Velocity	Unconstrained	-10^4 - 10^4 km/s		
Density/ Temperature	Constant	Wide range (e.g., LOC model)		
	Requires global simulations:			
Size	Wide range	Sub parsec to parsec		
Number	1	10^3 - 10^7		
Shape	Blobs, shells, slabs, filaments?	Directed stream vs. failed wind vs. mist		
Motion	Keplerian orbit vs. embedded in wind	Swarm vs. clumpy outflow		
Emission/ Absorption	Optically thick vs. thin	Self-shielding is important?		


Intercloud medium
Cloud core
Conductive
interface
e- e- e-
Classical evaporation:
tau_evap
(Cowie & McKee 1977)
$\lambda_F = 2\pi\sqrt{\kappa_{eq} T_{eq}/(\rho_{eq}\Lambda_{eq})}$
Steady state configuration:
line cooling balances conductive heating
Begelman & McKee (1990)

CLOUD DYNAMICS:
ACCELERATION, EVAPORATION, AND REGENERATION
(SPITZER CONDUCTIVITY T^5/2)



To view animation please visit

http://www.physics.unlv.edu/~twaters/simulations.html

CLOUD FORMATION AND ACCELERATION

DYNAMICS OF THE NONLINEAR REGIME OF TI

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0, \tag{1}$$

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v}\mathbf{v} + p\,\mathsf{I}) = \mathbf{f}_{rad}, \tag{2}$$

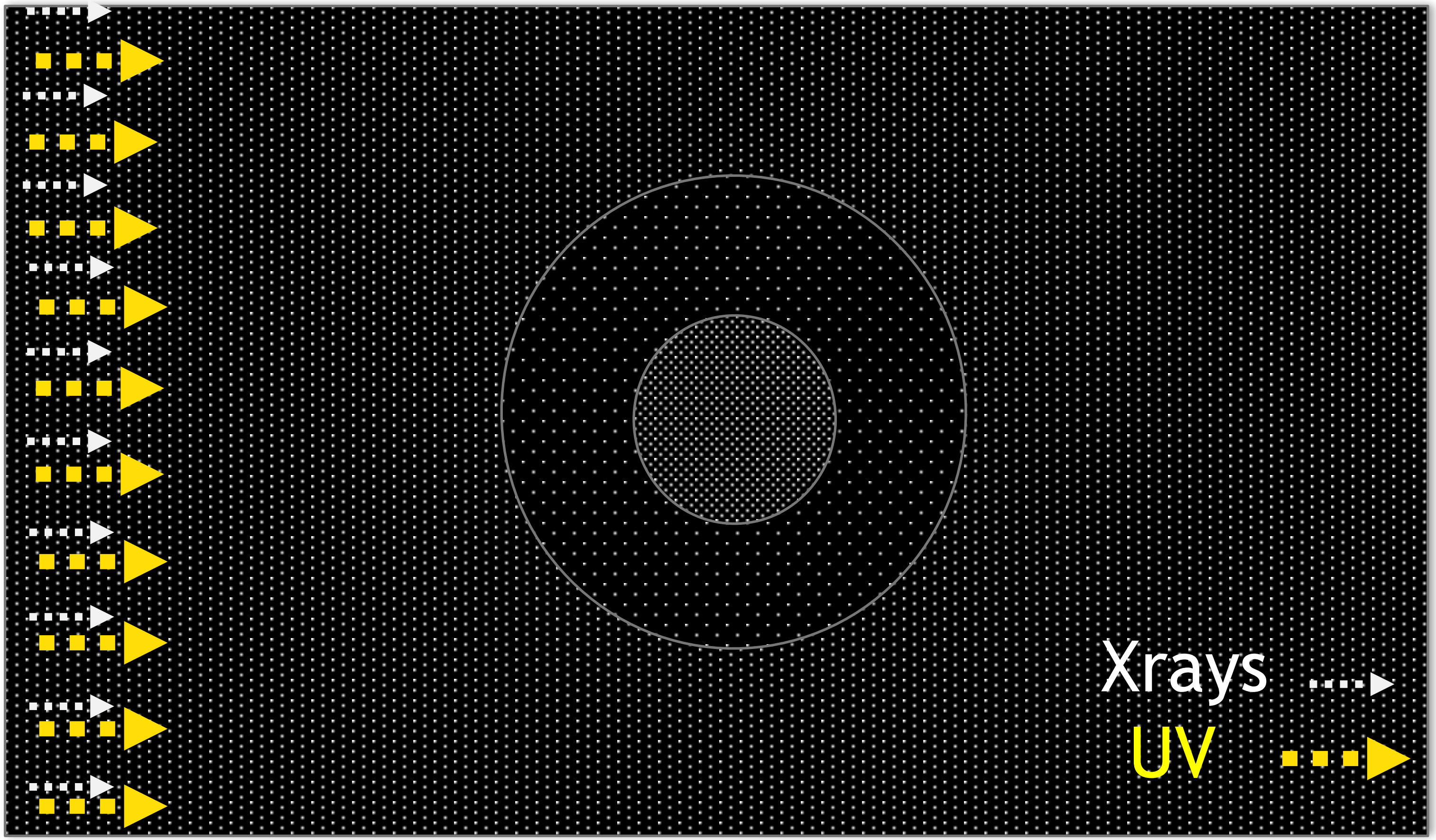
$$\frac{\partial E}{\partial t} + \nabla \cdot [(E+p)\mathbf{v}] = -\rho\mathcal{L} + \kappa_0 \nabla^2 T. \tag{3}$$

$$\begin{aligned}\mathbf{f}_{rad} &= \frac{\rho \sigma_{tot} \mathcal{F}_{tot}}{c} \hat{x} \\ &= \frac{\rho \sigma_e \mathcal{F}_X}{c} \left[(1 + f_{\rm UV}) + \sigma_X + f_{\rm UV} M_{\rm max} \right]\end{aligned}$$

See Proga & Waters (2015)

TI: THE NONLINEAR REGIME

Saturation of TI is a cloud formation process,
but it also naturally leads to <u>cloud acceleration</u> (PW15).



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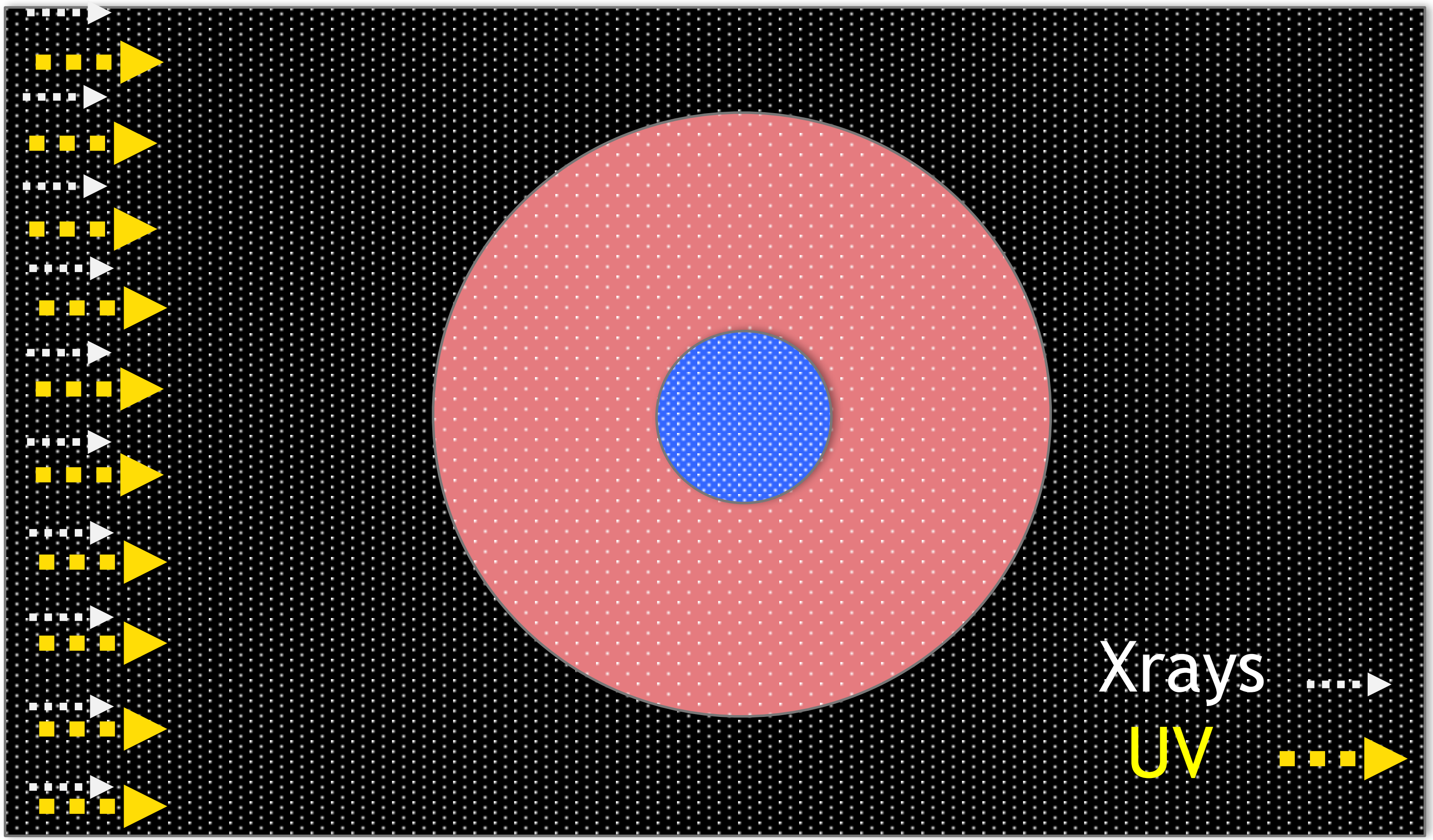

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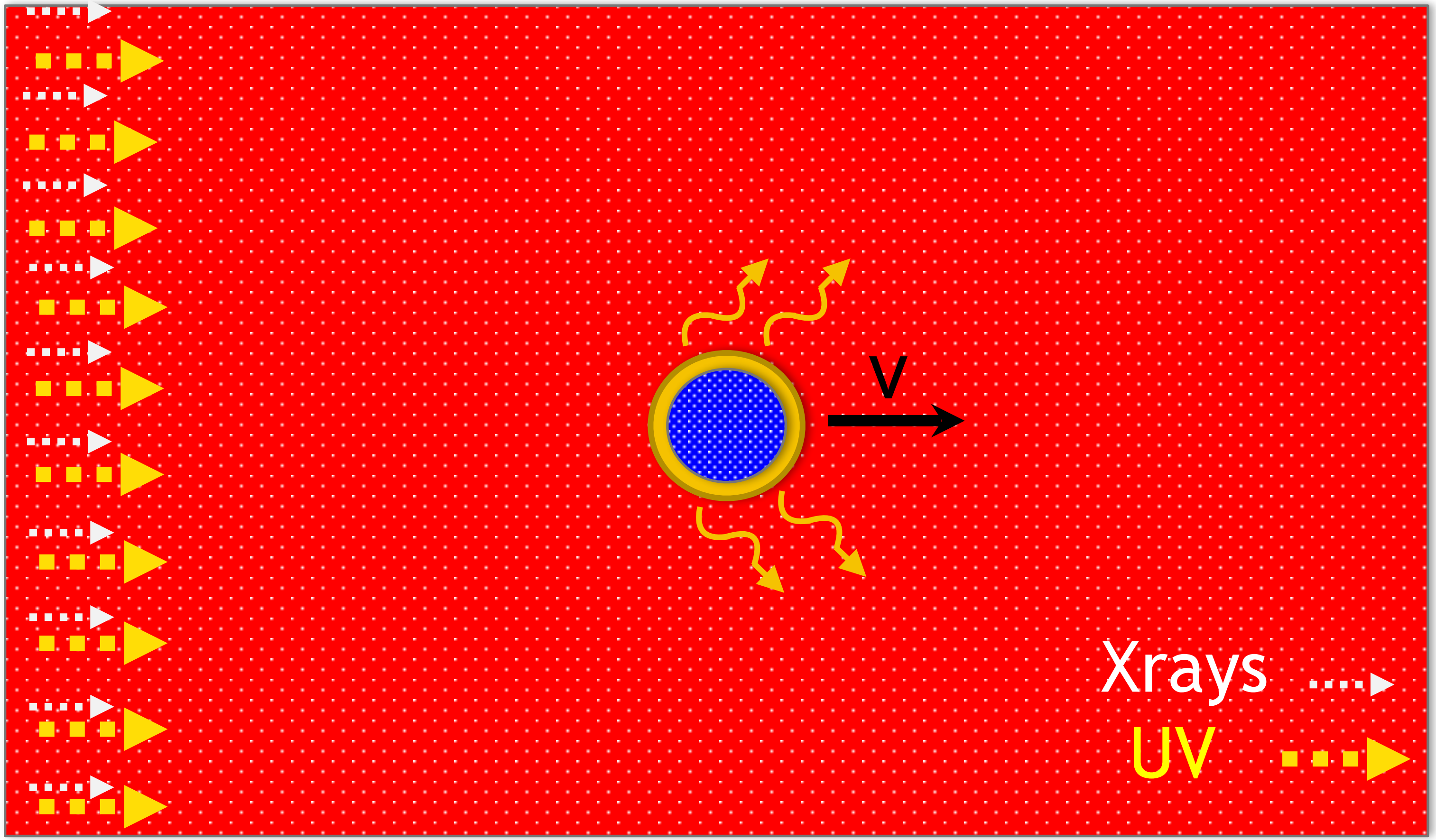

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Density/ Temperature	Constant	Wide range (e.g., LOC model)		
	Requires global simulations:			
Size	Wide range	Sub parsec to parsec	lambda of max growth rate?	
Number	1	10^3 - 10^7	1 becomes many	
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LOCAL OPTIMALLY EMITTING CLOUD PICTURE (LOC MODEL)

TABLE 1

OBSERVED AND PREDICTED LINE INTENSITIES

Emission Line (1)	Observed Intensity[a] (2)	Maximum Reprocessing (3)	LOC Integration[b] (4)
O VI λ1034 + Lyβ λ1026	0.1–0.3	0.28	0.16
Lyα λ1216	1.00	1.00	1.00
N V λ1240	0.1–0.3	0.06	0.04
Si IV λ1397 + O IV] λ1402	0.08–0.24	0.08	0.06
C IV λ1549	0.4–0.6	0.54	0.57
He II λ1640 + O III] λ1666	0.09–0.2	0.11	0.14
C III] + Si III] + Al III λ1900	0.15–0.3	0.28	0.12
Mg II λ2798	0.15–0.3	0.38	0.34
Hβ λ4861	0.07–0.2	0.08	0.09

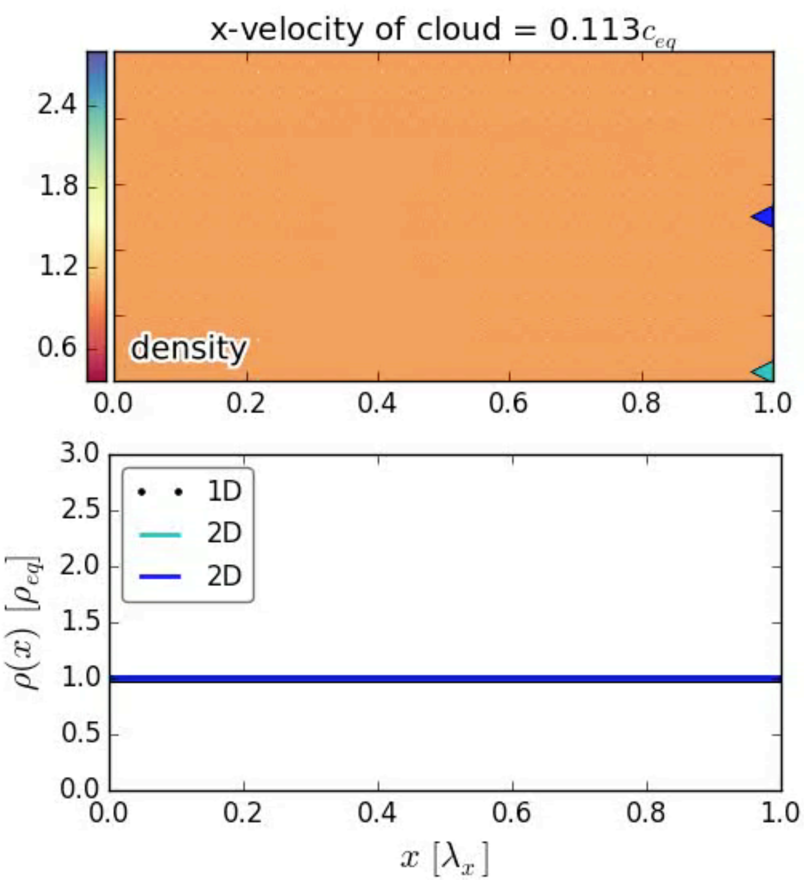
[a] Intensity relative to Lyα λ1216, combining data from Baldwin et al. 1989, Boyle 1990, Cristiani & Vio 1990, Francis et al. 1991, Laor et al. 1995, Netzer et al. 1995, and Weymann et al. 1991.

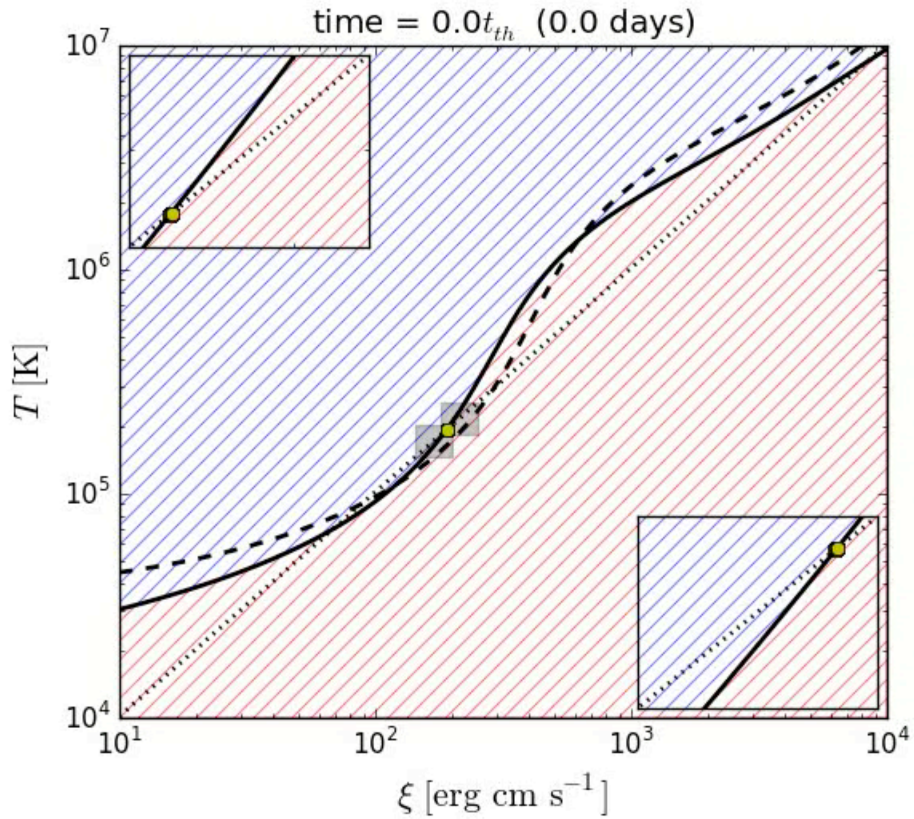
[b] Co-addition of emission from clouds as described in the text.

From Baldwin et al. (1995)

LUMINOUS
ORBITING
COVFEFE

CLOUD DENSITIES ARE CONSTRAINED TO RANGES DICTATED BY THE SED (AND CORRESPONDING S-CURVE)





Simulation by Tim Waters and Daniel Proga, UNLV

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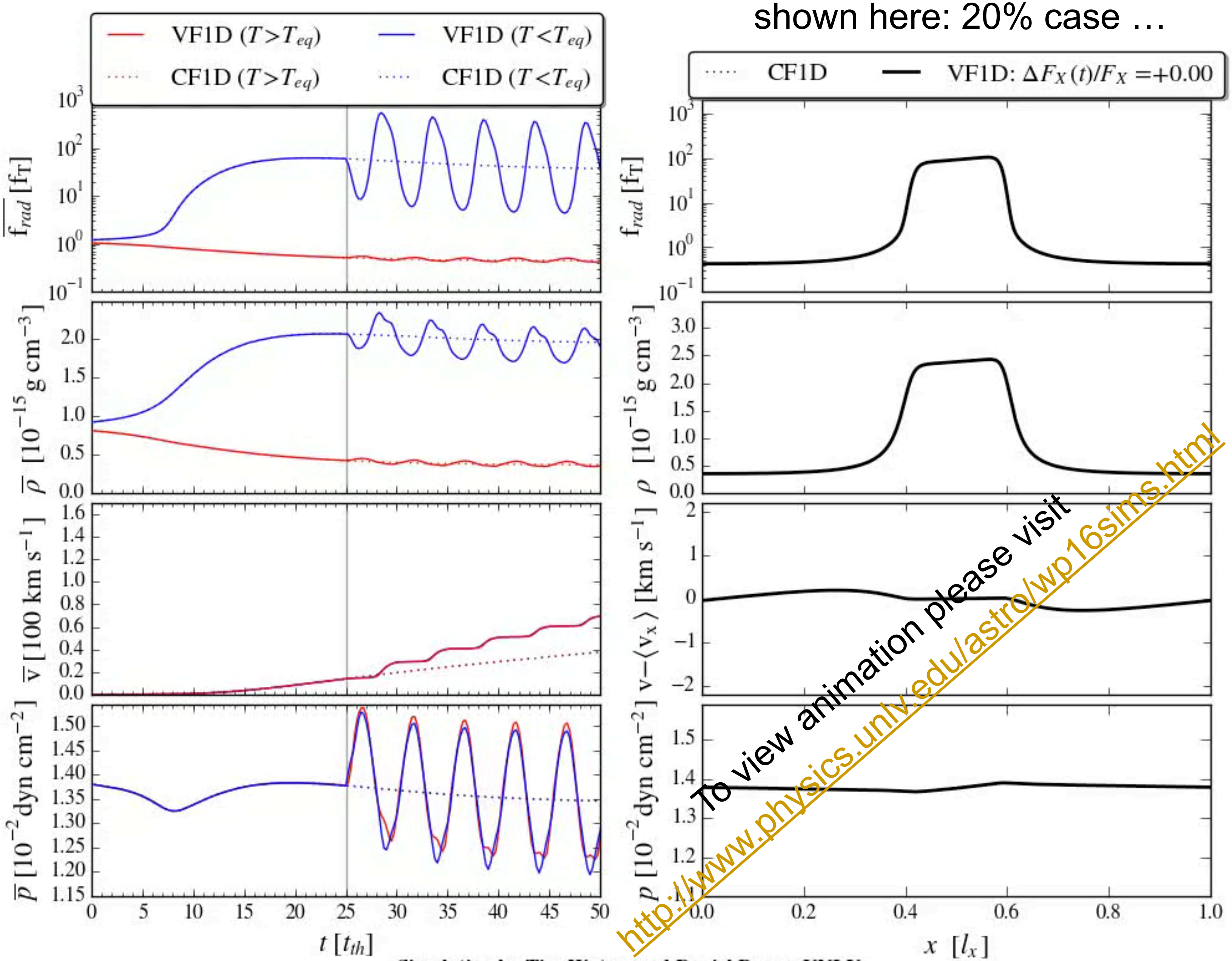
SINGLE ZONE != SINGLE CLOUD

CLUMPS RESPOND TO IONIZING FLUX VARIABILITY

shown here: 20% case …



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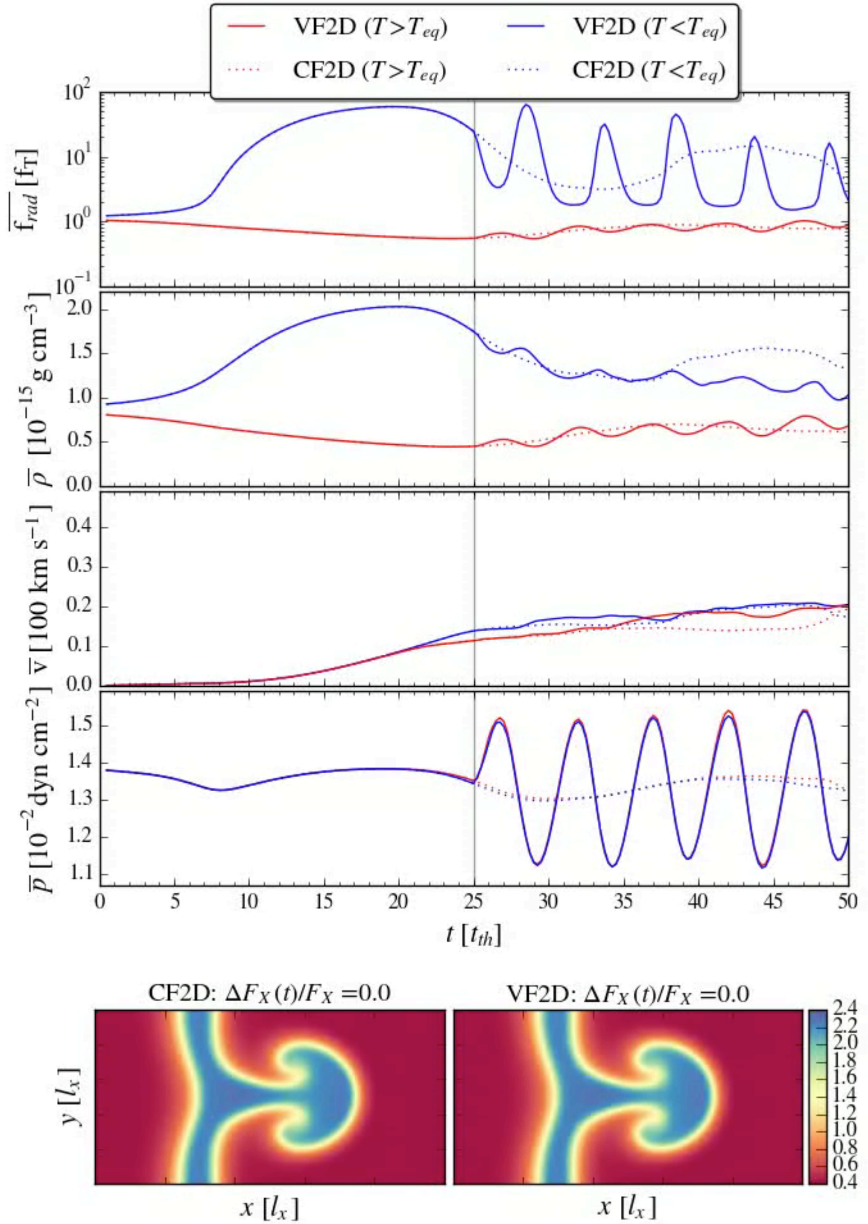


With (left) and without (right) 20% variability

From Waters & Proga (2016)

A SPECTRAL SIGNATURE FOR CLOUD ACCELERATION

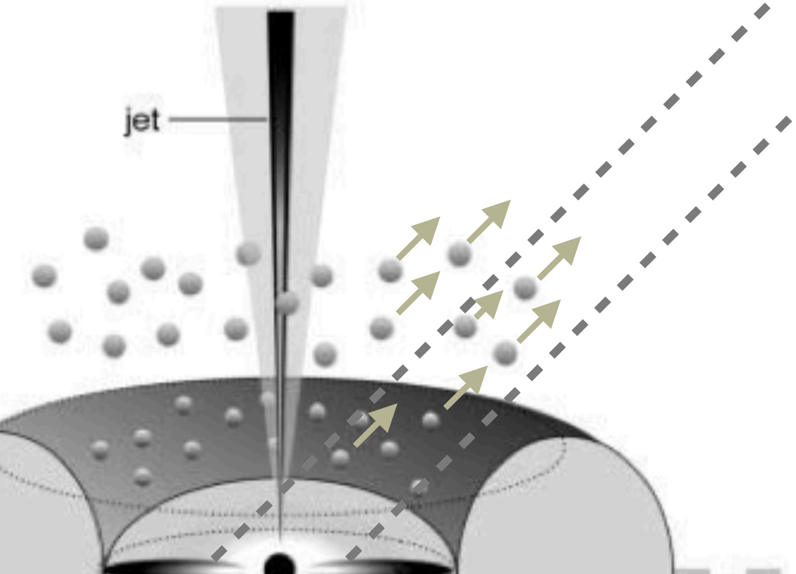
PPC model

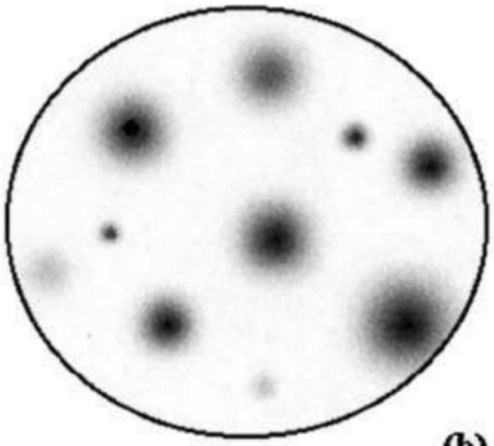
$$I_r = (1 - C_\nu) + C_\nu \, e^{-\tau_{\nu,r}};$$
$$I_b = (1 - C_\nu) + C_\nu \, e^{-2\,\tau_{\nu,r}}.$$

==>

$$\tau_{\nu,r} = -\ln I_r - \ln\left[\frac{I_r - I_b}{I_r - I_r^2}\right],$$
$$C_\nu = \frac{1}{1 + (I_b - I_r^2)/(1 - I_r)^2}.$$

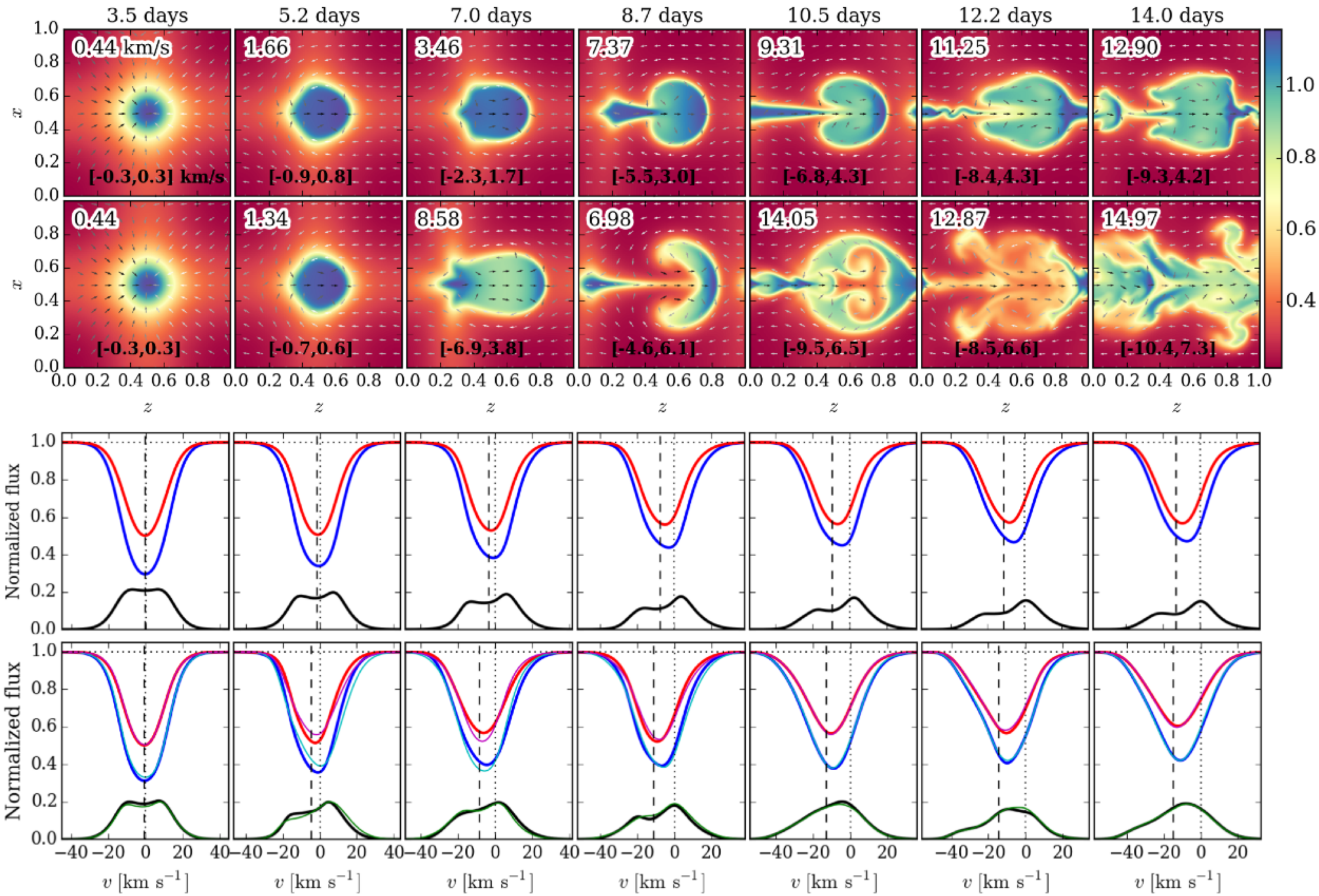
$$I_r - I_b = C_\nu e^{-\tau_{\nu,r}}(1 - e^{-\tau_{\nu,r}}),$$
$$\approx \begin{cases} C_\nu e^{-\tau_{\nu,r}} & \text{(near line center);} \\ \tau_\nu C_\nu e^{-\tau_{\nu,r}} & \text{(in the line wings).} \end{cases}$$





(b)

A SPECTRAL SIGNATURE FOR CLOUD ACCELERATION



From Waters et al. 2017

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Density/ Temperature	Constant	Wide range (e.g., LOC model)	d_min - d_max T_min - T_max	Determined by S-curve
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