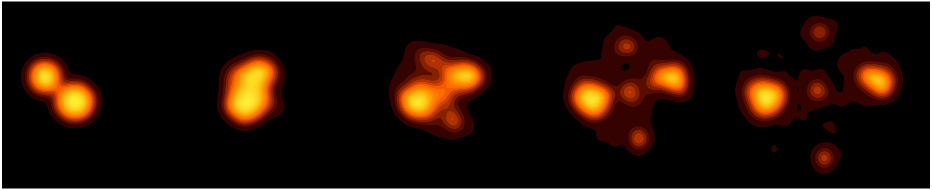
Searching for *isospin-drift sites* in **heavy dissipative** nuclear systems

P. Napolitani   IJCLab, Orsay

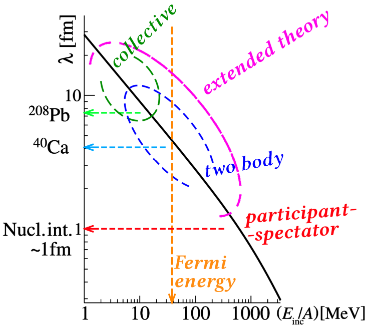
- *Isovector signals at Fermi energy* under the magnifying glass
- How can we deal with dissipative conditions ?

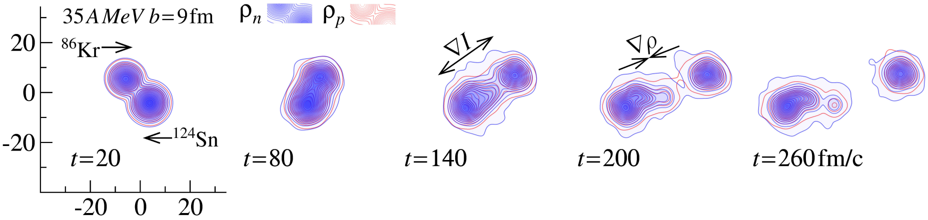


Dissipative collisions for the symmetry energy in a nutshell

- Transport models' usual assumptions : freeze-out, semiclassical EOM, locality...
- Hydrodynamic-like phenomenology :

$$j_n - j_p \propto \overbrace{\frac{\partial S(\rho)}{\partial \rho} I \nabla \rho}^{\textit{migration}} + \overbrace{S(\rho)\nabla I}^{\textit{diffusion}}$$





- Expectations : isovector signals (equilibration, neck...) ⇒ the form of S

Setting the (isovector) clock : a history of attempts

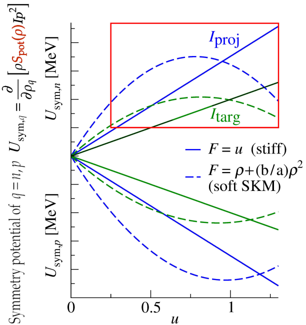
Dissipative collisions →
perturbations around saturation density

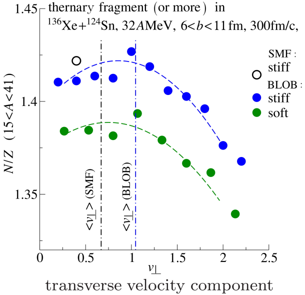
⇒ to the repulsive Coulomb, mean field adds a more or less repulsive contribution

⇒ *Exp.* : 'measure time" of asymmetry currents by using a portion of the system : *P-T overlap, neck, fragments, nucl. surface, LCP from compressed phase...*

⇒ *Theory* : build a model to test S vs ρ

MONTOYA ET AL. PRL73 (1994), BARAN ET AL. PREP410 (2005), LIONTI ET AL. PLB625 (2005), DITORO ET AL. EPJA30 (2006), B.A.LI ET AL. PREP464 (2008), BARAN ET AL. PRC85 (2012), HUDAN ET AL. PRC86 (2012), DE FILIPPO ET AL. PRC86 (2012), BROWN ET AL. PRC87 (2013), JEDELE ET AL. PRL118 (2017), RODRIGUEZ MANSO ET AL. PRC95 (2017), A.B. MCINTOSH, S.J. YENNELLO PPNP108 (2019), A. PAGANO ET AL., EPJA56 (2020)



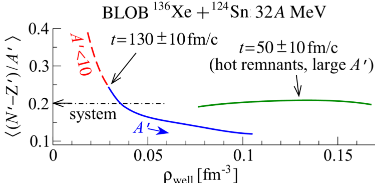


Distillation and clustering to further complexify the picture

- To higher-order effects from the combination of ∇I and $\nabla\rho$ we add :
- *phase separation (isospin distillation)* if ρ drops to low values.

→ If the ultimate fate is the disassembly of the system in a phase-transition-like process, the isospin content of the fragments is additionally affected by the phase separation (distillation).

[Chomaz,Colonna,Randrup Phys.Rep.389 (2004) ; Müller,Serot PRC52 (1995)]



- *clustering*, which may be related either to mean-field fluctuations or to inelastic particle collisions beyond two-body scattering truncation.

[P.Danielewicz G.F.Bertsch NPA533 (1991) 712, A.Ono JoP Conf.Series420 (2014) 012103, A.Ono PPNP105 (2019) 139]

Clustering may affect isospin transport [Coupland et al. PRC84 (2011) 054603 (2011)]

Adopting a stochastic Boltzmann-Langevin scheme

- Correlations beyond kinetic eq. approximately recovered by handling several mean fields

→ generated from the action of a fluctuating seed on the one-body density

For one MF trajectory n in τ_{BL} :

***Stochastic-TDHF* scheme**

$$i\hbar \frac{\partial \rho_1^{(n)}}{\partial t} \approx [k_1^{(n)} + V_1^{(n)}, \rho_1^{(n)}] + \overbrace{\bar{I}_{coll}^{(n)}}^{\text{average coll. term}} + \underbrace{\delta I_{coll}^{(n)}}_{\text{fluctuating coll. term}}$$

after τ_{BL}, it yields $\rho_1^{(n)} \to \{\rho_1^{(n_\lambda)}; \lambda = 1, ...\text{sub}_\lambda\}$

[Reinhard,Suraud AnnPhys 216 (1992); AnnPhys 355 (2015) Lacombe,Reinhard,Suraud,Dinh AnnPhys 373 (2016)]

Wigner tr. →

Boltzmann-Langevin

$f^{(n)}$: distribution functions → Fermi stat.at equilibrium

$$\frac{\partial f^{(n)}}{\partial t} = \{h^{(n)}, f^{(n)}\} + I_{UU}^{(n)} + \delta I_{UU}^{(n)}$$

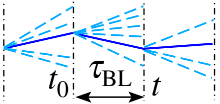
Markovian contrib. :

$$\langle \delta I_{UU}^{(n)}(\mathbf{r}, \mathbf{p}, t) \delta I_{UU}^{(n)}(\mathbf{r}', \mathbf{p}', t') \rangle = $$
$$= \mathbf{gain} + \mathbf{loss} = 2\mathcal{D}(\mathbf{r}, \mathbf{p}; \mathbf{r}', \mathbf{p}', t')\delta(t - t')$$

[Ayik,Grégoire PLB212(1988); NPA513(1990) Colonna,Chomaz,Randrup NPA567(1994)]

- Diffusion coeff. $\mathcal{D}$ from *Langevin term* →

→ intermittent fluctuation revival and bifurcations in the spirit of the *Brownian motion*



Mean-field point of view, adopting BLOB

Boltzmann-Langevin One Body

$$\frac{\partial f^{(n)}}{\partial t} - \{h^{(n)}, f^{(n)}\} = I_{\mathrm{UU}}^{(n)} + \delta I_{\mathrm{UU}}^{(n)} = g \int \frac{\mathrm{d}\mathbf{p}_b}{h^3} \int W(\mathrm{AB}\leftrightarrow\mathrm{CD})\, F(\mathrm{AB}\rightarrow\mathrm{CD})\, \mathrm{d}\Omega$$

transition rate occupancy

$$W(\mathrm{AB}\leftrightarrow\mathrm{CD}) = |v_{\mathrm{A}} - v_{\mathrm{B}}| \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\ ; \quad F(\mathrm{AB}\rightarrow\mathrm{CD}) = \Big[(1-f_{\mathrm{A}})(1-f_{\mathrm{B}}) f_{\mathrm{C}} f_{\mathrm{D}} - f_{\mathrm{A}} f_{\mathrm{B}} (1-f_{\mathrm{C}})(1-f_{\mathrm{D}})\Big]$$

A, B, C, D : extended equal-isospin phase-space portions of size=nucleon imposed by the variance $f(1-f)$ in h^3 cells at equilibrium

[Napolitani,Colonna PLB726 2013 ; PRC96 2017]

Clusters and fragments from fluctuations :

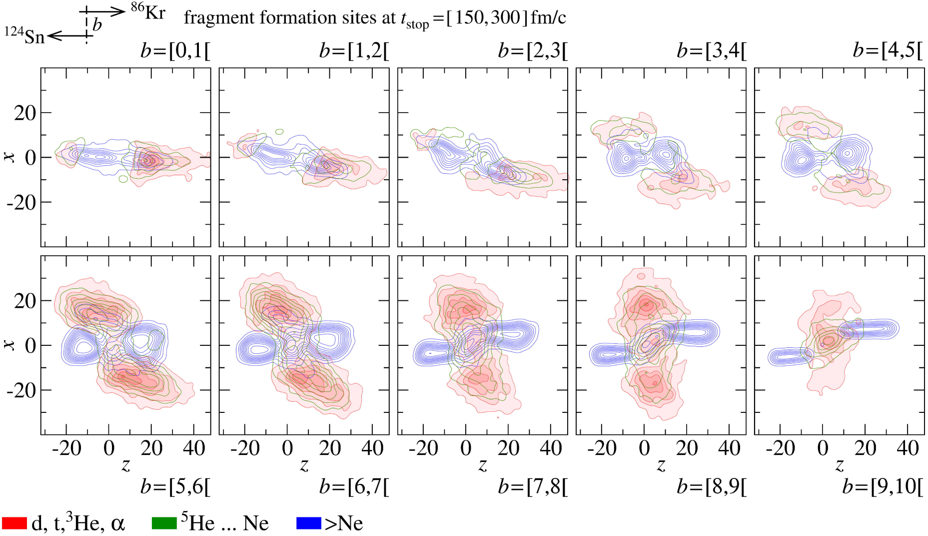
clusters, like heavier fragments, emerge naturally from potential ripples and are not related to a specific treatment

→ the same framework for distillation and clustering : variance δ^2 of $N'-Z'$ distr. of potential ripples in accordance with the fluctuation-dissipation th. : $\quad Y \approx \exp[-(\delta^2/A')\, C_{\mathrm{sym}}(\rho)/T]$

⇒ *Distillation behaviour* : $< N'-Z' >$ more n-rich in more volatile phases

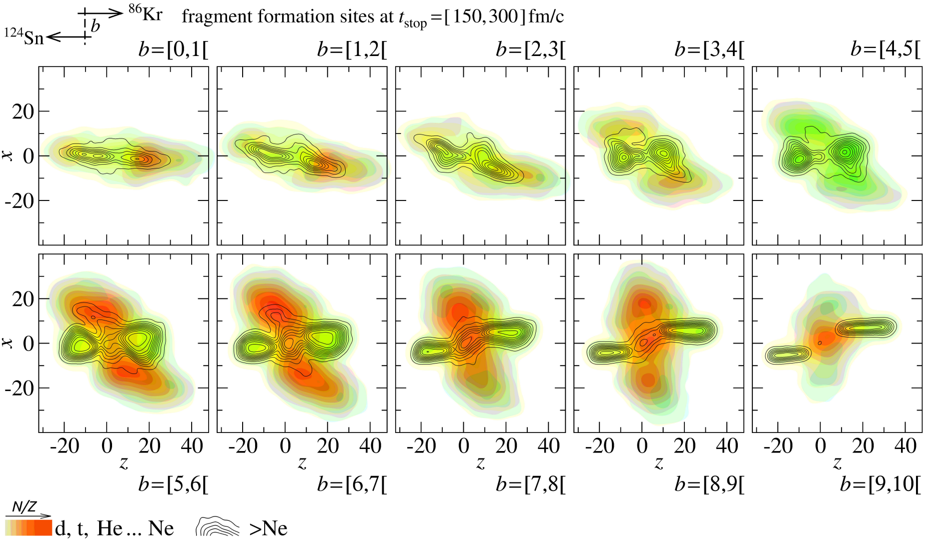
Step 1 : All dynamical mean-field trajectories in $^{86}Kr+^{124}Sn$ 35*A*MeV

- searching for low density mechanisms : neck and sideways emission



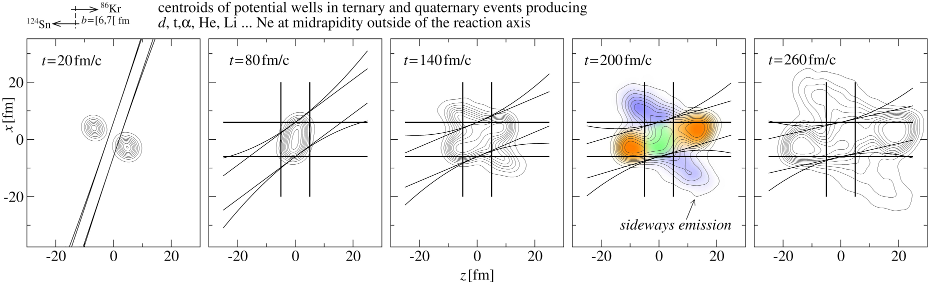
Step 2 : macroscopic survey of n and p densities

- we can associate both neck and sideways areas to iv-transport hotspots



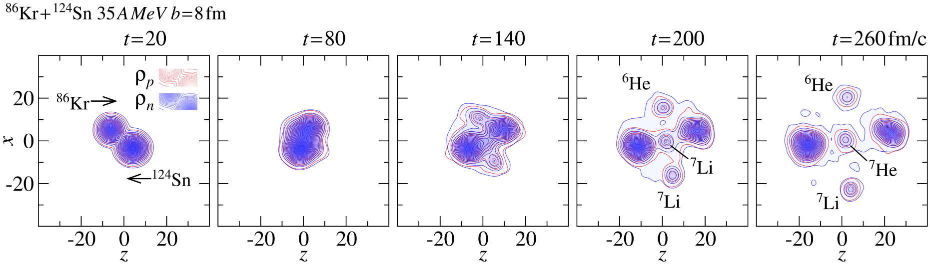
Step 3a Analysis of single stochastic events

centroids of potential wells in ternary and quaternary events producing
d, t,α, He, Li ... Ne at midrapidity outside of the reaction axis



Step 3b Analysis of single stochastic events

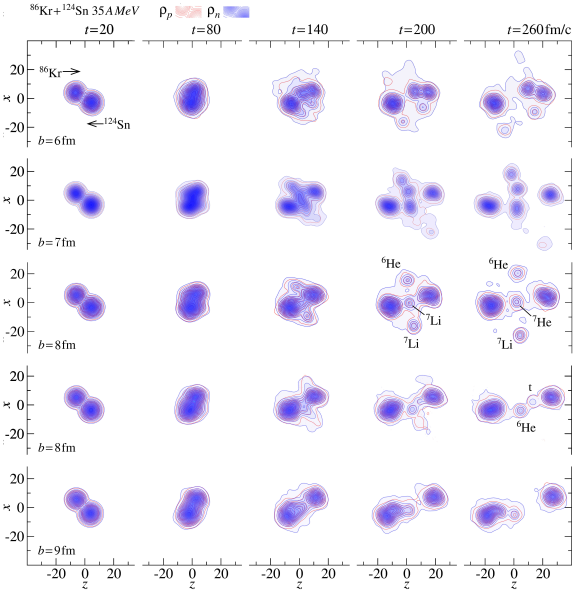
- paradigmatic event showing neck + sideways



At the level of single stochastic events, all mechanisms (sideways and neck) mix to a large extent and it is difficult to distinguish

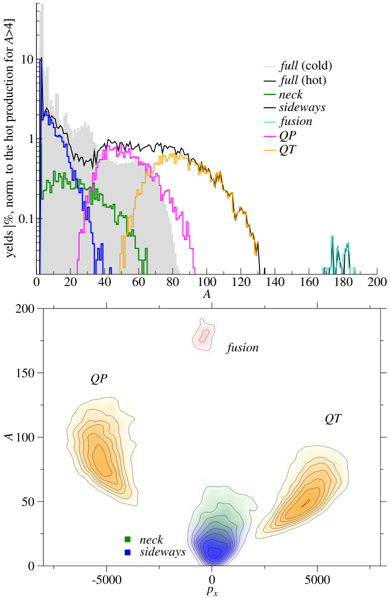
Microscopic insight : stochastic patterns

Gradual transition as a function of *b* from a multifragmentation-like contribution to neck, passing through a combination of the two (*b*=8fm)

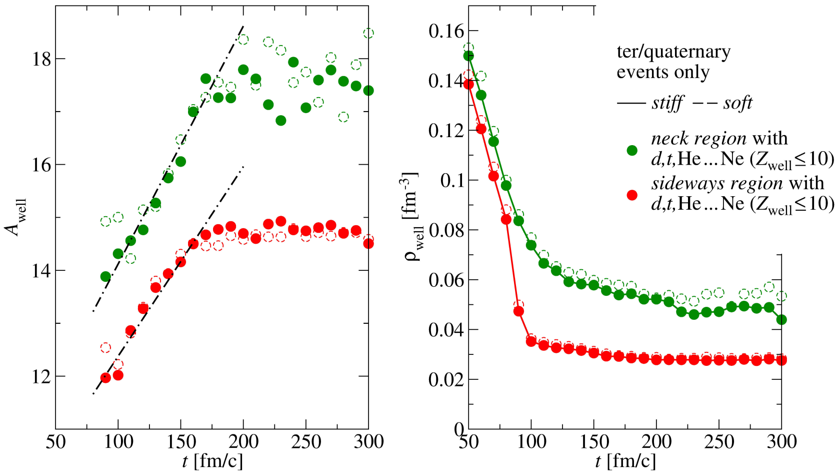


Global production survey

sideways and neck production compete in producing light fragments at midrapidity, sideways produces lighter clusters

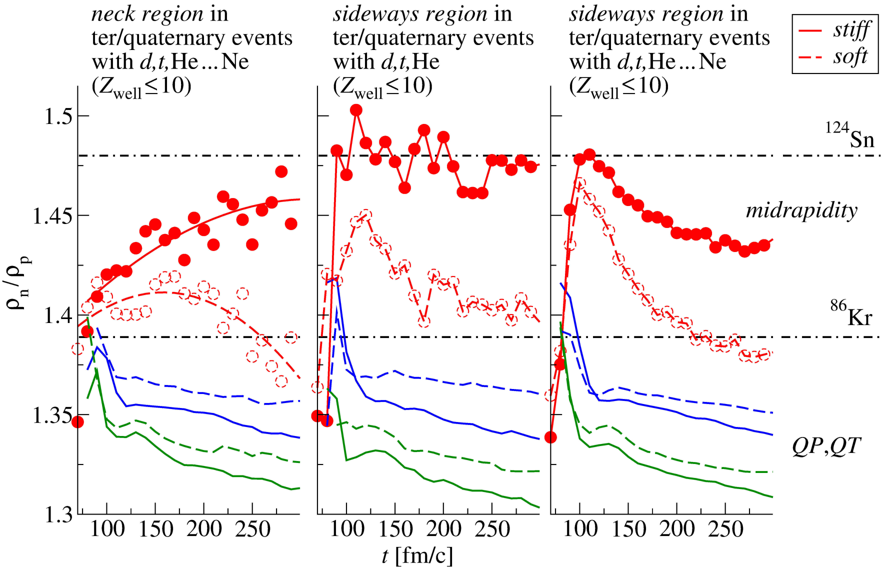


Tracking cluster/fragment formation properties



different densities and chronology, different growth rates
affected by interference (see next)

Microscopic tracking of cluster-/fragment-precursor properties



Conclusions

- Neck and sideways emission are totally different mechanisms : different grow rates, displaced in time, extension in time.

- Sideways emission is related to the phenomenology of phase-transition signals where the isospin signal arises abruptly. Later on it slows due to an interference with the neck process (drifts between the two hotspots).

- Requirements : stable mean field, stochastic character. Common statistical assumptions, i.e. freeze out or neck kinematics in absence of an environment, would not hold.

- Open question : what does a different combination of fluctuation+clustering prescription produce in situation of transition between two mechanisms ?

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