国家天文台青年学术交流

云核速度弥散探测分子云

钱磊

国家天文台

FAST运行和发展中心

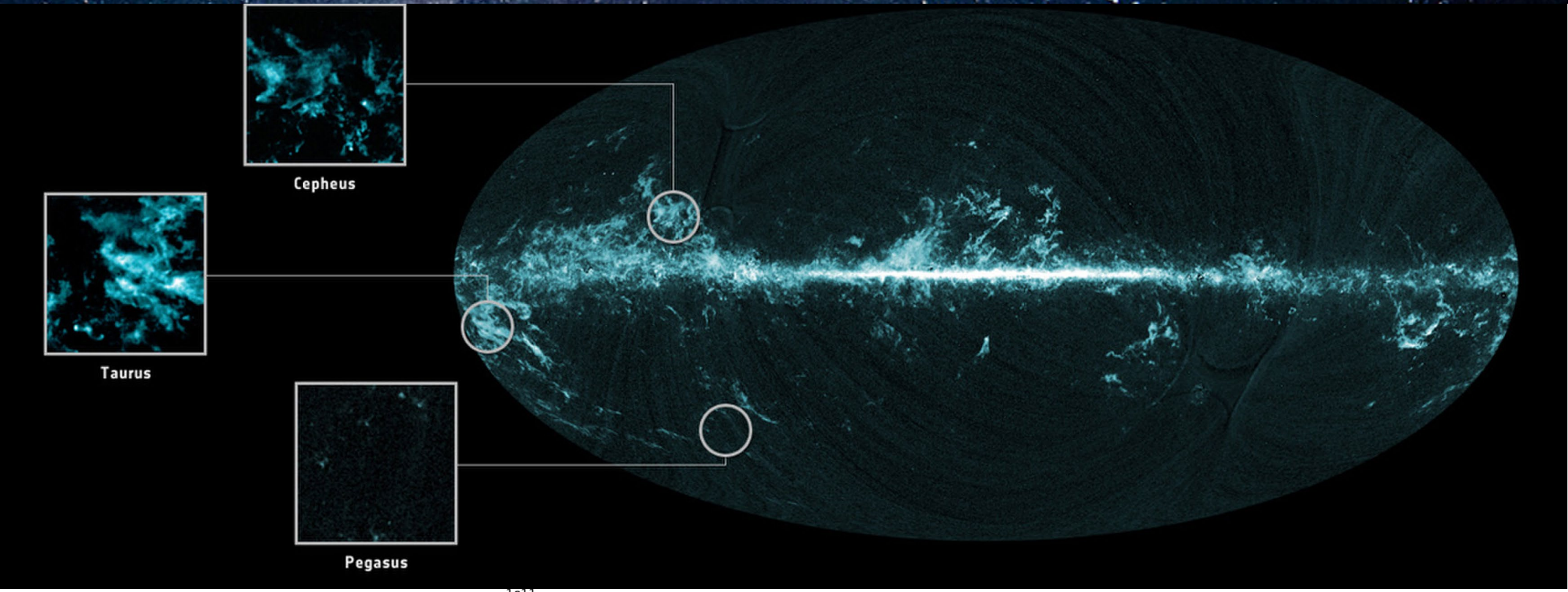
2022年11月 ·北京

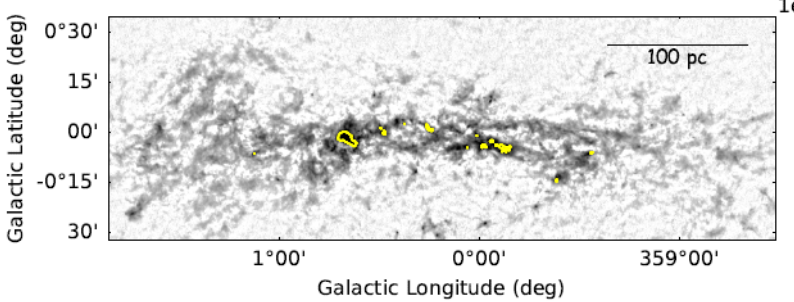
目录

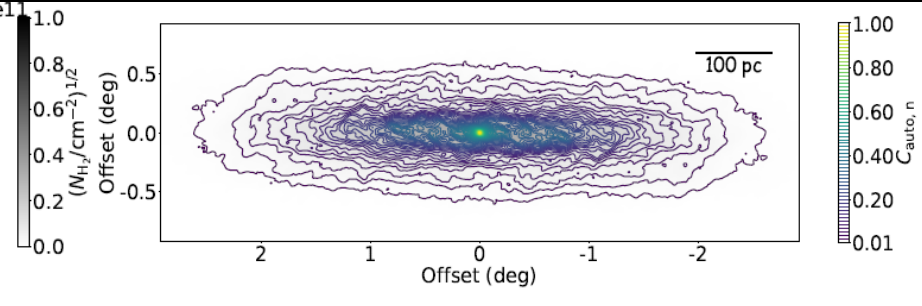
01

分子云结构和湍流运动

分子云结构和湍流运动







Cai, Li, Qian 2021, RAA, 21, 194

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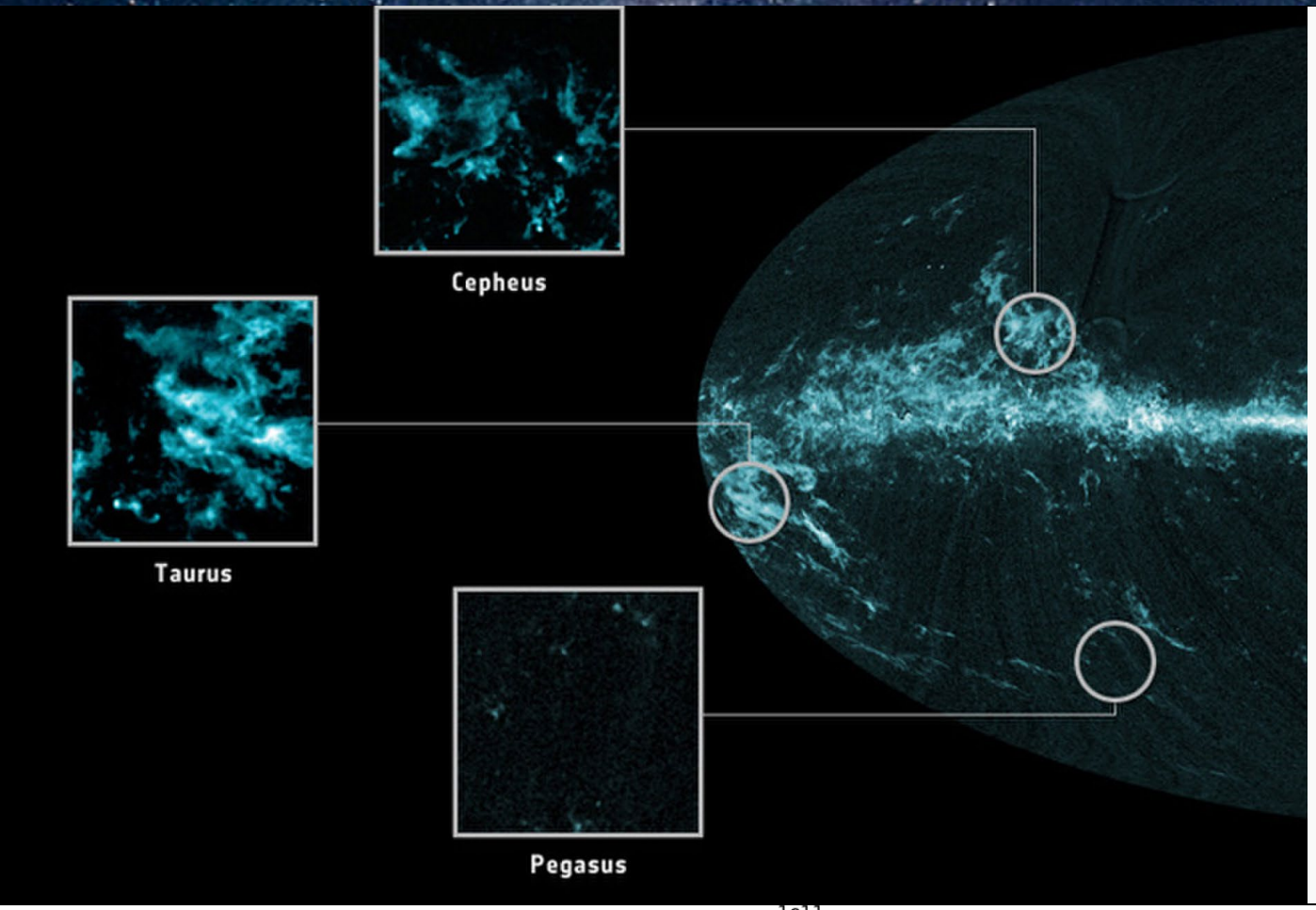
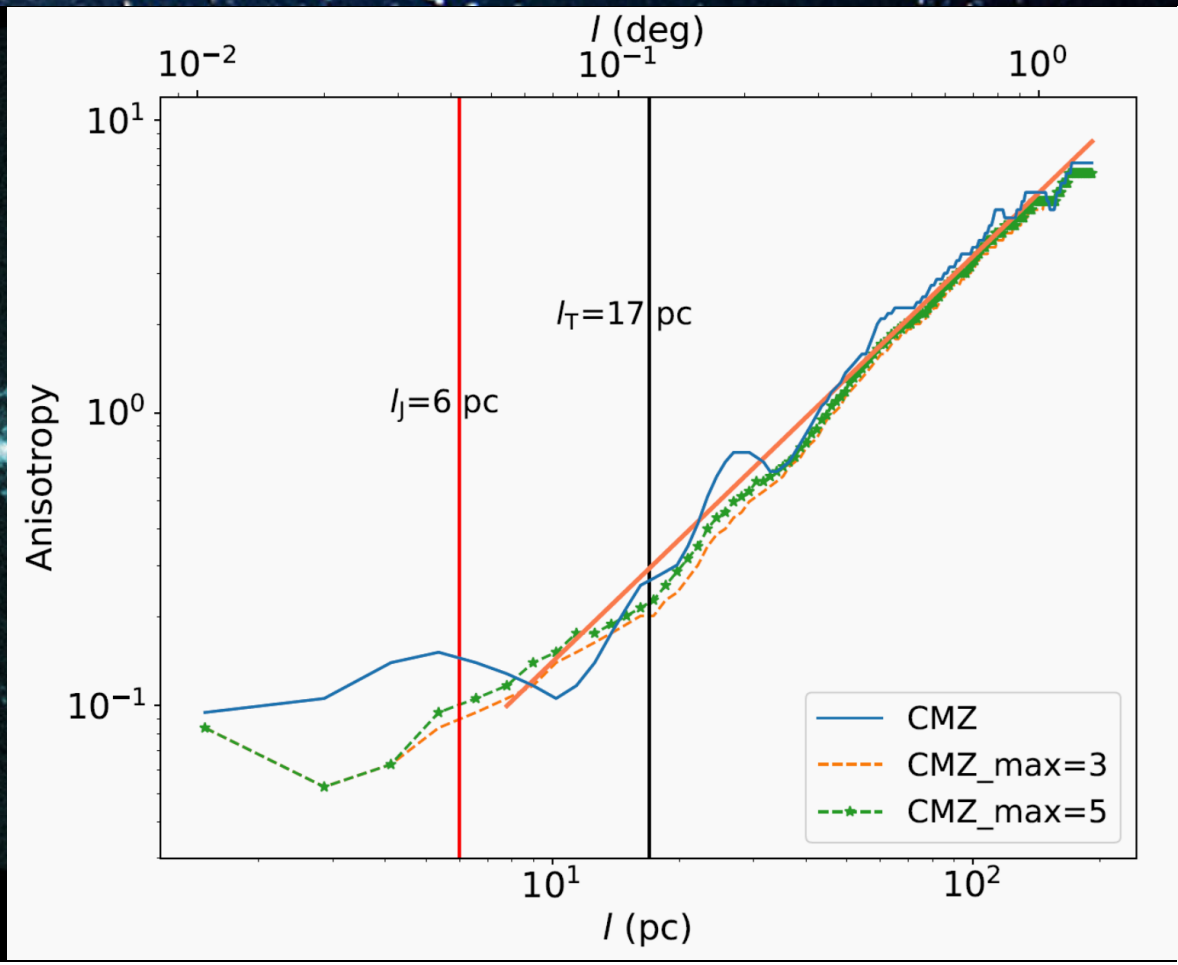
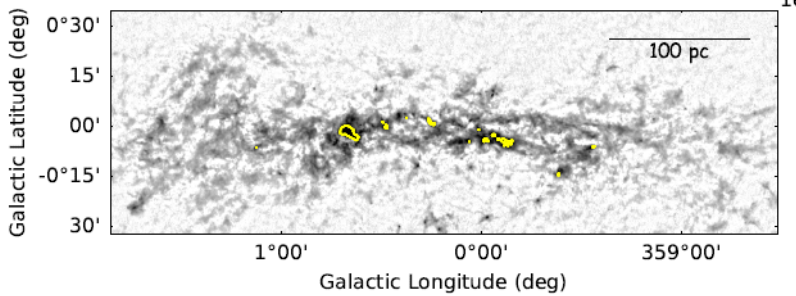
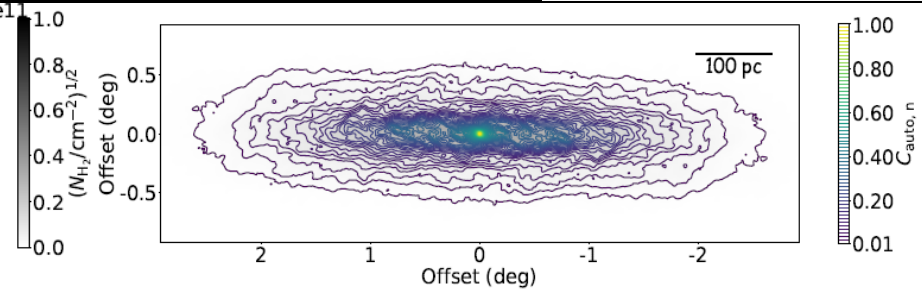








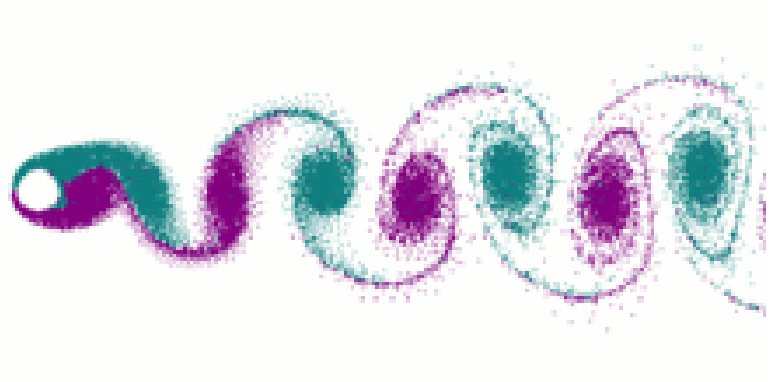
Cai, Li, Qian 2021, RAA, 21, 194

分子云结构和湍流运动

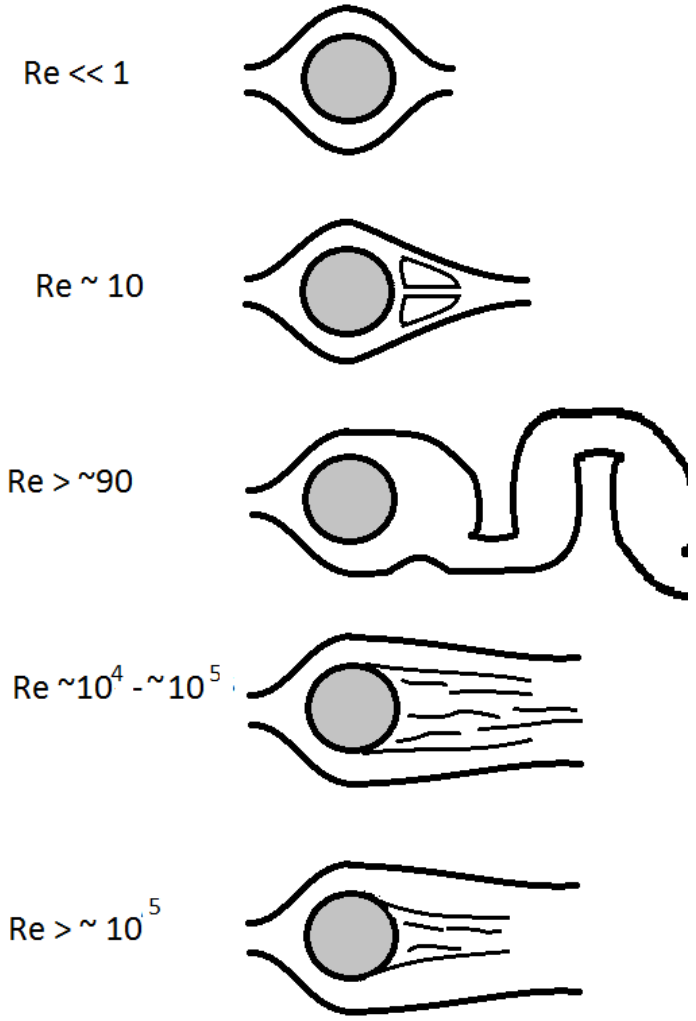
雷诺数

Reynolds Number

$$\mathrm{Re} = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{\rho \mathbf{v} L}{\mu} = \frac{\mathbf{v} L}{\nu}$$



——Wikipedia



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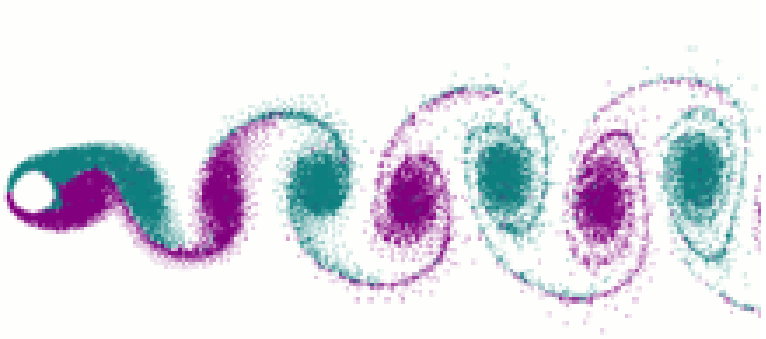
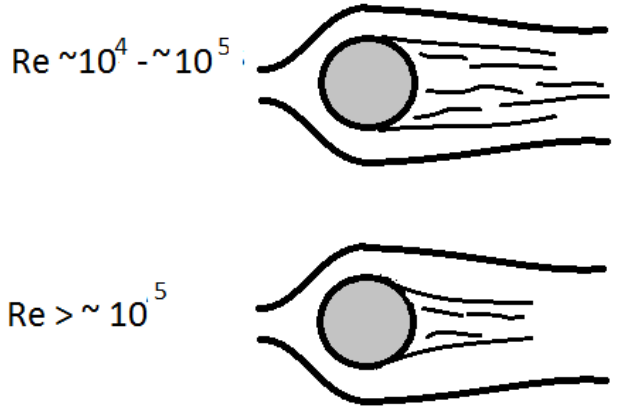


——Wikipedia

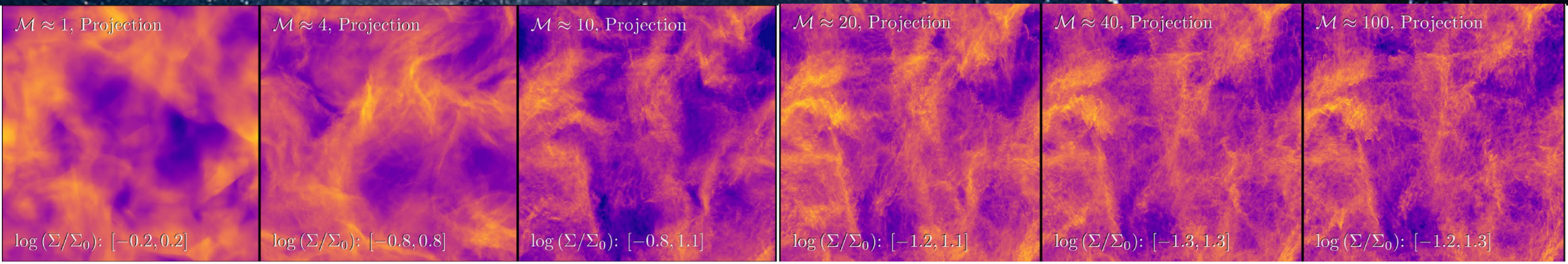
分子云

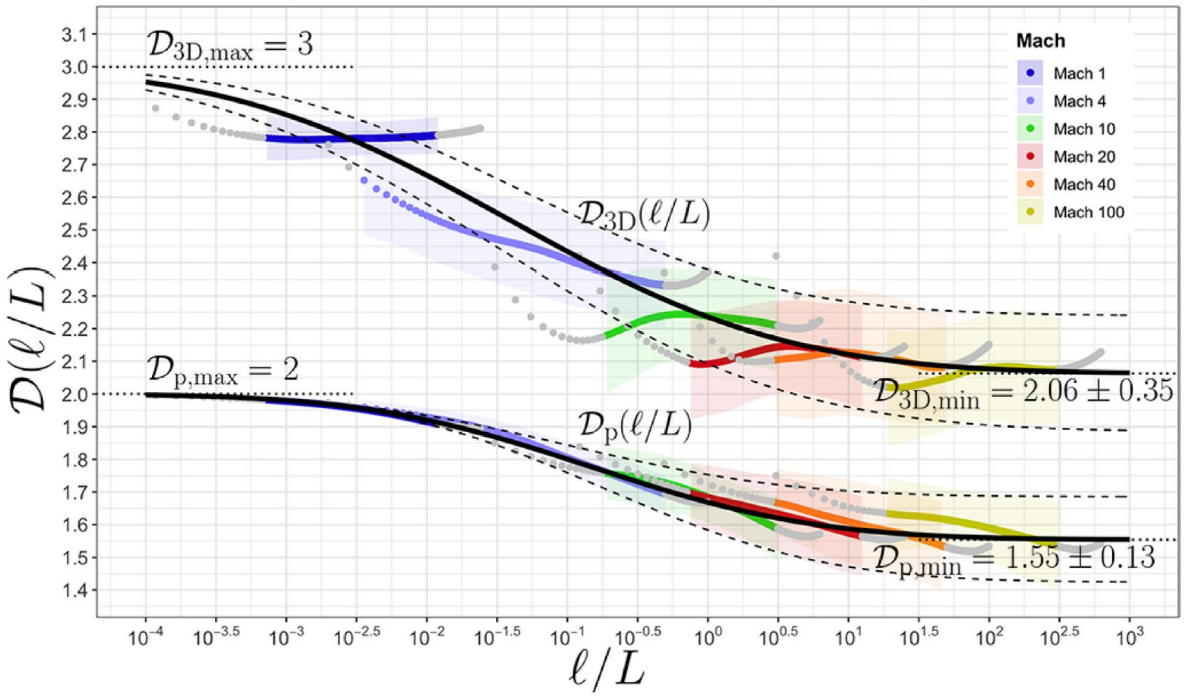
Molecular Clouds

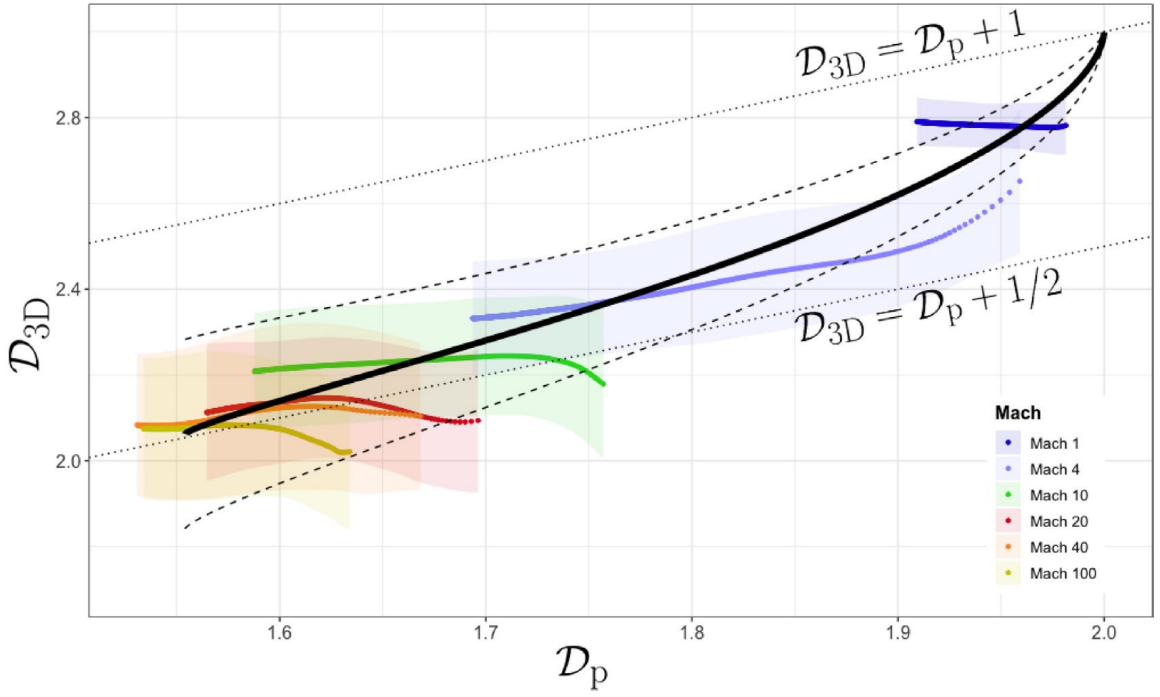


$$\rho = 1.67 \times 10^{-22}\ \mathrm{g/cm^3}$$
$$v = 10\ \mathrm{km/s}$$
$$L = 10\ \mathrm{pc}$$
$$\mu = 2.5 \times 10^{-7}\ \mathrm{kg\ /(m\ s)}$$
$$Re \sim 10^9$$

分子云结构和湍流运动







Beattie, Federrath, Klessen, 2019, MNRAS, 487, 2070

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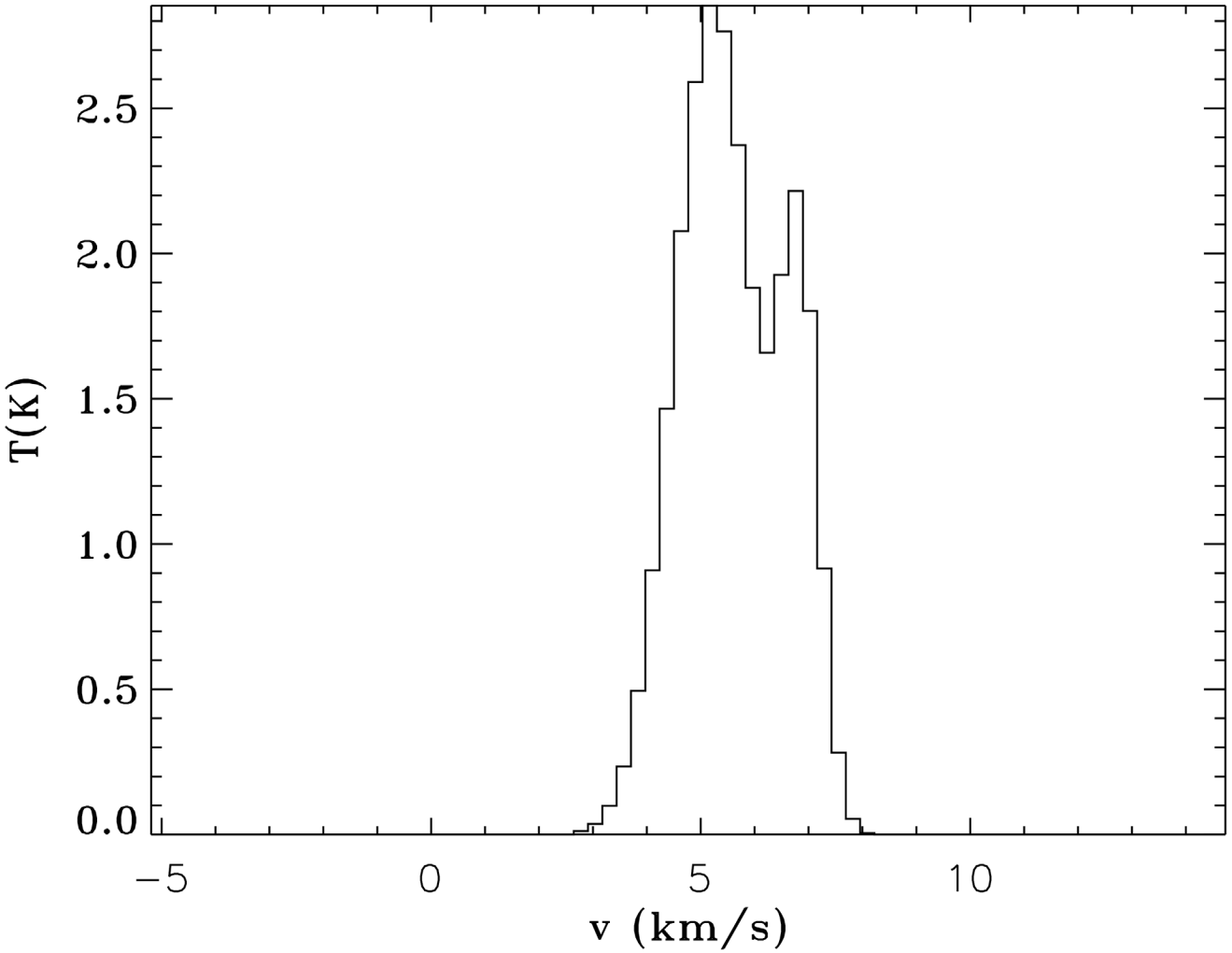
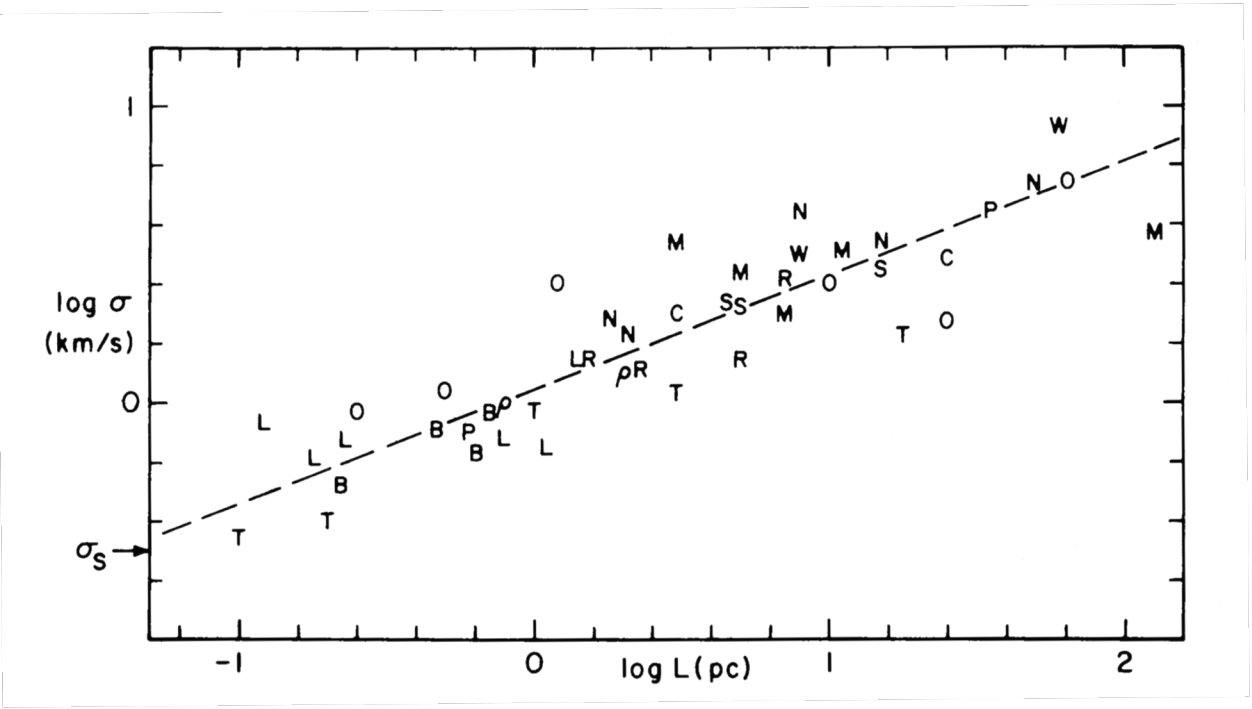


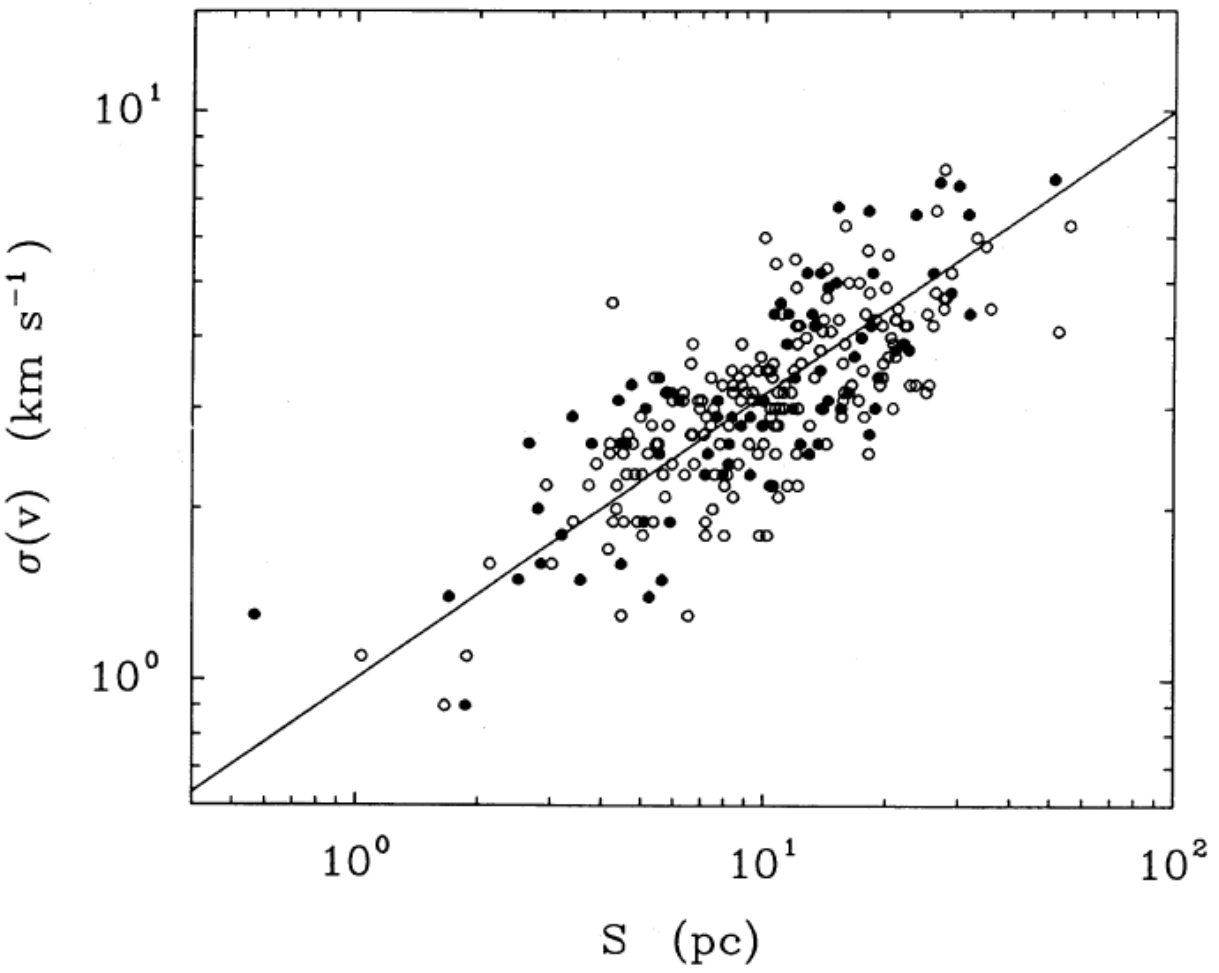
$$(kT/m)^{1/2}$$

$$\sim 0.05 \left(\frac{T}{10\mathrm{K}}\right)^{0.5} \left(\frac{m}{m_{\mathrm{CO}}}\right)^{-0.5} \mathrm{km\ s^{-1}}$$

Qian, Li, Goldsmith, 2012, ApJ, 760, 145

分子云结构和湍流运动





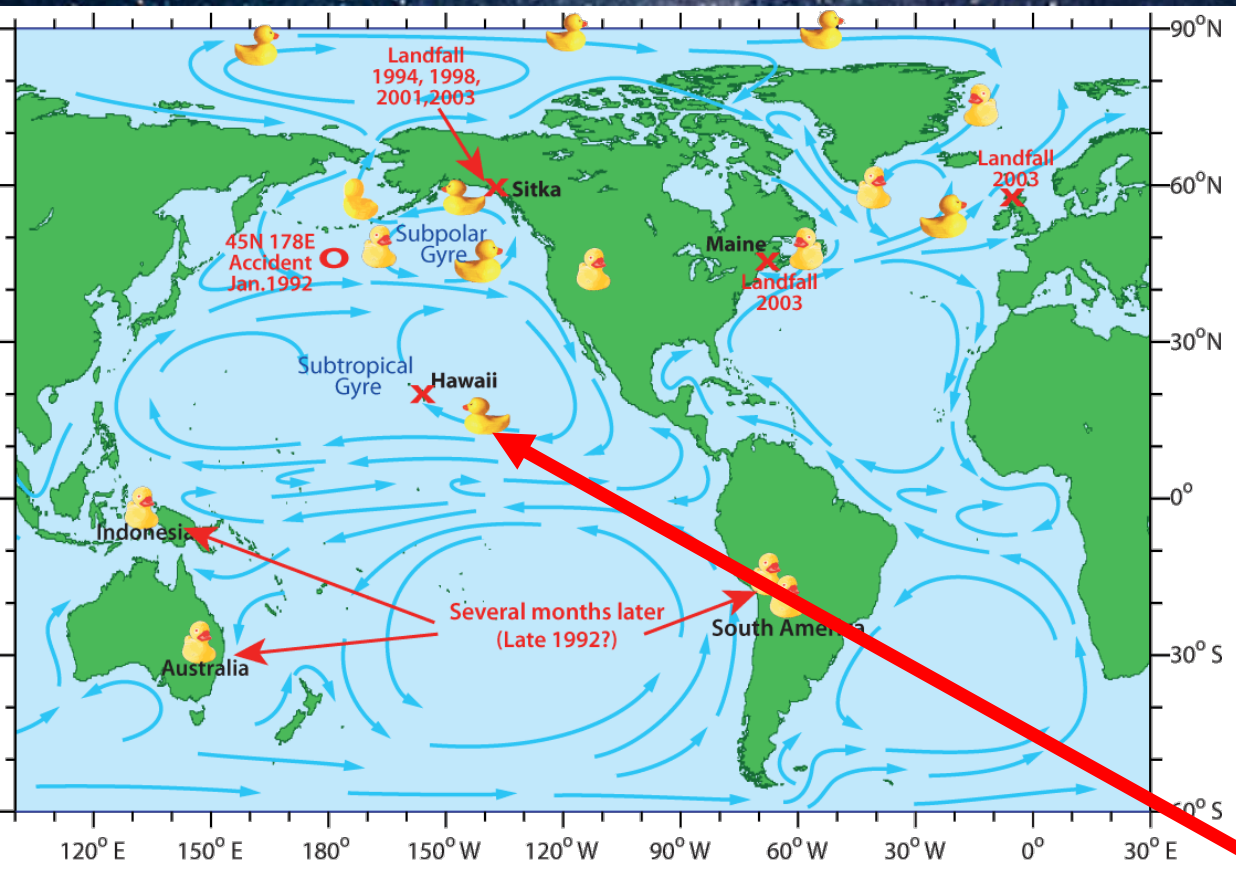
$\sigma \propto S^{0.38}$（Larson 关系）→不可压缩湍流

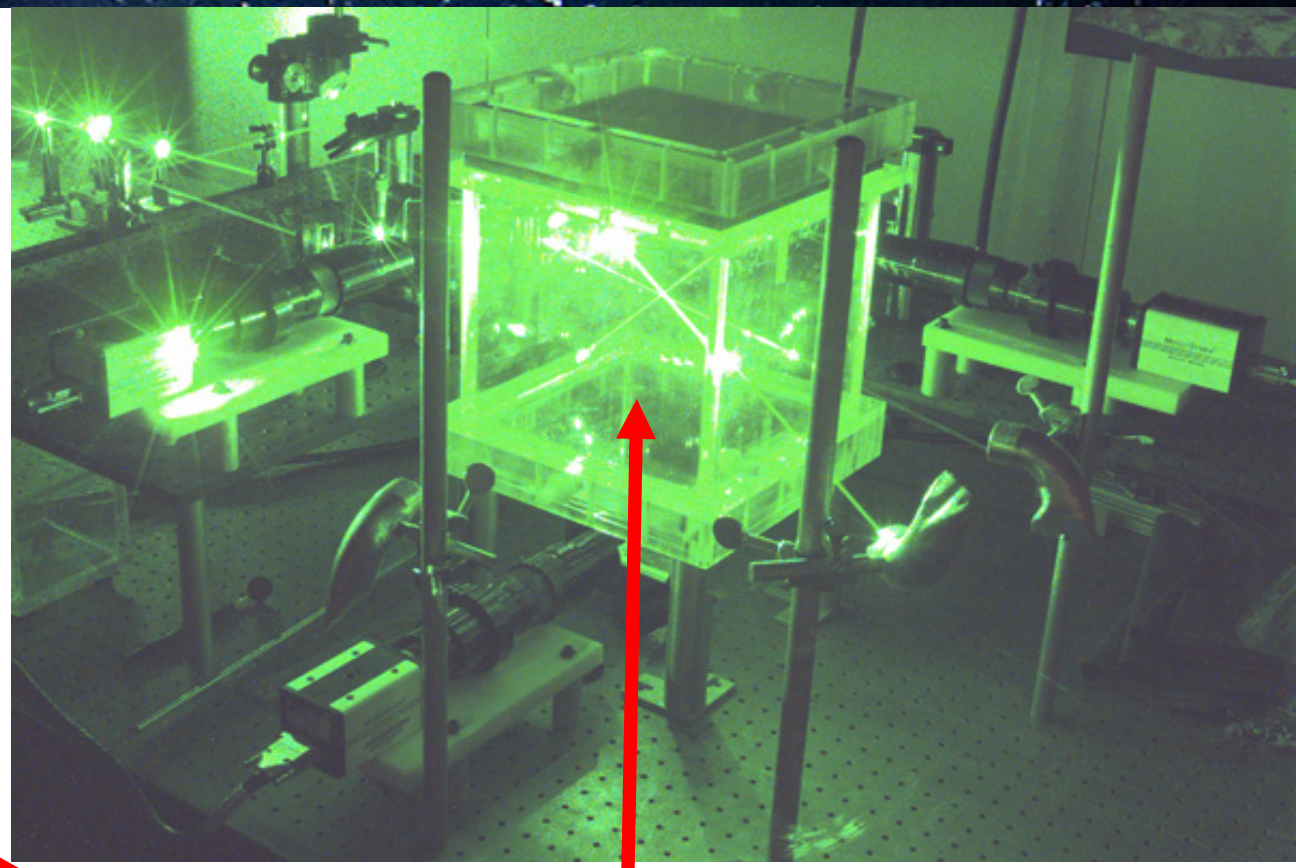
Larson, 1981, MNRAS, 194, 809

$\sigma \propto S^{0.5}$（修正的Larson 关系）→可压缩湍流

Solomon et al., 1987, ApJ, 319, 730

分子云结构和湍流运动





流动的实验测量

示踪粒子

分子云结构和湍流运动

Genus statistics
Dendrograms
Modified velocity centroids
Spatial power spectrum
Bispectrum and bicoherence
Velocity coordinate spectrum (VCS)
Velocity channel analysis (VCA)
Delta variance
Wavelet transform
Principal component analysis eigenvalues
Spectral correlation function
Intensity probability density function
Higher order statistical moments
Cramer statistic

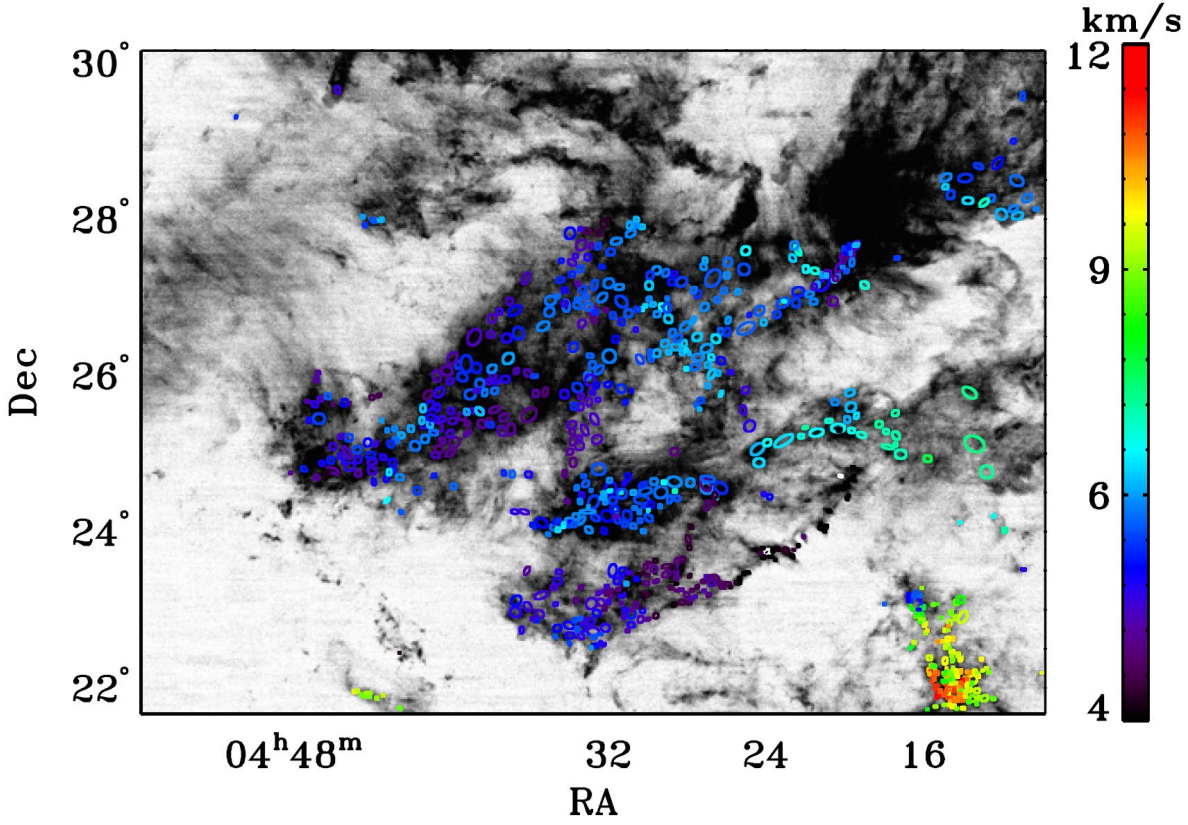
Statistic	Noiseless		Free-fall		Added noise	
	Noise *p*-value	Signal *p*-value	Noise *p*-value	Signal *p*-value	Noise *p*-value	Signal *p*-value
VCS	0	1	0	1	0.0751	0
VCS Large Scale	0	1	0	1	0.0689	0
SCF	0	1	0	1	0	1
Skewness	0	1	0	1	0	1
VCS Small Scale	0.0153	1	0.1534	0.9968	–	–
Del. Var. Centroid Curve	0.0001	1	0.0002	0.0147	0	0.9997
Kurtosis	0	1	0.0002	0.0001	0	0.2387
VCA	0	0.5308	0	0.2985	0	0.4956
Bispectrum	0.2442	0.3581	0	1	0.0993	0.3777
PDF Lognormal	0.0229	0.1963	0.0224	0.1306	0.0047	0.0012
Cramer	0	0.0299	0	0.0186	0	0.0272
Del. Var. Centroid Slope	0.0009	0.0412	0.0002	0.0056	0.0002	0.0961
MVC	0.0001	0.0008	0.0382	0	0.0003	0.0074
Spatial Power Spec.	0.0001	0.0008	0.0384	0	0.0003	0.0090
Genus	0.0051	0.0001	0.0109	0	0.0183	0.0004
Dendro. Num.	0.0992	0	0.0001	0.1830	0.0418	0.0007
PCA Eigenvalues	0.0060	0	0	0.6199	0.0404	0
Wavelet	0.0097	0	0.0870	0	0.0328	0
Del. Var. Curve	0.0315	0	0.0076	0	0.0848	0
Del. Var. Slope	0.0451	0	0.0044	0	0.0847	0
Dendro. Hist.	0.0122	0	0.0233	0	0.0083	0

Koch et al., 2017, MNRAS, 471, 1506

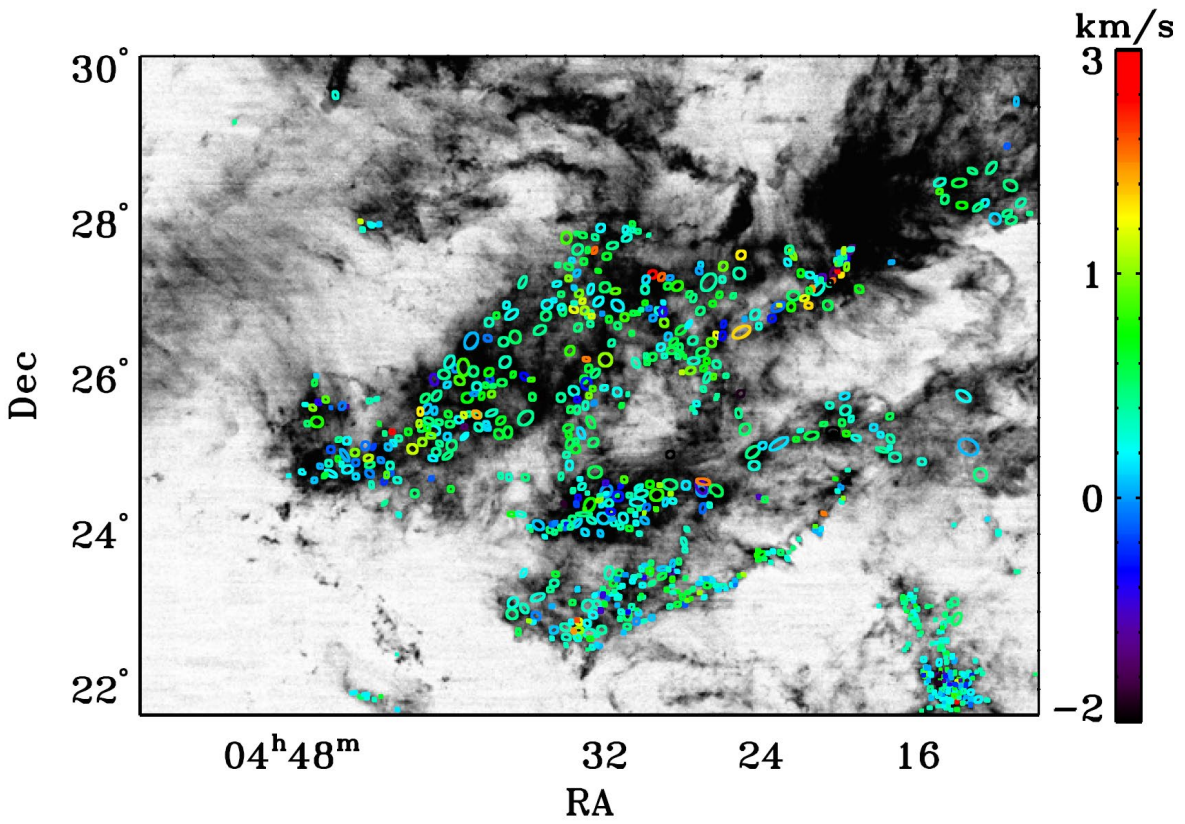
02

云核速度弥散方法

云核速度弥散方法



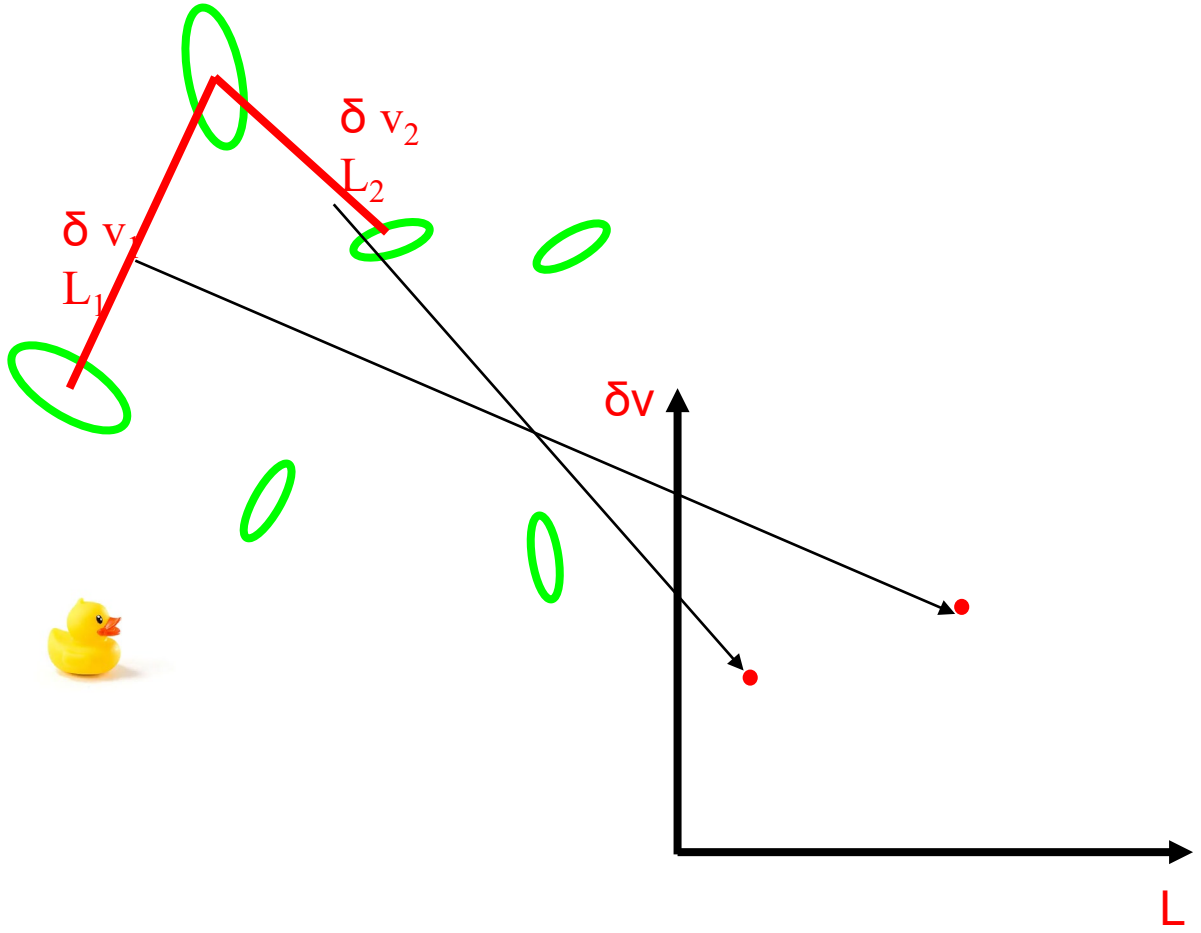
^{13}CO云核中心速度

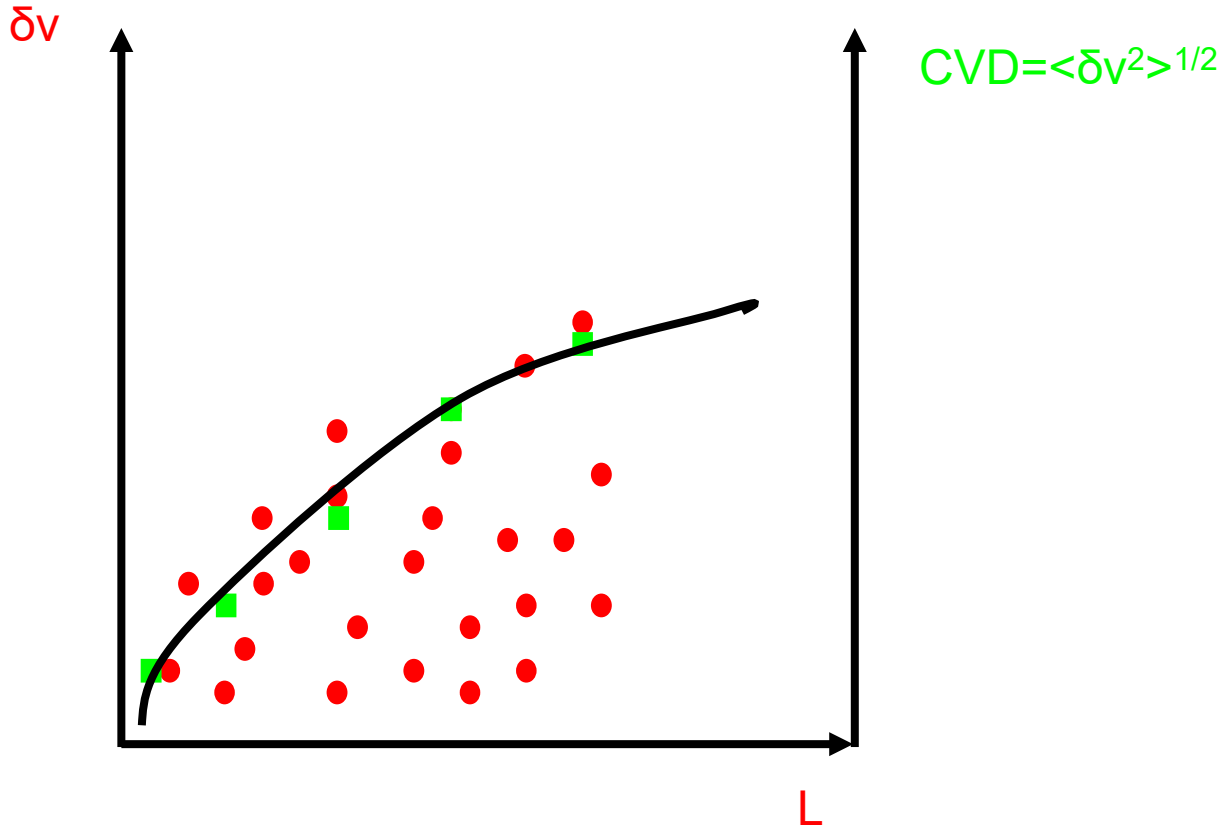


^{13}CO云核中心速度与^{12}CO平均速度的差

Qian, Li, Goldsmith, 2012, ApJ, 760, 145

云核速度弥散方法

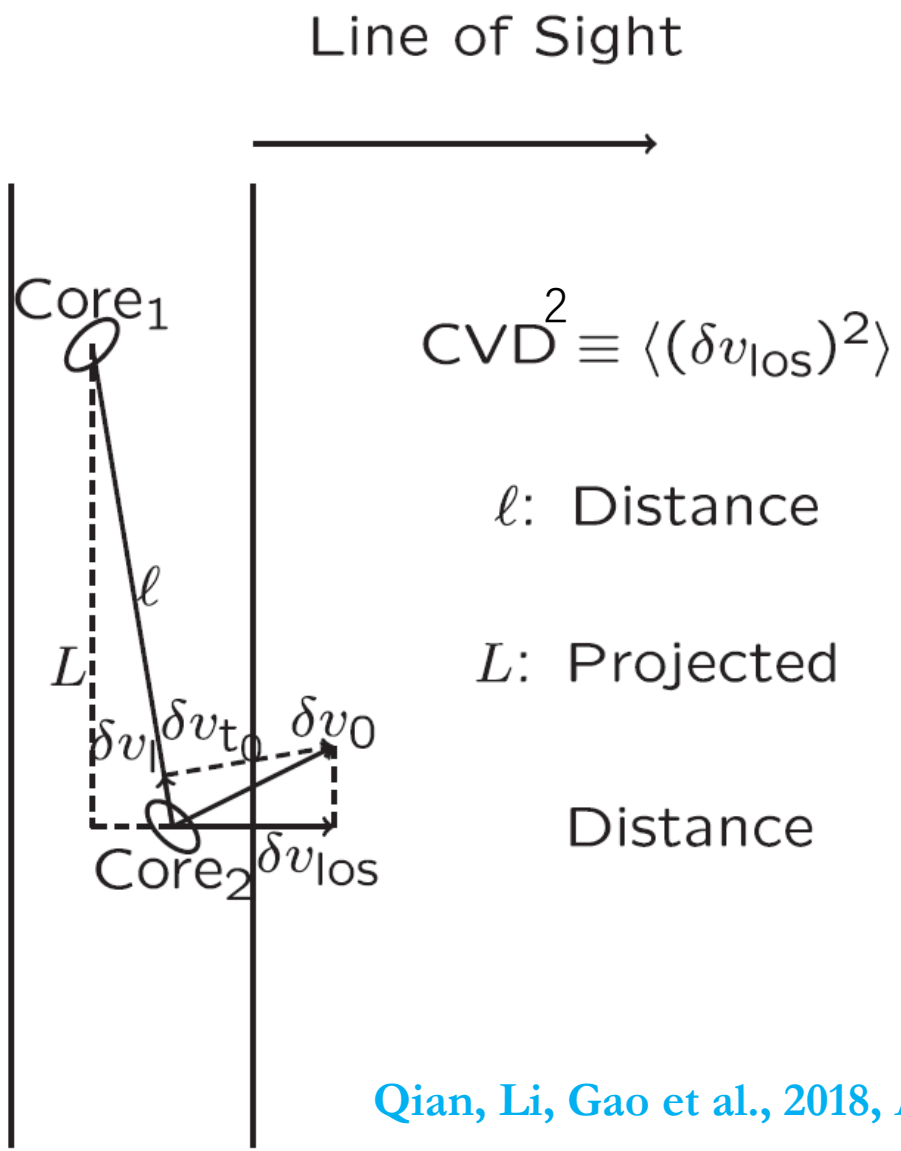




$$S_{\mathrm{tt}}^2(l) = \left\langle [u_{\mathrm{t}}(M') - u_{\mathrm{t}}(M)]^2 \right\rangle$$

$$\mathrm{CVD}^2 \equiv \langle \delta v^2 \rangle \approx \frac{1}{2} S_{tt}^2$$

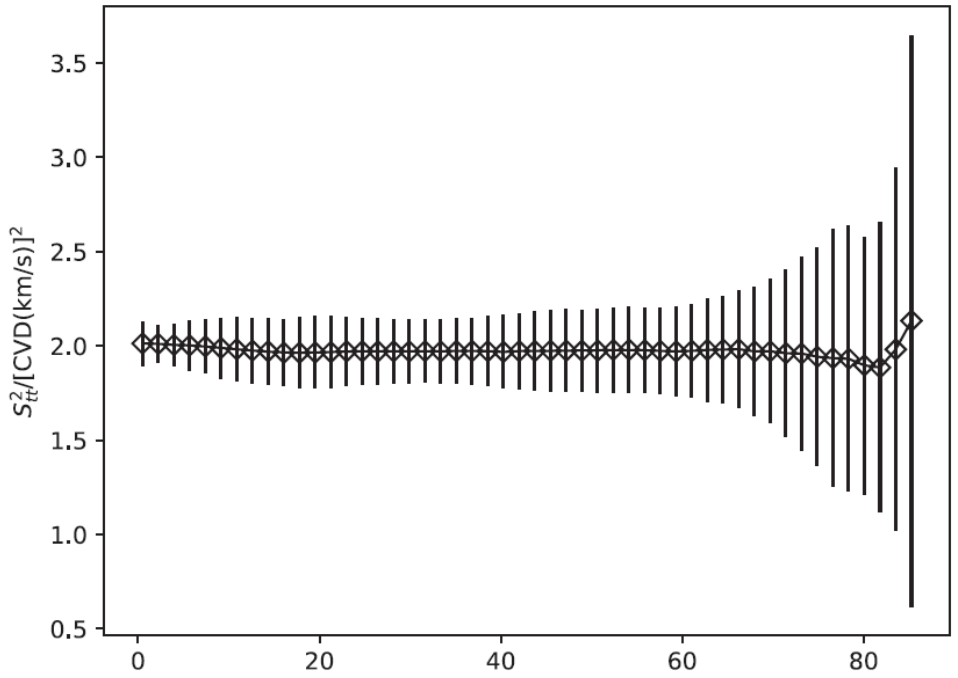
云核速度弥散方法



$\mathrm{CVD}^2 \equiv \langle (\delta v_{\rm los})^2 \rangle$

ℓ: Distance

L: Projected Distance



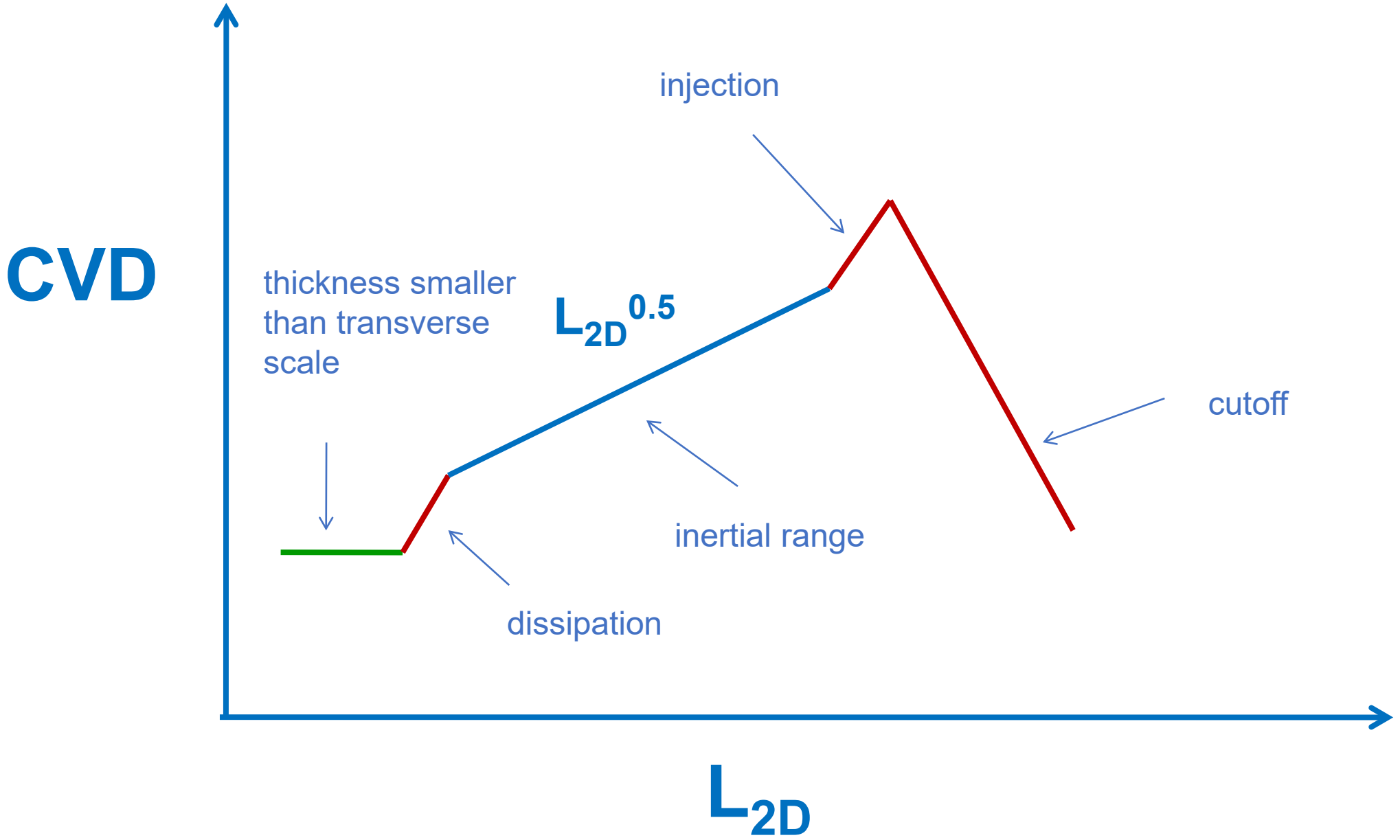
$$S_{\rm tt}^2 = \frac{8}{3} C_{12} \epsilon^{2/3} l^{2/3}$$

$$\mathrm{CVD}^2 \equiv \langle \delta v_{\rm los}^2 \rangle = \frac{1}{2} f S_{tt}^2$$

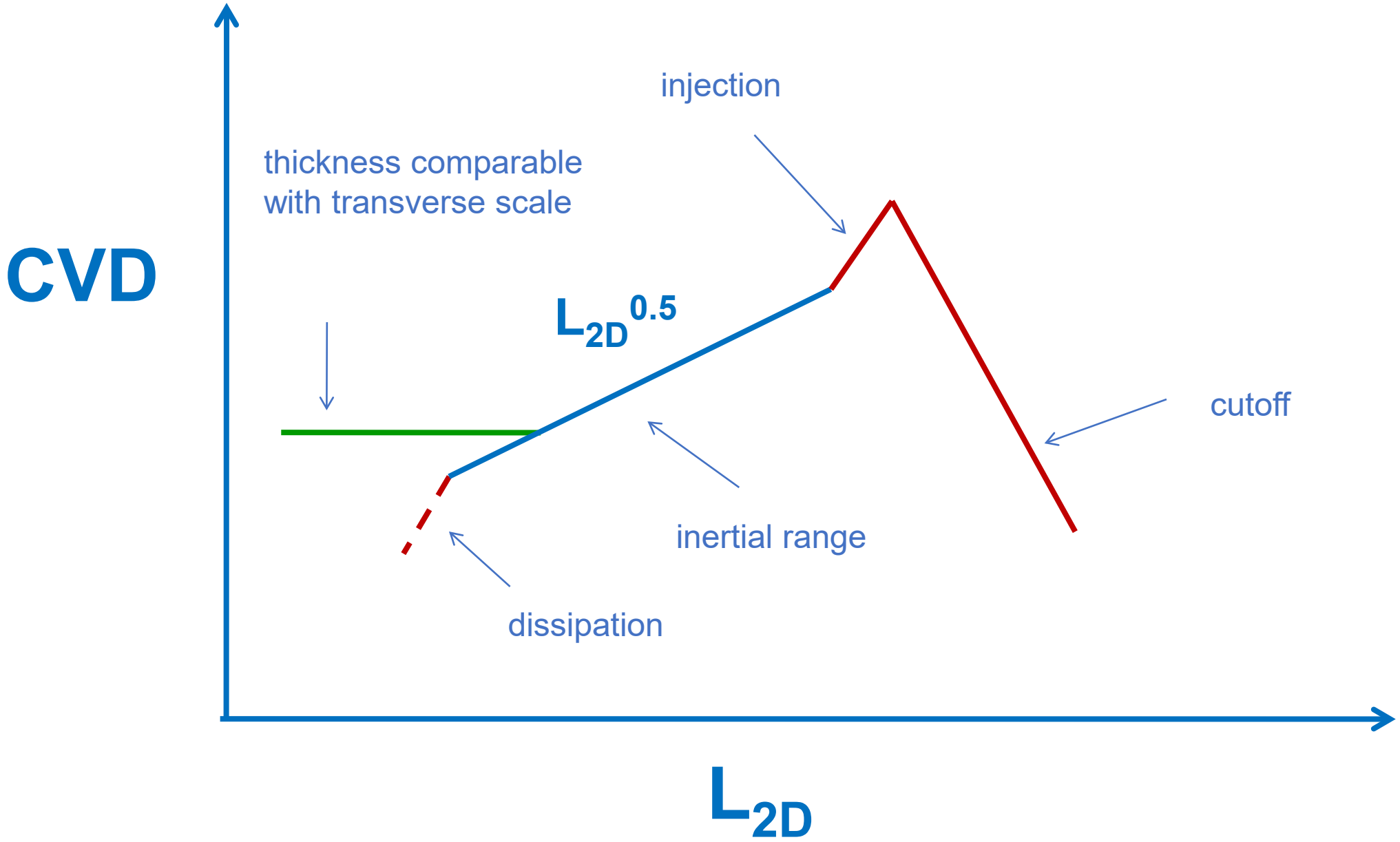
$$\epsilon = \frac{1}{L} \left(\frac{\mathrm{CVD}^2}{\frac{4}{3} C_{12} f} \right)^{3/2}$$

Qian, Li, Gao et al., 2018, ApJ, 864, 116

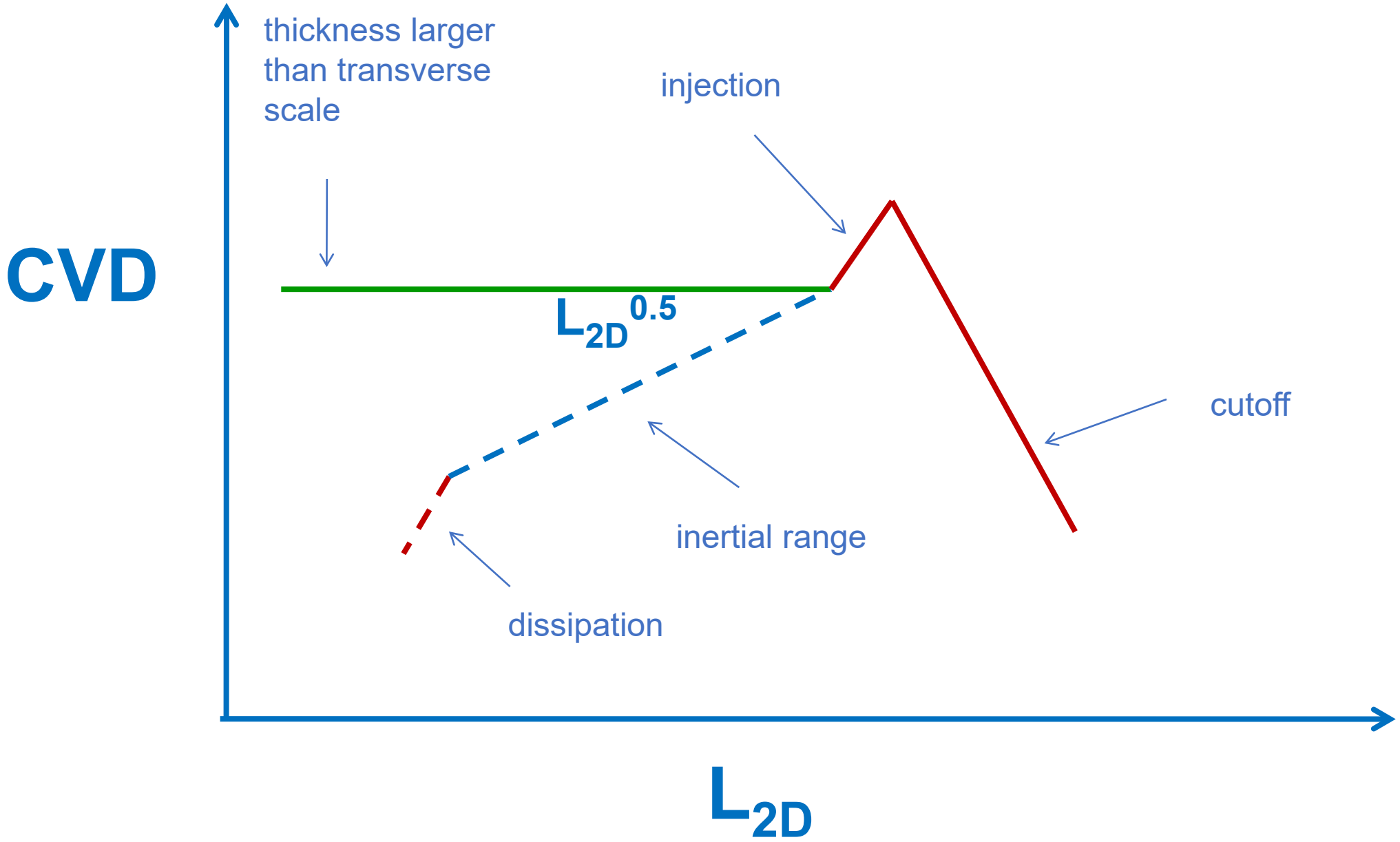
云核速度弥散方法


CVD
injection
thickness smaller than transverse scale
$L_{2D}^{0.5}$
cutoff
inertial range
dissipation
L_{2D}

云核速度弥散方法


CVD
injection
thickness comparable
with transverse scale
$L_{2D}^{0.5}$
cutoff
inertial range
dissipation
L_{2D}

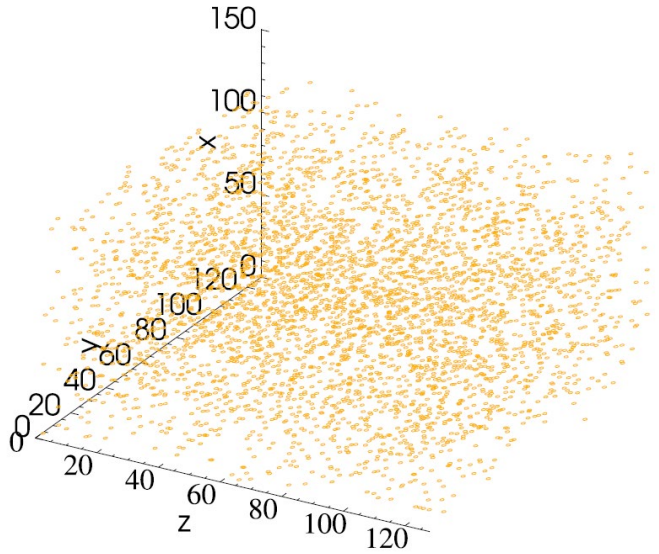
云核速度弥散方法

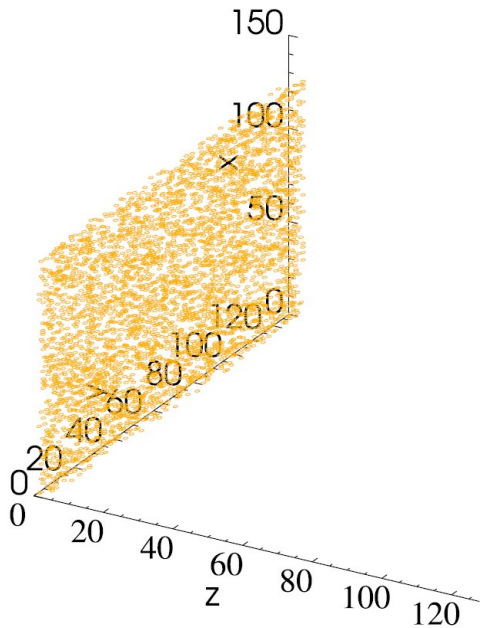

CVD
thickness larger than transverse scale
injection
$L_{2D}^{0.5}$
cutoff
inertial range
dissipation
L_{2D}

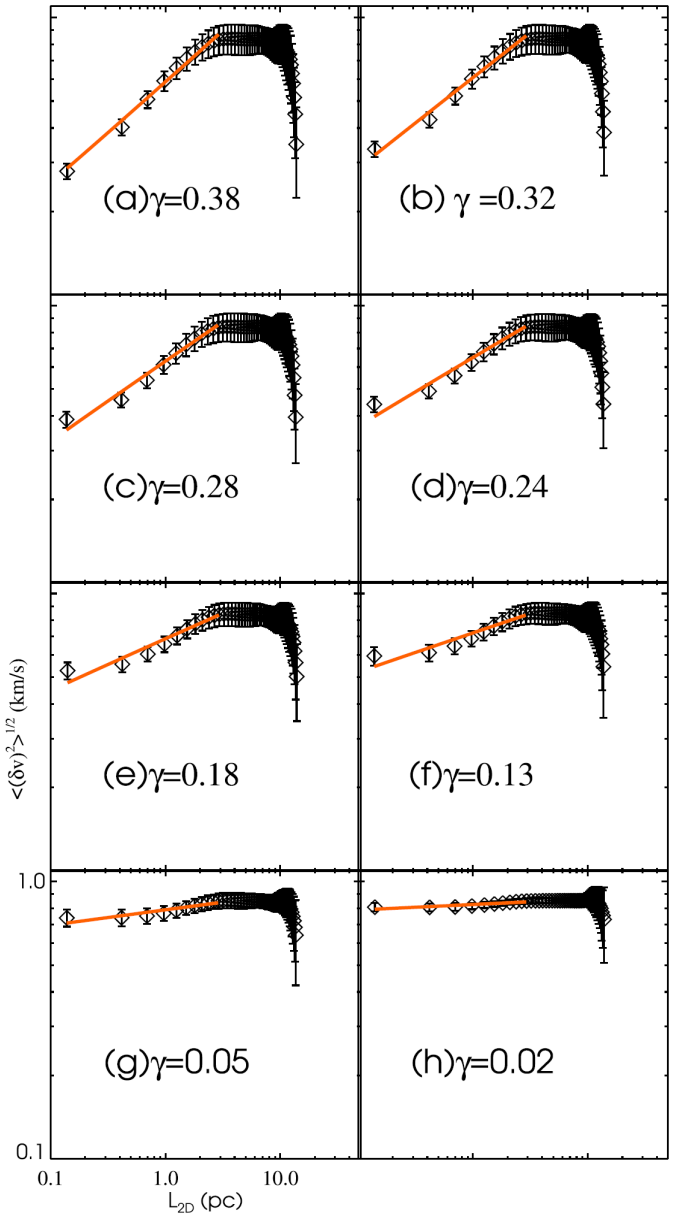
03

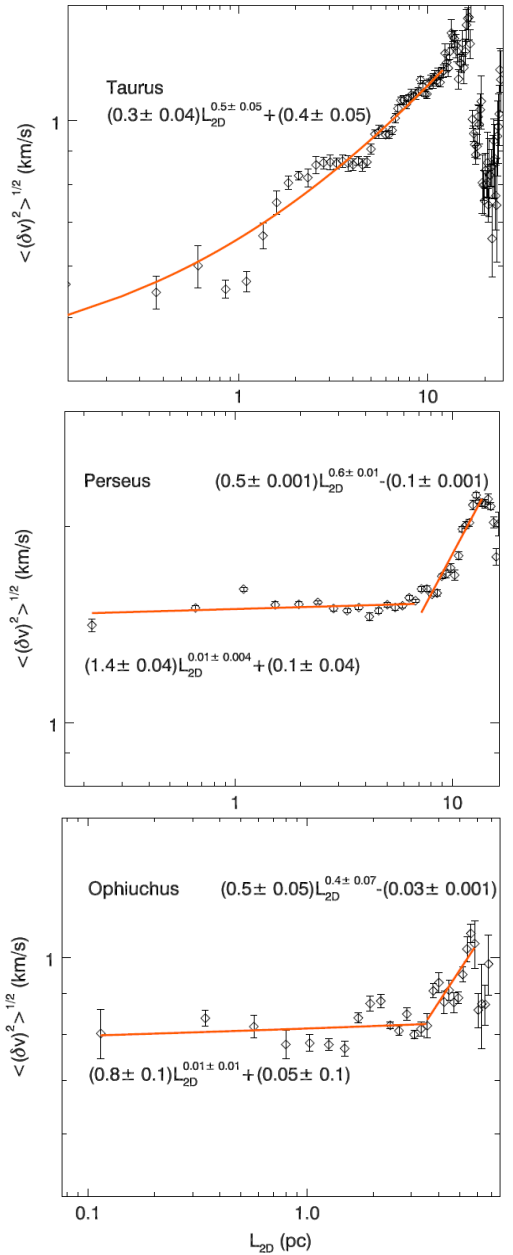
分子云厚度和湍流耗散率

分子云厚度和湍流耗散率

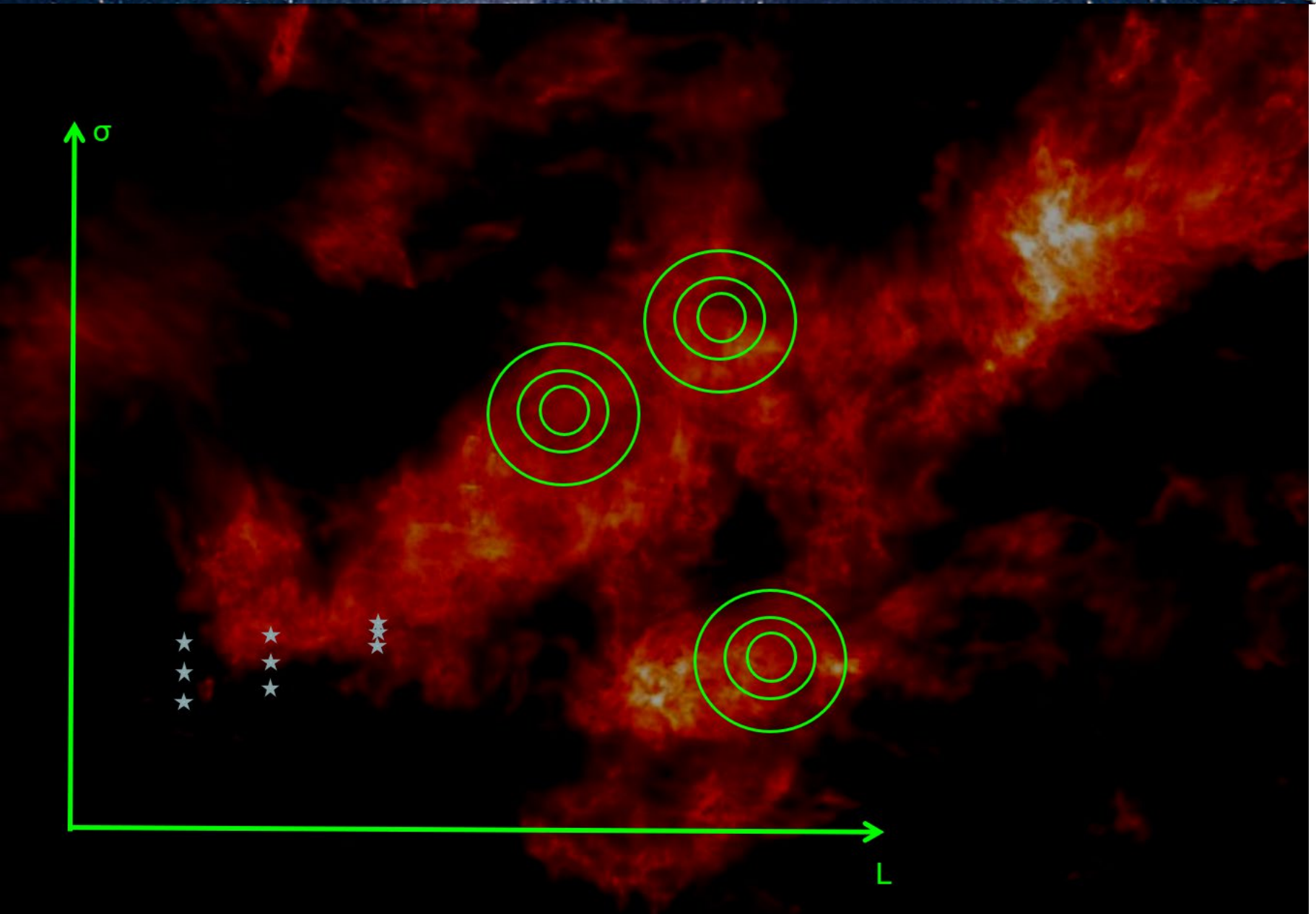


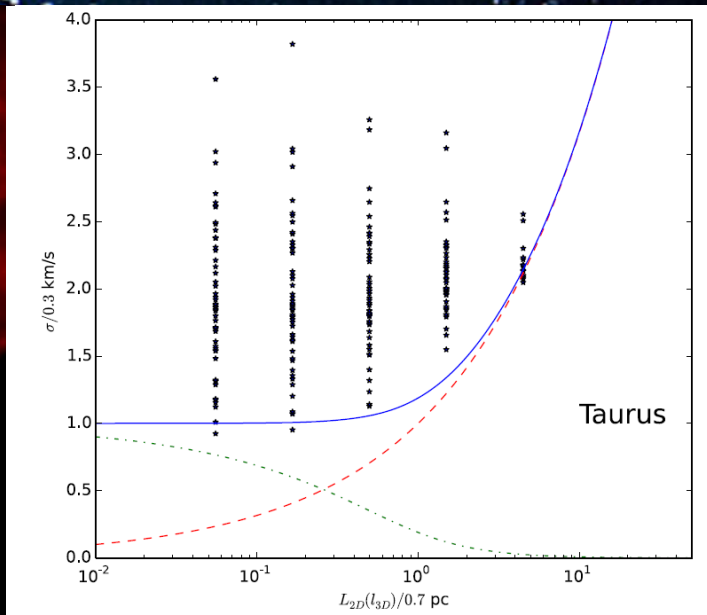


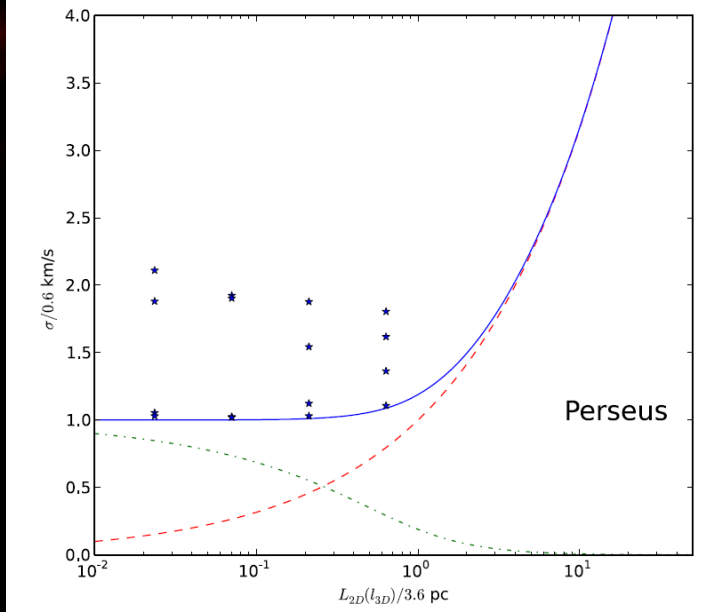




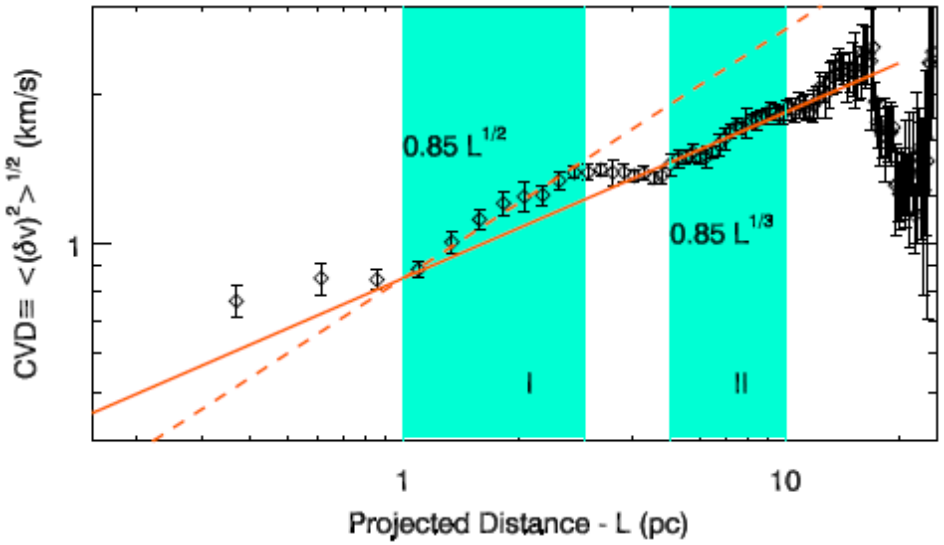
分子云厚度和湍流耗散率

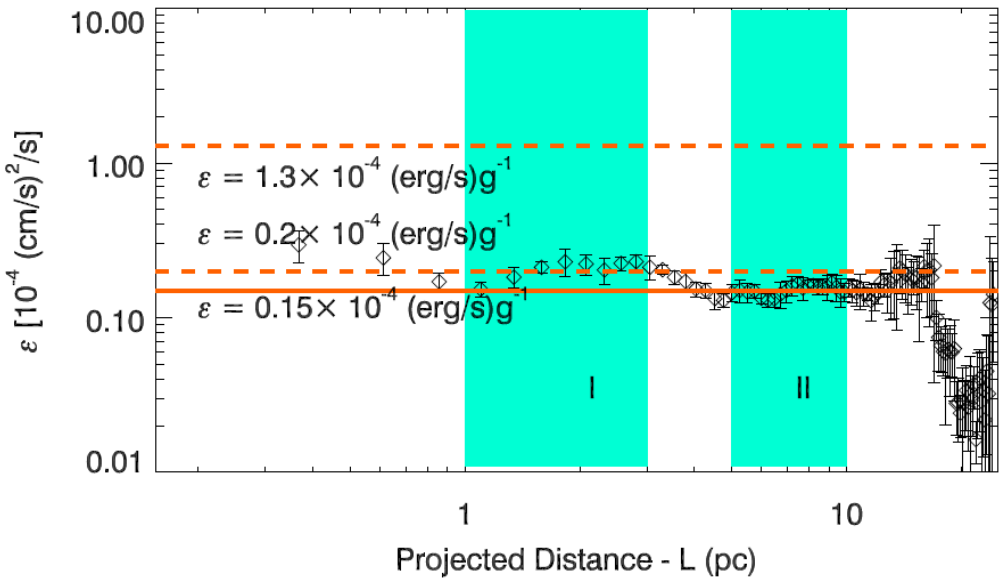


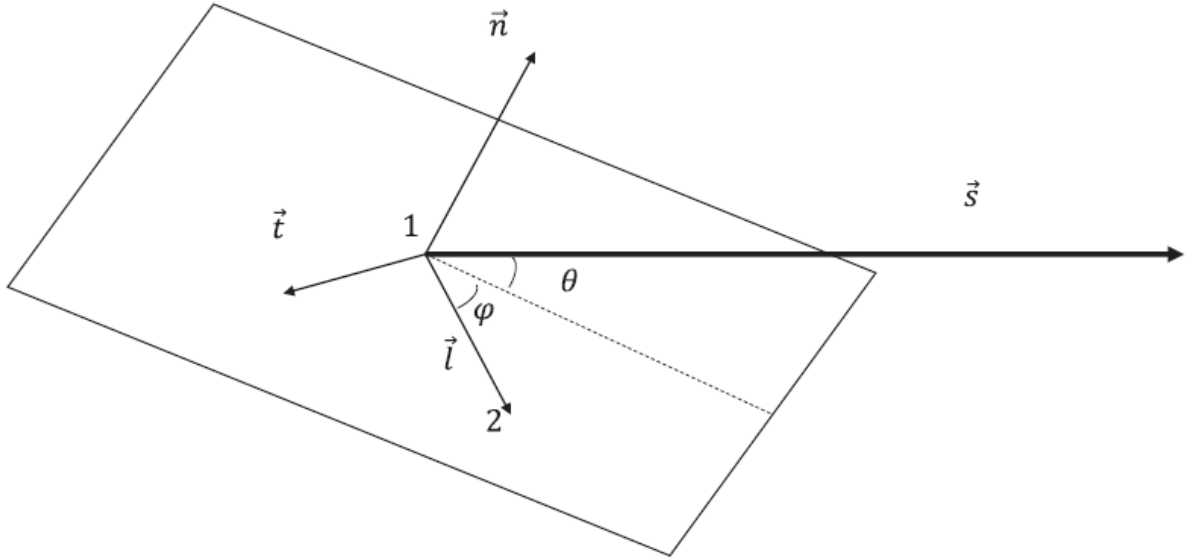




分子云厚度和湍流耗散率







$$\mathrm{CVD}^2 = \frac{1}{2} S_{tt}^2 \left(1 - \frac{1}{8}\cos^2\theta\right) R^{2/3}$$

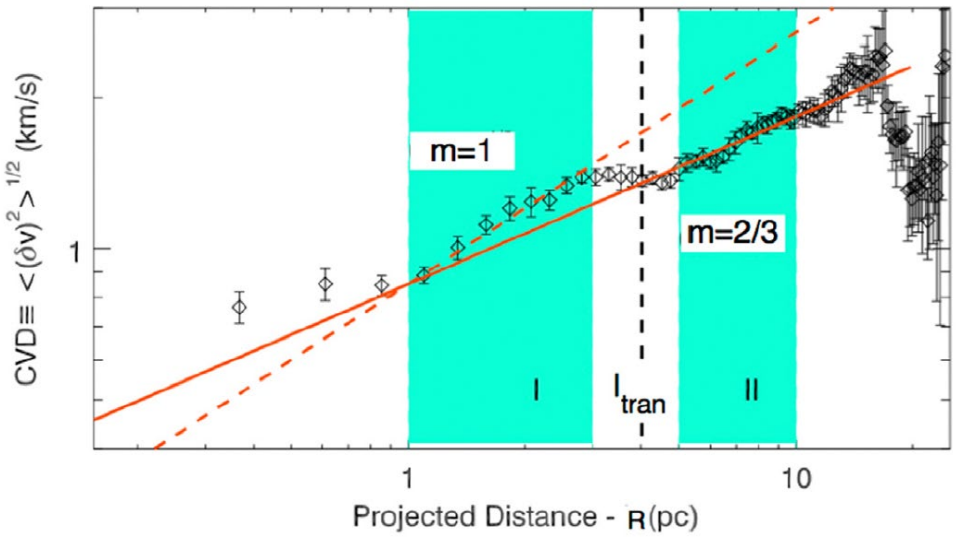
Qian, Li, Gao et al., 2018, ApJ, 864, 116

钱磊，2021，天文学报，62，7

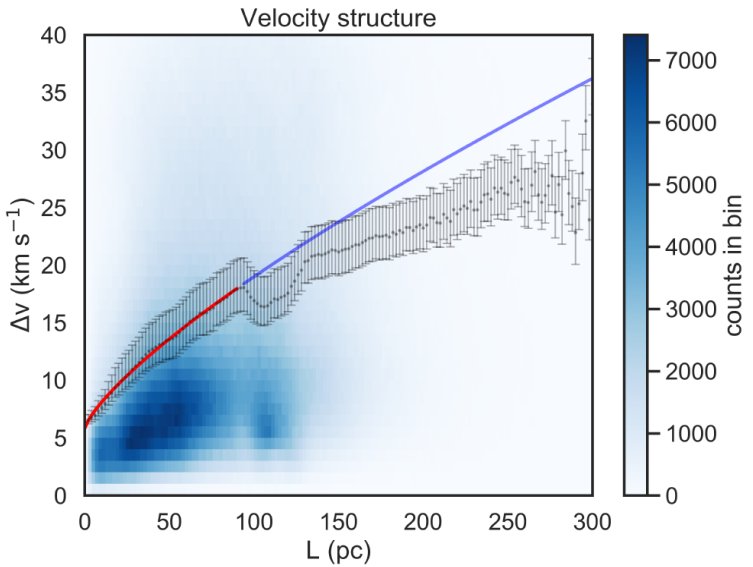
04

总结和展望

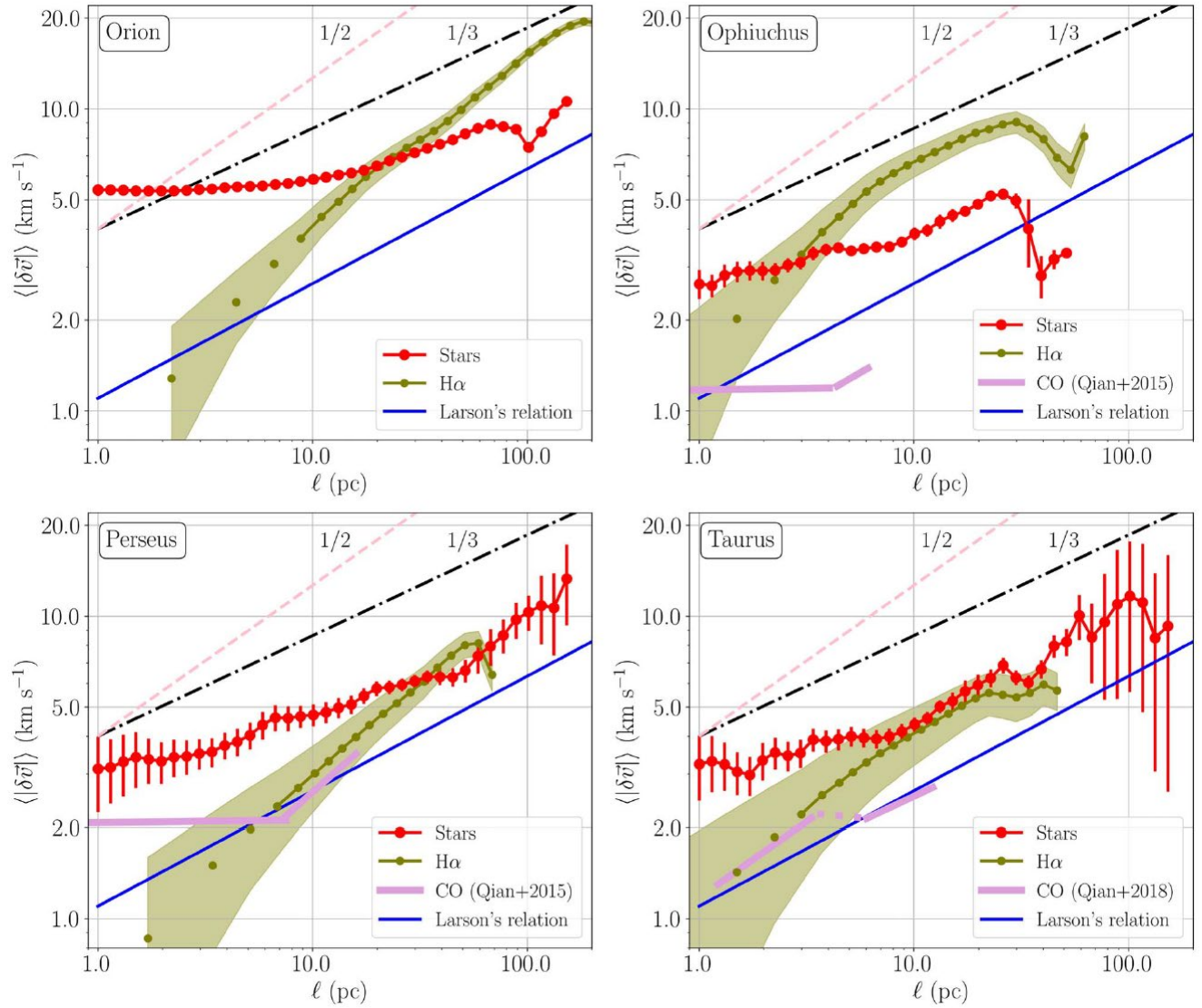
总结和展望



Xu, 2020, MNRAS, 492, 1044



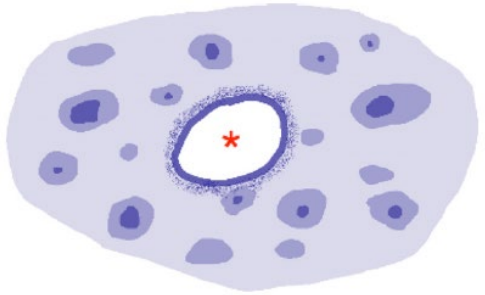
Zhang et al. in preparation

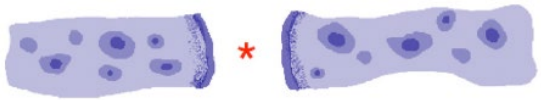


Ha et al., 2022, ApJ, 934, 7

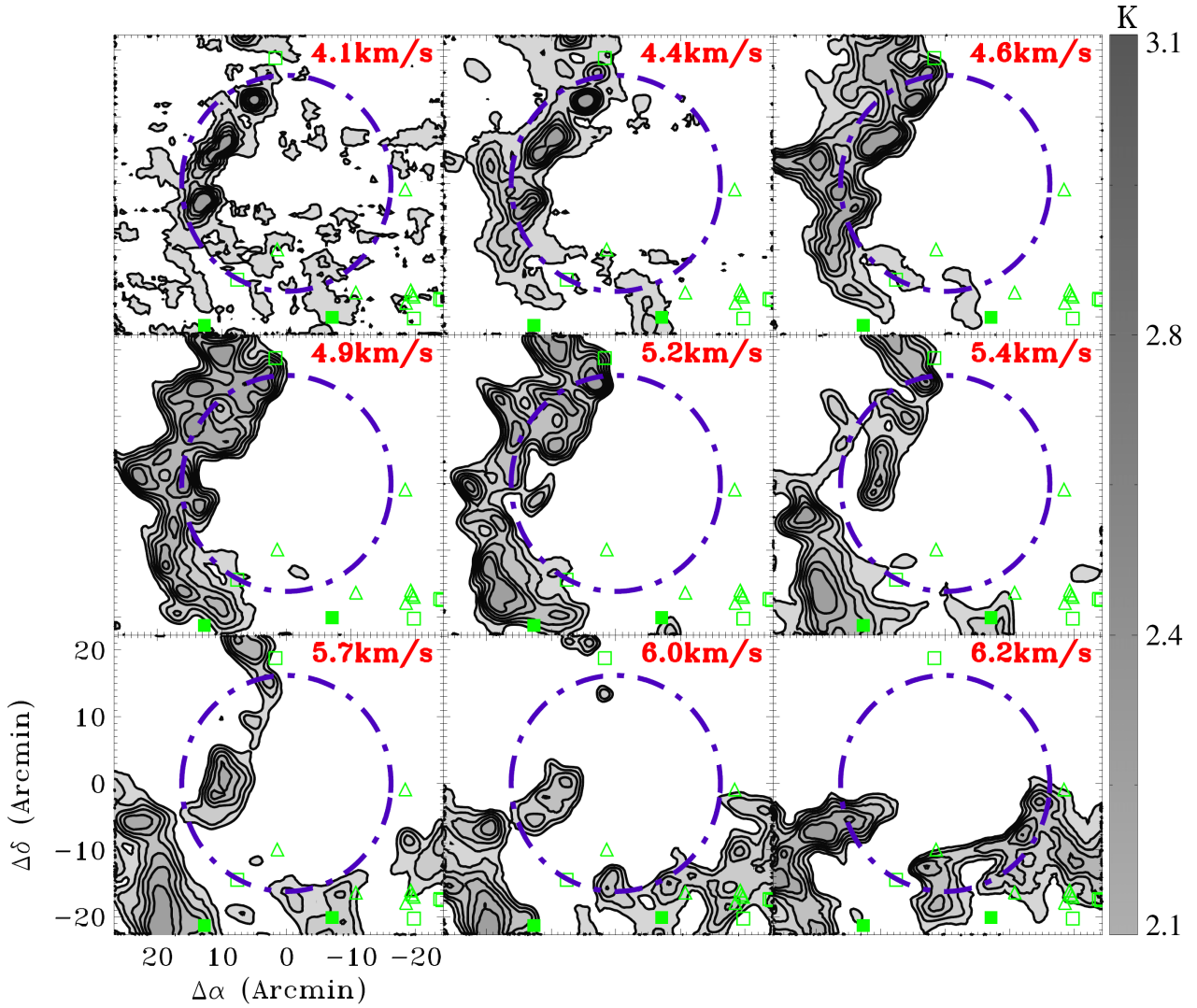

请各位老师批评指正
- 谢 谢 -

分子云结构和湍流运动

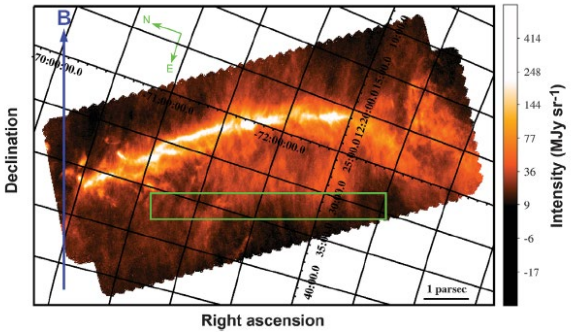


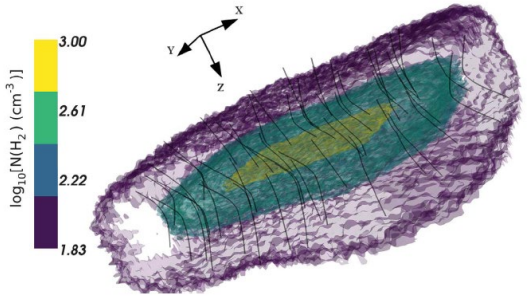


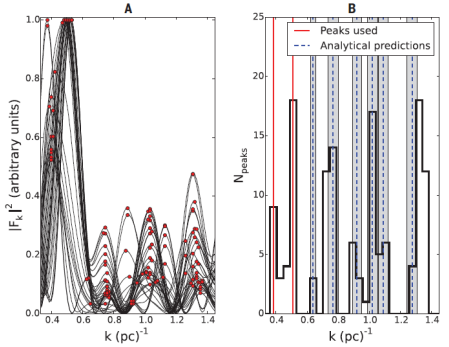
Beaumont, Williams 2010, ApJ, 709, 791



Li et al. 2015, ApJS, 219, 20







Tritsis, Tassis 2018, Science, 360, 635