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Turbulent Luminance in Impassioned van Gogh Paintings

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Abstract We show that the patterns of luminance in some impassioned van Gogh paintings display the mathematical structure of fluid turbulence. Specifically, we show that the probability distribution function (PDF) of luminance fluctuations of points (pixels) separated by a distance R compares notably well with the PDF of the velocity differences in a turbulent flow, as predicted by the statistical theory of A.N. Kolmogorov. We observe that turbulent paintings of van Gogh belong to his last period, during which episodes of prolonged psychotic agitation of this artist were frequent. Our approach suggests new tools that open the possibility of quantitative objective research for art representation.

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1 Introduction

Since the early impressionism, artists empirically discovered that an adequate use of luminance could generate the sensation of motion [1]. This dynamic style was more complex in the case of van Gogh paintings of the last period: turbulence is the main adjective used to describe these paintings. It has been specifically mentioned, for instance, that the famous painting *Starry Night*, vividly transmits the sense of turbulence and was compared with a picture of a distant star from the NASA/ESA Hubble Space Telescope, where eddies probably caused by dust and gas turbulence are clearly seen [2]. It is the purpose of this paper to show that the probability distribution function (PDF) of luminance fluctuations in some impassioned van Gogh paintings compare notably well with the PDF of the velocity differences in a turbulent flow as predicted by the statistical theory of A.N. Kolmogorov [3–5]. This is not the first time that this analogy with hydrodynamic turbulence is reported in a field far from fluid mechanics; it has been also observed in fluctuations of the foreign exchange markets time series [6].

The science behind the arts has been the source of inspiration and intense discussions for many people during the centuries [7]. Furthermore, many art critics have borrowed terms that evoke concepts that arise in scientific disciplines. Such use is free, without a precise meaning. Thus, it is valid to ask how precise are the adjectives used by critics in the description of art. In this article we try to answer this question by looking into the particular case of some van Gogh paintings since the adjectives that most of the critics use to describe his work are "turbulent" and "chaotic". For that goal, we mainly study van Gogh's *Starry Night* (June 1889), which more vividly transmits the feeling of turbulence. Also, as a sample of other turbulent pictures, we analyze *Two Peasant Women Digging in Field with Snow*

(March-April, 1890), *Road with Cypress and Star* (May, 1890) and *Wheat Field with Crows* (July, 1890). By considering the analogy with the Kolmogorov turbulence theory, from our results we conclude that the turbulence of the luminance of the studied van Gogh paintings shows similar characteristic to real turbulence. Our results reinforce the idea that scientific objectivity may help to determine the fundamental content of artistic paintings, as was already done with Jackson Pollock's fractal paintings [8, 9].

2 Luminance

Luminance is a measure of the luminous intensity per unit area. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle [10]. Its psychological effect is bright and thus luminance is an indicator of how bright a surface will appear. In a digital image, the luminance of a given pixel is obtained from its RBG (red, green and blue) components as [11]

$$0.299R + 0.587G + 0.114B. \tag{1}$$

This formula takes into account the fact that the human eye is more sensitive to green, then red and lastly blue. The luminance value of different colors is easily obtained with this formula; we quickly infer that the color with more green is brighter to the eye than the color with more blue, and some examples are as follows. Using RGB values in 24 bits per pixel (8 bits per color), black color $(0, 0, 0)$ has the lowest luminace (0) and white $(255, 255, 255)$ the higher one (255). Intermediate values corresponds, for instance, to blue $(0, 0, 255) \to 29$, red $(255, 0, 0) \to 76$, green $(0, 255, 0) \to 150$, cyan $(0, 255, 255) \to 179$, yellow $(255, 255, 0) \to 226$, etc. Interestingly, gray colors have the same RBG values, so $(10, 10, 10)$ is a dark gray with luminance 10 and $(200, 200, 200)$ is a light gray with luminance 200.

Luminance contains the most important piece of information in a visual context and has been used by artists to produce certain effects. For instance, the technique of equiluminance has been used since the first impressionist painters to transmit the sensation of motion in a painting. Notably Claude Monet in his famous painting *Impression, Sunrise* (1872), used regions with the same luminance, but contrasting colours, to make his sunset twinkle. The biological basis behind this effect is that colour and luminance are analyzed by different parts of the visual system; shape is registered by the region that processes colour information (ventral pathway) but motion is registered by the colour-blind part (dorsal pathway) [1]. Thus equiluminant regions can be differentiated by colour contrast, but they have poorly defined positions and may seem to vibrate [1]. It seems likely that van Gogh dominated this technique but some of the paintings of his last period produce a more disturbing feeling: they transmit the sense of turbulence. By assuming that luminance is the property that van Gogh used to transmit this feeling (without being aware of it), we will quantify the turbulence of some impassioned paintings by means of a statistical analysis of luminance, similar to the statistical analysis of velocities that Andrei Kolmogorov used to study fluid turbulence.

3 A Brief Account of the Statistical Theory of A.N. Kolmogorov

The statistical model of Kolmogorov [3, 4] is a foundation for modern turbulence theory. The main idea is that at very large Reynolds numbers, between the large scale of energy input (L) and the dissipation scale (η), at which viscous frictions become dominant, there is a myriad of small scales where turbulence displays universal properties independent of the initial and boundary conditions. In particular, in the inertial range, Kolmogorov predicts a famous scaling property of the second order structure function, $S_2(\mathbf{R}) = \langle(\delta v_R)^2\rangle$, where $\delta v_R = v(\mathbf{r} + \mathbf{R}) - v(\mathbf{r})$ is the velocity increment between two points separated by a distance $\mathbf{R}$ and v is the component of the velocity in the direction of $\mathbf{R}$. In his first 1941 paper [3], Kolmogorov postulates two hypotheses of similarity that led to the prediction that $S_2(\mathbf{R})$ scales as $(\varepsilon R)^{2/3}$, where $R = \|\mathbf{R}\|$ and ε is the mean energy dissipation rate per unit mass. Under the same assumptions, in his second 1941 turbulence paper [4] Kolmogorov found an exact expression for the third moment, $\langle(\delta v_R)^3\rangle$, which is given by $S_3(\mathbf{R}) = -\frac{4}{5}\varepsilon R$. Furthermore, he hypothesized that this scaling result generalizes to structure functions of any order, *i.e.* $S_n(\mathbf{R}) = \langle(\delta v_R)^n\rangle \propto R^{\xi_n}$, where $\xi_n = n/3$. Experimental measurements show that Kolmogorov was remarkably close to the truth in the sense that statistical quantities depend on the length scale R as a power law. However, the intermittent nature of turbulence (alternation in time of turbulent and non-turbulent motion of the fluid) causes that the numerical values of ξ_n to deviate progressively from $n/3$ when n increases, following a concave curve below the $n/3$ line [5]. In 1962, Kolmogorov [5] and Obukhov [12] recognized that turbulence is too intermittent to be described by simple power laws and proposed a refinement with a log-normal form of the probability density of ε_R, the energy dissipation rate per unit mass averaged at scale R.

An important function to characterize turbulence is the PDF of velocity differences δv_R, denoted by $P(\delta v_R)$. Different models have been proposed to describe the shape of this function at different scales R and we adopt here the approach by Castaign *et al.* [13] that, supported by experimental results, follows the idea of the log-normal form of ε_R. By

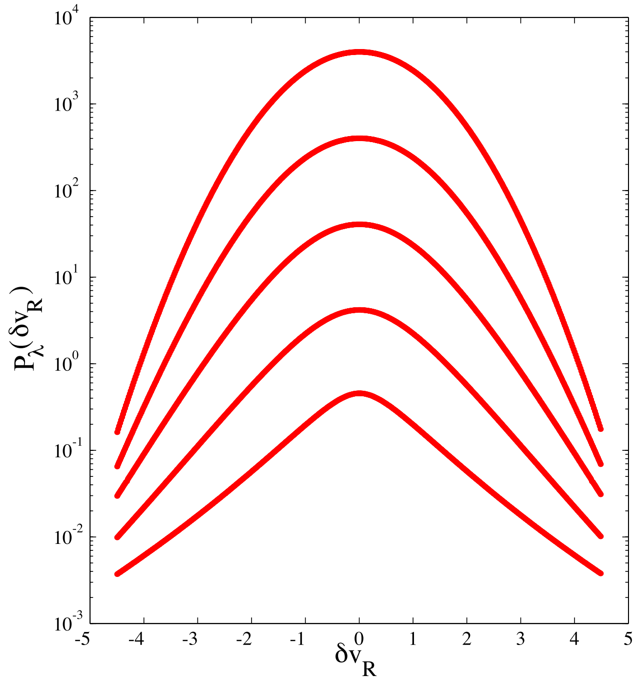

Fig. 1 Semi-log plot of (2) for $\lambda = 0.6, 0.3, 0.2, 0.11, 0.009$ (*from bottom to top*). The most probable variance σ_0 was set to 1.0 and curves have been vertically shifted for better visibility

superimposing several Gaussians at different scales, it is inferred that the shape of the PDF goes from nearly Gaussian at large scales R to nearly exponential at small scales. The number of superimposed Gaussians is controlled by a parameter, λ, which is the only parameter that must be fitted to the data. A large value of λ means that many scales contribute to the results, and thus the PDF develops tails that decays much slower than a pure Gaussian correlation [13]. Specifically, Castaign *et al.* proposed the following symmetric distribution with variance σ:

$$P_\lambda(\delta v_R) = \frac{1}{2\pi\lambda}\int_0^\infty \exp\left(-\frac{(\delta v_R)^2}{2\sigma^2}\right) \times \exp\left(-\frac{\ln^2(\sigma/\sigma_0)}{2\lambda^2}\right)\frac{d\sigma}{\sigma^2}, \quad (2)$$

where σ_0 is the most probable variance of δv_R. From the log-normal hypothesis it is inferred [13] that λ^2, which measures the variance of the log-normal distribution, decreases linearly with $\ln(R)$.

To summarize the previous discussion, sample PDF plots of turbulent flows, according to this model, are presented in Fig. 1 for several values of λ and $\sigma_0 = 1$. Notice that curves have been vertically shifted for better visibility. It is worthwhile remarking that $P_\lambda(\delta v_R)$ is a probability distribution and thus, for comparison purposes between different systems, usually δv_R is rescaled [13] in such a way that a new variable $\delta' v_R$ is defined as $\delta' v_R = (\delta v_R - \langle \delta v_R\rangle)/\sigma$. Using such rescaling, $\delta' v_R$ has zero mean and the second moment of $P_\lambda(\delta' v_R)$ is one. Thus, one can measure how much $P_\lambda(\delta' v_R)$ deviates from a Gaussian with zero mean and standard deviation one, since for example all Gaussians collapse in the same curve. As we will explain later, in our analysis of the paintings the same normalization was used. As a result, a quantitative and qualitative comparison can be made between the curves obtained from (2) and the paintings.

4 Methods

Our goal is to perform a statistical analysis of he differences of luminance of pixels separated by a distance R in a digital image, in order to compare with Kolgomorov's theory predictions. In this Section, we provide the details of the procedure, which can be summarized into three steps:

1. The luminance of each pixel is obtained from the digital image by using the formula (1).
2. The PDF of pixel luminance fluctuations is calculated by building up a matrix L whose rows contain the differences in luminance δu_R and columns contain separation between pixels R (see the example below).
3. From the above matrix, we determine the normalized PDF of the luminance differences:

$$P(\delta u_R) = (\delta u_R - \langle \delta u_R\rangle)/(\langle(\delta u_R)^2\rangle)^{1/2}. \quad (3)$$

To go into the details of the last two steps, consider the highly simplified example shown in Fig. 2a consisting of a 5×5 pixel gray scale image stored using 3 bits per pixel, which allows 8 shades of gray $0, 1, \dots 7$, where 0 corresponds to black and 7 to white. From the values shown in this figure, we obtain the matrix L shown in Fig. 3, where diagonal distances were approximated by the nearest integer function (`round`). An histogram of the differences in luminance for pixels separated by a distance $R = 3$ is directly obtained from the third column of the matrix L and shown in Fig. 2b. From this graphic, the PDF is obtained as follows. (a) The heights h_i, $i = 1, 2, \dots, 15$ of the histogram are normalized to the area A under its own curve, *i.e.*, h_i/A, $i = 1, 2, \dots, 15$ and the curve is displaced to get zero mean (measured mean is 0.0671); (b) According (3), the curve is now normalized to the standard deviation σ which is calculated as a expectation value (since the normalized histogram obtained in the previous step is itself a probability distribution), in this example we get $\sigma = 2.9235$ thus ordinates are scaled by σ and abscissas by $1/\sigma$. The semilog plot of $P(\delta u_3)$ for this example is shown in Fig. 3c.

In the analysis of the digital images of van Gogh paintings, comparisons with the theoretically predicted PDF curve (2) were carried out by finding, by a trial and error method the value of λ that yields the best fit to the measured PDF. In all the cases studied here, we consider $\sigma_0 = 1.0$.

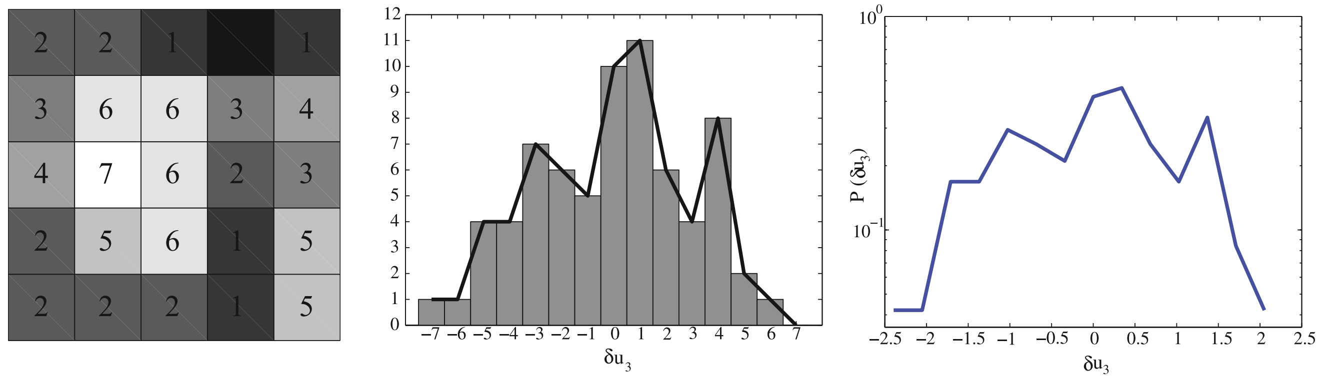

Fig. 2 Simplified example to illustrate the procedure for obtaining the PDF of the luminance differences of a gray scale image. (**a**) 5×5 pixel gray scale image stored using 3 bits per pixel; 0 corresponds to black and 7 to white. (**b**) Histogram of the differences of the luminance of pixels separated by $R = 3$, obtained from the matrix L (Fig. 3). (**c**) Semilog plot of the normalized PDF (see text for details)

Difference in luminance \ Distance between pixels	1	2	3	4	5	6	7
-7	0	0	1	0	0	0	0
-6	1	3	1	1	0	0	0
-5	2	4	4	3	0	0	0
-4	9	4	4	6	0	0	0
-3	7	9	7	5	2	1	0
-2	3	11	6	6	2	0	0
-1	11	5	5	12	2	1	0
0	12	6	10	12	0	0	0
1	9	9	11	15	1	0	0
2	5	7	6	6	1	0	0
3	4	5	4	2	0	0	0
4	5	8	8	1	0	0	0
5	4	6	2	1	0	0	0
6	0	1	1	0	0	0	0
7	0	0	0	0	0	0	0

Fig. 3 Luminace differences for different pixel separations for the example in Fig. 2a. Diagonal distances were approximated by the nearest integer function

Fig. 4 Vincent van Gogh's *Starry Night* (taken from the WebMuseum-Paris webpage: www.ibiblio.org/wm/)

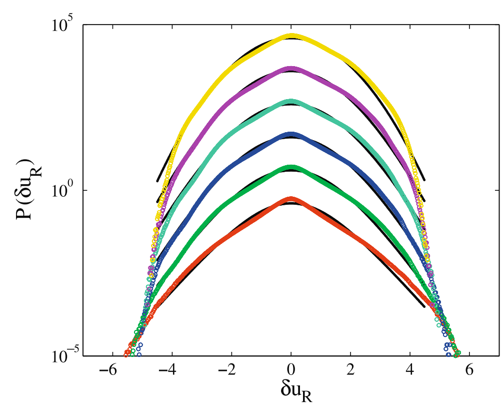

Fig. 5 Semi-log plot of the probability density $P(\delta u)$ of luminance changes δu for pixel separations $R = 60$, 240, 400, 600, 800, 1200 (*from bottom to top*). Curves have been vertically shifted for better visibility. Data points were fitted according to (2), and the results are shown in *full lines*; parameter values are $\lambda = 0.2$, 0.15, 0.12, 0.11, 0.09, 0.0009 (*from bottom to top*) and $\sigma_0 = 1.0$

5 Results

Starry Night (June, 1889), painted during his one year period in the Saint Paul de Mausole Asylum at Saint-Rémy-de-Provence, is undoubtedly one of the best known and most reproduced paintings by van Gogh (Fig. 4). The composition describes an imaginary sky in a twilight state, transfigured by a vigorous circular brushwork. To perform the luminance statistics of *Starry Night*, we start from a digitized, 300 dpi, 2750×3542 image obtained from The Museum of Modern Art in New York (where the original painting lies), provided by Art Resource, Inc. The PDF of pixel luminance fluctuations of the overall image was calculated as described in Sect. 4 and in Fig. 5 we show this function for six pixel separations, $R = 60$, 240, 400, 600, 800, 1200. In order to rule out scaling artifacts, we have systematically recalculated the PDF function for the same image at lower resolutions (with an adequate rescaling of the pixel separations R). No sig-

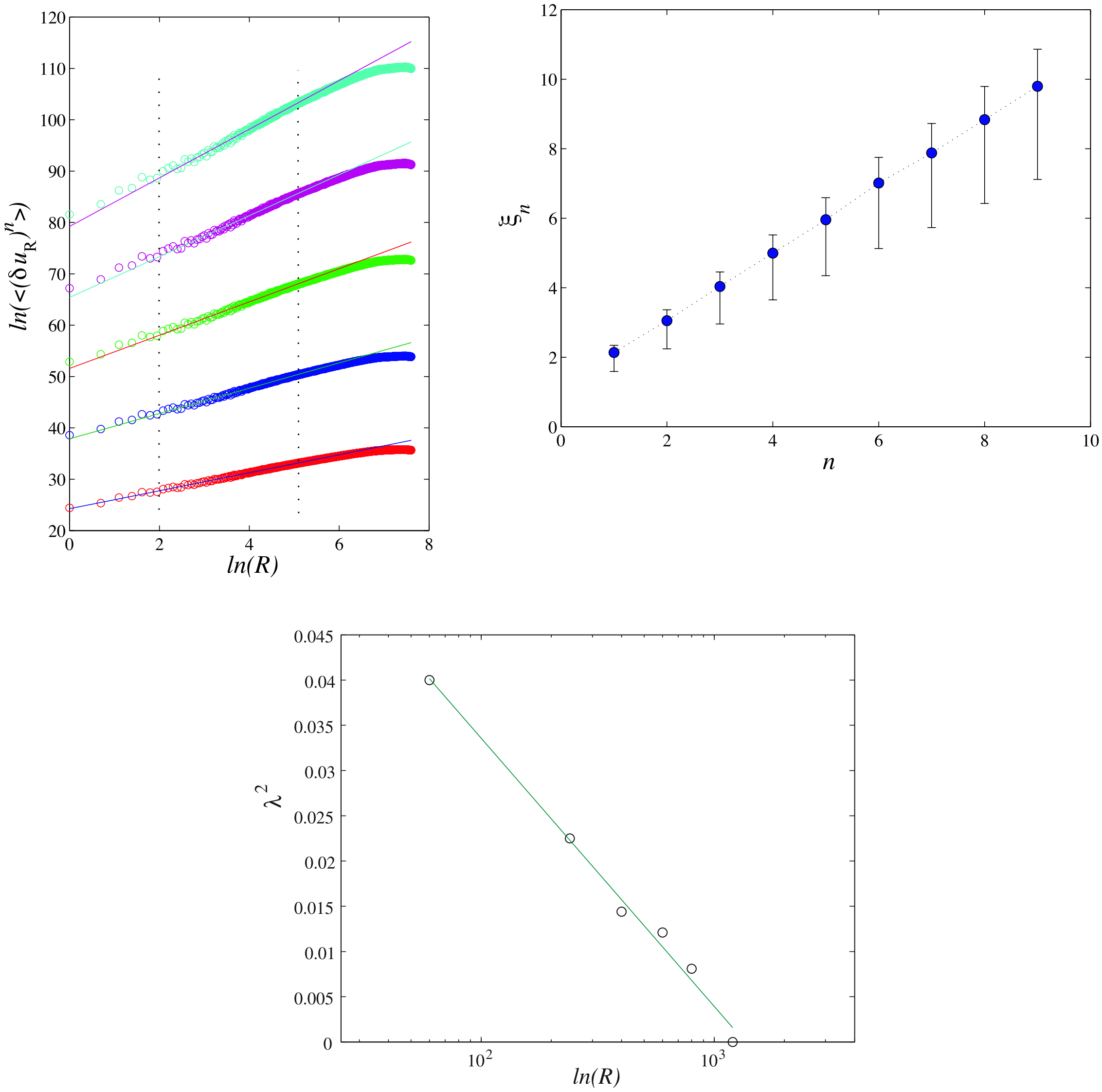

Fig. 6 (**a**) Log-log plot of the statistical moments $\langle(\delta u_R)^n\rangle$, with $n = 1, 2, 3, 4, 5$ (*from bottom to top*). In each case the *straight line* indicates the least-squares fit to the range of scales limited by the two *dashed lines* in the plot; (**b**) exponent ξ_n of the statistical moments as a function of n. For a given n, the exponent and error bar was calculated by the method proposed in Ref. [14]; (**c**) Dependence of λ^2 on R. Data points are fitted to a straight line by a least-square method

nificant differences appear down to images with resolutions lower than 150×117 pixels, where the details of the brushwork are lost.

We can take the analogy with fluid turbulence further. By considering the large length scale as $L = 2000$ pixels, which is size of the largest eddy observed in the *Starry Night*, in Fig. 6a we show a log-log plot of the statistical moments with $n = 1, 2, 3, 4, 5$ (from bottom to top), which show, in each case, a power-law behavior. This can be confirmed by a least-square fit of each curve; the straight lines indicate the least-squares fit to the range of scales limited by the two dashed lines in the plot. In Fig. 6b, the scaling exponent ξ_n, of the first nine statistical moments are shown as a function of n. Although the data points in the figure can be fitted with great accuracy to a straight line it would imply a simple scaling consistent with a self-similar picture of turbulence (*i.e.* $S_n(\mathbf{R}) = \propto R^{\xi_n}$) but no with intermittence, and we are comparing with the PDF's shown in Fig. 1, derived from a model that assumes intermittence. This apparent conflict is removed since scaling exponents show deviations from the self-similar values as indicated by the error bars. To determine scaling exponents and error bars, we follow the method proposed in Ref. [14], based on local slopes.

The PDF of luminance, for a given R, shown in Fig. 5 were fitted according to (2) using a trial and error method. The results, shown in the same figure with black lines (back

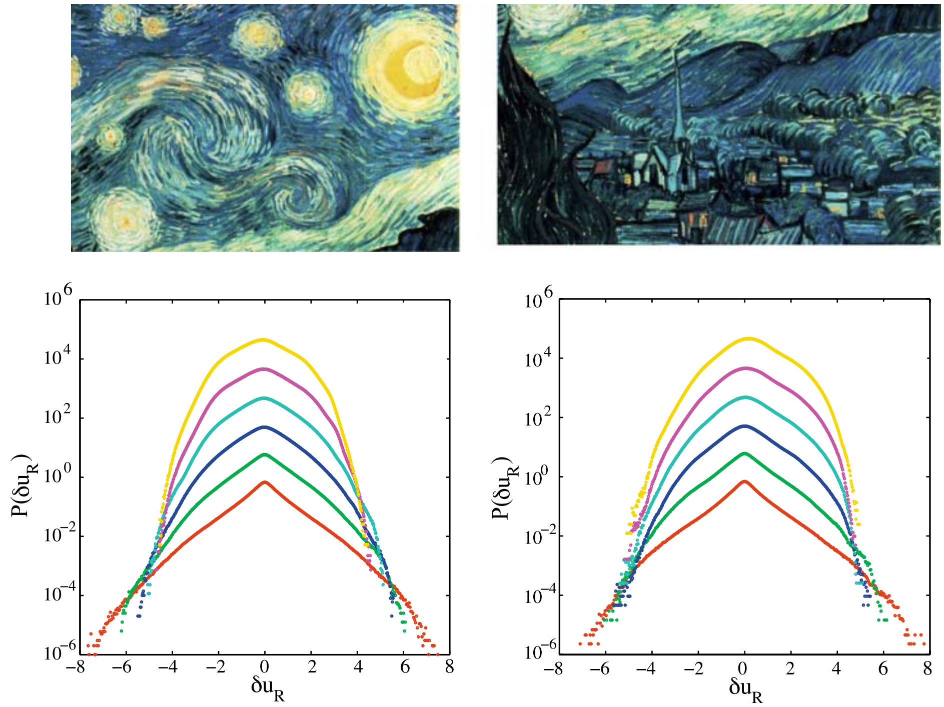

Fig. 7 Fragments of *Starry Night* (*top*) and its respective PDF of luminance fluctuations (*bottom*) for pixel separations $R = 5$, 10, 40, 80, 150, 250 (*from bottom to top*)

the calculated PDF's which are in colors), yield a notably good fit. Parameter values are $\lambda = 0.2$, 0.15, 0.12, 0.11, 0.09, 0.0009 (from bottom to top). In all the cases we considered $\sigma_0 = 1.0$. Finally, Fig. 6c shows the dependence of λ^2 on $\ln(R)$ for the six PDF's shown in Fig. 5. As expected, the parameter λ^2, decreases linearly with $\ln(R)$.

From his earliest years as an artist van Gogh was fond of landscapes involving "troubled" skies but it was not until his first days in the Saint Paul de Mausole Asylum that he used vigorous swirling brushwork to depict these turbulent skies (notably *Mountainous Landscape Behind Saint-Paul Hospital* painted at early June of 1889). It is interesting to note that in most landscapes with stormy skies the powerful swirling style extends to the overall painting. This is more evident in the *Starry Night* were even the mountains and the village of Saint-Rémy show a circular brushwork. The analysis of *Starry Night* presented above, and summarized in Figs. 5 and 6 was carried out in the overall painting but portions of the painting were also fed into the analysis with no significant changes. As an example, in Fig. 7 we show two fragments of the painting and its respective PDF of luminance fluctuations, for pixel separations $R = 5$, 10, 40, 80, 150, 250 (from bottom to top).

From van Gogh's 1890 period, we analyzed *Wheat Field with Crows*, which is one of his last paintings. Admired and over-interpreted, this painting is also an example of vitality and turbulence derived from each brush stroke. To perform the luminance statistics we use a digitized, 300 dpi, 5369×2676 image obtained from The Van Gogh Museum, in Amsterdam, provided by Art Resource, Inc. Figure 8 shows the PDF for pixel separations $R = 10$, 40, 80, 150, 250, 350 (from bottom to top). As it can be seen, the curves also show close similarity to the behavior of the PDF of fluid turbulence.

The same similarity is found in another landscapes of this period. *Road with Cypress and Star*, was painted in May 12–15, 1890, just after the last and most prolonged psychotic episode of van Gogh's life, lasting from February to April of 1890 [15]. In Fig. 9 we show the PDF of this painting for pixel separations $R = 2$, 5, 15, 20, 30, 60 (from bottom to top). We use a digitized, 300 dpi, 815×1063 image obtained from the WebMuseum, Paris, webpage. Just throughout the course of this February to April episode van Gogh painted *Two Peasant Women Digging in Field with Snow* (March to April, 1890) which also displays turbulent luminance; the PDF, calculated from a digitized 576×450 image, is shown in Fig. 10, for pixel separations $R = 7$, 30, 50, 75, 100, 150 (from bottom to top).

From the results, we deduce that the distribution of luminance on a given painting determines if it is turbulent. Nevertheless, it is not evident what are the particularities of this distribution of luminance that produces a turbulent painting. Albeit this topic is still under research, some words can be said here. Turbulence is a multiscale phenomenon and thus the appearance of eddies at different scales is a necessary condition. These are observed in all the analyzed paintings and it is even more evident in the *Starry Night*. The presence of several scales is not, however, a sufficient

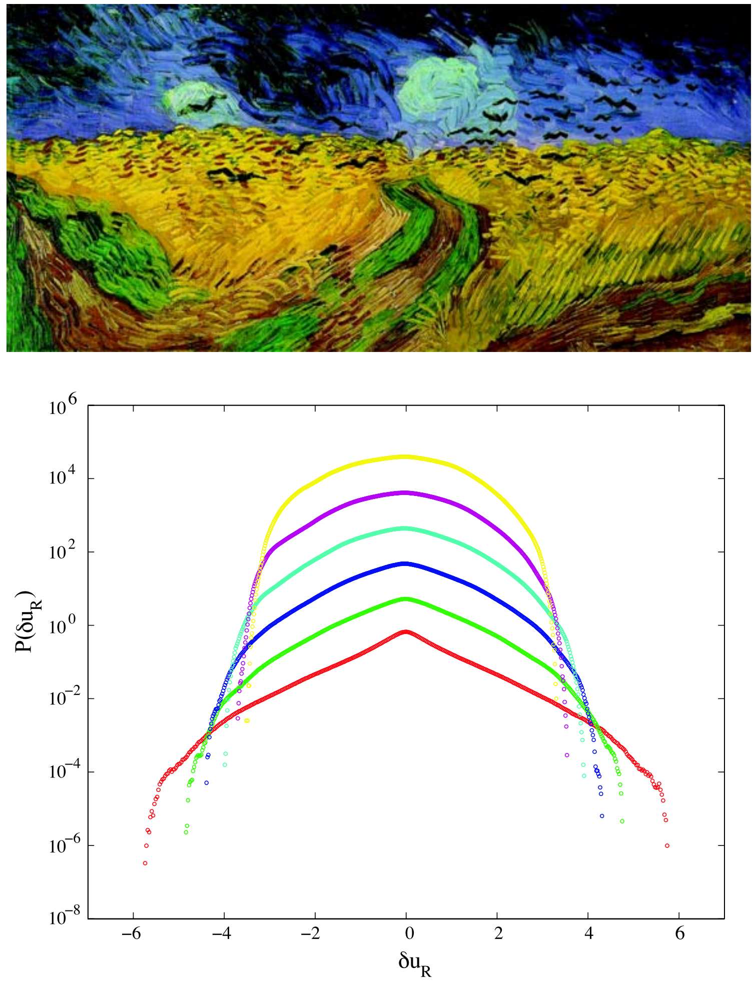

Fig. 8 *Wheat Field with Crows* (*top*) and its PDF (*bottom*) for pixel separations $R = 10$, 40, 80, 150, 250, 350 (*from bottom to top*). The image was taken from the WebMuseum-Paris webpage

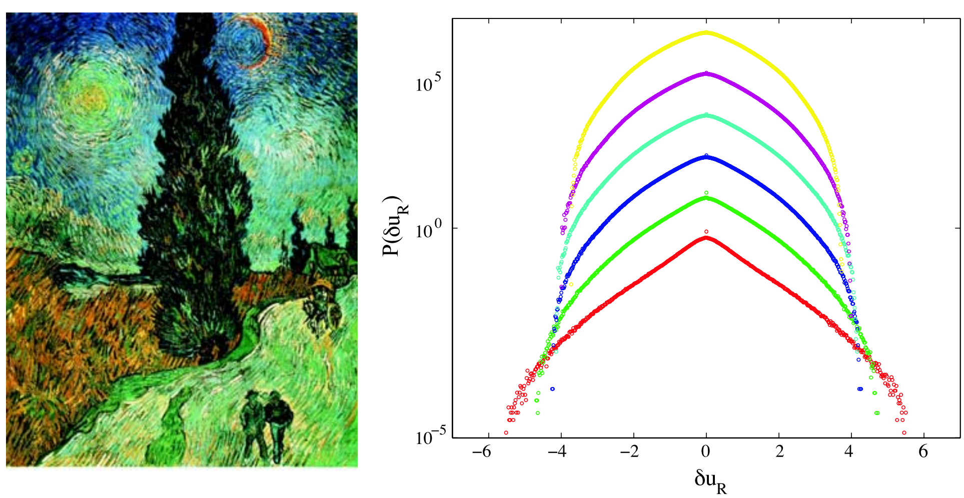

Fig. 9 *Road with Cypress and Star* (*left*) and its PDF (*right*) for pixel separations $R = 2$, 5, 15, 20, 30, 60 (*from bottom to top*). The 815×1063 image used for the calculations was taken from the WebMuseum-Paris webpage

condition; paintings such as *Cottages and Cypresses: Reminiscence of the North* (March-April, 1890) or *Wheat Field Under Clouded Sky* (July, 1890) display eddies at different scales but their PDF curves depart from what is expected (although in the former case the departure is not substantial). An interesting property of the paintings that we analyzed is the presence of an admixture of smooth variations and sharp transitions of luminance. This may produce an effect that

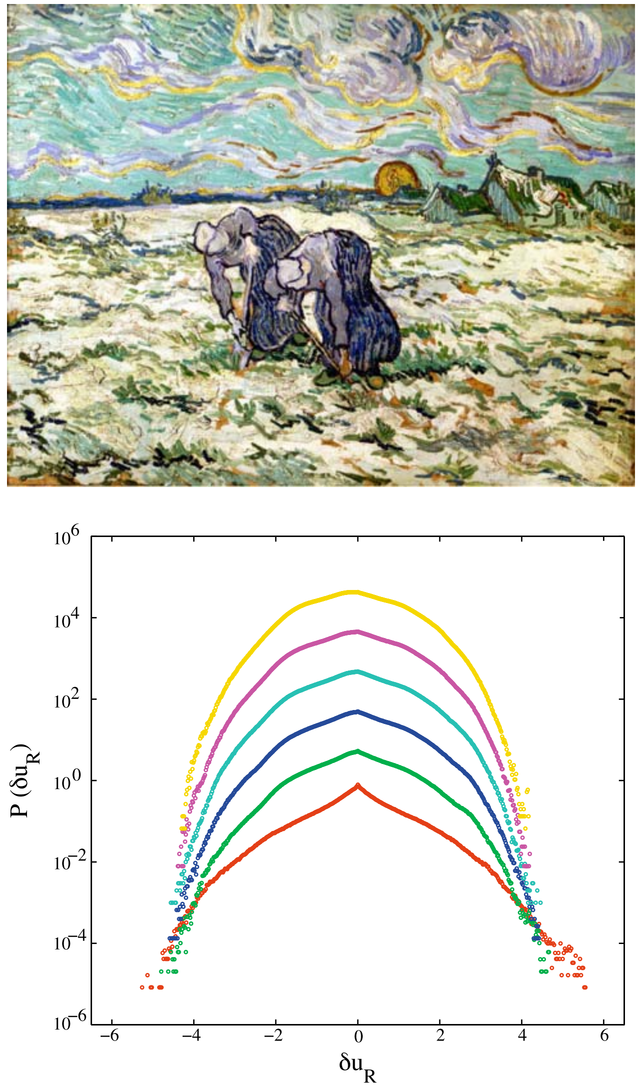

Fig. 10 *Two Peasant Women Digging in Field with Snow* (*top*) and its PDF (*bottom*) for pixel separations $R = 7, 30, 50, 75, 100, 150$ (*from bottom to top*). The 450×576 image used for the calculations was taken from the Foundation E.G. Bürle Collection webpage, and reproduced with permission

van Gogh himself described to his brother Theo when referring to the clouds and mountains of the *Starry Night* [16]: "their lines are warped as that of old wood" (letter 607, written 19 September, 1889). If it is so, a blurring process on the digital image may lead to a gradual reduction of the turbulence. To study this effect, we used the digital image of the *Starry Night*, reduced in size to speed up calculations (we commented that no significative differences are observed after reducing image sizes). Figure 11 shows the PDF of a 1375×1771 image, whose luminance was blurred using the image manipulation software GIMP [17]. It can be observed that in fact PDF curves depart from what is expected but we can not claim that this is the explanation (or the only one) but may give a clue to understand from where this turbulent

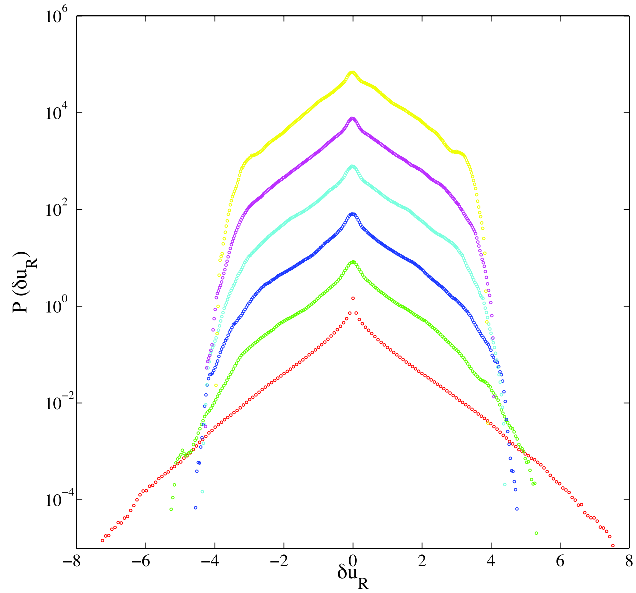

Fig. 11 PDF of a 1375×1771 image of the *Starry Night*, whose gray-scale version was blurred using the software GIMP, for pixel separations $R = 15, 60, 100, 150, 200, 300$ (*from bottom to top*)

effect comes from. Further study of this topic is currently underway.

6 Conclusion

In summary, our results show that *Starry Night*, and other impassioned van Gogh paintings, painted during periods of prolonged psychotic agitation transmitted the essence of turbulence with high realism. We use digital images of these paintings to show that the statistics of luminance contains the characteristic fingerprint of turbulent flow, according to a mathematical theory of turbulence based on the statistical approach developed by A. Kolmogorov. The analysis of the luminance of a painting presented here may be a useful tool for the relatively new field of using quantitative objective research for analyzing artwork.

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References

1. Livingstone, M.S.: Vision and Art: The Biology of Seeing. Harry N. Abrams, New York (2002)
2. Space Phenomenon Imitates Art in Universe's Version of van Gogh Painting. HUBBLESITE newscenter, News Release Number STScl-2004-10. http://hubblesite.org/newscenter/archive/releases/2004/10/. Acces date: October 1, 2007

3. Kolmogorov, A.N.: The local structure of turbulence in incompressible viscous fluid for very large Reynolds numbers. Dokl. Akad. Nauk SSSR **30**, 299–303 (1941). Reprinted in Proc. R. Soc. Lond. A **434**, 9–13 (1991)
4. Kolmogorov, A.N.: Dissipation of energy in the locally isotropic turbulence. Dokl. Akad. Nauk SSSR **32**, 16–18 (1941). Reprinted in Proc. R. Soc. Lond. A **434**, 15–17 (1991)
5. Kolmogorov, A.N.: A refinement of previous hypotheses concerning the local structure of turbulence in a viscous incompressible fluid at high Reynolds numbers. J. Fluid. Mech. **13**, 82–85 (1962)
6. Ghashghaie, S., Breymann, W., Peinke, J., Talkner, P., Dodge, Y.: Turbulent cascades in foreign exchange markets. Nature **381**, 767–770 (1996)
7. Kemp, M.: From science in art to the art of science. Nature **434**, 308 (2005). See also the section "Artists on science: scientists on art" in the same number
8. Taylor, R.P., Micolich, A.P., Jonas, D.: Fractal analysis of Pollock's drip paintings. Nature **399**, 422 (1999)
9. Mureika, J.R., Dyer, C.C., Cupchik, G.C.: Multifractal structure in nonrepresentational art. Phys. Rev. E **72**, 046101 (2005)
10. Hunt, R.W.G.: Measuring Colour. Fountain, Bibvewadi (1998)
11. González, R.C., Woods, R.E., Eddins, S.L.: Digital Image Processing Using MATLAB. Prentice Hall, New Jersey (2003)
12. Obukhov, A.M.: Some specific features of atmospheric turbulence. J. Fluid. Mech. **13**, 77–81 (1962)
13. Castaing, B., Gagne, Y., Hopfinger, E.J.: Velocity probability density functions of high Reynolds number turbulence. Physica D **46**, 177–200 (1990)
14. Mitra, D., Bec, J., Pandit, R., Frisch, U.: Is multiscaling an artifact in the stochastically forced Burgers equation? Phys. Rev. Lett. **94**(194501) (2005)
15. Arnold, W.N.: The illness of Vincent van Gogh. J. Hist. Neurosci. **13**, 22–43 (2004)
16. Harrison, R. (ed.): The Complete Letters of Vincent van Gogh. Bulfinch, Minnetonka (2000)
17. Peck, A.: Beginning the GIMP: From Novice to Professional. Apress, China (2006)

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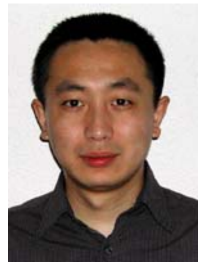

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