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# COLOUR TERMS IN ASTROPHYSICAL TEXTS: A CORPUS STUDY

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***Abstract***

*The aim of this paper is to present colour terms used by scientists in the field of astrophysics. We take into consideration both basic and non-basic colour terms – as understood by Berlin and Kay (1969). The research material, compiled in a corpus with AntConc, consists of abstracts published in selected astrophysical journals. The corpus size is 2,319,787 words.*

*The most frequent basic colour term found in the abstracts is* ***black*** *(612 occurrences), followed by* ***white*** *(167),* ***red*** *(160),* ***blue*** *(111) and* ***green*** *(98). It appears that the frequent word combinations in which these and other colour words are used happen to be specialized terms whose formation involved metaphorical or metonymic processes, e.g.* ***red giant, white dwarf, red planet, red noise and blue straggler****.*

***Keywords****: astrophysics, colour terms, corpus study, English, metaphor, metonymy.*

## *1. Introduction.*

Colour discrimination is distinguishing the differences in frequencies of various wavelengths of light that human eyes can perceive. In this paper, we concentrate on colour terms used in the abstracts of papers from the field of astrophysics. To conduct the analysis, we compiled a corpus of astrophysical texts. We concentrate on the uses of primary and secondary basic colour terms as well as of non-basic colour terms, especially in adjective + noun combinations, which – in numerous cases – appear to belong to scientific terminology. Many of these word combinations happen to be figurative expressions, both metonymic and metaphorical.

***2. Literature review.***

This section of the paper presents selected aspects of colour vocabulary and figurative language as well as scientific terminology and research on the use of colour terms in the sciences.

***2.1. Colour vocabulary.***

Numerous scholars have examined colour vocabulary from various perspectives: morphological, etymological, semantic and symbolic as well as comparative, to name just a few (see e.g. Anderson, Biggam, Hough & Kay, eds., 2014; Baran & Szeflińska-Baran, 2018; Berlin & Kay, 1969; Biggam, 2012; Biggam, Hough, Kay & Simmons, eds., 2011; Grzegorczykowa & Waszakowa, eds., 2000, 2003; Hardin & Maffi, eds., 1997; Kay & Maffi, 1999; Komorowska, 2010, 2017; Komorowska & Stanulewicz, 2018; Kosik-Szwejkowska, 2019; MacDonald, Biggam & Paramei, eds., 2018; MacLaury, 1997; Stala, 2011; Stanulewicz, 2009; Steinvall, 2002; Tokarski, 2004 [1995]; Warth-Szczygłowska, 2014; Wierzbicka, 1996).

For the purposes of this study, we employ the classification of colour terms proposed by Berlin and Kay (1969). Basing on the investigation of colour lexicons in 98 languages, Berlin and Kay claim that there are eleven basic colour terms which appear in the lexicon in a certain order (see Figure 1).

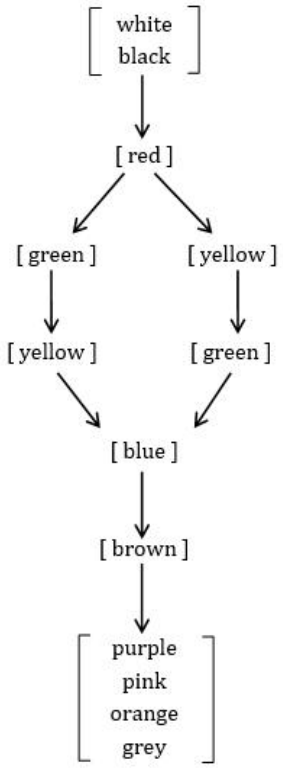


*Figure 1. The evolutionary sequence of basic colour terms (based on Berlin and Kay 1969, pp. 4, 104)*

According to Berlin and Kay (1969), the first colour categories appearing in a language are black and white, which are followed by red, green, yellow (or yellow, green), blue and brown. The remaining four categories – purple, pink, orange and grey – emerge later in any order. This evolutionary sequence has been modified, with new findings taken

into consideration (e.g. Kay, Berlin, Maffi & Merrifield, 1997; Kay & Maffi, 1999, 2005). In the new evolutionary sequence, it is made clear that the first two colour terms refer to (1) light and warm colours, and (2) dark and cool colours (see also Palmer 1999, p. 138). Table 1 presents a comparison of the two sequences (Berlin & Kay, 1969, vs. Kay & Maffi, 1999), accompanied by an interpretation of the modified sequence (Palmer 1999). As can be seen, the first six categories are taken into consideration.

**Table 1**

*Evolutionary sequences: Berlin and Kay (1969), Kay and Maffi (1999), and Palmer (1999)*

| Stage | Berlin and Kay (1969) | Kay and Maffi (1999) | Palmer (1999) |
|---|---|---|---|
| I (2 terms) | WHITE<br>BLACK | WHITE/RED/YELLOW<br>BLACK/GREEN/BLUE | LIGHT-WARM<br>DARK-COOL |
| II (3 terms) | WHITE<br>BLACK<br>RED | WHITE<br>RED/YELLOW<br>BLACK/GREEN/BLUE | WHITE<br>WARM<br>DARK-COOL |
| III (4 terms) | WHITE<br>BLACK<br>RED<br>GREEN (or YELLOW) | WHITE<br>RED/YELLOW<br>GREEN/BLUE<br>BLACK | WHITE<br>WARM<br>COOL<br>BLACK |
| IV (5 terms) | WHITE<br>BLACK<br>RED<br>GREEN<br>YELLOW | WHITE<br>RED<br>YELLOW<br>GREEN/BLUE<br>BLACK | WHITE<br>RED<br>YELLOW<br>COOL<br>BLACK |
| V (6 terms) | WHITE<br>BLACK<br>RED<br>GREEN<br>YELLOW<br>BLUE | WHITE<br>RED<br>YELLOW<br>GREEN<br>BLUE<br>BLACK | WHITE<br>RED<br>YELLOW<br>GREEN<br>BLUE<br>BLACK |

Berlin and Kay (1969) distinguish between basic and non-basic colour terms. A basic colour term must fulfil the following main criteria:

> "(i) It is *monolexemic*; that is, its meaning is not predictable from the meaning of its parts [...]
> (ii) Its signification is not included in that of any other color term. [...]
> (iii) Its application must not be restricted to a narrow class of objects. [...]
> (iv) It must be psychologically salient for informants. Indices of psychological salience include, among others, (1) a tendency to occur at the beginning of elicited lists of color terms, (2) stability of reference across informants and across occasions of use, and (3) occurrence in the idiolects of all informants. [...]"
>
> (Berlin & Kay, 1969, p. 6)

Moreover, Berlin and Kay (1969, pp. 6–7) present four subsidiary criteria a basic colour term may meet:

> "(v) The doubtful form should have the same distributional potential as the previously established basic terms. [...]

(vi) Color terms that are also the name of an object characteristically having that color are suspect [...]
(vii) Recent foreign loan words may be suspect.
(viii) In cases where lexemic status is difficult to assess [...], morphological complexity is given some weight as a secondary criterion. [...]"

The set of English basic colour terms includes the following words: *white*, *black*, *red*, *green*, *yellow*, *blue*, *brown*, *purple*, *orange*, *pink* and *grey* (see, among others, Corbett & Davies, 1995). The criteria quoted above exclude words such as *violet*, *cyan* and *magenta*. These lexical items belong to the set of non-basic colour terms.

Furthermore, it should be noted that basic colour terms may be divided into primary and secondary. Kay and McDaniel (1978, pp. 626–627, 633) called the categories RED, GREEN, YELLOW, BLUE, WHITE and BLACK "primary basic color categories", whereas in reference to BROWN, PURPLE, PINK, ORANGE and GREY, they employed the term "derived basic color categories". Corbett and Davies (1997, p. 198) use the term *secondary basic colour terms* to refer to the set of words representing the latter subset.

As our study is a corpus study, it is necessary to recall other corpus studies of colour vocabulary whose authors investigate not only the frequencies of particular words and word combinations, but also the contexts in which the examined colour words occur and their polysemy (see e.g. Bogushevskaya, 2020; Gieroń-Czepczor, 2011; Lototska, 2021; Stanulewicz, 2007, 2016; Stanulewicz & Grabarska, 2018; Stanulewicz & Komorowska, 2021; Stanulewicz & Pawłowski, 2018; Stanulewicz & Radomyski, 2021; Steinvall, 2002; Warth-Szczygłowska, 2014).

### *2.2. Studies on scientific terminology.*

*Terminology* is defined as "the sum total of terms used in a particular subject, e.g. chemistry or phonetics or swimming, and contained in special glossaries and dictionaries" (Hartmann and Stork, 1973, p. 236). *Terminology* also refers to a branch of linguistics concerned with investigating specialized terms (Sager, 1990, p. 3; de Bessé et al., 1997, p. 154; Michta, 2018, pp. 9–16). As Stoberski (1982, p. 83) claims, linguists ought to participate in examining and categorizing specialized vocabulary. Investigating specialized terms, scholars explore lexical units specific to a given discipline (see e.g. Ataboyev & Turg'unova, 2022, p. 382; Mikhojiddinovna, 2019, p. 50; Odiljonovich, 2020, p. 120).

Nowadays, a growing number of studies on the terminology of different scientific disciplines and professional fields may be observed, for instance, astronomy, including astrophysics (Łukasik, 2005, 2015; Stanulewicz & Radomyski, 2023; Waniakowa, 2003), aviation (Bielenia-Grajewska, 2017a; Kopecka, 2015; Kopecka & Mamet, 2022; Leśniczek, 2015), economics, business and management (Bielenia-Grajewska, 2019; Mamet, 2002, 2005; Szczygłowska, 2021), chemistry (Michta, 2007, 2018; Radomyski, 2023), law (Michta, 2022; Michta & Mroczyńska, 2022; Rzepkowska, 2020), medicine (Badziński, 2019; Bączkowska, 2018, 2019, 2020; Choryń & Sowińska-Mitas, 2015; Gonigroszek, 2017; Karwacka, 2020, 2021a, 2021b; Lu & Coxhead, 2020: Pluszczyk & Świątek, 2015; Zabielska & Żelazowska, 2015) and tourism (Bielenia-Grajewska, 2017b).

### *2.3. Studies on colour vocabulary used in the sciences.*

Colour is a phenomenon examined from various perspectives by numerous scholars representing different scientific disciplines, including physics, chemistry, mathematics, biology and medicine (see e.g. Chandrasekaran, 2001; Maciejewska and Maciejewska-

Szaniec, 2012; Zausznica, 2012). The uses of colour terms in scientific texts have been analyzed, among others, by Gonigroszek (2015) who concentrates on names of diseases deriving from colour words, Pułaczewska (2016) who examines metaphorical expressions containing colour terms employed in physics or Stanulewicz and Radomyski (2021, 2023) who investigate the uses of colour terms in inorganic chemistry as well as the uses of words related to colour terms, namely *light* and *dark*, in astrophysics.

### *2.4. Figurative language.*

The approach to metaphors and metonymies we adopt is the one proposed by Lakoff and Johnson (1980, 2003) and their followers. One of them is Kövecses who – in line with Lakoff and Johnson's understanding of metaphor, writes that metaphor is "understanding one conceptual domain in terms of another conceptual domain" (Kövecses, 2002, p. 4). According to Lakoff and Johnson, metaphor may not be considered only a figure of speech employed in literature, especially poetry, because metaphorical expressions are found in "ordinary" language: everyday conversations, political speeches, advertisements and scientific texts, to name but a few. Furthermore, Lakoff and Johnson (1980, p. 6) claim that "metaphor is not just a matter of language" because – actually – "human thought processes are largely metaphorical".

## *3. Aim and research questions.*

The aim of this paper is to investigate the use of colour terms in astrophysics. This study addresses the following research questions:

(1) What colour terms occur in the astrophysical texts compiled in the corpus?

(2) What is the frequency of basic and non-basic colour terms?

(3) What are the most common uses of colour terms in the corpus of the astrophysical texts?

(4) What metaphors can be identified in the astrophysical/astronomical terms containing colour words?

## *4. Methodology.*

In this research, we use corpus tools to identify colour terms in the astrophysical texts and to conduct an analysis of the terms in which they occur.

We compiled a corpus which includes abstracts from nine academic journals published in 2013–2022. They were chosen randomly from *ScienceDirect* (https://www.sciencedirect.com/) with *Research Randomizer* (https://www.randomizer.org/). The journals were selected on the basis of the search using the keyword *astrophysics*. As regards the corpus size, it contains 2,319,787 words (see Table 2).

**Table 2**

*The structure of the corpus*

| Journal | Number of words | Percentage |
|---|---|---|
| *Advances in Space Research* | 1,000,323 | 43.12 |
| *Journal of Atmospheric and Solar-Terrestrial Physics* | 397,709 | 17.14 |
| *Planetary and Space Science* | 388,615 | 16.75 |
| *New Astronomy* | 169,616 | 7.31 |
| *Astroparticle Physics* | 129,647 | 5.59 |
| *Physics of the Dark Universe* | 121,021 | 5.23 |
| *High Energy Density Physics* | 76,473 | 3.29 |

| Journal | Number of words | Percentage |
|---|---|---|
| *Journal of High Energy Astrophysics* | 26,741 | 1.15 |
| *Molecular Astrophysics* | 9,642 | 0.42 |
| Total | 2,319,787 | 100.00 |

We used the following research procedure. First, from the corpus, we extracted (1) primary basic colour terms, (2) secondary basic colour terms and (3) non-basic colour terms. Next, we concentrated on collocations that are formed with these colour terms. To be more specific, we identified colour adjective + noun combinations. The collected data were obtained with AntConc version 4.2.0 (Anthony, 2022).

Furthermore, we used two statistical measures, that is, the normalized frequency and t-score. Needless to say, normalized frequencies are usually calculated for studies which involve comparison of at least two corpora. However, as stated by Brezina (2018, p. 46):

> "When reporting frequency of words, we should report both the absolute (raw) and the relative frequency. The relative frequency needs to be normalized to the appropriate basis that is similar in size to the corpus or its parts (subcorpora or texts) that we are interested in."

Normalized frequencies of words or word combinations are calculated by employing the following equation (see e.g. Brezina, 2018, p. 46):

$$normalized\ \ frequency = \frac{f(x)}{N} \cdot 1{,}000{,}000$$

where: $f(x)$ = raw frequency of a word,
$N$ = number of words in the corpus.

T-score values were calculated to evaluate which two-word combinations were the most common for a given colour term. Brezina (2018, p. 276) defines *t-score* as a type of association measure which allows one to observe the colocation relationship between lexemes. T-score values are calculated by means of the following equation (Cvrček & Richterová, Eds., 2019):

$$t(xy) = \frac{f(xy) - \frac{f(x)f(y)}{N}}{\sqrt{f(xy)}}$$

where: $f(x)$ = raw frequency of word 1,
$f(y)$ = raw frequency of word 2,
$N$ = number of words in the corpus,
$f(x)f(y)/N$ = expected frequency.

Our study also focuses on the identification and analysis of figurative language, that is, metonymies and metaphors (Kövecses 2005, 2010 [2009], Lakoff and Johnson 2003 [1980]). We identified metonymic and metaphorical terms containing colour terms.

***5. Results.***

In this section, we report the results of our corpus study, that is, the frequencies of colour terms and word combinations consisting of a colour adjective and a noun.

***5.1. Primary basic colour terms.***

We first concentrate on the use of primary basic colour terms. In the corpus, all the six primary basics have been found. Table 3 presents their raw and normalized frequencies.

**Table 3**

*The frequencies of the primary basic colour terms*

| Colour term | Raw frequency | Normalized frequency (per 1,000,000) |
|---|---|---|
| *black* | 612 | 263.817 |
| *white* | 167 | 71.989 |
| *red* | 160 | 68.972 |
| *blue* | 111 | 47.849 |
| *green* | 98 | 42.245 |
| *yellow* | 21 | 9.053 |

As can be easily seen, the dominant primary basic colour term in the astrophysical texts is *black* (612 occurrences). The lexemes *white*, *red*, *blue* and *green* enjoy the frequencies ranging from 167 to 98, while *yellow* is found to be used only 21 times. Table 4 shows the identified combinations of these colour terms with nouns immediately following them.

**Table 4**

*Primary basic colour term + noun combinations*

| Colour term | Adjective + noun | Raw frequency | T-score |
|---|---|---|---|
| *black* | *black hole* | 556 | 23.57 |
| | *black carbon* | 22 | 4.67 |
| | *Black Sea* | 9 | 2.93 |
| | *black body* | 6 | 2.31 |
| *white* | *white dwarf* | 101 | 10.05 |
| | *white noise* | 23 | 4.79 |
| | *white light* | 16 | 3.97 |
| *red* | *red giant* | 19 | 4.36 |
| | *red shift* | 12 | 3.46 |
| | *red edge* | 7 | 2.64 |
| | *red planet* | 7 | 2.63 |
| | *red arc* | 6 | 2.44 |
| | *red supergiant* | 5 | 2.24 |
| | *red dwarf* | 5 | 2.23 |
| | *red clump* | 5 | 2.23 |
| | *red channel* | 5 | 2.22 |
| | *red noise* | 4 | 1.98 |
| | *red line* | 4 | 1.95 |
| | *red galaxy* | 2 | 1.38 |
| *blue* | *blue straggler* | 10 | 3.16 |
| | *blue jet* | 6 | 2.44 |
| | *blue light* | 6 | 2.42 |
| | *blue variable* | 4 | 1.98 |
| | *blue star* | 4 | 1.96 |

| Colour term | Adjective + noun | Raw frequency | T-score |
|---|---|---|---|
| | *blue aurora* | 2 | 1.41 |
| | *blue dragon* | 2 | 1.41 |
| | *blue supergiant* | 1 | 1.00 |
| *green* | *green roof* | 10 | 3.16 |
| | *green line* | 5 | 2.24 |
| | *green rust* | 5 | 2.24 |
| | *green channel* | 4 | 1.99 |
| | *green monopropellant* | 2 | 1.41 |
| | *green schist* | 2 | 1.41 |
| | *green valley* | 2 | 1.41 |
| *yellow* | *Yellow Sea* | 11 | 3.31 |
| | *Yellow River* | 3 | 1.73 |
| | *yellow hypergiant* | 1 | 1.00 |

The adjective *black* is used most frequently as part of the term *black hole*, defined as a "cosmic body of extremely intense gravity from which nothing, not even light, can escape. A black hole can be formed by the death of a massive star […]" (https://www.britannica.com/science/black-hole). As the data in Table 4 indicate, *black* occurs less frequently in the terms *black body* and *black carbon*, as well as in the geographical name *Black Sea*. The following examples illustrate selected uses of *black*:

(1) *Moreover, since the property of asymptotic flatness needs to be explicitly invoked, for instance, in relating the* ***black hole*** *and the white hole masses, it thereby raises a serious concern about the consistency of this model in view of the classical limit.*
(source: Mariam Bouhmadi-López, Suddhasattwa Brahma, Che-Yu Chen, Pisin Chen, Dong-han Yeom, "Asymptotic non-flatness of an effective black hole model based on loop quantum gravity", *Physics of the Dark Universe*)

(2) *When the AAEs were close to unity at Anshan, the absorption aerosol particles evidently consisted of* ***black carbon*** *from coal combustion and motor vehicles.*
(source: Huizheng Che, Hujia Zhao, Yunfei Wu, Xiangao Xia, Jun Zhu, Oleg Dubovik, Victor Estelles, Yanjun Ma, Yangfeng Wang, Hong Wang, Yaqiang Wang, Xiaoye Zhang, Guangyu Shi, "Application of aerosol optical properties to estimate aerosol type from ground-based remote sensing observation at urban area of northeastern China", *Journal of Atmospheric and Solar-Terrestrial Physics*)

(3) *The results show general consistence with the present geodynamics in the* ***Black Sea*** *coastal region. For example, our estimates support the general subsidence at Bourgas and Varna.*
(source: Nevin B. Avsar, Shuanggen Jin, S. Hakan Kutoglu, Gokhan Gurbuz, "Vertical land motion along the Black Sea coast from satellite altimetry, tide gauges and GPS", *Advances in Space Research*)

The most common word combinations with *white* include the terms *white dwarf, white noise* and *white light.* Let us present several contexts containing these expressions:

(4) *Novae are the observable outcome of a transient thermonuclear runaway on the surface of an accreting* ***white dwarf*** *in a close binary system.*
(source: Matthew J. Darnley, Martin Henze, "On a century of extragalactic novae and the rise of the rapid recurrent novae", *Solar and Stellar Astrophysics*)

(5) *The ICEEMD-MPCA denoising method is able to obviously eliminate **white noise** at high frequencies, remove systematic errors, and effectively preserve the earthquake wave signals.*
(source: Yanyan Li, Linqiao Han, Lei Yi, Shuhan Zhong, Chuanfa Chen, "Feature extraction and improved denoising method for nonlinear and nonstationary high-rate GNSS coseismic displacements applied to earthquake focal mechanism inversion of the El Mayor–Cucapah earthquake", *Advances in Space Research*)

(6) *Light curves observed in **white light** at a time resolution of a few seconds and with a duration of several hours, obtained in six nights and spanning a total time base of five months, were investigated using different time series analysis tools, as well as model fits.*
(source: Albert Bruch, "Photometry of the long period dwarf nova MU Centauri", *New Astronomy*)

*Red* stands in contrast to the previous colour terms since it is employed in a greater number of relatively frequent expressions. These expressions refer to galaxies (e.g. *red galaxy*), physical phenomena (e.g. *red shift*), planets (e.g. *red planet*) and stars (e.g. *red giant, red supergiant, red dwarf*), to name but a few. Consider the following examples:

(7) *From the graphical illustration of different physical measures like pressures, density, anisotropy, speeds of sound, equilibrium conditions, energy conditions and **red shift** etc., it is concluded that behavior of these parameters favors to realistic and viable models of compact star.*
(source: M. Zubair, Allah Ditta, Saira Waheed, "Physical viability of anisotropic strange spheres in non-linear teleparallel gravity", *New Astronomy*)

(8) *The evolutionary status of these stars are discussed and their nitrogen-to-carbon (N/C) and nitrogen-to-oxygen (N/O) ratios show that they are in their blue supergiant phase before the **red supergiant** region.*
(source: Taner Tanrıverdi, Özgür Baştürk, "Abundance analysis of the supergiant stars HD 80057 and HD 80404 based on their UVES Spectra", *Solar and Stellar Astrophysics*)

Likewise, the expressions containing *red,* expressions with *blue* are used to refer to light (e.g. *blue light*) and stars (e.g. *blue straggler*, *blue star*, *blue supergiant*). *Blue* is employed in expressions naming, among others, physical phenomena (e.g. *blue jet*, *blue aurora*). Exemplary contexts with these expressions are given below.

(9) *The **blue light** receptor cryptochrome that could form radical pairs after exposure to **blue light** was suggested to be a magnetoreceptor based on the proposition that radical pairs were involved in the magnetoreception.*
(source: Chunxiao Xu, Yan Lv, Chuanfang Chen, Yuxia Zhang, Shufeng Wei, "Blue light-dependent phosphorylations of cryptochromes are affected by magnetic fields in *Arabidopsis*", *Advances in Space Research*)

(10) *It is an eclipsing **blue straggler** and is most possibly formed by mass transfer between the two components.*
(source: K. Li, "Photometric study of the eclipsing blue straggler V205 in the globular cluster NGC 5139", *New Astronomy*)

(11) *Events like sprites and halos are caused by the upward quasi-electrostatic fields associated with intense cloud-to-ground discharges while jets (**blue starter**, **blue***

***jet**, gigantic jet) are caused by charge imbalance in thunderstorm during lightning discharges but they are not associated with a particular discharge flash.*
(source: Devendraa Siingh, R. P. Singh, Sarvan Kumar, T. Dharmaraj, Abhay K. Singh, Ashok K. Singh, M. N. Patil, Shubha Singh, "Lightning and middle atmospheric discharges in the atmosphere", *Journal of Atmospheric and Solar-Terrestrial Physics*)

*Green* is used in a fewer number of expressions. Interestingly, this colour term is mostly used in contexts describing substances and minerals (e.g. *green rust, green monopropellant, green schist*). Moreover, it describes objects abundant in vegetation (e.g. *green valley*). Here are some examples from the corpus:

(12) *In this analogy the hydrothermal mound is broadly comparable to the rocket while individual engines comprise the variable valence and conformationally flexible mineral, **green rust***
$(\sim [Fe_4^{2+}Fe_2^{3+}(OH)_{12}]^{2+}[CO_3 \cdot H_2O]^{2-})$ *dosed with Ni, Co, Mo and W.*
(source: Michael J. Russell, "Figuring out how life first took off is (much like) rocket science!", *Planetary and Space Science*)

(13) *Consequently, these findings indicated that the **green roof** has a significant effect on temperature reduction, especially by selecting the buildings with the above-mentioned characteristics.*
(source: Anahita Asadi, Hossein Arefi, Hafez Fathipoor, "Simulation of green roofs and their potential mitigating effects on the urban heat island using an artificial neural network: A case study in Austin, Texas", *Advances in Space Research*)

Lastly, *yellow* predominantly happens to be part of geographical names (i.e. *Yellow Sea, Yellow River*). The colour term is only used once in the expression *yellow hypergiant* referring to a star. Let us consider an example of this use of *yellow*:

(14) *It belongs to the category of **yellow hypergiants** and it is characterized by quite high mass loss episodes.*
(source: M. De Becker, D. Hutsemékers, E. Gosset, "The XMM-Newton view of the yellow hypergiant IRC +10420 and its surroundings", *Solar and Stellar Astrophysics*)

### *5.2. Secondary basic colour terms.*

As has been signalled, another set of colour terms we focus on is the group of the secondary basic colour terms. Table 5 shows the frequencies of these terms in the astrophysical texts we included in the corpus.

**Table 5**

*The frequencies of the secondary basic colour terms*

| Colour term | Absolute frequency | Relative frequency (per 1,000,000) |
|---|---|---|
| *brown* | 15 | 6.466 |
| *orange* | 4 | 1.724 |

| Colour term | Absolute frequency | Relative frequency (per 1,000,000) |
|---|---|---|
| *purple* | 2 | 0.862 |
| *grey* | 1 | 0.431 |

The secondary basic colour terms identified in the corpus are the following: *brown*, *orange*, *grey* and *purple*. They are employed in several adjective + noun combinations which are presented in Table 6.

**Table 6**

*Secondary basic colour term + noun combinations*

| Colour term | Adjective + noun | Raw frequency | T-score |
|---|---|---|---|
| *brown* | *brown dwarf* | 15 | 3.870 |
| *orange* | *orange subunit* | 4 | 2.000 |
| *purple* | *purple aurora* | 2 | 1.410 |
| *grey* | *grey discoloration* | 1 | 1.000 |

The lexeme *brown* is used in a term naming a type of star (*brown dwarf*) and *purple* occurs in an expression describing a physical phenomenon (*purple aurora*). Let us now present some contexts in which the secondary basic colour terms are found.

(15) *Observations and models suggest that the conditions to develop lightning may be present in cloud-forming extrasolar planetary and* ***brown dwarf*** *atmospheres.*
(source: G. Hodosán, Ch. Helling, I. Vorgul, "Exploring terrestrial lightning parameterisations for exoplanets and brown dwarfs", Planetary and Space Science)

(16) ***Violet/purple auroras*** *are significantly more abundant (98% probability) at times of low 14C production.*
(source: Dallas Abbott, Robert Juhl, "New historical records and relationships among 14C production rates, abundance and colour of low latitude auroras and sunspot abundance", *Advances in Space Research*)

In example (16) – as well as in (19) below – the authors of the text describe auroras using two colour terms: non-basic *violet* and basic *purple*, separating them with a slash. The colour violet, covering a narrower part of the colour spectrum, is considered a shade of purple – at least by English speakers. The online *Cambridge Dictionary* defines *violet* as follows: "having a bluish-purple colour" (https://dictionary.cambridge.org/dictionary /english/violet). The authors apparently refer to different shades of the colour: 'bluish-purple' and 'purple'.

Finally, it should be noted that one of the secondary basic colour terms, namely *pink*, has not been found to occur in the corpus.

### *5.3. Non-basic colour terms.*

The last group of colour terms which needs to be discussed is non-basic colour terms. The use of only one colour term belonging to this group – *violet* – is observed in the corpus. Its frequency is presented in Table 7.

**Table 7**

*The frequencies of the non-basic colour term*

| Colour term | Absolute frequency | Relative frequency (per 1,000,000) |
|---|---|---|
| *violet* | 19 | 8.190 |

It should be noted that *violet* is preceded 16 times by the prefix *ultra*. Let us now take into account the combinations of (*ultra-*)*violet* and nouns. As far as the nouns modified by this lexeme are concerned, they refer to a variety of physical phenomena, substances and instruments related to light, e.g.

(17) *The Raman lidar is designed for a nighttime operating system by employing a* ***ultra-violet (UV) laser*** *source and can measure the water vapor mixing ratio at an altitude up to 7km using vertically pointing observations.*
(source: Masanori Yabuki, Makoto Matsuda, Takuji Nakamura, Taiichi Hayashi, Toshitaka Tsuda, "A scanning Raman lidar for observing the spatio-temporal distribution of water vapor", *Journal of Atmospheric and Solar-Terrestrial Physics*)

(18) *The dust storm identification results were compared and analyzed with the AGRI true color, Aerosol Optical Depth products, and* ***Ultra Violet Aerosol*** *Index products.*
(source: Hong Jiang, Qing He, Jie Zhang, Ye Tang, Chunyan Chen, Xinsheng Lv, Yunhui Zhang, Zonghui Liu, "Dust storm detection of a convolutional neural network and a physical algorithm based on FY-4A satellite data", *Advances in Space Research*)

(19) *The positive correlation of* ***violet/purple auroras*** *with times of low 14C production rate and the lack of correlation of blue auroras with times of high 14C production is surprising, for this portion of the visible spectrum contains strong emission lines and some lines with high energies of excitation.*
(source: Dallas Abbott, Robert Juhl, "New historical records and relationships among 14C production rates, abundance and color of low latitude auroras and sunspot abundance", *Advances in Space Research*)

### *6. Discussion: Metonymies and metaphors.*

As has already been pointed out, colour terms are used to modify nouns with a view to explaining physical phenomena, such as appearance, heat or size. As Raad (1989, p. 133) notes,

> "A number of observed and hypothetical phenomena in space have been vividly described by compounding color and other physical signification, the colors normally suggesting qualities of light, heat, absorption or emission, and activity or inactivity, while other words suggest aspects of size or appearance."

In this section, we will concentrate on metonymies and metaphors which may be observed in the corpus containing astrophysical texts.

We have identified several metonymic terms. All of them can be classified as the Category and Property ICM. Kövecses (2010 [2002], p. 181) explains that "categories typically evoke, and may metonymically stand for, one or more of their defining or otherwise essential properties; conversely, a defining or essential property of a category may evoke,

and stand for, the category that it defines". In this analysis, the metonymy A PROPERTY (COLOUR) FOR AN OBJECT is observed, e.g. ***green roof***, ***green valley*** and ***red planet***. In the case of the expressions containing *green*, they are simply descriptions of objects and *green* stands for 'vegetation'. Similarly, the expression *red planet* is a descriptive expression. According to Bańko (2002, p. 46), it can be classified as a conventionalized circumlocution. In other words, it functions as an expression which can substitute an existing name of an object, in this case *Mars*. Additionally, Bańko (2002, p. 46) explains the origin of the Polish expression *czerwona planeta* 'red planet' (undoubtedly a calque) in the following way: "it owes this colour to the oxidation of rocks" (translation ours). To be more exact, it is the colour of hematite:

> "Powders of red hematite have an intense orange to red to purple color resulting from a steep absorption edge in reflectivity spectra through the red portion of the visible spectrum (600–700 nm). [...] Comparison of remote sensing band near data for Mars at visible and near-IR wavelengths to corresponding data for hematite and hematite-bearing materials has led to the inference well-crystalline that red (i.e., and pigmentary) hematite is a subordinate pigmenting phase on the optical surface of Mars where a band minimum near 850-870 nm is present" (Morris, Golden & Bell 1997, p. 9125)

Let us now consider the identified metaphorical expressions. Many terms referring to classes of celestial bodies contain names of mythical or folklore creatures. For this reason, we might argue that "mythicizing" metaphors are used in astrophysical texts. Interestingly, Kövecses (2010 [2002], p. 66) entertains the idea that UNCONTROLLABLE EXTERNAL EVENTS ARE LARGE, MOVING OBJECTS. The author states, for instance, that "Poseidon can thus be seen as the god of uncontrollable external events in general, and not just the god of the sea (or some other specific forceful entity)". Let us now concentrate on expressions containing *giant* and *dwarf*: ***red giant***, ***blue supergiant***, ***yellow hypergiant***; ***red dwarf***, ***white dwarf***, ***brown dwarf***.

The *Encyclopædia Britannica* provides the following definitions of *giant* and *dwarf*:

> "Giant, in folklore, huge mythical being, usually humanlike in form. The term derives (through Latin) from the Giants (Gigantes) of Greek mythology, who were monstrous, savage creatures often depicted with men's bodies terminating in serpentine legs. According to the Greek poet Hesiod, they were sons of Ge ("Earth") and Uranus ("Heaven"). […]"
> (https://www.britannica.com/topic/giant-mythology)

> "In Teutonic and especially Scandinavian mythology and folklore, the term dwarf (Old Norse: *dvergr*) denoted a species of fairy inhabiting the interiors of mountains and the lower levels of mines. Dwarfs were of various types, all of small stature, some being no more than 18 inches (45 cm) high and others about the height of a two-year-old child. […] Many legends show dwarfs as kindly beings, generous to those who pleased them but vengeful when offended. The Swiss dwarfs, or "earth-men," sometimes helped in agricultural work, found straying animals, and put out firewood or fruit for poor children to find. In Scandinavia and Germany also they were friendly to men, but occasionally they stole corn, teased cattle, and abducted children and young girls. [...]"
> (https://www.britannica.com/topic/dwarf-mythology)

In astrophysical terminology, the lexemes *giant* and *dwarf* are used in a metaphorical way to show the size of celestial bodies (see Crawford & Juricevic, 2022, p. 3). The metaphor underlying all the terms with *giant* and *dwarf* is A CELESTIAL BODY IS A MYTHICAL/FOLKLORE CREATURE. While *giant* and *dwarf* suggest the size, the colour terms point not only to the observed light and colour, but also to heat.

Another type of metaphor worth mentioning is animization, exemplified by the term ***blue straggler***. The lexeme *straggler* is typically used with reference to people or animals. The online *Cambridge Dictionary* provides the following definition of this word:

> "a person or animal that is last in a group to do something or the last to get to or leave a place".
> (https://dictionary.cambridge.org/dictionary/english/straggler)

Let us also consider an explanation why this word occurs in *blue straggler*, a term referring to stars:

> "Blue straggler stars are so named because they seem to lag behind in the aging process, appearing younger than the rest of the stars they formed with. Astronomers think that blue stragglers might emerge from binary systems – pairs of stars that orbit each other."
> (https://hubblesite.org/contents/media/images/2011/16/2853-Image.html)

Undoubtedly, the metaphor underlying the term *blue straggler* is A CELESTIAL BODY IS A HUMAN / AN ANIMAL.

Lastly, in the corpus of astrophysical texts, it is also possible to identify synesthetic metaphors. Let us consider the following terms: ***white noise*** and ***red noise***. The lexemes *white* and *red* refer to phenomena in the visual domain, while *noise* refers to phenomena in the auditory domain. In William's (1976, p. 463) view, colour terms "may shift only to sound". Such adjectives as *bright*, *brilliant*, *clear*, *dark* or *dim*, which are typically used to describe visual phenomena, may also be used to describe the quality of sound.

The colour words *white* and *red* in the terms *white noise* and *red noise* specify the quality of sound. *White noise* is defined as "a random signal with a flat (constant) power spectrum density, i.e. equal power within any frequency band of fixed width. White noise sounds very bright" (https://www.soundonsound.com/glossary/white-noise), whereas "red noise has a dampened or soft quality compared to traditional white noise. The sound is a low roar, reminiscent of the sounds encountered in a shower, or those produced by a waterfall or heavy rainfall" (Barozzi et al. 2017, p. 143).

### *7. Conclusions.*

As the results of our study indicate, almost all basic colour terms are used in astrophysical texts. The exception is *pink*, one of the secondary basic colour terms. As regards non-basic colour terms, we observe the use of only one lexeme, namely *violet*.

The frequency data point to three groups of colour terms: (1) one colour term with a frequency (612 occurrences) far surpassing the frequencies of the other terms: *black*, (2) four colour terms with frequencies from 167 to 98: *white*, *red*, *blue*, *green*, and (3) six colour terms with frequencies from 21 to 1: *yellow*, *violet*, *brown*, *orange*, *purple*, *grey* (see Figure 2).

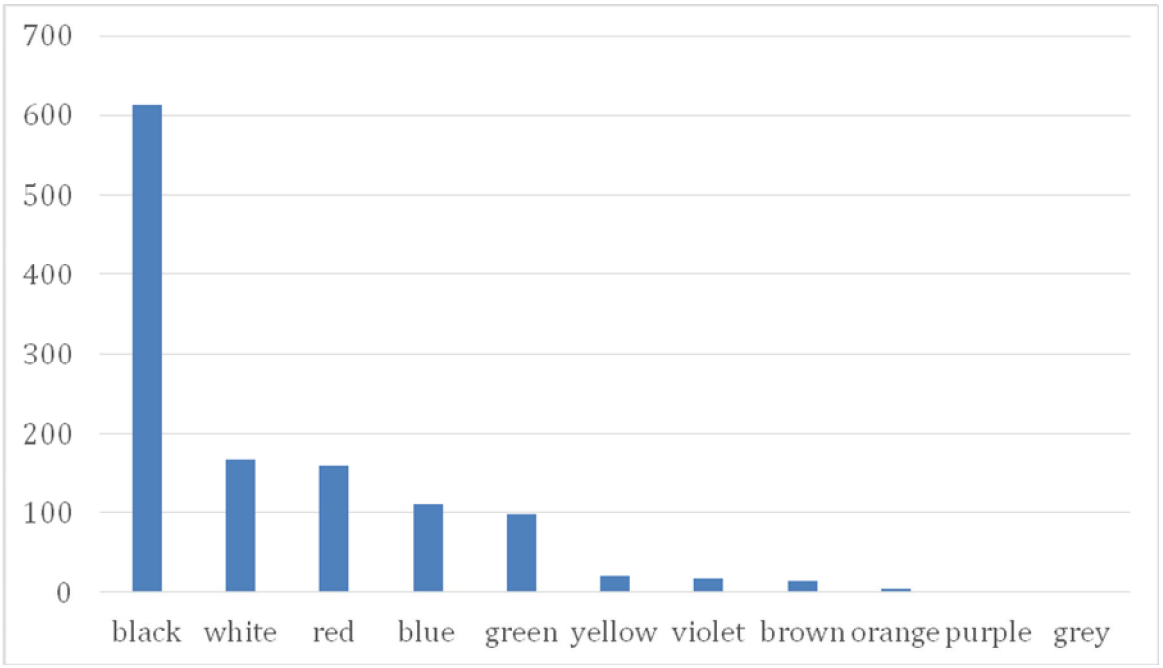


*Figure 2. The frequencies of colours terms in the corpus*

The frequent use of the colour term *black*, and especially the term *black hole*, points to the enormous popularity of the topic of black holes in the astrophysical journals published in the period 2013–2022 – in comparison with the popularity of the other "colour" phenomena. Obviously, we cannot predict whether this trend will continue in the future.

The study also emphasizes the fact that numerous astronomic/astrophysical terms containing colour words are figurative. The identified metaphors include synesthetic metaphors as well as animizing and mythicizing metaphors, such as A CELESTIAL BODY IS A HUMAN / AN ANIMAL and A CELESTIAL BODY IS A MYTHICAL/FOLKLORE CREATURE.

As regards prospects for further research, we intend to create a larger corpus of astrophysical texts, which will allow us to verify the results of this research, especially the ones concerning the use of non-basic colour terms. We also plan to compare the uses of the words *black* and *dark* (for a study of *light* and *dark* in astrophysical texts, see Stanulewicz & Radomyski, 2023).

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***Анотація***

*Метою статті є опис термінів – назв кольорів, які використовують вчені в галузі астрофізики. Ми беремо до уваги як базові, так і неосновні колірні терміни – як їх розуміють Берлін і Кей (1969). Дослідницький матеріал, зібраний у корпусі з AntConc, складається з рефератів, опублікованих у вибраних астрофізичних журналах. Розмір корпусу становить 2 319 787 слів.*

*Найчастішим базовим колірним терміном, який зустрічається в анотаціях, є* ***чорний / dark*** *(612 випадків), за ним йдуть* ***білий / white*** *(167),* ***червоний / red*** *(160),* ***синій / blue*** *(111) і* ***зелений / green*** *(98). Часто словосполучення, у яких використовуються ці та інші кольороназви, є спеціальними термінами, утвореними завдяки метафоричним чи метонімічним процесам, наприклад:* ***red giant, white dwarf, red planet, red noise and blue straggler***.

***Ключові слова****: астрофізика, колірні терміни, корпусне дослідження, англійська мова, метафора, метонімія.*