

天文科學數據基礎

何勃亮

國家天文臺 信息與計算中心

提綱

- ▶ 天文數據源流
- ▶ 普適圖像傳輸系統標準 (FITS)
- ▶ 虛擬天文臺表格 (VOTable)
- ▶ 文本型數據 (TXT、CSV等)

天文數據源流

史記天官書 原卷二十七

〔索隱〕案：天文有五官。官者，星官也。星座有尊卑，若人之官曹列位，故曰天官。〔正義〕張衡云：「文曜麗乎天，其動者有七，日月五星是也。日者，陽精之宗；月者，陰精之宗；五星，五行之精。衆星列布，體生於地，精成於天，列居錯峙，各有所屬，在野象物，在朝象官，在人象事。其以神著有五列焉，是有三十五名：一居中，謂之北斗；四布於方各七，爲二十八舍；日月運行，曆示吉凶也。」

中宮①天極星，②其一明者，太一常居也；③旁三星三公，④或曰子屬。後句四星，⑤末大星正妃，⑥餘三星後宮之屬也。環之匡衛十二星，藩臣。皆曰紫宮。⑦

①〔索隱〕姚氏案：「春秋元命包云：『官之爲言宜也，宣氣立精爲神垣。』又文耀鉤曰：『中宮大帝，其精北極星。含元出氣，流精生一也。』」

②〔索隱〕案：爾雅「北極謂之北辰」。又春秋合誠圖云「北辰，其星五，在紫微中」。楊泉物理論云「北極，天之中，陽氣之北極也。極南爲太陽，極北爲太陰。日、月、五星行太陰則無光，行太陽則能照，故爲昏明寒暑之限極也」。

③〔索隱〕案：「春秋合誠圖云：『紫微，大帝室，太一之精也。』」〔正義〕秦一，天帝之別名也。劉伯莊云：「秦一，天神之最尊貴者也。」

史記天官書

欽定四庫全書

唐開元占經卷六十五

瞿曇悉達撰

石氏中官占上一

攝提占一

石氏曰攝提六星夾大角

八角八度少去北極五十九度半在黃道內三十二度太

一名環樞一名天樞一名闕丘一名致法一名三老一

名天鈇一名天獄一名天楯一名天武一名天兵星東

火

唐開元占經

二

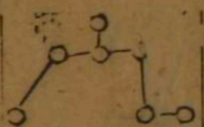
星經

卷一

二

星傾天子不安失位也訣曰火入紫微宮中天下大亂帝王失位

北斗



北斗星謂之七政天之諸侯亦為帝車魁四星為璇璣杓三星為玉衡齊七政斗為人君號令之主出號施令布政天中臨制四方第一名天樞為土星主陽德亦曰政星也是太子像星暗若經七日則大災第一名璇主金刑陰女主之位主月及法若星暗經六

欽定四庫全書

靈臺秘苑卷十三

北周 庾季才 原撰

宋 王安禮等 重修

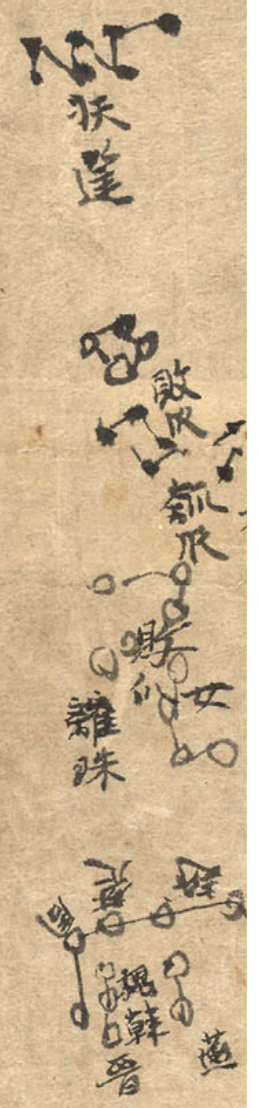
西方七宿 中外官附

奎宿

奎宿距西南大星去極七十二度半 星欲明則吉 若德政虧則星有角 動為兵 其中星明則大水月犯之其分亂邊兵水灾貴人憂民不安



自箕二度相風在廿七度於辰在日為星，記者言統已万物之終故曰星紀吳越之亦也



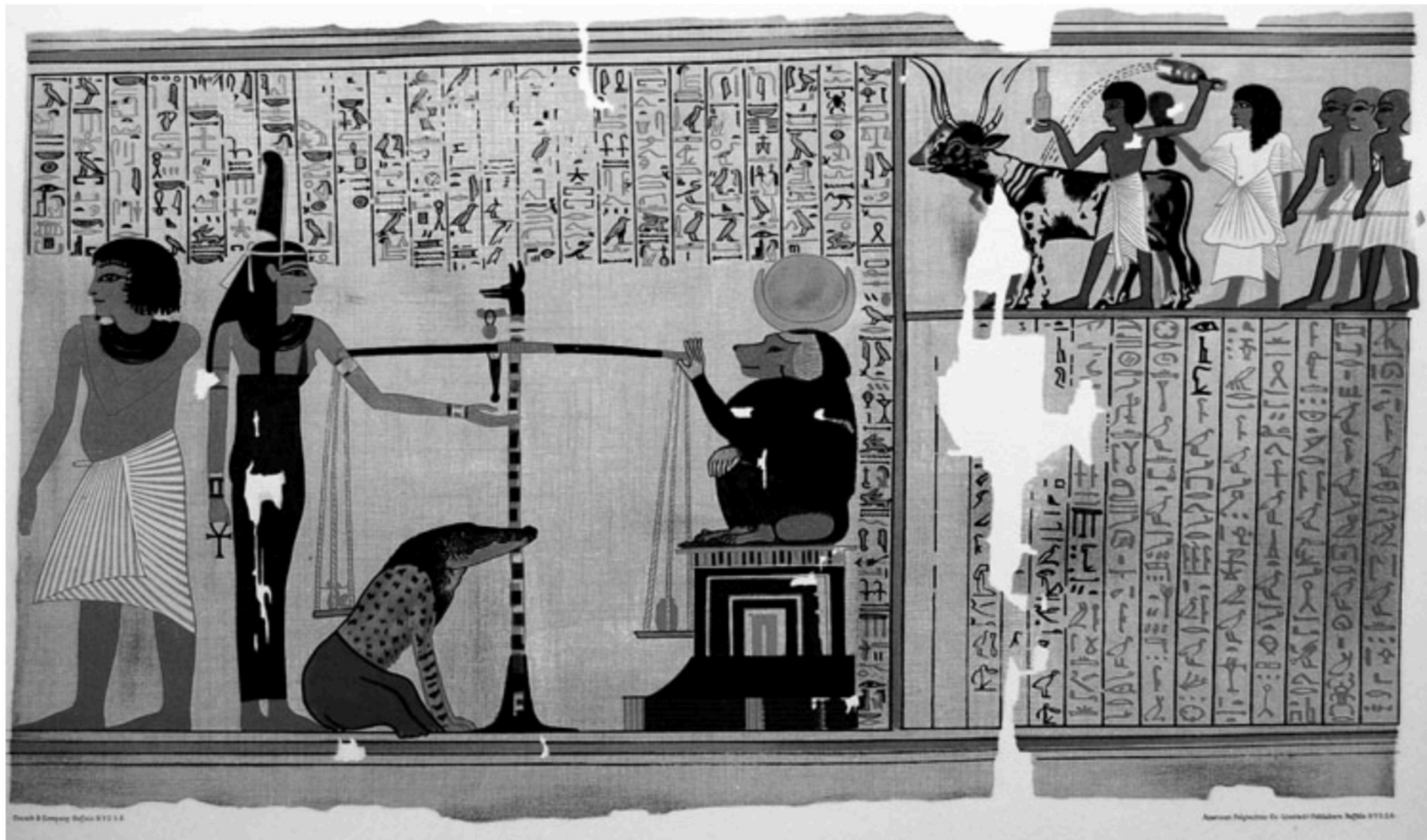
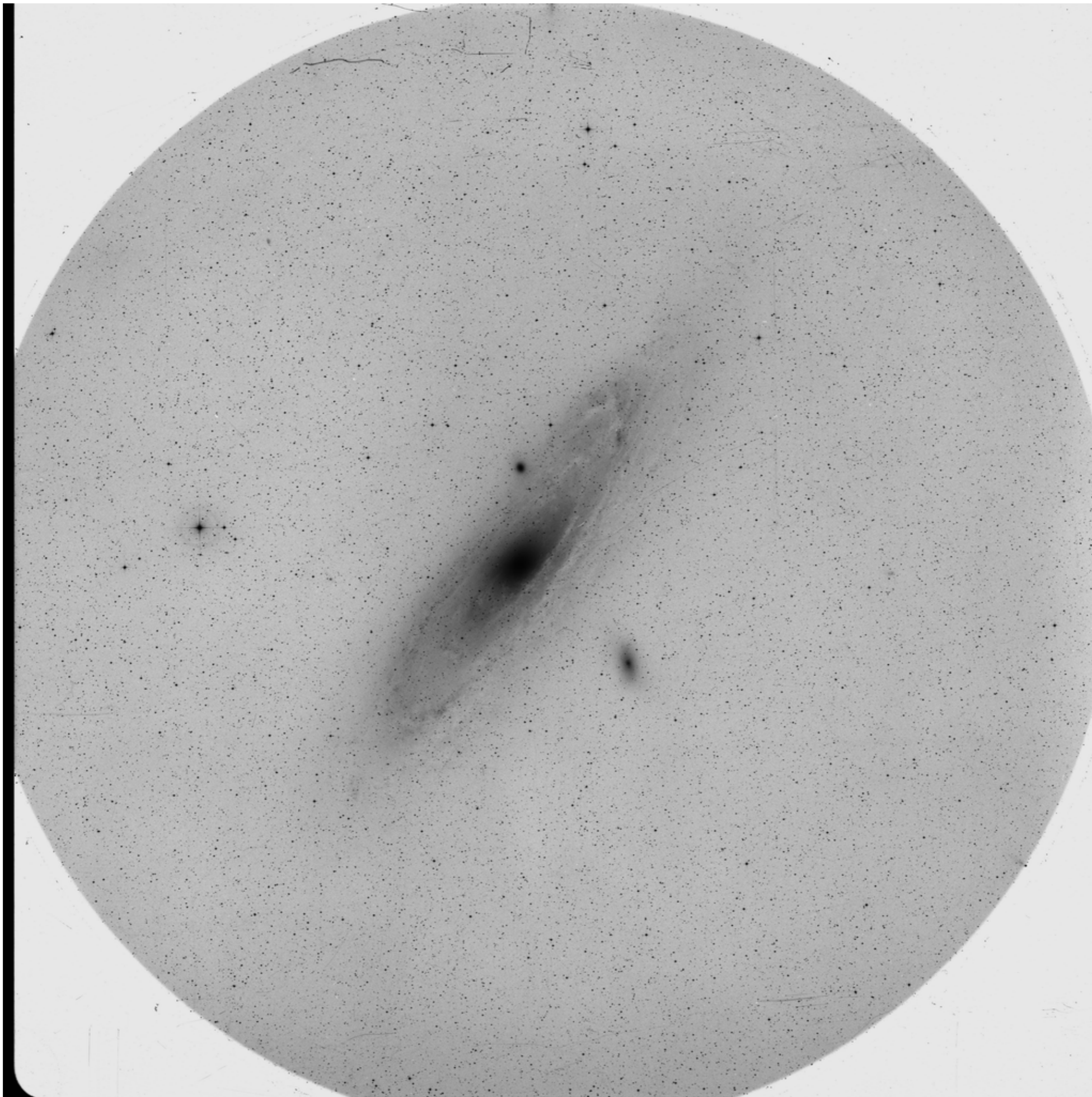


Figure 2.5. Chromolithograph of an Egyptian papyrus “Judgment of the Dead”, from Binion’s (1887) *Ancient Egypt or Mizraim*. 21 × 43.6 cm. Note the goddess of truth, Maat, presiding over the weighing of the heart of the deceased man on the left. Thoth, the god of wisdom and writing, is ready to record the outcome, and the “devourer” is waiting to destroy the heart if there is an unfavorable outcome. Being a lunar deity, Thoth has a Moon over his head. *See also* Color Section 1.





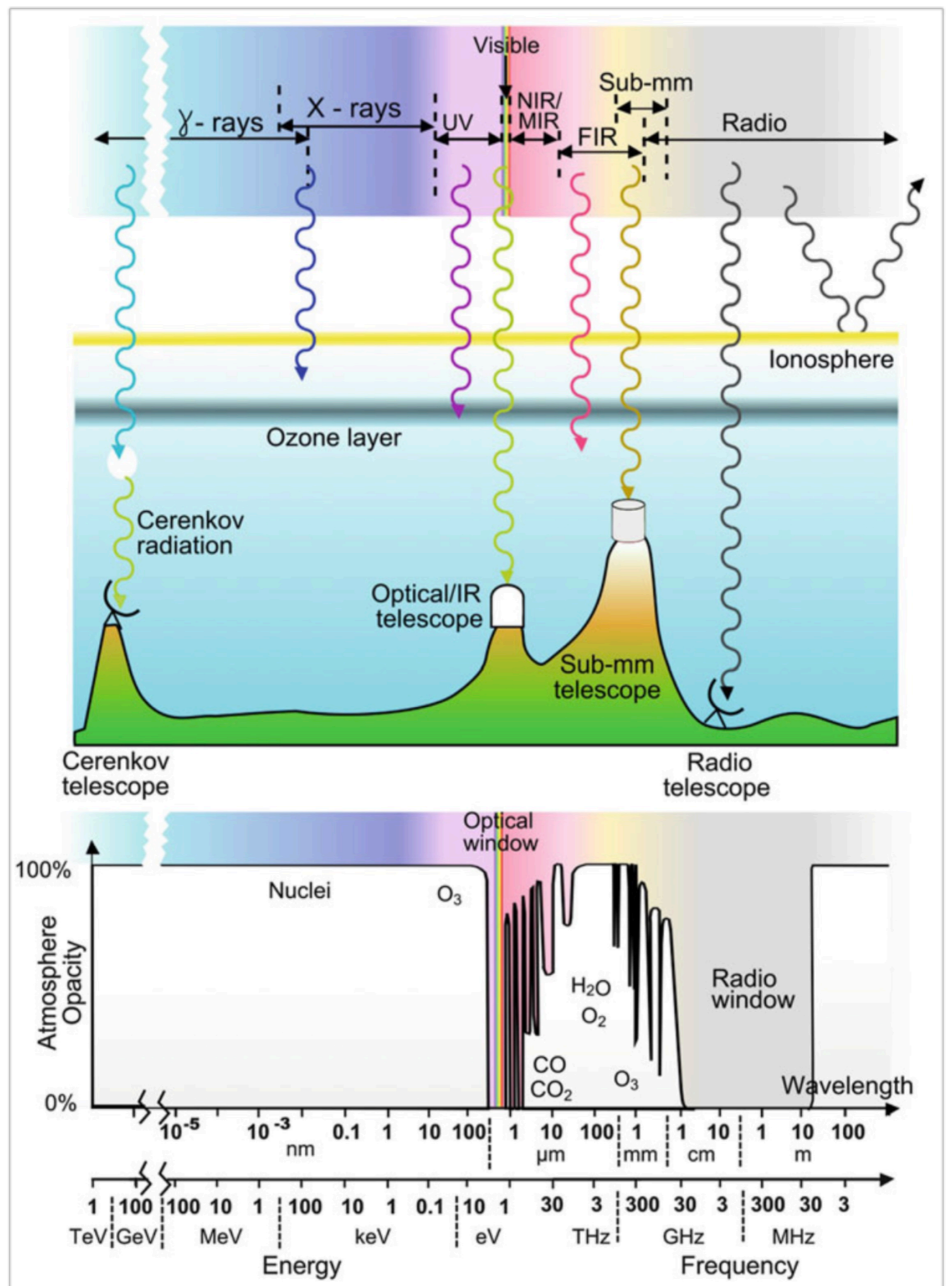
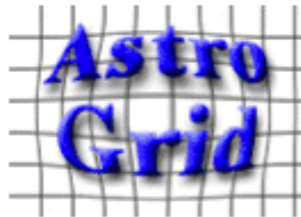


Fig. 2.1 Cartoon indicating absorption by the atmosphere versus wavelength, and the height needed to carry out astronomy at different wavelengths (Figure kindly provided by Dr Adam Woodcraft)



Chinese Astronomical Data Center

input coordinate or target name 30 arcsec

Sample: [15.51967109 -0.28502335, m31](#)



Domestic Dataset

- AST3 Image ⓘ 🔍
- AST3 Light Curve ⬇️ ⓘ 🔍
- AST3 Survey ⬇️ ⓘ 🔍
- BASS DR1 gradd ⬇️ ⓘ 🔍
- BASS DR1 Images ⬇️ ⓘ 🔍
- BASS DR2 gradd ⓘ 🔍
- BASS DR2 Images ⓘ 🔍
- BASS DR2 Stack ⓘ 🔍
- BASS EDR ⬇️ ⓘ 🔍
- CSTAR ⓘ 🔍
- GMG2.4m ⓘ 🔍
- MMDData SLFITS ⓘ 🔍
- SCUSS Catalogue ⓘ 🔍
- SCUSS Image ⓘ 🔍
- SCUSS Proper Motion ⓘ 🔍
- SHAO156 2013 ⓘ 🔍
- SHAO156 2014 ⓘ 🔍
- SHAO 65M ⓘ 🔍

Solar Dataset

- Huairou SOS ⓘ 🔍
- NVST ⓘ 🔍
- SBRS ⓘ 🔍

Other

- TwoMass ⬇️ ⓘ 🔍
- UCAC ⬇️ ⓘ 🔍
- WISE ⬇️ ⓘ 🔍
- Dragon on Silkroad ⬇️
- GAIA DR1 ⬇️
- GAIA DR2 ⬇️
- Casjobs 🔍
- SDSS DR12 ⬇️ 🔍
- Vizier ⬇️ 🔍
- Historical Plates ⬇️

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This is Data Release 15.

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普適圖像傳輸系統 (FITS)

Flexible Image Transport System

表 1: *FITS* 发展过程中的标志性里程碑

日期	里程碑
1979	Initial <i>FITS</i> Agreement and first interchange of files
1981	Published original (single HDU) definition (Wells et al. 1981)
1981	Published random-groups definition (Greisen & Harten 1981)
1982	Formally endorsed by the IAU (IAU 1983)
1988	Defined rules for multiple extensions (Grosbøl et al. 1988)
1988	IAU <i>FITS</i> Working Group (IAUFWG) established
1988	Extended to include ASCII-table extensions (Harten et al. 1988)
1988	Formal IAU approval of ASCII tables (IAU 1988)
1990	Extended to include IEEE floating-point data (Wells & Grosbøl 1990)
1994	Extended to multiple IMAGE-array extensions (Ponz et al. 1994)
1995	Extended to binary-table extensions (Cotton et al. 1995)
1997	Adopted four-digit-year date format (Bunclark & Rots 1997)
2002	Adopted proposals for world-coordinate systems (Greisen & Calabretta 2002)
2002	Adopted proposals for celestial coordinates (Calabretta & Greisen 2002)
2004	Adopted MIME types for <i>FITS</i> data files (Allen & Wells 2005)
2005	Extended to support variable-length arrays in binary tables
2005	Adopted proposals for spectral-coordinate systems (Greisen et al. 2006)
2005	Extended to include 64-bit integer data type
2006	Adopted WCS HEALPix projection (Calabretta & Roukema 2007)
2006	Established <i>FITS</i> convention registry
2014	Adopted proposals for time coordinates (Rots et al. 2015)
2016	Adopted proposals for compressed data
2016	Adopted various registered conventions
2018	General language editing

版本歷史

表 2: 标准的版本历史

版本	日期	状态
NOST 100-0.1	1990-12	第一版草案标准
NOST 100-0.2	1991-06	第二版修订草案标准
NOST 100-0.3	1991-12	第三版修订草案标准
NOST 100-1.0	1993-06	NOST 标准
NOST 100-1.1	1995-09	NOST 标准
NOST 100-2.0	1999-03	NOST 标准
IAUFWG 2.1	2005-04	IAUFWG 标准
IAUFWG 2.1b	2005-12	IAUFWG 标准
IAUFWG 3.0	2008-07	IAUFWG 标准
IAUFWG 4.0	2016-07	IAUFWG 标准 (批准)
IAUFWG 4.0	2018-08	IAUFWG 标准 (语言编辑版)

FITS文件結構

- ▶ Primary **header** and **data unit** (**HDU**).
- ▶ Conforming Extensions (*optional*).
- ▶ Other special records (*optional, restricted*).

FITS 類型

- ▶ **SIF** (Single Image *FITS*)
- ▶ **MEF** (Multi-Extension *FITS*)

FITS BLOCKS

- ▶ 每個FITS文件都是由若干BLOCKS組成的，而每個塊的固定大小是 2880 字節（23040位）
- ▶ $2880 = 80 \times 36$

頭信息 (Header)

- ▶ ASCII字符 (0x20-0x7E)

SIMPLE =

T /FITS STANDARD

- ▶ 2880 = 80 x 36
- ▶ 結構:
 - ▶ 1-8 字節：關鍵字
 - ▶ 9-10 字節： =
 - ▶ 11-80 字節：值和注釋，注釋以 / 開頭
- ▶ **END**結尾頭信息，之后如不足2880，以空格填充。

▶ CARD

▶ RECORD

▶ KEY

▶ VALUE

▶ COMMENT

EXPTIME = 1200. / [s] exposure time in seconds

頭信息—值（字符型）

▶ 單記錄字符型

```
KEYWORD1= ''           / null string keyword  
KEYWORD2= '  '        / empty string keyword  
KEYWORD3=              / undefined keyword
```

▶ 長字符型

頭信息—值（邏輯型）

▶ T (True)

▶ F (False)

頭信息—值（整數型）

- ▶ 11-30字節：右對齊
- ▶ 正數的 '+' 可忽略

頭信息—值（浮點數型）

- ▶ 11-30字節：右對齊
- ▶ 指數 'E' 'D' 需要大寫

頭信息—值（複數型）

- ▶ 整形復數 (12, 34)
- ▶ 浮點型復數 (12.234, 34.5678)

頭信息—值（日期型）

- ▶ ISO-8601格式 (YYYY-MM-DDThh:mm:ss[.sss])
 - ▶ **DATE** 关键字
- ▶ JD、MJD等格式 (2345675.22222, 23456.234)

單位

表 3: IAU-recommended basic units.

Quantity	Unit	Meaning	Notes
<i>SI base & supplementary units</i>			
length	m	meter	
mass	kg	kilogram	g gram allowed
time	s	second	
plane angle	rad	radian	
solid angle	sr	steradian	
temperature	K	kelvin	
electric current	A	ampere	
amount of substance	mol	mole	
luminous intensity	cd	candela	
<i>IAU-recognized derived units</i>			
frequency	Hz	hertz	s^{-1}
energy	J	joule	N m
power	W	watt	$J s^{-1}$
electric potential	V	volt	$J C^{-1}$
force	N	newton	$kg m s^{-2}$
pressure, stress	Pa	pascal	$N m^{-2}$
electric charge	C	coulomb	A s
electric resistance	Ohm	ohm	$V A^{-1}$
electric conductance	S	siemens	$A V^{-1}$
electric capacitance	F	farad	$C V^{-1}$
magnetic flux	Wb	weber	V s
magnetic flux density	T	tesla	$Wb m^{-2}$
inductance	H	henry	$Wb A^{-1}$
luminous flux	lm	lumen	cd sr
illuminance	lx	lux	$lm m^{-2}$

表 4: Additional allowed units.

Quantity	Unit	Meaning	Notes
plane angle	deg	degree of arc	$\pi/180$ rad
	arcmin	minute of arc	1/60 deg
	arcsec	second of arc	1/3600 deg
	mas	milli-second of arc	1/3 600 000 deg
time	min	minute	60 s
	h	hour	60 min = 3600 s
	d	day	86 400 s
	† a	year (Julian)	31 557 600 s (365.25 d), peta a(Pa) forbidden
	† yr	year (Julian)	a is IAU-style
energy*	† eV	electron volt	$1.6021765 \times 10^{-19}$ J
	‡ erg	erg	10^{-7} J
	Ry	rydberg	$\frac{1}{2} \left(\frac{2\pi e^2}{hc} \right)^2 m_e c^2 = 13.605692$ eV
mass*	solMass	solar mass	1.9891×10^{30} kg
	u	unified atomic mass unit	$1.6605387 \times 10^{-27}$ kg
luminosity	solLum	Solar luminosity	3.8268×10^{26} W
length	‡ Angstrom	angstrom	10^{-10} m
	solRad	Solar radius	6.9599×10^8 m
	AU	astronomical unit	1.49598×10^{11} m
	lyr	light year	9.460730×10^{15} m
	† pc	parsec	3.0857×10^{16} m
events	count	count	
	ct	count	
	photon	photon	
	ph	photon	
flux density	† Jy	jansky	10^{-26} W m ⁻² Hz ⁻¹
	† mag	(stellar) magnitude	
	† R	rayleigh	$10^{10}/(4\pi)$ photons m ⁻² s ⁻¹ sr ⁻¹
magnetic field area	†‡ G	gauss	10^{-4} T
	pixel	(image/detector) pixel	
	pix	(image/detector) pixel	
	†‡ barn	barn	10^{-28} m ²
<i>Miscellaneous units</i>			
	D	debye	$\frac{1}{3} \times 10^{-29}$ C.m
	Sun	relative to Sun	e.g., abundances
	chan	(detector) channel	
	bin	numerous applications	(including the one-dimensional analog of pixel)
	voxel	three-dimensional analog of pixel	
	† bit	binary information unit	
	† byte	(computer) byte	eight bits
	adu	Analog-to-digital converter	
	beam	beam area of observation	as in Jy/beam

Notes. (†) Addition of prefixes for decimal multiples and submultiples are allowed. (‡) Deprecated in IAU Style Manual (McNally 1988) but still in use. (*) Conversion factors from CODATA Internationally recommended values of the fundamental physical constants 2002 (<http://physics.nist.gov/cuu/Constants/>).

單位

表 5: Prefixes for multiples and submultiples.

Submult	Prefix	Char	Mult	Prefix	Char
10^{-1}	deci	d	10	deca	da
10^{-2}	centi	c	10^2	hecto	h
10^{-3}	milli	m	10^3	kilo	k
10^{-6}	micro	u	10^6	mega	M
10^{-9}	nano	n	10^9	giga	G
10^{-12}	pico	p	10^{12}	tera	T
10^{-15}	femto	f	10^{15}	peta	P
10^{-18}	atto	a	10^{18}	exa	E
10^{-21}	zepto	z	10^{21}	zetta	Z
10^{-24}	yocto	y	10^{24}	yotta	Y

EXPTIME = 1200. / [s] exposure time in seconds

頭結構

表 7: Mandatory keywords for primary header.

Position	Keyword
1	SIMPLE = T
2	BITPIX
3	NAXIS
4	NAXIS n , $n = 1, \dots, \text{NAXIS}$
	⋮
	(other keywords)
	⋮
last	END

BITPIX (Bits/Pixel)

Value	Data represented
8	Character or unsigned binary integer
16	16-bit two's complement binary integer
32	32-bit two's complement binary integer
64	64-bit two's complement binary integer
-32	IEEE single-precision floating point
-64	IEEE double-precision floating point

NAXIS

- 數據軸

$$N_{\text{bits}} = |\text{BITPIX}| \times (\text{NAXIS1} \times \text{NAXIS2} \times \dots \times \text{NAXIS}m)$$

- NAXIS 軸數目

- NAXIS1 第一個軸的數量

- ...

- NAXISn 第n個軸的數量

SIMPLE	=	T /FITS STANDARD
BITPIX	=	16 /FITS BITS/PIXEL
NAXIS	=	2 /NUMBER OF AXES
NAXIS1	=	14400 /
NAXIS2	=	14400 /

觀測類關鍵字

- ▶ DATE-OBS
- ▶ TELESCOP
- ▶ INSTRUME
- ▶ OBSERVER
- ▶ OBJECT
- ▶ EQUINOX

- ▶ **ORIGIN** (机构、单位)
- ▶ **AUTHOR**
- ▶ **REFERENC** (bibcode / doi)

注釋類關鍵字

▶ HISTORY

```
COMMENT  FITS (Flexible Image Transport System) format is defined in 'Astronomy  
COMMENT  and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
```

▶ COMMENT

```
COMMENT  FITS (Flexible Image Transport System) format is defined in 'Astronomy  
COMMENT  and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
```

▶ 0-10 字段留空

數據類關鍵字 (IMAGE)

▶ BSCALE

$$\text{physical_value} = \text{BZERO} + \text{BSCALE} \times \text{array_value}.$$

▶ BZERO

BITPIX	Native data type	Physical data type	BZERO
8	unsigned	signed byte	-128 (-2^7)
16	signed	unsigned 16-bit	32768 (2^{15})
32	signed	unsigned 32-bit	2147483648 (2^{31})
64	signed	unsigned 64-bit	9223372036854775808 (2^{63})

▶ BUNIT

▶ BLANK

▶ DATAMAX

擴展類關鍵字

- ▶ **EXTEND** (T/F)
- ▶ **EXTNAME**
- ▶ **EXTVER** 同名的擴展可以以此整數值進行標注
- ▶ **EXTLEVEL** 層次性數據的標注 (整數)

擴展 (XTENSION)

- ▶ IMAGE 圖像
- ▶ TABLE 文本表格
- ▶ BINTABLE 二進制表格

XTENSION-IMAGE

Position	Keyword
1	XTENSION= $_$ 'IMAGE $_$ $_$ $_$ '
2	BITPIX
3	NAXIS
4	NAXIS n , $n = 1, \dots, \text{NAXIS}$
5	PCOUNT = 0
6	GCOUNT = 1
	\vdots
	(other keywords ...)
	\vdots
last	END

IMAGE—關鍵字

- ▶ BIXPIX
- ▶ NAXIS
- ▶ NAXIS n
- ▶ PCOUNT 0
- ▶ GCOUNT 1
- ▶ END

XTENSION-TABLE

Position	Keyword
1	XTENSION= <u> </u> 'TABLE <u> </u> '
2	BITPIX = 8
3	NAXIS = 2
4	NAXIS1
5	NAXIS2
6	PCOUNT = 0
7	GCOUNT = 1
8	TFIELDS
	:
	(other keywords, including (if TFIELDS is not zero) ...)
	TTYPEn, $n = 1, 2, \dots, k$, where k is the value of TFIELDS (<i>recommended</i>)
	TBCOLn, $n = 1, 2, \dots, k$, where k is the value of TFIELDS (<i>required</i>)
	TFORMn, $n = 1, 2, \dots, k$, where k is the value of TFIELDS (<i>required</i>)
	:
last	END

TABLE-KEYWORDS

- ▶ **BITPIX** 8
- ▶ **NAXIS1** 表格的列長度, 每行記錄的字節長度
- ▶ **NAXIS2** 表格的行數
- ▶ **PCOUNT** 0
- ▶ **GCOUNT** 1 單表
- ▶ **TFIELDS** 列數 0-999 支持最多 999 列

TABLE-字段KEYWORDS

- ▶ **TTYPE n** 字段名 (推薦) , 注意, 此值大小寫不敏感, 推薦大寫
- ▶ **TBCOL n** 列序號, 從1~**TFIELDS** (必選)
- ▶ **TFORM n** 格式 (必選)

Field value	Data type
Aw	Character
Iw	Decimal integer
Fw.d	Floating-point, fixed decimal notation
Ew.d	Floating-point, exponential notation
Dw.d	Floating-point, exponential notation

TABLE-字段KEYWORDS (續)

- ▶ **TUNIT n** 單位
- ▶ **TSCAL n** 比例因子
- ▶ **TZERON** 零值
- ▶ **TNULL n** 空值
- ▶ **TDISP n** 顯示格式 (詳見下頁)

$$\text{physical_value} = \text{TZERON} + \text{TSCAL}n \times \text{field_value}$$

表 16: Valid TDISP n format values in TABLE extensions.

Field value	Data type
Aw	Character
Iw.m	Integer
Bw.m	Binary, integers only
Ow.m	Octal, integers only
Zw.m	Hexadecimal, integers only
Fw.d	Floating-point, fixed decimal notation
Ew.dEe	Floating-point, exponential notation
ENw.d	Engineering; E format with exponent multiple of three
ESw.d	Scientific; same as EN but non-zero leading digit if not zero
Gw.dEe	General; appears as F if significance not lost, else E.
Dw.dEe	Floating-point, exponential notation

TABLE 數據順序

- ▶ 二維表格的行列是嚴格確定的，每行的字符數和行數
- ▶ 按行存儲

XTENSION-BINTABLE

Position	Keyword
1	XTENSION= \lfloor 'BINTABLE'
2	BITPIX = 8
3	NAXIS = 2
4	NAXIS1
5	NAXIS2
6	PCOUNT
7	GCOUNT = 1
8	TFIELDS
	:
	(other keywords, including (if TFIELDS is not zero) ...)
	TTYPEn, $n = 1, 2, \dots, k$, where k is the value of TFIELDS (<i>recommended</i>)
	TFORMn, $n = 1, 2, \dots, k$, where k is the value of TFIELDS (<i>required</i>)
	:
last	END

BINTABLE-KEYWORDS

- ▶ BITPIX 8
- ▶ NAXIS 2
- ▶ NAXIS1 每行的字節數 (8位字節)
- ▶ NAXIS2 行數
- ▶ PCOUNT heap
- ▶ GCOUNT 1
- ▶ TFIELDS 列數

BINTABLE-KEYWORDS

- ▶ **TTYPE n** 字段名 (推薦) , 注意, 此值大小寫不敏感, 推薦大寫
- ▶ **TFORM n** 格式 (必選)

TFORM n value	Description	Eight-bit Byte
'L'	Logical	1
'X'	Bit	†
'B'	Unsigned byte	1
'I'	16-bit integer	2
'J'	32-bit integer	4
'K'	64-bit integer	8
'A'	Character	1
'E'	Single-precision floating point	4
'D'	Double-precision floating point	8
'C'	Single-precision complex	8
'M'	Double-precision complex	16
'P'	Array Descriptor (32-bit)	8
'Q'	Array Descriptor (64-bit)	16

$$n_{\text{row}} = \sum_{i=1}^{\text{TFIELDS}} r_i b_i$$

BINTABLE-字段KEYWORDS (續)

▶ **TUNIT_n** 單位

▶ **TSCAL_n** 比例因子

$$\text{physical_value} = \text{TZEROn} + \text{TSCALn} \times \text{field_value}$$

▶ **TZEROn** 零值

▶ **TNULL_n** 空值

TFORM _n	Native data type	Physical data type	TZEROn
'B'	unsigned	signed byte	-128 (-2 ⁷)
'I'	signed	unsigned 16-bit	32768 (2 ¹⁵)
'J'	signed	unsigned 32-bit	2147483648 (2 ³¹)
'K'	signed	unsigned 64-bit	9223372036854775808 (2 ⁶³)

▶ **TDISP_n** 顯示格式 (詳見下頁)

Field Value	Data type
Aw	Character
Lw	Logical
Iw.m	Integer
Bw.m	Binary, integers only
Ow.m	Octal, integers only
Zw.m	Hexadecimal, integers only
Fw.d	Floating-point, fixed decimal notation
Ew.dEe	Floating-point, exponential notation
ENw.d	Engineering; E format with exponent multiple of three
ESw.d	Scientific; same as EN but non-zero leading digit if not zero
Gw.dEe	General; appears as F if significance not lost, else E.
Dw.dEe	Floating-point, exponential notation

時間關鍵字

- ▶ ISO8601 格式
- ▶ **DATE-xxxx** CCYY-MM-DD [Thh:mm:ss [.s...]] 字符格式
[±C] CCYY-MM-DD [Thh:mm:ss [.s...]]

時間關鍵字— TIMESYS

▶ TIMESYS 時標, 默認 UTC

Value	Meaning
'TAI'	(International Atomic Time): atomic-time standard maintained on the rotating geoid
'TT'	(Terrestrial Time; IAU standard): defined on the rotating geoid, usually derived as $TAI + 32.184$ s
'TDT'	(Terrestrial Dynamical Time): synonym for TT (deprecated)
'ET'	(Ephemeris Time): continuous with TT; <i>should not</i> be used for data taken after 1984-01-01
'IAT'	synonym for TAI (deprecated)
'UT1'	(Universal Time): Earth rotation time
'UTC'	(Universal Time, Coordinated; default): runs synchronously with TAI, except for the occasional insertion of leap seconds intended to keep UTC within 0.9 s of UT1; as of 2015-07-01 $UTC = TAI - 36$ s
'GMT'	(Greenwich Mean Time): continuous with UTC; its use is deprecated for dates after 1972-01-01
UTC) ¹	(Universal Time, with qualifier): for high-precision use of radio-signal distributions between 1955 and 1972; see Rots et al. (2015) , Appendix A
'GPS'	(Global Positioning System): runs (approximately) synchronously with TAI; $GPS \approx TAI - 19$ s
'TCG'	(Geocentric Coordinate Time): TT reduced to the geocenter, corrected for the relativistic effects of the Earth's rotation and gravitational potential; TCG runs faster than TT at a constant rate
'TCB'	(Barycentric Coordinate Time): derived from TCG by a four-dimensional transformation, taking into account the relativistic effects of the gravitational potential at the barycenter (relative to that on the rotating geoid) as well as velocity time-dilation variations due to the eccentricity of the Earth's orbit, thus ensuring consistency with fundamental physical constants; Irwin & Fukushima (1999) provide a time ephemeris
'TDB'	(Barycentric Dynamical Time): runs slower than TCB at a constant rate so as to remain approximately in step with TT; runs therefore quasi-synchronously with TT, except for the relativistic effects introduced by variations in the Earth's velocity relative to the barycenter. When referring to celestial observations, a pathlength correction to the barycenter may be needed, which requires the Time Reference Direction used in calculating the pathlength correction.
'LOCAL'	for simulation data and for free-running clocks.

時間關鍵字—時間參考值

- ▶ **MJDREF** 默認0.0
 - ▶ MJDREFI 0
 - ▶ MJDREFF 0.0
- ▶ **JDREF** 默認none
 - ▶ JDREFI 0
 - ▶ JDREFF 0.0
- ▶ **DATEREF** 默認none

時間關鍵字—TREFPOS

► TREFPOS 默認 TOPOCENTER

表 31: Standard Time Reference Position Values

Value ¹	Meaning
'TOPOCENTER'	Topocenter: the location from where the observation was made (default)
'GEOCENTER'	Geocenter
'BARYCENTER'	Barycenter of the Solar System
'RELOCATABLE'	Relocatable: to be used for simulation data only
'CUSTOM'	A position specified by coordinates that is not the observatory location
Less-common, but allowed standard values	
'HELIOCENTER'	Heliocenter
'GALACTIC'	Galactic center
'EMBARYCENTER'	Earth-Moon barycenter
'MERCURY'	Center of Mercury
'VENUS'	Center of Venus
'MARS'	Center of Mars
'JUPITER'	Barycenter of the Jupiter system
'SATURN'	Barycenter of the Saturn system
'URANUS'	Barycenter of the Uranus system
'NEPTUNE'	Barycenter of the Neptune system

時間單位

Value	Definition
's'	second (default)
'd'	day (= 86,400 s)
'a'	(Julian) year (= 365.25 d)
'cy'	(Julian) century (= 100 a)

The following values are also acceptable.

'min'	minute (= 60 s)
'h'	hour (= 3,600 s)
'yr'	(Julian) year (= 'a' = 365.25 d)
'ta'	tropical year
'Ba'	Besselian year

全局時間關鍵字總結

- ▶ **DATE** HDU產生日期[時間]
 - ▶ YYYY-MM-DD
 - ▶ YYYY-MMDDThh:mm:ss [.ss]
- ▶ **DATE-OBS** 觀測的日期[時間] YYYY-MMDDThh:mm:ss [.ss]
- ▶ **DATE-BEG** 觀測開始日期時間 YYYY-MMDDThh:mm:ss [.ss]
- ▶ **DATE-AVG** 觀測中點時間 YYYY-MMDDThh:mm:ss [.ss]
- ▶ **DATE-END** 觀測結束時間 YYYY-MMDDThh:mm:ss [.ss]

- ▶ MJD-OBS 觀測時間
- ▶ MJD-BEG 觀測開始時間
- ▶ MJD-AVG 觀測中點時間
- ▶ MJD-END 觀測結束時間

數據校驗

- ▶ **DATASUM** (推薦) HDU的數據體的校驗碼，值為一個32位的無符號整數，左對齊
 - ▶ $2880 = 720 \times 4$
- ▶ **CHECKSUM** (推薦) HDU的校驗碼，值為16位字符串，左對齊

```
DATASUM = '2503531142'      / 2015-06-28T18:30:45  
CHECKSUM= 'hcHj jc9ghcEghc9g' / 2015-06-28T18:30:45
```



```

void checksum (
    unsigned char *buf, /* Input array of bytes to be checksummed */
                        /* (interpret as 4-byte unsigned ints) */
    int length,        /* Length of buf array, in bytes */
                        /* (must be multiple of 4) */
    unsigned int *sum32) /* 32-bit checksum */
{
    /*
    Increment the input value of sum32 with the 1's complement sum
    accumulated over the input buf array.
    */
    unsigned int hi, lo, hicarry, locarry, i;

    /* Accumulate the sum of the high-order 16 bits and the */
    /* low-order 16 bits of each 32-bit word, separately. */
    /* The first byte in each pair is the most significant. */
    /* This algorithm works on both big and little endian machines.*/
    hi = (*sum32 >> 16);
    lo = *sum32 & 0xFFFF;
    for (i=0; i < length; i+=4) {
        hi += ((buf[i] << 8) + buf[i+1]);
        lo += ((buf[i+2] << 8) + buf[i+3]);
    }

    /* fold carry bits from each 16 bit sum into the other sum */
    hicarry = hi >> 16;
    locarry = lo >> 16;
    while (hicarry || locarry) {
        hi = (hi & 0xFFFF) + locarry;
        lo = (lo & 0xFFFF) + hicarry;
        hicarry = hi >> 16;
        locarry = lo >> 16;
    }

    /* concatenate the full 32-bit value from the 2 halves */
    *sum32 = (hi << 16) + lo;
}

```

```

unsigned int exclude[13] = {0x3a, 0x3b, 0x3c, 0x3d, 0x3e, 0x3f, 0x40,
                           0x5b, 0x5c, 0x5d, 0x5e, 0x5f, 0x60 };

int offset = 0x30;                               /* ASCII 0 (zero) */
unsigned long mask[4] = { 0xff000000, 0xff0000, 0xff00, 0xff };

void char_encode (
    unsigned int value, /* 1's complement of the checksum */
                    /* value to be encoded */
    char *ascii)      /* Output 16-character encoded string */
{
    int byte, quotient, remainder, ch[4], check, i, j, k;
    char asc[32];

    for (i=0; i < 4; i++) {
        /* each byte becomes four */
        byte = (value & mask[i]) >> ((3 - i) * 8);
        quotient = byte / 4 + offset;
        remainder = byte % 4;
        for (j=0; j < 4; j++)
            ch[j] = quotient;

        ch[0] += remainder;

        for (check=1; check;) /* avoid ASCII punctuation */
            for (check=0, k=0; k < 13; k++)
                for (j=0; j < 4; j+=2)
                    if (ch[j]==exclude[k] || ch[j+1]==exclude[k]) {
                        ch[j]++;
                        ch[j+1]--;
                        check++;
                    }

        for (j=0; j < 4; j++) /* assign the bytes */
            asc[4*j+i] = ch[j];
    }

    for (i=0; i < 16; i++) /* permute the bytes for FITS */
        ascii[i] = asc[(i+15)%16];

    ascii[16] = 0;          /* terminate the string */
}

```

關鍵字總結

表 C.1: Mandatory *FITS* keywords for the structures described in this document.

Primary HDU	Conforming extension	Image extension	ASCII-table extension	Binary-table extension	Compressed images ⁶	Compressed tables ⁶	Random-groups records
SIMPLE	XTENSION	XTENSION ¹	XTENSION ²	XTENSION ³	ZIMAGE =T	ZTABLE =T	SIMPLE
BITPIX	BITPIX	BITPIX	BITPIX = 8	BITPIX = 8	ZBITPIX	ZNAXIS1	BITPIX
NAXIS	NAXIS	NAXIS	NAXIS = 2	NAXIS = 2	ZNAXIS	ZNAXIS2	NAXIS
NAXIS _{<i>n</i>} ⁴	NAXIS _{<i>n</i>} ⁴	NAXIS _{<i>n</i>} ⁴	NAXIS1	NAXIS1	ZNAXIS _{<i>n</i>}	ZPCOUNT	NAXIS1 = 0
END	PCOUNT	PCOUNT = 0	NAXIS2	NAXIS2	ZCMPTYPE	ZFORM _{<i>n</i>}	NAXIS _{<i>n</i>} ⁴
	GCOUNT	GCOUNT = 1	PCOUNT = 0	PCOUNT		ZCTYP _{<i>n</i>}	GROUPS = T
	END	END	GCOUNT = 1	GCOUNT = 1		ZTILELEN	PCOUNT
			TFIELDS	TFIELDS			GCOUNT
			TFORM _{<i>n</i>} ⁵	TFORM _{<i>n</i>} ⁵			END
			TBCOL _{<i>n</i>} ⁵	END			
			END				

(¹) XTENSION=_'IMAGE_'' for the image extension. (²) XTENSION=_'TABLE_'' for the ASCII-table extension. (³) XTENSION=_'BINTABLE' for the binary-table extension. (⁴) Runs from 1 through the value of NAXIS. (⁵) Runs from 1 through the value of TFIELDS. (⁶) Required in addition to the mandatory keywords for binary tables.

http://heasarc.gsfc.nasa.gov/docs/fcg/standard_dict.html

表 C.2: Reserved *FITS* keywords for the structures described in this document.

All ¹ HDUs	Array ² HDUs	ASCII-table extension	Binary-table extension	Compressed images	Compressed tables	Random-groups records	
DATE	EXTNAME	BSCALE	TSCAL n	TSCAL n	ZTILE n	FZTILELN	PTYPE n
DATE-OBS	EXTVER	BZERO	TZERO n	TZERO n	ZNAME i	FZALGOR	PSCAL n
ORIGIN	EXTLEVEL	BUNIT	TNULL n	TNULL n	ZVAL i	FZALG n	PZERO n
AUTHOR	EQUINOX	BLANK	TTYPER n	TTYPER n	ZMASKCMP		
REFERENC	EPOCH ³	DATAMAX	TUNIT n	TUNIT n	ZQUANTIZ		
COMMENT	BLOCKED ³	DATAMIN	TDISP n	TDISP n	ZDITHER0		
HISTORY	EXTEND ⁴		TDMAX n	TDIM n	ZSIMPLE	ZTHEAP	
TELESCOP	TELESCOP		TDMIN n	THEAP	ZEXTEND		
OBJECT	INSTRUME		TLMAX n	TDMAX n	ZBLOCKED		
OBSERVER			TLMIN n	TDMIN n	ZTENSION		
CONTINUE				TLMAX n	ZPCOUNT		
INHERIT ⁵				TLMIN n	ZGCOUNT		
CHECKSUM					ZCHECKSUM	ZCHECKSUM	
DATASUM					ZDATASUM	ZDATASUM	

表 C.3: General reserved *FITS* keywords described in this document.

Production	Bibliographic	Commentary	Observation
DATE	AUTHOR	COMMENT	DATE-OBS
ORIGIN	REFERENC	HISTORY	TELESCOP
BLOCKED ¹		~~~~~	INSTRUME
			OBSERVER
			OBJECT
			EQUINOX
			EPOCH ¹

FITS程序庫

Library	Language[s]	Level	Images	Groups	ASCII Table	Binary Table	Var. Len. Arrays
CFITSIO	C/Fortran	Low	rw	rw	rw	rw	rw
WCS FITS library	C (Fortran callable)	High	rw	-	r	r	-
fitsy/funtools	C	High	rw	-	rw	rw	-
qfits	C/Python	Low	rw	-	-	rw	-
CCfits	C++	Medium	rw	-	rw	rw	rw
C++ FITS	C++	Medium	rw	rw	rw	rw	rw
CSharpFITS	C-Sharp (.Net)	Medium	rw	rw	rw	rw	rw
FitsLib	C-Sharp (.Net)	Medium	rw	rw	rw	rw	rw
MIIPS FITS	Fortran	High	rw	-	-	-	-
DeLaFits	Pascal (Delphi & Lazarus)	High	rw	-	-	-	-
MRDFITS/ MWRFITS	IDL	High	rw	rw	rw	rw	rw
FX library	IDL	Low	rw	rw	-	rw	rw
READFITS/ WRITEFITS	IDL	High	rw	rw	rw*	r*	-
FITS_library	IDL	Medium	rw	rw	rw	r	-
IUEDAC	IDL	Medium	rw	-	rw	rw	-
nom.tam.fits	Java	Medium	rw	rw	rw	rw	rw
eap.fits	Java	Medium	rw	-	rw	rw	rw
jfits	Java	Medium	rw	-	rw	rw	-
STIL	Java	Medium	-	-	r	rw	rw
fitsjs	JavaScript	Medium	r	-	r	r	-
CFITSIO.pm	Perl	Low	rw	rw	rw	rw	rw
FitsTcl	TCL	Medium	rw	rw	rw	rw	rw
PDL FITS	Perl	High	rw	-	-	rw	-
MFITSIO	MatLab	Medium	rw	-	-	-	-
MatLab	MatLab	High/Low	rw	rw	rw	rw	rw
FITS static class	MatLab	High	rw	-	rw	rw	-
Canterbury	MatLab	High	rw	-	-	-	-
GFITSIO	LabVIEW	High	rw	-	rw	rw	-
PyFITS	Python	Low	rw	rw	rw	rw	rw
Python/fitsio	Python	Low	rw	rw	rw	rw	rw
PFITS	Python	Medium	r	-	r	r	r
Mathematica	Mathematica	High	rw	-	rw	-	-
IGOR Pro	IGOR Pro	High	r	-	r	r	-
R language	R	High	rw	-	-	r	-
Liberator	Photoshop plug-in	High	rw	-	-	-	-
FitsPlug	Photoshop plug-in	High	rw	-	-	-	-
golang FITS reader	golang (google go)	High	r	-	r	r	-
golang wrappers for CFITSIO	golang (google go)	High	rw	-	rw	rw	rw
pure-Go FITS package	golang (google go)	High	rw	-	rw	rw	rw

* using ancillary libraries.

CFITSIO/FITSIO

<https://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html>

- ▶ 官方版本
- ▶ C/Fortran
- ▶ 多平臺支持 (Unix、Linux、Windows、macOS、Android等)

一個例子

```
#include <string.h>
#include <stdio.h>
#include "fitsio.h"

int main(int argc, char *argv[])
{
    fitsfile *fptr;
    char card[FLEN_CARD];
    int status = 0, nkeys, ii; /* MUST initialize status */

    fits_open_file(&fptr, argv[1], READONLY, &status);
    fits_get_hdrspace(fptr, &nkeys, NULL, &status);

    for (ii = 1; ii <= nkeys; ii++) {
        fits_read_record(fptr, ii, card, &status); /* read keyword */
        printf("%s\n", card);
    }
    printf("END\n\n"); /* terminate listing with END */
    fits_close_file(fptr, &status);

    if (status) /* print any error messages */
        fits_report_error(stderr, status);
    return(status);
}
```

程序

- ▶ 打開FITS文件
- ▶ 讀寫HDU頭信息
- ▶ 讀寫HDU數據體
- ▶ 關閉文件

短名稱函數

```
int fits_open_file / fopen
    (fitsfile **fptr, char *filename, int iomode, > int *status)
```

```
int fits_write_key_str / ffpkys
    (fitsfile *fptr, char *keyname, char *value, char *comment,
     > int *status)
```

```
int fits_write_key_[log, lng] / ffpky[lj]
    (fitsfile *fptr, char *keyname, DTYPE numval, char *comment,
     > int *status)
```

短名稱函數

Long Names -----	Short Names -----	Data Type ----
_bit	x	bit
_byt	b	unsigned byte
_sbyt	sb	signed byte
_sht	i	short integer
_lng	j	long integer
_lnglng	jj	8-byte LONGLONG integer (see note below)
_usht	ui	unsigned short integer
_ulng	uj	unsigned long integer
_ulnglng	ujj	unsigned long long integer
_uint	uk	unsigned int integer
_int	k	int integer
_flt	e	real exponential floating point (float)
_fixflt	f	real fixed-decimal format floating point (float)
_dbl	d	double precision real floating-point (double)
_fixdbl	g	double precision fixed-format floating point (double)
_cmp	c	complex reals (pairs of float values)
_fixcmp	fc	complex reals, fixed-format floating point
_dblcmp	m	double precision complex (pairs of double values)
_fixdblcmp	fm	double precision complex, fixed-format floating point
_log	l	logical (int)
_str	s	character string

longnam.h

DEMO

FITS Tools: Handy FITS Utilities that illustrate how to use CFITSIO

<https://heasarc.gsfc.nasa.gov/docs/software/fitsio/cexamples.html>

- ▶ **fitscopy** - copy a file with optional filtering
- ▶ **listhead** - list header keywords
- ▶ **liststruc** - list the structure of a FITS file.
- ▶ **modhead** - write or modify a header keyword
- ▶ **imcopy** - copy an image with optional compression/decompression
- ▶ **imarith** - add, subtract, multiply, or divide an image by a constant or another image
- ▶ **imlist** - list pixel values in an image
- ▶ **imstat** - compute statistics of image pixels
- ▶ **tablist** - display the contents of a FITS table
- ▶ **tabcalc** - general table calculator
- ▶ **tabmerge** - merge rows from one table with another table.
- ▶ **cookbook** - additional example routines.

DEMO

FITSVERIFY – A FITS File Format–Verification Tool

<https://heasarc.gsfc.nasa.gov/docs/software/ftools/fitsverify/>

- ▶ **fitsverify -l filename.fits** (list all header keywords when verifying each file)
- ▶ **fitsverify -q *.fits** (Verify all *.fits files in the current directory in 'quiet' mode. This suppresses the detailed verification report and only writes a 1-line pass/fail message for each file)
- ▶ **fitsverify -e filename.fits** (only check for errors, ignore warnings)
- ▶ **fitsverify @textfile** (verify the FITS files listed in the text file, 1 file name per line)
- ▶ **fitsverify -h** (for complete help listing)

DEMO

FUNTOOLS

<https://github.com/ericmandel/funtools>

- ▶ **funcalc** [-n] [-a argstr] [-e expr] [-f file] [-l link] [-p prog] [-u] <iname> [oname [columns]]
- ▶ **funcen** [-i] [-n iter] [-t tol] [-v lev] <iname> <region>
- ▶ **funcnts** [switches] <source_file> [source_region] [bkgd_file] [bkgd_region|bkgd_cnts]
- ▶ **funcone** [-n] [-x|-X|-j|-J] [[-l|-L] list] [-r ra_col] [-d dec_col] <iname> <oname> <ra[hdr]> <dec[hdr]> <radius[dr'"]> [columns] fundisp [-f format] [-l] [-n] [-T] <iname> [columns|bitpix=n]
- ▶ **funhead** [-a] [-l] [-s] [-t] [-L] <iname> [oname ename]
- ▶ **funhist** [-n|-w|-T] <iname> [column] [[lo_edge:hi_edge:]bins] funimage [-a] [-l] [-p x|y] <iname> <oname> [bitpix=n] funindex <iname> <key> [oname]
- ▶ **funjoin** [switches] <ifile1> <ifile2> ... <ifilen> <ofile> funmerge <iname1> <iname2> ... <oname>
- ▶ **funsky** [switches] <iname1> [<lname2> <col1> <col2>]
- ▶ **funtable** [-a] [-i|-z] [-m] [-s cols] <iname> <oname> [columns] funt
- ▶ **funtbl** [-c cols] [-h] [-n table] [-p prog] [-s sep] [-T] <iname>f

DEMO

AstroPY—astropy.io.fits

- ▶ Python FITS讀寫庫（底層基于cfitsio）

- ▶ DEMO

虛擬天文臺表格 (VOTable)

VOTable	=	hierarchy of Metadata + associated TableData , arranged as a set of Tables
Metadata	=	Parameters + Infos + Descriptions + Links + Fields + Groups
Table	=	list of Fields + TableData
TableData	=	stream of Rows
Row	=	list of Cells
Cell	=	$\left\{ \begin{array}{l} \text{Primitive} \\ \text{or variable-length list of Primitives} \\ \text{or multidimensional array of Primitives} \end{array} \right.$
Primitive	=	integer, character, float, floatComplex, etc (see Table 1 below).

<VOTABLE>

⊕ <DESCRIPTION>

† <COOSYS>...

○ <INFO>...

○ <PARAM>...

○ <GROUP>...

⊕ <RESOURCE>...

⊕ <INFO>...

</VOTABLE>

<RESOURCE>

⊕ <DESCRIPTION>

○ <INFO>...

† <COOSYS>...

○ <GROUP>...

○ <PARAM>...

⊕ <LINK>...

⊕ <TABLE>...

⊕ <RESOURCE>...

⊕ <INFO>...

</RESOURCE>

<TABLE>

⊕ <DESCRIPTION>

○ <FIELD>...

○ <PARAM>...

○ <GROUP>...

⊕ <LINK>...

⊕ <DATA>

⊕ <INFO>...

</TABLE>

<FIELD>

⊕ <DESCRIPTION>

⊕ <VALUES>

⊕ <LINK>...

</FIELD>

<PARAM>

⊕ <DESCRIPTION>

⊕ <VALUES>

⊕ <LINK>...

</PARAM>

<DATA>

↳ <TABLEDATA>

⊕ <TR>...

⊕ <TD>...

↳ <BINARY>

⊕ <STREAM>

↳ <BINARY2>

⊕ <STREAM>

↳ <FITS>

⊕ <STREAM>

</DATA>

⊕ <INFO>...

<GROUP>

⊕ <DESCRIPTION>

○ <FIELDref>...^(t)

○ <PARAM>...

○ <PARAMref>...

○ <GROUP>...

</GROUP>

(t) only within <TABLE>

<VALUES>

⊕ <MIN>

⊕ <MAX>

⊕ <OPTION>...

○ <OPTION>...

</VALUES>

VOTABLE <i>(section 3)</i>
ID version

RESOURCE <i>(section 3.4)</i>
ID name type utype

TABLE <i>(section 3.6)</i>
ID name ucd utype ref nrows

INFO <i>(section 4.8)</i>
ID name value xtype ref unit ucd utype

STREAM <i>(section 5.6)</i>
type href actuate encoding expires rights

FITS <i>(section 5.2)</i>
extnum

TR <i>(section 5.1)</i>
ID

TD <i>(section 5.1)</i>
encoding

GROUP <i>(section 4.9)</i>
ID name ref ucd utype

PARAM <i>(section 4.1)</i>
ID unit datatype precision width xtype ref name ucd utype arraysize value

FIELD <i>(section 4.1)</i>
ID unit datatype precision width xtype ref name ucd utype arraysize type

FIELDref <i>(section 4.9)</i>
ref ucd utype

PARAMref <i>(section 4.9)</i>
ref ucd utype

MIN <i>(section 4.7)</i>
value inclusive

MAX <i>(section 4.7)</i>
value inclusive

OPTION <i>(section 4.7)</i>
name value

VALUES <i>(section 4.7)</i>
ID type null ref

LINK <i>(section 3.5)</i>
ID content-role content-type title value href action

datatype	Meaning	FITS	Bytes
"boolean"	Logical	"L"	1
"bit"	Bit	"X"	*
"unsignedByte"	Byte (0 to 255)	"B"	1
"short"	Short Integer	"I"	2
"int"	Integer	"J"	4
"long"	Long integer	"K"	8
"char"	ASCII Character	"A"	1
"unicodeChar"	Unicode Character		2
"float"	Floating point	"E"	4
"double"	Double	"D"	8
"floatComplex"	Float Complex	"C"	8
"doubleComplex"	Double Complex	"M"	16

AstroPY—astropy.io.votable

- ▶ Python

- ▶ DEMO

文本型數據

▶ CSV

▶ ECSV

▶ CDS

▶ 其他

▶ 參考: <http://docs.astropy.org/en/stable/io/ascii/index.html>

CSV

```
num,ra,dec,radius,mag  
1,32.23222,10.1211,0.8,18.1  
2,38.12321,-88.1321,2.2,17.0
```

ECSV

Enhanced Character Separated Values

```
# %ECSV 0.9
# ---
# datatype:
# - {name: a, unit: m / s, datatype: int64, format: '%03d'}
# - {name: b, unit: km, datatype: int64, description: This is column b}
a b
001 2
004 3
```

CDS

<http://vizier.china-vo.org/ftp/cats/V/153/ReadMe>

<http://vizier.china-vo.org/ftp/cats/V/53A/ReadMe>

IPAC

```
\keyword = value                                     # Keywords (optional)
\ Comment                                           # Comments (optional)
| name1      | name2      | name3      | name4      | name5      | # Column Names (required)
| double     | double     | int        | real       | char       | # Data Types (standard)
| unit       | unit       | unit       | unit       | unit       | # Data Units (optional)
| null       | null       | null       | null       | null       | # Null Values (optional)
165.466279  -34.704730   5          11.27      A string value # Data Rows (1 required)
160.1231    -4.7         3          2.3       value      # Data Rows (1 required)
```

DEMO

謝 謝
