可視光サーベイデータの使い方・見方 ~PanSTARRS1を中心に~

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http://skymapper.anu.edu.au/about-skymapper/
https://www.cfa.harvard.edu/news/2016-29

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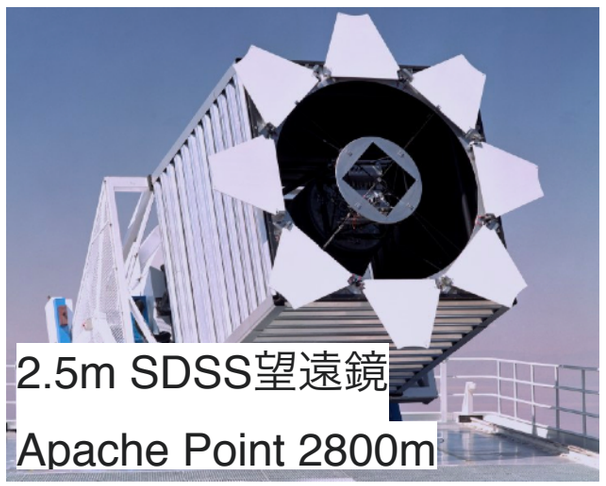
- イントロダクション: SDSSのデータを見る
- 可視撮像データの基礎概念 (分光は扱わない)
- PanSTARRS1パブリックデータリリース
    - 画像, 測光カタログ
    - データベースの利用
- 他のパブリックサーベイデータ

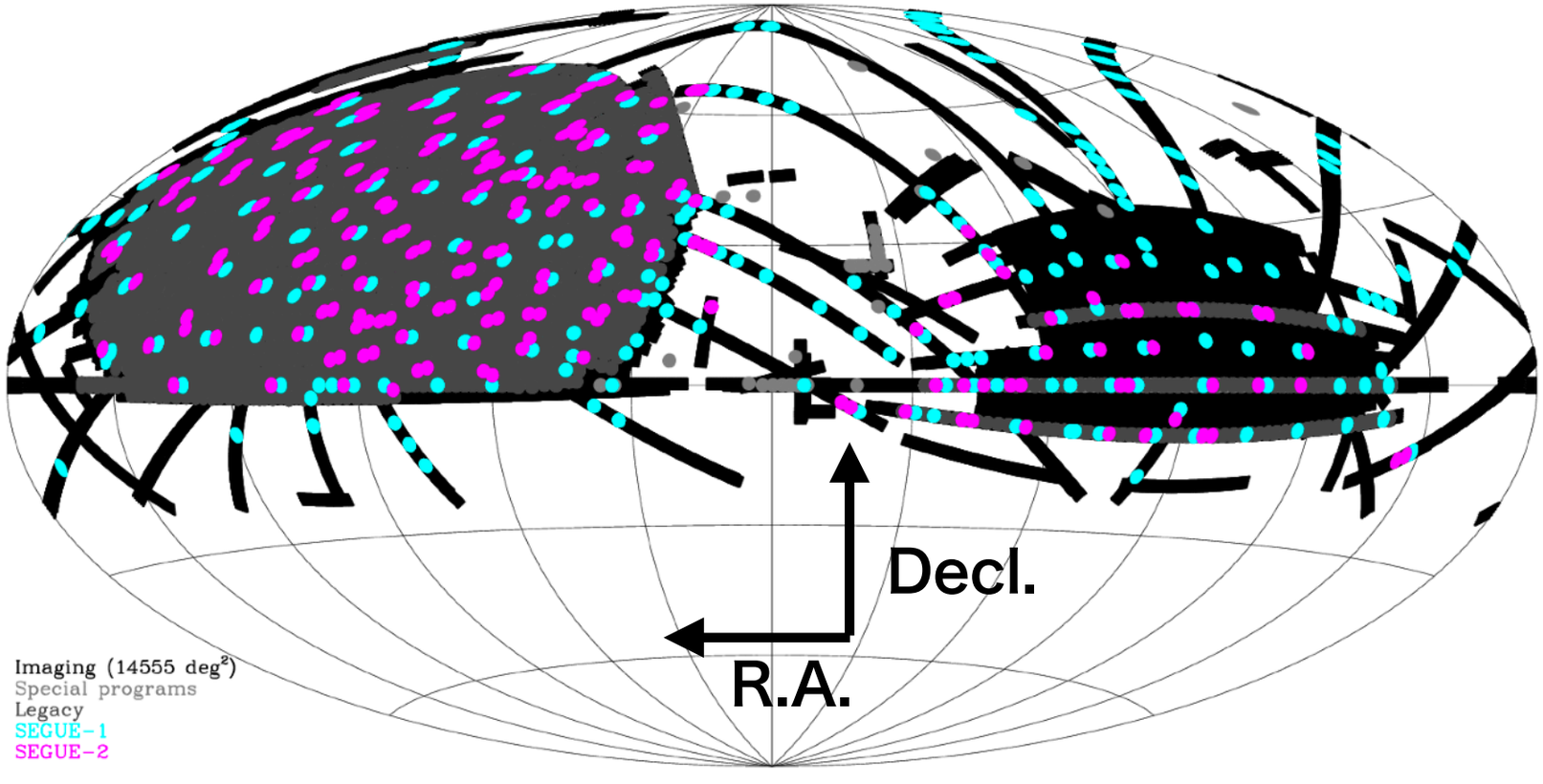
Sloan Digital Sky Survey

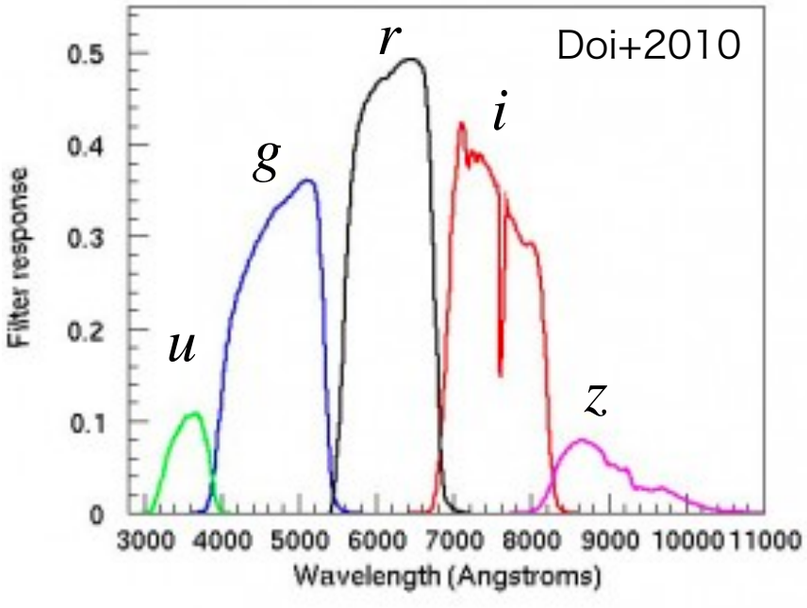


SDSS-I 2000-2005
SDSS-II 2005-2008
SDSS-III 2008-2014
SDSS-IV 2014-2020
SDSS-V 2020 —

撮像は2000-2001で完了
—> 撮像選択された天体を分光

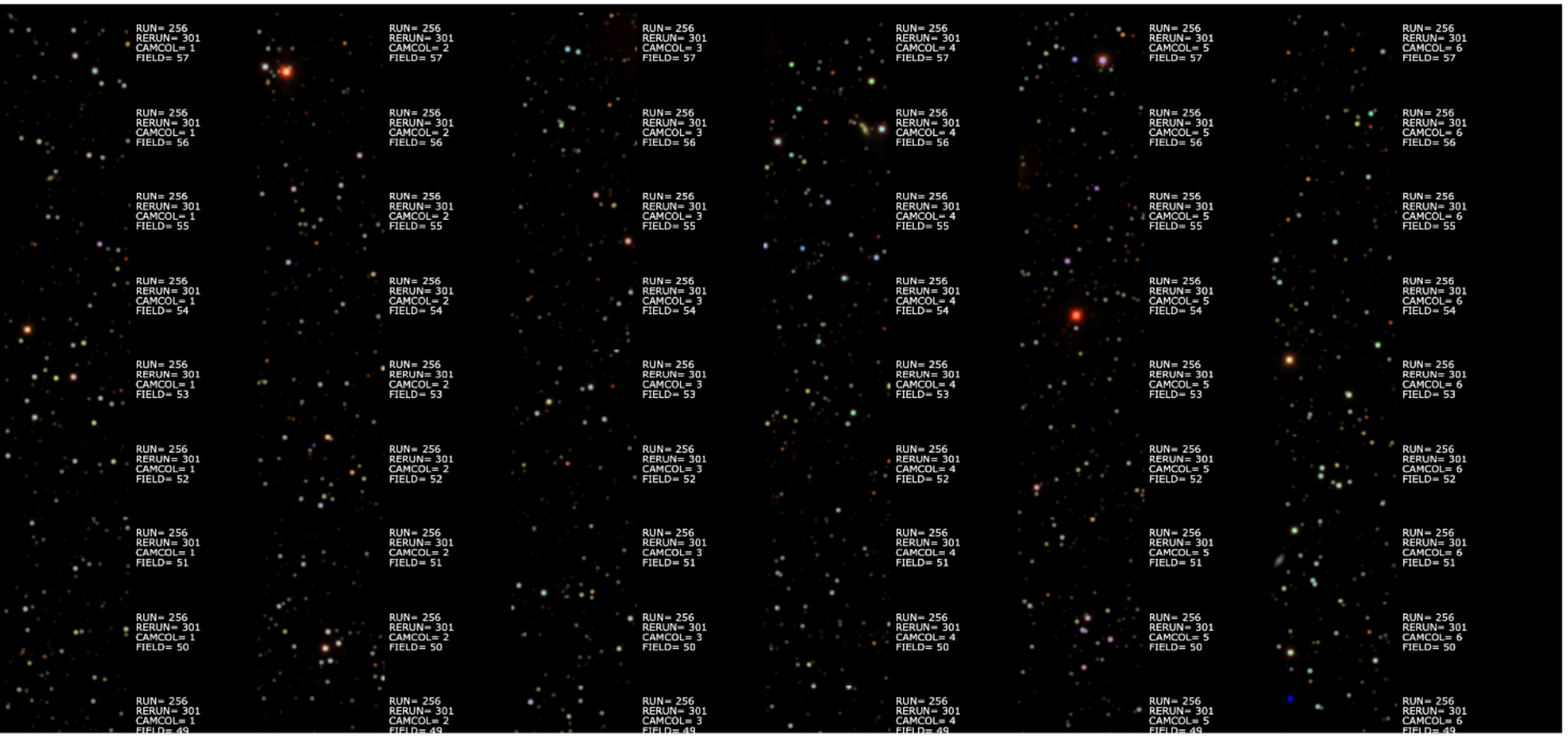
Band	5σ	Saturation
u	22.15	13
g	23.13	14
r	22.70	14
i	22.20	14
z	20.71	12

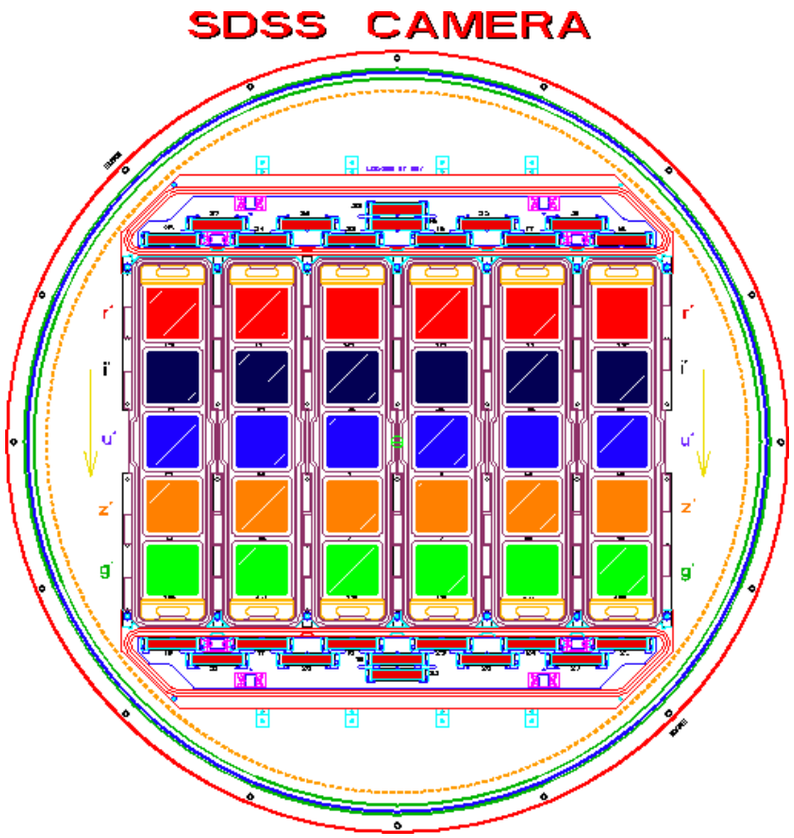




大きなデジカメ

Sloan Digital Sky Survey





Camcol 1 2 3 4 5 6

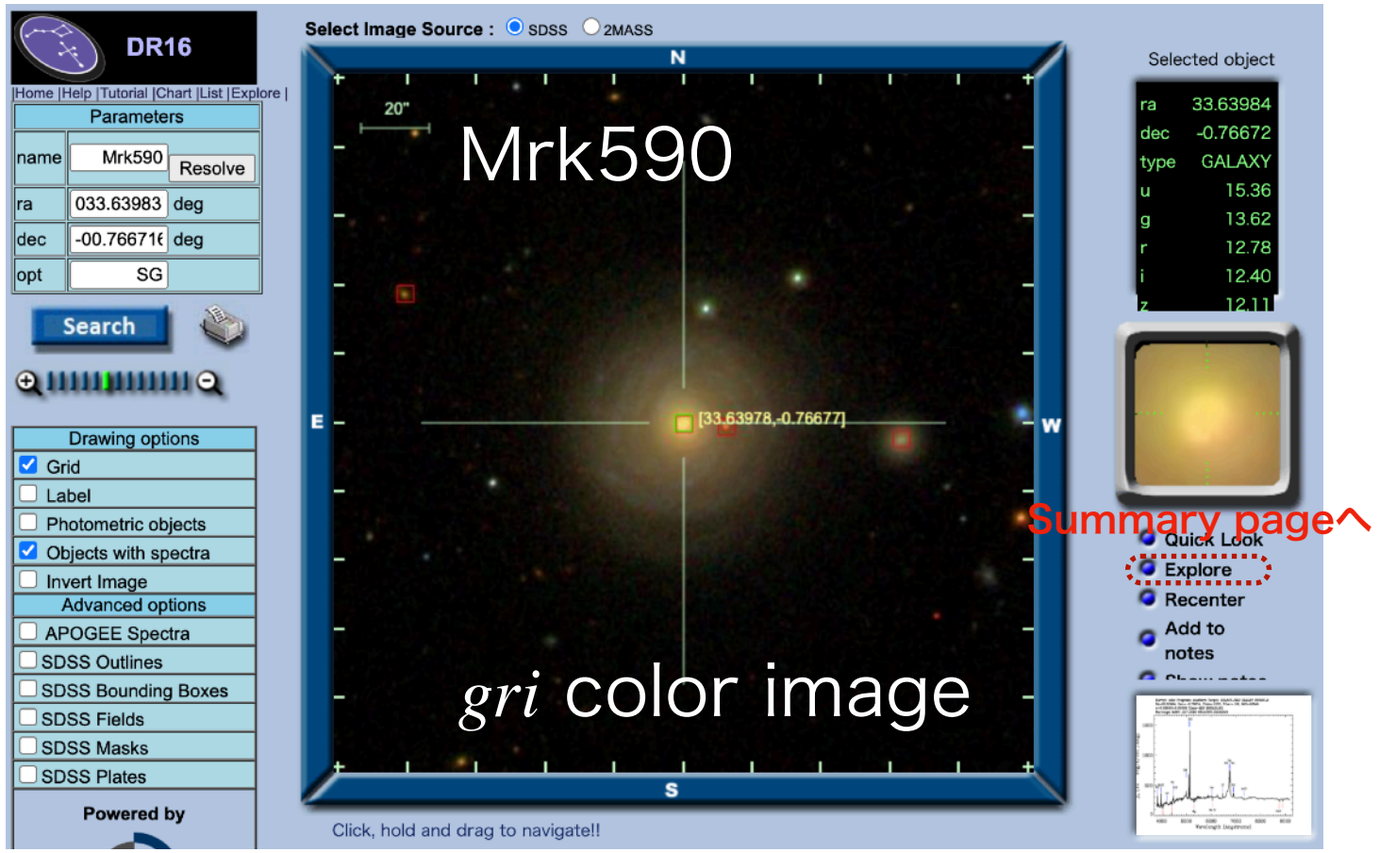
データベースに保管されている各画像は,
Filter
Run
Field
Camera Column
解析version(rerun)
で指定される.

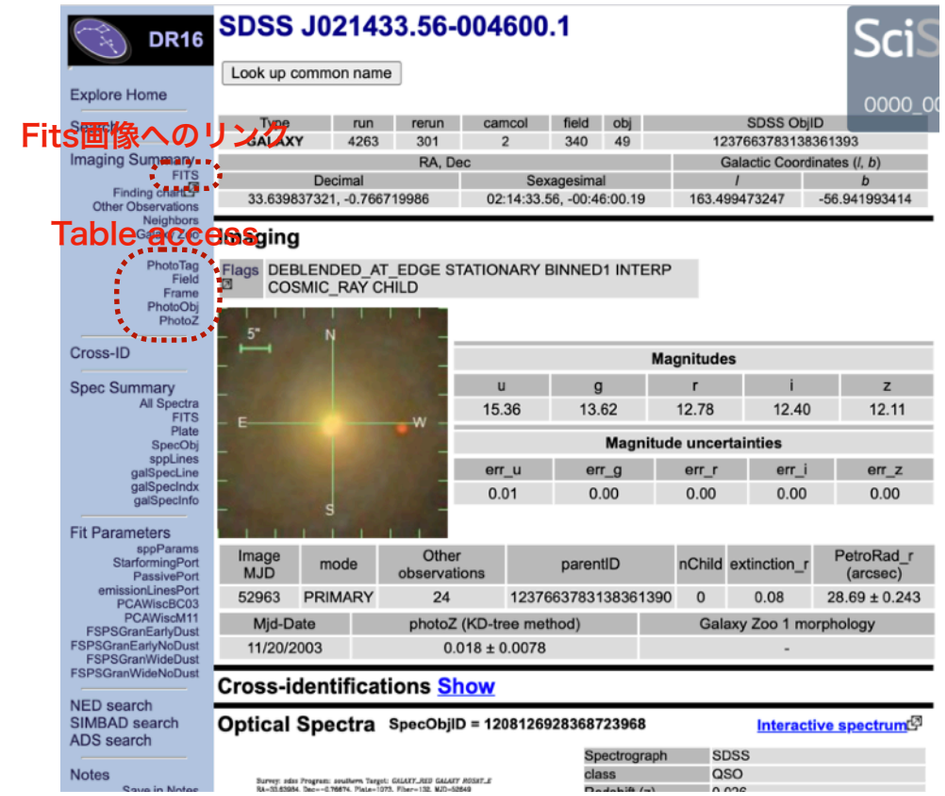
driftscan (run)
(各sky位置が54秒で1CCDを横切る)

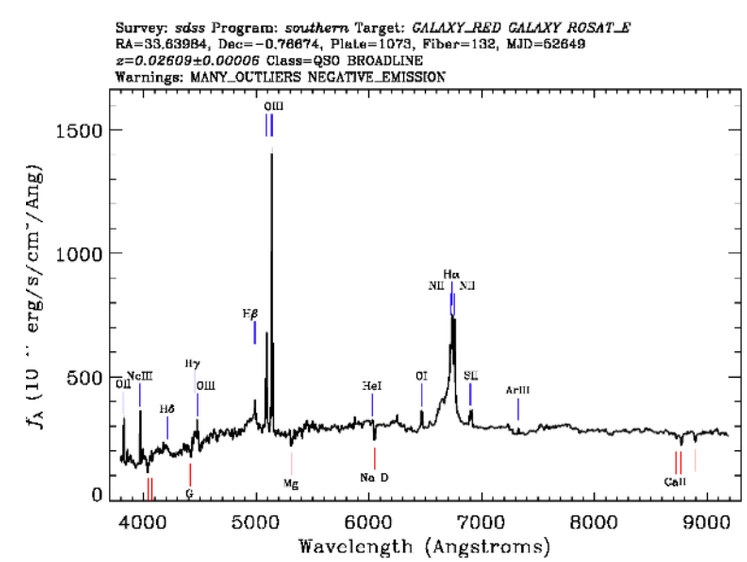
https://www.sdss.org/dr16/imaging/imaging_basics/

Sloan Digital Sky Survey

最新はData Release (DR) 16







- SDSS DR16 Navigator Tool
  1. 座標移動, zoom-in, drawing options
  2. Explore
  3. *photoObj* table
  4. Fits画像データ取得

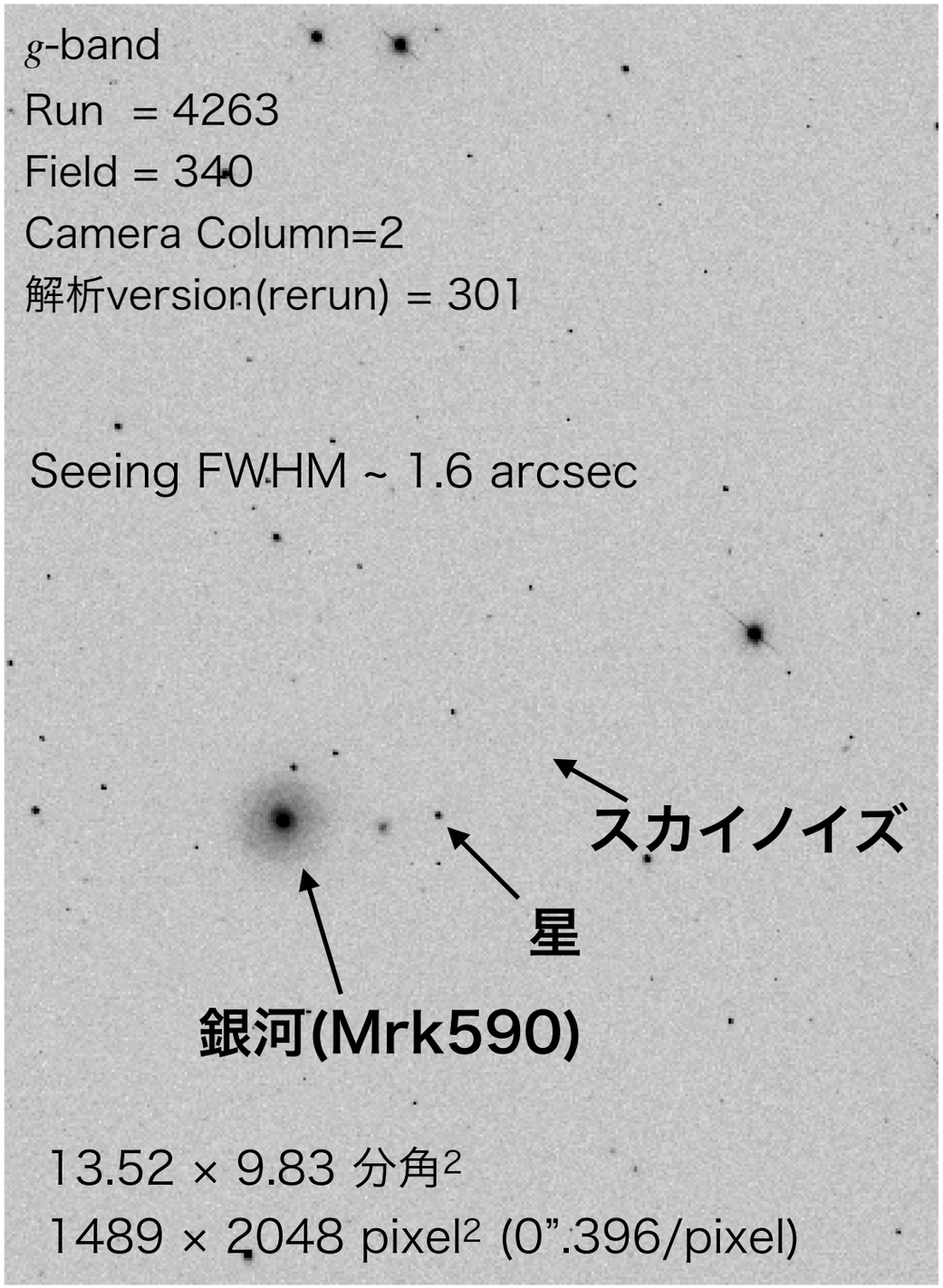
http://skyserver.sdss.org/dr16/en/tools/chart/navi.aspx

http://skyserver.sdss.org/dr16/en/tools/explore/Summary.aspx?id=1237663783138361393

安田さんによる資料: https://www.adc.nao.ac.jp/people/~furusawa/work/da_ws/2/slides/Yasuda_SDSS.pdf

SDSS測光値の定義：https://www.sdss.org/dr12/algorithms/magnitudes/

Sloan Digital Sky Survey : 画像データ



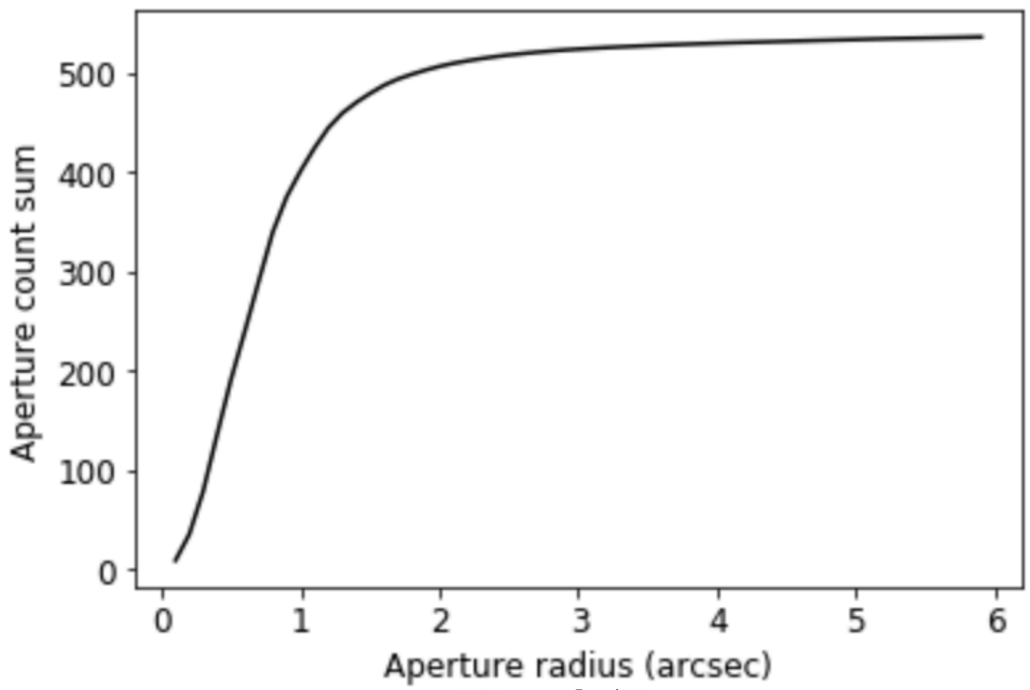
- 54秒積分 (1 epochのみ; 2000-2001)
- サーベイ領域の**モザイク画像**が
  2k × 1k 画像(*frame*)に小分けされている.
  FITS形式.
- Sky引き算, WCS座標較正済み
- 物理的に意味のあるcountに較正済み:
  ゼロ点等級 = 22.5 mag (1 nanomaggy
  [1 count が 22.5 mag に対応]
- カタログの測光値を使う or 自分で画像の測光を行う
  (銀河などのextended sourceは自分で画像を確認したほうが良いだろう)

http://dr16.sdss.org/sas/dr16/eboss/photoObj/frames/301/4263/2/frame-g-004263-2-0340.fits.bz2

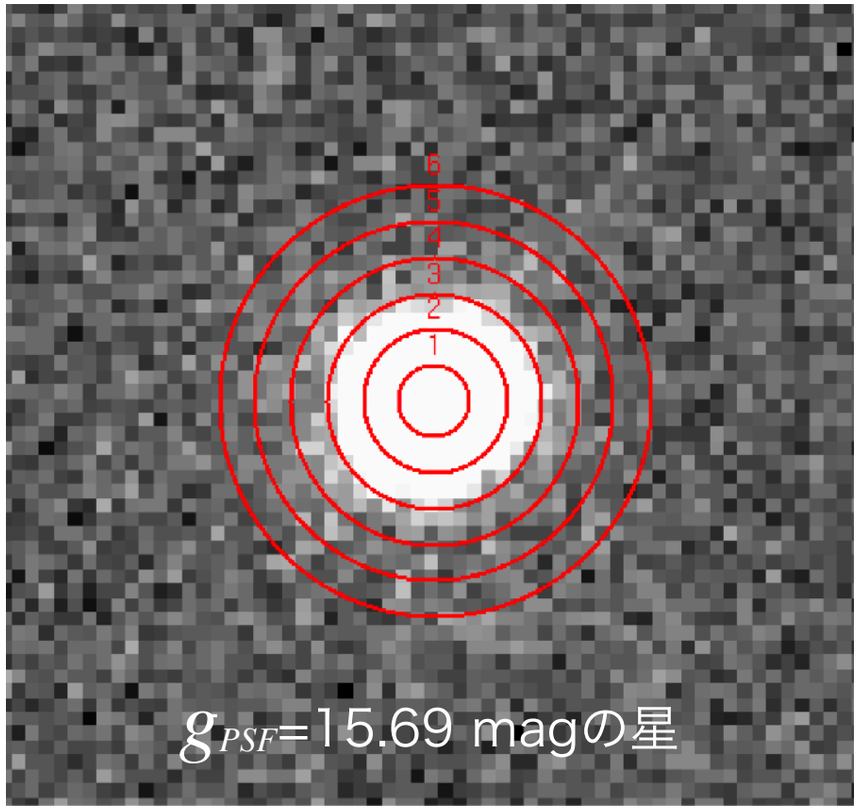
https://www.sdss.org/dr16/imaging/imaging_basics/
https://www.sdss.org/dr16/algorithms/magnitudes/#nmgy
Python access (astroquery) : https://astroquery.readthedocs.io/en/latest/sdss/sdss.html

Sloan Digital Sky Survey : 画像データ

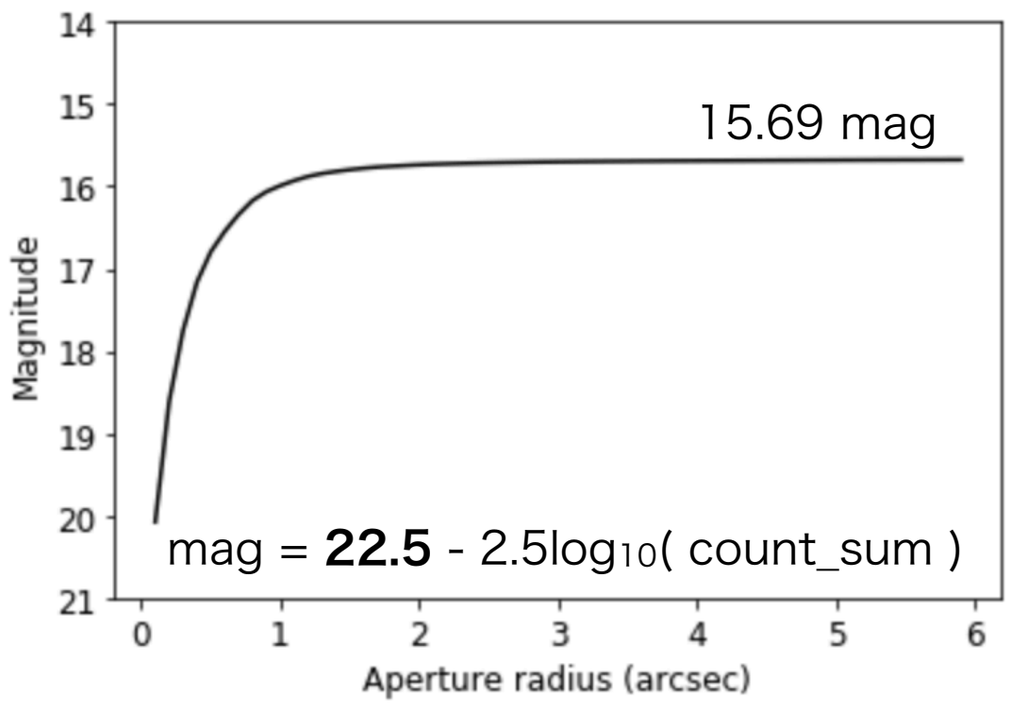
カウント合計



開口半径



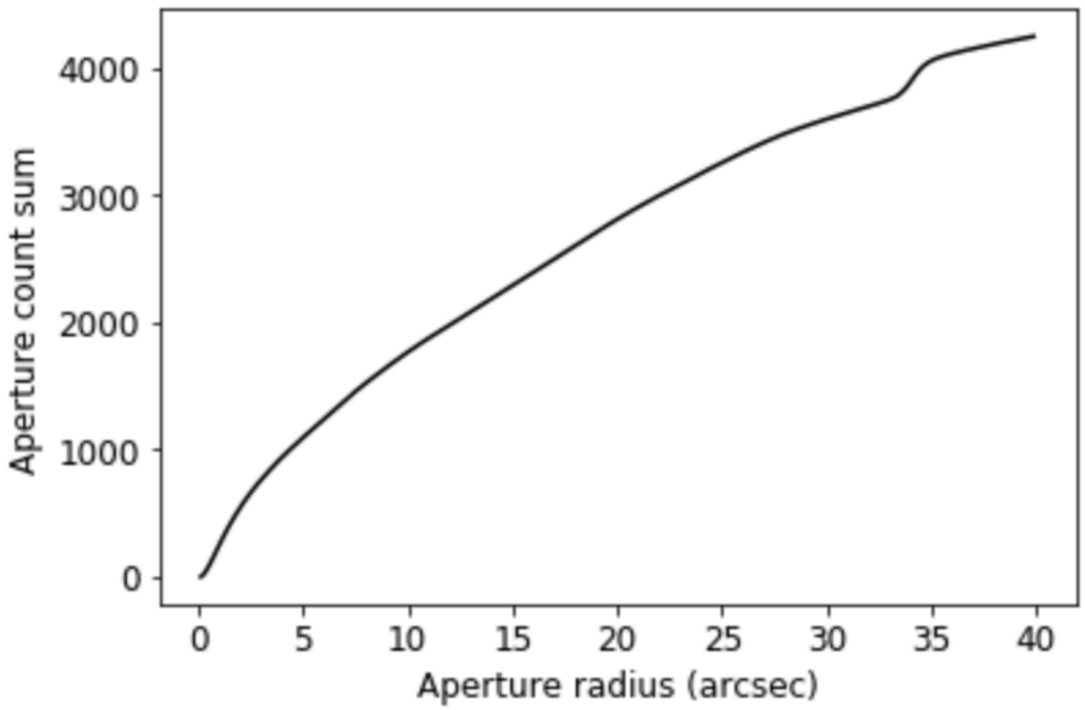
等級

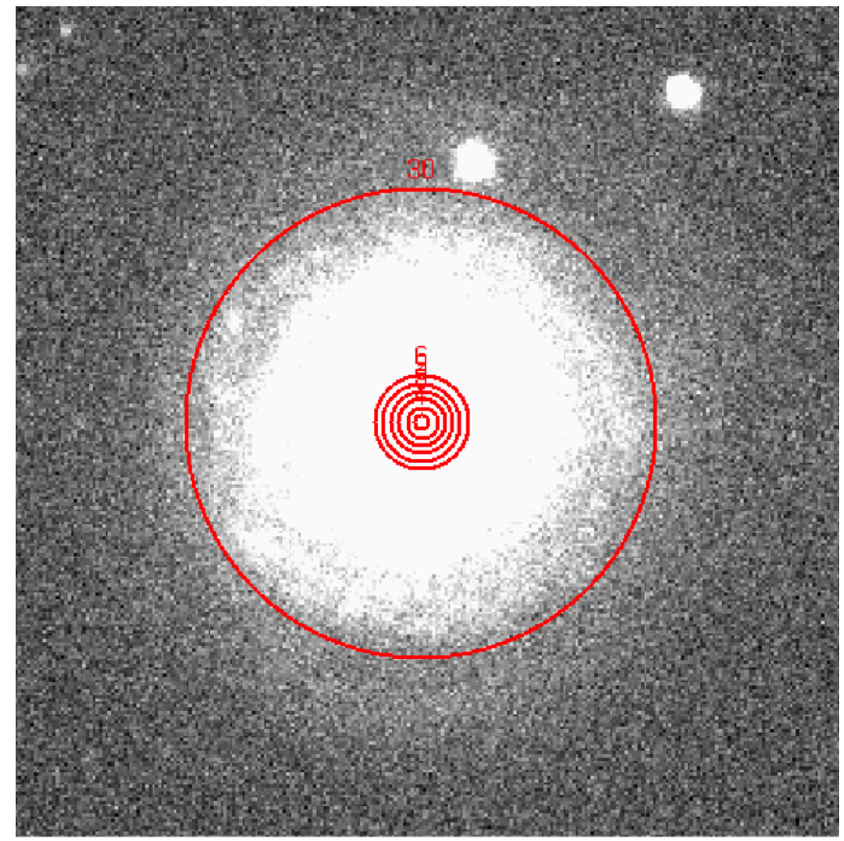


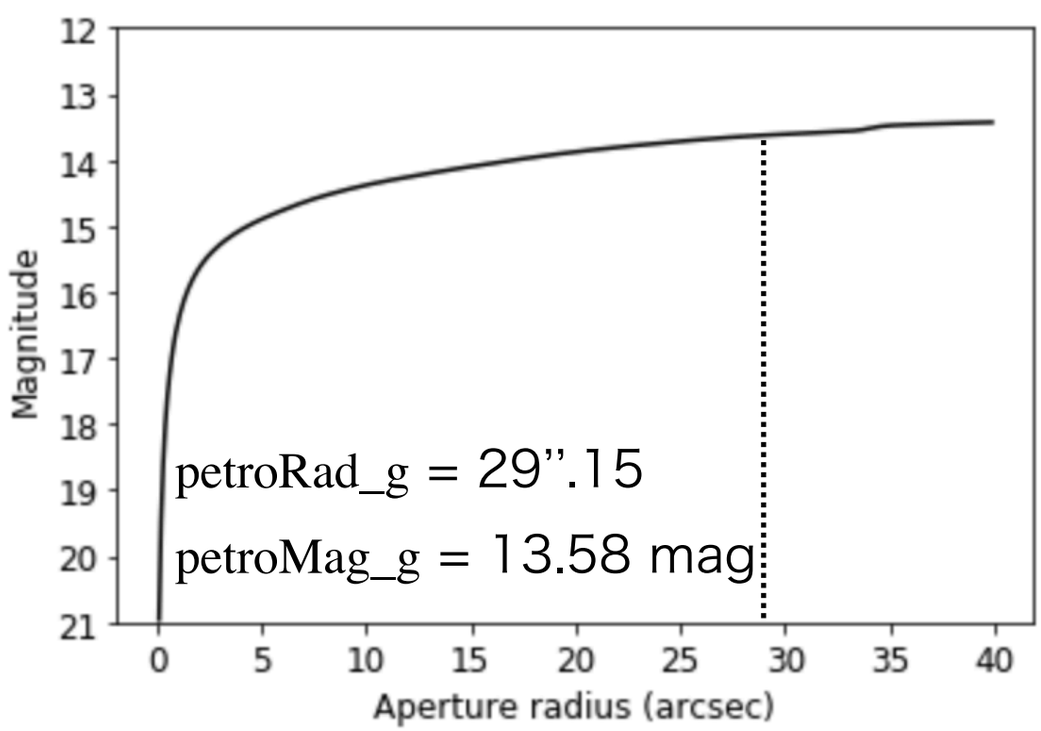
- 星のカタログ測光値としては**PSF等級**(PSF profileをfitしたもの; psfMag in *PhotoObj* table)を使う.
- 十分大きな開口をとってカウントを合計したものがPSF等級と等価.
  (小さい開口をとる場合はaperture correctionが必要)

PSF: http://astro-dic.jp/point-spread-function/
python/photutils: https://photutils.readthedocs.io/en/stable/#

Sloan Digital Sky Survey : 画像データ



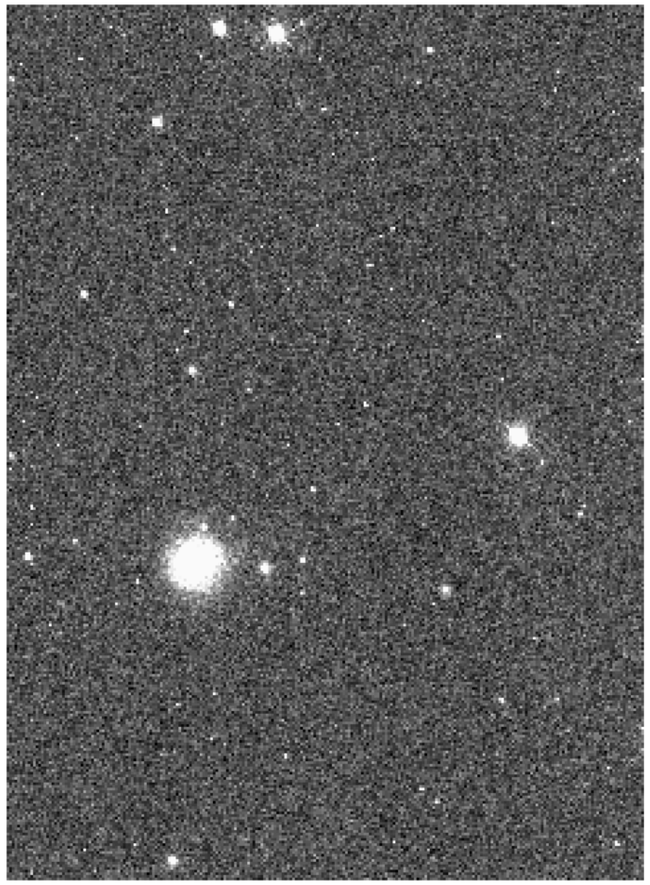




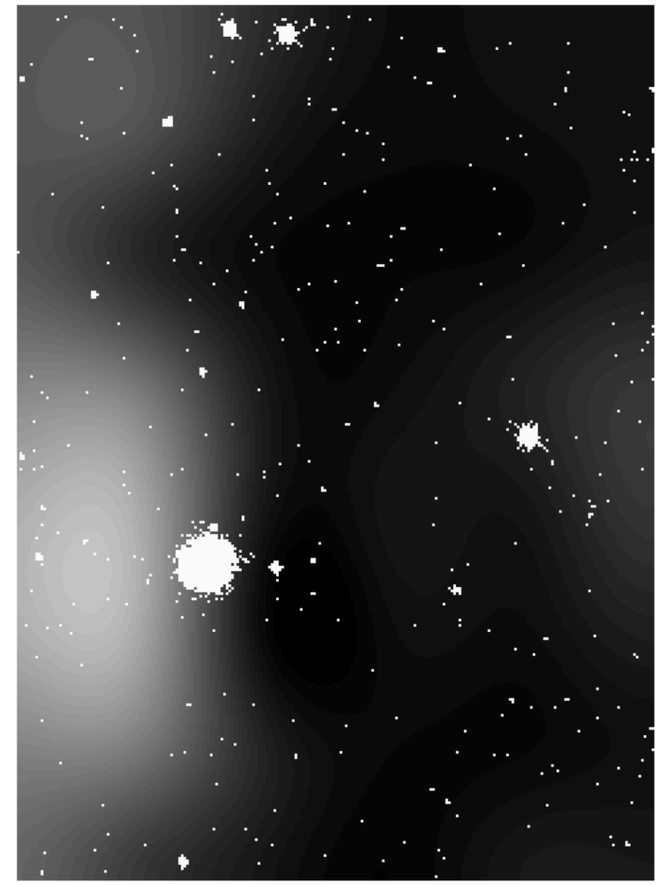
- 広がった天体の測光値は色々な定義がある
- modelMag [in *PhotoObj* table] がSDSSの推奨.
  (DeV, Exp, … モデルプロファイルfitによる測光値)
- ペトロシアン半径の開口測光値なども利用できる
  (in *PhotoObj* table)
- ds9でquickにでも自分で測光してみるのがbest

https://sites.google.com/cfa.harvard.edu/saoimageds9
https://www.sdss.org/dr16/algorithms/magnitudes/

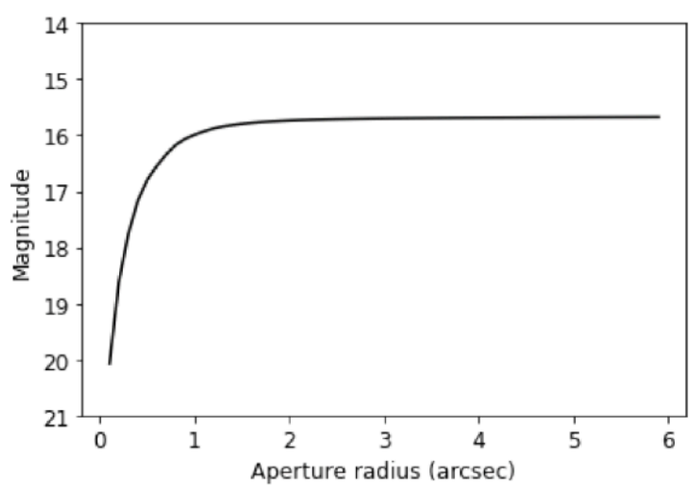
Sloan Digital Sky Survey : 画像データ

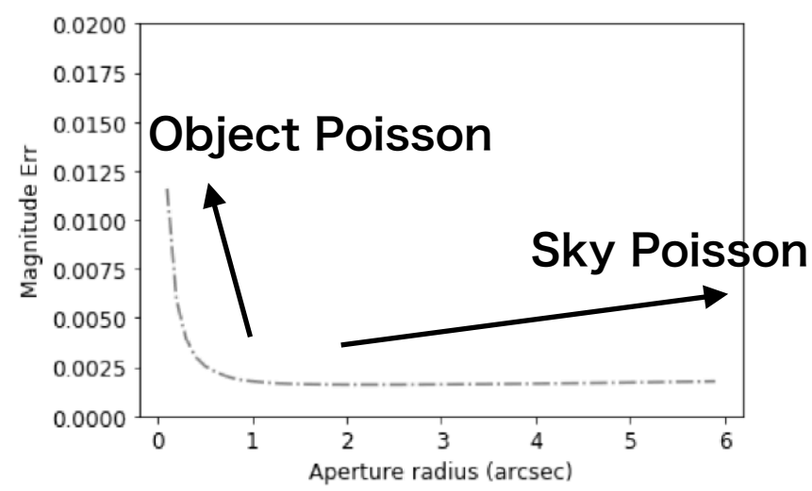


Image



sigma_map = sqrt(variance map)



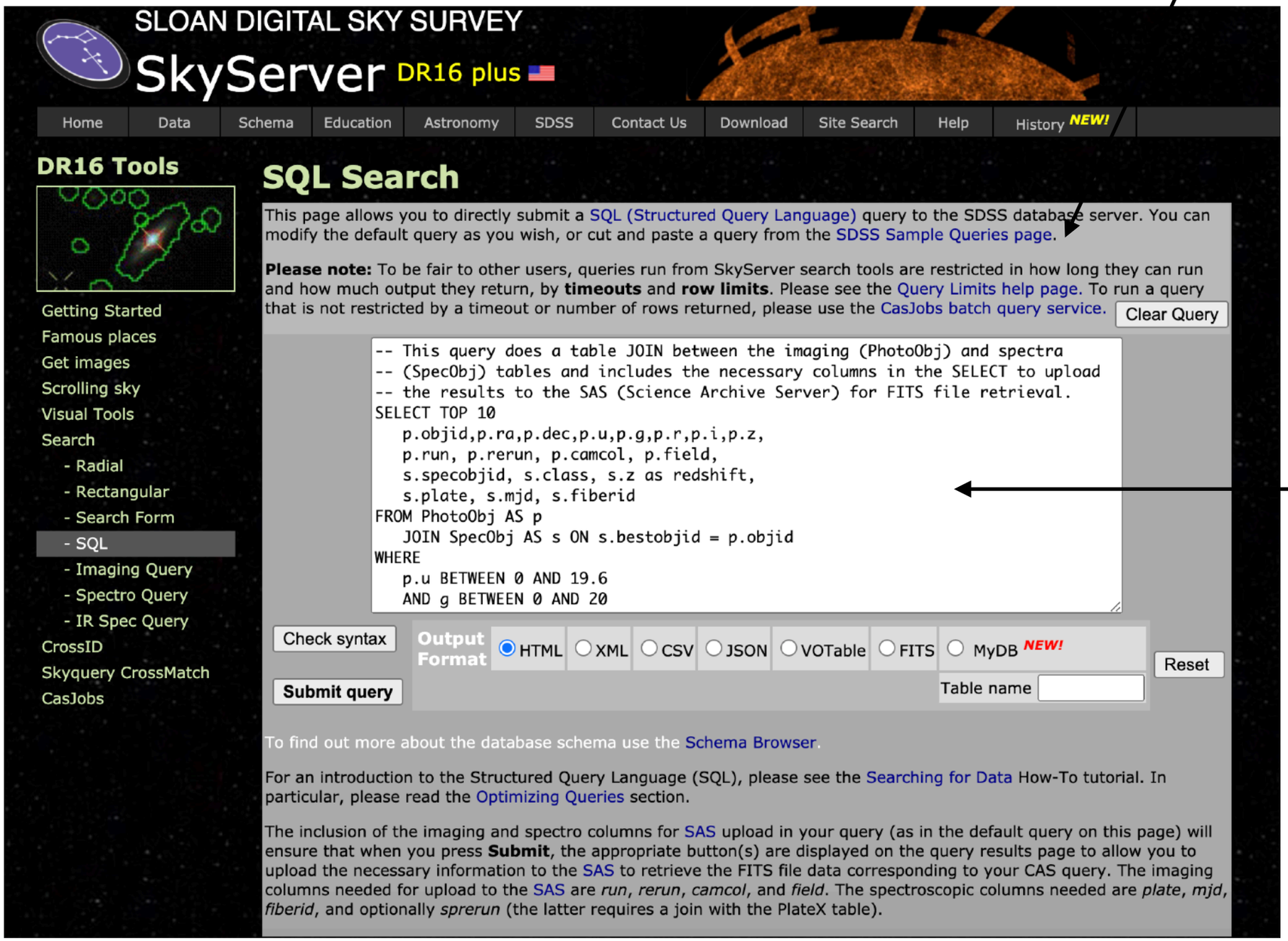


gain = 3.855 (tsField fileから取ってくる) : https://dr16.sdss.org/datamodel/files/SDSS_TARGET/data/tsField.html
Background RMSは photutils.background で見積もった: https://photutils.readthedocs.io/en/stable/background.html

Sloan Digital Sky Survey : 測光カタログ

一般的なカタログ (tables) アクセスはSQL :

SQL queries 実用例



- 測光カタログと分光カタログをくっつける.
- 条件にあう天体を10個表示

SDSSのSQL web interface: http://skyserver.sdss.org/dr16/en/tools/search/sql.aspx

Sloan Digital Sky Survey : 測光カタログ

SQLへのpython access

大量データ取得や,
変動天体探査自動pipelineへの
組み込み等で有用

```
: import sqlcl
  import numpy as np
  import pandas as pd
```

SQL query定義

```
: # http://skyserver.sdss.org/dr16/en/tools/search/sql.aspx

  sql_script="\
  SELECT TOP 10 \
     p.objid,p.ra,p.dec,p.u,p.g,p.r,p.i,p.z, \
     p.run, p.rerun, p.camcol, p.field, \
     s.specobjid, s.class, s.z as redshift, \
     s.plate, s.mjd, s.fiberid \
  FROM PhotoObj AS p \
     JOIN SpecObj AS s ON s.bestobjid = p.objid \
  WHERE \
     p.u BETWEEN 0 AND 19.6 \
     AND g BETWEEN 0 AND 20 \
  "
```

SQL query submit

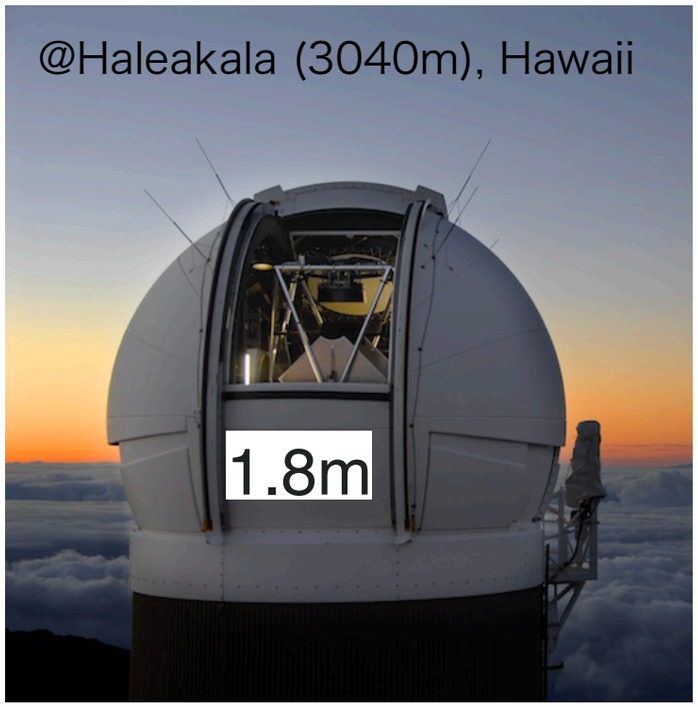
```
: lines = sqlcl.query(sql_script).readlines()
  print(lines)
```

任意のtable形式に変換

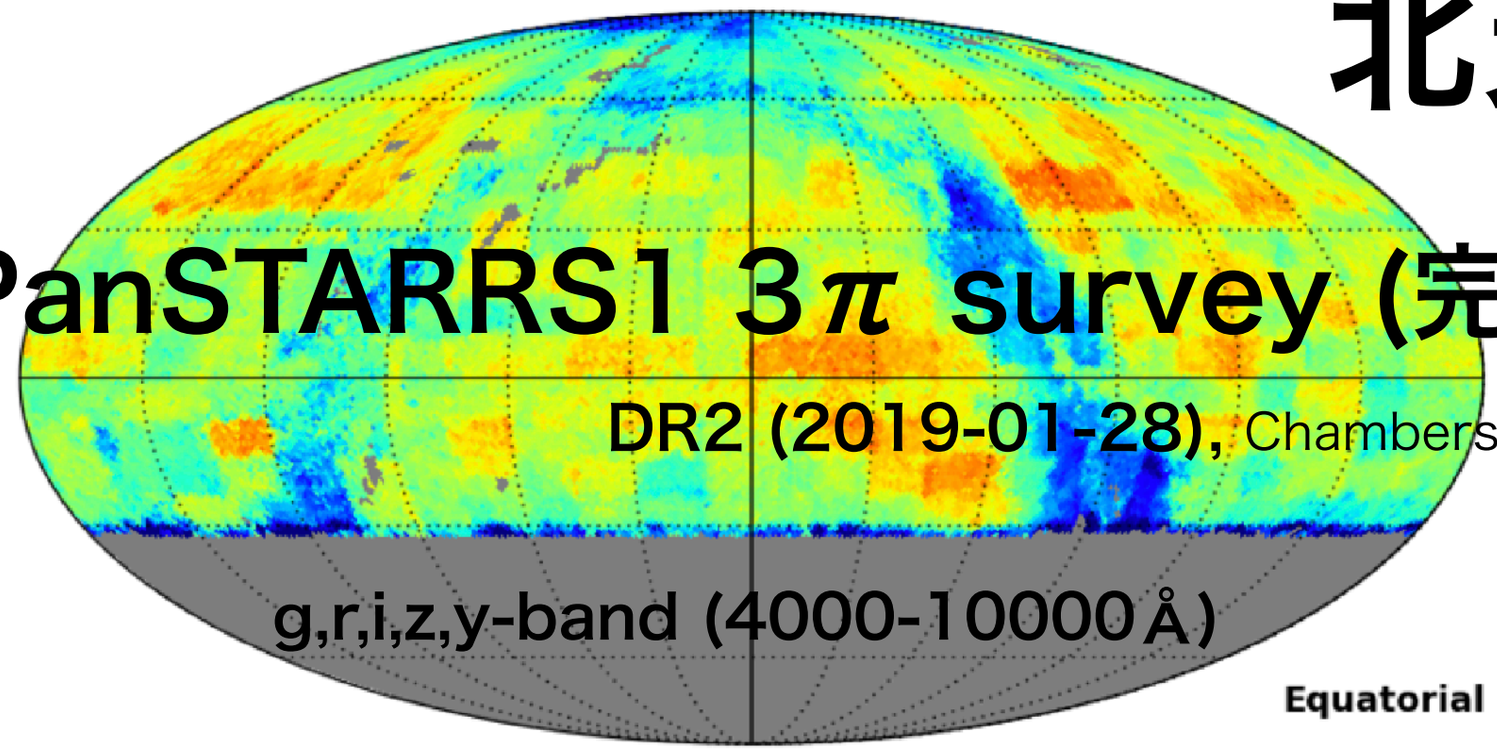
```
  data = []
  for line in lines[2:]:
      #data.append(map(float,line[:-1].split(',')))
      data.append( line[:-1].split(','))

  columns=lines[1].split(",")

  catalog = pd.DataFrame( data, columns=columns )
```

	objid	ra	dec	u	g	r	i	z	run	rerun	camcol	field	spec
0	1237645879551066262	348.902530171573	1.27188624932946	19.38905	18.24496	17.58728	17.20807	16.90905	94	301	6	94	4301949499510
1	1237645879578460255	51.4436950026148	1.27007271795861	19.52808	17.96541	17.03493	16.53754	16.14154	94	301	6	512	4662352927313
2	1237645879578460271	51.4835835170322	1.27201267342336	18.72268	17.3852	16.81134	16.51803	16.29502	94	301	6	512	4662328188301
3	1237645941291614227	49.6274851210218	-1.0417691497987	17.65612	16.17133	15.5894	15.3785	15.26744	109	301	1	100	17057955826620
4	1237645941824356443	40.2856904119424	-0.71495662825756	17.54884	15.75164	15.031	14.66728	14.36099	109	301	2	37	4593946803338
5	1237645941824356481	40.2721052364832	-0.642510265945889	19.23401	17.5333	16.8743	16.63157	16.49762	109	301	2	37	12047442798727
6	1237645942898229350	40.5820323404104	0.134770090982145	18.64558	16.44336	15.52452	15.18185	14.98858	109	301	4	39	82531204825699
7	1237645942905438473	57.025336578067	0.20884499634774	17.61444	16.17125	15.52131	15.15564	14.86996	109	301	4	149	13984884043704
8	1237645942905438495	57.0470524254038	0.0843042629762005	19.46874	18.18264	17.59063	17.26436	16.95295	109	301	4	149	17216016120335
9	1237645942905569371	57.281615211522	0.0187678802337251	16.4848	14.92993	14.56054	14.53054	14.19394	109	301	4	151	13984985748529

sqlcl: http://skyserver.sdss.org/dr16/en/help/download/sqlcl/sqlcl.aspx



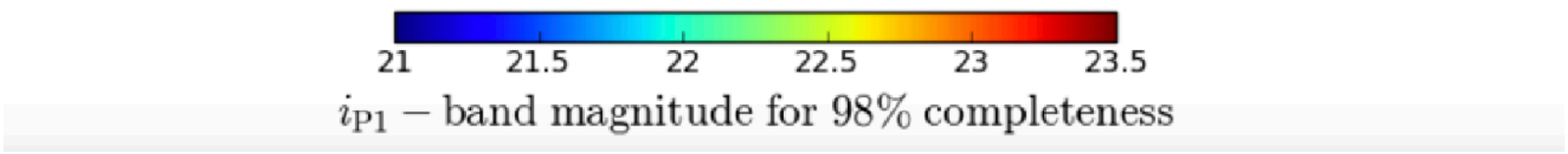
北天

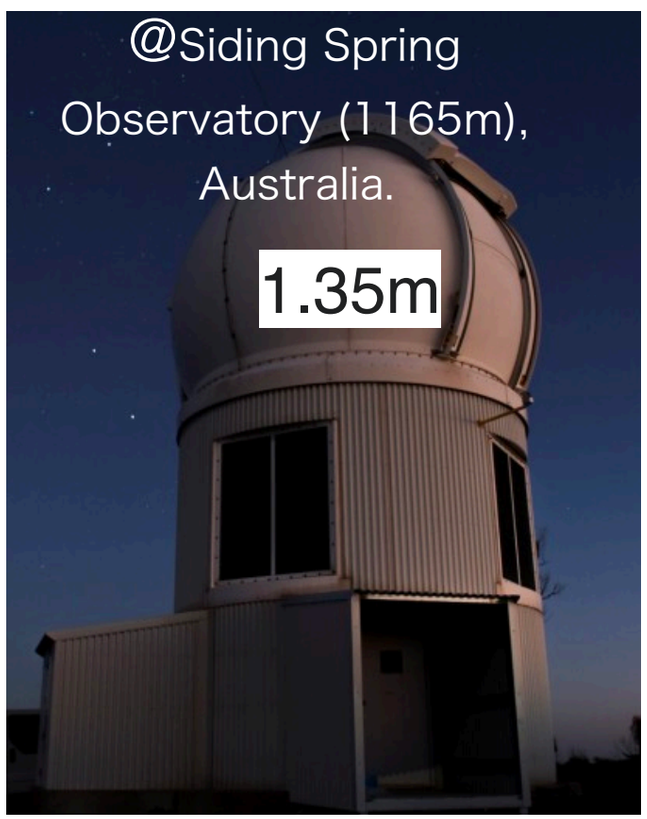


PanSTARRS1 3π survey (完了)

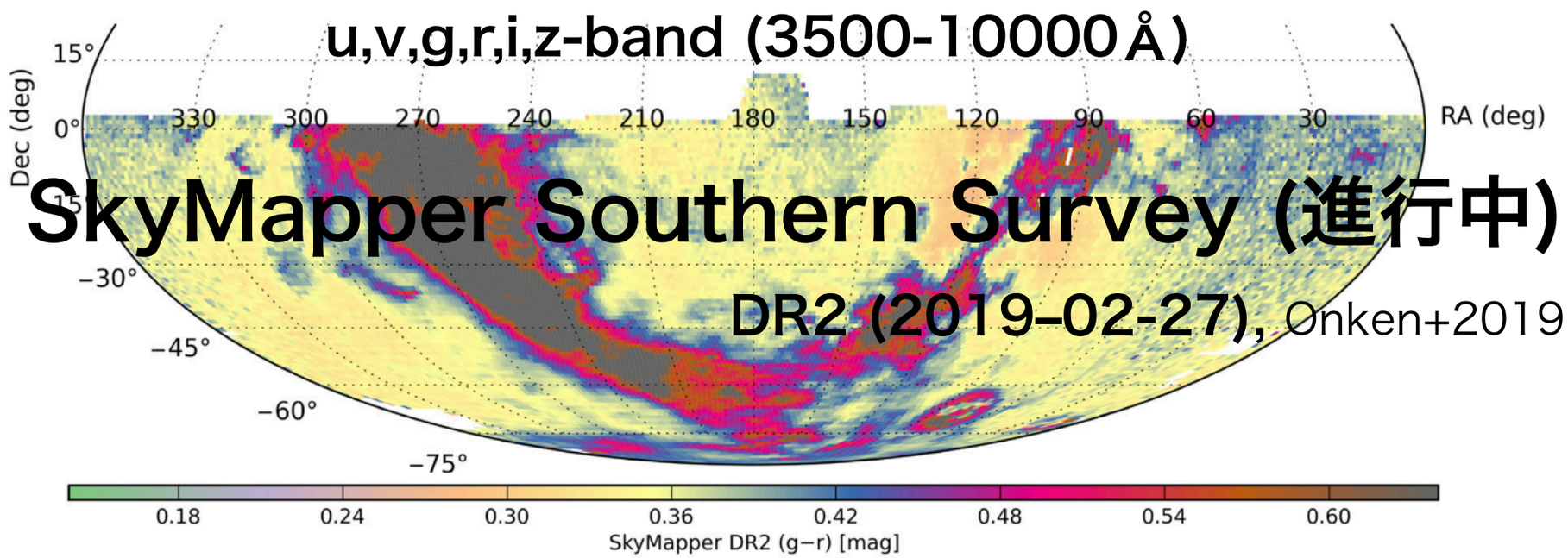
DR2 (2019-01-28), Chambers+2016

g,r,i,z,y-band (4000-10000Å)





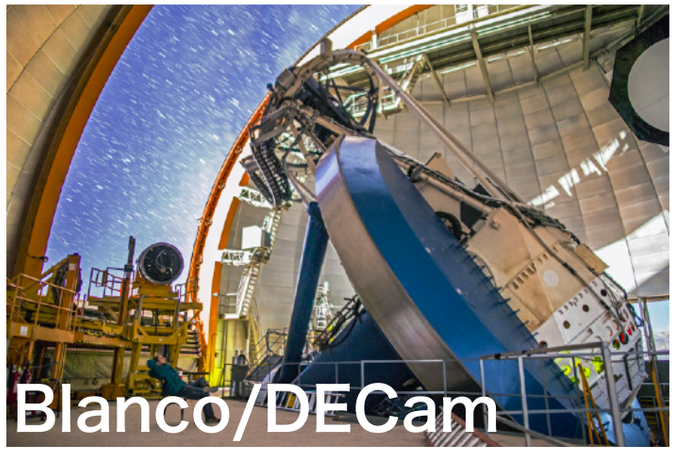
南天

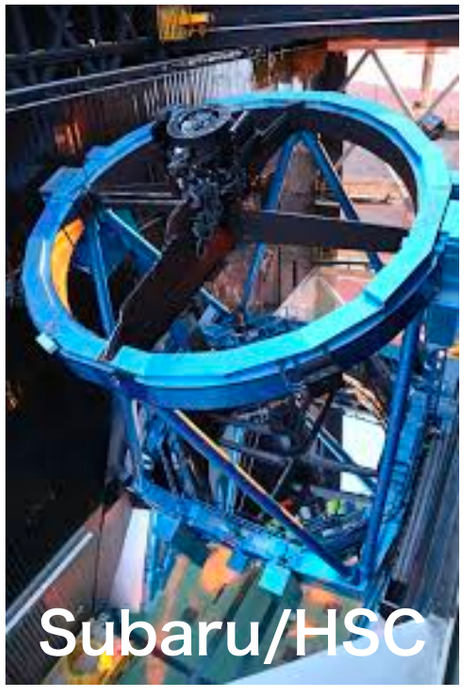


SkyMapper Southern Survey (進行中)

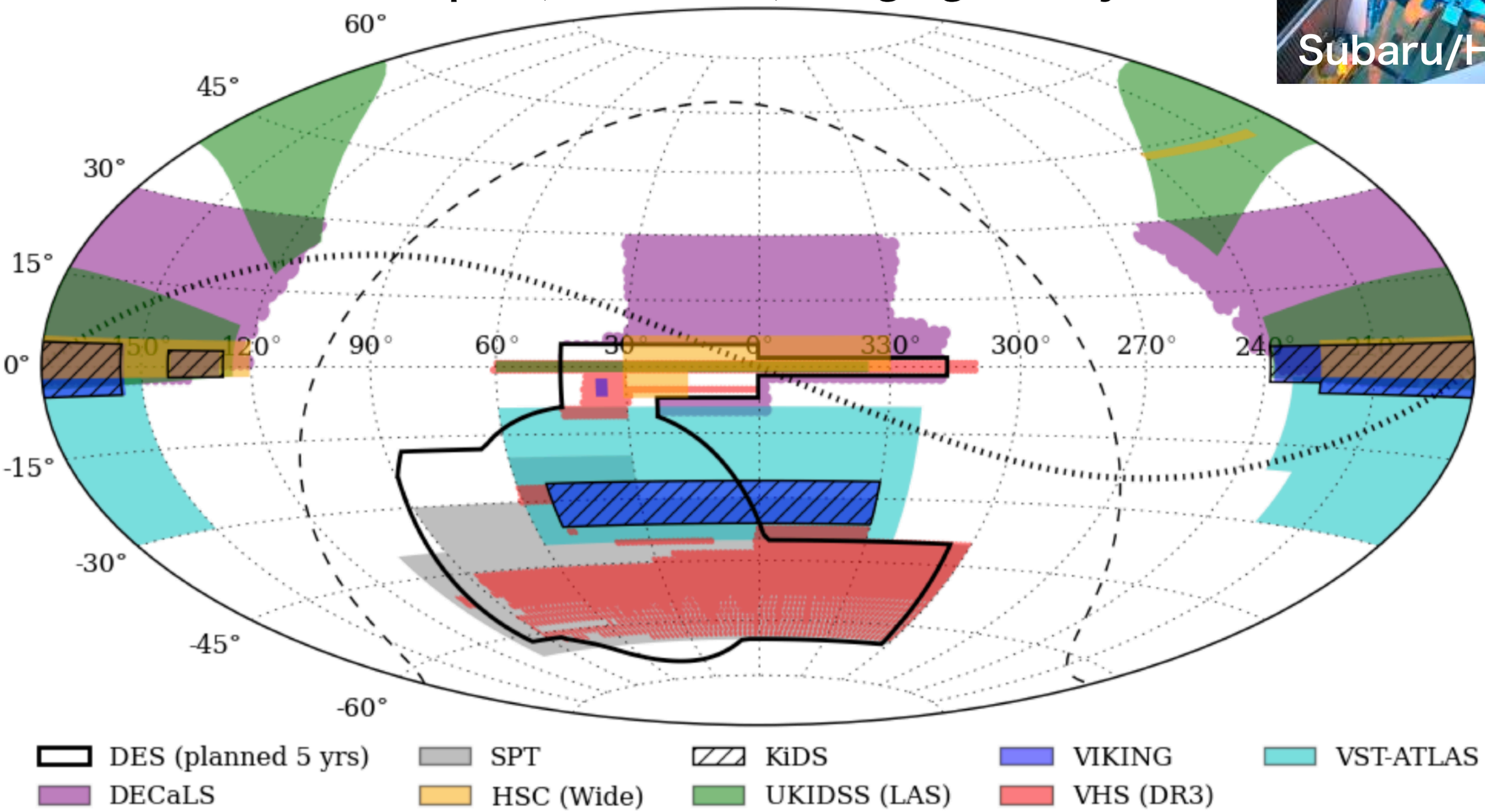
DR2 (2019–02-27), Onken+2019

u,v,g,r,i,z-band (3500-10000Å)

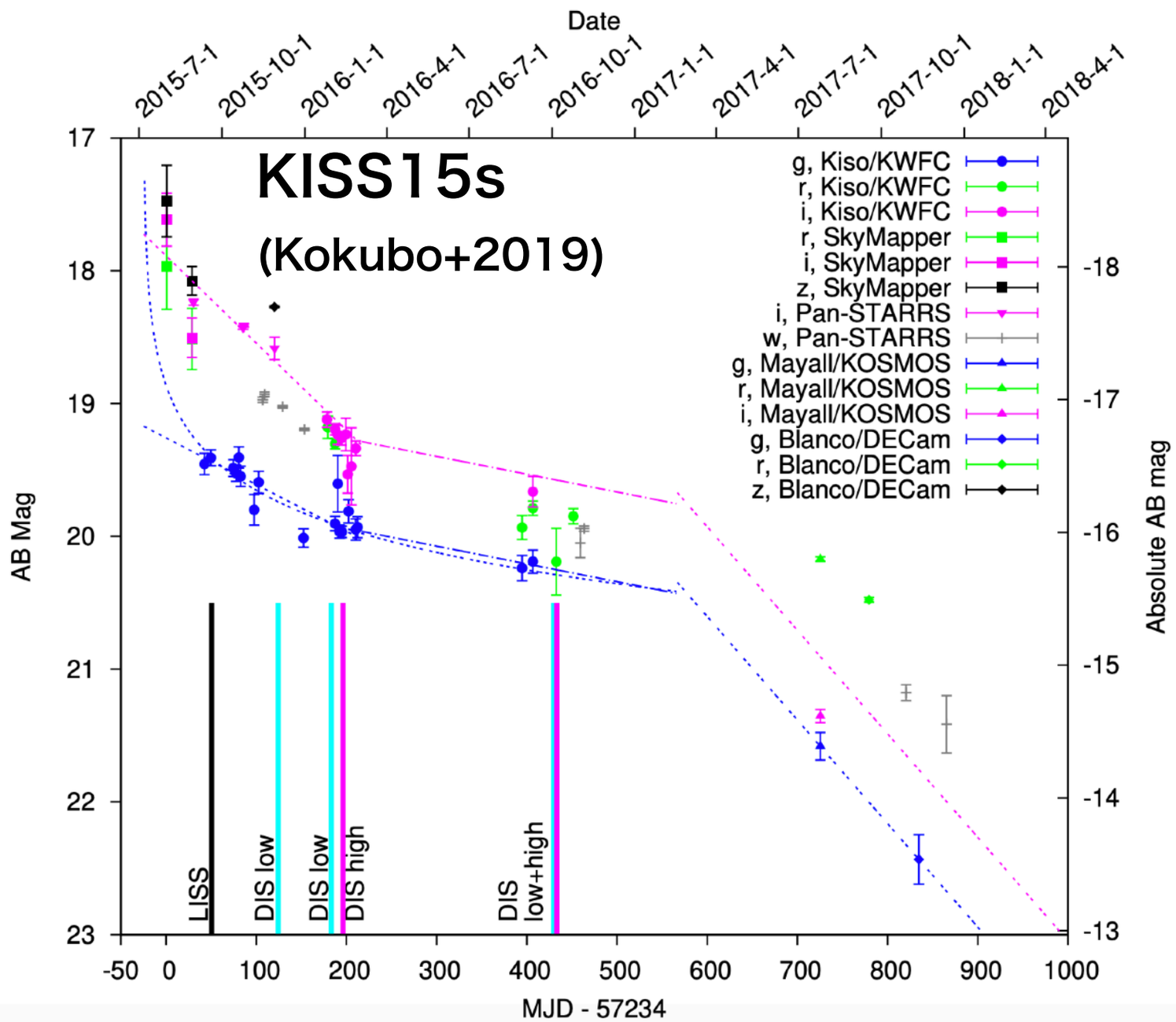


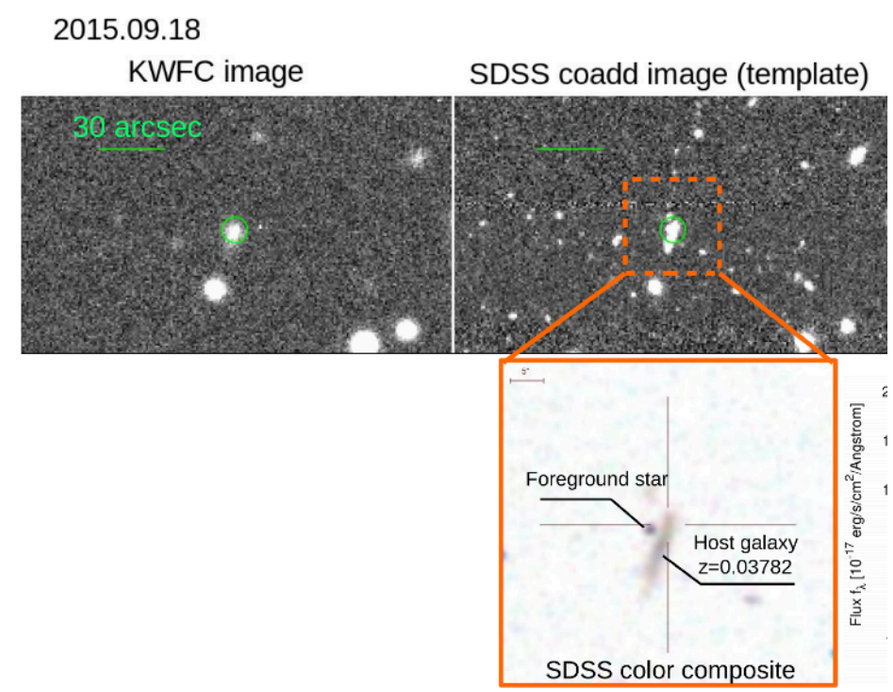


Deeper (=narrower) imaging surveys



HSC, Aihara+2018; DES+2016; NOAO public imaging surveys, DECaLS, Dey+2019





(<— image測光を自分でやり直した)

多くの可視・赤外線レガシーサーベイデータが自由に利用できる

—> 特にtime-domainで有用

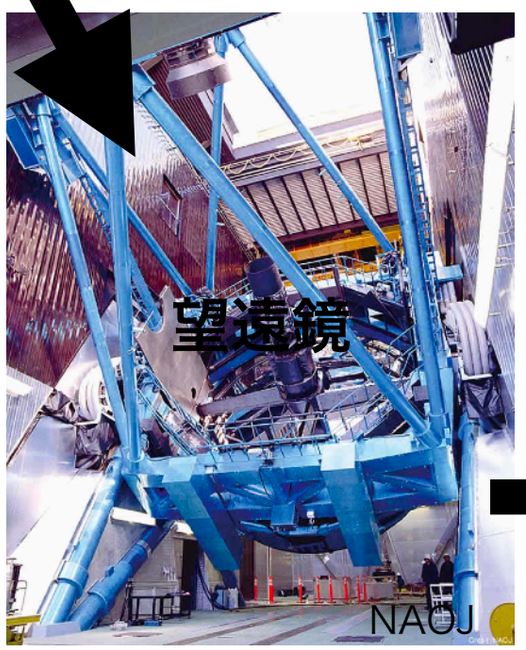
https://arxiv.org/pdf/1901.05508.pdf

可視撮像データの基礎

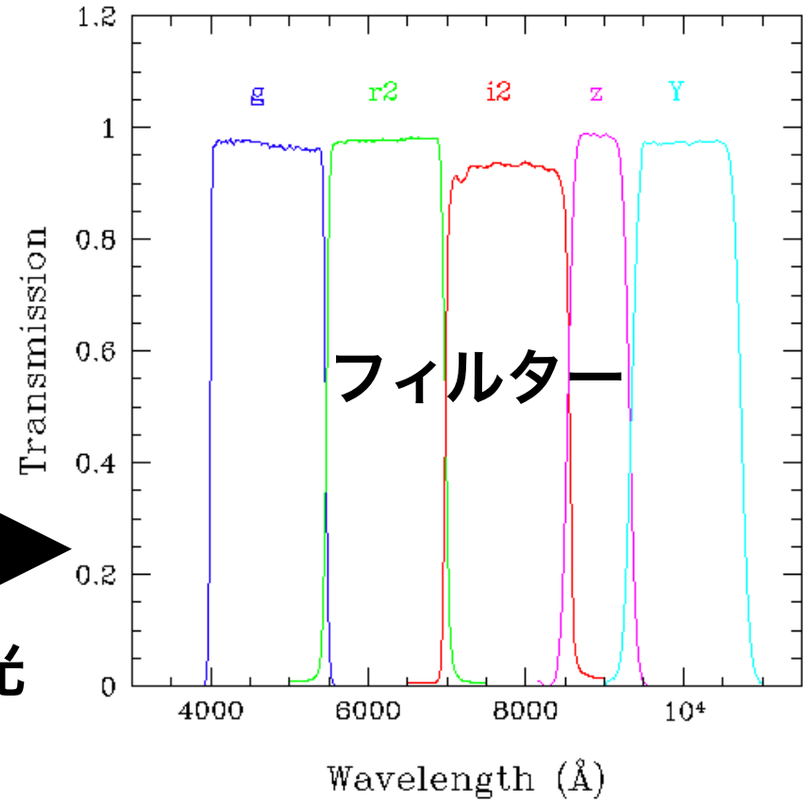
望遠鏡, フィルター, CCD検出器

光

大気

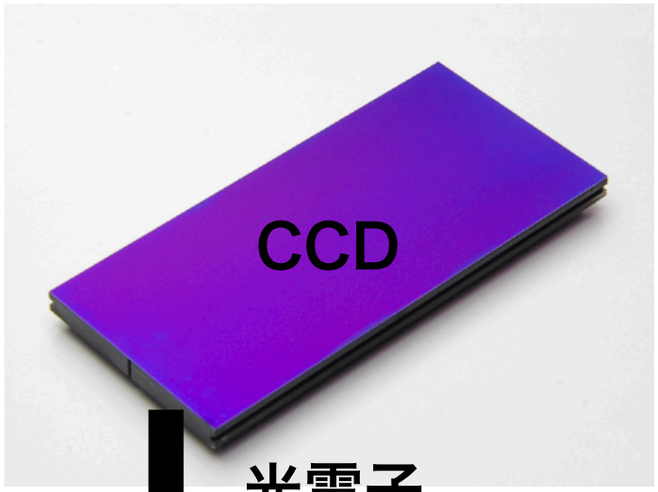


光



光

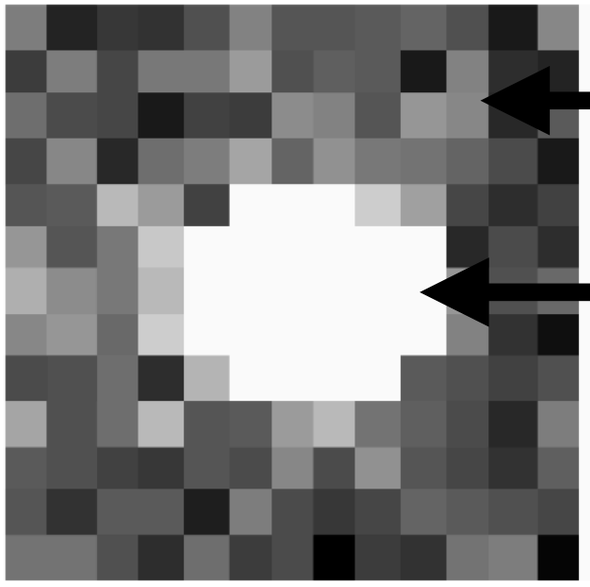
高い線型性



光電子

https://www.hamamatsu.com/jp/ja/why-hamamatsu/academic-projects/exploring-the-distant-universe/index.html

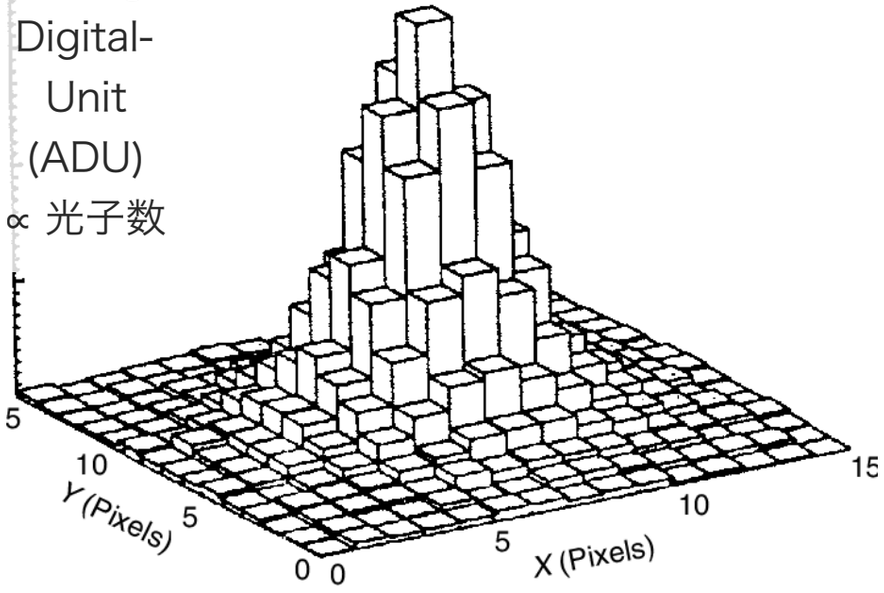
—> デジタル化



Sky Poisson noise
(+read noise)

Object

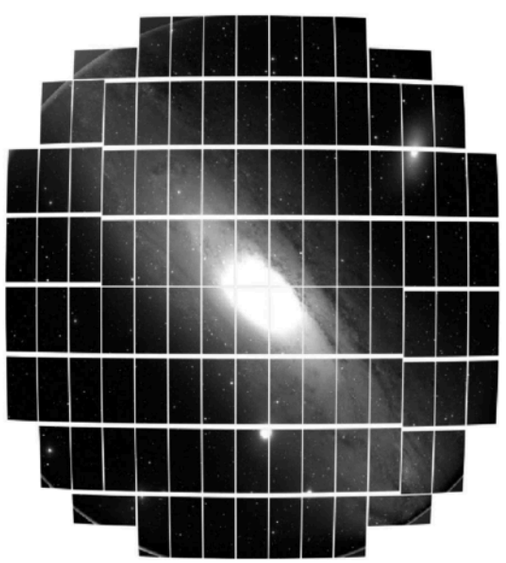
Raab 2003; Howell 2000

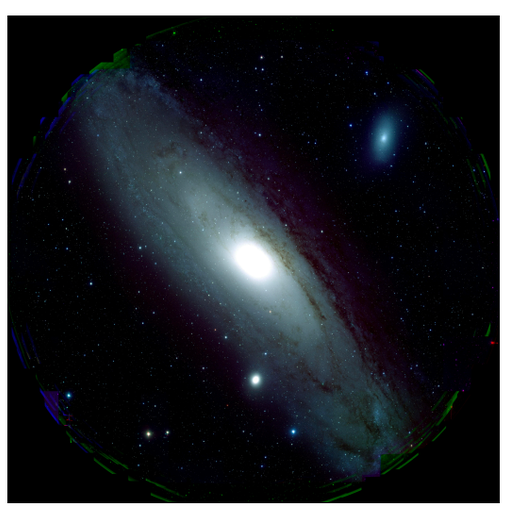


モザイクCCD

- 望遠鏡焦点面の視野を埋め尽くすように複数のCCD chipを並べる
  —> モザイクCCDカメラ (SDSS, PanSTARRS, SkyMapper, HSC, VISTA, LSST, …)

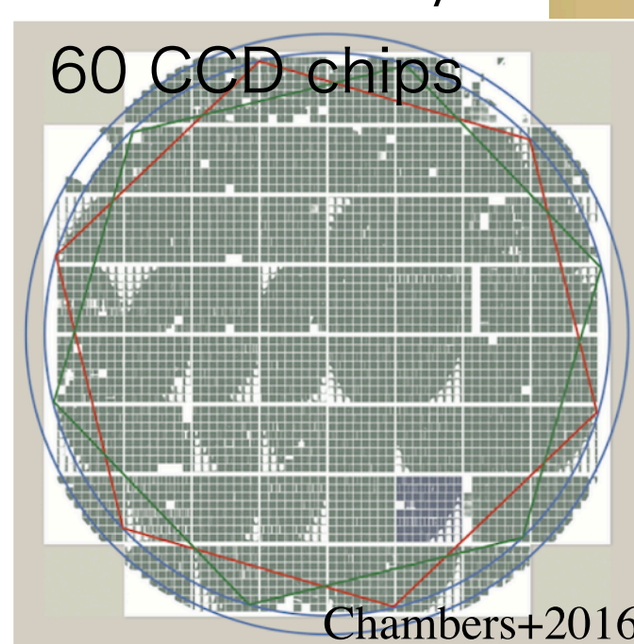
- chip間に物理的隙間ができる
  —> 少しずつ視野をずらして **足し算** (coadd, stack) することで
  隙間を埋める+**限界等級**を**深く**する

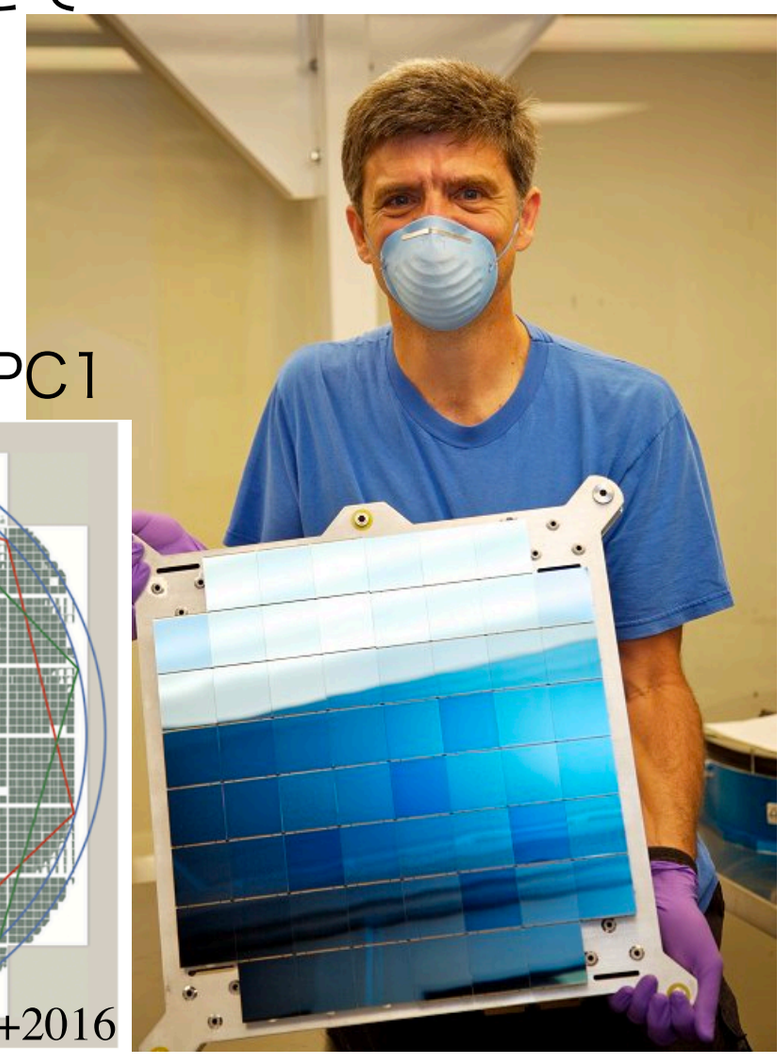




Subaru/Hyper Suprime-Cam
116 CCD chips

PanSTARRS1/GPC1





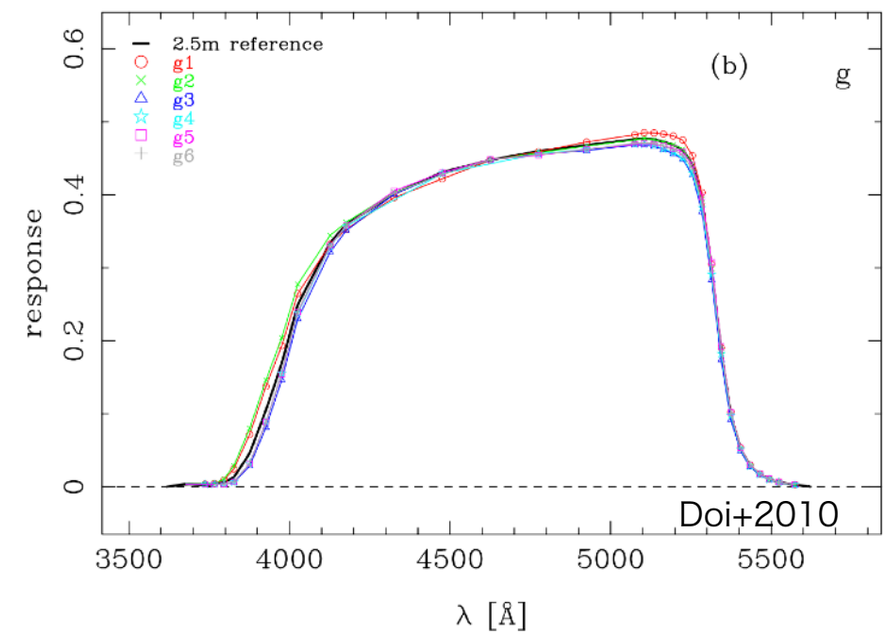
宮崎さんの月報記事: http://www.asj.or.jp/geppou/archive_open/2017_110_01/110_01_48.pdf
(Credit: HSC Project / NAOJ)

https://blog.nationalgeographic.org/2011/06/25/monster-astro-camera-on-the-hunt/

AB等級

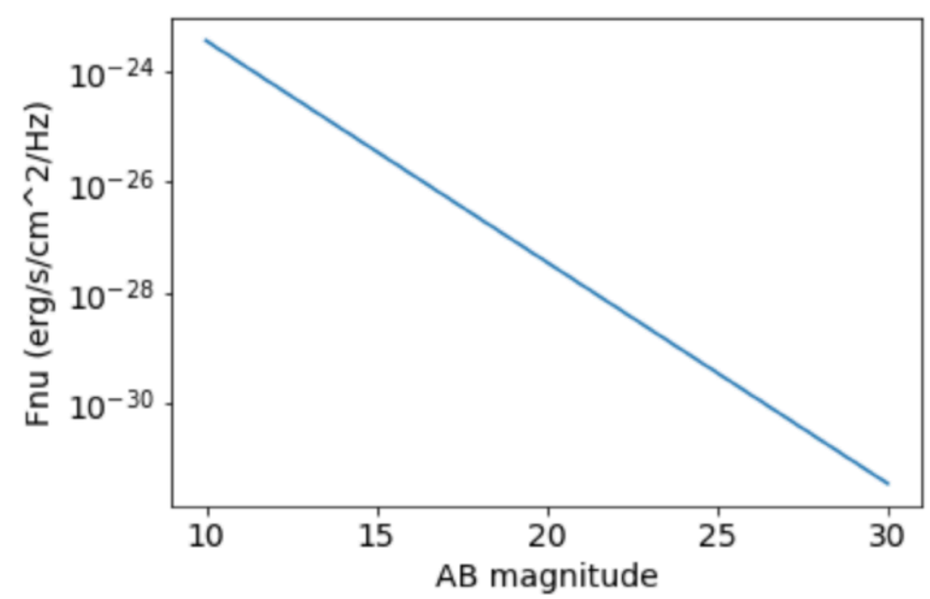
- Response関数 (=フィルター透過 × 光学系 × CCD量子効率…) × 光子数重みづけしたfluxが, そのフィルターでの <flux密度> :

$$f_\nu \leftarrow \frac{\int R_\nu \times \frac{f_\nu}{\nu}}{\int R_\nu \times \frac{1}{\nu}} d\nu$$



- AB等級: 3631Jansky (3.631×10^{-20} cgs) の星を0等星とする現代の可視光サーベイの測光システム"ほぼ"AB等級
(実際は~1%くらいズレているので、1%精度の話をしたいときは注意)

$$m_{\rm AB}(\nu) = -2.5\log(f_\nu/3631\ {\rm Jy})$$
$$= -48.600 - 2.5\log(f_\nu[{\rm erg/sec/cm^2/Hz}])$$

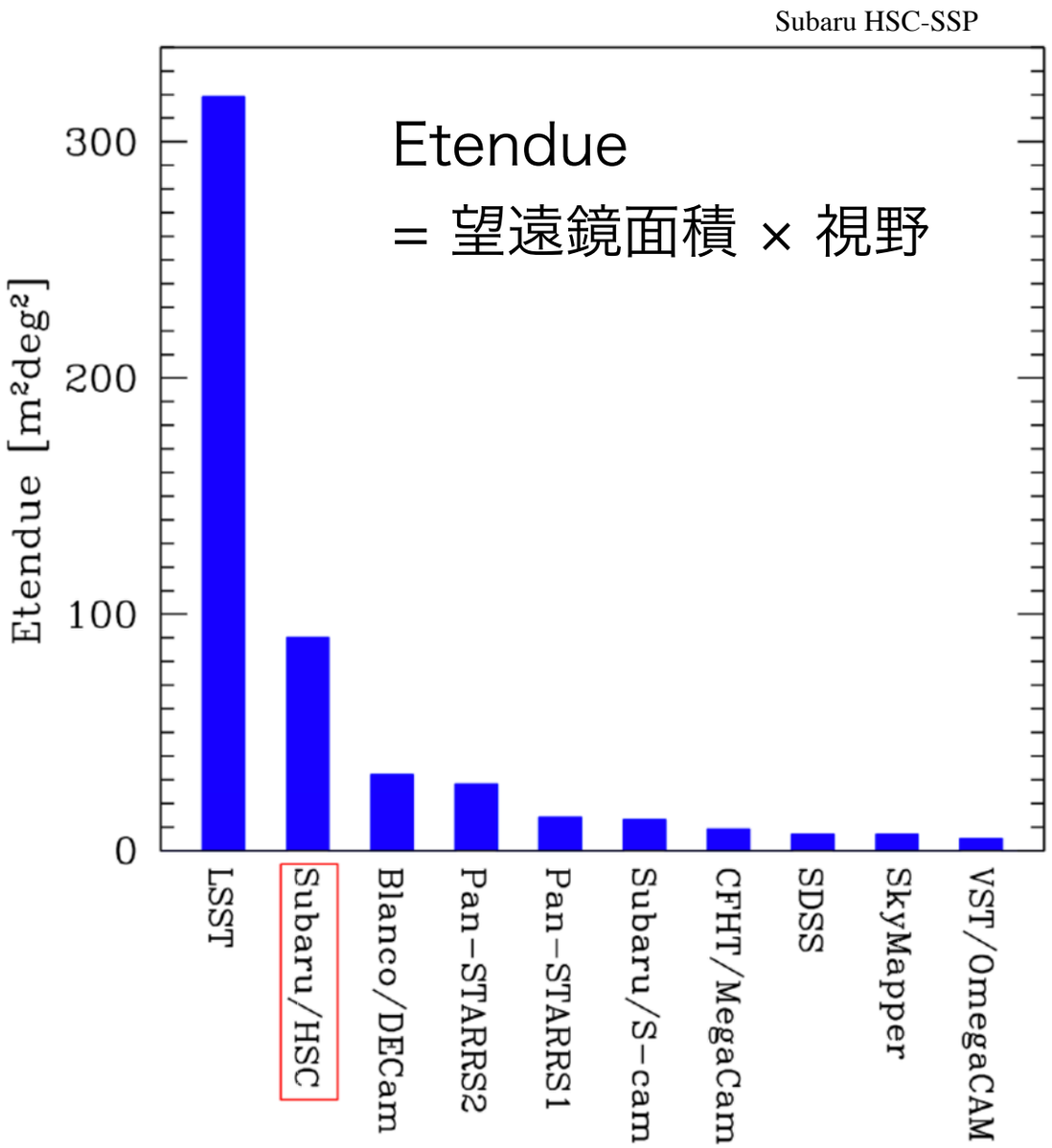


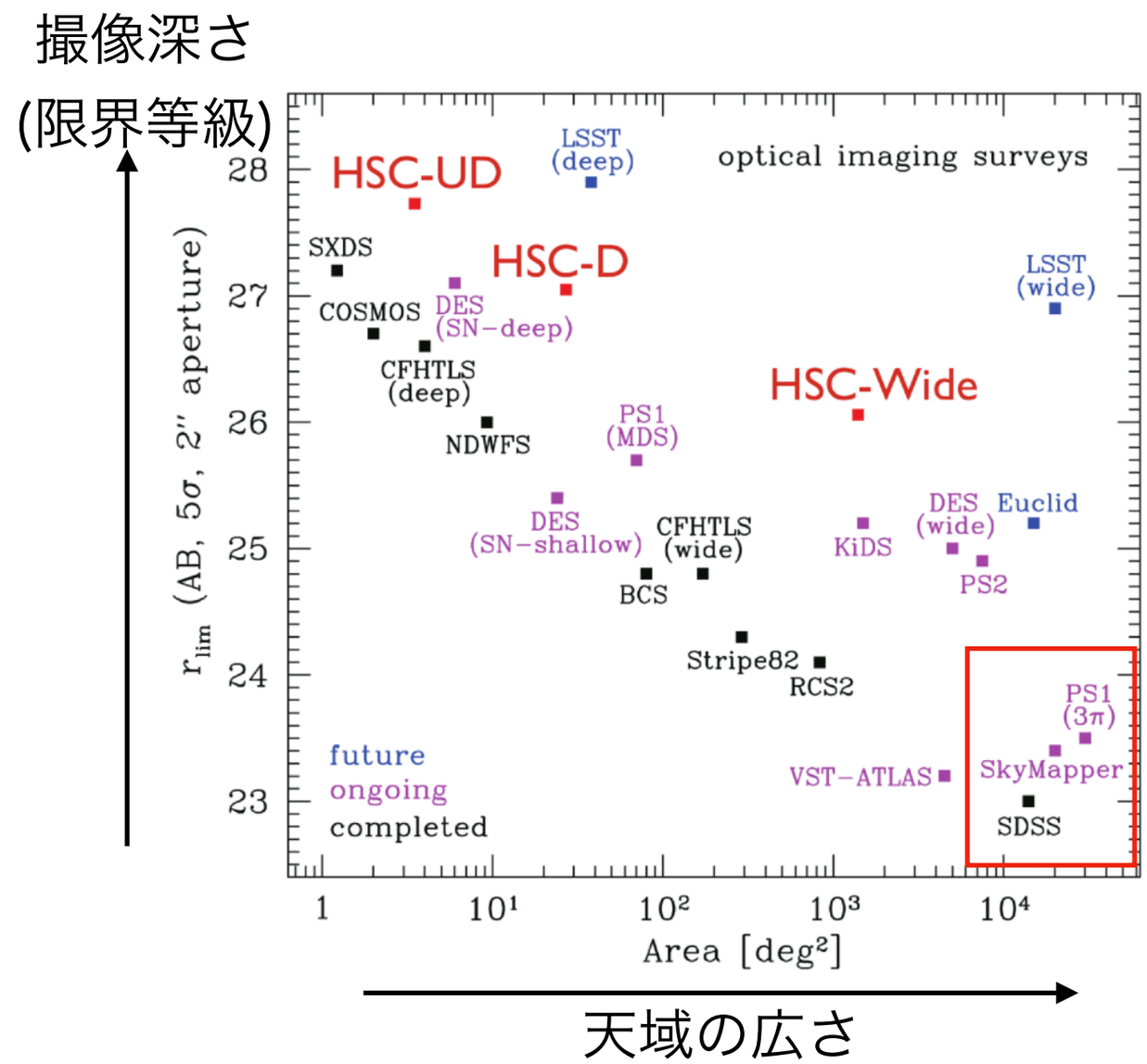
$$\Delta m_{AB} = -1.086 \times \frac{\Delta f_\nu}{f_\nu} \sim \frac{\Delta f_\nu}{f_\nu}$$

e.g., 10%のフラックス光度変動 ~ 0.1magの光度変動
1%のフラックス精度 ~ 0.01magの精度

Vega等級やAB等級の正確な定義は、以下の鈴木さんの資料に詳しい: http://gopira.jp/sym2020/2-1-Suzuki.pdf

Wide-field imaging surveys





- そこそこの口径の望遠鏡で超広視野 —> SDSS, PanSTARRS, SkyMapper
- 大口径の望遠鏡でそこそこの広視野 —> Blanco/DECam, Subaru/HSC,（LSST)

CCD image

- Pixelカウントの単位はADU (Analog-Digital Unit):

  photo-electrons[e^-] = gain[e^-/ADU] × counts[ADU]
  Poisson error[e^-] = sqrt(photo-electrons)
  Poisson error[ADU] = sqrt(photo-electrons) / gain
  = sqrt(counts / gain)

  where **gain[e^-/ADU]** is an instrument-specific constant (readout electronics)

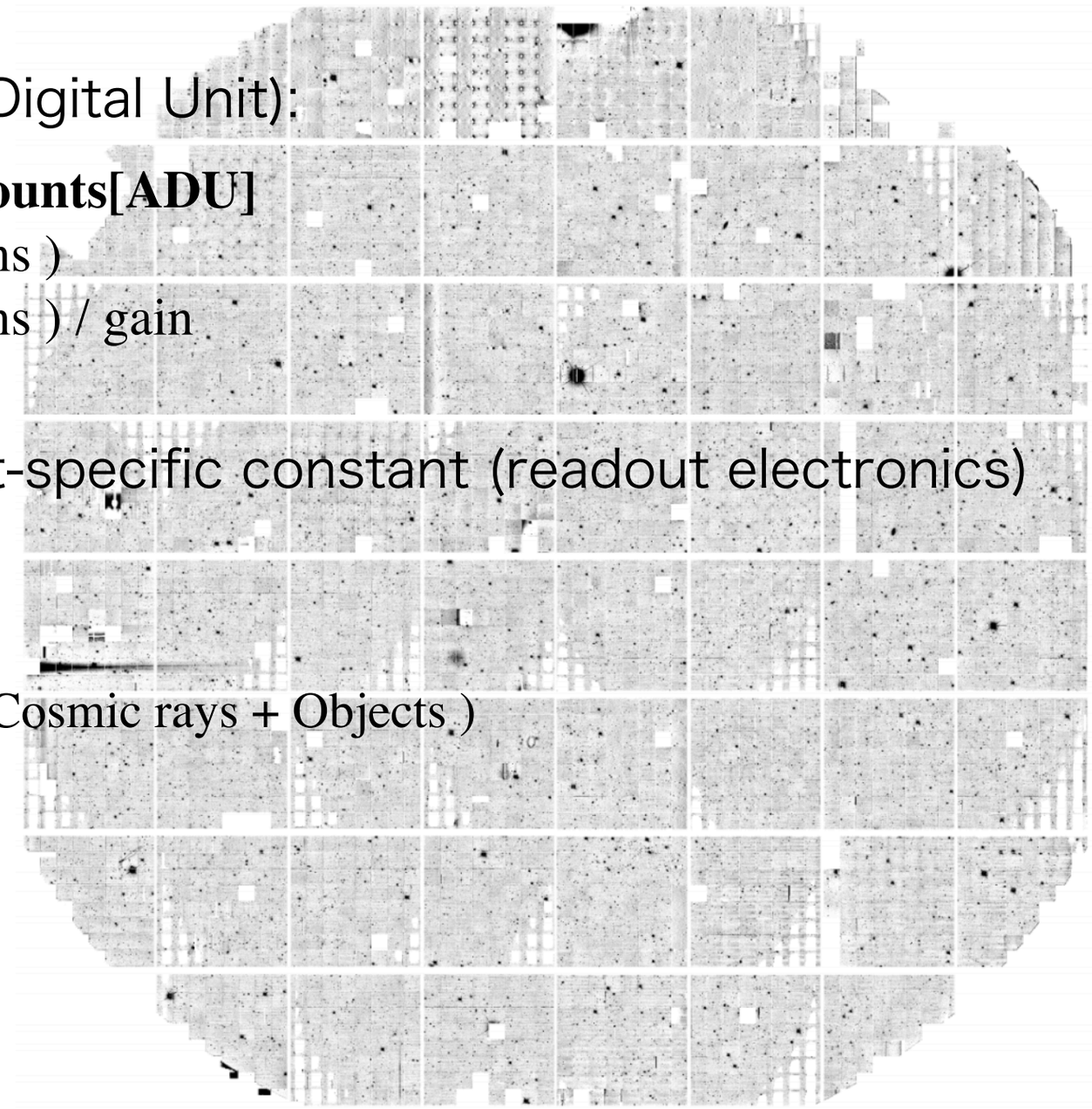
- Pixelカウント

  = (Bias + ~~Dark current~~ + Sky background + Cosmic rays + Objects)
  × Sensitivity variation + random noise

  1次処理後,

  Pixelカウント = Objects + random noise

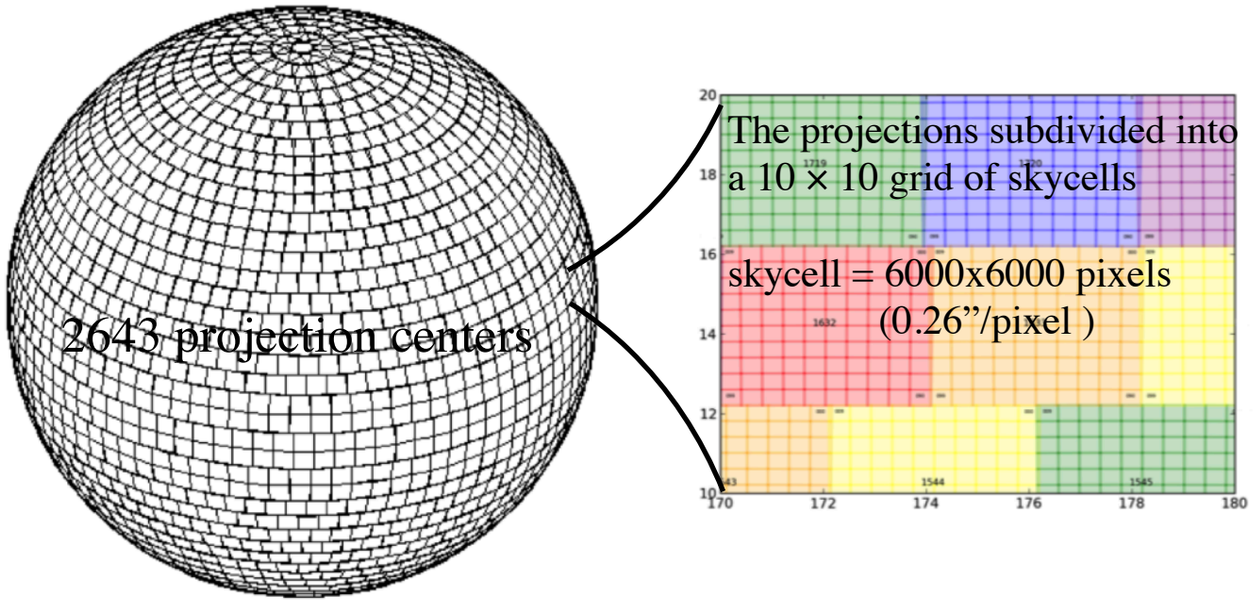
- 等級ゼロ点較正, WCS座標較正など.



PanSTARRS1 60 CCDs; Waters+2016

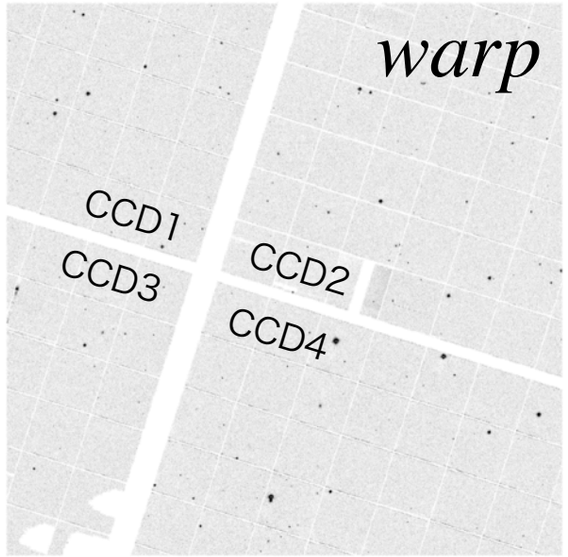
https://www.naoj.org/Observing/DataReduction/mtk/autumn10/calibT1.pdf

Resampled *warp* と *stack* images

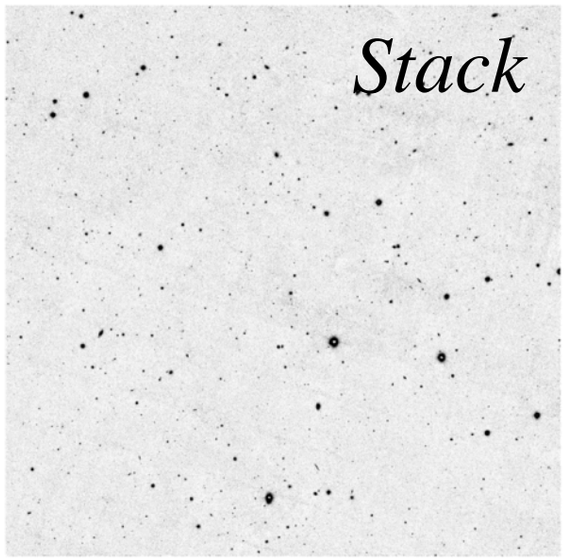


PanSTARRS 3π RINGS.V3 tessellations; Chambers+2016

Waters+2016



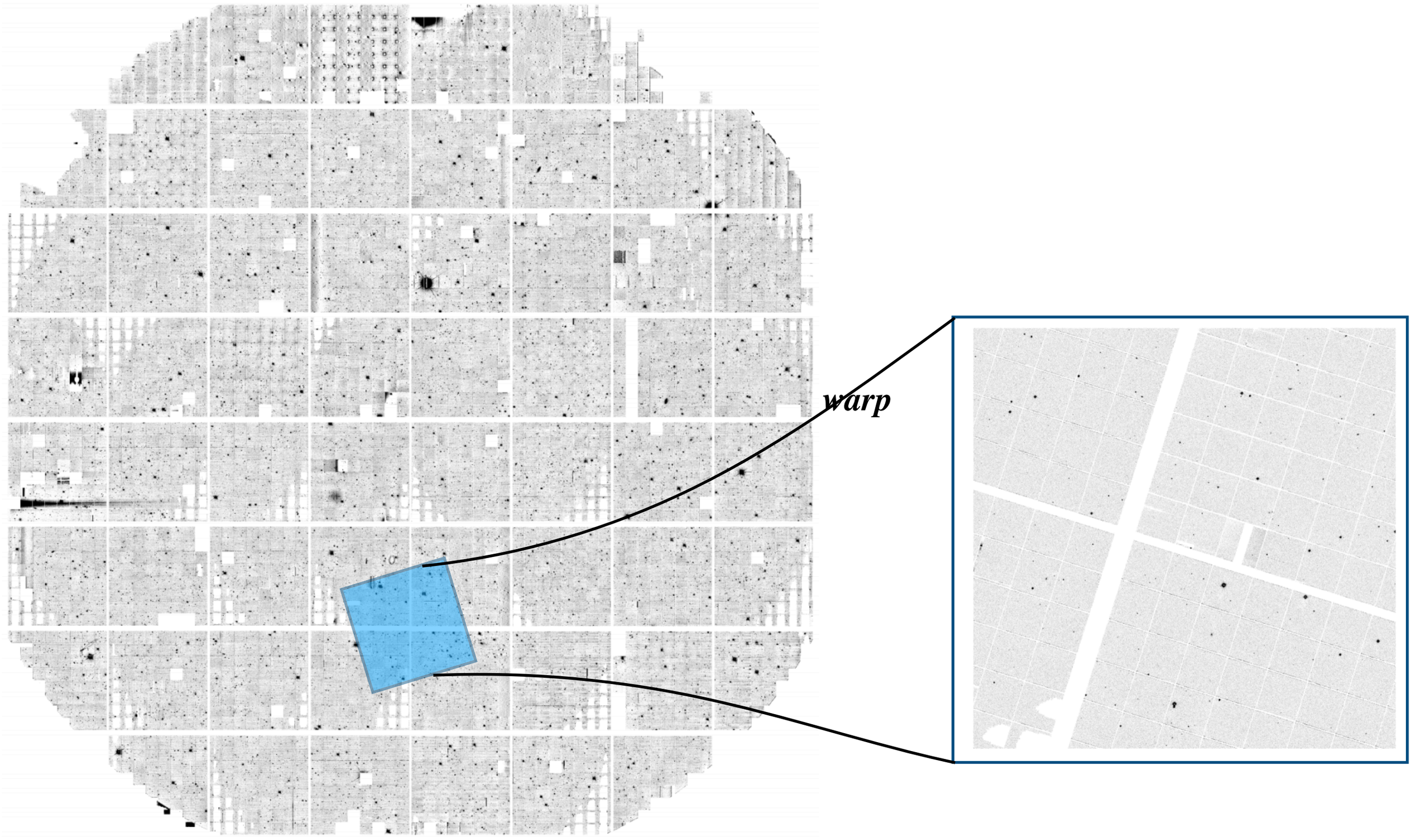
複数枚



- **1次処理**した画像を, 天球面を平面に分割した **pre-definedセル**上に投影する.
  - 画像の回転, ピクセルresamplingが必要 … ***warp***

    (画像のpixelサイズはあまり変えないようにする; PanSTARRSでは ~0.26”/pix —> 0.25”/pix)
- 複数の**single-epoch *warp*画像**を足して(***stack***)して, 隙間のないdeepなモザイク画像をつくる

よく使われるsoftwareとして***SWarp***がある; Bertin 2010



PanSTARRS1 60 CCDs; Waters+2016

分散

Variance map

- 自分でstack画像の測光を行う場合, 測光値のエラーを正しく推定するのは結構難しい.

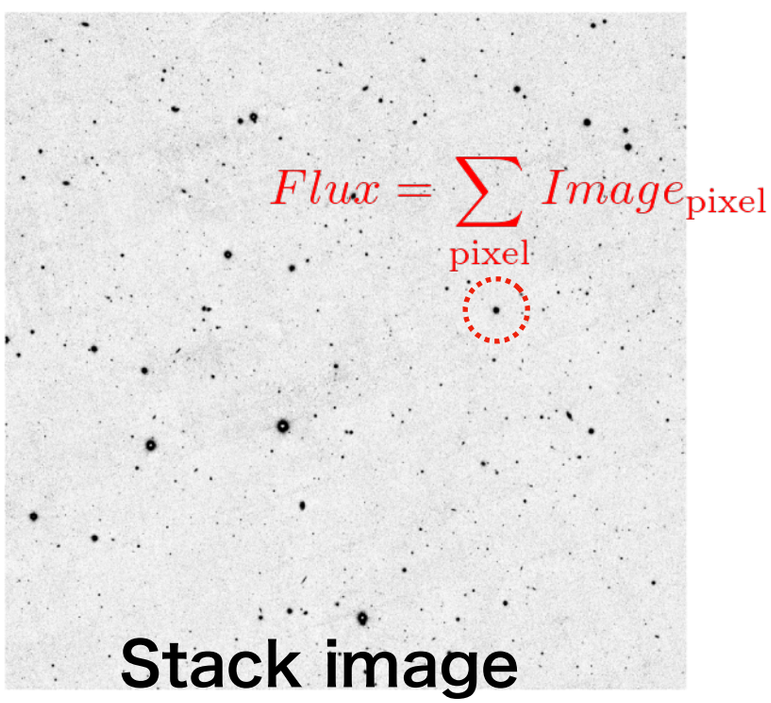
  $\sigma_{\rm sky}$ = Sky光 Poisson (+ readout) noise

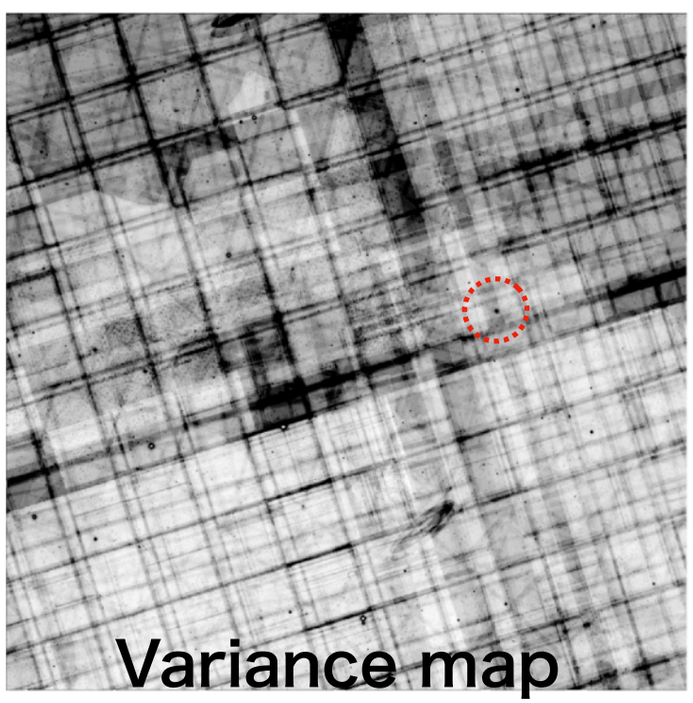
  $\sigma_{\rm obj}$ = Object光 Poisson noise

  Total variance = $(\sigma_{\rm sky})^2 + (\sigma_{\rm obj})^2$

- Stackingの過程で誤差伝播した最終variance [各pixelのGaussian variance σ^2] の画像 = Variance map を提供しているサーベイもある (e.g., PanSTARRS1)

  —> variance mapに対して同じ開口で”測光"して、 sqrt(variance_sum)でエラー評価





$$eFlux(1\sigma) = \sqrt{\sum_{\rm pixel} Variance_{\rm pixel}} = \sqrt{\sum_{\rm pixel} \sigma^2_{\rm pixel}}$$

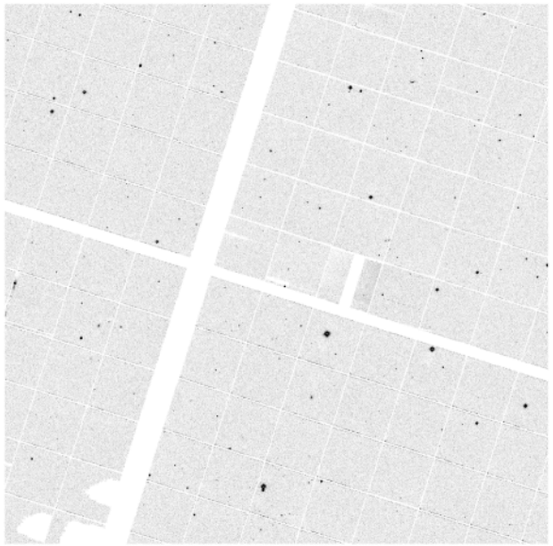
Waters+2016

Mask image

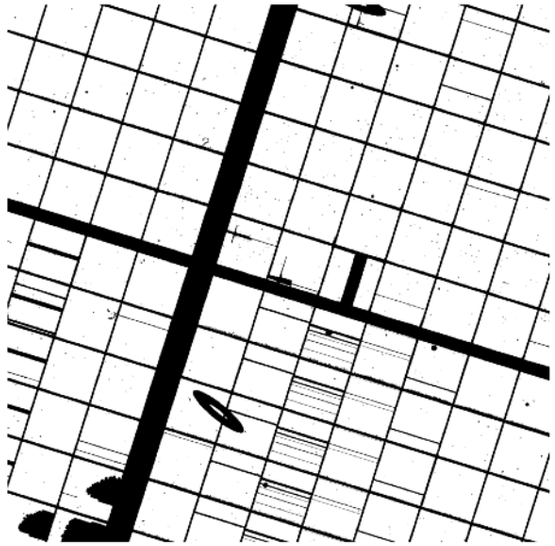
- 飽和した明るい星, 宇宙線, chip gapなどにより使えないpixelの画像 (e.g., good pixel=0, bad pixel=1)

- Stackingすることで, maskされる領域は減る

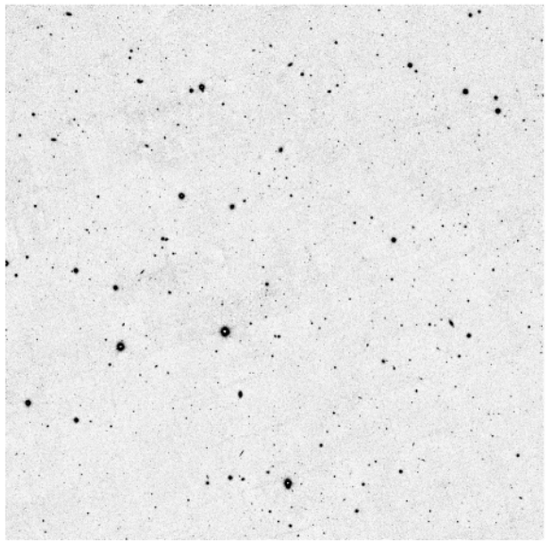
Waters+2016



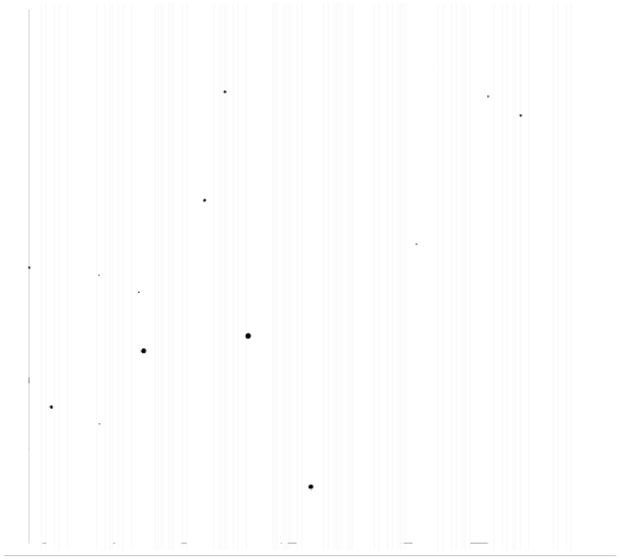
Warp image



Mask image



Stack image



Mask image

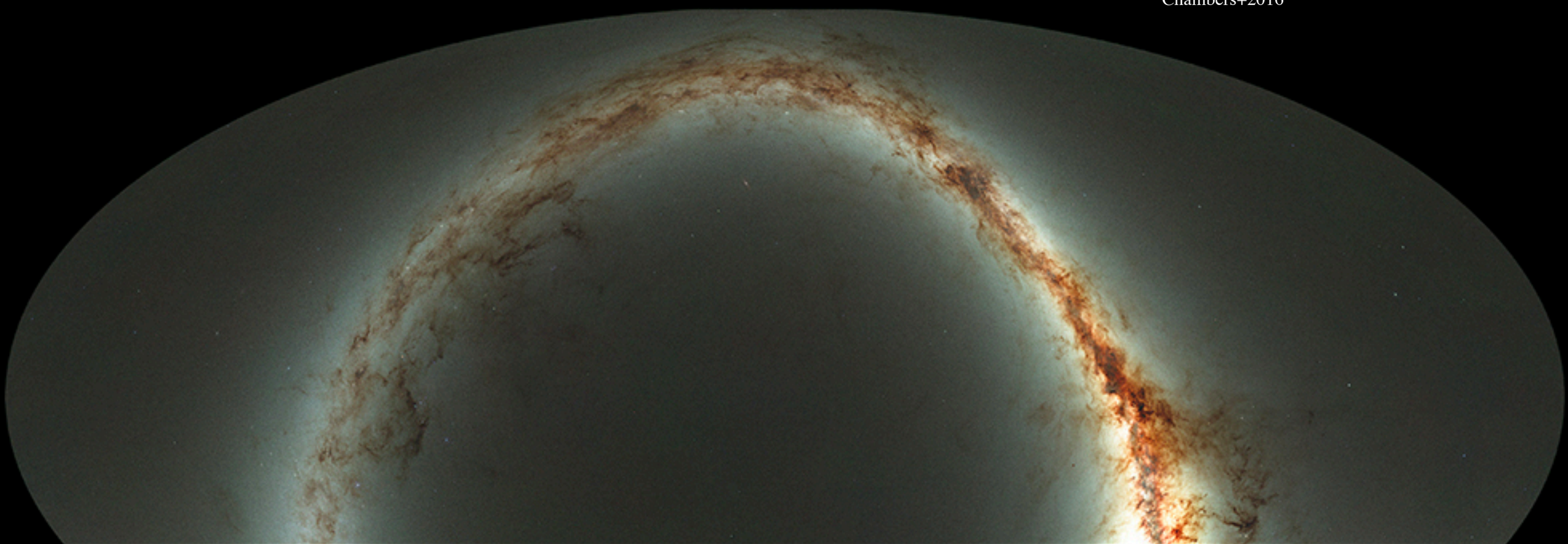
Data Release 2

PanSTARRS1 DR2 public data

- 画像: warp画像, stack画像(+mask画像,variance画像,...)
- 測光カタログ: warp測光, stack測光, warp forced測光

PanSTARRS 3π; g, r, i 3色合成

Chambers+2016



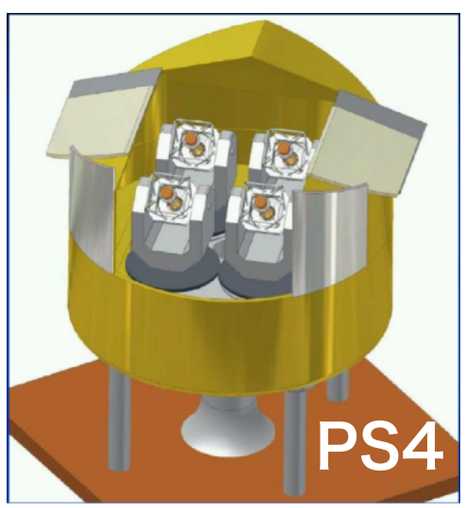
Pan-STARRS

- Panoramatic Survey Telescope and Rapid response System (PanSTARRS; PS)

- もともとの計画は4台の同型の**1.8m口径 telescopes** —> budget problem
  - **PS1** & **PS2** telescopes constructed
  - **Public survey was carried out by the PS1 telescope in 2010-2014**.

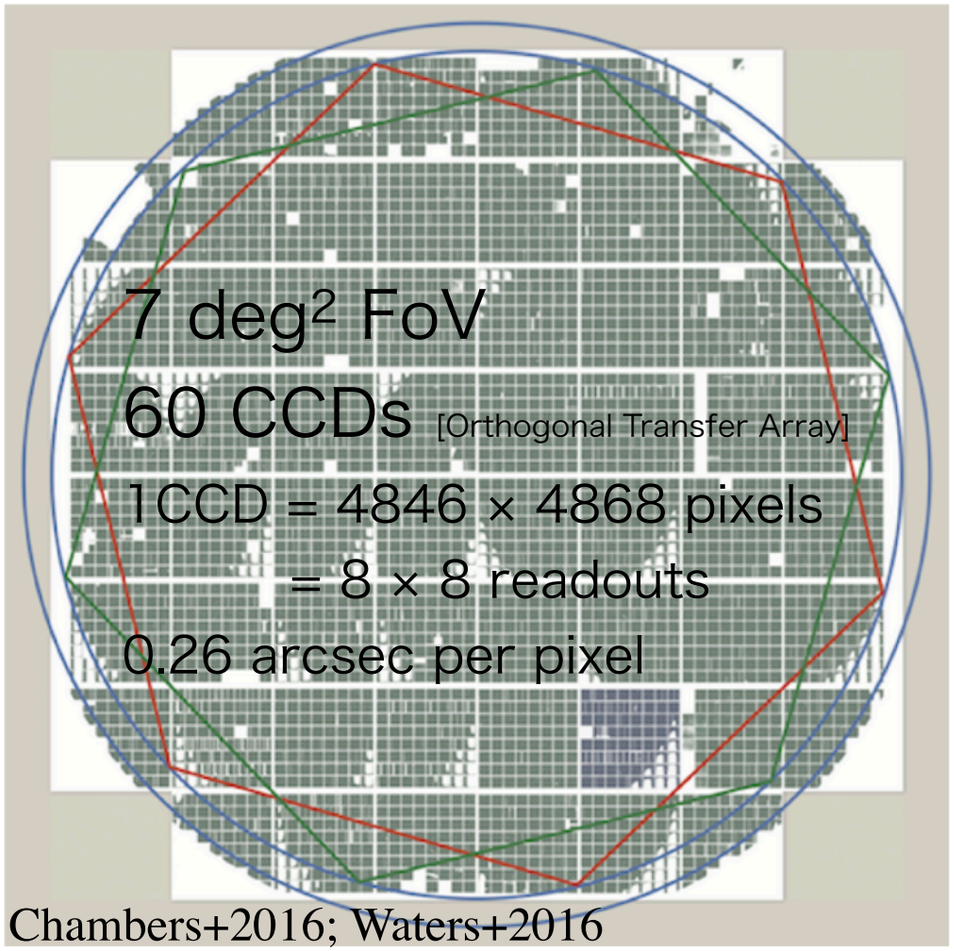
  - Wide-field time-domain surveys (Near Earth Objects, Asteroids, Galactic variables, SNe …)

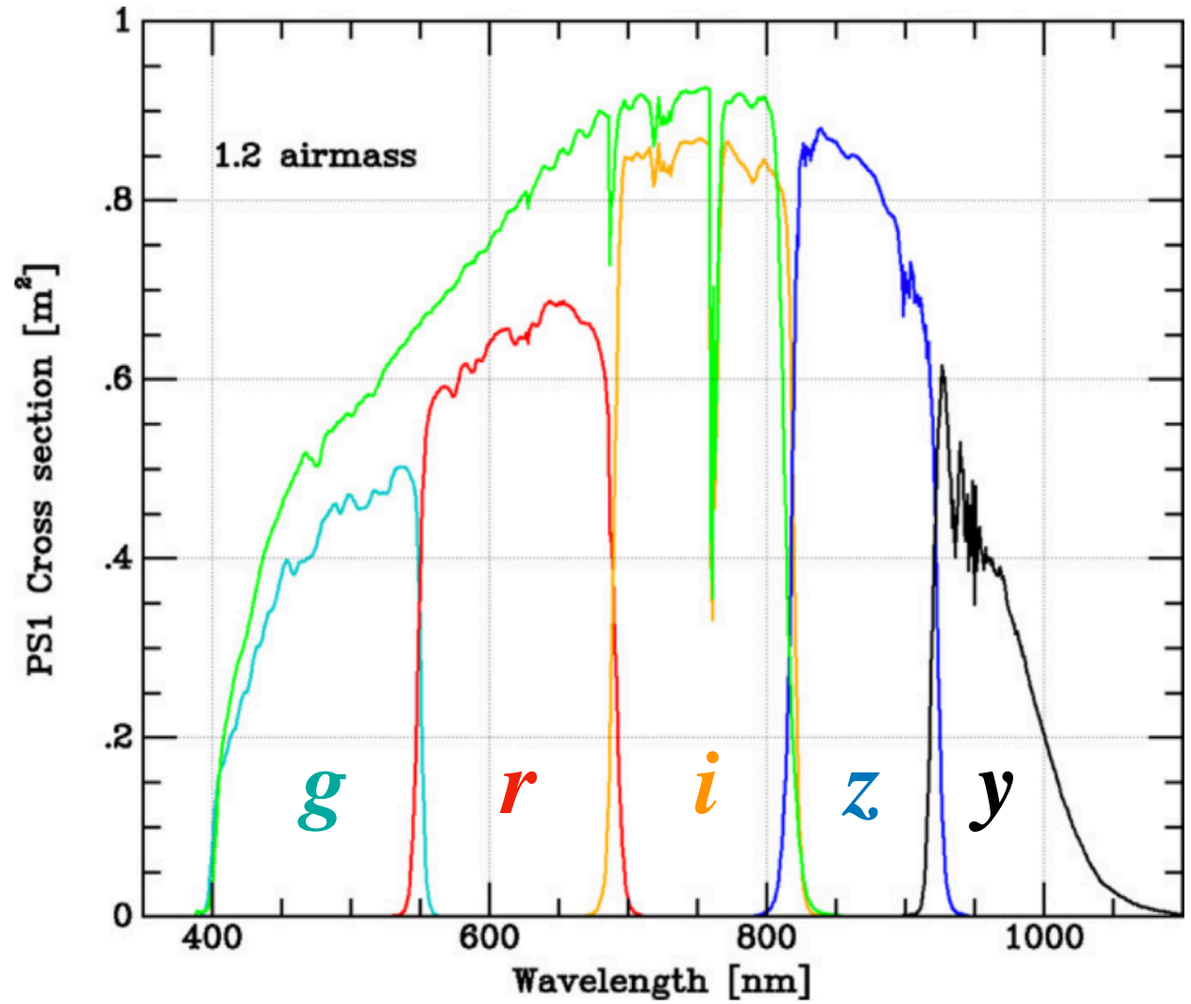
  - Deep stack images for extragalactic studies



"The Pan-STARRS1 Surveys": Chambers+2016: https://arxiv.org/abs/1612.05560

Giga Pixel Camera 1 (GPC1)





- 1.4 Gigapixels (14億ピクセル/1露出) mosaic camera
- 特に長波長側で高感度

https://panstarrs.stsci.edu/attachments/metcalfe_nam2015.pdf

The PS1 Surveys

	Survey	Area (sq.deg.)	Filters	Percent Time	Exposure (secs)
DR2	3 π	30,000	g,r,i,z,y	56	43/40/45/30/30
DR3?	Medium Deep	70	g,r,i,z,y	25	113/113/240/240/240
	Solar System	10,000	w	5	45
	Stellar Transit	40	i	4	15 or 30
	M31	7	r,i	2	60/60

Data collection started early in 2010 and completed in April 2014

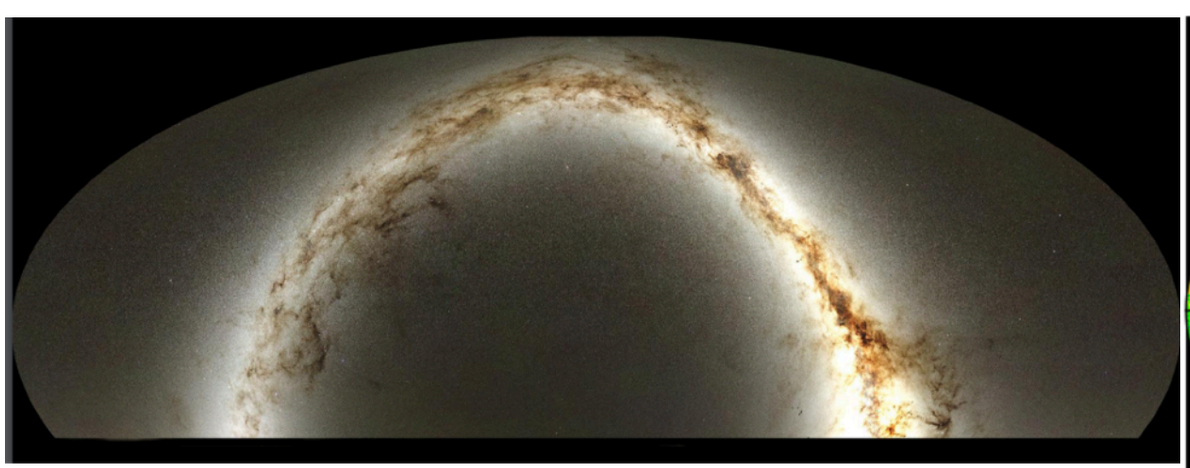
From https://panstarrs.stsci.edu/attachments/metcalfe_nam2015.pdf

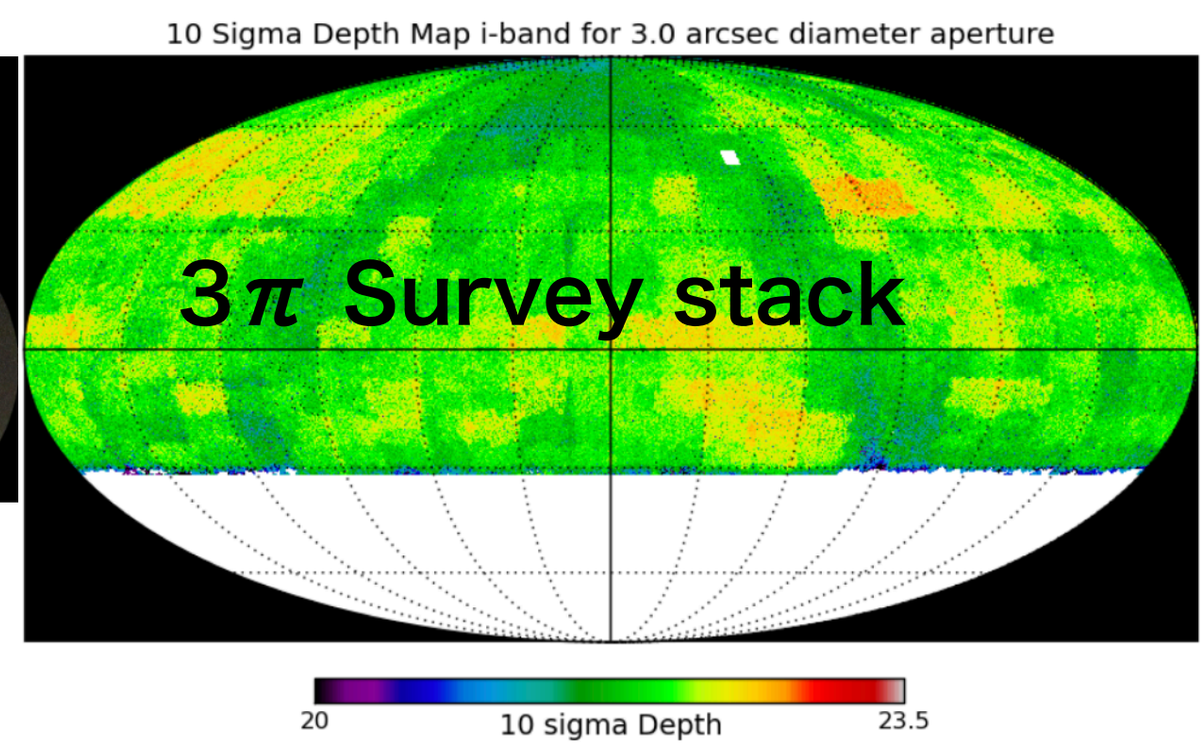
PS1 3π-steradian survey

- 2010 — 2014 (3.5 yrs), ***g, r, i, z, y***-band
- 3π 北天scan (Decl. < –30deg):
  各バンド12 exposures over 3.5 yrs
- **22-23 mag (final stack).** SDSSより~1 – 2等深い
- Excellent seeing (~1 arcsec in median)

Detection limits (AB mag.)

Band	5σ (single)	5σ (stack)	Saturation
g	22.0	23.3	14.5
r	21.8	23.2	15.0
i	21.5	23.1	15.0
z	20.9	22.3	14.0
y	19.7	21.4	13.0



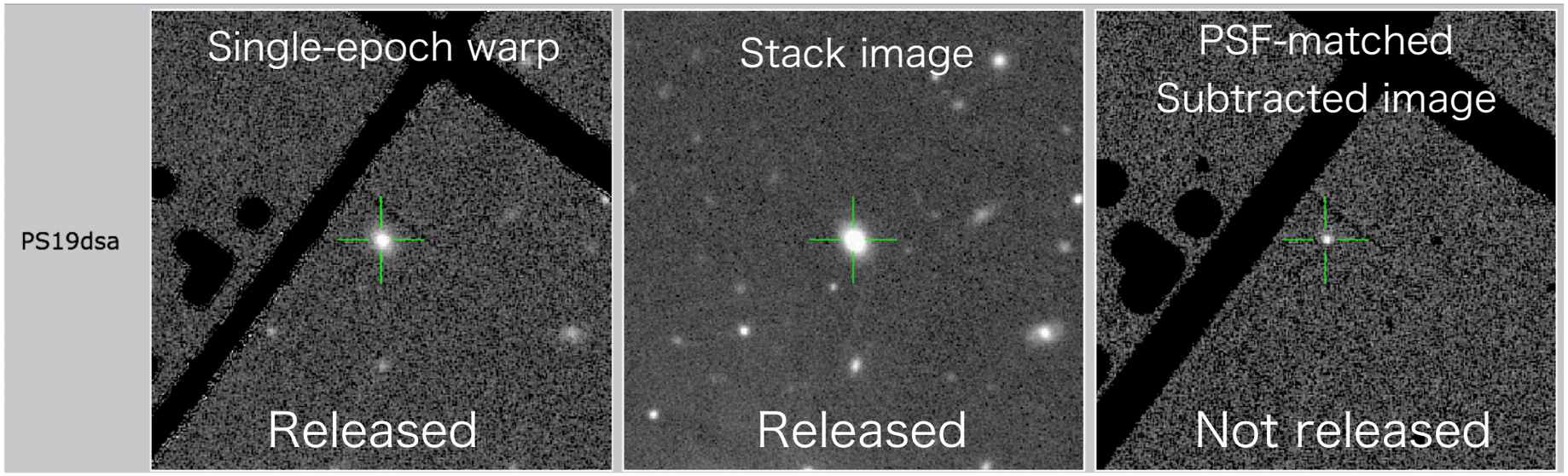


https://panstarrs.stsci.edu/attachments/metcalfe_nam2015.pdf

PS1 Data Release 2 (DR2) data product

- Pipeline(PV3)-reduced data products are available at STScI/MAST:
  - **Single-epoch warp images**
  - **Stack images**
  - たくさんの**photometry catalogs**

- **Not** included in the release (to be released in DR3):
  - Subtracted images and catalogues for transient detections
  - Data from other surveys (Medium Deep survey …)



https://star.pst.qub.ac.uk/ps1threepi/psdb/

アクロニム : Space Telescope Science Institute (STScI) , the Mikulski Archive for Space Telescopes (MAST)

Image Processing Pipeline stages and data products

processing stage	image class	file type	ID type	Avg No. components per ID	No. filters per ID	No. IDs in 3π Survey	location	Release
raw	raw image	fits	exp	60.0000	1	374k	UH[a]	···
chip	signal image	fits	exp	59.9984	1	374k	··· [b]	···
	variance image	fits	exp	59.9984	1	374k	···	···
	mask image	fits	exp	59.9984	1	374k	···	···
	detections	cmf	exp	59.9984	1	374k	both[c]	···
camera	detection table	smf	exp	1	1	374k	both	···
warp	signal image	fits	skycell	72.6060	1	1050k	MAST	DR2
	variance image	fits	skycell	72.6060	1	1050k	MAST	DR2
	mask image	fits	skycell	72.6060	1	1050k	MAST	DR2
	detections	cmf	skycell	72.6060	1	1050k	both	···
stack	signal image	fits	skycell	1	1	1050k	both	DR1
	variance image	fits	skycell	1	1	1050k	both	DR1
	mask image	fits	skycell	1	1	1050k	both	DR1
	number image	fits	skycell	1	1	1050k	both	DR1
	exp image	fits	skycell	1	1	1050k	both	DR1
	expwt image	fits	skycell	1	1	1050k	both	DR1
	convolved 6&8 signal	fits	skycell	1	1	1050k	···	···
	convolved 6&8 variance	fits	skycell	1	1	1050k	···	···
	convolved 6&8 mask	fits	skycell	1	1	1050k	···	···
	convolved 6&8 number	fits	skycell	1	1	1050k	···	···
	convolved 6&8 exp	fits	skycell	1	1	1050k	···	···
	convolved 6&8 expwt	fits	skycell	1	1	1050k	···	···
	detections	cmf	skycell	1	1	1050k	both	···
static sky	detections	cmf	skycell	1	5	201k	both	···
sky cal	detections	cmf	skycell	1	1	1050k	both	···
forced	detections	cmf	forced	19.1184	1	19m	both	···
diff	signal image	fits	skycell	51.6105	1	19m	···	···
	variance image	fits	skycell	51.6105	1	19m	···	···
	mask image	fits	skycell	51.6105	1	19m	···	···
	diff detections	cmf	skycell	51.6105	1	19m	both	DR2

Chambers+2016

Fundamental PSPS database tables

Table Class	PSPS Table Name	Release
Detection	Detection	DR2
Object	ObjectThin	DR1
	MeanObject	DR1
	GaiaFrameCoordinate	DR1
Stack	StackObjectThin	DR1
	StackObjectAttributes	DR1
	StackApFlx	DR1
	StackApFlxExGalUnc	DR1
	StackApFlxExGalCon6	DR1
	StackApFlxExGalCon8	DR1
	StackPetrosian	DR1
	StackModelFitExp	DR1
	StackModelFitDeV	DR1
	StackModelFitSer	DR1
Difference	DiffDetection	DR2
	DiffDetObject	DR2
Forced	ForcedMeanObject	DR1
	ForcedWarpMeasurement	DR2
	ForcedMeanLensing	DR2
	ForcedWarpLensing	DR2
	ForcedGalaxyShape	DR2
	ForcedWarpExtended	DR2
	ForcedWarpMasked	DR2

3π Steradian Survey Photometry Scope

Measurement	Scope
PSFMag	All objects
ApMag	All objects
KronMag	All objects
Fixed apertures R5-R7	All objects
Fixed apertures R3-R4, R8-R11	Objects outside Galactic plane
Petrosian	Objects outside Galactic plane with S/N> 20
Sersic	Objects outside Galactic plane with S/N> 20
Exponential	Objects outside Galactic plane with S/N> 20
de Vaucouleurs	Objects outside Galactic plane with S/N> 20

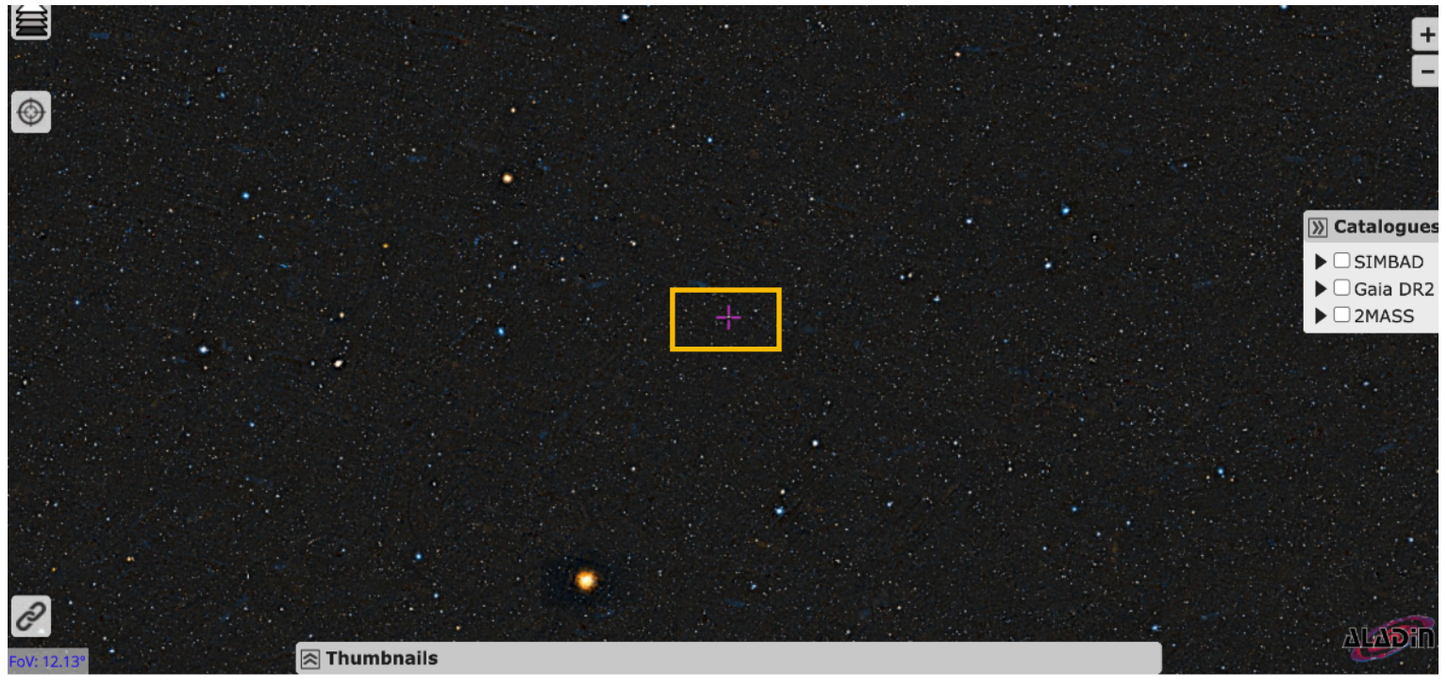
Chambers+2016

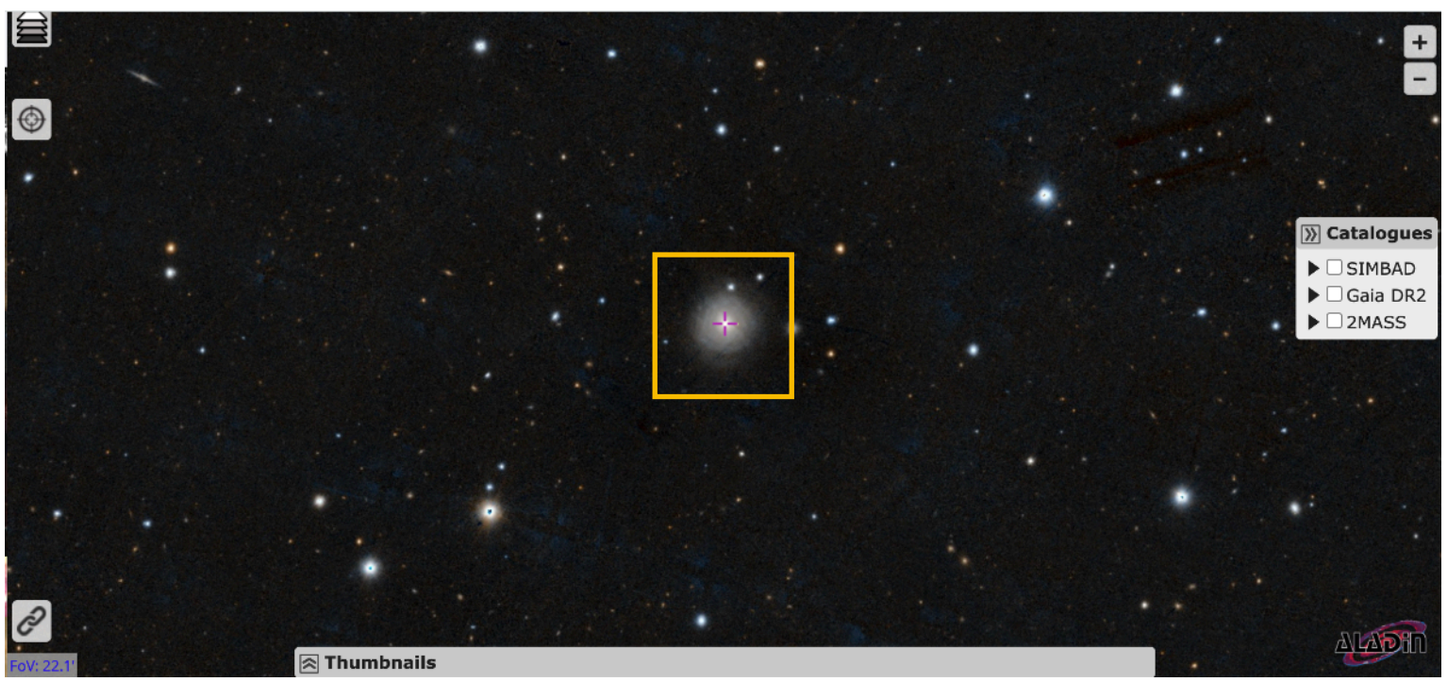
TABLE 9
CURRENTLY DEFINED VIEWS WITHIN PSPS

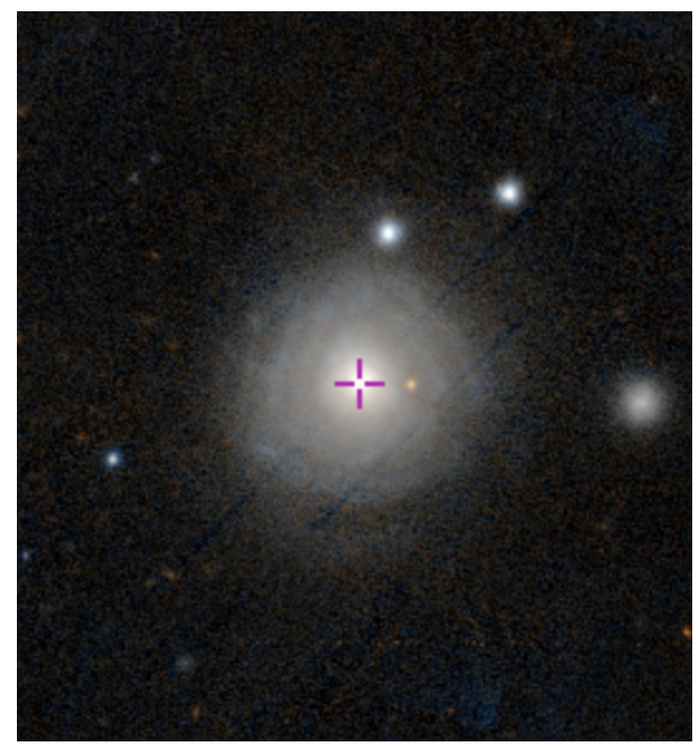
View Name	Tables used to create view
DetectionObjectView	ObjectThin, MeanObject, Detection
MeanObjectView	ObjectThin, MeanObject
StackObjectView	ObjectThin, StackObjectThin, StackObjectAttributes
StackApFlxObjectView	ObjectThin, StackApFlx
StackApFlxExGalUncObjectView	ObjectThin, StackApFlxExGalUnc
StackApFlxExGalCon6ObjectView	ObjectThin, StackApFlxExGalCon6
StackApFlxExGalCon8ObjectView	ObjectThin, StackApFlxExGalCon8
StackModelObjectView	ObjectThin, StackModelFitExp, StackModelFitDeV, StackModelFitSer, StackPetrosian
StackModelFitExpObjectView	ObjectThin, StackModelFitExp
StackModelFitDeVObjectView	ObjectThin, StackModelFitDeV
StackModelFitSerObjectView	ObjectThin, StackModelFitSer
StackModelFitPetObjectView	ObjectThin, StackPetrosian
StackObjectPrimaryView	ObjectThin,StackObjectThin,StackObjectAttributes,StackApFlx
DiffDetObjectView	DiffDetObject,DiffDetection
ForcedDetObjectView	ObjectThin,ForcedWarpMeasurement
ForcedMeanObjectView	ObjectThin,ForcedMeanObject
ForcedGalaxyModelView	ObjectThin,ForcedGalaxyShape

Flewelling+2016

Sky Viewer (AladinLite)



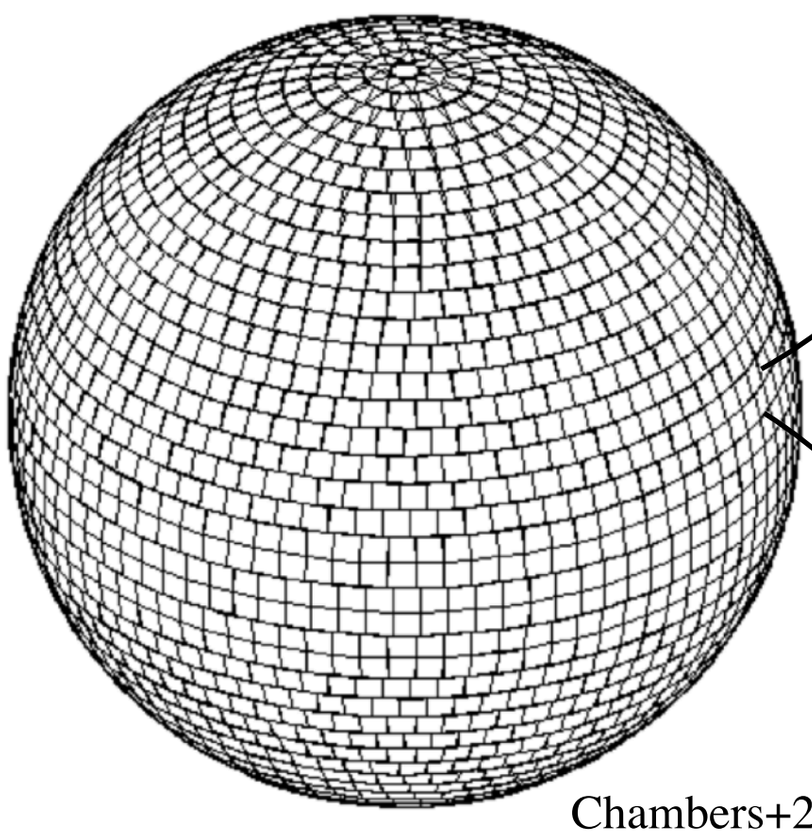




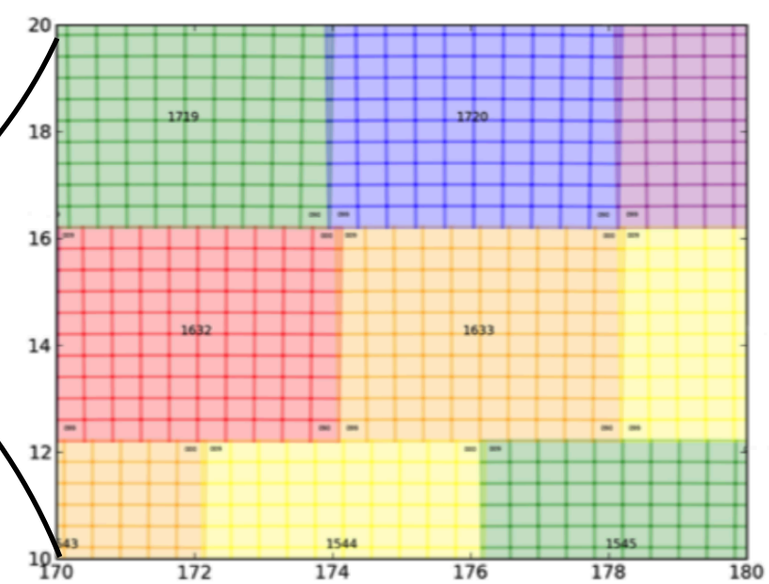
https://aladin.u-strasbg.fr/AladinLite/

Skycells in RINGS.V3 tessellations

- **skycell :** PanSTARRS1 imageの最小解析単位
  - PanSTARRS1の*warp* 投影座標の定義.
  - 全天 = 2643個のprojection cell, each projection cell = 10 ×10 **skycells**
  - **skycell** = 25’ × 25’ (6000 × 6000 pixel)



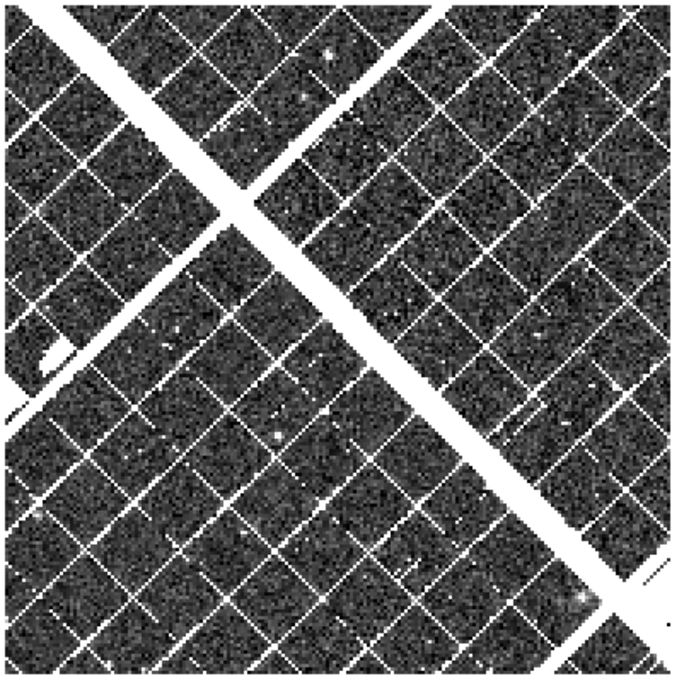
Chambers+2016



200900 skycells at Dec > −31.81

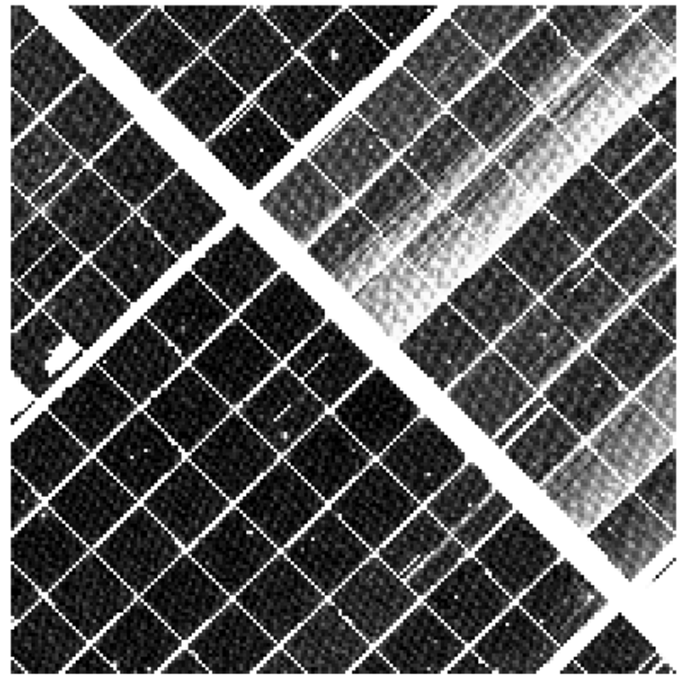
Data product: skycell images

skycell.1240.080 (6000 × 6000 pixels = 25’ × 25’)

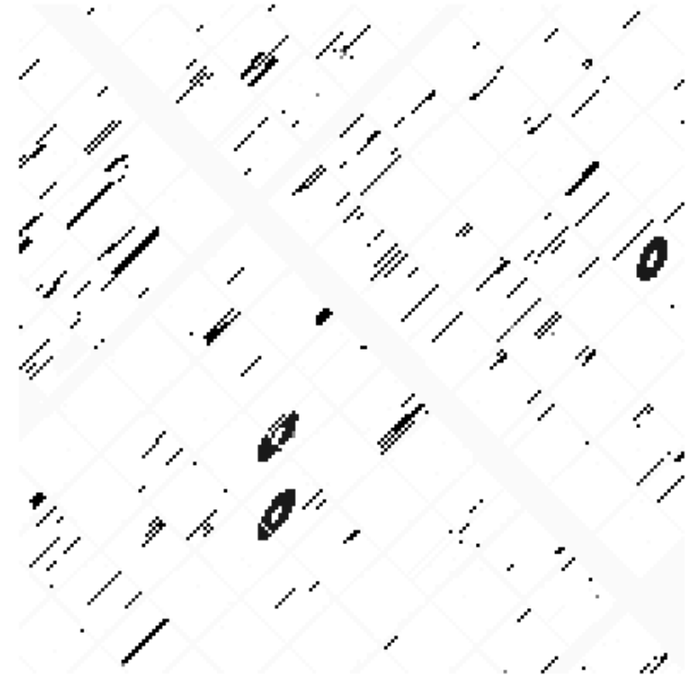


Warp (single-epoch; 43sec)

(大きい隙間はCCD gap,
細かい四角はreadout gap)



Warp variance map (wt)



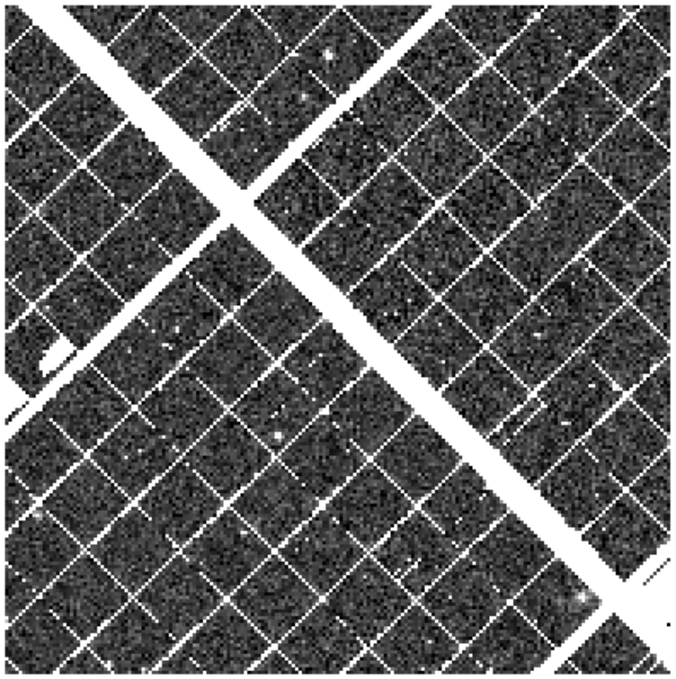
Warp mask

https://ps1images.stsci.edu/cgi-bin/fitscut.cgiで取得 (後述)

Warp	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.fits
Warp.wt	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.wt.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.wt.fits
Warp.mask	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.mask.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.mask.fits

Data product: skycell images

skycell.1240.080 (6000 × 6000 pixels = 25’ × 25’)



Warp (single-epoch; 43sec)

(大きい隙間はCCD gap,
細かい四角はreadout gap)

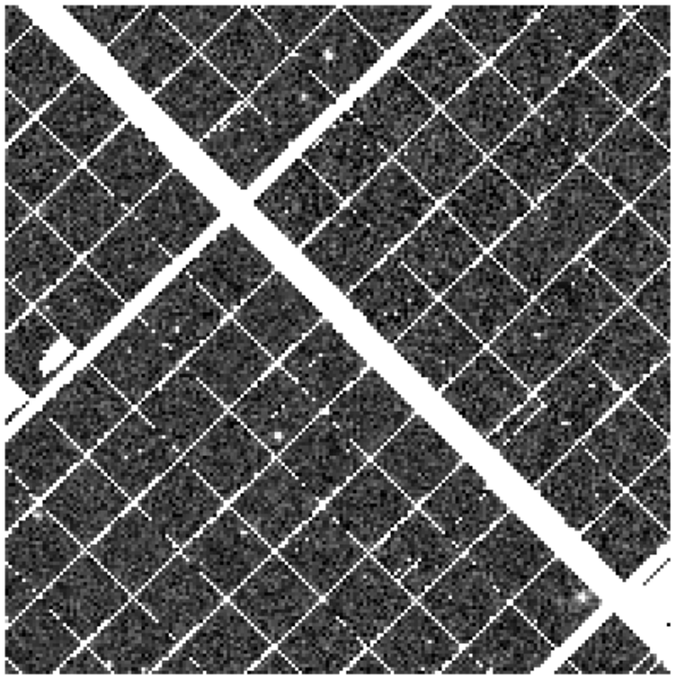
<— CCD gap以外に
OTA (Orthogonal Transfer Array)のreadoutによる
隙間が多くある. warpの開口測光は難しい(profile fitに頼る)

https://ps1images.stsci.edu/cgi-bin/fitscut.cgiで取得 (後述)

Warp	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.fits
Warp.wt	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.wt.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.wt.fits
Warp.mask	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.mask.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.mask.fits

Data product: skycell images

skycell.1240.080 (6000 × 6000 pixels = 25’ × 25’)



Warp (single-epoch; 43sec)

(大きい隙間はCCD gap,
細かい四角はreadout gap)

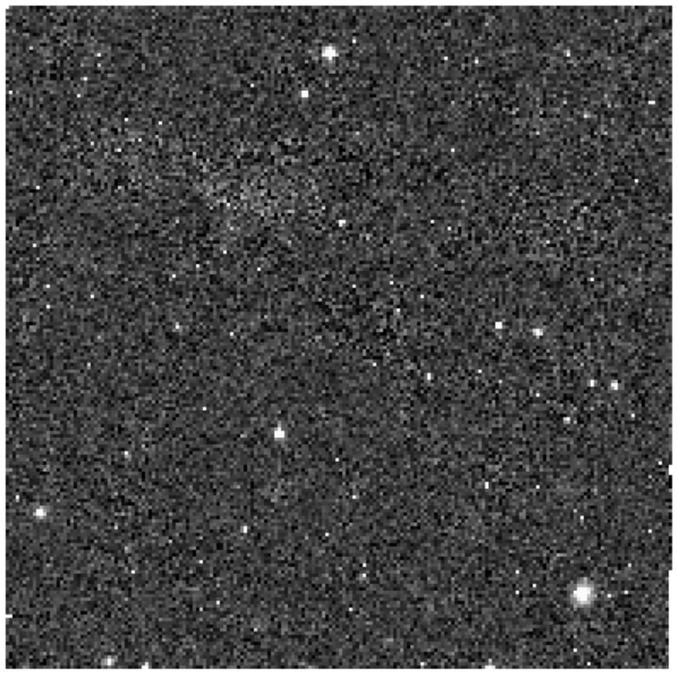
```
python
from astropy.io import fits

hdu = fits.open("cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.fits")

print( "GAIN,SEEING,MAG_ZP,EXPTIME", hdu[0].header['HIERARCH CELL.GAIN'],
hdu[0].header['HIERARCH CHIP.SEEING']
, hdu[0].header['HIERARCH FPA.ZP']
, hdu[0].header['EXPTIME'])


('GAIN,SEEING,MAG_ZP,EXPTIME', 0.9995898, 5.494817, 24.49128, 43.0)
```

https://ps1images.stsci.edu/cgi-bin/fitscut.cgiで取得 (後述)

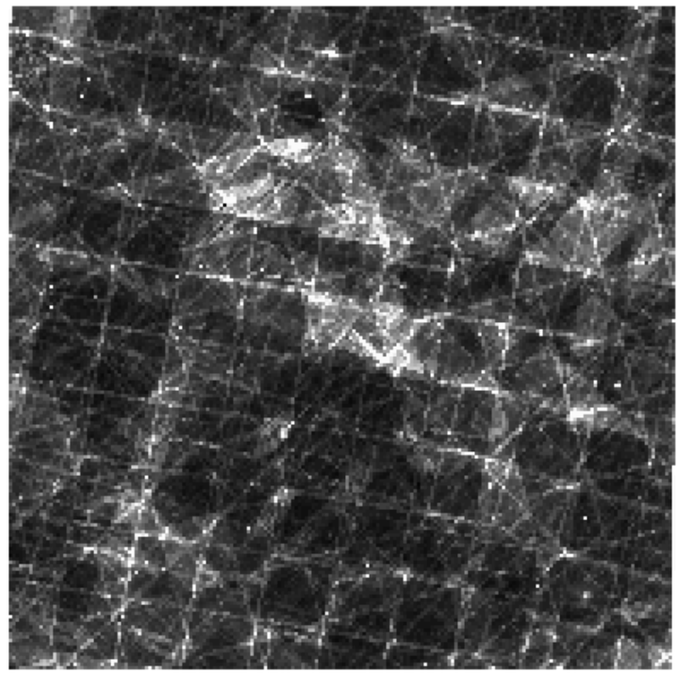
Warp	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.fits
Warp.wt	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.wt.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.wt.fits
Warp.mask	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.wrp.g.55479_49916.mask.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.wrp.g.55479_49916.mask.fits

Data product: skycell images

skycell.1240.080 (6000 × 6000 pixels = 25’ × 25’)



Stack(~400sec)



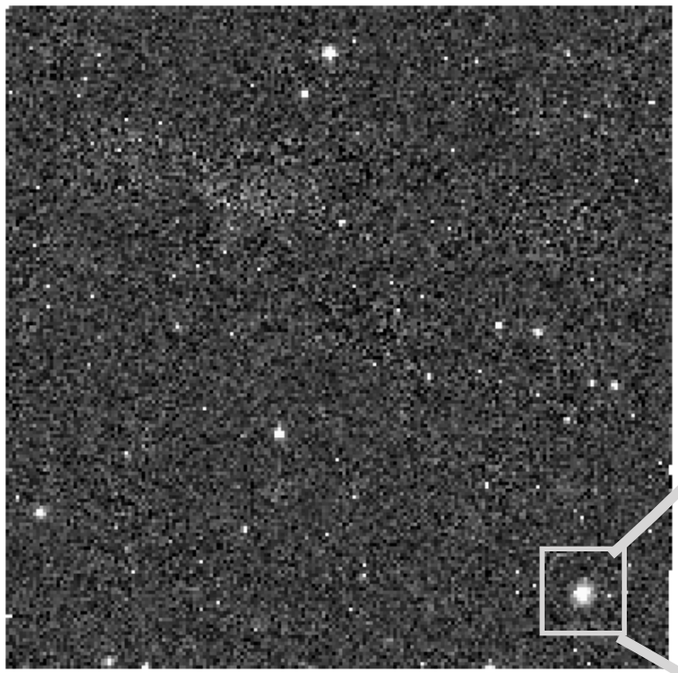
Stack variance map (wt)

Stack mask

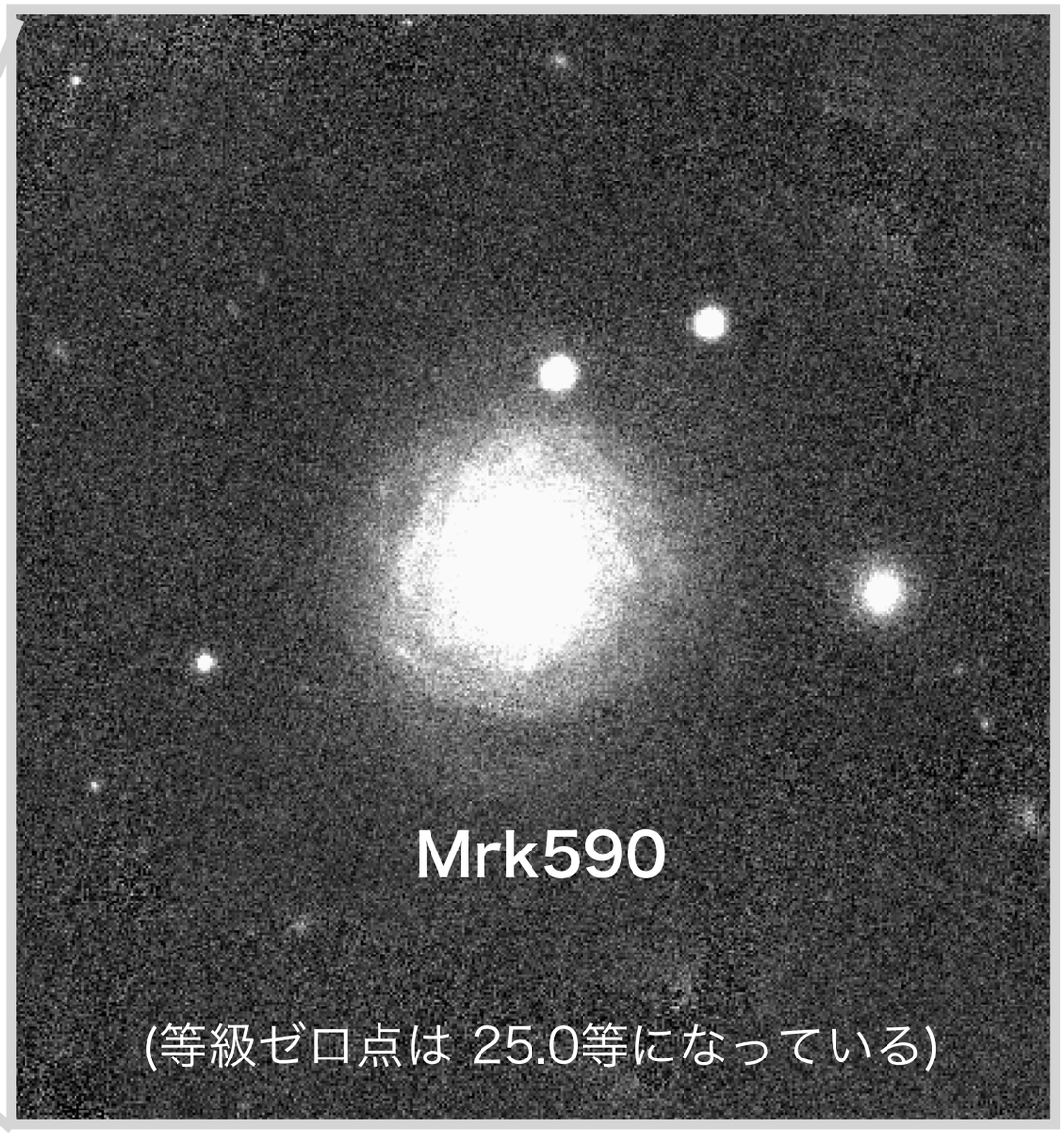
https://ps1images.stsci.edu/cgi-bin/fitscut.cgiで取得 (後述)

Stack	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.stk.g.unconv.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.stk.g.unconv.fits
Stack.wt	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.stk.g.unconv.wt.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.stk.g.unconv.wt.fits
Stack.mask	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.stk.g.unconv.mask.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.stk.g.unconv.mask.fits

Data product: skycell images



Stack(~400sec)

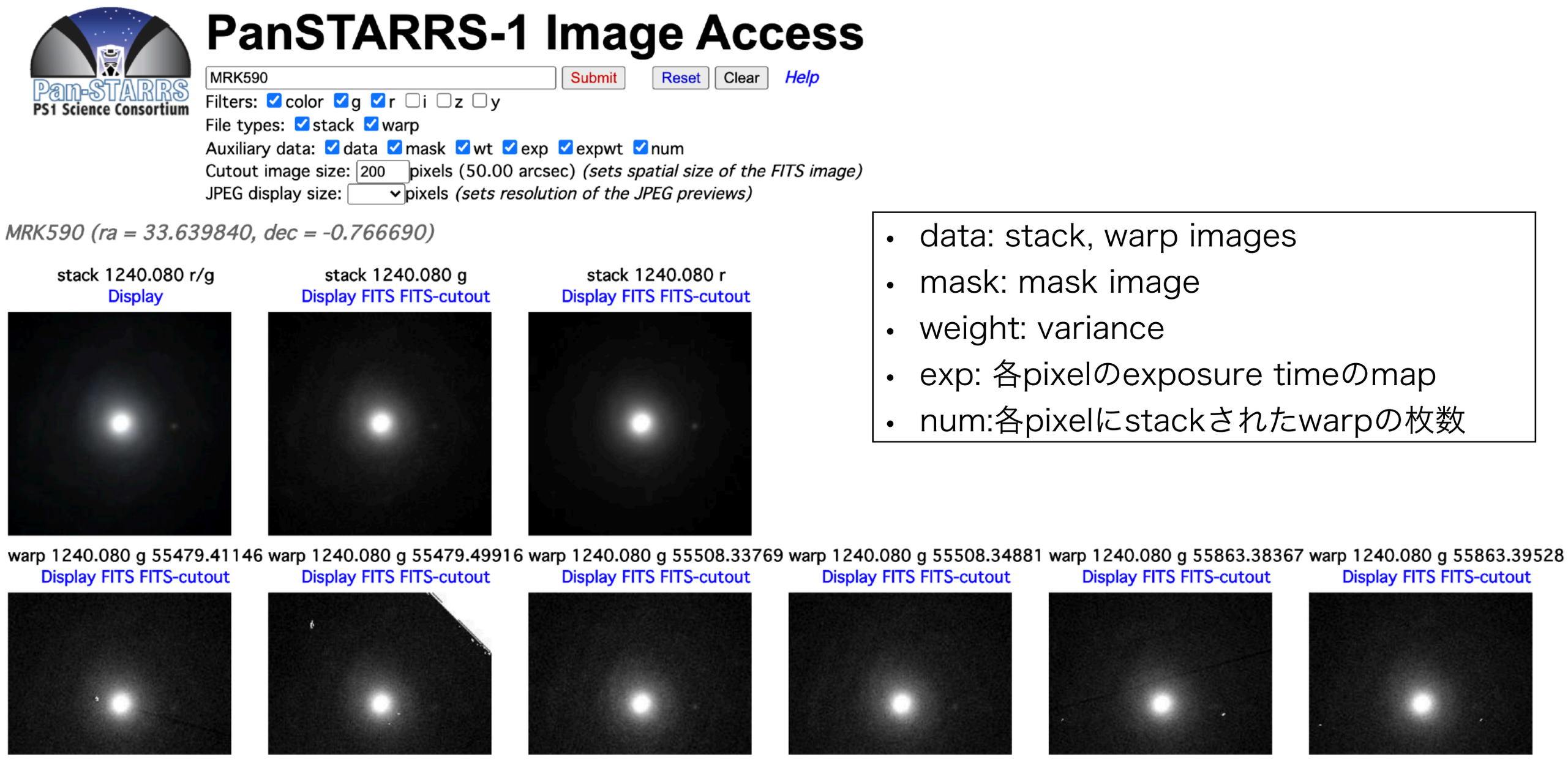


https://ps1images.stsci.edu/cgi-bin/fitscut.cgiで取得 (後述)

Stack	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.stk.g.unconv.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.stk.g.unconv.fits
Stack.wt	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.stk.g.unconv.wt.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.stk.g.unconv.wt.fits
Stack.mask	https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?red=/rings.v3.skycell/1240/080/rings.v3.skycell.1240.080.stk.g.unconv.mask.fits&format=fits&x=33.639840&y=-0.766690&size=18000&wcs=1&imagename=cutout_rings.v3.skycell.1240.080.stk.g.unconv.mask.fits

Data product: skycell images

- Web interface (PanSTARRS-1 Image Access)で視覚的にcheck & downloadできる



- data: stack, warp images
- mask: mask image
- weight: variance
- exp: 各pixelのexposure timeのmap
- num:各pixelにstackされたwarpの枚数

https://ps1images.stsci.edu/cgi-bin/ps1cutouts

詳細, 注意点(必読) —> https://outerspace.stsci.edu/display/PANSTARRS/PS1+Image+Cutout+Service

Data product: Photometry Catalogues

主なカタログを理解するための用語:

- Warp imageでの検出 (**Detections**)
  —> 1秒角以内のDetectionsを **Object** としてグループ化
  —> 各Objectsの複数epochの平均値 (**MeanObject**)

- Stack画像上の**Object** (**StackObject**)
  … 暗い天体まで検出できるが, stackingによる系統誤差(PSFの形).

- Stack画像上の**Object**の検出位置・形状パラメータをinputとして、warp画像上で**ForcedWarp**測光
  … warp画像単体では検出できていない暗い天体の測光値を得る

- 上記**ForcedWarp**測光の平均値をとったもの (**ForcedMean**)
  … StackObjectsよりも系統誤差の少ない高精度測光ができる

測光テーブル

Table Class	PSPS Table Name	Release
Detection	Detection	DR2
Object	ObjectThin	DR1
	MeanObject	DR1
	GaiaFrameCoordinate	DR1
Stack	StackObjectThin	DR1
	StackObjectAttributes	DR1
	StackApFlx	DR1
	StackApFlxExGalUnc	DR1
	StackApFlxExGalCon6	DR1
	StackApFlxExGalCon8	DR1
	StackPetrosian	DR1
	StackModelFitExp	DR1
	StackModelFitDeV	DR1
	StackModelFitSer	DR1
Forced	ForcedMeanObject	DR1
	ForcedWarpMeasurement	DR2
	ForcedMeanLensing	DR2
	ForcedWarpLensing	DR2
	ForcedGalaxyShape	DR2
	ForcedWarpExtended	DR2
	ForcedWarpMasked	DR2

Chambers+2016, Flewelling+2016

https://catalogs.mast.stsci.edu/panstarrs/

https://outerspace.stsci.edu/display/PANSTARRS/PS1+Source+extraction+and+catalogs

g-i vs. i

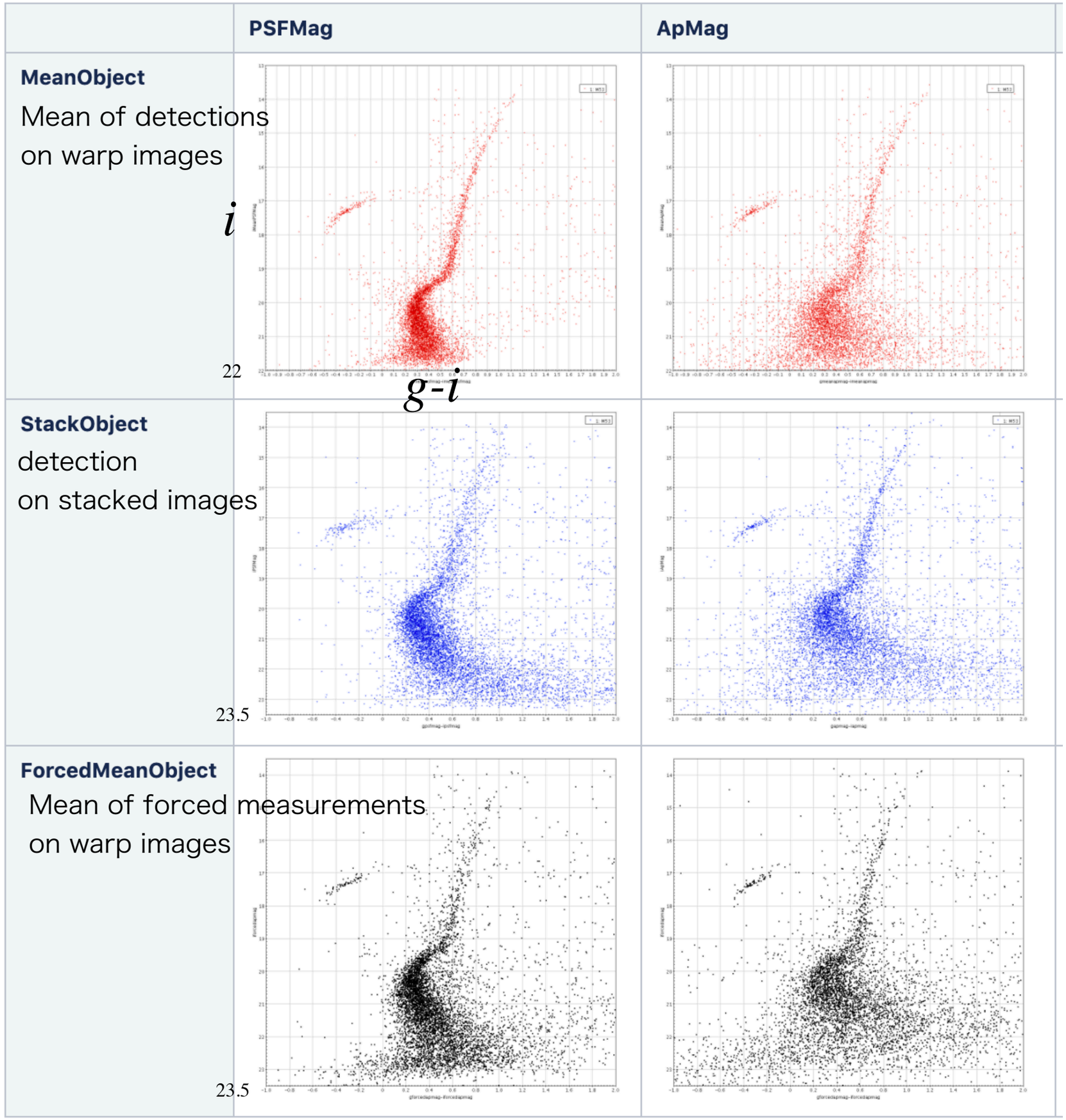
color-magnitude for stars in Messier 53

- **MeanObject** カタログは single exposureの深さまでしか行かないが、測定としてはscatterが一番小さい (系統誤差が最小)

- **StackObject** (stack画像で検出・測光) は MeanObject よりscatterが大きいが、深い撮像 (stack 画像のcomplex PSF shapeによる系統誤差)

- **ForcedMeanObject** は深く, scatterも比較的小さい

明るめの天体はMeanObject, 暗めの天体はForcedMeanObjectを使う.

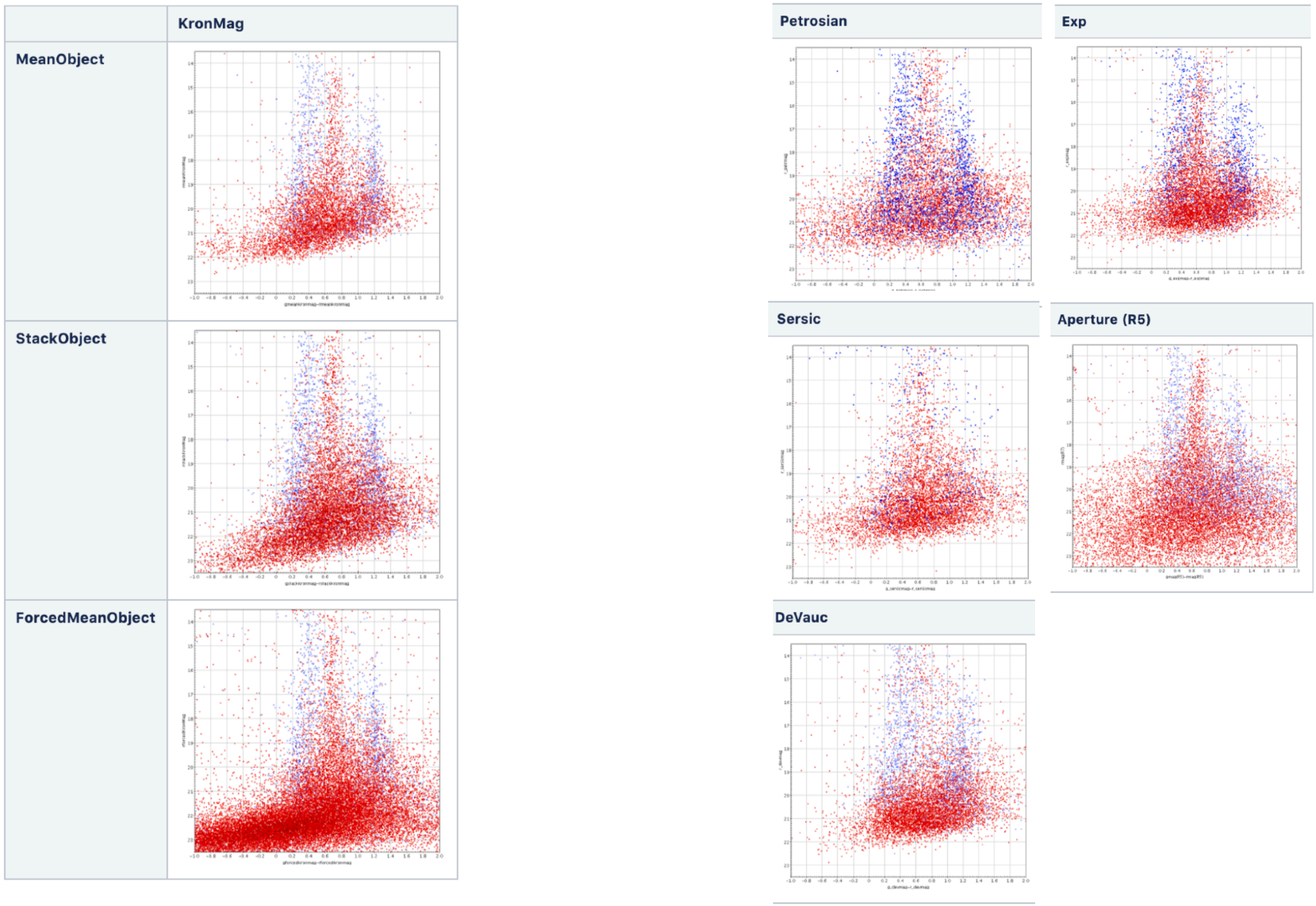


星, 銀河の測光値の比較は —> https://outerspace.stsci.edu/display/PANSTARRS/PS1+Comparison+of+different+photometric+measures

Galaxy magnitudes

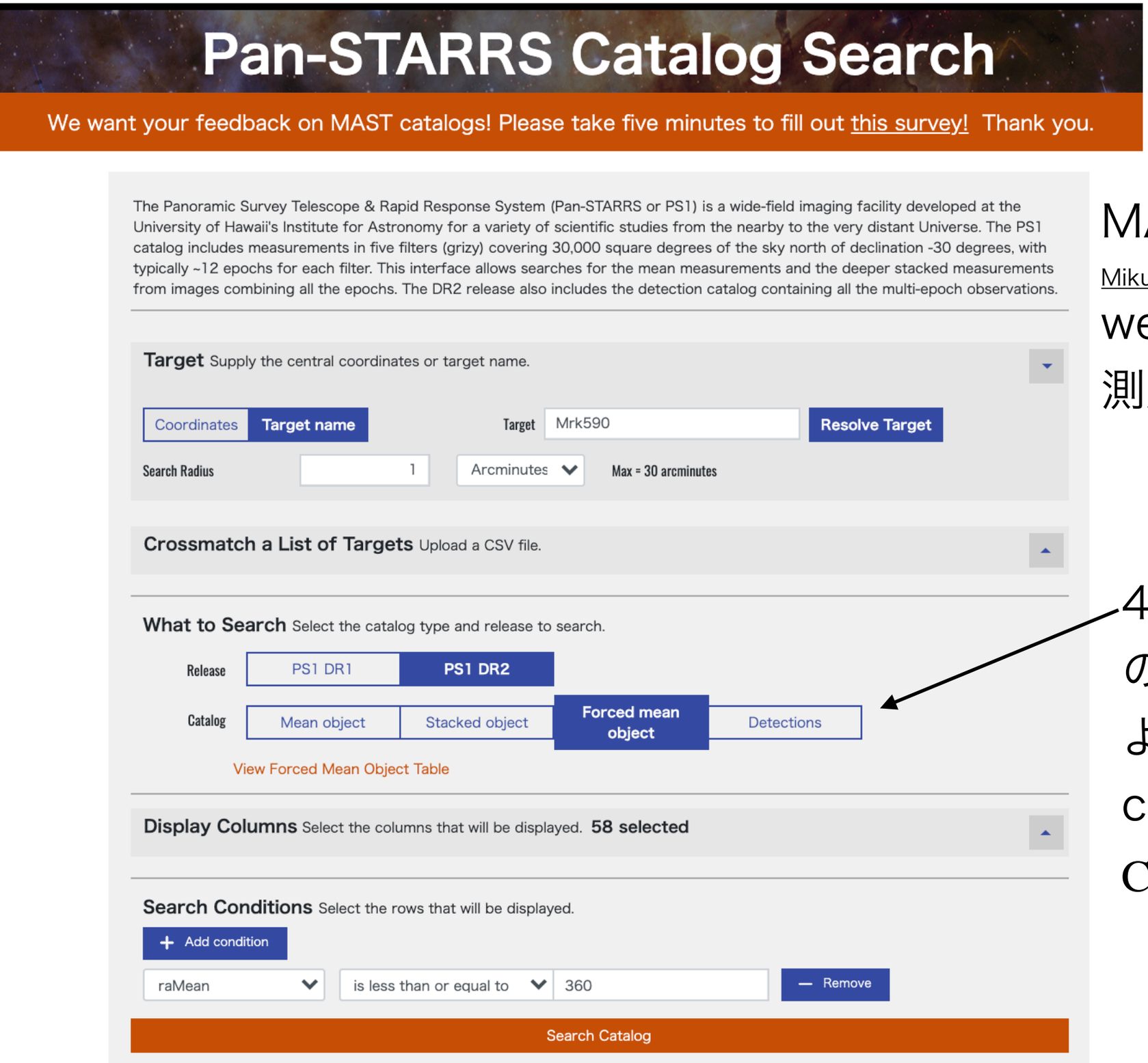
g-r vs. *r* color-magnitude diagram

stars are indicated in blue and **galaxies in red.**



https://outerspace.stsci.edu/display/PANSTARRS/PS1+Comparison+of+different+photometric+measures

Date product: Photometry Catalogues



MASTでホストされている

Mikulski Archive for Space Telescopes

web interfaceで 直感的に

測光カタログデータを取得可能

4つの必要十分なcatalogs

のみのsimpleなinterface.

よりカスタマイズした

catalog accessは

Casjobs SQL(後述)を用いる.

詳細は —> https://catalogs.mast.stsci.edu/docs/panstarrs.html

https://catalogs.mast.stsci.edu/panstarrs/

Date product: Photometry Catalogues

例: **ForcedMean**

dr2/forced_mean Target: **mrk590/NGC 0863** RA: **33.63984** Dec: **-0.76669** Radius: **0.08333**°

Export

objName	objID	nDetections	gnTotal	gFPSFFlux	gFPSFFluxErr	gFPSFFluxStd	gFKronFlux	gFKronFluxErr	gFKronFluxStd	gFApFlux	gFApFluxErr	gFApFluxStd
PSO J033.5587-00.7824	107060335586721562	0	12	0.000005807060006191023	0.000002623409955049283	7.042540073394775	0.000025748700863914564	0.000007156500032579061	11.137200355529785	0.000022776499463361688	0.000007986430318851 49	66.3520965576
PSO J033.5589-00.7745	107070335588340943	1	12	0.000002539220076869242	5.500199904417968e-7	1.3470300436019897	0.000004123330199945485	0.000001226020003741723 5	2.291029930114746	0.000003544389983289875	0.00000108348001504055	3.5850400924
PSO J033.5591-00.7735	107070335590502293	1	12	0.000001083820052372175 3	3.6332801300886786e-7	0.7818589806556702	0.000003251210046073538 3	0.000001794290028556133 6	1.2332799434661865	0.00000027474300168250 92	4.129690012177889e-7	1.2400100231
PSO J033.5595-00.7692	107070335594837354	0	12	6.295559842328657e-7	3.3027100698745926e-7	0.8068040013313293	7.933979873087083e-7	6.634990086240578e-7	0.6189829707145691	9.819150363910012e-7	6.759699999747681e-7	1.6883599758
PSO J033.5599-00.7753	107060335600719805	1	12	0.000002838939963112352 4	2.8340699032014527e-7	0.5684890151023865	0.00000544121985512902	0.000001616849999663827 5	3.846980094909668	0.000004134909886488458	0.000001260350018128519 9	6.1825699806
PSO J033.5600-00.7609	107080335599857300	0	12	0.000001964969897016999 3	0.000001618210035303491 2	2.4534499645233154	-5.802950227007386e-7	0.000006052170192560879 5	6.520579814910889	-3.4080900945809844e-7	0.000003722439942066557 7	12.996199607
PSO J033.5612-00.7398	107110335612292683	10	12	0.000001693150011305988 3	5.44421027370845e-7	0.7249739766120911	0.000004125310169911245	9.528529858471302e-7	0.4880790114402771	0.000002395519913989119 2	0.000001497709945397218 7	5.8249998092
PSO J033.5615-00.7816	107060335614272476	37	12	0.000008689099558978342	6.617070198444708e-7	1.096869945526123	0.000010779300282592885	0.000001539050003884767 6	2.8405098915100098	0.000012925200280733407	0.000001390450051985681	5.7856302261
PSO J033.5618-00.7801	107060335618184276	0	12	0.000001217640033246425 4	4.620069944394345e-7	0.4257600009441376	0.000006922030024725245	0.000001891820033961266 7	5.932799816131592	0.000005709940069209551 4	6.137299806141527e-7	0.4445729851
PSO J033.5620-00.7930	107040335619438541	0	26	0.000001470310053264256 6	1.8340099927627307e-7	0.2437279969453811 6	0.000005886419785383623	0.000002498989942978369	3.867919921875	3.322359987123491e-7	3.0067099032748956e-7	0.5773149728
PSO J033.5621-00.7694	107070335620327211	4	12	0.000001657999973758705 9	8.167339728970546e-7	1.2163699865341187	0.000003966769781982293	2.283759954480047e-7	0.26725199818611145	0.000002125000037267455	0.000001685200004430953 4	4.8672299385
PSO J033.5627-00.7827	107060335626901243	9	12	0.000001429389953955251 3	5.623360266326927e-7	0.5692870020866394	0.00000632859018878662	0.00000625120992481242 9	9.926799774169922	0.000001716010046948213 1	0.000004520959919318557	43.0586013793
PSO J033.5638-00.7630	107080335637454773	0	12	0.000007725209798081778	0.000001791819954632956	133.08799743652344	0.00004299830106901936	0.00003606699829106219	275.9549865722656	0.000031170900911092 76	0.000029566999728558585	1769.3199462
PSO J033.5639-00.7847	107050335639048834	0	26	0.000002574040081526618 5	2.5466201236667985e-7	0.27830201387405396	0.000001872939947134000 2	0.000001090630007638537 8	3.0968499183654785	0.000003344119932080502 6	0.000001358579993393505	10.5329999923
PSO J033.5640-00.7615	107080335639906580	0	12	0.000008874900231603533	0.000001410850018146447 8	-999	0.00003671320155262947	0.000002767719934126944 3	-999	0.00003091320104431361	0.000001410850018146447 8	-999

PSF flux, Kron flux, aperture flux … などが利用できる.

↑ Fluxは *Jansky* unit

* ForcedWarp, ForcedMean [FPSFFlux, FKronFlux など]はマイナス符号の場合もある

https://catalogs.mast.stsci.edu/panstarrs/

The Pan-STARRS1 data archive home page

Welcome to the starting point for access to data from the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). This page provides a brief summary of the facilities and data products to guide Pan-STARRS archive users. More complete information is provided on linked pages (see below).

Pan-STARRS is a system for wide-field astronomical imaging developed and operated by the Institute for Astronomy at the University of Hawaii. Pan-STARRS1 (PS1) is the first part of Pan-STARRS to be completed and is the basis for both Data Releases 1 and 2 (DR1 and DR2). The PS1 survey used a 1.8 meter telescope and its 1.4 Gigapixel camera (GPC1; see PS1 GPC1 camera) to image the sky in five broadband filters (g, r, i, z, y). The PS1 Science Consortium funded the operation of the Pan-STARRS1 telescope, situated at Haleakala Observatories near the summit of Haleakala in Hawaii, for the purposes of astronomical research. The PS1 consortium is made up of astronomers and engineers from 14 institutions from six countries.

The data from PS1 are archived at the Space Telescope Science Institute (STScI) in Baltimore Maryland, and can be accessed through MAST, the Mikulski Archive for Space Telescopes. Additional support for the PS1 public science archive is provided by the Gordon and Betty Moore Foundation.

The web site for Pan-STARRS1 in Hawaii also describes the project.

Quick links to the MAST PS1 Archive User Interface

The current PS1 data release is DR2 (2019 January 28). Use the following links to jump right to the MAST PS1 Science Archive interfaces and get started using PS1 data!

Object Catalog Search: **https://catalogs.mast.stsci.edu/**
Image Cutout Server: **https://ps1images.stsci.edu/cgi-bin/ps1cutouts**
Casjobs SQL Server: **https://mastweb.stsci.edu/ps1casjobs**

See How to retrieve and use PS1 data for more information on these access mechanisms. Note that all of these allow programmatic scripted access, and there are sample Python Jupyter notebook scripts.

The following image and catalog products are available in **DR2**:

- Warp images are the result of resampling and realigning the camera images into a skycell of the PS1 Sky Tessellation, a set of common pixel-grid images with simple projections from the sky. Warps are astrometrically and photometrically calibrated.
- Extracted photometry for point sources and extended objects from the warp images are available in DR2. The DR2 source database allows users to extract information on any time variation of source photometry or astrometry.
- Stack images are co-added images made from the multiple exposures taken over the survey. Stacks provide the best signal-to-noise, and the source catalogs created from the stacks are recommended as a starting point for data analysis.
- PS1 source extraction and catalogs describes how point-source and extended-object photometry is measured from the stack images. These source extractions are made available in DR1.
- Mean values of the point-source and extended-object photometry from the warp images are also available in DR1.

PS1 user information topics

There are five primary informational topics, with links below, that provide further details:

- The Pan-STARRS1 facilities and hardware
- PS1 Data processing procedures
- PS1 Image data products
- PS1 Source extraction and catalogs
- How to retrieve and use PS1 data
- PS1 sample queries

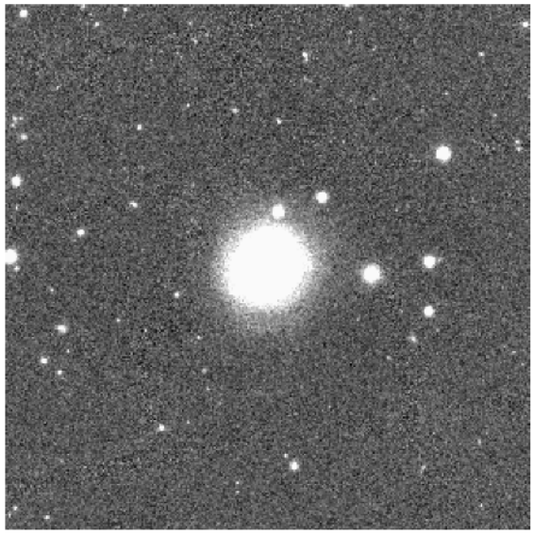
Detailed explanations of the products, sample Python Jupyter notebooks, …

https://panstarrs.stsci.edu/

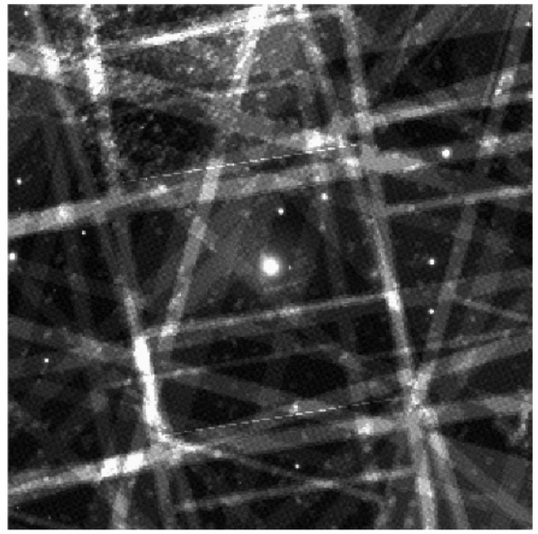
Data accessの例 (image):
image cutout web interfaceにpythonからaccess

例: cutout stack fits画像をdownload & plot

```python

# Mrk590 position
ra  = 033.6398378956147
dec = -00.7667167022724
size = 1280

####################
# accessするurlを生成
####################
fitsurl = geturl(ra, dec, size=size, filters="i", format="fits")
# --> 'https://ps1images.stsci.edu/cgi-bin/fitscut.cgi?ra=33.6398378956&dec=
#      -0.766716702272&size=1280&format=fits&red=/rings.v3.skycell/1240/080/
#      rings.v3.skycell.1240.080.stk.i.unconv.fits'


##########################
# 画像をlocalに読み込む (HDU)
##########################

image_url    = fitsurl[0]
variance_url = fitsurl[0].replace("unconv.","unconv.wt.")

fh          = fits.open(image_url)
fh_variance = fits.open(variance_url)

####################
# Fits画像をlocal fileに保存する.
####################

out_image    =    image_url.split("/")[-1]
out_variance = variance_url.split("/")[-1]

os.system("rm " + out_image   )
os.system("rm " + out_variance)
fh.writeto(            out_image  )
fh_variance.writeto(out_variance  )
```



Stack



Stack variance (wt)

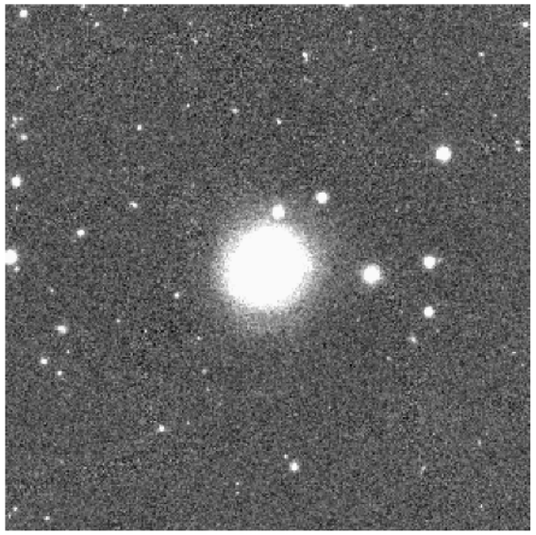
—> python/photutilsなどで測光解析できる (stack画像はゼロ点等級=25等; fits headerをみよ)

上記で用いたpython tasksは https://ps1images.stsci.edu/ps1image.html にある.

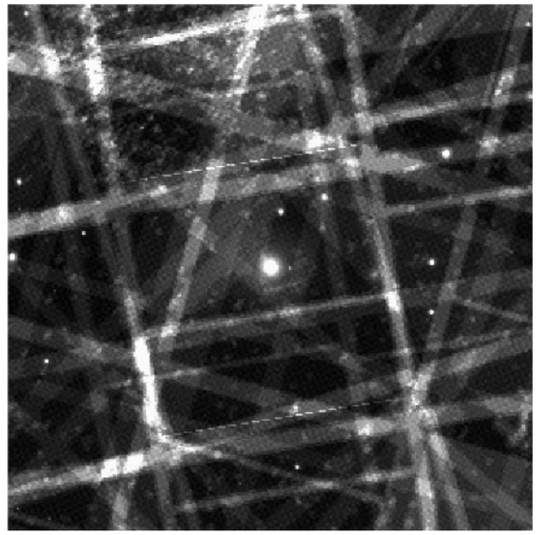
https://outerspace.stsci.edu/display/PANSTARRS/How+to+retrieve+and+use+PS1+data
https://ps1images.stsci.edu/ps1_dr2_api.html

Data accessの例 (image):
image cutout web interfaceに`python`からaccess

例: cutout stack fits画像をdownload & plot



Stack



Stack variance (wt)

`rings.v3.skycell.1240.080.stk.i.``unconv.fits`

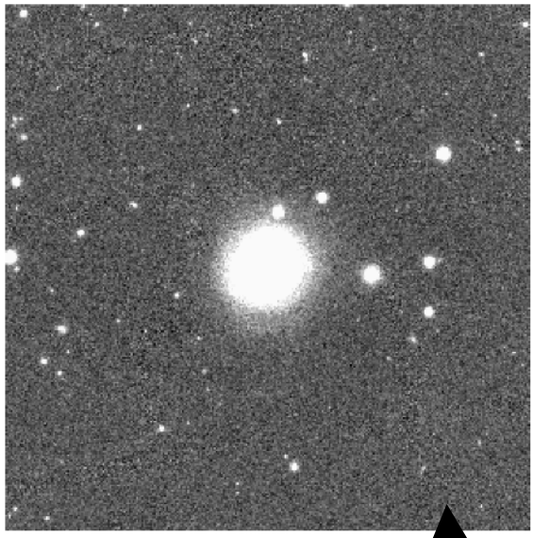
“rings.v3で定義されるx=1240,y=080のskycellのstack画像, i-band”

Data accessの例 (image):
image cutout web interfaceに`python`からaccess

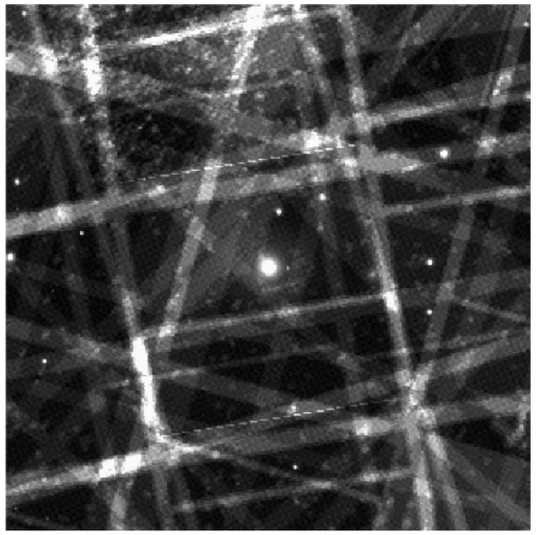
例: cutout stack fits画像をdownload & plot

普通のfits imageなので、ds9で表示したり

```
 ds9 -zscale \
rings.v3.skycell.1240.080.stk.i.unconv.fits \
rings.v3.skycell.1240.080.stk.i.unconv.wt.fits
```



Stack



Stack variance (wt)

astropy.ioでpythonで読み込んだりできる

```
python
from astropy.io import fits
hdu = fits.open(“rings.v3.skycell.1240.080.stk.i.unconv.fits")
hdu[0].header['EXPTIME']
hdu[0].header['HIERARCH FPA.ZP’]
```

ds9などで, stack画像の分散と
variance mapの値が大体あっているかを
checkしてみると、安心して使える

Data accessの例 (catalog): MAST web API にpythonからaccess

```python
#
# This searches the mean object catalog for objects within 50 arcsec of Mrk590.
# Note that the results are restricted to objects with nDetections>1, where nDetections is the total number
# of times the object was detected on the single-epoch images in any filter at any time.
# Objects with nDetections=1 tend to be artifacts, so this is a quick way to eliminate most spurious objects
# from the catalog.
#
# Mrk590の周辺r=50arcsecのMeanObjectを検索.
#
# nDetections>1 (どのfilterでもよいので, 2回以上single-epoch画像で検出されている)という条件をつける.
# nDetections=1は,ほとんどの場合spurious objects(ゴミ)なので、nDetections>1の条件でかなりの割合のゴミを排除できる.
#
# "Mean" catalogのcolumnの説明は
# https://outerspace.stsci.edu/display/PANSTARRS/PS1+MeanObjectView+table+fields
#


ra     = 33.6398378956147
dec    = -0.7667167022724
radius = 50.0/3600.0
constraints = {'nDetections.gt':1}

# Mean catalogの中のいくつかのcolumnを抽出する.
columns = """objID,raMean,decMean,nDetections,ng,nr,ni,nz,ny,
gMeanPSFMag,rMeanPSFMag,iMeanPSFMag,zMeanPSFMag,yMeanPSFMag""".split(',')
columns = [x.strip() for x in columns]
columns = [x for x in columns if x and not x.startswith('#')]

# ps1cone: web APIにquery urlを送り、APIが出力したcsvをresultsに読み込む.
results = ps1cone(ra,dec,radius,release='dr2',columns=columns,verbose=True,**constraints)

## print first few lines
#lines = results.split('\n')
#print(len(lines),"rows in results -- first 5 rows:")
#print('\n'.join(lines[:6]))

# astropy.table形式に変換.
tab = ascii.read(results)
# improve the format
for filter in 'grizy':
    col = filter+'MeanPSFMag'
    try:
        tab[col].format = ".4f"
        tab[col][tab[col] == -999.0] = np.nan
    except KeyError:
        print("{} not found".format(col))

# 表示
tab
```

- MASTのAPIにqueryを送り,

  python.requests.get

  でpythonに取り込む

https://catalogs.mast.stsci.edu/api/v0.1/panstarrs/dr2/mean.csv?dec=-0.766716702272&radius=0.0138888888889&ra=33.6398378956&columns=%5BobjID%2CraMean%2CdecMean%2CnDetections%2Cng%2Cnr%2Cni%2Cnz%2Cny%2CgMeanPSFMag%2CrMeanPSFMag%2CiMeanPSFMag%2CzMeanPSFMag%2CyMeanPSFMag%5D&nDetections.gt=1

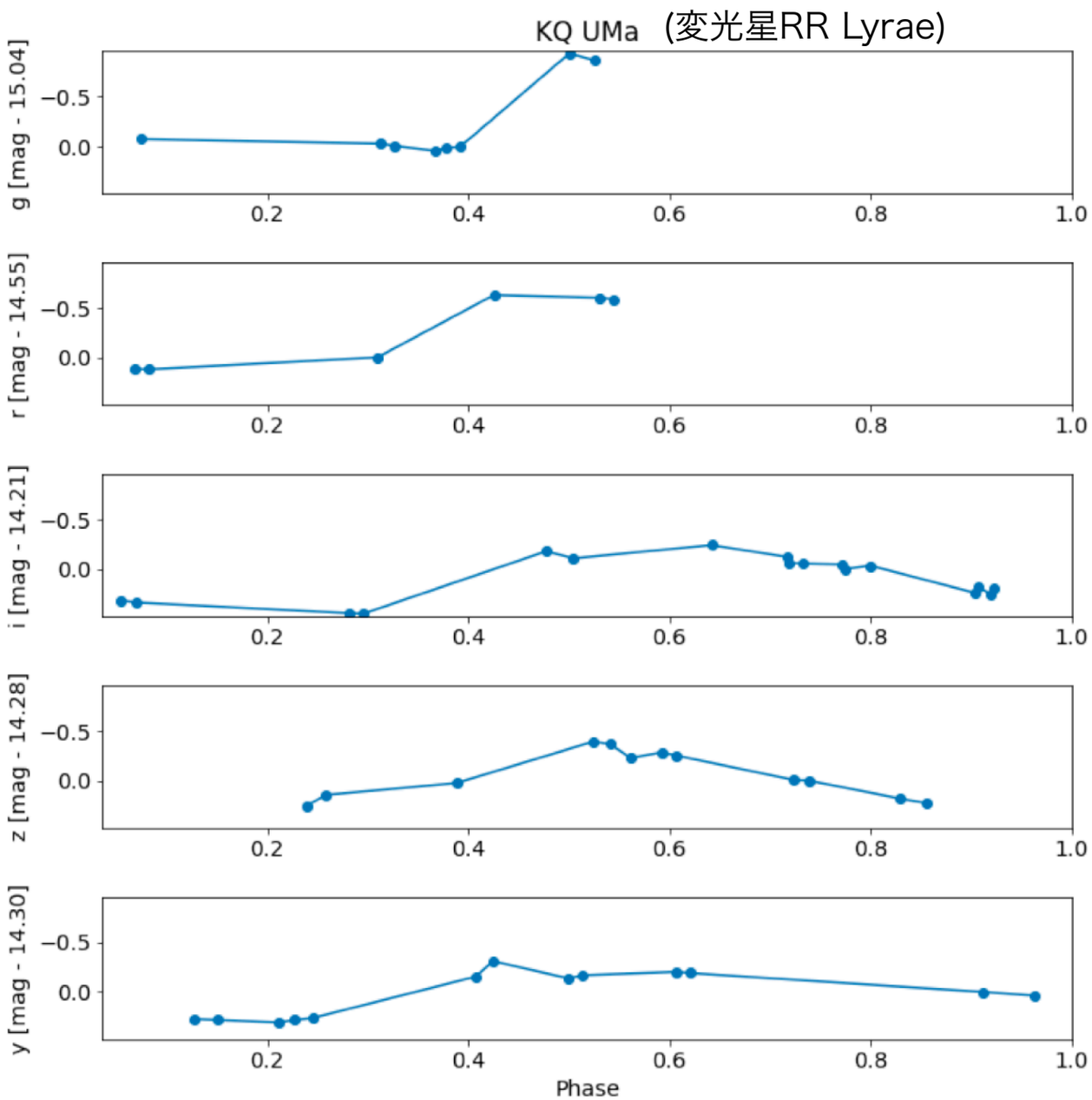
<Table length=31>

objID	raMean	decMean	nDetections	ng	nr	ni	nz	ny	gMeanPSFMag	rMeanPSFMag	iMeanPSFMag	zMeanPSFMag
int64	float64	float64	int64	int64	int64	int64	int64	int64	float64	float64	float64	float64
107060336410857640	33.64110938	-0.77741577	2	0	1	1	0	0	nan	21.4057	21.1266	nan
107060336422858569	33.64226204	-0.77667082	2	0	0	1	1	0	nan	nan	21.4750	20.7051
107070336320732430	33.63212833	-0.77334054	2	0	1	1	0	0	nan	21.3538	21.6887	nan
107070336336271423	33.63357657	-0.77408146	2	2	0	0	0	0	22.6118	nan	nan	nan
107070336390957480	33.63909535	-0.76912359	2	0	2	0	0	0	nan	nan	nan	nan
107070336394414750	33.6393077	-0.77123597	3	1	0	2	0	0	20.4766	nan	19.3916	nan
107070336402931774	33.64034712	-0.77376801	2	0	0	0	1	1	nan	nan	nan	20.6208
107070336426286779	33.64280825	-0.76983767	2	1	0	1	0	0	19.6913	nan	19.9995	nan
107070336454475298	33.64545022	-0.77098068	8	0	5	3	0	0	nan	20.3723	20.4459	nan
107080336281025128	33.62812549	-0.76267443	2	2	0	0	0	0	21.5735	nan	nan	nan

https://catalogs.mast.stsci.edu/docs/panstarrs.html

scriptは次のURLから持ってきた: https://ps1images.stsci.edu/ps1_dr2_api.html

Data accessの例 (catalog): MAST web API にpythonからaccess



- MASTのAPIにqueryを送り,

  python.requests.get

  でpythonに取り込む

<— *Detection* tableの

PSF flux測定値 light curve

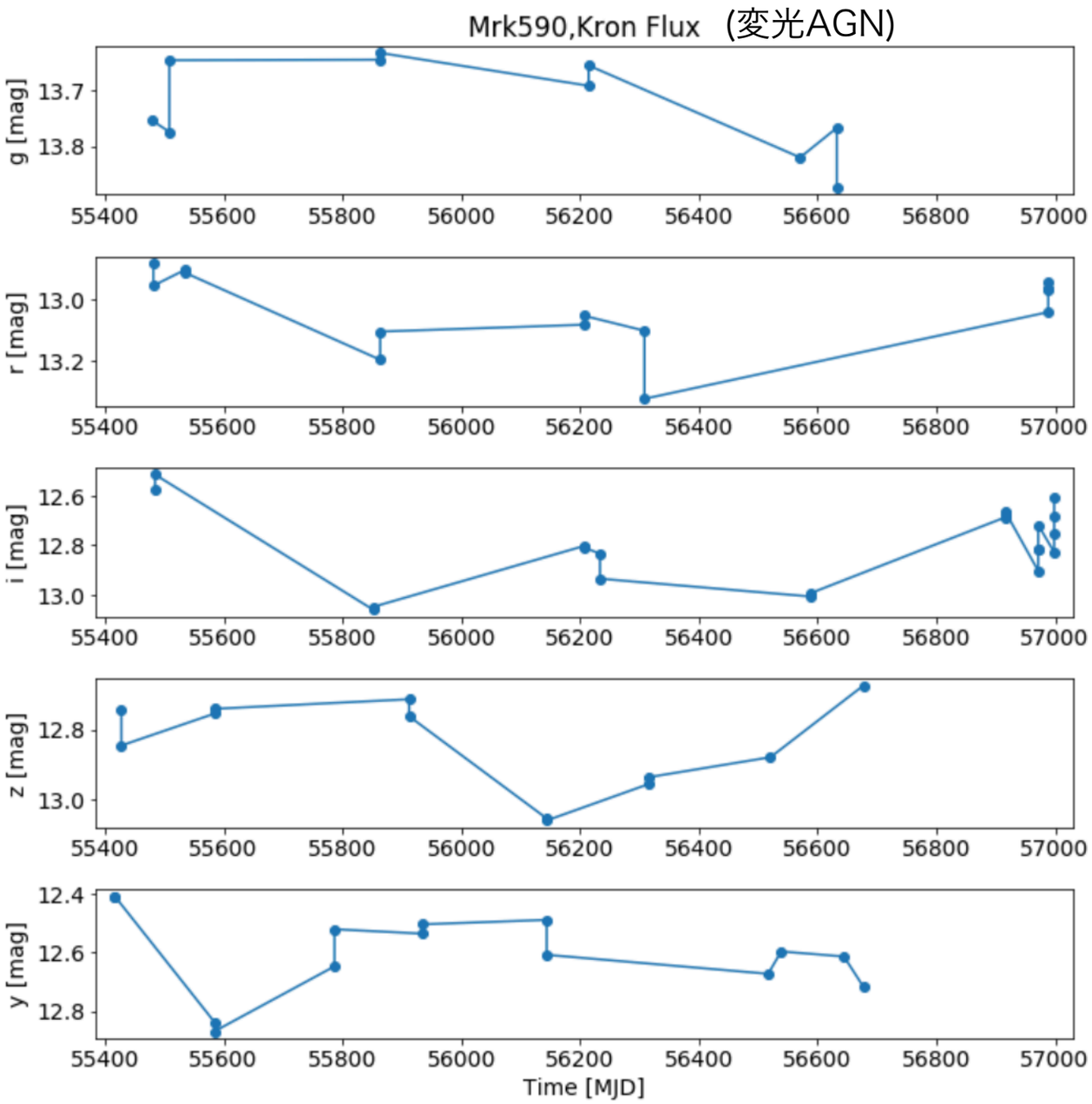
(0.4863日周期で折りたたみ)

星 (点源)の測光light curveは素性が良い

https://catalogs.mast.stsci.edu/docs/panstarrs.html

scriptは次のURLから持ってきた: https://ps1images.stsci.edu/ps1_dr2_api.html

Data accessの例 (catalog): MAST web API にpythonからaccess



- MASTのAPIにqueryを送り,

  python.requests.get

  でpythonに取り込む

<— *Detection* tableの
Kron flux測定値 light curve

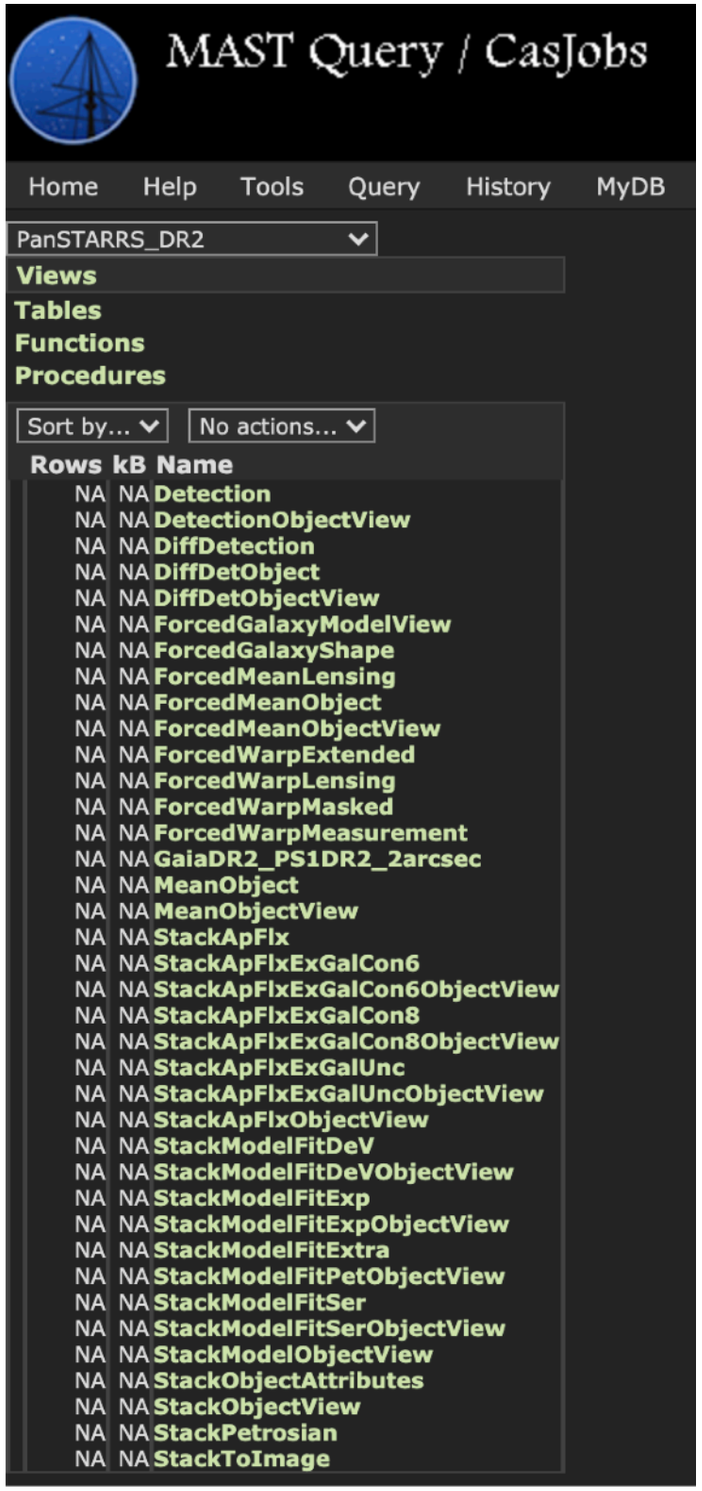
AGN (広がった天体)の測光light curveは要注意

https://catalogs.mast.stsci.edu/docs/panstarrs.html
scriptは次のURLから持ってきた: https://ps1images.stsci.edu/ps1_dr2_api.html

Data accessの例 (catalog): Casjobs SQL interface

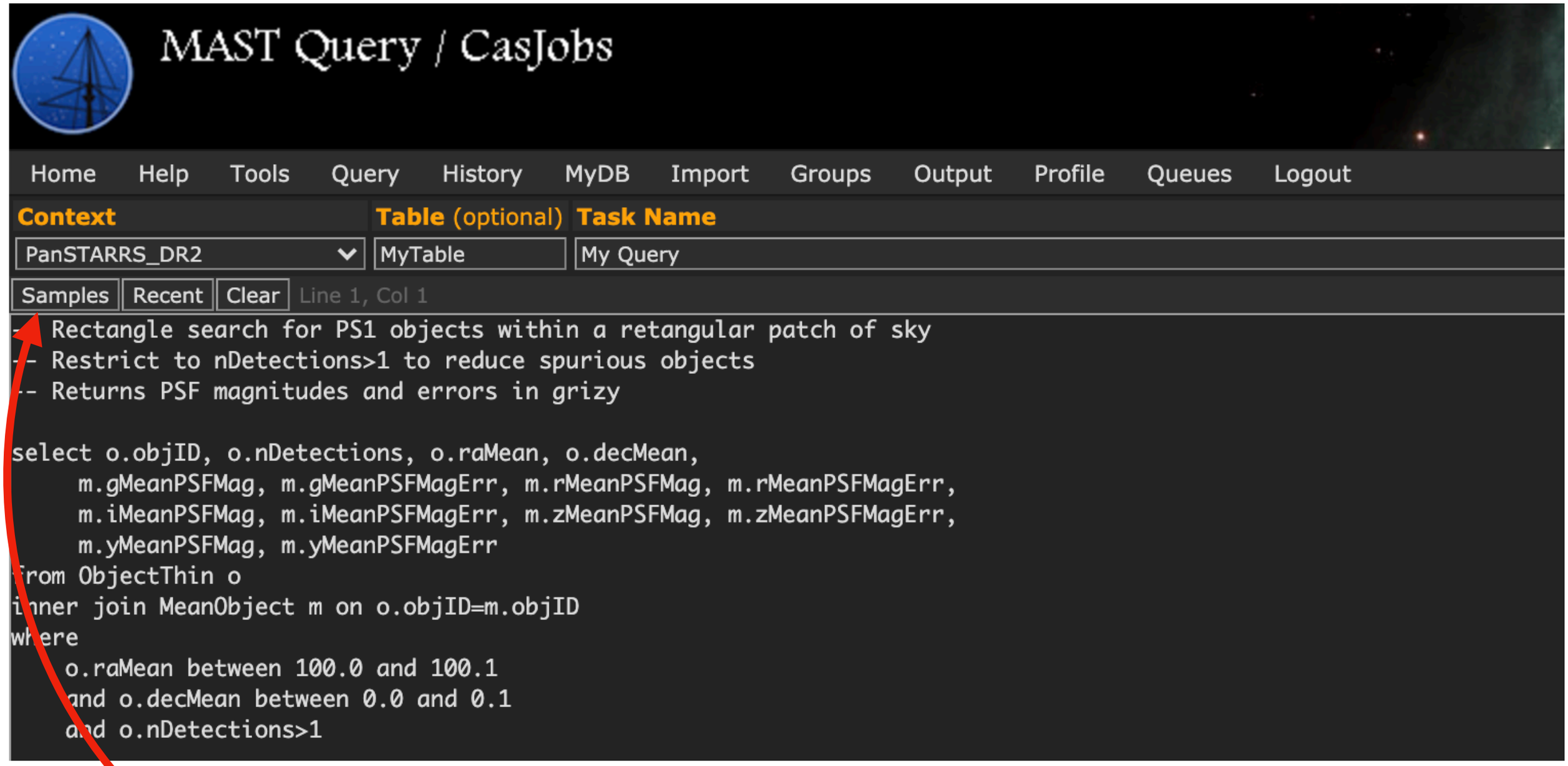
- 大量のカタログデータを読み込んだり、カタログ同士を組み合わせたりする場合、SQL serverにQueryを投げる
  - Create a MAST Query / casjobs account
  - Write a SQL query to get desired SQL table
  - Submit the query

SQLサーバで利用できるテーブル一覧→



https://mastweb.stsci.edu/ps1casjobs/

Data accessの例 (catalog): Casjobs SQL interface



Sample SQL queryも充実
(SDSS SQLと同じ)

Data accessの例 (catalog): Casjobs SQL interface

PS1 Sample queries

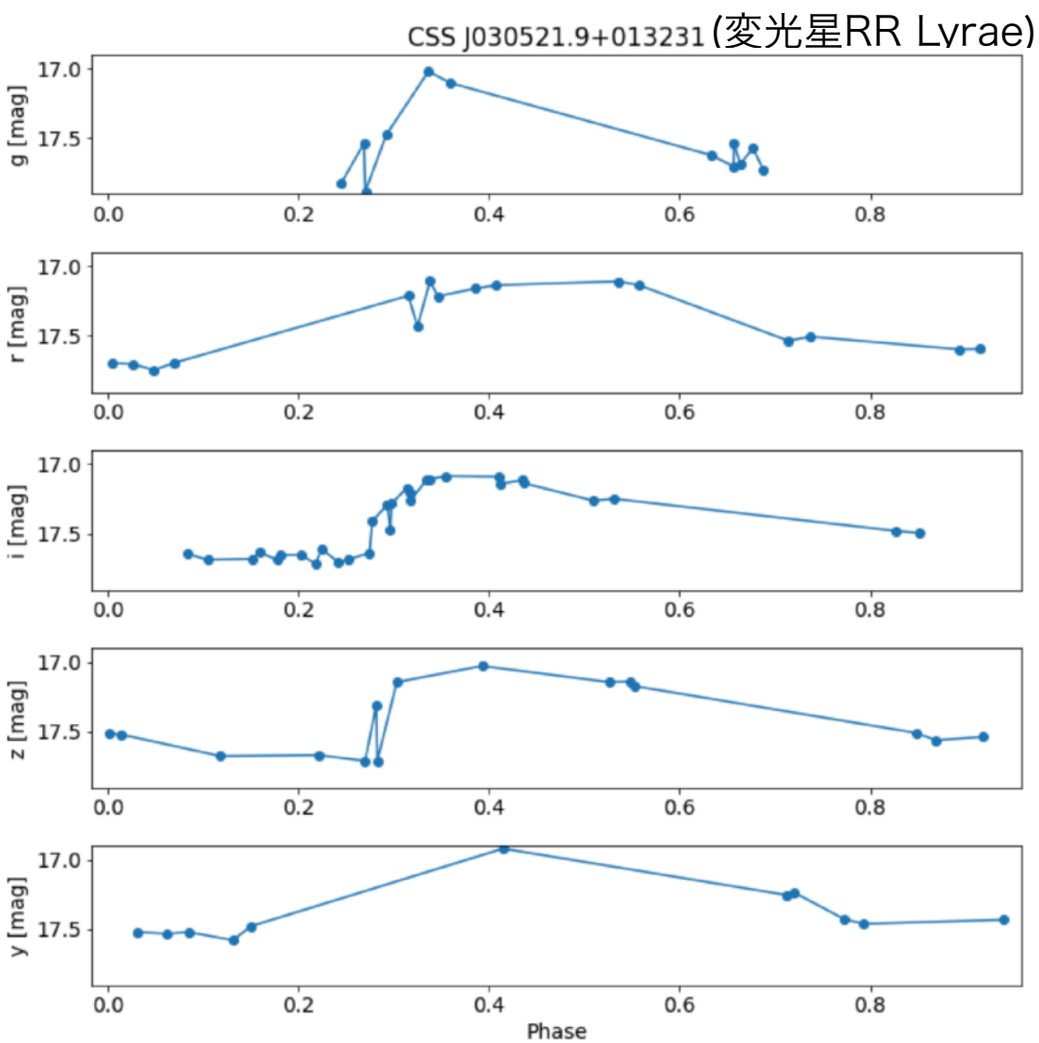
Armin Rest が作成し、2 13, 2019 に Rick White が最終更新

On this page

- Get high-fidelity stars in given area
  - Goal/Description
  - Tables used
  - Query
  - Results
- Galaxy Candidates for K2 SN Search
  - Goal/Description
  - Query
  - Results
- Obtain lightcurves for a given set of objects
  - Goal/Description
  - Query #1: Match Catalina RR Lyrae stars to PS1 objects
  - Results (25 minutes)
  - Query #2: Get the detections
  - Results (30 seconds)
  - Query #3: Get the forced detections
  - Results (3:45 minutes)
- Obtain lightcurves for a single object
  - Goal/Description
  - Query #1: Get the ObjID for the star
  - Results (1 entry, < 1 min)
  - Query #2: Get the detections
  - Results (92 entries, < 1 min)
  - Query #3: Get the forced detections
  - Results (84 entries, <1 min)
- Select mean objects and associated detections within 3 deg of HDF; compare photometry and astrometry with Gaia DR2
  - Step 1: Obtain mean objects in cone search, filtering for objects with a high probability of Gaia matches
  - Step 2: Obtain detections associated with objects selected in Step 1
  - Step 3: Match objects and detections with the closest Gaia DR2 source
  - Step 4: compare Gaia and PanSTARRS magnitudes for point sources
  - Step 5: Compute mean detection positions and compare to Gaia astrometry

https://outerspace.stsci.edu/display/PANSTARRS/PS1+Sample+queries

Data accessの例 (catalog): Casjobs SQL interface




```
script3 = "\
SELECT \
o.objID, o.raMean, o.decMean, \
fwm.detectID, \
 fwm.obstime, fwm.exptime, fwm.airmass, fwm.Fpsfflux, fwm.FpsffluxErr, \
fwm.FpsfQf, fwm.FpsfQfPerfect, fwm.FpsfChiSq, fwm.zp, fwm.FapFlux, \
fwm.FapFluxErr, \
fwm.forcedWarpID, fwm.filterID, \
fwm.Fsky, fwm.Fskyerr, fwm.Finfoflag, fwm.Finfoflag2, fwm.Finfoflag3, \
o.qualityFlag, \
o.gMeanPSFMag, o.gMeanPSFMagErr, o.gMeanPSFMagNpt, \
o.rMeanPSFMag, o.rMeanPSFMagErr, o.rMeanPSFMagNpt, \
o.iMeanPSFMag, o.iMeanPSFMagErr, o.iMeanPSFMagNpt, \
o.zMeanPSFMag, o.zMeanPSFMagErr, o.zMeanPSFMagNpt, \
o.yMeanPSFMag, o.yMeanPSFMagErr, o.yMeanPSFMagNpt, \
o.rMeanKronMag, o.rMeanKronMagErr, \
o.nDetections, o.ng, o.nr, o.ni, o.nz,o.ny, \
o.gFlags, o.gQfPerfect, \
o.rFlags, o.rQfPerfect, \
o.iFlags, o.iQfPerfect, \
o.zFlags, o.zQfPerfect, \
o.yFlags, o.yQfPerfect \
INTO mydb.[RRL_584630948352256_PS1forceddet] \
FROM mydb.[RRL_584630948352256_PS1] o \
JOIN ForcedWarpMeasurement fwm on fwm.ObjID = o.ObjID \
"
"java -jar casjobs.jar run -t 'PanSTARRS_DR2' -n 'RRL_584630948352256_PS1forceddet' " + "'" +  script3 +
```

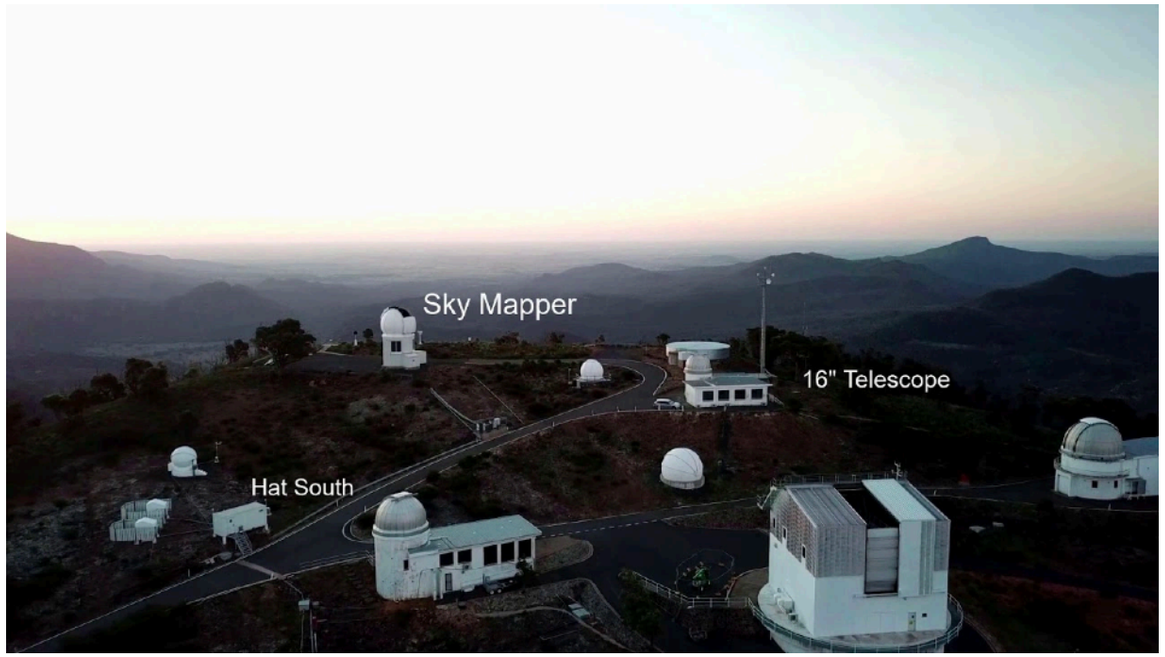
↑Command line tool casjobsで
CasjobsにSQL queryをsubmit
—> .csvでdownload

<— *ForcedWarpMeasurements* tableの
PSF flux測定値 light curve
(0.55547日周期で折りたたみ)

https://mastweb.stsci.edu/ps1casjobs/casjobscl.aspx
https://outerspace.stsci.edu/display/PANSTARRS/PS1+Sample+queries#PS1Samplequeries-Obtainlightcurvesforasingleobject

http://skymapper.anu.edu.au/about-skymapper/

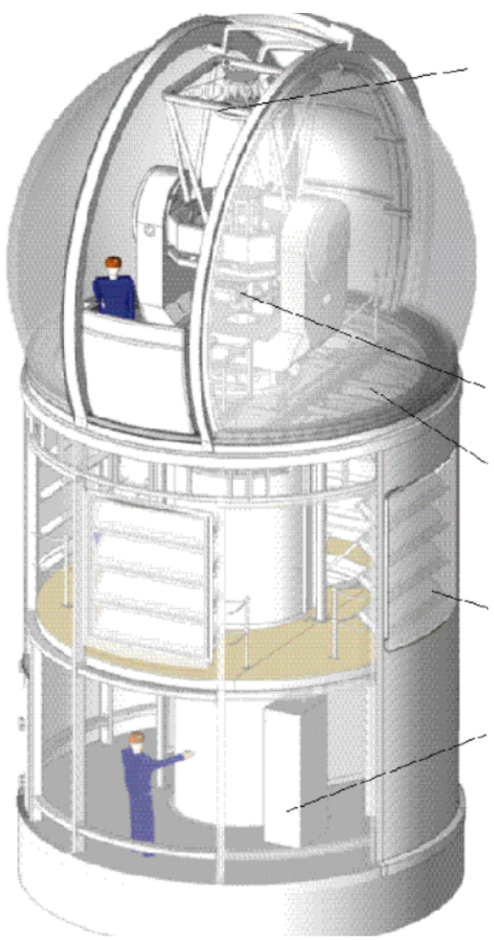
SkyMapper Southern Survey (SMSS)



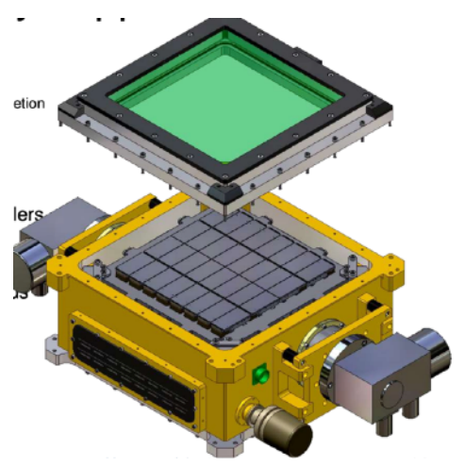
https://sciencesprings.wordpress.com/2020/10/10/meet-the-siding-spring-observatory/

SkyMapper Southern Survey (SMSS)

- 2014 — ongoing. 南天2π steradian.
- 最終目標は 20 — 22 mag in u, v, g, r, i, z-band

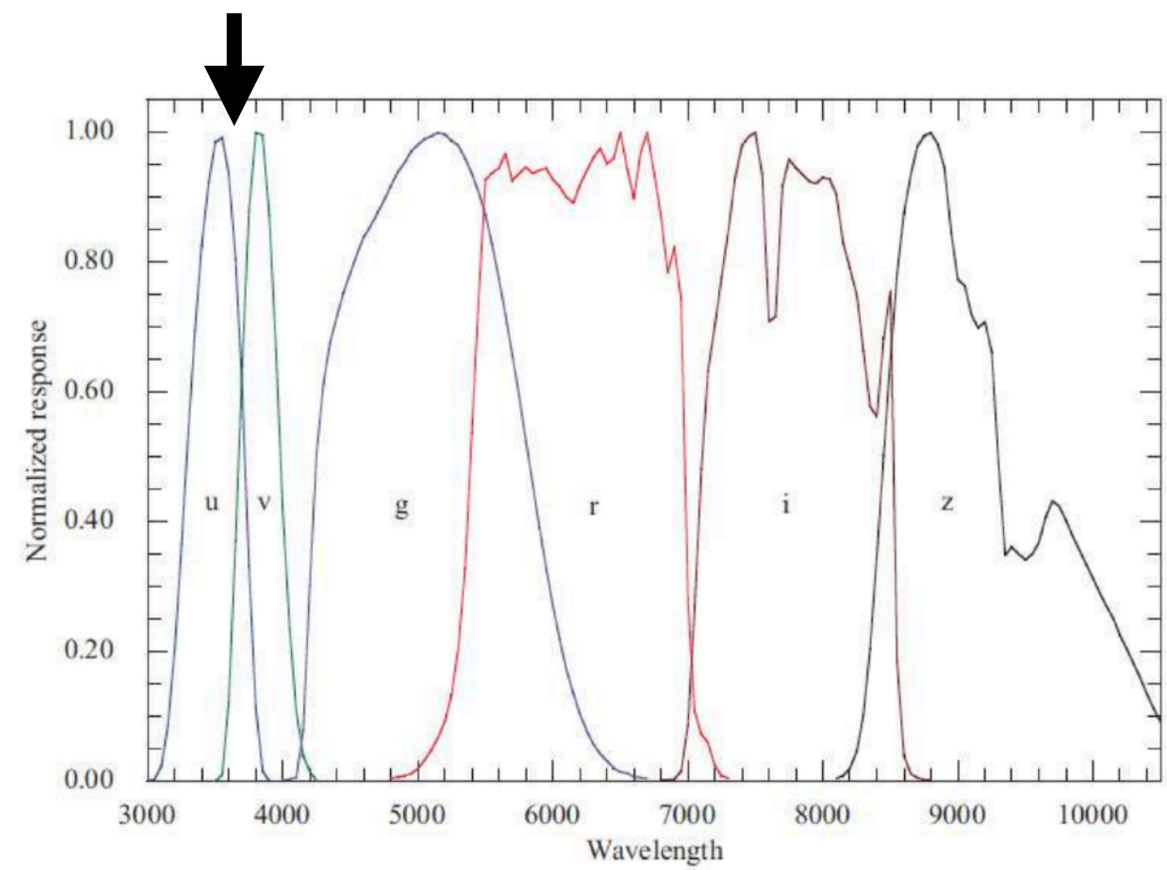


1.35m口径, 5.7deg²



32 E2V CCD4482 devices: 2048x4096 15 micron pixel CCDs

u-bandが2つ (QSO; 金属欠乏星selection)



Bessell et al. (2011).

https://www.eso.org/sci/meetings/2007/cal07/presentations/ESOCAL07_Keller.pdf
http://www.caastro.org/files/38/922819839/onken-chris---data-pipeline.pdf

Shallow survey & Main Survey

Shallow Survey

Wolf+2018

Filter	$\lambda_{cen}/\Delta\lambda$ (nm)	R_{band}	t_{exp} (s)	N_{image}	10σ-limit (ABmag)	FWHM (arcsec)
u	349/42	4.294	40	10 909	17.9	3.1
v	384/28	4.026	20	10 779	17.7	2.9
g	510/156	2.986	5	11 872	18.0	2.6
r	617/156	2.288	5	11 515	18.0	2.4
i	779/140	1.588	10	10 698	18.0	2.3
z	916/84	1.206	20	11 067	18.0	2.3

Main Survey

Onken+2020

	5σ depth (mag.)
u	20
v	21
g	22
r	22
i	21
z	20

- **Shallow Survey**: 短いexposureで2πステラジアンを掃き、~18等mapを作る. 2014-2015で完了. Data Release 1で公開.

- **Main Survey**: Shallow Survey完了後, ~22等を目指して長めのexposureで2πステラジアンを掃く. 現在進行中. Data Release 2で部分的に公開.

  - DR2の段階ではsingle-epochの画像, 測光値やその平均値のみ (instantaneous photometry only). stack画像やstack photometryは公開されていない … 現状だとあまり使い勝手がよくない

  - Stack画像の公開はDR3から (Onken+2020).

Log-in to SkyMapper

Australian National University

SkyMapper | Southern Survey

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- Data Releases
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- Data Access
- How To Access
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- Cone Search
- Image Cutouts
- Full Catalogue Search
- Table Metadata
- Sky Viewer
- Protected Science

Using a specially-built, 1.3-meter telescope at Siding Spring Observatory near Coonabarabran, the **SkyMapper Southern Survey** is producing a high-fidelity digital record of the entire southern sky for Australian astronomers.

Learn More →

SkyMapper's *Southern Survey* is led by the **Research School of Astronomy and Astrophysics** at the **Australian National University**, in collaboration with seven Australian universities and the Australian Astronomical Observatory. The goal of the project is to create a deep, multi-epoch, multi-colour digital survey of the entire southern sky. This will facilitate a broad range of exciting science, including discovering the oldest stars in the Galaxy, finding new dwarf galaxies in orbit around the Milky Way, and measuring the effects of Dark Energy on the Universe through nearby supernovae.

On this site you can **read about SkyMapper** and its **surveys**, browse the latest **data releases** and query **images and catalogues** using simple forms or Virtual Observatory web services. Before downloading or publishing data we ask that you review the **policies** section to familiarise yourself with the authorship and protected science policies. As part of SkyMapper's status as a National Facility, Australian

Latest Data Release

DR2

Feb 27, 2019

21,000 deg^2
505,176,667 objects
121,494 exposures
4.7 billion detections
Matched against 2MASS, AllWISE, ATLAS Refcat2, Gaia, GALEX, Pan-STARRS1, and UCAC4

Learn More →

Follow @SkyMapper on Twitter

SkyMapper Telescope
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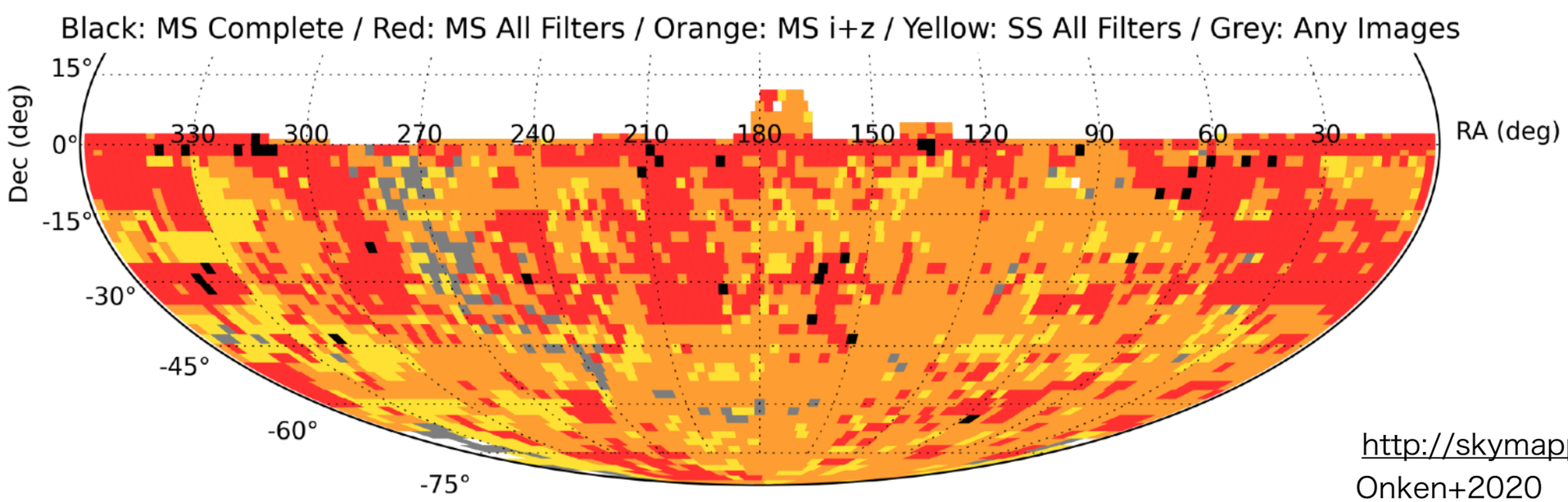
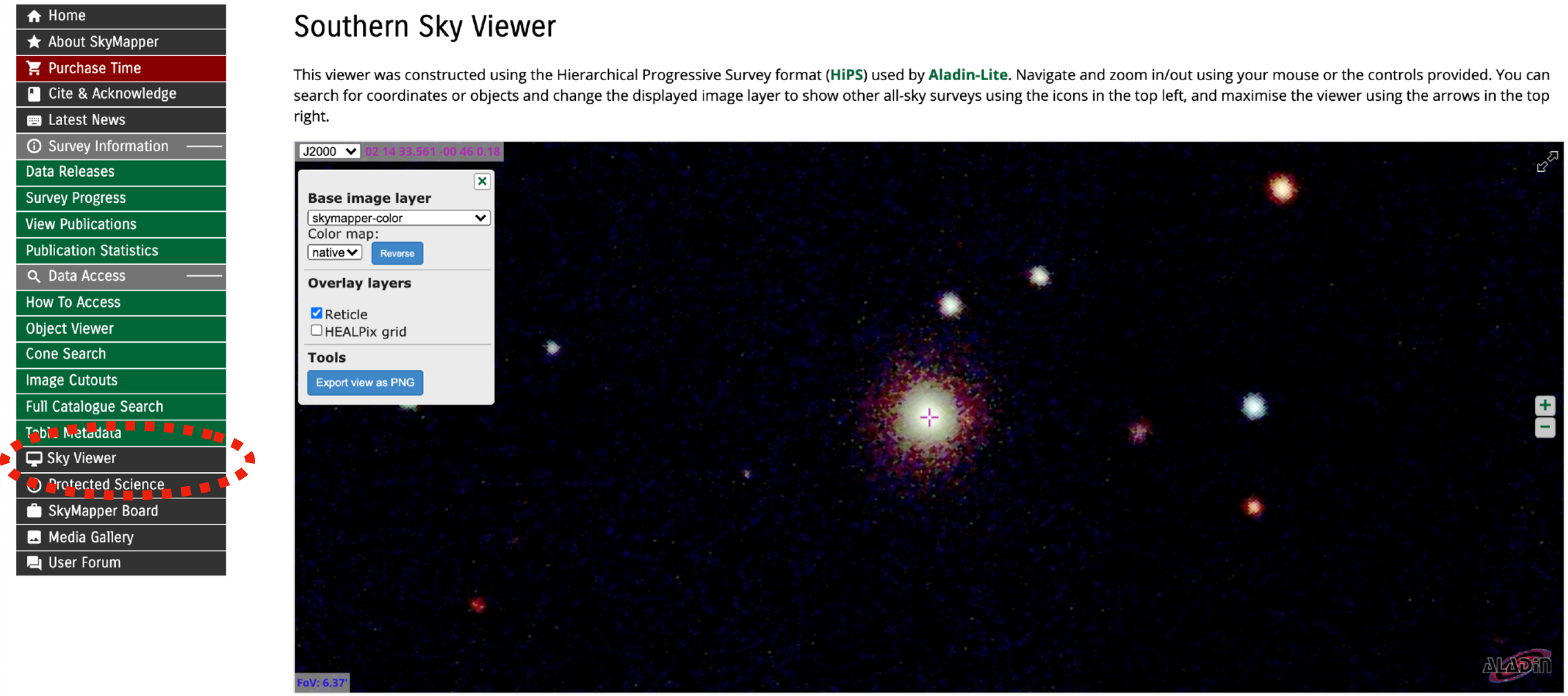
Data Release 2 from the SkyMapper Southern Survey is



http://skymapper.anu.edu.au/
Onken+2020

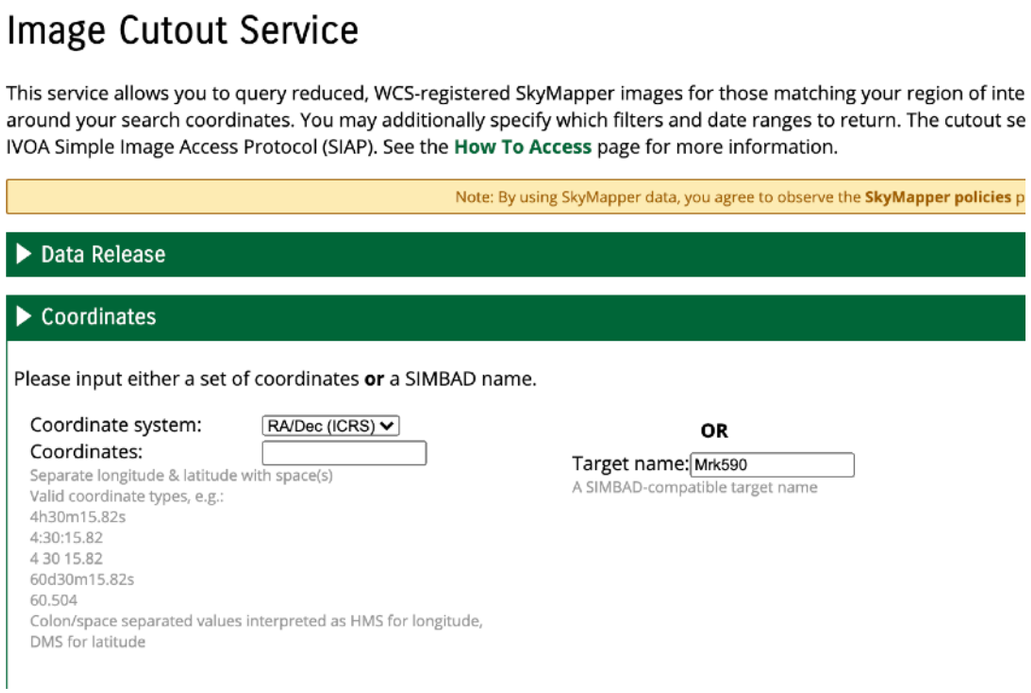
SkyViewer

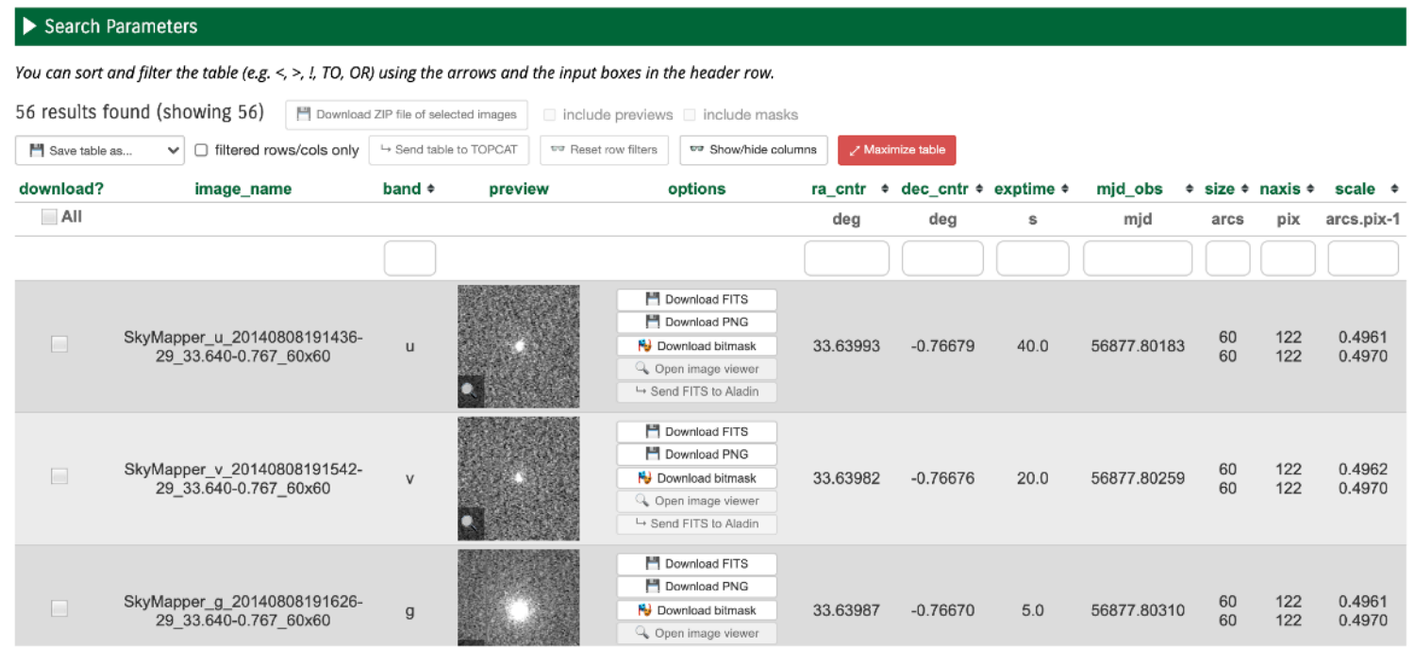


“見る”だけならSkyViewerで十分
(stack画像ではなく, おそらくbest single-epoch画像)

http://skymapper.anu.edu.au/sky-viewer/

Image cutout





- Image cutout serviceで視覚的に確認 & downloadできる
  (DR2では**single-epoch画像**のみ; cutoutの最大サイズは0.17deg × 0.17deg)

- スクリプトQueryをweb-APIに投げることもできる:

  あるRA, Declを含む画像のリストを取得 —> リストから画像をdownload

http://api.skymapper.nci.org.au/public/siap/dr2/query?POS=33.639837321,-0.766719986&SIZE=0.17,0.17&FORMAT=image/fits&INTERSECT=center&%20&RESPONSEFORMAT=HTML

http://skymapper.anu.edu.au/image-cutout/
http://skymapper.anu.edu.au/how-to-access/#World

Object catalog

dr2.master
dr2.ccds
dr2.images
dr2.mosaic
dr2.photometry

- DR2測光カタログは2種類
  - dr2.master: 複数epochの測光値の平均値
    [PanSTARRSのMeanObjectのようなもの]
  - dr2.photometry: 各epochの測光値
    [PanSTARRSのDetectionsのようなもの]

Cone Search Service (dr2.masterのみのシンプルなインターフェイス)

This service allows you to query the `master` table of mean photometry and object parameters around a given position. Please specify either Equatorial/Galactic coordinates or a SIMBAD-resolvable object name as well as a search radius in arcseconds (maximum 3,600" or 2,000 rows). You may increase the number of columns returned by increasing the metadata verbosity parameter. This service is also accessible through VO-aware clients like **TOPCAT** using the IVOA Cone Search standard. See the **How To Access** page for more information.

Note: By using SkyMapper data, you agree to observe the **SkyMapper policies** published on this website.

▶ Data Release

▶ Search Parameters

Please input either a set of coordinates **or** a SIMBAD name.

Coordinate system: RA/Dec (ICRS)
Coordinates:
Separate longitude & latitude with space(s)
Valid coordinate types, e.g.:
4h30m15.82s

OR

Target name:
A SIMBAD-compatible target name

Search radius: 60.0
Arcseconds
Metadata verbosity: Minimum metadata
Detail in returned metadata

http://skymapper.anu.edu.au/cone-search/

Object catalog

dr2.master
dr2.ccds
dr2.images
dr2.mosaic
dr2.photometry

- DR2測光カタログは2種類
  - dr2.master: 複数epochの測光値の平均値
    [PanSTARRSのMeanObjectのようなもの]
  - dr2.photometry: 各epochの測光値
    [PanSTARRSのDetectionsのようなもの]

- dr2.masterカタログのデータを、あるRA, Decl周辺で取得し, XML形式でoutput:
  http://skymapper.anu.edu.au/sm-cone/public/query?RA=33.639837321&DEC=-0.766719986&SR=0.1&VERB=3&CATALOG=dr2.master&RESPONSEFORMAT=XML

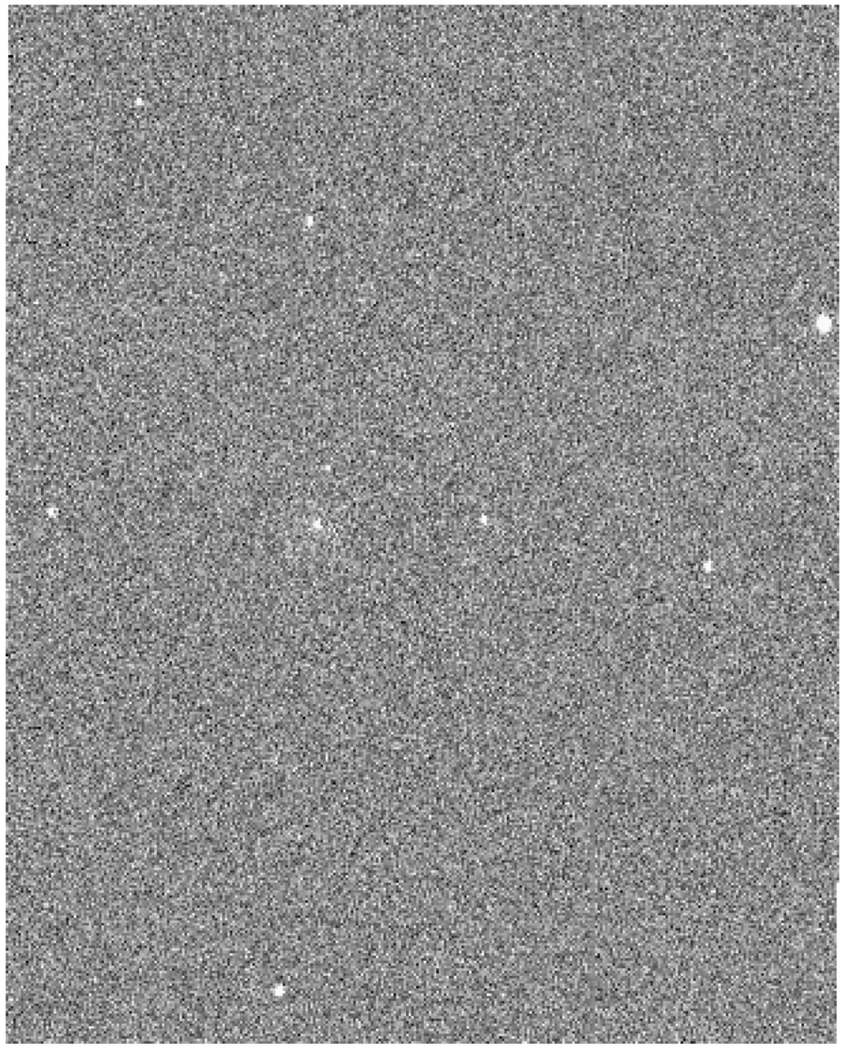
- dr2.photometryデータをCSV形式でoutput
  http://skymapper.anu.edu.au/sm-cone/public/query?RA=33.639837321&DEC=-0.766719986&SR=0.1&VERB=3&CATALOG=dr2.photometry&RESPONSEFORMAT=CSV

Tableの中身:http://skymapper.anu.edu.au/table-browser/
http://skymapper.anu.edu.au/how-to-access/#World

*python*からWeb-API Image cutout service —> download

```
# SkyMapper image cone search  CSV  pandas DataFrame  .
#
# query Mrk590  CCD   .
#
# http://api.skymapper.nci.org.au/public/siap/dr2/query?\
# POS=33.639837321,-0.766719986&SIZE=0.17,0.17&FORMAT=image/
↪fits&INTERSECT=center&%20&RESPONSEFORMAT=CSV

url = "http://api.skymapper.nci.org.au/public/siap/dr2/query?POS=33.
↪639837321,-0.766719986&SIZE=0.17,0.17&FORMAT=image/
↪fits&INTERSECT=center&%20&RESPONSEFORMAT=CSV"

#r = requests.get(url, params=payload)
r = requests.get(url)

df = pd.read_csv(io.BytesIO(r.content),sep=",")
```

```
                                          image_name      format band  \
0   SkyMapper_u_20140808191436-29_33.623-0.767_489…  image/fits    u
1   SkyMapper_v_20140808191542-29_33.623-0.767_488…  image/fits    v
2   SkyMapper_g_20140808191626-29_33.623-0.767_489…  image/fits    g
```



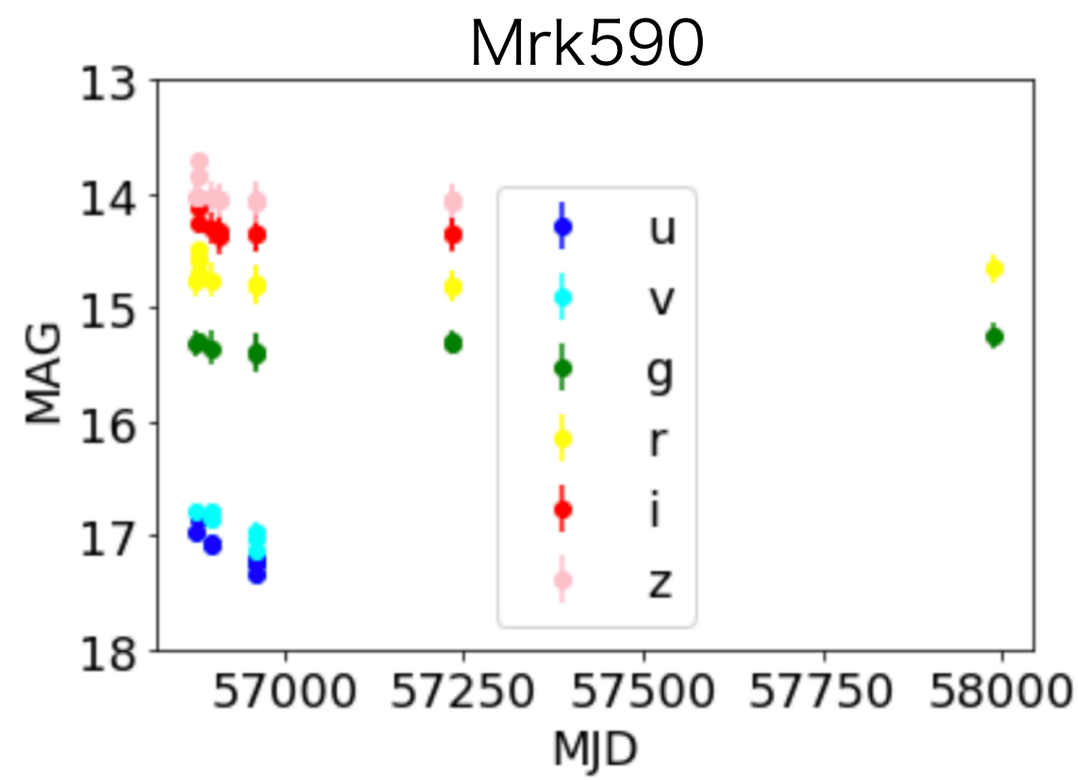
PanSTARRSの場合の利用法と同様

*python*からWeb-API catalog cone search —> download & plot

```
# dr2.photometry  CSV  output
# Mrk590     (SR=search radius in deg unit.)
# http://skymapper.anu.edu.au/sm-cone/public/query?RA=33.639837321&DEC=-0.
↪766719986&SR=0.0003&VERB=3&CATALOG=dr2.photometry&RESPONSEFORMAT=CSV
#

url = "http://skymapper.anu.edu.au/sm-cone/public/query?RA=33.639837321&DEC=-0.
↪766719986&SR=0.0003&VERB=3&CATALOG=dr2.photometry&RESPONSEFORMAT=CSV"

#r = requests.get(url, params=payload)
r = requests.get(url)

df_phot = pd.read_csv(io.BytesIO(r.content),sep=",")
```

```
df_phot.columns
```

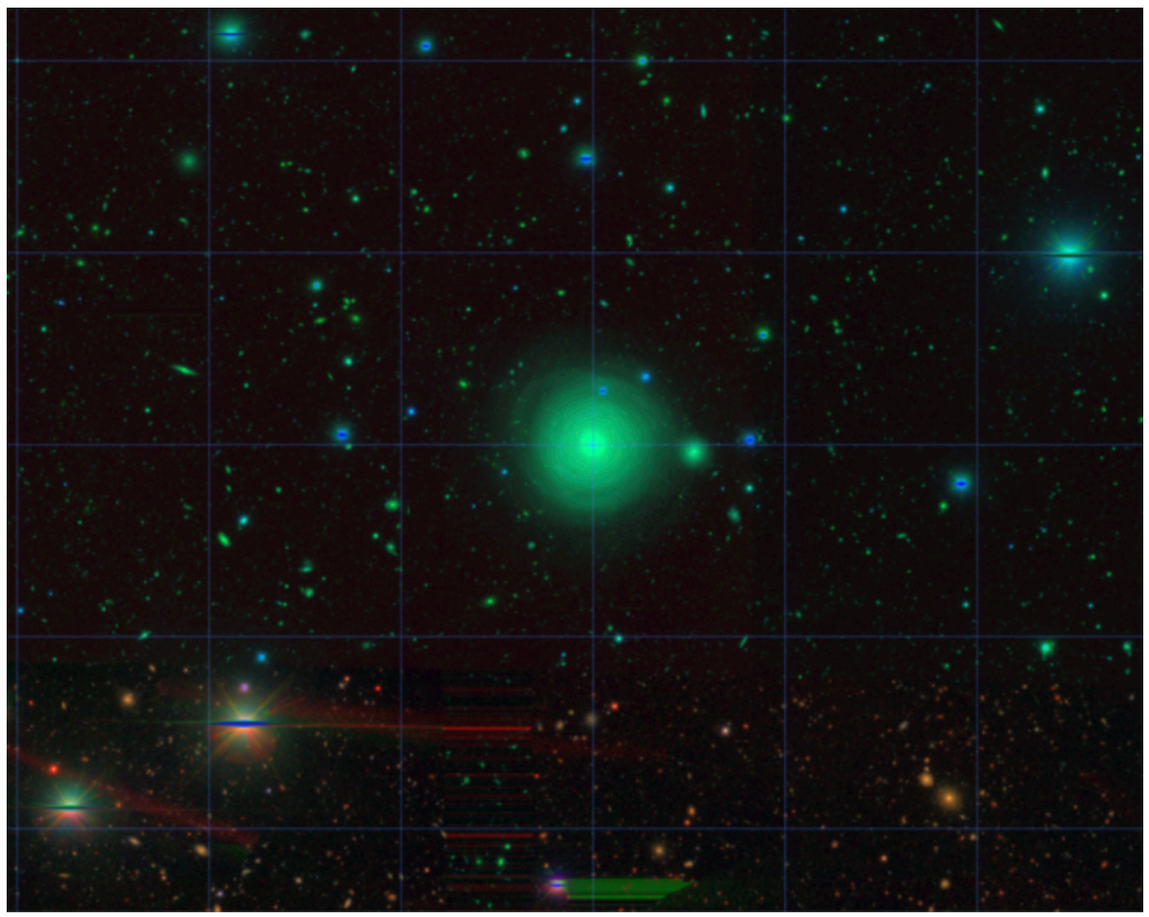
```
Index([u'r_cntr', u'object_id', u'object_id_local', u'image_id', u'ccd',
       u'filter', u'ra_img', u'decl_img', u'x_img', u'y_img', u'flags',
       u'nimaflags', u'imaflags', u'background', u'flux_max', u'mu_max',
       u'class_star', u'a', u'e_a', u'b', u'e_b', u'pa', u'e_pa', u'elong',
       u'fwhm', u'radius_petro', u'radius_kron', u'radius_frac20',
       u'radius_frac50', u'radius_frac90', u'chi2_psf', u'flux_psf',
       u'e_flux_psf', u'mag_psf', u'e_mag_psf', u'flux_petro', u'e_flux_petro',
       u'mag_petro', u'e_mag_petro', u'flux_kron', u'e_flux_kron', u'mag_kron',
```



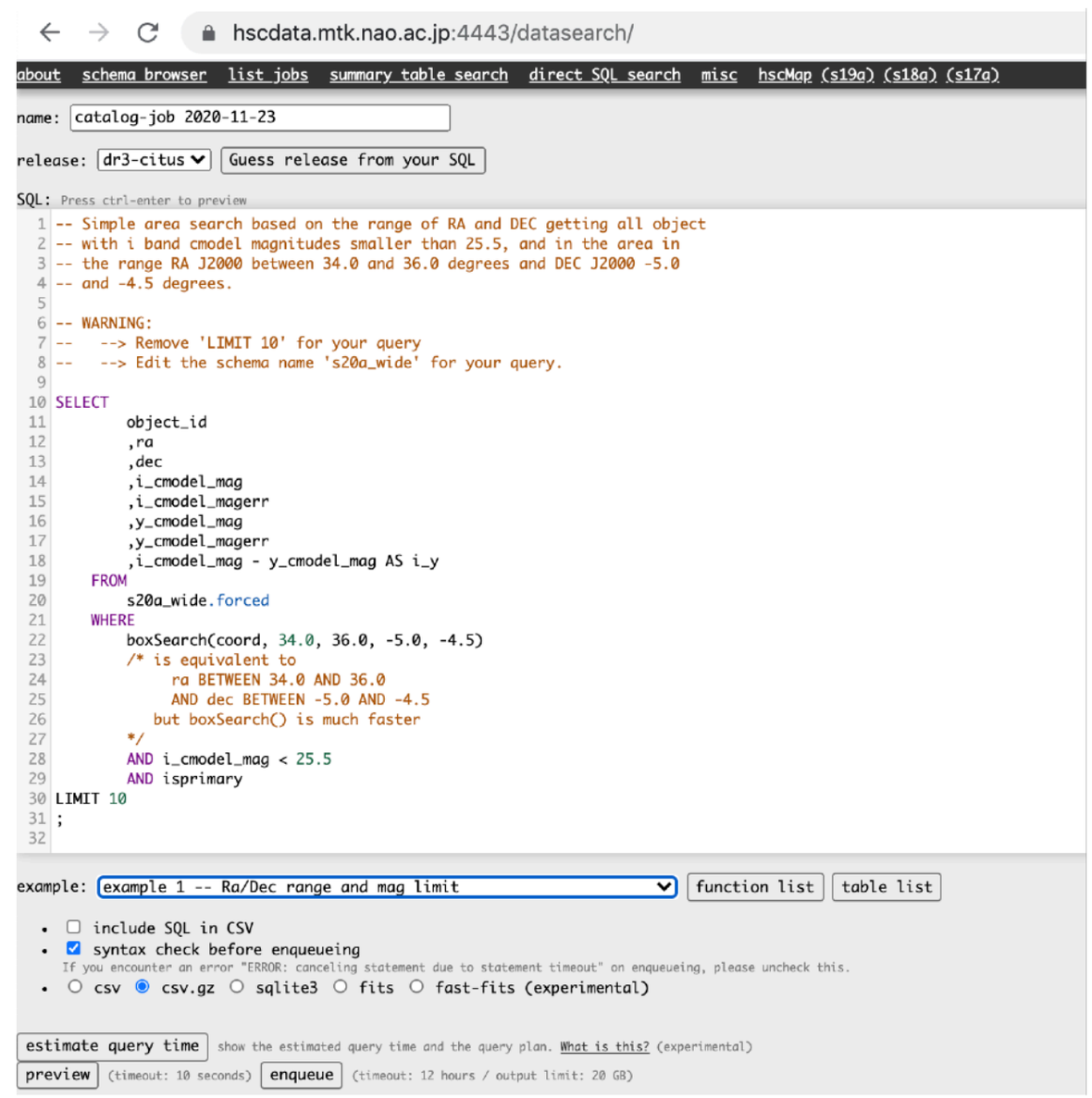
PanSTARRSの場合の利用法と同様

Subaru/HSC public/internal data release

- SDSSのデータベース同等 … sky viewer, SQL catalog/data archive server など共通



https://hsc-release.mtk.nao.ac.jp/hscMap-pdr2/app/



https://hsc.mtk.nao.ac.jp/ssp/japanese-data-access/

Summary

- SDSSレガシーサーベイでカバーされなかった天域に対する撮像サーベイが完了(PanSTARRS 3π)・進行中(SkyMapper Southern Survey).
  他にも, 本スライドでは触れなかった無数の掃天サーベイ, 突発天体サーベイがあり、公開データを提供しているものもある.

- 公開データの構造やアクセス方法はサーベイ間で共通点が多い.
  しかし残念ながら各サーベイの”癖"があるので、**Webページのマニュアルを読み込む必要がある.** Webページには大抵, 多くのquery例が掲載されており、少し改変すれば自分のサイエンスにすぐ使える.

- LSSTなどの将来計画でも、公開データは同様の方法で提供されるだろう.