# DETECTOR EFFECTS SIMULATION

# FOR CSST

Xianmin Meng @NAOC On behalf of the
simulation team

JUNE, 14$^{\text{TH}}$, 2021

# OUTLINE

- CSST/Survey Camera

  Mission, hardware, science goals, ...

- Image Simulation System

  Tasks & goals, Instrumental Effects Simulation

- Detector Effects Simulation

  Considerations and Implementations

- Plans

  Test & update

# CSST

- Telescope
  - 2m optical China Space Station Telescope
  - @400 km low earth orbit
  - off-axis TMA; $R_{80}$~0.15″

- Instruments
  - Survey Camera (SC), Terahertz Receiver (THz), Multichannel Imager (MCI), Integral Field Spectrograph (IFS), Cool-Planet Imaging Coronagraph (CPIC)

- Mission
  - Wide-area multiband imaging + slitless spectroscopic survey (7yr, ~17,500 □°)
  - Other key programs + GO programs (2+yr)

- Science goals
  - Cosmology: weak lensing, large-scale structure, BAO, …
  - Galaxy formation and evolution
  - Milky way, stellar to solar systems
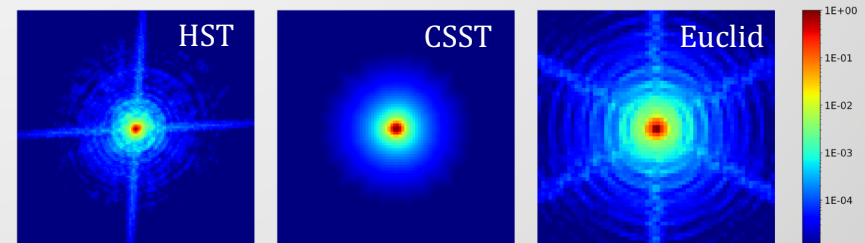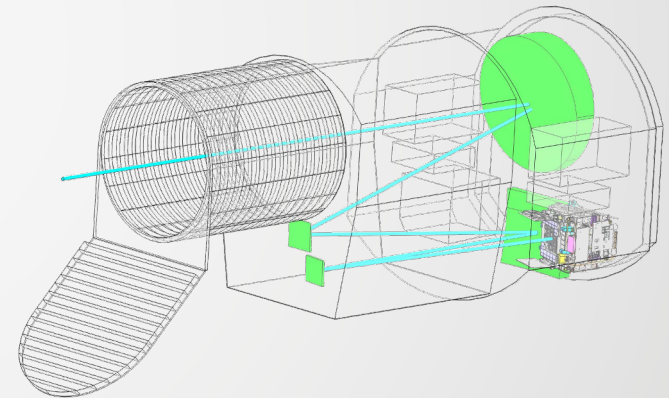
# SURVEY CAMERA

- 30 CCD290-99 / CMOS detectors array; 9k×9k each

18 imaging + 12 slitless spectroscopy
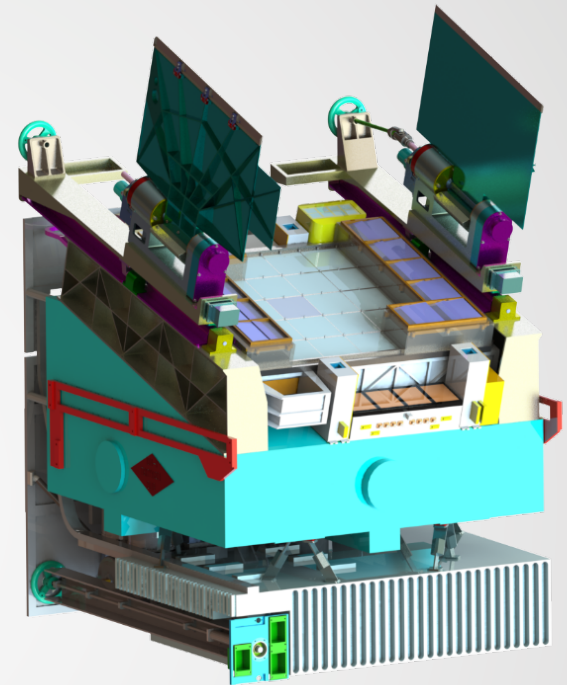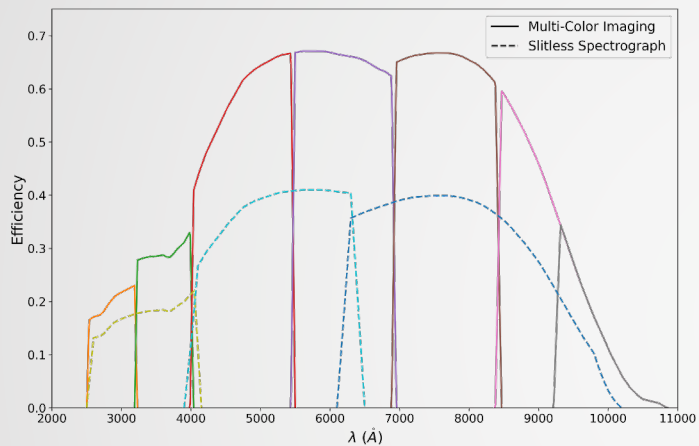




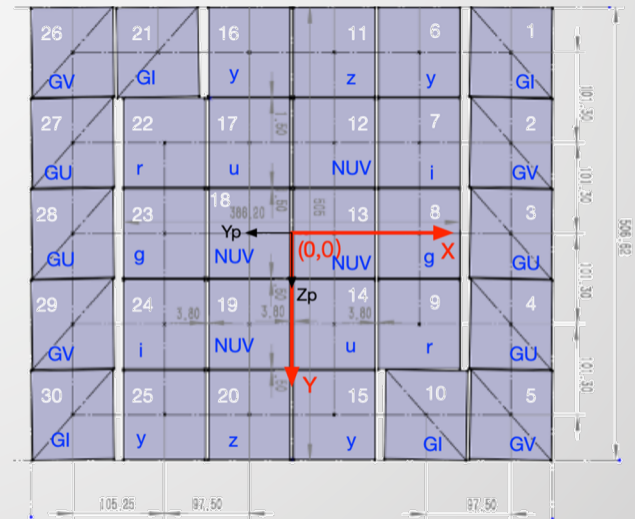| Limits (5$\sigma$) | NUV | $u$ | $g$ | $r$ | $i$ | $z$ | $y$ |
|---|---|---|---|---|---|---|---|
| main survey (150s×2) | 25.4 | 25.4 | 26.3 | 26.0 | 25.9 | 25.2 | 24.4 |
| deep survey (250s×8) | 26.7 | 26.7 | 27.5 | 27.2 | 27.0 | 26.4 | 25.7 |
| Spectroscopy (integrated) | GU | | GV | | GI | | |
| main survey (150s×4) | 23.2 | | 23.4 | | 23.2 | | |
| deep survey (250×16) | 24.3 | | 24.5 | | 24.3 | | |

# IMAGE SIMULATION SYSTEM

- Provide mock images & catalogs for Data Processing System

- Include weak-lensing effect for >1000 □°

- Support science groups requirements

- Perform SC, MCI, IFS, CPIC simulations
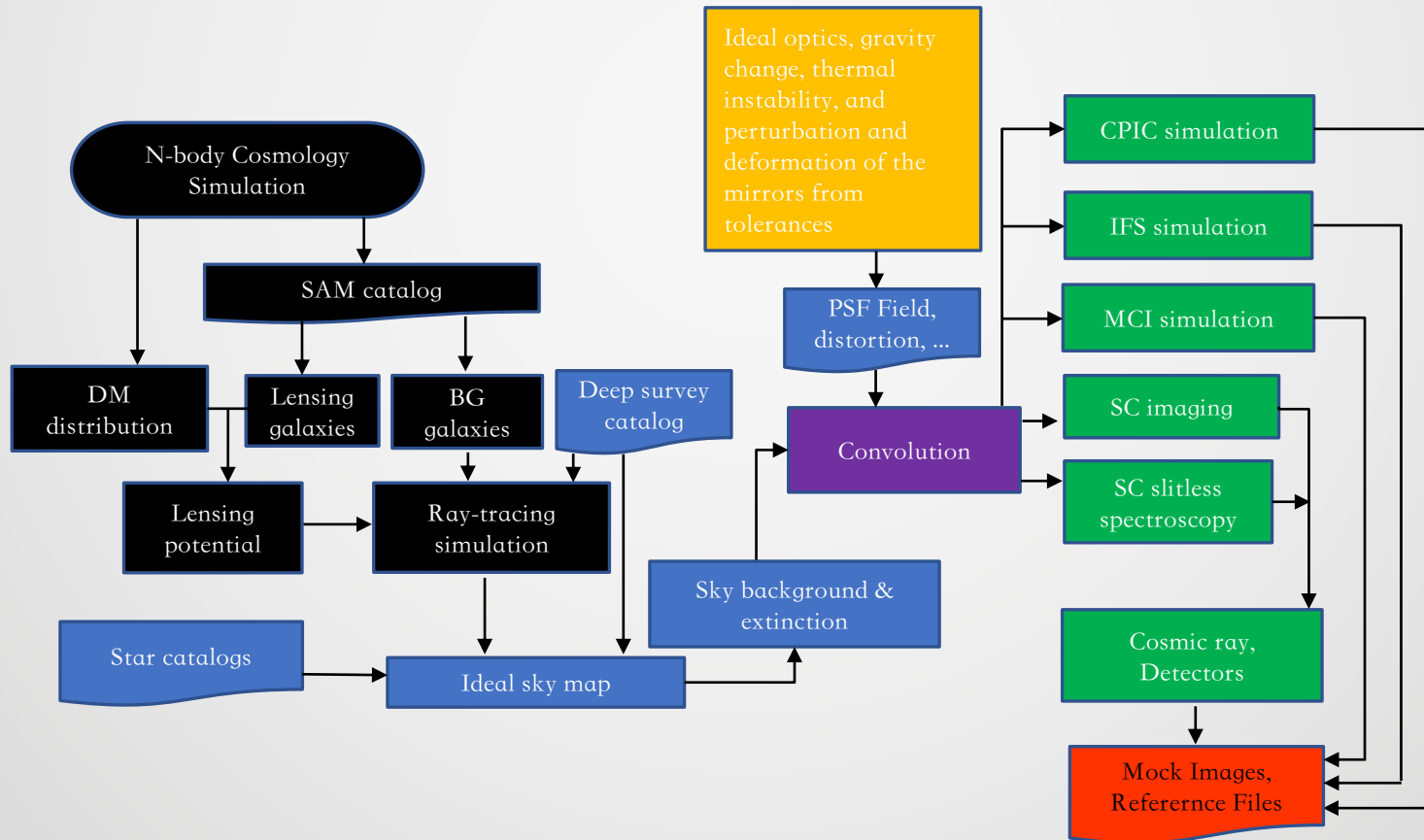
# SOFTWARES & TOOLS

- **Code V/Zemax**: optical simulation

  **Nastran, NX/TMG, Matlab/Sigfit**: structure analysis, thermal analysis, interface analysis

- **GalSim**: objects simulation, some instrumental effects, image rendering

- **Python 3**, numpy, astropy, mpi4py

- **Linux**: CentOS/Ubuntu/Debian/...

- **HPC** (current cycle):

  Hardwares: 1040 cores @2.4GHz, DDR4 6.6TB RAM, 1.4PB Volume

  Softwares: PBSpro; Intel & GNU compilers; open MPI & Intel MPI; etc.

# INSTRUMENTAL(&DETECTOR) EFFECTS

| GalSim implemented | Self developed |
|---|---|
| PSF convolution | PSF field and distortion |
| Poisson & Gaussian Noises | Mirror reflection rate |
| Focal plane definition | Filter transmission rate |
| Photon shooting | slitless spectroscopy |
| Non-linear response (on/off) | Vignetting (on/off) |
| Brighter-fatter effect (on/off) | Shutter shading (on/off) |
| Charge diffusion effect (on/off) | Quantum efficiency |
| Readout noise (on/off) | PRNU (on/off) |
| Quantization & 16-bit image output | Dark current (on/off) |
| | Bad lines (on/off) |
| | Defective pixels (on/off) |
| | 16 channel bias (on/off) |
| | Saturation and blooming (on/off) |
| | Charge transfer efficiency(CTE) (on/off) |
| | 16 channel gain (on/off) |
| | Reference files simulation (Flats, Darks, Biases) (on/off) |

# DETECTOR EFFECTS SIMULATION

## Focal plane definition

Use galsim Bounds :

galsim.PositionD(x,y) $\Longrightarrow$

galsim.CelestialCoord(),

galsim.AffineTransform(),

galsim.TanWCS() $\Longrightarrow$

wcs.toWorld() $\Longrightarrow$

galsim.BoundsD(ra,dec) in degree

## Photon shooting

galsim.SED() $\Longrightarrow$

galsim.Sersic() $\Longrightarrow$

GSObject.withFlux() $\Longrightarrow$

galsim.Shear() $\Longrightarrow$

galsim.Convolve() $\Longrightarrow$

GSObject.drawImage()

## Non-linear response

$$f(x) = x - \beta x^2$$

GSImage.applyNonlinearity(fx, beta1=5E-7, beta2=0)

## Brighter-fatter effect, Charge diffusion effect

galsim.SiliconSensor.accumulate(),

*strength*=2.3 until CCD290 test results provided

## Readout noise

galsim.GaussianNoise() $\Longrightarrow$

GSImage.addnoise()

## Quantization & 16-bit image output

GSImage.replaceNegative(replace_value=0) $\Longrightarrow$

GSImage.quantize() $\Longrightarrow$

GSImage=galsim.ImageUS(GSImage) $\Longrightarrow$

astropy.io.fits rendering

# DETECTOR EFFECTS SIMULATION

## Quantum efficiency

| NUV, *u*, GU | Standard Silicon Enhanced UV0 | QE: 0.5 ~ 0.6 |
|---|---|---|
| *g, r*, GV | Standard Silicon Astro Multi-2 Coating | QE: 0.6 ~ 0.92 |
| *i, z, y*, GI | Deep Depletion Astro Multi-2 Coating | QE: 0.9 ~ 0 |

## PRNU

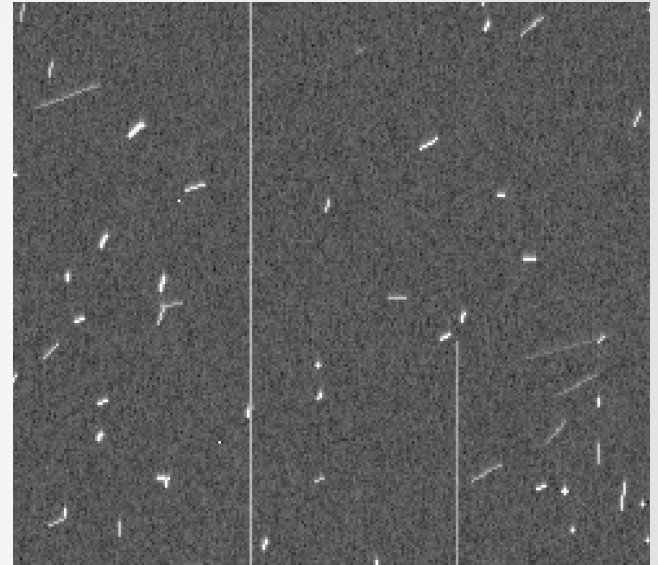Randomization for 30 CCD/CMOS, each has mean=1, sigma=0.01

## Defective pixels

- Total fraction: 0.005%
- Randomization for:
  - Dark/dead pixels:

    70% mean QE; $\sigma$=5 e$^-$ ; Higher than Bias level
  - Hot pixels:

    Current cycle: Gamma distribution, $\alpha$=2 e$^-$, $\lambda$=3000 e$^-$

    Planning: according to dark current distribution histogram
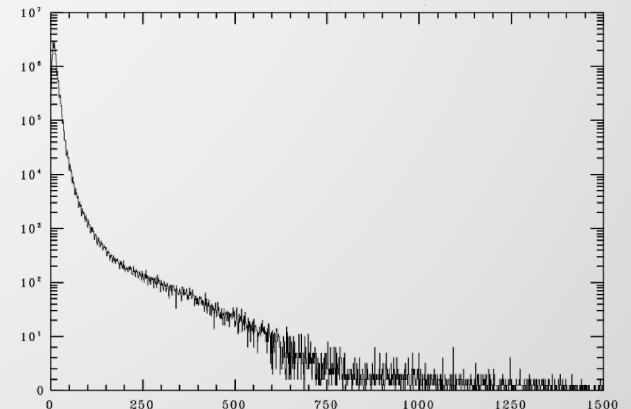
# DETECTOR EFFECTS SIMULATION

## Bad lines

- Consider bad lines brighter than background

- Science images, flat-fields, dark images

- Randomization for:
    - Number on each CCD chip (1~5 for section A/section D)
    - Positions (0.05~0.95 x-size)
    - Lengths (0.1~0.7 y-size)
    - Mean value: 1.3*mean_back+50 ~ 2*mean_back+150 (e$^-$)
    - Noises: 2*noise_back, Gaussian
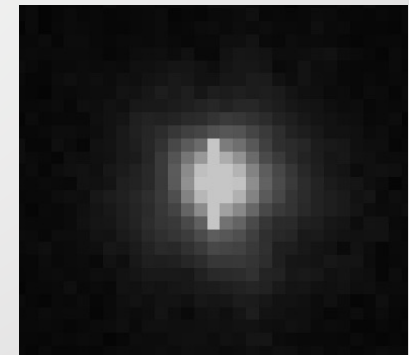
- Higher than Bias level

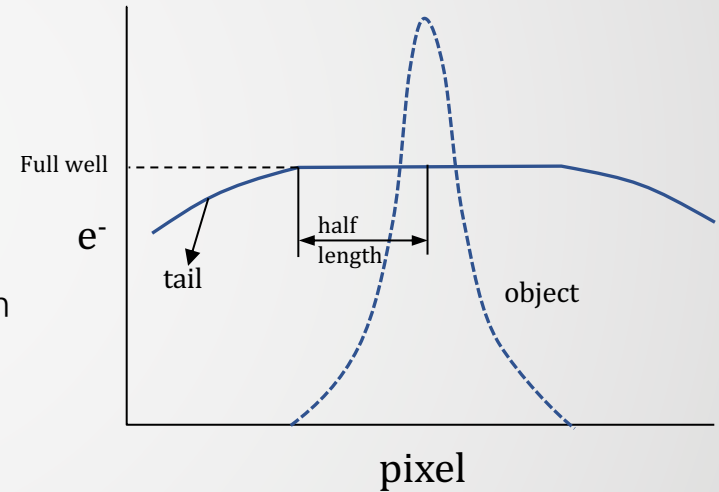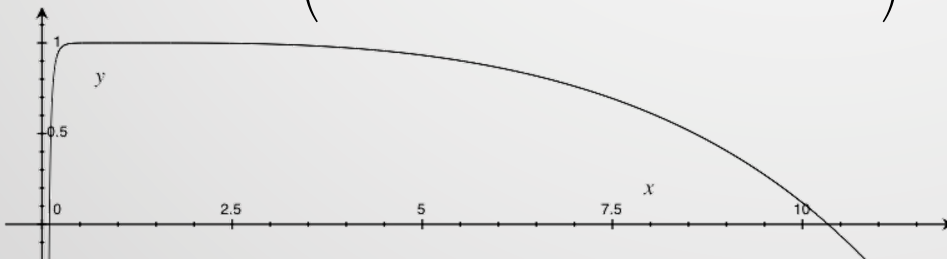# DETECTOR EFFECTS SIMULATION

## 16 channel bias

- mean=500 e-, randomize 16 channels within ±10 e-
- Randomization for 30 CCD/CMOS and fix pattern

## Saturation and blooming

- Full well: 90 ke$^-$
- blooming in two direction
- Ne$_{half}$ =0.45~0.55 Ne$_{saturated}$
- half lenghth $= a * \left[ \ln \left( \frac{Ne_{half}}{\text{Fullwell}} \right) \right]^{b}$ , shrinking blooming length
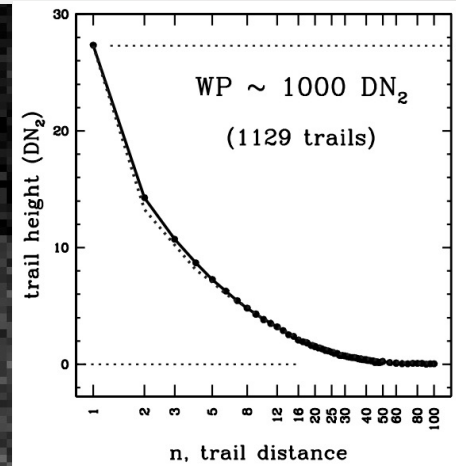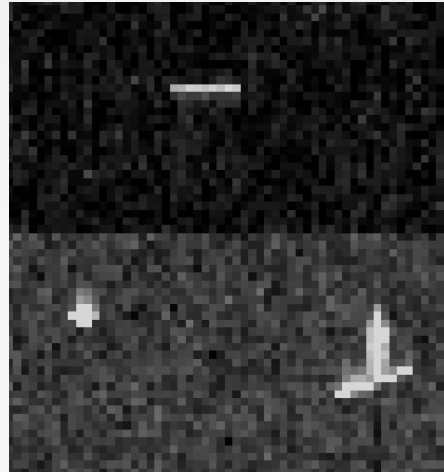
- $Ne_{tail} = Fullwell \cdot \left( 1 - 0.1 \cdot \frac{\left( 0.5 \cdot \left( e^{\frac{(\ln x)3}{5}} + e^{-\frac{(\ln x)3}{5}} \right) - 1 \right)}{0.5 \cdot \left( e + e^{-1} \right) - 1} \right)$



pixel

# DETECTOR EFFECTS SIMULATION

## Charge transfer inefficiency (CTI) effect

- phenomenological simulation

  - $Ne_{trail} = a * e^{-b*x} + c$

  - select row/column direction

  - adjustable length

  - will be revised after engineering test



Anderson & Bedin 2010

## Gain

- 30 CCD/CMOS randomization

- 16 channel randomization

- mean*(1±0.02)

# DETECTOR EFFECTS SIMULATION

## Reference files simulation

- Bias: 16 channel bias + readout noise + 0.01s cosmic-ray + 16 channel gain + quantization + 16 bit image output


- Dark: 300s dark level & Poisson noise + 300s cosmic-ray + CTE + bad lines + defective pixels + 16 channel bias + readout noise + quantization + 16 bit image output


- Flat-field: vignetting*PRNU & Poisson noise + 150s dark level & Poisson noise + 150s cosmic-ray + CTE + bad lines + defective pixels + 16 channel bias + readout noise + quantization + 16 bit image output

# Simulated $i$ -band in ~2 arcmin²
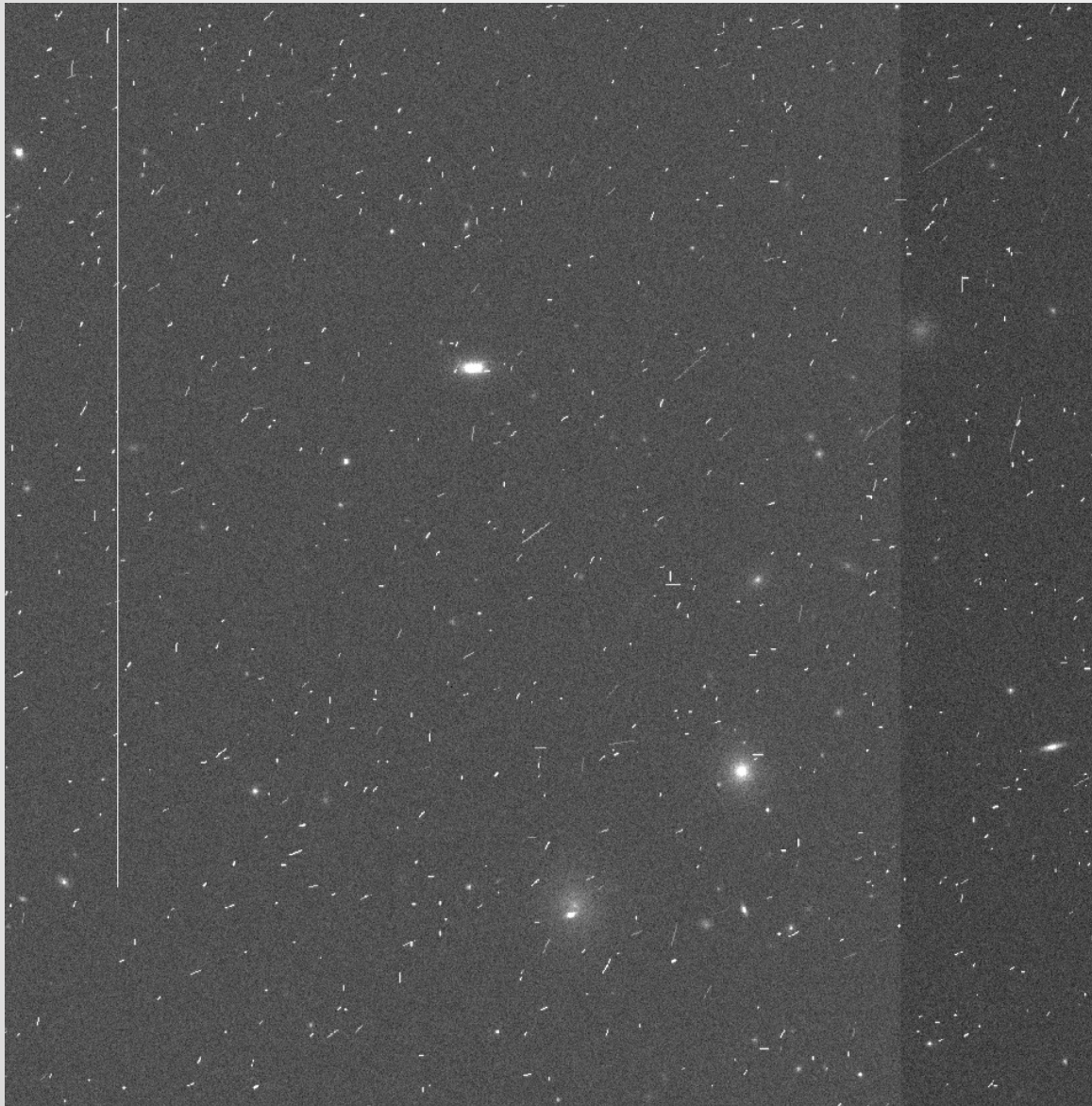
# GI-band slitless spectra
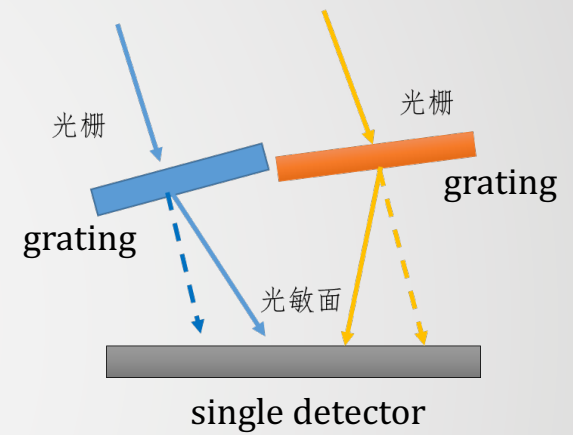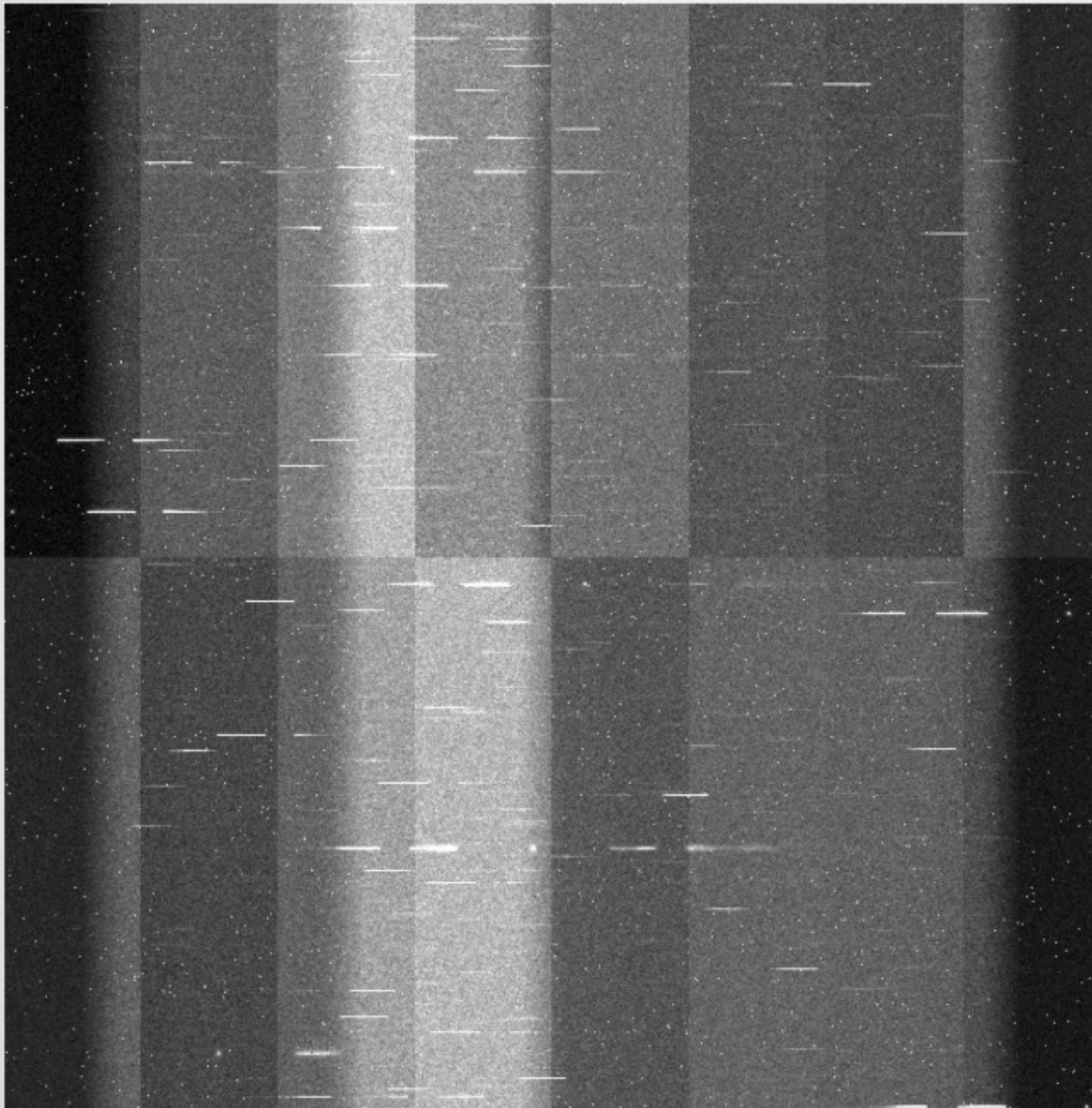
# PLAN TO DO

- Cross-talk effect

- inter/intra-pixel effect

- Revise non-linearity

- 16-channel readout into sub-images + prescan & overscan

- Qualification model test, statistics & update B-F, charge diffusion, hot pixels, etc.

- Cycle 3 now / Cycle 6

## Welcome Discussions!

Contact to: mengxm@nao.cas.cn