Image Processing Algorithms

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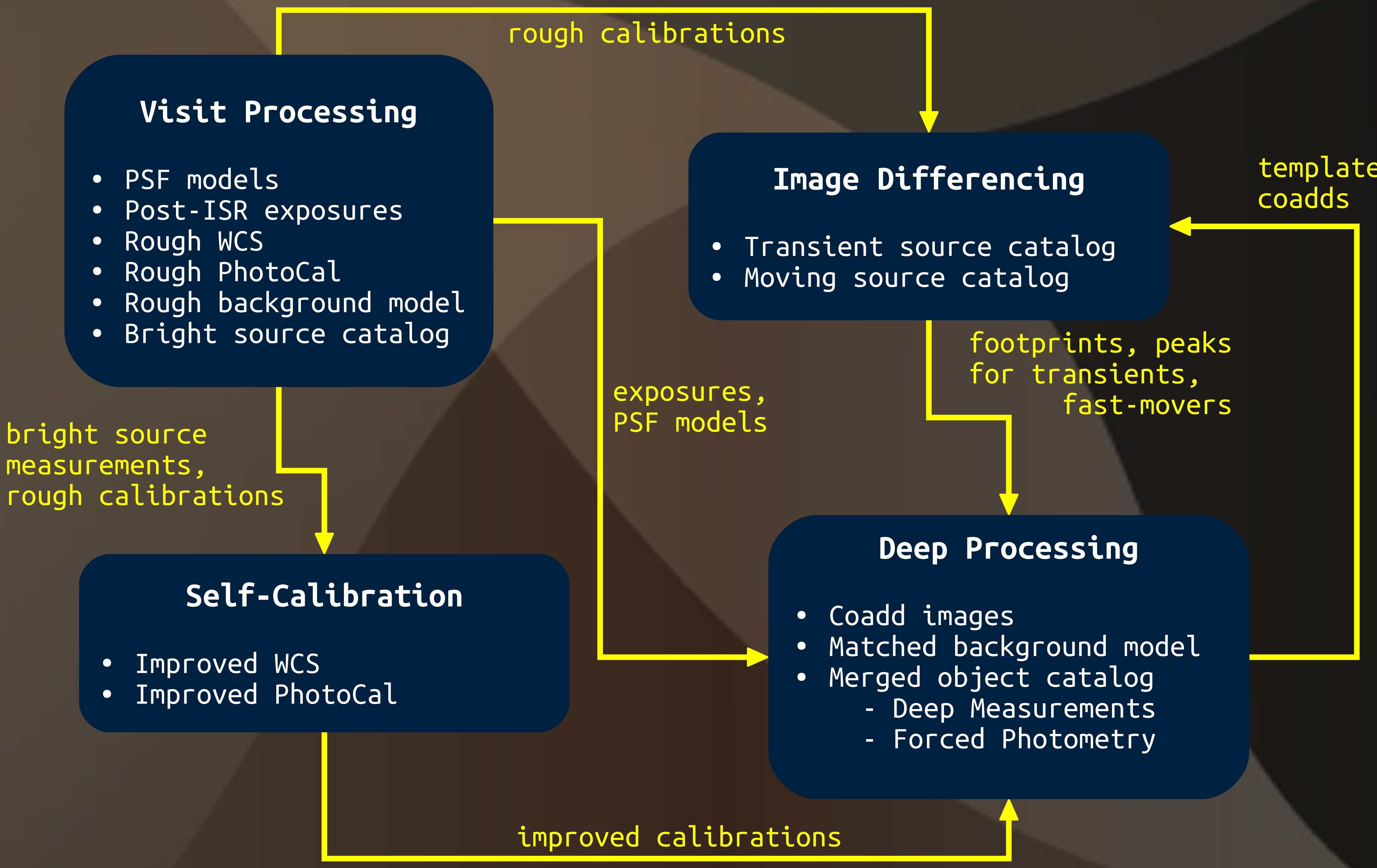
Image Processing Algorithms

- Overview of LSST Pipelines
  - Visit Processing
  - Self-Calibration
  - Image Differencing
  - Deep Processing

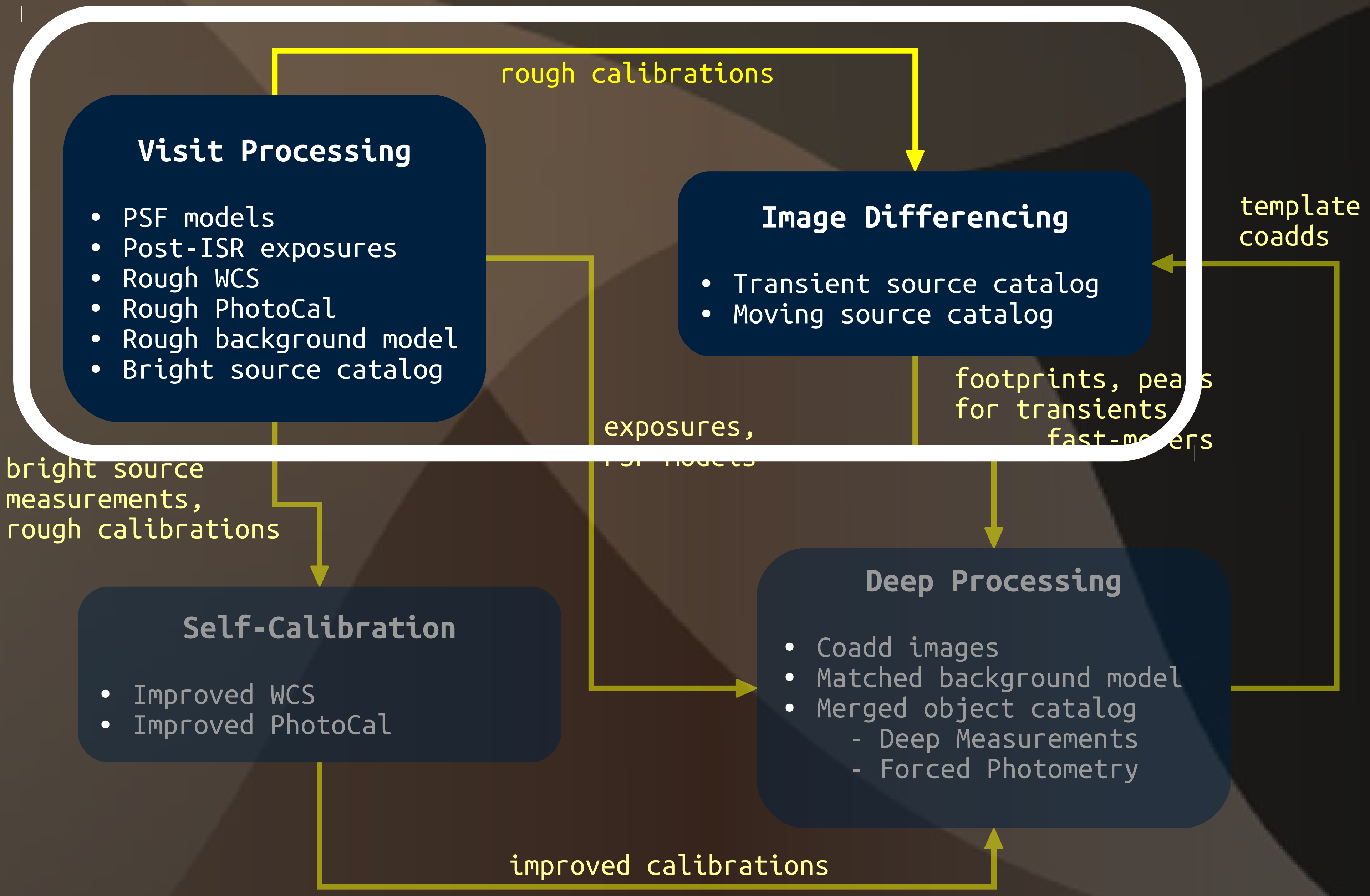
- Detection Algorithms
  - The Simple Case
  - Brainstorming Extensions

- Kinds of Coadds

LSST Data Release Pipeline (Yearly)



LSST Alert Pipeline (Nightly)



Visit Processing

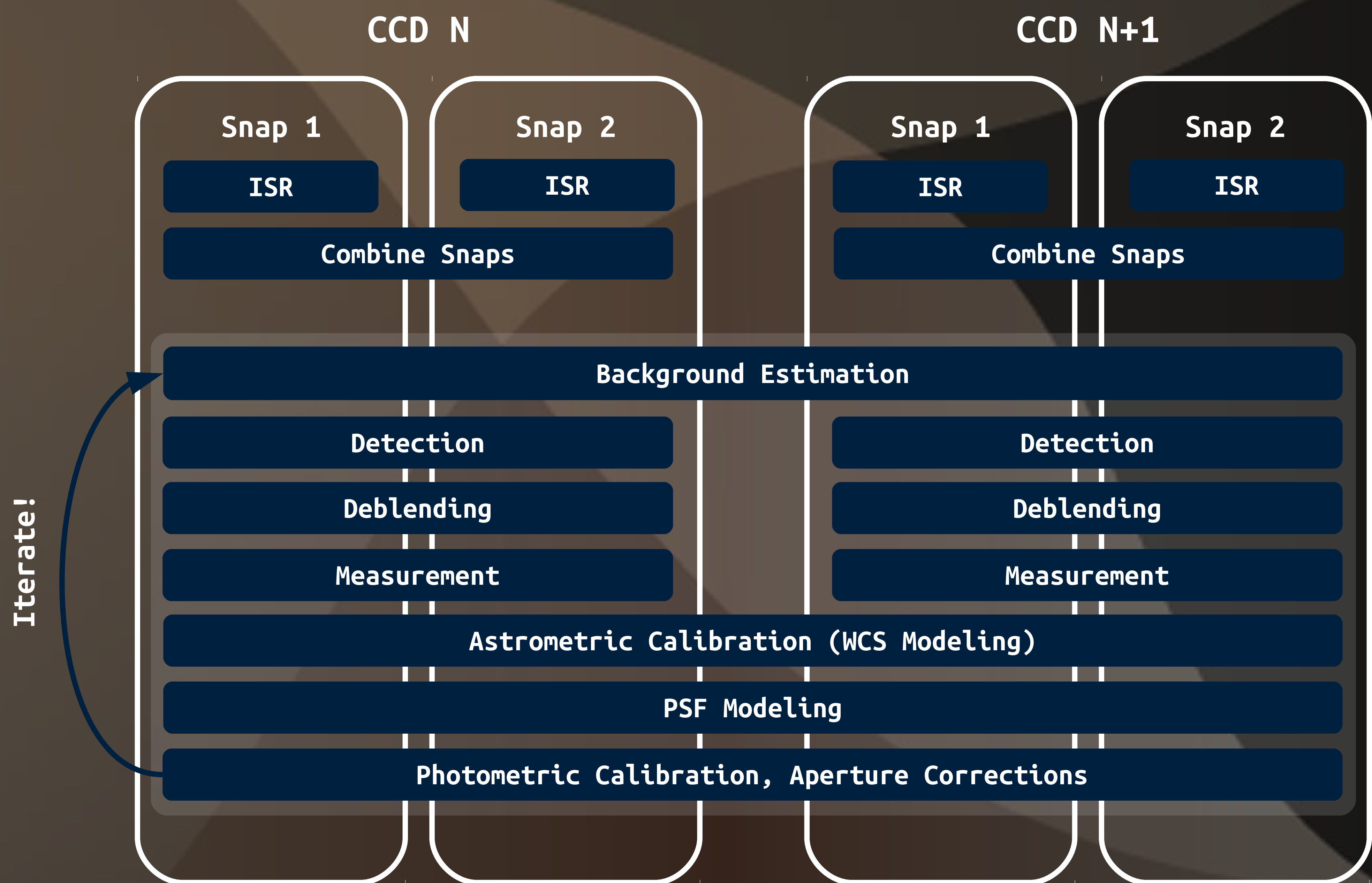
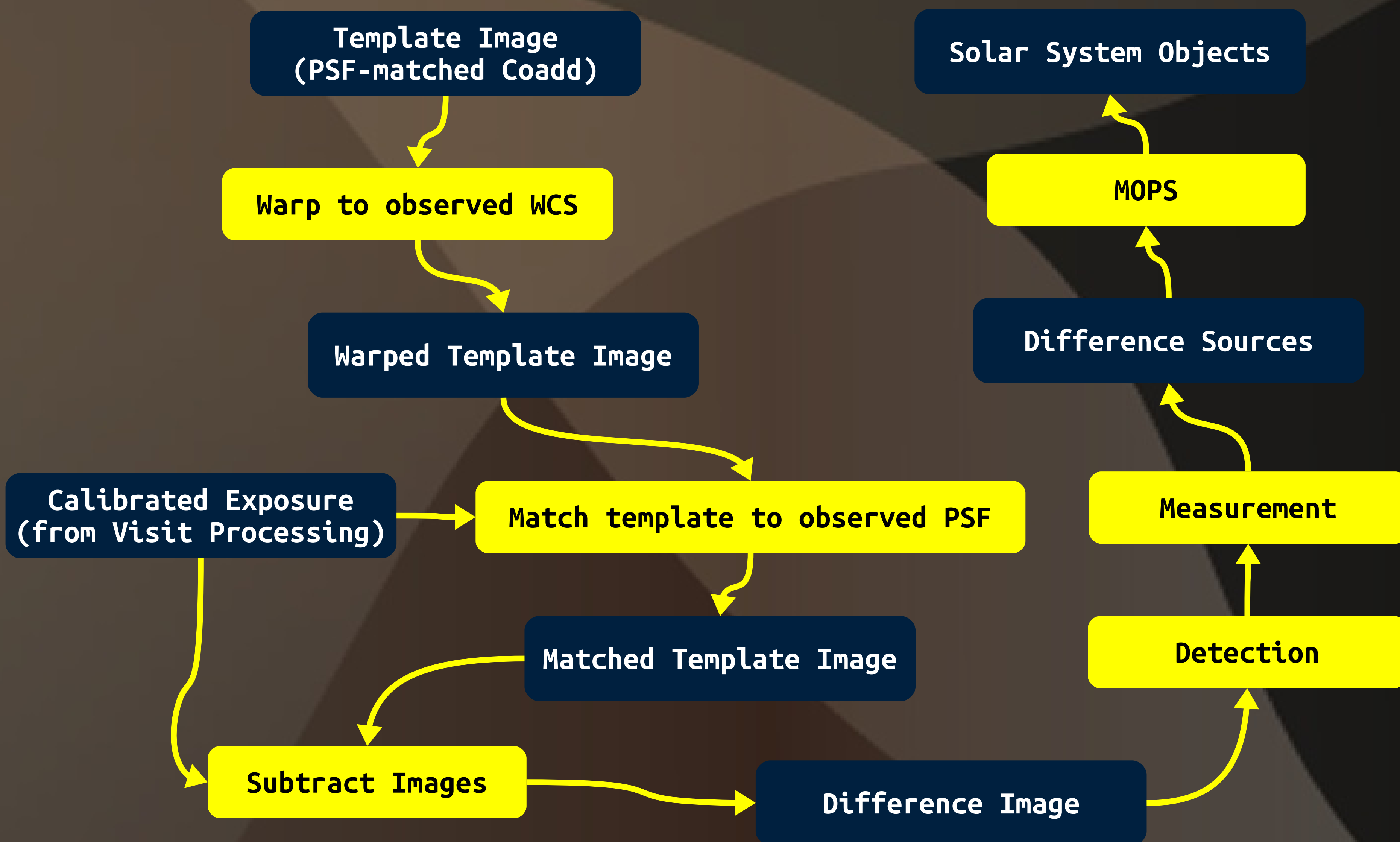
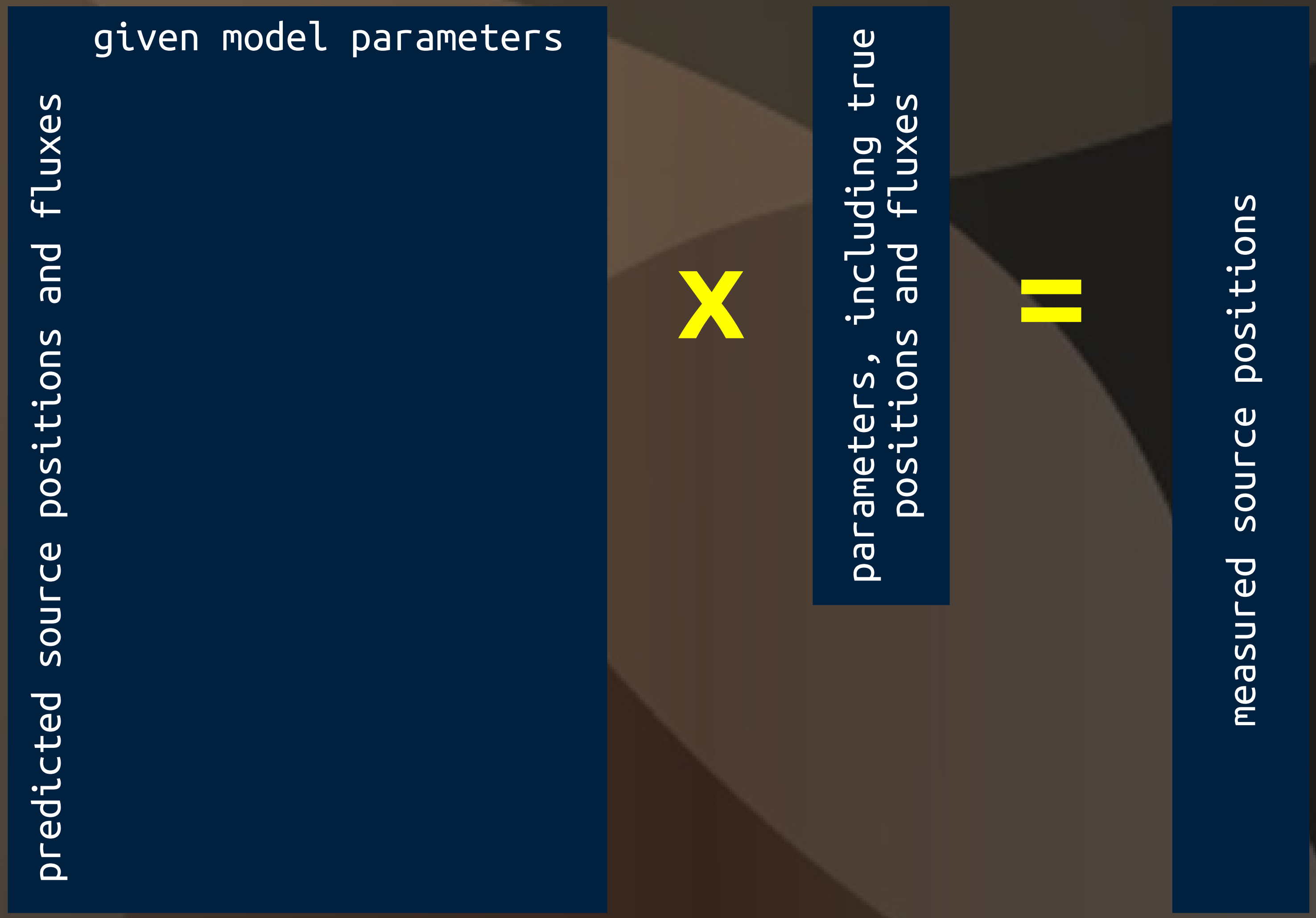


Image Differencing



All of this is one CCD at a time

Self-Calibration



Deep Processing

- Improve background models
  - demand consistency between epochs ("background matching")
- Detect sources at full depth
  - probably use some coadds; which ones?
- Associate deep sources with transient/moving sources
- Deblend everything consistently
  - probably use some coadds; which ones?
- Measure everything consistently
  - start on coadds
  - tune up fitting using all epochs together

Detection: Point Source, Single Image

- We want to find all point sources in an image with known Gaussian noise and known PSF, above a certain *significance*.

- Here's our log-likelihood:

$$L(\alpha, x, y) = -\ln P(I|x, y, \alpha)$$
$$= \frac{1}{2} \sum_{i,j} \left[\frac{I_{i,j} - \alpha p_{i,j}(x, y)}{\sigma_{i,j}} \right]^2$$

pixel indices

Detection: Point Source, Single Image

- We want to find all point sources in an image with known Gaussian noise and known PSF, above a certain *significance*.

source position our log-likelihood:

$$L(\alpha, \boxed{x, y}) = -\ln P(I|x, y, \alpha)$$

$$= \frac{1}{2}\sum_{i,j}\left[\frac{I_{i,j} - \alpha p_{i,j}(x, y)}{\sigma_{i,j}}\right]^2$$

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- We want to find all point sources in an image with known Gaussian noise and known PSF, above a certain *significance*.

- Here's our log-likelihood:

image data

$$L(\alpha, x, y) = -\ln P(I|x, y, \alpha)$$
$$= \frac{1}{2}\sum_{i,j}\left[\frac{\boxed{I_{i,j}} - \alpha p_{i,j}(x, y)}{\sigma_{i,j}}\right]^2$$

Detection: Point Source, Single Image

- We want to find all point sources in an image with known Gaussian noise and known PSF, above a certain *significance*.

- Here's our log-likelihood:

$$L(\boxed{\alpha}, x, y) = -\ln P(I | x, y, \boxed{\alpha})$$

$$= \frac{1}{2} \sum_{i,j} \left[\frac{I_{i,j} - \boxed{\alpha} p_{i,j}(x, y)}{\sigma_{i,j}} \right]^2$$

source flux

Detection: Point Source, Single Image

- We want to find all point sources in an image with known Gaussian noise and known PSF, above a certain *significance*.

- Here's our log-likelihood:

PSF model

$$L(\alpha, x, y) = -\ln P(I|x, y, \alpha)$$

$$= \frac{1}{2} \sum_{i,j} \left[\frac{I_{i,j} - \alpha \boxed{p_{i,j}(x, y)}}{\sigma_{i,j}} \right]^2$$

Detection: Point Source, Single Image

- We want to find all point sources in an image with known Gaussian noise and known PSF, above a certain *significance*.

- Here's our log-likelihood:

$$L(\alpha, x, y) = -\ln P(I|x, y, \alpha)$$

$$= \frac{1}{2} \sum_{i,j} \left[\frac{I_{i,j} - \alpha p_{i,j}(x, y)}{\boxed{\sigma_{i,j}}} \right]^2$$

pixel noise

Detection: Point Source, Single Image

$$L(\alpha, x, y) = \frac{1}{2} \sum_{i,j} \left[\frac{I_{i,j} - \alpha p_{i,j}(x, y)}{\sigma_{i,j}} \right]^2$$

Detection: Point Source, Single Image

$$L(\alpha, x, y) = \frac{\alpha^2}{2}\Phi(x, y) - \alpha\Psi(x, y) + K$$

$$\Phi(x, y) = \sum_{i,j} \frac{[p_{i,j}(x, y)]^2}{\sigma_{i,j}^2}$$

$$\Psi(x, y) = \sum_{i,j} \frac{I_{i,j}\ p_{i,j}(x, y)}{\sigma_{i,j}^2}$$

Detection: Point Source, Single Image

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$$\frac{\partial L(\alpha, x, y)}{\partial \alpha} = \alpha\Phi(x, y) - \Psi(x, y) = 0$$

$$\alpha_{ML} = \frac{\Psi(x, y)}{\Phi(x, y)}$$

Detection: Point Source, Single Image

$$L(\alpha, x, y) = \frac{\alpha^2}{2}\Phi(x, y) - \alpha\Psi(x, y) + K$$

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$$\frac{\partial L(\alpha, x, y)}{\partial \alpha} = \alpha\Phi(x, y) - \Psi(x, y) = 0$$

$$\alpha_{ML} = \frac{\Psi(x, y)}{\Phi(x, y)} \qquad L_{ML} = \frac{\Psi^2(x, y)}{2\Phi(x, y)}$$

Detection: Point Source, Single Image

Log-Likelihood for an object with flux α_{ML}:

$$L_{ML} = \frac{[\Psi(x,y)]^2}{2\Phi(x,y)} + K$$

Log-likelihood for zero flux: $L_0 = K$

Likelihood ratio: $\frac{e^{-L_{ML}(x,y)}}{e^{-L_0}} = e^{-[\nu(x,y)]^2/2}$

Significance: $\nu(x,y) = \frac{\Psi(x,y)}{\sqrt{\Phi(x,y)}}$

Detection: Point Source, Single Image

$$L(\alpha, x, y) = \frac{\alpha^2}{2}\Phi(x,y) - \alpha\Psi(x,y) + K$$

$$\Phi(x,y) = \sum_{i,j} \frac{[p_{i,j}(x,y)]^2}{\sigma_{i,j}^2}$$

$$\boxed{\Psi(x,y) = \sum_{i,j} \frac{I_{i,j}\; p_{i,j}(x,y)}{\sigma_{i,j}^2}}$$

correlation of image with PSF

$$\frac{\partial L(\alpha, x, y)}{\partial \alpha} = \alpha\Phi(x,y) - \Psi(x,y) = 0$$

$$\alpha_{ML} = \frac{\Psi(x,y)}{\Phi(x,y)} \qquad L_{ML} = \frac{\Psi^2(x,y)}{2\Phi(x,y)}$$

Detection: Point Source, Single Image

$$L(\alpha, x, y) = \frac{\alpha^2}{2}\Phi(x,y) - \alpha\Psi(x,y) + K$$

$$\boxed{\Phi(x,y) = \sum_{i,j} \frac{[p_{i,j}(x,y)]^2}{\sigma_{i,j}^2}}$$

depends only on
PSF model & noise

$$\Psi(x,y) = \sum_{i,j} \frac{I_{i,j}\; p_{i,j}(x,y)}{\sigma_{i,j}^2}$$

$$\frac{\partial L(\alpha, x, y)}{\partial \alpha} = \alpha\Phi(x,y) - \Psi(x,y) = 0$$

$$\alpha_{ML} = \frac{\Psi(x,y)}{\Phi(x,y)} \qquad L_{ML} = \frac{[\Psi(x,y)]^2}{2\Phi(x,y)} + K$$

Detection: Point Source, Single Image

Algorithm:

- Correlate image with PSF to get $\Psi(x,y)$
- Create $\Phi(x,y)$ as an image (or pretend it's constant)
- Find regions where $\nu(x,y)$ is greater than the target threshold (“footprints”)
- Within each footprint, find peaks

Detection: Point Source, ~~Single Image~~ Multiple Epochs

Algorithm:

- Correlate image with PSF to get $\Psi(x, y)$
- Create $\Phi(x, y)$ as an image (or pretend it's constant)
- Find regions where $\nu(x, y)$ is greater than the target threshold ("footprints")
- Within each footprint, find peaks

Detection: Point Source, ~~Single Image~~ Multiple Epochs

Algorithm:

- Correlate image with PSF to get $\Psi(x, y)$
- Create $\Phi(x, y)$ as an image (or pretend it's constant)
- Find regions where $\nu(x, y)$ is greater than the target threshold ("footprints")
- Within each footprint, find peaks

Detection: Point Source, ~~Single Image~~ Multiple Epochs

Algorithm:

- Correlate image with PSF to get $\Psi(x, y)$
- Create $\Phi(x, y)$ as an image (or pretend it's constant)
- Warp and Coadd $\Psi(x, y)$
- Warp and Coadd $\Phi(x, y)$
- Find regions where $\nu(x, y)$ is greater than the target threshold (“footprints”)
- Within each footprint, find peaks

Detection: Brainstorming Extensions

- Point sources, multiple epochs, multiple bands, unknown SED
- Galaxies, multiple epochs, single band
- Faint, high proper motion stars, multiple epochs, single band
- Faint supernovae, multiple epochs, multiple bands, known SED

Kinds of Coadds

- Why didn't we just coadd the pixels, instead of that $\Psi(x, y)$ thing?
- Ok, why don't we always just coadd $\Psi(x, y)$?
- What kinds of coadds might we want to create?

More Information

The official baseline pipeline outputs:

- Data Products Definition Document: http://ls.st/dpdd

DM's internal design documents (WIP; more to come) and long-term to-do list:

- https://confluence.lsstcorp.org/display/DM/Visit+Processing
- https://confluence.lsstcorp.org/display/DM/Deep+Processing

DM's short-term (~6-month) to-do list:

- https://jira.lsstcorp.org/secure/RapidBoard.jspa?rapidView=58&view=planning&epics=visible