The prospects of pulsating stars studies with ILMT

Peter De Cat

Royal Observatory of Belgium, Ringlaan 3, 1180 Brussels, Belgium

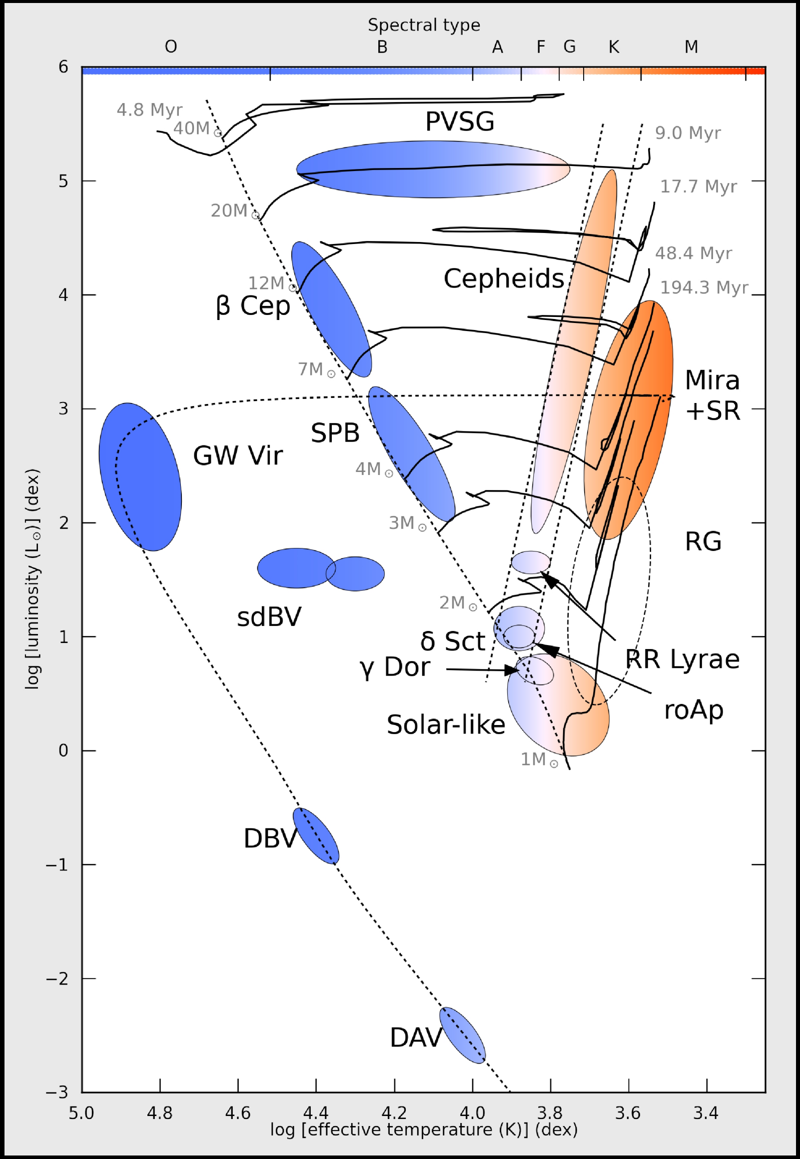
… with input from Brajesh Kumar, Brijesh Kumar & Jean Surdej

The prospects of pulsating stars studies with ILMT

Pulsating stars studies

- Different types and flavours

✗ Solar-like oscillators (solar-like)
✗ δ Scuti stars (δ Sct)
✗ γ Doradus stars (γ Dor)
✗ rapidly oscillating Ap stars (roAp)
✗ β Cephei stars (β Cep)
✗ Slowly Pulsating B stars (SPB)
✗ Periodically Variable Supergiants (PVS)
✗ RR Lyrae stars (RR Lyrae)
✗ Cepheids (Cepheids)
✗ Red Giant stars (RG)
✗ Mira variables (Mira)
✗ Semi-Regular variables (SR)
✗ sub-dwarf B Variables (sdBV)
✗ pulsating pre-white dwarfs (GW Vir)
✗ pulsating white dwarfs (DBV/DAV)



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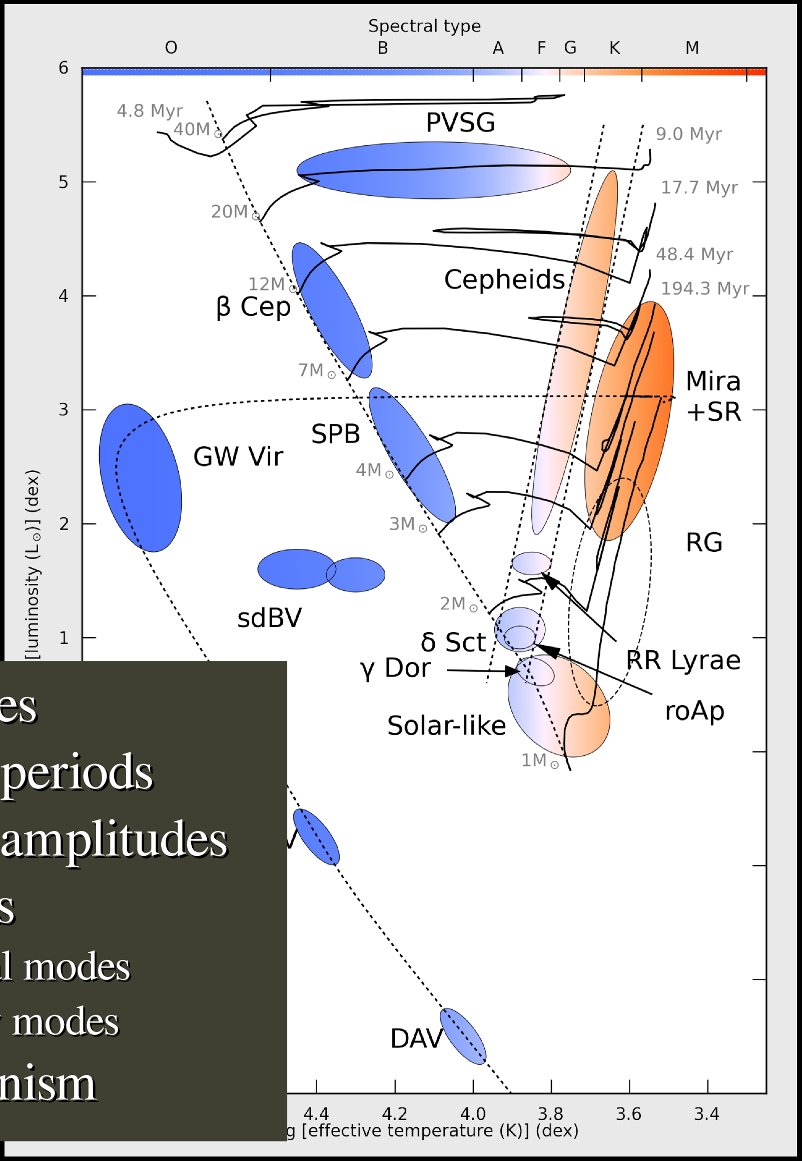
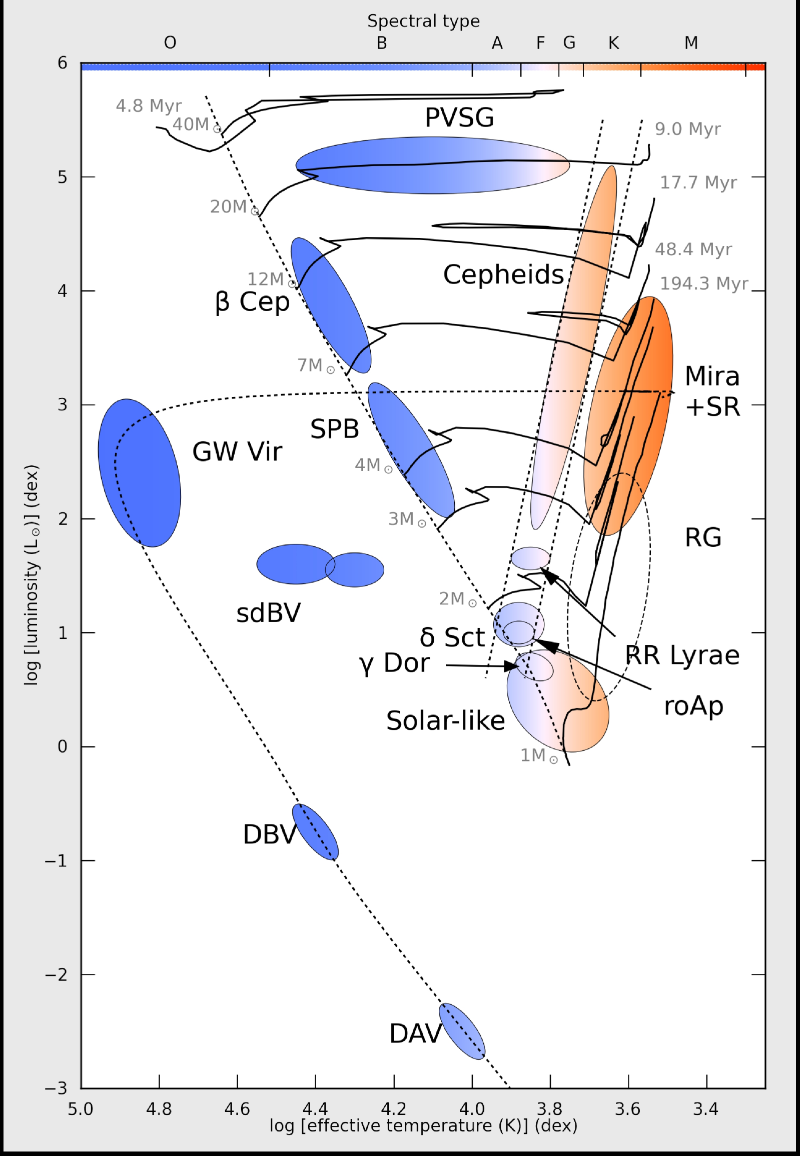


typical magnitudes
typical pulsation periods
typical pulsation amplitudes
type of pulsations
- radial/non-radial modes
- pressure/gravity modes

excitation mechanism

Pulsating stars studies

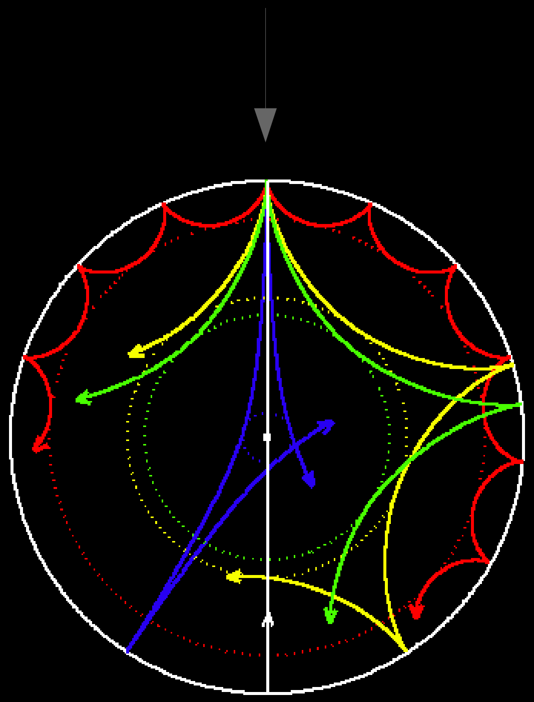
- Different types and flavours
- Asteroseismology
  - ➔ science in which stellar (aster) oscillations (seismo) are studied (logy) to gain information of stars
    - ✗ only way known to probe internal structure
    - ✗ derive stellar parameters with unprecedented precision (R, M, age,…)
    - ✗ direct tests to modeling of complex dynamical processes in stellar interiors (e.g. diffusion, convective overshoot)
    - ✗ improve understanding of stellar evolution



Requirements?

Requirements for asteroseismology

- large number of pulsation frequencies (each frequency probes specific layer)



Requirements for asteroseismology

- large number of pulsation frequencies (each frequency probes specific layer)
  - time series with sufficiently long time base
  - high-quality observations: photometry, radial velocities, line-profile variations

Kepler and K2

Gaia

- number of targets: few to millions
- magnitude range: bright to faint
- field of view: few deg^2 to all sky
- cadence of measurements: 20 sec to sparse
- total time base: 27 days to several years

lack of color information

Requirements for asteroseismology

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  - high-quality observations: photometry, radial velocities, line-profile variations
- identification of the pulsation modes (degree l, azimuthal number m)
  - Echelle diagram (in frequency for pressure modes, in period for gravity modes)
  - multi-colour photometry (amplitude ratios and phase differences)
  - high-resolution high-SNR spectroscopy

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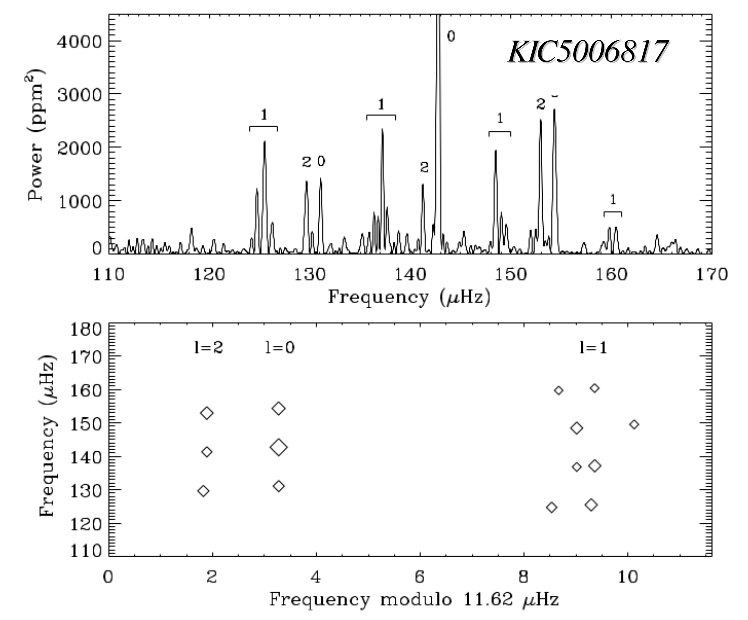

Bedding et al., 2010, ApJL 713, L176

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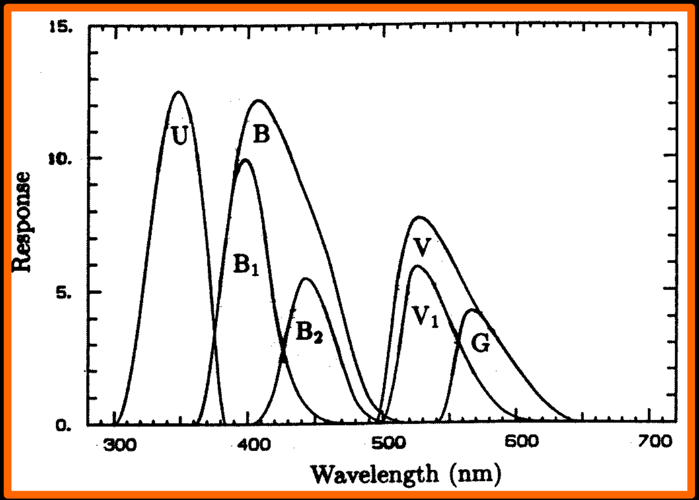
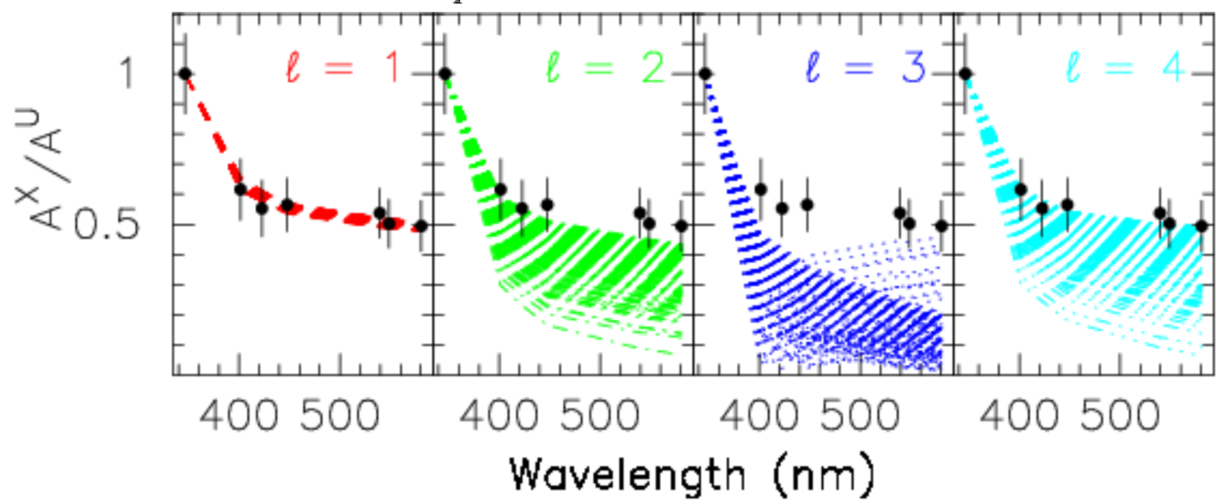


identification for f_1 = 1.1569 d^{-1} of HD 24587 (De Cat et al. 2005)



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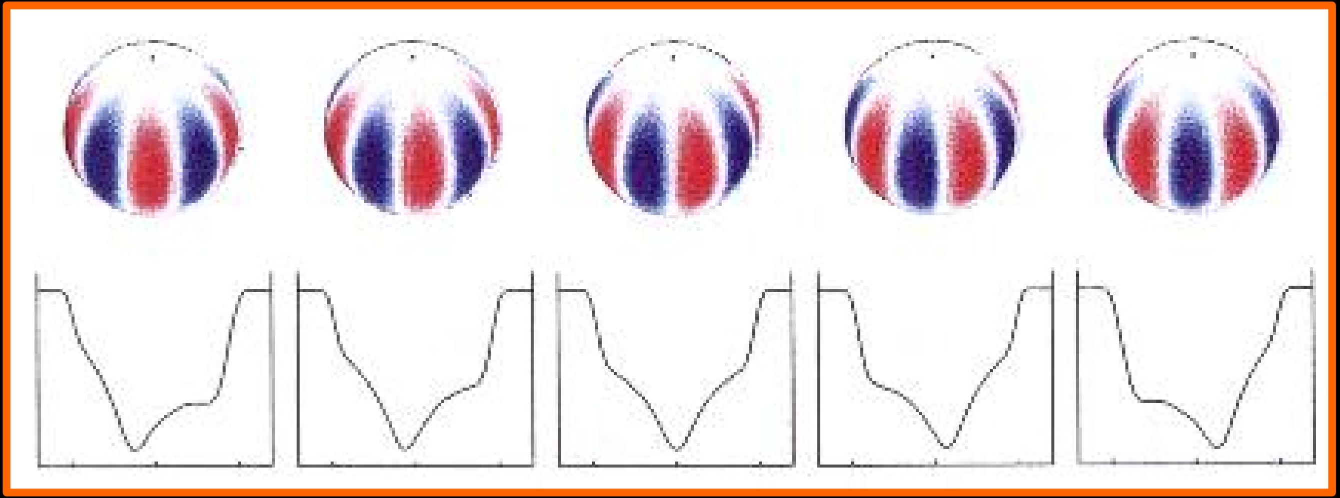

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- accurate stellar parameters
  - temperature (T_{eff}), surface gravity (log*g*), metallicity ([M/H])
  - projected rotational velocity (*v*sin*i*)
  - abundances

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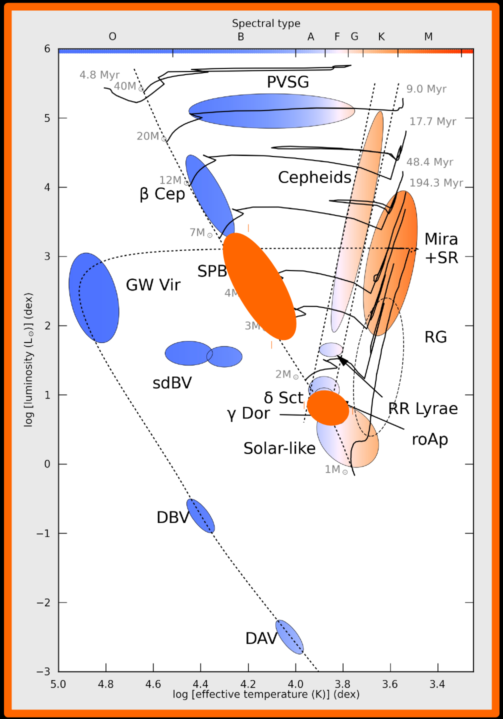

SPB and γ Dor stars

- gravity modes
- periods 0.3 – 3 days
- amplitudes up to 30 mmag

Requirements for asteroseismology

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  - time series with sufficiently long time base
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- identification of the pulsation modes (degree l, azimuthal number m)
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  - multi-colour photometry (amplitude ratios and phase differences)
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- accurate stellar parameters
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  - projected rotational velocity (*v*sin*i*)
  - abundances
- radial velocities can give extra constraints
  - multiple systems
  - cluster membership

Requirements for asteroseismology

- ➔ large number of pulsation frequencies (each frequency probes specific layer)
  - ✗ time series with sufficiently long time base
  - ✗ high-quality observations: photometry, radial velocities, line-profile variations

Frequency analysis

- ➔ identification of the pulsation modes (degree l, azimuthal number m)
  - ✗ Echelle diagram (in frequency for pressure modes, in period for gravity modes)
  - ✗ multi-colour photometry (amplitude ratios and phase differences)
  - ✗ high-resolution high-SNR spectroscopy

Mode identification

- ➔ accurate stellar parameters
  - ✗ temperature (T_{eff}), surface gravity (log*g*), metallicity ([M/H])
  - ✗ projected rotational velocity (v sin i)
  - ✗ abundances

Stellar parameters

- ➔ ~~radial velocities can give extra constraints~~
  - ✗ ~~multiple systems~~
  - ✗ ~~cluster membership~~

For which types of pulsating stars can ILMT observations have an added value to space-based observations?

The prospects of pulsating stars studies with ILMT

belspo
विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY

Peter De Cat
Royal Observatory of Belgium

Simulation of ILMT time series

- Assumptions
  - ➔ 5 years of observations: 01/01/2021 – 31/12/2026

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  - ➔ integration time: 102 sec

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period > 0.5 hrs

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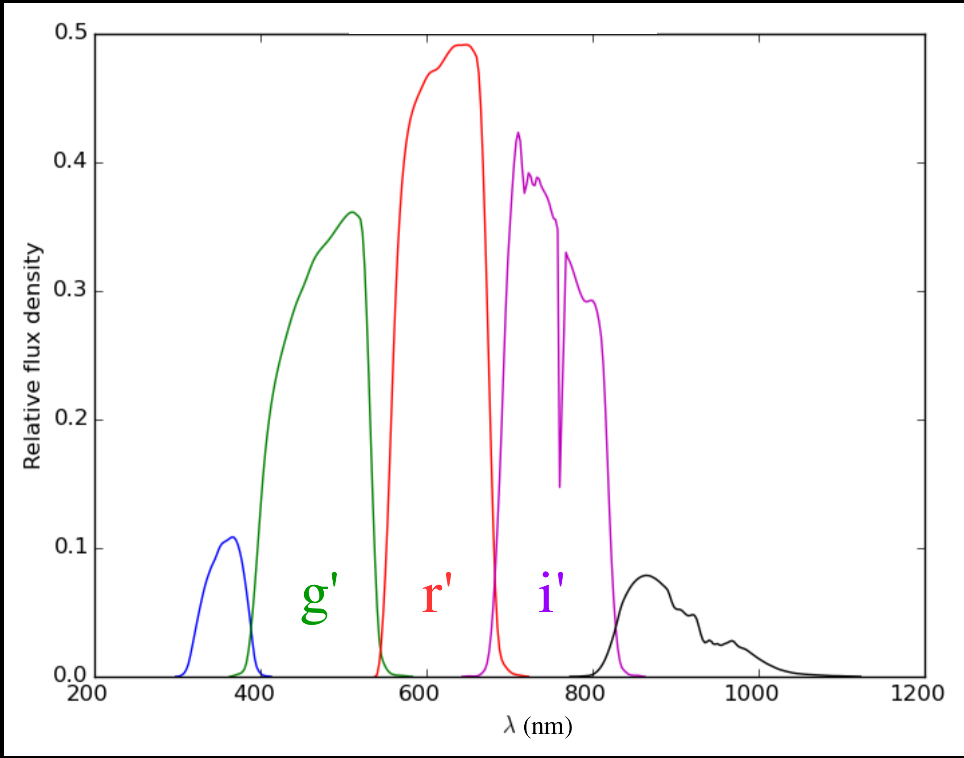
  - ➔ 3 filters: g', r', i'



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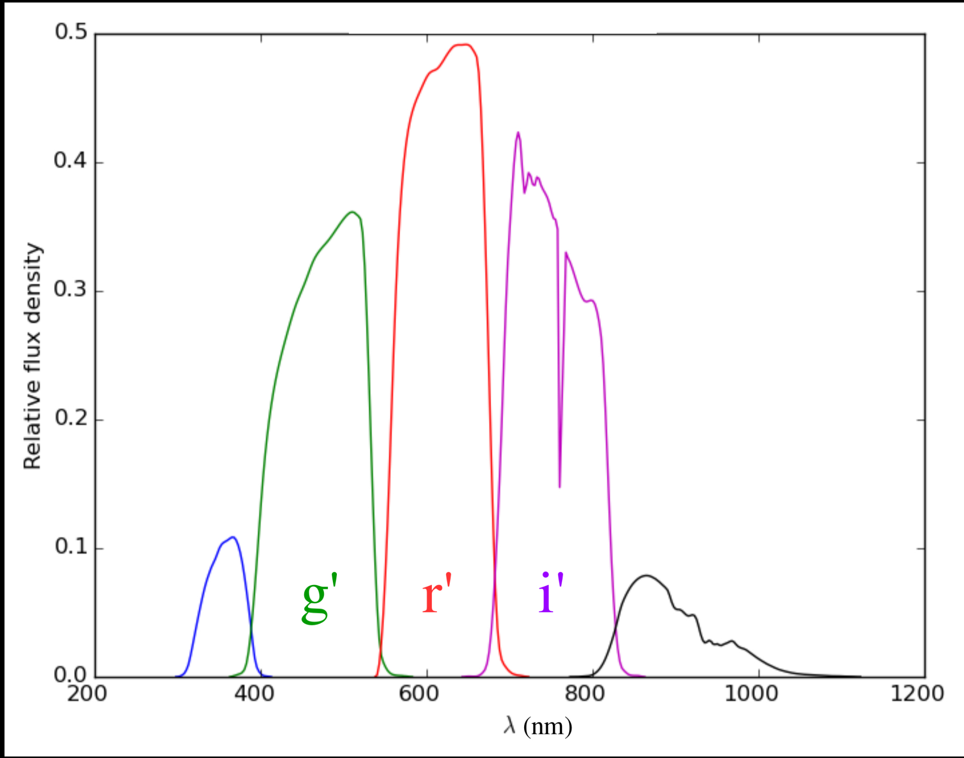
  - ➔ strategy: i', g', i', r', i', g', i', r',...



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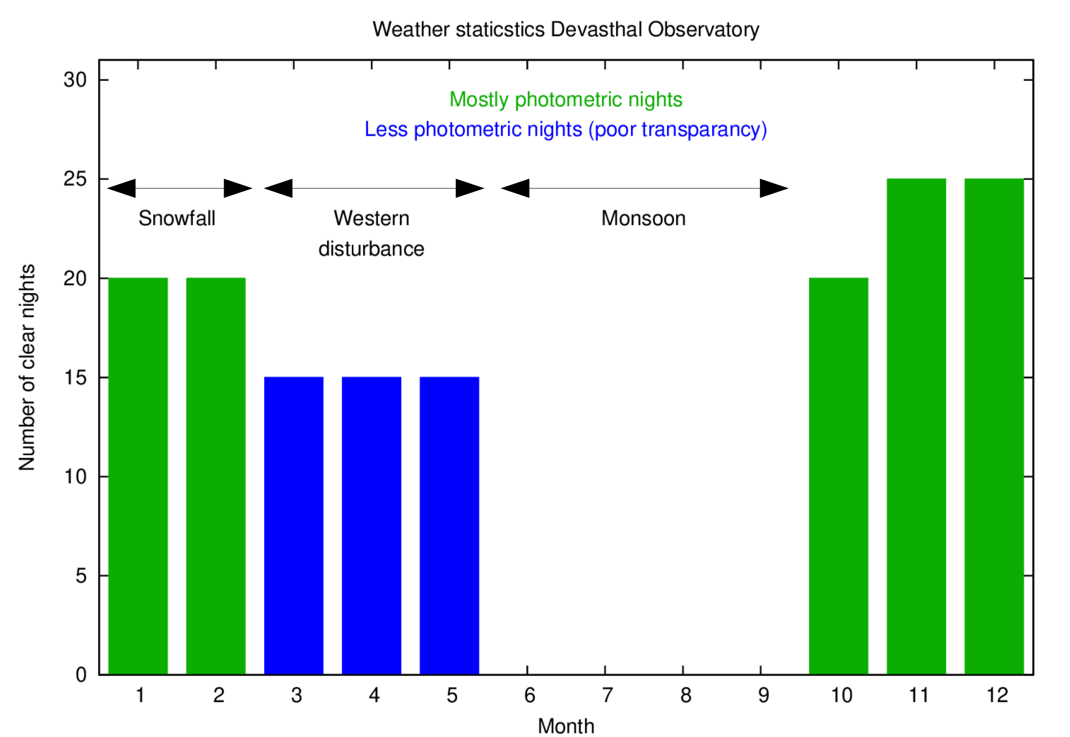
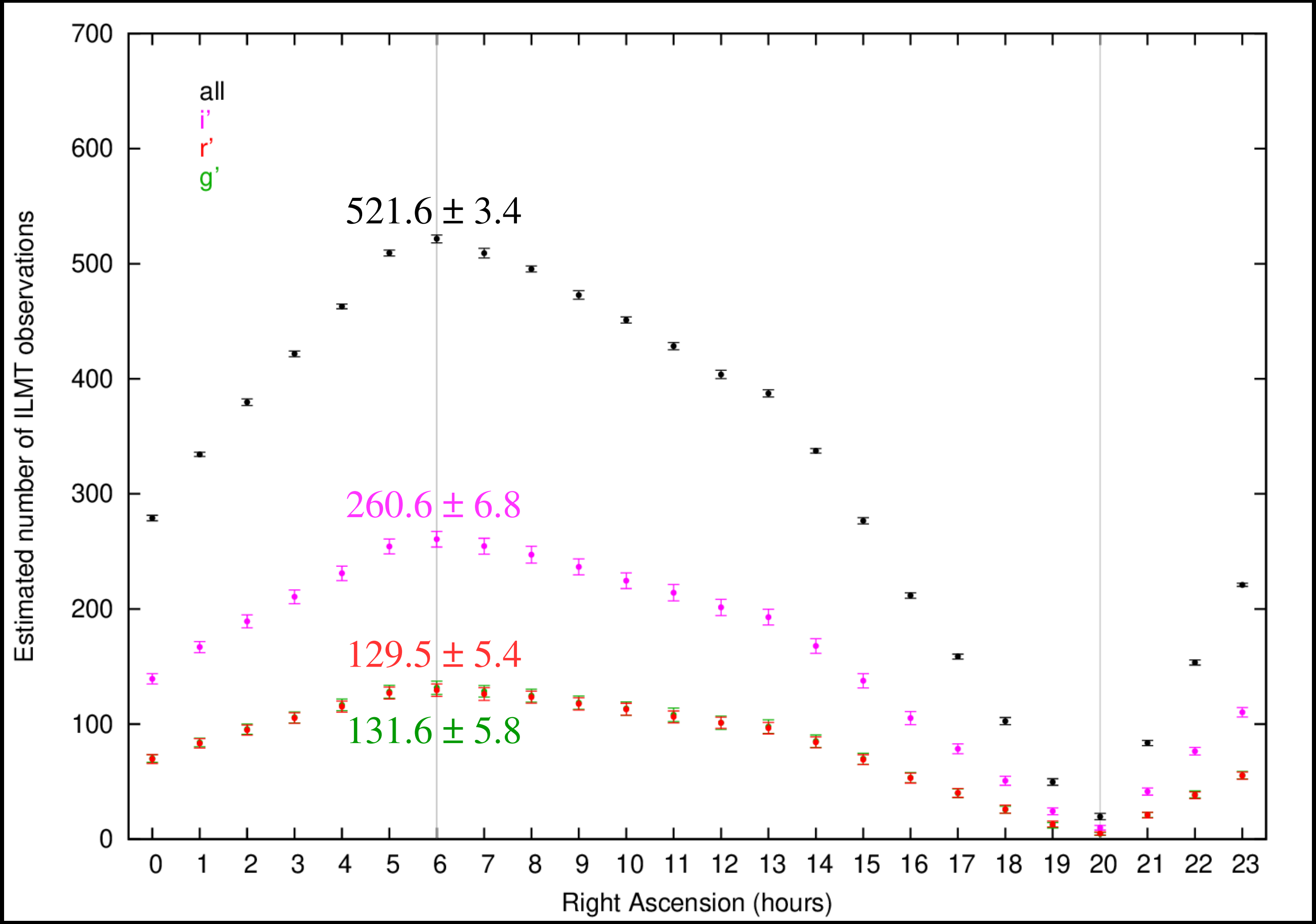
  - ➔ 3 filters: g', r', i'
  - ➔ strategy: i', g', i', r', i', g', i', r',...
  - ➔ weather statistics Devasthal:
    - ➢ based on last 2 years
    - ➢ random selection of nights within month



Brijesh Kumar, private communication

Simulation of ILMT time series

- Assumptions
- Results
  - → 100 simulations



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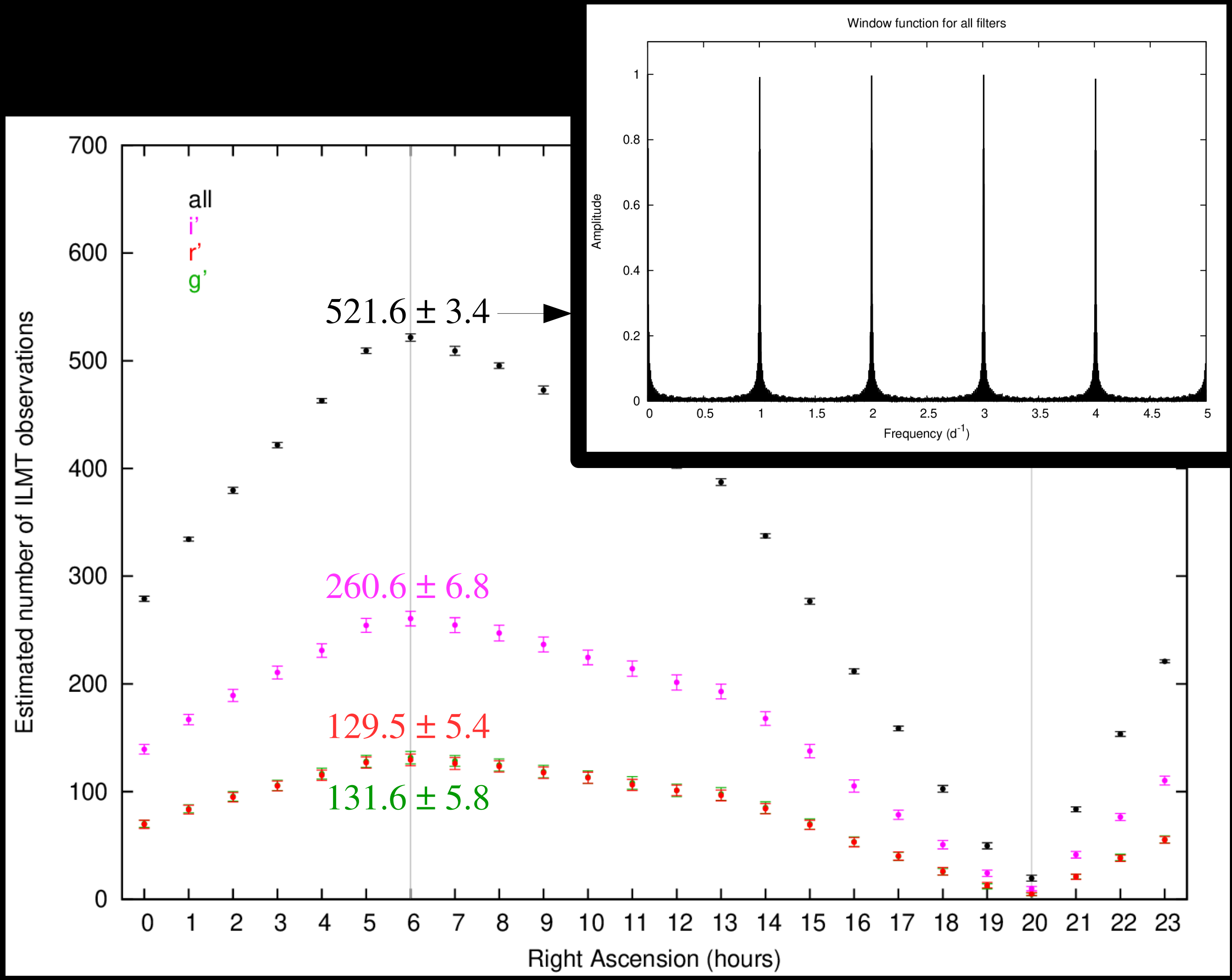

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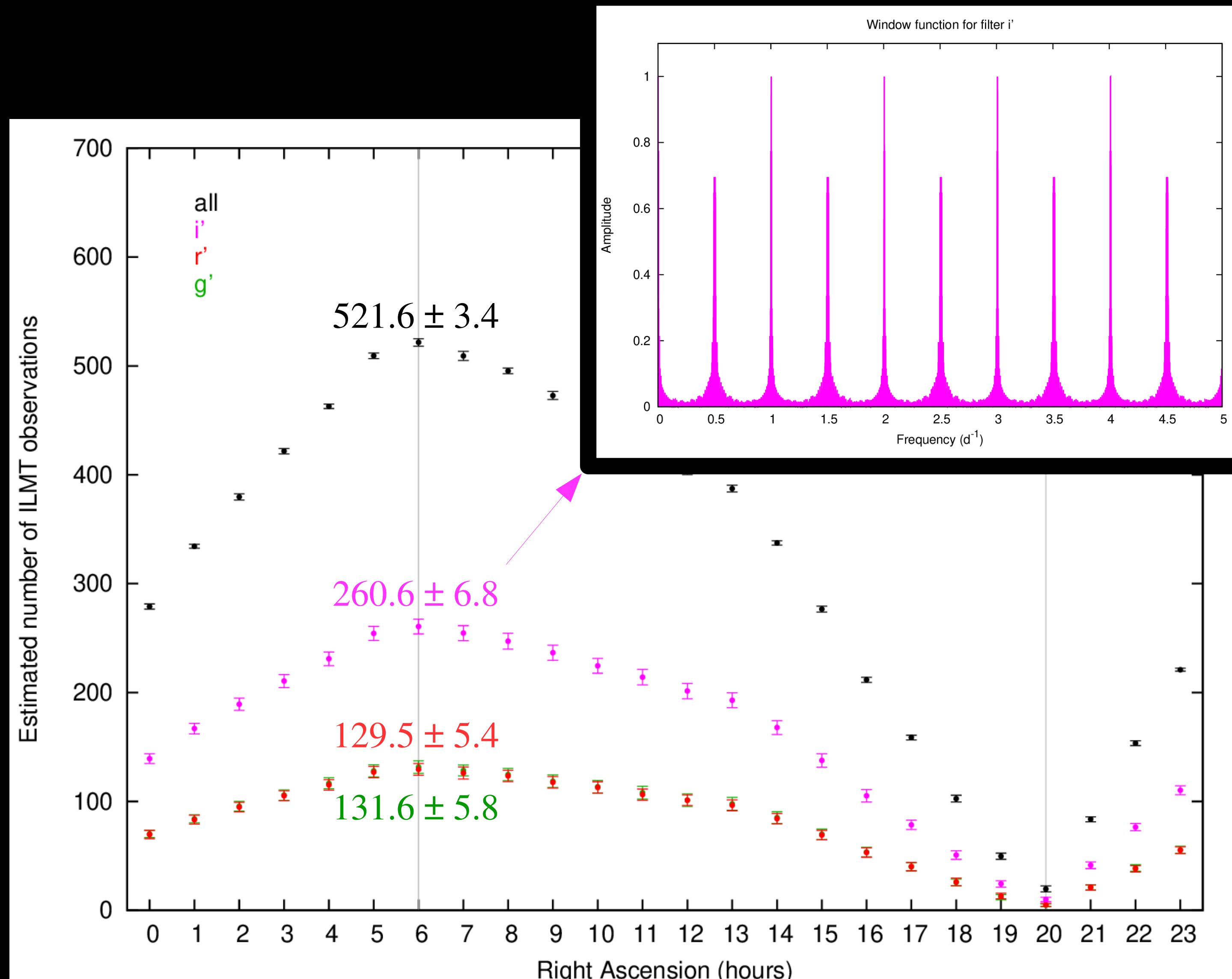

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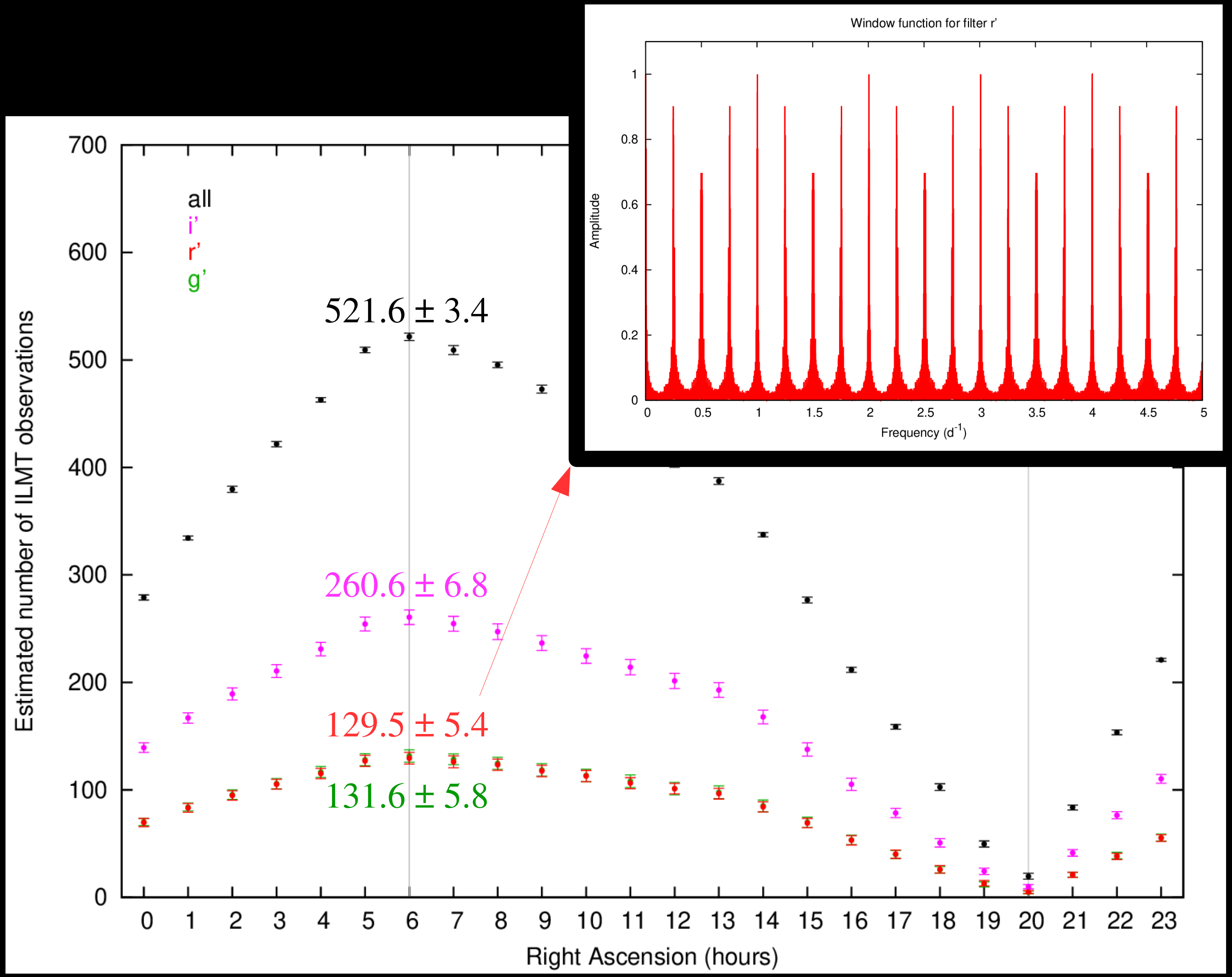

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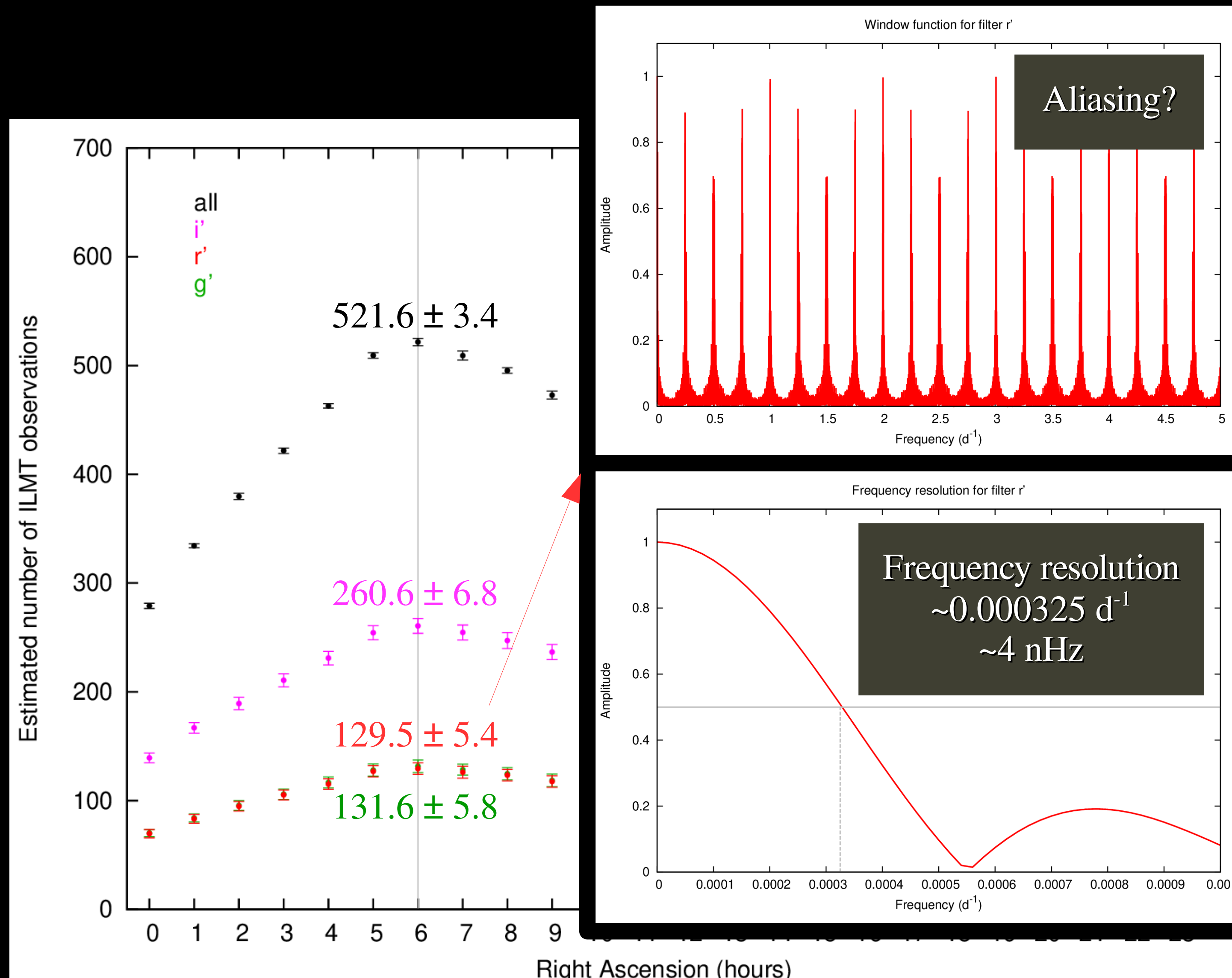

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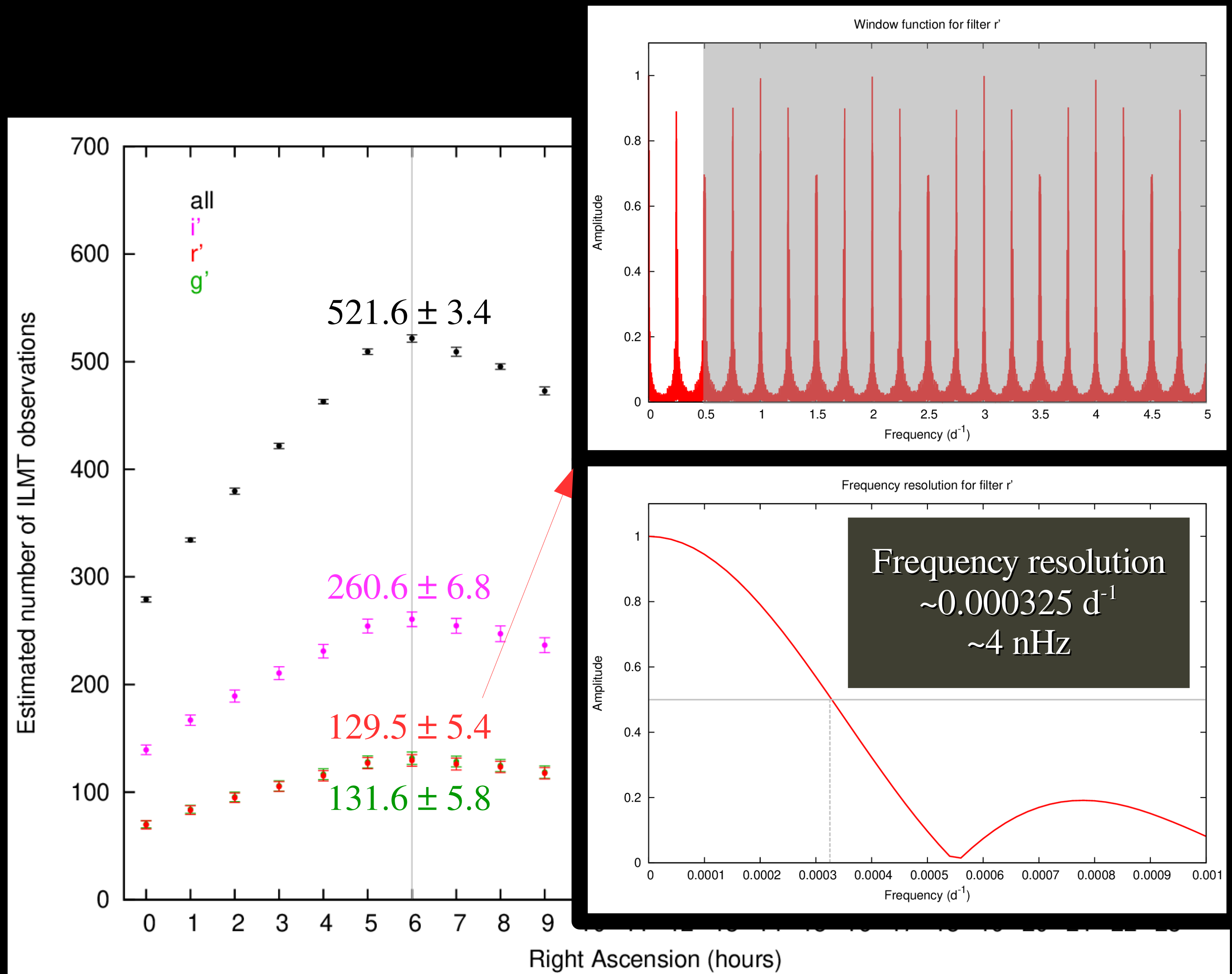
Lowest frequency 1/(2T):
~0.00027 d^{-1}
~3 μHz

Longest period: ~10 years

Nyquist frequency $0.5f_s$:
~0.50137 d^{-1}
~5.8 μHz

Shortest period: ~2 days

2 days – 10 years



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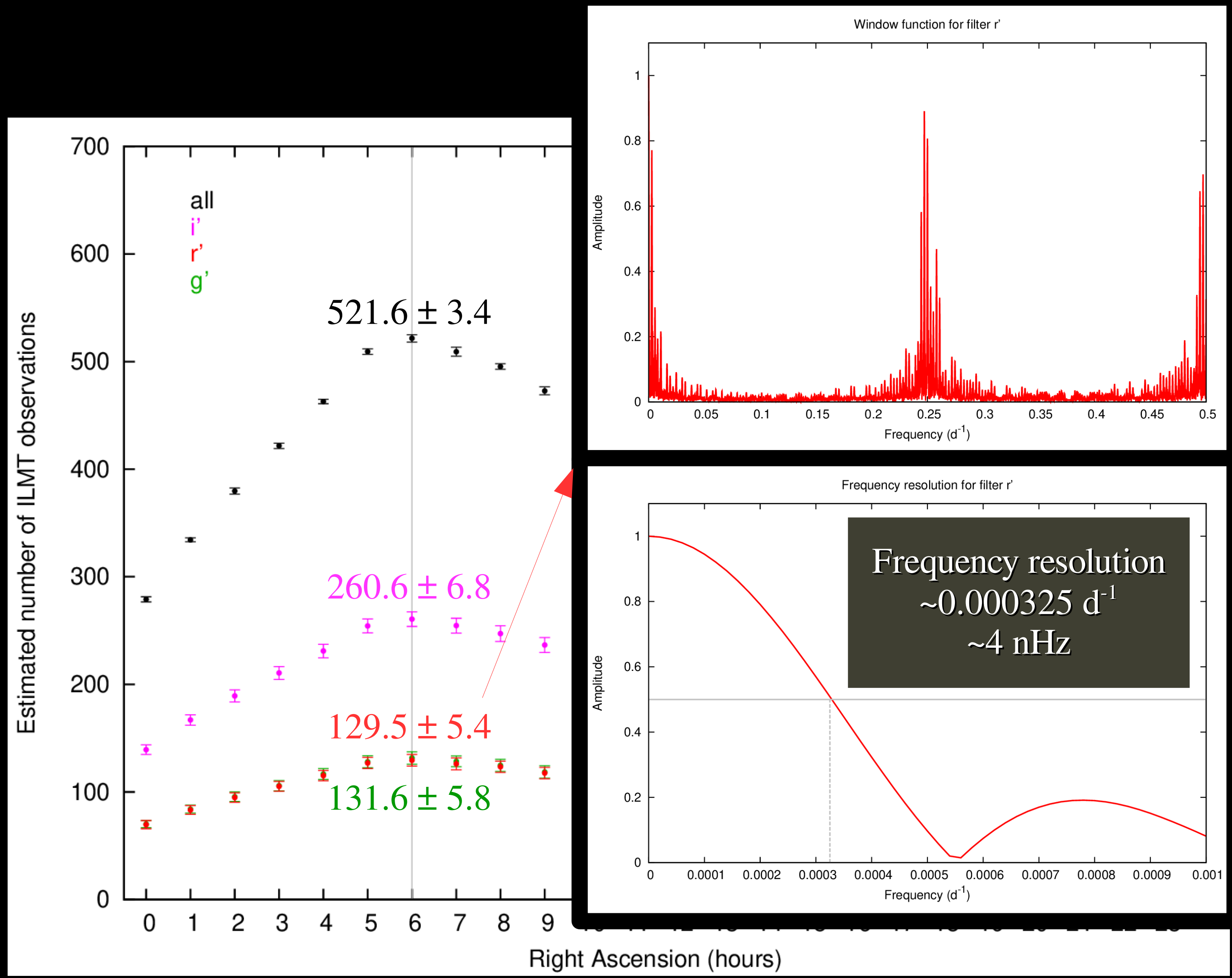

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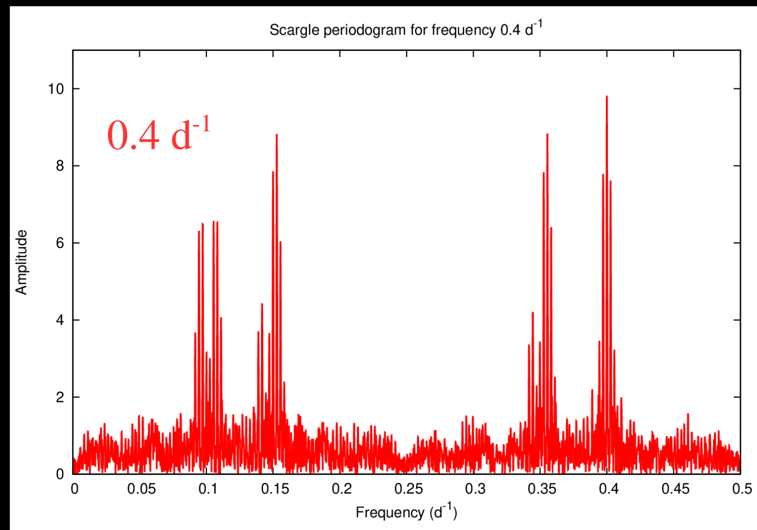

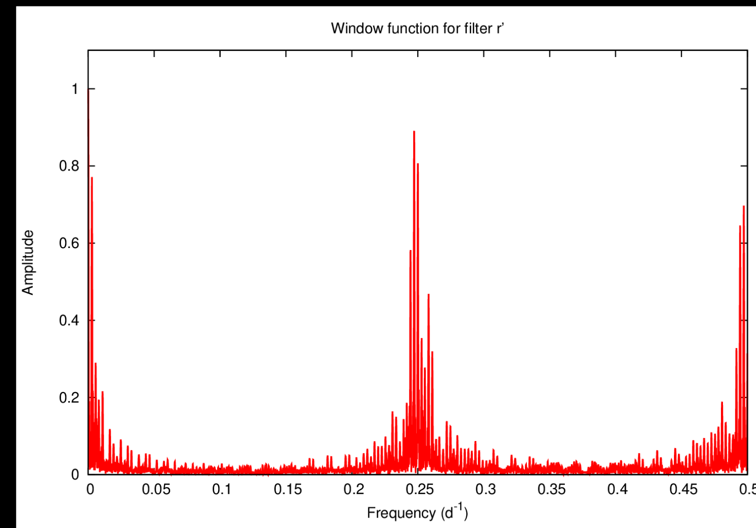

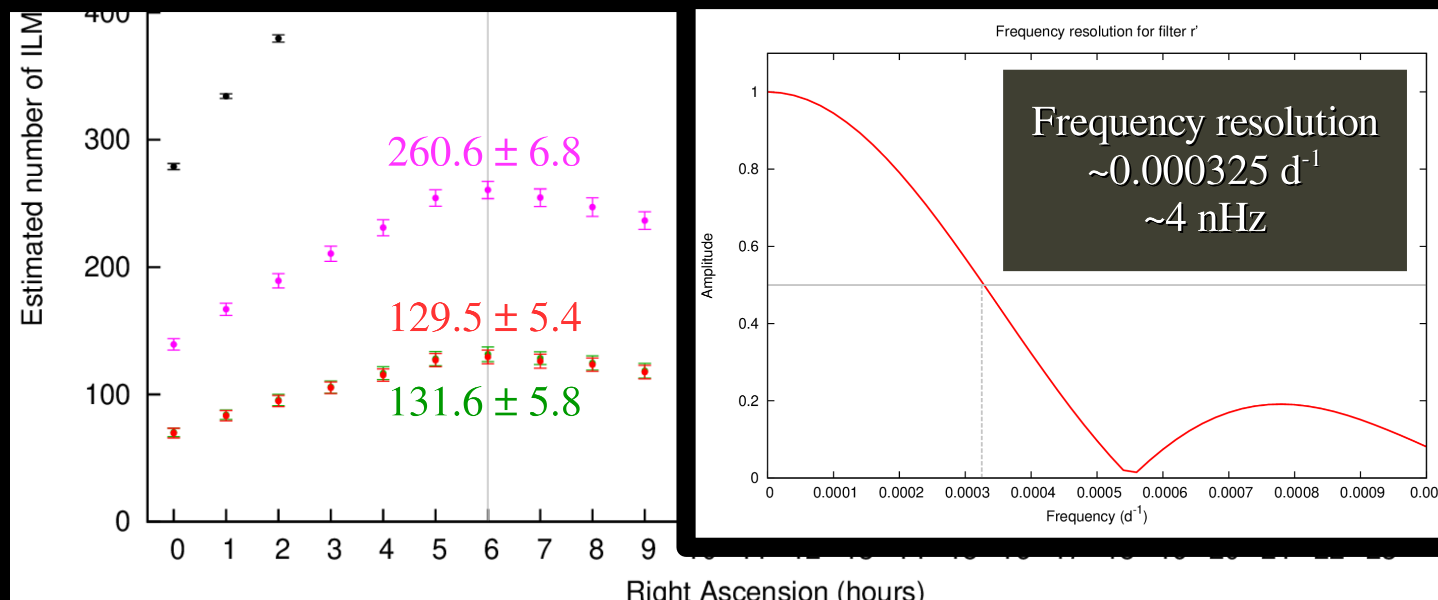

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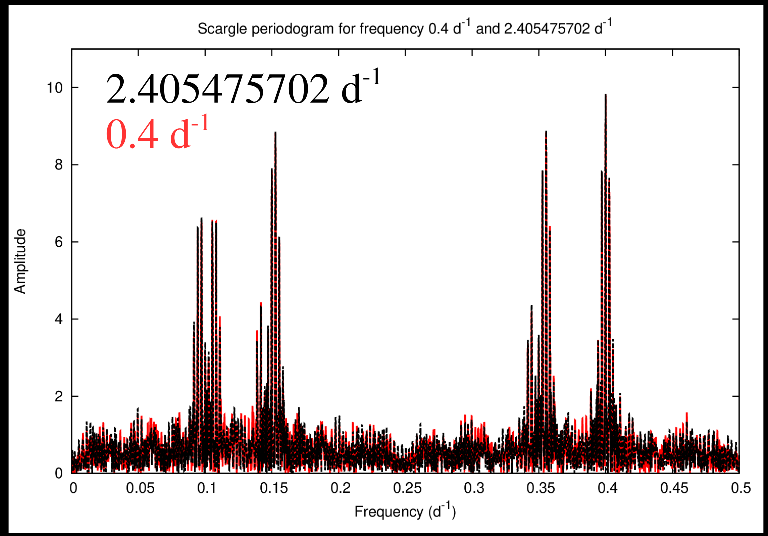

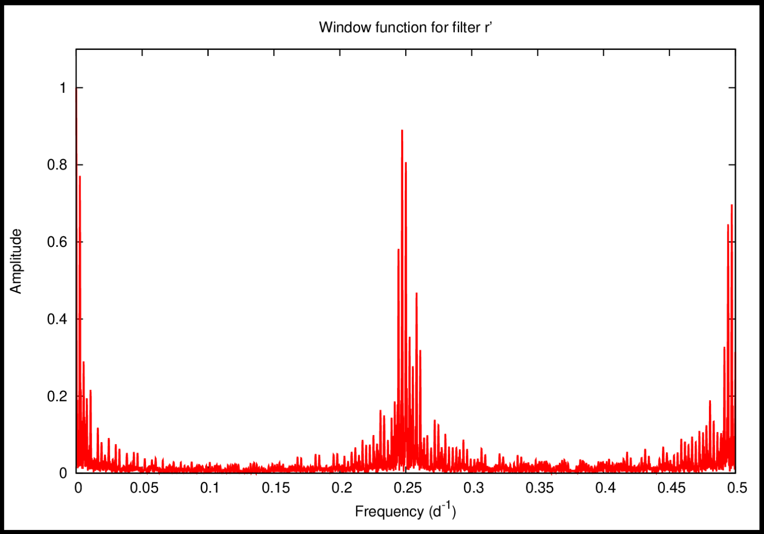

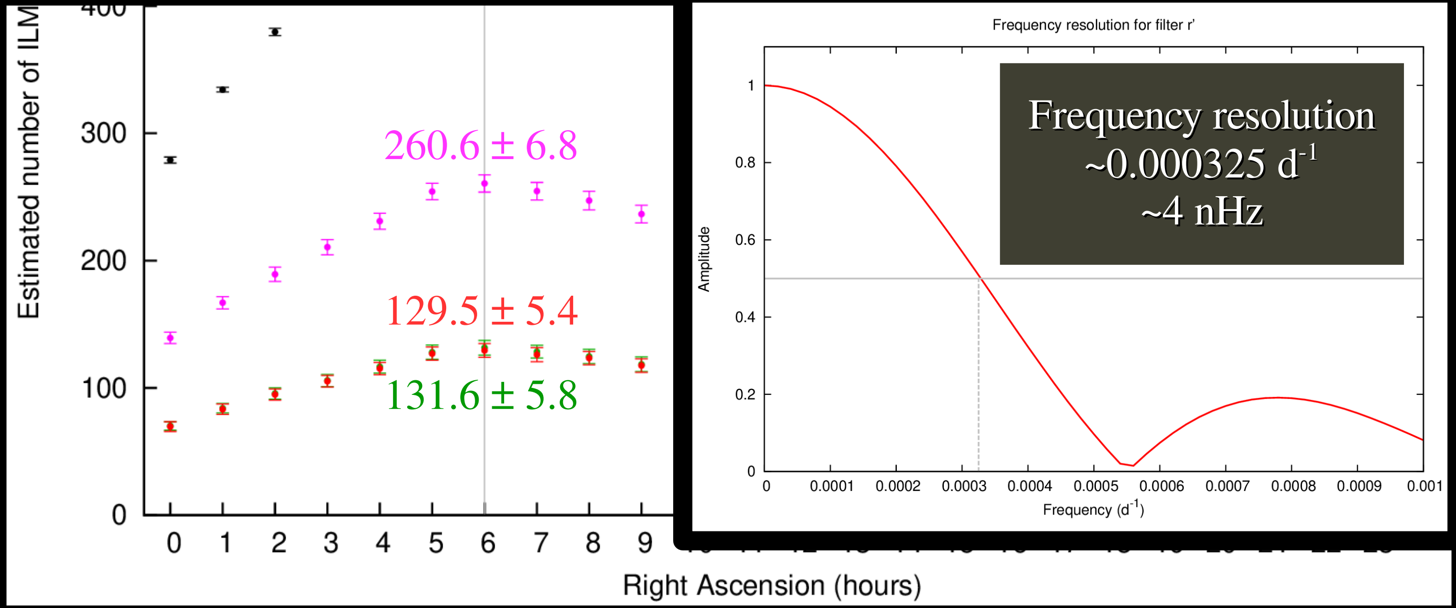

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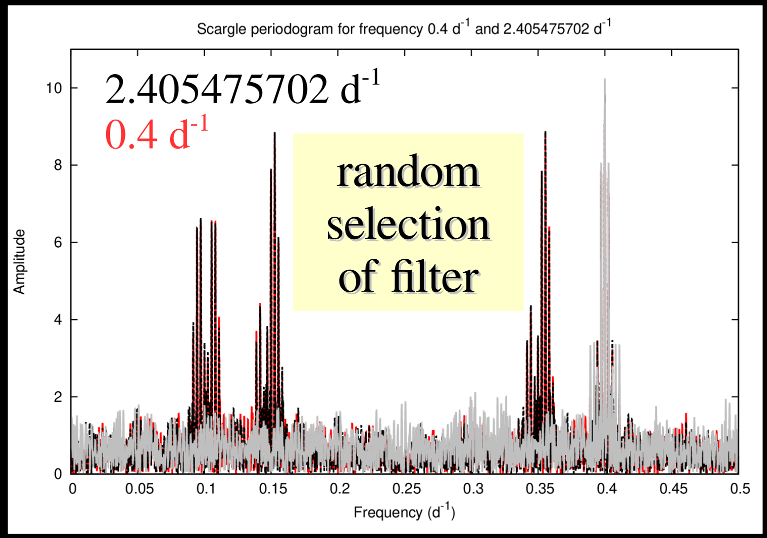
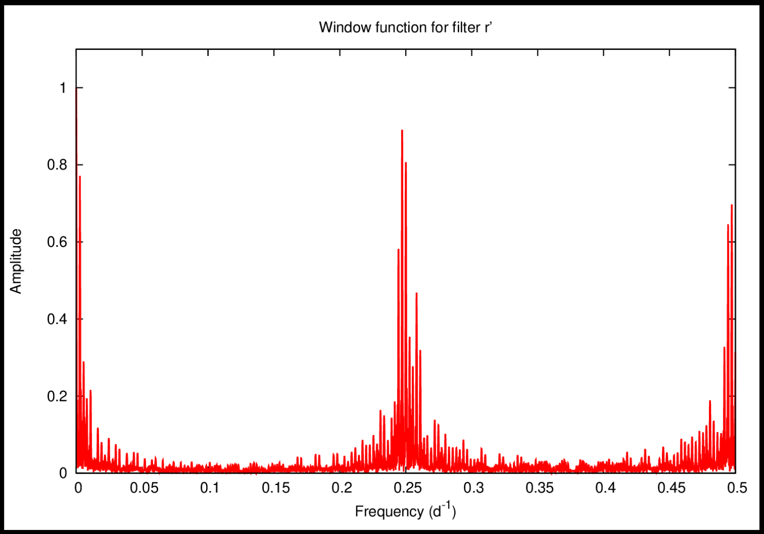
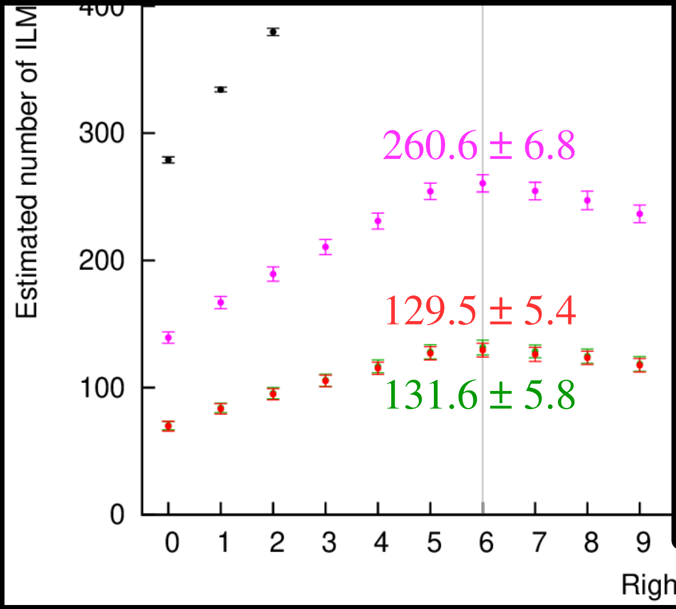
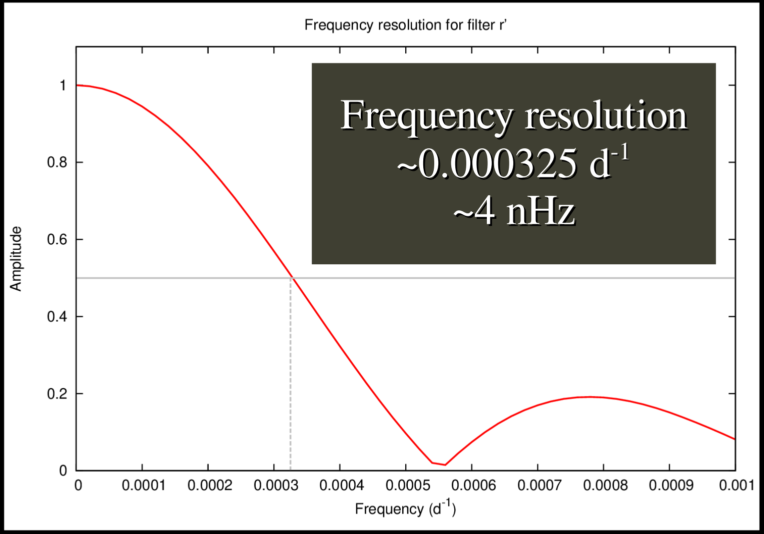


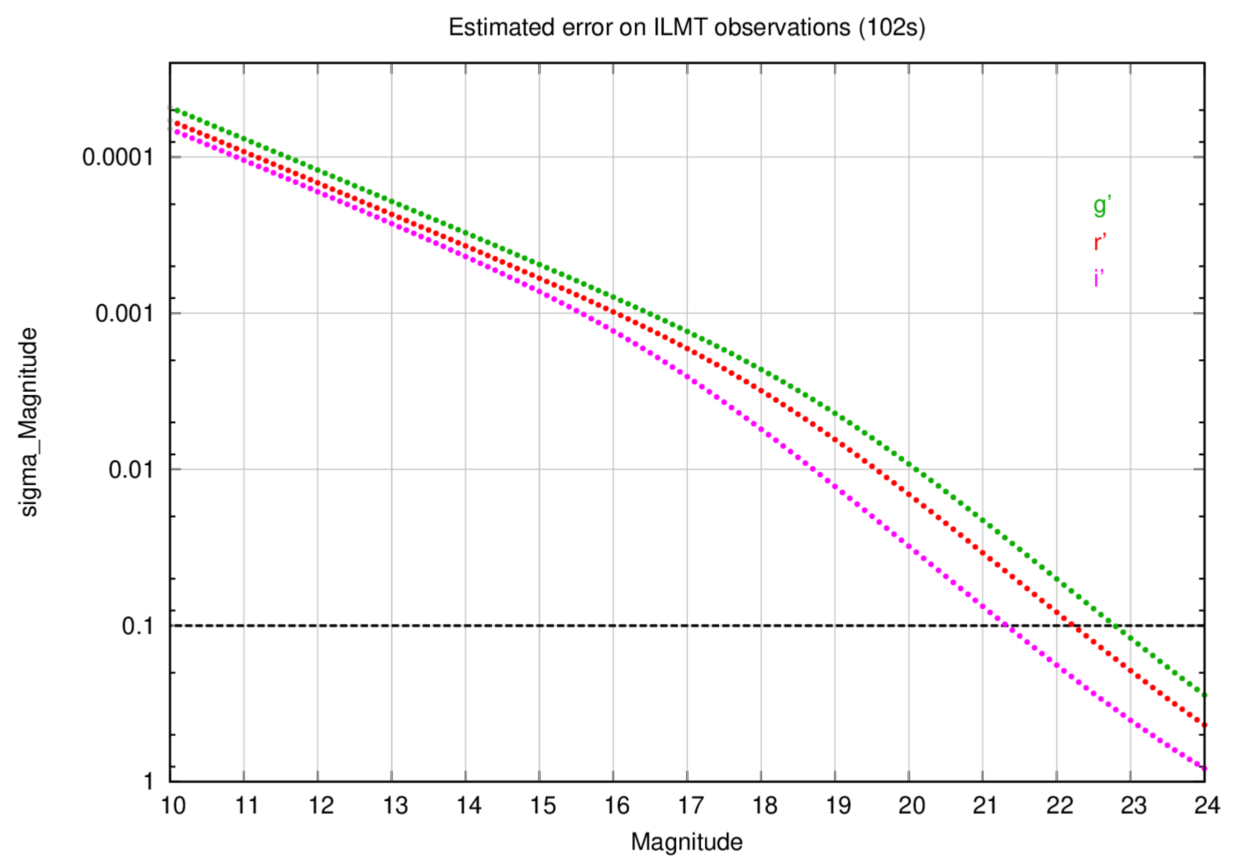






Simulation of ILMT time series

- Assumptions
- Results
- Error in magnitude
  - 1 observation: 102s



Brajesh Kumar, 2014, PhD thesis

Simulation of ILMT time series

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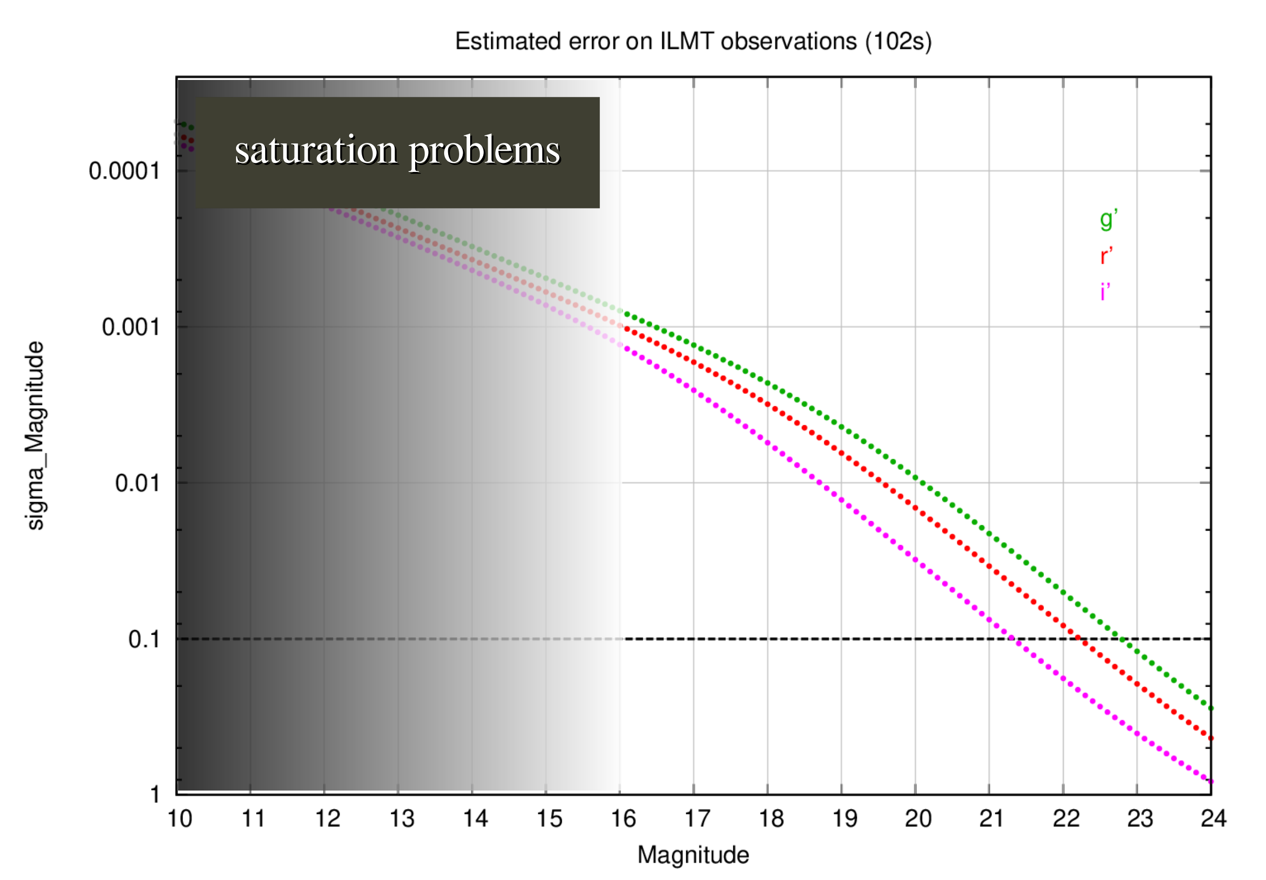
- Results
- Error in magnitude
  - ➔ 1 observation: 102s

roughly 16 - 22 mag

> 1 mmag



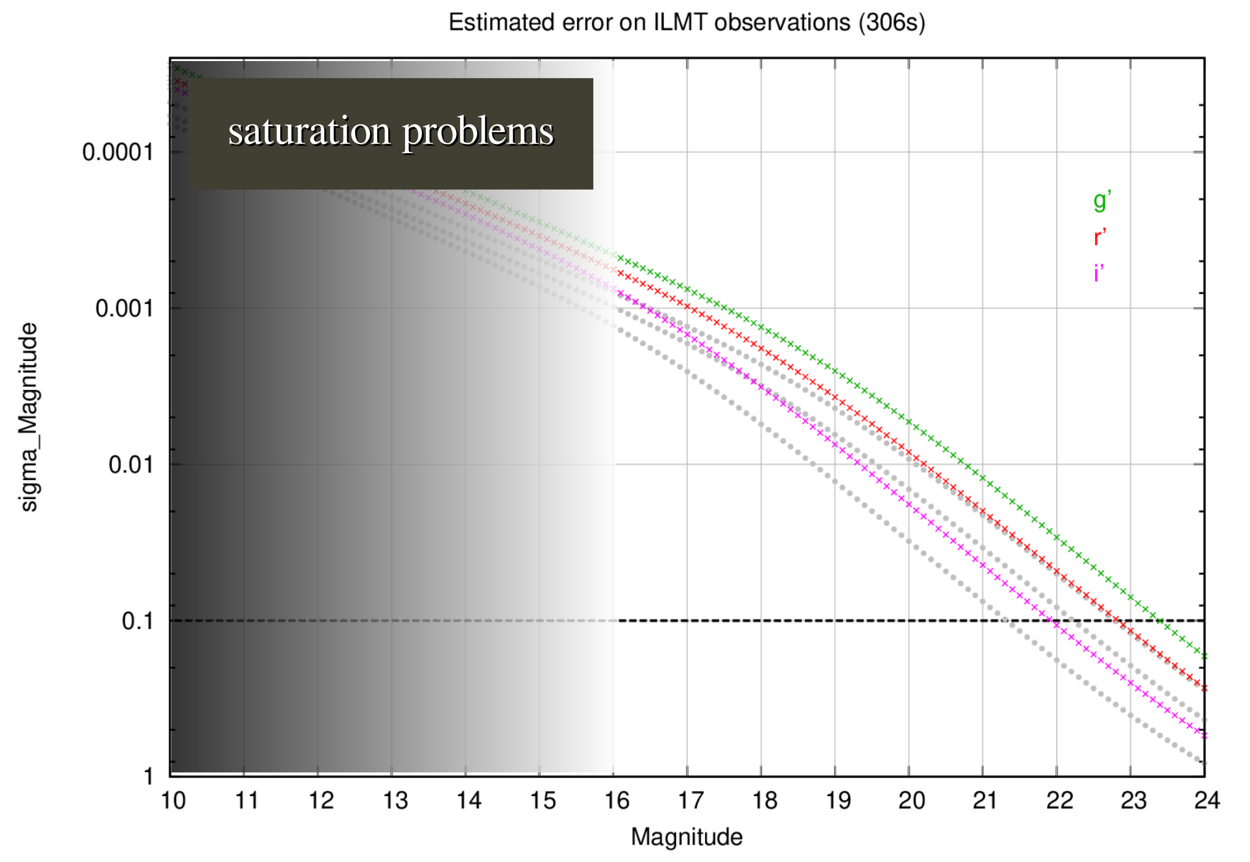
Brajesh Kumar, 2014, PhD thesis

Simulation of ILMT time series

- Assumptions
- Results
- Error in magnitude
  - ➔ 1 observation: 102s
  - ➔ 3 observations: 306s
    - ➢ gain of ~0.5 mag
    - ➢ loss in cadence

roughly 16 - 22 mag

> 1 mmag



Brajesh Kumar, 2014, PhD thesis

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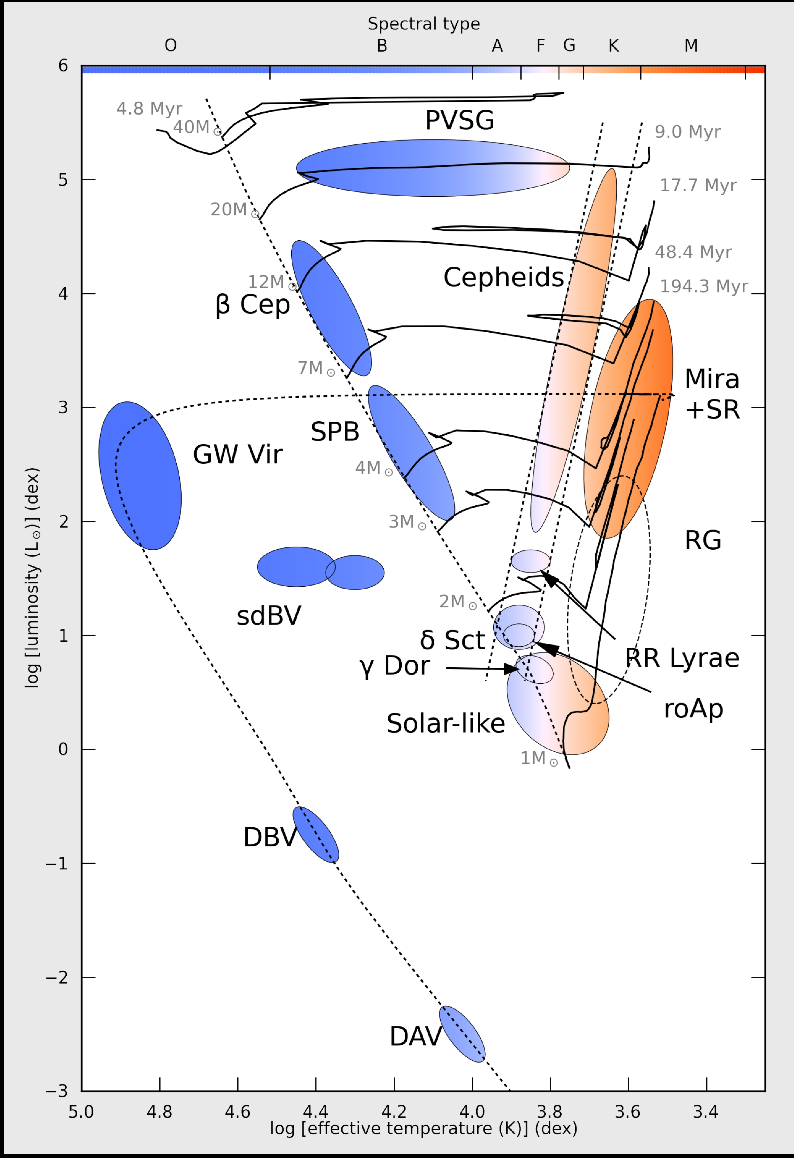


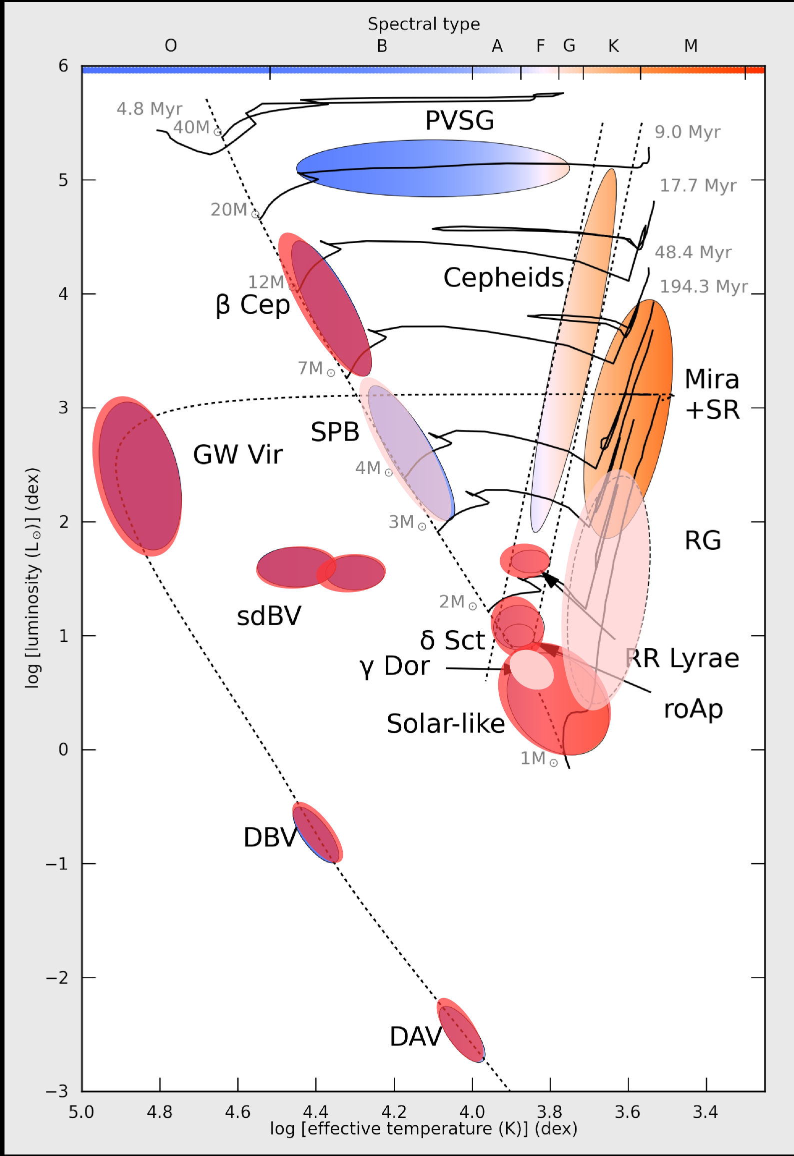
Prospects

Frequency analysis
Periods

- Periods

period > 0.5 hrs   2 days – 10 years

✗ Solar-like oscillators (solar-like)	order of min
✗ δ Scuti stars (δ Sct)	1 - 5 hrs
✗ γ Doradus stars (γ Dor)	0.3 – 3 d
✗ rapidly oscillating Ap stars (roAp)	5 – 25 min
✗ β Cephei stars (β Cep)	2 – 7 hrs
✗ Slowly Pulsating B stars (SPB)	0.3 – 3 d
✗ Periodically Variable Supergiants (PVS)	10 – 100 d
✗ RR Lyrae stars (RR Lyrae)	0.2 – 1 d
✗ Cepheids (Cepheids)	0.1 – 200 d
✗ Red Giant stars (RG)	1 hrs – 4 d
✗ Mira variables (Mira)	80 – 1000 d
✗ Semi-Regular variables (SR)	20 – 2000 d
✗ sub-dwarf B Variables (sdBV)	90 sec – 4 hrs
✗ pulsating pre-white dwarfs (GW Vir)	5 – 85 min
✗ pulsating white dwarfs (DBV/DAV)	100 – 1500 sec



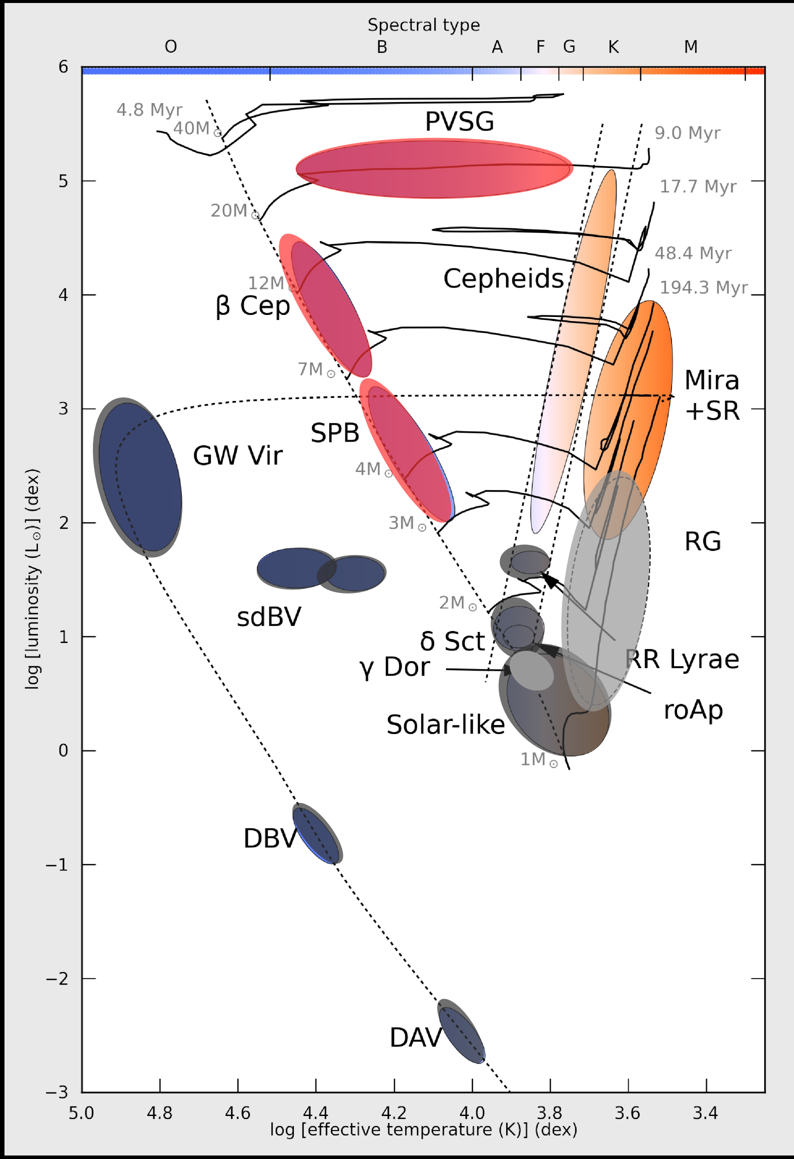
Prospects

Frequency analysis
Periods
Brightness

- Brightness

roughly 16 - 22 mag

- ✗ Solar-like oscillators (solar-like)
- ✗ δ Scuti stars (δ Sct)
- ✗ γ Doradus stars (γ Dor)
- ✗ rapidly oscillating Ap stars (roAp)
- ✗ β Cephei stars (β Cep)
- ✗ Slowly Pulsating B stars (SPB)
- ✗ Periodically Variable Supergiants (PVS)
- ✗ RR Lyrae stars (RR Lyrae)
- ✗ Cepheids (Cepheids)
- ✗ Red Giant stars (RG)
- ✗ Mira variables (Mira)
- ✗ Semi-Regular variables (SR)
- ✗ sub-dwarf B Variables (sdBV)
- ✗ pulsating pre-white dwarfs (GW Vir)
- ✗ pulsating white dwarfs (DBV/DAV)

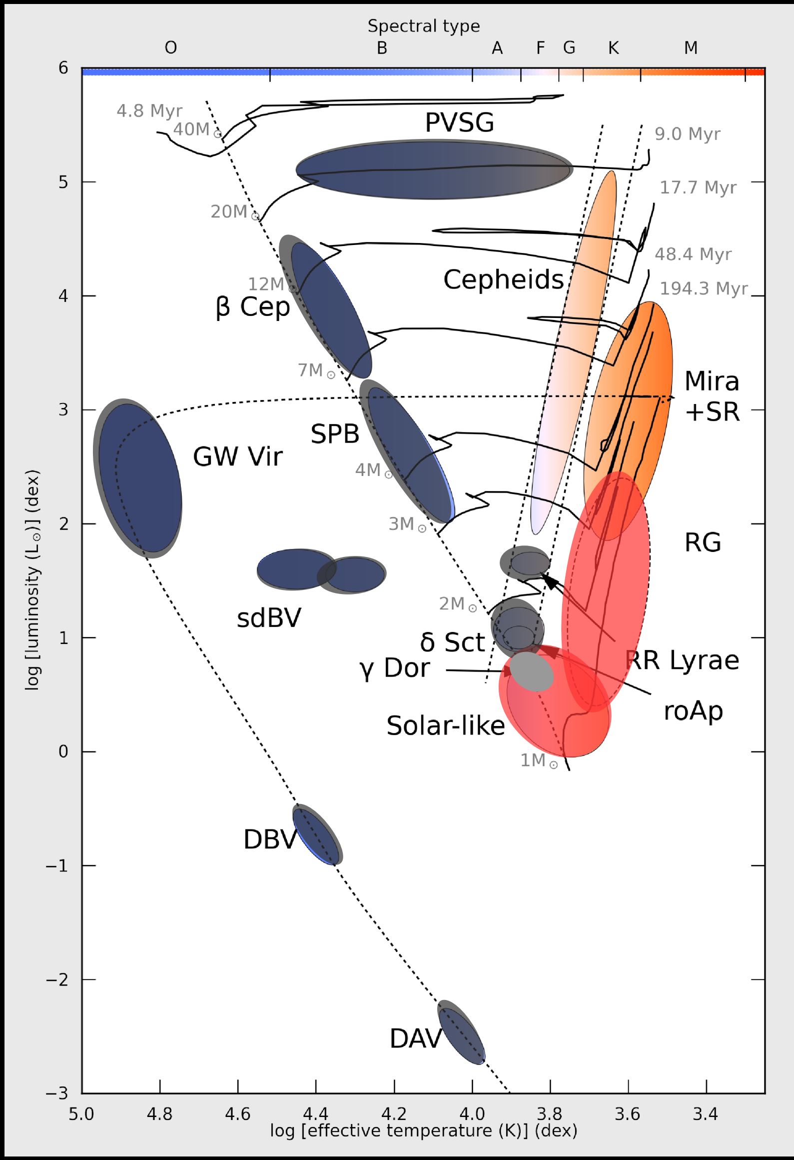


Prospects

- Amplitudes

> 1 mmag

✗	Solar-like oscillators (solar-like)	< 1 mmag
✗	δ Scuti stars (δ Sct)	0.8 mag
✗	γ Doradus stars (γ Dor)	0.03 mag
✗	rapidly oscillating Ap stars (roAp)	0.02 mag
✗	β Cephei stars (β Cep)	0.04 mag
✗	Slowly Pulsating B stars (SPB)	0.03 mag
✗	Periodically Variable Supergiants (PVS)	0.3 mag
✗	RR Lyrae stars (RR Lyrae)	1 mag
✗	Cepheids (Cepheids)	1 mag
✗	Red Giant stars (RG)	< 1 mmag
✗	Mira variables (Mira)	>2.5 mag
✗	Semi-Regular variables (SR)	4 mag
✗	sub-dwarf B Variables (sdBV)	0.3 mag
✗	pulsating pre-white dwarfs (GW Vir)	0.3 mag
✗	pulsating white dwarfs (DBV/DAV)	0.4 mag



Prospects

Frequency analysis
- Periods
- Brightness
- Amplitudes

- ✗ Solar-like oscillators (solar-like)
- ✗ δ Scuti stars (δ Sct)
- ✗ γ Doradus stars (γ Dor)
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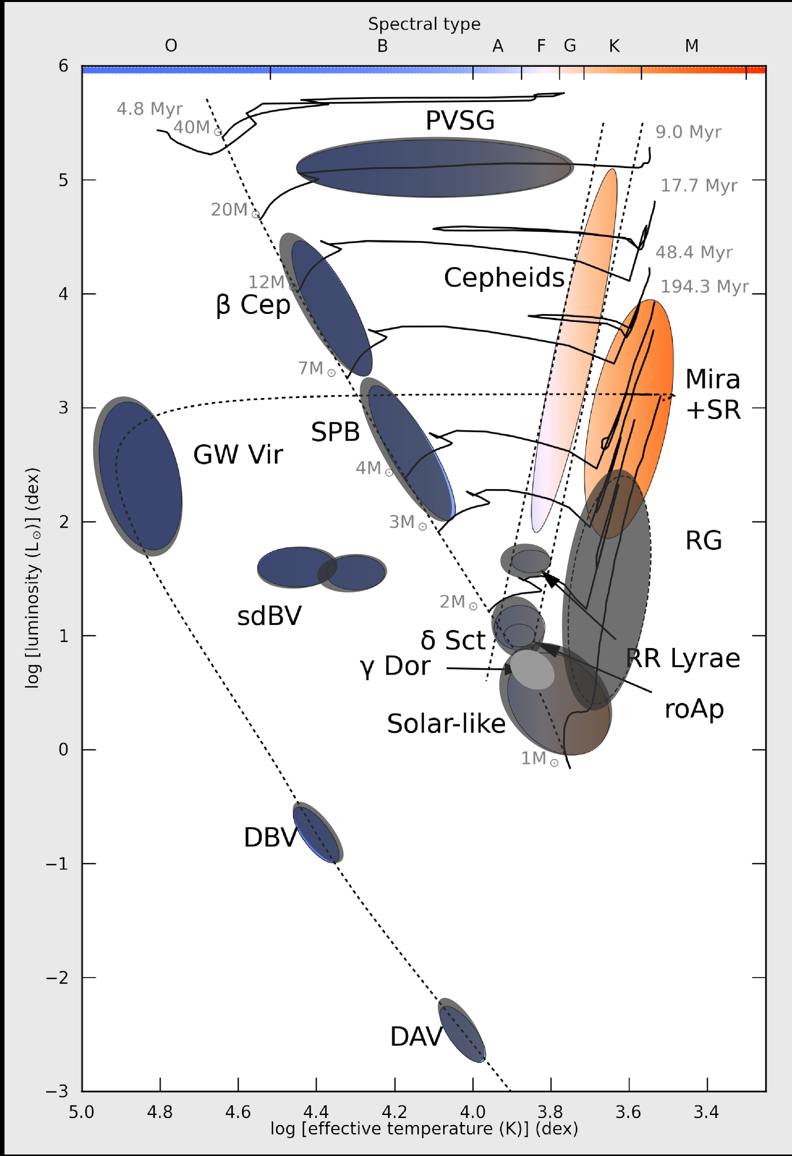

Prospects

Frequency analysis
- Periods
- Brightness
- Amplitudes

- ✗ Solar-like oscillators (solar-like)
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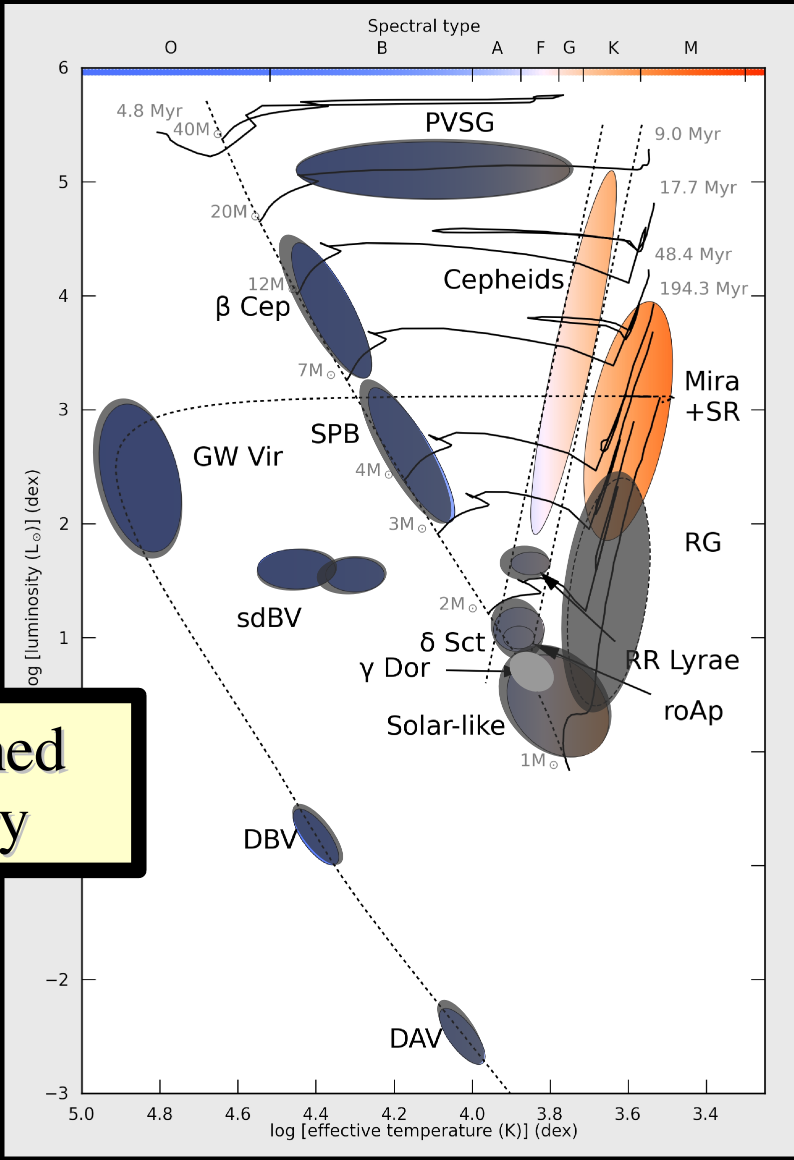
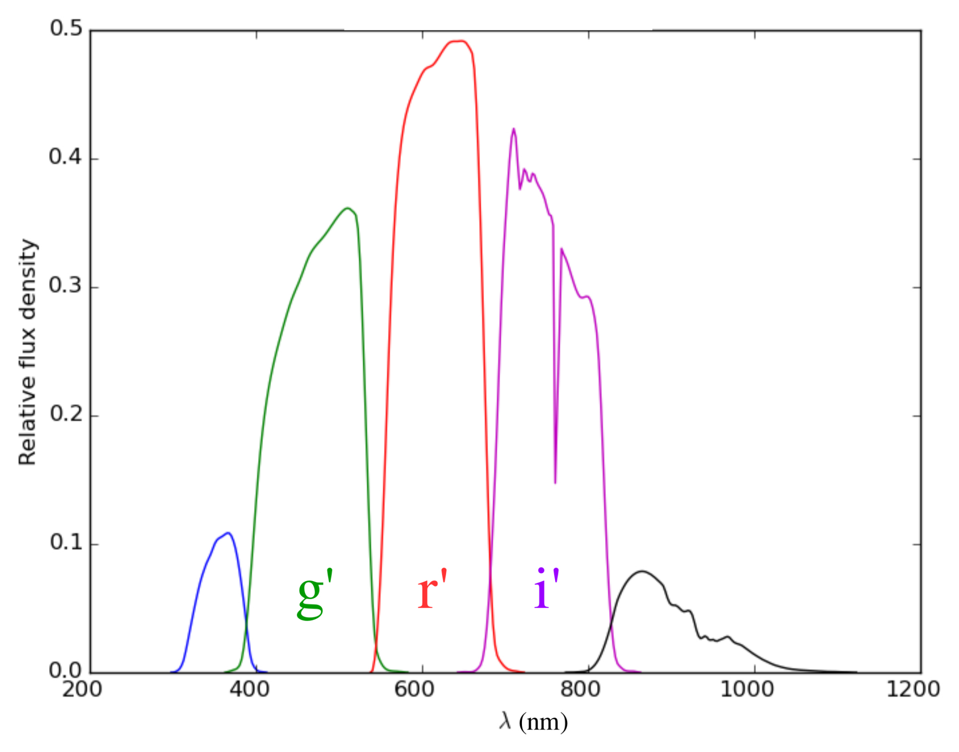
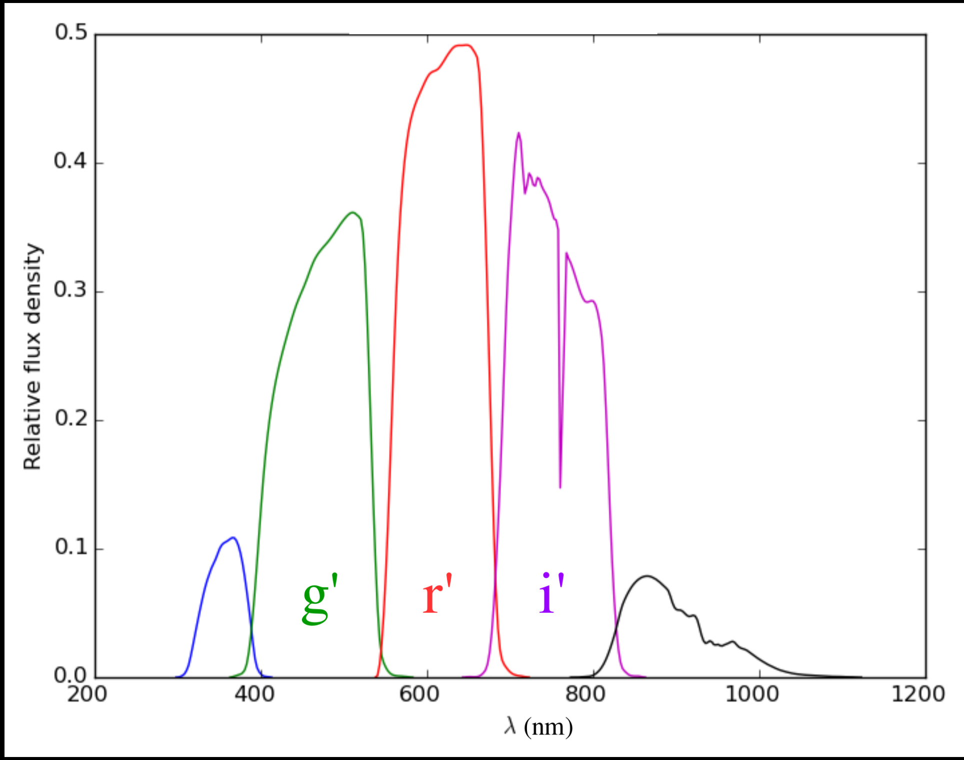
improves when combined with other observatory



- Mode identification
  - method:
    - amplitude ratios
    - phase difference
  - imposing known frequencies



- Mode identification
  - ➔ method:
    - ➢ amplitude ratios
    - ➢ phase difference
  - ➔ imposing known frequencies



- Stellar parameters
  - ➔ calibration photometric system (low accuracy for hot stars)
  - ➔ faint stars (first determination)
  - ➔ study variations of T_{eff} & logg (pulsating stars with large amplitudes)

The prospects of pulsating stars studies with ILMT

Conclusions

- The prospects are best
  - for pulsating stars with
    - right ascension close to 6 hours
    - high enough magnitude (roughly 16 – 22 mag)
    - long pulsation periods
      - integration time: > 0.5 hrs
      - frequency analysis: 2 days – 10 years
    - pulsation amplitudes above 1 mmag

    Cepheids
    Mira variables
    Semi-regular variables
  - for random selection of the filter (g', r' or i')
  - if observations can be combined with other observatories

Thank you for your attention!