IceCube Searches for transient sources

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GW+HEN Workshop
Paris 2009

Content

- IceCube Neutrino Telescope
- Offline Searches
  - Point Sources
  - GRBs
- Online Searches
  - Optical Follow-Up

The IceCube Collaboration

USA:
Bartol Research Institute, Delaware
University of California, Berkeley
University of California, Irvine
Pennsylvania State University
Clark-Atlanta University
Ohio State University
Georgia Tech
University of Maryland
University of Alabama, Tuscaloosa
University of Wisconsin-Madison
University of Wisconsin-River Falls
Lawrence Berkeley National Lab.
University of Kansas
Southern University and A&M College, Baton Rouge
University of Alaska, Anchorage

UK:
Oxford University

Sweden:
Uppsala Universitet
Stockholm Universitet

Netherlands:
Utrecht University

Belgium:
Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons-Hainaut

Germany:
DESY-Zeuthen
Universität Mainz
Universität Dortmund
Universität Wuppertal
Humboldt Universität
MPI Heidelberg
RWTH Aachen

Japan:
Chiba University

Switzerland:
EPFL

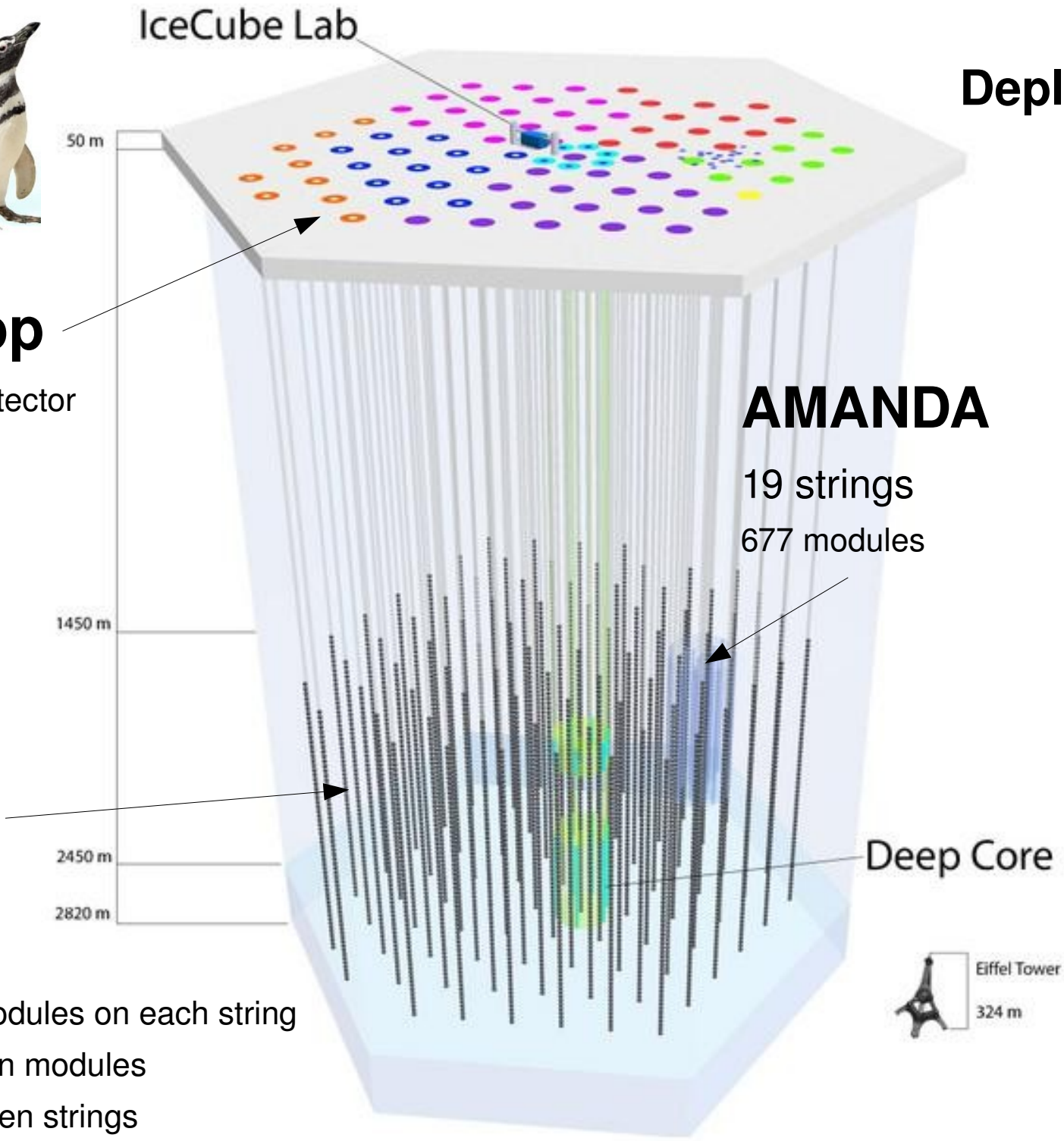
33 institutions, ~250 members
http://icecube.wisc.edu

New Zealand:
University of Canterbury

Antarctica:
South Pole Station

IceTop

airshower detector



AMANDA

19 strings

677 modules

InIce

80 strings

60 optical modules on each string

17 m between modules

125 m between strings

Deployed IceCube Strings

2004/05

1 string

2005/06

9 strings

2006/07

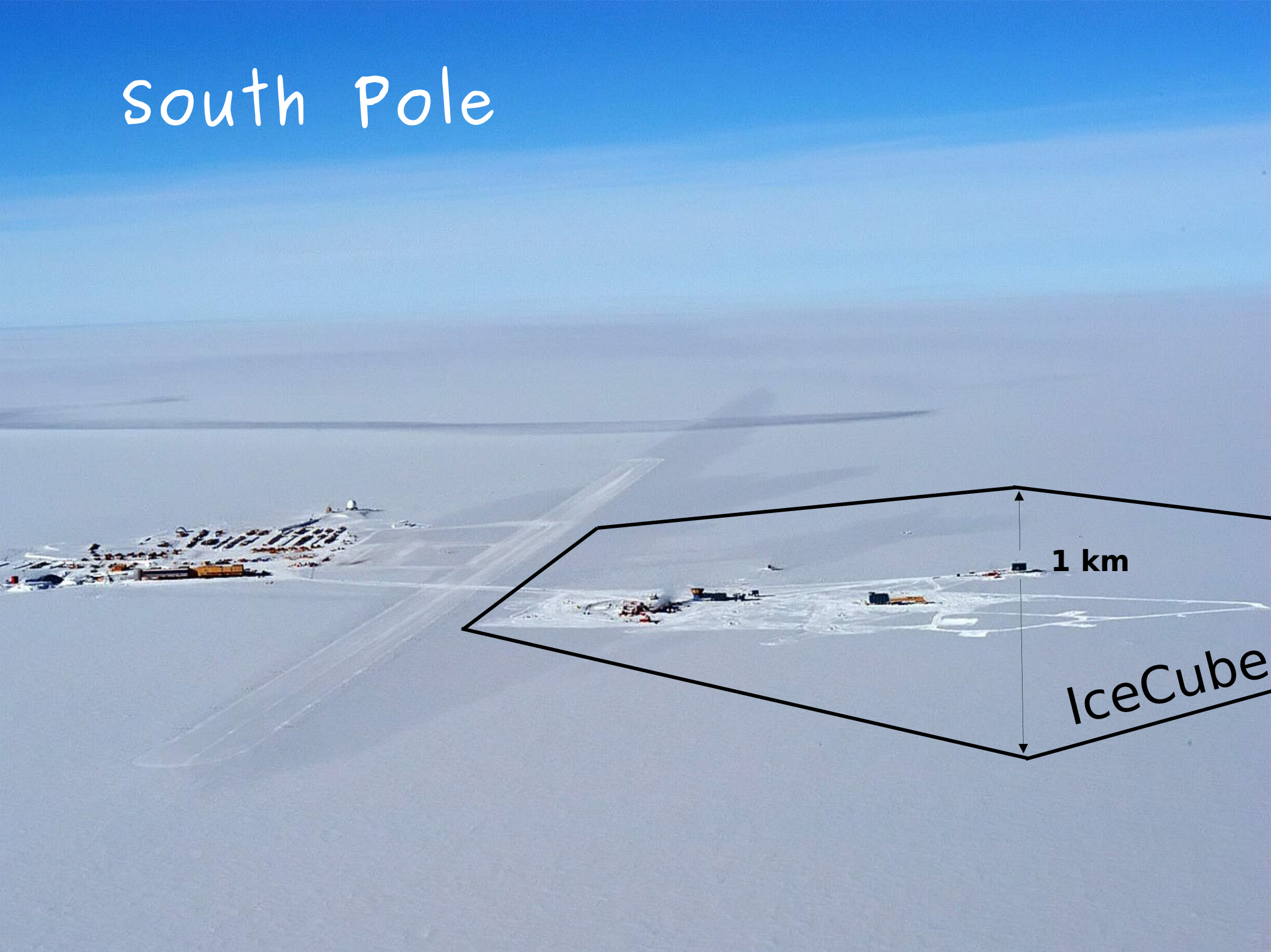
22 strings

2007/08

40 strings

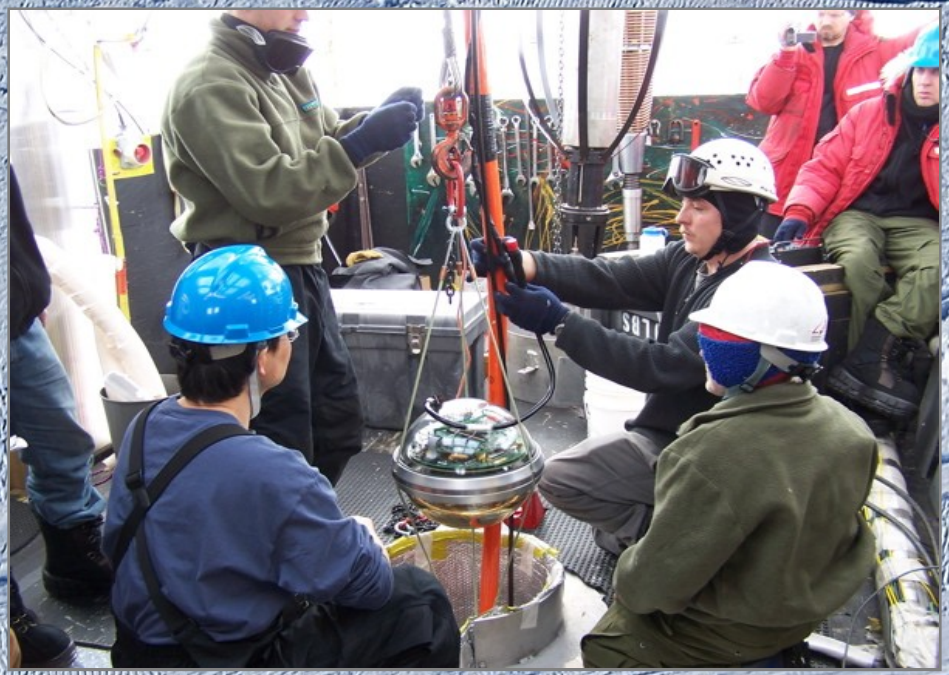
2008/09

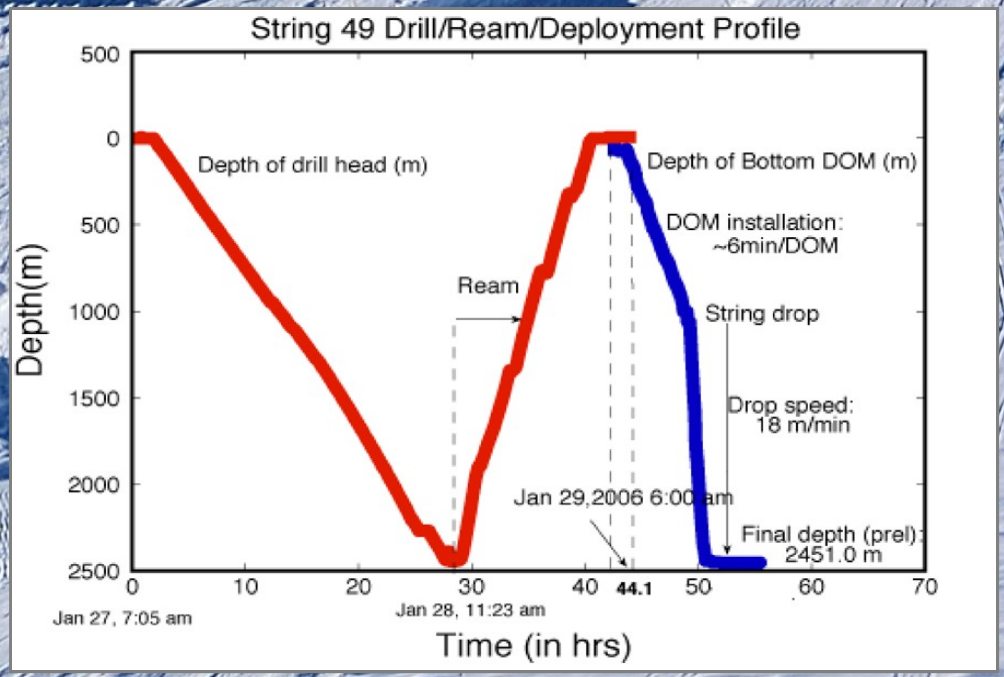
59 strings


South Pole
1 km
IceCube


Drilling

Drilling

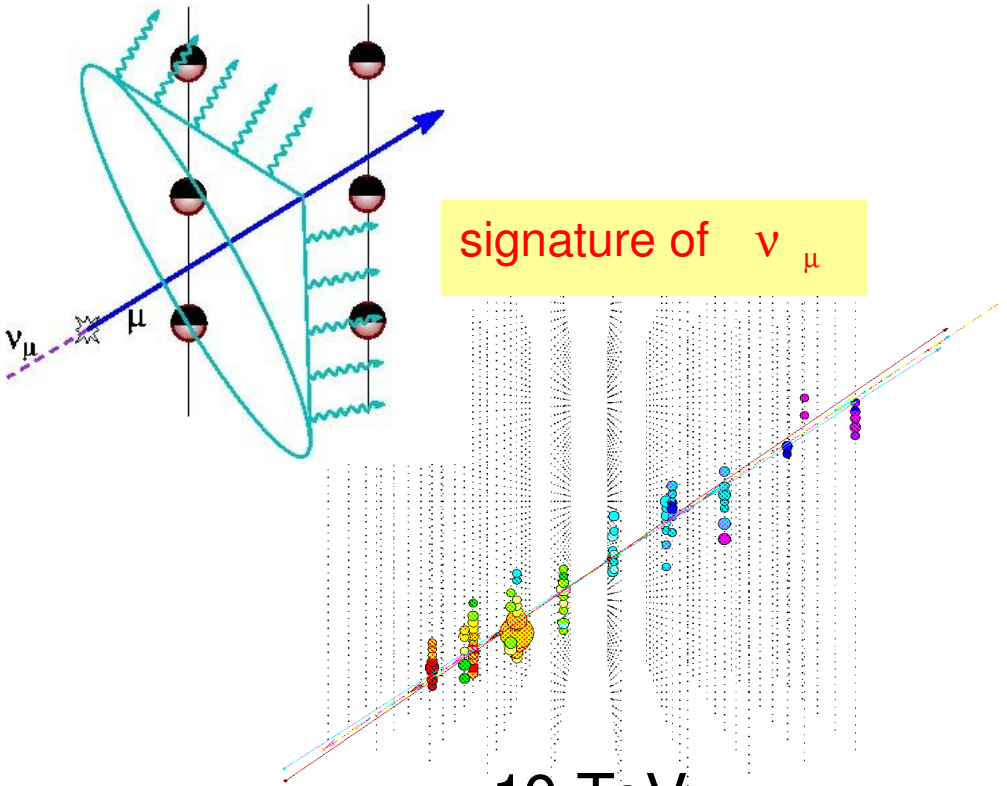


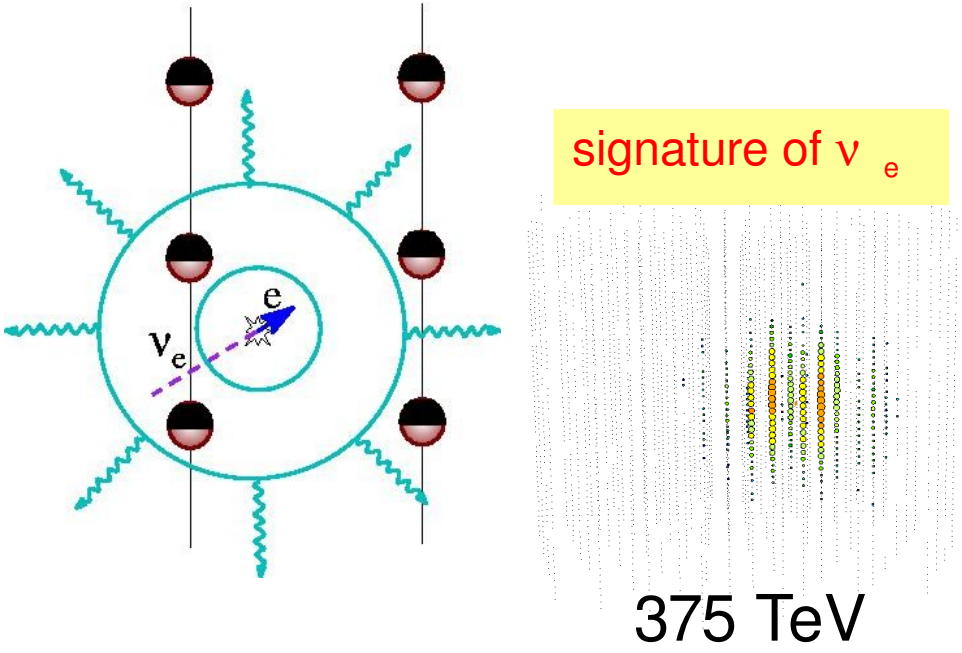

String 49 Drill/Ream/Deployment Profile
Depth(m)
500
0
500
1000
1500
2000
2500
Depth of drill head (m)
Ream
Depth of Bottom DOM (m)
DOM installation:
~6min/DOM
String drop
Drop speed:
18 m/min
Jan 29,2006 6:00 am
Final depth (prel):
2451.0 m
0
10
20
30
40
44.1
50
60
70
Jan 27, 7:05 am
Jan 28, 11:23 am
Time (in hrs)

Neutrino Signatures

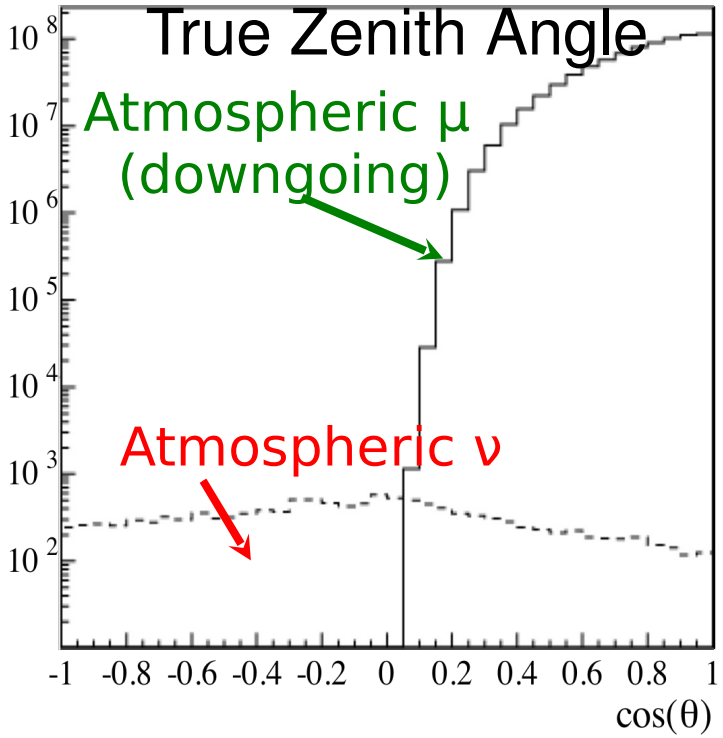
Muon-tracks:
+ good pointing (~1°)
+ large event rates due to long muon range

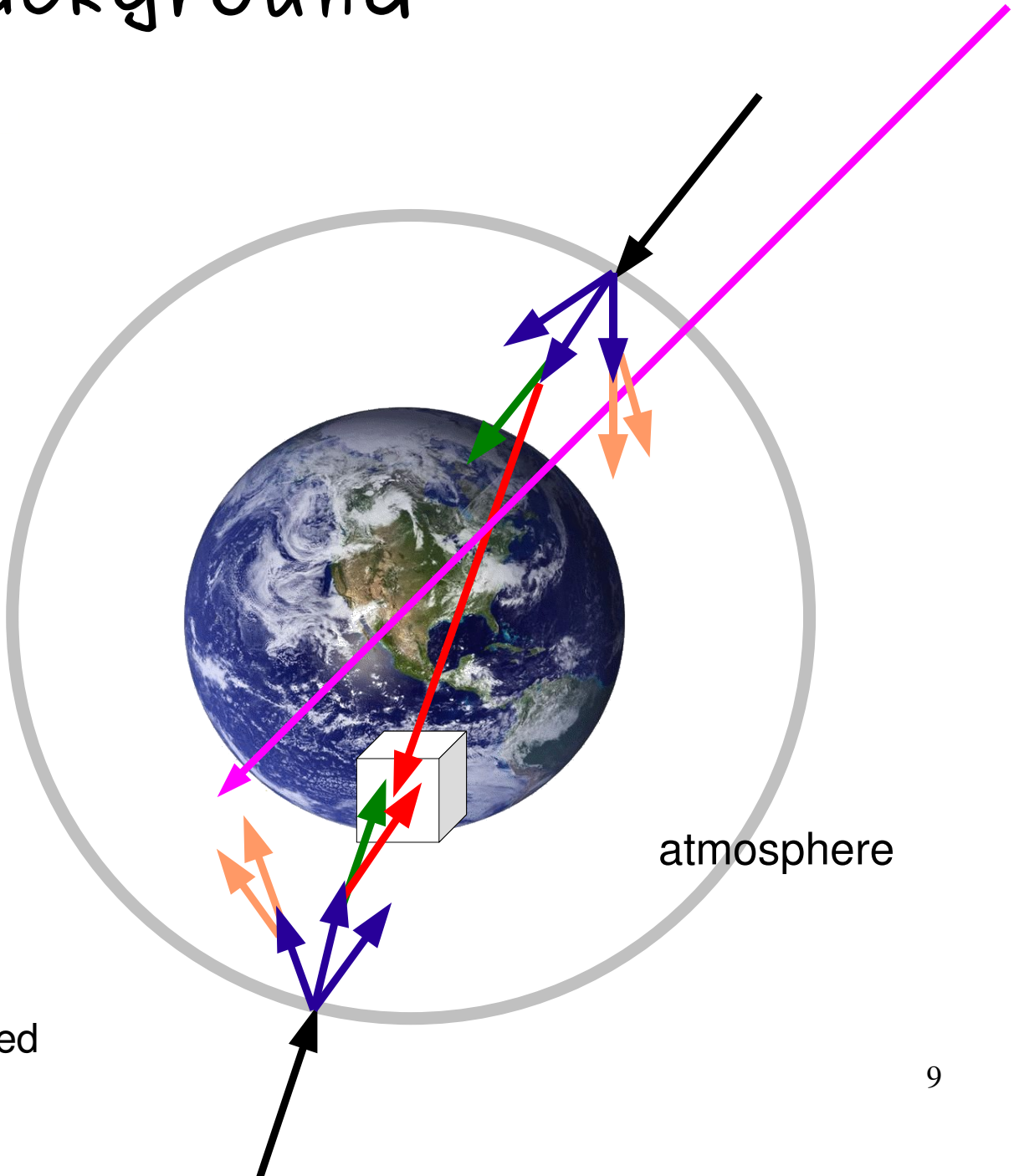
Cascades (particle showers): ν_e, ν_τ, (ν_μ)
+ good energy resolution (~0.2 in logE)
+ little background





Background





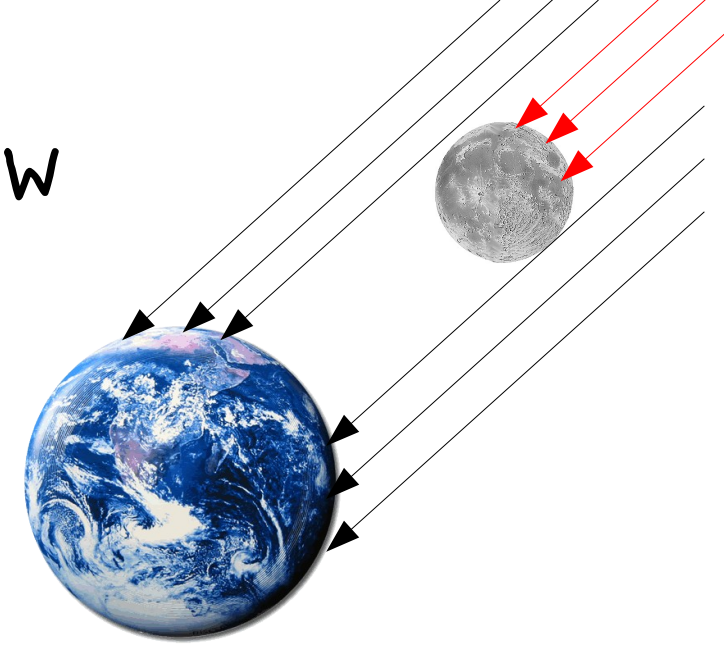
Atmospheric neutrinos

Atmospheric muons

Cosmic neutrino

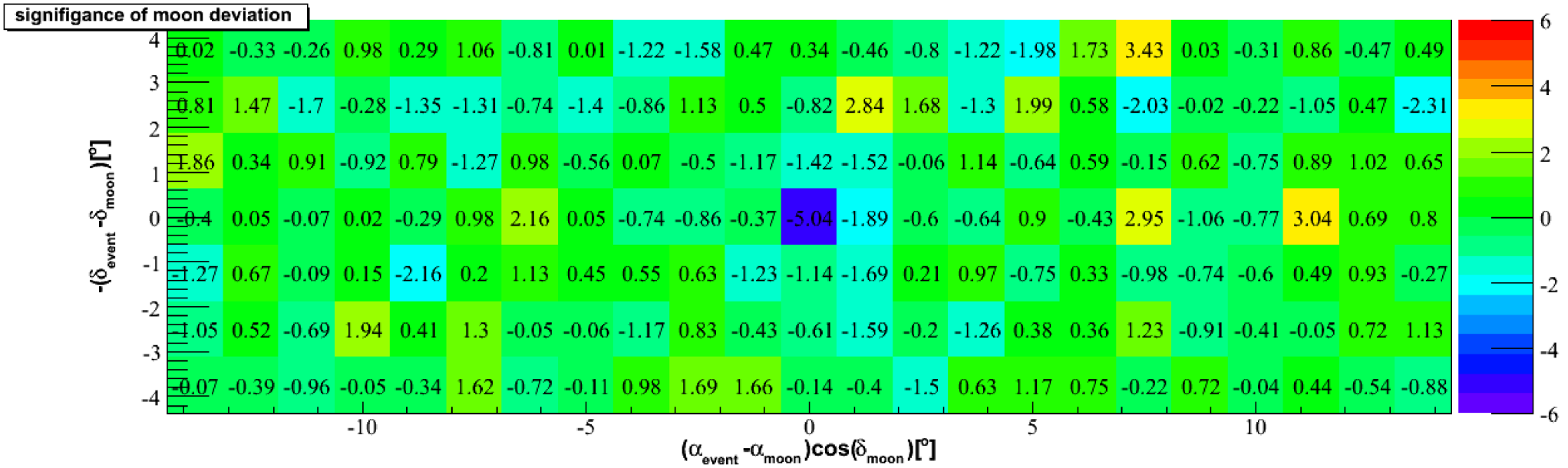
protons/charged particles

Moon Shadow



- Verification of absolute pointing
- 8 month of data (40 strings)
- 0.7° radius bin
- Deficit in direction of the moon observed with significance of 5.04σ

PRELIMINARY



Point Source Search

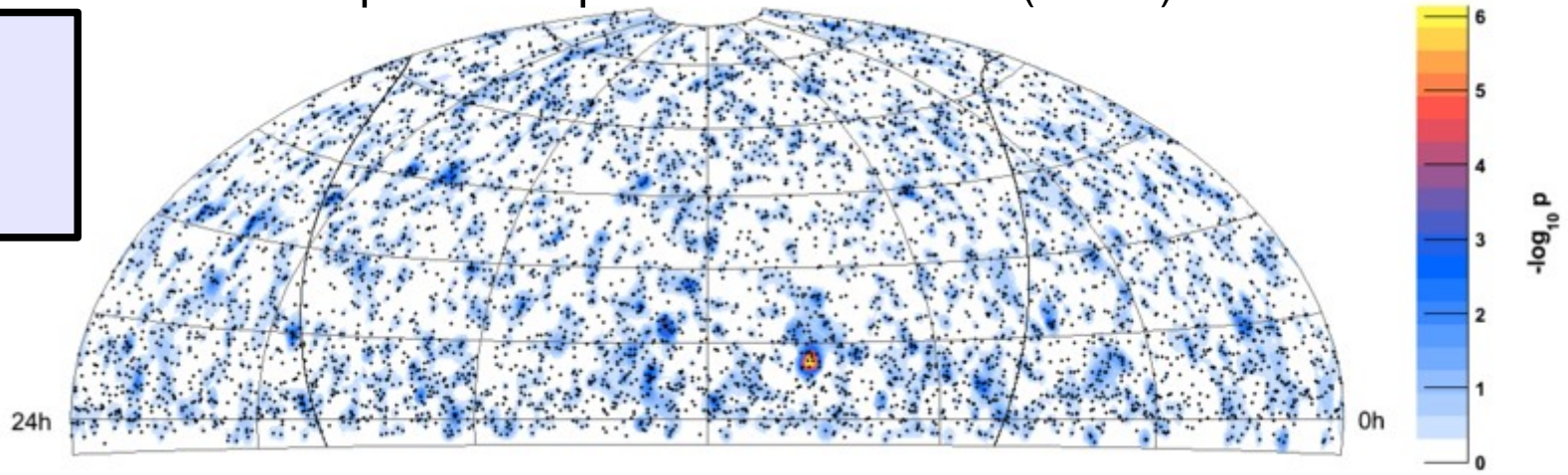
Point source search: 22-string results

- Selection of well reconstructed up-going events
- All sky search from -5° to 85°
  - High energy extension allows -50° to 85°
- Energy range: TeV-PeV
- A priori list of 28 source candidates

http://arxiv.org/abs/0905.2253

276 days of livetime
5114 data events
90% atm. neutrinos

Hottest spot at RA 153°, Dec 11° with post-trial p-value of ~1.34% (2.2 σ)



Ongoing Analysis

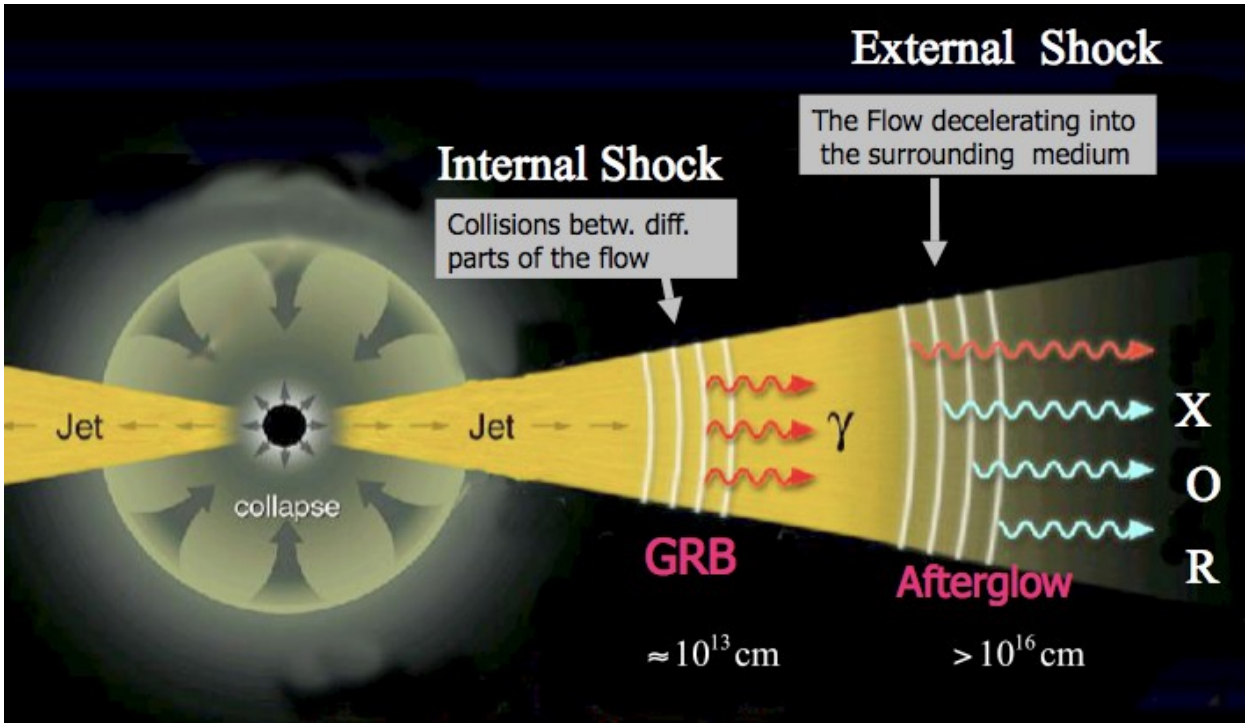
- Unified all sky search (-85°,85°)
- New reconstruction using charge: better performance
- Improved energy estimator: better muon energy resolution

GRB analysis

GRB neutrinos

Fireball Shock Model (Meszaros, Rees 1994)

- Relativistic jets with variations ~1s
- Internal shocks: Collisions within jets -> Gamma radiation
- External shocks: Collision with interstellar medium
  -> Afterglow (radio, x-ray, optical)



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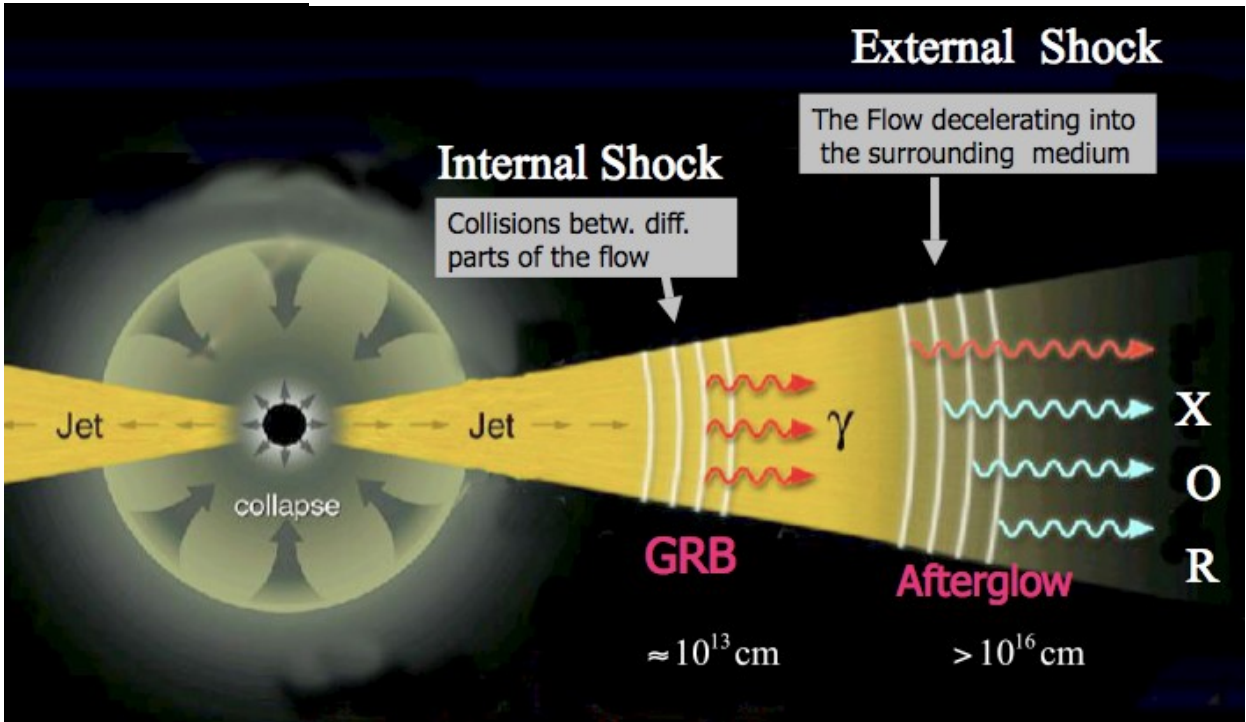
$$p\gamma \longrightarrow \Delta^+ \longrightarrow n\pi^+$$

$$\pi^+ \longrightarrow \nu_\mu \mu^+ \longrightarrow \nu_\mu e^+ \nu_e \bar{\nu}_\mu$$



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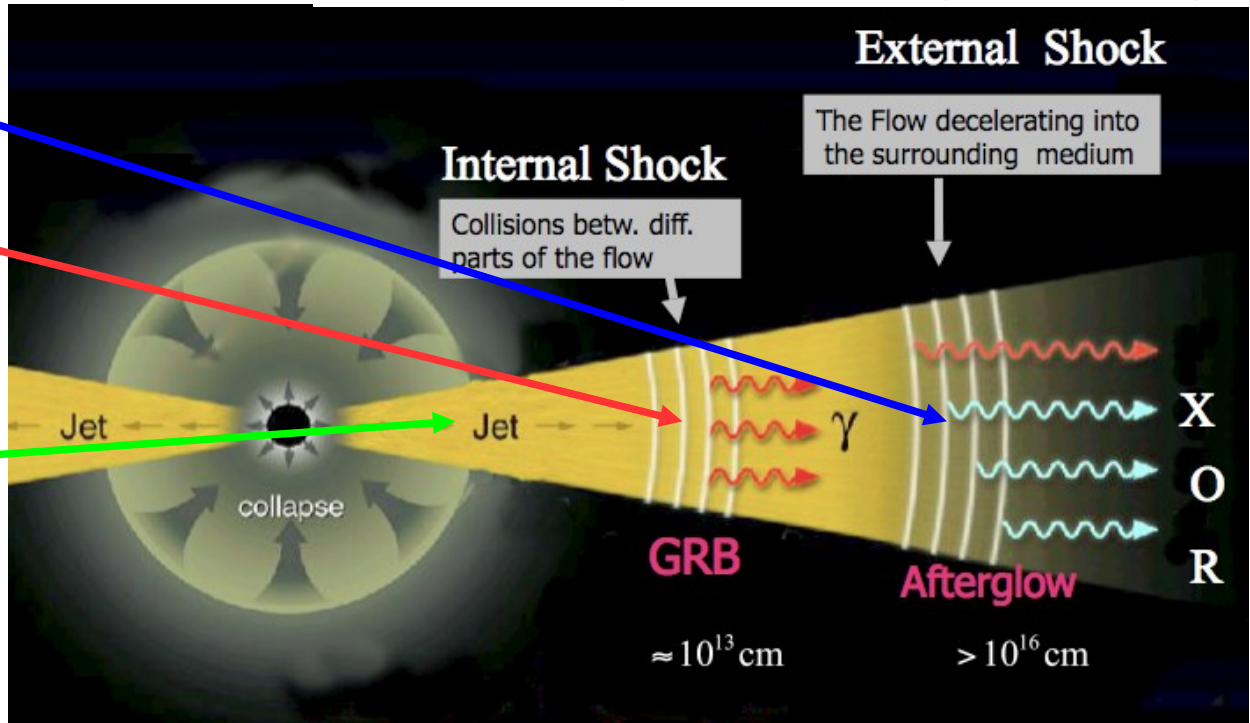
EeV Neutrinos from external Shocks
[Dermer 2001]
[Waxman & Bahcall, 2000]

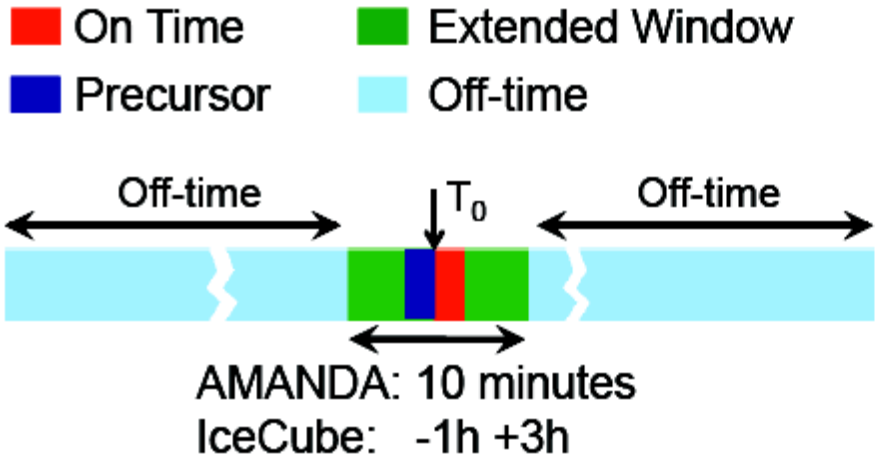
PeV Neutrinos from internal Shocks
[Waxman & Bahcall 1997]
[Gupta & Zhang, 2006]
[Murase & Nagataki 2006]

TeV neutrinos from inside the star
[Meszaros & Waxman, 2001]
[Razzaque et al. 2003]



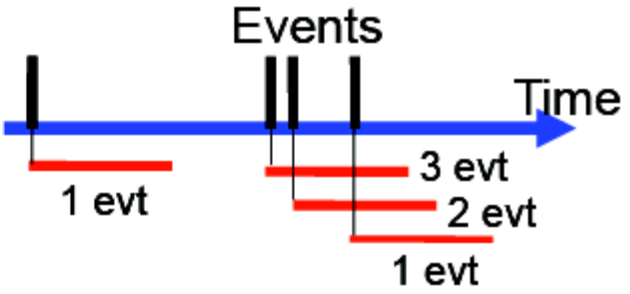
GRB searches

Triggered Search



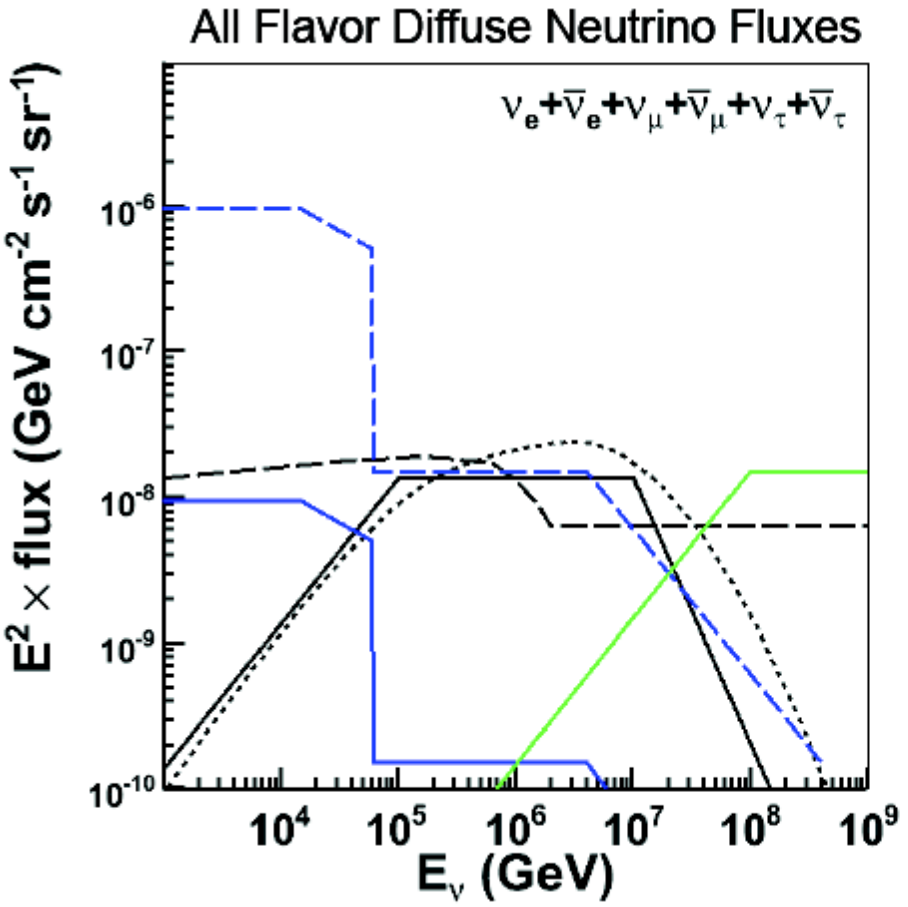
- Use satellite GRB list
- Low background: direction and time
- Low signal per GRB
  ⇒ Stacking
- Both ν_μ and cascades

Rolling Search



- Sliding windows: 1s, 100s
- Sensitive to γ-dark bursts
- Cascade search

GRB models



Prompt

—— Waxman & Bacall
PRL 78:2282 (1997)

----- Murase & Nagataki
PRD 73:063002 (2005)

– – Razzaque et al
PRL 90:241103 (2001)

Precursor / Choked

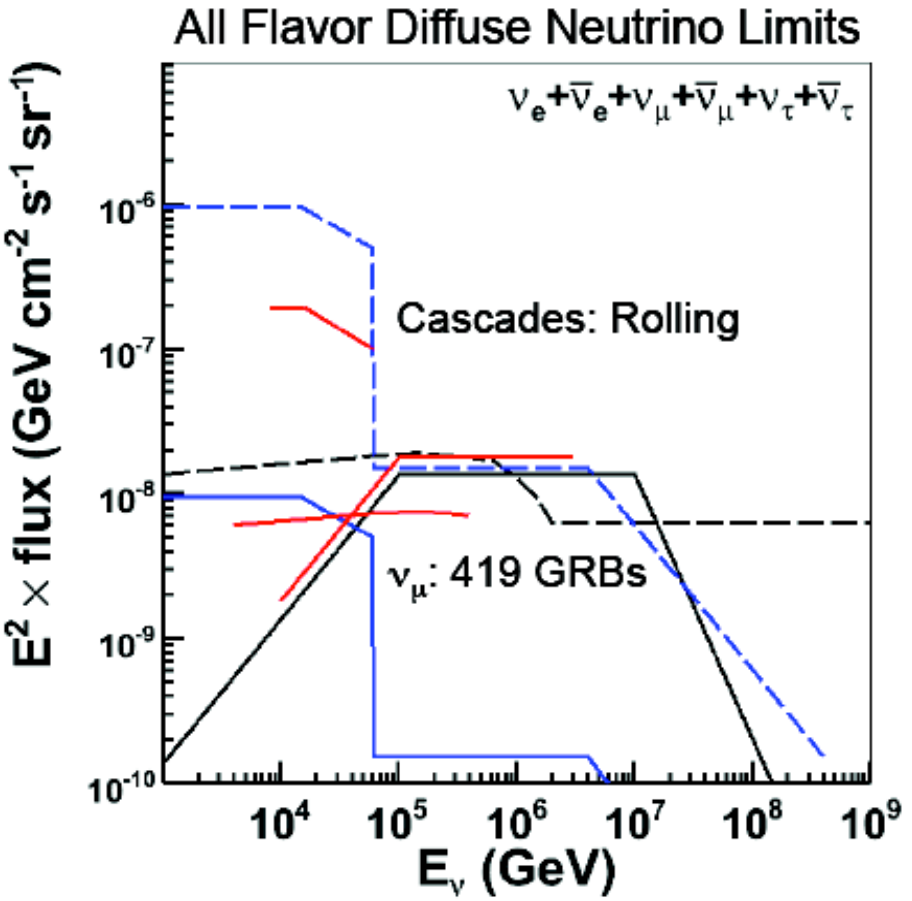
—— Razzaque et al.
PRL 90:241103 (2001)

– – Choked Bursts (idem)

Afterglow

—— Waxman & Bahcall
ApJ 541:707 (2000)

AMANDA results / Limits



Prompt

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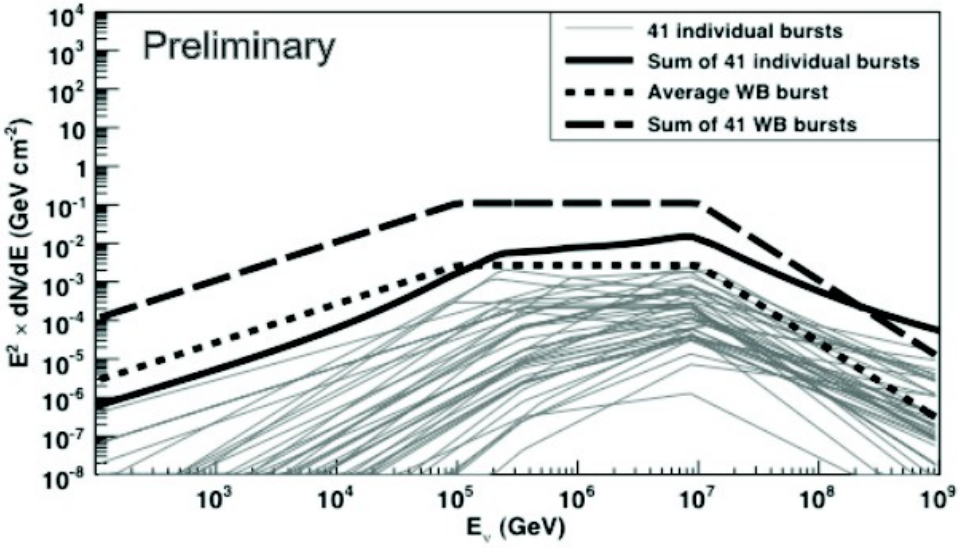
Afterglow

—— Waxman & Bahcall
ApJ 541:707 (2000)

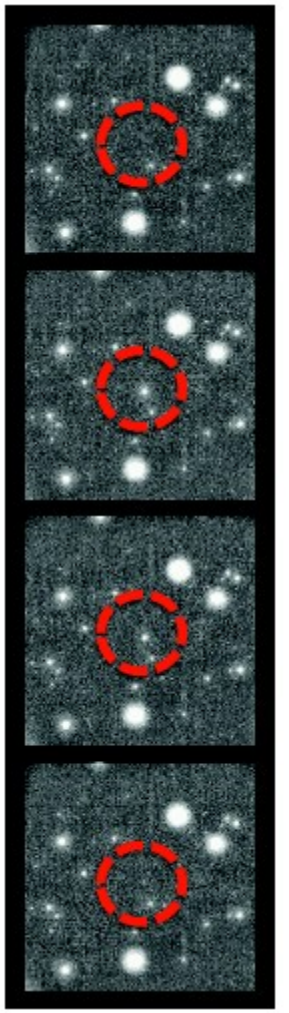
Astrophys. J. 664:397, 2007
Astrophys. J. 674:357, 2007

Triggered Search: 22-string results

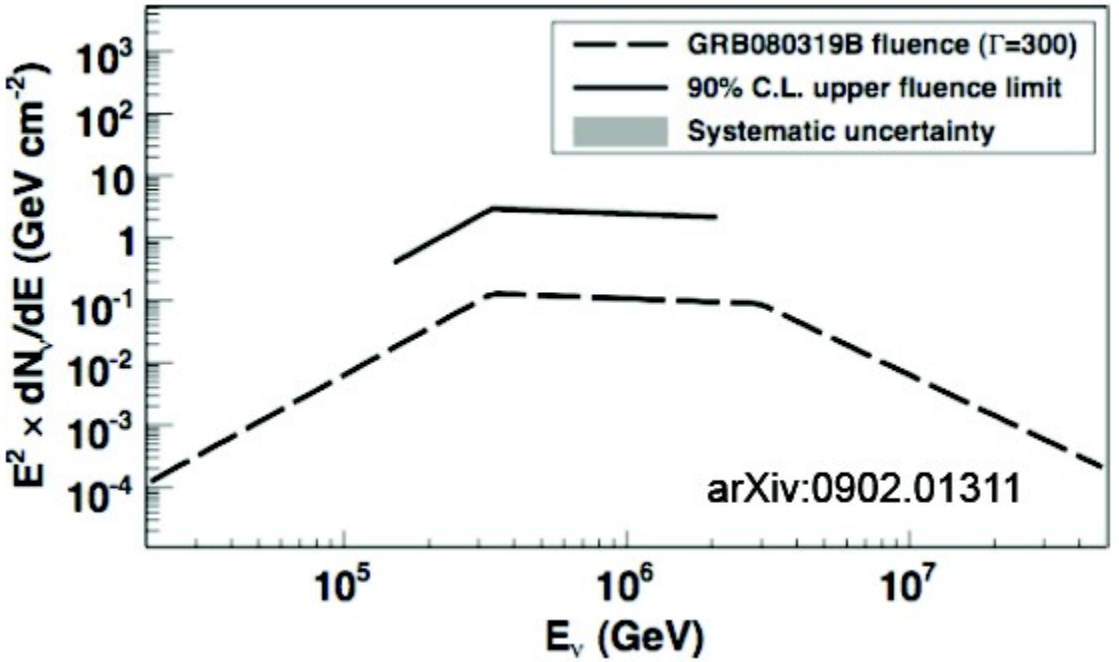
- One year of data with 22 strings (2007/08)
- 41 Northern hemisphere GRBs mostly from Swift
- GRB fluxes calculated individually
- Search windows:
  - Prompt: coincident with Γ-emission
  - Precursor: 100s before GRB
  - Extended: [-1h, +3h]
- Expected number of prompt events ~0.033 (typically low fluence from swift bursts)



Naked-eye GRB080319b



- Brightest optical GRB ever, at z=0.94
- IceCube running in maintenance mode with 9 out of 22 strings
- Signal expectation: ~0.1 events (Γ=300)

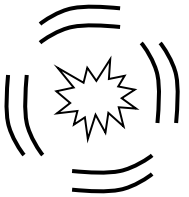


~1 event in 1km^3 detector

http://arxiv.org/abs/0902.0131

Optical Follow-Up

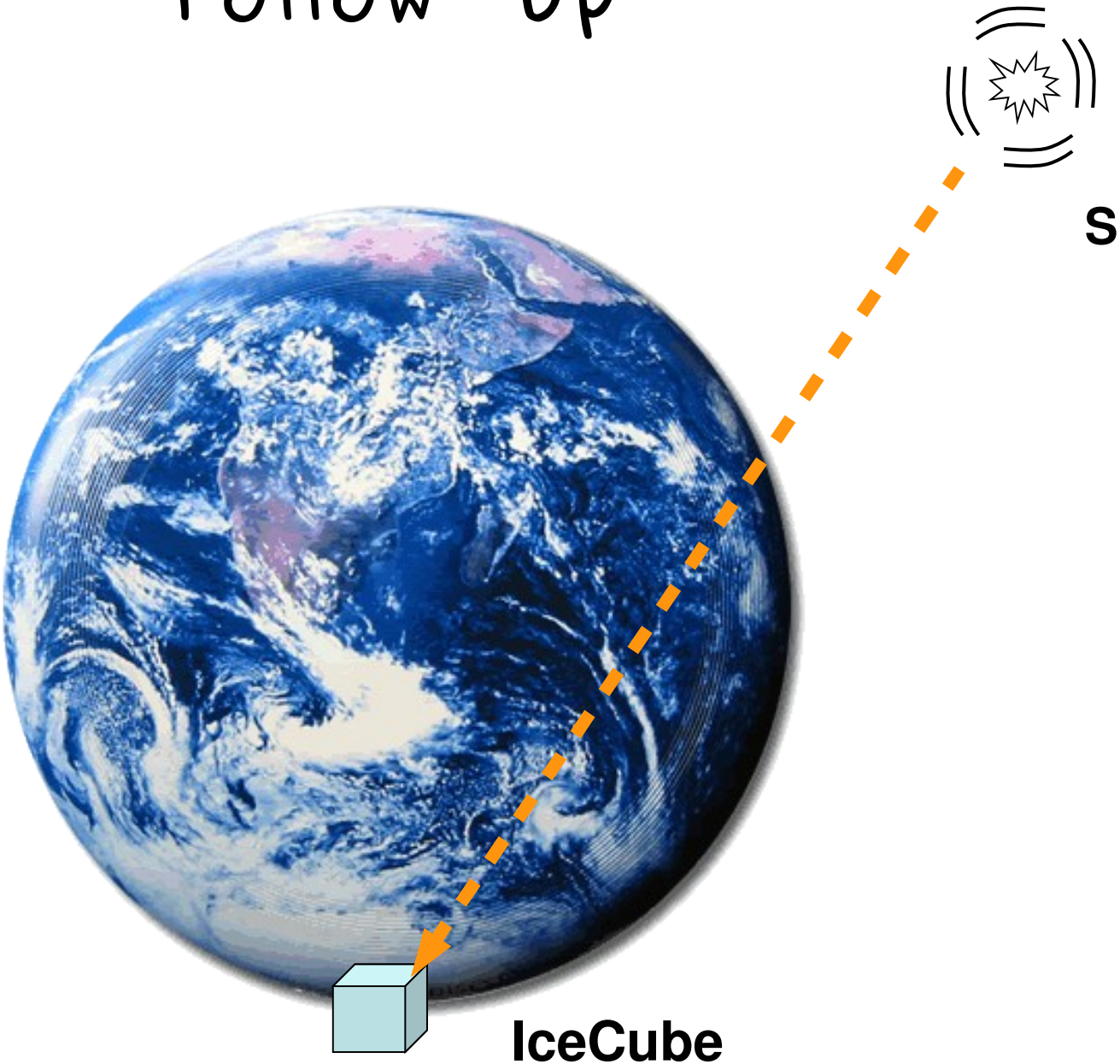
Concept of the Optical Follow-Up



SN/GRB

IceCube

Concept of the Optical Follow-Up



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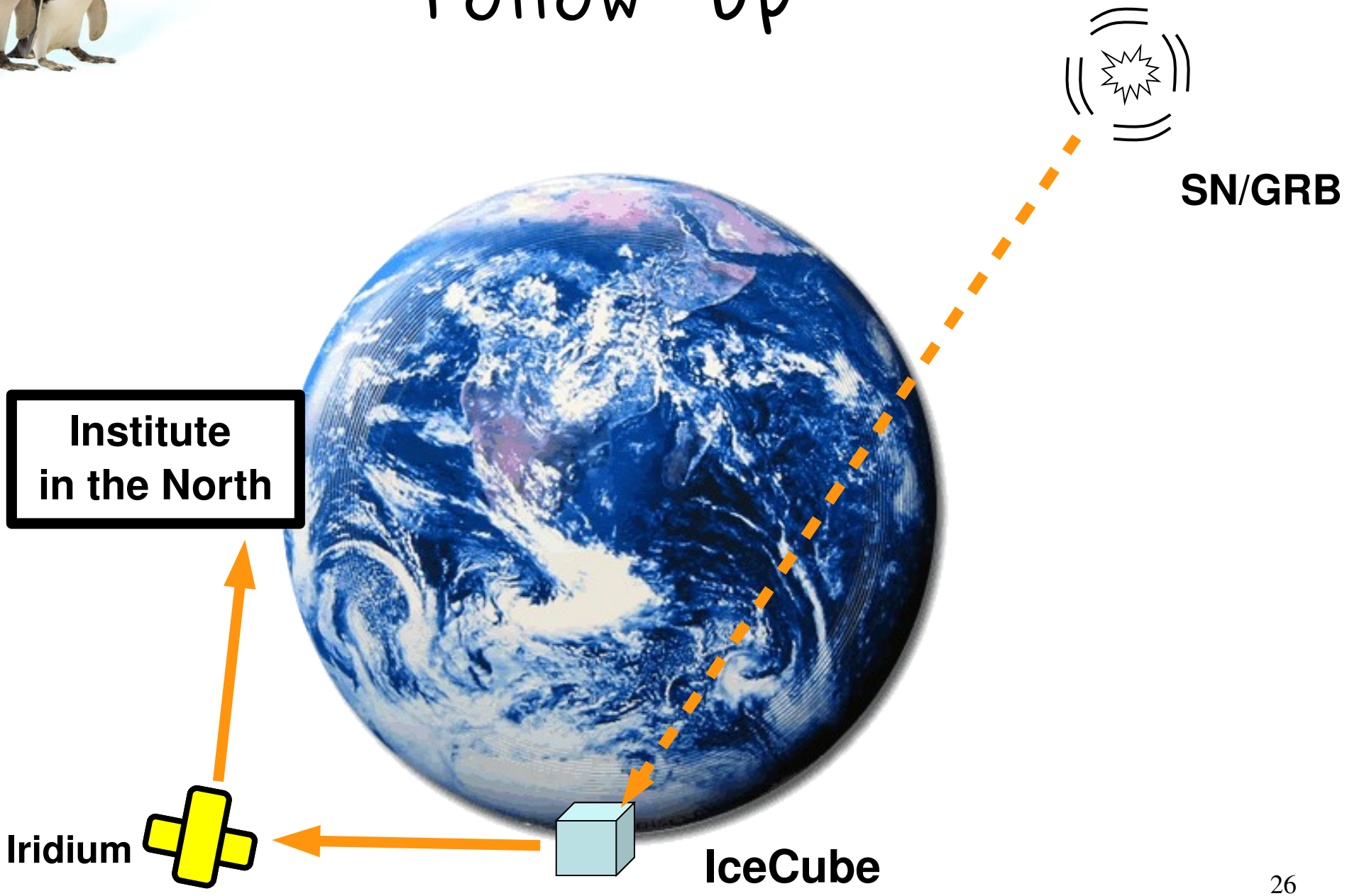

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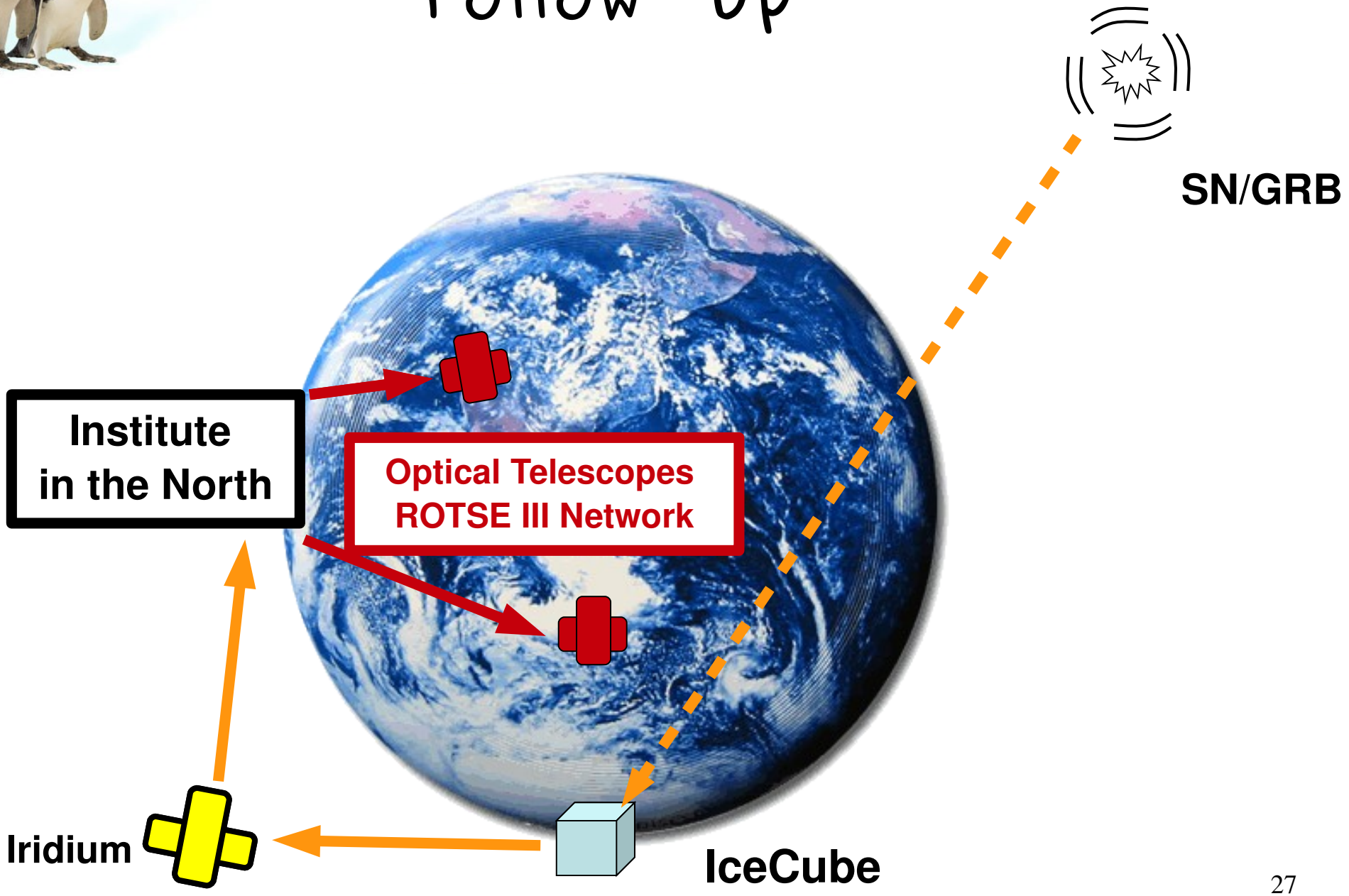

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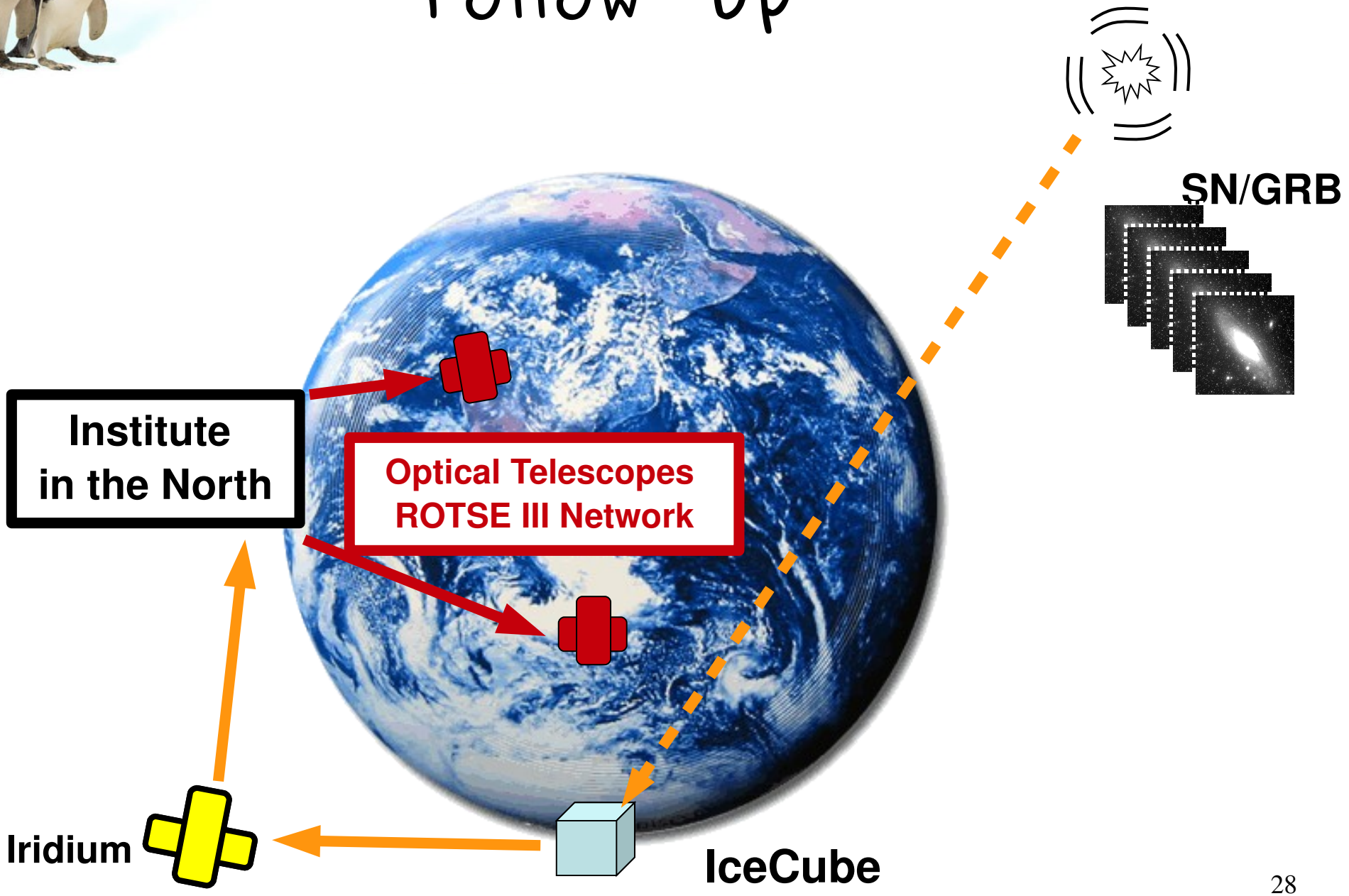

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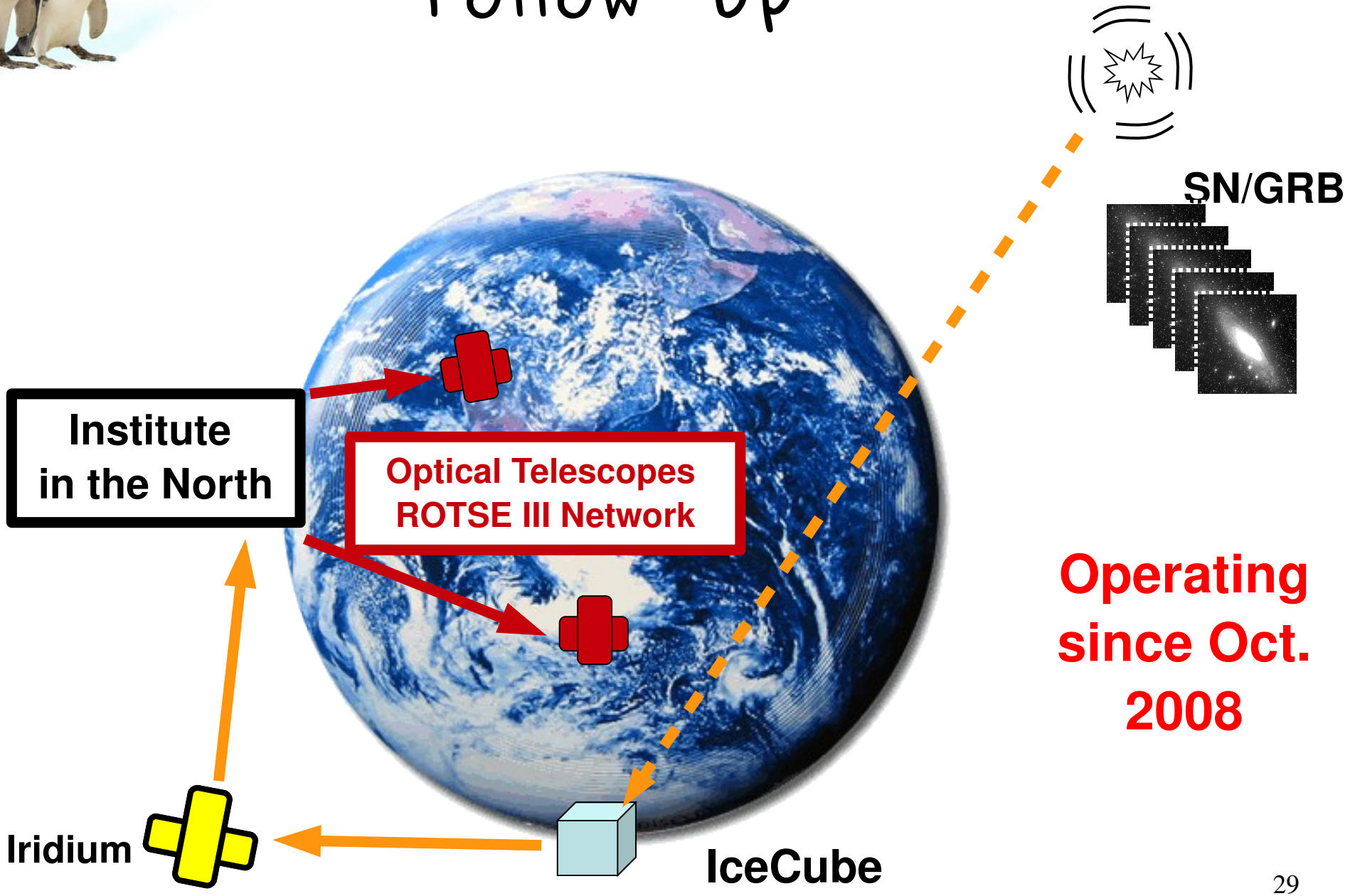
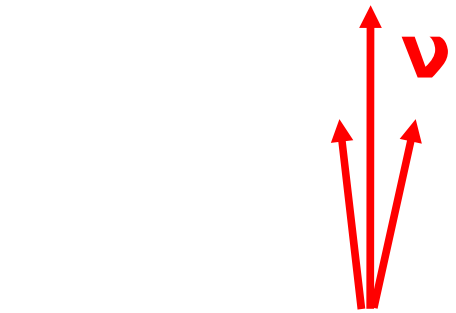
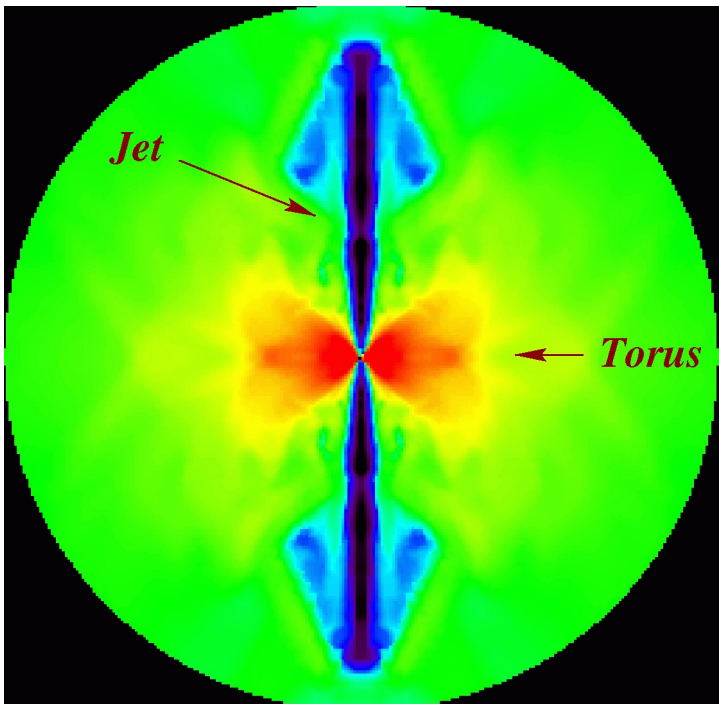


Operating since Oct. 2008

Motivation

- Observation of:
  - Gamma-dark bursts
  - GRBs (undetected by satellites, badly localized)
  - Supernovae with jets





Prediction: 30 Neutrinos (E>100GeV) in 10 sec by SN in 10 Mpc in 1km³ Detector (Ando & Beacom PRL2005)

Expected Signal:

Neutrino Bursts from SN or GRB – Coincident in

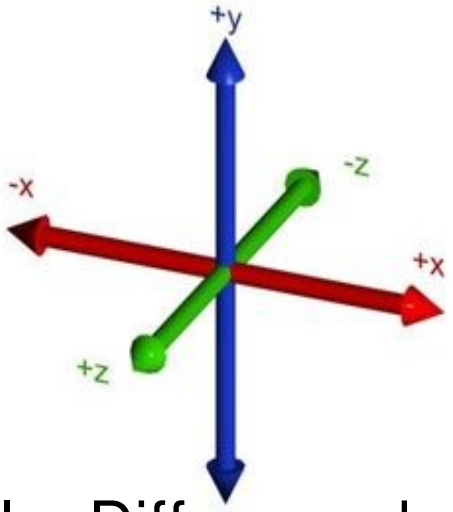
time

Time between events

$\Delta T < 100$ s

&

space



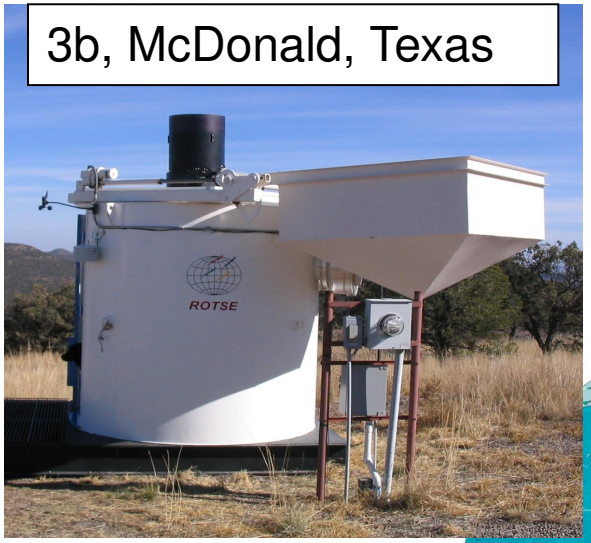
Angular Difference between reconstructed directions

$\Delta \Psi < 4°$

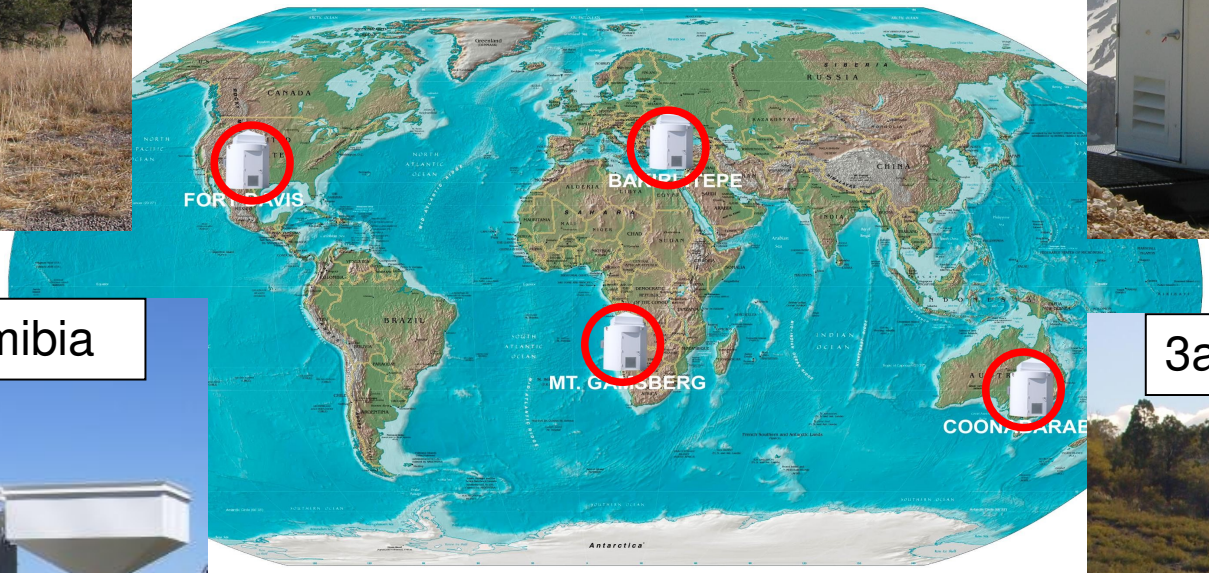
Requirement: At least 2 neutrinos
→ Reject background of atmospheric neutrinos

Searching for Optical Counterpart with ROTSE

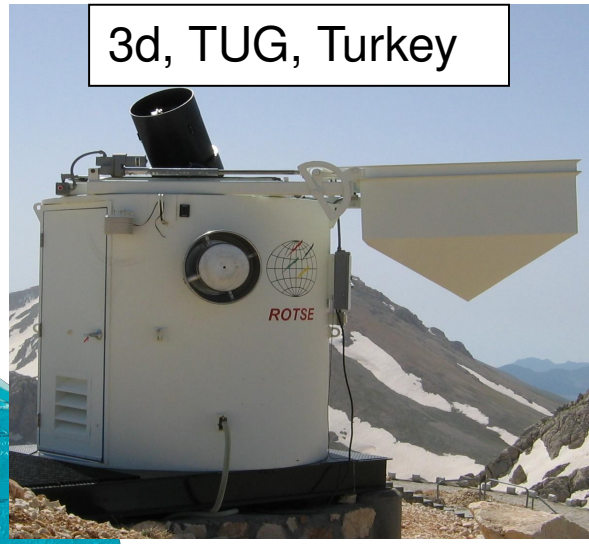
3b, McDonald, Texas



Robotic Optical Transient Search Experiment



3d, TUG, Turkey



3c, H.E.S.S., Namibia

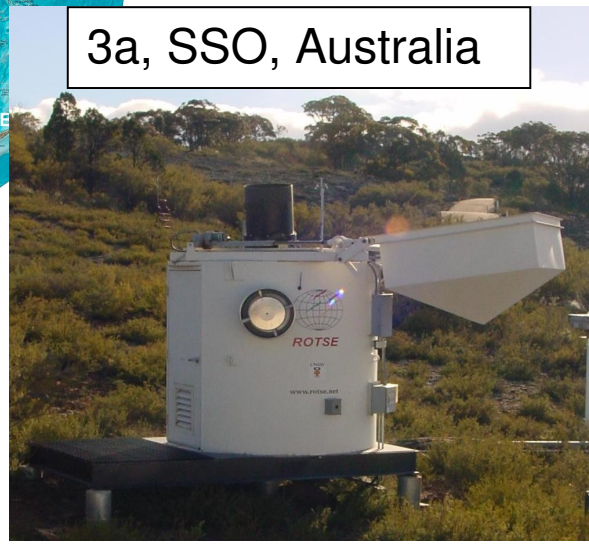
4 x 0.45m

FoV: 2° x 2°

fast follow-up

fully automated system

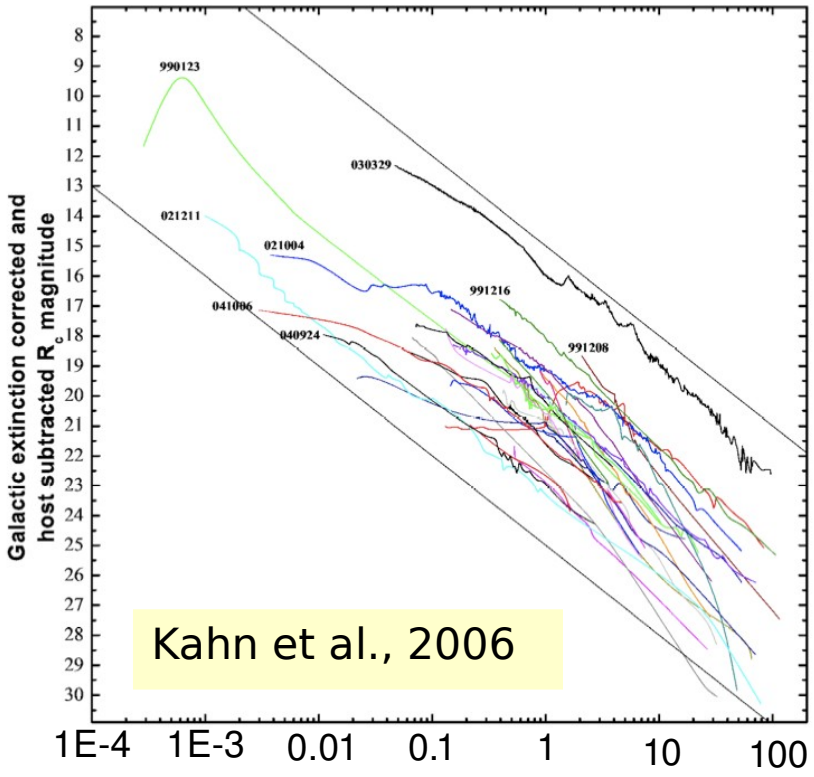
3a, SSO, Australia



Observation Schedule of IceCube Follow-Up

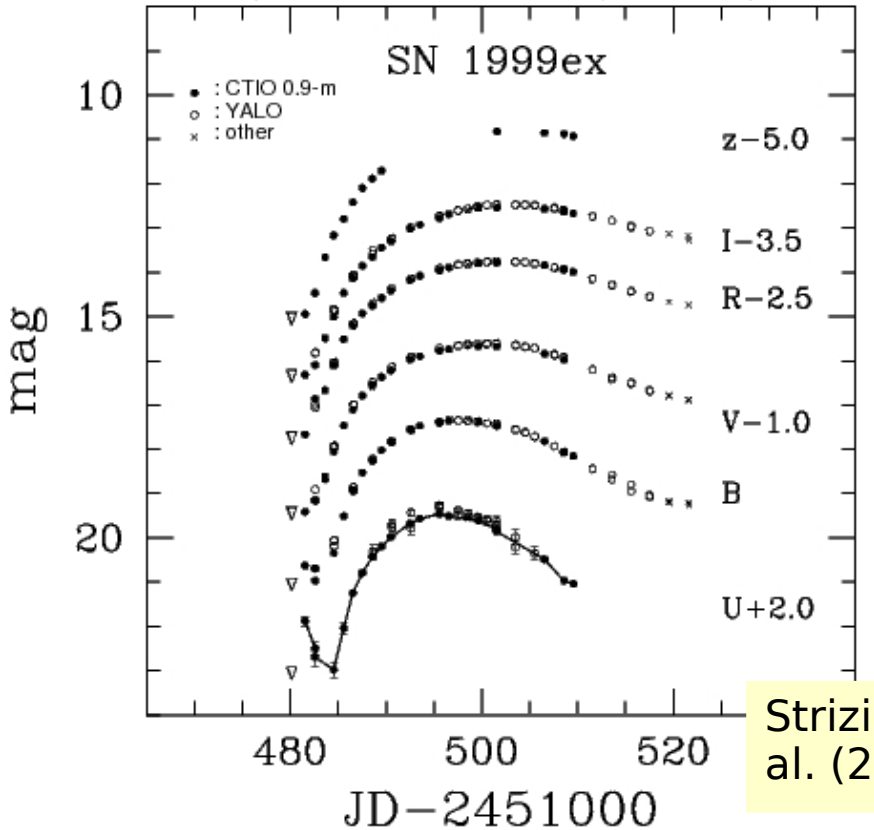
- First night: ten 5 sec, ten 20 sec, twenty 60 sec exposures
- Following 14 nights: Ten 60s exposures

GRB afterglow: power-law decay



Kahn et al., 2006

SN lightcurve: slowly rising



Strizinger et al. (2003)

ROTSE Data Processing

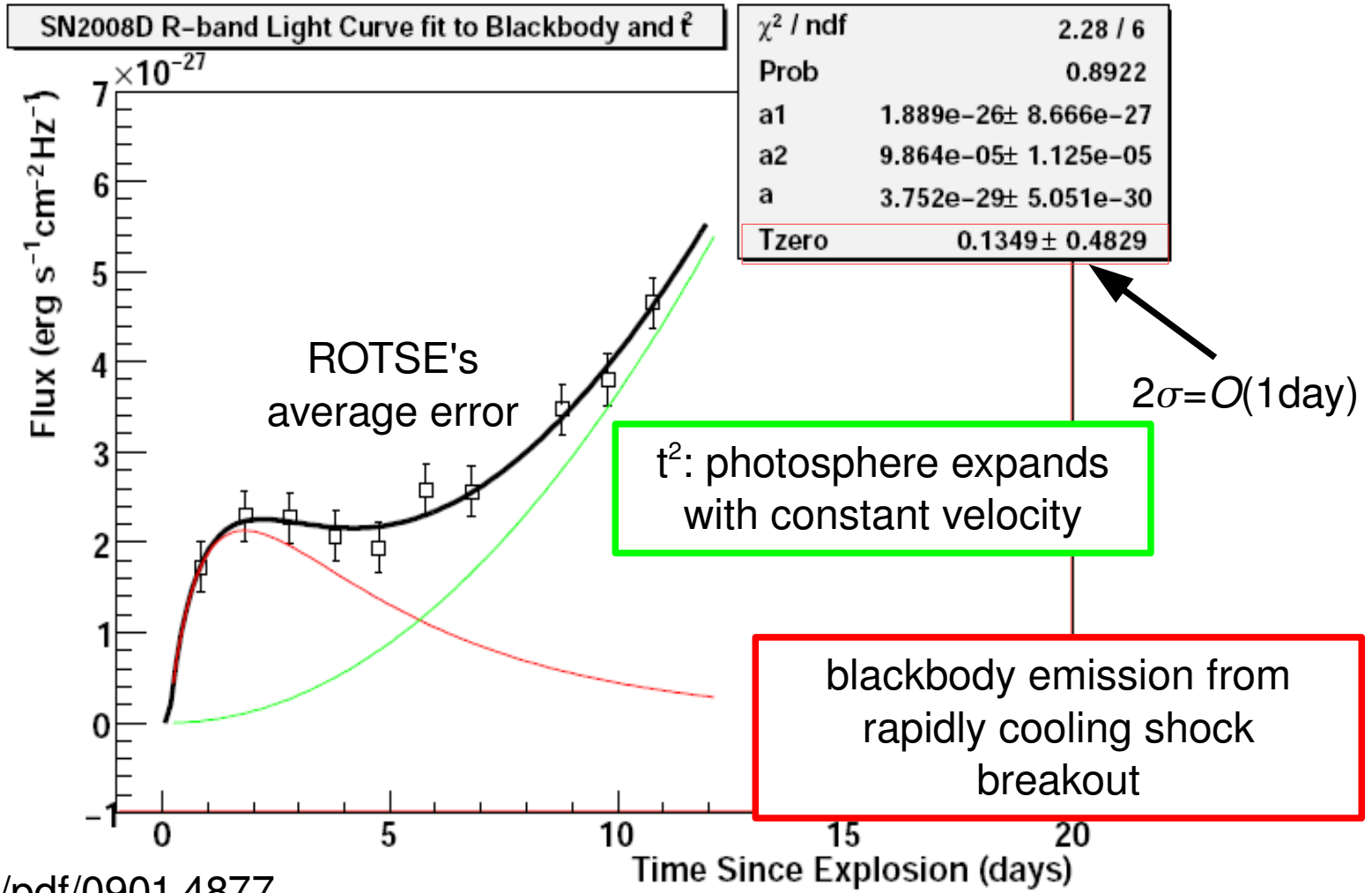
- Automated processing at the telescope side:
  - Calibration
  - Subtraction from reference image

image reference image subtraction

  - Candidate Identification

Fitting the SN lightcurve: Explosion Time Estimation

Real life example: SN2008D, explosion time known by initial x-ray flash



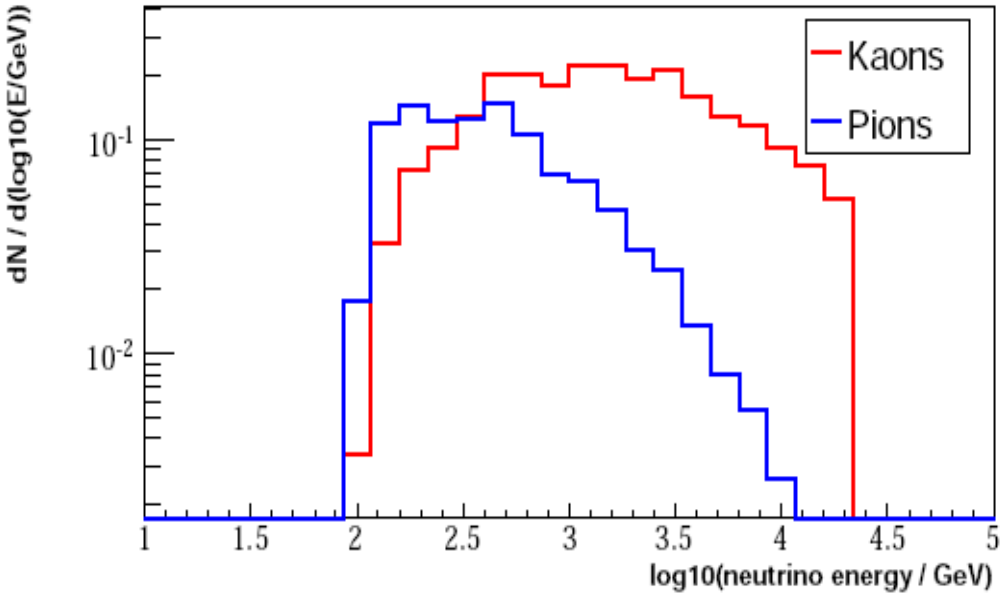
http://arxiv.org/pdf/0901.4877

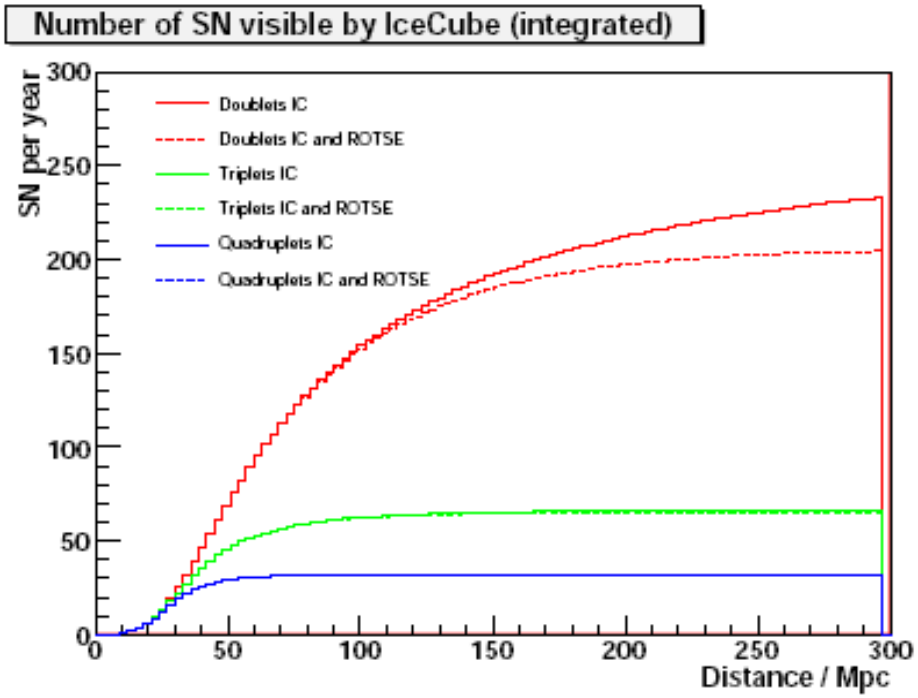
Sensitivity of IceCube and ROTSE to detect SN neutrinos

Following model of Ando and Beacon:
Kaon and pion production, assume jet energy of $3 \cdot 10^{51}$ ergs

Input spectrum

Number of SN visible by IceCube & ROTSE, assuming that all SN have a choked jet



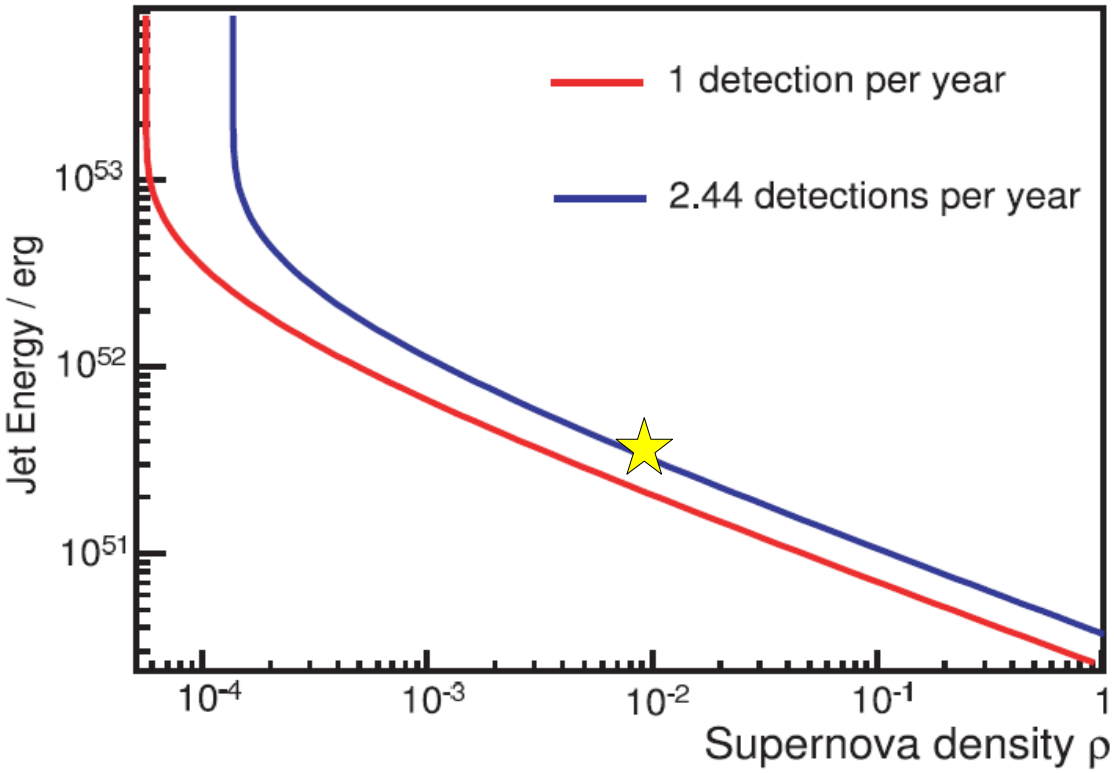


No Optical Counterpart discovered

- Upper limit on number of SN that could produce coincidence: $N^{\mathrm{IC}}_{\mathrm{ROTSE}} < 2.44$ (for 90% CL)
- This number scales with jet energy and the fraction of SN producing such a jet:

$$\rho^{\mathrm{SN}}_{2e-4}\left(\epsilon^{\mathrm{jet}}_{3e51}\right)^{3/2}$$

★ Model prediction of Ando and Beacom



Astropart.Phys.27:533,2007

Optical Follow-Up Future Plans

- Extend IceCube Filter
  - pairs of cascades and muons
  - Southern hemisphere high energy analysis
- Extend follow-up to
  - Other optical telescopes
  - Different wavelength (e.g. radio)
- Search for GCN neutrino multiplet coincidence planned
- Sending GCN notices by IceCube under discussion

Summary

- IceCube currently takes data with 59 string, will be completed in 2010/11
- Point source analyses
  - No significant excess in 22 string data
- GRB searches
  - Limits from AMANDA analyses, optimistic models excluded
  - 1 year of IceCube 80 (full detector) in coincidence with Fermi (Northern hemisphere) will lead to the observation of the Waxman-Bahcall flux at 5σ
- Optical Follow-Up will improve sensitivity and allows source identification


stay tuned!