The ALTO facility

M. Lebois, on the behalf of the ALTO team
The ALTO Facility: radioactive ions beams

+ Off-Line Separator (SIHL)
+ RIALTO

First photofission ISOL facility in the world (~10^{11} f/s)

- 50 MeV & 10 µA e⁻ beam
- UCx target (~70g, ~140 pellets)
- Z selection with: Surface/LASER ion source
- Mass Selection with PARRNe magnet -> mono-isotopic achievable
The ALTO Facility: radioactive ions beams

Accessible through Sulfidation/Fluoration
The ALTO Facility: stable beams

- Stable beam with spectrometer
- Stable beam w/o spectrometer
- Radioactive beam lines

**Standard Tandem beams**

- from H, $^3$He, $^4$He, ..., $^{14}$C, ... up to $^{127}$I
- terminal voltage: from $<1$ MV up to 14.5 MV
- beam pulsing: pulse width 1 – 2 ns; repetition rate – 200 ns or more
- **new ions source** purchased for higher intensity of difficult beams (Mg, Ca)

+ Source test bench
The ALTO Facility: neutron beam

Intensely focused monoenergetic neutron source: $10^7 \text{n/s/steradian}$

$n = 0.5 - 4 \text{ MeV}$
The ALTO facility: WP20 in ENSAR2 H2020 European program

Participants: 200 in 2016
113 in 2017
165 in 2018
60 in 2019

Beam-hours: 2544h in 2016
2300h in 2017
3384h in 2018
2532h in 2019

Users: 99/108, Project: 18/30

Deliverables: # Beam hours: 5088/2539, # Users: 99/108, # Project: 18/30
ALTO Beam Time distribution (2016-2019)
ALTO PAC # of projects

# projects vs Time

v-ball

12.4
Average number of publications per year
ALTO PAC # of UBT vs Beam Pressure

- **Asked UBT**
- **Rejection Rate**

- **2016**
- **2017**
- **2018**
- **2019**

- **93%**
- **23%**

- Vertical Axis: # UBT
- Horizontal Axis: Year
- Rejection Rate Line
### ALTO Budget 2016-2019 (k€)

<table>
<thead>
<tr>
<th>Running Costs</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
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<td><strong>Running Costs Total:</strong></td>
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<th>IN2P3 Master Projects</th>
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<td><strong>ISOL</strong></td>
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<td><strong>Tandem</strong></td>
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<td><strong>Total IN2P3:</strong></td>
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<th><strong>Other Sources</strong></th>
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<td><strong>ISOL (Labex P2IO+ SESAME &amp; UPSud in 2018)</strong></td>
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<td><strong>TOTAL:</strong></td>
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ALTO Human Ressources 2016-2019

HR @ ALTO

IJC Lab

??


0 5 10 15 20 25

IR  IE  AI  Tech.  Admin. T  Post-Doc  FTE
ALTO: Scientific Highlights
Stable beams
Nuclear astrophysics studies with the Split-Pole magnetic spectrograph: Status

Particle decay branching ratios for states of astrophysical importance in $^{19}$Ne

- States in $^{19}$Ne above $^{15}$O+$\alpha$ and $^{18}$F+p thresholds play an important role in explosive H-burning.
- Energetics in X-ray bursts [$^{15}$O($\alpha,\gamma$)$^{19}$Ne] & $\gamma$-ray emission in classical novae [$^{18}$F(p,$\alpha$)$^{15}$O].
- Reaction rate has a linear dependance to branching ratios (BR).

→ coincidence measurement of $^{19}$F($^{3}$He,t)$^{19}$Ne*(\alpha|p) with Split-Pole and a DSSSD array

$t$-$\alpha$ angular correlation

\[ E_{\gamma} = 6742 \text{ keV} \]

- Smaller binning (higher statistics)
- Better c.m. angular coverage toward 90°

→ better BR determination

Nuclear astrophysics studies with the Split-Pole magnetic spectrograph: near future

1 – PhD defense of A. Meyer jan. 2020

2 – Rejuvenation of detection (focal plane,...)

3 – Gas cell development for a new target to increase the range of possible transfer reaction with an astrophysical interest.

4 – Commissioning of the gas cell

5 – Needs to work on the articulation with RIB production (same experimental cave 210)
Potassium is a major element in many silicate minerals of the earth crust

**Decay**
- Decay of $^{40}\text{K} \rightarrow ^{40}\text{Ar} (T_{1/2} = 1.25 \text{ Ga})$
- Mineral acting as closed system, accumulating $^{40}\text{Ar}$

**Activation**
- Activation of $^{39}\text{K}(n,p)^{39}\text{Ar}$ in a fission reactor
- With a stable $^{39}\text{K}/^{40}\text{K}$ ratio, the $^{39}\text{Ar}$ represents K content

**Analysis**
- Noble gas mass spectrometry: $^{40}\text{Ar}/^{39}\text{Ar}$

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### Decay Table

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**Age of the mineral**

Measurement of the liquid argon energy response to nuclear and electronic recoils


- Response to 1.5MeV Neutrons
- Mesure of very low energy recoil to test sensitivity
Fast Neutron Tomography with LICORNE and NEDA (dec. 2017/June 2019)

1st Use of NEDA with FASTER BC501A
Fast Neutron Tomography with LICORNE and NEDA (dec. 2016/June 2019)

Neutron Beam Attenuation measurement
v-ball: hybrid LaBr$_3$-Ge array for fast timing spectroscopic studies


- Hybrid spectrometer Ge/LaBr
- "FASTER" Digital DAQ
  - 184-200 Independant Channels (Triggerless mode)
  - 500 Ms/s, 12 effective bits QDC for LaBr3
  - 125 Ms/s, 14 effective bits ADC for HPGe and BGO
- Coupling with neutron source
- Coupling with
- Calorimetry for mechanism selection
- Pulsed beam (2 ns width 400 ns period)
The $\nu$-ball campaign: the experiment list

**Heavy Ion Reaction $\gamma$ spectroscopy:**
- Half-life measurement and isomer spectroscopy in the neutron rich deformed nucleus $^{166}$Dy *(M. Rudigier et al., Phys. Lett. B, 801, 135140; + 1 PRC accepted)*
- Electromagnetic transition rates in the nucleus $^{136}$Ce
- Pinning down the structure of $^{66}$Ni by 2n- and 2p-Heavy-Ion transfer reactions and g-factor measurement
- A study on the transition between seniority-type and collectivity excitations in the YRAST 4$^+$ state of $^{206}$Po
- Measurement of the super-allowed branching ratio of $^{10}$C *(release date June)*
- Feeding of low-energy structures of different deformations by the GDR decay: the nuBall array coupled to PARIS *(Analysis going on)*

**Neutron induced reaction $\gamma$ spectroscopy:**
- Spectroscopy of the neutron-rich fission fragments produced in the $^{238}$U(n,f) and $^{232}$Th(n,f) reactions *(major results coming soon)*
- Spectroscopy above the shape isomer in $^{238}$U
Muti-quasiparticle sub-nanosecond isomers in $^{178}$W

M. Rudigier et al., Phys. Lett. B, 801, 135140

- 1st fast timing measurement with n-ball
- < ns measurement
- 4 qp isomers.
Half-life measurement and isomer spectroscopy in the neutron rich deformed nucleus $^{166}$Dy

R. Canavan et al., Phys. Rev. C, accepted

Measure of $2_1^+$ lifetime to get information on the deformation via $^{164}$Dy($^{18}$O,$^{16}$O)$^{166}$Dy reaction

$T_{1/2} = 2.3(2)$ ns for $2_1^+$

$Q_0 = 7.58(9)$ eb quadrupole moment
The ν-ball: $^{232}$Th fission fragments visibility

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<th>Elements</th>
<th>Yields (JAEA, En=500 keV)</th>
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**Prompt Condition:**
- Multiplicity $\geq 3$
- Add-Back Condition: 2 crystals in $\pm 50$ ns (no diagonal/no triple)
- Time of the first crystal kept and sum of the energy

**C.S. Condition:**
- $n$ HPGe crystals and BGO in $\pm 50$ ns to reject 23 fission events.
The ν-ball international collaboration

153 researchers from 16 different countries, 37 institutes, including ~80 thesis students

**UK (29)**
- University of Surrey (13)
- National Physical Laboratory (5)
- University of Brighton (2)
- University of West Scotland (4)
- University of Manchester (3)
- University of York (2)

**France (44)**
- IPN Orsay (16)
- CSNSM Orsay (6)
- CEA DAM/CEA Saclay (5)
- Subatech, Nantes (3)
- CENBG Bordeaux (6)
- IPHC Strasbourg (3)
- GANIL (2)
- LPC Caen (2)
- ILL (1)

**Germany (16)**
- TU Darmstadt (7)
- IFK-Koln (9)

**Poland (14)**
- IFJ-PAN Krakow (8)
- University of Warsaw (6)

**Japan (1)**
- Riken (1)

**Serbia (2)**
- University of Novi Sad (1)
- University of Belgrade (1)

**Norway (6)**
- University of Oslo (6)

**India (1)**
- Tata Institute (1)

**Canada (4)**
- University of Guelph (4)

**Romania (7)**
- IFIN-HH, Bucharest (1)
- ELI-NP, Bucharest (6)

**Bulgaria (8)**
- University of Sofia (8)
ALTO: Scientific Highlights
Radioactive beams
$^{83}\text{Ga} \rightarrow \ ^{83}\text{Ge} (15\text{-}40\%), \ ^{82}\text{Ge} (85\text{-}60\%)$

$^{80}\text{Ga} \rightarrow \ ^{80}\text{Ge} (98\%), \ ^{79}\text{Ge} (2\%)$

BEDO setup with large LaBr$_3$
§\textsuperscript{83}Ga: can GT trigger low-lying nuclear dipole oscillations?

Transition densities from QRPA

a) GT decay create a depletion of neutron density in the core; adds a proton on the surface

b) The excited §\textsuperscript{83}Ge states can then decay via E1 $\gamma$ emission with a «PDR-like» transition density

Radioactive In beam for $P_n$ measurement in the $^{132}$Sn region

Nov. 2018
Study of the $^{132}$Sn neighborhood:
$^{132}$In : $\sim 10^3$ pps
$^{133}$In : $\sim 10^2$ pps
$^{134}$In : $\sim 10^1$ pps

Beams of high purity and high selectivity

Neutron rich radioactive nuclei beams well separated in mass $A$

Laser Ion Source

In : 2 step- 2 colors

Efficiency: factor of 50/surface ionisation

rialto source success
RIALTO Highlights

- Uranium fission
- Neutron rich radioactive nuclei beams well separated in mass A
- Beams of high purity and high selectivity

Position Reliability

Scan en masse Ga 69,71 : Facteur 40

Juin 2019 : 15 days BT with a Ga Beam at ALTO

Efficiency : factor of 42/surface ionisation
PDR studies in very neutron rich nuclei around N=50 shell closure through β decay

G. Benzoni (INFN)/ I. Matea (IPNO)

PDR along closed neutron shell isotonic chains
"Can pygmy GT be a doorway to pygmy DR ? 82,83Ga case"
A.Gottardo et al., PLB772 (2017)

Decay spectroscopy with high and low gamma transitions

Energy matching between the two pygmy resonances (GT and Dipole)

Goal:
- study this phenomenon in neutron-rich nuclei along N=50 closed shell
- need to develop new RIB at ALTO

PhD Thesis of L. AL AYOUBI
The Project
Produce intense exotic ion beams through robust and innovative ISOL methods

The Method
Simultaneous optimization of all processes involved in ion production

June 2019
Tandem: First in-beam alkali production measurements

Fig 1: Vertical cross section of the TISS
SnS RIB experiment @ ALTO

A. Andrighetto (LNL-INFN)/M. Cheikh Mahmed (IPNO)

Framework: ENSAR2/EURISOL JRA/BEAMLAB
Involved Laboratories: ISOLDE-CERN, IPNO-CNRS, LNL-INFN, GANIL, SCK.CEN

Offline tests @ ISOL-ALTO

- SnS stable beams were produced by sulfurization of Sn
- Better control of S evaporation process is needed with the Online experiment conditions (target temperature ~ 2000 °C)
- Online experiment starts week 47
LINO @ ALTO

D. Balabanski (ELI-NP)/D. Yordanov (IPNO)

Colinear Laser Spectroscopy beam line

fluorescence detection

hyperfine structure

F=1
F=2
F=0
F=1

P_{3/2}
S_{1/2}

Beam diagnostics and handling
laser and ion beam coupling

post acceleration & neutralization

Na I

3p \ ^2P_{1/2}

589 nm, 6 x 10^{17} s^{-1}

3s \ ^2S_{1/2}
POLAREX @ ALTO Achievements: Publications & Conf.

Source: Implantation by fusion evaporation (d, $^{56}$Fe) à ALTO (Tandem)

- Geometry and solid angle correction
  - S. Roccia, C. Gaulard, A. Etilé, R. Chakma
  - NIMA 859 (2017) 18-22

- Nuclear magnetic moment of $^{57-58}$Fe (Ph.D. A. Etilé)

- Multipole mixing ratio of $^{57-58}$Fe (Ph.D. R. Thoer)
  - PolarEx, a Future Facility for On-Line Nuclear Orientation at ALTO: Multipolarity Mixing Ratio Data Analysis,
    Zakopane Conference on Nuclear Physics 2018,
    → + 1-2 conference/y

→ Publication to be submitted soon (draft ready) on the off-line commissioning
POLAREX @ ALTO Achievements: Off-line commissioning

Case Study: $^{57}\text{Fe}$

- Nuclear magnetic moment
  \[ \mu = (4.73 \pm 0.14) \mu_N \]
  \[ \mu_{litt} = (4.72 \pm 0.10) \mu_N \]

- M1:E2 mixing ratio $\delta$ of $122$ keV
  \[ \delta_{\text{Fox}} = 0.120(1) \]
  \[ \delta_{\text{Polarex}} = 0.124(9) \]

Preliminary
ALTO: Beam perspectives
v-ball2 campaign: October 2021 – December 2022

Result of negotiations with Gammapool, Jyvaskyla, PARIS collaboration

New Configurations

**v-ball/PARIS**
GDR studies. High energy gamma detection for light nuclei (ALTO high intensity $^6$, $^7$Li, $^{14}$C beams)

**v-ball/OUPS plunger and/or charged particle detector**
RDM lifetimes

**v-ball/Fast Timing**
24 clovers coupled with 40 FATIMA for best hybrid array performance. Lifetime measurements 10-ps 10ns range for weakly populated states

**v-ball/LICORNE**
Improve fission technique: Reduce gamma backgrounds from the source and intrinsic target activity. More primary beam. Low density targets for DPM lifetime measurements. $^{252}$Cf IC
The ALTO Facility: RIB line construction

- Laser-Induced nuclear orientation ($\mu, Q, J_p$)
- Parrne mass separator
- Identification station
- ISOL experimental cave (~100 m²)
- TETRA (existing)
- BEDO/TETRA (existing)
The ALTO Facility: BEDO upgrade


Transition from a low-lying $0^+$ state to the $0^+$ ground state

Main limitation with Si(Li) detector: huge Compton background!

Si(Li) spectrum
Ge spectrum

New design of the setup, adding a magnetic lens

G. Tocabens, PhD Thesis
The ALTO Facility: BEDO upgrade

Probing Vibrational Modes and Shape Coexistence in $^{118}$Cd through Conversion Electron Measurements

N. Marchini, A. Nannini, M. Rocchini, INFN

$^{118}$Ag $\beta^-$ $^{118}$Cd

- Measurement of internal conversion
- Spin assignment of 2.223 & 2.182 MeV states
- $q^2$(E0/E2) measurement
- Confirmation of quadrupole-octupole-coupled nature of states

![Graph showing excitation energy vs. mass number for different states](image)
Reaching Terra Incognita of Exotic Nuclei (ReTIEN)

ReTIEN project: 0.58 M€ equipment
Action financé par la Région Île de France

Financed end 2017
Started June 2018
Estimated end June 2021

February 2020 status
- On-track
- DR4 procurement ongoing process

Mass measurements
P2IO Labex

Beam transport section
Ion preparation section
RFQCB

90° Bender
59° Bender
35° Bender
Funding P2IO (delivered)
Funding ERM – UPSUD (delivered)
POLAREX @ ALTO: Scientific Program

- Study of Pm isotopic chain (A=147, 149, 151)
  Measurement of $H_{hf}$ of Pm in Fe
  Measurement of magnetic moments of Pm isotopes

- Study of magnetic moments of Sb (A = 130$^{g,m}$, 132$^{g,m}$, 134$^{g,m}$)

- Collectivity development from N=40 to N=50: the case of the $g_{9/2}$ mid-shell $^{77}$Ge

- Orientation of $^{137}$I and decay of high level excite states of $^{137}$Xe
  - Magnetic dipole moment of $^{137}$I
  - Parity admixture in excited states of $^{137}$Xe
  - Beta delayed neutron emission from $^{137}$Xe

- Magnetic moment measurements of Sb and I nuclei close to $^{132}$Sn
• Nuclear structure studies with high precision mass measurements.

• 2016 – 2024 : commissioning at ALTO, increase of MLLTRAP sensitivity (R&D), mass measurement campaigns.

• 2024 : Installation at DESIR, new mass measurement campaigns.
In color: Unknown masses or known masses with a low precision accessible with MLLTRAP.

→ Neutron rich nuclei around the magic numbers N=50 and 82.
Letter of Intent for Day 1 MLLTRAP experiments (approved in March 2017 by the ALTO scientific program advisory committee):
“High-precision mass measurement of silver isotopes (A=113 – 129) towards the N=82 shell closure with MLLTRAP at ALTO”

The physics behind these masses will allow to explore nuclear structure modifications, with a possible weakening of the shell gap around Z < 50 and to calculate the impact on mass A = 130 r-process elemental abundances. This inaugural scientific program will create new opportunities for wider collaboration and show readiness for upcoming national projects.
The ALTO Facility: RIB line construction

- MLLTRAP: Mass spectrometry
- POLAREX: Mass spectrometry
- LTNO: Mass spectrometry
- PARRNe: Identification station
- TETRA: CE spectroscopy
- BEDO: Gamma detection
- LINO: Collinear laser spectroscopy and laser pumping

A set of 3 complementary movable-tape-based detection arrays at the ALTO on-line mass separator.

Online 2020-21
The ALTO Facility: RIB line construction

Front-end modification (June 2020?)

Beam Line Construction + Commissioning before End of 2020

BEDO setup update

RLAMO: Ag beam development

Radioactive beam lines

Stable beam w/o spectrometer

Stable beam with spectrometer
The objective of the project:
- To meet the demands of industrials for electron, neutron and proton beams.
- Create within the ALTO platform, high-performance and functional experimental areas dedicated to irradiation.
- To have several automated and scalable stations to produce particle beams calibrated in energy, flux and dose.
- Offer irradiation possibilities to perfectly simulate the space radiative environment.
Thank you
Atouts GANIL-ALTO :

Variété des faisceaux primaires

Variété des cibles

Variété des installations

Actuellement et à moyen terme

In-flight SPIRAL2/S3 à moyen terme
p to U @ 0.75 MeV/n – 14.5 MeV/A → Cr to Cm cible mince

ISOL SPIRAL 1 existant
$^{12}$C à $^{238}$U (up to 95 MeV/A) → cible épaisse de graphite
$^{12}$C à 2 $\times$ $10^{13}$ pps (95 MeV/A) → cible épaisse, masse jusqu’au Nb
$^{12}$C à $^{238}$U, low energy → cible mince, jusqu’à l’U

ISOL ALTO existant
Ions lourds H à I @ 15 MeV → cible
Electrons @ 50 MeV → UCx

⇒ Nombreuses possibilités d’optimisation des dispositifs de production ISOL
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<tr>
<th>Years</th>
<th>Funding</th>
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<tr>
<td>2006-2010</td>
<td>ANR JCJC</td>
<td>150 k€</td>
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<td>Postdoc, moving from Canada, upgrade</td>
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<td>2011-2018</td>
<td>IN2P3</td>
<td>Env. 90k€</td>
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<td>30k€ structure at ALTO, 20k€ installation at ALTO, 5 à 8 k€/year</td>
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<td>2016-2019</td>
<td>Projet Emblématique – Labex P2IO</td>
<td>175 k€</td>
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<td>½ Ph.D. grant (R. Thoer), construction of vertical beam line</td>
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<td>2018</td>
<td>ERM – Université Paris-Sud</td>
<td>26,2 k€</td>
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<td>Construction of 90° deflector</td>
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<td>2018</td>
<td>SESAME – Ile de France</td>
<td>580 k€</td>
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<td>Construction of horizontal beam line</td>
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The collaboration

CSNSM, Orsay, FR  C. Gaulard, J. Guillot, S. Roccia, R. Thoer
IPNO, Orsay, FR  F. Ibrahim, F. Le Blanc, D. Verney
University of Maryland, College Park, USA  J.R. Stone, W. B. Walters
ILL Grenoble, FR  U. Köster
University of Surrey, Guildford, UK  P. M. Walker
University of Tennessee, Knoxville, USA  C.R.Bingham, R.Grzywacz, K. Kolos, M. Madurga, N.J. Stone
Niigata University, Niigata, JP  T. Otsubo
University of Novi Sad, Novi Sad, Serbia  M. Veskovic, J. Nikolov
Budget 2019 et demande 2020-22

Budget 2019 : 12 k€

R&D :
- Développement tripleur en fréquence pour faisceau Antimoine : 8 k€
- Fiabilisation position faisceau : 2 k€

Fonctionnement :
Consommables pour Ga (solvants, colorants, filtres) : 2 k€

Demande 2020 : 25 k€

R&D prévue :
- Asservissement de la position par les retours des faisceaux : 20 k€ (2 faisceaux sur 3)
- Développement faisceau Sb et Ag (colorants, solvant, filtres, optique) : 5 k€

Demande 2021 : 20 k€

R&D prévue :
- Asservissement du 3ème faisceaux : 10 k€

Fonctionnement :
- Maintenance YAG : 7 k€
- Consommables pour Zn : 3 k€

Demande 2022 : 12 k€

Fonctionnement :
- Optique : 7 k€
- Consommables : 5 k€
ν-ball: MEASURED PERFORMANCES

20 LaBr₃ 1.5”x2”  90°

- $d_{\text{center}} = 15.2$ cm
- $\Delta \theta = 14.3^\circ$

Time Resolution: ~250ps

Energy Resolution (@662 keV):

- 2.6%

Photopeak efficiency (@1.33 MeV):

- 0.5%